The Ontic Probability Interpretation of Quantum Theory – Part IV

QR/TOPI: How to Complete Special Relativity and Merge it with Quantum Theory

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ABSTRACT

We have ignored for a century that the incompleteness of Quantum Theory (QT) is inseparable from the incompleteness of Special Relativity (RT). In this article, I claim that the latter has been gravely incomplete vis à vis the former from 1927 until today. But completing RT in the light of QT is not as simple as merely postulating *nonlocality* and *stochasticity* as "elements of reality" (which is de facto done by most physicists and pragmatic philosophers); otherwise, RT would not still be in a "peaceful" conflict with QT after a century. Vice versa, I contend that QT is incomplete vis à vis RT, though not for the reasons claimed in the iconic EPR paper. We then show how to complete the *Ontology*, *Foundation*, and *Structure* of both RT and QT and merge them into an internally consistent embracive theory I call QR/TOPI. This theory offers a more cogent and simpler avenue to integrate RT with QT than positing exotic causal structures like 'retrocausality', 'future-input dependence', 'superdeterminism' – not to mention the extravagant 'Many-Worlds', 'Many-Minds', 'Parallel-Lives', and other interpretations of QT like Many-Histories, QBism, etc.

QR/TOPI provides the "radical conceptual renewal" wished by John Bell so as to integrate *probability* and *nonlocality* into an upgraded RT and, reciprocally, to integrate Frame-Invariance into QT while at the same time, as demanded by 2022 Nobel laureate Anton Zeilinger, providing basic physical meaning to the resulting encompassing theory. The old outcast notion of *absolute* simultaneity is resurrected without any conflict with Einstein's *relative* simultaneity, while Frame-Invariance is preserved via our Quantumlike Transformation (QLT), which is an extension of the Lorentz Transformation (LT): QLT includes what LT excludes: *nonlocality*.

Section 1 examines the *philosophical* foundations of Space and Time, focusing on RT, its plethora of empirical validations, and the tenets which make it incompatible with QT. Section 2 incorporates *stochasticity* into RT. Sections 3 through 5 gradually introduce QR/TOPI for mono-, bi-, and tri-quanton systems, with full consideration of Bell Theorem, *nonlocality*, *teleportation*, and their implications. Section 6 attempts to review the current status quo. Section 7 makes the case for the incompleteness of RT and QT. Section 8 explains how to complete and integrate both theories so as to formally develop QR/TOPI. Finally, in Section 9, via multiple experimental setups, I zero in on Zeilinger's basic question: "what does this really mean in a basic way?"

Prolegomenon

In **1987**, six decades after the 1927 Solvay meeting, John S. Bell said (my underscore):

BELL1: *It may be that a real synthesis of quantum and relativity theories requires not just technical developments but radical conceptual renewal.* [1]

In **1990**, during a colloquium Bell gave at CERN on January 22nd, he was asked whether he thought Relativity and Quantum theories could be incompatible, and he responded:

BELL2: *No, I can't say that, because I think someone will find one day a way to demonstrate that they are compatible. But I haven't seen it yet. To me, it's very hard to put them together, but I think somebody will put them together, and we'll just see that my imagination was too limited.*[2]

In **1994**, Tim Maudlin (Quantum Non-locality & Relativity [2]), after laboriously trying to merge Special Relativity Theory with Quantum Theory, glumly said (my underscore):

MAUD1: *Indeed, the cost exacted by those theories which retain Lorentz invariance is so high that one might rationally prefer to reject* Relativity *as the ultimate account of space-time structure.*

And, regarding the prospects for General Relativity (GRT), he reaffirmed the same sentiment:

MAUD2: *But discovering a truly relativistic theory that can deal with violations of Bell's inequality is an exceedingly difficult task, and the theories presently available entail such severe dislocations of our physical view that one must seriously consider whether our grounds for adhering to Relativity are really strong enough to justify such extreme measures.*

And, as recent as December **2023**, Jonathan Oppenheim, while proposing to abandon the half-century attempts to quantize spacetime via String and Loop Quantum Gravity theories, he stated:

OPPE1: *Yet, although we have candidates such as string theory, which is in its mid-50's [1], and loop quantum gravity turning just over 40 [2–4], a convincing theory of quantum gravity remains elusive.* [3]

As related by Colin Bruce in the chapter entitled "The New Age Warrior" (Anton Zeilinger) of his 2004 book 'Schrödinger's Rabbits' [4], when he asked Zeilinger at the dinner table which interpretation of Quantum Theory he favored, Zeilinger said:

ZEIL1: *I think there is a need for something completely new. Something that is too different, too unexpected, to be accepted as yet.*

Bruce then recounts that after asking him if that something would be "some variant of many-worlds", Zeilinger "brought his hand down on the table with a thump and gave a monstrous Teutonic snort" uttering: "No, I do not think many-worlds is right at all. Absolutely not!"

Some two decades later, after winning the **2022** Nobel Prize in Physics together with Alain Aspect and John F. Clauser "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science", Zeilinger said (my underscore):

ZEIL2: *The very fundamental question — what does this really mean in a basic way? — is unanswered and is an avenue for new research.*[3]

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[2] As cited by Antoine Suarez in 'What is Science', 22nd International Interdisciplinary Seminar "Science and the Quest for Truth", Clarendon Laboratory, Oxford, January 2nd, 2020.

[3] https://physicsworld.com/a/alain-aspect-john-clauser-and-anton-zeilinger-win-the-2022-nobel-prize-for-physics/.

Ironically, and very far from attempting to diminish the Nobel laureates' professional merit, Zeilinger is partly acknowledging what Nicholas Maxwell had said in 1988:

MAXW1: *As Einstein realized with anguish, the soul of natural philosophy has been betrayed. The quest to understand has disintegrated into expert puzzle solving, the hunt for Nobel prizes and defence contracts.* [5]

In November 2023, Del Santo and Gisin said:

DELS1: *Interpreting quantum mechanics remains one of the greatest challenges of modern science. But if one thinks twice, this challenge lies to a large extent above and beyond quantum physics and, hidden behind historically rooted dogmatisms, the great challenge has always been to interpret physics tout court.* [6]

Evidently, using the acronym QT (as we have done in Parts I, II, and III) to loosely cover all the theories, formulations, and interpretations developed in the past 100 years to match the accurate predictions of orthodox[4] (Copenhagen) quantum theory [7] [8] while attempting to explain away its perceived "unrealistic" features[5], it is palpable that we have been left with a powerful suite of predictive tools – with absolutely ***no*** clue as to what they fundamentally mean, let alone how to put them together with RT (and much less with GRT).

I will use the acronym **QR**/TOPI to refer to this long awaited integration of **Q**T with **R**T, replacing the acronym **Q**T/TOPI of my previous articles where only QT was considered and to which we referred as a *metatheory* [9] [10] [11]. But **QR**/TOPI is different from **Q**T/TOPI: it offers at once the needed "radical conceptual renewal" and the "basic" physical meaning behind its synthesis of **Q**T and **R**T. In fact, we will show that Relativity is ***not*** the "ultimate account of space-time structure" – though a fundamental part of it. Thus, considering that a physical theory is much more than its predictions, that it is obviously underdetermined by empirical evidence, and how paramount physical meaning and its potential for uncovering new phenomena are, we assert that **QR**/TOPI is a *new theory* of its own – simply because it drastically modifies the *Ontology*, *Foundation*, *Structure*, and *Interpretation* of both **Q**T (in all its variants) and **R**T.

[4] What Maudlin calls the "quantum recipe" in his Philosophy of Physics – Quantum Theory [93].

[5] Basically its irreducible stochasticity and the 'collapse' of the wavefunction (or 'reduction of the state vector') at a 'measurement', while evolving via the Schrödinger's Equation between 'measurements'.

List of Acronyms

RT	**Special** Relativity Theory	GRT	**General** Relativity Theory
QT	Quantum Theory	EPR	Einstein/Podolsky/Rosen Paper
EPRB	EPR-Bohm Experiment	TOPI	The Ontic Probability Interpretation
QT/TOPI	Non-Relativistic QT under TOPI	QR/TOPI	Theory integrating RT and QT
QFT	Quantum Field Theory	PI	Physical Interaction
MB	Milieu Basis	R-Time	Time as conceived in RT
R-Event	Event per RT (actual & evincing)	QR-Time	Time as conceived in QR/TOPI
QR-Event	Event as conceived in QR/TOPI	QR-Sync	Absolute Sync of Probable States
IF	Inertial Frame per RT	PD	Probability Distribution
SD	Standard Deviation of a PD	PTI	Pure-Transformation Interaction
PDI	Pure-Detection Interaction	GI	Gauge Interaction (PTI+PDI)
TM	True Measurement	QEI	Quanton Emission Interaction
PEI	Pure-Entanglement Interaction	ITI	Intrinsic Tele-Interaction
BI	Bell Interaction	BS	Beam Splitter
PF	Polarizing Filter	PBS	Polarizing Beam Splitter
MZI	Mach-Zehnder Interferometer	MWI	Many Worlds Interpretation

Introduction

In 2005, Nicolas Gisin wrote (my underscore):

GISI1: *And relativity, can it be considered complete? Well, if nonlocality is really real, as widely supported by the accounts summaries in this article, then all complete theories should have a place for it. Hence, the question is: "Does relativity hold a place for non-signaling nonlocal correlations?"* [12]

In Part II of this series ('Einstein's Incompleteness/Nonlocality Dilemma'), I said regarding Special Relativity and the EPR paper:

ALBA1: *Intriguingly, instead of relying on Relativity Theory (RT), EPR enforces locality by the very assumption of 'no interaction'. Per RT, the only way for two spacelike events to be correlated is through a common cause in their past. This is valid, of course, if RT itself is complete, i.e. if every possible "Element of Reality" has been included in its Ontology and represented in its Foundation, a topic to be argued in future articles.* [10]

In Part III ("Schrödinger's Cat and the 'Basis' and 'Measurement' Pseudo-Problems"), I wrote (footnotes are new):

ALBA2: *It is ironic that, using Einstein's own necessary condition for completeness, if RT forbids nonlocality (amply confirmed over four decades*[6]*), then RT must be* ***in****complete. Saying that what*

[6] Some researchers deny such empirical evidence implies nonlocality [96]. Others, specifically for the photon, refute the phenomenon of nonlocality as real altogether [214]. Both groups are thus upset by the 2022 Nobel Prize.

RT only forbids is faster-than-light signaling amounts to another strawman argument: Reality is that spacelike interactions do take place[7] *in our Universe, and RT does not seem to predict them.*

However, there is a big difference between a theory neither postulating nor predicting an "element of reality" [13], and holding a place for it. We will show that (against Einstein's stubborn stance) RT does "hold a place for non-signaling nonlocal correlations", which makes it **in**complete by (at a minimum) mere omission. In addition, we shall provide much stronger reasons for the **in**completeness of Special Relativity, which I intimated in Part III [11]:

ALBA3: … *the qualifiers 'previous', 'current', and 'next' applied to PIs, states, and MBs have a significance that transcends our classical notion of time. In RT, time (R-Time) is operationally defined and, thus, it can only be correlated to actual (**not** probable) states. Hence, only for actual states/properties, the adjectives 'previous', 'current', and 'next' have the meaning with respect to time that we accept in our common level of experience. That is not the case for probable states so, until we tackle the incompleteness of RT in future articles of this series, when our discourse calls for assigning a 'time' to a probable state, I will use the idiom 'QR-Time'. Notice that I am not implying there are two different types of time; I am implying that RT is **in**complete, and the notion of time should be reconceived so that what I call now 'QR-Time' as a mere faute de mieux would be integrated into a revised RT.*

This Part IV provides the rationale behind and characterization of this claim of **in**completeness for RT, as well as how to complete it in the light of QT – integrating both theories into a single theoretical body: QR/TOPI. As for QT, it is indeed **in**complete but not for the faulty reasons EPR alleged [13]. As highlighted in ALBA1, it is remarkable that EPR did not mention RT at all. Had they realized that *locality* was ***not*** demanded (let alone predicted) by RT but simply a hidden axiom masked as a purportedly universal *principle*, i.e. that *nonlocality* was forbidden by philosophical dogma, they would have recognized that RT and QT were both **in**complete in the sense that they had to be conceptually completed and integrated into a single theoretical scaffold – not just simply accepted as two separate theories which (for all practical purposes) seemed to peacefully but frailly coexist[8] (as is the case still today). QR/TOPI does that: incorporates *probability* and *nonlocality* as ontic into RT as well as integrates Einstein's *relativity* into QT.

At the outset, I need to stress that the well-established Quantum Field Theory (QFT) is only superficially contemplated here. Though QFT is known as the 'relativistic version' of QT, it is Lorentz-Invariant at the high cost of excluding *nonlocality*. It is a cliché to hear that QFT is *relativistic* because Schrödinger's equation is replaced by a Lorentz-Invariant one, and because all operators that represent field quantities at spacelike-separated events **do** commute [14] [2]. We will see that such a statement is false. In QR/TOPI lingo, QFT only deals with PTIs, avoiding the other part of any GI: the PDI. Clearly thus, the problem QR/TOPI tackles is not solved by QFT. In agreement with us, as recently as in February 2024, Gisin and Del Santo refers to this state of affairs as "a major scandal in the foundations of quantum physics" (their 'measurement' is our GI, i.e. a PTI plus a PDI; underscore is mine):

GISI2: *The theory that extends quantum mechanics to a relativistic framework is quantum field theory (QFT). Therein, all the problems with distant systems seem solved by the assumption of*

[7] The same researchers mentioned in the previous footnote deny that spacelike interactions do take place.

[8] The phrase 'peaceful coexistence' (well-known in Politics) was coined by Shimony. Euphemisms like "passion at a distance" instead of "action at a distance" have been also used to justify the adjective "peaceful" [211] [210] [205].

microcausality, i.e., the algebras of operators defined on any two space-like separated regions commute. However, QFT still lacks to date a complete theory of measurement (i.e., one that yields measurement outcomes and it is therefore able to explicitly model all known quantum phenomena), an issue that has been called "a major scandal in the foundations of quantum physics". [15]

Also, though we may mention GRT more than a few times, this Part IV deals exclusively with Special Relativity (RT) and, ergo, all QR/TOPI assertions and conclusions are claimed to be valid without restrictions only in those situations in which RT is known to be valid.

1. Philosophical Foundations of Space, Time, and Spacetime

Physics is the science of objective Reality: we develop *theories* and *measurement* techniques so we can attain conclusions which are *independent* of the subject who formulates them. Physics and the science of physical measurements replace the subjective *qualitative* knowledge acquired interacting quotidianly with our external world (explicanda) with objective *quantitative* notions and their lawful relations (explicantia). But in any *theory*, every physical law carries: (a) an *intrinsic* content which objectively explains/predicts Reality, allowing us to stay away from the multiplicity of perceptions; and (b) an *extrinsic* part associated with conventions we adopt to *quantify* our physical concepts and their lawful relations, as well as to achieve their *measurement*. This latter *operational* component is as necessary as arbitrary (within limits) but says nothing inherent in the objective world.

Because of the flawed identification of Reality with Actuality [11], *Operationalism* has played an excessive role in the so-called 'definition' of many physical magnitudes. The operationalist believes a physical property has no richer meaning than the one given by its *measurement* protocol. This is ***not*** true because well before we conceive a gauging technique and build/select the proper instrumentation, we must have a conceptual understanding of the supposedly ***real*** property. It is well known that Heisenberg defended his Matrix Mechanics contra Einstein's disapproval by stating he had applied the same positivist/operational approach Einstein himself had adopted in 1905 to refute absolute *time* and "define" simultaneity. Einstein famously rejoined: "possibly I did use this form of reasoning… but it is nonsense all the same…". Einstein was not a recalcitrant operationalist after all. However, his positivist approach to RT shows he knew very well that in our efforts to *measure* a physical magnitude we cursorily believe understand well, we may *discover* (and he did!) that some of the attributes we thought semantically essential were not such but only ad hoc features we had adopted as true because of our limited empirical exposure to the magnitude.

But Einstein's brazen response to Heisenberg also tells me he knew that, vice versa, due to the *pragmatic* character of any operational 'definition' of a physical magnitude, we may *miss* (and he did!) a truly essential part of the *semantics* inherent in the original concept. It therefore baffles me that Einstein did apply such wisdom to criticize QT (of which he was a co-founder) as **in**complete but not to allow for **in**completeness in his RT. We will see that both pros and cons of his operational 'definition' of *time* transpire in RT and QT. I wholly agree with Grünbaum when he said:

GRÜN1: *Thus, as I see it, operationism can contribute significantly to our knowledge, if it is construed as part of the restricted discipline of pragmatics but not if it is interpreted as an account of the logic of semantics of physics.* [16]

Because of the continuity hypothesis, Cantor's theory of the continuum and Riemann's theory of manifolds tell us that both *space* and *time* are metrically amorphous, i.e. they do not have an intrinsic *metric* which would allow us to *quantify* them sans an external reference [17] [18] [19] [20]. Without such standard, only *qualitative* relations of set inclusion are possible; nonetheless, the function of the standard is ***not*** merely epistemic because *space* without objects lacks *meaning* [21]. To achieve this *quantification*, we need a *convention* for the measurement *unit*; for instance, the standard *meter* still revered in Paris was conventionally the *unit* of length for a long time. Measuring an object/process consists in comparing it with the standard *unit* – so that consistent numbers can be assigned to the physical attribute. Even the process of comparing (congruence) has to be defined and agreed upon. Hence, on top of our conceptual understanding of the physical property, some *definitions* and *conventions* coherent with the Ontology, Foundation, and Structure [9] of a pertinent theory are necessary to determine when one of two instances of the measured magnitude is lower than, equal to, or higher than the other.

1.1 The Concept and Metric of Space

Physical Geometry studies those relations between m**a**cro-objects (matter and radiation) which are independent of the objects' nature and composition. Because of this independence, we take the linguistic license of abstracting from the matter/radiation needed to establish those relations and wholly refer to them as the 'geometry of space'. Qualitative relations characterize the *topology* of space; quantitative relations describe the *metrics* of space. Space is rich in *topological* properties which include our notions of continuity, dimension, finiteness, infiniteness, inclusion, openness, connectivity, closure, etc. When the Babylonians developed the notion of *distance* between two stakes in their crop fields and the technique to *measure* it, the intuitive concepts of *congruence* between two solid *objects* and of *straight line* were born. It was clear we could only discover the properties of *space* via the restrictions it imposes on *objects* when they interrelate [20].

Humanity first *defined* congruence between two *segments* identified by two marks on two 'rigid' bodies: two *segments* were congruent simply when we could make their *ends* coincide. Of course, the concept of 'rigidity' is also relational: only relative rigidity can be defined without circularity, as explained in detail in [20]. Abstracting the physical *segment* on a body, we defined a *non-physical* segment in *space* and said its ends *defined* two points in *space*. We then *defined* length (distance) and decreed: two segments are *equal* in length when they are congruent. Therefore, the equality between any two distances throughout *space* was governed by how the congruence between solid bodies behaved when they were *transported*. We chose the so-called 'congruence of the rigid body' and, ergo, even the notion of shape of an object depended on the *definition of* congruence/length. But to assign a unique numerical length to every object/segment we needed also to agree on the unit of length, and we did so by choosing an *object* as the standard. We then determined how many partial congruencies with the standard we needed to span the measured object/segment[9].

Evidently, neither the *length* of an object nor the distance between two points in *space* were intrinsic properties but *relations* between them and the standard object/segment. This relational *definition* was necessary because all non-degenerate segments of the linear continuum have the same cardinality, so we could not *define* the length of a segment simply as its 'number of points'. Note as well that *extension* and *length* are different; the former is *topological*, the latter is *metrical*, i.e. a relational number assigned to the extended segment – and this number reflects the congruency directly (standard *metric*) or indirectly via any biunivocal function of it [22] [17].

Newtonian Physics ignored that body and standard had to be at the same place and relatively at rest. Also, even though all the above described *operations* to determine length did require *time*, we postulated that the body's length and its endpoints corresponded to the same (abstract) instant. In sum, we took for granted that the *length* of an object was an absolute, i.e. independent of the Inertial Frame (IF)[10]. The rationale was that if we transported two *congruent* rigid bodies to a distant place by different paths, when we compared them (accounting, of course, for any

[9] The procedure delivers a rational number which is (ideally) indefinitely improvable – approaching a real number.

[10] Any of the class of physical frames in which Galileo's Principle of Inertia is valid, extended by Newton to his three Motion Laws, and by Einstein to Electromagnetics. Relative velocity between any pair of them is constant [23].

differential forces [18] [17]), we found they were still *congruent*. However, we overlooked we could not affirm they remained congruent during their respective trajectories: again, the relational definition of *congruence*/*length* did not allow to compare distant *objects* and/or in relative motion. Hence, we (consciously or not) introduced at the outset another *edict*: given that two *congruent* bodies remained *congruent* when compared irrespective of how they had gotten together, we decreed that they were *congruent* even when they were separated and/or in motion or, equivalently, we conventionally declared them self-congruent under transport. It was Einstein in 1905 who realized the blunder behind such an edict and that a new definition for the 'moving-length' of an object (i.e. referred to an IF in which the object was moving) was necessary – baptizing the Newtonian length as the 'rest-length' (or 'proper-length') and making it an IF-Invariant. Notice again that, because of the purely operational meaning of *congruence* and its relationship with *length*, the numbers (proper-lengths) Einstein declared equal by fiat were those obtained locally and with the standard at rest with each of the objects (distant and/or in relative motion).

To conclude, what is believed (still today) by most of us to be an indisputable fact, it is not so, but a convenient convention: given that the object/standard local congruence is an IF-Invariant, if (after Einstein) we convene in considering the ruler as the common unit of length in all IFs, we get the same number for the rest-length of a given object in all IFs. In brief, only the proper-length of an object is absolute; the moving-length is ***not***. But we will see that, in RT, the so-called 'proper-distance' between events (not betwixt mere points in space) is also an absolute. This highlights the difference between the conceptual definition of a physical property and the *operations* necessary to measure it, as well as the many (frequently tacit) *conventions* needed to extend its reach beyond the original conception.

Digressing a little to further emphasize the *conventional* nature of congruence/length/distance, Einstein -while conceiving GRT- faced a serious dilemma: if he insisted on preserving Euclidean geometry, he had to change the traditional congruence/length relation: when the termini of two segments coincided (were congruent), he had to assign them different *lengths*. Einstein was aware of the *conventional* character of such a relationship so no epistemic reason could prevent him from judiciously changing it to suit his needs. But, if he did, besides counterintuitive 'expansions' and 'contractions' of a solid body, he also had to accept that *light* would ***not*** travel in a Euclidean straight line. The other face of the dichotomy was to defenestrate the Euclidean dogma (already weakened by Gauss, Bolyai, Lobachevsky, and Riemann) and so he did: by choosing the non-Euclidean *geometry* of Riemann with variable curvature, he retained the millenarian relation between *congruence* and *length*, included *gravitation* into the geometry of a non-Euclidean *space* (as opposed to being a force) and *light* continued traveling in a non-Euclidean 'straight line', i.e. on the *geodesics* of a non-Euclidean *space*. Doing so, Einstein proved the presumed existence of some force *fields* (e.g. gravity) was relative to the *reference frame* and the *geometry* of space [23].

1.2 The Concept and Metric of Time

Local sensorial *simultaneity* is a primitive mundane notion and lies at the heart of the concept of time and its measurement. Einstein, in his 1905 iconic paper [24] said[11] (my underscore):

EINS1: *We have to take into account that all our judgments in which time plays a part are always judgments of simultaneous events. If, for instance, I say, "That train arrives here at 7 o'clock", I*

[11] All excerpts of [24] were translated by John Walker. The whole paper is available on http://www.fourmilab.ch/.

mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events".

Evidently, Einstein started by implicitly asserting that events (occurrences) -not only objects- are the fundamental entities of Nature. To emphasize the **un**analyzable character of local simultaneity and the abstraction needed to arrive at the concept of *point-Event* (involving the abstractions of *instant* and *point-location*), Einstein stated as a footnote to **EINS1**:

EINS2: *We shall not here discuss the inexactitude which lurks in the concept of simultaneity of two events at approximately the same place, which can only be removed by an abstraction.*

In qualitative terms, the "inexactitude" alludes to lack of discernable temporal order. In fact, the failure to distinguish sequential order (sensorially, instrumentally, and inferentially) between two events is nothing but the conceptual definition of the term 'simultaneity'. If the events occur "at approximately the same place", in many cases, such "inexactitude" in both the notions of local simultaneity and spatial contiguity can be "removed by an abstraction", with the two events characterized by a single point-Event (a spacetime coincidence). The same can be said to arrive at the concept of a second point-Event spatially separated from the first but, in such a case, we need to conceive a way to quantitatively (instrumentally/inferentially) distinguish the temporal order between those distant point-Events and, if failing, what is the nature of the *simultaneity* we must/can assign to them. Curtly: (a) the 'point-Event' abstraction is a key element in RT's *Foundation* [9]; and (b) the physical notion of distant *simultaneity* requires deeper analysis.

In his celebrated *Confessions* (circa 400AD), St. Augustine -aiming at confuting Astrology- relates the story of two women, one rich and one a servant, who gave birth *simultaneously* at two different places. ***Not*** to define *simultaneity* (it was a primitive notion in those days) but to determine/confirm it for the distant parturitions, and lacking accurate clocks that could be easily transported after being synchronized (à la Newton 12 centuries later), he devised an involved operational procedure (à la Einstein 15 centuries later!) describing it as follows (my underscore):

AUGU1: *Hence, both of them were constrained to allow the very same horoscope, even to the very smallest points. As soon as the women began to be in labor, they both gave notice to one another . . . and had messengers ready to send to one another as soon as each had notice of the child's birth. Thus, then, the messengers sent from one to the other met in such equal distance from either house that neither of the calculators could observe any other position of the stars than had the other. And yet the son of the rich woman throve well in riches, raised himself to honor, whereas that little servant . . . continued to serve his masters.*[12]

Obviously, Augustine believed that two events occurring at distant locations are *simultaneous* if, upon *instantly* dispatching two signals, their arrivals at the middle point are locally assessed as such. Distant *simultaneity* (of parturition events) was assessed/confirmed based on: (a) sensed local *simultaneity* betwixt parturition and messenger dispatch at both sites; (b) the assumption that the one-way transit time (duration) for each messenger (signal) to reach the middle point is the *same* (i.e. that they traveled at the *same* speed on a straight line); and (c) sensed local *simultaneity* of messengers' arrivals at the middle point between the sites. Though assumption (b) is not even insinuated in AUGU1, it constitutes the Gordian knot because *quantifying* the messengers' one-way speeds require the *synchronization* of two distant clocks. Augustine's method is probably the

[12] As cited in Max Jammer's *Concepts of Simultaneity* [197].

earliest example of an *operational* verification of *distant* simultaneity (***not*** definition). He anticipated Einstein's *operational* conception of distant simultaneity [24] except that, since its publication in 1905, Einstein's procedure -per his own words- is deemed a definition of *simultaneity* – instead of a (**not** always consistent) synchronization technique throughout *space* to quantify our elusive notion of *time.*

Humanity developed the concept of *time* by observing recurrent natural phenomena: day and night, phases of the Moon, motion of the Sun in the sky, motion of the stars on the celestial sphere, etc. In the same way the measurement of length required the concept of *unit* to be associated with a physical *object*, we started associating the idea of *unit of time* with a cyclic natural process, defining the *unit of time* as that 'something' elapsed between two consecutive occurrences (events) of the chosen cyclical process. Three natural *units* followed: *day*, *month*, and *year* [19]. Measuring *time* consisted in counting the number of cycles from an event taken as 'zero'. But only if the 'something' elapsed during a cycle was the same for all cycles, could we choose any cycle as the *unit of time* and then, simply counting the number of cycles would deliver a measure of the *time* elapsed between the start of the 'first' cycle and the end of the 'last'. But… how did we know if the process was uniform in its cycles? Whether we thought we knew it by then or not, there was only one answer: it was not a matter of *knowing* but of *convening*. Once we selected the cyclic natural process, we declared its cycles as having the same duration. Even though in this way we could only measure *integer* multiples of the standard cycle, by choosing wisely the *standard process*, resolution and accuracy could be gradually improved. It was the measurements plus the simplicity and consistency of the physical laws so obtained what determined the appropriateness of the selected standard process. Ergo, the latter evolved throughout history with the atomic clock being now the one used due to its supreme resolution, stability, and accuracy.

As said, the direct measurement of *time* using the cycle of a recurrent standard process did not allow us to measure *durations* shorter than the *standard* cycle – unless we changed the process. The way to measure shorter durations without changing the standard process was indirect, e.g. via the measurement of distances, angles, weights, etc. For example, using our planet's daily rotation, our *standard* cycle was the 'day', which we declared all to have the same *duration*. We then decreed that our planet covered equal *angles* in equal *times*, allowing us to subdivide the 'day' in shorter *time-intervals*, which were deemed equal for equal *angles* of rotation[13]. Stipulating the number of angles (meridians) as 24, we defined the unit of *duration* called 'hour', and we accepted the equality of each one of the 24 hours because we assumed that the Earth rotation was uniform.

The assumption of *uniformity* allowed us to discern when two successive *time-intervals* in the same *place* were equal. However, there were situations in which we needed to compare two *time-intervals* which were 'parallel' and occurred in contiguous or distant places. We soon realized that, when two events -even if contiguous- occur far away from us (e.g. lightning and thunder), their being *simultaneous* (***non****simultaneous*) per a local clock there, could be registered by our local clock *as* ***non****simultaneous* (*simultaneous*). Clearly, the only way for us not to be deceived by such disagreements was to combine our limited local sensorial abilities and separated local clocks with our intellect. In sum, any time-metrics must entail the following definitions and conventions: a) a unit of time to determine the *numerical* value of a time-interval; b) uniformity to establish the

[13] Relative to the fixed stars.

equality of successive time-intervals at a place; and c) distant simultaneity to assert the equality of time-intervals at different places. Note the similarities with spatial metrics.

As with spatial congruency, after we developed portable clocks (circa 15th century), when we transported two 'identical' synchronized clocks to a distant place by different paths, we found they were still in sync. Hence, we (consciously or not) ignored the provincialism of our daily experience and technology, proclaiming another *edict*: given that two synchronized clocks seemed to remain in sync when compared irrespective of how they had gotten together, Newton's 'Transported Synchrony' postulate (absolute time) was gradually adopted as an unquestionable fact. But in 1905, Einstein rejected such a postulate: while he accepted that the local congruence of 'rigid' rods was independent of the transportation path, he claimed the congruence (synchrony) of clocks was not. Once again, what was believed to be an indisputable fact (until Einstein) was so because of a convention plus a postulate based on very limited (*slow* clock transportation) experience.

1.3 The Concept and Metric of Spacetime

Using the abstract notions of spatial point and instant, physical events are abstracted to *point-Events* which occur at a *point-place* and at a *point-time*, i.e. in a tetra-dimensional abstract space called *spacetime*. In Newtonian and Einsteinian worlds, events are (in QR/TOPI's lingo [11]) actual (as opposed to probable) and always evincing, i.e. a straight record in spacetime can be detected. Events and their causal relations are objective and ergo absolute: contrary to our death event, we would not be happy learning our birth event did ***not*** happen from some vantage point (reference frame)[14]; or that the correlation between our success and hard work is only valid in some reference frames. Another example is the iconic event of the twins getting together after relative superfast space travel: regardless of the vantage point, either the 'traveler' twin is grayer with more wrinkles or the 'sedentary' is, or none. An event's existence, its qualitative and some metric properties are independent of any reference frame (Frame-Invariant), while other metric properties (e.g. time and location) depend on the frame and the behavior of clocks and rulers in it. The topology(metrics) of spacetime refers respectively to the qualitative(quantitative) interrelations among events and objects. They are different for Newtonian and Einsteinian worlds.

The most basic physical magnitude combining space and time is *velocity*, as it rests on the notions of *space-interval* and *time-interval*. For objects leaving simultaneously and traversing the same distance and back, a single analog clock at the departure and arrival common site with ***no*** metric can (by properly labeling on the dial the positions of its hand) order the arrival events and so topologically order the roundtrip velocities. Metricizing the clock, i.e. assigning consistent numbers to time-intervals via the time-unit, the roundtrip velocities are quantified with one clock as the ratio between the common traveled distance and the possibly different time-intervals indicated by the clock. Instead, for objects traveling one-way to a distant site, the intuitive notion of velocity is well defined but only topologically: using a clock (with ***no*** metric) at the contiguous arrival locations, we can order the arrival events for different objects that left *simultaneously* (per the departure-site clock) traversing the *same* distance, and sensibly state that those arriving earlier per the local clock traveled with higher speeds. Remarkably, we need neither *synchronization* nor a *metric* to determine which signal was the fastest. But metricizing those velocities, i.e. assigning

[14] This absoluteness of events was denied in Rovelli's Relational Quantum Mechanics (RQM). However, in 2020 he changed mind saying: *the set of 'quantum events' should be regarded as absolute, observer-independent features of reality in RQM, although quantum states remain purely relational* (https://arxiv.org/abs/2203.13342]).

consistent real numbers to those topologically ordered speeds, is not so simple: we need to synchronize 'identical' clocks at the two distant sites so that both run in unison indicating the same time at both the departure and arrival events for every and all objects. Pithily: we need to establish *simultaneity* of distant events; only then, the common local *time-interval* given by the two clocks for each object corresponds to its one-way trip and, for a given *space-interval*, the speeds are quantitatively determined as the ratios of the latter over the former intervals. Note again that we do ***not*** need synchronization to empirically determine that light (or any other object) is the fastest.

But as the termini of a space-interval get closer, synchronization of clocks at those endpoints gradually becomes trivial and the concepts of *continuity*, *limit of a sequence*, and *derivative* allow us to work with one-way *velocities* at a point in space and at a point in time – concealing the need for physical (finite) intervals of space and time as well as the need for synchrony. In this way, Newton gave Galileo's intuitive ideas of 'instant', 'spatial point', 'instant velocity', and 'instant acceleration' a rigorous *analytical* meaning – though ***not*** a clear *synthetic* one. The notions of instant velocity and acceleration disguise Newton's postulate of 'Transported Synchrony', which asserts that the synchrony of two clocks is preserved as they arbitrarily separate. Again, Einstein rejected such a postulate, rendering the metrics of space and time interdependent. In fact, the (then unsuspected) needed synchronization for Rømer's famous measurement of light's one-way speed from Jupiter's moon Io in the 17th century was unwittingly achieved via the 'slow transport' of the clock on Earth while traversing its solar orbit [18] [25].

In brief, velocity is an ontic relational (extrinsic) property of an object, and its one-way *quantification* requires establishing the *simultaneity* between distant events, which in turn requires an anthropic procedure to achieve it, viz: synchronizing distant clocks. And being anthropic, any such procedure will be restricted by our human limitations to transfer the clocks' readings throughout space. Besides, such an *operational* requirement will inevitably include *hypotheses* and pragmatic *conventions*, which not only may obscure the ontic character of the property by blending it with epistemic features of the measurement technique but also may miss some essential semantic component of the property as originally conceived. Even more, in ***non***-Inertial reference frames, such anthropic synchronization throughout the frame may not be possible at all.

1.3.1 Reality is Much More than what we can Observe/Measure in Spacetime

We all know (or at least suspect) that the Universe is much more than what we directly perceive and/or measure in our spacetime. In Part I of this series [9] we introduced the quanton[15] as the fundamental object in QR/TOPI Ontology, and -in Part III [11]- we proved the reality of its probable states – considering them as even more fundamental than its actual states. Shockingly, empirical data and the ontic character of probable states will compel us to postulate the reality of a probable quanton, an ontic entity whose morphing into an actual quanton depends on a probable state of another quanton becoming actual. We also anticipated in Part III [11], and now further elaborate and expand, the reality of four types of events:

PDI-Events: *Ontic* actual point-Events resulting from a quanton undergoing a PDI. They can be:

1. *Evincing* because they leave or may be arranged to leave a *local* m**a**croscopic record in spacetime. These are the only kind of events contemplated in RT; and

[15] As stated in Part I [9], we chose the appellative 'quanton' for the primitive entity posited in QR/TOPI's Ontology. Other locutions like 'propensiton', 'smearon', 'waviclon', etc. have been suggested in the literature [61] [5] [198].

2. *Non-evincing*, leaving ***no*** record in spacetime – with the evidence for their reality inferred (Section 4). Despite being *non-evincing*, they are pinpointable, i.e. -in a given IF- they have unique spacetime coordinates. The best example is the no-click event at a detector. In the literature they are called "interaction-free measurements" [26] [27] [28] [29]. In QR/TOPI, because the quanton is ***not*** a point-object, a no-click event is as real and actual as a click event and is therefore associated with an actual change in the quanton's state – all three events being abstractable to point-Events. Ergo, "interaction-free measurement" is a misnomer.

State-Events: *Ontic* actual point-Events that never *evince* per se. For instance (Section 4), we will see that -concurrently with a click/no-click by a detector- a photon adopts/dismisses one of its *probable* states as actual. State adoption and dismissal are actual ***non**-evincing* events. As another example, when an entangled sub-quanton adopts an actual pure state upon its distant partner undergoing a PDI [10] [11], such adoption is ***non**-evincing* – with the evidence for its occurrence obtainable via another PDI, so its reality is inferred (Section 5). Again, despite being ***non**-evincing*, they are actual and abstractable to point-Events. Note that PDIs are the triggers of State-Events. We will see that even the adoption of a probable state by a quanton (e.g. during teleportation of entanglement) is a State-Event and, ergo, actual (Section 9.5).

Probable-Events: *Ontic* probable, do ***not*** manifest in spacetime, are *inferred*, and are rarely abstractable to a spacetime point; they typically can be ascribed in toto to poorly defined regions of spacetime. Many of them may coexist while a quanton undergoes a PTI [11]. Per QR/TOPI, they are as ***real*** and more fundamental/ubiquitous than actual events – even more than the archetypical actual *evincing* events of RT. Note that the many *transitions* from current to next *states* implicated in the *state*-equation of a quanton are all ontically probable events, i.e. they are ***not*** State-Events. In Section 5 we will grasp the difference between a probable event and the event of adopting a probable state, which is a State-Event and, ergo, actual. Note also that the so-called 'collapse of the wavefunction' is the adoption of a probable state as actual, i.e. a State-Event. Hence, the last two events are abstractable to point-Events – while probable events are not.

Milieu-Events: *Ontic* actual, do manifest in spacetime, i.e. are *evincing* and consist in the establishment or alteration of a quanton's milieu, i.e. the network of PTIs and PDIs interacting with the quanton (including our instrumentation and its settings). Because the network occupies an extended region of space, only the R-Time for these events may be abstractable to an instant (e.g. the sudden insertion of a PDI). This milieu change may result in a change of the MB, the ITI between Probable-Events, and/or the R-Timing between PDI-Events and State-Events. Ergo, though *evincing* per se, some of its effects may be ***non**-evincing* and, we will see, *instantaneous*.

Summarizing, PDI-Events can be *evincing* (click) or *non-evincing* (no-click); State-Events and Probable-Events are always *non-evincing*; and Milieu-Events are per se *evincing*, with *non-evincing* effects. All of them are equally real in QR/TOPI. We will prove that, because RT assigns reality ***only*** to actual *evincing* point-Events, not only does it conspicuously ignore QR/TOPI's novel *ontic* category of ontically Probable-Events but it quietly disregards actual *non-evincing* point-Events. Furthermore, by restricting the semantics of *simultaneity* to the one strictly resulting from his operational "definition of simultaneity", Einstein surreptitiously assigned universal validity to the *Principle of Locality*. In QR/TOPI, this principle is only valid for actual *evincing* events, i.e. only for those events recognized by RT as real. Hence, we will see that QR/TOPI does not invalidate RT but extends it (completes it) to encompass a vast part of Reality that RT ignores.

1.3.2 Deterministic Causality, Causal Betweenness, and Genidentical Chains in Spacetime

As said, according to conventional wisdom (even today), only actual events evincing in spacetime are real, and likewise for their causal relations. Leibniz surmised our notion of *temporal order* between events could be associated with the more basic idea of their *causal order* [19]. Inspired by Reichenbach [18], an analysis of the C*ausal Theory of Time* exposing the difficulties of defining *time* from *Causality* without circularities was performed by Grünbaum [17].

As early as in the 80s, Abner Shimony said:

SHIM1: *The wiser course is to say that quantum mechanics presents us with a kind of causal connection which is generically different from anything that could be characterised classically, since the causal connection cannot be unequivocally analysed into a cause and an effect*. [30]

As recently as in February 2023, Justo P. Lambare in his "Critical Analysis of Nonlocality: On the polemic assessment of what Bell did" said (my underscore):

LAMB1: *The quantum nonlocality problem cannot be summarily dismissed by looking for defects or trivial conceptual loopholes within the Bell-type inequalities and Bell's arguments. Quantum mechanics may require a revision of our notion of causality, just as relativity prompted us to revise our concept of simultaneity. The other possibility is that quantum mechanics is emergent and, because of Bell's theorem, that would require the acceptance of superdeterminism*. [31]

And, in his "The Sagnac-Wang interferometers and absolute vs. relative simultaneity" (January 2024), he concludes (my underscore):

LAMB2: *As long as the relative nature of distant simultaneity does not lead to observable or logical contradictions, its absolute character shall remain a forsaken relic of our past metaphysical prejudices.* [32]

We will see that the analogy Lambare rightly points out between the revision of the concept of simultaneity prompted by RT and the revision of our notion of causality that QT may require (QR/TOPI does revise it), is more than just a parallel between unrelated concepts in unrelated theories: were the relative nature of distant simultaneity decreed valid for all events (as RT does), the copious empirical evidence supporting *nonlocality* would provide the observable contradiction Lambare sensibly requires to **re**-evaluate the notion that the absolute character of the simultaneity between all events is a "forsaken relic of our past metaphysical prejudices".

In a *deterministic* theory, and already deviating from the conventional notion of causality, I assert that -independently of the notion of *time order*- two events E_1 and E_2 are causally related when the occurrence of one is sufficient, or necessary, or both for the occurrence of the other: $E_1 \Rightarrow E_2 \lor E_2 \Rightarrow E_1$. Thus, being the latter an inclusive disjunction, the univocity of the appellations *cause* and *effect* (i.e. the **a**symmetry of the relation) is ***not*** necessary for causality to exist and manifest (directly or not) in our spacetime[16]. This explains why there are situations in which the terms *cause* and *effect* have a *synthetic* meaning and others in which the latter is simply *analytic* (pragmatic). For instance (including now the notion of *time*): for dynamic *reversible* (i.e. temporal *non-entropic*) processes we have $(E_1 \Rightarrow E_2) \land (E_2 \Rightarrow E_1)$ for the two possible directions of time, so the distinction between *cause* and *effect* is merely pragmatic with the physical law that

[16] Lucien Hardy considered this *indefinite* causal order as a way to understanding the quantum nature of gravity: https://www.quantamagazine.org/quantum-mischief-rewrites-the-laws-of-cause-and-effect-20210311/.

governs the process not establishing a causally derived time-direction. Instead, for dynamic ***i**rreversible* processes (the norm in our m**a**croworld), one disjunctive term is only true for *prediction* and the other only for *retrodiction*. That is because, due to energy dissipation, if by choosing our psychological sense of time E_2 occurs 'after' E_1 $(E_1 \Rightarrow E_2)$, choosing the opposite time direction, E_1 will **not** occur 'after' E_2 $(E_2 \Rightarrow \bar{E}_1)$. E_1 **is** the *cause* and E_2 **is** the *effect*, so the distinction is semantic (synthetic) [33] [19]. But, as we will see, not all physical phenomena are dynamic. Thus, logical *implication*, causal *order*, and time *order* are ***not*** fully equivalent.

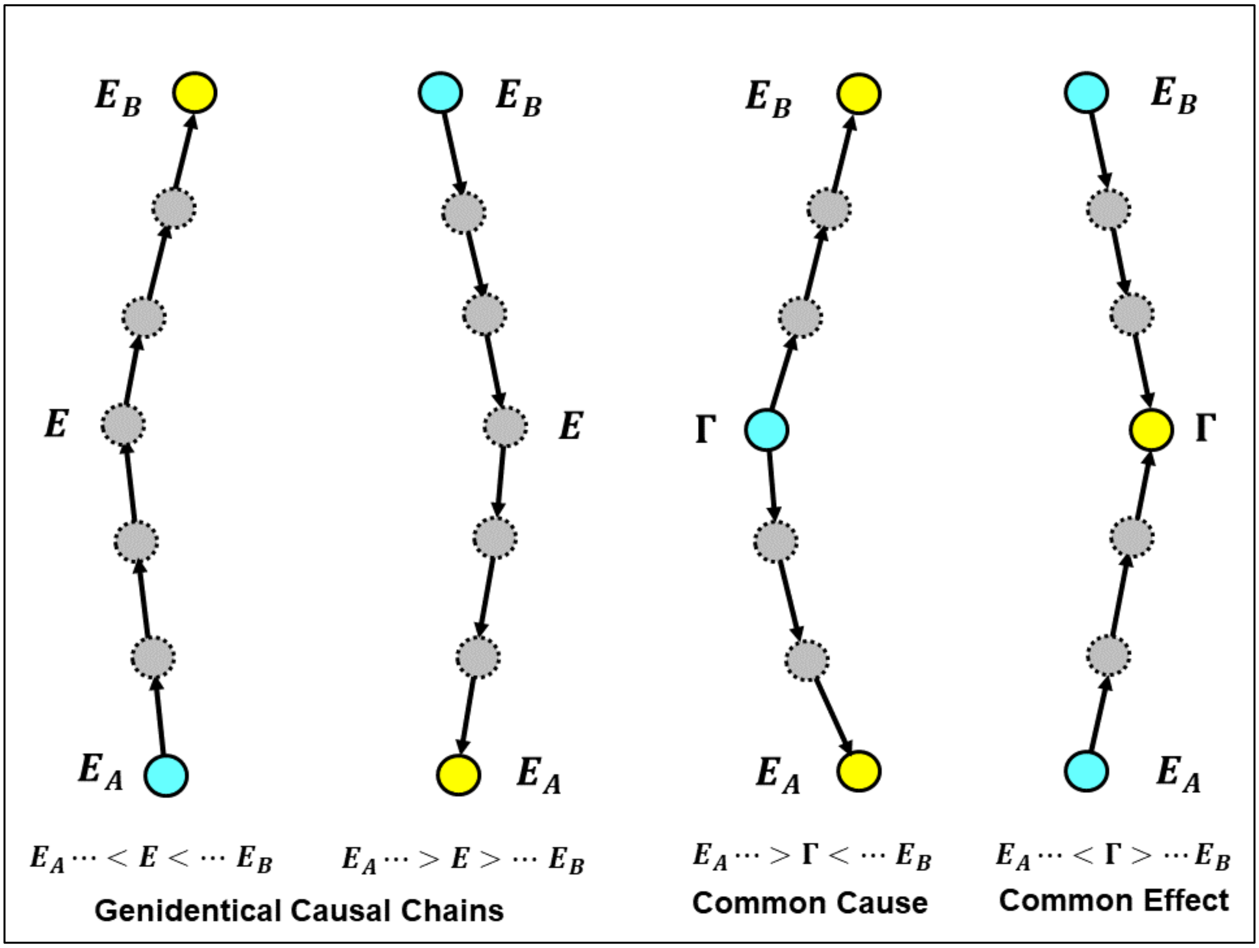

Figure 1 – Causal Betweenness, Genidentical Chains, and Common Cause/Effect

For three or more events, the concept of *causal net* -resulting from the structure of classical physical laws- establishes at most a betweenness relation for neighbor events [34]. Betweenness is an *order* relation among three events, and it is non-directional, i.e. **in**variant upon permutation of those two events between which the third is. A *causal net* (if posited to be open, i.e. **a**cyclic) reflects a global partial *order* between events but, because RT per se deals only with reversible dynamic processes, the direction between any pair of events is undetermined. Yet, once a direction is chosen for *one* pair of events (**i**rreversibility is independently recognized), *all* other directions in the *causal net* are fixed: it is said that the order is linear but ***not*** necessarily serial (the *net* may display bifurcations). Figure 1 outlines four basic types of causal nets, two equidirected (left) and two counterdirected (right).

Because events and their *causal* relations are objectively absolute, the betweenness relation among three or more different events is objectively invariant as well. For instance, the physical integrity of a film strip preserves only the *spatial* betweenness of the frames and their associated *temporal* betweenness (perceived when reeling the tape even if in reverse). But only when knowing which end of the strip corresponds to 'the first' when filmed (per our psychological sense of time), playing the tape (at the same speed as recorded) would show us the real sequence. Clearly, both reversible and **i**rreversible processes may display the same causal betweenness, with the **i**rreversible processes revealing the **an**isotropy of time in our m**a**croworld [33].

As a more basic and illuminating example, in an analog clock, the motion of any of its hands constitutes a chain of events related by their betweenness in space and, if we label appropriately the hand's positions on the dial, the associated *temporal* betweenness needed to fully characterize the causal chain is revealed. Such topological numerical labeling allows us to order the events via the 'earlier than' (or 'later than') relation *sans* the need for a time-metric. Choosing a *metric* that (via the time-unit) consistently assigns numbers to durations enables the device to fully *measure* time. But if the clock moves also as a whole, its positions plus its own temporal indication (by the hand's positions on the dial) reveal the *causal* chain of events inherent in a clock's motion in space. Evidently, unlike measuring rods, clocks are tetra-dimensional objects in the sense that they could provide a measure not of time alone but of some joint *metric* of space and time [18]. Pithily: the termini of the interval defined by two 'ticks' of a clock are *spacetime* events, while the termini of the interval defined by a standard rod are just points in space at a given *time*. Of course, we could think of two *simultaneous* spacetime events occurring at the rod's ends. Newton posited that (a) the *length* of an object was an absolute, i.e. the same in all IFs; and (b) two clocks synchronized before separating, would remain synchronized during motion; Einstein rejected both claims, endowing the locution 'spacetime' with a meaning beyond the mere aggregate of space and time.

1.3.2.1 The Principle of Locality and Genidentical Chains

Irrespective of the structural nexus between *space* and *time* a theory may claim, specifying an actual (evincing or non-evincing) point-Event E requires denoting a point-location and an instant $\big(E = (L, t)\big)$. Being objective, events are absolute (i.e. Frame-**In**variant) but their spacetime coordinates L and t are in general relative (viz Frame-**Co**variant), so the above equality is *numerically* valid only within a given Frame of Reference. All we say here can be carefully extended to region-Events, i.e. events associated with a spacetime region (e.g. instrument settings and local results in a Bell Experiment) which is well separated from the spacetime zone of all other region-Events – so that each region can be abstracted to a point-Event. In contrast, Probable-Events are ***not*** abstractable to point-Events, not even to well-defined sets of point-Events: they are associated with poorly delineated regions of spacetime set by the milieu and its resulting MB.

If actual *evincing* events $E_A = (A, t_A)$ and $E_B = (B, t_B)$ are causally related, ***with*** A and B different positions of the same point-object/process at different times t_A and t_B, the so-called *Principle of Locality* (or 'nearby action' or 'action by contact' or 'continuous action') postulates:

(a) Regardless of how close (but not coinciding) the two events are, there exists a one-dimensional continuum of *ordered* events $E = (L, t)$ at sites L, whose occurrence is necessary and whose respective times t verify either (a1): $t_A < t < t_B$ or (a2): $t_B < t < t_A$; and

(b) Upon E occurring at time t, the occurrence of E_B (a1) or of E_A (a2) is independent of all events occurring at $t' < t$. Thus, E screens off E_B from E_A or E_A from E_B respectively.

Sometimes, only postulate (a) is required for 'continuous action' and postulate (b) is referred to as the 'screening action', or 'Bell Screening Assumption (BSA)' [35], or (a case of) the 'Causal Markov Condition' [36]. The violation of (a) implies the violation of (b) but not vice versa.

Given postulates (a) and (b), we say that all those events E are between E_A and E_B, they are *serially* (though ***not*** consecutively[17]) ordered by the temporal relation 'earlier than' (or 'later than'), and all of them belong to the genidentical causal chain unique to the object/process [34] [37] [38]. The term 'genidentity' evokes the perdurance of identity (haecceity): characterizability over time as the 'same' entity. Evidently, if the causal chain is open, two *simultaneous* genidentical events must be identical. Notice that, even though the direction of time for the genidentical chain linking E_A and E_B is not determined, once it is chosen, it is the same for any two events inside the genidentical chain. The two causal nets in Figure 1 (left) are genidentical chains where only a few of the continuum of events are shown.

By definition of a genidentical chain as characteristic of a m**a**cro-object/process evolving in spacetime, the statement $[A = B \wedge t_A \neq t_B]$ correspond to e.g. a clock not moving as a whole but 'ticking', while $[A \neq B \wedge t_A = t_B]$ correspond to neither a clock nor any classical object because it would mean they could be in different places at the same time. Extending the meaning of the symbols $'<'$ and $'>'$ from time-numbers to events we say that, for genidentical chains, either $E_A < E < E_B$ or $E_A > E > E_B$; only one of them is true and absolute, i.e. either $E_A < E_B$ or $E_A > E_B$ in all reference frames (Figure 1 left). Besides, given that $A \neq B \Rightarrow t_A \neq t_B$, in ***no*** reference frame can any two different events of a genidentical chain be simultaneous. Examples are particle motion and wave propagation in its ray or guided (e.g. light in an optical fiber) regimes. We have referred to such processes as dynamic: for a m**a**cro-object, it takes time to continuously change its position. It is also known as 'retarded interaction'. Genidentical chains are the archetypical embodiment of local *causality* ('action by contact', 'nearby action', or 'continuous action') – the only type of *causality* recognized as real in RT.

The counterdirected *causal* relations in Figure 1 (right) correspond to the event Γ being the genidentical common cause or effect of E_A and E_B. Even if there is none or it is impossible for a genidentical chain to *directly* join the latter two events, they are causally related through a third event Γ whose links to E_A and to E_B entail genidentical chains. Note that, because of the bifurcation, they are ***not serially*** ordered, so they do ***not*** constitute a genidentical chain in toto[18]. Also notice again that their causal relation does not objectively determine the arrows' directions at Γ beyond being counterdirected; once the direction is chosen for one, it is fixed for all the others in the causal net [34].

Genidentical chains linking sites A and B are also known as 'signals' because, being all the *events* in the chain actual, evincing, and ***non***-simultaneous, energy or/and matter could be transferable from one place to the other in a recordable manner – allowing in principle for human communication (messaging) between the sites in a ***non***-zero time-interval. Quoting Tim Maudlin,

[17] "Not consecutively" because, for metrical consistency, the set of events must be a continuum [196]. With $\mathbb{R}$ the reals and $\mathcal{R}$ the rationals, $\mathcal{R}$ is dense in $\mathbb{R}$, i.e. every real is either a rational or is arbitrarily close to a rational: $\forall\, x \in \mathbb{R} \Rightarrow x\, \in \mathcal{R}\, or\, \forall\, \epsilon > 0\ \exists\, r \in \mathcal{R} :\ |x - r| < \epsilon$. Notwithstanding, $\mathcal{R}$ is denumerable and $\mathbb{R}$ is not.

[18] The bifurcation would create a case of 'double identity' for the purported object.

“The notion of a signal is doubly anthropocentric: it depends on a prior specification of what the sender can freely manipulate and what the observer can see… If there is no nomic correlation at all between transmitter and receiver, then no message can be sent” [2]. Ergo, even if the nomic relation exists, *manipulation* on the part of the sender and detectability at the other end are necessary. Of course, such processes can naturally occur sans human intervention as long as there are two physical entities ‘acting’ as transmitter and receiver.

But -against RT- not all causal relations are dynamic processes. From our definition of deterministic causal relation, genidentical chains (signals) are just one type that epitomizes *local* causality – a tacit but essential axiom of RT. We will see that all causal relations in RT must be implementable with direct signals or via signals from a common cause; however, ***not*** all genidentical chains (signals) are legitimate in RT – only those slower than light. Even so -as verbs- ‘to signal’, ‘to communicate’, and ‘to message’ are synonyms, so we are -linguistically- open to the possibility of ‘signaling’ (messaging) without a signal[19]. Therefore, when Gisin used the modifier “non-signaling nonlocal” preceding the noun ‘correlations’, I surmise that what he meant is instantaneous (“nonlocal”) causal links (“correlations”) which are useless for human communication (“non-signaling”). Obviously, such correlations cannot be achieved by a direct genidentical chain (signal) – ***not*** even superluminally.

1.3.2.2 Genidentical Chain/Common Cause as the only Subjunctive Bearers of Causality

The *causal* relation amongst two events must be objective and absolute (Frame-Invariant) and, for centuries, what I called a *genidentical chain* was considered the main physical process (mechanism) behind *causality*. Hence, *local causality* between two events was used as a gauge to assess the presumed absolute character of the *time order* between them. It was thus widely accepted (at least in principle) that for every pair of events in our Universe there were four possible cases:

Causal (a): The events are causally related in a way that -if not already as a matter of fact- they ***could*** be directly connected by the genidentical chain of *some* object/process, and **no** third event outside the chain ***could*** be genidentically connected to both of them. The statement $[A \neq B \wedge t_A = t_B]$ cannot be true because it would imply the existence of such an object in two places at once, so the ***non****-simultaneity* ($t_A \neq t_B$) between the two events is objective, independent of any *metric* for time-intervals, and absolute. ***Only*** how much ‘later’ or ‘earlier’ one event is with respect to the other ***could*** depend upon the *metric* only (Newton), or upon the *metric* and the IF (Einstein). Yet, we will see this case occurs neither in Newton’s nor in Einstein’s worlds.

Causal (b): The events are causally related in a way that they are ***not*** and ***could not*** be connected by a direct genidentical chain, but they are or ***could*** be related via a third event genidentically connected to both (their *common* cause). This case does ***not*** occur in Newton’s world, but it does in RT (where the events are called spacelike-separated). Absolute ***non****-simultaneity* exists only between the common cause and each one of the two events (each pair connected or connectible by a genidentical chain). The statement $[A \neq B \wedge t_A = t_B]$ does ***not*** imply such multiple occupancy for an object and ***could*** be true if the time-intervals for the two genidentical chains linking the two events to their common cause were *equal*, depending upon the (conventional) *metric* for durations and upon the IF. Despite the latter causal relations being (of course) objective, the *simultaneity* or

[19] We could say communication is achieved by a ‘signal’ with infinite velocity but ‘infinite’ -not being a number- has no meaning in Physics and, in Mathematics, only as a limit.

non**-simultaneity* between A and B -if based on causality- is ***not objective and, hence, stipulated by *convention* and the choice of IF. The following two subcases are therefore possible:

(**b1**): the events can be made absolutely *simultaneous* by impractical conventions (non-objective).

(**b2**): their time-order can be made **co**variant by convention, i.e. the time-metric and IF could render one event non-objectively *earlier*, *simultaneous*, or *later* than the other. This was Einstein's choice in RT.

Causal (c): The events are causally related in a way that -if not already as a matter of fact- they ***could*** be directly connected by the genidentical chain of *some* object/process and, besides, they are or ***could*** be causally related via a third event genidentically. In this combined case, it is immaterial whether -in addition to the direct genidentical chain- there is or could be a common cause: their ***non**-simultaneity* is objective and absolute by virtue of the direct genidentical chain, which (if light-limited) makes the events -in RT jargon- timelike-separated. This case occurs in Newton's and Einstein's worlds. ***Only*** how much 'later' or 'earlier' one event is than the other could depend upon the *metric* only (Newton) or upon both the *metric* and the IF (Einstein).

From **Causal (a)**, **Causal (b)** and **Causal (c)**, direct connectibility via a genidentical chain implies objective absolute time-order between the two events (albeit ***not*** absolute time-interval), but ***not*** so when the connectibility is ***only*** from a common cause to them.

Acausal (d): The events are ***not*** and ***could not*** be connected by a direct genidentical chain between them or indirectly via a third event genidentically connected to each of them, so it was assumed they are ***not*** causally related. Accepting this last conclusion was tantamount to denying absolute *fatalism* and upholding our (of course limited) *free will* – as every sensible person does (except some when philosophizing). By *fatalism* (Gisin [39] calls it 'hyper-determinism' and 't Hooft [40] calls it 'superdeterminism') I mean that even our most inconsequential decisions are preordained from some 'beginning' or even from the very beginning of the Universe (if the latter 'beginning' has a cogent meaning at all)[20]. I avoided the word *superdeterminism* because nowadays, as we will see, is used by many researchers in a narrower technical sense. Any temporal relation between these events ***cannot*** be objective ***on*** a genidentical causal basis. Like for **Causal (b)**, we would have the subcases:

(**d1**): the events can be made absolutely *simultaneous* by impractical conventions (non-objective).

(**d2**): their time-relation can be made **co**variant by convention, i.e. the time-metric, IF, etc. could render one event non-objectively *earlier*, *simultaneous*, or *later* than the other.

However, in both Newtonian and Einsteinian worlds, for any two events, there is always a third event in their common absolute past that is *connectible* via genidentical chains to them, *subjunctively* denying the reality of Acausal (d) and of Causal (a). Intriguingly, *fatalism* is (subjunctively) compatible even with RT (at the cost of potentially denying our revered *free will*). But we know Newton's theory is only an approximation to RT, and RT (even if it were not **in**complete in the sense we claim it is) has only a local validity as an approximation to GRT. Thus, the clash between *fatalism* and our *free will* is amid philosophical stances – not among matters of fact or dogmatic beliefs in theories widely accepted (though forgetfully with limited validity).

[20] In 't Hooft's hidden-variable model of QT, even our settings of a device are determined by the hidden state [40].

Postulating then that genidentical chains are the ***only*** *subjunctive* bearers of causality, for any two causally related events, either they are connectible by a direct genidentical chain, or indirectly via genidentical chains from a common cause, or by a combination thereof. If they are directly connectible, the events are objectively and absolutely ***non**-simultaneous*; otherwise, their temporal order may depend on both the *metric* for time-intervals and the IF. Hence, if (and only if) all causal relations between two events in the Universe conformed to Causal (a), Causal (b), or Causal (c), their ordinal and metrical temporal relations could be completely assessed from the *possibility* of genidentical chains among them. This is the rationale behind the characterization and measurement of *time* in Newton's and Einstein's worlds exclusively via the *possibility* of genidentical chains, namely: 'particle motion' in the former and 'light propagation' in the latter. However, ironically, Newton was more liberal than Einstein.

1.3.2.3 Newton's and Einstein's Stances on Locality

As an exception to the predominance of dynamic mechanisms for causality, Newton reluctantly postulated the existence of a fifth case:

Causal (e): events are causally related ***not*** because of a possible direct genidentical chain or common cause but because of what he called *gravitation*. And to make his new causal relation consistent with cases **(a)**, **(b)**, **(c)**, **(d)**, and with the Galilean fact that the distance between two ***non***-simultaneous events was relative, Newton declared that *gravity* occurred instantaneously in ***any*** IF. Only in that way, the gravitational force, masses, and distance between two bodies would be all absolute.

This is the meaning of 'nonlocality': causality without the possibility of genidentical chains and, ergo, among events absolutely *simultaneous* (i.e. in all IFs). Acausal (d) lacked genidentical chains so ***no*** causal relation at all was presumed to exist between the events (those chains were supposedly indispensable for causality); Causal (e) posits that the possibility of such chains is sufficient but ***not*** necessary for a causal relation to exist. Its essence is the relation itself, ***not*** its *subjunctive* genidentical instantiation. Even so, and despite its stunning success, Newton's inability to conceive a genidentical chain for *gravitation* led him to deprecate his magnificent creation as "so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it". And why? I surmise Newton realized that, despite his theory not being capable of representing the interaction between two distant *gravitational* masses in terms of a genidentical chain (and despite his gravitational force decreasing with the squared distance), his Gravitation Law would allow (in principle at least) for two people at two arbitrarily distant sites to communicate (signaling) instantly by purposely manipulating those local *gravitational* masses [39]. Using Gisin's language, 'signaling nonlocal correlations' would be possible. Being his gravitation *universal*, recondite regions of the Universe could be instantly communicated. That is what for Newton (I reckon) was "so great an absurdity".

Like Newton, Einstein could not imagine the existence of two events with ***no*** possible signal connecting them and ergo ***no*** possible *human* communication while, still, being causally related without a local common cause (which would allow for messaging between the latter and both events)[21]. But Newton -though obviously disappointed- accepted his *gravitation* theory's success, while Einstein reacted by fervently denying the existence of any direct causal relation that could

[21] In 1924, Einstein finally renounced to Mach's idea of bodies' inertia being the result of unmediated interaction between masses precisely because of its 'action at a distance' flavor [215].

be used (even if only in principle) for human instant communication. Fortunately for us, his firm conviction gloriously crystallized in his GRT with the prediction of a genidentical chain for *gravitation* (gravitational waves traveling at the speed of light in vacuum) – effectively eliminating Causal (e). Newton's n*onlocality* -accepted for over two centuries - was defenestrated[22].

1.3.2.4 QT's Resurrection of Nonlocality and the Foundation of QR/TOPI

But… precisely due to the great success of both RT (1905) and GRT (1915), after Einstein killing over two centuries of Newton's *nonlocality,* we started grandiosely taking for granted that Nature's modus operandi was as limited as human communication capabilities are, so the advent of QT resuscitating *nonlocality* (only a decade later in 1925) took everyone by a huge surprise and disconcertment – still reverberating without a solid resolution. Now, based on almost five decades of copious empirical evidence, our QR/TOPI postulates the reality of a sixth case:

Causal (f): There are distant point-Events which are *causally* related as we fundamentally defined it (the existence of one is assured by that of the other), while (banning *fatalism*, *superdeterminism*, and *retrocausality*) ***not*** being physically possible for any genidentical chain to connect them – either directly or through a common cause. Besides, these events are *objectively* and *absolutely* simultaneous via a quite sui generis reciprocal causal link because: (a) like for Newton' gravitation (Causal (e)), ***no non****simultaneous* events exist between the two events (nonlocality); and (b) **un**like for Newton's gravitation, ***no*** human communication (not even in principle) can be established between the events' sites. We will call this type of nonlocal causal relation a 'quantic link' which -using Gisin's phrase- yields "non-signaling nonlocal correlations". In QR/TOPI, the epitome for this case is the actualization of the nonlocal reciprocal interaction (ITI) between *probable* states of a single quanton (Section 4), between co-states of entangled quantons (Section 5), and even when co-states are created via the teleportation of entanglement. Incidentally, the so-called "virtual photons" in Quantum Electrodynamics (QED) were conceived to quasi-mechanically 'explain' this class of causal relations.[23] No virtual entities are needed in QR/TOPI.

Alas, the cyclopean feat behind his GRT blinded Einstein to the point of stubbornly opposing to the *nonlocality* inherent in QT – despite having been one of its prolific founders [41] [37] [38] [9] [10] [11]. Again, Einstein could not accept the existence of a causal relation between two events *without* the physical possibility of a genidentical chain (mechanism) connecting them or a common cause genidentically reaching both. That is why he tacitly bestowed universal validity to the *Principle of Locality* when, in fact, he simply had *conjectured* that causal relations occur only via slower-than-light genidentical chains.

QR/TOPI, instead, demotes the so-called *Principle of Locality* to a mere assertion about light-limited genidentical chains linking actual *evincing* events, while affirming there are events in spacetime for which $A \neq B \wedge t_A = t_B$ and -nonetheless- they are linked by a causal (and hence objective and invariant) ***non***-genidentical reciprocal chain (Section 4). We will see that in QR/TOPI, once RT is completed, *causality* and *simultaneity* are ***not*** incompatible any longer. We need first to better understand Newton's world.

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22 Seventeen years before Einstein (as stated by Maudlin in [2]), assuming that gravitation traveled at the speed of light, Paul Gerber had accurately predicted Mercury's perihelion (though not the bending of light).

23 For example to 'explain' the instant Coulomb's force between spacelike charged 'particles'.

1.3.3 Spacetime in the Newtonian Universe

Combining Kepler's superlunary laws with Galileo's sublunary law of constant acceleration, Newton deduced his *gravitational force* had to decrease with the squared distance and its direction had to be along the straight line joining both bodies, arriving at his *Law of Universal Gravitation*. He united the sidereal and terrestrial worlds, submitting his magnum opus to the Royal Society in 1686/1687. His First Law was essentially the *Principle of Inertia*, enunciated by Galileo as locally valid on our planet and employing frames in uniform motion relative to terra firma. Newton had the vision and nerve to postulate its *cosmic* validity. He knew of Galileo's *Principle of Relativity*, i.e. that while some physical magnitudes were relative because their values were **co**variant in different IFs, and others were absolute because their values were **in**variant in all IFs, it was difficult to prove the absolute motion of a frame because the laws of motion were structurally invariant under Galileo's Transformation. Newton also knew that Galileo's Relativity was not valid for all possible reference frames, and the potential that ***non****uniform* motion had to prove the existence of absolute *space*. Hence, for his *Laws of Motion* to have a cosmic validity he had to believe in the ideas of *Euclidean* absolute *space* as well as of absolute *time*; only then the notions of *repose*, *uniform motion*, and *straight line* would also become absolute (all referred to absolute and immobile *space*) and, ergo, would have univocal meaning. This is why sometimes the notion of *absolute* is still speciously associated with the existence of a 'preferred' frame for which the Laws of Nature are valid (even if such frame cannot be identified).

The Second Law was the well-known "Force equals mass times acceleration". Once assumed the existence of absolute *space*, *time*, and *geometry*, acceleration was also absolute**,** and Newton could introduce the notions of absolute *force* and absolute *mass*. Hence, an object could be brought to an arbitrarily *large* velocity by a sufficiently large force acting for a fixed time, by a fixed force acting for a sufficiently long time, or by any combination thereof. Thus, no matter how far two sites were from each other, they could be connected via an object's genidentical chain in an arbitrarily *short* but ***non***-zero time. Even so, Newton quickly accepted Rømer's astronomical data on the eclipses of Jupiter's moon Io, with his conclusion regarding the finiteness of light's speed; ergo, Newtonian objects could move arbitrarily *faster* than light. After all, for Newton, light was made of tiny corpuscles and, thus, another inherently mechanical process.

Newton accepted the trivial relativity of having to select a reference frame to coordinatize *space*, but he argued this mundane operational requirement did not affect the absolute character of *space* in the sense that it was, by its own nature, always "similar and immovable" and, hence, every point in space had an absolute *position* and the *length* of an object had an absolute value, even though we pragmatically referred those *position* and *length* to the frame. He made the same argument when forced to accept that, due to the Galilean Principle of Relativity, while the *distance* between two *simultaneous* events (viz the *length* of an object at whose termini those events occur) was absolute in his theory, the *distance* between ***non****simultaneous* events was relative to the frame[24]. With this backdrop, let us now focus on the ontology of time according to Newton.

1.3.3.1 'Before', 'Simultaneous', and 'After' in the Newtonian Spacetime

For Newton, given any two *events* in the Universe, no matter how far away and regardless of the vantage point, we could assert unambiguously that one of them occurred *before, simultaneously*

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[24] A genidentical chain can always be referred to a frame in which its end-events occur at the same place [44].

with, or *after* the other. *Past*, *present*, and *future* were independent of *space* and relative *motion* between reference frames. Newton believed that, even though *uniform* motion was *relative* in experience, it was ***absolute*** in its essence. He was ***no*** operationalist: despite his “hypotheses non fingo”, he kept his ontology (semantics) well apart from any epistemic procedures (pragmatics).

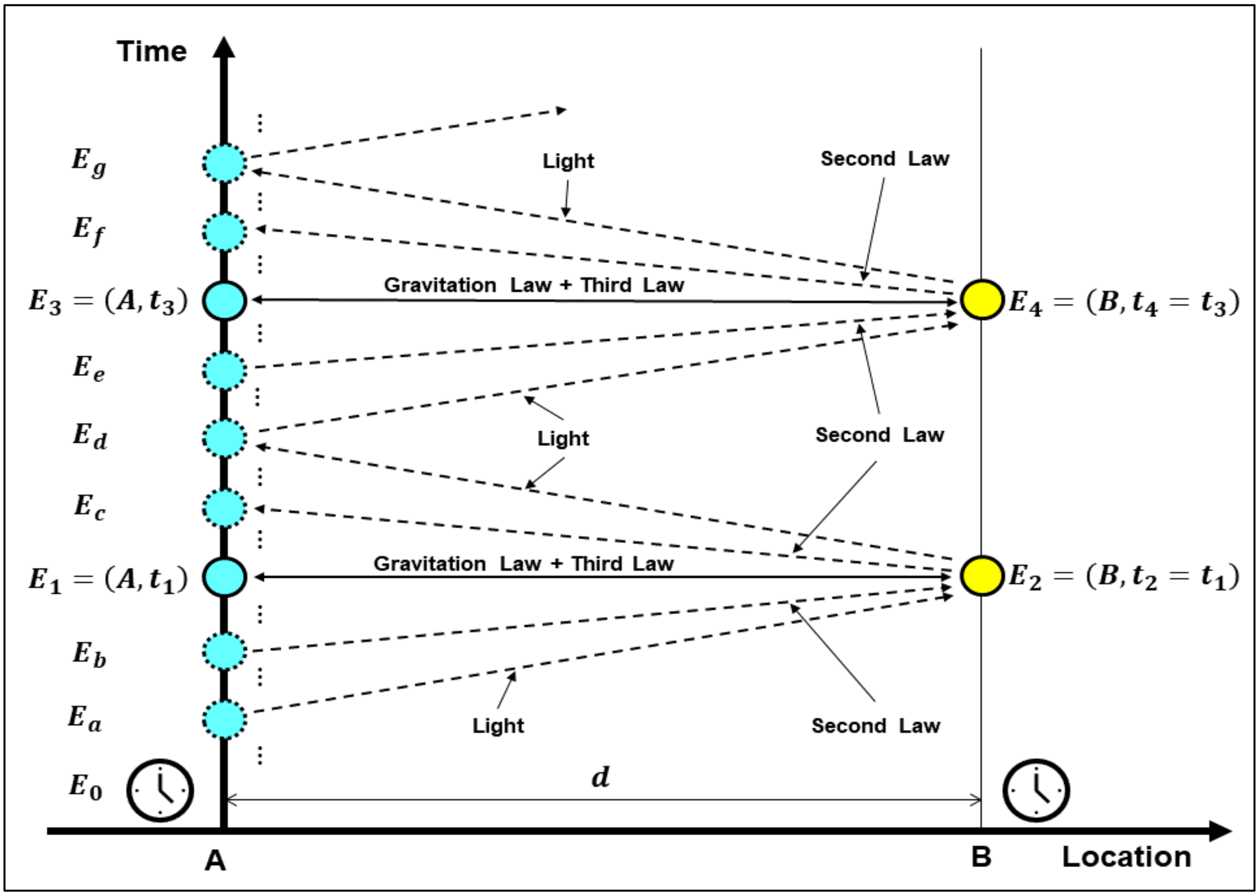

Figure 2 – Before, Simultaneous, and After in the Newtonian World

To expose the concepts graphically, we will innocuously take spacetime as two-dimensional, i.e. one dimension for time and one for space. The identical clocks at sites A and B (horizontal axis) in Figure 2 are at rest in an IF, so the time-axis and the other vertical line constitute the clocks’ respective spacetime careers (worldlines). As we saw in Section 1.3, events at each location can be *independently* ordered via the ‘earlier than’ relation revealed by each clock *without* the need for a time-metric or any mutual synchronism. Hence, we can say at site A that $\cdots E_a < E_b < E_1 < E_c < E_d < E_e < E_3 < E_f < E_g \cdots$, to mention a few of the *continuum* of generic events; and the same $\cdots E_2 < \cdots < E_4 \cdots$ for the events at site B. But such an approach would effectively define two independent *time* axes – in fact, one *time* axis for every possible location. To characterize the temporal relations between all events in the IF via a single time axis, we need to synchronize all clocks, namely we need to ascertain when and why, in Newton’s world, two distant events can/must be considered *simultaneous* and, ergo, their associated local clocks must display the same time-number. Synchronizing distant clocks does ***not*** consist in capriciously assigning the same time-number to them: the *Ontology*, *Foundation*, and *Structure* of the theory [9] govern which events can/must be considered *simultaneous* and which ones cannot. But, for the purpose, we cannot resort to one-way metric velocities (as St. Augustine unwittingly did) because they require synchronizing distant clocks – the possibility of which is precisely what we wish to elucidate.

From Newton's Second Law, for any event E_2 at B, there is an infinitude of event pairs at A, e.g. E_b, E_c verifying $E_b < E_c$ for which we can make E_b coincide with the departure from A of an object (e.g. a third traveling clock), E_2 coincide with its arrival at B and immediate return, and E_c with its arrival back at A. Being any Newtonian object's motion a genidentical chain, we can affirm *without* any prior *metric* or *synchrony* between the two clocks that the distant event E_2 must be temporally between E_b and E_c *regardless* of how close (but ***not*** equal) the latter two events might be. Thus, taking the limit as E_b and E_c get closer and closer, we conclude that there is a unique event E_1 at A such that $E_b < E_1 < E_c$ and is *simultaneous* with E_2 at B – simply because the time coordinates of E_1 (at A) and E_2 (at B) are both between those of the same arbitrarily close events (at A). This event E_1 divides all possible events at A into two disjoint open sets: those *earlier* and those *later* than the event E_2 at B. Note that E_1 and E_2 ***cannot*** be connected by any genidentical chain. And, of course, for every E_1 at A there is an E_2 at B and vice versa.

It is notable that neither *synchrony* nor *metrical* considerations are needed in the Newtonian world to ascribe *simultaneity* to distant events E_1 and E_2 because there is ***no*** need for the prior assumption that E_2 is metrically later than some event at A (e.g. E_0) by the same amount as E_1 is or, equivalently, ***no*** consistent assignment of numbers to durations is necessary. It is the opposite: because the time-intervals $[t_0, t_1]$ and $[t_0, t_2]$ $\forall\, t_0$ are one and the same, the time *metrical* equality of the Event-Intervals E_0E_1 and E_0E_2 $\forall\, E_0$ is assured irrespectively of any chosen *metric*. This would not be true if Newton's objects could ***not*** move arbitrarily fast because an ordinal gap would then exist around E_1 (say $[E_b, E_c]$) invalidating the limit argument to assert its *simultaneity* with E_2. But due to the Second Law in the Theory's *Foundation/Structure* (allowing for arbitrarily fast motion) there is no such hiatus, so *simultaneity* is based exclusively on ordinal (topological) grounds. Clearly -being based on genidentical chains- all we said is valid for every IF and, ergo, Newtonian *simultaneity* is non-conventionally absolute. What I have formally explained is, due to the provincialism of our daily experiences, nothing but our instinctive conception of *simultaneity*.

From above, the clock at B must be set to deliver the same time-number for the event E_2 as the clock at A for the event E_1. Obviously, the same argument can be made for events E_3 and E_4 and any other homologous pairs of distant events. Figure 2 also shows that there are pairs like E_a, E_d and E_d, E_g that, besides being connectible by a material object (via E_2 and E_4) they can be linked by a *light* ray in vacuo. Furthermore, any genidentical chains joining events prior to E_a and later than E_d, before E_d and later than E_g and so forth, could be connected by *light* rays traveling in different materials (lower roundtrip speeds). The point is that, in Newton's world, *light* plays ***no*** special role and travels *slower* than an infinitude of material objects: superluminal *locality* is lawful. In sum, once we metricize and initialize a master clock, Newton's Second Law governs the unique initial setting for all clocks throughout the IF (and for all IFs) so… how do we implement those initial settings? Because Newton's 'Transported Synchrony' postulate, which asserts that the synchrony of two clocks is preserved as they arbitrarily separate, is assumed true, the answer is simple: sheer clock transportation.

Once again, the 'Transported Synchrony' postulate affirms that when two 'identical' clocks are locally synchronized and then spatially separated, they remain synchronized (after taking, of course, differential forces into account [18] [17]). Pithily: all clocks transported from A to B -if synchronized when departing- will display when at B the same time as the clock at A – regardless of their careers. Newton's simultaneity based exclusively on ordinal considerations (***no*** metrics necessary) plus the assumption of transported-clock synchrony open the potential vicious circle betwixt metric one-way velocity and distant clocks' synchronism. Therefore, the one-way transit time is univocally determined by any transported clock's own reading at arrival and, hence, an intrasystemic synchronization consists in synchronizing all clocks with a master clock at a single site and transporting them throughout the IF. Alternatively, with all clocks at their places, a single clock locally synchronized with the master is repeatedly transported to locally synchronize all others by transferring its reading to them. Because the only *convention* used is the trivial one of which time-number is assigned to *simultaneous* events, not their status as such, Newtonian *simultaneity* is non-conventionally absolute, viz intrasystemically and intersystemically invariant.

Now, given that any two events in Newton's theory are metrically *simultaneous* or not based solely on the Second Law, what is the time-relation between the events of two bodies experiencing Newton's gravitational attraction? As we saw, it is also a relation of *simultaneity* but established by a reciprocal ***non**-genidentical* causal interaction: Einstein's "spooky action at a distance", technically known as *nonlocality*. In Figure 2, examples of such reciprocal ***non***-genidentical causal chains are $E_1E_2E_1$, $E_2E_1E_2$, $E_3E_4E_3$, and $E_4E_3E_4$. Being all three events *simultaneous*, and two of them equal, ***no*** betweenness relation exists in the chain, and ***no*** cause/effect distinction is possible (semantic or pragmatic). Thus, such a sui generis causal chain (displaying absolute *simultaneity*) does ***not*** constitute a closed genidentical loop (with all its potential paradoxes).

Succinctly: in Newton's world, due to force, mass, and acceleration being absolute, any two events stand in an **un**ambiguous *temporal* relationship to each other because either: (1) they can be the termini of **uni**directional genidentical causal chains of finite velocity, however large; or (2) they can be the termini of a **bi**directional ***non***-genidentical causal interaction (Gravitation + Third Law). In case (1) they are absolutely non-conventionally ***non**-simultaneous* because they are linked by a genidentical chain; in case (2) they are absolutely non-conventionally *simultaneous* because: (a) there is no limit to the finite velocity of an object, and (b) Newton's Gravitation Law.

Indeed, the *simultaneity* established by gravitation is fully compatible with the *simultaneity* implied by the Second Law as a limiting case. Had *instant* Newtonian gravity not existed or had existed but propagated with a finite velocity (as it does in GRT[25]), the relation of absolute ***non***-conventional *simultaneity* would have remained intact as the limit of the fully topological ***non**-simultaneity* asserted by the Second Law. Only if such hypothetical *gravitation* finite velocity were also an **un**attainable upper limit for all objects in all IFs while the 'Transported Synchrony' postulate still true, would *simultaneity* be conventional – though (with the same convention for all IFs) still absolute. Only if the *gravitation* velocity were also an **un**attainable upper limit for all objects in all IFs but the 'Transported Synchrony' postulate **un**true, would *simultaneity* be conventional ***and*** could be made non-objectively relative or absolute. These intricacies and nuances will be clarified as we move forward.

Evidently, despite his own disliking, the *nonlocality* of *gravitation* was an essential part of Newton's world. Certainly then, Newton's theory does "hold a place for non-signaling nonlocal correlations" – though, as we saw, his *nonlocal* gravitation went farther: it did allow for instant

[25] General Relativity reduces locally to Newtonian theory in two ways: a) the gravitational force between two bodies approaches Newton's Gravitation Law; b) spooky action at a distance is apparent only in steady-state conditions.

signaling (human communication). However, the theory did ***not*** *predict* nonlocality: Newton reluctantly *postulated* its existence (viz: it made it part of his *Ontology*). In Section 4, we will prove that RT does admit 'non-signaling nonlocality' as well (but ***not*** 'signaling nonlocality'), except that Einstein dogmatically *postulated* its **in**existence (signaling and non-signaling alike).

Wrapping up spacetime in Newton's universe, *space* and *time* are independent: there is one metric for a Euclidean *space* and another independent metric for *time*. If we find a reference frame where Newton's Laws are valid (i.e. an IF), we have eo ipso an infinite number of them: all moving at constant *velocity* with respect to one another. *Galileo's Transformation* relates the *space* and *time* coordinates of an event in any two IFs while Newton's Laws remain invariant (they do not include velocities). Differently: Newton's universe is Galilean-**In**variant. The *distance* between two *simultaneous* events is absolute (Galilean-**In**variant) and equal to the length of a rigid object at whose termini the events occur; instead, the *distance* between two ***non****-simultaneous* events is relative (Galilean-**Co**variant). That is why for the gravitation force to be absolute (Galilean-**In**variant), the interaction between the objects has to be *instantaneous*. But the *time-order* between two events and -once the metric is chosen- their *time-interval* are absolute so, despite Newton's world being tetra-dimensional, the metrics of *space* and *time* are ***not*** sensibly combinable into a single absolute tetra-dimensional metric. Newtonian spacetime is simply a *temporal* succession of Euclidean *spaces*. Each term in the succession is a snapshot of the tridimensional *space* because all places in the Universe are supposed to share the same *instant*.

1.3.4 Spacetime in the Special Theory of Relativity

By the end of the 19th century, the *luminiferous ether* had to exist and be omnipresent, offering absolutely no resistance and had not to be fully dragged by *matter* in *motion*: being aberration of stellar light a fact and the *luminiferous ether* presumed indispensable for *light* propagation, the *ether* had to be in absolute *repose* and Newton had to be correct [42]. However, given two IFs, if Maxwell's equations were assumed valid in one of them, applying *Galileo's Transformation*, the new equations contained terms which depended on the relative *speed* between the IFs. In short, Maxwell's equations were not Maxwell's any longer. This fact suggested that the laws of *electromagnetism*, as opposed to those of *mechanics*, were only valid in a privileged IF. Would this unique IF be the so wanted but elusive absolute *space*? If natural laws changed with the IF, the same experiment conducted in different frames would give different results and we could prove the absolute *motion* of the frame. Were the luminiferous ether universally penetrable and penetrating, omnipresent, and the epitome of absolute *repose*, well-thought accurate *optical* experiments conducted on our planet would be different when *light* propagated in different directions with respect to our planet motion in absolute *space*. In brief, against the emission theory of light, Newton/Maxwell *ether* theory affirmed that the velocity of light in the *ether* medium was independent of the motion of its source (like for a wave); however, its velocity in a frame in relative motion with the *ether* (e.g. Earth) would depend on that motion via the *Galileo's Transformation*.

In 1818, Francois Arago tried to measure the absolute *velocity* of our planet by measuring the refraction of light through a glass prism. Because Arago's prism was supposedly moving in absolute *space* with the same *velocity* as our planet, when light traveled in the same *direction* as the Earth, the *speed* of light relative to Earth (per *Galileo's Composition of Velocities*) would be lower than in ether; when light and Earth traveled in opposite *directions*, light's *speed* relative to the planet would be greater. Succinctly, the refractive index would change with the orientation of the refractometer on the bench and with the position of our planet along its annual orbit. Arago suffered an astronomical disappointment, and told his friend Fresnel, who developed a theory as effective as strange about matter partially dragging the ether. In 1851, Fizeau's interferometric results with light traveling in a water stream appeared to imply that light was only partially dragged by the water stream, also refuting the *Galilean Composition of Velocities*.

Maxwell had considered measuring the absolute *velocity* of our planet employing the variations of the eclipses of Jupiter's moon Io. He believed that measurements of light's *speed* in a laboratory had to be affected by our planet *motion*, but the effect was undetectable because it would require measuring a *time-interval* in the order of a femtosecond. Michelson, far from discouraged, decided in 1881 to measure such a small *time-interval* using a precise *interferometer* of his own design. He needed to figure out how to force light to split and traverse equal-length paths at different angles with our planet's *direction* of *motion* – so that the two beams would travel at (supposedly) different *speeds* and, ergo, reaching the detector at different *times*, a shift in the interference fringes would show up. Michelson's negative results were interpreted as confirming that the *ether* was fully dragged by our planet *motion*. But an ether fully dragged by the planet did explain neither star light aberration [42] nor the violation of the *Galilean Composition of Velocities* in Fizeau's experiment with water [23]. Lorentz, in 1886, decided that Michelson's calculations implying a fully dragged *ether* were flawed, and worked on a theory more in consonance with Fresnel's.

1.3.4.1 The Michelson-Morley (1887) Experiment

In 1887, Michelson and Morley repeated Fizeau's experiment in water confirming his partial *drag* coefficient, which compelled Michelson to resuscitate his belief in the 'ether wind'. In the same year, using a much-refined version of his interferometer, they conducted an experimentum crucis known as the Michelson-Morley Experiment (MME) [43]. About 28 years later and a decade after his inception of RT, Einstein said:

EINS3: *...The successes of the Lorentzian theory were so significant that the physicists would have abandoned the principle of relativity without qualms, had it not been for the availability of an important experimental result, ... namely Michelson's experiment.*[26]

Figure 3 schematizes the apparatus which floated on a mercury bath to minimize the effect of mechanical vibrations and facilitate its rotation. The apparatus had one light source, one half-silvered mirror at 45° with the *light* beam so as to 50/50 split it into two beams traveling through two perpendicular arms, two full mirrors perpendicular to the respective beams, and a telescope to observe the interference fringes after the two beams traveled through the arms and recombined. The identical mirrors in both arms of the interferometer imposed the same phase shift $(\pi/2)$ upon reflection so that their effects canceled out and could be ignored. But, besides the phase gained upon each *reflection* from the half-silvered and perfect mirrors, there were other contributions to the final phase: a) the small phase gained inside the mirror upon *transmission*; and b) the phase gained along the arms themselves. Because both beams would encounter one transmission and two reflections before reaching the telescope, and both arms had the same length (as accurately measured by a ruler[27]), any *phase* difference could only be due to differences in light *speed* along the two arms – purportedly due to the 'ether wind'. Figure 3 depicts the case when one of the arms is parallel to the supposed motion of Earth in the *ether*.

[26] Einstein, A., Die Relativitätstheorie, Physik; pp. 703 and 706; 1915. As cited in [17].

[27] The lack of an accuracy in lengths' equality, commensurate with the ether-theory-expected femtoseconds difference in arrival times, was theoretically compensated via its effect on the arrival times when rotating the apparatus [17].

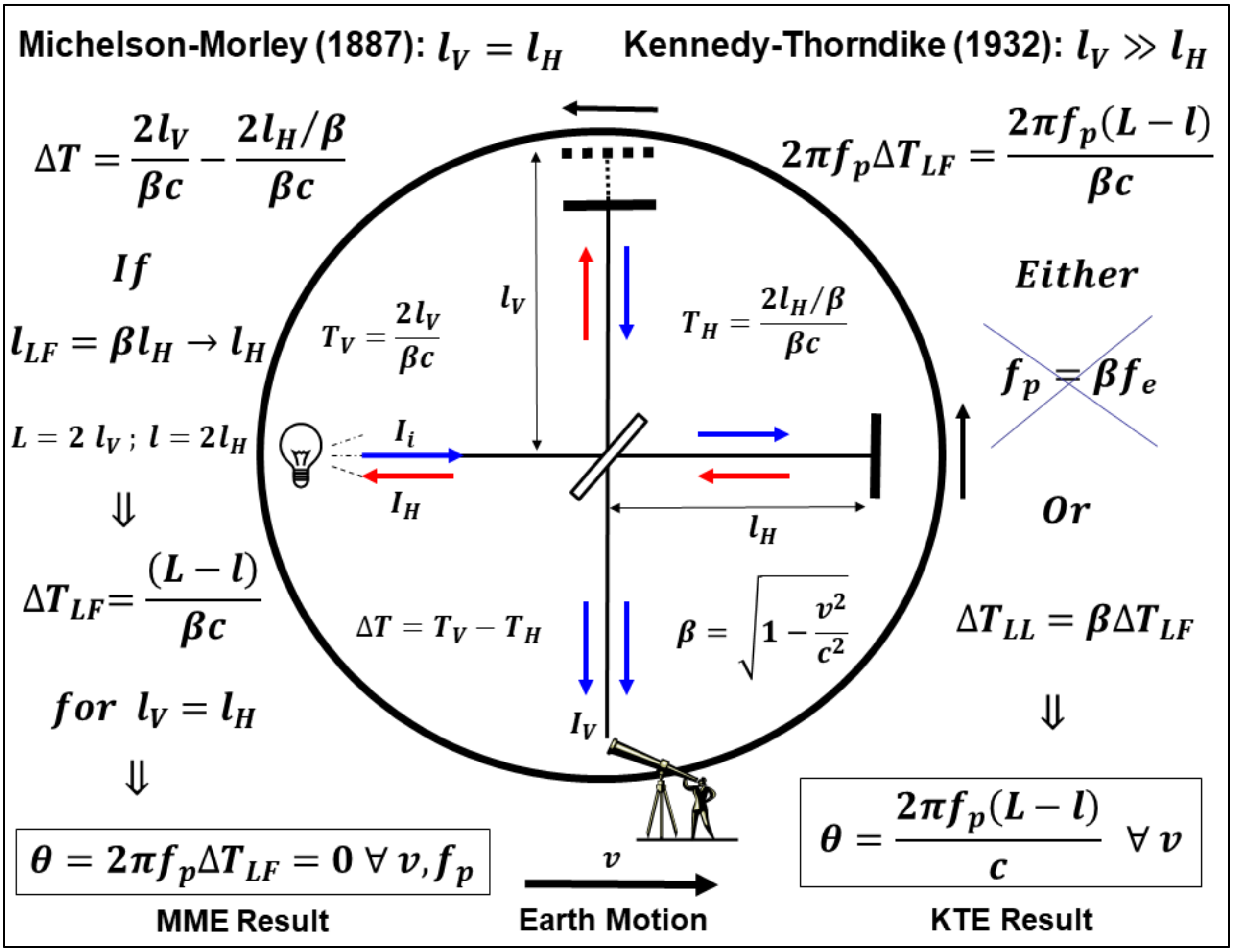

Figure 3 – Michelson-Morley (MME) and Kennedy-Thorndike (KTE) Experiments

According to the *ether* theory, the light's speed $c \cong 300{,}000\ km/s$ was relative to the *ether* frame in absolute repose and independent of the velocity of the source. But light's speed relative to an IF (Earth) moving itself in the *ether* frame with velocity $\vec{v}$ would vary per the *Galileo's Composition*. In the *ether* frame, with l_V the transversal (to $\vec{v}$) arm's length and T_V the beam's arrival time, due to the sawtooth path drawn by the beam, we have $l_V^2 + v^2 T_V^2 = c^2 T_V^2$ so, as shown in Figure 3, $T_V = 2l_V/\beta c$, with $\beta = \sqrt{1 - v^2/c^2}$. For the parallel (to $\vec{v}$) arm of length l_H, the arrival time T_H is obtained from the Galilean Composition of the to-and-fro velocities of light relative to the Earth frame: $T_H = l_H/(c-v) + l_H/(c+v) = (2\,l_H/\beta)/\beta c$. Notice that T_V was referred to the *ether* frame while the denominators in each summand (and hence T_H) are the speeds of light going and coming relative to the Earth's frame; however, *Galileo's Transformation* entails the absoluteness of *time* and *length* so, per Newton/Maxwell *ether* theory, T_V, T_H, l_V, and l_H are the same in both IFs and $\Delta T = T_V - T_H$ is an absolute. And assuming a monochromatic wave, that time difference between the partial beams would produce a phase difference upon arrival of $\theta = 2\pi f_p \Delta T = 2\pi f_p (2l_V - 2l_H/\beta)/\beta c$ – with f_p being the frequency of the light source in the Earth frame (presumed equal in both *ether* and Earth frames).

Thus, calling $L = 2l_V$ and $l = 2l_H$ and because the MME made $l_V = l_H$, the phase difference is $\theta = 2\pi f_p l(1 - 1/\beta)/\beta c$. Therefore, a shift in the *interference* fringes had to appear (via β) as

v varied (unless f_p changed with v in a fully compensatory manner). Furthermore, this *phase* difference would also change periodically with the apparatus *rotation*, and that particular *orientation* for which the instrument showed the maximum *phase* difference would pinpoint the absolute *direction* of our planet *motion* in absolute *space* at a moment in its diurnal and annual motion. Impeccable logic – if and only if *Galileo's Transformation* between frames was correct. Neglecting terms of the fourth order and higher, MME's authors arrived at $\theta \cong 2\pi f_p l\, v^2/c^3$and, considering only the velocity of the Earth traveling around the Sun and the frequency of yellow light, upon rotating the apparatus $90°$, the phase-difference shift $\Delta\theta$ was calculated to be 2θ or (in terms of the fringe pattern) 0.04 of the distance between the fringes [43].

But Michelson's disenchantment was again of galactic proportions: regardless of the apparatus orientation, the time of the day, the day in the month, or the month in the year, both beams reached the telescope in phase ($\theta = 0\ \forall\, v$) implying that the roundtrip *speed* of light with respect to our planet was independent of the *direction* of light's *motion* and the *direction* and *magnitude* of Earth's *motion* in the supposed *ether*. Due to the superb instrument's accuracy, this time its results were beyond dispute and plainly indicated that:

(a) The following dichotomy was in place:

1. The *ether* existed but was fully dragged by the Earth in its diurnal rotation and annual orbit around the Sun ($v = 0 \Rightarrow \beta = 1 \Rightarrow \theta = 0$). So it would be **un**detectable.
2. The *ether* did ***not*** exist. No IF was privileged by Nature. A drastic new philosophical paradigm would be needed.

(b) But, upon a complete drag of the *ether*, not only the *aberration* of stellar light would ***not*** occur, but also the *Galilean Composition of Velocities* had to be valid – something that Fizeau's experiment had disproved [44] [42]. The traits of a figment for the *ether* were mounting. An independent experiment rebutting *ether dragging* would irrefutably point to its **in**existence – even under the very *ether* theory!

(c) The lack of a shift in the interference pattern indicated that -in the Earth frame- the roundtrip speed of light was the same in both arms regardless of the different IFs set by the apparatus' orientation and Earth's rotation and translation. However, being θ constantly nil, ***no*** numerical value for the light's roundtrip speed in any of those IFs was calculable, so ***no*** constancy of the speed of light across IFs could be inferred. Likewise, it was impossible to infer that had the light source been in motion in the lab, the roundtrip speed of light would have been the same.

(d) Even though (lacking a numerical value) the constancy of light's speed between frames had not been proved, it was clear that -within a given arbitrary IF- being the light's roundtrip speed the same in all directions, the *Galilean Composition of Velocities* for the IF and the *ether* frame could ***not*** be valid. Instead, and again despite its numerical value not being calculable from the experiment, light's speed seemed to behave as an upper bound for that of all other objects – intimating a totally new type of composition and the impossibility of superluminal signaling.

Notwithstanding, instead of accepting (c), i.e. that light's roundtrip speed was the same in both arms, physicists insisted on the existence of the immobile *ether*, so Fitzgerald in 1889 and Lorentz in 1892 argued that if all bodies contracted in the *direction* of *motion* through *ether* by the factor β, l_H had to be replaced by $l_{LF} = \beta l_H = \beta l$ in the formula for ΔT (Figure 3/top-left), and MME's negative results would be 'explained' because $\theta = 2\pi f_p \Delta T_{LF} = 2\pi f_p (l - l_{LF}/\beta)/\beta c = 0 \; \forall \; v, f_p$. This alleged effect (a patch to the *ether* theory) was called the Lorentz-Fitzgerald Contraction (LFC) supposedly caused by the 'ether wind'. Such a causal explanation was thought necessary given the conception of *space* as a container of objects whose length was absolute, instead of a relation between them and a standard object to which the unity length was arbitrarily assigned. And, by the same token, to achieve consistency with the body of experimental data available at the moment, Lorentz and Larmor independently surmised that every object in motion through *ether* had not only to mysteriously *contract* but also experience a 'local time' – producing the effect known as 'Lorentz-Larmor Time Dilation' (LLD). Even Poincaré, who was very close to conceive RT before Einstein, distinguished between "the true time" and the "local time" in his famous 1904 publication in *The Monist* [23] [45].

Based on the above two patches to the original *ether* theory (we call it the LFC/LLD-amended *ether* theory), Lorentz developed his eponymous transformation (LT) relating the space and time coordinates in the moving frame with those in the immobile *ether*. Curiously, a slight variation of the LT had been conceived by Woldemar Voigt[28] in 1887. Both transformations were compatible with the MME results, though differing on the length-contraction/time-dilations effects. One common peculiarity was that (contra Galileo's Transformation) the speed of an object could not be made *higher* than *c* by simply piling up *moving* launching platforms. But if true, Newton's assumed superluminal genidentical chains achievable by ***any*** object seemed to be in doubt: forcing the MME results to conform to Newton/Maxwell's tenets (after two amendments), appeared to render the very same tenets untenable! It looked like neither matter nor radiation could surpass the speed of light, limiting how fast humans could communicate.

Digressing a bit, they could have equally theorized that the arm parallel to Earth's motion did not contract but, instead, it was light that traveled along it faster than along the perpendicular arm – so as to both arrive in sync at the telescope. This would have been easily refuted by resorting to our *free will*: imagine we could change the arm's length right after light left the source; in such a case, either the speed is set by the source based on the distance (in which case it is too late), or light continuously adjusts its actual speed with the distance it has still not traversed. We instinctively abhor the idea that Nature conspires to compel us to set the arms' lengths so as to meet its caprice (*fatalism*), or that our whim compels Nature to change light's speed at the source (*retrocausation*) or change it continuously 'on the fly' based on the space it still has not traveled through (*superdeterminism*). Even so, we will see that in order to achieve Lorentz-Invariance in QT, all three options have been proposed and vehemently defended by some researchers.

Back to history: setting aside the enigmatic 'local time' of the LLD effect for a jiffy, the LFC 'explanation' of MME results was very vulnerable to epistemic critique: because the *ruler* to measure the *contraction* was *moving* with the apparatus (and the whole planet), the *ruler* (and us) would also *contract* in the same proportion making it impossible to detect the arm's purported contraction. Only an individual located in an IF in *repose* with the *ether* could (allegedly) observe our 'real' physical *contraction*. A much simpler explication would be later proposed by Walter Ritz and others who claimed light was in between a *wave* and a *bullet*: it propagated as a *wave*, but its *speed* was ***not*** defined by the *medium*, but by the *source*. However, there existed plenty of evidence making such a hypothesis unsustainable [42]. It appeared that the LFC was an ad hoc

[28] The LT was obtainable from the Voigt Transformation multiplying the latter's right-side by $1/\beta$.

makeshift with the only purpose of explaining MME's unexpected results, so independent evidence was needed. Data for the electron seemed to confirm its *contraction*[29] when moving with respect to the experimenter but, in the MME, the bodies which supposedly *contracted* were in repose with respect to Earth. And, if the *contraction* was real and due to Earth's *motion* in *ether*, then -though undetectable using a *ruler*- there had to be some physical property that changed when their 'real' *length* changed (e.g. refractive index). We saw that various experiments had been designed to detect such a change of optical properties, and they had failed. The Trouton-Noble (1903), Trouton-Rankine (1908), and other experiments proved there was no change in electrical properties either. The LFC had to be real in order to explain the MME but Nature seemed not to allow us to detect it – neither by *mechanical* nor by e*lectromagnetic* means.

In brief, this causal explication of the MME via a physical *contraction* was very difficult to accept because, for a given *speed* in the *ether* frame, the *contraction* was the same regardless of the body's mechanical properties, and all attempts to detect it through changes of other physical properties associated with *length* had been unsuccessful. Likewise, in accordance with the same interpretation, the Lorentz Transformation affected the 'local' *time* on Earth in comparison with the 'real' *time* measured in absolute *space*, so that the clocks on Earth ran behind with respect to the absolute *time* indicated by a clock at rest with the *ether*. Ironically, as we will see soon, making the lengths of the interferometer's arms radically different is enough to **dis**prove the reality of the LFC as a single patch to the ether theory, so the status of *ad hoc* can only be assigned to the double LFC/LLD-amendment to the *ether* theory [17].

As of today, the MME has been multiply repeated with ever-increasing accuracy. Different setups with lasers, masers, optical resonators, microwaves, etc. have all fully confirmed its results. An independent experimental proof that the ether, if existed, was ***not*** dragged by the Earth motion came through the Sagnac Effect [46] [47].

1.3.4.2 The Sagnac Effect (1910) and the Michelson-Gale (1925) Experiment

In 1899, Georges Sagnac had developed a theory for the existence of a motionless mechanical ether, trying to explain all optical phenomena and the mentioned Fizeau experiment in a water stream. In 1910, vehemently opposing Einstein's RT, Sagnac designed an elaborate interferometer for detecting the 'whirlwind' experienced by two light beams circulating in opposite directions around the rim of a rotating disk. Assuming transmitter and receiver are integrated at the same rim location and the two beams launched simultaneously in the lab frame, then -under the *ether* theory and upon reception- the receiver has traveled the circular arc Δl with the speed $v = \omega R$ where ω is the angular speed and R the radius of the disk. Calling l the circumference, the beam traveling in the direction of the rotation travels the arc $l + \Delta l$, so the duration t^+ of its trip is $t^+ = (l + \Delta l)/c = \Delta l/v \Rightarrow t^+ = l/(c - v)$. The other beam travels the arc $l - \Delta l$ with the duration $t^- = l/(c + v)$, which makes their difference Δt equal to $l/(c - v) + l/(c + v) = 2\,l/c^2\beta^2 \cong 4\pi R^2\omega/c^2 = 4A\omega/c^2$ with A the disk area, and from which Sagnac obtained the phase difference in units of wavelength as $\theta = 8\pi A\omega/\lambda c$ – in good agreement with his data [47] [46].

So, unlike for the MME, Sagnac did measure a non-zero phase difference as predicted by the absolute space and time theory – so he believed he had proved the existence of the immobile *ether* [48]. Notice though that here we do not need (and we cannot) speculate about the *ether* being fully

[29] As well as, from Walter Kaufmann/Bucherer early work, an increase of its inertial mass with speed (1901-1903).

dragged by the disk because if $\omega = 0$ the *ether* theory (without any patches) predicts $\theta = 0$ (against evidence). In fact, it is proof that ***if*** the ether theory is true, ***no*** dragging occurs. Sagnac also predicted that the same effect would be observable from the diurnal rotation of our planet when using a very large interferometer, so the first option in the dichotomy (a) resulting from the MME could be put to the test. In the meantime, in 1920, Von Laue derived the Sagnac effect from the *local* application of RT[30] and, in 1921, Paul Langevin derived it from GRT [47] [46]. Relativity and ether theories agreed to first order in $R\omega/c$. Interest in the *ether* was fading. Nevertheless, as Lambare in his exposition of the Sagnac effect vis à vis the validity and consistency of RT maintains: "claims contesting the correctness and consistency of relativity still appear in the scientific literature… They result from an incomplete understanding of the relativity principles and the attachment to hard-to-overcome Newtonian ideas." [49] [32].

As suggested by Sagnac, his experiment was repeated in 1925 by Michelson & Gale replacing the rotating disc with our planet and reproducing the interference fringes[31]. This positive result irrefutably confirmed that the Earth -per the very *ether* theory- could not drag an already illusory *ether* while rotating. Ergo, to avoid concluding that there was ***no*** *ether*, LFC and LLD effects in the MME had to be true. To kill the *ether* (and its amended theory) once and for all, it only remained to totally discredit those effects. The coup de grâce came in 1932 with the Kennedy-Thorndike Experiment.

1.3.4.3 The Kennedy-Thorndike (1932) Experiment (KTE)

Though with very different experimental setups, the essential difference between the KTE [50] and the MME was that the two arms of the former's interferometer were as different in length as possible. Per the authors' description, a system was built in which "… ordinary interference rings were formed and photographed, and the problem became one of measuring very small changes in the diameters of the rings… with a probable error of a thousandth of a fringe (i.e., a thousandth of the shift that would be produced by changing path-difference by one wave-length) …". Following the rationale of the *ether* theory plus assuming the LFC was real (first patch), the difference in the beams' arrival phases had to be: $\theta = 2\pi f_p \Delta T_{LF} = 2\pi f_p (L - l)/\beta c$, where f_p was the frequency of the light source as measured by a clock at rest in the lab (the 'proper' frequency). Hence, the expected occurrence of a shift in the fringes pattern relied on the combined effects of f_p and the Earth velocity v in the *ether* (via β).

But, as in the MME, the KTE showed ***no*** fringes' shift whatsoever so, for θ to remain a (now non-zero) constant while our planet rotated and orbited the Sun, the following 'explanations' were available (as shown in Figure 3):

a) The proper-frequency of the source f_p varied with v according to $f_p = \beta f_e$ where f_e is the frequency the light source would show had it come to rest in the ether. In such a hypothetical case $\theta = 2\pi f_p \Delta T_{LF} = 2\pi f_e (L - l)/c$ would be independent of v and the LFC-amended ether theory would be confirmed. However, there is plenty of independent experimental evidence showing that the proper-frequency of a light source does not vary with its state of motion [17]. Thus, this interpretation of the results must be abandoned.

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[30] There exist non-inertial frames (the rotating disk) without gravitation: they have a *Metric Tensor* different from Minkowski's though with a nil Riemann-Christoffel *curvature Tensor*.

[31] See implementation with entangled photons on https://comms.iop.org/c/11brhflYfQYKsIt6lxbXXzPrnRXm.

b) The proper-frequency of the source f_p was an invariant $(f_p = f_e)$ so that it was the rate of the *moving* clock the one that changed with v via $\Delta T_{LL} = \beta \Delta T_{LF}$, i.e. the LLD effect was presumed as real as the already assumed-real LFC effect (double patch). In such a hypothetical case we would have $\theta = 2\pi f_p \Delta T_{LL} = 2\pi f_p (L - l)/c$, which is again independent of v and therefore in full agreement with the KTE null results. However, this agreement with experiment was achieved by proposing another hypothetical effect (the LLD) with the only purpose of salvaging a presumed-real effect (LFC) which, otherwise, would have been confuted by the very same experiment. As a result, the combined LFC/LLD hypothesis becomes logically *ad hoc*, viz ***no*** independent refutation of both working together is conceivable, which is scientifically unacceptable and leads us to the next interpretation.

c) By itself, the LFC was not an *ad hoc* hypothesis (as originally thought) because the KTE confuted it by making the two arms of different lengths and showing ***no*** shift in the fringes. But most importantly, unlike for the MME, because in the KTE θ is a non-nil constant and the invariant proper-frequency (in terms of clock times) of the light source was known, the numerical calculation of the roundtrip speed of light in all IFs was possible verifying it was invariant and equal to the light speed in the postulated *ether* frame. However, because Voigt's variation of LT also conserved light's speed in all frames, the KTE was (as the MME) compatible with both transformations. The Ives-Stilwell experiment would settle the issue in favor of the LT in 1938.

Being $\theta = 2\pi f_p (L - l)/c$ with c IF-invariant, the interference pattern depended exclusively upon the ratio between the arms' length difference and the invariant proper wavelength of the light beam: $\theta = 2\pi (L - l)/\lambda_p$. Therefore, assuming ***no*** losses and referring to Figure 3, the input beam intensity I_i is split 50/50 at the entrance and again 50/50 when recombining, so the intensity I_V reaching the telescope must be $I_i/2$ when the beams arrive in phase, i.e. $\theta = 0$ $(L = l)$; it must be zero when they arrive in contra-phase, i.e. $\theta = \pi$ $(L - l = \lambda_p/2)$, and -for a monochromatic signal- it must vary sinusoidally in between. The other half (I_H) goes back towards the light source and comprises the reflected beam from the transversal arm $(I_i/4)$ plus the transmitted beam from the horizontal arm $(I_i/4)$. But the former was reflected twice -once at the entrance and once at the exit- imposing a phase gain of π, while the latter was transmitted twice (no phase change). Ergo, they come out the interferometer in contra-phase when $\theta = 0$ $(L = l)$ so I_H must be zero; they come out in phase when $\theta = \pi$ $(L - l = \lambda/2)$ so I_H must be $I_i/2$ and vary sinusoidally in between verifying $I_i = I_V + I_H \ \forall \theta$. It is thus easy to conclude the beam intensities should be:

$$I_V = \frac{I_i}{2}(1 + cos\theta) = I_i cos^2\left(\frac{\theta}{2}\right) \quad ; \quad I_H = \frac{I_i}{2}(1 - cos\theta) = I_i sin^2\left(\frac{\theta}{2}\right) \qquad (1)$$

In sum, stellar light aberration, the Fizeau's data of light in a water stream, the MME, the Michelson-Gale experiment, the KTE and others jointly refuted the existence of absolute space and time or, equivalently, the existence of and need for a preferred frame (the 'ether' frame[32]). They cooperatively validated Einstein's dismissal of the 'ether' as "superfluous", his *Principle of Special Relativity*, and other postulates about the constancy and limiting character of the light's speed he had instinctively enunciated almost three decades before in his seminal article of 1905.

[32] Or any other clever selection, e.g. the *Cosmic Microwave Background Radiation* (CMBR).

1.3.4.4 Einstein's Seminal article of 1905: '*On the Electrodynamics of Moving Bodies*'

All through his iconic paper of 1905, Einstein implicitly used a postulate that has been widely unnoticed in the literature because he never mentioned it as an axiom but (later on) as the 'Principle of Locality' – which he defended as if it were a universal fact till his death [9] [10] [11]. As we saw, it affirms that all causal chains are genidentical (*signals*), namely: a) ***no*** events in such chains are *simultaneous*; and b) they carry energy and momentum.

After a brief introduction stating that "Maxwell's electrodynamics leads to **a**symmetries which do not appear to be inherent in the phenomena", Einstein said:

EINS4: *Examples of this sort, together with the unsuccessful attempts to discover any motion relatively to the "light medium" [ether] suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, ... the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.* [24]

Einstein elevated the above conjecture after the ellipsis to the status of **Postulate #1**, effectively extending Newton's *Principle of Relativity* (extended from Galileo's) to include electromagnetics as the *Principle of Special Relativity* and, consequently, redefining what an IF is. Immediately, Einstein enunciated **Postulate #2**, known as the *Principle of the Constant Velocity of Light in Vacuum*, which he articulated as:

EINS5: *We will introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body.* [24]

Admittedly, the above phraseology is not unambiguous. Special Relativity deals exclusively with Reality as described from IFs. The *Principle of Special Relativity* asserts that not only Newton's laws of motion but also Maxwell's equations must be structurally invariant when appropriately transformed between IFs. But while under the *Galilean Transformation* such formal invariance was true of Newton's laws, it was not true of Maxwell's equations. This is the 'apparent irreconcilability' between the two postulates; differently: the *Galilean Composition of Velocities*, being a simple arithmetic sum, could never produce a "definite velocity c which is independent of the state of motion of the emitting body". Remember the mental gymnastics behind the LFC and LLD to explain the MME.

Postulate #2 tacitly refers to the one-way speed of light, so it implied more than what we saw MME's results[33] warranted, viz the constancy of only the roundtrip speed with respect to different directions and paths within an IF. Besides, the equality of the two-way speed was determined from (a) the pathlength as measured by rigid rods and (b) the equality of roundtrip times as assessed by light itself via the lack of a shift in interference fringes (***not*** by clocks). And, by running the experiment throughout the year (different IFs), it was simply proved that the roundtrip speeds for both beams were always the same for different directions within the different IFs. It did ***not*** prove that the roundtrip speed in different IFs had the same value c, as measured by rods and clocks stationed in them. As we saw, the latter was proved by the KTE decades later in 1932. In 1905, Einstein instinctively based the overreaching nature of **Postulate #2** on the generality of his

[33] Albeit historians disagree on Einstein' awareness of MME, the phrase *unsuccessful attempts to discover any motion relatively to the "light medium"* (and the very nature of his postulates) gives me no doubts he was aware of it.

Postulate #1, which categorically denied the existence of a privileged IF. But… how did he transition from the roundtrip speed to the one-way speed? Einstein silently rejects Newton's 'Transported Synchrony' allowing him to proceed with his "Definition of Simultaneity":

EINS6: *We have so far defined only an "A time" and a "B time". We have not defined a common "time" for A and B, for the latter cannot be defined at all unless we establish by definition that the "time" required by light to travel from A to B equals the "time" it requires to travel from B to A.*

This statement in English is a mistranslation of Einstein's German: it gives the impression that the requested equality of times is *necessary*, while the original passage wisely said that it was only *sufficient* [51]. And after assuming "this definition of synchronism is free from contradictions", reflexive, symmetric, and transitive, Einstein invokes available evidence on the roundtrip speed of light to declare (t_A, t'_A are respectively departure from and arrival at site A; underscore is mine):

EINS7: *In agreement with experience we further assume the quantity $2AB/(t'_A - t_A) = c$ to be a universal constant—the velocity of light in empty space.* [24]

Which is **Postulate #2** now explicitly referring to the one-way speed of light as a universal constant, formally calculated (via his definition of synchronism) from the evidence available for the roundtrip speed. As I said, he clearly though tacitly rejected the general validity of Newton's 'Transported Synchrony', stating instead that $c = AB/\{(t'_A - t_A)/2\}$ by convention, i.e. that the time-interval taken by light for $A \rightarrow B$ is equal to the time-interval for $B \rightarrow A$ – effectively using light as the *synchronizing* process (instead of transporting a clock locally *synchronized* at site A).

And, for such a move to be consistent (avoiding *retrocausality*), he implicitly took avail of another (topological) postulate: ***no*** genidentical chain can be faster than light in vacuum, i.e. if traveling the *same* distance, ***no*** object (matter/radiation) leaving from A *simultaneously* (per its local clock) with a light pulse in vacuum will arrive at B *earlier* (per its local clock) than the light pulse. Again: it is noteworthy that we can factually assess that a light ray is faster (or not) than another genidentical chain (object/process) without metricizing any of the distant clocks and without synchronizing them – just by simply launching them simultaneously (a local non-metrical assessment) and assessing their arrival events' order (another local non-metrical judgment). As we saw, the *metrical* one-way velocities are the ones that need *synchronization*, with the latter providing numbers for the former that must be always smaller[34] than c. The above empirically based axiom (though only insinuated, as we saw, by MME and KTE) is referred to as the **Light-Limiting Postulate**[35] and we will see that, together with the rejection of Newton's 'Transported Synchrony', they are inseparable from Einstein's "definition" of *simultaneity*. In other words: once Einstein refused that clocks defined absolute simultaneity under transport, the **Light-Limiting Postulate** was silently presupposed even in Einstein's **Postulate #2.**

Incidentally, the Light-Limiting Postulate would exclude the de Broglie's wave of a non-zero proper-mass object traveling with speed $v < c$ because it propagates with speed $c^2/v > c$. However, despite its termini-Events being absolutely ***non****simultaneous*, de Broglie's wave is ***not***

[34] Though ***no*** two objects can move faster than light in a frame K, their separation in K (***not*** a genidentical chain as it has ***no*** direction) ***can*** increase faster than light. But the same separation process in a frame K' in which one of the objects is at rest ***cannot*** increase faster than light because it constitutes the genidentical chain of the other object.

[35] This limiting character of light remains true in GRT, though the number $c \cong 3 \cdot 10^{10}$ cm/sec has no significance, except for local inertial frames where GRT reduces to RT. Landsman believes that this Postulate should be demoted to be valid only statistically (like Entropy) [89].

genidentical because -carrying neither energy nor momentum[36]- it is **un**detectable per se (***non***-evincing in my QR/TOPI jargon), so Einstein's postulate does not apply [37].

We refer to the combination of the Principle of Locality, Postulate #2, and the Light-Limiting Postulate as the hidden **Nonlocality-Exclusion Axiom** – simply because they quietly though effectively exclude from RT's Ontology not only the superluminal *locality* of objects' motion in Newton's world but, as importantly, the innate *nonlocality* ("spooky action at a distance") allowed by Newton's Universal Gravitation Law as well as our Causal (f) type of causal relation.

1.3.4.5 'Before', 'Simultaneous', and 'After' in the Spacetime of Special Relativity

We saw that Newton's *Ontology*, *Foundation*, and *Structure* made simultaneity an *absolute* topological fact. And because transported clocks' synchrony was considered a matter of fact, *distant* metrical *simultaneity* was objective and *absolute* (IF-**In**variant). Einstein rejected both transported-clocks' synchrony and absolute *simultaneity*. By (tacitly) decreeing that ***all*** direct causal relations can be instantiated via light-limited genidentical chains, any two events so linkable must be objectively and absolutely ***non****simultaneous* in Einstein's world; that is why I said that he eliminated *nonlocality* from RT's Ontology at the outset [9] [10] [11]. For him, if two events in Nature directly influence each other, it must be possible for a light-limited signal to link them. Otherwise, they are (per Reichenbach's parlance) *topologically* simultaneous and for any event at site $A(B)$ there is a continuum of distant events at site $B(A)$ *topologically* simultaneous with it. Hence, their *metrical* simultaneity requires (per Einstein) a "definition" (better: a convention). Thus, any resulting time-relation between such causally **un**connectable events ***cannot*** have an *objective* meaning – even if we managed to make it *absolute* via rather contrived conventions. Please, see our subtle difference between 'objective' and 'absolute': the former, besides being the antonym of 'subjective' (and because of it), refers to the lack of non-trivial[37] conventions; the latter refers to IF-**In**variance (which could be the result of natural or very contrived conventions).

As in Figure 2, the clocks at sites A and B in Figure 4 are at rest in an IF, and events at each location can be *independently* ordered via the 'earlier than' relation *without* the need for a specific time-metric for each clock or synchrony between them. Hence, we can say at site A that $\cdots E_1 < E_a < E_b < E_c < E_3 < E_d < E_e < E_f < E_5 \cdots$; and the same for the *continuum* of events at site B $(\cdots E_2 < \cdots < E_6 \cdots)$. And, again, to characterize the time-relations between all events in the IF via a single time-axis (a master clock), we need to synchronize identical clocks and, to achieve that, we need to ascertain when -in Einstein's RT world- two distant events are or can be *simultaneous*, i.e. when their local clocks must or can display the same time-number.

Taking for granted the validity of the hidden Nonlocality-Exclusion Axiom, viz that all causal chains in Nature are genidentical and slower than light, the time-relation between any pair of distant events should be fully discernable from the relations imposed by light-signals ('messengers') linking them. Consequently, those light-signals could be used to consistently synchronize all clocks in the IF. Furthermore, Fizeau had empirically proven that -in an IF- two light beams *simultaneously* leaving A in opposite directions around the same loop returned to A also *simultaneously* [17] [52]. Similar results (though without clocks) were provided by the MME for same-length roundtrips over different paths. And the latter is the only kind of space/light

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[36] For such a wave the energy-momentum vector is spacelike, i.e. $E^2 - c^2\|\vec{p}\|^2 < 0$ (not the invariant ${m_0}^2c^4$) [201].

[37] Trivial conventions are the choice of a physical unit and the choice of a 'zero'.

isotropy[38] than can be asserted without a *metric* and without distant *synchronism*. As already explained, because metricizing the one-way velocity requires synchronizing two distant clocks, to avoid Petitio Principii, we cannot use one-way metric velocities to determine when and how two clocks must or can be synchronized (i.e. set them to coherently display the same time-number).

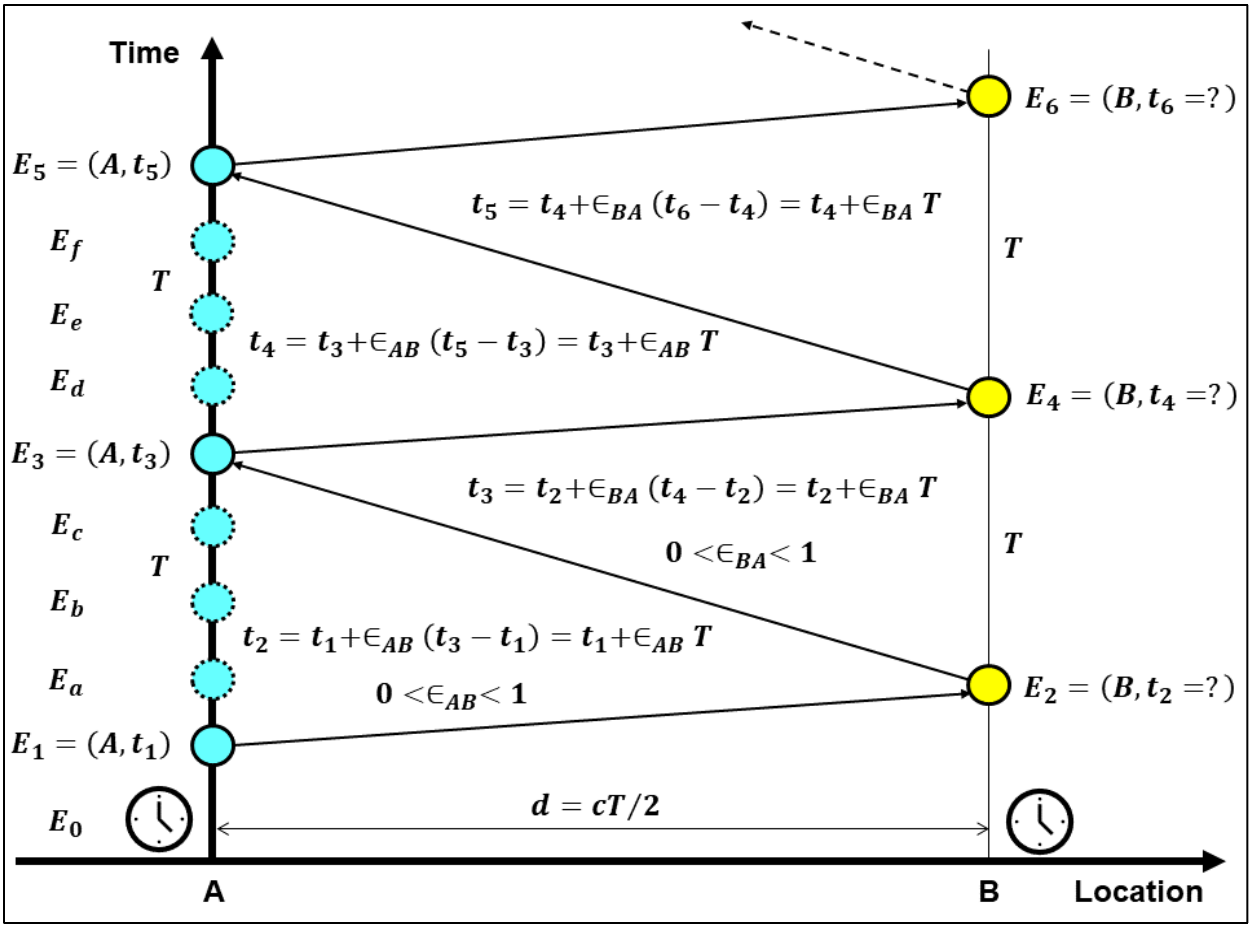

Figure 4 – Einstein-Reichenbach Signal Synchronization in Special Relativity

Formally and graphically, if E_1 is the departure event at A of a light ray, E_2 its reflection at B, and E_3 its arrival back at A, because light's motion constitutes a genidentical chain, we can affirm *without* any prior metric/synchronism for the clocks that the distant event E_2 must be timewise between the local E_1 and E_3 and, based on the Light-Limiting Postulate, that none of the events at A in the continuum between E_1 and E_3 (e.g. E_a, E_b, E_c) can be connected with E_2 at B via a light pulse, let alone via any other (slower) genidentical chain. And, due to Einstein's concealed Nonlocality-Exclusion Axiom, no causal reciprocal instantaneous chain (à la Newton's gravity) is allowed either. Likewise for any other light's roundtrip between A and B (e.g. $E_3 \rightarrow E_4 \rightarrow E_5$). Ergo, none of the events between E_1 and E_3 at A can be objectively said to be earlier than, simultaneous with, or later than E_2 at B; the same for the events between E_2 and E_4 at B with respect to E_3 at A; and so forth. Thus -unlike in Newton's world- for every pair of distant sites A and B, there is a topological gap in the continuum of those events at $A(B)$ that could be unambiguously ordered with respect to an event at $B(A)$. The events outside the gap at $A(B)$ are

[38] We saw that such 'isotropy' does not obtain in a non-Inertial Frame (Sagnac and Michelson & Gale experiments).

said to be timelike-separated from the event at $B(A)$; the events within the gap at $A(B)$ are said to be spacelike-separated from the event at $B(A)$; and the events on the endpoints of the gap at $A(B)$ are lightlike-separated from the event at $B(A)$. Recall that in Newton's universe, this gap degenerated to a point-Event – making simultaneity a purely ordinal objective and absolute notion.

Thus, because only roundtrip transit times are *quantifiable* without synchronization, and Einstein rejected Newton's 'Transported Synchrony' axiom, the number t_2 assignable to the clock at B after the one-way transit from A is not univocally determined: any value in the open temporal gap (t_1, t_3) is acceptable, namely: $t_2 = t_1 + \in_{AB} (t_3 - t_1)$ with $0 < \in_{AB} < 1$. Mutatis mutandis for t_4 and t_6. For all IFs, all events in the gap (E_1, E_3) at A are *topologically* simultaneous with E_2 at B; all events in (E_2, E_4) are *topologically* simultaneous with E_3, and so on (Figure 4). Because of this ordinal hiatus imposed by the limiting character of light's speed (absence of Newton's genidentical chains with arbitrarily high speeds), ***no*** mathematical limit can be claimed (as we did in Newton's world) to unequivocally set the clock at B; a conventionally selected value for $\in_{AB}$ is required. Even if the 'Transported Synchrony' postulate were true, the mere agreement between the readings of the A-clock when, say, E_a occurs and that of a clock transported from $E_0 < E_a$ at A arriving at B when E_2 occurs would not ensure the *simultaneity* between E_a and E_2. A metric consistently assigning *equal* durations to E_0E_a and E_0E_2 $\forall E_0 < E_a, \forall E_a \in (E_1, E_3)$ would be needed to call E_a and E_2 *simultaneous*, time-ordering the events within the ordinal hiatus (E_1, E_3) vis à vis E_2 [25].

In RT, metrical simultaneity depends upon the choice of $\in_{AB}$ within a given IF, and Einstein judiciously chose the value that provided maximum descriptive simplicity and made the simultaneity relation symmetric and transitive[39], namely $\in_{AB} = \in_{BA} = 1/2$. In short, he set $t_2 = t_b$, $t_4 = t_e$, etc. in Figure 4 and, ergo, by convention: $E < E_2 \; \forall E < E_b$; $E > E_2 \; \forall E > E_b$, etc. Furthermore, he sensibly chose the same synchrony criterion for all spatial directions in each IF (intrasystemic) as well as for all IFs (intersystemic). It is called the *standard* synchronization. Calling T the quantifiable roundtrip transit time, Einstein's synchronization technique is equivalent to assigning the same number $c = 2d/T$ to the one-way speed of light in all directions and, hence, all one-way transit times are equal to $T/2 = d/c$. Thus, unlike for the Newtonian universe, the following time intervals are metrically (though conventionally) equal: $t_2 - t_1 = t_b - t_1 = t_3 - t_2 = t_3 - t_b = T/2$. Graphically, E_2 is shifted up to align with E_b, E_4 with E_e, etc.

In RT, *simultaneity* requires positing some ***non***-factual metrical relations (deemed factual in Newton's world), making the resulting temporal order ***not*** always *objective* and, ergo, ***not*** always *absolute*. With his convention, Einstein proved that, besides the IF in which E_2 is *simultaneous* with E_b, there are IFs in which E_2 occurs *before* E_b, and others in which E_2 occurs *after* E_b. Again, these time-orders are not objective but non-trivially conventional: E_2 at B and any of the events at A in the gap (E_1, E_3) are topologically *simultaneous* and then their pairwise metrical *temporal* order changing from one IF to another does not contradict any facts in RT's Ontology. It is this ordinal gap and Einstein's *simultaneity* "definition" what made *simultaneity* between spacelike events to be relative to the IF, ***not*** the relative motion between IFs per se (as typically stated in the literature). Recall that in Newton's world, absolute *simultaneity* and relativity of *motion* coexisted.

Of course this relativity of time-order in RT is valid only for pairs of events ***not*** connectable by light-limited genidentical chains, the latter being (by decree) the only possible causal chains.

[39] Topological simultaneity is ***not*** transitive [19].

The events in such pairs are said to be *spacelike*-separated because there is always an IF in which both events would coincide in time and, ergo, their spacetime separation would be purely *spatial*. Note that two *spacelike*-separated events could still be causally related **in**directly via a common cause (from which they would be reachable via two light-limited genidentical chains) but that does ***not*** make their time-order objective. Instead, if they are directly and genidentically connectible, one of the events is objectively and absolutely either earlier or later than the other. When the genidentical chain is ***not*** light, they are *timelike* separated because there is always an IF in which both events would coincide in space and, hence, their spacetime separation would be purely *temporal*. If their connectivity via light is possible, they are called *lightlike* events, and there is no physical IF in which their spacetime separation is purely *spatial* or purely *temporal*.

In this fashion, with an imaginary stationary clock at each place of an IF -all of them so synchronized with a master stationary clock- Einstein calls *time* of an event the one given by the local clock *simultaneously* with the event's occurrence. Once Einstein's convention is adopted, *time* is common throughout the IF, i.e. *simultaneity* is absolute intrasystemically, but it is conventionally relative intersystemically[40]. In contrast, Newton's *simultaneity* was absolute both intrasystemically and intersystemically without requiring any (non-trivial) convention. It should be understood that in RT:

A. It is imperative for the synchronizing signal to be the fastest in the RT universe (it so happens that it is *light*)[41]. For, referring to Figure 4 (with $\in_{AB}=\in_{BA}=1/2$), if the gap (E_1,E_3) associated with E_2 corresponds to a synchronizing signal *slower* than light, the arrival event E_2' at B for any quicker signal from E_1 would be earlier than E_2; likewise, the return event E_3' at A would be earlier than E_3. Hence, the topological gap at A associated with E_2' would contain E_1 and, ergo, there would be an IF in which the termini events E_1 and E_2' for such a quicker signal from A to B would have their temporal order reversed. Dramatically: from the latter vantage point, a signal faster than the synchronizer one could arrive at B before it departed from A. More silly melodrama: a signal could be sent to the past! which is obviously against RT's tacit Ontology (and any other theory which proscribes *retrocausation* [53]). In RT (and in our QR/TOPI), *retrocausality* is avoided by synchronizing the clocks via the fastest signal (i.e. genidentical chain) in the Universe. But lamentably, it is commonplace to read that a "signal faster than light would make travel to the past possible"; to debunk such a cliché, all we would have to do is to use the allegedly faster signal as the synchronizer[42]. To be consistent with RT, whatever 'goes' faster than light ***cannot*** be a genidentical chain, whose events are all actual and *evincing* (carrying energy and momentum). As for *Retrocausality*[43], it is not logically impossible and cannot be proven physically impossible (though it would produce paradoxes galore). Its impossibility is an empirically backed conjecture in RT and in QR/TOPI.

B. It is Einstein's choice of $\in_{AB}=\in_{BA}=1/2$ within each and for all IFs (not the relative motion among IFs per se) that makes *simultaneity* IF-**Co**variant, i.e. relative to the IF. In fact, given any two spacelike events, they could be made absolutely (IF-**In**variant) *simultaneous* by using a different $\in_{AB}$ within and for each IF [17]. Notice though that, because of the ordinal gap (due

[40] For ***non***-inertial frames, Einstein's synchronization is not doable, so *simultaneity* is relative within the frame [217].

[41] Remember that the notion of 'fastest' does not require synchronization between clocks at origin and destination; the signal only needs to reach the destination first – as determined by the local clock (not even a metric is needed).

[42] The new fastest signal would have to replace *light* in Postulate 2 as the *universal constant*.

[43] Theories that admit retrocausality are also called 'causally symmetric' [152] [88] [29].

to the limiting character of light's speed), such absolute *simultaneity* would still be ***not*** objective because of its non-trivial concocted conventionality. Recall again that in Newton's theory, *simultaneity* was objective and absolute while velocity was objective and relative.

1.3.4.6 Shorter, Congruent, and Longer in the Spacetime of Special Relativity

As we saw, the *length* of an extended object is the *distance* between two simultaneous *events* at the object's termini. In Newtonian physics -being simultaneity absolute- the *length* of an object was the same regardless of its state of *motion* in the frame and so absolute across IFs. This assumption was considered one of those a priori synthetic truths admitting no doubt. However, we realized that the notion of *congruence* is meaningless unless the standard body (*ruler*) and the *object* are contiguous and relatively at rest. It was ignored for millennia that, even though we do need to displace the *ruler* over the object/segment, while the *ruler* is performing its *metric* function both bodies are in relative repose. And if the object is at rest in the IF, the time needed to complete the *congruence* is also unimportant. Einstein thus realized we needed to agree in what we mean by *length* of a *moving* object, viz an object at rest in an IF moving with respect to another IF in which the ruler is at rest [24]. As always, this new *definition* would have some *arbitrariness*, but it had to be a consistent extension of our prior *definition* based on the *congruence* of the rigid body. However the *length* of a *moving* object was to be defined, when the latter was at rest relative to the standard object, the new *definition* had to produce the same result as the traditional one.

As we already discussed, the first epistemic conundrum we face is that, from the very concept of measuring a length, two rulers which are in relative motion cannot be compared – so it is impossible to assess how many units of one correspond to the other. This is a clear sign of the need for a convention regarding the unit-length in different IFs: we convene in assigning the same length to a ruler regardless of its state of motion. Differently: the unit of length in an IF is (by convention) the unit of length in all IFs. Notice this has nothing to do with *simultaneity* [18].

Given inertial frames K and K', Einstein called *length* of a 'moving' object (at rest in K') the length obtained when measured with a ruler at rest in K, i.e. when no direct comparison is possible. Ergo, such a measurement can only be **in**direct and must involve the measurement of *time*, which means that it will depend on the convention chosen for simultaneity in both IFs. At a given instant in K, the object's physical termini (at rest in K') determine a *segment* in K: the simultaneous (in K) projection of the object in K' onto K. Keeping this *segment* now at rest in K, the standard procedure for measuring its length can be conducted, and the result is the 'moving-length' of the body at rest in K'. But in RT, two simultaneous events at the termini of the *segment* at rest in K are not simultaneous in K' (and vice versa), so the moving-length of an object is different from its rest-length. Tersely: the moving-length (the length in K) of an object at rest in K' is the distance between *simultaneous* positions of its termini in K [18]. We will denote this length by $l_{K'/K}$. Obviously, in the special case in which the relative speed between the *object* and *ruler* is zero (K and K' in relative repose) the new *definition* delivers the classical *rest-length*, i.e. $l_{K/K}$, which will be independent of the chosen convention for metrical simultaneity. But, in general, the simultaneity convention affects the *length* of an object in *motion* and, ergo, the measurement of *space* depends upon the measurement of *time*. Once we adopt a convention for *simultaneity* for all

IFs, the *moving-length*[44] is different from the *proper-length* $\left(l_{K'/K} \neq l_{K/K}\right)$ and depends upon the *speed* with which the body (at rest in K') is moving with respect to the reference frame (K).

By decreeing the *invariance* of object/standard *congruence* and convening in using the standard object as the common unit in all IFs, the rest-length (or proper-length) became a metrical *invariant* $\left(l_p = l_{K'/K'} = l_{K/K}\right)$. Besides, Einstein showed that if his "definition" of *simultaneity* $(\epsilon_{AB}=\epsilon_{BA}=1/2)$ was used throughout each and in all IFs, and its Postulate #2 (c is invariant) was valid, then the *moving-length* of a body *at rest* in K' (i.e. moving in K) is always shorter than its *length* when it is *at rest* in K, and such contraction factor is the same for the 'moving' length of a body at rest in K, i.e. moving in K'. Formally: $l_{K'/K} = \beta l_p$ with $\beta = \sqrt{1 - v^2/c^2} \leq 1$ with $v = v_{K'/K} = -v_{K/K'}$ the relative speed between frames[45]. The *moving-length*, viz the *length* referred to a frame in which the object is moving, changes with the frames' relative *speed* and the reason is its very definition – which involves the discordant *simultaneity* of the events at the object's termini in the two frames. Also, being the effect fully reciprocal $\left(l_{K/K'} = \beta l_p\right)$, it is pointless to ask which the 'real' or 'true' length is. They are **co**variant manifestations of the same Reality due to the relative motion between frames and Einstein's simultaneity convention being adopted in both of them.

We now see that the 'explanation' of the MME's negative result offered by the LFC/LLD-amended ether theory is flawed simply because -besides being ad hoc- it incorrectly assumes Newtonian behavior as intuitively self-evident so that any deviation from it mistakenly demands a physical cause. However, to be precise, RT does ***not*** explain MME's negative result either; it axiomatically adopts it: Einstein realized that *comparing* the proper-lengths of relatively moving rods required another convention and took avail of it by endowing two rods behaving as in the MME with the same proper-lengths $\left(l_{K'/K'} = l_{K/K} = l_p\right)$. In the MME, $l_{K'/K'}$ would be the rest-length of the parallel (to Earth motion) arm as measured in the 'moving' Earth (lab), and $l_{K/K}$ would be the same length of the same arm were it at rest in the 'immobile' ether. Instead, $l_{K'/K}$ would be the 'moving' length of the arm (at rest on Earth) in the 'immobile' ether. The numerical value of the LFC was not due to a physical contraction: it was due to a change in vantage point.

1.3.5 The Lorentz Transformation (LT)

After the MME, Lorentz deduced his eponymous transformation from the LFC/LLD-amended ether theory, a transformation he interpreted as relating the two sets of *spacetime* coordinates of an event in an arbitrary moving IF, e.g. the laboratory for the MME (where length and time-interval were 'apparent'), and the *ether* frame in absolute repose with absolute time (where length and time-interval were 'real'). Einstein arrived in 1905 at the same transformation, but he interpreted it as relating the *spacetime* coordinates of an event in any two IFs, abolishing the need for the privileged *ether* frame. The difference then was neither structural nor numerical (they were identical) but epistemic as well as ontic. Being so, historians, scientists, and philosophers who did not understand in depth the philosophical content and transcendence of RT, unjustly minimized Einstein's innovation [17] [18].

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[44] This length of a 'moving' object should not be confused with how we would actually see it: eye detection of photons emitted by/scattered from the object depends also on propagation time delays from its edges, optical aberration, etc.

[45] These are numerically the same β and v in the MME/KTE, where K' was the Earth and K was the immobile ether.

Without committing yet to Einstein's explicit/hidden postulates, given any inertial frame K, we assume the spatial geometry is Euclidean and consider two events $E_A = (x_1, x_2, x_3, t_A)$ and $E_B = (x_1 + \Delta x_1, x_2 + \Delta x_2, x_3 + \Delta x_3, t_A + \Delta t)$ connectable via a causal genidentical chain. We further assume that we managed to synchronize all clocks within each and all IFs so that arbitrary one-way speeds v_{AB} are univocally defined intrasystemically. Under those very general conditions, their space-interval for the two events must be equal to the causal chain's speed times their time-interval within any and for all IFs. Thus,

$$(\Delta x_1)^2 + (\Delta x_2)^2 + (\Delta x_3)^2 - v_{AB}^2 \Delta t^2 = 0 \qquad \forall\ E_A, E_B, K \tag{2}$$

Considering two frames K and K', and referring for now to the product of the speed with the time-interval as the fourth coordinate in each IF ($\Delta x_4 = v_{AB}\Delta t$; $\Delta x'_4 = v'_{AB}\Delta t'$), the following relation between the four intervals in K and in K' must be true:

$$(\Delta s')^2 = (\Delta x'_1)^2 + (\Delta x'_2)^2 + (\Delta x'_3)^2 - (\Delta x'_4)^2 \ ;\ (\Delta s)^2 = (\Delta x_1)^2 + (\Delta x_2)^2 + (\Delta x_3)^2 - (\Delta x_4)^2$$

$$(\Delta s')^2 = (\Delta s)^2 = 0 \qquad \forall\ E_A, E_B, K, K' \tag{3}$$

We call $(\Delta s')^2$ and $(\Delta s)^2$ the Event-Intervals for the events E_A and E_B in K' and K respectively. Choosing the coordinates of one of the events as the origin, to relate the two frames' four coordinates of the other event, we need an automorphism $x'_i = f_i(x_1, x_2, x_3, x_4),\ i = 1 \ldots 4$, i.e. a bijection within the class of IFs under which the Event-Interval is preserved in mathematical form and equal to zero in both frames. This is a well-known mathematical problem with a family of linear transformations as solutions. There is also another family of ***non***-linear transformations as solutions though, because all its members display a singularity, the *Principle of Locality*, spatial isotropy, and the homogeneity of space and time are violated – so it is discarded [18]. As for the linear solutions, each member of the family is identified by the value of an arbitrary parameter p:

$$x'_i = \sum_{j=1}^{j=4} a_{ij} x_j \quad with \quad a_{ij}: \left\{\sum_{k=1}^{k=3} a_{ki}\, a_{kj}\right\} - a_{4i} a_{4j} = \begin{cases} p^2 \ for\ i = j = 1, 2, 3 \\ 0\ for\ i \neq j \\ -p^2\ for\ i = j = 4 \end{cases} \tag{4}$$

Being all transformations in this family linear, the Galilean Transformation is included. Also, when we accept Postulate 2 ($x'_4 = ct'$; $x_4 = ct$) and $p = 1$, the resulting transformation is the Lorentz Transformation (LT), which has the property that not only $(\Delta s')^2 = (\Delta s)^2$ when their value is zero but always, i.e. all possible Event-Intervals are IF-Invariant (even when $(\Delta s)^2 < 0$). That is why many textbooks derive the LT in a straightforward mathematical manner from assuming such an IF-Invariance. But… what are the epistemic and ontic grounds for the family parameter p to be unity?

If we, in addition to Postulate 2, reject Newton's 'Transported Synchrony' and accept the Light-Limiting Postulate, then light can be used for synchronizing all clocks. As a result, we can use Equation 2 with $v_{AB} = c$, and Equations 3 with $\Delta x_4 = c\Delta t$ and $\Delta x'_4 = c\Delta t'$ in all IFs. Further, if we adopt Einstein's simultaneity convention, the convention on the metrical invariance of the proper-length of a rod (standard object as the common unit in all IFs), and use the definition of the length of a 'moving' rod, then the family's parameter p becomes unity, and the unique member of the family so identified is the Lorentz Transformation (LT) in its most general tetra-dimensional form [18]. It is thus crucial to realize that there is more behind the Lorentz Transformation than just the IF-invariance required by Equations 3 for lightlike events – even after having adopted Einstein's Postulate 1, Postulate 2, and his "definition" of simultaneity. Of course, as we saw, its verisimilitude can only be, and has been, determined by putting it to the empirical test.

Under all those conditions, when the origins of both IFs coincide, the 16 coefficients a_{ij} in Equation 4 reduce (besides light's speed c) to only one: $\vec{v}_{K'/K} = -\vec{v}_{K/K'}$, i.e. the reciprocal velocity between frames. Moylan in [54] explains in quite detail why the reciprocity of velocity is not necessary for the *Principle of Relativity* to hold, and which additional hypotheses (like homogeneity/isotropy of spacetime and preservation of time-order) are required for its validity – all of which and more have been already assumed. In four dimensions and in vectorial form (i.e. coordinate-independent), the LT (Equation 4 with $p = 1$) becomes:

$$\vec{r}' = \beta^{-1}\{\beta\vec{r} + \vec{v}_{K'/K}v^{-2}(\vec{v}_{K'/K}\cdot\vec{r})(1-\beta) - \vec{v}_{K'/K}t\} \quad ; \quad t' = \beta^{-1}\{t - (\vec{v}_{K'/K}\cdot\vec{r})/c^2\}$$

Where $\vec{r}'$ and $\vec{r}$ are the position vectors for the event in K' and K respectively; $\vec{v}_{K'/K}$ is the velocity of K' in K; $\beta = \sqrt{1 - \|\vec{v}\|^2/c^2}$; and the dot betwixt vectors denotes their scalar product[46].

Returning now to Cartesian coordinate-systems and, to simplify the math and focus on the concepts, we assume that K and K' have their coordinate-axes parallel, that they move relatively along the positive direction of their <u>common</u> x_1-axis (i.e. ${x_2}' = x_2$; ${x_3}' = x_3$), and the first coordinates x_1, x_1' will be simply referred to as x, x'. Doing so, $\vec{r} = x$; $\vec{v}_{K'/K} = v_{K'/K}$; $\vec{v}_{K'/K}\cdot\vec{r} = xv_{K'/K}$, and the LT takes its well-known simpler form[47]:

$$\begin{bmatrix} x' \\ t' \end{bmatrix} = \beta^{-1}\begin{bmatrix} 1 & -v_{K'/K} \\ -v_{K'/K}/c^2 & 1 \end{bmatrix}\begin{bmatrix} x \\ t \end{bmatrix} \quad ; \quad \begin{bmatrix} x \\ t \end{bmatrix} = \beta^{-1}\begin{bmatrix} 1 & -v_{K/K'} \\ -v_{K/K'}/c^2 & 1 \end{bmatrix}\begin{bmatrix} x' \\ t' \end{bmatrix} \qquad (5)$$

We see that direct and inverse LT transformations (Equations 5) are structurally identical, indicating that LT is fully <u>reciprocal</u> and, given that Newton's and Maxwell's Equations in the two frames are formally invariant, i.e. they transform via LT into themselves, no frame can be said to be moving or stationary, except pragmatically – demonstrating the equivalence and symmetry between the inertial frames and the impossibility of detecting ***not*** even their <u>relative</u> motion (without an external reference). This mathematical *group* property is referred to in the literature as Lorentz-Covariance or as Lorentz-Invariance. We will always use the latter idiom with the understanding that there are magnitudes which are IF-**Co**variant (they co-change with the IF), magnitudes which are IF-**In**variant, and equations (physical Laws) which are IF-**In**variant in their form[48]. For instance, Newton's Second Law remains in RT formally the same, i.e. IF-**In**variant but

[46] This LT for the spacetime coordinates is the basis for the LTs between other physical properties, e.g. the frequency of an electromagnetic wave. By comparing the LT for the *frequency* of a *plane electromagnetic wave* with the LT for the energy-momentum of a single *photon*, the Planck-Einstein relation $E = hf$ follows.

[47] It is the LT for a speed 'boost'. A boost plus a rotation plus a shift in spacetime is an element of the Poincaré group.

[48] The term 'covariance' is used in the literature to refer to the <u>in</u>variance of a physical Law in its <u>form</u> under a given group of transformations. We prefer to use the term 'formal invariance' and use 'covariance' in its etymological meaning: a magnitude covaries with another from IF to IF so as to preserve the form of their relation.

with *mass* and *force* now IF-**Co**variant ($m = m_0/\beta$) and *acceleration* IF-**In**variant. We say that those Laws (and the pertinent theory as a whole) are Lorentz-**In**variant. This invariance of the physical laws ensures that neither the MME nor any other experiment will allow us to detect the 'absolute' motion of our planet. Moreover, changing t and t' to $-t$ and $-t'$ we obtain:

$$\begin{bmatrix}\Delta x' \\ \Delta t'\end{bmatrix} = \beta^{-1}\begin{bmatrix}1 & v_{K'/K} \\ v_{K'/K}/c^2 & 1\end{bmatrix}\begin{bmatrix}\Delta x \\ \Delta t\end{bmatrix} \;\; ; \;\; \begin{bmatrix}\Delta x \\ \Delta t\end{bmatrix} = \beta^{-1}\begin{bmatrix}1 & v_{K/K'} \\ v_{K/K'}/c^2 & 1\end{bmatrix}\begin{bmatrix}\Delta x' \\ \Delta t'\end{bmatrix} \tag{6}$$

Equations 6 show that reversing the direction of time in both frames results in merely reversing the direction of motion between frames. Therefore, the processes obeying LT are fully <u>reversible</u>, confirming that no energy degradation is included in RT [33]. The equations also show that two events *simultaneous* in K ($\Delta t = 0$) will ***not*** be simultaneous in K' ($\Delta t' \neq 0$) – unless they occur in the plane perpendicular to the direction of motion ($\Delta x = 0$). In addition, the LT plus all its properties and consequences are still valid if time is assumed to be <u>discrete</u> while space remains continuous [55].

Finally, from Equations 5, it follows that the Galilean simple summation of an object's velocities $\vec{v} = (v_1, v_2, v_3)$ and $\vec{v}' = (v'_1, v'_2, v'_3)$ in the above-defined two IFs (i.e. K'moving along the x_1-axis of K) is replaced by:

$$\begin{aligned} v'_1 &= (v_1 - v_{K'/K})/(1 - v_1 v_{K'/K}/c^2) \quad ; \quad v_1 = (v'_1 - v_{K/K'})/(1 - v'_1 v_{K/K'}/c^2) \\ v'_2 &= \beta\, v_2/(1 - v_1 v_{K'/K}/c^2) \quad ; \quad v_2 = \beta\, v'_2/(1 - v'_1 v_{K/K'}/c^2) \\ v'_3 &= \beta\, v_3/(1 - v_1 v_{K'/K}/c^2) \quad ; \quad v_3 = \beta\, v'_3/(1 - v'_1 v_{K/K'}/c^2) \end{aligned} \tag{7}$$

Equations 7 are clearly IF-Invariant and tell us: (a) $(|\vec{v}'| < c) \wedge (|v_{K/K'}| < c) \Rightarrow |\vec{v}| < c$, so we cannot make the speed of a cannon's shell higher than c by simply piling up moving launching platforms: its ever growing speed would simply approach asymptotically the speed of light without ever achieving it; and (b) the composition of the speed of light with that of any slower object gives again the speed of light. Notice though that the condition $|v_{K'/K}| = |v_{K/K'}| < c$ in (a) is a given (otherwise β would be imaginary) but object's speeds equal or larger than c in both frames are ***not*** forbidden by Equations 7, which corroborates that Einstein's Light-Limiting Postulate is not contained in this new velocity composition and that -as explained before- MME/KTE did <u>suggest</u> such limiting character of light but ***not*** implied it. Equations 7 are implied by LT (but not the way around in toto); as we saw, it is the LT the one that has the Light-Limiting Postulate (among others) built-in [23] [17].

Nothing better than a few numbers and their graphical depiction to understand the new composition of velocities given by Equations 7. Because the latter equations will become integral part of our Quantumlike Transformation (QLT) and because -to fully develop QR/TOPI- we shall use such an experimental setup profusely, Figure 5 corresponds to two quantons (e.g. photons in optic fibers) simultaneously launched in frame K with effective velocities $v_A = -0.69c$ and $v_B \cong +0.53c$ along the x-axis towards stations A and B where PDI-Events may occur. We will see in Section 3.1 that, under the appropriate conditions, despite the quanton ***not*** being a point-object, it can be considered as following a m**a**cro-trajectory in spacetime (a genidentical chain as it were).

Different velocities in opposite directions are assumed because, in an optic fiber implementation, effective outer speeds much lower than the actual inside the fiber ($\sim 0.69c$) can be obtained by coiling the fiber to increase its length while keeping/reducing the outside distance from the emitter to the detector. The plot assumes the product of the coil diameter with the number of turns is 0.1. Frame K' moves relative to frame K with velocity $v_{K'/K} \in (-c, c)$; v'_A (blue curve) and v'_B (red curve) are the quantons' velocities in frame K' per the Lorentz Transformation (Equations 7-top). The dotted straight lines correspond to the Galilean Transformation.

We see that: (a) only when the frames are in relative repose the photon's velocities in K' are equal to the values in frame K; (b) when K' moves towards $A(B)$ at the photon's speed $v_A(v_B)$ in K, then the corresponding photon's speed $v'_A(v'_B)$ in K' is zero; (c) when $v_{K'/K}$ approaches $\mp c$, the photons' velocities approach equality towards $\pm c$; and (e) in between, when $v_{K'/K}$ varies from $-c$ to $+c$, both velocities in K' monotonically decrease from c to $-c$.

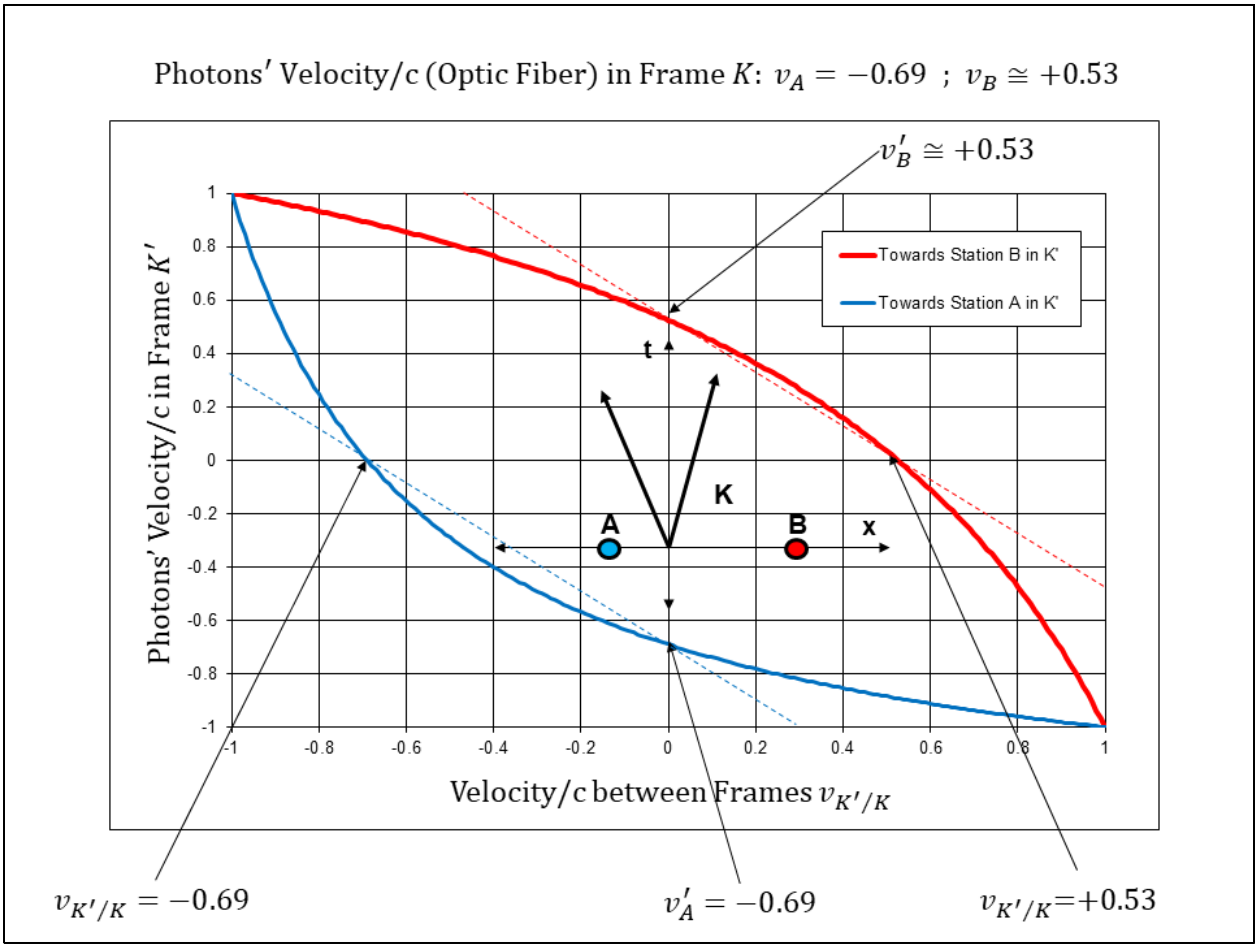

Figure 5 – Velocities of two Photons separating in Frame *K* as described in Frame *K'*

The shown blue and red curves in K' fall between two (not shown) extreme behaviors: (1) when the quantons' speed in K approaches zero, the two curves (and their Galilean straight counterparts) get together as a straight line with slope -1 because the velocities in K' are the opposite of K' speed in K $(v_{K'/K})$; (2) when the quantons approach light's speed in K, the blue curve drops abruptly from c to $-c$ for $v_{K'/K} = -c$ and stays there regardless of the frames relative speed, while the red curve stays horizontal at c from $v_{K'/K} = -c$ all the way to $v_{K'/K} = c$, at which it drops abruptly to $-c$.

1.3.6 The Metrics of Spacetime in the Special Relativity Theory

In 1908, Minkowski focused on the invariance of Δs^2 and its implications. Using again $v_{K'/K} = -v_{K/K'} = v$, such invariance can be easily confirmed from Equations 5:

$$(\Delta s')^2 = \Delta x'^2 - c^2\Delta t'^2 = \beta^{-2}\{\Delta x - v\Delta t\}^2 - c^2\beta^{-2}\{(-v/c^2)\Delta x + \Delta t\}^2 = \Delta x^2 - c^2\Delta t^2 = \Delta s^2$$
$$\Downarrow \qquad (8)$$
$$(\Delta s)^2 = (\Delta x)^2 - c^2(\Delta t)^2 = (\Delta x')^2 - c^2(\Delta t')^2 = (\Delta s')^2 \quad \forall\, \Delta x \ \forall\, \Delta t$$

Time and space intervals for two generic events E_0 and E depend on the frame, but $(\Delta s)^2$ (in form and value) does not, i.e. it is an absolute[49]. Besides, if $(\Delta s)^2 > 0$, the quantity $\delta = +\sqrt{(\Delta s)^2}$ is clearly also an absolute and is called the proper-distance betwixt E_0 and E. And, if $(\Delta s)^2 < 0$, the quantity $\tau = +\sqrt{-(\Delta s)^2}/c$ is also an absolute called the proper-time between E_0 and E.

From all the above, the Event-Interval defines a *metric* providing *spacetime* with a unique hyperbolic geometry. The opposite sign for *time* and *space* coordinates in the *metric* patently indicates the utter difference between *space* and *time*. Note also that the *metric* does not contain cross-products between the coordinate increments and that the coefficients are constant throughout each IF and IF-**In**variant. Most generally: using super-indices for the spacetime coordinates with $x^4 = ct$ and applying Einstein's summation convention, the tetra-dimension differential version of Equation 8 is $ds^2 = \eta_{ij}dx^i dx^j \;\; i,j = 1,2,3,4$ with $[\eta_{ij}] = Diag(1,1,1,-1)$ being the *Metric Tensor*. Hence, despite RT-*spacetime* being non-Euclidean, its *Curvature Tensor* is zero and it is said that *spacetime* in Special Relativity is 'flat'[50] [56]. Instead, in a non-Inertial Frame, even with a nil *Curvature*, the *Metric Tensor* would depend on the *spacetime* coordinates and would not be invariant under a general transformation that kept the Event-Interval invariant [49] [32].

In Figure 6, E_0 is chosen as the common origin of the coordinate systems for K and K', which are superposed in the same graph. Because Einstein chose $\epsilon_{AB} = 1/2$ for all IFs, and due to our choice of units for space (light-sec) and for time (sec), c is equal to one light-sec/sec and the light's worldlines (at 45º and 135º) must bisect the coordinate axes in all IFs. Time and space axes of K' are thus determined by v, approaching K axes as $v \to 0$ and the invariant light's worldline as $v \to c$. The blue and green hyperbola branches are the loci of the spacetime K-coordinates of all event E for which their Event-Intervals with E_0 are equal to -1 and $+1$ respectively. Being the Event-Interval absolute ($(\Delta s)^2 = (\Delta s')^2$), those branches allow us to understand and assess the intrasystemic and intersystemic relations in a single graph. Figure 6 also shows three possible E events: a) E_1 (blue) on K' time-axis (red) and blue hyperbola branch ($\Delta s^2 = -1$); b) E_2 (green) on K' space-axis (red) and green hyperbola branch ($\Delta s^2 = +1$); and c) E_3 (orange) on the light's worldline ($\Delta s^2 = 0$).

[49] Likewise, other combinations, e.g. 'energy-momentum' and 'electric charge-electric current' are IF-invariants.
[50] The Minkowski spacetime is a particular solution of the GRT's field equations in vacuum.

Though superposing the coordinate systems for the two IFs is very powerful, its interpretation is thorny because -despite geometrical appearances for K'- both coordinate systems are Cartesian (i.e. orthogonal). Hence, care is to be taken when drawing graphical conclusions. For instance, being the *metric* hyperbolic, the Event-Interval between two events agrees with their graphical distance only when it is purely temporal (e.g. $E_b E_1$) or purely spatial (e.g. $E_f E_c$). Otherwise, e.g. events E_1 and E_a have very different distances to the origin, despite having the same Event-Intervals with the origin in K because they both lie on the hyperbola $\Delta s^2 = -1$. And, because the Event-Interval is absolute, $(\Delta s')^2 = -1$, so Event-Intervals $E_0 E_1$ and $E_0 E_a$ are also equal in K'.

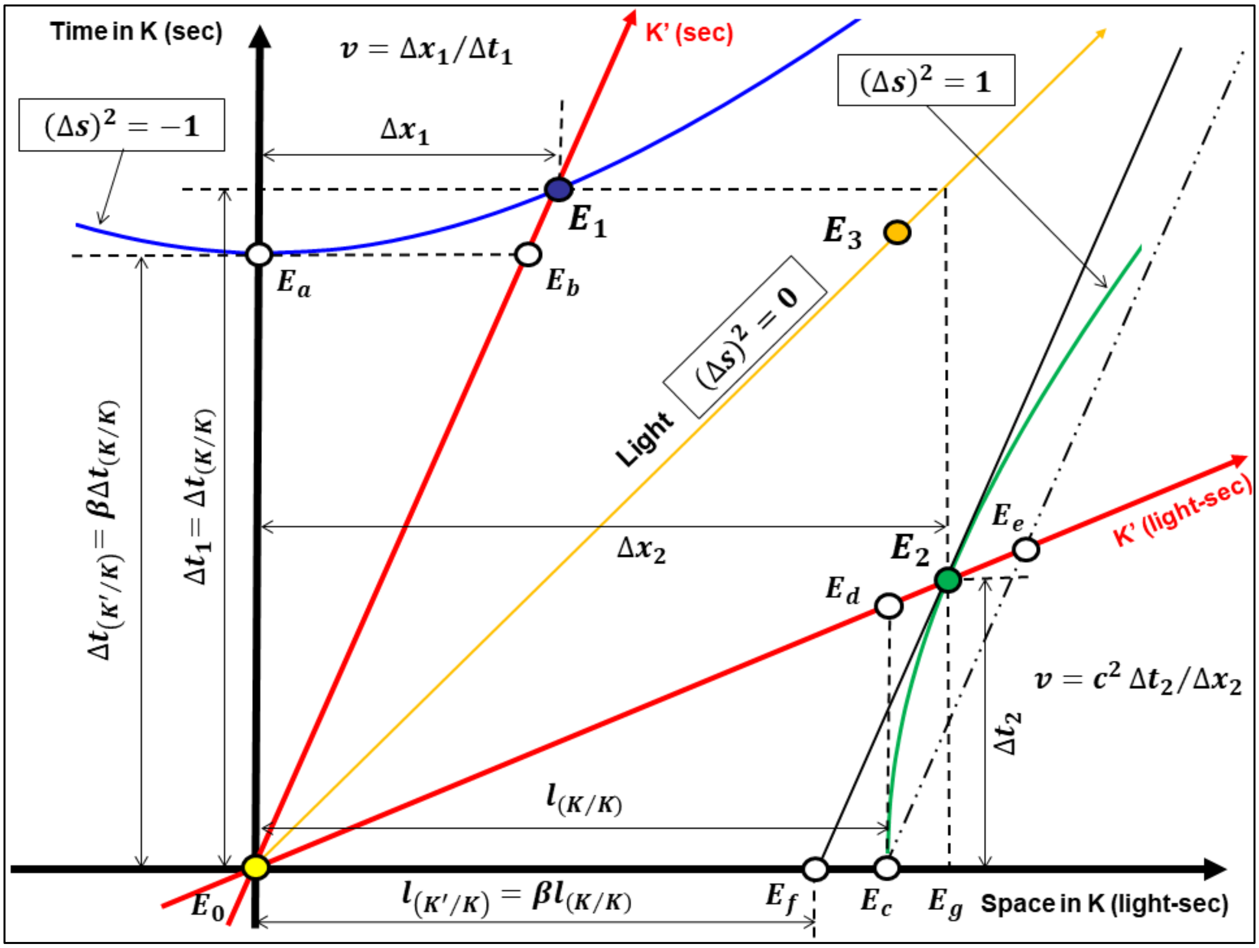

Figure 6 – Kinematic Time Dilation (KTD) and Length Contraction (LC)

With that caveat, it is clear that the time-axis of K' is also its own worldline in K. Differently: a clock at rest in K' is uniformly moving in K with speed v so if E_1 is its tick-Event ($\Delta t'_1$), then $\Delta x_1 = v \Delta t_1$, with Δt_1 the time-interval displayed by a clock at rest in K and Δx_1 its space-coordinate in K when E_1 occurs. It is also evident that the K'*space*-axis and any other line parallel to it contain all the events that occur at the same *time*[51] in K', though they constitute a succession of events in K: two events simultaneous in K' are sequential in K. This is the relativity of simultaneity due to the Light-Limiting Postulate and Einstein's same simultaneity convention for

[51] In a 3-dimensional spacetime there are two space-axes and those *simultaneity* lines in each frame are *simultaneity* planes. In our 4-dimensional spacetime, they are *simultaneity* hyperplanes (3-dimensional Euclidean space).

all IFs. In addition, graphical symmetry shows that as long as E_1 stays on K'-time-axis and E_2 on K'-space-axis, the relative velocity between frames is $v = \Delta x_1/\Delta t_1 = c^2\,\Delta t_2/\Delta x_2$ with the spacetime-coordinates being those of K. This is because the two angles between prime and unprimed corresponding axes are equal, while $c^2 = 1$ simply adjusts the physical units.

1.3.7 Types of Event-Intervals

In RT, recalling that all events are *actual* and *evincing*, four disjoint types are possible for the invariant Event-Interval between any pair of events E and E_0:

Type 0 Even-Interval

$E = E_0$ so $\Delta x = \Delta y = \Delta z = \Delta t = 0$ and $\Delta s^2 = 0$ for all IFs. This simply means that the intersection of two worldlines must be absolute. More practical (due to continuity): two events contiguous in spacetime in one IF must be so in all IFs. The spatial coincidence of two point-objects is an event and, ergo, with objective significance. Thus, the two objects' spacetime coordinates for the coincidence event within an IF -albeit different for each IF- must be respectively equal to each other in all of them[52]. But the objects may be clocks (or carry clocks with them) so their spatial contiguity allows for comparison of two clocks in relative motion and, thus, may not display the same time. Those different times displayed by the two clocks are not to be confused with the time coordinate at which the spatial coincidence occurs in a given IF (which only agrees with the reading of any clock at rest in that IF).

Type 1 Event-Interval (Timelike Separation)

E is *timelike*-separated from E_0 if and only if they are connectible by a subluminal genidentical chain. In such a case: (a) $\Delta s^2 < 0$; (b) their time-order is IF-Invariant; (c) their ***non***-zero time-interval is IF-Covariant; (d) the time-magnitude $\Delta\tau = +\sqrt{-\Delta s^2}/c$ is called the proper time-interval and is clearly IF-Invariant; and (e) there is a unique frame K' in which E and E_0 have the same space-coordinates, i.e. they lie on its time-axis, making the Event-Interval purely temporal. For any other IF, the Event-Interval would comprise both *timelike* and *spacelike* components along the frame's axes. Event E can be any within the past and future light-hypercones of E_0, viz in the zone defined by the two $45°$ and $135°$ golden diagonals and containing the K time-axis. We chose E to be E_1, which is on the blue hyperbola $\Delta s^2 = -1$, intersecting the K time-axis on event E_a. Thus, being $E_o E_a$ and $E_o\, E_1$ respectively on K and K' time-axes, E_a marks the end of the first period (tick) of the master clock in K $\left(\Delta\tau = +\sqrt{-\Delta s^2}/c = 1\right)$, and E_1 marks the end of the same period of the master clock in K' $\left(\Delta\tau' = +\sqrt{-(\Delta s')^2}/c = 1\right)$. Their equality is due to E_1 and E_a lying on $K'$and K time-axes, both being on the unit-hyperbola $\Delta s^2 = -1$, and the invariance of the proper time-interval. In sum, because the tick-Events of a clock are timelike-separated, unlike in Newton's theory, in RT a clock moving in K does ***not*** mark its coordinate time-interval Δt but the proper time-interval $\Delta\tau = +\sqrt{\Delta t^2 - (\Delta x^2 + \Delta y^2 + \Delta z^2)/c^2}$, which is an absolute and only agrees with Δt if the clock is at rest in K $(\Delta x = \Delta y = \Delta z = 0)$.

Type 2 Event-Interval (Spacelike Separation)

[52] Incidentally, this was Einstein's "point-coincidence argument" for requesting the 'general covariance' of a physical law – a property dismissed by Kretschmann in 1917 as merely mathematical without physical meaning [215].

Event E is *spacelike*-separated from event E_0 if and only if they are ***not*** connectable by any RT-genidentical chain (not even by light). In such a case: (a) $(\Delta s)^2 > 0$; b) their *topological* simultaneity is absolute but their *metrical* simultaneity and time-*order* are relative to the IF, i.e. ***not*** objective but conventionally established by the LT; (c) the space-magnitude $\Delta\delta = +\sqrt{\Delta s^2}$ is called the proper-distance and is clearly IF-Invariant; and (d) there is a unique frame K' in which E and E_0 are simultaneous, viz the events lie on its space-axis, so the Event-Interval is purely spatial. For any other IF, the Event-Interval would comprise both *timelike* and *spacelike* components. Event E can be any outside the hyper light-cones, i.e. the zone defined by the two $45°$ and $135°$ golden diagonals and containing the K space-axis. For graphical and conceptual simplicity, we chose E to be E_2, which lies on the space-axis of the unique frame for Type 1, making the referred unique IFs for E_1 and E_2 equal (K'). Thus, E_2 lies on the green hyperbola $\Delta s^2 = 1$, which intersects the K space-axis on event E_c. Ergo, being $E_o E_c$ and $E_o\, E_2$ respectively on K and K' space-axes, E_c occurs at the end of a unit-segment in K $\left(\Delta\delta = +\sqrt{\Delta s^2} = 1\right)$, and E_2 occurs at the end of a unit-segment in K' $\left(\Delta\delta = +\sqrt{(\Delta s')^2} = 1\right)$. Their equality is based on E_2 and E_c lying on $K'$and K space axes, both being on the unit-hyperbola $\Delta s^2 = 1$, and the invariance of the proper-distance. Hence, due to the distinctive symmetry of LT, we could say that -in contrast to Newton's theory- a ruler moving in K does ***not*** measure the coordinate space-interval $+\sqrt{(\Delta x^2 + \Delta y^2 + \Delta z^2)}$ between simultaneous events occurring at the object's termini at rest (proper-length) but the proper-distance $\Delta\delta = +\sqrt{\Delta s^2}$, which is an absolute and only agrees with the proper-length $\left(\Delta\delta = l_p = +\sqrt{(\Delta x^2 + \Delta y^2 + \Delta z^2)}\right)$ if the ruler is at rest in K $(\Delta t = 0)$.

Type 3 Event-Interval (Lightlike Separation)

Event E is *lightlike*-separated from event E_0 if and only if they can belong to a light's genidentical chain. In such a case, in ***no*** unique IF the Event-Interval is either purely temporal or purely spatial. Such light's worldline bisects the axes of any IF; the Event-Interval (Δs^2), the proper time-interval $\left(+\sqrt{-\Delta s^2}/c\right)$, and the proper-distance $\left(+\sqrt{\Delta s^2}\right)$ are null. The event E is displayed in Figure 6 as E_3 and can be any event along the light-hypercone. Notice that in this case (as in Type 1) the events are genidentically connectible so their temporal order is IF-Invariant but now, because ***no*** positive-rest-mass object can move at the speed of light, ***no*** IF exists in which the events lie on the time-axis or on the space-axis. ***Only*** light can connect them.

1.3.7.1 Type 1 Event-Intervals → Kinematic Time Dilation (KTD)

For Type 1 events $(E_o\, E_1)$ we can state: (a) because the clock at rest in K' is moving in K uniformly with speed v, we have $\Delta x_1 = v\Delta t_1$ where $\Delta t_1 = \Delta t_{K/K}$, i.e. the time-interval in K displayed by a clock stationary in K; (b) $(\Delta s_1)^2 = (\Delta x_1)^2 - c^2(\Delta t_1)^2 < 0 \Rightarrow \Delta\tau = +\sqrt{-\Delta s^2}/c = +\sqrt{c^2(\Delta t_1)^2 - (\Delta x_1)^2}/c$; and (c) being both events on K' time-axis we have $\Delta x_1' = 0 \Rightarrow (\Delta s_1')^2 = -c^2(\Delta t_1')^2 \Rightarrow \Delta\tau' = +\sqrt{-(\Delta s')^2}/c = \Delta t_1'$, with $\Delta t_1' = \Delta t_{K'/K'}$. Therefore, based on the invariance of the proper time-interval across frames, we obtain:

$$\Delta\tau' = \Delta t_1' = \Delta\tau = +\sqrt{c^2(\Delta t_1)^2 - (v\Delta t_1)^2}/c = +\sqrt{(1 - v^2/c^2)}\,\Delta t_1 \Rightarrow \Delta t_{K'/K'} = \beta\Delta t_{K/K} \quad (9)$$

The last relation is between the readings of each clock at rest in relatively moving frames. Curtly: moving clocks lose synchrony. To refer this difference to a single frame (K), calling $\Delta t_{K'/K}$ the time at the intersection (E_a) of the blue unit-hyperbola with the K time-axis, and being $\Delta s_1'$ and Δs_a equal and both purely temporal, we have $(\Delta s_1')^2 = -c^2(\Delta t_1')^2 = (\Delta s_a)^2 = -c^2 \Delta t_{K'/K}^2$, from which we get $\Delta t_{K'/K} = \Delta t_1' = \Delta t_{K'/K'}$, arriving at $\Delta t_{(K'/K)} = \beta \Delta t_{(K/K)}$. Notice I used both the invariance of the Event-Interval on the hyperbola within K and the invariance of the Event-Intervals across frames. This intersystemic relation (now referred to a single frame) shows that, using K as the reference ('stationary'), the time-interval elapsed in K' ('moving') is β times shorter than the time-interval elapsed in K. This is the 'Kinematic Time Dilation' (KTD) effect[53]. That is why it is loosely said that a velocity boost on a clock makes it run 'slower'.

Graphically, as the clock at rest in K' moves in K, it has still not finished its first period (E_b still away from the unit-hyperbola) by the time the clock at rest in K has (E_a already on the unit-hyperbola). Equivalently, when the 'moving' clock completes its first period (E_1), the 'stationary' clock is already at a fraction of its second period. Reciprocally (a source of deep confusion), given the symmetry of the LT, it is also true that $\Delta t_{(K/K')} = \beta \Delta t_{(K'/K')}$.

Summing up, this KTD effect (retardation of a 'moving' clock) is ***not*** a phenomenon that needs a causal explanation: it is a reciprocal[54] effect between any two IFs: describing Reality from K, a time-interval between two events given by a clock stationary in frame K' (in relative motion with K) is β times ***shorter*** than the one given by a clock stationary in K and, reciprocally, describing Reality from frame K', the time-interval between the same events but given by a clock stationary in K (in relative motion with K') is β times ***shorter*** than the one given by a clock stationary in K'. But being the Event-Interval of Type 1, i.e. realizable by a subluminal genidentical chain, the *time-order* is absolute (Lorentz-**In**variant); only the *metrical* time-interval for a given time-order is relative (Lorentz-**Co**variant). In RT the *time-interval* is relative to the IF and it is only when this symmetry between alternative frames (presumed *inertial*) is erroneously taken for granted that the famous paradoxes appear (e.g. the Twin/Clock Paradox).

1.3.7.2 Type 2 Event-Intervals → Length Contraction (LC)

The length of an object in an IF is the space-interval between two simultaneous (ergo Type 2) events at the object's termini. For simultaneous events E_o and E_2 in K' we can state: (a) $(\Delta s_2')^2 = (\Delta x_2')^2 \Rightarrow \Delta\delta' = \Delta x_2'$; (b) $\Delta t_2 = v\,\Delta x_2/c^2$ (see Figure 6); and (c) $(\Delta s_2)^2 = (\Delta x_2)^2 - c^2(\Delta t_2)^2 > 0 \Rightarrow \Delta\delta = +\sqrt{(\Delta x_2)^2 - c^2(\Delta t_2)^2}$. Thus, based on the invariance of the proper-distance across frames, we obtain:

$$\Delta\delta' = \Delta x_2' = \Delta\delta = \sqrt{(\Delta x_2)^2 - c^2(v\,\Delta x_2/c^2)^2} = \sqrt{(1 - v^2/c^2)}\,\Delta x_2 \;\;\Rightarrow\;\; \Delta x_2' = \beta \Delta x_2 \qquad (10)$$

The last equation relates quantities in different frames but because E_0 and E_2 are simultaneous in K' but ***not*** in K, the relation is ***not*** between proper-lengths of an object in each frame; it could not be because, in RT, the rest-length of an object is IF-Invariant. The spatial distance $\Delta x_2'$ is the

[53] Before Einstein, $\Delta t_{(K/K)}$ was the absolute 'real' time, $\Delta t_{(K'/K)}$ the 'apparent local' time, and β the LLD factor.

[54] As opposed to Gravitational Time Dilation in GRT, which is ***not*** reciprocal [56] [18] [23].

proper-length $\left(l_{K'/K'}\right)$ of a unit-rod at whose termini the events E_0 and E_2 occur, while the spatial distance Δx_2 is merely the spatial K-coordinate of the event E_2.

To refer Equation 10 (Right) to a single frame (K), from the hyperbola's tangent at E_2, we get $\overline{E_o E_c} = \sqrt{\overline{E_o E_f} . \overline{E_o E_g}} \Rightarrow \overline{E_o E_f} / \overline{E_o E_c} = \overline{E_o E_c} / \overline{E_o E_g} \Rightarrow \overline{E_o E_d} / \overline{E_o E_2} = \overline{E_o E_f} / \overline{E_o E_c} = \beta$ and, given that E_2 and E_c are on the hyperbola $(\Delta s)^2 = +1$, if $\overline{E_o E_c} = l_{K/K}$, i.e. the length in K of an object at rest in K (proper-length), then $\overline{E_o E_f} = l_{K'/K}$, viz the 'moving length' in K of the same unit-rod. Thus, because $\Delta s_2'$, Δs_2, and Δs_c are all equal, we have $l_{K'/K} = \beta l_{K/K}$. This intersystemic relation (referred to K) is the 'Length Contraction' (LC) effect and the reason why it is loosely said that a velocity boost to an extended object makes its length (or the distance between two co-moving point-objects) shorter. It is instructive to realize that, according to Galileo/Newton, as K' moves in K, E_c moves along the twice-dotted-line parallel to K' time-axis (rod's length for them was absolute) but, according to RT, it moves along the parallel solid-line starting at E_f and meeting (of course) E_2 – showing that $\overline{E_o\, E_d} < \overline{E_o\, E_2}$ because of Einstein's contraction, and that $\overline{E_o\, E_2} < \overline{E_o\, E_e}$ because of the LFC. Notice as well that $\overline{E_o E_2} / \overline{E_o E_e} = \beta$, explaining the numerical agreement between Einstein's and Lorentz's contractions despite being semantically very different. Remember again that the Event-Intervals $E_o\, E_2$ and $E_o\, E_c$ are equal to unity because they are on the unit-hyperbola and that, because they are on the respective space-axes, they are purely *spatial* (the termini-Events are simultaneous) in their respective frames.

Like the KTD, the LC is ***not*** a phenomenon that requires a causal explanation; it is a reciprocal effect between any two IFs due to Einstein's definition of *length* for a *moving* object. Also, the *contraction* occurs only in the direction of *motion*; the object's dimension in the direction perpendicular to that of the *motion* does not change. Describing Reality from frame K, the *length* for an object stationary in frame K' (in relative *motion* with K) is β times ***shorter*** than its length had the object been *at rest* in K and, reciprocally, describing Reality from frame K', the *length* of an object stationary in K (in relative *motion* with K') is β times ***shorter*** than its length had the object been at rest in K'. In RT the *space-interval* for simultaneous events (length of a rod at whose termini the events occur) is relative to the IF and, being the Event-Interval of Type 2 (***not*** realizable by a light-limited genidentical chain), their *time-interval* and ***even*** their *time-order* are relative. But recall that what is IF-relative is the moving length of the rod; instead, the proper-length is IF-Invariant because by definition the rod has to be at rest in the IF (where the ruler lies). And, let me emphasize again that it is only when this symmetry between alternative frames (presumed *inertial*) is erroneously taken for granted that the famous paradoxes appear (e.g. the Clock/Twin Paradox).

1.3.8 The LT vis à vis LFC/LLD Effects and other Transformations

It is worth noting once more that the ratio β of RT is numerically equal to that of the infamous LFC and LLD effects. However, their meanings are starkly different: in RT, β is the ratio between the lengths of a rod and time-intervals of a clock at rest in different IFs when described from a single IF and within (of course) the same theory; while in LFC and LLD effects, β is the ratio between the lengths of the rod and time-intervals in the same IF (ether) for two different theories: the 'doubly amended ether theory' and the 'original ether theory'. Despite their utter semantic difference, both 'contractions' and 'dilations' are numerically equal (Figure 6). Those who are still looking for a physical cause for such 'contraction' and 'dilation' are simply unwilling to admit that (despite abundant evidence to the contrary) they subconsciously attribute universal validity to the immobile-ether theory of Newton/Maxwell and, ergo, they believe that any deviation from it must be explained by a physical cause. It is illuminating to understand that even RT has LFC and LLD, simply because Einstein's contraction/dilation numerically agree with the LFC/LLD-amended theory and hence it differs from the original ether theory in the same way [18].

Finally, it is also interesting to highlight once again that the Voigt's variation of LT was also compatible with both MME and KTE, and that its difference with the LT was the magnitude of KTD and LC. The Ives-Stilwell experiment in 1938 (confirming the relativistic Doppler effect), its many modern versions, the Mössbauer's rotor experiment, data on disintegration of mesons, and a plethora of high-precision experiments have confirmed the validity of the LT and, ergo, the falsity of Voigt's and many other -still fiercely defended- transformations.

1.3.9 Slow-Clock-Transport Synchronization vis à vis Einstein's Synchronization

Postulates like Newton's 'Transported Synchrony' are, of course, based on some factual evidence already available when adopted so… if Einstein rejected it while we are still successfully using Newton's theory in a multitude of situations, who was right? or better, when is Newton's assumption valid within Einstein's theory? Even better: how can we transport a clock without destroying its synchrony with another clock? After all, had Augustine of Hippo known of pocket chronometers, he would not have imagined his ornate messaging scheme to confute Astrology. Einstein's rejection of Newton's axiom consisted in asserting that the spontaneous readings of clocks synchronized at A will in general differ upon arriving simultaneously at B via different worldlines. Hence, merely transporting a clock cannot establish a *common* time in an IF – rendering intrasystemic synchronization a matter of convention and, choosing Einstein's convention ($\in_{AB}=\in_{BA}=1/2$) throughout, the intersystemic discordant time-order between spacelike events in two IFs are related via the LT. Is then clock-transport synchronization absolutely useless? Of course not: clocks are objects, so their RT behavior at relative speeds much lower than the speed of light approaches the one predicted by Newton's theory and, strikingly, the synchronization attained by such slow transport practically agrees with Einstein's synchronization technique via light signals. Following Grünbaum in [25], let us formally prove it.

Initializing the clock at A as indicated with $t_0 = 0$, Figure 7 depicts the referred intrasystemic discordance (per RT) among the final time-numbers t_{Fj} (on the right) displayed by clocks departing from A at ever earlier times $t_j \to -\infty$ per the local clock (left), while all arriving at the same event E_B, i.e. *simultaneously* per the local clock at B. Hence, regardless of the *time* shown by a clock when arrives at B, the earlier it departed from A, the lower the speed it has had to reach B. It would thus be inconsistent to assign to the local clock at B the time displayed by a clock that was synchronized with the clock at A and transported to B with an arbitrary velocity. Let us validate this claim by quantifying all the traveling clocks' readings.

Choosing E_A to be lightlike-connected to E_B, under Einstein's convention, we have $t_B = t_E$ where t_E is half the A-local time the light beam departing at t_A takes to return to A after reflecting from B, viz: $t_B = t_A + d/c$. This makes the speed v_j of a clock departing from A at time $t_j < t_A$ and arriving at B at time t_B to be $v_j = d/(t_B - t_j) \to 0$ as $t_j \to -\infty$. So for a clock that leaves at $t_0 = 0$, upon arriving at B we have $t_B = d/v_0$, which makes the departure time for the light beam to be $t_A = d/v_0 - d/c$. Remember that t_A and t_B are respectively the departure and arrival times for a light beam, so $t_B = d/v_0$ is (per RT) the time of arrival at B for all clocks departing from A with decreasing velocities and all arriving at the same event E_B. Therefore, we can state that the departure time t_j for a transported clock with velocity v_j must verify $t_j = d/v_0 - d/v_j$.

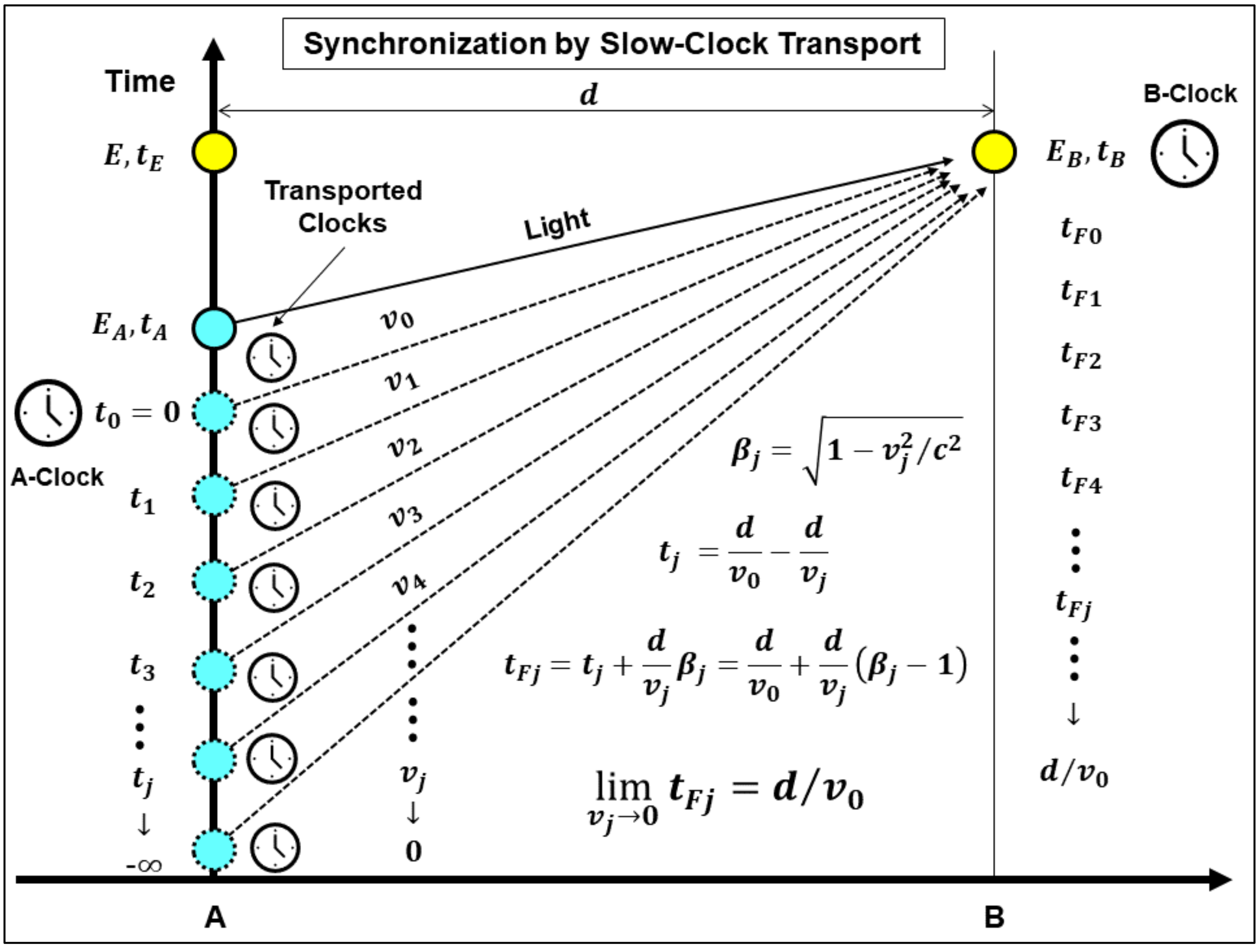

Figure 7 – Synchronization via Slow Clock-Transport

From the KTD, the time-interval $\Delta t^j_{K'/K'} = (t_{Fj} - t_j)$ displayed by the 'moving' clock j and the time-interval $\Delta t^j_{K/K} = (d/v_0 - t_j)$ displayed by the 'stationary' A-clock verify $(t_{Fj} - t_j) = \beta_j(d/v_0 - t_j)$ with $\beta_j = \sqrt{1 - v_j^2/c^2}$. Hence, $t_{Fj} = t_j + \beta_j d/v_j = d/v_0 + (\beta_j - 1)\, d/v_j$. Let us now take the limit of t_{Fj} as $v_j \to 0$ $(t_j \to -\infty)$:

$$\lim_{v_j \to 0}\{d/v_0 + (\beta_j - 1)\, d/v_j\} = d/v_0 + d \lim_{v_j \to 0}\left\{\left(\sqrt{1 - v_j^2/c^2} - 1\right)/v_j\right\}$$

And applying L'Hospital's rule for the limit of a quotient whose numerator and denominator tend to zero, we find:

$$\lim_{v_j \to 0} \left\{ \left(\sqrt{1 - v_j^2/c^2} - 1 \right) / v_j \right\} = \lim_{v_j \to 0} \frac{-v_j}{c^2 \sqrt{1 - v_j^2/c^2}} = 0$$

$$\Downarrow$$

$$\lim_{v_j \to 0} t_{Fj} = d/v_0 = t_B \equiv RT\ Synchonism$$

In practice, this means that when a clock is transported very slowly and transfers its reading to all the clocks in the IF, they become standardly synchronized, i.e. with Einstein's convention, justifying the use of portable clocks in our common level of experience. It must be stressed though that this alternative operational method does not lead to Newton's *absolute* simultaneity: the obtained simultaneity is as intrasystemically *conventional* and intersystemically *relative* as with Einstein's synchronization via light beams. The only factual truth is that the slow-clock-transport technique creates -in the limit- the same synchrony as Einstein's [25] and, in that sense constitutes an additional empirical validation for Einstein's convention – coming from the very Newton's Transported Synchrony postulate (applied when his theory asymptotically agree with Einstein's). There is a cornucopia of experimental data [23] confirming RT, so it was only natural to expect that validating a slow-enough version of Newton's technique would be nothing but innocuous. Differently: albeit the synchronizer clock has to be transported throughout the IF very slowly (i.e. non-relativistically), the theory based on such synchronization is nothing but RT and hence valid for all relativistic speeds among IFs $\left(0 \leq \left|v_{K'/K}\right| = \left|v_{K/K'}\right| < c\right)$.

1.3.10 The 'Twin/Clock Paradox'

In *Galloping with Light* [23], I discussed the famous 'Twin space traveler' thought experiment, the real Mount Washington experiment with cosmic radiation, and the real Hafele-Keating experiment with traveling clocks around the globe. The last two real experiments validated RT and GRT working together. However, when only RT is applied, the three experiments display the infamous 'Clock Paradox' or 'Twin Paradox'. Let us dissect the iconic space-travel thought-experiment to sharply define the putative 'paradox' and understand why, applying RT and Einstein's 'Principle of Equivalence' (the genesis of GRT), it does ***not*** exist in any of them.

1.3.10.1 The Roundtrip to a Star vis à vis Special Relativity

When portraying Reality from the presumed *inertial* 'Earth-Star' frame (K), E_0 and E_1 of Figure 6 are the events of the Spaceship's departure from Earth and its arrival at a Star light-years afar. Clearly, the spacecraft can be abstracted to a single point-object at rest in and located at the spatial origin of a 'moving' frame (K') while K remains 'stationary'. To ensure K' is also an IF, i.e. to avoid any acceleration between K and K', we ideally assume the 'moving' twin passes by the 'sedentary' one at speed v, their clocks are instantly initialized and, when the 'traveler' passes by the Star (at rest in K), his/her clock is instantly contrasted with the clock on the Star (synchronized with the clock on Earth). Instead, when describing Reality from the Spacecraft frame (K'), E_0 corresponds to the 'departure' of the K frame 'moving' as a whole in the opposite direction while K' can be considered 'stationary', and E_1 corresponds to the Star (at rest in K) 'arriving' to the Spacecraft (at rest in K'). Irrespective of the vantage point (K or K'), E_0 and E_1 are the same contiguity events, viz Spaceship/Earth the former and Spaceship/Star the latter. Their

Event-Intervals are Type 0, i.e. coincidences in spacetime. When those encounters occur, the stationary clocks in each frame are face-to-face, with their readings for E_0 agreeing by having set them to zero and those for E_1 differing due to their relative motion; those face-to-face equal and different clock readings should be independent of the vantage point. And, because each clock's reading corresponds to the time elapsed in the IF in which is at rest, their readings are interpretable as different rates of aging between the twin at rest on Earth and the twin at rest in the Spacecraft. However, for a one-way trip, ***no*** tête à tête comparison between twins (who are light-years apart) is possible. A round trip is mandatory if irrefutable evidence entering our eyes is required, and the so-called paradox arises because a hasty (though incorrect) application of RT implies that, depending on the vantage point, the same twin is predicted to be younger and older than the other.

Could we assume the 'traveler' twin turns around at the Star heading back to Earth and legitimately use RT to predict the clocks' readings when face-to-face? For a significant difference between the clocks (decades in human terms), looking at the respective wrinkles/gray-hair would be very convincing. We avoided the departing *acceleration* to reach the cruise speed, and we could do the same with the corresponding *deceleration* at the end of the roundtrip by not requiring the 'traveler' twin to stop on Earth but simply pass by – while (ideally) instantly comparing wrinkles and gray hair with the 'sedentary' twin. However, the necessary change of speed from v to $-v$ near the Star (even if accomplished in a negligible time) is inescapable and, ergo, RT by itself is ***not*** totally valid for the roundtrip because, if K is inertial, K' is ***not***. The 'nomad' twin cannot turn around but must pass by the Star at the same constant speed: the roundtrip seems intractable in RT.

But Grünbaum [57] conceived a skillful conceptual scheme to fully remain in the realm of RT until the 'traveler' gets home: he assumed that "the traveling twin has an *alter ego*" who passes in the opposite direction (towards Earth) when the real astronaut passes the Star. The alter ego, who has the same age at the crossing point and moves in K with speed $-v$ "can rightfully simulate" the return to Earth of the real twin – in spite of, in fact, the latter having kept moving farther away from the Star. The full analysis of this new situation will require the conceptual manipulation of three IFs: K (Earth-Star), K' (where the real astronaut in his Spaceship is at rest), and K_{AE} (where the alter ego is at rest). In the K frame, the K' frame moves at v and the K_{AE} frame moves at $v_{AE} = -v$. Instead, in K', K moves at speed $-v$ and K_{AE} moves at a speed v'_{AE} determined by Equations 7. They all move relative to the other two at constant speed so, if K is inertial, so are K' and K_{AE}.

1.3.10.2 The One-Way Trip to the Star from the Earth-Star Vantage Point ($\boldsymbol{K}$)

To get a feeling for actual numbers, let us assume $v/c = 0.8 \Rightarrow \beta = \sqrt{1-(v/c)^2} = 0.6$, and the Earth-Star distance is $l_{K/K} = l_p = 20$ light-years, so we have $\Delta t_{K/K} = l_p/v = 20/0.8 = 25$ years. Ergo, the Earth's and Star's clocks (at rest with each other and synchronized) will display 25 years when the astronaut rushes by the Star. Notice that $\Delta t_{K/K}$ can be expressed as $\sqrt{-(0-c^2 25^2)}/c$ because clocks on Earth and Star do not change positions in K during the trip. However, the magnitude between parentheses is not the Event-Interval between E_0 and E_1; it corresponds to the Event-Interval between E_0 and an event simultaneous with E_1 but occurring on Earth or -equivalently- between E_1 and an event simultaneous with E_0 but occurring on the Star. Pithily: the time passed during the trip on Earth and on the Star is 25 years. But the proper time-Interval $\Delta\tau$ is IF-Invariant and hence $\Delta\tau = \sqrt{-\Delta s^2}/c = \sqrt{-(\Delta s')^2}/c = \sqrt{-l_p^2 + c^2\Delta t_{K/K}^2}/c =$

$\sqrt{-0^2 + \Delta t^2_{K'/K'}}/c = \sqrt{-20^2 + 25^2} = 15$ years, making $\Delta t_{K'/K'} = 15$ years. Note that $\Delta x' = 0$ because the astronaut is at rest in K'. For the same reason, because the astronaut's clock (at rest in K') is moving in K and is initialized with the Earth's clock when passing by, upon event E_1 (contiguous to the Star), we obtain $\Delta t_{(K'/K)} = \beta \Delta t_{(K/K)} = 0.6 \cdot 25 = 15$ years. Notice that $\Delta\tau = \Delta t_{K'/K} = \Delta t_{K'/K'} \neq \Delta t_{K/K}$. Ergo, at the end of the one-way trip, four clocks are face-to-face: the clock on the Star reads 25 years (like the one on Earth); the clock on the Spaceship displays 15 years (like the one in K' contiguous to Earth). It looks like the 'nomad' twin is a decade younger than the 'sedentary' twin by the time the former reaches the Star. But ***no*** tête à tête comparison between twins (who are 20 light-years apart) is possible to convincingly confirm it.

1.3.10.3 The One-Way Trip to the Star from the Spaceship Vantage Point (K')

We will now pragmatically think of K' as the 'stationary' frame, in which the Spaceship is in repose at its spatial origin, while the 'moving' frame is K (the Earth-Star frame). Again, astronaut and Earth clocks read 0 years at E_0 which is the initial event of contiguity. The segment joining Earth and Star now constitutes a 'moving' segment with proper-length $l_p = 20$ light-years. From the LC effect, the Earth-Star distance in K' (Spacecraft) is $l_{K/K'} = \beta l_p = 0.6 \cdot 20 = 12$ light-years so, moving with $v = -0.8c$, upon the Star 'arrival' at the Spaceship the astronaut's clock will read $\Delta t_{K'/K'} = \beta l_p/v = 0.6 \cdot 20/0.8 = 15$ years, i.e. the time shown by the astronaut's clock when E_1 occurs is 15 years – we already knew that from the invariance of the Event-Interval.

But when describing the trip from K', what happens on Earth when the Star 'arrives' at the spacecraft? Namely: what is the reading of the Earth clock for an event that, per the simultaneity criterion in K', is simultaneous with E_1 but occurs on Earth? A clock in K' contiguous to the Earth clock and simultaneous with E_1 must read $(\beta l_p)/v = 15$ years, so the corresponding reading of the 'moving' Earth clock (per KTD) is $\Delta t_{K/K'} = \beta \Delta t_{K'/K'} = \beta^2 \, l_p/v = 0.6 \cdot 15 = 9$ years.

What about the Star clock when E_1 occurs? Clocks synchronized in K' are not synchronized in K so the clock on the Star upon E_1 does ***not*** read 9 years. Per LT, its reading t_s is equal to $\beta^{-1}(t'_s + vc^{-2}x')$ where t'_s is the time-coordinate of E_1 from the Spaceship's perspective, viz $\beta \, l_p/v$. But given that the Spaceship is at the spatial origin of K', $x' = 0$ making $t_s = \beta^{-1} t'_s = \beta^{-1}\beta \, l_p/v = l_p/v = 25$ years – perfectly agreeing with the reading of the same clock when described from the Earth-Star Frame.

And the Star clock when E_0 occurs? Namely: what is the reading of the Star clock for an event that, according to the simultaneity criterion in K', is simultaneous with E_0 (Spaceship and Earth contiguous) but occurs on the Star? The time elapsed in K' during the trip is $\beta \, l_p/v$ so (per KTD) $\Delta t_{K/K'} = \beta^2 \, l_p/v$ so that the corresponding reading of the 'moving' Star clock when E_0 occurs would be $25 - \beta^2 \, l_p/v = 25 - 9 = 16$ years. Despite, from the K' perspective, Earth and Star clocks not being in sync, they run at the same pace (they are in relative repose) so that the Earth twin and aliens on the Star seem to have aged 9 years during the trip, while the now 'static' astronaut aged 15 years as when the trip was described from K.

From any one of the two vantage points: a) for E_0 (both twins contiguous), Earth and Spaceship clocks read 0 years by being set so; and b) for E_1 (astronaut and Star contiguous), the clock on the

Star reads 25 years and the clock on the ship shows 15 years. The readings of the two clocks when contiguous do not depend on the IF. The initial and final clock readings as described in each IF agree but their elapsed times do not: if the reference is the Earth-Star IF (K), the time elapsed in it is 25 years while the time elapsed in the Spaceship IF is 15 years – making the astronaut a decade younger than the Earth twin; but if the reference is the spacecraft IF (K'), the time passed in it is again 15 years, but the time passed in the Earth-Star IF is only 9 years – making the astronaut 6 years older that the Earth twin. *Reciprocity* (Equations 5) -the very essence of RT- reverts the age relationship depending upon the frame we choose which, of course, is **in**admissible because Reality (what is cruelly more real that our aging?) must be **in**dependent of our vantage point. How do we explain it?

1.3.10.4 Is there a Physical Effect missing in Special Relativity?

Let us assume that K is inertial but K' is not – invalidating RT predictions from the latter frame. We saw that, from the Spaceship perspective (K'), at the end of the one-way trip $(E_0 \rightarrow E_1)$, the 'static' astronaut is older by 6 years so, to agree with the 10 years younger result based on the Earth-Star frame (the one assumed to be inertial), there would have to exist another physical effect (clearly missing in RT) which would dilate the astronaut's time to make him $GTD = 10 + 6 = 16$ years younger upon E_1. Differently: the time experienced by the twin on Earth when using the Earth-Star frame ($\Delta t_{K/K} = l_p/v$ years) minus the time s/he experiences when using the Spaceship frame ($\Delta t_{K/K'} = \beta^2 l_p/v$ years) must be equal to the time dilation GTD the astronaut would have to experience due to the missing effect when using his/her own Spacecraft as a reference. A theory that predicted such an **a**symmetric effect would complete RT in this specific sense – making both frames fully equivalent for the forward one-way trip. Let us express this difference formally:

$$GTD\ (one\ way) = l_p/v - \beta^2 l_p/v = \frac{\beta^2 l_p}{v}\left\{\frac{(v/c)^2}{\beta^2}\right\} = \Delta t_{K/K'}\left\{\frac{(v/c)^2}{1-(v/c)^2}\right\} \qquad (11)$$

For our specific numerical example, $GTD = 20 \cdot 0.8 = 9 \cdot 0.8^2/(1 - 0.8^2) = 16$ years as it should be $(25 - 9)$ if the same amounts of gray and wrinkles are to be on the same twin regardless of the vantage point at the end of $E_0 \rightarrow E_1$.

The reader may have already inferred that I chose the acronym GTD to stand for Gravitational Time Dilation, an effect that Einstein predicted as a consequence of his *Principle of Equivalence* in 1907, well before finishing his GRT masterpiece in 1916. It was confirmed four decades later by the Pound-Rebka experiment and many others [56]. Because it expresses GTD in terms of KTD, the last expression in Equations 11 will be useful when fully explaining away the Twin Paradox. But for now, what about Grünbaum's clever scheme to stay within the realm of Special Relativity without any additional effects?

1.3.10.5 Grünbaum's Ego/Alter Ego Round Trip from the Earth-Star Vantage Point (K)

We already discussed the one-way trip $E_0 \rightarrow E_1$ from frame K (Earth-Star). During this trip, the alter ego astronaut was coming to meet the real one at the Star. Now, we will add the alter ego's return trip $E_1 \rightarrow E_2$ and combine the results. In K, the IF K' moves at v and the IF K_{AE} moves at $v_{AE} = -v$. Recall that the speed in K with which the distance between the alter ego 'traveler' and the real 'traveler' increases could easily surpass the speed of light, e.g. $0.8c - (-0.8c) =$

$1.6c$. This is not a violation of Einstein's Light-Limiting Postulate because ***no*** object (genidentical chain) is traveling at that superluminal speed from K vantage point (or any other).

Using then K as the reference frame, at E_1 the Earth-Star clocks read l_p/v years and because the real astronaut's clock reads $\beta\, l_p/v$, the alter ego's clock is so instantly initialized while crossing each other and heading towards Earth. For this alter ego's one-way trip, the Earth's clock starts reading l_p/v and increments its count with another l_p/v so it reads $2l_p/v$ when the alter ego passes by; however, the alter ego's clock started reading $\beta\, l_p/v$ and incremented its reading by another $\beta\, l_p/v$ so when passing by Earth it shows $2\beta\, l_p/v$.

Using as before $v = 0.8c$ and $l_p = 20$ light-years, at the end of the roundtrip, we have two clocks face-to-face: the one for the 'sedentary' twin reading 50 years and the one for the alter ego of the real astronaut displaying 30 years (15 of its own and 15 received when crossing each other). But now, the tête à tête comparison is possible though <u>only</u> with the alter ego of the real 'traveler' twin who -according to Earth time- had departed 50 years in the past but, according to the spacecraft's clock, s/he aged <u>only</u> 30 years. With such a discrepancy, even allowing for individual differences, the alter ego of the 'nomad' twin should look much younger than the 'sedentary' twin. We have simply doubled our previous results. Let us now describe the round trip from the real astronaut point of view (K').

1.3.10.6 Grünbaum's Ego/Alter Ego Round Trip from the Spaceship Vantage Point (K')

We already discussed the one-way trip $E_0 \to E_1$ from frame K' (Spaceship). Now we will add the alter ego's <u>return</u> trip $E_1 \to E_2$ and combine the results. As highlighted, when the reference was K, the speed with which the distance between the origins of K' and K_{AE} increased could easily surpass the speed of light; but when K' is the reference frame, the same separation process now becomes the genidentical chain of K_{AE} (the alter ego's spacecraft) as it moves in K' and, ergo, at a velocity governed by Equation 7. Therefore, while K moves in K' at $-v$, K_{AE} moves at a speed $v'_{AE} = (-2v)/(1 + v^2/c^2)$ – which is approximated by $-2v$ when $v \to 0$ (Galilean composition) and by $-v$ for $v \to c$ (composition of two light velocities). We see that $v < |v'_{AE}| < c$ so that the alter ego's spaceship travels in K' faster than the Earth twin does and, ergo, they eventually meet.

We are interested in the reading $t_{K/K'}$ of the Earth clock and the reading $t_{AE/K'}$ of the clock in K_{AE} when the alter ego of the real astronaut meets the twin on Earth (E_2). Remember it is the whole K frame (Earth and Star separated by l_p) that is moving away from K' (the real astronaut's frame) with speed $-v$, and the alter ego is also moving away from K' with speed v'_{AE} such that $|v'_{AE}| > v$. Thus, -in K'- the alter ego's clock has to travel the distance βl_p to meet the twin on Earth. And what is the speed v_{AEE} with which the distance between the alter ego's spaceship and Earth decreases in the K' frame? Must we use Equations 7 again? NO; this is a directionless approaching process, ***not*** a genidentical chain, so the two speeds algebraically add to obtain $v_{AEE} = v'_{AE} - (-v) = -v\beta^2/(1 + v^2/c^2)$; hence, when the alter ego arrives at Earth, the clocks on K' have incremented their readings by $\Delta t_{K'/K'} = (\beta l_p)/v_{AEE} = l_p(1 + v^2/c^2)/\beta v$.

Now we ask again what the reading is for a clock in K' which, when E_2 occurs (the alter ego passes by the Earth), is contiguous with both the clocks on Earth and the alter ego's Spaceship. Given that, at the start of the return trip, the clock in K' read $\beta l_p/v$, such a reading will be $\beta l_p/v + l_p(1 + v^2/c^2)/\beta v = 2l_p/\beta v$. This means that the reading of the alter ego's clock should be dilated by the factor $\beta_{AE} = \sqrt{1-(v'_{AE}/c)^2}$ so, given that the alter ego's clock adopted the reading of the real twin at E_1, its final reading at E_2 will be $\beta l_p/v + \beta_{AE}\{l_p(1+v^2/c^2)/\beta v\} = 2\beta l_p/v$, which agrees with the reading we obtained when describing the return trip from the Earth-Star vantage point. It only remains now to calculate the time increment for the Earth clock during the return trip, which should be β times the reading the clock in K' has so it is $\beta(2l_p/\beta v) = 2l_p/v$ – agreeing as well with the reading for the Earth clock when describing the return trip from the Earth-Star vantage point.

Evidently, adopting Grünbaum's skillful stratagem, RT consistently delivers the same aging predictions for the roundtrip: for our numerical example, the time elapsed in the Earth-Star frame is 50 years, while the time passed in the Spacecraft is 30 years. With 20 years discrepancy, if RT is correct and the alter ego "can rightfully simulate" the return to Earth of the real twin, the latter should enjoy less gray hair and fewer wrinkles than his/her twin on Earth – no matter how we look at it. However, only one of the real twins was present at the tête à tête reencounter; the other was the alter ego.

Grünbaum's astute and illuminating scheme produced the correct **in**variant aging results for the roundtrip at the cost of including a third unrealistic protagonist whose clock had to be reset with the reading of the real twin's clock as they crossed their paths at the Star. **No** theory should require two versions of the same person/thing to produce the correct predictions. Reality is that the real astronaut has to turn around and, ergo, his/her frame (K') is temporarily accelerated relative to the Earth-Star frame (K) so… if K is inertial then K' is ***not*** and RT alone cannot globally and accurately describe Reality from the latter. The need for a third fictitious frame (K_{AE}) highlights the **a**symmetry betwixt K and K', explaining the paradoxical results delivered by the improper application of RT. But, most significantly, the aging **in**consistency between vantage points remains for the one-way trip (for which no alter ego is necessary), unequivocally pointing us to explore the already-entertained idea that there must be a new physical effect missing in RT.

1.3.10.7 Explaining away the Twin Paradox

The so-called Twin Paradox is resolved by understanding that if we choose the Spacecraft as the frame of reference ('stationary'), to achieve symmetry between the two opposite vantage points during the acceleration stages, the rest of the Universe is 'moving in free-fall', i.e. with a common acceleration in the equivalent gravitational field [23] [58] [56]. This 'free-fall' disappears when the relative speed is constant (RT valid again). And, because of the *Principle of Equivalence* between acceleration and gravity[55], the mere use of the Doppler Effect implies that two clocks experiencing different gravitation field intensities ticktock at different rhythms, with the one at the higher intensity being behind the other. Before explaining how we arrive at precisely Equation 11 (right) when describing Reality from the Spacecraft ('stationary'), let us review all the distinct stages for the trip:

1. When the trip starts (E_0) and until the cruise speed is attained, a gravitational field exists pointing away from the Spaceship and the rest of the Universe is in free-fall. For high enough acceleration, the cruise speed is achieved while the twins' positions in the gravitational field

[55] For the intricacies associated with Einstein's original 'Principle of Equivalence' (homogeneous gravity) and the (never endorsed by Einstein) infinitesimal (local) version of it (arbitrary gravity), see Norton's review and its references [215].

are still contiguous, so **no** appreciable Gravitational Time Dilation (GTD) exists (their clocks run in unison) [56] [58]. This effect can thus be reduced to negligible, and the stage ignored.

2. While at cruise speed the gravitational field disappears. There is KTD but **no** GTD.
3. When Star and Spacecraft are nearing, except for the latter, the Universe 'starts braking' and a gravitational field directed from Earth towards the Spaceship appears, which perdures while the rest of the Universe stops (E_1), reverses its motion, and 'accelerates' until attaining cruise speed towards Earth. With the field intensity sufficiently high, this deceleration/acceleration can be completed again in a negligible time. However, now -as opposed to Stage 1- Earth and Spaceship are in very different positions in the gravitational field; the 'static' twin (in the Spacecraft) is in a much more intense field than the 'traveler' twin (on Earth) and, ergo, endures a large GTD (capable of overcorrecting the opposite KTD effects during Stage 2 and Stage 4). Note that the direction of the field is the same for decelerating as for accelerating, so a not-zero GTD effect exists in both the forward ($-v \to 0$) and backward ($0 \to v$) transitions.
4. While Earth returns at cruise speed there is **no** gravitational field. There is KTD but **no** GTD.
5. Nearing the end of the roundtrip, a field reappears and the rest of the Universe free-falls until ship and Earth are in relative repose and the twins embrace (E_2). As in Stage 1, for high enough deceleration, the twins' positions in the gravitational field are contiguous, so **no** appreciable GTD exists. This stage can also be ignored.

We see that only during Stage 3 there exists a sizable (irreducible to negligible) GTD. Grünbaum did eliminate it by postulating the existence of an alter ego for the astronaut and letting the real astronaut continue his/her trip into deep space with no return – eliminating the aging paradox for the roundtrip but not for the one-way journey.

During this unique Stage 3, by virtue of Einstein's *Principle of Equivalence*, the Spacecraft (with the 'static' twin) is submerged in a gravitational field much more intense than the one where the 'traveler' twin is (on Earth). Ergo, gravity can be transformed into a kinematic problem and GTD calculated via the Doppler Effect. Max Born in [59] explains that, for a constant gravitational field g existing in K', and a clock at rest in K experiencing a time-interval $\Delta t_{K/K'}$ when such a field does ***not*** exist (i.e. per only RT), the time dilation GTD experienced by a clock at rest in K' at a distance l_p from the K-clock can be calculated as $GTD = \Delta t_{K/K'}\{(gl_p/c^2)/(1 - gl_p/c^2)\}$. Thus, in trying to obtain Equation 11, we need to start with the time-interval $\Delta t_{(K/K')}$ due exclusively to KTD (i.e. within RT) for the one-way trip and to calculate the time dilation exclusively due to the constant field g (i.e. GTD without KTD). Thus, during deceleration $(-v \to 0)$ we have $\Delta v = v \Rightarrow g = v/\Delta t_{K/K'}$ and since $l_p = v\Delta t_{K/K'} \Rightarrow gl = v^2 \Rightarrow GTD = \Delta t_{K/K'}\{(v^2/c^2)/(1 - v^2/c^2)\} = \Delta t_{K/K'}\,(v^2/c^2)/\beta^2 = l_p\,(v^2/c^2)/v$. This is Equation 11, which we had arrived at by calculating how strong a hypothetical time dilation effect would have to be so as to make RT consistent for a forward one-way trip from different frames of reference, one of which is not inertial. But during the subsequent acceleration $(0 \to v)$ necessary for the return one-way trip $\Delta v = v$ again, so we have a total $GTD = 2\Delta t_{(K/K')}\{(v^2/c^2)/(1 - v^2/c^2)\}$, which must be added to the KTD that takes place for the two twins to embrace on Earth. During the latter trip, the astronaut ('sedentary') clock accumulates another $\beta l_p/v$ so it ends reading

$2\beta l_p/v$, while the clock on Earth reads $2\beta^2 l_p/v + 2l_p\,(v^2/c^2)/v = 2\beta^2 l_p/v + 2l_p v/c^2 = 2l_p/v$, delivering the same results as when Reality is described from the Earth-Star frame.

Summing up for our numerical example: from the astronaut's vantage point, the clock in the Spaceship runs 12 years $(30 - 18)$ ahead of the clock on Earth because of the KTD (making the 'astronaut' inconsistently older), but it runs 32 years behind the clock on Earth because of the GTD (making him/her younger). The net result is that the clock on the Spaceship experiences a net retardation of $32 - 12 = 20$ years when compared to the clock on Earth. This makes the 'astronaut' 20 years younger than his/her twin on Earth, no matter how you look at it.

The above extension of RT to non-inertial frames was done by Einstein well over a century ago and is totally unrelated to the completion of RT our QR/TOPI achieves. For those who enjoy (and struggle like me!) reading the original writings of the masters [58] [59], keep in mind that the underscored "twice" in the phrase by Einstein in [58] ("The calculation shows that this speeding ahead constitutes exactly twice as much as the lagging behind…), as well as the formula in page 356 given by Born in [59] are only valid for $v/c \ll 1$. Instead, Formula 11 is valid for $(v/c) \in [0, 1)$. The purpose of its detailed inclusion in this work was to attain as a deep conceptual understanding of RT as possible before diving into how QR/TOPI completes it vis à vis QT.

Closing our revision of the *deterministic* RT, we saw that its spacetime Minkowski structure is clearly non-Euclidean. Even so, we can say it is semi-Euclidean because once an IF is chosen, the tridimensional *space* so obtained is always Euclidean. Light propagates in a straight *line* and with identical *speed* in all IFs; objects free of any external influence move *uniformly*; objects under the influence of a *force* move *non-uniformly*; the *distance* between two *points* in tridimensional space obeys the Pythagorean Theorem; the sum of the angles of a triangle is always 180º; the ratio between the length of a circumference and its diameter is always π, and so forth. But a frame in accelerated motion relative to an IF is non-Inertial, i.e. out of the realm of RT. However, every non-Inertial frame is locally and momentarily *inertial* because in such a limited portion of *spacetime*, it can always be considered as in uniform *motion* with respect to some IF and hence (from the *Principle of Special Relativity*) must be *inertial* – with RT, its spacetime Minkowski metric, and its associated LT becoming asymptotically more accurate. This fact is the foundation for GRT. It is time now to incorporate *stochasticity* into RT.

2. Stochastic Causality and its Incorporation into RT

All events in RT are actual *evincing* and abstractable to a spacetime point. Per ALBA3, the idiom R-Time[56] refers to *time* as operationally "defined" by Einstein and implemented by either light-signaling or slow-clock transport. RT is a *deterministic* theory; however, whether you think it is due to our ignorance or not, *Determinism* is against our daily experiences – so it can be sensibly considered as an approximation only valid (per QR/TOPI) when the ontic *probabilities* involved are exceptionally close to unity or zero (or when all probability density distributions approximate delta functions)[57].

For our integration of RT and QT to be successful, RT must be compatible with *probabilities* – regardless of whether they are considered epistemic or ontic. Paraphrasing Gisin but now for the

[56] It is what some authors refer to as 'external time' when writing about QT [203] [202].

[57] Newtonian/Einsteinian Dynamics can be also formulated in a Hilbert space, in which physical properties are represented by Hermitian operators which are all commuting (compatible and dispersion-free variables) [206].

compatibility betwixt RT and stochastic causality, we ask: does relativity hold a place for ontic **in**determinacy? Del Santo and Gisin in 2021 dissected/invalidated the argument put forward independently by Rietdijk (1966) and Putnam (1967) for their **in**compatibility, answering our question in the affirmative [60]. However, their argument -albeit arriving at the correct conclusion- is plagued with anthropic considerations that conflate the *time* of an event's occurrence in an IF with the *time* at which distant *observers* at rest in it could know of such occurrence. Ignoring the anthropic baggage, their rebuttal survives only because they believe that *information* is physical and, ergo, that the truth value of a statement propagates by itself in RT-spacetime at the speed of light. We do not agree with the physical character of *information* and will scrutinize it as we progress in the development of QR/TOPI and answer Zeilinger's "very fundamental question". We will continue using the acronym RT for our *stochastic* extension of the *deterministic* RT. Let us start discussing *stochastic causality* in general, *stochastic* genidentical chains, and *stochastic* common cause/effect.

Pithily, the causal relation between two events is *stochastic* when there is a *deterministic* relation between any one of them and the probability for the other. What makes causality *stochastic* is that at least one of the terms in the *deterministic* relation is not an event per se but its probability. We say the joint occurrence of n events $\{E_i\}$ is a 'chance coincidence' when it occurs despite their being independent, viz $Pr(E_1, E_2, \dots E_n) = \prod_{i=1}^{i=n} Pr(E_i)$ (their joint probability being given simply by factorization). Otherwise, factorization may still be possible if those probabilities are adequately conditioned. Adopting a direction for the causal net and calling $Parents(E_i)$ the set of all unmediated (no intermediaries) causes of E_i, the so-called 'Causal Markov Condition' says that, when conditioned on its *Parents*, E_i is independent of everything except its effects, i.e. those conditional probabilities are factorizable. In plain words, the parents screen off the n events from everything else. In symbols: $Pr(E_1, E_2, \dots E_n) = \prod_{i=1}^{i=n} Pr(E_i/Parents(E_i))$ [36]. Notice its weak but existing relationship with the Principle of Locality in deterministic RT.

For the simplest case of two events E_A and E_B, when they are ***not*** independent, they are causally related, and we can state:

$$Pr(E_A, E_B) \lesseqgtr Pr(E_A)Pr(E_B) \begin{array}{c}\Leftarrow\\ \Longrightarrow\\ \Leftarrow\end{array} \begin{cases} Pr(E_B/E_A)Pr(E_A) \lesseqgtr Pr(E_A)Pr(E_B) \Leftrightarrow Pr(E_B/E_A) \lesseqgtr Pr(E_B) \\ and \\ Pr(E_A/E_B)Pr(E_B) \lesseqgtr Pr(E_A)Pr(E_B) \Leftrightarrow Pr(E_A/E_B) \lesseqgtr Pr(E_A) \end{cases} \quad (12)$$

No physical actual connection between the events is presumed to 'explain' their causal relation. Note as well that Relations 12 are symmetric: they do ***not*** single out any event as the cause or the effect. Thus, the relation between the notion of *probability* and its physical meaning in spacetime is thorny, particularly when different theories assign different structures to spacetime.

The inequality on the left implies both inequalities on the far right, while any one of the latter implies the former. In English: if two events jointly occur less/more frequently than if they were independent (left inequality), conditioning the probability of anyone of them on the other makes it lower/higher. In symbols: $E_A\, CR\, E_B$. S*tochastic* causality includes *deterministic* causality as a limit: $E_A \Rightarrow E_B \equiv \{Pr(E_B/E_A) = 1\} \wedge \{Pr(E_A/E_B) = Pr(E_A)/Pr(E_B)\}$ and (top bar means negation): $E_A \Rightarrow \overline{E}_B \equiv \{Pr(E_B/E_A) = 0\} \wedge \{Pr(E_A/E_B) = 0\}$.

Replacing $' \lesseqgtr '$ with $' = '$ in Relations 12 implies the events are ***not*** causally related: $E_A\, \overline{CR}\, E_B \Leftrightarrow Pr(E_B/E_A) = Pr(E_B) \Leftrightarrow Pr(E_A/E_B) = Pr(E_A)$. We will soon see that this is how

John Bell expressed his controversial "free will", or "no-conspiracy", or "measurement independence", or "statistical independence", or "future input independence", or "non-superdeterministic" hypothesis for the causal relation between the instruments' settings and his local hidden variables λ in the eponymous theorem. And why the adjective "controversial" for Bell's hypothesis? Because the above-used terms 'joint' and 'jointly' imply neither simultaneity nor spatial proximity. Probabilistic relations per se are **a**temporal and **a**spatial, so not even the conditional event in a conditional probability is necessarily an *actual* event that has already occurred or preceded the other in *space* or in *time*. Those relations ***only*** involve *time* and/or *space* via the spacetime-coordinates of the events they relate (if the events do occur and are pinpointable in spacetime). Furthermore, under QR/TOPI the events can be ontically *probable* or ontically *actual*, so probability relations between ontically *probable* events are as valid (and more fundamental) than those amid *actual* events. Probability Theory is fully retained by QR/TOPI as a mathematical tool – whose physical meaning in each case is carefully crafted.

Being more specific, the 'controversy' comes from the difficulty we have had for centuries in separating *causality* from *time*. There exist in the literature interpretation proposals involving the well-known notion of ontic 'propensity' initially introduced by Pierce, Popper and others [61] [41]. In a very recent proposal called by Del Santo and Gisin "Potentiality Realism" [6], they correctly emphasize that 'propensity' quantifies a weaker *causality* relation than the deterministic one but, because they do ***not*** separate *causality* from *time*[58], to avoid the so-called Humphreys' paradox (presumed retrocausality due to the reversibility of probability relations), they depart from standard probability calculus by dropping those "Kolmogorov's axioms that lead to the derivation of the Bayes' rule" while retaining *Bernoulli's Law of Large Numbers*. The supposed 'paradox' goes as follows: assuming what they say is "the standard definition of causality" (not ours of course), i.e. that 'cause' C and 'effect' E are always synthetic and actual with C occurring time-before E, they have $[Pr(E/C) \neq \mathrm{Pr}(E)] \wedge \left[Pr(C/E) = Pr\left(C/\overline{E}\right) = Pr(C)\right]$. But, from Bayes' Theorem, they obtain $Pr(E/C) = Pr(C/E)Pr(E)/Pr(C) = Pr(E)$, which contradicts the hypothesis of C being the cause of E, viz $Pr(E/C) \neq \mathrm{Pr}(E)$. This is simply due to forcing the anisotropy of *time* [33] into probability relations which are inherently reversible: if we did not mutilate the reversible equations behind the fundamental Laws of Classical Physics despite knowing that *time* is anisotropic; why should we mutilate the laws of stochastic causality? QR/TOPI takes avail of the full power of Probability Theory and superimposes (when appropriate) the anisotropy of *time*.

Obviously, the causal relations described by Relations 12 are very generic, not only because they are ***non***-deterministic, **a**spatial, and **a**temporal but also because **no** mechanism or intermediate events are assumed or required to exist between the causally related events – whatever the spacetime structure claimed by a theory may be. But it could certainly exist a deterministic genidentical chain between the two events, with the *stochasticity* of one of them *deterministically* transferred to the other. Or, per QR/TOPI, all or some events in a probabilistic relation can be ontically probable [11] and, being so, they may ***not*** be abstractable to point-Events in spacetime, so their causal relation is not as restricted by spacetime as that of actual *evincing* events (those in RT) is. And remarkably, we will see that actual State-Events (which are all ***non**-evincing*) may have a causal relation which is, of course, absolute – defining a new type of Event-Interval among them and between them and some PDI-Events.

[58] Quote: "Causality and time are two intimately related concepts, for causes are happening *before* their effects" [6].

2.1 Stochastic Direct Causal Relation, Causal Betweenness, and Genidentical Chains

As said, Relations 12 between E_A and E_B may obtain without any intermediary events at all, establishing the simplest of what we will call a Direct Causal Relation (DCR) and say: $E_A \; DCR \; E_B$. But a DCR may also comprise intermediate events, leading to the concept of a causal chain effected via the *betweenness* (BTW) causal relation. Given events $E_A, E,$ and E_B, E is causally *between* E_A and E_B and denoted $E = BTW(E_A, E_B)$ if and only if:

$$0 < Pr(E_B) < Pr(E_B/E_A) < Pr(E_B/E) < 1$$

$$0 < Pr(E_A) < Pr(E_A/E_B) < Pr(E_A/E) < 1 \qquad (13)$$

$$Pr(E_B/[E_A, E]) = Pr(E_B/E)$$

From Relations 12, the top line in Relations 13 implies that E_A and E_B as well as E and E_B are causally related; and from the second line E_A and E are also causally related. Besides, the top-line says that E_A makes E_B more probable and E even more probable, and those in the second line say the reverse: E_B makes E_A more probable and E even more probable. The equation in the bottom-line states that E screens off E_B from E_A, i.e. that the occurrence of E makes that of E_A irrelevant for E_B. Notice that the causal betweenness for events derives from the numerical order between their conditional probabilities: as in the deterministic case (in which the specific coordinates for the actual events did not matter), the specific numbers for those probabilities are immaterial for causal betweenness. Also note that so far there is no need for spatial and/or time continuity, viz no need for any intermediate events in Figure 1 (left).

Because it can be proved that if E screens off E_B from E_A, then E screens off E_A from E_B [34], we have $E = BTW(E_A, E_B) \Rightarrow E = BTW(E_B, E_A)$, i.e. the *stochastic betweenness* relation (as for the deterministic case) is symmetric and, hence, Relations 13 do ***not*** provide the causal direction of the arrows in Figure 1. The same conclusion is derived from the *deterministic* reversible causal nets established by Classical Laws, which require the additional recognition of the anisotropy of *time* in our m**a**croworld to determine, via the direction of a single arrow, the direction of all arrows.

But, in contrast with *deterministic* RT which requires the additional postulate of ***no*** retrocausality to avoid causal loops, it can also be proven [34] that, in the *stochastic* case, given three events only one of them can screen off the other two from each other, so only that one can be *causally between* the other two, i.e. their causal betweenness link is open and, ergo, ***no*** retrocausality among three or more events are possible by the very definition of *stochastic* causal betweenness:

$$E = BTW(E_A, E_B) \;\Rightarrow\; E_{\mathrm{A}} \neq BTW(E, E_B) \;\wedge\; E_{\mathrm{B}} \neq BTW(E_A, E) \qquad (14)$$

Notice that -so defined- the prefix '*retro*' in retrocausality does ***not*** refer to the notion of *time* at all but to the *stochastic* causal relation 13 between the events. Note as well that this '*time*-free' rejection of retrocausality inherent in the stochastic causal *betweenness* relation may ***not*** hold for the *generic* causal relation between two events as defined by Relations 12. In the latter, the causal relation is not limited to the unique type of causal chain defined by Relations 13 so, because of the reversibility of *probability*, the causal relation $E_{\mathrm{A}} \leftrightarrow \cdots \leftrightarrow E_{\mathrm{B}}$ (with or without intermediaries) is possible with ***no*** *betweenness* among them. In such cases, once *time* is assigned to each event, chains like $(E_{\mathrm{A}} \ldots E_{\mathrm{B}} \ldots E_{\mathrm{A}})$ and $(E_{\mathrm{B}} \ldots E_{\mathrm{A}} \ldots E_{\mathrm{B}})$ are possible, so the only way to avoid retrocausality is to assume all those events so related are *simultaneous* (as Newton did with *gravity*). However, *simultaneity* in RT is relative: *simultaneity* in an IF implies temporal *order* in another. QR/TOPI solves this conundrum without tossing Bayes' theorem.

Because bifurcations in the causal net may invalidate some of the Inequalities 13, in general, BTW is nontransitive (though ***not*** intransitive):

$$E = BTW(E_A, E') \ \wedge \ E' = BTW(E, E_B) \nRightarrow \ E = BTW(E_A, E_B) \qquad (15)$$

Only without bifurcations multiple betweenness relations may form a direct *stochastic* causal chain, implementing a chain version of DCR, and we say again: $E_A \ DCR \ E_B$. Assuming that E_A, E, and E_B are actual *evincing* (as in RT) and that between them there exists a one-dimensional continuum of time-ordered actual *evincing* events in spacetime verifying Relations 13 with *transitivity* valid, the stochastic causal chain becomes genidentical (Figure 1 left) – constituting the *stochastic* version of the 'Principle of Locality'. Note that now we have included the notion of *time*. In such a case, the continuous causal chain from $E_A(E_B)$ to $E_B(E_A)$ must intersect any spacetime hypersurface that encloses $E_B(E_A)$ and does not enclose $E_A(E_B)$. The intersected E on any such hypersurface screens off $E_B(E_A)$ from $E_A(E_B)$, videlicet: $Pr\{E_B(E_A)/[E_A(E_B), E]\} = Pr\{E_B(E_A)/E\}$. Notice again that E_A and E_B are ***not*** independent; it is the assumption of stochastic local causality between them (with the successive screening off by all intermediate events) that any event E in the genidentical chain makes $E_A(E_B)$ to be **i**rrelevant for the probability of $E_B(E_A)$.

And rejecting (as RT does) *retrocausality*, once we choose a time-direction for the genidentical chain (say $E_A \rightarrow E_B$), the above intersecting event E cannot occur later than the event E_B. In plain terms: the future cannot affect the past, limiting the possible screening events E in any such hypersurfaces. And adopting RT as true and complete, due to the Light-Limiting Postulate, the possible intersecting events E are further limited to be in the future light-hypercone of event E_A and in the past light-hypercone of event E_B, with the *stochastic* extension for Types 0, 1, 2, and 3 Event-Intervals being straightforward. We say that an RT-DCR exists between E_B and E_A. Note that this type of DCR is necessarily a chain (unless $E_B = E_A$).

It is thus when we embed the events in the Minkowski spacetime structure of actual *evincing* events and light-limited genidentical chains that, if their Event-Interval is Type 2 (spacelike), ***no*** DCR between them is admissible. And if their Event-Interval is Type 1(Type 3), a DCR is possible – meaning that one event is in(on) the past light-hypercone of the other. Therefore, it is because of RT's Nonlocality-Exclusion Axiom that a DCR between two events is proscribed by fiat when their Event-Interval is spacelike. Differently: in stochastic RT, a DCR between two events may exist ***only*** if a luminal or subluminal stochastic genidentical chain is possible between them. We will see that, in the QR/TOPI spacetime structure, despite ***not*** existing superluminal signals, such a claim is false.

2.2 Stochastic Common Cause and Common Effect

It is also possible that ***no*** DCR exists at all between the events but, still, Relations 12 are true. Formally: $\left(E_A \ \overline{DCR} \ E_B\right) \wedge (E_A \ CR \ E_B)$. This could be so if the presence/absence of a third event Γ *swayed* the probabilities of E_A and E_B, establishing a correlation otherwise inexistent. We say that

$E_A\ C\underline{S}R\ E_B$, and that such event Γ, which could be a disjunction of events $(\cup\Gamma_i)$, is their *Common Swayer* [34] denoting it as $\Gamma = C\underline{S}(E_A, E_B)$. Formally:

$$\{E_A\ \overline{DCR}\ E_B\} \wedge \{\Gamma = CS(E_A, E_B)\} \Leftrightarrow \begin{cases} Pr(E_A, E_B/\Gamma) = Pr(E_A/\Gamma\ )Pr(E_B/\Gamma) \\ Pr(E_A, E_B/\overline{\Gamma}) = Pr(E_A/\overline{\Gamma})Pr(E_B/\overline{\Gamma}) \\ Pr(E_A/\Gamma) \lesseqgtr Pr(E_A/\overline{\Gamma})\,; Pr(E_B/\Gamma) \lesseqgtr Pr(E_B/\overline{\Gamma}) \end{cases} \tag{16}$$

From the top two equations on the right, Γ screens off E_A and E_B from each other but notice that $\overline{DCR}$ must be true. Even so, the inequalities in the right-third line state that the probabilities for E_A and for E_B are lower/greater when Γ occurs than when it does not, **in**directly establishing their stochastic dependence $(E_A\ CSR\ E_B)$. Differently: the first two equalities on the right assert that when conditioning the joint probability for E_A and E_B to Γ or to $\overline{\Gamma}$ they are independent, i.e. ***no*** DCR exists. In Symbols: $(E_A\ \overline{DCR}\ E_B) \wedge (E_A\ CR\ E_B) \Rightarrow \exists\ \ \Gamma = CS(E_A, E_B)\colon E_A\ CSR\ E_B$. It is paramount to understand that $\overline{DCR}$ excludes not only stochastic causal chains (genidentical or not) but also Causal (e) (Newton's gravity), our Causal (f) in QR/TOPI, and what have you. Only then, Γ can be ensured to exist – being the only reason for the causal link betwixt E_A and E_B.

Indeed, it can be proven that once Relations 16 are valid, Relations 12 and more are also valid:

$$Pr(E_B/E_A) \lesseqgtr Pr(E_B) \qquad ; \qquad Pr(E_A/E_B) \lesseqgtr Pr(E_A)$$
$$Pr(E_A)Pr(E_B) \lesseqgtr Pr(E_A, E_B) \lesseqgtr Pr(\{E_A, E_B\}/\Gamma) \tag{17}$$
$$Pr(E_A/\overline{\Gamma}) \lesseqgtr Pr(E_A) \lesseqgtr Pr(E_A/\Gamma)\,;\ Pr(E_B/\overline{\Gamma}) \lesseqgtr Pr(E_B) \lesseqgtr Pr(E_B/\Gamma)$$

The first line and the first inequality of the second line restate Relations 12. The second inequality of the second line affirms that the presence of Γ sways the joint probability of E_A and E_B. The third line asserts that the absence/presence of Γ affects the probability for E_A and for E_B. Being Γ and $\overline{\Gamma}$ the conditioning events, Relations 16 <u>seem</u> to naturally correspond to the *Common Cause* case in Figure 1 (right) in which the arrows depart from Γ, with no events beyond the three necessary. Of course, the causal links from Γ towards E_A and E_B could be implementa<u>ble</u> via stochastic genidentical chains, constituting another variant of *stochastic <u>local</u> causality* between E_A and E_B <u>exclusively</u> by means of two genidentical chains from Γ. As we will see, if the latter chains are light-limited, we have Bell's Local Causality.

But, again, the same Causal Relation 16 can be stated in its <u>inverse</u> form [34], in which the conditional events are E_A, E_B, and $E_A \wedge E_B$ (in lieu of Γ and $\overline{\Gamma}$); specifically:

$$\{E_A\ \overline{DCR}\ E_B\} \wedge \{\Gamma = CS(E_A, E_B)\} \Leftrightarrow \begin{cases} Pr(E_A)Pr(E_B) \lesseqgtr Pr(\Gamma) \lesseqgtr Pr(\Gamma/E_A, E_B) \\ Pr(\overline{\Gamma}/E_A) \lesseqgtr Pr(\Gamma) \lesseqgtr Pr(\Gamma/E_A) \\ Pr(\overline{\Gamma}/E_B) \lesseqgtr Pr(\Gamma) \lesseqgtr Pr(\Gamma/E_B) \end{cases} \tag{18}$$

It says that the probability for the event Γ is higher/lower when any or both events E_A and E_B occur. Equivalently, the occurrence of the latter events reduces/increases the probability of Γ not to be present. But now, these inequalities <u>seem</u> to naturally relate to the *Common Effect* case in

Figure 1 (Right) where the arrows converge on Γ. This is telling us again that we have no way of discriminating between the two cases on the right in Figure 1 (i.e. between the two arrow directions) because both of them may verify Relations 16 or, equivalently, Relations 18. Either because of a common *cause* or of a common *effect* or both, the joint occurrence of the two events is more/less probable than a pure *chance* coincidence – establishing a CSR. The three events are said to constitute a *conjunctive* fork [34].

We see once more that probabilistic relations are reversible; that is why I chose the name *Common Swayer*, and the reason QR/TOPI does not mutilate this reversibility (as Del Santo and Gisin do [60]) is because we will see that copious empirical data imply the existence of causality without causal order. Thus, in our m**a**croworld, if based only on Relations 16-18, *cause* and *effect* for actual *evincing* events would be just pragmatic analytic names without synthetic meaning. It is the empirically based anisotropy of time the one that allows us to distinguish one from the other, forcing us to reject any explanation based on a *common effect* of E_A and E_B in favor of the *common cause* for E_A and E_B. Albeit the coincidence of two light bulbs failing in your office may occur by mere chance, if it did not, common effects cannot explain why; common causes can, and that is why you would go straight to check the electrical panel for a blown fuse (common cause) – instead of checking whether your room is dark (common effect). In fact, it was the *common effect* what prompted you to look for a *common cause* to fix the problem – instead of assuming a mere haphazard blow up of both bulbs which would prompt you to change them without -most probably- light returning. Furthermore, as in this simple case, *common cause* and *common effect* may coexist but, if there is ***no*** DCR between E_A and E_B, a *common cause* may exist with or without a *common effect* but not vice versa [34] [33] [41]. The names *cause* and *effect* are the ones inextricably associated with the notion of time, ***not*** the *causal* relationship per se.

And like for the DCR, adopting the RT's Minkowski spacetime structure of actual *evincing* events and light-limited genidentical chains, if the Event-Interval between E_A and E_B is Type 2 (spacelike), ***no*** RT-DCR between them is admissible, and any CSR must be implementable by light-limited genidentical chains with the common cause event(s) belonging to the common absolute past of E_A and E_B and the common effect event(s) belonging to their common absolute future (as defined by their past and future light-hypercones respectively). Differently: in RT, any CSR between two events may exist ***only*** if light-limited genidentical chains are possible from the *Common Cause* to them (RT-CCR) or from them to their *Common Effect* (RT-CER).

Summarizing: under QR/TOPI, in its most *stochastic* general form we can state that E_A and E_B are causally related ($E_A\ CR\ E_B$) when either:

- There is a DCR of any type (RT or non-RT) between them ($E_A\ DCR\ E_B$); or
- There is a CSR of any type (RT or non-RT) between them, i.e. $\exists\ \Gamma\colon\ \Gamma = \mathrm{CS}(E_A, E_B)$; or
- Combinations thereof.

Finally, having extended the concepts of deterministic causal genidentical chains and common cause/effect to *stochastic* causality, the generalization of **Causal (a)**, **(b)**, **(c)**, and **Acausal (d)** for the classes of causal relations is straightforward – with their conclusions regarding time-order, time metrics, and needed conventions in Newton and Einstein's worlds all valid.

3. Special Relativity, Quantum Theory, and Reality

Our *free will* is essential for conducting Science. In our experiments we conceive of instrument settings that we can choose freely (within limits) and hence they can be correlated ***only*** with actual events in their future, i.e. those settings are presumed **un**determined by any actual events in their past. Despite each one by itself being (subjunctively) compatible with Newton and Einstein's worlds, *fatalism* and our *free will* are mutually exclusive. RT, orthodox QT, and QR/TOPI reject *fatalism*, and posit that our *free will* cannot change actual events in the past, viz ***no*** *retrocausation* is possible in any IF. Tersely: *free will* neither obeys nor controls the past, affecting only (within limits) the future. Disconcertingly, in QT, despite being structurally identical to the Diffusion Equation (which is **i**rreversible), the presence of the imaginary unit in the Schrödinger's Equation makes it time-reversal invariant, i.e. reversible [62] [17]. In QR/TOPI this is explained by realizing the iconic equation governs the joint evolution ***not*** of actual *evincing* events (in R-Time) but of the *probability* amplitudes for the Probable-Events (in QR-Time) [11].

Since RT and QT inceptions, the lexicon employed to talk about Reality was plagued with ambiguities and inconsistencies. The ill-defined notions of 'observer' and 'measurement' were and still are abused to purportedly provide RT and QT with physical meaning. None of those notions have (and should not have) anything to do with any physical theory (except, obviously, for supplying validation/falsification data) [23] [41] [37] [38]. After Einstein endowing the *Principle of Locality* with universal validity (RT, 1905), and masterfully succeeding in abolishing Newton's 'action at a distance' by describing *gravity* as a light-speed causal genidentical chain (GRT, 1916), the scientific community uncritically took for granted that *causality* invariably implied *time-order* ('cause' preceding 'effect') and that Reality was synonymous with 'Lorentz-Invariant local causality'. Realism has also been speciously associated with the belief that the results of any observation must be a mere consequence of pre-existing properties carried by the physical object – muddling the waters even further by demanding indiscriminate counterfactual definiteness.

Upon the advent of QT, *nonlocality* appeared back on the scene to Einstein's and Schrödinger's dismay and, striving to still hold tight to time-ordered causality and uncritical counterfactual definiteness, the locutions 'local realism' (pre-existing properties plus time-ordered *causality* plus *locality*) and 'nonlocal realism' (pre-existing properties plus time-ordered *causality* plus ***non****locality*) were used, confused, and abused. After all, Einstein had equated lack of causal connectability with lack of objective time-order and asserted that causality implied locality – from which his "definition" of *simultaneity* ensued (turning it relative to the IF). This led to speciously interpreting any violation of a Bell-type Inequality as a breach of 'local realism' (as if such violation were **un**real).

But Einstein -one of the main QT's founding fathers- stubbornly sustained that *nonlocality* was incompatible with his RT, which -jointly with orthodox QT's *stochastic* makeup- he claimed made QT **in**complete [13] [9] [10]. Had the main players realized that *locality* was ***not*** predicted by RT but simply a hidden axiom masked as a universal *principle*, i.e. that *nonlocality* was only forbidden by philosophical dogma, they would have recognized that RT and QT were ***both*** incomplete in the sense that they had to be conceptually completed and integrated into a single theoretical framework – not just simply accepted as two distinct theories which seemed to frailly coexist (as is the case still today). But they did not, so the melodrama of reconciling our preconceived notions of Reality with both RT and QT started between Einstein and Bohr around 1927… and continues.

3.1 Overt and Concealed Quantic Behavior - Coherence

The relations between the quanton's energy E, momentum $\vec{p}$, the source's frequency f, and wavenumber $\vec{k}$ are well known: $E = hf$; $\vec{p} = h\vec{k}$. Due to this Planck/Einstein/de Broglie nexus between the m**a**cro and m**i**cro worlds, the equi-surfaces for the Maupertuisian Action (A_M) and Hamiltonian Action $(A_H = A_M - Et)$ have a space and time periodicity they did not have for a Newtonian particle. The homology started by Hamilton in the 1800s between the equi-Action A_M and the equi-Phase surfaces, as well as between the equi-Action A_H and the wavefronts, was finally complete [37] [38]. There is a close relation between QT and steady-state classical relativistic wave equations: the time-independent Schrodinger's Equation is obtainable from the Helmholtz's Equation (the time-independent part of the classical relativistic wave equation). By combining the expression $\Psi e^{i2\pi(kq-ft)}$ for a monochromatic wave with the above m**i**cro/m**a**cro relations, the quantic expression $\Psi e^{(i/\hbar)A_H}$ was obtained, extended by de Broglie to non-zero rest-mass 'particles', used by Schrödinger to develop his famous equation, and became the basis of Bohmian Mechanics, as well as the integrand in Feynman's path integral formulation. In fact, Hamilton's classical mechanics is obtained from Feynman's path integral formulation of QT when $h \to 0$ [38] [37] [41] [11].

High-intensity light emission is a multi-frequency non-continuous process: a *real* source can only approximate a *monochromatic* wave over limited spacetime intervals, intermittently emitting trains of millions of cycles with random and abrupt changes in *phase* and *polarization*. The maximum distance/time the wave travels with a given frequency/phase/polarization is the coherence length/time for the source. Laser light is special because it can sustain extended coherence. Typical laser coherence lengths are: ~20cm for multi-mode helium/neon lasers; ~100m for single-mode lasers; ~20cm to ~100m for semiconductor lasers; and over 100 km for single-mode fiber lasers[59]. There is also a coherence minimum length/time for the quanton itself [60]: once the intensity of a light source is dimmed to the single-photon level, the display of quantic behavior depends upon the relation between the quanton's de Broglie wavelength (h/p)[61] and the m**a**cro-distances at play [63] [14]. For the photon to manifest quantic behavior, the photon source's length/time coherence is an upper bound ($\lesssim m/ns$ or even $\lesssim km/\mu s$) and the photon's length/time phase coherence is a lower bound ($\gtrsim \mu m/fs$). Decoherence is the degradation of quantic behavior due to the **i**rreversible interaction of the quanton with its environment.

For instance, as described in [64], the coherence length for the pump laser was $30m$ (upper bound) and that for the photon was $10\mu m$ (lower bound) so, to preserve the quantic behavior, the length of the interferometer's arms had to be shorter than $30m$[62], while their path difference had to exceed $10\mu m$. Under such conditions, the photon cannot be abstracted to a point-object, its states inside the interferometer are all probable, with its quantic behavior being overt and provable via interference, entanglement, and nonlocality data [11]. Otherwise, either because those conditions are breached or because we include a PDI in one of the arms of the interferometer, a narrative

[59] In the best fibers (loss=0.15 dB/km), transmission of one bit via a single-photon is limited to about 500 km [209].

[60] Frequency has physical import only for *time intervals* including multiple cycles, and wavenumber has physical meaning only for *space intervals* including several wavelengths [11].

[61] For a quanton with a positive rest-mass, it is commonly used the Compton wavelength, which is the wavelength of a photon whose energy equals the rest-energy of the quanton. For the electron, it is 2.42631023867(73) $\times 10^{-12}$ m.

[62] Measurements of the fringe visibility in the Michelson-Morley interferometer when the pathlengths' difference is greater than the mean lifetime of the atom producing the photon were made in [200].

describing the photon as a classical point-object with one actual state, i.e. as traversing either one or the other arm would be possible – with ***no*** interference occurring. As another example, two identical photons arriving to the inputs of a 50/50 Beam Splitter (BS) *simultaneously* within their coherence times will (randomly) fire one and the same output detector (Bosonic behavior); otherwise, both detectors may fire (Fermionic behavior). Furthermore, this overt quantic behavior is gradually modifiable by varying the time-interval between the photons' arrivals to the BS. Similar quantic behavior is displayed if they agree/differ in polarization instead of in arrival time, which was used by Zeilinger's group to achieve 600m-teleportation under the Danube river [65].

Under QR/TOPI, the two types of coherence are needed for the ITI among the quanton's probable states in PTIs to occur either in the m**i**crocosm or -under extremely controlled situations- in the m**a**crocosm [11]. In essence, preserving coherence requires controlling the quanton's milieu so it only undergoes PTIs (***no*** unplanned PDIs). A PTI (with its inherent ITI) corresponds to steady-state behavior (linear and reversible); a PDI is a transient **i**rreversible process to another steady-state; it is non-linear (non-unitary) and includes dephasing[63] and energy dissipation. In Part III [11], we briefly elaborated upon the traits of a PTI as opposed to those of a PDI and found the quanton has to be sufficiently isolated from heat-baths interactions, requiring low temperatures and/or time scales shorter than the characteristic thermal time [66] [67] [68]. For instance, meeting those requisites and using diffraction gratings, interference patterns have been created for molecules comprising around 2000 atoms and, using an acoustic-wave-resonator technique[64], coherences up to $40\mu s$ were achieved for massive crystals (10^{16} atoms).

For superconducting qubits like in the IBM's 'Condor' (>1000 qubits) and the Google's 'Sycamore' quantum computers, the coherence time is at most a millisecond. It turns out that the best qubits for computing might end up being atoms/molecules[65]. Recently, USA/UK researchers extended the lifetime of molecular qubits by altering the symmetry of their crystal's structure. The qubits (chromium-based ions attached to carbon-based molecules) were shielded from magnetic fields by the crystal's **a**symmetry, increasing the qubits' coherence time from $2\,\mu s$ to $10\mu s$[66]. According to an article in 'New Scientist' dated October 24, 2023, a quantum computer developer has built a computer with more than 1000 qubits using ytterbium atoms, with impressive coherence times reaching 60 sec. We see then that, under adequate physical conditions, quantic behavior is exhibited for simple as well as for highly complex objects/phenomena – as long as energy, momentum, frequency, and wavelength interact at levels comparable to the Planck's constant. In brief, complex composite quantons can behave as quantically as elementary quantons (presumably without internal structure).

It is also important to understand that the continuity requirement for deterministic and stochastic genidentical chains is an abstraction whose applicability obtains at different scales according to the situation. Hence, a causal net of discrete events for the states of a quanton, the transition between which obeys the *stochastic* laws of QT, may be abstractable in the appropriate scale to a *deterministic* genidentical chain. Thus, despite the quanton ***not*** being a point-object,

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[63] Randomization of the relative phases among the quantic states.

[64] A tiny sapphire slab cooled down to 0.01°C above 0K vibrating at $6\,GHz$. The crystal (10^{16}atoms) is coupled piezoelectrically to a superconducting circuit acting as a qubit. In this way, Fadel et al created a quantic state for the crystal. They found quantum behavior in the vibration of the crystal for up to $40\mu s$.

[65] Ball, Philip, *The Best Qubits for Quantum Computing Might Just Be Atoms*. Quanta Magazine, March 25, 2024.

[66] Visit www.anl.gov (10/13/2022).

there are cases in which the quanton can be considered as following a m**a**cro-trajectory in spacetime (a genidentical chain as it were), so that its State-Events are abstractable to point-Events in our spacetime. A case in point is a photon in an optical fiber entering a BS: knowing the high-intensity light's speed in the output fibers and their lengths, though being ***non***-evincing (as all State-Events), we can imagine each of the photon's probable states associated with each fiber evolving as a genidentical chain and assign an R-Time to a potential encounter of the photon with a detector (PDI) in each fiber (even if it does not click). In QR/TOPI, *non-evincing* actual events are pinpointable in spacetime – like Sherlock Holmes famous dog's ***non***-barking event which had well-defined space and time coordinates (and real consequences).

Another case is the evolution of an 'elementary particle' in the Wilson chamber: its trajectory looks like a m**a**croscopic genidentical chain because the quanton experiences non-destructive PDIs with large obstacles inducing condensation of supersaturated vapor (water droplets) at spatially discrete centers which, in our level of common experience, are close enough to globally look like a continuous path. Likewise when an atom is ionized creating a detectable spot in a cloud of a bubble chamber, or when a silver bromide molecule dissociates creating a speck of silver in a photographic emulsion [69]. Between those adjacent discrete actual overt (*evincing*) PDI-Events, there was a continuum of concealed (***non****-evincing*) probable states for the quanton [11].

4. Single-Quanton Phenomena: The Need for QR/TOPI

Well before his 1935 EPR paper [13] condemning the apparent *nonlocality* among two 'particles', Einstein -via thought experiments- had decried the 'one-particle nonlocality' at the 1927 Solvay conference[67]. Albeit surely aware that his "spooky action at a distance" warranted energy conservation of single-quanton events, Einstein believed that such a "causal anomaly" was incompatible with RT and that, if proven a reality, his theory would be irreparably annulled. Nonetheless, even today, the term *nonlocality* is associated mainly with the EPR type, i.e. with the so-called 'Bell nonlocality' between two or more quantons. But Bell's nonlocality is only applicable to multi-quanton[68] state-spaces with non-prime dimension $D \geq 4$; and the contextuality of Bell-Kochen-Specker (BKS)[69] only to state-spaces with $D \geq 3$ [70] [71] [72] [73]. Instead, per QR/TOPI, single-quanton *nonlocality* occurs in all state-spaces of any dimension $D \geq 2$, so it is the fundamental one and the genesis of them all [9] [10] [11]. In fact, the pioneers of quantum cryptography initially relied on the *nonlocal* behavior of a single qubit [38].

4.1 Implementation of Einstein's Solvay 1927 Gedankenexperiment

In Figure 8, per our QR/TOPI lingo, we see a GI (a PTI plus a PDI) while the laser embodies a QEI; the SPDC (Spontaneous Parametric Down Converter)[70] implements a PEI creating a pair of photons relayed via opposite paths: the heralding (also called 'idler') photon to the left, and the heralded (also called 'signal') one entering the BS. The latter instantiates a PTI with its inherent

[67] Einstein sketched a single-slit setup for light diffraction. After the slit, the Schrödinger wave for the photon is a spherical wave, so the probability for the photon to impinge on any point of a hemispherical screen is uniform.
[68] Bell nonlocality does not apply, for instance, to a single 3/2-spin quanton whose state-space dimension is four [72].
[69] Bell wrote his contextuality paper before his famous theorem, but it was published two years later [70].
[70] The SPDC is a non-linear birefringent crystal that, upon receiving a high-energy photon (e.g. 532 nm), emits two lower-energy photons (e.g. 810 nm and 1550 nm) [74].

ITI among the probable states for the photon. Detectors D_A and D_B jointly embody the PDI for the heralded photon. The firing of the detector D_H heralds the creation of a photon pair and the entrance of the heralded photon to the BS, whose transmission path (after a delay line) is monitored by D_A while its deflection path is checked by the mobile D_B. The respective optic-fiber pathlengths to and the distance between detectors D_A and D_B determine the type of Event-Interval (1, 2, or 3) between their click/no-click PDI-Events. Ergo, adjusting the location of D_B and the delay-line, timelike, lightlike, or spacelike separations are possible. 'CC' stands for Coincidence Counter, which is triggered by the D_H signal and counts the firing coincidences for the three detectors.

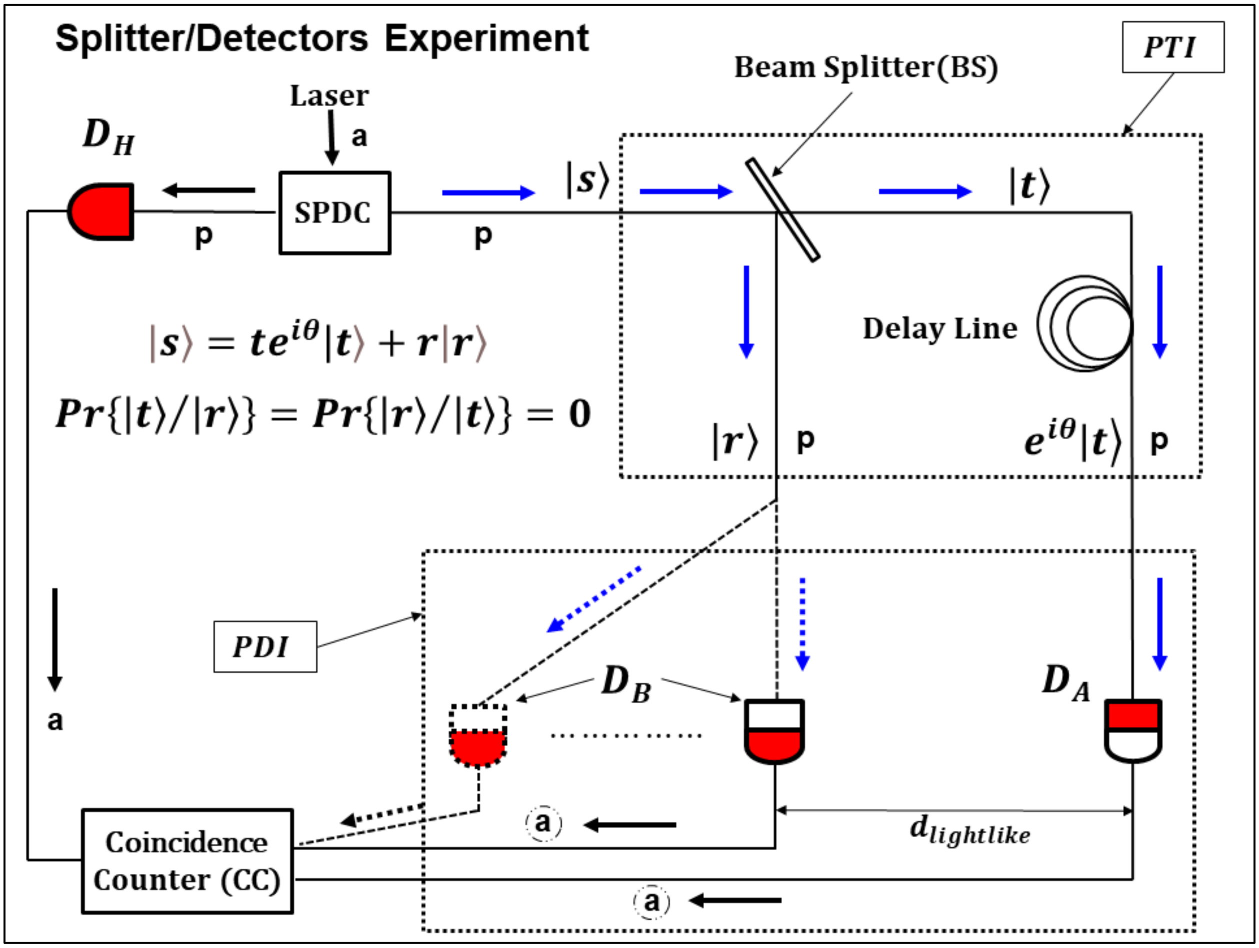

Figure 8 – Splitter/Detectors Experiment (SDE)

In the paper "Single-photon space-like antibunching" [74], Guerreiro et al described a setup in which both fibers leaving the BS were $10m$ long and the detectors' jitter was $\sim 1ns$. Clearly, light-limited 'messaging' between the detectors would have been only possible had their mutual distance been $d < 10^{-9} \cdot 3 \cdot 10^{8} = 0.3m$. Hence, when d was also $10m \gg 0.3m$, the click and no-click PDI-Events were certainly spacelike-separated, and their *simultaneity* in the lab's IF proven at least within $1ns$. They found that "whether the separation between detectors' events was timelike or spacelike, the number of coincidences was three orders of magnitude smaller than what would be expected had the events been uncorrelated"[71]. Pithily: the PDI-Events occurred in a mutually

[71] Albeit tiny, there is a chance for the SPDC to create two pairs (each detector fired by a photon in a different pair).

exclusive 'coordinated' way – even when (according to RT) ***no*** signal could be exchanged to realize such 'coordination'. Recall that ***no*** other type of causal relation exists in RT.

Per the BS operation [11], calling $A(B)$ a random variable equal to $+1$ if the detector $D_A(D_B)$ clicks and to -1 if it does not, Guerreiro et al found that $A.B = \langle A.B \rangle = -1$. And calling a the high-intensity split-ratio[72] for the D_A arm, we get $\langle A \rangle = 2a - 1; \langle B \rangle = -2a + 1; A^2 = \langle A^2 \rangle = B^2 = \langle B^2 \rangle = 1$; $\langle A \rangle . \langle B \rangle = -4a^2 + 4a - 1; SD_A = SD_B = 2\sqrt{a(1-a)}$. Therefore, we calculate $Corr\,(A,B) = \{\langle A.B \rangle - \langle A \rangle . \langle B \rangle\}/SD_A SD_B = 4a(a-1)/\{4a(1-a)\} = -1\ \forall\ a \neq 0, 1$. Hence, another way of expressing Guerreiro et al experimental results is: the PDI-Events at the two detectors were perfectly anti-correlated despite no light-limited signaling between them being possible. We will refer to this basic experiment as the Splitter-Detectors Experiment (SDE).

4.1.1 The SDE vis à vis Special Relativity

Let us understand what the SDE actually proves and why does it imply the **in**completeness of Special Relativity. As said, given the length of the optic fiber from the BS to a detector and the speed of light in the fiber, despite being ***non***-*evincing*, a no-click event can be pinpointed in spacetime by its absence at the expected R-Time and the location of the detector. Hence, the results of the two detectors (click/no-click) can be arranged to be timelike, lightlike, or spacelike-separated – in all cases SDE corroborating the perfect anti-correlation between the click/no-click PDI-Events. Given so, the *stochasticity* of the SDE could be modeled as follows:

1. **Epistemic** Stochasticity. As hoped by EPR, QT could be epistemically *stochastic*, i.e. RT-*deterministic* (ergo light-limited local) with its *stochasticity* relegated to the source and as a surrogate for lack of knowledge. Being the detectors' firing *stochastic* but the anti-correlation perfect, which detector fires on each run could be *stochastically* fixed at the source and ***no*** DCR (RT or ***non***-RT) would be needed between distant detectors. Note though that we would be simply shifting the PD from the detectors (Copenhagen view) to the 'particle' source – turning everything between source and each detector into a *deterministic* RT-genidentical chain. But there is more: by combining the 'particle' with a ghost 'wave' splitting at the BS (according to its setting a) while the 'particle' going alternatively only through one of its outputs, we could at once: (1) fully eliminate *stochasticity*, (2) avoid *retrocausality* (our at-will 'on the fly' change of setting a affecting the past state of the 'particle' at the source), and (3) account for the *interference* that would happen when directing the outputs of the BS into a second BS (Quantic MME). This corresponds to the de Broglie's pilot-wave theory, which is fully *local* and *deterministic*. However, we will see it miserably failing for more than one 'particle', e.g. in a Bell Experiment where correlation between distant PDI-Events is not perfect but spans the whole range $(-1, +1)$: unless we embrace fatalism, retrocausality, superdeterminism, or the lavish 'Many-Worlds'/'Many-Minds'/'Parallel Lives', *nonlocality* is inevitable and, ergo, in conflict with Special Relativity. More of this in Section 5.
2. **Ontic** Stochasticity: The theory could be ontically *stochastic* all the way up to the detectors, with the PD being the *stochastic* signature for the quanton interacting with the BS (PTI). The perfect anti-correlation between the spacelike click/no-click events would be enough to calling for a 'coordinating' ***non***-RT DCR, and given that SDE displays such perfect anti-correlation

[72] Because high intensities are proportional to the number of photons, such ratio approaches the probability for a single photon to reach detector A.

for all types of Event-Intervals (1, 2, and 3), single-quanton *nonlocality* is the only option. In fact, allowing only for RT-DCRs (i.e. only light-limited *local* influences) between detectors would make the theory *local* (with ***no*** hidden variables) but it could only achieve the perfect anti-correlation for types 1 and 3 Event-Intervals, while for Type 2 (spacelike) the theory sometimes would predict two 'clicks' and two 'no clicks'. And, being so, energy could only be conserved on the average and ***not*** for the single event, all against SDE experimental evidence [75] [76] [77]. Single-quanton *nonlocality* is a basic tenet of QR/TOPI, calling for the completion of RT with -among other features- what we anticipated as a 'quantic link'.

4.1.2 The SDE under QR/TOPI

Quoting Wittgenstein, "Philosophical problems arise when language goes on holiday"[73]. And, by "language goes on holiday" I understand not only failing to precisely define the specific meaning applied to existing words or failing to create new words if necessary for better understanding of a controversial subject, but also disingenuously blurring the precise meaning of established words or euphemistically creating new ones with the purpose of making one's position more believable (as most politicians do). Failing to linguistically act when is necessary and acting when is not needed lead to similar philosophical problems. With this generic observation, we need to further tune up a little some semantics we agreed on in Part III when I said:

> *... to be able to proceed, we must also tighten the semantics underlying English words that normally refer indifferently to space or to time: we convene in that the terms 'first', 'intermediate', 'last', 'input', 'before', 'output', 'after', 'serial', and 'parallel' refer **only** to the topology*[74] *of PIs in our physical space (not to R-Time)* [11].

Indeed, to continue developing QR/TOPI, I need to liberate from the shackles of the above linguistic convention so that -when referring to QR-Time (which includes R-Time)- I will use the phrases 'time-first', 'time-before', 'time-intermediate', 'time-last', time-after, time-between, and so forth. Without the 'time' qualifier, the terms continue referring exclusively to regions of space and their relational status in a network of PIs. Even the terms 'previous', 'current', and 'next' we have used for states/PIs/MBs and state-transition equations may require the 'time' qualifier for disambiguation. Were all point-Events joined by genidentical chains, this semantic nuance would be unnecessary within the chain because time and space would go continuously hand in hand, explaining why during our common daily discourse the context usually determines whether we are referring to space or to time. Now to the point. In Part III, when referring to qubits, I said:

> *... after the quanton undergoes a PDI, i.e. a photodetector in one channel does(does not) fire, the quanton's probable state on that(the other) channel becomes actual and, ergo, the state on the other(that) channel is meaningless.* [11]

Recall the 'channel' language for a qubit made sense because, at the level of a single-quanton, GIs are ***not*** fully abstractable to a point in spacetime: A GI for spin, polarization, momentum, energy, etc. typically involves a PTI to associate each quanton's probable state with a distinct spatial region ('physical channels', e.g. different optical fibers), and a PDI (one or more detectors) to expose (pinpoint) the quanton somewhere in one of those regions. So, because RT deals only

[73] L. Wittgenstein, *Philosophical Investigations*, Basil Blackwell, 1953.

[74] By 'topology' we mean the connectedness structure among the PIs (which outputs go to which inputs) plus the spatial extension of those links (providing a phase factor to the ontic probable state associated with each of them).

with actual *evincing* point-Events and recalling that in QR/TOPI -though both are actual- PDI-Events can be *evincing* or *non-evincing* while State-Events are always *non-evincing*, let us revise and improve the above excerpt accordingly:

ALBA4: *… after the quanton undergoes a PDI and a detector fires (an evincing PDI-Event), the probable state corresponding to that physical channel becomes the actual state for the quanton (a local State-Event) while the probable state corresponding to the other channel dissociates from the quanton (a* ***non****local State-Event); if such detector does* ***not*** *fire (a* ***non****-evincing PDI-Event), the probable state corresponding to that physical channel dissociates from the quanton (a local State-Event), while the probable state corresponding to the other channel becomes the actual state for the quanton (a* ***non****local State-Event). In both cases, nonlocality is the key element.*

Note again that in QR/TOPI the no-click PDI-Event (a ***non***-Event in RT) is as actual as the click event, albeit ***non****-evincing* (Sir Conan Doyle's "dog that didn't bark"). As for the dissociation of a quanton's probable state and the adoption of the other probable state as actual[75], they are State-Events which are always ***non****-evincing* and occur upon a PDI-Event (*evincing* or ***non****-evincing*). As long as these events are abstractable to a spacetime point, we can apply our definition of Types 0, 1, 2, and 3 for R-Event-intervals (i.e. actual *evincing*) to them, whether *evincing* or ***not***. As said before [9] [10] [11], the above makes sense because the quanton is the posited real object and, while its events, states, and properties are also real by association, they come and go as the quanton interacts with its milieu. Furthermore, a new Type 4 of Event-Interval will soon be defined.

Under QR/TOPI, with θ the total phase difference at the detectors inputs, the photon's state and ITI equations for the SDE experimental setup are:

State Equation/Probability Distribution

$$|s\rangle = te^{i\theta}|t\rangle + r|r\rangle \qquad Pr\{|t\rangle/|s\rangle\} = \left|te^{i\theta}\right|^2 = |t|^2 \qquad Pr\{|r\rangle/|s\rangle\} = |r|^2 \tag{19}$$

⇓

Intrinsic Tele-Interaction (ITI)

$$Pr\{|t\rangle/|r\rangle\} = \frac{Pr\{|t\rangle|r\rangle\}}{Pr\{|r\rangle\}} = Pr\{|r\rangle/|t\rangle\} = \frac{Pr\{|r\rangle|t\rangle\}}{Pr\{|t\rangle\}} = 0 \tag{20}$$

When interacting with the BS, Equation 19 (left) expresses the photon's input state $|s\rangle$ as a 2-superposition of its two (ontic and co-extant) *probable* output states $|t\rangle$ and $|r\rangle$ (the MB), while Equations 19 (Right) express their respective probabilities. As explained in Part III, even the input state $|s\rangle$ could be ontically *probable* (as determined by the previous PI) [11]. Also, recall the difference between the *state* and its *expression* in a given basis. Any basis but the MB would be legitimate albeit more cumbersome (Born Rule would not be directly valid).

The detectors' behavior is indicated in the graph by a solid red (fired) for the heralding detector and mutually exclusive half white (not fired), half red (fired) for D_A and D_B. Notice (as accorded

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75 This is so because the dimension of the state-space is 2 and agrees with the number of channels, so 'no-click' implies the quanton did adopt the other state. Otherwise, what becomes actual is ***not*** an eigenstate but a 2-superposition of eigenstates, and such a no-click event is called -again misleadingly- a "***partial*** measurement" [27].

in Part III [11]) that the 'p' labels denote (ontic) probable states, the 'a' labels indicate actual *states* or *signals*, while 'dot-encircled a' labels signify 'exclusively actual' *states* or *signals*. We see that the *states* associated to the deflected and transmitted channels are *probable* and co-extant; that the two 'p' at the SPDC outputs correspond to *probable* co-extant *states* for different photons; and that the two 'a' after the detectors D_A and D_B are dot-encircled because they correspond to *actual* states for the same photon and, being *actual*, they are mutually exclusive so (ideally) only one high-intensity signal goes to the coincidence counter from the GI. Likewise, after D_H there is an RT-signal and, ergo, light-limited, *actual*, and *evincing*. That is what a detector does upon clicking: convert and amplify the quanton's *probable* or *actual* state into a high-intensity signal.

Equations 20 specify the ITI inherent in such a PTI: a reciprocal relation between the conditional probabilities of those two *probable* states[76]. Once again: setting a *probable* state as the condition does ***not*** mean: (a) that it is assumed to be *actual*; and/or (b) that it occurs time-before the other state. States and their probabilities are ***not*** objects inhabiting spacetime: what Equations 20 specify is how the probabilities of the two *probable* states (each associated with a different spatial region) interrelate **a**temporally – imposing upon a PDI their mutual exclusivity (leaving the quanton in one *actual* state). They are the single-quanton version of the ITI we introduced for a composite quanton in [11] [10] – to be further scrutinized in Section 5. Though redundant, let us show more conditional probability relations explicitly showing how firing and ***not*** firing are interdependent PDI-Events and, ergo, detectors D_A and D_B make up a single composite PDI (as indicated by the dotted-rectangle in the graph). The equations are (top bar meaning negation):

$$Pr\{\overline{|t\rangle}/|r\rangle\} = Pr\{\overline{|r\rangle}/|t\rangle\} = Pr\{|t\rangle/\overline{|r\rangle}\} = Pr\{|r\rangle/\overline{|t\rangle}\} = 1 \qquad (21)$$

Single-photon detectors are building blocks of a PDI and, when multiply installed in *distant* physical channels associated with the probable states of a single photon, they constitute a single composite PDI. Suarez (co-author of the SDE paper [74]) interpreted their results as confirmation of "nonlocality at detection" or "decision at detection", instead of the "decision at the BS" implied by the de Broglie/Bohm theory and MWI [75] [76]. However, under QR/TOPI this behavior is not intrinsic to the detectors but to the quanton and the unique milieu (the BS PTI) with which interacts during the GI. The PDI (embodied by one or two detectors) actualizes the *nonlocal* ITI (Equations 20) that existed all along upon the photon entering the BS. Statistically speaking, the PDI samples the PD implicit in the State-Equation via a probability measure given by the Born's Rule.

From the energy-conservation viewpoint, while the PTI (with its ITI) is active, i.e. until the interaction with a detector (click/no-click) occurs, the PD for the photon's energy is the one conserved; afterwards, energy must conserve factually[77] so if there are two detectors, only one can and must fire (regardless of whether their PDI-Events are spacelike, timelike, or lightlike-separated). Initially, Bohr -refusing the reality of the photon- had proposed that energy conserved only on the average but the discovery of the Compton Effect and further experiments by Compton, Geiger, and Bothe proved that energy and momentum did conserve during single photon/electron collisions [37]. And the SDE as reported by Guerreiro et al irrefutably proves it [74]. Under

[76] Another more abstract way: the projector $|t\rangle\langle t|$ has the eigenvector/eigenvalue pair $(|t\rangle/1, |r\rangle/0)$ and the projector $|r\rangle\langle r|$ has the eigenvector/eigenvalue pair $(|t\rangle/0, |r\rangle/1)$.

[77] Note that the non-factual conservation (PD conservation) is as real as (and more fundamental than) the factual one.

QR/TOPI, single-quanton *nonlocality* is not only posited real but required for energy conservation at the quanton level.

Finally, notice that Equations 20 (ITI) are valid regardless of the probability amplitudes $te^{i\theta}$ and r in Equation 19 (left) for the quanton state, i.e. regardless of the BS setting a ($a = |t|^2$) – accounting for the perfect anti-correlation between the PDI-Events at the detectors. That is why, as we already saw, a local deterministic model is possible in which the *stochasticity* is transferred back to the source and can be interpreted as epistemic (lack of knowledge). And, in the single 'particle' case, the lack of knowledge and potential *retrocausality* (if setting a is adjusted 'on the fly' right before the 'particle' enters the BS) can also be eliminated by adding a 'ghost' pilot wave which splits at the BS per its settings. But we anticipated and will soon see that such a model quickly fails for two or more 'particles' (Section 5).

4.2 Single-Photon Michelson-Morley and Kennedy-Thorndike Experiments

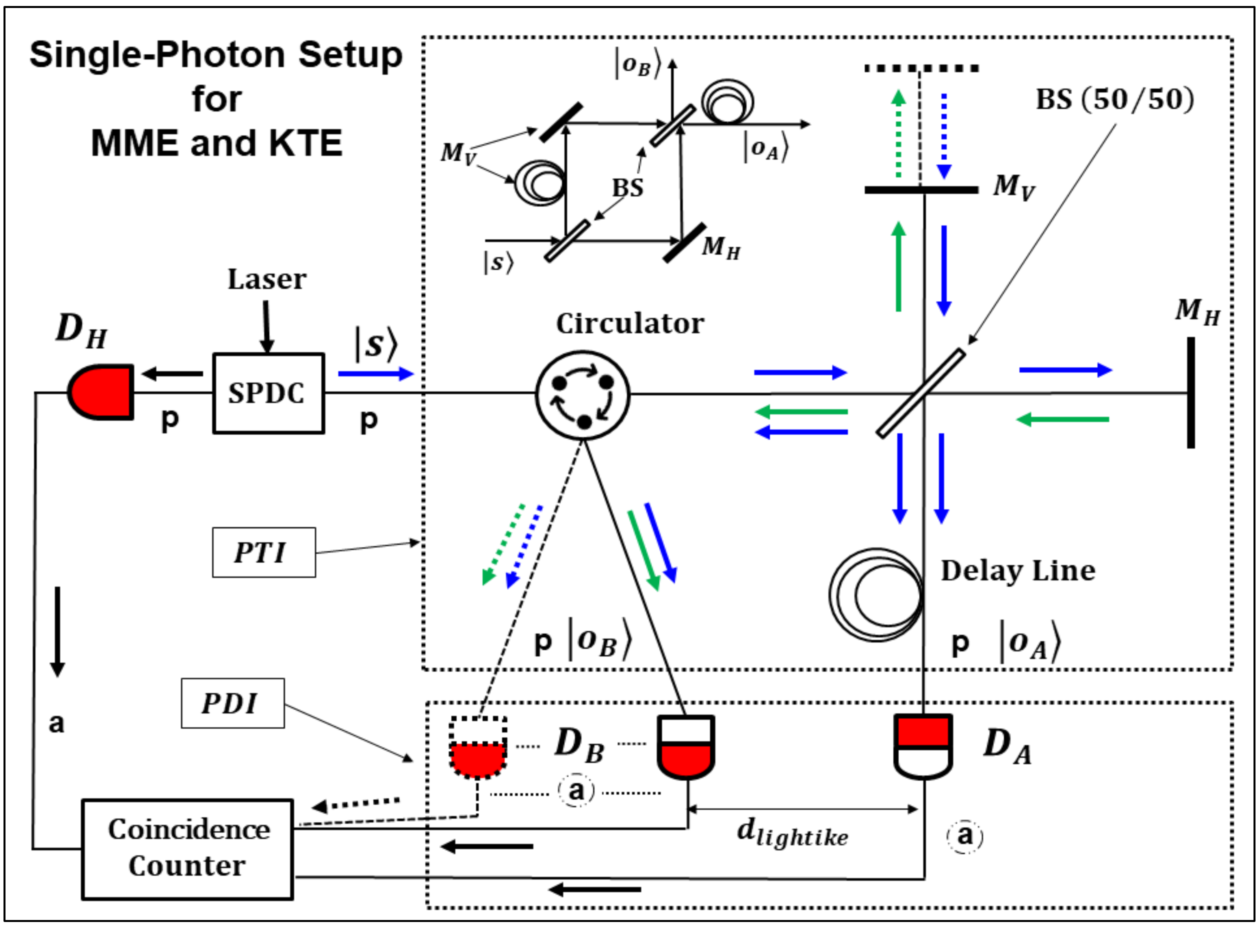

Figure 9 – Single-Photon MME (QMME) and KTE (QKTE)

Many papers proposing the single-photon version of the MME exist [78] [79] [80] [77] [81] [82] [83]. Combining the previous setup for the SDE in Figure 8 with the interferometer for MME/KTE, Figure 9 sketches an experimental setup for a single-photon realization of MME (QMME) and KTE (QKTE). From Figure 3 (where L and l are twice the pathlengths l_V and l_H due to the single half-silvered mirror's bidirectionality), the mobile mirror M_V allows us to conduct

QMME ($L = l$) or QKTE ($L > l$). The single-photon detector D_A replaces the telescope in MME/KTE, and the 'Circulator'[78] lets us direct the photon when 'leaving' the PTI towards the mobile detector D_B which, together with the delay line in the other output, allow for the PDI-Events (click/no-click) at both detectors to be timelike, spacelike, or lightlike separated.

As discussed at length in [11] [41] [37] [38], the *interference fringes* in a high-intensity optical setup are homologous to the detectors' *click rates* in its single-photon version. We also saw that, because light intensities are proportional to the number of photons, their ratios for large number of photons should approach the probabilities for a single photon to adopt one state or the other. At the top-left corner in the dotted-box for the PTI, a Mach-Zehnder Interferometer (MZI) [11] is shown to be equivalent to the original interferometer after replacing its single BS (which acted bidirectionally) with two BSs (acting unidirectionally), and replacing the mobile mirror with a fixed one plus another adjustable delay line. This equivalency (which of course is also valid for high-intensity setups) allows us to use all we learned in Part III [11] about MZIs.

The high-intensity Equations 1 for MME/KTE should turn into the probability equations for QMME/QKTE when applying the bijections $I_V/I_i \leftrightarrow Pr\{|o_A\rangle/|s\rangle\}$ and $I_H/I_i \leftrightarrow Pr\{|o_B\rangle/|s\rangle\}$. You may recall from Part III [11] that, calling θ the total phase difference between the two arms of the MZI, δ the phase difference due to the different pathlengths from the MZI to the two detectors, and for 50/50 symmetric BSs ($a = 1/2$), we can simply add δ to the equations developed in Equation 16 of Part III [11], obtaining the state equations, probabilities, and ITI between the single photon's probable states:

State Equations and Probability Distribution for QMME/QKTE Setup

$$|s\rangle = \frac{ie^{i\delta}}{2}\{e^{i\theta}+1\}|o_A\rangle + \frac{1}{2}\{e^{i\theta}-1\}|o_B\rangle$$

$$\Downarrow (Born\ Rule)$$

$$Pr\{|o_A\rangle\} = \left|\frac{ie^{i\delta}}{2}\{e^{i\theta}+1\}\right|^2 = \frac{1}{2}(1+cos\theta)\ ;\ Pr\{|o_B\rangle\} = \left|\frac{1}{2}\{e^{i\theta}-1\}\right|^2 = \frac{1}{2}(1-cos\theta) \qquad (22)$$

Intrinsic Tele-Interaction (ITI)

$$Pr\{|o_A\rangle/|o_B\rangle\} = Pr\{|o_A\rangle|o_B\rangle\}/Pr\{|o_B\rangle\} = Pr\{|o_B\rangle/|o_A\rangle\} = Pr\{|o_A\rangle|o_B\rangle\}/Pr\{|o_A\rangle\} = 0$$

Note that, as expected, Equations 22 are -after the referred bijections- identical to Equations 1 for the high-intensity setup. Thus, the long-term click rates for detectors D_A and D_B depend only on the phase difference θ as calculated by $\theta = 2\pi(L-l)/\lambda_p$ and, ergo, the same for all IFs. Notice also that (a): for QMME ($L = l \Rightarrow \theta = 0$), $|s\rangle = ie^{i\delta}|o_A\rangle$, so $Pr\{|o_A\rangle/|s\rangle\} = 1$, i.e. there is constructive interference for $|o_A\rangle$ (100% click rate) and destructive for $|o_B\rangle$ (0% click rate), which corresponds to the negative result of the original (high-intensity light) MME; and (b): for QKTE ($L > l \Rightarrow 0 < \theta < \pi$), the click rates for D_A and D_B go 100% → 0% and 0% → 100% respectively and regardless of our planet motion in a hypothetical 'quantum ether'. In all cases, the fringes in the original high-intensity setup and the click rates in the single-photon setup depend exclusively

[78] A 'Circulator' is a device whose output port is always (circularly) the one next to the input port.

on the source's proper-frequency and the proper pathlength difference, implying that the roundtrip velocity of light is independent of the different IFs established by our planet's daily rotation and annual translation.

From the MME (1887), the KTE (1932), and the SDE (2012), we conclude that the QMME and the QKTE should produce the same *click rates* regardless of the apparatus' orientation, the time of the day, the day in the month, or the month in the year. Ergo, the same conclusions obtainable from MME/KTE that motivated/justified RT are obtainable from QMME/QKTE. Besides, we confirm that what made QT to be in conflict with RT was ***not*** MME or any other experimental data available at the time Einstein conceived RT but, instead, some of the implicit postulates he adopted by philosophical fiat: what I called the 'Nonlocality-Exclusion Axiom'.

4.3 QR/TOPI: Timing Single-Quanton Nonlocality

The SDE is the basic building block of the QMME/QKTE and a cornucopia of other experimental setups, so we will focus on its *timing* aspects per QR/TOPI. In our lab frame, using the word in vogue (*teleportation*) we already applied in Part III [11], it looks as if one detector were 'teleporting' its no-click(click) to the other so the latter would click(not click). Unfortunately, the pretentious term *teleportation* (rejecting of course its *psychokinesis* acceptation[79]) conveys a sense of *directional* travel from one place to another[80]. But the *state* of a quanton is ***not*** an object moving in spacetime: there is ***no*** *portage* but the *actualization* of the reciprocal immanent tele-interaction (ITI) that exists among its probable *states* (***not*** betwixt detectors). Ergo, a much better word would be *tele-interaction*. However, the term 'teleportation' instantly captured everyone's imagination entrenching to stay – so not using it in QR/TOPI would create more confusion than enlightenment.

We could also say that it appears as if the two detectors were 'entangled' so that only 'click/no-click' and 'no-click/click' results are possible. Otherwise, i.e. were 'click/click' and 'no-click/no-click' also possible, energy -as I already said- could still be conserved but only on the average (against SDE evidence). Again, there is no 'entanglement' between detectors but the actualization of the quanton/milieu ITI. This application to a single-quanton of the 'entanglement' language used for bi-quanton composites in Part III [11] is possible in virtue of a remarkable *fractal* structure to be uncovered in Section 8 ('How to Merge Special Relativity with Quantum Theory').

Based on our discussions of Guerreiro et al evidence [74], if the PDI has only one detector, the following PDI-Events and State-Events occur depending upon whether the detector fires or not:

(a) If it 'clicks', such *evincing* PDI-Event (an R-Event), the adoption by the quanton of the corresponding actual state (a *local* State-Event), and the **di**ssociation from the quanton of the *probable* state coupled with the other channel (a *teleportation* State-Event) must be all simultaneous. The common R-Time for those three simultaneous events is determined by the 'travel' time the quanton would have undergone as a classical particle to reach the detector. A second ideal (i.e. 100% reliable) detector in the other channel at a greater distance from the BS than the first ideal detector is guaranteed ***not*** to click.

(b) If it does ***not*** fire, such *non-evincing* PDI-Event, the **di**ssociation from the quanton of the corresponding *probable* state (a *local* State-Event), and the adoption of the *probable* state

[79] Merriam-Webster's Acceptation 1: "the act or process of moving an object or person by psychokinesis".
[80] Acceptation 2: "*in fiction*: instantaneous travel between two locations without crossing the intervening space".

associated with the other channel as actual (a *teleportation* State-Event) must be all simultaneous. The common R-Time for those three simultaneous events is determined by the 'travel' time the quanton would have undergone as a classical particle had it produced a click in the putative channel. A farther away second ideal detector in the other channel would confirm the quanton is in such actual state: an R-Event (click) is guaranteed to occur.

We see that *teleportation* is a State-Event that consists in the adoption (*dissociation*) of an actual (*probable*) state by the quanton in one of two channels by virtue of a no-click (*click*) in the other channel. And, remarkably, despite not being able to observe/measure *teleportation* per se, we are able to experimentally confine its occurrence in time between the occurrences of two distant PDI-Events which can be made virtually *simultaneous* in a given (arbitrary) IF while delivering the same experimental data (PD). Ergo, the R-Time for the PDI-Event in one channel becomes the QR-Time for two State-Events – one local and one distant: these two QR-Events (as all R-Events) can be abstracted to point-Events, i.e. are fully characterizable by a point in spacetime. In sum, this *simultaneity* must be objectively absolute, viz independent of the IF and of whether there is in fact a second detector or not. Is this absolute *simultaneity* in conflict with RT?

It is NOT: in the above case (a) the absolute *simultaneity* occurs between one R-Event (click) and two ***non***-R-Events (all State-Events are ***non***-*evincing*), while in case (b) it occurs among three ***non***-R-Events (one ***non***-*evincing* PDI-Event and two State-Events). Consequently, despite being all three events actual, no conflict with RT's relative *simultaneity* of actual *evincing* events is created. And, under QR/TOPI, the *simultaneity* between the two PDI-Events (one evincing and the other non-evincing) is (when spacelike-separated) relative. However, because the causal relation is ***not*** between detectors, the reversal of their time-order events among IFs causes no philosophical consternation as to which is the *cause* and which is the *effect*. But, to achieve consistency, symmetry and reciprocity, we will see that in order to calculate the spacetime coordinates for all actual events (evincing or not) in all IFs, the LT needs to be revised (better: to be extended).

4.4 No Human Communication via Single-Quanton Teleportation

Looking at the QMME/QKTE setup, we see that between activating the laser source and a detector firing there is a local causal relation (events absolutely ***non****simultaneous*) despite the photon ***not*** traveling -inside the interferometer- via well-defined trajectories in spacetime. Upon our turning the laser on, the *probability* of firing changes instantly for both detectors; it is the actual click/no-click in one of the detectors that takes time. Likewise, the causal relation between the adjustable arm's length and the click rates is ***not*** reciprocal: we can control the click rates by adjusting the arm's length (our *free will* Milieu-Event), but we cannot directly manipulate the click rates (Nature's *free will*) so as to modify the arm's length and, thus, there is an absolute R-Time order between them – with the locutions 'cause' and 'effect' having a synthetic meaning. In ***no*** IF can a change of the firing rate precede its associated change in the arms' length difference: they are absolutely ***non****simultaneous*. And notably again, despite this time order being absolute, the photon does not traverse the interferometer following a continuous path in spacetime [11]. This is because, despite the *cause* being a single actual *evincing* event in spacetime (the R-Event of changing the arm's length) and the detectors' click/no-click events being actual evincing/non-evincing events, the deterministic *effect* is not the click/no-click but their probability – which of course not only is neither an event nor an object, but it is ***not*** in our spacetime. The stochastic relation between events is **a**temporally reciprocal ***only*** inside the interferometer, in which there are

no PDI-Events. Otherwise, the existence of a PDI-Event inside the interferometer would convert a *probable* state into *actual*, screening off the future from the past and destroying *interference* [11].

Nonetheless, by Alice's free-will manipulation of the arm's length, she could send a message that Bob could decipher by jointly conducting a large number of single-photon runs and assessing the click rates of the detectors (there is a nomic relation between arm's length and long-term click rates). However, Bob cannot reciprocate via the same communication channel (he is on the side of Nature's *free will*). The *deterministic* RT obviously does not contemplate such unique type of stochastic *causation* because in the high-intensity setup the macro-object called light does indeed split into the different arms and recombines – with the detectors' intensities ratio encoding the arm-length. But even in this high-intensity case, human communication of data is in only one direction and -of course- speed-limited by light.

As for the click/no-click events of the detectors (which can be simultaneous or arbitrarily time-ordered), they are -per QR/TOPI- the result of the *actualization* of the causal relation between the photon's State-Events (adoption/dissociation) which ***is*** reciprocal without a time order between them, i.e. they are absolutely *simultaneous* – even though the time-order of the click/no-click events is relative when spacelike separated (Section 8). However, being the State-Events ***non***-evincing and governed by stochastic Equations 22, they cannot be freely manipulated, so they are useless to establish instant human communication.

Concluding: the commonplace assertion that the impossibility of superluminal signaling impedes the *simultaneity* between any two events to be absolute is untrue: it is based ***not*** on facts but on Einstein's hidden 'Nonlocality-Exclusion' postulate – masked as the (supposedly universal) *Principle of Locality*. We have been prisoners of our own prejudices (and Einstein's well-deserved authority) for over a century. We will see that in QR/TOPI there are two types of *simultaneity*: relative that may obtain among PDI-Events (*evincing* or not), and absolute (like Newton's gravity but sans *signaling*) that may exist betwixt a PDI-Event and State-Events as well as between State-Events. There is much more to Reality than Einstein's R-Events. From this point on, Zeilinger's "very fundamental question" will be progressively answered – reaching its pinnacle in Section 9.

5. Multi-Quanton Phenomena: The Need for QR/TOPI

We used the electron's spin interacting with a Stern-Gerlach (SG) magnet to discuss the famed EPRB experiment from various perspectives and for different reasons in Part II [10], Part III [11], and will do so again in Section 5.3. But EPRB is just one of the platoon of experiments referred to as 'Bell-type Experiments'. They are all characterized by:

1. Two quantons (e.g. photons) are created together and travel to distant stations A and B, where quanton *A(B)* may undergo a GI-$A(B)$ whose State-Event $E_A(E_B)$ delivers a property $P_A(P_B)$. As an example, GI-$A(B)$ could comprise a Polarizing Filter (PTI) plus a photodetector (PDI) with $P_A(P_B)$ being the photon's polarization.
2. The PTI in the GI-$A(B)$ has a setting $a(b)$ (e.g. the optic axis of the PF or the split-ratio of a BS), which we could adjust at will up to just time-before the GI-$A(B)$. By $a(b)$ we refer indistinctly to the value of the setting as well as to the event consisting of its setting.
3. Both GIs do occur (i.e. PDIs take place at both sites), with their Event-Interval experimentally arranged to be spacelike.

4. A global property P_{AB} is defined as $P_{AB} = P_A P_B$
5. Multiple runs (conducted/confirmed over decades) deliver the following statistical inference:
    a. Attributes P_A and P_B are ***not*** independent, displaying a correlation.
    b. The attribute $P_A(P_B)$ is **in**dependent of the setting $b(a)$.

Were RT complete (we contend it is not), such correlation between the two distant quantons' properties would suggest that, lacking an RT-DCR due to their spacelike separation, there should be an RT-CCR emanating at the common source – like identical twins carrying their shared birth traits, which are unveiled when (being far away and **un**able to communicate) they are subjected to private tests (whose results are afterwards contrasted). Bell was interested in finding out how far such analogy -engraved in us to the marrow- could go while still matching QT predictions.

5.1 The EPRB Experiment under Special Relativity – Bell's Theorem

In 1932, von Neumann had speciously claimed that ***no*** additional variables could be introduced such that QT's **in**deterministic description would be transformed into a *deterministic* one [8]. In 1935, Einstein et al -unaware of this purported impossibility- ended EPR with "We believe, however, that such a theory is possible". In 1952, Bohm proved von Neumann wrong – albeit Einstein considered such a *deterministic* (better: epistemically *stochastic*) solution "too cheap" [1].

Initially in Einstein/Bohm's philosophical camp[81] and after thoroughly weighing EPR, Bell knew QT was *nonlocal* and set his mind to prove that, by including additional variables, a so-called Hidden Variables Theory (HVT) would emerge in which 'causality' and 'locality' could be restored making QT 'complete' – with the meaning of the first two words in quotes as used in the *deterministic* RT and of the third as used in EPR. Alas, Bell showed in 1964 that QT predictions were **in**compatible with those of any (per Bell's conception) 'Local Hidden-Variable Theory' (BLHVT) [84]. Later in 1976, Bell did not mention EPR at all and wrote a new version where he defined his notion of 'local causality' in *stochastic* terms – formally proving that it was violated by QT, and giving a physico-philosophical explanation for the 'free will' hypothesis he thought needed for the proof [85] [86]. This more elaborated version is the one we will refer to as BLHVT.

Bell's allegiance to Einstein's 'Principle of Local Causality' was clear:

BELL3: *The direct causes (and effects) of events are nearby, and even the indirect causes (and effects) are no further away than permitted by the velocity of light.* [86]

But the original RT was *deterministic* and QT (according to the Copenhagen camp) was irreducibly *stochastic* so, to obtain a *deterministic* theory whose predictions agreed with a *stochastic* theory, Bell had to move the *stochasticity* occurring (per Copenhagen) at the GIs all the way back to the creation event of the two quantons. He did so by adding some new 'hidden' variable $\lambda = \cup\lambda_i$ (not appearing in the quantic state $|s\rangle$) so that $\Lambda = \{|s\rangle, \lambda\}$ would produce the stochastic result for each GI as a deterministic function of the GIs' settings (a, b) and of the value of λ (different for each run of the experiment per some probability distribution). In that way, λ

[81] In the 1950s, Bohm's philosophical stance seemed to morph from Copenhagen's to *determinism*: in the same year (1952), he published both 'Quantum Theory' [136] explaining Copenhagen's views and "A suggested interpretation of the quantum theory in terms of hidden variables" [90] [91]. Notwithstanding, he was always a defender of *reality*, *causality*, and striving to find an 'infinite-level ***non**-mechanistic* theory' [213].

overrode/supplemented $|s\rangle$, and the *stochasticity* of the results would be simply due to our ignorance of the particular value of λ for each run. The distribution of λ was unknown and uncontrollable, but its existence and uniqueness for a given experimental setup postulated. This possibility related someway to Einstein's dream and suggestion in EPR [13] [9] [10].

But to really please Einstein, those hidden variables would have to be actual *evincing* properties for the quantons in the pair, obeying his *Principle of Locality* from their creation until their GIs [84] [87] – which seemed to go against the meaning of 'hidden'[82]. Keep in mind as well that RT bans *retrocausality* by synchronizing all clocks with light-signals, whose speed is IF-Invariant and higher than that of any other object with positive rest-mass – which makes those quanton's properties non-contextual. Some authors refer to those required features as 'Einstein-Bell Realism' or as 'local realism', or as a 'classical ontology' [88]. But, even if all those features inherent in RT were realized, Landsman in [89] states that *truly deterministic hidden variable theories are those in which well-defined experiments have determined outcomes given the initial state and no appeal has to be made to irreducibly random samplings from this state*. Landsman argues that the necessary appeal to irreducible randomness for the initial state defeats the very purpose of hidden variable theories like Bohm's [90] [91] and 't Hooft's [40] [92]. But let us not abuse the benefit of hindsight and continue our path to understanding Bell's rationale for his theorem as well as the rationale behind our QR/TOPI.

5.1.1 Bell's Local Causality (BLC)

As said, in 1976, Bell went further and defined a "locally causal theory" stochastically. In essence, he stated that a theory is said to be locally causal if the probabilities attached to values of his local beables in a space-time region $A(B)$ are unaltered by specification of values of local beables in a spacelike separated region $B(A)$, when the values of local beables in some part of the backward light-hypercone of $A(B)$ are already sufficiently specified [85].

From BELL3, our stochastic extension of RT, and the above underscored words, it is evident that Bell's stochastic definition of *local causality* amounts to an acceptance of RT as regards its full equivalence betwixt causality and connectability via light-limited *genidentical chains*, as well as its rejection of *retrocausality*. It is also clear that his definition is equally applicable whether the stochasticity is epistemic (e.g. de Broglie/Bohm's theory) or ontic (QR/TOPI). Therefore, being his spacetime regions A and B spacelike-separated, Bell excluded at the outset direct causal genidentical chains faster than light and, of course, any ***non****local* influences – which means that he assumed there could ***not*** be a DCR of ***any*** type between those regions. Hence, the only way for the values of beables in those regions to be correlated would be through an RT-CCR, viz via light-limited genidentical chains emanating from a common cause. However, though such common cause had to originate in the absolute common past of regions A and B, because of the screening-off feature of genidentical chains, only the values of local beables in their respective absolute near past regions needed to be "sufficiently specified". Differently: because the setting parameter $a(b)$ could happen to be changed in the near absolute past of only $A(B)$, i.e. at a spacelike-separation from $B(A)$, the probability for $P_B(P_A)$ could not be a function of $a(b)$. All this is the consequence of RT restricting causal relationships to only those implementable directly or indirectly by light-

[82] The qualifier 'hidden' is highly contested in the literature, e.g. some claim that the 'hidden' variables in Bohm's theory are not hidden because they "actually appear directly in the results of measurements", while the wavefunction "can never be measured directly" [199]. Regardless of their name, their character should be clear in our exposition.

limited genidentical chains. Curtly: the empirical violation of any necessary feature of BLC would imply at the very least that RT is **in**complete.

Recalling that $E_A(E_B)$ is the State-Event that delivers the property $P_A(P_B)$ upon GI-$A(B)$, that $\Lambda = \{|s\rangle, \lambda\}$, and assuming the validity of BLC and the spacelike-separation of (E_A, E_B), (a, E_B), and (b, E_A), it is a commonplace to express those two necessary conditions (exclusion of any DCR and acceptance of only RT-CCR) as 'Output Independence' and 'Parameter Independence'. Breaching any of them would invalidate BLC, ergo, would prove RT's **in**completeness.

Output Independence: No DCR between spacelike E_A and E_B – Only CSR

$$Pr(E_A, E_B/a, b, \Lambda) = Pr(E_A/a, b, \Lambda)Pr(E_B/a, b, \Lambda)\begin{cases}\text{Breached by QT with } \Lambda = |s\rangle \\ \text{Obeyed by Bohm's HVT [1] [2] [93]}\end{cases}$$

This is known as 'Output Independence' (OuI)[83]. It is the first line of Relations 16, which is necessary when $\{E_A\ \overline{DCR}\ E_B\} \wedge \{\Gamma = CS(E_A, E_B)\}$ with $\Gamma = \{a, b, \lambda, |s\rangle\}$. It states the absence of any direct causal relation betwixt E_A and E_B (***not*** only RT-DCR) and leaves open the presence of any CSR, i.e. arbitrary Common Swayers (not only RT-CCR and/or RT-CER). Because of the spacelike-separation, the only way to breach OuI would be via ***non***-RT DCRs, namely: a purported *superluminal* local causal influence or simply a *nonlocal* DCR (both of which verify Relations 12 but are **in**admissible in RT) – a breach that, if empirically proven, would pinpoint the failure of BLC. In fact, we will see that if $\Lambda = \{|s\rangle, \lambda\}$ is simply $|s\rangle$, i.e. if QT is accepted as it is without hidden variables λ, then OuI is breached regardless of the events' separation (Section 5.3). Instead, Bohm's HVT does respect OuI. Thus, based only on OuI, QT is already ***non****local*, while Bohm's theory is still *local*.

Parameter Independence: No CR between spacelike events (b, E_A) and (a, E_B)

$$Pr(E_A/a, b, \Lambda) = Pr(E_A/a, \Lambda)\,; Pr(E_B/a, b, \Lambda) = Pr(E_B/b, \Lambda)\begin{cases}\text{Obeyed by QT with } \Lambda = |s\rangle \\ \text{Breached by Bohm's HVT [93] [1]}\end{cases}$$

This is known as 'Parameter Independence' (PaI)[84], where a and b denote the events of setting the parameters a and b for the PTIs at stations A and B. These two equalities are implied by Inequalities 12, expressing the lack of a causal relation of any type between E_A and setting b as well as between E_B and setting a, viz: $\{E_A\ \overline{CR}\ b \Leftrightarrow Pr(E_A/b) = Pr(E_A)\}$ and $\{E_B\ \overline{CR}\ a \Leftrightarrow Pr(E_B/a) = Pr(E_B)\}$. We will see that if Λ is simply $|s\rangle$, i.e. if QT is accepted as it is, then PaI is obeyed (Section 5.3). Epistemically, no statistical analysis of data collected with a given setting at one site could uncover which the setting at the other site was.

But again, though -due to the spacelike-separation- BLC forbids any RT-DCR between E_A and b or between E_B and a, PaI could still be breached because of a ***non***-RT-DCR (i.e. a CR not producible by light-limited genidentical chains) – a breach that would pinpoint the inadequacy of BLC. That is the case for Bohm's theory and, ergo, it is ***non****local* because of breaching PaI.

[83] Shimony coined the name, referring to its breach as "uncontrollable non-locality" or "passion-at-a-distance" [205].
[84] Shimony coined the name; he also referred to its breach as "controllable non-locality" [205].

Incidentally, in an interesting paper, Aerts et al discuss m**a**cro-physical (elastic bands pulled by Alice and Bob) as well as *cognitive* systems in which both OuI and PaI[85] are violated [94].

From above, QT obeys PaI but does ***not*** conform to BLC by virtue of violating OuI. And because in QT (for a given $|s\rangle$) only the settings a and b are controllable by us, obeyance of PaI is sufficient to guarantee ***no*** signaling between A and B sites (not even superluminal). Thus, the correlations displayable by QT are non-signaling nonlocal. But, being obeyed by both RT and QT, some researchers mistakenly claim that this PaI feature is the only one relevant for *locality* and, being so, there would be no conflict between the two theories [95] [31]. Curiously, though clearly understanding that it was *nonlocal*, Bell intimated such a stance by saying: "relativistic quantum mechanics is locally causal in the *human* sense that faster than light signaling is not possible" [85]. As we already pointed out, the above flawed argument for *locality* underpins the wrong claim that QFT is fully *relativistic*. Furthermore, as emphasized by Maudlin [2], Bohm's HVT violates PaI but does not allow for sending signals either because, despite a and b being controllable, the precise value of the hidden variables λ cannot (not even in principle) be known – much less controlled. Hence, in general, $\overline{PaI} \nRightarrow signaling$. Ergo, like QT, Bohm's HVT is a non-signaling nonlocal theory.

Consequently, combining OuI and PaI for any spacelike-separated events E_A and E_B, we conclude that any BLHVT, i.e. any HVT respecting BLC, must verify:

$$Pr(E_A, E_B/a, b, \Lambda) = Pr(E_A/a, \Lambda)Pr(E_B/b, \Lambda) \begin{cases} \text{Breached by QT with } \Lambda = |s\rangle \\ \text{Breached by Bohm's HVT with } \Lambda = \{|s\rangle, \lambda\} \end{cases}$$

Notice that no reference at all has been made to the famous Bell's Theorem yet, and we have already determined that QT and Bohm's HVT are *nonlocal*. In fact, Bohm was forced to include PaI *nonlocality* to match QT's 'questionable' predictions (due to the latter's OuI *nonlocality*).

Thus, being QT highly empirically successful and obviously ***not*** a BLHVT, to fully reject the latter type of theories some experimental data must exist which cannot be accurately predicted by any BLHVT– while it is by QT. If true, RT (on which BLHVTs are fully based) must be **in**complete, and my case would be closed even before discussing Bell's Theorem. What the notable theorem did, at a time when there were still not large amounts of experimental data, was to provide a straightforward experimental way of distinguishing between all BLHVTs and the *nonlocal* QT without having to contrast both types of theories for every conceivable experimental setup. In brief: it provided a criterion (a Bell-type Inequality) which, if violated by the datapoints, ***no*** BLHVT could predict them. Tersely, a practical way of proving the breach of OuI and/or PaI.

Alas, because Bell presented the intrinsic No-Retrocausality (NRC) feature of a BLHVT not as such but intermingled with his 'Free Will' requirement, plenty of confusion and controversy accumulated over the years – recently crystalized after some imprecisions in the Press Release from the Swedish's Academy for the 2022 Physics Nobel Prize, and the statement by some (e.g. Tim Maudlin[86]) that the only conclusion from the violation of a Bell-type Inequality is that *nonlocality* is a real feature of Nature [96] [97]. Let us then dissect Bell's 'Free Will' feature.

[85] Sometimes OuI is referred to as 'surface locality' and PaI as 'hidden locality' [89].
[86] "Tim Maudlin Corrects the 2022 Nobel Physics Committee About Bell's Inequality": https://youtu.be/OduDEz77h9U.

5.1.2 Bell's 'Free Will' Argument

Please recall that despite each one by itself being (subjunctively) compatible with Newton and Einstein's worlds, *fatalism* and our *free will* are mutually exclusive. Given that Newton's theory is only an approximation to RT, and RT only an approximation to GRT… and GRT only…, the clash between *fatalism* and our *free will* is amid philosophical stances – not among dogmatic beliefs in accepted theories with only limited validities.

If a and b are free parameters and we have *free will* to change their value at leisure (within a range) then, no matter what the value and distribution of the hidden variable λ in Λ is, we can assert $Pr(a,b/\Lambda) = Pr(a,b)$ and, if we rely exclusively on Probability Theory we get:

$$Pr(a,b,\Lambda) = Pr(a,b/\Lambda)Pr(\Lambda) = Pr(a,b)Pr(\Lambda) = Pr(\Lambda/a,b)Pr(a,b) \Rightarrow Pr(\Lambda/a,b) = Pr(\Lambda)$$

$$\Downarrow$$

Bell 'Free Will' Condition (mingled with No Retrocausality)

$$Pr(a,b/\Lambda) = Pr(a,b) \iff Pr(\Lambda/a,b) = Pr(\Lambda) \begin{cases} \text{Obeyed by QT with } \Lambda = |s\rangle \\ \text{Obeyed by Bohm's HVT with } \Lambda = \{|s\rangle, \lambda\} \end{cases}$$

Which, besides stating our *free will*, also says that the PD for the hidden variable should be independent of a and b [85] [98]. This presumed equivalence is multiply referred to as 'Statistical Independence', 'Measurement Independence', 'No Conspiracy', 'No Superdeterminism', 'No Retrocausality', 'Free Will', 'No Future-Input Dependent', or 'No Finetuning'. The well-engrained term 'Statistical Independence' is unfortunate because both OuI and PaI also posit a type of statistical independence. 'Measurement Independence', 'No Conspiracy', and 'No Finetuning' are anthropic; so we are left with 'Free Will' (anthropic by Bell's conception), 'No Retrocausality' (NRC), 'No Superdeterminism', and 'No Future-Input Dependent'.

Regarding NRC, Λ is -by conception- in the past of both a and b, and a BLHVT (being based on RT) bans *retrocausality* so $Pr(\Lambda/a,b) = Pr(\Lambda)$ is inherently true in such theories, which implies the *free will* relation $Pr(a,b/\Lambda) = Pr(a,b)$ and makes the term 'No Retrocausality' to characterize it redundantly **in**appropriate. But, despite these two relations being equivalent per Probability Theory, they may not be factually so depending upon the experimental setup: for instance, under Probability Theory, were a and b ***not*** free parameters (entirely possible in a BLHVT), or were they free but had we ***no*** *free will*, then we could have $Pr(a,b/\Lambda) \neq Pr(a,b)$ and we might have $Pr(\Lambda/a,b) \neq Pr(\Lambda)$ which would imply *retrocausation* – forbidden in a BLHVT. Obviously, Bell's 'Free Will' requisite is compatible with but **in**dependent of the NRC inherent in any BLHVT. Probability Theory is a useful theoretical tool, ***not*** a body of Physical Laws.

Regarding the phrases 'No Superdeterminism', and 'No Future-Input Dependent', as we will see when elaborating upon them in Section 6, *Superdeterministic* and *Future-Input Dependent* models simply negate the validity of $Pr(\Lambda/a,b) = Pr(\Lambda)$ inherent in BLHVTs, so the terms are simply declaring what a BLHVT is ***not*** – without explicitly asserting/denying the independent 'Free Will' condition $Pr(a,b/\Lambda) = Pr(a,b)$. Thus, of all the idioms used in the literature for Bell's 'free will/no-conspiracy' condition, *free will* seems to be the most independently appropriate simply because the **a**spatial, **a**temporal, and reversible character of probabilities may not apply in all physical situations – like the reversibility of classical motion laws do not apply when there is friction. Differently: though our *free will* is of course a philosophical stance, given that the settings a and b are actual and evincing, their *free* character -if true- is an experimental fact, while NRC ($Pr(\Lambda/a,b) = Pr(\Lambda)$) is foundational to RT. Interestingly, neither Bell nor the literature in general differentiates (to my knowledge) between the two probabilistic relations, and it is (ironically) the NRC relation the only one used explicitly in deriving any Bell-type Inequality. In sum, 'No Retrocausality' and 'Free-Will' are physically different:

'No Retrocausality' (NRC)	**'Free Will'**
$Pr(\Lambda/a,b) = Pr(\Lambda)$	$Pr(a,b/\Lambda) = Pr(a,b)$

And, albeit they are equivalent per Probability Theory, they are ***not*** in essence. NRC is part of RT and tantamount to prohibiting *contextuality* for physical properties; *Free Will* is the result of a free parameter (an experimental fact) plus a philosophical stance regarding human beings. To defend his 'Free Will' formal characterization, Bell said in 1981:

BELL4: ..., *we cannot be sure that a and b are not significantly influenced by the same factors lambda that influence A and B. But this way of arranging quantum mechanical correlations would be even more mind boggling than one in which causal chains go faster than light*. [99].

Because, as said, whether a and b are free parameters or not is an experimental fact, Bell is shyly admitting that our *will* could be hijacked so that our *choice* for the values of a and b turned out to be controlled by λ (Nature's caprice) without our knowledge. I admire (but honestly lack) his über-open mind, while adamantly agreeing with him that -if true- it would be much more mind-boggling than superluminal genidentical chains or simply *nonlocality*. After all, what is the point of our obsessive questioning of Nature if She is subliminally imposing us what questions to ask?

Attempting to strengthen his argument, Bell envisioned that we could arrange for the values of a and b to be determined by a pseudo-randomizer (algorithmic randomness [89]) whose binary output depended upon the parity of the millionth digit in the decimal expansion of a real number. Again with an open mind, Bell surmised that it was not impossible though implausible that the so-obtained values for a and b could conspiratorially and consistently influence or being influenced by the hidden variables (or anything else in the Universe). For some reason beyond my reach, he thought that such pseudo-random number generation could be less vulnerable to Nature's conspirative whim than our own venerable *free will* when, in fact, being the output of a pseudo-randomizer (of course) computable, its input could be made part of Λ, defeating the very notion of a and b being *free* parameters. So he humbly stated (my underscore):

BELL5: *Of course it might be that these reasonable ideas about physical randomizers are just wrong—for the purpose at hand. A theory may appear in which such conspiracies inevitably occur, and these conspiracies may then seem more digestible than the nonlocalities of other theories. When that theory is announced, I will not refuse to listen, either on methodological or other grounds.* [1]

From BELL4 and BELL5, we see that Bell believes his 'free will/no-conspiracy' hypothesis warrants that neither Λ influences a and b nor the latter two influence the former. As we saw, the way Bell expressed his 'Free Will' condition (mingled with NRC) is vulnerable to critique: $Pr(a,b/\Lambda) = Pr(a,b) \Leftrightarrow Pr(\Lambda/a,b) = Pr(\Lambda)$ simply denies a correlation between the settings a and b and the hidden variable Λ (and, a fortiori, any deterministic functional relationship). It is thus sufficient for guaranteeing the experimenter's *free will*, but it is ***not*** necessary. The experimenter could retain his/her *free will* to set a and b at leisure while -in practice- only a one-way influence $(a \vee b \rightarrow \Lambda)$ being possible and constantly holding. Think of the volume (v), pressure (p), and temperature (T) in a car motor's piston: their *steady-state* functional relationship follows Boyle-Mariotte Law quite accurately, so thinking of v as one of the settings (a or b) and of $p \wedge T$ as the hidden variable Λ, Bell's 'Free Will' is patently breached by virtue of such Law. Nonetheless, we can willfully decrease v down to before ignition occurs by firmly moving the piston upwards – while the causal influence acting only in one direction: $v \rightarrow p \wedge T$. As the piston went up decreasing v, variables p and T changed accordingly, but those changes did ***not*** change v (until our *free will* further moved the piston). The experimental setup (milieu) determined the direction of the causal influence: Bell's 'Free Will' condition is breached $(Pr(\Lambda/a,b) \neq Pr(\Lambda)$ without breaching our *free will* $(Pr(a,b/\Lambda) = Pr(a,b))$. However, it is crucial to realize that in this case v (the homologous of a or b) is in the past of $p \wedge T$ (the homologous of Λ), viz there is ***no*** *retrocausation* (as RT demands). The purpose was to show that the reversibility of probability relations may or may not physically obtain. Apropos, in Bohm's HVT, the wavefunction influences the position of the particles but ***not*** vice versa.

But, again, in a BLHVT the setting of a and b can be in the future of Λ and to guarantee our *free will* we only need to ensure that the evolution of Λ from the composite quanton's creation up to the GIs does ***not*** affect the values of a and b (which are supposed to be controllable by us up to just time-before the GIs). Free will-respecting theories in which there is ***only*** a one-way causal influence toward the past $(a \vee b \rightarrow \Lambda)$ are sometimes called superdeterministic and, were 'Einstein-Bell Realism' valid, that unilateral influence would amount to *retrocausation* – openly against RT and, ergo -though still possibly *local*- they would ***not*** be BLHVTs. Equivalently, Λ would depend on the future 'inputs' a and b, so another name for those theories is sometimes 'Future-Input Dependent' (FID). Nonetheless, were instead the hidden variable(s) ***non****-evincing* (against Einstein's dreams), the latter claim would not be that controversial: *retrocausality* is normally meant to refer to actual *evincing* events (the only ones real in RT) and, even if we admitted such links to be *retrocausal*, ***no*** *retro-signaling* would be possible because the events do not evince (for the same reason there is ***no*** *onward-signaling* in Bohm's theory). It should be then clear that, because RT bans *retrocausation*, Bell's formalization of our *free will* via the above symmetric stochastic relations is not **in**consistent – as long as we remain within the confines of RT. Any breach of NRC without breaching our *free will* breaches RT, even if to avoid *retro-signaling* we declare the hidden variables to be ***non****-evincing* (simply because all events in RT are actual and evincing).

Bell understood that his 'Free Will' condition was valid in RT and QT $(\Lambda = |s\rangle)$, and he assumed it to be valid for his generic hidden variable $\Lambda = \{|s\rangle, \lambda\}$ in the hope that the resulting BLHVT would fully agree with QT predictions (or even better, predict some new falsifiable phenomena). Epitomizing the Spirit of Science, Bell proved himself wrong and, even better, he proposed how to experimentally collect and interpret the necessary data to corroborate his stumble.

5.1.3 The Correlation between P_A and P_B, and its Expression in a BLHVT

Bell had to prove that the predictions of such a BLHVT theory could fully reproduce all the predictions of QT, and chose the EPRB setup for the purpose. Referring thus to the EPRB, the local attributes $P_A(a,b) \in \{-1,+1\}$ and $P_B(a,b) \in \{-1,+1\}$ delivered by the events $(E_A/a,b)$ and

$(E_B/a,b)$ are multiplied to obtain the composite attribute $P_{AB}(a,b) = P_A P_B(a,b) \in \{-1,+1\}$. To assess the *correlation* between P_A and P_B, we need the mean value of P_{AB} which is:

$$\langle P_{AB}/a,b\rangle = +1 \cdot Pr([P_{AB} = +1]/a,b) - 1 \cdot Pr([P_{AB} = -1]/a,b) \tag{23}$$

And, regardless of the theory we may spouse, the way to experimentally estimate $\langle P_{AB}/a,b\rangle$ is via a statistically sound number N of data points (P_A^i, P_B^i) as follows:

$$\langle P_{AB}/a,b\rangle = \lim_{N\to\infty}\left(\frac{1}{N}\right)\sum_{i=1}^{N} P_A^i(a,b)P_B^i(a,b)\ ;\ P_A \text{ and } P_B \text{ random variables} \tag{24}$$

But in any BLHVT the *stochasticity* is transferred to the hidden variable λ so that, for each value of λ, $Pr(P_A, P_B/a,b,\lambda)$ must be unity for one pair of attribute values and zero otherwise – defining a *deterministic* function. Applying OuI, because the only two probabilities whose product is unity are unity themselves, for each value of λ we have $Pr(P_A/a,b,\lambda) = 1$ for one value of P_A and zero otherwise; and likewise for $Pr(P_B/a,b,\lambda)$. Finally, from PaI we get $Pr(P_A/a,b,\lambda) = Pr(P_A/a,\lambda)$ and $Pr(P_B/a,b,\lambda) = Pr(P_B/b,\lambda)$. Hence, for each data point (P_A^i, P_B^i), and calling $E(a,b)$ the mean value under <u>any</u> BLHVT, we obtain:

$$P_A^i(a,b) = \alpha(a,\lambda_i)\ ;\ P_B^i(a,b) = \beta(b,\lambda_i)\ ;\ with\ \alpha\ and\ \beta\ deterministic\ functions$$

$$\Downarrow$$

$$E(a,b) = \lim_{N\to\infty}\left(\frac{1}{N}\right)\sum_{i=1}^{N}\alpha(a,\lambda_i)\beta(b,\lambda_i) = \sum_{h=1}^{M}\lim_{N\to\infty}\frac{N_h}{N}\alpha(a,\lambda_h)\beta(b,\lambda_h) = \sum_{h=1}^{M}\rho(\lambda_h)\alpha(a,\lambda_h)\beta(b,\lambda_h)$$

$$\Downarrow$$

$$for\ \lambda\ a\ continuous\ variable:\ \rho(\lambda_h) \to f(\lambda)d\lambda\ \ and\ \ \textstyle\sum_{h=1}^{M} \to \int_\Omega \tag{25}$$

$$\Downarrow$$

$$E(a,b) = \int_\Omega \alpha(a,\lambda)\beta(b,\lambda)f(\lambda)d\lambda\ \ ;\ \ \alpha(a,\lambda),\beta(b,\lambda) \in \{-1,+1\}$$

In the first line, by virtue of λ, we replace random variables with deterministic functions. In the second line, those N data points are hypothetically subdivided into M subsets each one corresponding to a single value λ_h for the hidden variable, so that the ratio $\rho(\lambda_h) = \lim_{N\to\infty} N_h/N$ becomes its probability to assume the value $\lambda_h: h \in \{1,2,..M\}$, which, as a function (i.e. in value and in domain) is assumed ***not*** to depend on a and b because of NRC. Finally, assuming the hidden variable is continuous, we replace $\rho(\lambda_h)$ with the probability density function $f(\lambda)$ and the summation with an integral over the domain Ω. Again, $f(\lambda)$ (and ergo its domain Ω) does not depend on the settings a and b. We can now discuss the most popular Bell-type Inequalities.

5.1.4 Original Bell Inequality (1964)

In his seminal paper of 1964 entitled 'On the Einstein-Podolsky-Rosen paradox' [84], Bell considered three different settings a, b, and b'. He then used $P_A(a,b) = \alpha(a,\lambda)$, $P_B(a,b) =$

$\beta(b,\lambda)$, and $P_{AB} = \alpha(a,\lambda)\beta(b,\lambda)$ and expressed $E(a,b)$, $E(a,b')$, and $E(b,b')$ via Equation 25-bottom to prove that they had to verify the following inequality:

$$BLHVT \Rightarrow |E(a,b) - E(a,b')| \leq 1 + E(b,b')$$

After proving that QT sometimes violated such inequality, Bell said (my underscore):

BELL6: *In a theory in which parameters [λ] are added to quantum mechanics to determine the results of individual measurements, without changing the statistical predictions, there must be a mechanism whereby the setting of one measuring device can influence the reading of another instrument, however remote. Moreover, the signal involved must propagate instantaneously, so that such a theory could not be Lorentz invariant.*

In my words: such inequality constrained the correlations predictable by all BLHVTs so that they could not always agree with QT. Ergo, the putative 'completion' of QT via a light-limited genidentically causal theory (as suggested by EPR) was impossible – unless Bell's 'Free Will' condition was overly restrictive (specifically: its NRC component), or we accepted *nonlocality* (both options departing from RT). Bell was committed to NRC (part of his 'Free Will' requisite) so he called for *nonlocality*, concluding that the resulting amended theory "could not be Lorentz invariant" – making RT flagrantly **in**complete (if not wrong). On the other hand, if we rejected NRC and retained *locality*, Lorentz-Invariance could survive but…were the hidden variables claimed to be ***evincing*** or ***not***, RT would be **in**complete anyway. RT could not handle some QT's predictions. Einstein's dreadful nightmare for his magnificent creature became real.

This is Bell's Theorem, and no empirical work is needed to confirm it because it is a theorem: under Bell's hypotheses, some inequalities are to be true – tout court. But, given the mentioned theoretical discrepancy with QT, what required abundant experimental work (conducted for the last 50 years) was to determine which one was the correct theory (QT or a BLHVT type), and Bell's theorem provided an efficient experimental path to reject all theories based on BLC.

5.1.5 The CHSH Bell-Type Inequality

In 1969 [100], the Clauser/Horne/Shimony/Holt (CHSH) Inequality was proposed, involving four products of the results at the two sites, one for each pair of settings: (a,b), (a,b'), (a',b), and (a',b'). Given that CHSH is very popular, we will further elaborate upon it so as to conceptually clarify further the subtleties behind the subject matter. Each setting pair corresponds to a different experiment so, in a BLHVT, the pair is conceptually associated with a different (unknown and uncontrollable) value of $\lambda \in \{\lambda_{ab}, \lambda_{ab'}, \lambda_{a'b}, \lambda_{a'b'}\}$, each one of which varies throughout their large ensemble of experimental runs. This corresponds to statistically sampling the probability densities $f_{ab}(\lambda) = f(\lambda/a,b)$; $f_{ab'}(\lambda) = f(\lambda/a,b')$; $f_{a'b}(\lambda) = f(\lambda/a',b)$; and $f_{a'b'}(\lambda) = f(\lambda/a',b')$.

From Equations 25-top, combining all four setting pairs, the CHSH expression is defined as:

$$CHSH = \alpha(a,b,\lambda_{ab})\beta(a,b,\lambda_{ab}) - \alpha(a,b',\lambda_{ab'})\beta(a,b',\lambda_{ab'}) + \alpha(a',b,\lambda_{a'b})\beta(a',b,\lambda_{a'b}) +$$

$$+\alpha(a',b',\lambda_{a'b'})\beta(a',b',\lambda_{a'b'})$$

Because $\alpha(a,b,\lambda), \beta(a,b,\lambda) \in \{-1,+1\}\ \forall\ a,b,\lambda \Rightarrow CHSH \in \{-4,-2,\ 0,+2,+4\}$. Only if λ did not vary when switching among setting pairs, a quick allowed factorization shows that $CHSH$

values would belong to $\{-2,+2\}$. Lambare in [101] lucidly explains why, ignoring such nuance, has led many authors to obtain the correct CHSH inequality via **in**correct reasoning – and others to pronounce Bell's Theorem wrong [102]. To create a Bell Inequality, using Equation 25-bottom, we have $|\langle CHSH\rangle| = |E(a,b) - E(a,b') + E(a',b) + E(a',b')|$ and, applying the rest of Bell's defining features and necessary properties of a BLHVT, we obtain:

$$|\langle CHSH\rangle| = \left|\int \alpha(a,\lambda)\beta(b,\lambda)f_{ab}(\lambda)d\lambda - \int \alpha(a,\lambda)\beta(b',\lambda)f_{ab'}(\lambda)d\lambda + \cdots\right|$$

$$\Downarrow$$

$$|\langle CHSH\rangle| = \left|\int [\alpha(a,\lambda)\beta(b,\lambda) - \alpha(a,\lambda)\beta(b',\lambda) + \cdots]f(\lambda)d\lambda\right|$$

$$\Downarrow$$

$$|\langle CHSH\rangle| \leq \int |[\alpha(a,\lambda)\beta(b,\lambda) - \alpha(a,\lambda)\beta(b',\lambda) + \cdots]|f(\lambda)d\lambda$$

$$\Downarrow$$

$$|\langle CHSH\rangle| \leq \int |[\alpha(a,\lambda)\{\beta(b,\lambda) - \beta(b',\lambda)\} + \alpha(a',\lambda)\{\beta(b,\lambda) + \beta(b',\lambda)\}]|f(\lambda)d\lambda$$

$$\Downarrow$$

$$|\langle CHSH\rangle| \leq 2\int f(\lambda)d\lambda \;\Rightarrow\; |\langle CHSH\rangle| \leq 2 \quad \forall\, a, a', b, b', f(\lambda)$$

$$\Downarrow$$

$$|\langle \boldsymbol{CHSH}\rangle| = |\boldsymbol{E}(\boldsymbol{a},\boldsymbol{b}) - \boldsymbol{E}(\boldsymbol{a},\boldsymbol{b}') + \boldsymbol{E}(\boldsymbol{a}',\boldsymbol{b}) + \boldsymbol{E}(\boldsymbol{a}',\boldsymbol{b}')| \leq \mathbf{2}$$

Note that -as we saw in Section 5.1.3- the first line already contains OuI and PaI. The second line was obtained applying $f_{ab}(\lambda) = f_{ab'}(\lambda) = f_{a'b}(\lambda) = f_{a'b'}(\lambda) = f(\lambda)$, presumably by applying Bell's 'Free Will' but, in fact, we are only applying NRC, viz $Pr(\lambda/a,b) = Pr(\lambda)$ which, again, is inherent in any BLHVT (non-contextual properties). A potential experimental loophole related with this theoretical step is discussed and resolved in [102] [103] [104]. After applying the triangle inequality (the absolute-value bars moved inside the integral) in the third line, notice that the term inside the absolute-value bars in the integral is a version of the CHSH expression but with the same value for λ so now factorization is possible, and easy to see that its absolute value is always 2, leading to the well-known inequality: $|\langle CHSH\rangle| \leq 2$. This is Bell Theorem again with a different inequality: $BLHVT \Rightarrow |\langle CHSH\rangle| \leq 2$.

Given the appropriate experimental setup, the Mean $\langle CHSH\rangle$ can be empirically estimated via Equation 24 applied to the four ensembles associated with each pair of settings – to find out that for certain values of the settings we obtain $2 < |\langle CHSH\rangle| \leq 2\sqrt{2}$, i.e. in disagreement with all BLHVTs though in agreement with QT. It is thus concluded (as with the original Bell's Inequality) that the alleged 'completion' of QT via a light-limited local causal theory (as suggested by EPR) is impossible – unless NRC is breached (something ***not*** true in QT in which $\Lambda = |s\rangle$, i.e. ***no*** λ). Otherwise, we would have to accept *nonlocality*. In both cases we deviate from RT concluding (ironically for Einstein) that RT is in fact **in**complete, while we will soon declare QT **in**complete as well – albeit not because of EPR alleged reasons.

5.1.6 The Original and CHSH Bell-Type Inequalities as Specific Cases.

As previously related, in 1976 Bell formalized his ideas about *local causality* using Probability Theory, and developed a generic Inequality based exclusively on probabilities that included his original as well as the CHSH one. He did it again more cogently in 1981 in his well-known paper 'Bertlmann's socks and the nature of reality' [99]. Bell wanted to eradicate the erroneous idea that he had assumed *determinism* – instead of deducing it for the perfect correlation case [99].

If we plainly assume that the function $f(\lambda/a,b)$ is the probability density for $\lambda/a,b$, the joint probability density for $P_A, P_B, \lambda/a,b$ must be $Pr(P_A,P_B/a,b,\lambda)f(\lambda/a,b)$ so, integrating over λ and applying OuI+PaI+NRC (necessary features of BLC) we obtain[87]:

$$Pr(P_A,P_B/a,b)=\int_{\Omega_{ab}} Pr(P_A,P_B/a,b,\lambda)f(\lambda/a,b)d\lambda=\int_{\Omega} Pr(P_A/a,\lambda)Pr(P_B/b,\lambda)f(\lambda)d\lambda$$

$$Pr([P_{AB}=+1]/a,b)=\int_{\Omega}\{Pr(+1/a,\lambda)Pr(+1/b,\lambda)+Pr(-1/a,\lambda)Pr(-1/b,\lambda)\}f(\lambda)d\lambda$$

$$Pr([P_{AB}=-1]/a,b)=\int_{\Omega}\{Pr(+1/a,\lambda)Pr(-1/b,\lambda)+Pr(-1/a,\lambda)Pr(+1/b,\lambda)\}f(\lambda)d\lambda$$

And applying the equation for the mean value (Equation 23), we get:

$$E(a,b)=\langle P_{AB}/a,b\rangle=\int_{\Omega}\{Pr(+1/a,\lambda)-Pr(-1/a,\lambda)\}\{Pr(+1/b,\lambda)-Pr(-1/b,\lambda)\}f(\lambda)d\lambda$$

$$\Downarrow$$

$$E(a,b)=\int_{\Omega}\mathbb{A}(a,\lambda)\,\mathbb{B}(b,\lambda)\,f(\lambda)d\lambda \quad ; \quad |\mathbb{A}(a,\lambda)|\le 1\,;\,|\mathbb{B}(b,\lambda)|\le 1 \qquad (26)$$

$$\Downarrow$$

$$|E(a,b)\pm E(a,b')|\le\int_{\Omega}|\mathbb{A}(a,\lambda)||\mathbb{B}(b,\lambda)\pm\mathbb{B}(b',\lambda)|\,f(\lambda)d\lambda\le\int_{\Omega}|\mathbb{B}(b,\lambda)\pm\mathbb{B}(b',\lambda)|\,f(\lambda)d\lambda$$

$$|E(a',b)\mp E(a',b')|\le\int_{\Omega}|\mathbb{A}(a',\lambda)||\mathbb{B}(b,\lambda)\mp\mathbb{B}(b',\lambda)|f(\lambda)d\lambda\le\int_{\Omega}|\mathbb{B}(b,\lambda)\mp\mathbb{B}(b',\lambda)|f(\lambda)d\lambda$$

$$\Downarrow$$

$$\boldsymbol{|E(a,b)\pm E(a,b')+E(a',b)\mp E(a',b')|\le|E(a,b)\pm E(a,b')|+|E(a',b)\mp E(a',b')|\le 2}$$

$$\boldsymbol{if\ a'=b'\ \wedge\ E(b',b')=-1\Rightarrow\ |E(a,b)-E(a,b')|\le 1+E(b',b)} \qquad (27)$$

Where we see that both the CHSH and Bell's original inequalities are specific cases of the inequalities in the penultimate line.

At the end of the paper, Bell makes the following very important observation (my underscore):

---

[87] The variability of the local instruments realizing the GIs can be easily included by adding independent random hidden variables and integrating first over them [1] [204].

BELL7: *It is notable that in this argument nothing is said about the locality, or even localizability, of the variable λ. These variables could well include, for example, quantum mechanical state vectors, which have no particular localization in ordinary space-time. It is assumed only that the outputs A [P_A] and B [P_B], and the particular inputs a and b, are well localized.* [99]

It is clear then that, to arrive at Inequalities 27, the RT's hypotheses OuI, PaI are only required for the causal relation between the spacelike-separated events E_A, E_B as well as between E_A, b and betwixt E_B, a. Instead, as regards the causal relation between the common cause λ and the events E_A and E_B, any (local or nonlocal) unidirectional causal relation would do. This justifies our denoting $\Lambda = \{|s\rangle, \lambda\}$ as the general common cause, as well as my prior statement that "λ overrides/supplements $|s\rangle$ and the *stochasticity* of the results would be simply due to our ignorance of the particular value of λ for each run". As for NRC $(a, b \nrightarrow \lambda)$, we know it is inherent in RT when λ is evincing – while the free character of a and b plus our *Free will* $(\lambda \nrightarrow a, b)$ ensures no forward influence. And, most importantly, the empirical violation of the Inequalities ***cannot*** be avoided by a nonlocalizable Λ or by a *nonlocal* unidirectional causal relation between the common cause and the spacelike events E_A and E_B or by both. What other options are then left?

5.2 The Meaning and Consequences of Bell Theorem

The CHSH Bell's inequality is useful to assess the **in**completeness of RT because -as we saw- it is bounded differently in any BLHVT than in QT: $|CHSH(BLHVT)| \leq 2$, while $|CHSH(QT)| \leq 2\sqrt{2}$ (Tsirelson bound)[88]. Notice the overlapping: observed values over 2 or under -2 indicate RT is **in**complete, while experimental values over $2\sqrt{2}$ or under $-2\sqrt{2}$ would imply a type of QT's **in**completeness. Obviously then, RT is **in**complete. As for QT, it is easy to envisage a set of results which would exceed the Tsirelson bound while preventing *signaling* between spacelike events; they are called super-quantum (SQ) correlations: $2\sqrt{2} \leq |CHSH(SQ)| \leq 4$ [105] [106]. They have not been observed so far, so -as of today- QT is ***not*** incomplete on that account; and it is ***not*** incomplete either per EPR's faulty claims – as I thoroughly explained in Part I and Part II [9] [10].

Were the CHSH Inequality not ever breached, there could still exist a non-RT causal relation (superluminal genidentical or non-genidentical DCR or CSR) between quantons A and B – even though a BLHVT (a theory entirely based on RT) could explain the correlations (at least in a given IF). Instead, if the CHSH Inequality is violated (as it is) then either: (a): DCR-*locality* is breached and NRC is true; or (b) DCR-*locality* is valid and NRC is violated; or (c) both DCR-*locality* and NRC are breached. In all cases, either DCR-*locality* or NRC or both are breached so RT is violated and the derivation of Bell's inequalities does not follow. It should thus be clear that the mere violation of a Bell-Type Inequality does ***not*** ipso facto 'prove' DCR-*nonlocality*: (1) it may imply *retrocausality* between evincing events – violating RT; or (2) all events related to the hidden variables are non-evincing, admitting the existence of a new type of events not included in RT. No matter how you look at it, the conclusion that RT is **in**complete is unavoidable.

[88] Ghose argues that "entanglement and CHSH-like violations are neither unique signatures of quantumness nor of nonlocality—they only signify an underlying Hilbert space structure and non-separability" [206].

5.2.1 Dropping DCR-Locality and Keeping NRC

If we decided to keep NRC, then the only way to match QT predictions would be to drop Einstein's *locality*, which can be done in two ways: (a) retaining *locality* but rejecting the Light-Limiting Postulate, i.e. allowing for superluminal signaling; and (b) fully rejecting *locality*, i.e. admitting the reality of our Causal (f) type of causal relation between point-Events: $\overline{RT - DCR} \wedge \overline{RT - CCR} \wedge \overline{signaling} \wedge DCR$. Let us elaborate further on (a) and (b):

(a) By allowing for *superluminal* causal chains (though not limitlessly fast, otherwise we would be back to Newton's absolute ether), many events that in RT were *spacelike* would be now *timelike* with an absolute time-order, reducing the breadth of possible events for which their time order is relative. The problem is that ***no*** superluminal signal has been empirically found, and -to avoid *retrocausality*- a Lorentz-Invariant theory admitting superluminal signals would require a synchronizing signal whose speed is IF-invariant and higher than all others. But, even if such new limiting superluminal invariant signal existed, abundant experimental data show that the quantic correlations remain valid no matter how narrow the range of Type 2 Event-Intervals is – taking us back to Newton's spacetime structure.

(b) By fully rejecting *locality* (our Causal (f)), it is obvious that such a deterministic theory cannot be Lorentz-Invariant. Gisin argues that -being the model deterministic and *nonlocal*- the result at the first GI for a given $\Lambda = \{|s\rangle, \lambda\}$ can only depend on the local setting, while the result at the second GI must depend on both the local and distant settings. But changing the IF so as to revert the GIs' time-order and imposing the IF-invariance of their results, Gisin finds that such a *nonlocal* deterministic model must be *local* – contradicting the original assumption and, ergo, if a deterministic model is *nonlocal*, it ***cannot*** be IF-invariant. But intriguingly, Gisin instead infers from such contradiction an 'equivalence' between ***non****local* and *local* models, to deduce -via Bell's Theorem- that a deterministic *nonlocal* IF-invariant model could not agree with QT predictions. He asserts (his 'covariant' corresponds to our 'IF-Invariant'):

GISI3: *Hence, any [deterministic] covariant nonlocal model is equivalent to a Bell-local model and, consequently, contradicts well tested quantum predictions, the violation of Bell's inequality. In conclusion, we have shown that there is no [deterministic] covariant nonlocal models of quantum correlations, not more than local models*. [107]

After my highlighting the adjective 'deterministic', Gisin's conclusion is correct, but the alleged 'equivalence' is unfounded: per his reductio ad absurdum, there are ***no*** deterministic *nonlocal* models which are *covariant,* tout court[89]. A similar convoluted argument is made by Blood [108], when proves that the CHSH Inequality is derivable "from the relativity of simultaneity". He states that because the LT and its relativity of simultaneity "seem to be on a very firm footing", then "the relativity of simultaneity plus Bell's argument and the Aspect experiment prohibit the existence of any hidden variable theory underlying quantum mechanics". Blood forgets that without light-limited locality there is no LT and its relativity of simultaneity.

But it must be understood that ***non****local* deterministic (i.e. epistemically *stochastic* respecting NRC) HVTs allow to perfectly reproduce QT in a given IF (as claimed by e.g. de Broglie/Bohm theory) – though without Lorentz-Invariance [107]. Hence, to attain Lorentz-Invariance with an

[89] Criticisms of a different kind to Gisin's logic were given by Laudisa [207] – to whom Oldofredi rejoined by saying "every step of Gisin argument is logically correct" [171].

HVT while agreeing with QT, *nonlocality* (Einstein's 'spooky action at a distance') must be avoided, and the only way available is to fully keep *locality* and drop NRC while saving the experimenter's *free will*.

5.2.2 Keeping Locality and dropping NRC

As we already pointed out, and easy to see from the product of probabilities in a BLHVT, a perfect correlation between spacelike events allows for *determinism*. In fact, in a *deterministic* theory attempting to reproduce QT, and thus being only epistemically *stochastic* (*stochasticity* only at the pair creation event), such a perfect correlation is easy to reproduce within RT: the objects can carry an 'instruction set' for how to 'behave' at the GIs. But ***no*** single 'instruction set' would do for ***non***-perfect correlations, so the only way to reproduce QT predictions while respecting OuI+PaI would be to adjust the unknown probability distribution of the hidden variable in accordance with the settings a and b, viz to allow for overt/hidden *retrocausality*. Contrariwise, being QR/TOPI ontically *stochastic* (*stochasticity* all the way up to the GI events) and respecting NRC, the mere existence of a perfect correlation between spacelike events is enough to discard an RT-causal relation (BLC), calling for a ***non***-RT one. Pithily: ontic *stochasticity* $\wedge$ NRC $\Rightarrow$ DCR-*nonlocality*. QR/TOPI and orthodox QT are NRC *nonlocal* theories. We will see that QR/TOPI completes RT with *nonlocality*, sacrificing neither NRC nor IF-Invariance – covering violations and non-violations of any Bell-Type Inequality.

Keeping OuI+PaI valid and breaching NRC, Brans showed in 1988 that, ***any*** experimentally observed correlation between spacelike events could be theoretically modeled. Notice though that, paraphrasing Lambare, Einstein's 'spooky action at a distance' would be replaced by 'spooky hidden variables' [109]. It has also been proven that only minor violations of NRC are necessary to reproduce the predictions of QT via OuI+PaI [110]. M.J.W. Hall found that "only 1/15 of a bit of measurement dependence [$\overline{\text{NRC}}$] is required to model the singlet state, in comparison to 1 bit of communication in nonlocal models, and 1 bit of shared randomness in nondeterministic[90] models" [111]. He also stated: "no more than $2\log_2 d$ bits of correlation are required to model the statistics of all Hermitian observables on two *d*-dimensional quantum systems" [112] [110].

Finally, it is interesting to note that for a composite of three or more entangled distant quantons the GHZ Theorem proves, without explicitly using the NRC requisite, the impossibility for a BLHVT to reproduce some QT predictions – even for perfect correlations [113] [114] [2] [103] [93] [65]. It is also known as the 'Bell Theorem without inequalities', clearly dismissing most of the loopholes usually claimed in the literature to explain away the violation of Bell Inequalities. In these cases the difference between a BLHVT and QT can be (for the CHSH expression) not just ~40% $\left(\sqrt{2}-1\right)$ but quite dramatic: one prediction precisely the opposite of the other. This is because, besides nonlocality and contextuality (forbidden in a BLHVT), in QT the product of three or more operators is not commutative.

5.3 The EPRB Experiment under QR/TOPI

In our non-relativistic discussions of two **en**tangled ½-spin qubits in Part III [11], we proposed a chronicle of what happens if -in a given IF- any one of the qubits undergoes a GI: both qubits become **de**tangled, though correlated because the opposite of the actual state randomly adopted by

[90] It seems that by 'nondeterministic', the author refers to what we call deterministic but epistemically *stochastic*.

the one that experiences the GI is (using the catchphrase) *teleported* to the other. Remember though that there is ***no*** *portage* between sub-quantons but a reciprocal *instantaneous* causal relation between them – with the composite quantic state and the GI as the common cause. The composite quanton undergoes a GI as a whole, irrespective of whether only (any) one of the sub-quantons was or both (simultaneously) were directly involved.

As we saw for the two detectors in the single-quanton setup, if the GIs undergone by the two qubits are ***not*** spacelike-separated events, a narrative based on *teleportation* as a directional transfer from one to another presents no inconsistencies because the time-order between those events is absolute. But if those GI-Events are spacelike-separated, the RT edifice crumbles because their time-order is relative and such a narrative is inconsistent from one IF to another: the putative *cause* in one IF becomes the *effect* in another. In fact, in such a case, RT admits ***no*** causal relationship – just a non-objective relative time-order (including simultaneity).

Instead, the QR/TOPI edifice (integrating RT and QT) does ***not*** collapse because we will see that *teleportation* (as proved for the State-Events of a single quanton) is ***not*** between two *evincing* actual events but among actual events of which at most one is *evincing* (i.e. an R-Event). Per QR/TOPI, in the same way that for a single qubit to adopt an actual state there is no need for two detectors, the occurrence of *teleportation* does ***not*** require 'measuring' the two qubits as usually stated in the literature; one GI is enough; only its experimental confirmation demands properly 'measuring' both qubits. RT is all about *evincing* actual events, and Einstein did operationally 'define' R-Time accordingly. As we saw, the problem with RT is its hidden Ontology: if a direct causal relation between two events is postulated to only occur in Nature if they are connectible via light-limited genidentical chains, no wonder we find inconsistencies when pretending to include *nonlocality* within RT – simply because the time-order between *spacelike* events in RT is a mere IF-**co**variant convention.

When describing Reality from a single IF, the terms *time-before, simultaneous,* and *time-after* are unambiguous – though only objective for ***non****-spacelike* events. If qubit-$A(B)$ undergoes GI-$A(B)$ (a PDI-Event) adopting an actual state (a State-Event), qubit-$B(A)$ adopts another state via *teleportation* (another State-Event). But, despite qubit-$B(A)$ having (upon GI-$A(B)$) adopted an actual state, it does not *evince* as such in our spacetime until and if it undergoes its own GI-$B(A)$ (and only if the latter is a TM). A GI produces an actual state and may produce a record (click) in our spacetime or ***not*** (no-click); *teleportation* (upon the actualization of an ITI) produces an actual state ***without*** a record (*non-evincing*). As regards achieving *simultaneity* between GI-$A(B)$ and (if occurs) GI-$B(A)$, because the emission time (per the master clock in the IF) of the two entangled qubits and the distances from the source (PEI*)* to the GIs cannot be made exactly equal, one of them will always be slightly time-before the other. As already stated, the *equality* relation is not computable, i.e. experimentally unfeasible (except as an approximation).

From above, the result of a single GI on a composite quanton whose state was given by Equation 11 (top) of Part III [11] (reproduced here as Equation III) was two isolated quantons in actual *pure* related states: one the opposite of the other. Hence, a PTI that rotated by 180º the spin of the quanton that did not experience the GI would have left it in the same state as the quanton that did (though still without a record). The two distant quantons would have been *clones* because of a GI on one, *teleportation*, and a PTI on the other (which could take place even time-after the putative GI). Whether the quanton with the teleported state will ever undergo a GI is immaterial. Alternatively, and to facilitate our current discussions, permuting sines with cosines in the referred

State Equation in Part III leads to the composite state for two entangled qubits for which the actual state adopted by the qubit that undergoes a GI is *teleported* straight (**no** 180º rotation) to the other quanton. Upon any single GI undergone by anyone of the sub-qubits, they would become **de**tangled but in identical actual *pure* states (clones). From now on, we will use the new composite State Equation, PDs, and ITI resulting from such sine/cosine permutation:

State Equations and Probability Distributions

$$|s_A\rangle = s_{A1}|s_{A1}\rangle + s_{A2}|s_{A2}\rangle \quad ; \quad |s_B\rangle = s_{B1}|s_{B1}\rangle + s_{B2}|s_{B2}\rangle$$

$$|s\rangle = cos\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A1}\rangle|s_{B2}\rangle - cos\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A2}\rangle|s_{B1}\rangle + sin\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A1}\rangle|s_{B1}\rangle - sin\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A2}\rangle|s_{B2}\rangle \qquad \text{(III)}$$

$$\Downarrow$$

$$sin \leftrightarrow cos$$

$$\Downarrow$$

$$|s\rangle = sin\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A1}\rangle|s_{B2}\rangle - sin\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A2}\rangle|s_{B1}\rangle + cos\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A1}\rangle|s_{B1}\rangle - cos\left(\frac{\theta}{2}\right)\frac{\sqrt{2}}{2}|s_{A2}\rangle|s_{B2}\rangle =$$

$$\Downarrow$$

$$|s\rangle = sin\left(\frac{\theta}{2}\right)|B1\rangle + cos\left(\frac{\theta}{2}\right)|B3\rangle$$

$$\Downarrow \qquad (28)$$

$$|s\rangle = |s_{A1}\rangle\left\{\frac{\sqrt{2}}{2}cos\left(\frac{\theta}{2}\right)|s_{B1}\rangle + \frac{\sqrt{2}}{2}sin\left(\frac{\theta}{2}\right)|s_{B2}\rangle\right\} + |s_{A2}\rangle\left\{-\frac{\sqrt{2}}{2}sin\left(\frac{\theta}{2}\right)|s_{B1}\rangle - \frac{\sqrt{2}}{2}cos\left(\frac{\theta}{2}\right)|s_{B2}\rangle\right\} =$$

$$= |s_{B1}\rangle\left\{\frac{\sqrt{2}}{2}cos\left(\frac{\theta}{2}\right)|s_{A1}\rangle - \frac{\sqrt{2}}{2}sin\left(\frac{\theta}{2}\right)|s_{A2}\rangle\right\} + |s_{B2}\rangle\left\{\frac{\sqrt{2}}{2}sin\left(\frac{\theta}{2}\right)|s_{A1}\rangle - \frac{\sqrt{2}}{2}cos\left(\frac{\theta}{2}\right)|s_{A2}\rangle\right\} =$$

$$= |s_{B/A1}\rangle|s_{A1}\rangle + |s_{B/A2}\rangle|s_{A2}\rangle = |s_{A/B1}\rangle|s_{B1}\rangle + |s_{A/B2}\rangle|s_{B2}\rangle$$

$$\Downarrow$$

$$Joints: Pr\left(|s_{Xi}\rangle|s_{Yj}\rangle\right) = \begin{cases} 0 \;\; \forall\, X = Y \;\; X,Y \in \{A,B\} \;\; \forall\, i \neq j \;\; i,j \in \{1,2\} \\ (1/2)cos^2(\theta/2) \;\; \forall\, X \neq Y \;\; X,Y \in \{A,B\} \;\; \forall\, i = j \;\; i,j \in \{1,2\} \\ (1/2)sin^2(\theta/2) \;\; \forall\, X \neq Y \;\; X,Y \in \{A,B\} \;\; \forall\, i \neq j \;\; i,j \in \{1,2\} \end{cases} \qquad (29)$$

$$Marginals: \; Pr(|s_{Xi}\rangle) = \sum_{j=1}^{2} Pr\left(|s_{Xi}\rangle|s_{Yj}\rangle\right) = 1/2 \;\; \forall\, X \neq Y \;\; X,Y \in \{A,B\} \;\; \forall\, i \in \{1,2\} \qquad (30)$$

$$Pr\left(|s_{Xi}\rangle|s_{Yj}\rangle\right) \neq Pr(|s_{Xi}\rangle)Pr\left(|s_{Yj}\rangle\right) \;\; \forall\, X \neq Y \;\; X,Y \in \{A,B\} \;\; \forall\; i,j \in \{1,2\} \;\; \forall\, \theta \neq \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2} \ldots$$

$$(31)$$

$$|s\rangle = \left\{\frac{\sqrt{2}}{2}|s_{A1}\rangle - \frac{\sqrt{2}}{2}|s_{A2}\rangle\right\}\left\{\frac{\sqrt{2}}{2}|s_{B1}\rangle + \frac{\sqrt{2}}{2}|s_{B2}\rangle\right\} \quad \forall\, \theta = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2} \ldots$$

$$\begin{array}{lllll} Local\ Operators: & \mathcal{P}_A\ and\ \mathcal{P}_B & ; \ \langle\mathcal{P}_A\rangle = \langle\mathcal{P}_B\rangle = 0 & ; \ \Delta\mathcal{P}_A = \Delta\mathcal{P}_B = 1\ \forall\ \theta & \\ Global\ Operator: & \mathcal{P} = \mathcal{P}_A\mathcal{P}_B = \mathcal{P}_B\mathcal{P}_A & ; \ \langle\mathcal{P}\rangle = cos\theta & ; \ \Delta\{\mathcal{P}\} = |sin\theta| & (32) \\ Correlation: & \multicolumn{3}{l}{Corr = \{\langle\mathcal{P}\rangle - \langle\mathcal{P}_A\rangle\langle\mathcal{P}_B\rangle\}/\Delta\mathcal{P}_A\Delta\mathcal{P}_B = \langle\mathcal{P}\rangle = cos\theta} & \end{array}$$

$$\Downarrow$$

Reciprocal Intrinsic Tele-Interaction (ITI)

$$Pr\big(|s_{Ui}\rangle|s_{Vj}\rangle/|s_{Xk}\rangle|s_{Yl}\rangle\big) = \begin{cases} 0 \ \forall\ U \neq X\ V \neq Y\ \ U,V,X,Y \in \{A,B\}\ \forall\ i \neq k, j \neq l\ \ i,j,k,l \in \{1,2\} \\ 1\ \forall\ U = X\ V = Y\ \ U,V,X,Y \in \{A,B\}\ \forall\ i = k, j = l\ \ i,j,k,l \in \{1,2\} \end{cases} \quad (33)$$

$$Pr\big(|s_{Xi}\rangle/|s_{Yj}\rangle\big) = \begin{cases} 0\ \forall\ X = Y\ \ X,Y \in \{A,B\}\ \forall\ i \neq j\ \ i,j \in \{1,2\} \\ cos^2(\theta/2)\ \forall\ X \neq Y\ \ X,Y \in \{A,B\}\ \forall\ i = j\ \ i,j \in \{1,2\} \\ sin^2(\theta/2)\ \forall\ X \neq Y\ \ X,Y \in \{A,B\}\ \forall\ i \neq j\ \ i,j \in \{1,2\} \end{cases} \quad (34)$$

The first line of Equations 28 expresses the composite state in the direct Milieu Basis $MB = \{|s_{A1}\rangle|s_{B1}\rangle, |s_{A1}\rangle|s_{B2}\rangle, |s_{A2}\rangle|s_{B1}\rangle, |s_{A2}\rangle|s_{B2}\rangle\}$, where the two eigenstates for sub-quanton $A(B)$ are associated with the orientation of magnet SG-$A(B)$, and θ is the angle between the axes of SG-A and SG-B. Alternatively, the second line shows the same state expressed in the Bell Basis $BB = \{|B1\rangle, |B2\rangle, |B3\rangle, |B4\rangle\}$ [11]. How are these two different mathematical representations for the same physical state understood vis à vis QR/TOPI? If we could arrange for an experimental setup whose MB is BB, the physical state -upon the GI- would transition to $|B1\rangle$ with probability $sin^2(\theta/2)$ and to $|B3\rangle$ with probability $cos^2(\theta/2)$ and, clearly, were the initial physical state $|B1\rangle$ or $|B3\rangle$, it would go through the GI without changing. Remember though that θ is still the angle between the two SG magnets' axes, i.e. between the spatial directions associated with the eigenstates $|s_{A1}\rangle$ and $|s_{B1}\rangle$. In fact, we see that $|B1\rangle$ corresponds to $\theta = \pi$ and $|B3\rangle$ to $\theta = 0$ so that: $|B1\rangle = \big(\sqrt{2}/2\big)(|s_{A1}\rangle|s_{B2}\rangle - |s_{A2}\rangle|s_{B1}\rangle)$ and $|B3\rangle = \big(\sqrt{2}/2\big)(|s_{A1}\rangle|s_{B1}\rangle - |s_{A2}\rangle|s_{B2}\rangle)$ – as we know they are defined.

Lines 3 through 5 of Equations 28 are other forms of the State Equation, with line 5 showing that the concept of a conditional state can be grasped straight from the concept of conditional probability. Equations 29-34 are specific stochastic relations all entailed in the State-Equation 28 (first line). From Relations 29-31 we learn that the eigenstates for the two qubits are ***not*** independent, except when the two SG magnetic fields are in quadrature $(\theta = \pi/2;\ 3\pi/2; \dots)$; only in those cases, the joint probability $(1/4)$ is equal to the product of the two eigenstates probabilities $(1/2)$. Otherwise, the joint probability can be greater or smaller than the product:

$$Pr(|s_{A1}\rangle|s_{B1}\rangle) = Pr(|s_{A2}\rangle|s_{B2}\rangle) = \frac{1}{2}cos^2(\theta/2)\begin{cases} > 1/4 & 0 < \theta < \pi/2\ ;\ 3\pi/2 < \theta < 2\pi \\ = 1/4 & \theta = \pi/2\ ;\ \theta = 3\pi/2 \\ < 1/4 & \pi/2 < \theta < 3\pi/2 \end{cases} \quad (35)$$

$$Pr(|s_{A1}\rangle|s_{B2}\rangle) = Pr(|s_{A2}\rangle|s_{B1}\rangle) = \frac{1}{2}sin^2(\theta/2)\begin{cases} < 1/4 & 0 < \theta < \pi/2\ ;\ 3\pi/2 < \theta < 2\pi \\ = 1/4 & \theta = \pi/2\ ;\ \theta = 3\pi/2 \\ > 1/4 & \pi/2 < \theta < 3\pi/2 \end{cases} \quad (36)$$

When the joint probability is greater or smaller than their product, it is an indication of correlation between the states (Equations 32-last line), e.g. if $\theta = 0 \Rightarrow Pr(|s_{A1}\rangle/|s_{B1}\rangle) = 1 > Pr(|s_{A1}\rangle) = 1/2$ and $Pr(|s_{A2}\rangle/|s_{B2}\rangle) = 1 > Pr(|s_{A2}\rangle) = 1/2$. Also, $Pr(|s_{A1}\rangle/|s_{B2}\rangle) = 0 < Pr(|s_{A1}\rangle) = 1/2$ and $Pr(|s_{A2}\rangle/|s_{B1}\rangle) = 0 < Pr(|s_{A2}\rangle) = 1/2$. In both cases, the distant eigenstates are maximally correlated: they occur/***not*** occur together with unity probability. This agrees with Equations 12 but is in blunt violation of BLC – specifically of OuI. Instead, from Equation 30, we find that even though the local eigenstates depend upon the orientation of the local magnets (settings a or b), the local probabilities for each of them at both sites are independent of each other's setting and even of their own local setting. Hence, given that in QT the only *common cause* (Λ) for whatever happens at A and B is $|s\rangle$, the 'Parameter Independence' condition is met, and *signaling* via the GIs' settings (the only controllable parameters) is ***not*** possible – not even for ***non***-spacelike GIs. As expected, violating OuI but not PaI, QT's correlations are ***non****local* but ***non****signaling*. The latter is due to the commutability of the two local operators ($[\mathcal{P}_A, \mathcal{P}_B] = 0$). Notice though that -as already highlighted- PaI is sufficient for nonsignaling but not necessary: de Broglie/Bohm theory violates PaI and is ***non****signaling*.

From another perspective, such commutability of the two local operators is compatible with the spacetime structure of RT because: were $[\mathcal{P}_A, \mathcal{P}_B] \neq 0$, in the case of their GIs being spacelike, there would exist an IF in which definite values for two ***non***-commuting properties would be *simultaneous* – against the 'Principle of Uncertainty'. Differently: Heisenberg's Inequalities at the two sites are independent of each other. Were it possible to conceive a global property out of local non-commuting operators, Heisenberg's Inequalities would be violated with nonlocal signaling being possible. That is why in all quantum field theories spacelike operators commute, making nonlocal signaling impossible. However, RT is based on more than simply excluding superluminal interactions: QT's *nonlocality* obviously violates the Lorentz Transformation and that is why I said that Quantum Field Theory, despite its promotion as such, it is not fully relativistic.

The violation of OuI requires a ***non***-RT-DCR and that is the reason behind the clash between RT and QT. Differently: in terms of the CHSH Bell-type Inequality, there are sets of settings $a, a', b,$ and b' for which $|\langle CHSH(QT)\rangle| > 2$. For instance: given $a = 0°$, $a' = 90°$, $b = 45°$, and $b' = 135°$ and using Equations 32, we obtain:

$$\langle CHSH(QT)\rangle = \langle P_{AB}/a, b\rangle - \langle P_{AB}/a, b'\rangle + \langle P_{AB}/a', b\rangle + \langle P_{AB}/a', b'\rangle$$
$$\Downarrow$$
$$\langle CHSH(QT)\rangle = \cos(45°) - \cos(135°) + \cos(45°) + \cos(45°) = 2\sqrt{2} > 2$$
$$\Downarrow$$

Violating Inequality 27 (top), we conclude that ***no*** BLHVT can describe/predict the full behavior of two **en**tangled ½-spin qubits.

Figure 10 depicts the **de**tangled actual pure states in red(blue) when the qubit undergoing the time-first GI in a given IF is $A(B)$. Calling t_{DA} and t_{DB} the respective times for the PDIs in the two GIs, red corresponds to $t_{DA} < t_{DB}$ and blue to $t_{DB} < t_{DA}$. The double-arrows are in black and correspond to 'time-second' GIs that may or may not occur at all. As for the ITI for the composite quanton: (1) Equations 33 are the homologues of the single-quanton's Equations 20 and 21 (now for a 4-D Hilbert space), and they are implicit in the representation of the composite state as a complex vector with unity Euclidean norm; (2) Equations 34 express the intrinsic tele-interaction between the probable eigenstates of the two sub-quantons. The equations at the top, which define the ITIs for qubits A and B as independent pure states (Equation 20), simply say that actual cases (a) and (b) in Figure 10 are mutually exclusive (again implicit in the representation of a pure state as a complex vector with unity 2-norm). But remember that probable states are as ***real*** as actual ones so the condition in a conditional probability is ***not*** actual – until it becomes so due to a GI.

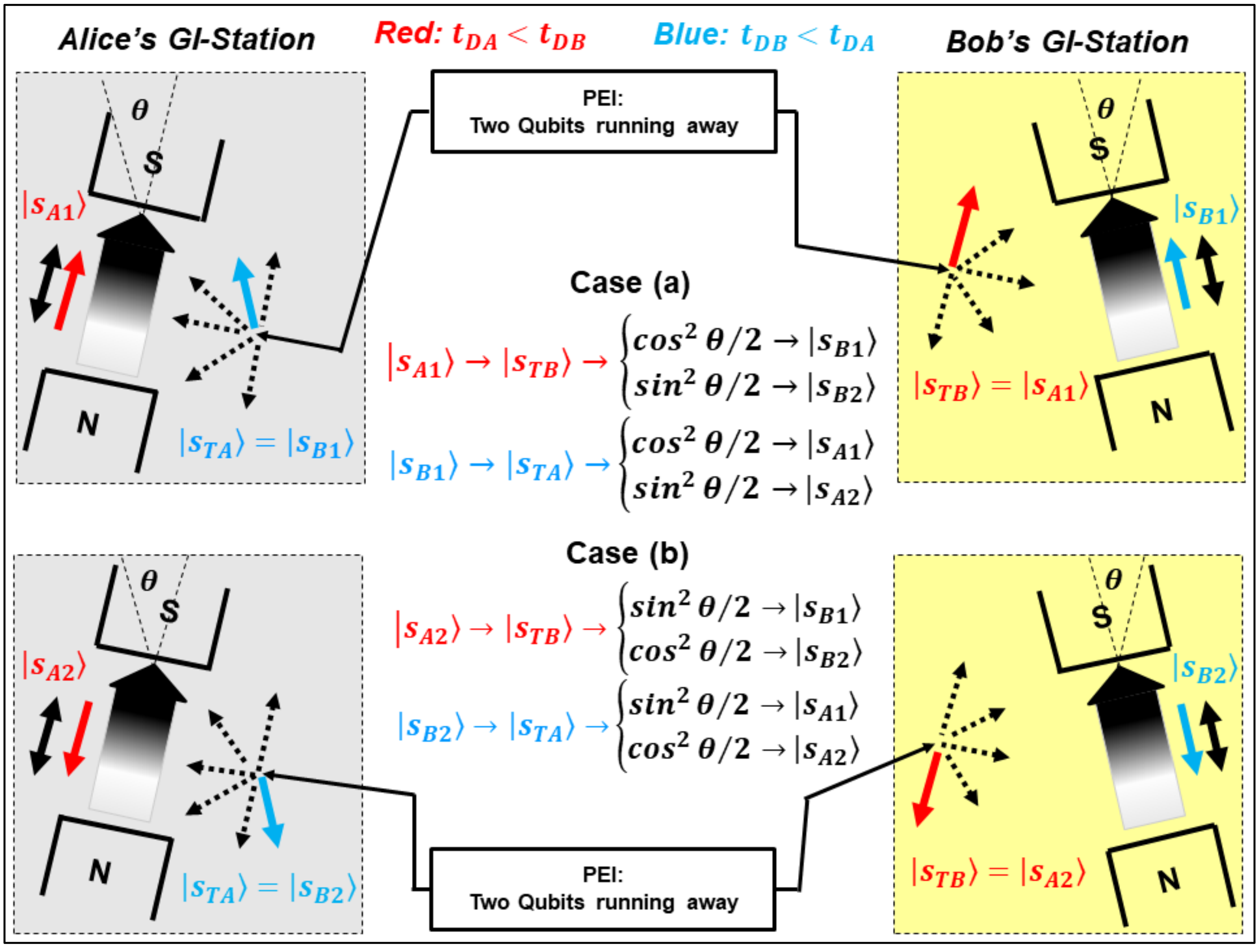

Figure 10 – A single GI undergone by anyone of the qubits creates two actual clones.

From Equations 34 (middle line) and Figure 10 we see that $\theta = 0$ corresponds to the qubit-$B(A)$ state (teleported upon GI-$A(B)$) aligned with the $B(A)$ magnet and ergo passing it unchanged. Hence, calling $|s_{TB(A)/A(B)}\rangle$ the teleported state to qubit-$B(A)$ when qubit-$A(B)$ undergoes a GI, we obtain: $|s_{TB(A)/A(B)}\rangle = |s_{A(B)}\rangle$. Notice, as displayed in Figure 10, that the teleported states for each of the cases (a) or (b) are the same regardless of which GI is the time-first, so the ideal case of $t_{DA} = t_{DB}$ is already included and the time-order between the GIs in the chosen IF does not matter. What matters is which case (a) or (b) does happen and that is perfectly random (50/50) for both Alice and Bob (Equation 30). Finally, note that the state-equation also exhibits rotational and translational invariance because only the angle θ between the two magnetic fields at GI -A and GI-B matters.

5.4 Timing Bi-Quanton Nonlocality I: Nature's Teleportation/Cloning

Figure 11 schematizes the two traveling quantons in a spacetime diagram. The PEI, plus Alice's and Bob's GI instrumentation are all in relative repose defining our lab frame K with its origin at the PEI which launches simultaneously the two quantons in the composite state given by Equation 28 (top). For each experiment, the locations for Alice's and Bob's GI-stations can be adjusted with their possible (vertical) worldlines in gray and yellow respectively. The slope of the worldline for quanton $A(B)$ depends on the actual distance it covers to reach the Station $A(B)$, e.g. a photon guided by a coiled optic fiber has a higher slope than for an uncoiled fiber. Consistently with Figure 5, Figure 11 shows the effective velocity for quanton A slightly higher than for quanton B. The spacetime coordinates for the intersection of the stations' worldlines with the two quantons' careers are displayed as circles – representing possible PDI-Events E_{DA} and E_{DB}.

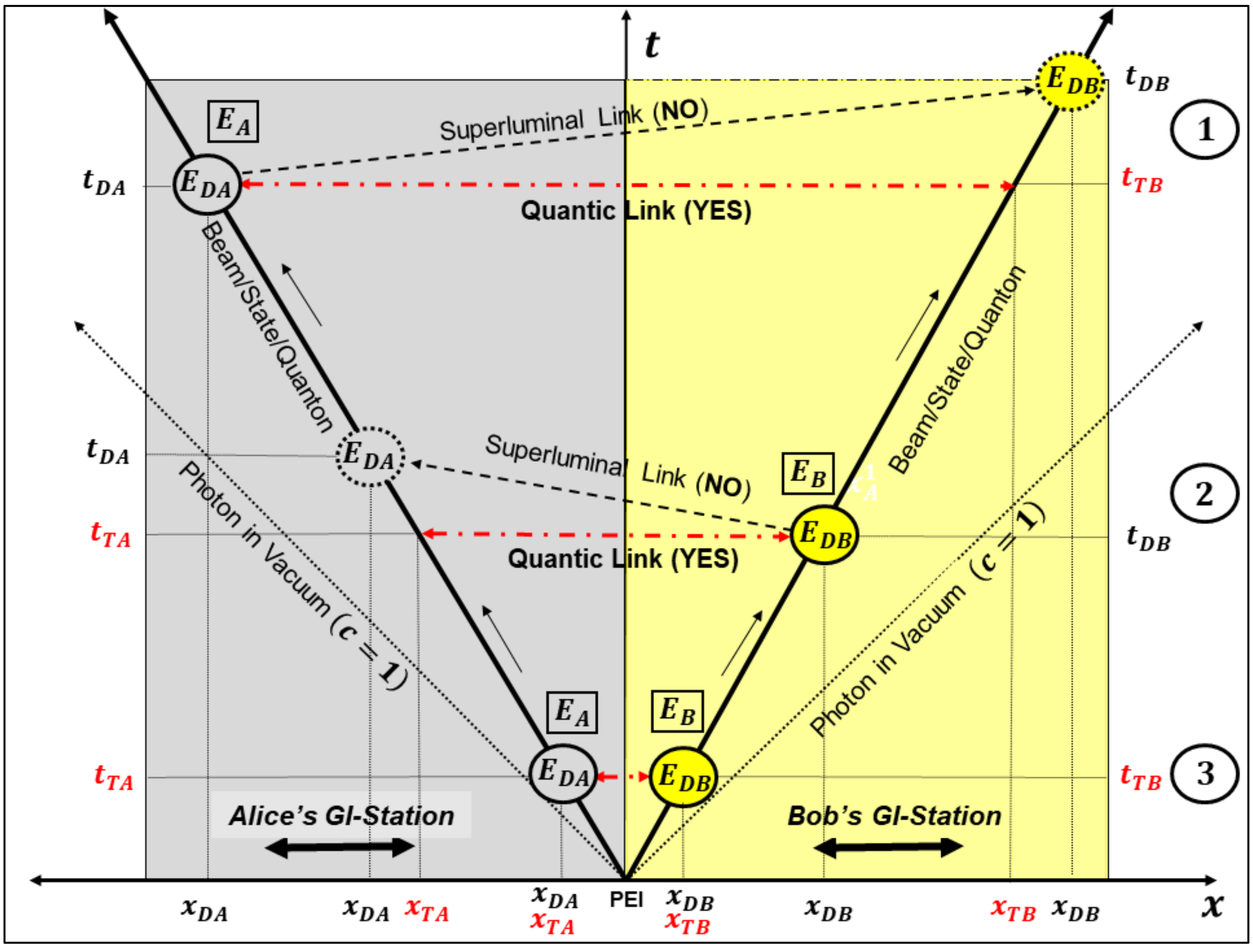

Figure 11 – Timing the 'Teleportation' Event for two Entangled Quantons

Three spacelike-separated PDI-Events at the two stations are shown in K: Case 1 for E_{DA} time-first ($[t_B - t_A] > 0$); Case 2 for E_{DB} time-first ($[t_B - t_A] < 0$); and Case 3 for E_{DA} and E_{DB} simultaneous ($[t_B - t_A] = 0$). For Cases 1 and 2 the circle for the time-first PDI-Event is solid and the time-second is dotted, indicating that it may or may not actually occur. For Case 3 both circles are solid because both PDI-Events do take place and simultaneously. Corresponding State-Events E_A and E_B are depicted inside squares. Under QR/TOPI, those three Type 2 cases can be realized by moving the stations (or changing the optic fiber's length) in the same frame (K) or, equivalently, by changing to a different IF (K'). To see the equivalence, using LT Equations 5 and 7, Figure 12 shows the time-interval $(t'_{DB} - t'_{DA})$ between the PDI-Events at stations A and B in K' when they are simultaneous in K: Case 3 in K turns into Case 1 for $v_{K'/K} < 0$ and into Case 2 for $v_{K'/K} > 0$ in K'. Notice that $v_{K'/K} = 0$ corresponds to $K' = K$.

Likewise, Figure 13 depicts what happens in K' when we have Case 1 in K: the value of $v_{K'/K}$ at which the time-order inversion occurs is shifted to the right, to the left of which Case 1 stays as such and to the right of which Case 1 becomes Case 2. Note that, being Type 2 Event-Intervals, Figures 12 and 13 show that the time taken by light (blue) is always greater than the absolute value of the time-interval between the PDI-Events (green).

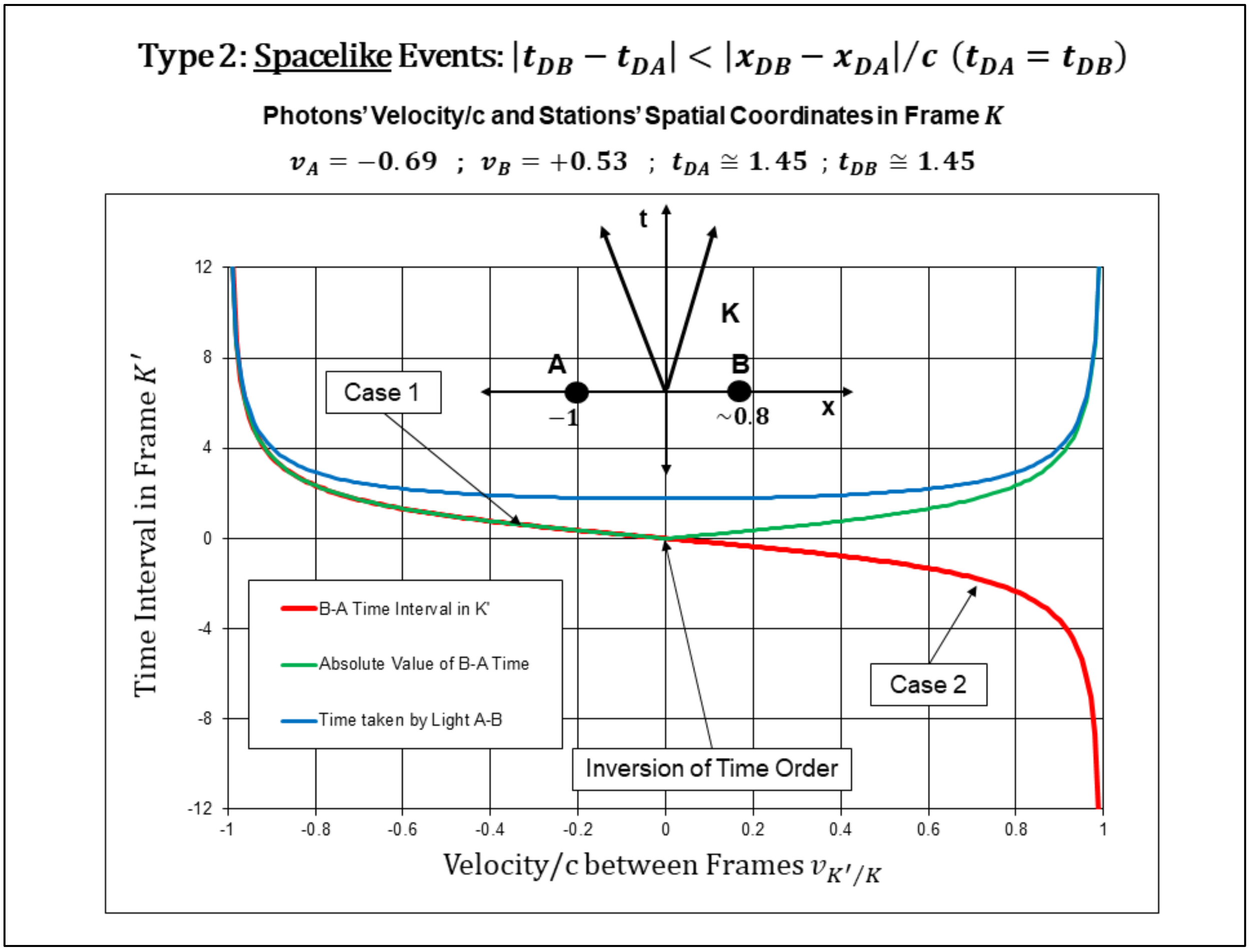

Figure 12 – Type 2 with $t_{DA} = t_{DB}$: $K \rightarrow K'$ ⇒ 'Case 3 → Case 1' or 'Case 3 → Case 2'

Figure 11 does not display the lightlike and timelike situations, so Figure 14 shows the lightlike case: the three curves coincide because the time-interval between the PDI-Events is always equal to how long light takes to join them. Besides, the time-order for Cases 1 and 2 is Lorentz-Invariant and Case 3 (simultaneity) does not occur because light is genidentically causal.

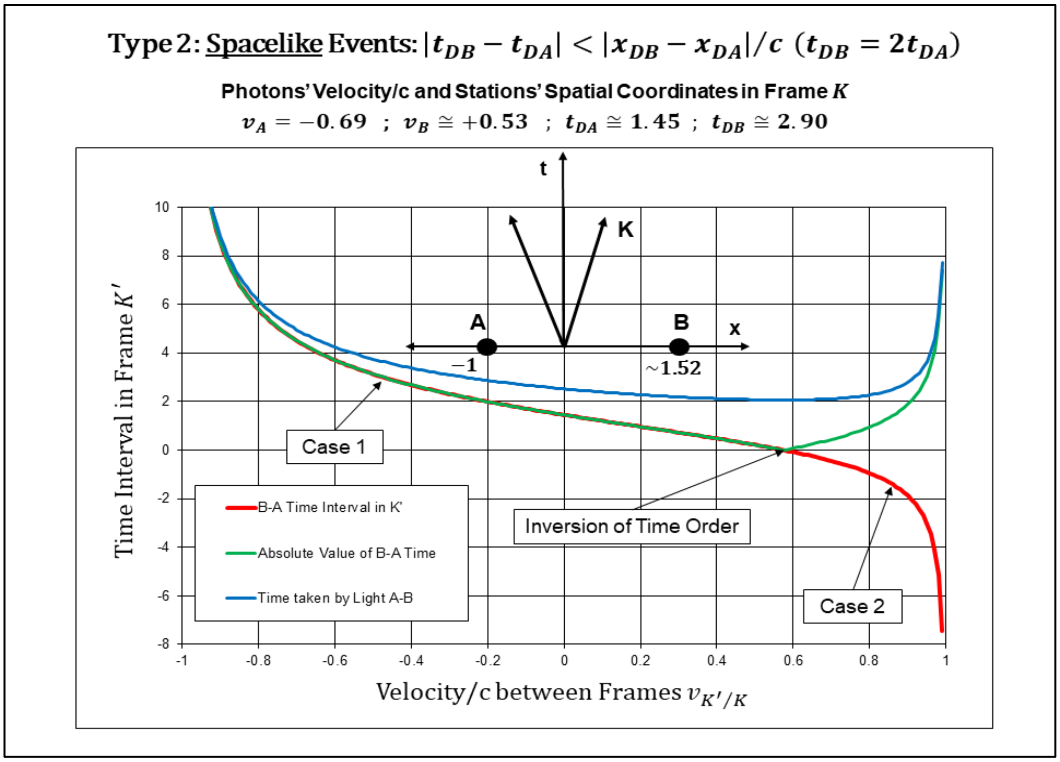

Figure 13 – Type 2 with $t_{DB} = 2t_{DA}$: $K \rightarrow K'$ ⇒ 'Case 1 → Case 1' or 'Case 1 → Case 2'

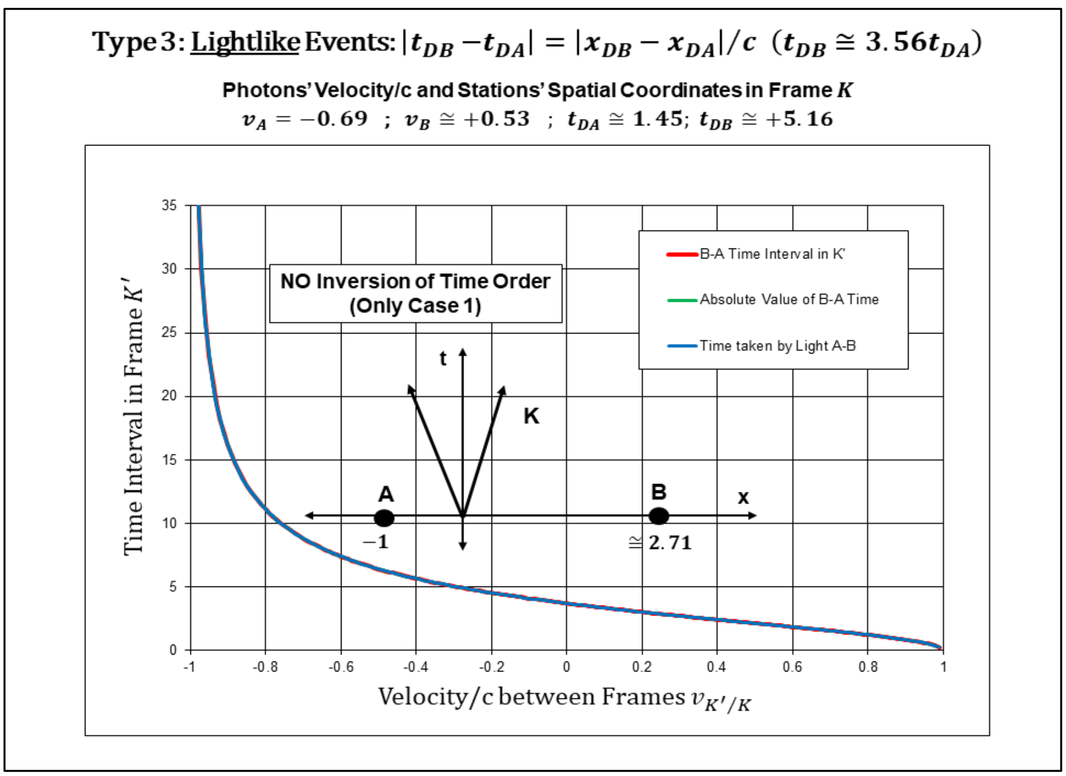

Figure 14 – Type 3 with $t_{DB} = 3.56t_{DA}$: $K \rightarrow K'$ ⇒ 'Case 1 → Case 1'

Finally, Figure 15 depicts the timelike condition: the time taken by light (blue) is always shorter than the time-interval between PDI-Events, so time-order is also Lorentz-Invariant (events inside the light hypercone) making Cases 1 and 2 invariant and Case 3 impossible. Combining Figures 11 through 15, we have covered all possible cases in all possible IFs.

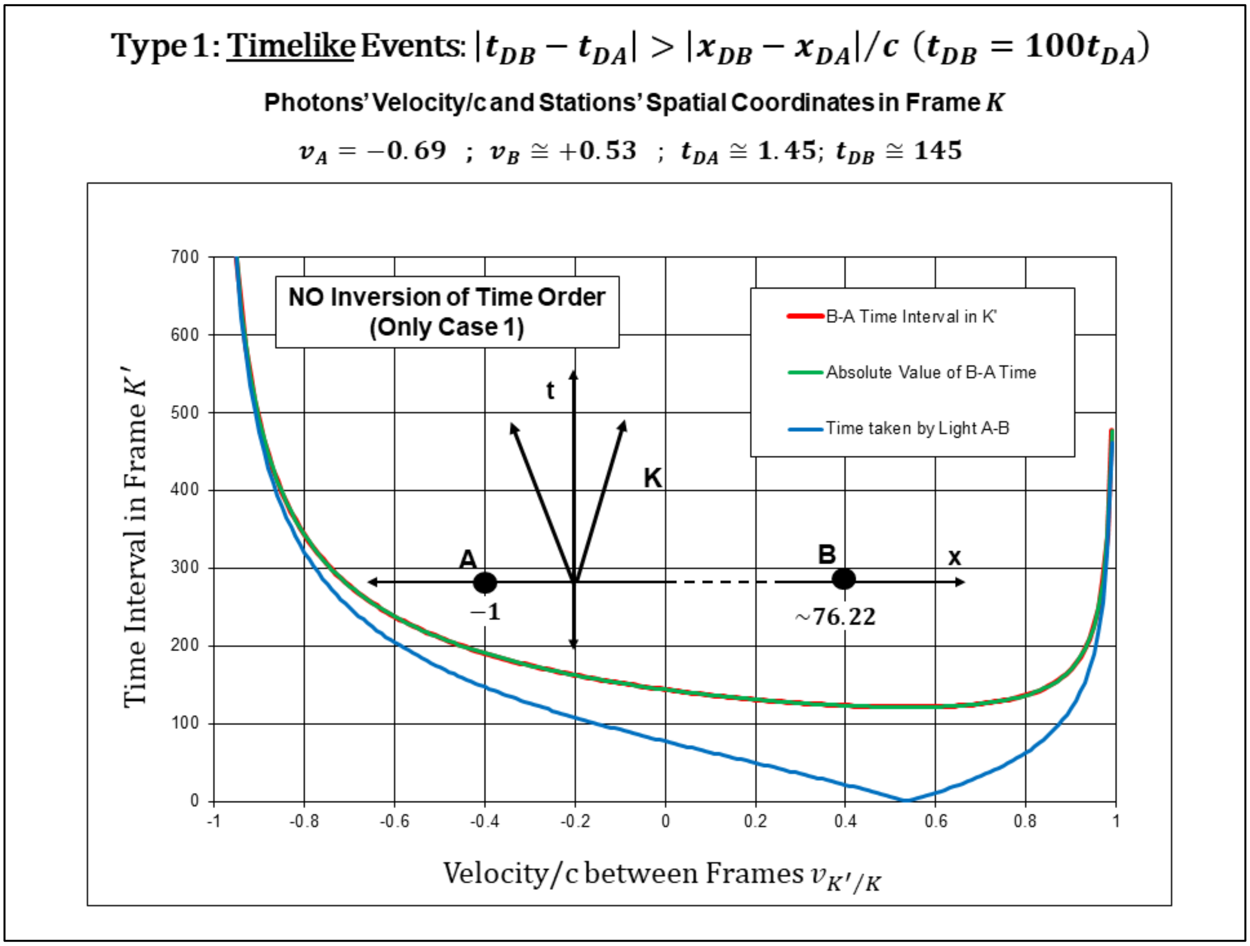

Figure 15 – Type 1 with $t_{DB} = 100t_{DA}$: $K \rightarrow K'$ ⇒ 'Case 1 → Case 1'

Strikingly, multiple runs for the three spacelike cases (Figures 11, 12, and 13) and also for ***non***-spacelike cases (Figures 14 and 15) have been thoroughly conducted/reported in the literature with their statistics proving that Equations 29-32 are confirmed (e.g. [115] [74] [12]). Remember that to convert those equations for a pair of ½-spin electrons into those for a pair of entangled photons, all we need to do is to replace θ by 2θ. Based on such abundant empirical evidence, the above plots (based on the LT) shall considerably assist us in understanding our new Quantumlike Transformation (QLT) that replaces the LT – making QR/TOPI an IF-Invariant theory.

5.4.1 Enclosing the Teleportation QR-Event between two Arbitrarily Close R-Events

In an IF, calling $t_{TB(A)}$ the QR-Time for the *teleportation* State-Event $E_{TB(A)/A(B)}$ experienced by quanton $B(A)$ due to the simultaneous events $E_{DA(B)}$ and $E_{A(B)}$ undergone by quanton $A(B)$, and assuming $E_{DB(A)}$ does occur time-after, then we can assert: $t_{DA(B)} \leq t_{TB(A)} \leq t_{DB(A)}$. The lower bound would correspond to an instant 'delivery' of quanton $A(B)$ state to quanton $B(A)$; the upper bound to an on time 'release'; all others to an in time 'transfer'; and all three times would be equal for the ideal case when $t_{DA} = t_{DB}$ (Case 3). But besides the data already mentioned, in 2001, the same statistics consistent with Equations 29-32 for the photon $(\theta \to 2\theta)$ was proven by Gisin's research group (Zbinden et al) with one of the GI-stations *moving* and the two photons arriving at their detectors within 5ps (detectors in two villages near Geneva separated by more than 10 km) [116]. And, in a related paper, Gisin's team (Stefanov et al) concluded (my underscore):

> *This refutation stresses the oddness of quantum correlations. Not only are they independent of the distance, but also it seems impossible to cast them in any real time ordering. Hence one can't maintain any causal explanation in which an earlier event influences a later one by arbitrarily fast communication.* [115]

Therefore, what we called instant 'delivery' is the real one for all IFs and, ergo, neither 'delivery', nor 'release', nor 'transfer' would be fully appropriate locutions – if we were thinking of genidentical chains (which they are not because in QR/TOPI -like in RT- there are ***no*** "arbitrarily fast" genidentical chains). What we have is clearly the sui generis ***non***-directional causal 'quantic link' between State-Events (horizontal red dotted lines in Figure 11) we described as Causal (f) (and dismissed by Einstein based on sheer philosophical predilections). The red double-arrow-dotted lines indicate ***not*** bidirectionality but non-directional reciprocity.

I insist: if in frame K $t_{DA} < t_{DB}$ and if by making $t_{DB} \to t_{DA}$ the experimental evidence (PD) is invariant (Equations 29-32), then, because $t_{DA} \leq t_{TB} \leq t_{DB}\ \forall\ t_{DB} > t_{DA}$, t_{TB} must be equal to t_{DA} no matter how distant Bob's station for quanton B could still be when quanton A undergoes its GI, and whether or not quanton B ever undergoes its GI at Bob's station. Furthermore, because of the reversibility of the conditional probabilities (Equations 32-34), all this is also valid (mutatis mutandis) when qubit-B is the one that time-first undergoes a GI $(t_{DB} < t_{DA})$ and $t_{DA} \to t_{DB}$. Regarding the case $t_{DA} = t_{DB}$, we have $t_{TA} = t_{TB}$ and there would be ***no*** time-first PDI-Event, exposing the inadequacy of describing *teleportation* as a (superluminal or not) genidentical chain with a beginning and an end. In all cases (Equations 32), $\langle \mathcal{P}_A \rangle = \langle \mathcal{P}_B \rangle = 0\,; \Delta\mathcal{P}_A = \Delta\mathcal{P}_B = 1\,; \langle \mathcal{P}_A \mathcal{P}_B \rangle = cos\theta\ ;\ \Delta\{\mathcal{P}_A \mathcal{P}_B\} = |sin\theta|$, and the correlation between the quantons' properties is $Corr = cos\theta$ $(\theta \to 2\theta$ for the photon). The QR-Time $t_{TB(A)} = t_{DA(B)}$ is the *instant* at which both co-states *simultaneously* become actual pure states with their joint probability given (as always) by Equations 29. This *instant* is of course IF-**Co**variant; the *simultaneity* must be IF-**In**variant.

It follows that, because the *teleportation* State-Event consists in the adoption of an actual state by quanton $B(A)$ by virtue of a GI undergone by quanton $A(B)$, the R-Time for GI-$A(B)$ becomes the QR-Time for the *teleported* state adopted by the distant quanton $B(A)$. We see that despite being *non-evincing* (all State-Events are), an actual QR-Event has an R-Time because it can be confined between two arbitrarily close R-Times – those of experimentally possible PDI-Events E_{DA} and E_{DB}. Hence, in all cases, the spacetime coordinates in the lab frame K for the teleportation QR-Event experienced by quanton $B(A)$ are $x_B, t_A(x_A, t_B)$ regardless (in principle) of how farther away Bob's (Alice's) detector might be (or not exist at all) – explaining why only θ appears in Equations 28-32 and that its value can be changed at the very last instant before GI-$B(A)$. We see again that this *teleportation* QR-Event (as all R-Events) is abstractable to a point-Event, i.e. fully characterizable by a spacetime point; and that its *simultaneity* with the State-Event undergone by the other quanton is objectively absolute, viz IF-Invariant without non-trivial conventions. No such simultaneity exists in RT.

It is remarkable that despite not being able to observe/measure *teleportation* per se, we are able to experimentally confine its occurrence between the occurrences of two distant GIs which can be made virtually *simultaneous* in any IF while delivering the same experimental data but, of course, occurring at different spacetime coordinates in different IFs. Thus, repeating it at nauseum, the very adoption by quanton $B(A)$ of a *teleported* actual (non-evincing) *state* must be considered *simultaneous* with the GI experienced by quanton $A(B)$ in all IFs, viz: $t_{TB(A)} = t_{DA(B)}$ irrespective of whether or not quanton $B(A)$ undergoes a GI.

In the ***non***-spacelike case (Figures 14 and 15), despite having proved that the teleported state of a sub-quanton must be simultaneous with the GI undergone by the other sub-quanton, a time-ordered narrative (a chronicle) of teleportation between two GIs (as we did in Part III [11]) is possible and the same for all IFs: the time-first GI involves the transformation of the local co-state into a pure state plus its teleportation towards the remote sub-quanton, which then undergoes (if it does) the time-second GI as an isolated (but still correlated) quanton. But possibility of explanation based on our prejudices is not the same as Reality: in the spacelike case, a chronicle based on purported superluminal genidentical chains is **in**consistent because the LT reverses the time order between two GI-Events (Figures 12 and 13). The only possible explanation within RT fails and, ergo, RT must be **in**complete.

Wrapping up, all it can be said is that any single local GI in any IF involves the joint transformation of two co-states into two pure isolated (though related) states; anything else would be inconsistent because, depending upon the IF, the same sub-quanton if time-first would enter its GI in a co-state (entangled) 'causing' teleportation, and if time-second would enter its GI in a pure state (as the 'effect' of teleportation). But remember that -in RT- temporal order between spacelike events is ***not*** objective but conventional, so any time-ordered storyline (chronicle) of events is necessarily associated with some IFs but not with all. And postulating a 'preferred frame' (an indiscernible 'quantum ether') in which one GI is always the time-first would be equivalent to claiming by fiat which one is the first and which one is the second. Clearly, the solution is to admit that (based on solid empirical grounds) our Causal (f) (quantic link in which causality is **de**coupled from time-order) is real or, equivalently, that the *simultaneity* characteristic of *nonlocality* is objectively absolute and must coexist with the relative simultaneity of RT. But… is this co-existence possible? Yes: realizing that this symmetric causality occurs ***never*** between two PDI-Events but always either between two State-Events (actual ***non***-evincing) or between a PDI-Event and a State-Event, RT and QT are consistently integrated by QR/TOPI. But, as we said for the single-quanton nonlocality, for QR/TOPI to be IF-Invariant, the LT will need to be revised (better: extended) so as to regulate all actual QR-Events (R-Events as well as actual ***non***-R-Events).

5.4.2 No Human Communication via Bi-Quanton Teleportation

Given that, per QR/TOPI, Nature achieves *teleporting* and *cloning* all the time, Alice and Bob might speculate again about the possibility of 'spookily' (instantly) communicating between each other. The GIs' results are *stochastic* and beyond Alice's and Bob's control so they can only choose the orientation of their SG magnets (free settings a and b). Ergo, statistical analysis of a large dataset is inevitable: either (1) a legion of GIs at Alice's site are allowed to occur, with each resulting state teleported by Nature to the corresponding quanton at Bob's site so his corresponding GIs directly produce a wealth of data to analyze; or (2) the resulting quanton's state of a single GI at Alice's site is teleported by Nature to Bob's quanton and Bob's somehow manages to produce lots of *clones* for statistical analysis. Were any of these approaches possible, despite the necessary statistical analysis, the process -with the proper technology- could still be accomplished faster than via a conventional light-limited genidentical chain. In fact, let us see why they are impossible.

Approach (1), viz using a large number of natural teleportation events, resembles the scheme when Alice changed the arm's length in the QMME/QKTE interferometer and conducted multiple runs so Bob could statistically assess his click rates and, from the latter, deduce the arm's length set by Alice (the message). There was a clear nomic relationship between length and click rates. Could it work here? We know from Equations 32 that for $\theta = 0$ Alice and Bob's states are always the same ($\langle \mathcal{P} \rangle = 1;\ \Delta\{\mathcal{P}\} = 0$), while for $\theta = \pi$, they are always one the opposite of the other ($\langle \mathcal{P} \rangle = -1;\ \Delta\{\mathcal{P}\} = 0$). Hence, if e.g. Bob kept the orientation of his SG magnet fixed and Alice oriented her magnet parallel to Bob's to send a '0' and anti-parallel to send a '1', could Bob determine which bit Alice sent via the statistics of his large number of GIs? NO, unless the pure state into which Alice's qubit transitioned upon each local GI were governed by a PD different from a perfectly **un**biased 50/50 (Equation 30). Were the correlation law the same, any biased PD could be successfully harnessed for communication: for instance, a 70/30 PD at Alice's site would manifest as a 70/30 PD at Bob's site when $\theta = 0$ and as a 30/70 when $\theta = \pi$. Obviously, being the PD a perfect 50/50, Nature's whimsical (unpredictable) *free will* blocks the possibility of using Her teleportation as a means of human communication – at least via a large number of GIs at the sender's site. This is why quantic randomness is claimed to be 'true randomness' – in contraposition to the pseudo-random sequences generated by clever algorithms (i.e. deterministic).

What about approach (2), viz Bob attempting to figure out which bit Alice sent after a single GI at her site? If they agreed in using the same orientation for their SG magnets ($\theta = 0$) and Bob could emulate Nature and produce *clones* of his qubit at will before allowing for any GI-B, they could instantly communicate as follows: when Alice wants to transmit a '0' she lets her qubit go through the magnetic field; to transmit a '1' she simply moves away the magnet, so her qubit does not experience the GI-A. Bob, in turn, makes and stores platoons of *clones* of his only one qubit for posterior offline analysis. He then let all the *clones*, one by one, go through his magnet and assesses the statistics: if he gets a perfectly random distribution of output states (50% collinear and 50% anti-collinear), he knows that Alice transmitted a '1' (***no*** GI-A so ***no*** teleportation occurred and Bob's *clones* were all in the co-state with qubit-A the original qubit-B was); if all the *clones* going through his magnet come out on the same stream (same spin state because a GI-A/teleportation occurred and the actual pure state for all the *clones* is -as the original qubit-B was- an eigenstate for all the GI-Bs), Bob knows Alice transmitted a '0'. Note that the *cloning* process conceived by Bob must be a PTI, i.e. it must ***not*** contain a PDI; otherwise, the probable *co-state* in which Bob's quanton is when Alice transmits a '1' would be converted into a *pure* actual state.

Notice now the stark difference with Alice changing the arm's length in the QMME/QKTE interferometer. In that case: (a) she was 'sending' multiple times the same determinate number (arm's length) she could control at will and Bob statistically analyzing the data, while now -in a single run- she is 'sending' either a 50/50 PD (did not insert the magnet) or a random *actual* state (did insert the magnet), which needs to be multiply *cloned* (PTIs) by Bob for posterior 'measuring' (PDIs); and (b) the different results of the different runs controlled by Alice were Bob's very object of analysis so as to determine the click rate (PD), i.e. the single message sent by Alice, while now, different runs by Alice (each one requiring Bob's making a large set of *clones*) correspond to different bits of a message.

Obviously, Bob -in both approaches (1) and (2)- would need to spend much time and effort statistically analyzing many real qubits or many *clones* to extract a single bit of information from Alice. However, the actual 'transfer' (*teleportation*) of the state would be virtually instantaneous because t_{DA} and t_{DB} could be very close (while Alice's hardware still receiving her qubit slightly earlier to carry out her communication scheme). And specifically for approach (2), like Alice's sending scheme, Bob's post-analysis could be automated so all *clones* would be created and analyzed in real time – achieving human communication, if not instant, faster than via standard signal (i.e. light-limited genidentical) propagation. Acceptable statistics require a large but finite number of clones so it would not be a problem: something subtler makes such a feat **un**achievable (perhaps making Einstein a little happier in his grave).

After mutually agreeing in using collinear magnetic fields, Alice's *free will* can certainly control whether *teleportation* and *cloning* occur or not (by inserting the magnet/detector or not) but, when it occurs, Nature's *free will* controls which of the two possible states along that direction is *teleported* to Bob's station converting qubit-B into a *clone* of qubit-A. Tersely: when qubit-A (in a *co-state* with qubit-B) interacts with the magnet, which spin state is *teleported* and *cloned* is determined by a 50/50 PD. Ergo, Bob -regardless of whether Alice allowed or not for *teleportation* to occur- will merely receive out of his magnet one of the same two possible states, so it is impossible for him to discriminate between a *teleported* state that went through his magnet without changing its state (because it was an eigenstate for the GI-B), and the same output state which was randomly adopted because, without a GI on qubit-A and its *teleportation*, his qubit-B is in a co-state for the still-composite state. For this composite quanton, *teleportation* and *cloning* go together and are the result of entanglement via the State Equation 28 (top), so that for Bob to be able to manufacture even one of the many *clones* he needs for statistical analysis, he would have to entangle the received unknown qubit with a clone-to-be qubit, encountering the same '50/50 probability' insurmountable difficulties. Though presented here differently, this is what is known in the literature as the 'No-Cloning Theorem' [117].

To avoid misunderstandings, of course we can prepare legions of ½-spin quantons in the same state by sending them through the same SG magnet and collecting only those in the same output, or by sending many photons through the same polarizing filter [11]; but we cannot (not even in principle) duplicate an **un**known arbitrary state: if we could create a clone, we could arrange for the SD for position in the original and the SD for momentum in the clone (whose operators are non-commutative) to be zero – against Heisenberg's Inequalities [38] [9]. Differently: it is impossible to univocally determine the quanton's state from a single realization of it via a GI: the state belongs to a continuous Hilbert space so, even if its dimension is finite, the coefficients in the 2-superposition are continuous complex numbers. Consequently, by using only *entanglement*, neither instant nor superluminal nor subluminal human communications are possible. Of course, the latter is achievable by classical means every day with our phones, radio, TV, etc.

In sum, aleatoric *teleportation* and *cloning* -as Nature does them- are ubiquitous; anthropic (at our will) *teleportation* and *cloning* are only doable if -as to be described next- we include a modicum of *human* communication via a process propagating at a finite speed in our spacetime, namely a genidentical chain generically known as a *signal* which, in RT and QR-TOPI, must be light-limited. Briefly: **no** superluminal (let alone instant) human communication is possible via teleportation – not even in principle. This is radically different from the nonlocality in Newton's gravitation, and the most important reason is that the latter theory is *deterministic* while QR/TOPI is ontically *stochastic*. This also explains why all *deterministic* nonlinear generalizations of the Schrödinger equation failed: they allowed for arbitrarily fast human communication [118] [119] [120] [39]. There is much more to Reality than Einstein's R-Events. Let us continue our thrust to answer Zeilinger's very "very fundamental question".

5.5 Timing Tri-Quanton Nonlocality: Anthropic Teleportation/Cloning

Recall that (in our lab frame K) the state *teleported* by Nature in Figures 10 and 11 is not the co-state in which qubit-A is time-before reaching Alice's station, but the **un**controllable (random) pure state it adopts upon the GI-A. If Alice wanted to teleport *at will* a pure state to Bob's qubit, she would have to know and alert Bob time-before his qubit arrives whether she got the state she wanted to 'transmit' or not (which in this simple case would obviously defeat the purpose); but now Bob could also obtain the state Alice told him she had in mind by appropriately transforming the teleported state of his qubit with a PTI (doing nothing or flipping it). This useless exercise would require increasing Bob's qubit traveling R-Time (e.g. a photon in a long-enough optic fiber) so it would arrive time-after the *signal* (e.g. a radio wave) carrying Alice's message.

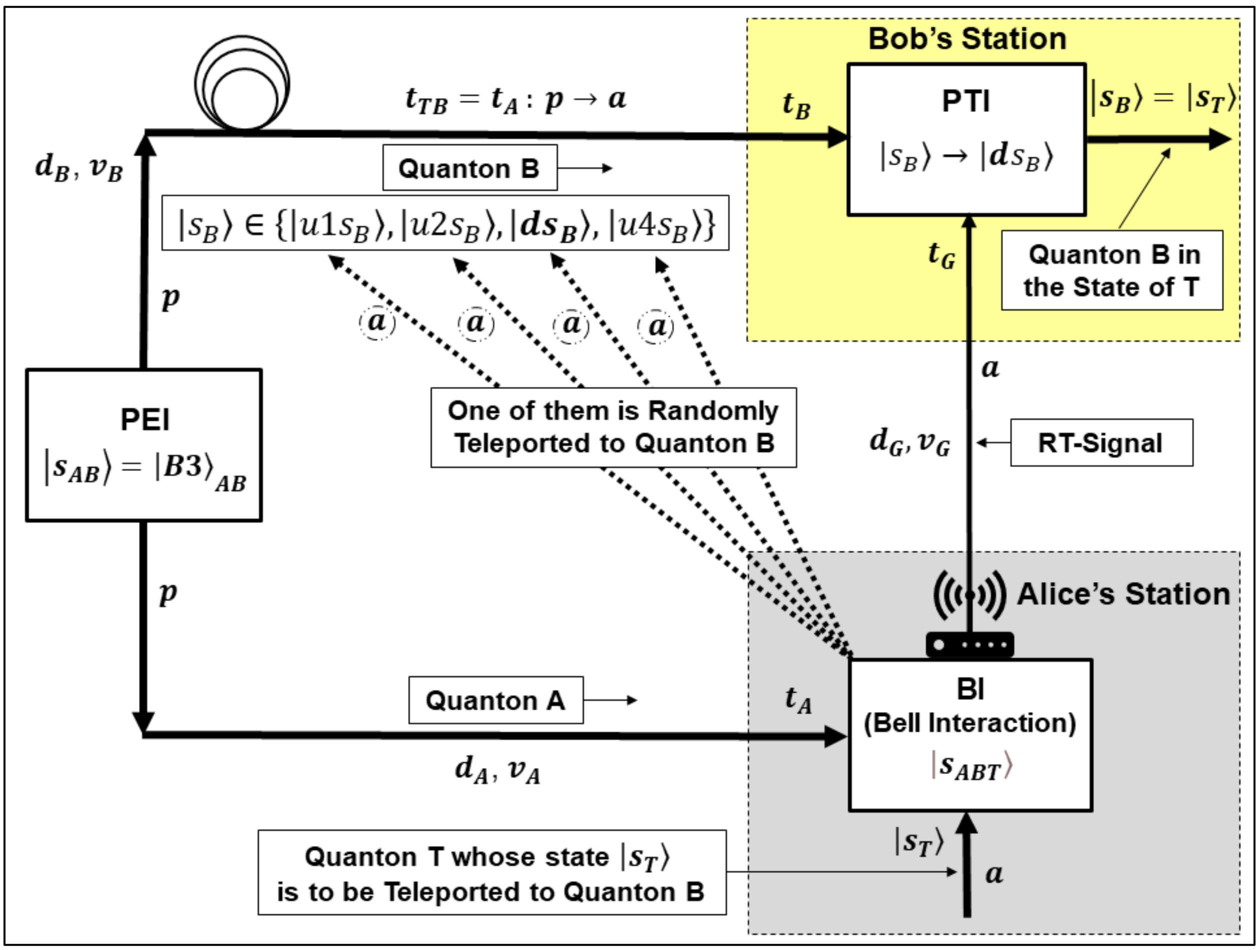

Figure 16 – Anthropic Teleportation requires a Human Communication Channel between Stations

With such a scheme in mind, we would like now to teleport *at will* the **un**known pure state of one quanton onto another. Appendix-A describes the anthropic *teleportation* process via QT's formalism. In Figure 16, there are three quantons A, B, and T with originally individual state-spaces S_A, S_B, and S_T. A and B are entangled after a PEI created them in one of the four Bell States $|B1\rangle_{AB}$, $|B2\rangle_{AB}$, $|B3\rangle_{AB}$, or $|B4\rangle_{AB}$, each qubit respectively sent to Alice's and Bob's stations. Let us assume the composite state is $|B3\rangle_{AB} = \sqrt{2}/2\,\{|s_{A1}\rangle|s_{B1}\rangle - |s_{A2}\rangle|s_{B2}\rangle\}$, i.e. Equation 28 for $\theta = 0$. Being entangled, qubits A and B endure an ITI in the subspace $S_{AB} = S_A \otimes S_B$ (Equations 34). Quanton T (whose ***unknown*** state we wish to teleport to quanton B) is in a pure state $|s_T\rangle$ and undergoes a Bell Interaction (BI) [11] with quanton-A. This latter PI is also a PEI that entangles quantons T and A with milieu basis $MB = \{|B1\rangle_{TA}, |B2\rangle_{TA}, |B3\rangle_{TA}, |B4\rangle_{TA}\}$. But, because A is entangled with B, all three quantons are now entangled in such a way that each one of those four Bell States in $S_T \otimes S_A$ is uniquely paired with one of four states of quanton B (Equation A5). When the PDI in the BI occurs, quanton B (while traveling to Bob's Station in a tri-co-state) adopts the actual pure state associated with one actual (albeit *random*) composite Bell State in the above MB.

More precisely: the tri-composite state can be expressed in terms of four *probable* states, each one comprising one *pure* composite Bell State in $S_T \otimes S_A$ and one *pure* state of quanton B in S_B. One of those four *probable* states for quanton B is a clone of the *pure* state $|s_T\rangle$ in which T was originally ($|\boldsymbol{ds_B}\rangle$ in Figure 16); the other **u**ndesirable three ($|u1s_B\rangle, |u2s_B\rangle,$ and $|u4s_B\rangle$) are rotations of $|s_T\rangle$ (Equation A5). An ITI between the *probable* states of the three quantons is established persisting until the actual tri-composite state is broken: upon the PDI in the BI, one of the four *probable* composite states in its MB randomly becomes *actual*. Being random, Alice needs to determine which one it is and let Bob know. For the purpose, she includes in the BI's PDI the appropriate electronics to detect, amplify, codify, and transmit the information to Bob's station via an RT-signal (light-limited genidentical chain). Using two bits to codify the four possible results of the interaction between quantons T and A, if the resulting state is $|B3\rangle_{TA}$ (the one associated with $|s_T\rangle$), the received signal at Bob's station sets the PTI to do nothing; otherwise, the received code sets the PTI (e.g. an electro-optical modulator or a rotatable half-wave plate) to duly rotate the state of the upcoming qubit-B so as to become the same state that the faraway quanton T was originally in. Note that merely two bits of information are subluminally transmitted, which is enough for the at-will teleportation of quanton T ***unknown*** state onto quanton B. Fully transmitting the state (a continuous complex variable) via a light-limited genidentical chain would have required an infinite number of bits.

Setting the R-Time coordinate origin at the PEI, assuming all the electronic processing takes negligible R-Time, and calling v_A, v_B, v_G the effective velocities for quantons A and B and for the signal respectively, three arrival R-Times are well defined: a) $t_A = d_A/v_A$ for the arrival of quanton A at the BI; b) $t_G = t_A + d_G/v_G$ for the arrival of the signal at the PTI; and c) $t_B = d_B/v_B$ for the arrival of quanton B at the PTI. Evidently, v_B must be selected (e.g. by coiling the optic fiber) so that, when quanton B arrives, the PTI has already been suitably set by the signal sent from the BI's hardware in Alice's Station, namely: $t_B \geq t_G$. Note the PEI produces two quantons in ontically probable co-states; the BI receives quanton A in a co-state and quanton T in an actual unknown state; and the PTI receives quanton B in an actual state and an RT-signal created by the PDI in the BI. Let us prove again that Nature's teleportation must be absolutely *instantaneous* and determine the appropriate R-Timing for this at-will teleportation scheme to work.

5.5.1 Enclosing the Teleportation QR-Event between two Arbitrarily Close R-Events

From Section 5.4, we expect quanton B to instantly adopt the randomly teleported actual state upon the PDI in the BI, i.e. $t_{TB} = t_A$. Let us prove the latter and confirm the correct operation of the teleportation scheme by (1) using a known $|s_T\rangle = |\boldsymbol{ds_B}\rangle$; and (2) adding a PDI (not shown) after the PTI and gradually increasing t_B (with the delay line) from below t_A to above t_G:

(a) When $t_B < t_A$, quanton B arrives at the PTI time-before A and T could entangle at the BI. No *teleportation* and no at-will *cloning* occur because no tri-quanton entanglement exists; only A and B are entangled with state $|B3\rangle_{AB} = \sqrt{2}/2\,\{|s_{A1}\rangle|s_{B1}\rangle - |s_{A2}\rangle|s_{B2}\rangle\}$. Ergo, upon repetition, the added PDI at the output detects for quanton B the typical 50/50 dull sequence.

(b) When $t_A \leq t_B < t_G$, *teleportation* occurs so $t_A \leq t_{TB} \leq t_B$. However, quanton B arrives time-before the RT-signal, so the PTI is ***not*** suitably set. For $0 < t < t_{TB}$, quantons A and B are in co-states with their ITI (between their respective probable states) active. For $t_{TB} \leq t \leq t_B$, quanton B is in a randomly *teleported* actual state. Upon repetition, the output PDI detects ***any*** *state* in the set $\{|u1s_B\rangle, |u2s_B\rangle, |\boldsymbol{ds_B}\rangle, |u4s_B\rangle\}$, each one with 25% probability (Equation A6) – confirming that random *teleportation* does happen while *cloning* does ***not***.

(c) When $t_B \geq t_G$, *teleportation* occurs so $t_A \leq t_{TB} \leq t_G \leq t_B$. For $0 < t < t_{TB}$, quantons A and B are in co-states with their ITI (between their respective probable states) active. For $t_{TB} \leq t \leq t_B$, quanton B is in the randomly *teleported* actual state. At-will c*loning* does occur because the PTI is properly set, rotation (if needed) is performed and $|s_B\rangle = |s_T\rangle$. Upon repetition, the added output PDI always detects the state $|\boldsymbol{ds_B}\rangle$.

From (b), we find again that -despite not being able to observe/measure *teleportation* per se- we are able to experimentally time-confine its occurrence between two R-Times (t_A and t_B), which can be made virtually *equal* in any IF by adjusting the delay line. Therefore, the very (***non-****evincing*) adoption by quanton B of the *teleported* state must be considered *simultaneous* with the BI ($t_{TB} = t_A$) irrespective of how far the PTI still is (if there is one). Despite the *teleportation* QR-Event being recordless per se, its QR-Time is well-defined as a limit – via inference based on experimental data. The insertion of the PDI after the PTI is used only to corroborate the success of the teleportation for a known quanton T state. Once confirmed the system works, the output PDI is removed and the PTI delivers quanton B with the same state as the **un**known quanton T.

From above, quanton B's adoption of its new teleported *pure* state and the PDI-Event at the BI are absolutely *simultaneous* events, but both are timelike (viz absolutely ***non****simultaneous*) events with respect to the acquisition of quanton B's final *pure* state time-after the PTI. This is because, unlike *state-teleportation*, both quanton B (a m**i**cro-object guided by, say, an optical fiber) and the electromagnetic signal (a m**a**cro-object) take a finite non-zero time to cover a finite non-zero distance. Once again, *teleportation* cannot be a causal dynamic process in our spacetime (a light-limited genidentical chain) and, hence, the referred distant *simultaneity* ($t_{TB} = t_A$) can be neither intrasystemically conventional nor intersystemically relative as processes in RT are; *teleportation* is instantaneous in any IF without non-trivial conventions and, ergo, objectively absolute. Recall though that this absolute *simultaneity* exists between three events: one PDI-Event (part of the BI); one State-Event whose interval with the PDI-Event is Type 0 (Quantons A and T randomly adopting a composite state); and another distant State-Event (Quanton B adopting a new teleported state). Being only one of the three actual events *evincing*, no conflict with RT exists.

Notice as well that, during the process of cloning the state of T onto B, the former -which was in a *pure* actual state- became entangled with A and B, i.e. evolved into a probable tri-*co-state*, so any breaking of such entanglement would deliver a random pure state for T making impossible for T to transfer its state to B while *retaining* it. There is no way to purposely get quanton T back to it (except by chance). By including some minor (2 bits) human communication, we certainly managed to *teleport* the pure state of an unknown quanton creating a *clone* of it – though at the cost of (besides the whole process taking a distance-dependent R-Time) irrecoverably altering its original state. This means that not even by adding some minimal human communication can we produce multiple co-extant clones of an unknown quanton at will – rendering Alice's and Bob's dream of instant communication a blatant chimera no matter how we look at it. There is much more to Reality than Einstein's R-Events.

Having so far discussed single-, bi-, and tri-quanton natural and anthropic teleportation, let us now do an intermezzo by reviewing the current status quo for QT vis à vis RT, so we can right after understand why (still after a century) both theories are still **in**complete and ***not*** integrated, and how upon their integration, QR/TOPI answers Zeilinger's "very fundamental question".

6. Status Quo in 2024: "Peaceful Coexistence" without Integration

Intensifying the drama initiated by Bohr and Einstein in 1927, physicists/philosophers have forgotten the basic lesson learned from Galileo when he surmised that motion per se (against what Aristotle had claimed) did not demand a physical cause. The moral should have been that the correct explanation of factual evidence may entail reassessing what is to be stipulated as 'natural' and thus not requiring an 'explanation' via a physical cause (Galileo's tactic); alternatively, and more drastically, it may entail reexamining the notions of causality, time, and their mutual relation (QR/TOPI's approach). Ignoring the lesson, because (as Bell said) "correlations cry out for explanation" and to solve the so-called 'measurement problem' ('collapse' of the wavefunction) [11], a flurry of approaches -from moderate through flamboyant to extravagant- gradually appeared over the decades – selectively aiming at making *stochasticity* epistemic, eliminating the wavefunction's 'collapse', building the 'collapse' into the wavefunction's dynamics, removing *contextuality, nonlocality,* and/or even our *free will*. Any review of them could only be incomplete.

To mention only a few on the *moderate* side, scientists insisted on time-ordered causality to 'explain' *nonlocality* and *contextuality*. But we know that by virtue of the Principle of Locality, the Light-Limiting Postulate, and Einstein's "definition" of time, the time-order between *spacelike* events in RT is IF-**co**variant. Hence, some physicists (e.g. de Broglie/Bohm) eliminated the wavefunction's 'collapse' and -by adding additional variables to the quantic state- returned to *determinism* (epistemic *stochasticity*) on a preferred-frame/basis scheme; others (e.g. Ghirardi et al) modified Schrödinger's Equation to include a dynamics for discrete stochastic collapses (with the usual *deterministic* dynamics between them), again on a preferred-frame scheme. Both cases entailed positing absolute space and time and, ergo, noticeably against RT (after all, the original QT did not claim to be relativistic). We will argue that none of those approaches can be improved to become fully Lorentz-Invariant.

Bordering on the *flamboyant* side, other researchers (e.g. Suarez and Scarani) tried to conceive a sui generis kind of Relativity by admitting that the time-order of spacelike-separated events is relative but positing 'multiple preferred frames' responsible for the absolute causal/time order between distant events in relative motion – leading to perplexing "before-before" timings among events and to some (always welcome) falsifiable predictions in disagreement with QT. We will see that -displaying the best scientific spirit- such conjectures (and others closely related) have been empirically debunked by their very own authors. Even so, I include their work in Section 6.3 because their empirical results/conclusions go beyond the mere falsification of their theories.

On the *flamboyant* side (though hard to distinguish them), we will present with some detail and argue against "exotic causal structures" [121] [88] like 'Retrocausal', 'Future Input-Dependent', and 'Superdeterminism theories/toy-models'. As for the *extravagant* proposals I am dumbfounded by interpretations/theories like MWI [122], 'Many-Minds', 'Parallel-Lives', 'QBism' (quantum Bayesianism), etc. QR/TOPI rejects on principle all those (flamboyant and extravagant) philosophical stances. Notwithstanding, in Section 9 where I round off my answer to Zeilinger's "very fundamental question", I will thoroughly discuss experiments used by David Deutch in [123] and by Colin Bruce in [4] to claim those experiments "could be said to demonstrate not only that worlds in which history unfolds different are real, but also that communication between worlds is possible, at least in a carefully defined and limited way." Deutch's contributions to quantum computing are too important to ignore his philosophical views (which he claims led him to achieve those contributions). QR/TOPI proves all those experiments can be rationally explained within a single world.

6.1 No-Collapse Hidden Variable Theories/Models

We will consider two main theories/models with ***no*** collapse of the wavefunction; their purpose was to restore some type of 'Einstein-Bell Realism' while matching QT's predictions. Though it is possible to develop HVTs which are ontically *stochastic*, one of these theories is *deterministic* (i.e. epistemically *stochastic*) and the other *fatalistic*. None of them can be made Lorentz-Invariant.

6.1.1 Nonlocal de Broglie-Bohm HVT – Position Basis of Hilbert Space

Proposed by de Broglie in 1927, David Bohm fully developed it in 1952. Being well-known, we have mentioned it often in previous sections. Besides *determinism*[91], he assumed the existence of a privileged frame (a preferred foliation of spacetime) with a universal clock -a sort of quantum *ether*- in which the causal relation would manifest in a universal temporal order/simultaneity. Based on a *Primitive Ontology* [95] of classical particles[92] with definite positions[93], and inspired by the Hamilton-Jacobi formalism of Classical Mechanics, Bohm formulated an equation of motion for them – following continuous trajectories. All m**a**cro-objects comprised these local m**i**cro-beables, which were neither created nor destroyed; they simply moved around. The s*tochasticity* necessary to agree with orthodox QT was purportedly due to our *ignorance* concerning the exact (fundamentally uncontrollable) initial positions of the m**i**cro-particles. The spatial configuration of the particles' positions (the hidden variables) supplemented the standard *wavefunction* (defined in *Configuration Space*[94]) to constitute the state of the quantic system. The dynamics comprised two motion laws: the Schrödinger's Equation for the *wavefunction*, and the Guiding Equation for the particles (whose velocity vector depended upon the phase of the

[91] Hidden-Variables theories in which the additional variables evolve stochastically also exist.
[92] Non-Primitive Ontology versions of Bohmian Mechanics have also been proposed [95]. Contrariwise, while it is commonplace not to do so, Allori et al have suggested including a Primitive Ontology in the Many-Worlds theory.
[93] No need for the wavefunction to be an eigenfunction of the position operator.
[94] Each point in *Configuration Space* conveys the positions in ordinary space of all particles.

wavefunction). Ergo, the particles were pushed around not by Newtonian forces but by the guidance exerted via the *wavefunction*. This guiding equation can be derived from the assumption of Galilean invariance, time-reversal invariance, rotational invariance, and equivalence of proportional wavefunctions [2]. The causal influence between the *wavefunction* and the particles' *velocities* is only in one direction: from the former to the latter.

Besides the preferred IF, there is a preferred basis (the position basis $\{|q\rangle\}$) for the expansion of the wavefunction: $|\psi(t)\rangle = \int \psi(q,t)|\psi\rangle dq$. Momenta, energy, spin, etc. emerge as particle positions in the corresponding experimental setups. For instance, in a 'measurement' of spin with a SG-setup, the particle has ***no*** internal degrees of freedom: it is simply -quoting Bell- "dragged one way or another depending only on its *initial* position" [1]. The wavefunction, even for a system containing observers and measuring devices, always obeys Schrodinger's equation and never collapses. Despite the wavefunction supposedly being just a field with ***no*** connection to probability, the probability (epistemic) distribution for $q(t)$ is given by $f_\psi(q,t) = |\psi(q,t)|^2$ (Born Rule) and known as the 'quantum equilibrium' distribution. It is (for a closed system) invariant throughout the state's Schrödinger's evolution in spacetime – implying, if the initial PD is $f_\psi(q,0) = |\psi(q,0)|^2$, a full empirical agreement with orthodox QT. Valentini and Westman argued (via numerical simulations) that the equilibrium distribution is not fundamental but arises from a non-equilibrium one under Schrödinger's evolution [124].

Because the velocity term depends only on the gradient of the wavefunction's phase and not on its modulus, vanishingly small wavefunctions may have a finite non-zero influence on the particles' positions, an influence which -despite being local in *Configuration Space*- is nonlocal in our physical tri-dimensional space. For example, in the EPRB experiment, per this theory, first it is ***not*** true that all pairs are created the same at the source: the *wavefunction* is the same but the particles' different *positions* between runs produce different results; and second, if particle 1 is sent through one of the magnets, its trajectory depends (through the Hamiltonian) on the magnet's setting, which in turn changes the velocity of the other particle going into the distant magnet. Clearly, Bohm's HVT ***does*** violate *Parameter Independence*, though it does ***not*** violate *Output Independence* because both outputs are deterministically fixed by the initial state and the two settings via a RT-CCR (screening the outputs off), and by which of the particles is detected first[95]. However, it does not allow for sending signals because, despite respecting NRC and settings a and b being controllable, the precise value of the hidden variables cannot (not even in principle) be known – much less controlled. Notice that as priorly remarked, the breach of *parameter independence*, against common belief, does ***not*** imply *signaling*.

Soon after Bohm's publication, in 1953, Pauli boldly (and, in my opinion, accurately) said:

PAUL1: *The hypothesis of a general probability distribution for the hidden variables that is determined by the single [wave] function is not justified from the point of view of a deterministic scheme: it is borrowed from a theory which is based on the totally different hypothesis that the [wave] function provides a complete description of the system*[96]. [125]

Counteracting such objection, Bell in 1971 emphasized that the only way to understand Bohm's theory was to interpret the wavefunction not as encrypting probability amplitudes and phases (as in orthodox QT) but as a "real objective field" [69] – despite not propagating in our

[95] Remember Bohm's Theory requires a preferred frame.

[96] As cited by Landsman in [89].

ordinary space but in the higher-dimension *Configuration Space*. Oddly, the very Bohm did not agree with Bell's statement as he had written in 1957:

BOHM1: *While our theory can be extended formally in a logically consistent way by introducing the concept of a wave in a 3N-dimensional space, it is evident that this procedure is not really acceptable in a physical theory and should at least be regarded as an artifice that one uses provisionally until one obtains a better theory in which everything is expressed once more in ordinary three-dimensional space.* [126]

And in the same year 1957, Bohm and his student Aharonov, said (my underscore):

BOHM2: *It must be admitted, however, that this quantum potential seems rather artificial in form [...] that it implies instantaneous interactions between distant particles, so that it is not consistent with the theory of relativity.* [127]

We will see that stronger fundamental objections have been published recently (Section 6.1.3).

Summing up, Bohm's HVT, based on de Broglie's/Einstein's ideas of 'ghost waves', is claimed to be empirically undistinguishable[97] from non-relativistic orthodox QT – though at the cost of requiring the dubious concept of an **un**identifiable preferred frame and being conspicuously *nonlocal* (violating RT on both accounts). Pithily: though ***not*** Lorentz-Invariant, Bohm's is a HVT as EPR had imagined achievable, albeit with the *nonlocality* Einstein so deeply detested [13] [9] [10]. Its supporters claim that it does not rely on ill-defined notions such as *measurement*, *observer*, and that solves the infamous collapse/measurement problem [95]. We showed in Part III that you do not need Bohm's HVT to eradicate all those notions and pseudo-problems [11].

6.1.2 't Hooft's Cellular Automaton Model – "Ontological Basis" of Hilbert Space

Though he refers to it as *superdeterministic*, the 'cellular automaton model' of 1999 Physics Nobel laureate Gerard 't Hooft's corresponds to what we have called *Fatalism* or to Gisin's *Hyper-determinism*. Here is his definition (my underscore):

HOOF1: *Superdeterminism may be defined to imply that not only all physical phenomena are declared to be direct consequences of physical laws that do not leave anything anywhere to chance (which we refer to as `determinism'), but it also emphasises that the observers themselves behave in accordance with the same laws. They also cannot perform any whimsical act without any cause in the near past as well as in the distant past*. [40]

The above definition undoubtedly corresponds to our *Fatalism*. He differentiates his theory from Copenhagen (orthodox QT) as follows (my underscore):

HOOF2: *The most important point where we depart from Copenhagen is that we make some fundamental assumptions: (a) We postulate the existence of an ontological basis. It is an orthonormal basis of Hilbert space that is truly superior to the basis choices that we are familiar with. In terms of an ontological basis, the evolution operator for a sufficiently fine mesh of time variables does nothing more than permute the states. Probabilities enter only if, due to our ignorance, we seek our refuge in some non-ontological basis. (b) When we perform a conventional quantum mechanical calculation, we employ a set of templates for what we thought the wave function is like. These templates, such as the orthonormal set of solutions of the hydrogen atom,*

[97] In [216] an experiment with photon pairs is proposed to distinguish between QT and the de Broglie/Bohm Theory.

just happen to be the states for which we know how they evolve. However, they are in a basis that is a rather complicated unitary transformation of the ontological basis. (c) Very probably, there are more than one different choices for the ontological basis, linked to one another by Nature's continuous symmetry transformations such as the elements of the Poincare group, but possibly also by the local diffeomorphism group used in General Relativity. Only one of these ontological bases will be `truly' ontological. Which of them will be truly ontological will be difficult or <u>*impossible*</u> *to determine. The fact that we shall not be able to distinguish the different possible ontological bases will* <u>*preclude*</u> *the possibility of* <u>*using*</u> *this* <u>*knowledge*</u> *to perform predictions beyond the usual quantum mechanical ones.* [40]

Thus, as Bohmian theory did for the positional basis $\{|q\rangle\}$, 't Hooft postulates the existence of an "ontological" (preferred) basis $\{|n\rangle\}$ in which the system's evolution is *deterministic*, and of "templates" (superpositions) for which $|\psi\rangle = \sum c_n|n\rangle$ and $f_\psi(n) = |c_n|^2$ where the apparent (not "ontological") *probabilistic* evolution occurs. Not being able to "distinguish the different possible ontological bases" from the "truly" one, this is a sui generis version of epistemic *stochasticity* in which the latter appears not because we do ***not*** know the initial state (hard to know how we could know it) but because we do not know the supposedly ontological basis. Quite contrived indeed.

Well aware of the conflict between his *superdeterminism* (our *fatalism*) and humans' *free will*, 't Hooft (in my opinion **un**successfully) attempts to make them compatible (underscore mine):

<u>**HOOF3**</u>: *In the ontological basis, the evolution is deterministic. However, this term must be used with caution. "Deterministic" cannot imply that the outcome of the evolution process can be foreseen. No human, nor even any other imaginable intelligent being, will be able to* <u>*compute*</u> *faster than* <u>*Nature*</u> <u>*itself*</u>*. The reason for this is* <u>*obvious*</u>*: our intelligent being would also have to employ Nature's laws, and we have no reason to expect that Nature can duplicate its own actions more efficiently than having them happen in the first place. This is how one may restore the concept of "free will": whatever happens in our brains is* <u>*unique*</u> *and* <u>*unforeseeable*</u> *by anyone or anything.*

So 't Hooft restores *free will* but only as an <u>illusion</u> – due to our impossibility of *foreseeing* the puppeteer's intentions (not even by Laplace's Superman/supermachine). Nevertheless, he seems to be able to *foresee what happens in the brains* of those of <u>us</u> who refuse to be mere automata, reattempting a more technical defense/attack (you choose) of our *free will* (my underscore):

<u>**HOOF4**</u>: *In a Bell-type experiment, suppose we start from a configuration with given settings a and b of Alice's and Bob's filters [our GIs] ... What `free will' then means is that our theory not only yields a unique* <u>*prediction*</u> *for this* <u>*setting*</u>*, but it should also give a unique prediction of what happens when we look at a* <u>*different*</u> *initial state, such as the* <u>*one*</u> <u>*we*</u> <u>*get*</u> *if we make a slight modification in Alice's setting a, without modifying anything in the* <u>*approaching*</u> *particles or Bob's setting b. We then don't care to check which* <u>*modifications*</u> *would be needed in the* <u>*past*</u> <u>*events*</u> *to realise this particular modification. The theory should produce a prediction. However, Bell derived his inequalities for the outcomes of different initial states that he chose, and these inequalities are violated by quantum mechanics.*

So even though "we don't care", our decision to change the setting 'on the fly' changes "the past events" into a new initial state consistent with the new setting. Such a statement makes 't Hooft's theory conceptually undistinguishable from the 'superdeterministic' variant to be soon discussed: when I commit my most "whimsical act" of choosing the GI's settings, the Universe's initial state (perhaps at the Big Bang?) changes appropriately for his theory to be able to *deterministically* 'predict' both the GI's outcomes as well as ***my*** "whimsical act". We already learnt that if we rejected NRC, then any correlation could be predicted by a *local* HVT. And to calm/increase (you choose) our philosophical anxiety, 't Hooft further calls for restraining our "religious or emotional overtones":

HOOF5: *The issue of `conspiracy' may still be worrisome to the reader, even if it is clear that our theory will not allow us to predict anything about the settings to be used by Alice and Bob. The notion of `free will' can be addressed without religious or emotional overtones; it is simply a statement about correlation functions in the initial state.*

Regarding the raison d'être for my current paper (the integration of RT and QT), 't Hooft admits how "extremely difficult" is to make his theory Lorentz-Invariant:

HOOF6: *If the model is self-consistent in different inertial frames, and space-like operators commute at equal times, then relativity theory tells us they must commute everywhere outside the light cone. Now, most of our cellular automaton models fail to obey special relativity – not because we might doubt on the validity of the theory of special relativity, but because relativistically invariant cellular automaton models are extremely difficult to construct. Consequently, our effective Hamiltonians for these models tend to be non-commutative also outside the light cone, in spite of the fact that the automaton cannot send signals faster than light.*

And finally, he issues his verdict (underscore is mine):

HOOF7: *We see that the inner product rule can be used in two ways; one is to describe the probability distribution of the initial states of a system under consideration, and one is to describe the probability that a given classical state is reached at the end of a quantum process. If the Born rule is used to describe the initial probabilities, the same rule can be used to calculate the probabilities for the final states. Of course this does not mean that standard quantum mechanics would be wrong. Our knowledge of the template states, and how these evolve, is very accurate today. It is only because it is not yet known how to relate these template states to the ontological states, that we have to perform superpositions all the time when we do quantum mechanical calculations. They do lead to statistical distributions in our final predictions, rather than certainties. This could only change if we would find the ontological states, but since even the vacuum state is expected to be a template, and as such a complicated superposition of uncountably many ontic states, we should expect quantum mechanics to stay with us forever - but as a mathematical tool, not as a mystic departure from classical logic.*

Throughout the above prose, fallacies already denounced when scrutinizing EPR in Part I and Part II are apparent [9] [10]. In essence, 't Hooft affirms that orthodox QT is "simply an instrument to statistically describe a world where the physical laws, at their most basic roots, are not quantum mechanical at all" [40]. However, whether 't Hooft's contrived reasoning is true or not, i.e. whether QT is merely a mathematical tool of not, it certainly does not need of a "mystic departure from classical logic" (an opinion quite popular indeed). In any case, he is a faithful believer in *hyper-determinism* and -besides saying it is extremely difficult- offers ***no*** hint as to how to make his theory IF-Invariant. All other approaches/theories/models share the same "extreme difficulty".

6.1.3 Against such Deterministic Theories in a Preferred Frame/Basis

As said, Bohm's Pilot equation for the particle velocity is Galilean-Invariant by design: both the particle velocity and the wavefunction are Galilean-**co**variant so that the Pilot-Wave Equation provides the correct velocity in any IF after transforming the wavefunction and the position coordinates via the Galilean Transformation [128] [2]. However, Bohm's HVT is inherently *nonlocal* (the wavefunction is *local* only in *Configuration Space*) so, as a whole, it cannot be Galilean-Invariant. Furthermore, Minkowski's spacetime is very different from Galileo's; the very concept of a spatial configuration of particles at a given time is ***not*** Lorentz-Invariant.

Many attempts to make Bohm's theory Lorentz-Invariant exist, all of them using either an arbitrary spacelike preferred slicing, a preferred synchronization of the worldlines, etc. [129] [130] [131] [132] [133] [2]. In brief, all violate the philosophical bedrock of RT. Differently: Bohm's Theory, 't Hooft's Model and all others assuming time-ordered causality for spacelike events conflict with MME (1887) and KTE (1932), their quantic versions QMME and QKTE, as well as with the empirical evidence provided by the so-called 'before-before' experiment (Section 6.3). Ergo, such a putative 'quantum ether' is undetectable (as was the historical ether), implying that it is a matter of sheer choice which of the nonlocally related events we call the 'cause' ('first') and which we call the 'effect' ('second'). Moreover, if the chosen IF happens to be the one for which the two distant events are *simultaneous*, ***no*** time-ordered causal relation could be alleged to 'explain' the still-existing correlation. In addition, Suarez, via a 'Michelson-Morley entanglement experiment' showed that Bohm's infinite-speed time-ordered quantum potential cannot explain the results [134].

From above, the time-order in any of those theories cannot be objective, with the terms 'cause' and 'effect' being only *analytic* at best and useless at worst. In brief: deterministic single preferred frame/basis theories (e.g. Bohm's and 't Hooft's) cannot be integrated with RT (as it is) simply because they cannot be made Lorentz-Invariant.

In his defense of 'power ontology hylomorphism', Koons [135] provided in 2021 a detailed argument against Bohm theory's ability to "underwrite the reliability of our perception of the positional states of our measuring devices". Among the many facets of his argument, he states:

KOON1: *To be empirically adequate, Bohm's theory must give an account, not just of the "pointer settings" of measuring instruments, but also of our perceptions of those* settings *(as Bohm himself admitted, Bohm 1951, p. 583* [136]*)… Non-local quantum effects threaten to destroy any reliable correlation between the functional states of the environment and local particle positions and therefore to destroy any correlation between brain states and particle positions.*

And he elaborates upon the subject matter (my underscore):

KOON2: *Is this problem of perceiving pointer settings any greater for the Bohmians than it was in classical, Newton-Maxwell physics? Yes, it is, precisely because of the radically non-local character of Bohmian dynamics. All distant bodies in Newtonian mechanics have a negligible influence on local phenomena, an influence that decreases proportionally to the square of the distance. This is not the case in Bohmian mechanics. There is, therefore, real grounds for doubting whether we can reliably detect the actual positions of Bohmian particles…*

A more fundamental strain of criticism came from Landsman in 2019 [89], who went much farther than Pauli in 1953 by cogently arguing:

LAND1: *Deterministic interpretations of quantum mechanics (like Bohmian mechanics or 't Hooft's Cellular Automaton interpretation) are strictly speaking incompatible with the Born rule.*

Landsman remarks that both theories achieve their statistical equivalence with orthodox QT by averaging the initial total state with respect to a PD for the hidden variables ($f_\psi(q)$ or $f_\psi(n)$ respectively) and, ergo, they rely on the possibility of its unbiased *sampling*. The difference is that in Bohmian mechanics [90] [91] the total state (hidden particles' spatial configuration plus pilot wavefunction) determines only the GI's outcomes (the settings are free variables), whereas in 't Hooft's theory [40] the hidden state determines both the outcomes and the settings. As Landsman says: "So at best the source of **in**determinism has been shifted". And because in Bohmian and 't Hooft's theories the probability measures are the Born's measure ($|\psi(q)|^2$ or $|c_n|^2$ respectively), he continues saying: "so one wonders what has been gained against Copenhagen quantum mechanics". I would bet that Einstein strongly felt the same way – justifying (in my opinion) his "too cheap" qualifier when assessing Bohm's approach in a letter to Born [1].

And if, because the initial conditions are normally seen as ***not*** part of a *deterministic* theory the *stochasticity* is exclusively blamed on them, Landsman warns to those who claim these theories reveal a deeper reality underneath orthodox QT (underscore mine):

LAND2: *But in a Laplacian deterministic theory one can either predict or retrodict and these procedures should be equivalent; so within the context of a deterministic hidden variable theory of the kinds under discussion, copenhagenists attributing the origin of randomness to the outcomes of measurement and our hidden variable theorists attributing it to the initial conditions for measurement, should be equivalent. Once again, this makes it impossible to regard the hidden variable theories in question as deterministic underpinnings of (Copenhagen) quantum mechanics.*

Landsman's argument is clearly established for the frictionless pendulum in Part III (Equation 4 of [11]). Therefore, besides these deterministic theories not being Lorentz-Invariant, I agree with Landsman in that they at best merely shifted the source of **in**determinism – without being more fundamental than the orthodox QT (as claimed by supporters of *determinism* in all its guises).

6.1.4 Local 'Retrocausality' / 'Superdeterminism' / 'Future-Input Dependence'

I pointed out that Bell's formal expression for his 'Free Will' hypothesis was sufficient but not necessary for the experimenter to exert his *free will*: we could retain our *free will* to set a and b at leisure while -in practice- only a one-way influence ($a \vee b \rightarrow \lambda$) being possible and constantly holding. But I also remarked Bell's definition of *local causality* embraces RT and thus outlaws *retrocausality* (NRC) so, prima facie, such one-way influence appears forbidden unless λ is in the future hypercone of $a \wedge b$ (which is ***not*** by design). However -as we saw- if λ is ***non****-evincing*, the latter requisite may not be overly controversial: *retrocausality* is normally meant to refer to actual *evincing* events (the only ones real in RT) so even if we admitted such hidden links as *retrocausal*, retro-signaling (messaging to the past) would not be possible. This backward influence is also referred to as 'causal symmetry' and we saw that theories or models that negate NRC are assigned names like 'Retrocausal', 'Future-Input-Dependent' (FID) or 'Superdeterministic', and they are ***local*** but ***not*** BLHVTs. The purpose of adopting *causal symmetry* is to elude Bell, Kochen-Specker, PBR[98], and Spekkens so-called 'no-go theorems', allowing for the conception of theories/models whose hidden variables are *local*, ***non****contextual*, agree with QT, and are Lorentz-Invariant. Differently: causal symmetry presumably allows for a wavefunction which, albeit purely

[98] The PBR theorem (which also assumes NRC) shows that two quantons prepared with different wavefunctions cannot be physically identical [208] [93].

epistemic, represents an underpinning reality of local beables while retaining *locality* and the highly misconstrued 'counterfactual definiteness'. As Lambare says, the use of counterfactuals is philosophically problematic, physically unconvincing, and experimentally inconsistent [103].

In my opinion, the proponents of those classes of *local* (though ***not*** Bell's *local*) HVTs claim distinctions among them without essential differences. Their common appeal resides in that, if the local hidden variables evolve anywhere inside or on the past and future light-hypercones (an *invariant* hypervolume for the Lorentz-Transformation), the resulting local theories/models would be automatically Lorentz-Invariant, with the high-dimensional QT's Hilbert's state-space replaced by our ordinary physical spacetime and their integration with RT and GRT less difficult. It all started in 1953 when Costa de Beauregard proposed the "Parisian zig zag causality"[99] to explain entanglement via *lightlike* causal chains, i.e. propagating along the light-hypercone back and forth in time: for instance, in a Bell-type Experiment, the 'first' GI-Event influences the 'second' GI-Event not directly but via changing the state of the composite quanton at the source [137] [138] [139] [140]. Cramer's 'Transactional Interpretation' [141] [142] and Aharonov et al 'Two-State-Vector Formalism' can also be envisioned as FID, *Retrocausal*, or *Superdeterministic* models [143] [144]. The first *superdeterministic* model was published by Carl H. Brans in 1988 [145]. Other models were proposed in 2010 by Michael Hall [111] [112], and in 2021 by Donadi and Hossenfelder [146]. In the last two decades, considerable research has been conducted on the so-called 'toy models' for these three types of HVTs [138] [35] [53] [147] [148] [149].

In 2020, Hossenfelder blurs the difference between FID and *superdeterminism* and credits the former for the latter not conforming to Bell's "conspiracy/fine-tuning" characterization of violating his 'Free Will' condition (my underscore and hyperlinks):

HOSS1: *Future-input dependence, hence, is the reason why superdeterminism is not a conspiracy theory. It demonstrates that there is a simple way to write down the dynamical law that does not require much information. It does away with the collapse postulate by positing a violation of Statistical Independence. Finetuning is not required because all it takes to get Born's rule is the detector setting, not the details of the hidden variables. In the same limit where the toy model reproduces quantum mechanics, it also does not allow for superluminal signaling*. [147]

Hossenfelder is well aware of the huge obstacles *superdeterminism* has to overcome:

HOSS2: *The two biggest problems with superdeterminism at the moment are (a) the lack of a generally applicable fundamental theory and (b) the lack of experiment... what is required is a mathematical formalism that will give rise to a non-linear evolution law of the type discussed above, where the locations of the attractors depend on the detector settings. The difficulty is that the detector settings themselves are degrees of freedom in the model… The difficulty is that these have to effectively appear in the dynamical law and play the role of attractors… We are looking for a theory from which quantum mechanics derives on the average. The toy model put forward in [5] should be understood as an effective limit of a superdeterministic theory. In this effective limit, the detector settings are hard-coded into a modified Hamiltonian evolution. The theory we are looking for would explain how one obtains such an effective limit*. [147]

In 2021, Donadi and Hossenfelder summarized the nature of these "toy models" very well, and why they do not "make sense as a fundamental theory" (my underscore):

[99] Costa de Beauregard, *Méchanique quantique*, Comptes Rendus Académie des Sciences 236, 1632–34 (1953).

DONA1: *Eventually, the goal of developing such a model is to remove the instantaneous measurement update, and hence make it easier to combine quantum mechanics with general relativity… This new model should not be taken too seriously as a viable description of nature. It is neither pretty nor does it make sense as a fundamental theory for reasons that will be discussed later.* [146]

And they continue saying (my underscore):

DONA2: *This toy model avoids non-local interactions by hard-coding the dependence on the detector settings into the evolution law. This is another reasons why one should not take this model too seriously: A good, fundamental, model should allow us to derive that the effective law for the prepared state depends on the detector settings. This requires that the to-be-found fundamental model includes the detectors and the environment and possibly other transformation devices that are part of the experimental setup. This has to be the case because otherwise we would lack information to define what the detector eigenstates are. All these issues are resolvable in principle but given that this model is not intended to make a lot of sense, putting more effort into it seems not a good time-investment.* [146]

6.1.5 Against such "Exotic Causal Structures"

As said, the so-called 'no-go' Gleason's [150], Kochen-Specker's [71], Spekkens' [151], and Bell's theorems [70] [1] implied that (when their premises are met) in order to match QT predictions, a deterministic (epistemically *stochastic*) HVT must be *nonlocal* and *contextual*.

In their 2018 paper "Causation does not explain contextuality" [121], Shrapnel and Costa refer to the above theories/models (retrocausal/superdeterminism/FID) as relying on "exotic causal structures" and, even for completely arbitrary causal structures, they assert (my underscore):

SHRA1: *Standard no-go theorems show that quantum theory is not consistent with ontological models where the properties of a system exist prior to and independently of the way they are measured. A possible interpretation is that properties do exist, but they are in fact dependent on future actions. Here we have shown that hidden variable models that attempt to leverage such influence from the future have to violate some broader form of non-contextuality.*

And they conclude that (underscore mine):

SHRA2: *… quantum predictions require a deeper form of contextuality: even allowing for arbitrary causal structure, no model can explain quantum correlations from non-contextual ontological properties of the world, be they initial states, dynamical laws, or global constraints.*

And -sensibly- the only door Shrapnel and Costa leave open is for those theories/models that would make some different (as compared to QT) falsifiable predictions (my underscore):

SHRA3: *Finally, we draw attention to the fact that our results rely on complete matching to the operational predictions of quantum theory. This leaves open the possibility that particular ontological models might allow for some experimentally testable, different predictions. Thus, for proponents of particular retrocausal models, the door remains open to develop their ontology such that they can predict some possible deviation from quantum statistics. In the face of such statistical deviation, the possibility of a non-contextual ontological model remains open.*

In his "The End of a Classical Ontology for Quantum Mechanics?" [88], Evans (one of the prior proponents/defenders of retrocausality [152]) argues that such "exotic causal structure" approaches have been seriously undermined by the above-mentioned Shrapnel and Costa new "no-go theorem". Evans admits that Shrapnel-Costa's theorem removes the loophole opened by the breach of the NRC part in Bell's 'Free Will' condition (my underscore):

EVAN1: *In short, the Shrapnel–Costa theorem removes the loophole open to 'exotic causal structure', and so implies that no ontological model, now including causally symmetric models, that satisfy the noncontextuality assumptions of the theorem can reproduce the statistical predictions of quantum mechanics.* [88]

In fact, it shows that *any* ontology underpinning quantum behavior must be contextual; moreover, (he says) "what is contextual is not just the traditional notion of 'state', but any supposedly objective feature of the theory, such as a dynamical law or boundary condition, which is responsible for the experimentally observed statistics". And he continues (my underscore):

EVAN2: *Thus, this loophole is closed off in the Shrapnel–Costa theorem, rendering causally symmetric approaches just as contextual as the rest of the models captured by the ontological models framework… So causally symmetric local hidden variable approaches, on account of being ontological models, must violate one of the assumptions of the Shrapnel–Costa theorem to hope to match the statistical predictions of quantum mechanics. Superdeterministic hidden variable models, also on account of being ontological models, fare no better at meeting this challenge.*

Evans concludes (my underscore and hyperlinks):

EVAN3: *If the primary motivation for adopting a causally symmetric framework is to rescue Einstein–Bell realism, then we have just seen that the Shrapnel–Costa theorem renders this task either impossible, or at best beholden to the possibility of some further account explaining how, say, apparent contextuality arises from some noncontextual footing. However, and importantly, even if such an account could be found, it still may not be enough to rescue Einstein–Bell realism. Whether it does or not hangs on how 'natural' the account is. As we saw in Section 2.2, one of the strengths of causally symmetric approaches that rescue Einstein–Bell realism from the traditional no-go theorems is that the ideology of causal symmetry is more economical than a rejection of classical ontology. However, it is difficult to see how any account that introduces potentially artificial constraints or complex mechanisms can be proposed without significantly reducing the ideological economy of causal symmetry, jeopardising the very grounds upon which one might consider the approach more virtuous… In so far as this unlikely logical possibility is the last refuge for Einstein–Bell realism, it looks like we should give up on Einstein–Bell realism and, with it, classical ontology.*

Finally, Valia Allori, defending the Pilot-Wave theory and in contrast with *superdeterminism*, argues that because the particle *position* in the former theory is the only ***non***-contextual property, she can affirm (my underscore):

ALLO1: *I show that even if the former [pilot-wave] is nonlocal and the other [superdeterministic] is not, both are contextual. Nonetheless, in contrast with the pilot-wave theory, superdeterminist contextuality makes it impossible to test the theory (which therefore becomes unfalsifiable and unconfirmable) and renders the theory uninformative (measurement results tell us nothing about the system).* [153]

And, regarding the nature of the contextuality in *superdeterminism*, Allori states:

<u>ALLO2</u>: *The only thing that we should expect is that the results will be contextual because this is what superdeterminism is designed to do. Contextuality comes from the desire to reproduce the data, not from an analysis of what an experimental apparatus does to the system. Namely, the system-apparatus interaction will explain the observed report. Therefore, superdeterministic contextuality is ad hoc.* [153]

6.2 Collapse built in the Wavefunction's Dynamics

To 'solve' the so-called 'measurement problem'[100] in QT, any theory claiming the wavefunction as <u>complete</u> in its specification of a system's state, needs a ***non***-Schrödinger's physical <u>process</u> somewhere in its dynamics (unless you believe in MWI, 'Many-Minds' and the like). It is known as the wavefunction 'collapse' or 'reduction of the state vector' [154] [155] [156]. It may be associated with a 'measurement' as in the orthodox QT and in some theories with deterministic nonlinear dynamics, or not related at all with any physical interaction per se but simply responding to a nonlinear *stochastic* dynamics. There are many versions of theories with ***non***-Schrödinger's dynamics. For instance, Pearle in [154] introduced a modified dynamics for the moduli and phases of the quantum amplitudes which, depending upon the initial phases' before a 'measurement', all probability amplitudes but one went to zero. Others included also additional (hidden) variables [157]. Even the already-mentioned Cramer's 'Transactional Interpretation' [141] [142] could be considered a modified-dynamics theory. In general, modified-dynamics theories do ***not*** agree perfectly with QT's predictions. We will only discuss a few that have quite survived since their inceptions.

In 1986 Ghirardi, Rimini, and Weber proposed a ***non****relativistic stochastic* <u>and</u> *nonlinear* modification of the Schrödinger equation[101]; it is known as the GRW Theory [155] [156]. Via a spontaneous random collapse embedded in the new motion equation, its predictions deviated very little from the Schrödinger equation for m**i**croscopic systems while suppressing ('collapsing') any superposition of states for m**a**croscopic systems. Being randomly 'spontaneous' in space and time, the collapse was ***not*** restricted to 'measurements' as in the orthodox QT. The collapse is determined by a 'constant of nature' whose value can be <u>adjusted</u> to agree with QT. Typically, e.g. in our SDE experiment <u>without</u> any detectors, there would be a photon localization in one of the channels roughly every million years. A second 'constant of nature' is the width of the Gaussian curve describing the localization. As for where the localization takes place, the probability density that the gaussian curve will be centered at a given point in space is calculated from the convolution of the absolute squares of the Gaussian curve and the pre-collapse wavefunction at that point. On the time scale of centuries, the GRW dynamics effectively agrees with QT for single and small collections of particles. But for m**a**croscopic objects, containing legions of particles bound to one another, a single collapse will almost instantaneously localize each particle's wavefunction to a region of about 10^{-5}cm [93].

As is typically the case with every theoretical formalism, the same GRW math admits different *primitive ontologies* producing different versions commonly known as: (a) GRW0 with ***no*** ontology, just the formalism; (b) GRW**m** whose ontology entails a continuous <u>**m**atter</u> field density introduced by Benatti et al [158]; and (c) GRW**f** whose ontology is a set of <u>events</u> introduced by

[100] In Part III [11], we argued that the so-called 'Measurement Problem' in its most common form is a pseudo-problem.
[101] Gisin had published a similar approach in 1984 [212] [118].

Bell[102] in 1987 and referred to as '**f**lashes' by Tumulka in 2006 [159] [160]. While the consensus seems to be that GRW**m** cannot be made Lorentz-Invariant, several attempts to develop a Lorentz-Invariant QRW**f** exist using discrete and continuous spontaneous localization [161] [162] [163].

In summary, the predictions of all GWR models deviate slightly from orthodox QT in their probabilities: their free parameters, viz the collapse rate and the width of its localization, are empirically adjusted so as to minimize the deviation from QT predictions [159] [156] [160].

6.2.1 Tumulka Relativistic (Lorentz-Invariant) Theory for GRWf

Roderich Tumulka developed a version of QRW**f** claimed to be Lorentz-Invariant despite displaying *nonlocality* [159]. This **r**elativistic theory -referred to as **r**QRWf- was inspired by Bell who found the GRW formalism is time-translation invariant [164]. Tumulka says (my underscore):

TUMU1: *As suggested by Bell, we take the primitive ontology, or local beables, of our model to be a discrete set of space-time points, at which the collapses are centered. This set is random with distribution determined by the initial wavefunction. Our model is nonlocal and violates Bell's inequality though it does not make use of a preferred slicing of space-time or any other sort of synchronization of spacelike separated points. Like the GRW model, it reproduces the quantum probabilities in all cases presently testable, though it entails deviations from the quantum formalism that are in principle testable. Our model works in Minkowski space-time as well as in (well-behaved) curved background space-times.*

He also states that by 'relativistic' he means that the LT between frames must be valid and explains how close this relativistic model is to the nonrelativistic GRWf:

TUMU2: *… what we shall mean by "relativistic" is "Lorentz invariant", or its analogue in curved space-time. Our relativistic model is surprisingly similar to the original GRW model, which it approaches in the nonrelativistic limit. Its structure is in no way more complicated than that of the GRWf. The two models have the following features in common: (i) the only objects in the universe (beyond the given space-time geometry) are the wavefunction and the flashes; (ii) two new constants of nature are needed, the collapse rate 1/τ per particle and the width a of the localization; (iii) time reversal invariance is broken, while (in flat space-time) rotation, space translation, time translation, parity, and gauge invariance are obeyed; (iv) the dynamics is intrinsically stochastic.*

Tumulka concludes (my underscore):

TUMU3: *A somewhat surprising feature of the present situation is that we seem to arrive at the following alternative: Bohmian mechanics shows that one can explain quantum mechanics, exactly and completely, if one is willing to pay the price of using a preferred slicing of space-time; our model suggests that one should be able to avoid a preferred slicing if one is willing to pay the price of a certain deviation from quantum mechanics.*

Likewise, in the paper entitled "Collapse and Relativity" [160] he concludes (my underscore):

TUMU4: *Thus, with the presently available models we have the alternative: Either the conventional understanding of relativity is not right, or quantum mechanics is not exact.*

[102] According to Bell: "a piece of matter then is a galaxy of such events" [164].

Given that QT predictions have been empirically confirmed with plentiful data, the first dichotomy implies that the only way to fully agree with QT is via a "preferred slicing of space-time", i.e. violating RT; while the second dichotomy implies that our "conventional understanding of relativity is not right". QR/TOPI will solve both dilemmas at once.

6.2.2 Against Non-Relativistic and Relativistic Spontaneous Collapse Theories

Koons [135], again in his defense of 'power ontology hylomorphism' and against both GRWf and GRWm, contends (my underscore):

KOON3: *The Bell flash ontology can only provide a relatively small number of "flashes" of determinacy, too small a number to ground the existence of stable molecules and organisms: The alternative version of GRW theory is the matter density interpretation. On this view, objective collapses result in relatively dense concentrations of expected mass in spacetime regions that resemble the objects of our classical world. The matter density interpretation shares with Bohmian theory the problem of verifying the reliability of our sense perception, and for similar reasons (both theories involve a high degree of causal non-locality).*

Stefeld and Gisin in [165] scrutinize **r**GWRf, issuing a more philosophical argument against Tumulka's claim that his theory is fully relativistic. They assert (my underscore):

STEF1: *Tumulka's rGRWf theory is in a certain sense not a collapse theory: the collapse of the wave function is not part of the ontology of this theory. Only an initial configuration of flashes and the initial wave function as figuring in the rGRWf law are necessary to obtain histories of flashes in space-time and probabilities attached to them… There is no question here of an ontology that admits superpositions of configurations of flashes that then are somehow reduced to one configuration through wave-function collapse. In particular, they cannot simulate those violating any Bell inequality. Consequently, neither rGRWf nor any other theory can account for the occurrence of the Alice-flash and the occurrence of the Bob-flash in a Lorentz-invariant manner… The reason is that the occurrence of some flashes depends on where in space-time other flashes occur: in one frame, Alice's outcome flash is independent of the flashes that constitute Bob's setting and outcome; in another frame, Alice's outcome flash depends on and is influenced by the flashes that constitute Bob's setting and outcome. The same goes for Bob's outcome flash.*

I agree with Stefeld and Gisin: ***no*** theory can uphold their chronicle of events "in a Lorentz-invariant manner" for all the data collected in a Bell-type Experiment. The crux of the matter resides in: (a) assuming that Reality consists only of actual evincing events; and (b) conflating the gist of *relativity* (viz the symmetry provided by IF-Invariance) with a despotic Lorentz-Invariance. QR/TOPI avoids both mistakes, replacing them with: (a) there is more to Reality than Einstein's R-Events; and (b) the symmetry of the Newtonian world is provided by the Galilean group; the symmetry of RT is provided by the Lorentz group; the symmetry of QR/TOPI is achieved by a novel extension of the LT (the latter remaining valid for all R-Events).

6.2.3 The "ETH Approach to Quantum Mechanics"

All new interpretations/reformulations/theories for QT are in essence attempts to complete it in some sense – as the title "A Tentative Completion of Quantum Mechanics" of a very recent paper from Fröhlich et al reveals. I include this work here because I wholeheartedly agree with the authors' premises (FRÖH1 and FRÖH2). They start with Dirac's old words: *It seems clear that the present quantum mechanics is not in its final form*. And they strongly state:

FRÖH1: *We think it is a mistake to imagine that the problems and paradoxes of text-book QM can be cured by some sort of "interpretation" of QM, such as "Relational QM," "QBism", "Consistent Histories", "Many-Worlds Interpretation", "Information ontologies" etc... As David Mermin put it: New interpretations appear every year. None ever disappear.* [166]

And they continue (my hyperlinks):

FRÖH2: *We expect it to be equally unlikely that these problems and paradoxes can be eliminated by supplementing text-book QM with some "ad-hoc mechanisms" such as ones based on decoherence, spontaneous wave-function collapse (which may remind one of electromagnetic or mechanical mechanisms used to explain Lorentz contraction before the advent of the theory of special relativity), or by attempting to reproduce the predictions of quantum mechanics by using cellular automata, etc.*

Without attempting to seriously criticize their approach, for the sake of completion, let us see how the authors describe their "ETH approach to QM" (underscore is mine):

FRÖH3: *In the following we attempt to convince the reader that the fundamental problem to solve in order to "complete" QM is to find a universal quantum-mechanical* ***law*** *that determines the* *nonlinear stochastic* *time evolution of states of* ***individual*** *systems, with the properties that it correctly describes what is seen in experiments and that it reproduces the linear deterministic Schrödinger von Neumann evolution of states when averaged over an ensemble of very many identical isolated systems.* [166]

And the authors conclude asking whether the basic principle on which ETH's approach is based is more than speculation and whether it could be tested – while stating its weaknesses :

FRÖH4: … *We thus should ask whether the Principle of Diminishing Potentialities (PDP), which is a corner stone of the ETH - Approach to QM, is more than a speculative idea and whether it can be tested. It is clear that this principle can only be established in quantum theories of systems with infinitely many degrees of freedom ... We thus have strong reasons to expect that a completion of QM satisfying the spectrum condition and solving the "measurement problem" will succeed only in the guise of local relativistic quantum theory on even-dimensional space-times featuring massless bosons, photons and gravitons.* [166]

6.3 Multiple Preferred Frames for Relativistic Time-Ordered Causality

Antoine Suarez and Valerio Scarani proposed in 1997 a *nonlocality* test with entangled photons and *moving* BSs. They speculated that -against QT predictions- the timing between the events at Alice's and Bob's GIs (say splitters plus detectors) would affect the PD of their click/no-click events – setting the respective devices in relative motion to prove/disprove their conjecture. Committed to time-ordered causality, they posited that QT's correlations would disappear when both entangled photons arrived at their splitters before than the other. This uniquely contrived 'before-before' state of affairs was entertained because they conjectured that the relevant IF for any device to exert its function was the one in which the device was at rest so that, being both splitters 'the first', they could only 'use' *local* settings to interact with the photon – effectively (so they thought) thwarting QT's *nonlocality* [167]. In a subsequent article Suarez called this theory

‘Relativistic Nonlocality’ (RNL), claimed it “unified relativity of simultaneity and superluminal nonlocality (without superluminal signaling)”, provided the new predicted PD for the “2 non-before” case, and proposed an experiment using moving polarizers to test it [168]. The theory could not of course be Lorentz-Invariant. In 1998 he referred to the same theory as ‘Multisimultaneity’, proposed a new experiment with a photon impinging a series of BSs at rest to test it and -if successful- he delineated how to complete orthodox QT [169] [170].

In January 2001, H. Zbinden, J. Brendel, and Gisin reported their work to resolve the “tension between quantum nonlocality and relativity”. Entangled photons sent via optical fibers to two villages near Geneva about 10 km apart were analyzed. The two photons arrived at the detectors within 5 picoseconds. One detector was in motion so that “both detectors, each in its own inertial reference frame, are first to do the measurement!” They concluded: “The data always reproduces the quantum correlation…” [116]. Hence, this experiment confuted the idea that the IFs in which the detectors are at rest are relevant to assess the PD of their click/no-click events.

In October 2001, Stefanov, Zbinden, and Gisin “tested the Multisimultaneity theory using acousto-optic modulators as moving beam-splitters and interferometers separated by 55 m”. They concluded: “We didn’t observe any disappearance of the correlations, thus refuting Multisimultaneity” [115]. Furthermore, as pointed out by Suarez in [76], theories predicting disappearance of the nonlocal influences like Eberhard, Suarez-Scarani, and Leggett’s lead to violation of energy conservation for the single quantum event. Even more: the first two allowed for superluminal signaling, and all of them have been experimentally falsified by the SDE experiment [74].

Though already stated as not complete, the above review of the status quo allows as to issue a pithy contrasting preview of QR/TOPI.

6.4 QR/TOPI Preview: Brief Comparison between the Status Quo and QR/TOPI

In contrast to the theories/models/interpretations we have reviewed, per QR/TOPI, the quanton’s current *state* and *milieu* (which may be controllable) are independent. As explained in Part III [11], the current *milieu* (e.g. the GIs with their settings in a Bell-type Experiment) may seem to change the current *state*, but it does ***not***; the *milieu* only changes the MB, i.e. that unique *representation* for the current ontic *state* which exposes the PD for the next *state* via the simple Born Rule. The Hilbert’s vector space structure allows for the ontic *state* to encompass the quanton’s reaction to all possible *milieus*, so any other basis for the state-space would do [11] [38]. The *physical* state is non-contextual simply because it includes all possible contexts; its *mathematical* representation using the MB is the one that is different for each context (milieu). Different milieus (different PIs) entail different MBs but the reality of the quanton’s *state* (whether ontically *actual* or *probable*) is prior to, and independent of, any future PI. The quanton’s *state* is ontic but not a beable (in Bell’s sense of the word); our quanton is the beable though -unlike Bell’s- it can display *local* as well as *nonlocal* behaviors. And being the *current* state all-inclusive in the above sense, all *next* states in all possible MBs and all state-transition PDs are determining parts of the *current* state and, ergo, ontic as well [11]. Please remember that the terms ‘previous’, ‘current’, and ‘next’ in a state-transition equation refer to QR-Time because some or all of the states can be ontically probable; only when they are actual their meanings agree with R-Time.

In brief, the next state depends stochastically upon the current state and current milieu – with the latter influencing ***neither*** the current ***nor*** the previous states. Therefore, even if all states are *probable* (***no*** PDIs), the quanton's *state* transition PD for a *milieu* to be established in the future depends upon such future *milieu* and the quanton's *state* by ***then***. Ergo, QR/TOPI fully respects Bell's 'Free Will' (*free will* + NRC) and it is ***neither*** deterministic, ***nor*** epistemically stochastic, ***nor*** Retrocausal, ***nor*** 'Future-Input-Dependent', ***nor*** 'Superdeterministic' – much less *fatalistic*.

We will soon show that QR/TOPI offers a much more cogent and simpler avenue to integrate RT and QT than positing exotic causal structures – not to mention spousing the extravagant 'Many-Worlds', 'Many-Minds', 'Parallel-Lives' and the like interpretations of QT. Regarding the latter extravagances, I fully share Gisin's sentiment: "I am always astonished that some people seriously believe in that" [39]. Even so, as already said, we will seriously discuss Deutch's [123] and Bruce's [4] defense of their 'Multiverse' when wrapping up in Section 9 my answer to Zeilinger's "very fundamental question". Let us now document my claim of **in**completeness for both QT and RT.

7. The Incompleteness of Quantum and Special Relativity Theories

The notion of *completeness* is remarkably difficult to grasp because it is intimately related to the elusive concept of Reality. Thus, EPR [13] could not define *completeness*, only proposing a sensible *necessary* condition that included the vague idiom "element of the physical reality":

EPR1: *Whatever the meaning assigned to the term complete, the following requirement for a complete theory seems to be a necessary one: every element of the physical reality must have a counterpart in the physical theory*. [13] [9]

EPR admitted it is us who identify the posited ***ontic*** entities/properties/facts (the "elements of the physical reality") which we *expect* the theory to describe/explain/predict. Thus, *completeness* relates to known ***facts*** and also our *expectations*, which could be rooted in a priori philosophical beliefs. Therefore, as long as we judiciously assess the aforesaid ambiguities case by case, the following criteria for ***in****completeness* seem to me reasonable:

(1) There is at least one "element of the physical reality" the theory's *Ontology* does not include so there ***cannot*** be a counterpart in the theory's *Foundation* for it, **or**

(2) Even though, due to abundant empirical evidence, its *Ontology* does include an "element of the physical reality", the theory -as it is- ***cannot*** consistently integrate such fact into its *Foundation* and *Structure* and, thus, can neither explain/predict it nor accept it as a postulate.

7.1 The Incompleteness of Quantum Theory

Aware of the antinomy between *nonlocality* and Lorentz-Invariance, Einstein worryingly believed that were *nonlocality* real, his Special Relativity Theory would be in considerable trouble. As said, Einstein's claim of ***in****completeness* for QT started when, in the 1927 Solvay meeting, he criticized the 'one-particle nonlocality'. Though not entirely satisfactory to him, de Broglie's particle/pilot-wave combination seemed to *locally* 'explain' the *single-photon nonlocality* setup we thoroughly analyzed in Section 4. For a single 'particle', *configuration* and *physical* spaces coincided so the pilot wave could be considered as actually 'traveling' in our real space. Einstein thus needed a stronger argument in which *nonlocality* could ***not*** be explained *locally* via the pilot "ghost" wave, namely: the 'multi-particle nonlocality' denounced in his 1935 EPR paper [13].

7.1.1 Faulty EPR's Claim of Incompleteness for Quantum Theory

In this iconic publication, Einstein et al presented their final rationale for the claim of QT's **in**completeness – which I carefully scrutinized in Parts I and II and pronounced utterly **in**adequate [9] [10]. Let us recap its major fallacious arguments and conclusions.

Because of a conceptual confusion (TCC) I found engraved in EPR, but to honor its valuable spirit, I reinterpreted its *reality* criterion (TRC) [9] [10]. As said, EPR admitted it is us who identify the posited ***ontic*** entities/properties/facts ("elements of the physical reality") which we *expect* the theory to explain/predict. Ergo, *completeness* relates to known ***facts*** and also to our *expectations*, the latter of which could be rooted in a priori philosophical beliefs. Among them, for Einstein, using *probability* amounted to confessing *ignorance* of the (mandatory for Spinoza) underpinning *deterministic* causal local processes, which I called 'The Reality Preconception 1' (TRP1): only attributes with definite values were ***real***, so two conjugate properties could not be "simultaneously real" (unless QT was **in**complete). I identified a second Reality Preconception (TRP2): despite QT predicting a change in state for the distant entangled 'particle', EPR decreed the latter was in the same ***real*** state simply (and unjustifiably) because of his supreme *Principle of Locality* [9] [10].

Hence, EPR made two kinds of flawed ***in****completeness* claims for QT: **(a)** the same ***abstract*** state represents more than one ***real*** state ('real' by virtue of TRP1) so that a "counterpart in the physical theory" for many a 'real' state was missing (EPR speciously widened QT's Ontology); and **(b)** the same ***real*** state ('real' by virtue of TRP2) links to more than one ***abstract*** state so that many a "counterpart in the physical theory" exists for a single 'real' state (EPR wrongly reduced QT's Ontology). Claim **(a)** falsely states that QT underrepresents Reality, meeting both **Criteria (1)** and **(2)** for ***in****completeness*; claim **(b)** curiously and erroneously states the opposite, meeting again both criteria. In sum, EPR dogmatically removed *probability* and *nonlocality* from QT's *Ontology* and, inevitably, preordained not only its ***in****completeness* but also its ***in****correctness*: Petitio Principii at work.

7.1.2 QR/TOPI takes over QT/TOPI to integrate QT and RT

The original QT was avowedly ***non***-relativistic. As for QFT, as said in the Introduction, though it is known as the 'relativistic version' of the original QT, it 'is' Lorentz-Invariant at the high cost of excluding *nonlocality*. It is commonplace to state QFT is *relativistic* because the Schrödinger's equation is replaced by a Lorentz-Invariant one, and because all operators representing field quantities at spacelike-separated events **do** commute [14] [2]. It is simply not true because, using the QT/TOPI's lingo we created in Part III [11], QFT only deals with PTIs, avoiding the other part of any GI: the PDI. So, as of today, QT and QFT are ***non***-relativistic. Quoting Oldofredi in 2019:

OLDO1: *However, as already underlined, the problem to find a consistent relativistic QFT remains open: (i) standard relativistic QM inherits by construction the conceptual issues of ordinary QM (furthermore, even standard model is not genuine relativistic), (ii) the algebraic approach to QFT is not empirically adequate and relies on debatable metaphysical assumptions, and (iii) BQFTs [Bohmian QFTs] are not yet relativistic theories.* [171]

And citing again Gisin and Del Santo (their 'measurement' is our GI, i.e. a PTI plus a PDI):

The theory that extends quantum mechanics to a relativistic framework is quantum field theory (QFT). Therein, all the problems with distant systems seem solved by the assumption of microcausality, i.e., the algebras of operators defined on any two space-like separated regions *commute. However, QFT still lacks to date a complete theory of measurement (i.e., one that yields measurement outcomes and it is therefore able to explicitly model all known quantum phenomena), an issue that has been called "a major scandal in the foundations of quantum physics".* [15]

In a recent paper (July 2023) Landry and Moffat [172] extended QFT by defining a *nonlocal* scalar field operator in the sense that, at a given spacetime point, it depends on all spacetime. In their conclusion they state: "The nonlocality aims to reconcile the approach of relativistic field theory with the nonlocality observed experimentally on entangled quantum systems. The nonlocal QFT satisfies microcausality and no signals faster than light can be transmitted between two spacelike separated events." The paper is exclusively and highly theoretical – missing a simple application of their theory to, say, the EPRB experimental setup and data, which would have gone a long way to support their approach and claims.

In sum, given that there is plenteous evidence for the trueness of RT in a multitude of situations involving quantons (e.g. the famous 1963 Mount Washington Experiment[103] with cosmic radiation [45] [56]), QT is **in**complete per Criteria **(1)** and **(2)**. Besides, we found in Part III that, in the light of QT/TOPI (the precursor of QR/TOPI), we may arguably consider QT **in**complete because it ignores: (a) *actual* but recordless events and their causal relations; and (b) the reality of *probable* states/events in PTIs and their ITIs. Ontic actual ***non****-evincing* events are a natural extension of R-Events (always actual and *evincing*); instead, ontic probable events are as objective and absolute, but always ***non****-evincing*. In Part III, we probed and proved the stunning ***reality*** of probable states, PTIs, and ITIs but -most impressively- it has been proven beyond doubt by modern quantum cryptography and quantum computer technologies [11] [38]. In order to integrate **Q**T with **R**T, **QR**/TOPI reaffirms and greatly expands those concepts introduced by QT/TOPI in Part III [11].

Under QR/TOPI, probable states, properties, and events of a quanton are as ***real*** as, and more fundamental than, their actual counterparts. But unlike actual QR-Events, probable QR-Events in PTIs and ITIs are ***not*** point-Events: insofar as all *states* in the MB of a PI are probable, none of their associated probable events can be pointlike: they may 'occupy' an extended region of space and 'occur' at QR-Times ***not*** in a one-to-one relation with R-Time (as QR-Times for actual QR-Events are). This is because, for a given PTI, its ITI consists of the reversible/**a**spatial/**a**temporal probability relation between probable states of a single quanton or entangled sub-quantons. The ITI remains active over an extended RT-spacetime region as long as ***no*** PDI occurs. Some writers say that "time is effectively 'frozen' until the experimental setup has been probed". Others state that "The past consists of *facts*, namely histories of *actualities*, while the future consists of *potentialities* (much in the sense in which *Aristotle* originally conceived these notions)" [166].

Under QR/TOPI -instead- the time in our lab (R-Time) is (of course) ***not*** frozen: the ITI evolves without *evincing* until a PDI takes place so that, at any R-Time between PDIs, neither the past states towards the previous PDI nor the future states till the next PDI are actual: all states and their transitions are ontically probable. Once again, recall that the adjectives 'current' and 'next', we respectively use to denote the *state* on the left side and those *states* on the right side of the quanton's state-equation for a sub-PTI in a network of PTIs, refer to QR-Time (based on the network's *topology*), not to R-Time. Differently: the same adjectives ('previous', 'current', 'next') for State-Events and PDI-Events (being actual) refer to different R-Times, while for Probable-Events they

[103] D.H. Frish and J.H. Smith, *American Journal of Physics* 31 (1963): 242-355.

all 'occur' at the same R-Time and evolve in QR-Sync with it. If coherence requisites are met, the ITI persistently evolves in R-Time as an indivisible block. It is sheer Reality without Actuality.

Summarizing: insofar as cogently explaining and proving the ***reality*** of actual and probable events, QT/TOPI [11] already completed QT – leaving still unresolved its lack of symmetrical IF-Invariance (the essence of RT). The latter is achieved by QR/TOPI. But, to this purpose, we have ignored for a century that the **in**completeness of QT is inseparable from the **in**completeness of RT.

7.2 The Incompleteness of Special Relativity

I fully agree with Grünbaum when he says in 'Operationism and Relativity' (my underscore):

GRÜN2: *... If natural clocks happen to be synchronized via light in the manner of Einstein's definition and if material rods are copresent with such clocks in the various Galilean Frames, then these physical recording devices will show the readings required by the Lorentz transformations quite apart from any conscious human observer or "operator" ...* [16]

But I fully **dis**agree with Grünbaum's conclusion in his 'The Philosophical Significance of Relativity Theory':

GRÜN3: *In brief, Einstein's innovation is that the physical relatedness which makes for the very existence of the temporal order has a structure that precludes the existence of objectively and uniquely obtaining relations of metrical simultaneity. Thus, the failure of our measuring operations to disclose relations of absolute simultaneity is only the epistemic consequence of the fact that these relations do not exist.* [173]

Assuming it is true that we have indeed failed to disclose relations of absolute simultaneity, his immediate conclusion is only valid if what he calls "Einstein's innovation" is also true. As we proved in Sections 4.3 and 5.4, we have succeeded in revealing relations of absolute simultaneity and, ergo, "Einstein's innovation" is also ***not*** true: such a "structure that precludes the existence of objectively and uniquely obtaining relations of metrical simultaneity" is only true amongst R-Events, i.e. events that:

(a) Can be *associated* to a point-object and/or *abstracted* to a spacetime point.

(b) Are actual, namely: they *occur* in RT-spacetime.

(c) Are evincing, viz: leave or can be made to leave local *simultaneous* records, and

(d) Any causal relation among them can be instantiated via a *deterministic* genidentical chain whose speed is limited by the absolute speed of light. For this to be postulated, (a), (b), and (c) are necessary. This makes *topological* simultaneity absolute but *metrically* nonunivocal so that, adopting Einstein's or slow-transport-clock synchronization methods, *metrical* simultaneity becomes univocal but conventionally relative to the IF via the LT as stated in GRÜN2.

As I overly said, Einstein removed *nonlocality* from RT by fiat in 1905 which, in the light of the plethora of experimental data supporting it as of 2024, makes RT trivially **in**complete by Criterion **(1)** (omission of *nonlocality* in RT's Ontology). However, simply correcting the omission (as it has been tacitly done for the last few decades), still leaves RT bluntly **in**complete by virtue of Criterion **(2)**. Let us be specific within the framework of our QR/TOPI.

7.2.1 As QT does, RT Misses Recordless Actual Events and their Causal Relations

As explained in Section 3.1, despite the quanton in general not being abstractable to a point-object, there are cases in which it makes sense to consider it as following a m**a**cro-trajectory in spacetime, so that its evolution can be abstracted to a genidentical chain of actual point-Events (*evincing* or not). This is the case of e.g. a photon while guided in an optical fiber and encountering a detector or adopting a teleported state (Sections 4.1, 5.4, and 5.5). Referring now to two of those distant chains, we saw that between two actual point-Events (one in each chain) of which at least one is ***non****-evincing* (non-RT), relations of "objective and unique" (absolute) *simultaneity* may be inferable as part of Reality (against GRÜN3) – whether they are spacelike-separated or not. Those two events can correspond to a single-quanton (SDE) or to multiple-quanton systems. Hence, any operation that purportedly (as Einstein claimed) "defines" distant *simultaneity* via light-limited genidentical chains is doomed to ignore any QR-Event (despite being actual) which either does not produce a local *simultaneous* record or is not genidentically connectible to an R-Event. Such QR-Event is a ***non***-RT-event: it obeys RT-requisites (a) and (b) but violates (c) and (d).

Pithily: RT assigns an objective IF-Invariant time-order to ***non***-spacelike events, a conventional time-order/simultaneity to spacelike events, and dismisses by design any causal relation sans time-order in every IF (absolute *simultaneity*). Ergo, RT can neither predict/explain *nonlocality* nor proclaim it as a postulate. Doing only the latter (to satisfy Criterion **(1)**), RT would remain **in**complete by Criterion **(2)**.

7.2.2 The Lorentz Transformation rejects Frame-Invariant Simultaneity

In 1982 Karl Popper said:

POPP1: *It is only now, in the light of the new experiments stemming from Bell's work, that the suggestion of replacing Einstein's interpretation by Lorentz's can be made. If there is action at a distance, then there is something like absolute space. If we now have theoretical reasons from quantum theory for introducing absolute simultaneity, then we would have to go back to Lorentz's interpretation.* [174]

I **dis**agree with Popper: we have shown and will continue showing via multiple experimental setups that we can "introduce absolute simultaneity" without "going back to Lorentz's interpretation". By "Lorentz's interpretation" I assume that Popper meant Lorentz's ether theory. However, such "interpretation" has been confuted by the combination of Michelson-Morley, Michelson-Gale (Sagnac Effect), Kennedy-Thorndike experiments and many others, so any going back to it would bring more problems with no solutions. On the other hand, the Lorentz Transformation in Einstein's RT rejects ***any*** absolute *simultaneity* so (again), given that actual ***non****-evincing* events ***do*** occur in our RT-spacetime displaying objective and unique relations of absolute simultaneity between them and with R-Events, RT would remain **in**complete by Criterion **(2)** even after we included those events in RT's Ontology (to satisfy Criterion **(1)**). Though expressed in novel terms, this is the infamous century-long clash between RT and QT that QR/TOPI solves.

7.2.3 As QT does, RT misses PTIs and their ITIs

Ontic probable QR-Events, the quintessence of QR/TOPI, are inconceivable in RT: they breach all RT-requisites (a), (b), (c), and (d). Equating Reality with *evincing* Actuality and banning any

non-genidentical causal relations by decree, Einstein's RT was also fated to miss the epitome of quantum quirks, viz what QR/TOPI calls 'Pure-Transformation Interactions' (PTIs) and their 'Intrinsic Tele-Interactions' (ITIs) between probable states. Therefore, RT can neither predict nor explain quantic *interference* – not even proclaim it as a postulate. Once more: doing just the latter (to satisfy Criterion **(1)**), RT would remain **in**complete by Criterion **(2)**.

7.2.4 Conclusion: As of today, RT and QT are Incomplete by both Criteria (1) and (2)

Applying our **in**completeness Criteria **(1)** and **(2)** to RT, it is notable that (as highlighted in ALBA1) EPR authors did not mention Special Relativity Theory at all in their discussions and claims (when they were struggling to save it!). Being EPR1 conceived to demolish QT as **in**complete, it is ironic that the unfulfilled Criterion **(1)** describes RT's status quo from 1927 until copious evidence for *nonlocality* accumulated in the last three decades of the 20th century, while the unfulfilled Criterion **(2)** characterizes RT's current status quo (despite QFT's claims). Ergo, discounting of course the fact that RT is incomplete per se because it is only a local approximation to GRT, it has been gravely **in**complete vis à vis QT from 1927 on till today. But completing RT in the light of QT is ***not*** as simple as merely postulating *nonlocality* and *stochasticity* as "elements of reality" (which is de facto done by most physicists and some pragmatic philosophers); otherwise, RT would not still be in a peaceful conflict with QT after a century. What QR/TOPI does for RT and QT is to complete their *Ontology*, *Foundation*, and *Structure* and merge them into an internally consistent embracive theory.

7.3 Wrapping up the Need for QR/TOPI

As said, against commonly stated to the contrary, QFT is ***not*** fully relativistic and, ergo, has ***not*** resolved the frail "peaceful coexistence" betwixt QT and RT. QFT tackles only the quanton's evolution between PDIs. To fully integrate QT with RT, we first -per Criterion **(1)**- need to merge all frame-invariant R-Events with those of QT, making up the QR-Events (all frame-invariant) into the *Ontology* of an encompassing theory. And second -per Criterion **(2)**- we need to consistently integrate such combined *Ontology* into the *Foundation* and *Structure* of the embracive theory. Failing to do both, the current status quo will persist, and the flurry of bamboozling interpretations will continue. This is what QR/TOPI accomplishes. Besides, integrating QT with RT is a natural sine qua non for and the first step to eventually succeeding in the century-long failed attempts to do the same with GRT.

Paraphrasing Bell, QR/TOPI provides the radical *conceptual* renewal he thought we needed to integrate *probability* and *nonlocality* into an upgraded RT's *Foundation* and *Structure* and, reciprocally, to integrate Frame-Invariance into QT while at the same time, as requested by Nobel laureate Zeilinger, providing *physical* ***meaning*** to the resulting encompassing theory. How these dual reciprocal completion and integration are done to attain QR/TOPI has been incrementally hinted throughout this article via well-known simple experimental setups for single and multiple-quanton *nonlocality*, and now will be formally achieved and explained in detail.

8. QR/TOPI: How to Merge Special Relativity with Quantum Theory

We have shown that if *Fatalism*, *Superdeterminism*, *Retrocausality*, and *Future-Input-Dependency* are rejected while *free will* (ours and Nature's) is embraced, experimental evidence compels us to accept that there exist some causal relations which are instantaneous, reciprocal, and symmetrical so they cannot be instantiated by genidentical chains of any finite speed ('cause' and 'effect' are merely pragmatic names for each IF). Incidentally, the so-called 'quantum switch' [175] [176] [177] network superposes the order in which two PTIs act and has been lately used to experimentally prove the lack of causal order in its operation [178].

As a result, in QR/TOPI there are QR-Events which are ***not*** R-Events and, among them, there are probable (in the ontic sense) and actual QR-Events [11]. We also saw that actual events can be pointlike (State-Events and PDI-Events) or not (Milieu-Events), and that they can be *evincing* or *non-evincing*: while State-Events are always *non-evincing*, Milieu-Events are always *evincing*, and PDI-Events s may be *evincing* ('clicks') which are the only ones acknowledged by RT, and *non-evincing* ('no-click'). Ergo, pinpointable actual QR-Events may infringe RT-Requisite (c), i.e. they may ***not*** *evince*; they may also violate RT-Requisite (d), viz non-genidentical causal relations (quantic links) among them are possible. Instead, Milieu-Events are actual but not abstractable to a spacetime point; only their R-Time is abstractable to an instant, so they breach RT-Requisites (a) and (d). As for the ***ontic*** probable events, they breach all RT-Requisites.

We have seen that the (using EPR's idiom) "element of reality" called *nonlocality* was ***not*** originally in RT's *Ontology* and is ***not*** currently represented in its *Foundation* nor integrated in its *Structure* [9]. No wonder Einstein adamantly despised its innate presence in QT's formalism. Neither are our ***ontic*** probable and ***ontic*** *non-evincing* actual states and properties: they are brand-new concepts unique to QR/TOPI. Only punctiform *evincing* actual events meeting RT-Requisite (d) belong to RT's *Ontology*, are represented in RT's *Foundation* and integrated in its *Structure*. In EPR's jargon, only events verifying all four RT-Requisites are considered "elements of the physical reality"; everything else is ***not*** and, hence, does not have "a counterpart in the physical theory". Therefore -ironically- the Special Theory of Relativity is **in**complete by Einstein's very own necessary condition he used to claim QT's ***in***completeness.

Defect 7.2.1 of RT and QT is fixed in QR/TOPI by including in its *Ontology* the reality of non-genidentical causal chains and of pointlike actual events which can be absolutely *simultaneous* (only one of them -at the most- can be evincing). As for Milieu-Events, they are actual, evincing, and not spacetime-pinpointable; however, being their R-Time pinpointable, absolute *simultaneity* can also occur upon them with ensuing changes in the quanton's MB, the ITI between Probable-Events, and/or the R-Timing between PDI-Events and State-Events. Against Popper's assertion, this absolute simultaneity does not require the hypothesis of a preferred (ether) frame: only if the *simultaneity*'s IF-Invariance were asserted between two or more actual evincing events, a preferred frame would be needed. There is no conflict with standard RT because ***no*** two distant R-Events can be absolutely simultaneous. Related Flaw 7.2.2 of RT is fixed in QR/TOPI by replacing the Lorentz's Transformation (LT) with our Quantumlike Transformation (QLT).

Fault 7.2.3 of RT and QT is fixed in QR/TOPI by including in its *Ontology* our 'Pure Transformation Interactions' (PTIs) with their 'Intrinsic Tele-Interactions' (ITIs). Both types of PI involve several ontically probable events, each of which can be associated with a spacetime region and are in QR-Sync with the others, i.e. they are absolutely *simultaneous*. But again: R-Time does not freeze: the probability relations in an ITI evolve in unison and perdure until a PDI occurs. All their QR-Events violate all RT-Requisites so that there is no conflict with standard RT. Differently: being all quanton's states in a PTI ontically probable, they are ***non****-evincing* and, ergo, ***no*** contradiction with orthodox RT exists. As for the absolute *simultaneity* between Milieu-Events and other events, we saw that Milieu-Events violate RT-Requisites (a) and (d) so there is no conflict either. Now to the specifics.

8.1 "Radical Conceptual Renewal I": Absolute Simultaneity of some Actual Events

In QR/TOPI, all R-Events are actual QR-Events but not vice versa: there are actual QR-Events which are ***not*** R-Events because they do ***not*** *evince* in spacetime: they are recordless non-entropic point-Events. QR/TOPI extends the classification of Event-Interval types (0, 1, 2, and 3) to them and adds a new Type 4. The epitome of actual but *non-evincing* point-events is the no-click of an ideal detector (a PDI-Event) at the location and time *would* have evinced had it clicked; another less evident example is any State-Event. There are also *actual* and *evincing* events (the Milieu-Events), which are not R-Events because they are not abstractable to a spacetime point.

As we explained, in Newtonian theory, two distant events are absolutely *simultaneous* when they are -time wise- between the same pair of arbitrarily close-in-time events at anyone of their distant locations; otherwise, they are absolutely *time-ordered*. This is due to the 2nd Law, which allows for arbitrarily fast genidentical chains. In Einstein's RT, they are relatively *simultaneous* or *time-ordered* when they are spacelike; otherwise, they are absolutely *time-ordered*. Briefly: in RT the past and future light-hypercones and interiors are -as separate sets of events- Lorentz-Invariant. Note that the fact that a causal relation could be instantiated by a light-limited genidentical chain does not mean that Nature actually does it always that way; it simply means RT's preconceived only way of causally producing correlations is available for us to explain what Nature does.

But we saw that the SDE and Bell-type Experiments produced the same *correlations* whether the events were spacelike-separated or ***not,*** so we conclude that:

- The quanton's state-transition PD, besides being (as we proved in Part III) ***invariant*** under a change of basis in Hilbert Space, it must also be ***IF-Invariant***. Ergo, the probability distribution is ***ontic*** and absolute[104].
- There are causal links (hence ***IF-Invariant***) among actual Events, whose existence is independent of whether the events are connectible via genidentical chains or not. Here is where the clash between QT and RT resides and would remain were it not for QR/TOPI.

Consequently, QR/TOPI posits that the Event-Interval betwixt two actual QR-Events may be:

(a) Type 0: they are absolutely *simultaneous*. It can occur due to the standard coincidence of two R-Events, or between a PDI-Event (*evincing* or ***not***) and its resulting State-Event (always ***non-****evincing*). The two events share both *space* and *time* coordinates in any IF.

(b) Type 1/Type 3 (***non***-spacelike): their *time-order* is objectively absolute with their *time* and *space* intervals relative.

(c) Type 2 (spacelike): their s*imultaneity*, *time-order*, *time-interval*, and *space-interval* are all relative.

(d) **New** Type 4: their *simultaneity* is objectively absolute because -whether spacelike or not- they occur upon the actualization of an ITI among the probable states of a single quanton or amongst the probable states of entangled sub-quantons in a composite quanton. Given that the

[104] A physical quantity can be *ontic* and ***not*** absolute, i.e. IF-**co**variant (e.g. mass, energy).

actualization is triggered by a PDI-Event (*evincing* or not), the latter and its resulting local State-Event are Type 0 absolutely *simultaneous*, while both of them are Type 4 absolutely *simultaneous* with a distant State-Event (the 'teleportation' State-Event). The latter (***non**-evincing*) event shares only the time-coordinate with the other two in any IF. Of the three, only the PDI-Event may be *evincing*.

As we have shown in Sections 4.3, 5.4.1, and 5.5.1, by confining the occurrence of a recordless actual QR-Event (e.g. an actual change of state for a quanton) between two arbitrarily close-in-time distant PDI-Events while collecting the same PD data, we concluded that irrespective of whether those two PDI-Events are in fact spacelike or not, the inferred *simultaneity* between that QR-Event and one of the PDI-Events must be objectively univocal and absolute. This absolute simultaneity in which at least one of the two events is ***non**-evincing* (but pinpointable in RT-spacetime) is added by QR/TOPI to the Minkowski's structure of RT's spacetime – without any conflict whatsoever with the relative simultaneity of R-Events (all *actual* and *evincing*). But, of course, the Lorentz Transformation will have to be extended to regulate how ***non***-R-Events transform between IFs.

In sum, under QR/TOPI, given a pair of pointlike actual events, either they are absolutely *simultaneous,* or they are not. If they are, they either share all *spacetime* coordinates in all IFs (e.g. a PDI-Event and its local State-Event or two Type 0 R-Events), or they are the actualization of an ITI (triggered by a PDI-Event), sharing only the *time* coordinate in all IFs. If they are not Type 0 R-Events, none or only one event of the pair can be evincing. Instead, if they are ***not*** absolutely *simultaneous,* none/one/both can be evincing; they are relatively *simultaneous*/*time-ordered* when they are spacelike (their time order is conventional) and absolutely *time-ordered* otherwise. There is ***no*** inconsistency with RT because in the absolute *simultaneity* of case a, the two events share both their space and time coordinates; while in the new absolute simultaneity of case d, at most only one of the *simultaneous* events can be evincing (i.e. an R-Event). ***No*** two or more R-Events are absolutely simultaneous unless their Event-Interval is Type 0; otherwise, it would constitute an insuperable conflict with RT. Let us formalize and graphically explain all of the above.

8.1.1 Fractal (Self-Similarity) Structure of Nonlocality

In Section 4.3, dissecting the operation of the SDE, I stated that "we could also say that it appears as if the two detectors were 'entangled' so that only click/no-click and no-click/click results are possible", and continued saying "This application to a single-quanton of the 'entanglement' language used for multi-quanton composites in Part III is possible in virtue of a remarkable *fractal* structure to be uncovered in Section 8". In fact, in Figure 10 and Figure 11 depicting the behavior of two entangled quantons, each GI-Event was abstracted to a point-Event; however, magnifying the GI-Event undergone by each single sub-quanton, we find the basic SDE structure of a PTI plus a composite PDI, which responds again to the very same structure drawn in Figures 10 and 11. This remarkable *fractal* structure is illustrated in Figure 17 highlighting what we already said: *nonlocality* of the single quanton is the fundamental one and the genesis of it all.

In Figure 17, three of the four detectors are dotted to schematize four cases: **(a)** both GI stations have two detectors in their PDI; **(b)** one station has two detectors and the other only one; **(c)** both stations have only one detector; and **(d)** only one station has a single detector. All other possibilities are already covered by simply permuting the names of the frames, stations, and detectors. Note again that Station $A(B)$ is simply an SDE, with the EPRB magnet $SG\text{-}A(B)$ being the PTI and the two detectors being the composite PDI for quanton $A(B)$. Hence, their composite PDI-Events (*evincing* or not) and State-Events (always ***non**-evincing*) are abstract<u>able</u> to a spacetime point if convenient. To emphasize the fractal structure, we use the same symbols A and B for the two arms of the EPRB experiment as well as for the two arms in each of the two SDEs. So, to distinguish the EPRB from the two SDEs we use green for the former and black for the latter. For instance, in SDE-A and SDE-B we have detectors D_A and D_B with event pairs E_{DA}, E_A and E_{DB}, E_B all in black; but for EPRB, SDE-A is a point-Station with a single (composite) detector D_A with events E_{DA}, E_A, while SDE-B is the other point-Station with a single (composite) detector D_B with events E_{DB}, E_B.

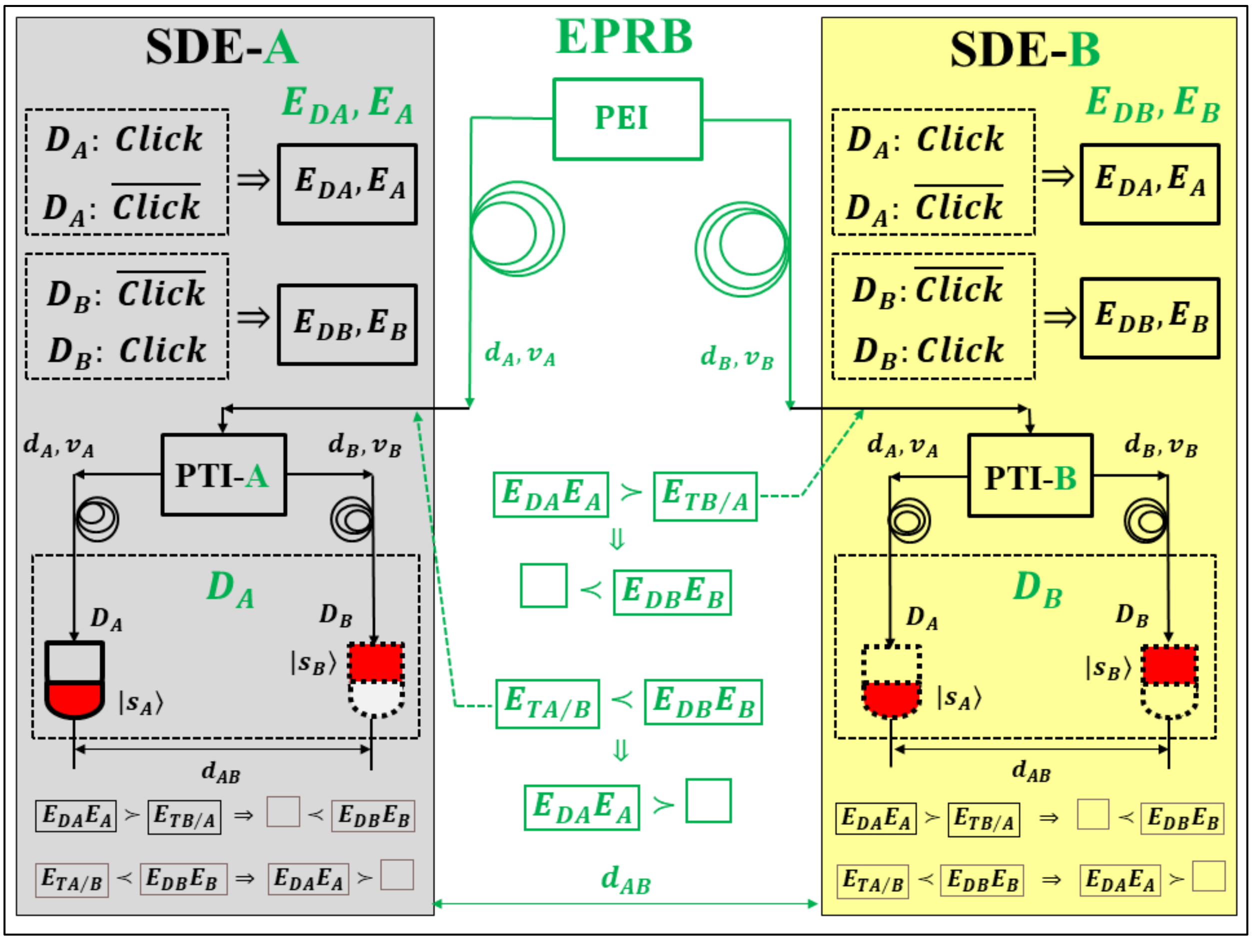

Figure 17 – Fractal Structure of Nonlocality

Ignoring for now a strange 'box notation', Figure 17 also shows that in SDE-A a click/no-click PDI-Event $E_{DA}(E_{DB})$ of detector $D_A(D_B)$ triggers the State-Event $E_A(E_B)$, which corresponds to the adoption/dissociation of state $|s_A\rangle$ ($|s_B\rangle$) by/from quanton A. In the click case, the <u>black</u> event $E_A(E_B)$ and the <u>green</u> E_A consist in the adoption by quanton A of $|s_A\rangle$ ($|s_B\rangle$). In the no-click case, the <u>black</u> event $E_A(E_B)$ and the <u>green</u> E_A comprise the dissociation of state $|s_A\rangle$ ($|s_B\rangle$) and the adoption of state $|s_B\rangle$ ($|s_A\rangle$) by quanton A. Mutatis mutandis for SDE-B. In all cases, each single quanton adopts one of its two possible states and the composite quanton decomposes into two isolated quantons (in <u>correlated</u> states). This name sharing and color distinction allow us to take full advantage of the fractal structure, describing any single or composite quanton with the same physical and conceptual language – as clearly shown in Figure 18.

Figure 18 is simply a reproduction of the spacetime diagram in Figure 11 with some didactic addons but now representing at once both the single quanton (**1q**) and the bi-quanton (**2q**) cases. The origin of the spacetime diagram corresponds: for (**1q**) to the entrance of a single quanton to the PTI (e.g. a BS); and for (**2q**) to the creation event in a PEI of a pair of entangled quantons (e.g. with a SPDC). The solid oblique worldlines inside the light-hypercone correspond: for (**1q**) to the hypothetically alternative careers a single quanton would follow were it traveling as a classical particle (which the quanton is ***not***), or to how the two *probable* states for a quanton could (mistakenly) be thought of 'traveling', or to how (in our m**a**croworld) a high-intensity light beam (trillions of photons) would actually split upon the BS; and for (**2q**) they correspond to the worldlines of two entangled quantons separating after the PEI. The events circle-marked as E_{DA} and E_{DB} at different sites (Alice's and Bob's GI-stations) are: for (**1q**) the click/no-click PDI-Events at the detectors D_A and D_B respectively; and for (**2q**) the composite PDI-Events at the composite detectors undergone by quantons A and B (Figure 17).

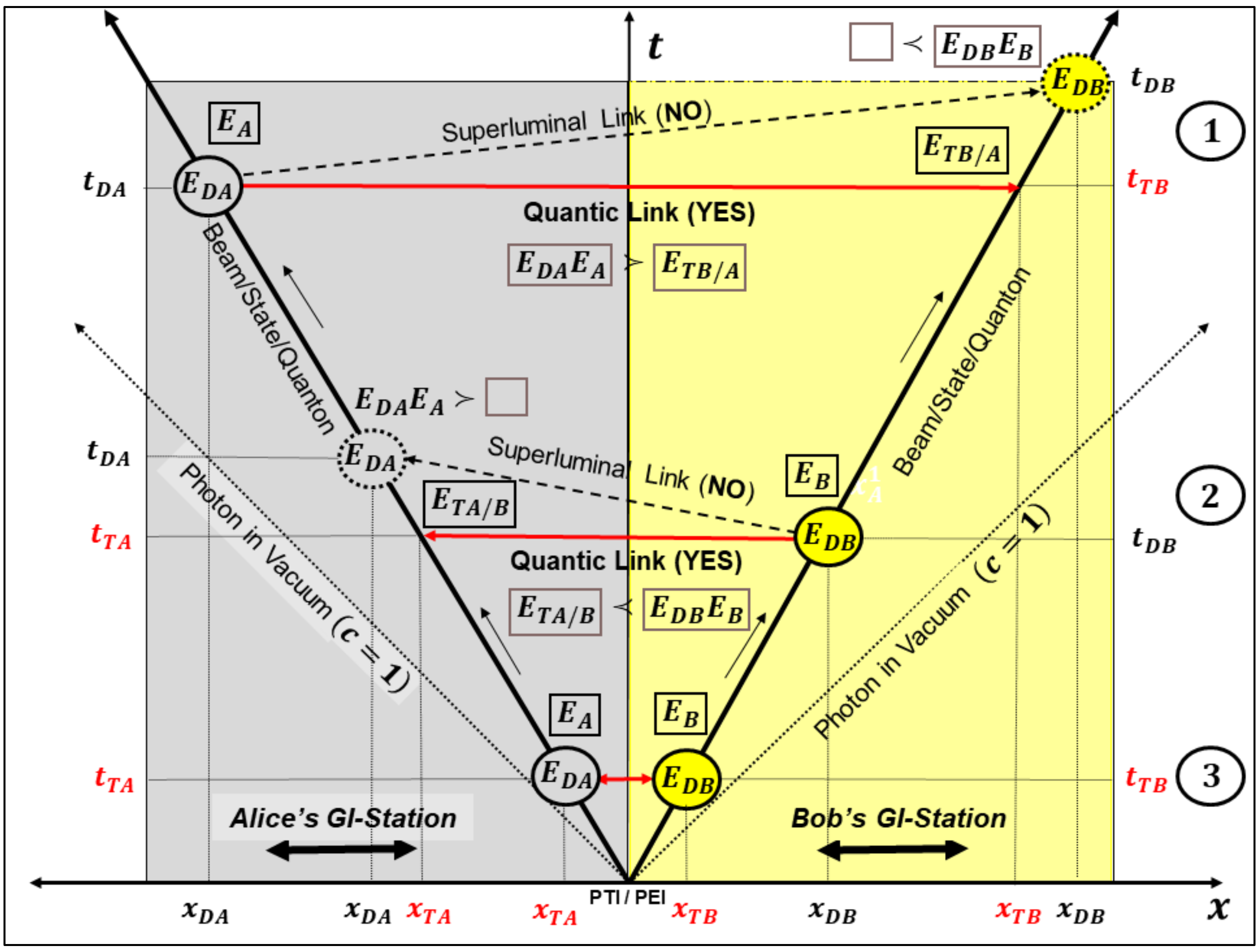

Figure 18 – Timing the 'Teleportation' Event for Single AND Two Entangled Quantons

A solid circle in Figure 18 indicates the PDI-Event is (in the lab frame) either time-first or simultaneous with the other; a dotted circle means that it occurs as time-second, or not occur at all. The State-Event $E_A(E_B)$ has the same spacetime coordinates as the PDI-Event $E_{DA}(E_{DB})$ in **all** IFs, i.e. they are Type 0 absolutely simultaneous. Thus, $E_A(E_B)$ will transform between IFs along with $E_{DA}(E_{DB})$, i.e. by means of the LT – extending the latter to ***non***-evincing PDI-Events. State-

Event $E_{TB/A}(E_{TA/B})$ represents: for **(1q)** the *teleported* dissociation/adoption-as-actual of the probable state associated with site $B(A)$ for a single quanton upon a click/no-click of $E_{DA}(E_{DB})$; and for **(2q)** the adoption by quanton $B(A)$ of a state teleported by quanton $A(B)$ upon the PDI-Event $E_{DA}(E_{DB})$. Let us now formally define the new Type 4 Event-Interval, namely what we have also referred to as the 'Quantic Link'.

8.1.2 The New Type 4 Event-Interval – The Quantic Link

Now it is time to introduce the 'box notation' appearing in Figures 17 and 18. In a given IF (Figure 18), a time-first PDI-Event, say E_{DA}, *actualizes* the ITI immanent in a PTI/PEI, resulting in two spatially separated State-Events E_A (local) and $E_{TB/A}$ (teleported). We say events E_{DA} and E_A are *quantumlike*-separated from $E_{TB/A}$ and we write: $\boxed{E_{DA}E_A} \succ \boxed{E_{TB/A}}$ with $' \succ '$ the symbol for the *quantic link*. As we said, the *actualization* defines a new type of Event-Interval (Type 4), which relates the three events as follows:

- E_{DA} and E_A share their space and time coordinates in any IF, i.e. they are Type 0 absolutely simultaneous with their shared coordinates transforming between IFs via the LT. Instead, only the time-interval between E_{DA} and $E_{TB/A}$ and between E_A and $E_{TB/A}$ is nil, i.e. the events in each pair are Type 4 absolutely simultaneous. Thus, the three events are simultaneous, and this quantic *simultaneity* is *objectively* absolute, i.e. IF-Invariant in virtue of a causal relation. Ergo, the direction suggested by the symbol $' \succ '$ is only *pragmatically* associated with the IF.
- The common space-interval between both E_{DA}& E_A and $E_{TB/A}$ is IF-**co**variant because it corresponds for each IF to that space-interval between E_{DA} and a hypothetical PDI-Event E^H_{DB} whose time-interval with E_{DA} would be zero. Clearly, the teleportation event $E_{TB/A}$ does ***not*** transform according to the LT, but remember that it is a State-Event, ergo, ***non***-evincing.
- Upon *actualization* by E_{DA}, the ITI ceases to exist, so any PDI-Event E_{DB} (if occurs) would ***only*** have a *local* effect E_B: $\boxed{} \prec \boxed{E_{DB}E_B}$. Notice that the State-Event E_B is the result not only of the PDI-Event E_{DB} but also of the prior State-Event $E_{TB/A}$, and that there is ***no*** $E_{TA/B}$ (empty left box). E_{DB} and E_B share space and time coordinates, which transform via the LT.
- Events $E_{DA}, E_A, E_{TB/A}$ (plus E_{DB} and E_B if occur) transform between IFs per the (to be defined) Quantumlike Transformation (QLT), which differs from LT only when acting on $E_{TB/A}$.
- Mutatis mutandis all the above when the PDI-Event that actualizes the ITI is E_{DB}, which we denote: $\boxed{E_{TA/B}} \prec \boxed{E_{DB}E_B}$. Therefore, we can state:

$$\left\{\boxed{E_{DA}E_A} \succ \boxed{E_{TB/A}}\right\} \Rightarrow \left\{\boxed{} \prec \boxed{E_{DB}E_B}\right\} \text{ as well as } \left\{\boxed{E_{TA/B}} \prec \boxed{E_{DB}E_B}\right\} \Rightarrow \left\{\boxed{E_{DA}E_A} \succ \boxed{}\right\}$$

Thus, assuming both E_{DA} and E_{DB} do occur, if E_{DA} is time-first (Case 1 in Figures 18-22) we have: $\left\{\boxed{E_{DA}E_A} \succ \boxed{E_{TB/A}}\right\} \wedge \left\{\boxed{} \prec \boxed{E_{DB}E_B}\right\}$; if E_{DA} is time-second (Case 2 in Figures 18-20) we have: $\left\{\boxed{E_{TA/B}} \prec \boxed{E_{DB}E_B}\right\} \wedge \left\{\boxed{E_{DA}E_A} \succ \boxed{}\right\}$; and if they are (ideally) simultaneous (Case 3 in Figures 18-20):

$$\left\{\boxed{E_{DA}E_A} \succ \boxed{E_{TB/A}}\right\} \wedge \left\{\boxed{E_{TA/B}} \prec \boxed{E_{DB}E_B}\right\} \Rightarrow \boxed{E_{DA}E_A E_{TA/B}} \succ\prec \boxed{E_{DB}E_B E_{TB/A}}$$

We see that in the IF for which E_{DA} and E_{DB} are simultaneous (case 3), the three actual events $E_{DA}, E_A, E_{TA/B}$ as well as $E_{DB}, E_B, E_{TB/A}$ have the same spacetime coordinates. Notice that, in this ideal simultaneity case, the two State-Events in each trio are such that they must correspond to the same state (of a single quanton or of a sub-quanton in the composite case).

Now that we know the meaning of the box-notation, notice in Figure 17 that, due to the fractal structure, the above box-relations for the three cases are identical for each SDE on its own as well as for the EPRB composite. With this box-notation, we can formally define the new transformation QLT between inertial frames.

8.1.3 The New Quantumlike Transformation (QLT)

In QR-TOPI, all PDI-Events (*evincing* or not) transform their spacetime coordinates per the LT so that, if they are determined for E_{DA} and E_{DB} in frame K, so they are in frame K'. Based on them, QLT transforms the spacetime coordinates of all actual events according to the (well-known by now) three cases in the destination frame K':

Case 1. $\boxed{E_{DA}E_A} \succ \boxed{E_{TB/A}}$: either E_{DB} does not occur or it is time-second in K'. The spacetime-coordinates of E_A and the time-coordinate of $E_{TB/A}$ in K' coincide with the coordinates in K' per LT for E_{DA}. The space-coordinates of $E_{TB/A}$ in K' are fixed by Equations 7 for the effective velocity of the worldline B in K' (Figure 5) and the time-coordinate of E_{DA} in K'. The so-obtained spacetime-coordinates of the teleported event $E_{TB/A}$ in K' correspond to those of a hypothetical PDI-Event E_{DB}^{H} whose time-interval with E_{DA} would be zero. The red curve in Figures 19 through 22 indicates the space-coordinate of E_{DB}^{H} for all K' $\left(-1 < v_{K'/K}/c < 1\right)$, with the associated teleportation depicted with red up-arrows. If any real E_{DB} occurred, then $\boxed{\;\,} \prec \boxed{E_{DB}E_B}$ and the spacetime-coordinates for E_B in K' would be those of E_{DB} (which transformed from K per LT).

Case 2. $\boxed{E_{TA/B}} \prec \boxed{E_{DB}E_B}$: Either E_{DA} does not occur or it is time-second in K'. The spacetime-coordinates of E_B and the time-coordinate of $E_{TA/B}$ in K' coincide with the coordinates in K' per LT for E_{DB}. The space-coordinates of $E_{TA/B}$ in K' are fixed by Equations 7 (for the effective velocity of the worldline A in K') and the time-coordinate of E_{DB} in K'. The so-obtained spacetime coordinates of the teleported event $E_{TA/B}$ correspond to those of a hypothetical PDI-Event E_{DA}^{H} whose time-interval with E_{DB} would be zero. The violet curve in Figures 19 through 20 indicates the space-coordinate of E_{DA}^{H} for all K' $\left(-1 < v_{K'/K}/c < 1\right)$, with the associated teleportation depicted with violet down-arrows. If any real E_{DA} occurred, then $\boxed{E_{DA}E_A} \succ \boxed{\;\,}$ and the spacetime coordinates for E_A in K' would be those of E_{DA} (which transformed from K per LT).

Case 3. $\boxed{E_{DA}E_A E_{TA/B}} \succ\prec \boxed{E_{DB}E_B E_{TB/A}}$: Both events E_{DA} and E_{DB} occur and are *simultaneous* in K'. The spacetime coordinates for E_A and $E_{TA/B}$ in K' are those given by the LT for E_{DA} and the spacetime coordinates for E_B and $E_{TB/A}$ are those given by the LT for E_{DB}. The associated teleportation is depicted with black bi-directional arrows in Figures 19 and 20 at the $v_{K'/K}$ at which the time-order between E_{DA} and E_{DB} is inverted (viz: for the particular K' in which E_{DA} and E_{DB} are *simultaneous*). Note that, being E_{DA} and E_{DB} PDI-Events (whether *evincing* or not), their *simultaneity* is relative so, because in Figure 19 they are *simultaneous* in K, the inversion of time-order can only occur for $v_{K'/K} = 0$, i.e. when $K' = K$. Instead, in Figure 20, they are ***not*** simultaneous in K, so there is a $K' \neq K$ in which they are. And, in Figures 21 and 22, the events are lightlike and timelike in K (which is an absolute time-order state of affairs) so, again, ***no*** inversion of time-order occurs in any K' so that this Case 3 is impossible in any IF.

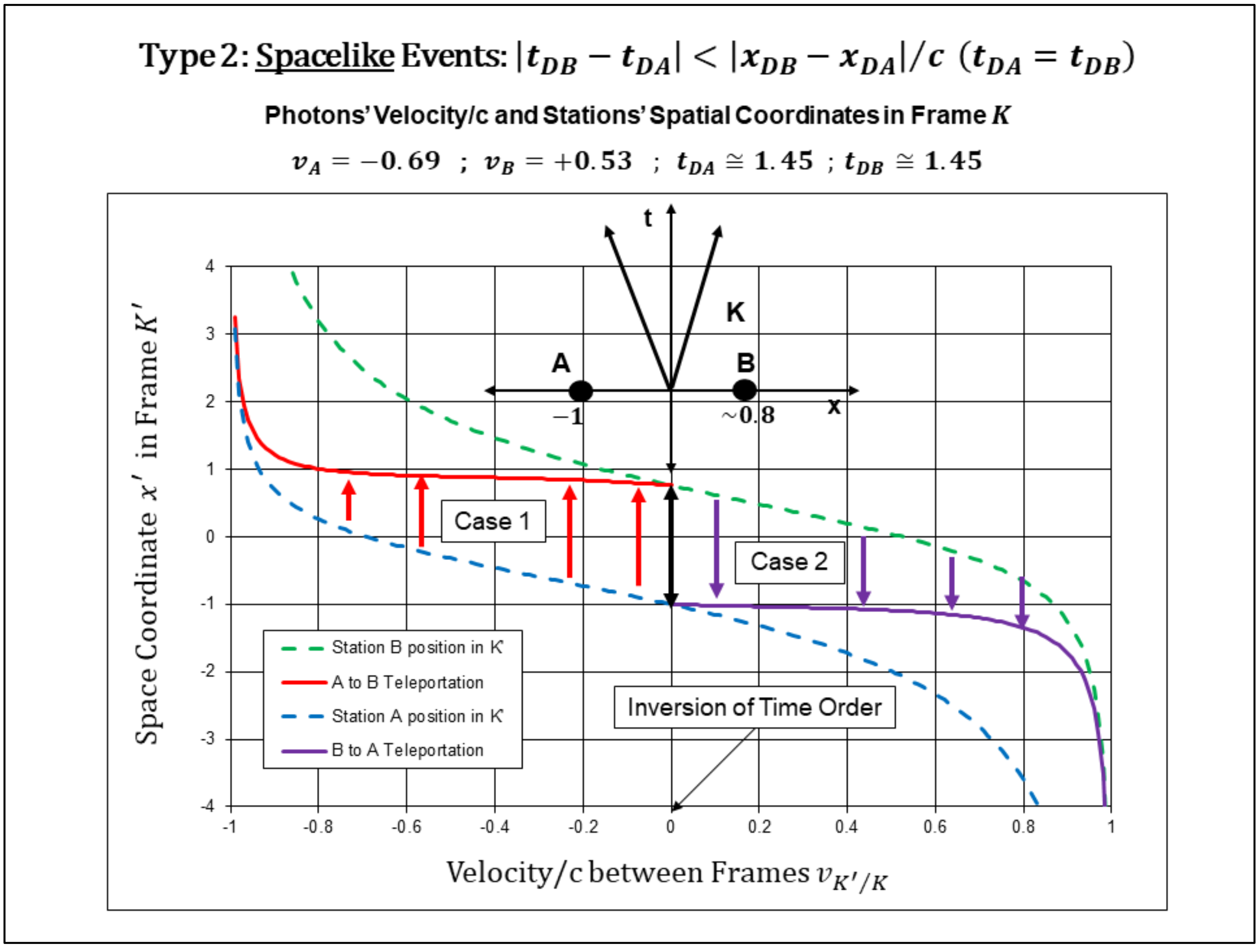

Figure 19 – State Teleportation in K' for Single/Two Entangled Quantons when Simultaneous in K

We see that per QLT, events inside a notational box share the spacetime coordinates, which are IF-**co**variant; events in different boxes have only the time coordinate equal in **all** IFs. Events E_{DA}, E_A, E_{DB}, and E_B fully transform per the LT, with the first two events as well as the second two events sharing the same IF-Covariant spacetime coordinates. Events $E_{TA/B}$ and $E_{TB/A}$ may (**Case 3** in K') or may ***not*** (**Case 1** and **Case 2** in K') transform per the LT. But all actual events (*evincing* or ***non****-evincing*) transform per our new QLT. We say that QR/TOPI is IF-Invariant under QLT or equivalently: QLT-Invariant. Obviously, Lorentz-Invariance is a major part of QLT-Invariance but not all of it: the latter includes what the former excludes: *nonlocality*.

I am sure a questionable feature of the QLT in some quarters would be that, besides depending on the relative velocity $v_{K'/K}$ of K' in K as the LT does, for some State-Events (teleportation) it depends also on which one of the two PDI-Events breaks the ITI in K'. But it is precisely this dependency which makes the *simultaneity* between $E_A(E_B)$ and $E_{TB/A}(E_{TA/B})$ absolute, i.e. independent of the IF as objectively demanded by empirical evidence – while respecting LT otherwise. We must recall that it was Einstein's decision to use the same *simultaneity* "definition" within each and across all IFs what led to the LT and the *relativity* of the simultaneity/time-order between spacelike-separated events. We also emphasized -as lucidly proved by Grünbaum [17]- that a (cumbersome and impractical) different convention within and for each IF could have led to an absolute (though still conventional) *simultaneity* – without altering the absolute objective time-order of ***non***-spacelike pairs of events. Instead, the transformation in RT for spacelike events is the most mathematically convenient (automatic): the direct analytical continuation of Equations 5 for ***non***-spacelike events onto the spacelike domain. That's the simplicity and effectiveness of Einstein's RT – despite having realized that his "definition" of *simultaneity* was a mere convention [24]. Of course, had predictions based on such convention been experimentally falsified, it would have been discarded a long time ago.

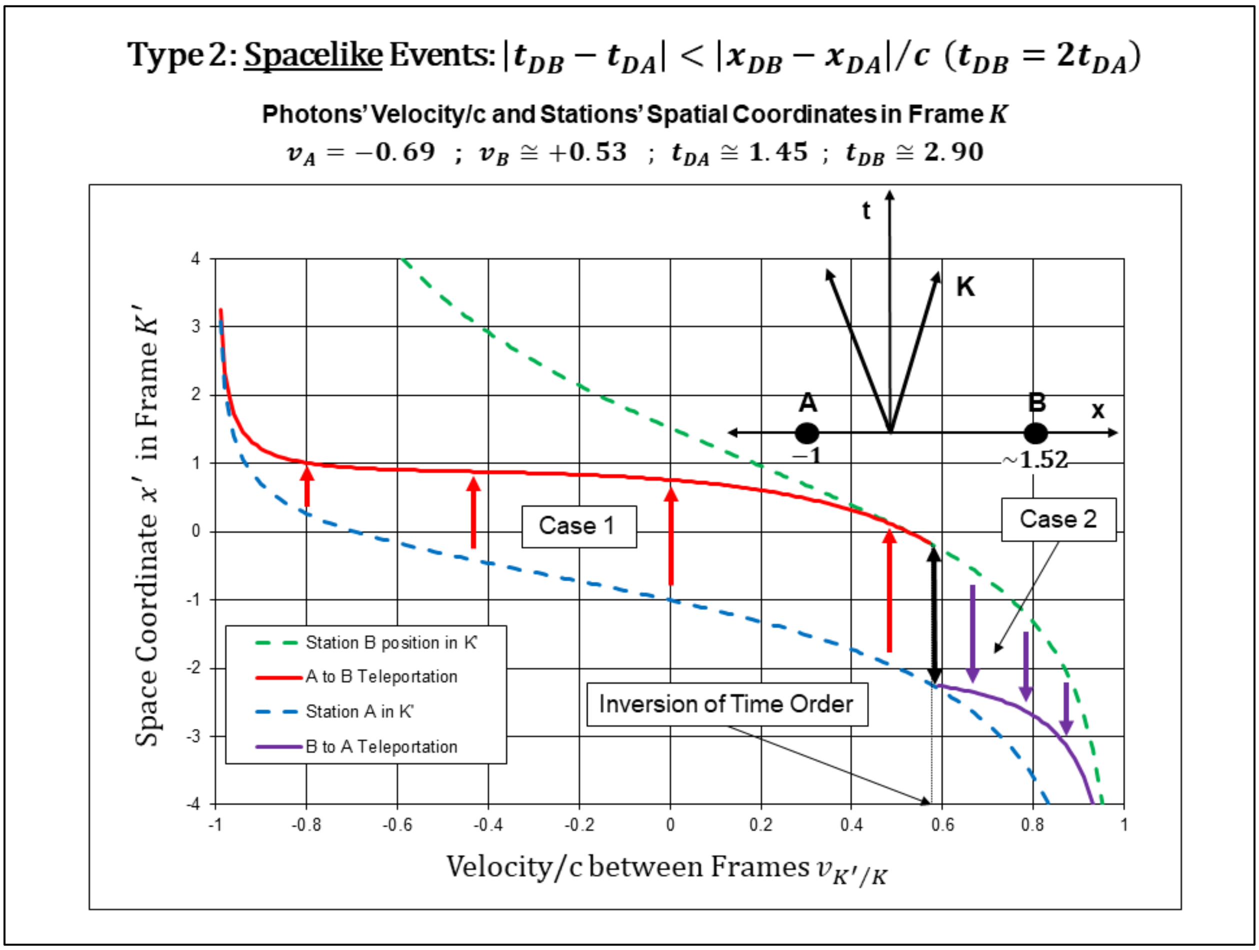

Figure 20 – State Teleportation in K' for Single/Two Entangled Quantons when $t_{DB} = 2t_{DA}$

But, as Maudlin said and we amply proved, the Minkowski's spacetime behind LT is **un**tenable as the "ultimate account of space-time structure": to integrate QT and RT, our QR/TOPI extends

LT – with the physical meaning provided by TOPI. Absolute and relative *simultaneity* coexist coherently without conflict. There is no need any longer for Shimony's euphemistic qualifier 'peaceful' before 'coexistence' or for frivolous expressions like 'passion at a distance'. The bedrock under the notion of *Relativity* is: (a) IF-Invariance, ***not*** the choice of a particular type of transformation to achieve it (e.g. Galilean in Newton's world or LT in Einstein's world); and (b) the symmetrical reciprocity displayed by the LT (and the Galilean) betwixt two IFs, which makes it impossible to determine which one is moving. QLT does ***not*** break RT's hallmark symmetry because the relationship between the spacetime coordinates of any pair of actual evincing events still transform via the LT. Besides, when LT by itself fails, QLT also displays the needed symmetrical reciprocity – as its operational description and the symmetry of the LT's velocity composition reveal. It is the wealth of empirical evidence acquired over a century in the m**i**croworld that unveils QLT as the correct transformation, instead of LT. Nonetheless, LT remains triumphant as the heart of QLT – as it should, given the tremendous empirical success of Einstein's Special Relativity Theory.

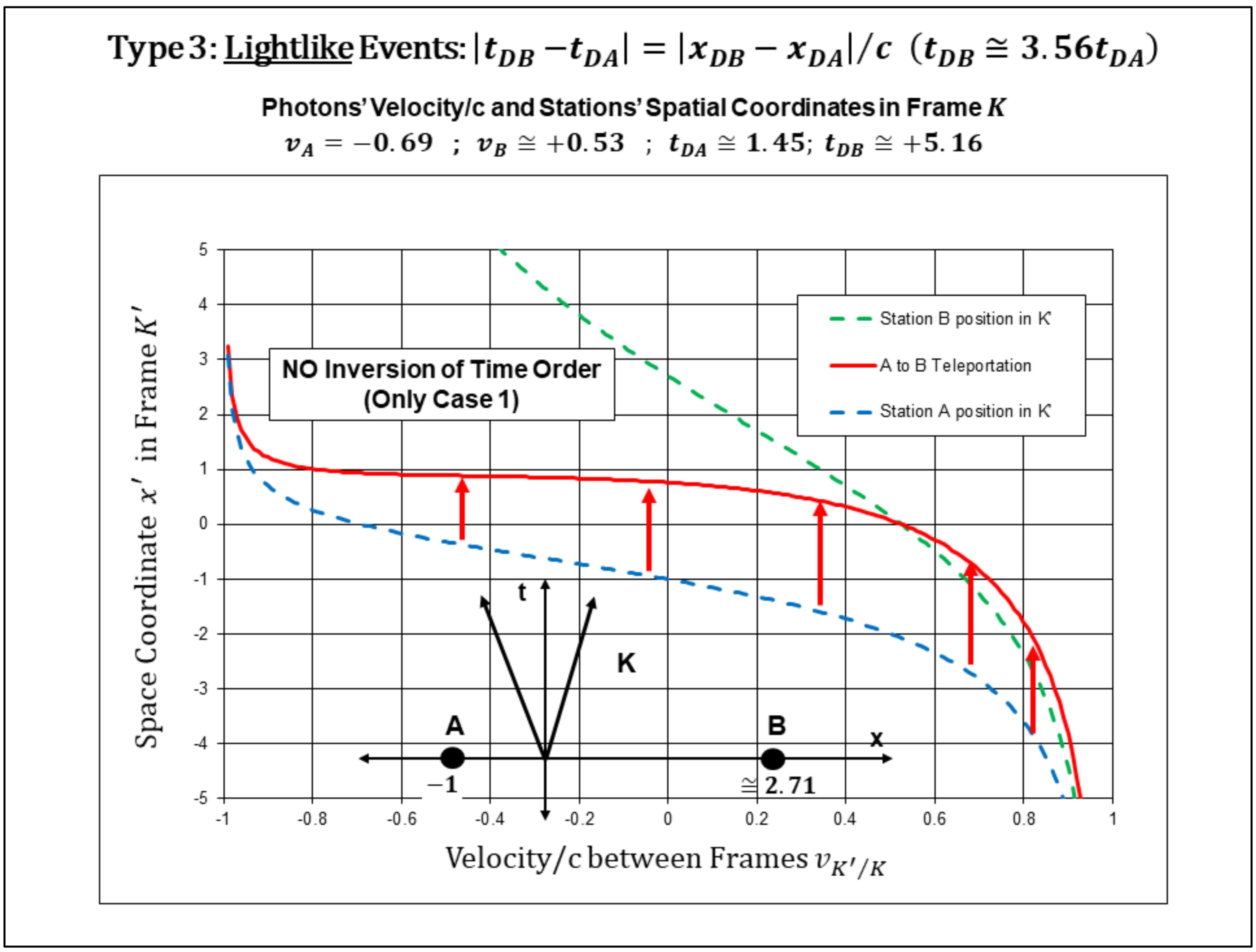

Figure 21 – State Teleportation in K' for Single/Two Entangled Quantons when Lightlike

Summing up, I insist: RT deals exclusively with actual evincing events and causal relations only implementable via light-limited genidentical chains. We saw that with such limited *Ontology* and Einstein's synchronization technique, *nonlocality* was de facto excluded. QR/TOPI includes actual *evincing* (click) and ***non****-evincing* (no-click) point-Events (PDI-Events) which transform also per the LT, as well as actual State-Events (always ***non**-evincing*) which may be absolutely simultaneous among them and with PDI-Events, transforming per our QLT. As remarked, this minimalist extension of LT is ***not*** inconsistent with orthodox RT because Type 4 Event-Intervals do not occur among R-Events (always evincing) but between State-Events (always ***non**-evincing*) or between one PDI-Event (*evincing* or not) and a State-Event. But simultaneity/time-order among spacelike PDI-Events (even if one is ***non***-evincing) is relative, explaining a century of failed attempts to find a time-ordered causal relationship between clicks and no-clicks.

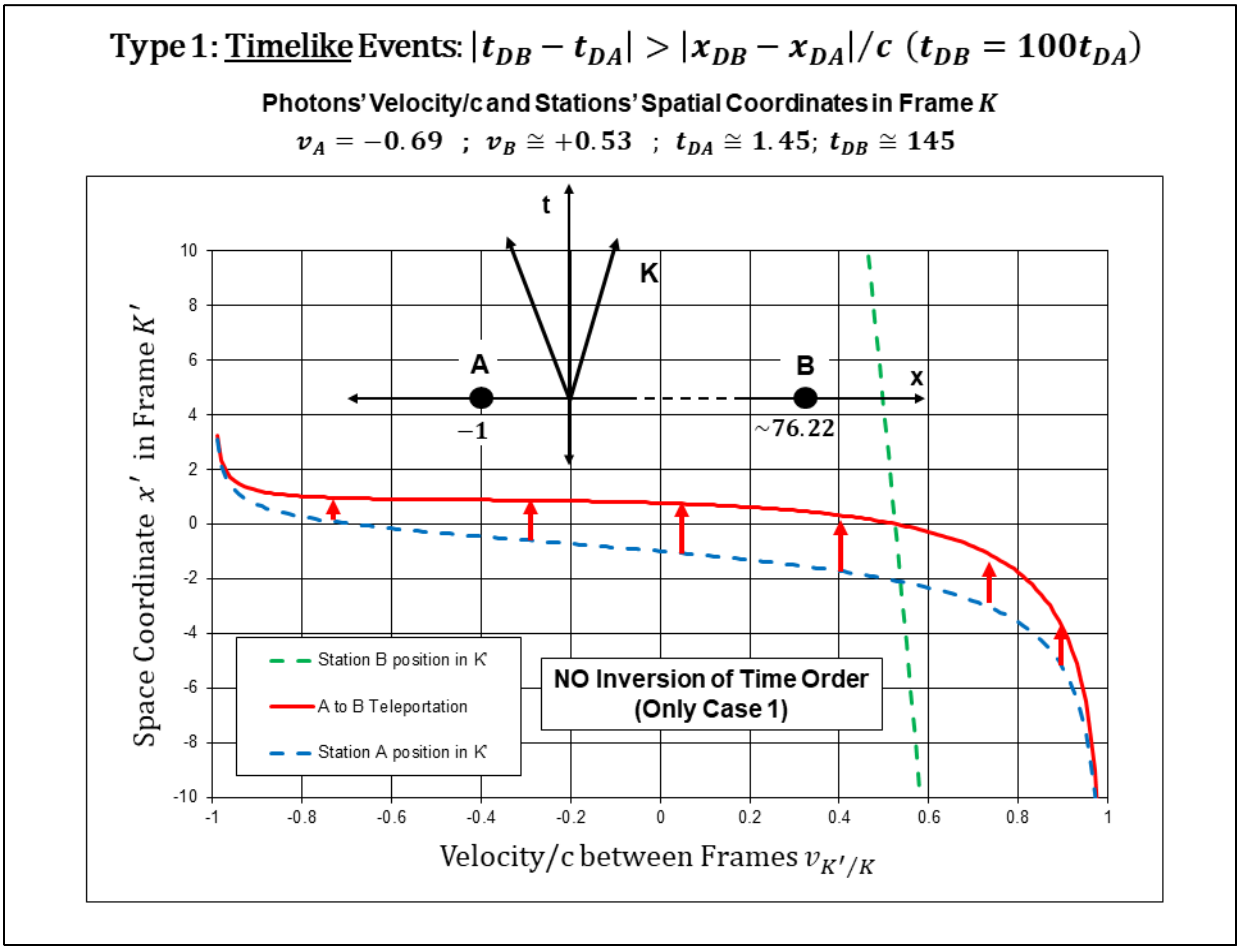

Figure 22 – State Teleportation in K' for Single/Two Entangled Quantons when Timelike

With this first radical conceptual renewal, we can now present a unified *relativistic* description of single-quanton nonlocality and multi-quanton nonlocality.

8.1.4 Unified Relativistic Account of Single and Multi-Quanton Nonlocality

We are now equally referring to anyone of the two SDE subsystems on their own or to their combination as a EPRB system in Figure 17, as well as to Figure 18 in its **(1q)** and **(2q)** interpretations. Thus, the word 'quanton' can refer to a single or to a composite one. Once again: because -in any IF- the delay lines to and distance between PDIs can be adjusted to make their PDI-Events virtually *simultaneous* without change in the quanton's PD, the *simultaneity* between PDI-Events is relative as in RT, while the *simultaneity* between some PDI-Events and some State-Events is absolute. There is ***no*** direct causal relation between the PDI-Events; the correlation of their results is due to the 'Causal (f)' relation between some of the quanton's State-Events – what we call now a quantum link.

Focusing on Figure 18 and regardless of its single or bi-quanton interpretation, if we start in frame K with $\boxed{E_{DA}E_A} \succ \boxed{E_{TB/A}}$ (Case 1) then we have the following narratives:

In *K*: The PDI-Event E_{DA}, the *local* State-Event E_A, and the *nonlocal* State-Event $E_{TB/A}$ are *simultaneous*. $E_{TB/A}$ can be considered as the 'teleported' event with coordinates (x_{TB}, t_{TB}). The common R-Time for E_{DA} and E_A is recorded by the clock in K, their common space-coordinates coincide with those of D_A, and the equal R-Time and the space-coordinates for $E_{TB/A}$ are inferred as the limit when the time-intervals needed to reach D_A and D_B from the PTI/PEI approach equality. Those spacetime-coordinates for $E_{TB/A}$ are valid whether E_{DB} occurs virtually simultaneously with E_{DA} (Type 2), well-enough time-after E_{DA} (Type 1 or Type 3), or never (no D_B). In symbols: $t_{DA} = t_A = t_{TB} \leq t_{DB}$ – thereby rejecting any superluminal signal accounting for the 'Causal (f)' relation between E_A and $E_{TB/A}$. Events E_{DA}, E_A, and $E_{TB/A}$ are simultaneous, with the first two events *quantumlike*-separated (Type 4) from the last one.

Transforming the coordinates of $E_{DA}, E_A, E_{TB/A}$ as well as E_{DB} and E_B (if E_{DB} occurs) per QLT, we obtain the following description from K' vantage point:

In *K*′: If D_B does not exist, per QLT, the spacetime coordinates for E_{DA} and E_A and the time-coordinate for $E_{TB/A}$ in K' are determined by the LT applied to E_{DA} in K, while the space-coordinates for $E_{TB/A}$ in K' are obtained from Equations 7 for the B-worldline and the time-coordinate of $E_{TB/A}$. If D_B exists, E_{DB} may be delivered by the LT in K' as time-before or simultaneous with E_{DA}. If time-before, the local State-Event E_B, and the nonlocal State-Event $E_{TA/B}$ are all *simultaneous*. In symbols: $\boxed{E_{TA/B}} \prec \boxed{E_{DB}E_B}$ (Case 2), and $E_{TA/B}$ is the 'teleported' event occurring at (x_{TA}, t_{TA}). The common R-Time for E_{DB}, E_B, and $E_{TA/B}$ is recorded by the clock in K', the common space-coordinates of E_{DB} and E_B coincide with those of D_B, and the space-coordinates for $E_{TA/B}$ in K' are obtained from Equations 7 for the A-worldline and its time-coordinate. Thus: $t_{DB} = t_B = t_{TA} \leq t_{DA}$ – thus rejecting again any superluminal signal to account for the 'Causal (f)' relation between E_B and $E_{TA/B}$. If LT delivers E_{DA} and E_{DB} as *simultaneous*, we have Case 3 so the spacetime coordinates for E_A and $E_{TA/B}$ in K' are those given by the LT for E_{DA} and the spacetime coordinates for E_B and $E_{TB/A}$ are those given by the LT for E_{DB}.

And mutatis mutandis if we start in frame K with $\boxed{E_{TA/B}} \prec \boxed{E_{DB}E_B}$ (Case 2). Note again that the teleportation event's coordinates $(x_{TA(B)}, t_{TA(B)})$ are IF-**Co**variant; it is the *simultaneity* among the PDI-Event $E_{DA}(E_{DB})$ and the two State-Events $E_A(E_B)$ and $E_{TB/A}(E_{TA/B})$ that is absolute, while the simultaneity/time-order for PDI-Events E_{DA} and E_{DB} (if spacelike) is relative.

Summarizing: the local and nonlocal State-Events require different symbols in different frames to match the different (albeit equivalent) narratives emanating from the changing time-order of the spacelike-separated PDI-Events. Despite the spacetime-coordinates of these quantumlike-separated State-Events being IF-covariant, they retain their *simultaneity* in all frames: under QR/TOPI, two actual events can be absolutely *simultaneous* and still be causally related. The *simultaneity* inherent in *nonlocality* is neither intrasystemically conventional nor intersystemically relative as it is in RT (where *locality* reigns and *nonlocality* is rejected). Even so, it is fully consistent with RT because State-Events are actual but ***non**-evincing*, viz ***not*** R-Events. But we must remember that, except for their didactic value, those chronicles (i.e. time-ordered narratives) are **i**rrelevant and misleading because: a) the time-order for spacelike-separated PDI-Events is not objective but merely conventional, and b) given that in QR/TOPI ***not*** all causal relations are genidentical (viz time-ordered), there is an IF-Invariant core in both chronicles: the causal quantum link between State-Events. Remember that the symbols ≻ and ≺ are ***not*** associated with objective time-order.

The combination of prejudices about *causality* and its relationship with *time*, a flawed *identity* between IF-Invariance and Lorentz-Invariance, and the mistaken *focusing* on a presumed 'coordination' between detectors instead of on the inherent behavior of the quanton via its *probable* and *actual* states, have detracted us for a century from successfully integrating RT with QT. QR/TOPI is QLT-Invariant – which implies that, despite the absolute *simultaneity* between some actual events, all actual *evincing* events (the only ones real in RT) are Lorentz-Invariant and, ergo, their *simultaneity* is relative. Even ***non***-evincing PDI-Events are Lorentz-Invariant.

8.1.5 QR/TOPI Absolute Simultaneity of Point-Events vs. Newton's Absolute Simultaneity

Despite Einstein's synchronization scheme having rendered *simultaneity* relative, it still allowed us to pinpoint the correct R-Time for the absolutely instantaneous teleported QR-Event via a mathematical limit process – in the same way Newton's Second Law allowed us to determine absolute simultaneity as a limit (before introducing gravity). There are two differences though:

a) In Newton's world there was no limit to how fast an object could move, and that is why absolute simultaneity could be inferred even without Newton's *instantaneous* gravitation law. Instead, in QR/TOPI (as in RT) objects ***cannot*** move arbitrarily fast, creating the topological gaps in Figure 4, so that absolute *simultaneity* does ***not*** follow – with *nonlocality* postulated as part of QR/TOPI Ontology. This makes possible the existence of actual QR-Events whose simultaneity is absolute – as long as at most ***one*** of the actual events is *evincing*.

b) Newton's world allowed for *signaling nonlocal correlations* while our new QR/TOPI world, being ontically probabilistic ***and*** absolute simultaneity ***never*** occurring between two actual *evincing* events, only allows for "*non-signaling nonlocal correlations*". Therefore, QR/TOPI resolves Gisin's conundrum in the affirmative.

8.2 "Radical Conceptual Renewal II": Absolute Simultaneity of Probable Events

QR/TOPI posits the reality of a type of absolute *simultaneity* even more revolutionary than the Type 4 between actual point-Events. Clearly -in general- neither a quanton nor its probable events can be abstracted to a point-object or to point-Events respectively. Hence, probable states and properties of a quanton cannot be associated to a point in RT-spacetime; only actual (*evincing* or not) can. And only the insertion of a PDI (to make up a GI from a PTI) in a network of PTIs can produce an actual event for a quanton. But though violation of coherence requisites do ***not*** produce actual events per se (which could change the network's topology), it makes the quanton behave like a classical object would for the same topology and, ergo, probabilities (instead of probability amplitudes) to add for disjunctive paths and multiply for conjunctive ones – making *interference* phenomena disappear. As you may remember, there was obviously ***no*** *interference* between the beans' states in the Galton/Popper bean machine [11].

Let us recall that a PTI is purely transformational and upon which, unless the *current* state is already actual and belongs to the *current* MB, all *next* states in the latter basis are ontically probable. Besides, if the *current* state (a member of the *previous* MB) is probable, all other states in the *previous* MB are also probable and 'determining parts' of the *previous* state. Thus, all transitions in a PTI are ontically probable as well – the quanton evolving without revealing itself in our RT-spacetime. *Previous* and *current* MBs for each PTI within a network are related via a unitary transformation, which can be viewed as a state transformation under a single basis – with the state's components transforming as the bases do [11]. Thus, the basis transformation also rules how the components of the *previous* state morph into the components of the *current* state and the latter into the components of the *next* state. Remember that those components are probability *amplitudes* and the terms *previous*, *current*, and *next* do not refer to R-Time but to QR-Time, which is based on the network's topology. Every local PTI has an ITI and every ITI corresponds to a PTI. As proved in Part III, the global ITI among probable states across different local MBs takes place not via their probabilities but their probability *amplitudes* [11].

Ontically probable events are utterly foreign to RT, as well as to orthodox QT and its many other formulations and/or interpretations. They are not point-Events but regional events, i.e. each associated with a different region of spacetime and linked one to another by ontic **a**temporal probability relations (ITI) characteristic of a global PTI. This **a**temporality refers to a lack of R-Time order between probable events: under QR/TOPI, all probable events for a quanton/milieu are absolutely *simultaneous*, evolving in R-Time as a whole and in unison until an *actualization* of the ITI occurs (triggered by a PDI). The latter conversion of probable into actual screens off the future from the past – destroying future quantic interference. Differently: the *state*, when actual, contains in itself only a fraction of the past which, in turn, affects the future while, when probable, it is (via a persistent ITI) coupled to all the co-extant probable states in the global current MB since the last actual state. As long as the coherence requirements are met, all co-extant probable states evolve in R-Time as a block until undergoing a PDI, with a much richer dependence of the future on the past (all the way back to the last PDI). However, we cannot point-localize the probable states, properties, and events in RT-spacetime, unless an intermediate PDI is inserted in which case we create a Milieu-Event changing the quanton's milieu – with any quantic interference disappearing. Not being actual, no additional extension of our QLT transformation is needed for probable events.

Dealing in general with co-extant probable states, PTIs and their ITIs ***cannot*** be instantiated by stochastic genidentical chains. However, because (while the coherence conditions are met) they can -despite spanning over extended regions of space- be confined between very close R-Times or let them 'evolve' for extended R-Times, PTIs and ITIs can be considered (from the perspective of our RT-spacetime) as getting *instantly* established and persisting *continuously* in R-Time (without inner R-Time *chronicles*) – explaining the success of the temporal Schrödinger's equation [11].

Finally, this **a**temporality and regional spatiality of ITI's probabilistic relations (among *probable* states) should not be confused with Cramer's backward causality (between *actual* states) in his 'Transactional Interpretation' – of which he said it was "only a pedagogical convention" because "the process is atemporal" [141] [142]. Likewise regarding the distinction between our ITI and the already-discussed flurry of retrocausal/superdeterministic/'Future-Input Dependent' (FID) "toy models" during the last few decades.

8.3 "Radical Conceptual Renewal III": Instantaneous Effects of Milieu-Events

On the event of suddenly removing a pin from the Galton/Popper Bean machine (Quincunx), an obvious m**a**cro-object down to its basic components (pins and ball), I stated in Part III [11]:

ALBA5: *…Upon the removal of a pin, it is the milieu that changes with* ***no need*** *for any physical 'communication' between the places where the pin was removed and where the ball was at the time. If you insisted on postulating a causal dynamic action between the pin-removal event and the change in the PD for the ball, then you would have to embrace Einstein's 'spooky action at a distance' (or at least superluminal causal chains) as a ubiquitous occurrence in our quotidian activities. It is certainly ubiquitous and real, but not a causal dynamic process in RT-spacetime; 'nonlocality' or 'spacelike interaction' are better terms.*

Having thus shown the *instantaneous* effects of Milieu-Events for m**a**crosystems [11] and after all the quantic phenomena we have scrutinized in previous sections, it should not be surprising at all that such *simultaneity* is ubiquitous and absolute in the quantum world and, consequently, it is adopted as a basic tenet in QR/TOPI. Nonetheless, we always request a solid empirical foundation. In 2007, Branning et al published experimental evidence for the *simultaneity* between changes on the photon's milieu and the effect on its state-transition PD. They dealt with the prediction by Quantum Electrodynamics (QED) that the spontaneous emission by an excited atom is suppressed when sitting between two parallel mirrors (boundary conditions) and asked one of the many variants of Zeilinger's "very fundamental question": "… if the atom is prohibited from emitting a photon, then how can it "know" that the cavity is there?" Should the atom "wait to 'find out' about the absence of the mirror via a change in the mode structure of the cavity?" The authors crisply introduce the conundrum and their conclusions in their very Abstract (my underscore):

BRAN1: *We present an experimental realization of a "sudden mirror replacement" thought experiment, in which a mirror that is inhibiting spontaneous emission is quickly replaced by a photodetector. The question is, can photons be counted immediately, or only after a retardation time that allows the emitter to couple to the changed modes of the cavity, and for light to propagate to the detector? Our results, obtained with a parametric downconverter, are consistent with the cavity QED prediction that photons can be counted immediately, and are in conflict with the retardation time prediction.* [179]

Discussing the data in the light of their setup's practical limitations, they state (my underscore):

BRAN2: *Even after taking into account the practical limitations of our experiment due to visibility, stability, and background rates, the data in Fig. 3 remain a strong indication of the immediate detection of photons from an inhibited spontaneous emitter.* [179]

They further characterize their experiment as:

BRAN3: *In our experiment we have taken the analogy with the "sudden replacement thought experiment" several steps further, by changing the boundary condition in a time dependent way, and by using a spontaneous down conversion arrangement that is "a generalization of cavity QED experiments to a situation where the separation between the emitter and mirrors greatly exceeds the wavelength" [reference to [180]].*

Finally, they conclude (underscore and hyperlinks mine):

BRAN4: *In conclusion, we have experimentally demonstrated that there is a nonzero chance to detect a photon from inhibited spontaneous emission immediately after the inhibiting mirror [PTI] is replaced with a detector [PDI]. The photons arrive at the earliest possible time, 29 standard deviations before the retardation time 2d/c has elapsed.*

Based then on available empirical evidence and its resulting internal consistency within the *Foundation* and *Structure* of QR/TOPI, there are Milieu-Events whose effects on the quanton's evolution are absolutely *instantaneous*. Once again, such events are actual *evincing* but their teleported effects (State-Events) are actual ***non**-evincing* – so there is ***no*** incompatibility with RT.

8.4 "Radical Conceptual Renewal IV": Even the Quanton can be Ontically Probable

As anticipated in Section 1.3.1, the very inclusion of ontically probable states in QR/TOPI *Ontology, Foundation,* and *Structure* [11] inevitably leads to postulating the reality of probable quantons. The best way of understanding this novel type of physical entity is through an experimental setup to be described in Section 9.6, where the input to a Spontaneous Parametric Down Converter (SPDC) is ***not*** an actual quanton but one of its probable states. Now it is about time to demonstrate that QR/TOPI is powerful enough to answer all imaginable variations of Zeilinger's basic question.

9. Zeroing in on Zeilinger's "What does this Really Mean in a Basic Way?"

We have discussed at length the physical meaning under QR/TOPI of single-quanton (Section 4), as well as bi-quanton and tri-quanton phenomena (Section 5). Let us summarize what we have learned so far and then proceed to discuss even subtler single and multi-quanton phenomena, which are considered the epitome of quantum quirkiness and whose different physical meanings attached in the literature are, if not more eldritch than the phenomena themselves, blatantly incoherent and even circular. Examples are 'wave-particle duality', retrocausality', 'erasing the past', 'interaction-free detection', 'changing the real trajectory of a photon millions of years ago', and whatnot.

Zeroing in now on Zeilinger's "very fundamental question", it is paramount to keep in mind that not everything real leaves a direct, local, and immediate record in our RT-spacetime. Once more: RT is about actual *evincing* events – not about probable, not even about actual but ***non**-evincing* events, both of which do not belong to RT's Ontology and are considered by many as paradoxical (calling for retarded and advanced waves [29]). Besides, *chronicles* are RT's coin of the realm to the point that we forgot they are ***not*** objective for spacelike-separated events. Under QR/TOPI, the ITIs of PTIs are fully reciprocal: they are relations among joint and conditional probabilities for the quanton's probable states; ergo, they may not conform with a particular IF-invariant *chronicle*. Nonetheless, as the sub-acronym 'TOPI' in 'QR/TOPI' indicates, it is precisely those **a**temporal probabilities the ones that are ontic, objective, and absolute, i.e. valid regardless of the chosen basis in Hilbert Space to represent the quanton's state, of the IF, and of whether the GI-Events statistically revealing those probabilities are spacelike-separated or not.

We also saw that for both single and multi-quanton systems, *teleportation* takes place *instantly* upon the occurrence of a single PDI. Uncritically presuming that every actual event must produce a record is the reason why all literature insists on referring to the two spacelike PDIs in the SDE or to the two GIs (and their ***non***-invariant time order) when discussing Bell's *nonlocality*. We saw that the adoption of a teleported state is an actual but ***non**-evincing* event, which is ***not*** subject to LT but to QLT. Its simultaneity with the teleporter event is *objectively* absolute (i.e. IF-Invariant *without* non-trivial conventions) but its spacetime coordinates are IF-**co**variant so its time-order with respect to other PDI may revert from one IF to another – the latter PDI becoming the teleporter event. Ergo, the appellatives 'teleporter' and 'teleportee' for the sub-quantons' events of a composite quanton (or for the State-Events of a single quanton) are relative to the IF only having an unambiguous meaning in a given frame: despite its catchy name, *teleportation* has ***no*** direction, ***not*** even portage!

As anticipated in Part III [11] and referring now to Figures 10 through 15, were we to conduct many experiments under the same (arbitrary) angle θ between the two GIs' magnetic fields, both sites would see a dull (50/50) sequence of $+1/-1$ (same PD) regardless of the actual orientation of each local magnet and of which GI was time-first. Note though that the MB for each site does depend on the local magnet orientation. However, if for each θ, upon getting together: (a) we separated the data points in subsets $\{+1,+1\}$, $\{-1,-1\}$, $\{+1,-1\}$, and $\{-1,+1\}$, we would find a PD per Equations 29; and (b) if the results in one site were grouped in subsets that corresponded to a given result in the other site, each experimenter would find a conditional PD per Equations 34 – again regardless of which GI was time-first or their being simultaneous, i.e. for all IFs. Whether the GIs are spacelike-separated or not, it is immaterial which quanton undergoes a GI first, even though (time-before their GI*s*) the time-first one would have been in a *co-state* (whose PD does not depend on the local milieu, only the MB does) and the time-second in a *pure* state (whose MB and PD depend on the local milieu). But we learned that a *co-state* of a sub-quanton is ***not*** a state of the latter but a mutual state with the other sub-quanton. Both sub-quantons are in *co-states* time-before the entanglement is broken and both go to isolated (though related) *pure* states time-after. Either they both are in *co-states*, or they both are in *pure* but related states. For spacelike PDI-Events their time-order is conventional so, being the simultaneity of *teleportation* absolute, which sub-quanton is 'first' per Einstein's convention is immaterial: *entanglement* is simply broken at a different location and time depending upon the IF.

At nauseum: the sub-quantons are in *co-states* until anyone of them undergoes a GI – regardless of the latter being considered with respect to the other as (conventionally if spacelike) time-first in some IF and as (conventionally) time-second in another IF. For all IFs, it is the composite quanton in its composite state (Equation 28, top) that undergoes a GI via one of its sub-quantons; which one is the 'time-first' in the particular IF is irrelevant, as the 'time-second' may not even happen at all. Both sub-quantons are initially in co-states and, upon one GI, they detangle and become pure states. The composite quanton's behavior is absolutely the same because, upon the 'first' GI, the quantons become isolated but with their actual pure states related in such a way that, upon the 'second' GI, their *correlation* is absolute. A given *chronicle* involving PDI-Events is only valid for a particular IF, giving us the false impression of a better understanding (it pleases our prejudices) – while deceitfully disappointing us when we find it does not work for other IFs. The same conceptual statements are valid for the tri-quanton composite needed for teleportation at will (Figure 16) and the tetra-quanton composites we will soon discuss.

It is true that two quantons may be in the same or related state by chance or by design (preparation) despite never having been entangled. It is *reproducibility* what entitles us, via statistical analysis, to affirm they were in an entangled state before their coming up with the same or related state. The conclusion that they were or were not entangled is absolute and can only be reached after both GIs have been repeatedly completed. It does not matter whether the sub-quanton undergoing the local GI is in a co-state or in a pure state. They can even occur at the same time (in a given IF) or at different times in another IF (which means nothing if they are spacelike). What matters is whether, when a GI takes place in a given IF, the quanton is still a composite of two entangled sub-quantons or just an aggregate of them in pure (but related) states. If it is a composite, both sub-quantons are **a**ffected; if it is not, only the one undergoing the GI is (***no*** teleportation).

9.1 The Double-Slit/Mach-Zehnder Interferometers under Deutsch's Multiverse

David Deutsch at Oxford has been a prominent supporter of the MWI of QT initially proposed by Hugh Everett (student of Wheeler) in 1957, and to which Deutsch refers as the 'Multiverse'. In order to explain the interference phenomenon in the ubiquitous double-slit experiment, in Chapter 2 titled 'Shadows' of his 1997 book 'The Fabric of Reality – The Science of Parallel Universes—and Its Implications' [123], Deutsch includes the following Multiverse terminology:

Tangible/shadow: "For the purposes of exposition in this chapter only, I called particles in this universe *tangible,* and particles in other universes *shadow particles.*"

Multiverse: "The whole of physical reality. It contains many parallel universes."

Parallel universes: "They are 'parallel' in the sense that within each universe particles interact with each other just as they do in the tangible universe, but each universe affects the others only weakly, through interference phenomena."

And then he disregards his distinction between 'tangible' and 'shadow' for particles and even for us humans as merely pedagogical, with a bold and provocative statement about himself:

> *Many of those Davids are at this moment writing these very words. Some are putting it better. Others have gone for a cup of tea.*

Farther ahead, in his Chapter 13 'The Four Strands', he narrates the story of Bryce DeWitt initially opposing Everett by informally saying that he could not feel himself 'split' into multiple, distinct copies every time a decision was made – to which Everett replied: 'Do you feel the Earth move?' Deutch thus claims that the Multiverse theory "explains why one does not feel such splits, just as Galileo's theory of inertia explains why one does not feel the Earth move". And that is why he says that "DeWitt conceded". I am quite sure most readers would require a little more than this dubious analogy with "Galileo's theory or inertia" to believe in the reality of the Multiverse.

Given the homology we discussed in Part III [11] between the double-slit set up and the Mach-Zehnder Interferometer, let us see now how Deutsch explains the latter via his Multiverse:

DEUT1: *In all universes in which the experiment is done, the photon and its counterparts are traveling towards the interferometer along the same path… But as soon as the photon strikes the semi-silvered mirror [1st BS], the initially identical universes become differentiated. In half of them, the photon passes straight through and travels along the top side of the interferometer. In the remaining universes, it bounces off the mirror and travels down the left side of the interferometer… Thus they end up arriving simultaneously at the semi-silvered mirror on the bottom right [2nd BS] and interfere with one another… The versions of the photon in these two groups interfere strongly. The net effect depends on the exact geometry of the situation, but Figure 9.3 shows the case where in all universes the photon ends up taking the rightward-pointing path through the mirror, and in no universe is it transmitted or reflected downwards. Thus all the universes are identical at the end of the experiment, just as they were at the beginning.* [123]

And, from above, he -with an unfathomable degree of confidence- concludes (my hyperlinks):

DEUT2: *This remarkable non-random interference phenomenon is just as inescapable a piece of evidence for the existence of the multiverse as is the phenomenon of shadows. For the outcome that I have described is incompatible with either of the two possible paths that a particle in a single universe might have taken.*

We will soon see that these Multiverse (MWI) explanations become even more uncanny when the complexity and subtleties of the experimental setup increases. Let us first scrutinize in some detail experimental setups that expose the clash between the infamous 'particle-wave duality' and *retrocausality*.

9.2 Milieu-Events: The Delayed 'Quantum Eraser'

Figure 23 schematizes the perennial double-slit setup now with two milieus (in black and red). In black: a movable photographic plate is ON; in red: the photographic plate is OFF allowing one of two separated photodetectors -each focused on a different slit- to detect the photon. Regarding its operation, John A. Wheeler stated in 1978 (my underscore):

WHEE1: *In the one case [screen ON] the quantum will transform a grain of silver bromide and contribute to the record of a two-slit interference fringe. In the other case [screen OFF] one of the two counters will go off and signal in which beam—and therefore from which slit—the photon has arrived.* [181]

The fallacious implication embedded in the above excerpt is that -with the black milieu- the quanton passes though the two slits, acting like a wave and contributing to an interference fringe pattern, while with the red milieu (no photographic plate), which detector clicks indicates which slit the quanton passes through. But then -if true- by delaying the choice of milieu in each run, e.g. by suddenly inserting the photographic plate time-after the photon has (supposedly) passed through one of the slits, the interference pattern (so they say) could ***not*** develop – unless *retrocausality* was at play 'erasing' the past particle-behavior and making the photon pass through both slits. Mutatis mutandis for the plate's sudden removal. The same erroneous interpretation is made regarding the MZI when stating that the rapid inclusion of the second splitter (while the photon is on its way to the existing PDI) 'erases' the 'which-way information' after the first splitter (particle behavior), the wave behavior is turned on (*retrocausality*), and interference occurs. Experimental evidence proves that interference does occur, and we have proven that QR/TOPI does not need *retrocausality* or the anthropic concept of *information* to explain it "in a basic way". There is nothing to 'erase': the sudden inclusion of the second splitter (or the photographic plate) is a Milieu-Event that instantly changes the PTI to which the quanton is subjected – together with its inherent ITI amongst its probable states. Probability is ontic, reciprocal, **a**spatial, and **a**temporal.

Ten years later, regarding polarization, Wheeler was considerably more careful by only asserting our "right to say about what we call the past" (my underscore):

WHEE2: *There is an inescapable sense in which we, in the here and now, by a delayed setting of our analyzer of polarization to one or other angle, have an inescapable, an irretrievable, an unavoidable influence on what we have the right to say about what we call the past.* [182]

In the same vein (though a little riskier), in 2004, Zeilinger talks about the "physical interpretation" of events that "just happen" (my underscore):

ZEIL3: *The important conclusion is that, while individual events just happen, their physical interpretation in terms of wave or particle might depend on the future; it might particularly depend on decisions we might make in the future concerning the measurement performed at some distant spacetime location in the future.* [183]

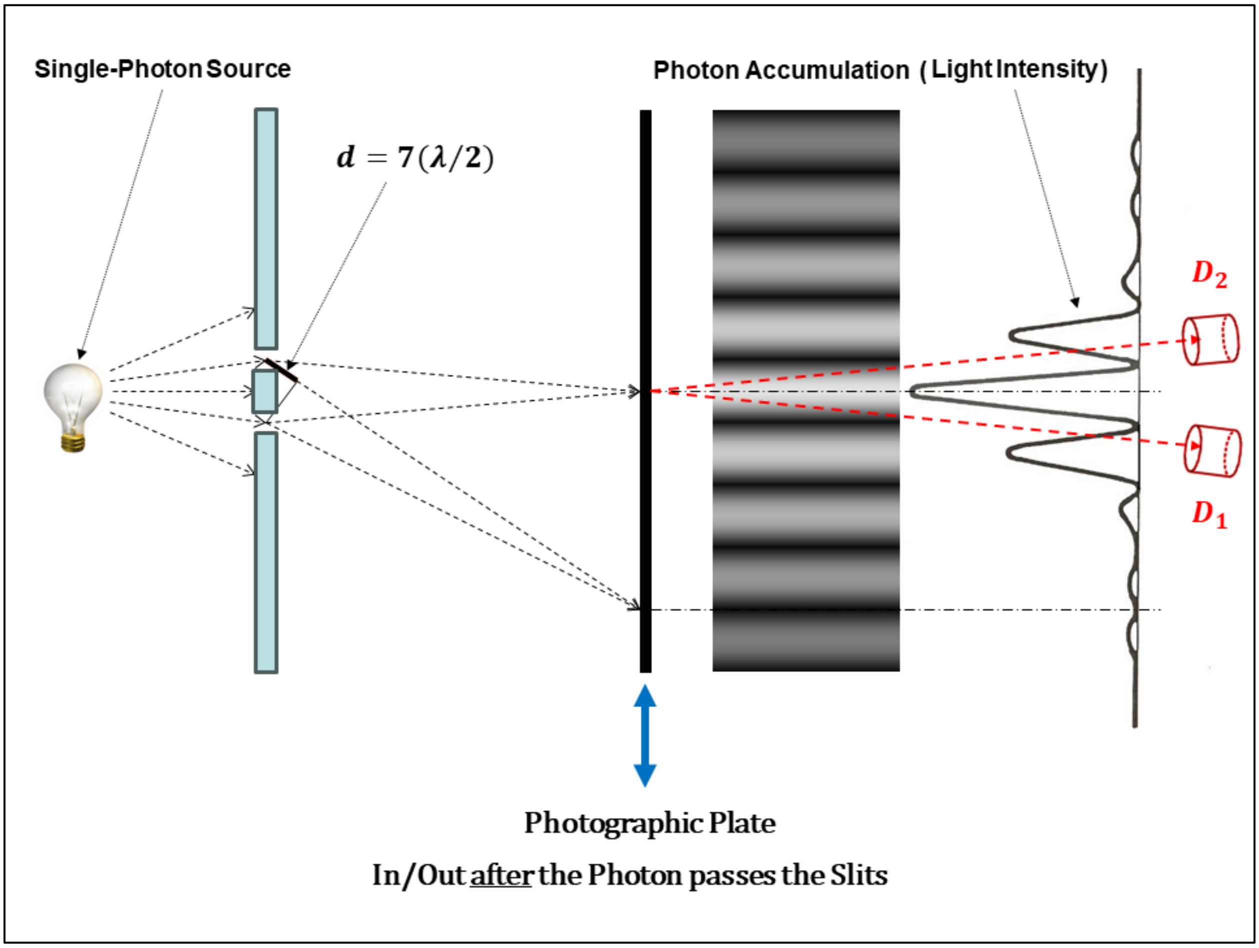

Figure 23 – Wheeler's Delayed-Choice Double-Slit Experiment

Weeler settled for "our right to say", and Zeilinger was careful in stating that only the "physical interpretation" (not what actually happened) "might depend on the future". However, on Wheeler's famous quasar-galaxy account of the delayed-choice experiment, Zeilinger was considerably less careful and talked about the reality of "the path the photon took" millions of years ago based on what we decide to do now (my underscore):

ZEIL4: *We decide, by choosing the measuring device, which phenomenon can become reality and which one cannot. Wheeler explicates this by example of the well-known case of a quasar, of which we can see two pictures through the gravity lens action of a galaxy that lies between the quasar and ourselves. By choosing which instrument to use for observing the light coming from that quasar, we can decide here and now whether the quantum phenomenon in which the photons take part is interference of amplitudes passing on both sides of the galaxy or whether we determine the path the photon took on one or the other side of the galaxy.* [184]

We already explained why our experimental decision "here and now" does not (and cannot) affect whether a photon emitted millions of years ago "passes on both sides of the galaxy" or goes via only one side. I surely accept that a new better physical theory to be obtained in the future will prompt us to reinterpret what happened in the past, but I firmly reject the idea that, depending on what milieu we could subject the quanton to in the future, the physical interpretation provided by a given theory of what that quanton did in the past can be different. Under the very same theory, the physical interpretation of what actually happens now and here cannot depend on our future experimental caprice. The fallacy resides in our insistence for a century on the 'wave-particle duality' paradigm. As we know very well by now, under QR/TOPI, quantons are neither *waves* nor *particles*: any "physical interpretation in terms of wave or particle" is doomed to failure by deceiving us into dumbfoundingly accepting *retrocausality* (with the only purpose of not rejecting our prejudices).

On a more elaborated experimental setup introduced by Scully and Drühl in 1982 to check the same 'quantum eraser' misguided idea, Brian Greene (whose explanation is also based on the anthropic notion of *information*) says in the Section "Erasing the Past" of his book "The Fabric of the Cosmos":

GREE1: *If you can't change something that has already happened, can you do the best next thing and erase its impact on the present?... Only when an event in the past seems definitively to preclude another event's happening in the future… would we think there was something awry if we were subsequently told that the precluded event had actually happened. The quantum eraser, first suggested in 1982 by Marlan Scully and Kai Drühl hints at this kind of strangeness in quantum mechanics.*

We will formally analyze in detail this experiment to show that there is nothing more here than the well-known fact that two PFs (PTIs) with orthogonal optic axes stop light, while inserting a third PF between them with a diagonal optic axis allows light to go through [11]. Figure 24 schematizes a possible implementation of the alluded experiment, which includes a PF before the double-slit screen, retains the photographic plate (PDI) adding means to analyze the polarization (PDI), and considers three milieus (different PTIs) for the photon to undergo before reaching the PDI. The first PF (common to all milieus) simply assures the photon entering the double-slit screen has a fixed linear polarization [11]. Choosing a 45° PF maximizes both the vertical and horizontal components delivered by the two orthogonal PFs included right after the slits in Milieus II and III.

We can define a 'Click Operator' $\mathcal{C}$ at the location in the photographic plate in such a way that the mean value of its associated property is equal to the probability for the local detector to click, namely:

$$Click\ Property\ (Eigenvalue\ of\ \mathcal{C})\ = \begin{cases} 1: & Click \\ 0: & No\ Click \end{cases} \quad \Rightarrow \quad \langle \mathcal{C} \rangle = \langle s|\mathcal{C}|s\rangle = Pr(Click/|s\rangle)$$

We then express the photon's state $|s\rangle$ before hitting the double-slit screen (after the black PF) in terms of its two probable states $|s_1'\rangle$ and $|s_2'\rangle$:

$$|s\rangle = s_1|s_1\rangle + s_2|s_2\rangle \overset{PF}{\Rightarrow} |s_1\rangle = |\nearrow\rangle|s_1'\rangle \ ; \ |s_2\rangle = |\nearrow\rangle|s_2'\rangle \ ; \ |s\rangle = s_1'|\nearrow\rangle|s_1'\rangle + s_2'|\nearrow\rangle|s_2'\rangle$$

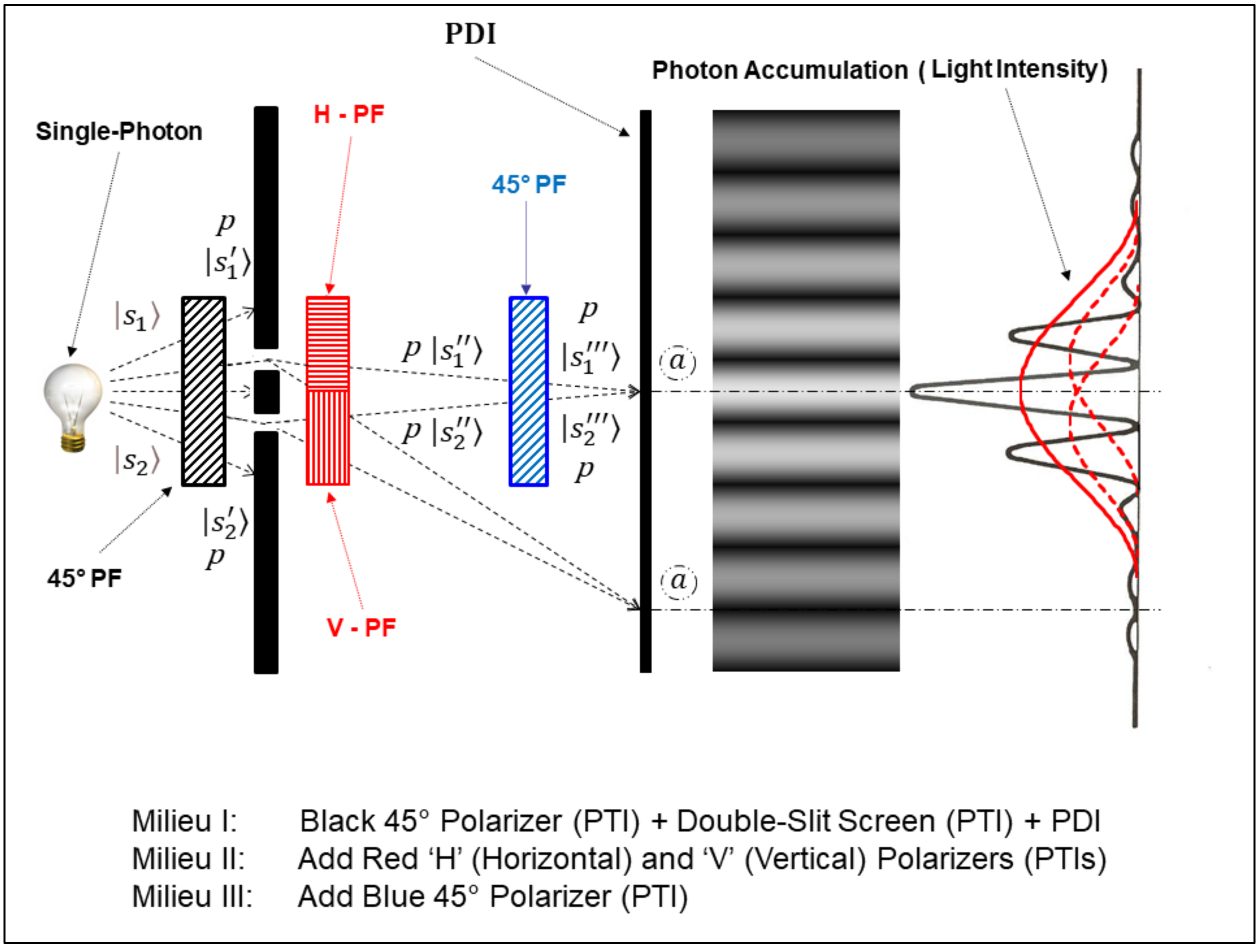

Figure 24 – Alleged "Marking/Erasing" of "Which-Slit Information"

Let us now analyze what happens to the photon for each one of the three milieus.

Milieu I (in black)

$$Pr(Click/|s\rangle) = \langle s|\mathcal{C}|s\rangle = \langle s'_1|\nearrow\rangle|s'_1\rangle + s'_2|\nearrow\rangle|s'_2\rangle|\mathcal{C}|s'_1|\nearrow\rangle|s'_1\rangle + s'_2|\nearrow\rangle|s'_2\rangle\rangle =$$
$$= \langle s'_1|\nearrow\rangle|s'_1\rangle + s'_2|\nearrow\rangle|s'_2\rangle|s'_1\mathcal{C}|\nearrow\rangle|s'_1\rangle + s'_2\mathcal{C}|\nearrow\rangle|s'_2\rangle\rangle = \langle s'_1|s'_1\rangle\langle|\nearrow\rangle|s'_1\rangle|\mathcal{C}|\nearrow\rangle|s'_1\rangle\rangle +$$
$$+\langle s'_1|s'_2\rangle\langle|\nearrow\rangle|s'_1\rangle|\mathcal{C}|\nearrow\rangle|s'_2\rangle\rangle + \langle s'_2|s'_1\rangle\langle|\nearrow\rangle|s'_2\rangle|\mathcal{C}|\nearrow\rangle|s'_1\rangle\rangle + \langle s'_2|s'_2\rangle\langle|\nearrow\rangle|s'_2\rangle|\mathcal{C}|\nearrow\rangle|s'_2\rangle\rangle =$$
$$= \langle\nearrow|\nearrow\rangle\{|s'_1|^2\langle s'_1|\mathcal{C}|s'_1\rangle + \langle s'_1|s'_2\rangle\langle s'_1|\mathcal{C}|s'_2\rangle + \langle s'_2|s'_1\rangle\langle s'_2|\mathcal{C}|s'_1\rangle + |s'_2|^2\langle s'_2|\mathcal{C}|s'_2\rangle\} =$$
$$= \langle s'_1|\mathcal{C}|s'_1\rangle|s'_1|^2 + \langle s'_2|\mathcal{C}|s'_2\rangle|s'_2|^2 + \{\boldsymbol{\langle s'_1|\mathcal{C}|s'_2\rangle\langle s'_1|s'_2\rangle + \langle s'_2|\mathcal{C}|s'_1\rangle\langle s'_2|s'_1\rangle}\} \qquad (37)$$

$$|s'_1|^2 = Pr(|s'_1\rangle) \quad \Downarrow \quad |s'_2|^2 = Pr(|s'_2\rangle)$$

$$Pr(Click/|s\rangle) = Pr(Click/|s'_1\rangle)\,Pr(|s'_1\rangle) + Pr(Click/|s'_2\rangle)\,Pr(|s'_2\rangle) + \boldsymbol{Interference}$$

As we know from Part III [11], the first(second) term is the probability for the detector to click if the lower(upper) slit is closed (red-dotted curves), while their sum corresponds to the click-probability when both slits are open but with a non-destructive PDI interacting with $|s'_1\rangle$ or/and $|s'_2\rangle$ before the photographic plate (red-solid curve). However, besides the photographic plate, as indicated in Figure 24, Milieu I only includes two PTIs and ***no*** PDI and that is why there is interference shown by the cross-terms in bold case (black-solid curve).

It is instructive to apply the homology with one of the output states of a MZI that we developed in Section 3.3.3 of Part III [11]: calling now $|o_A\rangle$ and $|o_B\rangle$ the two output states of the second BS, $s_1' = e^{i\theta}\frac{\sqrt{2}}{2}$ (with θ the phase difference between the two arms) and $s_2' = i\frac{\sqrt{2}}{2}$, we get:

$$|s\rangle = e^{i\theta}\frac{\sqrt{2}}{2}|\nearrow\rangle|s_1'\rangle + i\frac{\sqrt{2}}{2}|\nearrow\rangle|s_2'\rangle = \frac{\sqrt{2}}{2}\left\{e^{i\theta}|\nearrow\rangle\left[i\frac{\sqrt{2}}{2}|o_A\rangle + \frac{\sqrt{2}}{2}|o_B\rangle\right] + i|\nearrow\rangle\left[\frac{\sqrt{2}}{2}|o_A\rangle + \frac{\sqrt{2}}{2}i|o_B\rangle\right]\right\} =$$

$$= \left\{\frac{i}{2}[e^{i\theta}+1]|o_A\rangle + \frac{1}{2}[e^{i\theta}-1]|o_B\rangle\right\}|\nearrow\rangle \; (Eq.16 \; in \; Part \; III)$$

$$\Downarrow$$

$$Pr(|o_A\rangle) = \left|\frac{i}{2}[e^{i\theta}+1]\right|^2 = \frac{1}{2}(1+cos\theta) \Rightarrow \boldsymbol{Interference} \; (Black \; pattern \; on \; the \; right)$$[105]

Milieu II (Add Horizontal and Vertical Polarizers in Red)

$$|\nearrow\rangle = \frac{\sqrt{2}}{2}[|\rightarrow\rangle + |\uparrow\rangle]^{106} \Rightarrow |s\rangle = s_1'|\nearrow\rangle|s_1'\rangle + s_2'|\nearrow\rangle|s_2'\rangle = \frac{\sqrt{2}}{2}[|\rightarrow\rangle + |\uparrow\rangle][s_1'|s_1'\rangle + s_2'|s_2'\rangle]$$

$$\Downarrow$$

$$|s\rangle = \frac{\sqrt{2}}{2}\{s_1'|\rightarrow\rangle|s_1'\rangle + s_2'|\uparrow\rangle|s_2'\rangle\} + \frac{\sqrt{2}}{2}\{s_1'|\uparrow\rangle|s_1'\rangle + s_2'|\rightarrow\rangle|s_2'\rangle\}$$

$$\Downarrow$$

$$Horizontal \; PF \; on \; |s_1'\rangle: \quad |\uparrow\rangle|s_1'\rangle = 0|\rightarrow\rangle|s_1''\rangle + 1|a_V''\rangle \quad ; \quad |\rightarrow\rangle|s_1'\rangle = |\rightarrow\rangle|s_1''\rangle + 0|a_V''\rangle$$

$$Vertical \; PF \; on \; |s_2'\rangle: \quad |\uparrow\rangle|s_2'\rangle = |\uparrow\rangle|s_2''\rangle + 0|a_H''\rangle \quad ; \quad |\rightarrow\rangle|s_2'\rangle = 0|\rightarrow\rangle|s_2''\rangle + 1|a_H''\rangle$$

$$\Downarrow$$

$$|s\rangle = \frac{\sqrt{2}}{2}s_1''|\rightarrow\rangle|s_1''\rangle + \frac{\sqrt{2}}{2}s_2''|\uparrow\rangle|s_2''\rangle + \left[\!\left[\frac{\sqrt{2}}{2}|a_H''\rangle + \frac{\sqrt{2}}{2}|a_V''\rangle\right]\!\right]$$

$$PF \; Blockage \; and \; Normalization \Rightarrow |s\rangle = s_1''|\rightarrow\rangle|s_1''\rangle + s_2''|\uparrow\rangle|s_2''\rangle$$

$$\Downarrow$$

$$Pr(Click/|s\rangle) = \langle\mathcal{C}\rangle = \langle s|\mathcal{C}|s\rangle = \langle\{s_1''|\rightarrow\rangle|s_1''\rangle + s_2''|\uparrow\rangle|s_2''\rangle\}|\mathcal{C}|\{s_1''|\rightarrow\rangle|s_1''\rangle + s_2''|\uparrow\rangle|s_2''\rangle\}\rangle =$$

$$= \langle\{s_1''|\rightarrow\rangle|s_1''\rangle + s_2''|\uparrow\rangle|s_2''\rangle\}|\{s_1''\mathcal{C}|\rightarrow\rangle|s_1''\rangle + s_2''\mathcal{C}|\uparrow\rangle|s_2''\rangle\}\rangle = \langle s_1''|s_1''\rangle\langle|\rightarrow\rangle|s_1''\rangle|\mathcal{C}|\rightarrow\rangle|s_1''\rangle\rangle +$$

$$+\langle s_1''|s_2''\rangle\langle|\rightarrow\rangle|s_1''\rangle|\mathcal{C}|\uparrow\rangle|s_2''\rangle\rangle + \langle s_2''|s_1''\rangle\langle|\uparrow\rangle|s_2''\rangle|\mathcal{C}|\rightarrow\rangle|s_1''\rangle\rangle + \langle s_2''|s_2''\rangle\langle|\uparrow\rangle|s_2''\rangle|\mathcal{C}|\uparrow\rangle|s_2''\rangle\rangle =$$

$$= |s_1''|^2\langle s_1''|\mathcal{C}|s_1''\rangle\langle\rightarrow|\rightarrow\rangle + |s_1''s_2''|\langle s_1''|\mathcal{C}|s_2''\rangle\langle\rightarrow|\uparrow\rangle + |s_2''s_1''|\langle s_2''|\mathcal{C}|s_1''\rangle\langle\uparrow|\rightarrow\rangle + |s_2''|^2\langle s_2''|\mathcal{C}|s_2''\rangle\langle\uparrow|\uparrow\rangle$$

$$\langle\rightarrow|\rightarrow\rangle = \langle\uparrow|\uparrow\rangle = 1 \;\; ; \;\; |s_1''|^2 = \Pr(|s_1''\rangle/|s\rangle) \;\; \Downarrow \;\; \langle\rightarrow|\uparrow\rangle = \langle\uparrow|\rightarrow\rangle = 0 \;\; ; \;\; |s_2''|^2 = \Pr(|s_2''\rangle/|s\rangle)$$

---

[105] Disregarding the attenuation of light with distance (shown in the diagrams).
[106] This decomposition can also be obtained by applying the identity operator $I = (|\rightarrow\rangle\langle\rightarrow| + |\uparrow\rangle\langle\uparrow|)$ to $|\nearrow\rangle$.

$$Pr(Click/|s\rangle) = Pr(Click/|s_1''\rangle)\,Pr(|s_1''\rangle) + Pr(Click/|s_2''\rangle)\,Pr(|s_2''\rangle) \Rightarrow \boldsymbol{No\ Interference} \quad (38)$$

The $|a_H''\rangle$ and $|a_V''\rangle$ state symbols correspond to the absorbed component in each PF. As before, each term in the above sum (red-solid curve on the right) corresponds -for different positions in the photographic plate- to each one of the red-dotted probability curves (whose peak is aligned with the corresponding slit). Upon repetition, they can be isolated from the solid PD by separating vertical from horizontal polarization data-points in the dataset. Due to the orthogonality betwixt the PFs' axes, there is ***no*** interference. Applying again the homology with the MZI [11]:

$$|s\rangle = e^{i\theta}\frac{\sqrt{2}}{2}|\rightarrow\rangle|s_1''\rangle + i\frac{\sqrt{2}}{2}|\uparrow\rangle|s_2''\rangle = \frac{\sqrt{2}}{2}\left\{e^{i\theta}|\rightarrow\rangle\left[i\frac{\sqrt{2}}{2}|o_A\rangle + \frac{\sqrt{2}}{2}|o_B\rangle\right] + i|\uparrow\rangle\left[\frac{\sqrt{2}}{2}|o_A\rangle + \frac{\sqrt{2}}{2}i|o_B\rangle\right]\right\}$$

$$\Downarrow$$

$$|s\rangle = \frac{1}{2}ie^{i\theta}|\rightarrow\rangle|o_A\rangle + i\frac{1}{2}|\uparrow\rangle|o_A\rangle + \frac{1}{2}e^{i\theta}|\rightarrow\rangle|o_B\rangle - \frac{1}{2}|\uparrow\rangle|o_B\rangle\ (Compare\ with\ Eq.16, Part\ III)$$

$$\Downarrow$$

$$Pr(|o_A\rangle) = \frac{1}{2}\ \forall\ \theta \Rightarrow \boldsymbol{No\ Interference}\ (Red - solid\ pattern\ on\ the\ right)$$

We see that, after the 'H' and 'V' polarizers, the probable spatial state $|s_1''\rangle$ is correlated with the *horizontal* polarization state, while $|s_2''\rangle$ is correlated with the *vertical* polarization state. Greene, as most physicists and philosophers, says that we have effectively 'marked' or 'tagged' the photon because by measuring its polarization at the detector's site, we could determine which slit the photon went through. So he asserts in [185] (my underscore):

GREE2: *The new tagging devices allow which-path information to be gleaned, and which-path information singles out one history or another; the data show that any given photon passed through either the left [our upper] slit or the right [our lower] slit. And without the combination of left-slit and right-slit trajectories, there are no overlapping probability waves, so no interference pattern is generated.*

In presuming that the data indicate the photon's past trajectory, Greene commits the same error Wheeler did in WHEE1. Greene continues the anthropic/information narrative and, mentioning Scully and Drühl's idea, he wonders: *What if, just before the photon hits the detection screen, you eliminate the possibility of determining through which slit it passed by erasing the mark imprinted by the tagging device?* Let's analyze such a situation.

Milieu III (Add 45° Polarizer in Blue)

$$|s_1''\rangle = |\nearrow\rangle|s_1'''\rangle + 0|\searrow\rangle|s_1'''\rangle\ ;\ |s_2''\rangle = |\nearrow\rangle|s_2'''\rangle + 0|\searrow\rangle|s_2'''\rangle \Rightarrow |s\rangle = s_1'''|\rightarrow\rangle|\nearrow\rangle|s_1'''\rangle + s_2'''|\uparrow\rangle|\nearrow\rangle|s_2'''\rangle$$

$$\Downarrow$$

$$|s\rangle = s_1'''|\nearrow\rangle\left[\frac{\sqrt{2}}{2}|\nearrow\rangle + \frac{\sqrt{2}}{2}|\searrow\rangle\right]|s_1'''\rangle + s_2'''|\nearrow\rangle\left[\frac{\sqrt{2}}{2}|\nearrow\rangle - \frac{\sqrt{2}}{2}|\searrow\rangle\right]|s_2'''\rangle$$

$$PF\ Blockage\ and\ Normalization\ \Rightarrow\ |s\rangle = \{s_1'''|s_1'''\rangle + s_2'''|s_2'''\rangle\}|\nearrow\rangle$$

$$\Downarrow$$

$$Pr(Click/|s\rangle) = Pr(Click/|s_1'''\rangle)\,Pr(|s_1'''\rangle) + Pr(Click/|s_2'''\rangle)\,Pr(|s_2'''\rangle) + \boldsymbol{Interference} \quad (39)$$

Formally proceeding as we did to arrive at Equation 37, we see that the interference non-nil cross terms reappear because both spatial eigenstates $|s_1'''\rangle$ and $|s_2'''\rangle$ share the same polarization as $|s_1'\rangle$ and $|s_2'\rangle$ did in Milieu I. And applying the homology with the MZI [11]:

$$|s\rangle = e^{i\theta}\frac{\sqrt{2}}{2}|\rightarrow\rangle|\nearrow\rangle|s_1'''\rangle + i\frac{\sqrt{2}}{2}|\uparrow\rangle|\nearrow\rangle|s_2'''\rangle =$$

$$= \frac{\sqrt{2}}{2}\left\{e^{i\theta}|\rightarrow\rangle|\nearrow\rangle\left[i\frac{\sqrt{2}}{2}|o_A\rangle + \frac{\sqrt{2}}{2}|o_B\rangle\right] + i|\uparrow\rangle|\nearrow\rangle\left[\frac{\sqrt{2}}{2}|o_A\rangle + \frac{\sqrt{2}}{2}i|o_B\rangle\right]\right\}$$

$$\Downarrow$$

$$|s\rangle = \frac{\sqrt{2}}{2}\left\{\frac{1}{2}ie^{i\theta}|\nearrow\rangle[|\nearrow\rangle + |\searrow\rangle]|o_A\rangle + i\frac{1}{2}|\nearrow\rangle[|\nearrow\rangle + |\searrow\rangle]|o_A\rangle + \frac{1}{2}e^{i\theta}|\nearrow\rangle[|\nearrow\rangle - |\searrow\rangle]|o_B\rangle - \frac{1}{2}|\nearrow\rangle[|\nearrow\rangle - |\searrow\rangle]|o_B\rangle\right\}$$

$$PF\ Blockage\ and\ Normalization \Rightarrow |s\rangle = \left\{\frac{i}{2}\left[e^{i\theta} + 1\right]|o_A\rangle + \frac{1}{2}\left[e^{i\theta} - 1\right]|o_B\rangle\right\}|\nearrow\rangle$$

$$\Downarrow$$

$$Pr(|o_A\rangle) = \left|\frac{i}{2}\left[e^{i\theta} + 1\right]\right|^2 = \frac{1}{2}(1 + cos\theta) \Rightarrow \boldsymbol{Interference}\ (Black\ pattern\ on\ the\ right)$$

Again, with very few exceptions (I commend Ellerman who strongly states that "there is no which-way information to be erased" [186]), most physicists and philosophers erroneously agree that the function of another 45° PF (blue in Figure 24) acting on both paths is to 'erase' the which-way information and, ergo, 'explaining' why *interference* reappears. But such a stance opens again the door to *retrocausality* because -per their own doctrine- the photon must now behave as a *wave* (passing through the two slits when it is too late for that to happen). Once again, per QR/TOPI, the difference between all three milieus only involves PTIs, which transform (via their ITIs) the quanton's ontic probable states in different ways. The onset of a new ITI is absolutely *simultaneous* with the Milieu-Event that sets the new PTI, so it only needs to be done right-before the PDI (the photographic plate plus the polarization analyzer). Nothing to erase in the past: the quanton is neither a wave nor a particle. Its current state and milieu determine the PD for its next state.

9.3 Interferometric 'Interaction-Free' Bomb Detection – Deutsch's Multiverse

Colin Bruce, another defender of what he calls the Oxford's MWI, describes in his book "Schrödinger's Rabbits" the Elitzur-Vaidman's "interaction-free bomb detector" (1993) [4] [26]. From our detailed discussions in Part III [11] and here in Section 4.2, recall that inserting a non-destructive PDI in one of the branches of the MZI, whether it clicks or not, one of the quanton's prior probable states before entering the second BS is actual and, ergo, if both BSs have split-ratio $a = 0.5$, the probability of firing for the 'bright' detector (which, sans the inserted PDI, was 100%) goes down to 50%, while the probability of firing for the 'dark' detector (which, sans the inserted PDI, was 0%) increases to 50%. Thus, whether the inserted PDI clicks or not, the efficiency of detecting its presence is $\eta = Pr\ (dark)/(Pr(dark) + Pr\ (Click)) = 0.5$. If, instead, the inserted PDI is destructive (fully absorbing or scattering the photon or, say, serving as a bomb detonator), only 50% of the photons can reach the second BS and the firing probability for the 'bright' detector goes down to 25% and that of the 'dark' detector goes up to 25%. Hence, the efficiency of detecting the bomb sans exploding is $\eta = Pr\ (dark)/(Pr(dark) + Pr\ (blast)) = 0.25/(0.25 + 0.5) = 1/3$. Because a click of the 'bright' detector means nothing as regards the existence of the destructive PDI (bomb), this efficiency indicates that out of a large number of runs only 75% of them mean something: in 50% of the runs the bomb explodes and in 25% of them the 'dark' detector clicks without a blast, signaling the existence of the bomb. Note that a single click of the 'dark' (ideal) detector allows us to infer that there is a bomb.

Using **a**symmetrical BSs, it is possible to increase the detection efficiency from 33% up to 50%. Let us call the split-ratios for first and second BS a and $a' = 1 - a$ respectively and insert the bomb on the a-arm of the MZI. The probability for the 'dark' detector to fire is $(1 - a)a$, and for the 'bright' detector is $(1 - a)^2$. Thus, $\eta = (1 - a)a/((1 - a)a + a) = (1 - a)/(2 - a)$, which tends to 0.5 when $a \to 0$. For instance, if $a = 0.1$; $a' = 0.9 \Rightarrow \eta = 0.9/1.9 \cong 0.47$, which means that for a large number of runs, $100 \cdot (1 - 0.1)^2 = 81\%$ are meaningless as regards the existence of the bomb but of the $100 \cdot 0.1 \cdot 0.9 = 9\%$ of runs in which the 'black' detector fires, $100 \cdot 0.9 = 90\%$ of them did ***not*** explode the bomb, making a detection efficiency of $9/(9 + 10) = 0.47$. The number of meaningless runs increased from 50% to 81% but the harmful fraction of those meaningful decreased from 50% to 10%. Mutatis mutandis, if the bomb is inserted in the a'-arm of the MZI, the ideal (lossless) maximum efficiency for an "interaction-free" detection of the bomb is $\eta = 100a/(a + 1) \to 50\%$ when $a \to 1$. The term 'interaction-free' for a non-evincing PDI-Event (no blast) is commonly used, albeit misleading and incorrect because: a) only if the inserted object is fully opaque, any photon detected by the otherwise 'dark' detector could be said to have gone the other 'route'; b) per QR/TOPI, 'no-click' events are as real as 'click' ones, so the photon always interacts with the whole milieu (both 'routes').

In his book Bruce asks himself another quintessential variant of Zeilinger's "very fundamental question": "How can a photon that never went near the detonator tell us whether it is present?" And, while stressing the bomb detection's low efficiency, he resorts to the work of a respected "arch-opponent" to delicately (via irony) imply that the only way to answer such a question is by means of MWI (my underscore):

BRUC1: *The Elitzur-Vaidman bomb detector is not very efficient: It is twice as likely to set the bomb off as it is to give a useful warning. It is ironic that a much more effective method has been devised and demonstrated by one of the arch-opponents of many-worlds, Anton Zeilinger.* [4]

Bruce refers above to the collaborative work between Kwiat et al from Los Alamos National Laboratory and Zeilinger's group at the University of Innsbruck [187]. Let us conceptually examine the essentials of their experimental setup.

9.3.1 Los Alamos/Innsbruck High-Efficiency Bomb Detection – The Multiverse

In 1999 those two research groups showed how to obtain theoretical efficiencies close to 100% for the 'interaction-free' detection of the non-transmitting object (bomb), with practical values reaching 85%. They refer to their technique as a combination of Elitzur-Vaidman interferometric ideas with an application of the Quantum Zeno Effect [187]. We will see that, in our QR/TOPI lingo, it corresponds to a recurring transformation of the quanton's actual state by means of the spatial probable states created by a PTI (MZI) and sustained by its ITI – unless the insertion of a PDI (bomb) in one of its arms converts one of the probable states into actual, destroying their otherwise *coherence* and -upon exiting the MZI with no blast- going back to its original state. Though their actual implementation corresponded to an involved version of a polarization Michelson Interferometer, Figure 25 depicts their simpler conceptual schematic.

An optical circuit is created by four (outer) mirrors in which a photon with horizontal ($|H\rangle$) polarization (blue) is somehow inserted and extracted after N cycles of clockwise circulation. In each cycle a polarization rotator (PTI) adds a polarization angle $\Delta\theta = \pi/2N$ (blue) clockwise so that, because the polarizing MZI (top-right corner) does not change the photon's polarization [11], when extracted after N cycles, its polarization is $N\pi/2N$, viz Vertical polarization (green). Per QR/TOPI lexis, this is a global GI to which we refer as GI-NB (milieu with No Bomb). Notice that for all cycles, the photon has two co-extant probable states (blue 'p') inside the MZI and a single (of course) actual state outside the MZI (blue 'a').

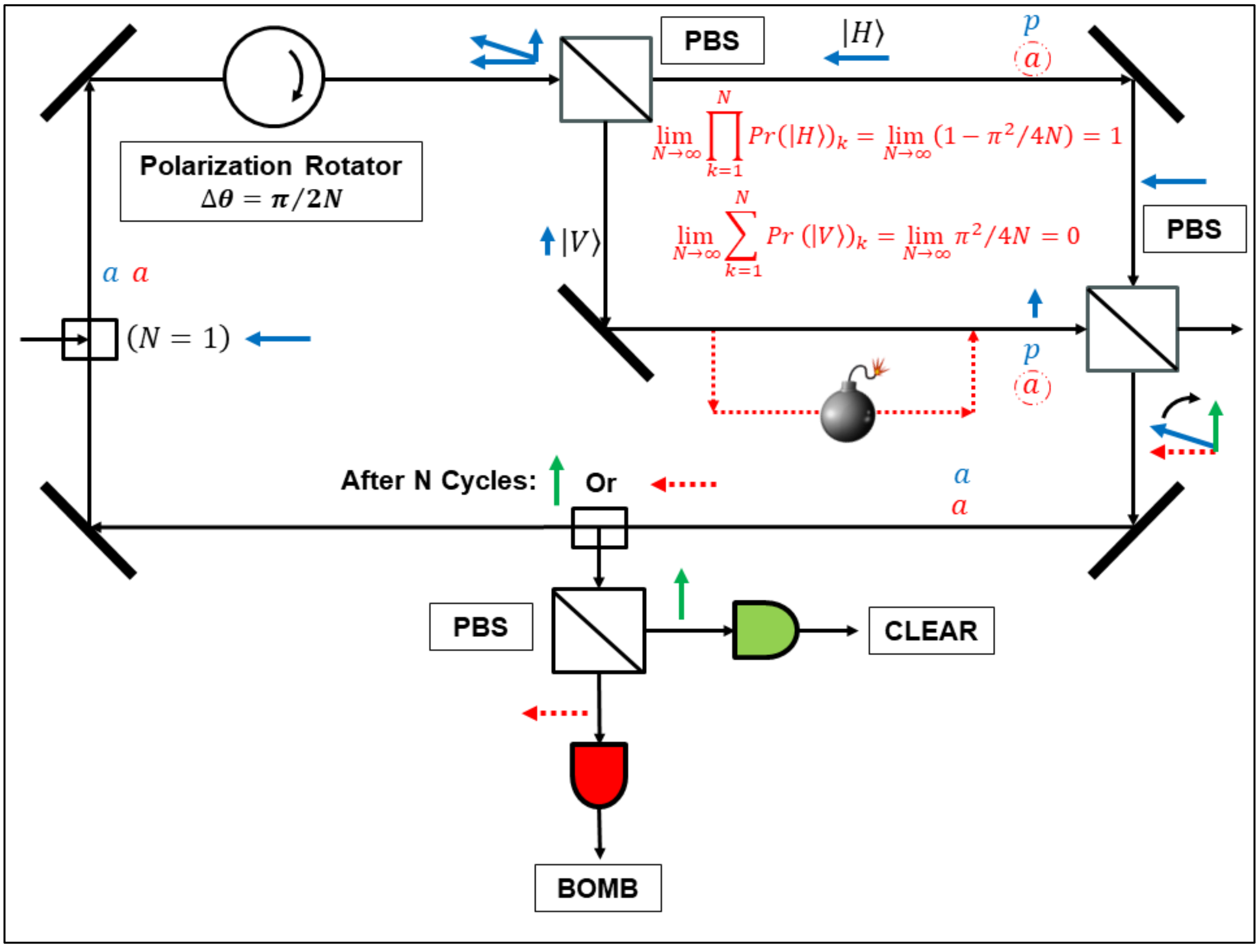

Figure 25 – High-Efficiency "Interaction-Free" Bomb Detector

But if the milieu is changed to include the bomb (GI-B in dotted-red), whether exploding or not, the two co-extant probable states morph into a single actual one (dotted-encircled red 'a'), so the photon -if there is no blast- returns to its original polarization $|H\rangle$ irrespective of in which of the N cycles the Milieu-Event happened. Therefore, subjecting the extracted photon to an external PBS, the non-existence or existence of a non-detonated bomb can be determined unambiguously: if $|V\rangle \Rightarrow$ No Bomb (GI-NB); if $|H\rangle \Rightarrow$ Bomb (GI-B).

Quantifying now, if the bomb is present and from the operation of the PBS [11], given that each time the photon avoids the bomb reenters the MZI with the same $\Delta\theta$ polarization, the probability for the photon to avoid the bomb after N cycles is $\prod_1^N cos^2(\pi/2N) = cos^{2N}(\pi/2N) \cong 1 - \pi^2/4N$ and, ergo, $Pr(blast) \cong \pi^2/4N$ – showing that as $N \to \infty$ the probability for the bomb to explode goes to zero. Hence, in the ideal lossless case, the efficiency of this 'interaction-free' detection of the bomb goes to 100%. The authors explain why the actual instrumentation imperfections and losses impair the theoretical efficiency: an 'interaction-free' detection of the bomb requires that the photon avoided the bomb in all N cycles, while hitting the bomb could occur in any cycle so -on average- the 'doomed' photon stays around fewer than N cycles and, ergo, the losses are less. They say: "the net effect is that, whereas $\eta \rightarrow 1$ for a large number of lossless cycles, in the presence of losses η reaches a maximum value less than one before falling again towards zero" [187].

Going back to Bruce's "Schrödinger's Rabbits", given that the photon could meet the bomb in any cycle, the probability for a blast after N roundtrips is $Nsin^2(\pi/2N)$. Therefore, if the rotator rotates the photon's polarization 1° each time, the odds of a blast after 90 trips are 1 in about 36 ($\{90 \cdot sin^2(1°)\}^{-1}$), and Bruce once again attempts to defend MWI by, perplexingly portraying Nature's behavior as an anthropic 'impressive achievement' (my underscore):

BRUC2: *We have achieved something even more impressive than exchanging information between one world and another. We have in some sense communicated a bomb warning from a small set of worlds where the bomb detonated to a set 36 times larger that remains safe.* [4]

Obviously, Bruce firmly believes that Reality is nothing but *evincing* Actuality (***no*** Sherlock Holmes' dogs, much less ontic probabilities), so that the only way for us to know that something bad could have happened and in fact did not is for the latter 'worlds' (ours and another 35 more!) to receive a "warning" message from the (proportionally speaking) single 'world' in which the calamity did occur. In what possible sense is that a 'warning'? Unfathomable indeed.

9.4 Resonance 'Interaction-Free' Bomb Detection – Deutsch's Multiverse

A properly designed (geometry/refractive index) block of transparent material can trap a high-intensity light wave -via total internal reflection (TIR)- in a circulating path for considerable time. The condition for TIR is that all light incident angles θ inside the block verify $sin\theta > n_O/n_I$, with n_I the interior and n_O the exterior refractive indexes ($n_I/n_O > 1.41$ for a square ring). The light beam can be injected to and extracted from the crystal block with negligible losses (~0.3%) by partially 'frustrating' the TIR (FTIR) through optical tunneling from/to other blocks [188] [189].

Dimming light intensity to the single-photon regime, Harry Paul and Mladen Pavǐcić in 1997 showed that "with an efficiency exceeding 99% one can use a monolithic total–internal–reflection resonator [MOTIRR] in order to ascertain the presence of an object [bomb] without transferring a quantum of energy to it." [190] [191]. A conceptual drawing is shown in Figure 26. The tunneling in and out of light is achieved by the $P1$ and $P2$ FTIR prisms, whose tiny gaps and minimal reflectivity at their entrance and exit surfaces -together with the polarization of the incident beam-determine the reflectivity $R1$ towards the detector 'B' (purple) as well as the transmissivity $(1 - R1)$ into and $(1 - R2)$ out of the monolith towards the detector 'NB' (green). The range $(10^{-5}, 0.99995)$ for those reflectivity values is achievable. With high-intensity light, when the length of the optical ring is an integer multiple of the light's wavelength, wave resonance (constructive interference) occurs. The bomb is inserted in the optical circuit by submerging it into a cavity with a liquid of the same refractive index as the monolith.

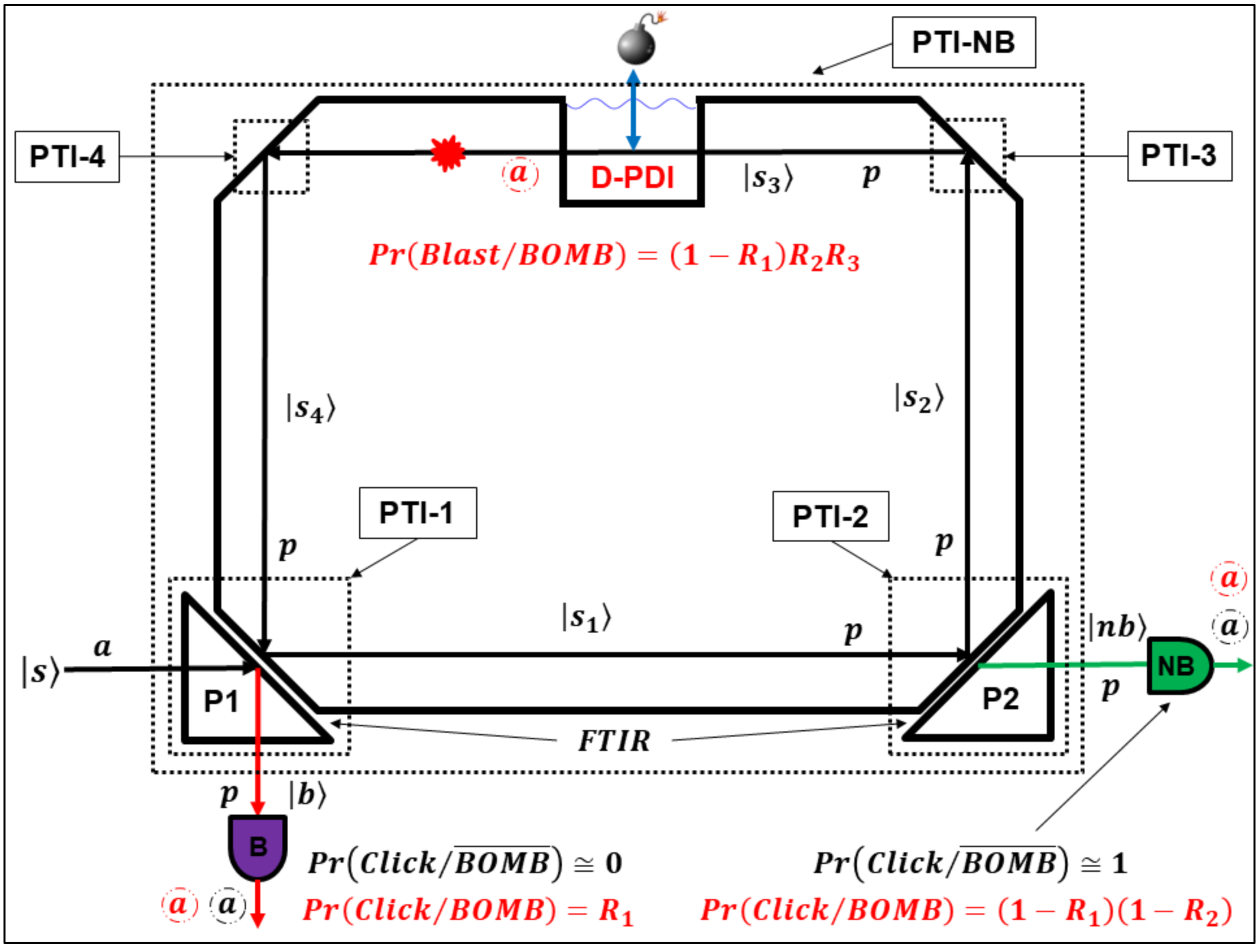

Figure 26 – High Efficiency Total Internal Reflection 'Interaction-Free' Bomb Detector

Per QR/TOPI lexicon, we have two global milieus (GIs): GI-NB comprising of the MOTIRR, the two FTIR prisms, and the 'B' (purple) and 'NB' (green) detectors; and GI-B which includes the bomb inside the liquid cavity – with its associated labels and equations in red. Four sub-PTIs can be identified: the left prism coupled to the monolith via optical tunneling constitute PTI-1 (a BS with two inputs and two outputs); the right prism/block coupling constitutes PTI-2 (a BS with one input and two outputs); reflector PTI-3, and reflector PTI-4. Being the bomb a dramatically Destructive detector (D-PDI), when the milieu is GI-B, the optic feedback path breaks, light never undergoes PTI-4, and PTI-1 has only one input ($|s\rangle$). In sum, GI-NB has one input ($|s\rangle$) and two outputs; GI-B has the same single input but three outputs. Evidently -lacking the feedback loop-GI-B is simpler, so let us first dissect its operation for the high-intensity and single-photon regimes.

9.4.1 GI-B Milieu: High-Intensity and Single-Photon Regimes

When the bomb is inserted, i.e. when the milieu is GI-B, the feedback loop is open. We know very well by now [11] [41] [37] [38] that when a single photon enters GI-B, the steady-state high-intensity ratios become probabilities for detection events (PDIs) while, between the latter, i.e. while the quanton undergoes PTIs, the probability *amplitudes* (the components of the quanton's probable states) are the ones that intermingle per the ITI characteristic of the network topology. In plain words: the probabilities we will obtain via QR/TOPI for the single-photon regime should agree with the intensity ratios for the high-intensity steady-state regime. Let us prove it.

High-Intensity Regime

Calling I the high-intensity steady-state amplitude for the Incident wave, the amplitude at the B-detector is $B = I\sqrt{R_1}e^{i\varphi_{r1}}$, the amplitude at the NB-detector is $I\sqrt{1-R_1}e^{i\varphi_{t1}}\sqrt{1-R_2}e^{i\varphi_{t2}}$, and the amplitude hitting the bomb is $I\sqrt{1-R_1}e^{i\varphi_{t1}}\sqrt{R_2}e^{i\varphi_{r2}}\sqrt{R_3}e^{i\varphi_{r3}}$, so that $|B|^2/|I|^2 = B \cdot B^*/I \cdot I^* = R_1$; $|NB|^2/|I|^2 = (1-R_1)(1-R_2)$, and the intensity ratio reaching the bomb is $(1-R_1)R_2R_3$. For instance, if $R_1 = R_2 = 0.99$ and $R_3 = 1$, then 99% of the intensity will report at the B-detector, 0.01% at the NB-detector, and 0.99% would go to detonate the bomb, becoming the only way to (catastrophically) detect its existence. Now, let us consider the single-photon case.

Single-Photon Regime

Referring to Figure 26, GI-B has one input ($|s\rangle$) and three output channels, one entering detector 'B', one entering detector 'NB', and the third entering D-PDI (the bomb). The photon's states in all of them are co-extant ontically probable; its states after the three detectors are actual and, therefore, mutually exclusive (dotted-encircled 'a'). The relevant Milieu Bases are: MB-1 = $\{|b\rangle, |s_1\rangle\}$; MB-2 = $\{|nb\rangle, |s_2\rangle\}$; MB-3 = $\{|s_3\rangle, |l_3\rangle\}$; and global MB-B = $\{|b\rangle, |nb\rangle, |s_3\rangle, |l_3\rangle\}$ – with $|l_3\rangle$ representing the losses in PTI-3. As always, to predict the probabilities of interest under QR/TOPI, we need to express the photon's input state $|s\rangle$ in the global MB-B. We start by expressing the photon's state in MB-1, its component $|s_1\rangle$ in MB-2, and the latter's component $|s_2\rangle$ in MB-3:

$$|s\rangle = \sqrt{(1-R_1)}e^{i\varphi_{t1}}|s_1\rangle + e^{i\varphi_{r1}}\sqrt{R_1}|b\rangle$$

$$|s_1\rangle = \sqrt{(1-R_2)}e^{i\varphi_{t2}}|nb\rangle + e^{i\varphi_{r2}}\sqrt{R_2}|s_2\rangle \quad ; \quad |s_2\rangle = \sqrt{(1-R_3)}|l_3\rangle + e^{i\varphi_{r3}}\sqrt{R_3}|s_3\rangle$$

Merging the three equations, we can express $|s\rangle$ in the MB-B as:

$$|s\rangle = \sqrt{(1-R_1)(1-R_2)}e^{i(\varphi_{t1}+\varphi_{t2})}|nb\rangle + e^{i(\varphi_{t1}+\varphi_{t2}+\varphi_{r3})}\sqrt{(1-R_1)R_2R_3}|s_3\rangle +$$

$$+e^{i(\varphi_{t1}+\varphi_{r2})}\sqrt{(1-R_1)R_2(1-R_3)}|l_3\rangle + e^{i\varphi_{r1}}\sqrt{R_1}|b\rangle$$

$$\Downarrow$$

$$Pr(|b\rangle/BOMB) = R_1 \; ; \; Pr(|nb\rangle/BOMB) = (1-R_1)(1-R_2) \; ; \; Pr(Blast) = (1-R_1)R_2R_3$$

As expected, those probabilities agree with the corresponding high-intensity ratios. Notice that those three probabilities do no sum up to unity; the difference is the term $(1-R_1)R_2(1-R_3)$, which corresponds to the actual losses in PTI-3 (R_3 may also lump the losses in PTI-1 and PTI-2), i.e. the probability that the photon is absorbed/scattered instead of reflected.

Figure 27 depicts the above three probabilities in red, blue, and green respectively for the case $R_1 = R_2 = R$ and $R_3 = 1$. We see that if we set the reflectivity R of the 'frustrating' prisms as close to unity as possible, the probability for the B-detector to click approaches unity, the one for the NB-detector approaches zero, and the probability for the photon to hit the bomb goes to zero.

The bomb detection efficiency using the B-detector is $\eta = Pr(|b\rangle)/[Pr(|b\rangle) + Pr(blast)] = 1/(2-R)$, which tends to unity when $R \to 1$, e.g. for $R = 0.999 \Rightarrow \eta \cong 99.9\%$. And, if $R \to 0$, $Pr(|b\rangle) \to 0$; $Pr(|nb\rangle) \to 1$, and the detection efficiency using the NB-detector is $\eta = Pr(|nb\rangle)/[Pr(n|b\rangle) + Pr(blast)] = (1-R) \to 1$ as well. It seems like the click of any detector could prima facie be an excellent indicator of the existence of the bomb without (mostly) ever exploding it. However, for that to be true, we need to prove that when the milieu is GI-NB, i.e. when the bomb is ***not*** present, the B-detector mostly never clicks (ideal yellow line in Figure 27) or, alternatively, the NB-detector almost always clicks (ideal purple upper line in Figure 27). In fact, the labels 'B' and 'NB' for the detectors were chosen to correspond to which of them clicks when the bomb is present, namely: R was chosen to be close to unity. Let us now prove that for the GI-NB milieu, the detectors do behave as needed.

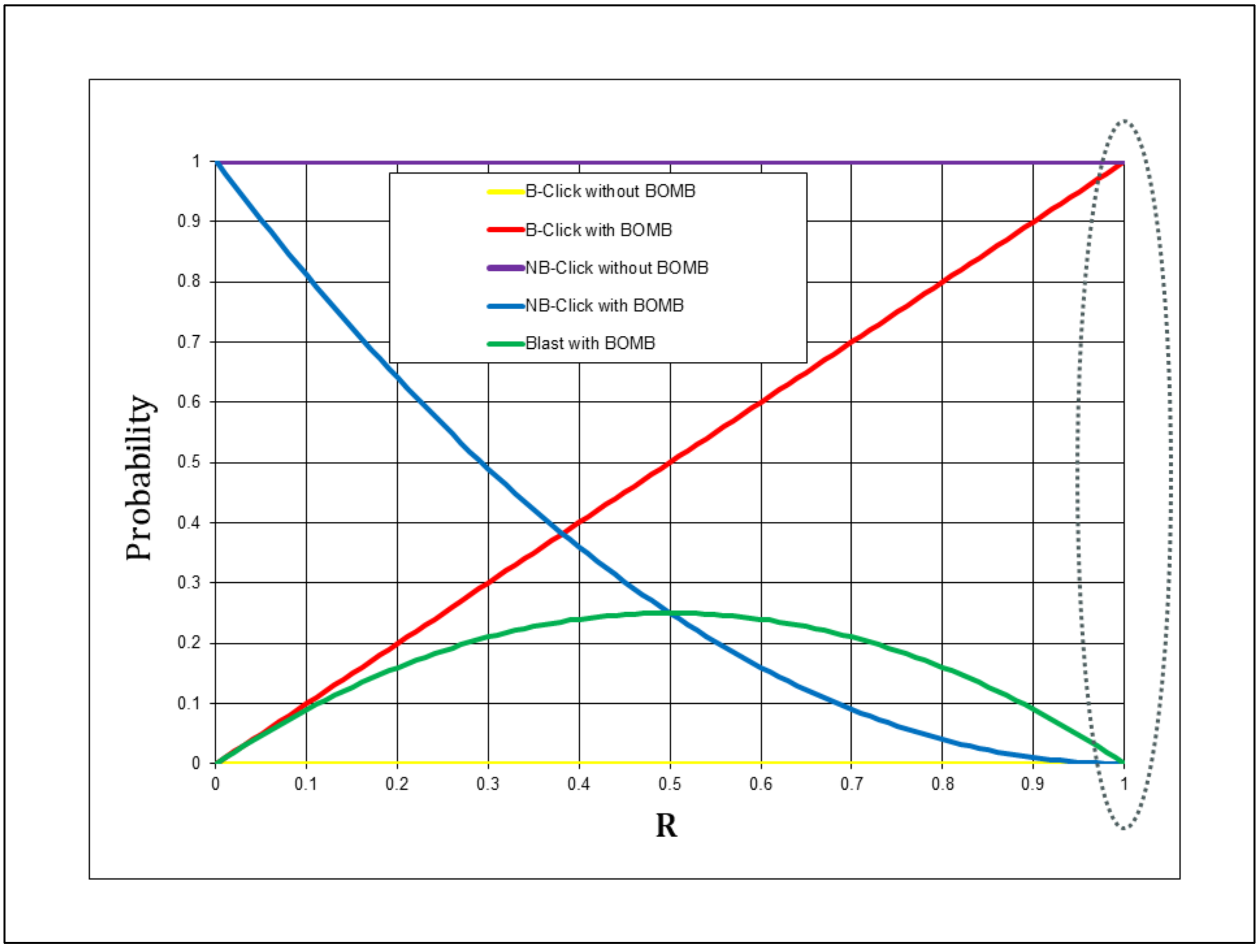

Figure 27 – Ideal Detectors' click Probabilities Without and With the Bomb

9.4.2 GI-NB Milieu: High-Intensity and Single-Photon Regimes

In the high-intensity ideal monochromatic lossless case, with ***no*** bomb in the circuit, we will prove that, upon reaching steady-state ($t \to \infty$), the fraction of the incident intensity that reaches the 'B' detector at the resonance frequency[107] is zero, while that of the 'NB' detector is unity. Its

[107] Using a continuous wave laser, the width of the spectral line can be about 10 kHz in the visible range and with coherence lengths up 300 km [191].

relationship with the single-photon case points to another oddity of quantic behavior beyond the mere 'how can it detect the presence of the bomb sans interacting with it'. To simplify matters, let us assume perfect reflection for PTI-3 and PTI-4 ($R_3 = R_4 = 1$), and also $R_1 = R_2 = R$.

High-Intensity Regime

With I being again the incident wave-amplitude, the wave amplitude B reaching the B-detector is the sum of the reflected amplitude $B_r = -I\sqrt{R}$ plus the cumulative amplitude B_{rt} for the multiple trips around the optical circuit needed to achieve steady-state. After the 1st cycle: $B_{rt}^1 = I\sqrt{1-R}\sqrt{R}\sqrt{1-R}e^{i\delta} = I\sqrt{R}(1-R)e^{i\delta}$, where $\delta = (\omega - \omega_R)T$ is the total phase added per cycle, with ω the angular frequency of the incident wave, ω_R the resonance frequency, and T the roundtrip time. After the 2nd cycle: $B_{rt}^2 = I\sqrt{1-R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{1-R} = I\sqrt{R}(1-R)Re^{i2\delta}$. After the 3rd roundtrip is completed: $B_{rt}^3 = I\sqrt{1-R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{1-R}e^{i3\delta} = I\sqrt{R}(1-R)R^2e^{i3\delta}$. Therefore, after the roundtrip k, we have $B_{rt}^k = I\sqrt{R}(1-R)e^{i\delta}\left(Re^{i\delta}\right)^{k-1}$, arriving (for $k \to \infty$) at a geometric series:

$$B_{rt} = \sum_{k=1}^{\infty} B_{rt}^k = I\sqrt{R}(1-R)e^{i\delta}\left\{\sum_{k=0}^{\infty}\left(Re^{i\delta}\right)^k\right\} = I\sqrt{R}(1-R)e^{i\delta}\left\{\frac{1}{1-Re^{i\delta}}\right\}$$

$$\Downarrow$$

$$B = B_r + B_{rt} = I\sqrt{R}\left\{-1 + (1-R)e^{i\delta}/\left(1-Re^{i\delta}\right)\right\} = I\sqrt{R}\left\{\left(e^{i\delta}-1\right)/\left(1-Re^{i\delta}\right)\right\}$$

$$\Downarrow$$

$$\frac{|B|^2}{|I|^2} = \frac{B \cdot B^*}{I \cdot I^*} = \left.\frac{2R(1-cos\delta)}{1-2Rcos\delta+R^2}\right|_{\delta=0} = 0$$

Had we clattered our previous deduction with the imperfect (lossy) reflectivity values $R_3 < 1$ and $R_4 < 1$ plus different values of reflectivity for $P1$ and $P2$ (with $\rho = \sqrt{R_3R_4}$), we would have gotten:

$$\frac{|B|^2}{|I|^2} = \left.\frac{R_1 + \rho^2R_2 - 2\rho\sqrt{R_1R_2}cos\delta}{1-2\rho\sqrt{R_1R_2}cos\delta + \rho R_1R_2}\right|_{\delta=0} = \frac{R_1 + \rho^2R_2 - 2\rho\sqrt{R_1R_2}}{1-2\rho\sqrt{R_1R_2} + \rho R_1R_2}$$

Notice that due to losses and the inequalities of the prisms' reflectivity, the intensity reaching the B-detector at resonance is not nil. Similarly, the amplitude NB reaching the NB-detector is the sum of the straight-path amplitude $NB_{sp} = I\sqrt{(1-R)}\sqrt{(1-R)} = I(1-R)$ plus the cumulative wave amplitudes NB_{rt}. For the 1st cycle: $NB_{rt}^1 = I\sqrt{1-R}\sqrt{R}\sqrt{R}\sqrt{1-R}e^{i\delta} = I(1-R)Re^{i\delta}$; for the 2nd: $NB_{rt}^2 = I\sqrt{1-R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{1-R}e^{i\delta 2} = (1-R)R^2e^{i\delta 2}$; after the third roundtrip: $NB_{rt}^3 = I\sqrt{1-R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{R}\sqrt{1-R}e^{i\delta 3} = I(1-R)R^3e^{i\delta 3}$; so after the roundtrip k, we have $NB_{rt}^k = I(1-R)\left(Re^{i\delta}\right)^k$ obtaining:

$$NB_{rt} = \sum_{k=1}^{\infty} NB_{rt}^k = I(1-R)\left\{\sum_{k=0}^{\infty}\left(Re^{i\delta}\right)^k - 1\right\} = I(1-R)\frac{Re^{i\delta}}{1-Re^{i\delta}}$$

$$\Downarrow$$

$$NB = NB_{sp} + NB_{rt} = I(1-R) + I(1-R)\frac{Re^{i\delta}}{1-Re^{i\delta}} = I\frac{(1-R)}{1-Re^{i\delta}}$$

$$\Downarrow$$

$$\frac{|NB|^2}{|I|^2} = \frac{NB \cdot NB^*}{I \cdot I^*} = \frac{(1-R)^2}{(1-2Rcos\delta + R^2)}\bigg|_{\delta=0} = 1$$

Again, with losses, we see now less than the full input intensity reaching the NB-detector:

$$\frac{|NB|^2}{|I|^2} = \frac{(1-R_1)(1-R_2)}{1-2\rho\sqrt{R_1R_2}cos\delta + \rho R_1R_2}\bigg|_{\delta=0} = \frac{(1-R_1)(1-R_2)}{1-2\rho\sqrt{R_1R_2} + \rho R_1R_2}$$

Let us now calculate the steady-state wave-amplitude C and intensity for the beam entering the liquid Cavity (assuming $\rho = 1$). The straight amplitude right before the liquid bath is $I\sqrt{1-R_1}\sqrt{R_2}$. After the 1st cycle: $C_{rt}^1 = I\sqrt{1-R_1}\sqrt{R_2}\left(\sqrt{R_1R_2}\right)e^{i\delta}$. After the 2nd cycle, we have $C_{rt}^2 = I\sqrt{1-R_1}\sqrt{R_2}\left(\sqrt{R_1R_2}\right)^2 e^{i2\delta}$. After the 3rd roundtrip: $C_{rt}^3 = I\sqrt{1-R_1}\sqrt{R_2}\left(\sqrt{R_1R_2}\right)^3 e^{i3\delta}$. Therefore, after the roundtrip k, we have $C_{rt}^k = I\sqrt{1-R_1}\sqrt{R_2}\left(\sqrt{R_1R_2}e^{i\delta}\right)^k$, arriving at:

$$C = I\sqrt{1-R_1}\sqrt{R_2} + \sum_{k=1}^{\infty} C_{rt}^k = I\sqrt{1-R_1}\sqrt{R_2}\left\{\sum_{k=0}^{\infty}\left(\sqrt{R_1R_2}e^{i\delta}\right)^k\right\} = I\sqrt{1-R_1}\sqrt{R_2}\frac{1}{1-\sqrt{R_1R_2}e^{i\delta}}$$

$$\Downarrow$$

$$\frac{|C|^2}{|I|^2} = \frac{C \cdot C^*}{I \cdot I^*} = \frac{(1-R_1)R_2}{1-2\sqrt{R_1R_2}cos\delta + R_1R_2}\bigg|_{\delta=0;R_1=R_2=R} = \frac{R}{(1-R)}$$

Likewise, the wave amplitude BP in the bottom straight path between the two prisms is:

$$BP = I\sqrt{1-R_1}\left\{1 + \sqrt{R_1R_2}e^{i\delta} + \left(\sqrt{R_1R_2}\right)^2 e^{i\delta 2} + \cdots\right\} = I\sqrt{1-R_1}\frac{1}{1-\sqrt{R_1R_2}e^{i\delta}}$$

$$\Downarrow$$

$$\frac{|BP|^2}{|I|^2} = \frac{BP \cdot BP^*}{I \cdot I^*} = \frac{(1-R_1)}{(1-2\sqrt{R_1R_2}cos\delta + R_1R_2)}\bigg|_{\delta=0;R_1=R_2=R} = \frac{1}{(1-R)}$$

So, at resonance, for say $R_1 = R_2 = R = 0.99$, if the input intensity is unity, the intensity in the liquid cavity is 99, the one in the bottom path between the FTIR prisms is 100, and the input intensity fully reappears at the NB detector (intensity at the B-detector is zero). The high-energy storage in the block due to resonance is apparent. But… what does this mean when we dim the input intensity down to a single-photon at a time? Could this huge steady-state intensity ratio inside the block be interpreted as the probability for a single photon to circulate around the block until such steady-state is reached? No, because this ratio is higher than unity so… what is the meaning of 'steady-state' for a single photon? Steady-state requires a transient we do know exists for high-intensity light (legions of photons). Is there then a transient for the single-photon regime upon a Milieu-Event (bomb in or out) taking place? Perhaps the transient-state is a phenomenon inherent in the m**a**croworld – non-existent in the m**i**croworld? We already saw that a tenet of QR/TOPI is that a Milieu-Event and its ***non**-evincing* effects (State-Events) are absolutely *simultaneous*. Let us formally analyze the single-photon regime.

Single-Photon Regime

When entering GI-NB, the actual state $|s\rangle$ of the photon undergoes PTI-1 jointly with its own state $|s_4\rangle$ inside the block after having successfully undergone PTI-2, 3, and 4. Notice that -per QR/TOPI- ***no*** two or more actual states of a quanton can be co-extant; only one of them can be actual, from which $|s_4\rangle$ can only be ontically probable. Ergo, because the quanton only undergoes PTIs[108] inside the crystal block, $|s_1\rangle, |s_2\rangle$, and $|s_3\rangle$ must be ontically probable as well.

Again referring to Figure 26 and in contrast to PTI-B, now PTI-NB has one input ($|s\rangle$) and only two output channels, one entering detector 'B' and one entering detector 'NB'. The photon's states in the monolith and before the detectors are all co-extant ontically probable; its states after the two detectors are actual and, therefore, mutually exclusive (dotted-encircled 'a'). The relevant Milieu Bases are: MB-1 = $\{|b\rangle, |s_1\rangle\}$; MB-2 = $\{|nb\rangle, |s_2\rangle\}$; MB-3 = $\{|s_3\rangle\}$; MB-4 = $\{|s_4\rangle\}$; and the global MB-NB = $\{|b\rangle, |nb\rangle\}$. Their respective expansions are:

$$|s\rangle = \sqrt{(1-R)}e^{i\varphi_{t1}}|s_1\rangle + e^{i\varphi_{r1}}\sqrt{R}|b\rangle \quad ; \quad |s_1\rangle = \sqrt{(1-R)}e^{i\varphi_{t2}}|nb\rangle + e^{i\varphi_{r2}}\sqrt{R}|s_2\rangle$$

$$|s_2\rangle = e^{i(\varphi_3+\varphi_4)}|s_4\rangle \quad ; \quad |s_4\rangle = \sqrt{(1-R)}e^{i\varphi_{t1}}|b\rangle + e^{i\varphi_{r1}}\sqrt{R}|s_1\rangle$$

And, again, to predict the probabilities of interest, we need to express the photon's input state $|s\rangle$ in the global MB-NB. We started by expressing the photon's state in MB-1, its component $|s_1\rangle$ in MB-2, the latter's component $|s_2\rangle$ in MB-3 followed by MB-4. But, because of the feedback loop, the last expansion contains $|s_1\rangle$ again, so the whole process can iteratively be continued ad infinitum. From the experience we had handling the high-intensity steady-state case, and $\delta = \varphi_1 + \varphi_2 + \varphi_3 + \varphi_4$, it is straightforward to arrive at the same geometrical series and replace them by their closed-form limit arriving at:

$$|s\rangle = e^{i\varphi_{r1}}\left\{\frac{\sqrt{R}\left(e^{i\delta}-1\right)}{1-Re^{i\delta}}\right\}|b\rangle + e^{i\varphi_{t2}}\left\{\frac{(1-R)}{1-Re^{i\delta}}\right\}|nb\rangle$$

$$\Downarrow$$

$$Pr\left(|b\rangle/\overline{BOMB}\right) = \left|\frac{\sqrt{R}\left(e^{i\delta}-1\right)}{1-Re^{i\delta}}\right|^2 \quad ; \quad Pr\left(|nb\rangle/\overline{BOMB}\right) = \left|\frac{(1-R)}{1-Re^{i\delta}}\right|^2$$

From which we see that at resonance: $Pr\left(|b\rangle/\overline{BOMB}\right) = 0$ and $Pr\left(|nb\rangle/\overline{BOMB}\right) = 1$. And we already know from the analysis of the bomb case (GI-B) that $Pr(|b\rangle/BOMB) = R \xrightarrow[R\to 1]{} 1$ and

[108] If the photon is (due to non-ideal lossy devices) absorbed, there is simply no datapoint to consider.

that $Pr(|nb\rangle/BOMB) = (1-R)^2 \xrightarrow[R\to 1]{} 0$. Ergo, the B-detector clicks with high probability when there is a bomb in the cavity, practically does not click when there is no bomb, and the probability of exploding ($[1-R]R$) when there is a bomb is negligible.

As said, one of QR/TOPI's basic tenets is the absolute simultaneity between changes on a quanton's milieu and the effect on its state-transition PD. Therefore, the relationship between mi**i**cro and m**a**cro-worlds is subtler than a mere straightforward correspondence between intensity ratios and probabilities. In fact, Paul and Pavĭcić in [190] were clearly puzzled by the relation between the *resonance* established for high-intensity light only time-after reaching steady-state on one side and the one-at-a-time photon situation on the other. Using a Pockels cell[109] (to simulate the bomb rapidly being inserted/removed in/from the cavity), they proposed an experiment "which would decide whether sudden changing of boundary conditions" would redirect each photon to register in detector NB (instead of in detector B) "instantaneously (classically untenable) or after a delay which would allow for sufficiently many round trips to build up the interference". As we saw in Section 8.3, Branning et al published solid experimental evidence for the simultaneity between changes on the photon's milieu and the effect on its state-transition PD [179]. The *transient* needed for high-intensity light to reach *steady-state* seems to disappear for the single-photon regime.

Going back again to Bruce defense of Oxford's MWI, he says (my underscore):

BRUC3: … *we are now making use of a world that is in a sense ahead of our own in time, a world in which the photon will already have triggered the bomb if it is present. The importance of the monolithic reflector is that it delays a photon by trapping it, unmeasured, for a significant period—thus preserving communication with that other world…. You might be making use of information from worlds where, if a real bomb had been present, you would already have been dead.* [4]

And comparing the MOTTIR with quantum tunneling in which a 'particle' appears to tunnel faster than the speed of light, he resorts again to anthropic/information narratives (my underscore):

BRUC4: … *This is analogous to thinking that the photon in Figure 10-7 [the MOTIRR] must have gone faster than the speed of light in order to have had time to explore the region of space that contains the bomb. The truth is subtler: We are making use of information from other-worldly variants of the photon that traveled no faster than light, but simply left the source earlier.* [4]

Uncanny indeed. As we saw, under QR/TOPI, when there is ***no*** bomb, there is ***no*** direct relation between the resonant steady-state intensity inside the block if fed with high-intensity light on one side, and the probability of a single photon to circle the block on the other. In the ideal lossless case, upon the photon entering the MOTIRR, its probability to be reflected into the B-detector is nil and its probability to go out into the NB-detector is unity – tout court. The MOTIRR does not delay the photon "by trapping it, unmeasured, for a significant period—thus preserving communication with that other world". And, when there is a bomb, there is ***no*** optical circuit.

No wonder Bruce (to somehow convince us that MWI is the simplest way of understanding our Uni(Multi)verse) repeatedly in his book resorts to statements from the non-believer Zeilinger (now Nobel laureate) and to the fact that David Deutsch conceived of and made foundational contributions to quantum computing [192] [193] as early as in 1985 – based on his conviction that the only way to understand the massive (from the classical computers' point of view) parallelism

[109] A crystal whose refractive index is controllable by an electronic signal.

displayed by a quantic computer is through the existence of parallel universes. Deutsch claims in [123] that factorizing a 250-digit number with the Shor's algorithm involves in the order of 10^{500} "interfering universes", despite the algorithm requiring "only a few thousand arithmetic operations". His rationale is as follows:

DEUT3: *There are only about* 10^{80}*atoms in the entire visible universe, an utterly minuscule number compared to* 10^{500}. *So if the visible universe were the extend of physical reality, physical reality would not even remotely contain the resources required to factorize such a large number.*

With Zeilinger and Gisin, I am flabbergasted that there are scientists/philosophers who seriously believe in such a preposterous vision of Reality. But please, do not misunderstand me: though I resolutely disagree with the MWI, I fully agree with Deutsch when he says (my underscore): a) "There is indeed no logically necessary connection between truth and explanatory power"; b) "most relativists today understand Einstein's theory better than he did" and c) "The founders of quantum theory made a complete mess of understanding their own theory" [123]. I salute Einstein, all the founders of QT, as well as Deutsch, Zeilinger, Gisin, Bruce, and many others for their convictions and contributions, irrespective of whether they were (are) motivated by beliefs I personally consider non-verisimilar – in the same way the bizarre 'wheels and gears' approach employed by James Maxwell in the 1860s to understand and develop his celebrated equations cannot be used to weaken the importance and usefulness of his magnificent achievement.

9.5 Tetra-Quanton Phenomena: Teleportation/Cloning of Entanglement

A composite state can also be teleported by Nature – and by us if we use a modicum of signaling as we demonstrated we must for a single-quanton state. It was first proposed by Zukowski et al in 1993 under the name of "entanglement swapping" and experimentally realized by Pan et al in 1998. By then, the quality of the teleported composite state was not good enough to confirm the violation of a Bell's Inequality. Finally, such violation was achieved by Jennewein et al in 2001. All those authors were members of Zeilinger's team in Innsbruck [65].

Figure 28 shows two independent PEIs, PEI-1 and PEI-2 producing respectively two pairs of entangled photons $(iX, iY), i = 1,2$, with each pair encircled in solid green indicating the sub-quantons are in co-states of one Bell State $|s\rangle_i$ in $MB_i = \{|B1\rangle_i, |B2\rangle_i, |B3\rangle_i, |B4\rangle_i\},\ i = 1,2$. Being the PEIs fully independent, the tetra-composite state is $|s\rangle = |s\rangle_1 \otimes |s\rangle_2$. Two milieus for the four photons are made possible. In the first milieu, drawn in black-dotted lines, the two quantons in each pair go through two GIs, each of the four probable states morphing into actual states. This network is a standard double EPRB-type of setup (Figure 10) – albeit with photons. Upon repetition, statistical analysis of the whole dataset confirms that the quantons in each pair were entangled upon creation (dotted-encircled) but quantons in different pairs were ***not***, viz they were fully independent. The second milieu (in red) is the one we are interested in: two photons, one from each pair ($1Y$ and $2X$ to be referred to as the 'inner quantons') undergo a Bell Interaction and the other two (the 'outer quantons') go straight to their respective GIs with their arrival R-Times arranged to occur time-after the BI. This is similar to the anthropic teleportation setup in Figure 16 except that the then to-be-teleported quanton T is now not a mono-quanton in an isolated pure state but a sub-quanton in a co-state with another, i.e. entangled with another quanton: $1Y$ (entangled with $1X$) undergoes a BI with $2X$ (entangled with $2Y$).

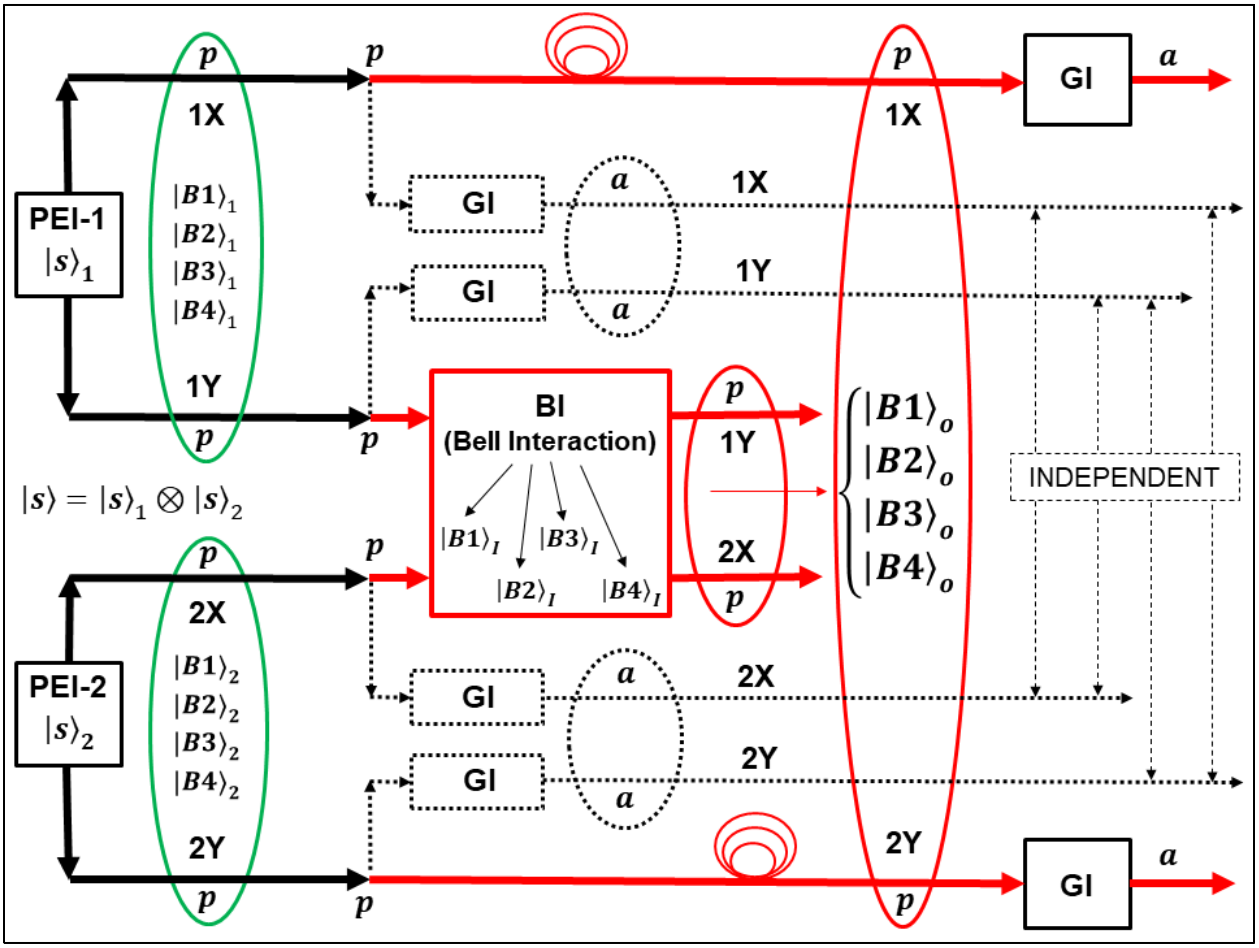

Figure 28 – Nature's Teleportation/Cloning of Entanglement

As we know, the BI is a GI whose PTI has the Milieu Basis $MB_I = \{|B1\rangle_I, |B2\rangle_I, |B3\rangle_I, |B4\rangle_I\}$, where here the sub-index 'I' stands for '**I**nner quantons'. Ergo, upon the PDI in the BI, one of those four probable bi-composite states comprising $1Y$ and $2X$ (encircled in solid red) becomes actual like quantons A and T did in Figure 16 (making quanton B's probable state also actual by *teleportation*). But now -before the PDI in the BI occurs- by virtue of the prior external entanglement with two other quantons, instead of a tri-composite state (A, B, T), a tetra-composite state $(1X, 1Y, 2X, 2Y)$ is formed – involving the outer photons. Hence, upon the BI's PDI, one bi-composite state in MB_I becomes actual at random while the outer photons ($1X$ and $2Y$ encircled in solid red) adopt by *teleportation* corresponding co-states of an actual bi-composite state in $MB_O = \{|B1\rangle_O, |B2\rangle_O, |B3\rangle_O, |B4\rangle_O\}$, where the subindex '$O$' stands for '**O**uter'. Note that these two bi-composite states are actual, while the co-states for their respective sub-quantons ($1Y$ with $2X$ and $1X$ with $2Y$) are probable – showing that what is *teleported* is not a state of a single-quanton as in Figure 16 but a composite entangler state between the outer quantons.

The entangler state randomly formed in the BI and the one teleported onto the outer photons are the result of State-Events, ergo actual, ***non***-*evincing*, and pinpointable in our RT-spacetime. By submitting the outer photons to GIs and, upon repetition, the statistical analysis proves they were indeed entangled. However (as in Figure 16), for a human being to avail of the latter entanglement resource, it would require that two bits (codifying which one of the four Bell States was randomly created in the BI) be transmitted via an RT-signal to the required place, from which the receiver (knowing also which Bell States were delivered by PEI-1 and PEI-2) could determine which is the particular Bell State the *outer* quantons are in. Notice as well that the *outer* quantons are entangled even though they were created by fully independent sources and never interacted directly one with another. Their entanglement is the result of *teleportation*.

This teleportation/cloning of entanglement is formally described in Appendix B, in which we see that -as long as the Bell States for the two input pairs are the same- the Bell State randomly adopted by the inner quantons is directly *teleported* onto the outer quantons, viz: the outer entangler state is a clone of the inner entangler state. Otherwise, when the Bell States for the two input pairs are different, the bi-composite state *teleported* to the outer quantons is different than the one randomly adopted by the inner quantons. Which one is *teleported* in each case is predicted in Appendix B. Now we will conceive a new milieu altering the R-Timing between events.

9.5.1 Zeilinger asks: How can two non-existent photons become entangled?

In his delightful book 'Dance of the Photons' [65], Zeilinger refers to an idea proposed by Asher Peres as "ghostly… rather strange, surprising, and elegant". Figure 29 shows basically the same topology with the same two milieus as in Figure 28 – though with minor changes to achieve a different R-Timing. The two GIs undergone by the *outer* photons are made (to stress the point) destructive (D-GI) and performed immediately after their creation by the two PEIs at Bob's Station. Having the outer photons been absorbed, only the results of the D-GIs can be sent to Alice's Station so that -for the milieu in black dotted lines- the *inner* photons undergo their own GIs and Alice, upon repetition and comparison of her data with Bob's data, finds out that (as in Figure 28) each of them were random by itself but entangled with its corresponding (also random by itself) *outer* photon. This is shown by the black-dotted encirclement of the respective records. Note that now the input states to these dotted GIs are both actual while before they were probable – albeit sans any experimental consequences: the GIs in Alice's Station being delayed with respect to their respective D-GIs in Bob's Station makes no difference (as long as the coherence requisites are not breached).

But, of course, we are interested in the second milieu (solid red) in which the BI now takes place well time-after the two *outer* photons ceased to exist, leaving only their records (in Alice's possession via RT-signaling). Zeilinger's team in Viena realized this gedankenexperiment with glass fibers in 2001 and later (in 2009) Xiaosong Ma et al made the choice at Alice's Station betwixt the black-dotted or red-solid milieus (a Milieu-Event) via a quantum random number generator spacelike-separated from Bob's Station. They found the same results as in the setup of Figure 28. What they found "ghostly" was that because the BI entangles its two input quantons, each one of which is entangled with another quanton, then the four quantons would become entangled only if -and after- the BI took place. But by the time the BI occurs, the two *outer* photons do not exist any longer so… how can they become entangled with the *inner* photons, adopting a specific entangler state? This is one more embodiment of Zeilinger's "very fundamental question", which he unsuccessfully attempts to answer in his book [65] and -per ZEIL2- seems to be still unresolved in 2024. In his book, Zeilinger states (my underscore):

ZEIL5: *So Alice can decide at a point in time when Bob's photons Y and B [outer photons 1X and 2Y in Figure 29] no longer exist, when their polarizations have already long ago been measured and the results written down somewhere, whether these photons are entangled or not. How can* *that be? How is this possible? Certainly, Alice's measurement [our BI] cannot act back into the past and influence the earlier measurement [our D-GIs] results on Bob's photons Y and B… Changes of written-down measurements records certainly do not happen.* [65]

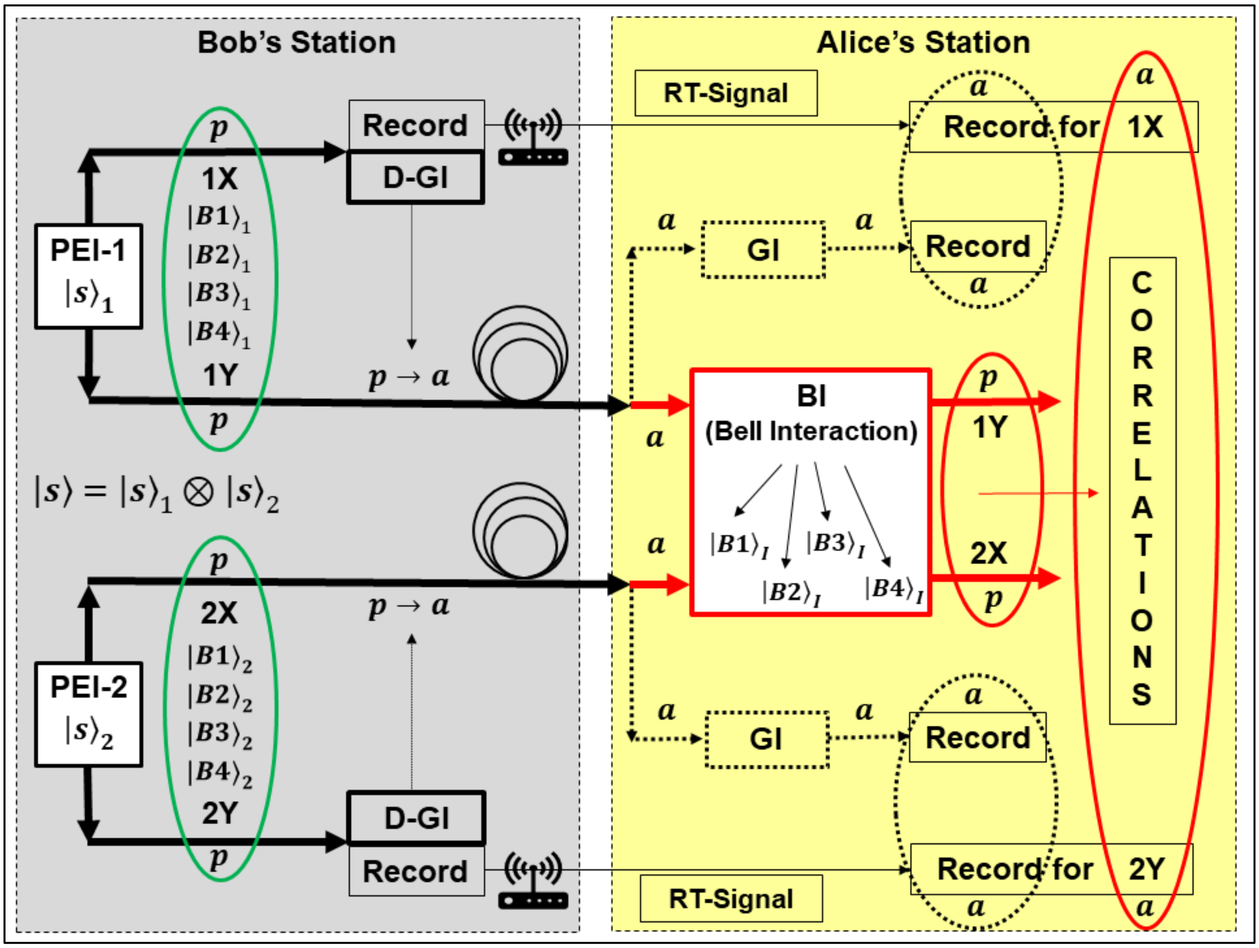

Figure 29 – Delayed Choice of Milieu

And contrasting our dotted-black and solid-red milieus, Zeilinger continues (my underscore):

ZEIL6: *On the other hand, Alice could decide to perform on her photons A and X [1Y and 2X in Figure 29] a joint Bell-State measurement [BI]… It entangles A and X. This means that Bob's photons B and Y [1X and 2Y] now become entangled also. But wait a minute, these two photons have already been registered by Bob, and the measurement results have been written down on a piece of paper or stored in a computer… How can the measurement results now reflect that B and Y are entangled, just because Alice decided to perform a Bell-State measurement on A and X? Even though before, when Alice measured her photons separately, Bob's photons B and Y were not entangled, their measurement results were completely uncorrelated? How is that possible?*

No wonder Zeilinger calls the situation "ghostly": combining ZEIL4 (Wheeler's quasar) and ZEIL5, he is bewildered to find out that two ***non***-existing photons "become entangled". He is conflating quantic entanglement with data correlation, and continues (my underscore):

ZEIL7: *Philosophically speaking, we have a very interesting situation. The data obtained by Bob long before Alice decided what kind of measurement to perform can be part of two completely* *different physical stories. The specific physical picture depends on Alice's later measurement. In a sense, the data have no story to tell before Alice makes her decision and does her measurement accordingly and this decides the meaning of Bob's data. One might very well say that Bob's data are a primary reality in no need of explanation. If we wish to have an explanation, we need to complete the experiment. This completion of the experiment requires Alice to make a decision that defines the meaning of the data already obtained.*

"Philosophically speaking", though he is a little more careful than he was in ZEIL4 because he talks about "physical stories" (instead of what "can become reality"), the above statements are wrong on many levels:

- Alice does ***not*** decide whether the *outer* photons are entangled or not: when Bob's *outer* quantons are 'measured' (undergo D-GIs) in advance to the BI, not only they cease to be entangled with their corresponding *inner* quantons but they decease, while the *inner* ones adopt actual states resulting from the actualization of each PEI's characteristic ITI (PEI-1 and PEI-2 may deliver different Bell States). The eigenvalues associated with these teleported eigenstates are related to the eigenvalues already recorded for the entangled quantons upon the D-GIs. Even if the GIs were not destructive (i.e. the *outer* quantons continued toward Alice's Station), the two entanglements would cease to exist, but -upon repetition- their datasets would be correlated. Because of the GIs, Figure 29 shows that -for each run- the two quantons entering the BI have actual states. Only if the GIs occurred time-after the BI (as in Figure 28), the original entanglement of the quanton pairs $(1X, 1Y)$ and $(2X, 2Y)$ would persist, and the states for quantons $1Y$ and $2X$ would be probable when entering the BI. Until those GIs occurred, the ITI for the tetra-composite quanton (with product state given by $|s\rangle = |s\rangle_1 \otimes |s\rangle_2$) would be preserved and, because the BI entangles $1Y$ with $2X$, which were respectively entangled with $1X$ and $2Y$, the latter (outer) quantons would become entangled as well. But the GIs occurred time-before the BI: *Entanglement* and *correlation* should not be conflated: the former occurs among quantons (no "ghosts" allowed); the latter between corresponding datasets obtained upon repetition of a given quanton/milieu setup. It is also important, as emphasized in Section 8.4, not to confuse a non-existent quanton (a "ghost") with an ontically probable quanton (to be empirically met in next section).
- Datasets are sets of datapoints, all of which -for a consistent assessment of their correlation- are to correspond to the same milieu. For each run, those datapoints may have been gathered at different times within the milieu, or even with different milieus (if the Milieu-Event establishing each milieu was randomly created). Alice's (or her random number generator's) decision to suddenly include a BI on the *inner* photons entails submitting state-related photons to a different milieu, so the new datapoints cannot be intermingled with those of the milieu experienced by the composite quanton when ***no*** BI existed. In the first case there is a correlation between the *outer* photons' datasets (whether in each run the *outer* photons exist or not by the time the BI occurs); in the second there is not. Furthermore, to confirm the entanglement of the outer photons via its associated correlation (Figure 28) or the same correlation without the outer photons' entanglement (Figure 29), datapoints corresponding to each one of the four possible Bell States delivered by the BI are to be distinguished. The sudden change of milieu produces a sudden change of probabilities for some or all of the subsequent events – in the same way that taking a m**a**croscopic pin off in Galton's quincunx right before being hit by the ball instantly alters it probability to eventually fall into a given bin [11].

- ➢ The outer-photons dataset for the milieu without the BI has a "physical story" and meaning per se (even if it comprises random subsets) – without a purported "completion" of the experiment. The dataset for the milieu with the BI only changes the physical meaning of the first dataset in terms of their mutual relationship. The inclusion of the BI by Alice simply provides a new dataset that when contrasted and adequately sorted together with Bob's data, allows them to discover a correlation which they knew did ***not*** exist when the BI was not part of the milieu. The BI dataset tells Bob and Alice the adequate partitions of the *outer* quantons datasets (one partition for each of the four Bell States randomly provided by the BI) within which four correlations betwixt them are exposed. And these data correlation sets are the same whether, for each run, the BI between the *inner* photons occurs R-Time after (Figure 29) or R-Time before (Figure 28) the GIs undergone by the *outer* photons. In the latter case, the *inner* photons entering the BI are in *co-states* (ergo probable); in the former case, they are in *pure* actual states. Their datasets reveal the same PDs in both cases.

9.6 Probable Quantons: The Delayed-Choice 'Quantum Eraser' via Entanglement

In Figure 24 we saw how the alleged "marking/erasing" of "which-slit information" can be attained by subjecting the quanton to the appropriate local PTIs. But then, as proposed by Scully and Drühl in 1982, were the quanton a sub-quanton of a composite quanton (i.e. were it entangled with another), the 'marking/erasing' could be the result of events occurring to its entangled twin – which could be arbitrarily spacetime-separated (as long as the coherence requisites were met). In the year 2000 Kim et al conducted such an *entanglement* variant of the "Delayed-Choice Quantum Eraser". From the philosophical viewpoint, the language used in their paper's Abstract says it all (underscore mine):

KIM1: ... *The experimental results demonstrated the possibility of simultaneously observing both particle-like and wave-like behavior of a quantum via quantum entanglement. The which-path or both-path information of a quantum can be erased or marked by its entangled twin even after the registration of the quantum.* [194]

In 2001, Walborn et al confidently spouses the same philosophical stance (underscore mine):

WALB1: *Therefore, it is enough that the which-path information is available to destroy interference. Moreover…, one can erase the which-path information and recover interference by correlating the particle detection with an appropriate measurement on the which-path markers. Such a measurement is known as quantum erasure. In addition, if the which-path marker is capable of storing information, the erasure can be performed even after the detection of the particle.* [195]

Figure 30 outlines in green a double-slit setup via a beam splitter BS_{DS} (left) to represent the actual Double-Slit screen and a detector D_{PP} (right) with two inputs to represent a detection spot on the Photographic Plate. As we know, clicks on different spots of the plate are equivalently obtained by changing the pathlength (and hence the relative phase) on one of the arms (symbolized by the coiled optic fiber). A distinctive feature in this setup is that the two arms reaching the detector D_{PP} are ***not*** connected to the two outputs of the BS_{DS} but coming from the outputs of two SPDCs, each of which transforms a photon of a given energy (frequency) into two photons each with half the energy. But even more unique is that the input to each of those two SPDCs is ***not*** a photon but one of the two probable states of the single photon entering BS_{DS} with an actual state. We will retain the heralding/heralded photon vocabulary we used before, so we can now talk about two pairs of heralding (red)/heralded (green) probable *photons* created from each one of the two probable states (green) of the referred actual input *photon*. Only upon the two green probable states morphing into one actual state, we can talk about one heralded actual photon and one heralding actual photon. Otherwise, there are two probable heralded photons with states $|s_{A1}\rangle, |s_{B2}\rangle$ and two probable heralding photons with states $|s_{A2}\rangle, |s_{B1}\rangle$. In this fashion, the interference pattern (if any) on the double-input green detector D_{PP} can be affected not only by the relative phase between $|s_{A1}\rangle$ and $|s_{B2}\rangle$ (as in a regular double-slit or MZI setups) but by the GI to which their respective entangled heralding states $|s_{A2}\rangle$ and $|s_{B1}\rangle$ are subjected to.

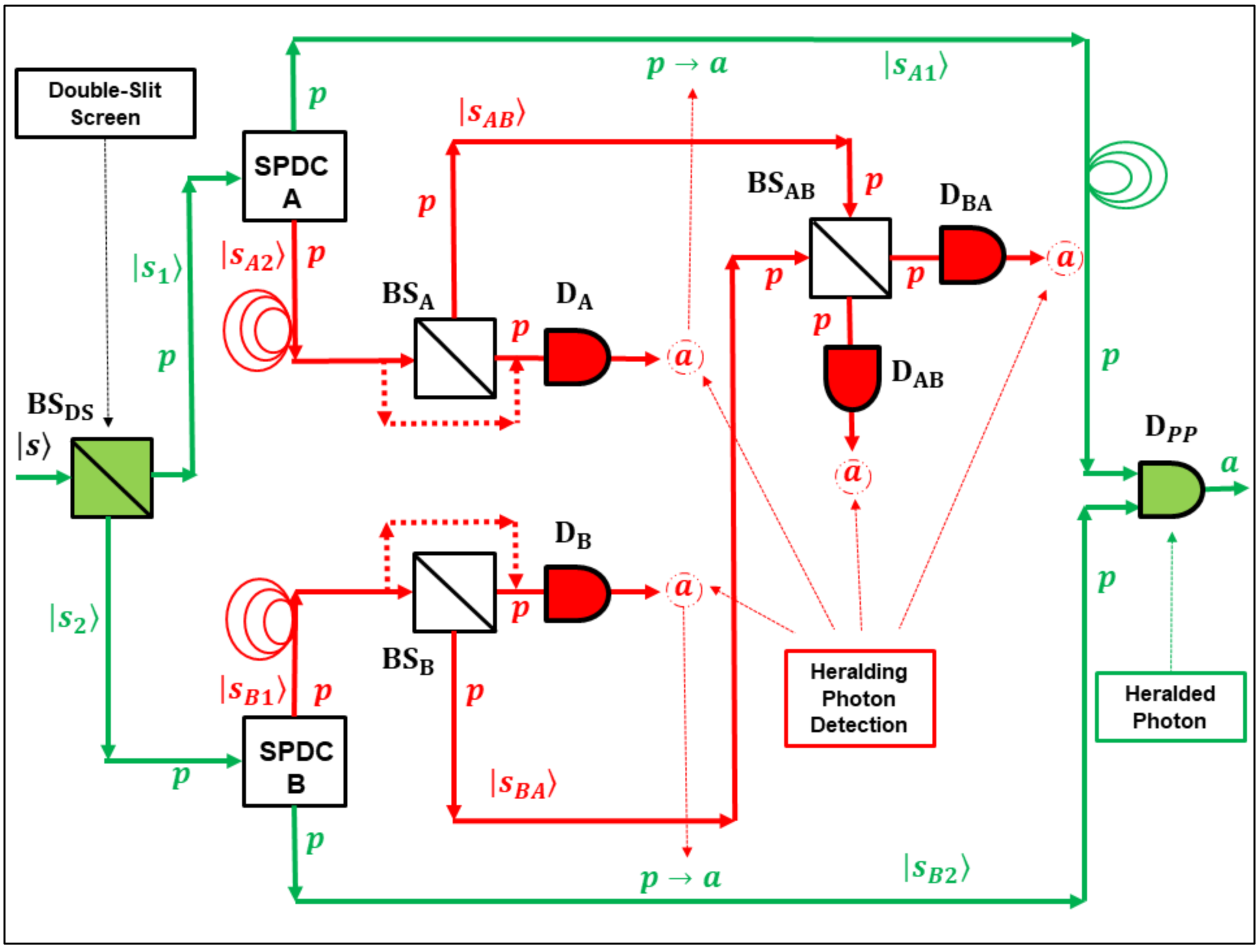

Figure 30 – Ontically Probable Quantons: Delayed Choice of Milieu via Entanglement

Referring to such a setup, once again in the 'anthropic/information/marking/erasing/wave-particle' language, Brian Greene in the Section "Shaping the Past" of his book "The Fabric of the Cosmos" [185], asserts (my underscore):

GREE2: *Before you have the results of the idler [heralding] photon measurements, you really can't say anything about the which-path history of any given signal [heralded] photon. However, once you have the results, you conclude that signal photons whose idler partners were successfully used to ascertain which-path information can be described as having—years earlier—traveled either left [upper] or right [lower]. You also conclude that signal photons whose idler partners had the which-path information erased cannot be described as having—years earlier—definitely gone one way or the other… We thus see that the future helps shape the story you tell of the past.*

I can certainly see why Greene states the above in his attempts to make the phenomena mysterious but intelligible. But, as I said before: "under the very same theory, the physical interpretation of what actually happened just now and here cannot depend on our future experimental caprice". I likewise reckon why Kim et al say that "The experimental results demonstrated the possibility of simultaneously observing both particle-like and wave-like behavior of a quantum via quantum entanglement", by which I believe they mean that some of the quantons allegedly passed through only one slit (no interference) and some through both slits (interference). It is also apparent what they mean when they say that the which-path information is 'erased' when there is interference. However, understanding what they mean is not the same as their providing a coherent physical meaning free of anthropic references.

Obviously, QR/TOPI rejects those contrived narratives: the quanton's current state plus its current milieu determine the PD for the next state, full stop. The analysis, description, and prediction for the setups implied in Figure 30 could of course be achieved using the same mathematical formalism we extensively used for previous setups (main text and appendices) but, as the last century has abundantly proved, formalisms are efficient for *prediction* but useless for *answering* Zeilinger's fundamental question. Therefore, as a coda to this already-long article and to demonstrate once again the conceptual power of QR/TOPI, I will qualitatively discuss this quantic system with its different milieus exclusively under the ontic basic categories of actual and probable *states* and, for the first time, also of actual and probable *quantons*.

Returning then to Figure 30, the heralding probable states $|s_{A2}\rangle$ and $|s_{B1}\rangle$ (in red) may be submitted to four different milieus so they can undergo four GIs: (1) GI-1 consisting in their straight detection, indicated by red-dotted lines going to $\mathrm{D_A}$ and $\mathrm{D_B}$ (after respectively bypassing $\mathrm{BS_A}$ and $\mathrm{BS_B}$), and the coiled optic fibers such that the PDI-Events at $\mathrm{D_A}$ and $\mathrm{D_B}$ occur time-before the PDI-Events at $\mathrm{D_{PP}}$; (2) GI-2, which is the same as GI-1 but with $\mathrm{D_A}$ and $\mathrm{D_B}$ firing time-after $\mathrm{D_{PP}}$; (3) GI-3 (red-solid) in which each heralding probable state enters a BS ($\mathrm{BS_A}$ or $\mathrm{BS_B}$) with one output going to a detector ($\mathrm{D_A}$ or $\mathrm{D_B}$) and the other to a third common BS ($\mathrm{BS_{AB}}$) and then detected by detectors $\mathrm{D_{AB}}$ and $\mathrm{D_{BA}}$; and (4) GI-4, which is the same as GI-3 but with detectors $\mathrm{D_A}, \mathrm{D_B}, \mathrm{D_{AB}}$, and $\mathrm{D_{BA}}$ firing time-after $\mathrm{D_{PP}}$.

In GI-1, because $\mathrm{D_A}(\mathrm{D_B})$ fires time-before $\mathrm{D_{PP}}$, being state $|s_{A2}\rangle(|s_{B1}\rangle)$ entangled with state $|s_{A1}\rangle(|s_{B2}\rangle)$, the latter state as well as state $|s_1\rangle(|s_2\rangle)$ morph from probable to actual, and state $|s_2\rangle(|s_1\rangle)$ dissociates from the input photon. Notice that $\mathrm{D_A}$ and $\mathrm{D_B}$ cannot click together because -due to entanglement- that would make both $|s_1\rangle$ and $|s_2\rangle$ actual – impossible for a single quanton. As long as the heralding detectors can only fire time-before $\mathrm{D_{PP}}$, a destructive $\mathrm{D_A}(\mathrm{D_B})$ on $|s_{A2}\rangle(|s_{B1}\rangle)$ acts as a ***non***-destructive PDI on $|s_{A1}\rangle(|s_{B2}\rangle)$ and $\mathrm{D_{PP}}$ receives only one actual state per run. Ergo, as explained many times throughout this series, the probability for $\mathrm{D_{PP}}$ to click is simply the sum of the two probabilities for $|s_{A1}\rangle$ and $|s_{B2}\rangle$ (the two red-dotted curves in Figure 24), giving rise to the red-solid curve: there is ***no*** interference.

However, not acting on a heralded but on a heralding state, $\mathrm{D_A}$ and $\mathrm{D_B}$ can now be arranged to click well time-after $\mathrm{D_{PP}}$ does (within the same IF by the coiled fiber or by changing the IF), creating the GI-2 milieu. But then, by the R-Time the heralding detectors have a chance to click/no-click, the heralded photon has been absorbed by $\mathrm{D_{PP}}$, which, given that it presumably had received two probable states, we could conclude that now interference would have occurred and there is nothing we can do about it, correct? NO: once again, the ITI associated with the common PTI for GI-1 and GI-2 constitutes a set of reciprocal probabilistic relations between probable states which evolve in QR-Sync with R-Time. When $\mathrm{D_{PP}}$ fires, $|s_{A1}\rangle$ and $|s_{B2}\rangle$ become actual with the states $|s_{A2}\rangle$ and $|s_{B1}\rangle$ of their respective entangled probable photons (as well as states $|s_1\rangle$ and $|s_2\rangle$ of the input actual photon) remaining co-extant probable. Note that this partial actualization of the ITI has occurred without $\mathrm{D_A}$ or $\mathrm{D_B}$ having fired yet (only $\mathrm{D_{PP}}$). Please realize as well that no changing of any past states occur because these are *teleportation* phenomena, so they are absolutely *simultaneous* with the firing of $\mathrm{D_{PP}}$ and (again): being the latter PDI-Event the only evincing actual event, there is no conflict with RT. In the future, only one of the two heralding detectors $\mathrm{D_A}$ or $\mathrm{D_B}$ will fire – otherwise states $|s_1\rangle$ and $|s_2\rangle$ would both be actual, which is impossible for a single quanton. As long as the coherence requisites remain valid, the ITI remains the same irrespective of the R-Timing between events, leaving all PDs invariant.

Summarizing for GI-1 and GI-2, whether we delay the firing of the heralding detectors or not, if looking at all datapoints without any sorting, we would find the red-solid curve in Figure 24; and when grouping the datapoints based on whether $\mathrm{D_A}$ or $\mathrm{D_B}$ fired, we would find the two red-dotted curves. In the stereotyped anthropic/informational language, by erroneously concluding that because $\mathrm{D_A(D_B)}$ clicked the input photon did actually travel the upper(lower) arm of the green $\mathrm{BS_{DS}}$, they would say that the availability of the which-path information destroyed interference.

GI-3 and GI-4 (solid red) are more interesting milieus because both heralding states $|s_{A2}\rangle$ and $|s_{B1}\rangle$ are combined in a fashion that such 'availability' of the 'which-path information' is lost, opening the door to the misguided notions of 'marking' and 'erasing' such information even after $\mathrm{D_{PP}}$ has fired (falsely implying *retrocausality*). Clearly, the conclusions for GI-1 and GI-2 would be still valid had we only added beam splitters $\mathrm{BS_A}$ and $\mathrm{BS_B}$ with the existing $\mathrm{D_A}$ and $\mathrm{D_B}$ and respectively explicit or implicit detection on the new outputs. The nuance appears when those two new outputs enter another beam splitter ($\mathrm{BS_{AB}}$) because now the firing of $\mathrm{D_{AB}}$ or $\mathrm{D_{BA}}$ time-before the firing of $\mathrm{D_{PP}}$ induces neither $|s_{A1}\rangle$ nor $|s_{B2}\rangle$ to change from probable to actual so, in either of those two cases interference is possible. It is also evident (as for GI-1 and GI-2) that, besides the detector $\mathrm{D_{PP}}$, only one of the four heralding detectors (red) can click in any given run – showing that there are only two actual quantons, despite existing (when the photon enters any of the four milieus) four probable photons.

Let us start with GI-3, i.e. when one of the four heralding detectors fires first. If it is $D_A(D_B)$, we conclude again that $|s_{A1}\rangle(|s_{B2}\rangle)$ becomes actual time-before reaching $\mathrm{D_{PP}}$ and there is ***no*** interference. Separating their datapoints based on which detector clicked, we have the red-dotted curves; not doing so we have the red-solid curve in Figure 24. But any statistically sound dataset will also contain the cases when D_{AB} fired and those when D_{BA} fired. In any of those two cases, the only teleportation that occurs is the one that ensures their mutually exclusive clicking as thoroughly explained in Section 4 – anything else would be inconsistent with the PTIs and their topology. The states $|s_{A1}\rangle, |s_{B2}\rangle$ as well as $|s_1\rangle, |s_2\rangle$ remain ontically probable opening the door for interference when $\mathrm{D_{PP}}$ occurs. But because anyone of the four heralding detectors randomly fire in any run, interference only is present within some data subsets so, to identify it, we need to organize the large set of datapoints by grouping them according to which detector fired. The data subsets corresponding to D_{AB} or D_{BA} will display interference; those corresponding to D_A or D_B will not. In general, the complete dataset will not show interference.

As for GI-4, namely when $\mathrm{D_A}$, $\mathrm{D_B}$, $\mathrm{D_{AB}}$, and $\mathrm{D_{BA}}$ can only click well time-after $\mathrm{D_{PP}}$ does, by the R-Time they have a chance to click/no-click, the heralded photon has been absorbed by $\mathrm{D_{PP}}$, which, given that it presumably had received two probable states, we could conclude that now interference would have occurred regardless of which one has clicked. Not true again: the ITI associated with the common PTI for GI-3 and GI-4 constitutes a set of reciprocal probabilistic relations between probable states which evolve in QR-Sync with R-Time. When $\mathrm{D_{PP}}$ fires, $|s_{A1}\rangle$ and $|s_{B2}\rangle$ become actual (they correspond to different photons), with the states $|s_{A2}\rangle$ and $|s_{B1}\rangle$ of their respective entangled probable photons (as well as states $|s_1\rangle$ and $|s_2\rangle$ of the input actual photon) remaining co-extant probable. Note again that this partial actualization of the ITI has occurred without none of the four heralding detectors having fired yet (only $\mathrm{D_{PP}}$, of which we have only data). Please realize as well that no changing of any past states occur because these are *teleportation* phenomena, so they are absolutely *simultaneous* with the firing of $\mathrm{D_{PP}}$ and (again): being the latter PDI-Event the only evincing actual event, there is no conflict with RT. In the future, only one of the four heralding detectors shall fire, triggering the adoption/dissociation as actual of either $|s_1\rangle$ or $|s_2\rangle$. The ITI remains the same irrespective of the R-Timing between events, leaving all PDs invariant. Nothing to erase.

Summarizing for GI-3 and GI-4, whether we delay the firing of the heralding detectors or not, if looking at all datapoints without any sorting, we would find a curve like the red-solid one in Figure 24; when grouping the datapoints based on whether D_A or D_B fired, we would find the two red-dotted curves; and when grouping the datapoints based on whether either D_{AB} or D_{BA} clicked, we would find a pattern like the black curve in Figure 24. Interference/no interference is revealed when the full dataset is appropriately sorted.

Conclusions

RT is all about *evincing* actual events, and Einstein did operationally 'define' R-Time accordingly. The problem with RT is its hidden Ontology: if a direct causal relation between two events is postulated to only occur in Nature when they are connectible via light-limited genidentical chains, inconsistencies when pretending to include *nonlocality* within RT are inevitable – simply because the time-order between *spacelike* events in RT is a mere IF-**co**variant convention. We have shown that if *Fatalism*, *Superdeterminism*, *Retrocausality*, and *Future-Input-Dependency* are rejected while *free will* (ours and Nature's) is embraced, experimental evidence compels us to accept that there exist some causal relations which are instantaneous, reciprocal, and symmetrical so they cannot be instantiated by genidentical chains of any finite speed. In those cases, 'cause' and 'effect' are merely pragmatic names. Also, we have proved via multiple experimental setups that we can introduce absolute simultaneity without going back to absolute space and time. On the other hand, the Lorentz Transformation in Einstein's RT rejects ***any*** absolute *simultaneity* so, given that actual ***non****-evincing* events ***do*** occur in our RT-spacetime displaying objective and unique relations of absolute simultaneity between them and with R-Events, we can only conclude that RT is incomplete.

QT is **in**complete not in the EPR sense but because it ignores: (a) *actual* but recordless events and their causal relations; (b) the reality of *probable* states/events in PTIs and their ITIs; and (c) IF-Invariant *simultaneity*. Ontic actual ***non****-evincing* events are a natural extension of R-Events (always actual and *evincing*); instead, ontic probable events are as objective and absolute, but always ***non****-evincing*. As for QT's relativistic character, not even QFT is fully relativistic and, ergo, has ***not*** resolved the frail "peaceful coexistence" betwixt QT and RT. This is because QFT tackles only the quanton's evolution between PDIs. To the effect, QR/TOPI completes RT and QT with *nonlocality,* sacrificing neither NRC nor IF-Invariance. There is no conflict with standard RT because ***no*** two distant R-Events can be absolutely simultaneous.

To fully integrate QT with RT, we merged all Frame-Invariant R-Events with those of QT, making up the QR-Events (all Frame-Invariant) and integrating them into the *Ontology*, *Foundation* and *Structure* of QR/TOPI. The Lorentz's Transformation (LT) is replaced with our Quantumlike Transformation (QLT). Thus, QR/TOPI is QLT-Invariant, with Lorentz-Invariance a major part of QLT-Invariance but not all of it: the latter includes what the former excludes: *nonlocality*. Another QR/TOPI's basic tenet is the absolute *simultaneity* between changes on a quanton's milieu and the effect on its state-transition PD. Therefore, the relationship between m**i**cro and m**a**cro-worlds is subtler than a mere straightforward correspondence between high-intensity ratios and probabilities. This integration is a sine qua non for -and the first step to- eventually succeeding in the century-long failed attempts to do the same with GRT.

In QR/TOPI absolute and relative *simultaneity* coexist coherently without conflict. The bedrock under the notion of *Relativity* is: (a) IF-Invariance, ***not*** the choice of a particular type of transformation to achieve it (e.g. Galilean in Newton's world or LT in Einstein's world); and (b) the symmetrical reciprocity displayed by the LT (and the Galilean) betwixt two IFs, which makes it impossible to determine which one is moving. QLT does ***not*** break RT's hallmark symmetry because the spacetime coordinates of any pair of actual evincing events still transform via the LT. Besides, when LT by itself fails, QLT also displays the needed symmetrical reciprocity – as its operational description and the symmetry of the LT's velocity composition reveal. It is the wealth of empirical evidence acquired over a century in the m**i**croworld that unveils QLT as the correct transformation, instead of LT. Nonetheless, LT remains triumphant as the heart of QLT – as it should, given the tremendous empirical success of Einstein's Special Relativity Theory.

In contrast to the status quo, under QR/TOPI, the quanton's current *state* and *milieu* are independent. The current *milieu* may seem to change the current *state*, but it does ***not***; the *milieu* only changes the MB, i.e. that unique *representation* for the current ontic *state* which exposes the PD for the next *state* via the simple Born Rule. The *physical* state is non-contextual simply because it includes all possible contexts; its *mathematical* representation using the MB is the one that is different for each context (milieu). Different milieus entail different MBs but the reality of the quanton's *state* is prior to, and independent of, any future PI. And being the *current* state all-inclusive in the above sense, all *next* states in all possible MBs and all state-transition PDs are determining parts of the *current* state and, ergo, ontic as well. The terms 'previous', 'current', and 'next' in a state-transition equation refer to QR-Time because some or all of the states can be ontically probable; only when they are actual their meanings agree with R-Time. Hence, the quanton's *state* transition PD for a *milieu* to be established in the future depends upon such future *milieu* and the quanton's *state* by ***then***. Ergo, QR/TOPI fully respects Bell's 'Free Will' (*free will* + NRC) and it is ***neither*** deterministic, ***nor*** epistemically stochastic, ***nor*** Retrocausal, ***nor*** 'Future-Input-Dependent', ***nor*** 'Superdeterministic' – much less *fatalistic*.

Analyzing a potpourri of experimental setups under QR/TOPI, we answered Zeilinger's basic question: "what does this really mean in a basic way?" Among the many conclusions, we learned that (and explained why) entanglement and its associated data correlations are different; that our experimental decision "here and now" cannot affect whether a photon emitted eons ago "passes on both sides of the galaxy" or goes via only one side; that there is nothing to erase in the past because the quanton is neither a wave nor a particle; and so forth. The quanton's current *state* and *milieu* determine the PD for its next *state*, tout court.

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APPENDIX A

At-Will Teleportation/Cloning of a Pure Single State

For the three quantons $A, B,$ and T in their original individual subspaces we can state:

$\mathbf{S}_{\boldsymbol{T}}: |s_T\rangle = s_{T1}|s_{T1}\rangle + s_{T2}|s_{T2}\rangle$; $\mathbf{S}_{\boldsymbol{A}}: |s_A\rangle = s_{A1}|s_{A1}\rangle + s_{A2}|s_{A2}\rangle$; $\mathbf{S}_{\boldsymbol{B}}: |s_B\rangle = s_{B1}|s_{B1}\rangle + s_{B2}|s_{B2}\rangle$

The entangler state between quantons A and B in $S_A \otimes S_B$ is mutually agreed on and set up in advance by Alice and Bob. It could be any of the four maximally entangled Bell states:

$$|B1\rangle_{AB} = \frac{\sqrt{2}}{2}\{|s_{A1}\rangle|s_{B2}\rangle - |s_{A2}\rangle|s_{B1}\rangle\} \quad ; \quad |B2\rangle_{AB} = \frac{\sqrt{2}}{2}\{|s_{A1}\rangle|s_{B2}\rangle + |s_{A2}\rangle|s_{B1}\rangle\}$$
$$|B3\rangle_{AB} = \frac{\sqrt{2}}{2}\{|s_{A1}\rangle|s_{B1}\rangle - |s_{A2}\rangle|s_{B2}\rangle\} \quad ; \quad |B4\rangle_{AB} = \frac{\sqrt{2}}{2}\{|s_{A1}\rangle|s_{B1}\rangle + |s_{A2}\rangle|s_{B2}\rangle\} \qquad (A1)$$

Because they constitute a basis for $S_A \otimes S_B$, we can invert Equations A1 to obtain:

$$|s_{A1}\rangle|s_{B2}\rangle = \frac{\sqrt{2}}{2}\{|B1\rangle_{AB} + |B2\rangle_{AB}\} \quad ; \quad |s_{A2}\rangle|s_{B1}\rangle = \frac{\sqrt{2}}{2}\{|B2\rangle_{AB} - |B1\rangle_{AB}\}$$
$$|s_{A1}\rangle|s_{B1}\rangle = \frac{\sqrt{2}}{2}\{|B3\rangle_{AB} + |B4\rangle_{AB}\} \quad ; \quad |s_{A2}\rangle|s_{B2}\rangle = \frac{\sqrt{2}}{2}\{|B4\rangle_{AB} - |B3\rangle_{AB}\} \qquad (A2)$$

Likewise, the Bell states $|B1\rangle_{TA}, |B2\rangle_{TA}, |B3\rangle_{TA}, |B4\rangle_{TA}$ in $S_T \otimes S_A$ are the eigenstates in terms of which any other basis can be spanned, videlicet:

$$|s_{T1}\rangle|s_{A2}\rangle = \frac{\sqrt{2}}{2}\{|B1\rangle_{TA} + |B2\rangle_{TA}\} \quad ; \quad |s_{T2}\rangle|s_{A1}\rangle = \frac{\sqrt{2}}{2}\{|B2\rangle_{TA} - |B1\rangle_{TA}\}$$
$$|s_{T1}\rangle|s_{A1}\rangle = \frac{\sqrt{2}}{2}\{|B3\rangle_{TA} + |B4\rangle_{TA}\} \quad ; \quad |s_{T2}\rangle|s_{A2}\rangle = \frac{\sqrt{2}}{2}\{|B4\rangle_{TA} - |B3\rangle_{TA}\} \qquad (A3)$$

Being independent, the composite state for the three quantons is the tensor product between the state to be teleported $|s_T\rangle$ and the Bell State in which quantons A and B were set a priori. Let us assume for reasoning purposes that, as shown in Figure 16, the latter is $|B3\rangle_{AB}$ (Equations A1) so the composite state $|s\rangle$ for the three quantons is:

$$|s\rangle = |s_T\rangle \otimes |B3\rangle_{AB} = \{s_{T1}|s_{T1}\rangle + s_{T2}|s_{T2}\rangle\} \otimes \left\{\frac{\sqrt{2}}{2}[|s_{A1}\rangle|s_{B1}\rangle - |s_{A2}\rangle|s_{B2}\rangle]\right\} \qquad (A4)$$

Distributing the tensor product, grouping the eigenvectors from S_T with those from S_A, and expressing their products in terms of the Bell Basis in $S_T \otimes S_A$ (Equations A3), we get:

$$|s\rangle = \frac{1}{2}|B1\rangle_{TA} \otimes \{s_{T1}|s_{B2}\rangle - s_{T2}|s_{B1}\rangle\} + \frac{1}{2}|B2\rangle_{TA} \otimes \{s_{T1}|s_{B2}\rangle + s_{T2}|s_{B1}\rangle\} +$$

$$+\frac{1}{2}|B3\rangle_{TA} \otimes \{s_{T1}|s_{B1}\rangle + s_{T2}|s_{B2}\rangle\} + \frac{1}{2}|B4\rangle_{TA} \otimes \{s_{T1}|s_{B1}\rangle - s_{T2}|s_{B2}\rangle\} \qquad (A5)$$

Equations A4 and A5 represent the same tri-quanton composite state $|s\rangle$ in different bases: the former combines the basis of S_T with the Bell's eigenstate $|B3\rangle$ of $S_A \otimes S_B$; the latter combines the Bell Basis of $S_T \otimes S_A$ with the basis of S_B.

Looking at Equation A5, we first notice that the components of the third state in curly brackets are precisely those of the state $|s_T\rangle$ in S_T, while the corresponding eigenstates are those of S_B. This means that, were quanton B in such a state, it would be in the same state as the state in which quanton T originally was, i.e. the state of the latter would have been *teleported* onto the former. Let us denote such **d**esired state of quanton B by $|\boldsymbol{ds_B}\rangle$. Second, $|\boldsymbol{ds_B}\rangle$ appears together with $|B3\rangle_{TA}$, which is the homologous in $S_T \otimes S_A$ to the Bell State $|B3\rangle_{AB}$ in $S_A \otimes S_B$ that Alice and Bob agreed upon beforehand for the result of the a priori PEI entangling A with B. It is not hard to prove that had Alice and Bob chosen another Bell State for the prearranged entanglement between A and B (Equations A1), $|\boldsymbol{ds_B}\rangle$ would have appeared together with the homologous Bell State (Equations A3). As for the other three states of quanton B in curly brackets, they are unitary transformations of $|\boldsymbol{ds_B}\rangle$ (rotations in the Bloch sphere of S_B). Denoting those three **un**desired states by $|u1s_B\rangle, |u2s_B\rangle$ and $|u3s_B\rangle$, Equation A5 becomes:

$$|s\rangle = \frac{1}{2}|B1\rangle_{TA} \otimes |u1s_B\rangle + \frac{1}{2}|B2\rangle_{TA} \otimes |u2s_B\rangle + \frac{1}{2}|B3\rangle_{TA} \otimes |\boldsymbol{ds_B}\rangle + \frac{1}{2}|B4\rangle_{TA} \otimes |u4s_B\rangle \qquad (A6)$$

Equation A6 shows that the four eigenstates in the Bell Basis of $S_T \otimes S_A$ are entangled with four specific states for the quanton B – one desired and three undesired. Ergo, upon the PDI-Event in the BI (Figure 16), the composite state $|s\rangle$ adopts with equal probability of 25% (0.5^2) one of those four tri-quanton states, each one containing a corresponding state ($|u1s_B\rangle, |u2s_B\rangle, |\boldsymbol{ds_B}\rangle$ or $|u4s_B\rangle$) for quanton B. Finally, implementing the hardware to identify which one of the four probable Bell States becomes actual, determines which state has been teleported to quanton B while traveling, stipulating the classical signal that must be transmitted to Bob's station to transform (if needed) the state of quanton B into the state quanton T was originally in.

APPENDIX B

Teleportation of Entanglement

Referring to Figures 28 and 29, for the two pairs of quantons $iX, iY, i = 1, 2$ in their original individual subspaces we can state:

$$\mathbf{S}_{\boldsymbol{X}}^{\boldsymbol{i}}\colon \; |s_X^i\rangle = s_{X1}^i|s_{X1}^i\rangle + s_{X2}^i|s_{X2}^i\rangle \;\; ; \; \mathbf{S}_{\boldsymbol{Y}}^{\boldsymbol{i}}\colon \; |s_Y^i\rangle = s_{Y1}^i|s_{Y1}^i\rangle + s_{Y2}^i|s_{Y2}^i\rangle \quad i = 1, 2$$

The four Bell States for the quantons iX and iY in $S_X^i \otimes S_Y^i,\; i = 1, 2$ are:

$$|s\rangle_i = |B1\rangle_i = \frac{\sqrt{2}}{2}\{|s_{X1}^i\rangle|s_{Y2}^i\rangle - |s_{X2}^i\rangle|s_{Y1}^i\rangle\} \;\; ; \;\; |s\rangle_i = |B2\rangle_i = \frac{\sqrt{2}}{2}\{|s_{X1}^i\rangle|s_{Y2}^i\rangle + |s_{X2}^i\rangle|s_{Y1}^i\rangle\}$$
$$(B1)$$
$$|s\rangle_i = |B3\rangle_i = \frac{\sqrt{2}}{2}\{|s_{X1}^i\rangle|s_{Y1}^i\rangle - |s_{X2}^i\rangle|s_{Y2}^i\rangle\} \;\; ; \;\; |s\rangle_i = |B4\rangle_i = \frac{\sqrt{2}}{2}\{|s_{X1}^i\rangle|s_{Y1}^i\rangle + |s_{X2}^i\rangle|s_{Y2}^i\rangle\}$$

If the choice of milieu is the one in red, the MB for the BI undergone by the inner quantons $2X$ and $1Y$ is the Bell Basis in $\boldsymbol{S}_{\boldsymbol{X}}^{\boldsymbol{2}} \otimes \boldsymbol{S}_{\boldsymbol{Y}}^{\boldsymbol{1}}$:

$$|B1\rangle_I = \frac{\sqrt{2}}{2}\{|s_{X1}^2\rangle|s_{Y2}^1\rangle - |s_{X2}^2\rangle|s_{Y1}^1\rangle\} \;\; ; \;\; |B2\rangle_I = \frac{\sqrt{2}}{2}\{|s_{X1}^2\rangle|s_{Y2}^1\rangle + |s_{X2}^2\rangle|s_{Y1}^1\rangle\}$$
$$(B2)$$
$$|B3\rangle_I = \frac{\sqrt{2}}{2}\{|s_{X1}^2\rangle|s_{Y1}^1\rangle - |s_{X2}^2\rangle|s_{Y2}^1\rangle\} \;\; ; \;\; |B4\rangle_I = \frac{\sqrt{2}}{2}\{|s_{X1}^2\rangle|s_{Y1}^1\rangle + |s_{X2}^2\rangle|s_{Y2}^1\rangle\}$$

For future reference, the Bell Basis in the space-state $\boldsymbol{S}_{\boldsymbol{X}}^{\boldsymbol{1}} \otimes \boldsymbol{S}_{\boldsymbol{Y}}^{\boldsymbol{2}}$ of the outer quantons $1X$ and $2Y$ (Figures 23 and 24) are:

$$|B1\rangle_O = \frac{\sqrt{2}}{2}\{|s_{X1}^1\rangle|s_{Y2}^2\rangle - |s_{X2}^1\rangle|s_{Y1}^2\rangle\} \;\; ; \;\; |B2\rangle_O = \frac{\sqrt{2}}{2}\{|s_{X1}^1\rangle|s_{Y2}^2\rangle + |s_{X2}^1\rangle|s_{Y1}^2\rangle\}$$
$$(B3)$$
$$|B3\rangle_O = \frac{\sqrt{2}}{2}\{|s_{X1}^1\rangle|s_{Y1}^2\rangle - |s_{X2}^1\rangle|s_{Y2}^2\rangle\} \;\; ; \;\; |B4\rangle_O = \frac{\sqrt{2}}{2}\{|s_{X1}^1\rangle|s_{Y1}^2\rangle + |s_{X2}^1\rangle|s_{Y2}^2\rangle\}$$

Inverting Equations B2 the bi-composite eigenstates in the state-space $\boldsymbol{S}_{\boldsymbol{X}}^{\boldsymbol{2}} \otimes \boldsymbol{S}_{\boldsymbol{Y}}^{\boldsymbol{1}}$ can be spanned in terms of its Bell Basis and are:

$$|s_{X1}^2\rangle|s_{Y2}^1\rangle = \frac{\sqrt{2}}{2}\{|B1\rangle_I + |B2\rangle_I\} \quad ; \quad |s_{X2}^2\rangle|s_{Y1}^1\rangle = \frac{\sqrt{2}}{2}\{|B2\rangle_I - |B1\rangle_I\}$$
$$(B4)$$
$$|s_{X1}^2\rangle|s_{Y1}^1\rangle = \frac{\sqrt{2}}{2}\{|B3\rangle_I + |B4\rangle_I\} \quad ; \quad |s_{X2}^2\rangle|s_{Y2}^1\rangle = \frac{\sqrt{2}}{2}\{|B4\rangle_I - |B3\rangle_I\}$$

There are 10 different tetra-composite input states $|s\rangle$, one for each pair of bi-composite Bell States created by the two PEIs in Figures 23 and 24. And being the two PEIs independent, $|s\rangle$ is simply the tensor product between the two chosen Bell States (Equations B1). For example, assuming that the entangler state of the two quantons out of both PEIs is $|B1\rangle$, the state $|s\rangle$ for the four quantons is the tensor product between those two bi-composite states:

$$|s\rangle = |B1\rangle_1 \otimes |B1\rangle_2 = \frac{\sqrt{2}}{2}\{|s_{X1}^1\rangle|s_{Y2}^1\rangle - |s_{X2}^1\rangle|s_{Y1}^1\rangle\} \otimes \frac{\sqrt{2}}{2}\{|s_{X1}^2\rangle|s_{Y2}^2\rangle - |s_{X2}^2\rangle|s_{Y1}^2\rangle\} \quad (B5)$$

Below, we tediously though straightforwardly distribute the tensor product, group the eigenstates from $\boldsymbol{S_X^2}$ with those from $\boldsymbol{S_Y^1}$ (underscored <u>inner</u> quantons), express their products in terms of the Bell Basis in $\boldsymbol{S_X^2} \otimes \boldsymbol{S_Y^1}$ (Equations B4), and identify the Bell Basis in $\boldsymbol{S_X^1} \otimes \boldsymbol{S_Y^2}$ (Equations B3 for the underscored <u>outer</u> quantons):

$$|s\rangle = \frac{1}{2}\left\{|s_{X1}^1\rangle\underline{|s_{Y2}^1\rangle|s_{X1}^2\rangle}|s_{Y2}^2\rangle - |s_{X1}^1\rangle\underline{|s_{Y2}^1\rangle|s_{X2}^2\rangle}|s_{Y1}^2\rangle - |s_{X2}^1\rangle\underline{|s_{Y1}^1\rangle|s_{X1}^2\rangle}|s_{Y2}^2\rangle + |s_{X2}^1\rangle\underline{|s_{Y1}^1\rangle|s_{X2}^2\rangle}|s_{Y1}^2\rangle\right\}$$

$$\Downarrow$$

$$|s\rangle = \frac{1}{2}\left\{|s_{X1}^1\rangle|s_{Y2}^2\rangle\frac{\sqrt{2}}{2}(B1_I + B2_I) - |s_{X1}^1\rangle|s_{Y1}^2\rangle\frac{\sqrt{2}}{2}(B4_I - B3_I) - |s_{X2}^1\rangle|s_{Y2}^2\rangle\frac{\sqrt{2}}{2}(B3_I + B4_I) + |s_{X2}^1\rangle|s_{Y1}^2\rangle\frac{\sqrt{2}}{2}(B2_I - B1_I)\right\}$$

$$\Downarrow$$

$$|s\rangle = \frac{1}{2}\left\{B1_I\,\underline{\frac{\sqrt{2}}{2}(|s_{X1}^1\rangle|s_{Y2}^2\rangle - |s_{X2}^1\rangle|s_{Y1}^2\rangle)} + B2_I\,\underline{\frac{\sqrt{2}}{2}(|s_{X1}^1\rangle|s_{Y2}^2\rangle + |s_{X2}^1\rangle|s_{Y1}^2\rangle)} + B3_I\,\underline{\frac{\sqrt{2}}{2}(|s_{X1}^1\rangle|s_{Y1}^2\rangle - |s_{X2}^1\rangle|s_{Y2}^2\rangle)} - B4_I\,\underline{\frac{\sqrt{2}}{2}(|s_{X1}^1\rangle|s_{Y1}^2\rangle + |s_{X2}^1\rangle|s_{Y2}^2\rangle)}\right\}$$

$$\Downarrow$$

$$|s\rangle = +\tfrac{1}{2}|B1\rangle_I \otimes |B1\rangle_O + \tfrac{1}{2}|B2\rangle_I \otimes |B2\rangle_O + \tfrac{1}{2}|B3\rangle_I \otimes |B3\rangle_O - \tfrac{1}{2}|B4\rangle_I \otimes |B4\rangle_O \quad (B6)$$

Equations B5 and B6 represent the same tetra-quanton composite state $|s\rangle$ in different bases: the former combines the Bell's eigenstate $|B1\rangle_1$ of $\boldsymbol{S_X^1} \otimes \boldsymbol{S_Y^1}$ with $|B1\rangle_2$ of $\boldsymbol{S_X^2} \otimes \boldsymbol{S_Y^2}$; the latter combines the Bell Basis of $\boldsymbol{S_X^2} \otimes \boldsymbol{S_Y^1}$ (the inner quantons entering the BI) with the Bell Basis of $\boldsymbol{S_X^1} \otimes \boldsymbol{S_Y^2}$ (the outer quantons) – telling us that when the PDI in the BI delivers with equal 25% probability one of the bi-composite states in $\{|B1\rangle_I, |B2\rangle_I, |B3\rangle_I, |B4\rangle_I\}$, the outer quantons adopt by teleportation the same Bell State in $\{|B1\rangle_O, |B2\rangle_O, |B3\rangle_O, |B4\rangle_O\}$.

With the same procedure for the other nine combinations delivered by the two PEIs, we have:

$$|s\rangle = |B2\rangle_1 \otimes |B2\rangle_2$$
$$\Downarrow \quad (B7)$$
$$|s\rangle = +\frac{1}{2}|B1\rangle_I \otimes |B1\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B2\rangle_O - \frac{1}{2}|B3\rangle_I \otimes |B3\rangle_O + \frac{1}{2}|B4\rangle_I \otimes |B4\rangle_O$$

$$|s\rangle = |B3\rangle_1 \otimes |B3\rangle_2$$
$$\Downarrow \quad (B8)$$
$$|s\rangle = +\frac{1}{2}|B1\rangle_I \otimes |B1\rangle_O - \frac{1}{2}|B2\rangle_I \otimes |B2\rangle_O + \frac{1}{2}|B3\rangle_I \otimes |B3\rangle_O + \frac{1}{2}|B4\rangle_I \otimes |B4\rangle_O$$

$$|s\rangle = |B4\rangle_1 \otimes |B4\rangle_2$$
$$\Downarrow \quad (B9)$$
$$|s\rangle = -\frac{1}{2}|B1\rangle_I \otimes |B1\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B2\rangle_O + \frac{1}{2}|B3\rangle_I \otimes |B3\rangle_O + \frac{1}{2}|B4\rangle_I \otimes |B4\rangle_O$$

We see that, when the two bi-composite states are in an arbitrary but the <u>same</u> Bell State, the outer quantons are entangled in the <u>same</u> Bell State as the randomly adopted by the inner quantons at the BI. Now let us do the same calculation when the two bi-composite states differ.

$$\begin{gathered} |s\rangle = |B1\rangle_1 \otimes |B2\rangle_2 \\ \Downarrow \\ |s\rangle = +\frac{1}{2}|B1\rangle_I \otimes |B2\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B1\rangle_O - \frac{1}{2}|B3\rangle_I \otimes |B4\rangle_O + \frac{1}{2}|B4\rangle_I \otimes |B3\rangle_O \end{gathered} \tag{B10}$$

$$\begin{gathered} |s\rangle = |B1\rangle_1 \otimes |B3\rangle_2 \\ \Downarrow \\ |s\rangle = +\frac{1}{2}|B1\rangle_I \otimes |B3\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B4\rangle_O + \frac{1}{2}|B3\rangle_I \otimes |B1\rangle_O - \frac{1}{2}|B4\rangle_I \otimes |B2\rangle_O \end{gathered} \tag{B11}$$

$$\begin{gathered} |s\rangle = |B1\rangle_1 \otimes |B4\rangle_2 \\ \Downarrow \\ |s\rangle = +\frac{1}{2}|B1\rangle_I \otimes |B4\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B3\rangle_O - \frac{1}{2}|B3\rangle_I \otimes |B2\rangle_O + \frac{1}{2}|B4\rangle_I \otimes |B1\rangle_O \end{gathered} \tag{B12}$$

$$\begin{gathered} |s\rangle = |B2\rangle_1 \otimes |B3\rangle_2 \\ \Downarrow \\ |s\rangle = +\frac{1}{2}|B1\rangle_I \otimes |B4\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B3\rangle_O + \frac{1}{2}|B3\rangle_I \otimes |B2\rangle_O - \frac{1}{2}|B4\rangle_I \otimes |B1\rangle_O \end{gathered} \tag{B13}$$

$$\begin{gathered} |s\rangle = |B2\rangle_1 \otimes |B4\rangle_2 \\ \Downarrow \\ |s\rangle = +\frac{1}{2}|B1\rangle_I \otimes |B3\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B4\rangle_O - \frac{1}{2}|B3\rangle_I \otimes |B1\rangle_O + \frac{1}{2}|B4\rangle_I \otimes |B2\rangle_O \end{gathered} \tag{B14}$$

$$\begin{gathered} |s\rangle = |B3\rangle_1 \otimes |B4\rangle_2 \\ \Downarrow \\ |s\rangle = -\frac{1}{2}|B1\rangle_I \otimes |B2\rangle_O + \frac{1}{2}|B2\rangle_I \otimes |B1\rangle_O + \frac{1}{2}|B3\rangle_I \otimes |B4\rangle_O + \frac{1}{2}|B4\rangle_I \otimes |B3\rangle_O \end{gathered} \tag{B15}$$

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