Disproof of observational claims regarding ultrashort-lived unstable particles

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Abstract — The physics literature contains many claims that ultrashort-lived unstable particles have been observed. These claims are a matter of applying the so-called 5σ-convention: an observation of an ultrashort-lived unstable particle can be claimed when the condition is satisfied that its predicted decay products have been observed with a significance of 5σ. This paper, however, shows that it is simply not true that these ultrashort-lived unstable particles have been "observed": what is claimed to be an observation is an *act of reasoning*, not an *act of the senses*—this category mistake is laid bare by rigorously proving in a suitable frame for modal propositional logic that the condition laid down in the 5σ-convention is *insufficient* for an observational claim. The main implication is that such observational claims have to be dismissed as overstatements. A further implication is expressed by two incompleteness theorems for physics, respectively stating (i) that experiments cannot prove completeness of a physical theory predicting ultrashort-lived unstable particles, and (ii) that experiments cannot prove correctness of such a theory—one can at most test its empirical adequacy. On a general note, the conclusion is that the importance of analytical-philosophical arguments for physics is herewith demonstrated.

1 Introduction

In recent years, the claim that a Higgs boson has been observed at the LHC has had an enormous impact on the physics community. Chronologically, at a press conference at CERN in 2012 where the preliminary results of the hunt on the Higgs boson were presented, first the claim was made that "we have observed a new boson with a mass of 125.3 ± 0.6 GeV at 4.9σ significance"; see Figure 1. This claim was repeated in two papers in *Physics Letters B*: in these papers, "observation of a new boson" and "observation of a new particle" was claimed right in the titles [1, 2]. These claims were followed by the claim that the new boson is indeed the Higgs boson [3]. The leading journals *Science* and *Nature* hailed the discovery of the Higgs boson as the "Breakthrough of the Year" [4] and "the biggest particle-physics discovery in a generation" [5]. In addition, the 2013 Nobel prize for physics was awarded to Peter Higgs and François Englert "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle" [6].

Two things are then important. Firstly, these papers have had such an enormous impact *precisely because of* the use of the word 'observation'—it is *therefore* that the existence of the Higgs boson is widely believed to be confirmed. Secondly, one might be inclined to think that these claimed

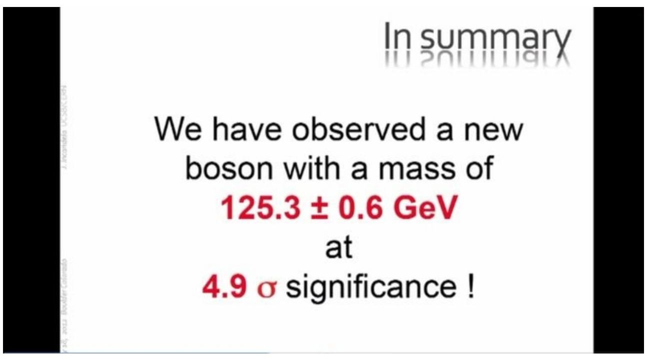

Figure 1: Slide shown at a press conference at CERN in July 2012. Source: CERN Document Server.

observations are sheer **facts** but that is *not true*: it is merely the **opinion** of the authors that the results obtained from a statistical analysis of the raw data can be called an 'observation' of a Higgs boson c.q. a new boson c.q. a new particle. This opinion is shared by virtually the whole physics community; communication with experimental physicists has revealed that the observational claims concerning ultrashort-lived unstable particles are merely a matter of applying the following convention in particle physics, which will henceforth be called the '5σ-convention':

> **5σ-convention**: the observation of an ultrashort-lived unstable particle can be claimed if the predicted decay products with the predicted properties have been observed with a significance of 5σ.[i]

So to put it explicitly: this convention expresses the opinion that an 'observation' can be claimed whenever the said condition is satisfied, and that opinion is shared by virtually all physicists. However, the plural of 'opinion' is not 'fact'. That is, *even though* virtually all physicists are of the opinion that an 'observation' of an ultrashort-lived unstable particle can be claimed when the condition in the 5σ-convention is met, it is *absolutely not* a fact that we then indeed can claim an observation.

That said, while not questioning the *existence* of Higgs bosons and other postulated ultrashort-lived unstable particles—i.e. postulated particles with an expected lifetime of less than 10^{-20} s—the purpose of this paper is to prove that it is simply not true that a Higgs boson and other postulated ultrashort-lived unstable particles have been *observed* by proving that the condition in the 5σ-convention is insufficient for an observational claim.[ii] It is emphasized that it is thus **not** the purpose of this paper to contribute to a more general philosophical discussion, and that this paper is purely about **the physicists' use** of the term 'observation', which—physicists insist on it!—should not be confused with potentially different definitions of "observation" in philosophy, e.g. by Maxwell [7], Van Fraassen [8], Shapere [9], Falkenburg [10], and Fox [11]. Furthermore, it is emphasized that this paper is **absolutely not** meant to belittle the theoretical and experimental work involved in preparing and performing the experiments: the calculations involved in deriving testable predictions, the experimental work itself and the statistical analyses of the experimentally obtained data are all state-of-the-art, and are not questioned—this paper only questions the opinion that the results obtained from a statistical analysis of the experimental data can be called "observations".

2 Method

To disproof the observational claims, it has to be proved that the condition laid down in the 5σ-convention is insufficient. The logical form of the 5σ-convention is that of an implication

$$S \Rightarrow C \tag{1}$$

where C is the desired claim that the ultrashort-lived unstable particle X has been observed and S the (allegedly) sufficient condition for that claim, being that the predicted decay products have been observed with a significance of 5σ. A standard method to prove that the condition S is *insufficient* is then to prove implications

$$C \Rightarrow N \tag{2}$$

$$S \Rightarrow \neg N \tag{3}$$

for some condition N: Eq. (2) means that N is a necessary condition for C, and Eq. (3) means that this necessary condition N is not satisfied when S is satisfied—that proves that S is insufficient.

The proof that the condition in the 5σ-convention is *insufficient* will be given in a frame for modal propositional logic, which consists of a formal language $\mathcal{L}$, a set of possible worlds W, an accessibility relation R, and a real-world meaning that is represented by Kripke possible worlds semantics. This frame for modal propositional logic will be described in Sect. 2.1. Thereafter, Sect. 2.2 summarizes the method. The appendix A (trivially) completes the description of the present frame for modal propositional logic, but the material in the appendix is not needed for the main result of this paper.

2.1 The present frame for modal propositional logic

The formal language $\mathcal{L}$ consists of a vocabulary and a syntax. In addition, the formalism has an interpretation.

Definition 2.1. The **vocabulary** of $\mathcal{L}$ consists of:

(i) the atomic propositions '$\mathcal{O}X$', '$\mathcal{O}\delta_X$', '$\mathcal{E}X$', '$\mathcal{E}\delta_X$';

(ii) the modifier '$\rhd$', used in front of an atomic proposition;

(iii) the standard modalities '$\Box$', and '$\Diamond$', used in front of a proposition;

(iv) the standard propositional-logical connectives '$\neg$', '$\Rightarrow$', '$\wedge$', '$\vee$', and '$\Leftrightarrow$'.

■

The **syntax** of $\mathcal{L}$ is then just the standard syntax for modal propositional logic, with the additional clause that if Ψ is an atomic proposition, then $\rhd\Psi$ is also a formula—so $\rhd \rhd \Psi$ is not a well-formed formula in $\mathcal{L}$!

Definition 2.2. The **interpretation** of $\mathcal{L}$ is determined by the following clauses:

(i) '$\mathcal{O}X$' means 'the ultrashort-lived unstable particle X has been observed';

(ii) '$\mathcal{O}\delta_X$' means 'the decay products of the ultrashort-lived unstable particle X have been observed';

(iii) '$\mathcal{E}X$' means 'the ultrashort-lived unstable particle X exists in the system under observation';

(iv) '$\mathcal{O}\delta_X$' means 'the decay products of the ultrashort-lived unstable particle X exist in the system under observation';

(v) the modifier '$\rhd$' means 'it can be claimed that';

(vi) the modalities '$\Box$' and '$\Diamond$' mean 'it is necessarily true that' and 'it is possible that', respectively.

■

The set of possible worlds has precisely seventeen elements:

$$W = \{w_0, w_1, w_2, \ldots, w_{16}\} \tag{4}$$

The accessibility relation R is *irreflexive*:

$$\forall w \in W : \neg wRw \tag{5}$$

Furthermore, *if* a possible world $w' \in W$ is accessible from a possible world $w \in W$, *then* $w = w_0$:

$$\forall w, w' \in W : wRw' \Rightarrow w = w_0 \tag{6}$$

That means thus that the possible world w_0 is *inaccessible* from any other possible world, and that no possible world $w' \neq w_0$ can be accessed from any possible world $w \neq w_0$:

$$\forall w \neq w_0 : \neg wRw_0 \tag{7}$$

$$\forall w, w' \neq w_0 : w \neq w' \Rightarrow \neg wRw' \tag{8}$$

Proceeding, if a (modal) proposition Ψ is true in a possible world w_j then this is denoted by

$$\models_{w_j} \Psi \tag{9}$$

The possible worlds $w_j \neq w_0$ are distinguished by the validity of the atomic propositions in w_j:

$$\models_{w_1} \mathcal{O}X \wedge \mathcal{O}\delta_X \wedge \mathcal{E}X \wedge \mathcal{E}\delta_X \tag{10}$$

$$\models_{w_2} \mathcal{O}X \wedge \mathcal{O}\delta_X \wedge \neg\mathcal{E}X \wedge \neg\mathcal{E}\delta_X \tag{11}$$

$$\models_{w_3} \neg\mathcal{O}X \wedge \neg\mathcal{O}\delta_X \wedge \mathcal{E}X \wedge \mathcal{E}\delta_X \tag{12}$$

$$\models_{w_4} \neg\mathcal{O}X \wedge \neg\mathcal{O}\delta_X \wedge \neg\mathcal{E}X \wedge \neg\mathcal{E}\delta_X \tag{13}$$

etcetera (there are just 16 possibilities for the four atomic propositions of Def. 2.1).

The accessibility of these possible worlds from w_0 is determined by the modal propositions that are true in w_0 and by (standard) Kripke possible world semantics. As to the modal propositions in w_0, the modality '$\overline{\Diamond}$', to be read as 'it is at best possible that', is hereby defined as follows:

$$\models_{w_0} \overline{\Diamond}\Phi \Leftrightarrow \Diamond\Phi \wedge \Diamond\neg\Phi \tag{14}$$

The possible world semantics for the present frame for modal propositional logic are then as follows:

(i) If $\models_{w_0} \Box\Psi$, then Ψ is true in every—and at least one—possible world $w \in W$ accessible from w_0, and vice versa; a possible world $w' \in W$ in which $\neg\Psi$ is true is then inaccessible from w_0.

(ii) If $\models_{w_0} \overline{\Diamond}\Phi$, then Φ is true in at least one possible world $w \in W$ that is accessible from w_0 *and* $\neg\Phi$ is true in at least one possible world $w' \in W$ that is accessible from w_0, and vice versa.

See Fig. 2 below for an illustration.

Definition 2.3. The **real-world meaning** represented by the above semantics is the following:

(i) the possible world $w_0 \in W$ represents the 'world of theory';

(ii) the other possible worlds $w_j \in W$ represent possible real worlds.

(iii) if $\models_{w_0} \Box\Psi$, then the real world can <u>only</u> be a world in which Ψ is true;

(iv) if $\models_{w_0} \overline{\Diamond}\Phi$, then the real world <u>can</u> be a world in which Φ is true, but the real world can <u>also</u> be a world in which $\neg\Phi$ is true.

■

The motivation for distinguishing a *world of theory* from *possible real worlds* is that an observation is an event in the *real world*, while an observational claim is a statement in the *world of theory*—the social construct built by the claims in the scientific literature. We could also call it the 'international scientific discussion forum', but in the remainder of this text we will use *world of theory*.

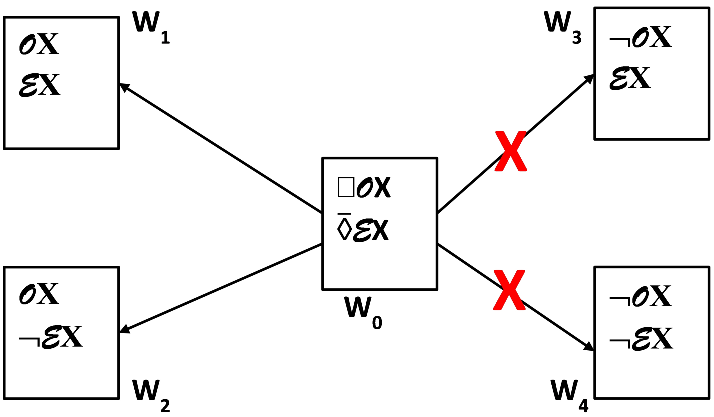

Figure 2: Illustration of the possible world semantics of modal statements in w_0. The four squares in the corners represent the possible worlds w_1-w_4 in which the atomic propositions $\mathcal{O}X$ and $\mathcal{E}X$ have the truth-value as in Eqs. (10)-(13). The truth value of other propositions in w_1-w_4 is not shown, and the other possible worlds w_5-w_{16} are not shown either. The square in the middle represents the possible world w_0 in which for illustrative purposes the modal propositions $\Box\mathcal{O}X$ and $\overline{\Diamond}\mathcal{E}X$ are assumed to be true as indicated. Because $\Box\mathcal{O}X$ is true in w_0, the worlds w_3 and w_4 in which $\neg\mathcal{O}X$ is true are not accessible (as indicated by the red crosses). On the other hand, $\overline{\Diamond}\mathcal{E}X$ being true in w_0 means that there is an accessible possible world in which $\mathcal{E}X$ is true, but there is also an accessible possible world in which $\neg\mathcal{E}X$ is true. So, if both $\Box\mathcal{O}X$ and $\overline{\Diamond}\mathcal{E}X$ are true in w_0, then the possible worlds w_1 and w_2 are accessible in which respectively $\mathcal{O}X$ and $\mathcal{E}X$ are true, and $\mathcal{O}X$ and $\neg\mathcal{E}X$.

2.2 Summary of the method

The present frame for modal propositional logic is the smallest possible frame in which **all** possibilities regarding observation and existence of the ultrashort-lived unstable particle X and its predicted decay products can be considered: as such, it is suitable for an critical discussion of the 5σ-convention. For starters, the 5σ-convention can be expressed in our formal language $\mathcal{L}$ as follows:

$$\models_{w_0} \rhd\mathcal{O}\delta_X \Rightarrow \rhd\mathcal{O}X \tag{15}$$

This reads as: *if* it can be claimed that the predicted decay products of that ultrashort-lived unstable particle X have been observed, *then* it can be claimed that an ultrashort-lived unstable particle X has been observed.

The proof that the condition $\rhd\mathcal{O}\delta_X$ in Eq. (15) is insufficient then consists of two parts. In the first part, an implication

$$\models_{w_0} \rhd\mathcal{O}X \Rightarrow \Psi \tag{16}$$

is proven: that lays bare a necessary condition Ψ for an observational claim regarding an ultrashort-lived unstable particle. *Reductio ad absurdum* is used to show that Ψ is indeed a necessary condition.

In the second part an implication

$$\models_{w_0} \rhd\mathcal{O}\delta_X \Rightarrow \neg\Psi \tag{17}$$

is proven: that shows that the necessary condition Ψ for an observational claim regarding an ultrashort-lived unstable particle is **not satisfied** when it can be claimed that the predicted decay products of the ultrashort-lived unstable particle X have been observed.

We can then immediately conclude from the implication (16), the implication (17), and the tautology

$$(\Phi \Rightarrow \Theta) \wedge (\Upsilon \Rightarrow \neg\Theta) \Rightarrow (\Upsilon \Rightarrow \neg\Phi) \tag{18}$$

that

$$\models_{w_0} \rhd\mathcal{O}\delta_X \Rightarrow \neg \rhd \mathcal{O}X \tag{19}$$

That renders the 5σ-convention of particle physics, Eq. (15), *inadequate.*

It is emphasized that in this second part, the 5σ standard is "absorbed" in the assumption

$$\models_{w_0} \rhd\mathcal{O}\delta_X \tag{20}$$

used to derive Eq. (17). An axiom for this part of the proof is

$$\models_{w_0} \rhd\mathcal{O}\delta_X \Leftrightarrow \neg\Diamond\neg\mathcal{E}\delta_X \tag{21}$$

That is, a necessary and sufficient condition for a claim that the predicted decay products of the ultrashort-lived unstable particle X have been observed is that it is not possible that the predicted decay products of that ultrashort-lived unstable particle X do not exist in the system under observation. The underlying idea is that the decay products are merely *detected* by laboratory equipment: from a statistical analysis of the particle detector data it can then be inferred that it is not possible that the predicted decay products are not present in the system under observation when the significance of the signal is 5σ—this significance excludes that the detector signal has any other cause than the predicted decay products. That is, with the assumption (20) in the second part we implicitly assume that the condition for an observational claim regarding an ultrashort-lived unstable particle laid down in the 5σ-convention is satisfied.

3 Results

3.1 Overview of the outcome

The following scheme constitutes the proof that the condition laid down in the 5σ-convention is insufficient:

$$\begin{array}{ll} \text{(i) } \textbf{major}: & \models_{w_0} \rhd\mathcal{O}X \Rightarrow \Box\mathcal{E}X \\ \text{(ii) } \textbf{minor}: & \models_{w_0} \rhd\mathcal{O}\delta_X \Rightarrow \overline{\Diamond}\mathcal{E}X \\ \hline \text{(iii) } \textbf{conclusion}: & \models_{w_0} \rhd\mathcal{O}\delta_X \Rightarrow \neg\rhd\mathcal{O}X \end{array} \tag{22}$$

The major—in words: if it can be claimed that the ultrashort-lived unstable particle X has been observed, then it is necessarily true that the ultrashort-lived unstable particle X exists in the system under observation—holds for any X in general. That is, the major also holds for observations of other things than ultrashort-lived unstable particles.

The minor—in words: if it can be claimed that the predicted decay products of the ultrashort-lived unstable particle X have been observed, then it is at best possible that the ultrashort-lived unstable particle X exists in the system under observation—**only applies** when X stands for an ultrashort-lived unstable particle, but it is true even when the condition of the 5σ-convention has been satisfied—cf. Sect. 2.2, last paragraph. That is, the minor is true whenever the predicted decay products of an ultrashort-lived unstable particle X have been observed with a significance of 5σ.

The conclusion—in words: if it can be claimed that the predicted decay products of the ultrashort-lived unstable particle X have been observed, then it cannot be claimed that the ultrashort-lived unstable particle X has been observed—is then *inevitable*: it derives from the major, the minor, the tautology $\overline{\Diamond}\Psi \Rightarrow \neg\Box\Psi$, and the tautology (18). This conclusion is thus obtained *even though* the condition of the 5σ-convention has been satisfied. That shows that the condition laid down in the 5σ-convention is *insufficient*: the 5σ-convention is thus *inadequate*—cf. expression (15).

3.2 On the major

Regardless of how we define the term 'observation' precisely, the crux is that it is an *act of the senses*: consequently, if it can be claimed that X has been observed then the real world can only be a world in which the sensum X exists, and not one in which X does not exist—in the language of modal logic, it is then *necessarily true* that X exists. Suppose, for example, that the discovery of a new species, that is, the first time observation of a new species, has been claimed by a group of investigators during a biological expedition: the real world is then one in which this species exists, not one in which this species doesn't exist—it is, then, necessarily true that this new species exists. So, the major in scheme (22) expresses a necessary condition of any observational claim.

We can use *reductio ad absurdum* to show that this indeed is a necessary condition. So, let's assume the *physical* negation of the major of scheme (22):

$$\models_{w_0} \rhd\mathcal{O}X \Rightarrow \overline{\Diamond}\mathcal{E}X \tag{23}$$

In words, this is to assume the view that if it can be claimed that X has been observed, it is *at best possible* that X exists in the system under observation.[iii] Using the postulate of meaning (14) this view comes down to the view that if we can claim that X has been observed, then the real world can be a world in which X exists, but the real world can also be a world in which X does not exist: existence of X in the real world is then no longer a necessary condition for a claim that X has been observed. That is patently absurd. In a similar vein, Kant argued that we must realize ourselves that if we perceive a phenomenon, there must be a thing in itself whose appearance we perceive; "[f]or, otherwise, we should require to affirm the existence of an appearance, without something that appears—which would be absurd" (preface to the 2nd edition of *Critique of Pure reason*, 1787). That proves that the denial of the major in scheme (22) leads to an absurdity: the major can, thus, **not** be denied—those who nevertheless hold the view (23) are cordially invited on an expedition to spot a unicorn.

Therefore, any claim that X has been observed *implies* an assertion that the existence of X is necessarily true: this holds, thus, **also** for observational claims by physicists. Thus, when physicists claim that they have *observed* an ultrashort-lived unstable particle, they **implicitly allege** that it is *necessarily true* that the ultrashort-lived unstable particle exists in the system under observation—that is, that the real world can only be a world in which that ultrashort-lived unstable particle exists.

3.3 On the minor

Recall from Sect. 2.2 that assumption (20) and axiom (21) are the starting point of this analysis. That is, it is assumed that experimentally each decay mode of the ultrashort-lived unstable particle X has been analyzed separately, that experimental results are positive, and that the required significance of 5σ has ruled out any alternative explanation for the obtained signal: we thus assume that

$$\models_{w_0} \neg\Diamond\neg\mathcal{E}\delta_X \tag{24}$$

has been inferred from the empirical data.

In the search for the Higgs boson, for example, the diphoton mass spectrum of Fig. 3 was obtained. From the analysis it can then be concluded that, as predicted from the decay mode $H \to \gamma\gamma$ of the Higgs boson, it is not possible that no excess of photon pairs with a total mass of ± 125 GeV existed in the system under observation. But a Higgs boson has several decay modes: the conclusion (24) is thus the conjunction of the conclusions of the separate analyses.

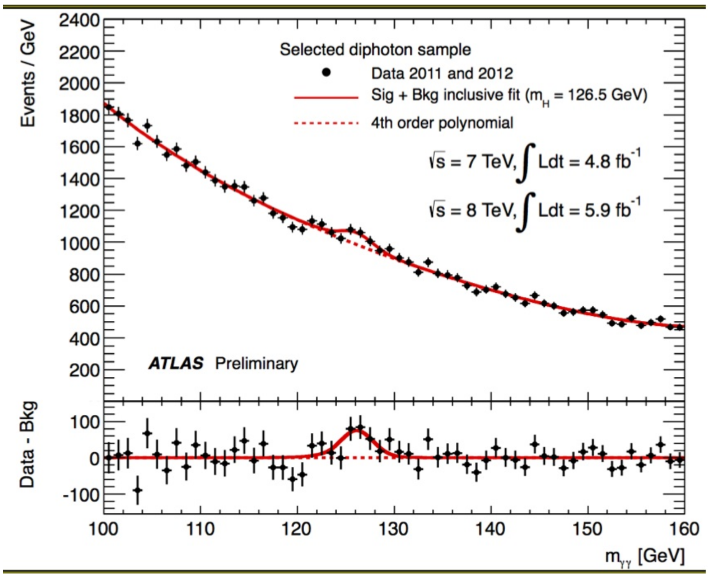

Figure 3: Diphoton mass spectrum obtained in the hunt for the Higgs boson. The lower curve with the peak at around 125 GeV is obtained from the upper one by substraction. Source: CERN Document Server.

The crux is then that the relation between the existence of an ultrashort-lived unstable particle and the existence of its predicted decay products has the logical form of a necessary implication. In the present frame for modal propositional logic, this can be formalized as

$$\models_{w_0} \Box(\mathcal{E}X \Rightarrow \mathcal{E}\delta_X) \tag{25}$$

meaning that the real world can only be a world where the predicted decay products of the ultrashort-lived unstable particle X exist in the system under observation if the ultrashort-lived unstable particle X exists in the system under observation. One might object that premise (25) is too weakly formulated, and should include also the reverse necessary implication, as in

$$\models_{w_0} \Box(\mathcal{E}X \Rightarrow \mathcal{E}\delta_X) \wedge \Box(\mathcal{E}\delta_X \Rightarrow \mathcal{E}X) \tag{26}$$

But the problem is with the second member of this conjunction, that is, with $\Box(\mathcal{E}\delta_X \Rightarrow \mathcal{E}X)$: this is **circular reasoning**. The point is, namely, that with our experiment we have set out to prove the existence of X: with the latter necessary implication, we *tacitly* assume the existence of the ultrashort-lived unstable particle X, whose existence we want to prove. See Fig. 4 for an illustration.

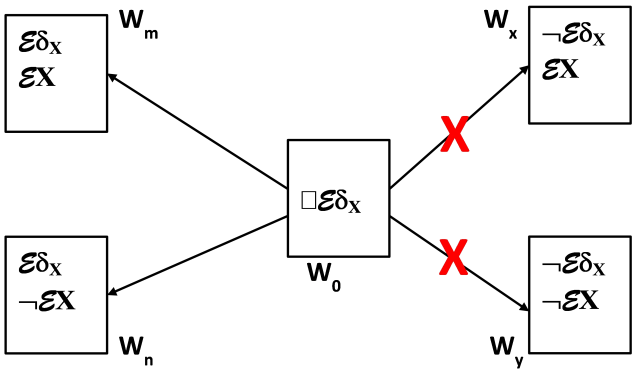

Figure 4: Illustration of the circular reasoning. All we know from the analysis of the experimental data is expression (24): this is represented by the square in the middle. Now $\Box\mathcal{E}\delta_X$ being true in w_0 means that possible worlds $w_m \in W$ in which $\mathcal{E}\delta_X \wedge \mathcal{E}X$ is true are accessible from w_0, but also possible worlds $w_n \in W$ in which $\mathcal{E}\delta_X \wedge \neg\mathcal{E}X$ is true; it also means that possible worlds $w_x, w_y \in W$ in which $\neg\mathcal{E}\delta_X \wedge \mathcal{E}X$ or $\neg\mathcal{E}\delta_X \wedge \neg\mathcal{E}X$ is true are not accessible from w_0, as indicated by the red crosses. From this picture expression (25) obtains. But if we instead assume that expression (26) has to be true, then that means that the possible worlds $w_n \in W$ in the lower left corner of the picture are also inaccessible from w_0. But that leaves that only the possible worlds $w_m \in W$ in which $\mathcal{E}\delta_X \wedge \mathcal{E}X$ is true are accessible: by assuming (26) we have thus assumed that the real world can only be a world in which X exists. But that is what we want to prove: this is, therefore, circular reasoning.

So we assume that the experiment has been done and the results have been analyzed and found to be positive: the premises (25) and (24) are then true. The *desired* conclusion is then

$$\models_{w_0} \Box\mathcal{E}X \tag{27}$$

This would, arguably, warrant a conclusion $\models_{w_0} \rhd\mathcal{O}X$. But this desired conclusion (27) cannot be *logically* inferred from the premises (25) and (24): that would be a logical fallacy called *affirming the consequence*.[iv] That means that we are left with inference to the best explanation (IBE), which is an *act of reasoning*: the *only* conclusion that we can draw is that the existence of the ultrashort-lived unstable particle X is the best explanation for the empirical data.

But IBE is weaker than logical inference: the desired conclusion (27) is **not warranted** on the basis of IBE. To see that, suppose that an experiment has been performed, and suppose that the existence of the ultrashort-lived unstable particle X is the best explanation for the obtained result (24). In the world of theory w_0 of our frame for modal propositional logic we can, then, still not infer that the existential proposition $\mathcal{E}X$ is necessarily true: the crux is that the existence of the ultrashort-lived unstable particle X is **currently** the best explanation of the empirical data, but it may **later** turn out that X doesn't exist in the real world and that the empirical data are caused by an object about which currently not even a theory exists—there is, thus, still a possible real world w_j accessible from w_0 in which $\neg\mathcal{E}X$, that is, the real world can still be a world in which $\neg\mathcal{E}X$. To illustrate this with an example, consider the case of the Higgs boson. This has the essential property P that it 'gives mass' to other particles. But this property P is not reflected in its decay products: from merely observing the decay products, it cannot be concluded that the source is $X(P)$, i.e. an ultrashort-lived unstable particle X with the property P—the decay products may also have originated from a particle $X'(\neg P)$ that has the same decay reactions as the Higgs boson but not the property P. So, in w_0 it is still possible that the existential proposition $\mathcal{E}X$ is false, *even though* the existence of the ultrashort-lived unstable particle X is the best explanation now. Thus speaking, we are forced to admit that

$$\models_{w_0} \overline{\Diamond}\mathcal{E}X \tag{28}$$

which yields premise (ii) in scheme (22)—recall that (20) was assumed.[v] It is emphasized that this result is obtained from an analysis of the mere concept of IBE: the entire debate on IBE, leading to highly differentiated analyses of the circumstances under which IBE can justify knowledge claims, is irrelevant for the present argument—which, as said before, applies only to experiments aimed at proving the existence of postulated ultrashort-lived unstable particles.

Based on the fact that the post-World War II physics community has gradually replaced the traditional notion of *truth* by *general consensus* [12], one might argue that it is not possible that an ultrashort-lived unstable particle doesn't exist when there is *general consensus* about the existence of that ultrashort-lived unstable particle. So, one might argue that it is necessarily true that Higgs bosons exist **because** the general consensus is that Higgs bosons exist. However, one ought to realize that history provides numerous counterexamples to the idea that 'there is general consensus that S' implies 'it is necessarily true that S': this idea should thus be rejected. In other words: it should be realized that reaching general consensus about the existence of Higgs bosons does **not** warrant the conclusion that it is therefore necessarily true that these bosons exist!

One may ask: how can we *then* prove the existence of ultrashort-lived unstable particles? The answer is then: (absent divine intervention) we can't—proving the existence of ultrashort-lived unstable particles is *beyond* the limit of the scientific method. That is, the condition laid down in the present 5σ-convention is *necessary* for an observational claim, but there is nothing we can add to make it *sufficient*. Existential propositions concerning ultrashort-lived unstable particles remain, thus, always an object of *existential belief*—a belief in the truth of an existential proposition [13].

Summarizing, an observation of the predicted decay products of an ultrashort-lived unstable particle postulated by the Standard Model with the required significance of 5σ provides a justification for a belief in the existence of that ultrashort-lived unstable particle—this is an existential belief on the basis of IBE—but **does not** yield a justification for a claim that this ultrashort-lived unstable particle has been observed: the 5σ-convention is <u>inadequate</u> because its condition is <u>insufficient</u>.

4 Discussion

4.1 Implications of the present findings

Obviously, the direct implication of the inadequacy of the 5σ-convention is that *all* published observational claims concerning ultrashort-lived unstable particles have to be dismissed as overstatements. In fact, these claims should be *retracted*, because the use of the word 'observation' is misleading: it suggests that the existence of the ultrashort-lived unstable particles in question is necessarily true, but that is not the case as shown above in Section 3. Examples of such particles and corresponding observational claims are given in table 1; the list is not exhaustive but the point is that none of these particles can be said to have been "observed".

particle	**lifetime**	**observational claim**
Higgs boson*	$1.56 \cdot 10^{-22}$	[1, 2, 3]
$W^{\pm}$ bosons*	$3 \cdot 10^{-25}$	[14]
Z^0 boson*	$3 \cdot 10^{-25}$	[15, 16]
Υ meson	$1.21 \cdot 10^{-20}$	[17]
J/Ψ meson*	$1.56 \cdot 10^{-22}$	[18]
Ω_b^-	$1.13 \cdot 10^{-12}$	[19]
$Z(4430)^-$	?	[20]

Table 1: examples of unstable particles that are claimed to have been observed on the basis of the 5σ-convention; an asterisk in the first column marks cases where the observational claim led to a Nobel prize award. It is true that the Ω_b^- baryon has a lifetime longer than 10^{-20} s and that the tetraquark $Z(4430)^-$ has an unknown lifetime, but both observational claims are based on the 5σ-convention.

Further implications are far more general and can be stated in the form of two incompleteness theorems for physics. These concern the *completeness*[vi] and the *correctness*[vii] of a physical theory, two notions that were introduced in the EPR-paper as important for the evaluation of the success of a physical theory [21].

Theorem 4.1. No experiments can prove *completeness* of a physical theory predicting the existence of short-lived unstable particles.

Theorem 4.2. No experiments can prove *correctness* of a physical theory predicting the existence of short-lived unstable particles.

Proof: To prove completeness, one has to prove that the particles predicted by the theory exist. But as demonstrated in Section 3, the existence of ultrashort-lived unstable particles cannot be proven by any experiment—**regardless of the research effort**. Hence a theory predicting such particles cannot be proven to be complete by experimental physical research. Likewise, to prove correctness one has to prove that the predictions of the theory are true. But a prediction that an ultrashort-lived unstable particle has this or that (expectation value of) position cannot be proven to be true by any experiment. Hence, a theory predicting such particles cannot be proven to be correct by experimental physical research. Q.E.D.

Consequently, all we can do with physical theories that predict ultrashort-lived unstable particles is testing their *empirical adequacy*. This notion has been defined by Van Fraassen: a theory is *empirically adequate* if and only if all observations—past, present *and future*—in its area of application can be described as predictions of the theory [8]. So this is a somewhat weaker notion than correctness as defined in the EPR-paper: correctness implies empirical adequacy, but the converse is not necessarily true. What is important then is that the fact that the ultrashort-lived unstable particles postulated by the Standard Model are fundamentally unobservable does not render the empirical adequacy of the Standard Model any less.

4.2 Replies by Physicists

Criticisms of observational claims, in particular the Higgs claim, have been discussed with top physicists. Some of their replies are worth a discussion: these are paraphrased below and discussed.

Reply 4.3. *Huh, what? No Higgs, no J/Ψ-mesons, no $W^{\pm}$ bosons, no Z^0 boson? This is naive and bad philosophy, a golden opportunity for every physicist who wants to show how irrelevant and pompous philosophy is [sic].*

Emotional reactions like this, received several times, stem from a gross misinterpretation of the paper: what is disputed is not the *existence* of these particles, but the claims that they have been *observed.* This should not be mistaken for an attempt to prove that the ultrashort-lived unstable particles postulated by the Standard Model do not exist, or that the Standard Model is at fault in some way, or anything like that.

Reply 4.4. *The statement that a new boson has been observed is in essence based on testing the hypothesis that the measured diphoton mass spectrum is only due to known processes ("background") versus the hypothesis that it is due to background plus the production of a new particle (here a boson). On account of the analysis the no-new-particle hypothesis can be rejected, and the convention is to call this an observation of a new state decaying in the particular decay channel $H \to \gamma\gamma$. This is a perfectly valid statistical procedure.*

The physicists thus seem to think that they can conclude to the existence of the Higgs boson because of a clever formulation of the hypotheses. However, the above formulation of the hypotheses is **false**: each decay mode is analyzed separately, and by each such analysis one tests a hypothesis 'predicted-decay-product-exist' versus 'no-predicted-decay-product'. E.g. with the obtained diphoton mass spectrum of Fig. 3 one accepts the hypothesis 'the 125 GeV photon pairs predicted by Higgs decay exist‘, and rejects the hypothesis ‘the predicted 125 GeV photon pairs do not exist‘: this is, thus, **not** a matter of testing ‘Higgs bosons exist’ versus ‘no Higgs boson exist’! The conjunction of accepted hypotheses obtained from the analyses yields the conclusion (24): the whole point of Section 3 is thus that this **cannot** be called an ‘observation’ of a new state!

Reply 4.5. *The enhanced signal at 125 GeV in the diphoton mass spectrum stems from something. If this something did not exist, there would be no enhancement. So of course, the observation of the enhancement can be called an ‘observation’ of a Higgs boson, but with the understanding that an **indirect** observation is meant.*

As stated in the Introduction, it is not questioned that an excess of photon pairs with a combined mass of 125 GeV has been found. It is also not questioned that this excess comes from something. But that doesn’t mean that it can be claimed that this “something” has been *observed*. That doesn’t change if we want to call it an *indirect* observation. The crux is namely—as already remarked by Fox [11]—that a claim of an indirect observation **presupposes** knowledge of the cause of the observed phenomenon. In other words, if the observed signal is called an *indirect* observation of a Higgs boson, then the existence of Higgs bosons is tacitly assumed to be known already. In other words: by calling it an indirect observation of a Higgs boson one *tactitly* assumes to already know what yet has to be proven, and as such it is a form of circular reasoning. Thus speaking, the Higgs boson is (currently) the best explanation for the data, but it cannot be claimed that a Higgs boson has been observed.

Reply 4.6. *The stance of physicists is that if you observe the decay products, you observe the thing that has decayed. For a physicist, to claim that you accept the observation of a photon in your detector but to deny that these photons stem from a resonance if the diphoton mass spectrum is consistent with the existence of a resonance is **perverse** [sic]. Hardly any physicist would agree with making a distinction between the excess and the thing causing the excess.*

The crux is that the peak at 125 GeV in the diphoton mass spectrum evidences the presence of lots of photon pairs with a combined mass of 125 GeV in the system under observation: **it doesn’t evidence anything else**—in other words: the peak is caused by the presence in the system under observation of an excess of pairs of photons with a combined mass of 125 GeV, **not** by a Higgs boson. Of course the presence of Higgs bosons in the system under observation is currently the best explanation for the observed excess of 125 GeV photon pairs, but that doesn’t justify a claim that Higgs bosons have been ‘observed’. So, the whole point is to sharply distinguish between an *observed* excess of photon pairs and the thing *assumed* to have caused that excess, and to sharply distinguish between ‘*having observed a Higgs boson*’ and ‘*believing that Higgs bosons exist on the basis of IBE*’.

4.3 Conclusions

The main conclusion is that the observation of ultrashort-lived unstable particles cannot be claimed on the basis of empirical data obtained in particle accelerators: erroneous claims are category mistakes in that an *act of reasoning* is presented as an *act of the senses*—these mistakes stem from not realizing that an observational claim is not warranted when the existence of the ultrashort-lived unstable particle is inferred on the basis of IBE. In the Higgs case, at best one can claim that the predictions of the Standard Model, including the Higgs boson, have been confirmed by the CMS and ATLAS experiments at the LHC. This is a substantially different claim.

The present result does absolutely not mean that the Standard Model should be viewed as a pseudo-scientific theory: even when the existence of the ultrashort-lived unstable particles postulated by the Standard Model cannot be proven experimentally, the theory (including these particles) still leads to verifiable predictions. Furthermore, the argument in the present paper is strictly limited to existential propositions concerning ultrashort-lived unstable particles: by no means is this intended to be applied to existential propositions concerning things, living or lifeless, that can be directly observed—e.g. ‘cows exist’. However, the physics literature contains many more observational claims that in fact are category mistakes in which the *observation of a thing* and the *inference of the existence of a thing based on IBE* have been confused; a recent example is the claimed observation of a gravitational wave [22], which led to the award of the 2017 Nobel prize in physics.

Another conclusion is that the testing of predictions that have been derived from assuming the existence of ultrashort-lived unstable particles *at best* yields a justification for a belief in the theory postulating these particles: absent divine intervention, any proposal for a correct and complete fundamental theory of physics can thus *at best* be an object of a justified belief. This raises the question whether the scientific method isn't bound to leave us on the long run with a *postmodernism in physics*—a scenario where several empirically adequate theories coexist without the possibility to decide between these theories.

On a more general note, the final conclusion is that this paper demonstrates the importance of analytical philosophy for elementary particle physics: the papers claiming observations of ultrashort-lived unstable particles have had such an enormous impact *precisely because* of the use of the word 'observation', but the present paper has demonstrated that this use is not justified. So, as a physicist one may—rightfully—consider philosophical contemplations to be irrelevant when doing calculations or when performing experiments, but it is plain wrong to think that philosophy is irrelevant for physics altogether—which is the prevailing view among physicists. That said, Hawking recently claimed that "philosophy is dead" [23]; a correct reply is then: *no it isn't, but the Higgs claim is.*

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A Appendix

With the material presented in Sect. 2 the truth-values of some propositions cannot be determined in some possible worlds $w \in W$. This appendix is to (partially) solve that incompleteness.

First of all, it is necessary to introduce a notion of *meaninglessness* by the expression

$$\not\not\models_{w_j} \Psi \tag{29}$$

which has to be read as 'Ψ is meaningless in w_j.' The Bochvar theory of meaninglessness applies:

(i) if $\not\not\models_{w_j} \Phi$, then $\not\not\models_{w_j} \neg\Phi$;

(ii) if $\not\not\models_{w_j} \Phi$, then $\not\not\models_{w_j} \Upsilon \Rightarrow \Phi$ for any formula Υ;

etc., see [24]. Ergo, a formula is meaningless in w_j when a subformula is meaningless.

That said, modal propositions have a meaning <u>only</u> in the world of theory, since the possible real worlds $w_i \neq w_0$ are neither related to themselves nor to any other possible real world $w_j \neq w_0$ by the accessibility relation R. Therefore, for any proposition Ψ we have

$$\forall w_j \neq w_0 : \not\not\models_{w_j} \Diamond\Psi \tag{30}$$

$$\forall w_j \neq w_0 : \not\not\models_{w_j} \Box\Psi \tag{31}$$

meaning that modal propositions are meaningless in the real world. The symbol '$\not\not\models_{w_j}$' here captures that the w_j's are not in the domain of the accessibility relation R, so the possible world semantics do not apply.

Note that Eq. (30) is different from $\models_{w_j} \neg\Diamond\Psi$: the latter, namely, implies $\models_{w_j} \Box\neg\Psi$, and because we have $\Box\Theta \Rightarrow \Diamond\Theta$ in the present frame (see Sect. 2.1) that gives $\models_{w_j} \Diamond\neg\Psi$. But that would mean that there is at least one $w_k \in W$ with $w_j R w_k$ with $\models_{w_k} \neg\Psi$. But there is no $w_k \in W$ such that $w_j R w_k$, so that is not true. Ergo, $\not\not\models_{w_j} \Diamond\Psi$ is not the same as $\models_{w_j} \neg\Diamond\Psi$. A similar reasoning holds for expression (31).

Furthermore, claims are propositions in the world of theory w_0 only, so we have

$$\forall w_j \neq w_0 : \models_{w_j} \neg \rhd \Psi \tag{32}$$

meaning that in the real world it cannot be claimed that Ψ. The point is that a claim can be *communicated* by a physical signal in the real world, e.g. words in a printed issue of a journal, but the communicated *meaning* of the signal, i.e. the actual claim, only 'lives' in the world of theory.

On the other hand, one doesn't observe a thing X in the world of theory: that happens in the real world. Likewise, a (physical) thing X doesn't exist in the world of theory: it exists in the real world. Ergo,

$$\models_{w_0} \neg\mathcal{O}X \tag{33}$$

$$\models_{w_0} \neg\mathcal{O}\delta_X \tag{34}$$

$$\models_{w_0} \neg\mathcal{E}X \tag{35}$$

$$\models_{w_0} \neg\mathcal{E}\delta_X \tag{36}$$

This concludes the description of the frame for modal propositional logic. Further study may be aimed at identifying additional criteria for various claims, such as $\models_{w_0} \rhd\mathcal{O}X \Rightarrow \rhd\mathcal{E}X$. But this is purely philosophic: for the present study, this is irrelevant.

Notes

[i] This 5σ-*convention* must be distinguished from the 5σ-*standard*, i.e. the agreement that the significance of the signal has to be 5σ.

[ii] Throughout this paper the term 'particle' refers to individuals in the ontology of the Standard Model: the term 'particle' is thus **not** used in the classical sense as a small massive object with definite position and momentum. E.g. the Higgs boson is a quantum excitation of the Higgs field, but is referred to as an ultrashort-lived unstable 'particle'.

[iii] The *logical* negation of the major of scheme (22) is $\models_{w_0} \rhd\mathcal{O}X \wedge \Diamond\neg\mathcal{E}X$. But besides that, one would of course still accept $\models_{w_0} \rhd\mathcal{O}X \Rightarrow \Diamond\mathcal{E}X$ on physical grounds. The tautology $(\Phi \wedge \Psi) \wedge (\Phi \Rightarrow \Upsilon) \Rightarrow (\Phi \Rightarrow \Psi \wedge \Upsilon)$ then yields expression (23), which can therefore be called the *physical* negation of the major of scheme (22).

[iv] From Eq. (25) and the tautology $\Box(\Psi \Rightarrow \Phi) \Rightarrow (\Box\Psi \Rightarrow \Box\Phi)$ we have $\models_{w_0} \Box\mathcal{E}X \Rightarrow \Box\mathcal{E}\delta_X$. But if we from that and from Eq. (24) draw the desired conclusion (27), then we commit the fallacy of affirming the consequence—which is when a conclusion P is drawn from premises $P \Rightarrow Q$ and Q. In other words: premises (25) and (24) are true, but from there we cannot infer *logically* that **thus** the desired conclusion (27) is also true.

[v] In analytical philosophy one shouldn't indulge in metaphors, but the following illustrates the previous point. Suppose the phone rings in someone's house: the signal is clearly distinguishable from the background noise, so there is no doubt that it is *the phone* that generates the signal. The person in the house then infers on the basis of IBE that there is (i.e., exists) a person who is calling him/her. But that is not necessarily true. In fact, this author has worked at a technical services department of a telecommunication company, which has sold phones that could ring due to current fluctuations in the device. This led to a flood of complaints about stalking and disrupted calls: all those who filed a complaint were thinking that someone was calling. Yet that wasn't the case: there was no one calling, the signal had a completely different explanation (in this case: a technical error in the telephone device). Of course a ringing phone isn't a metaphor for a particle physics experiment that is comparable in every detail, but the essence is the same: on the basis of the observed signal one infers an existential proposition on the basis of IBE, but that existential proposition is not necessarily true.

[vi] A theory is *complete* if and only if (i) every element in the physical world has a counterpart in the theory, and (ii) every element in the physical world, predicted with certainty by the theory, indeed exists.

[vii] A theory is *correct* if and only if all its predictions are true.

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