Physics and Philosophy

The structure of the vacuum and the role of the Higgs

Robert Harlander
RWTH Aachen University

supported by

Deutsche
Forschungsgemeinschaft
DFG

I am not a philosopher.

I’m just trying to understand
what they are trying to understand.

We all have opinions about

- what a theory should look like
- how knowledge is acquired
- what is real and what is not
- …

That doesn't make us philosophers.
It's what makes us interesting for philosophers.

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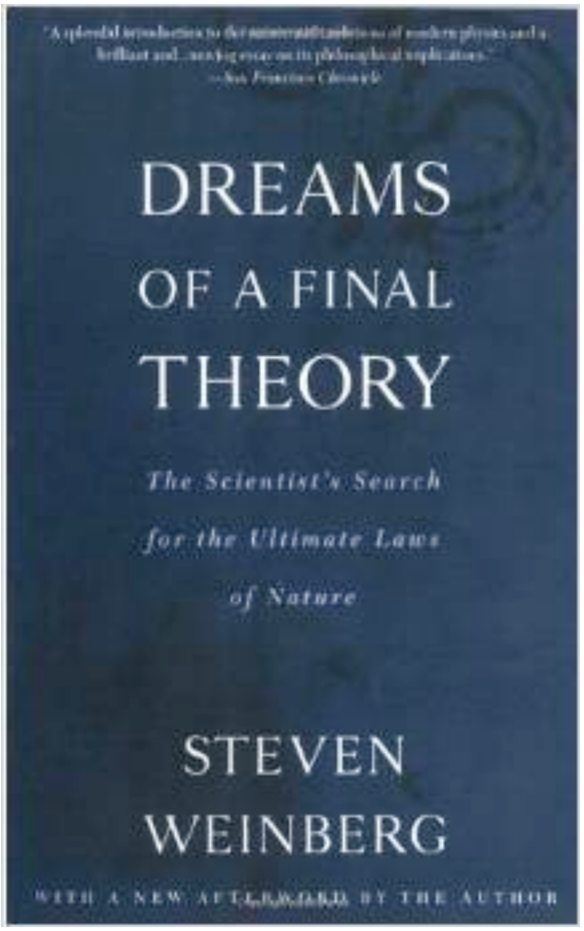
Philosophy of physics

Philosophy *for* physics?

“we should not expect [philosophy] to provide today’s scientists with any kind of useful guidance about how to go about their work or about what they are likely to find.

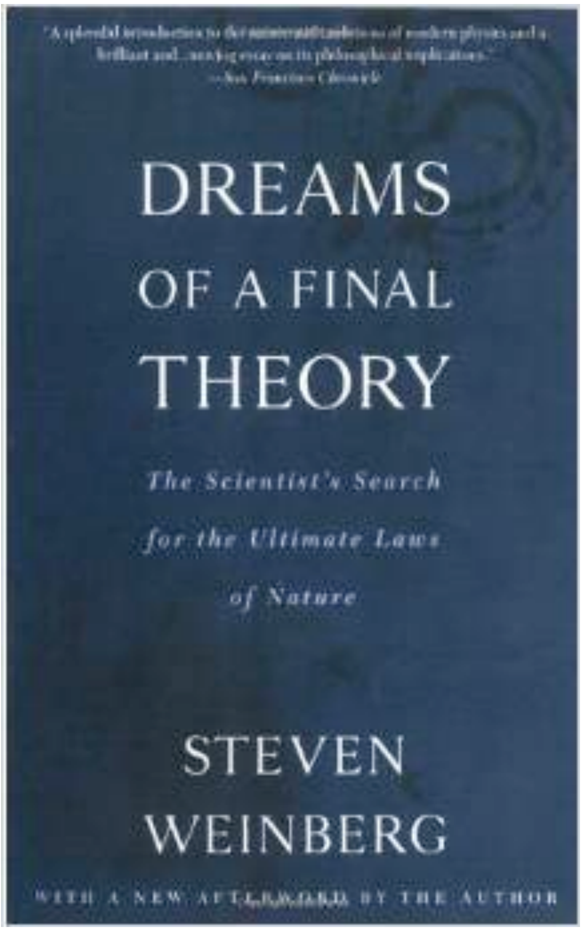
I should acknowledge that this is understood by many of the philosophers themselves.”



I agree.

Philosophy *for* physics?

"Some of it I found to be written in a jargon so impenetrable that I can only think that it aimed at impressing those who confound obscurity with profundity."



I agree.

5.9 Definition. Let $\mathcal{K}$ be a partially ordered set (e.g. regions in some manifold ordered by inclusion). Let $O \mapsto \mathfrak{A}(O)$ and $O \mapsto \mathfrak{B}(O)$ be nets of C^*-algebras over $\mathcal{K}$. A *net morphism* $\alpha : \mathfrak{A} \to \mathfrak{B}$ is a natural transformation between the functors. That is, α consists of a collection of morphisms

$$\{\alpha_O : \mathfrak{A}(O) \to \mathfrak{B}(O) : O \in \mathcal{K}\},$$

that is natural in O. In other words, for each $f \in \mathrm{Hom}(O_1, O_2)$, $\alpha_{O_2} \circ \mathfrak{A}(f) = \mathfrak{B}(f) \circ \alpha_{O_1}$, which just means that the following diagram commutes

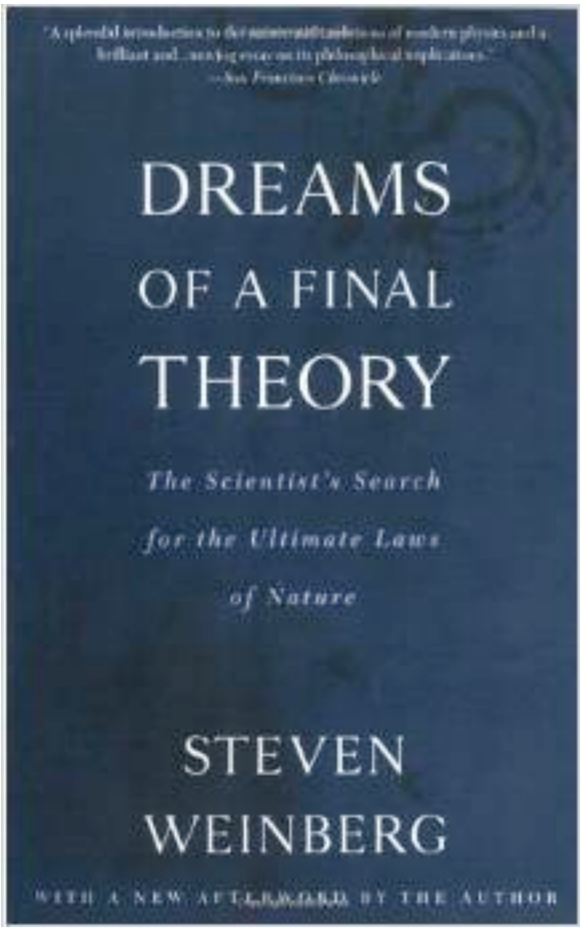
$$\begin{tikzcd}
\mathfrak{A}(O_1) \arrow[r, "\alpha_{O_1}"] \arrow[d, "\mathfrak{A}(f)"'] & \mathfrak{B}(O_1) \arrow[d, "\mathfrak{B}(f)"] \\
\mathfrak{A}(O_2) \arrow[r, "\alpha_{O_2}"'] & \mathfrak{B}(O_2)
\end{tikzcd}$$

in: *Handbook of the Philosophy of Physics*

Philosophy *for* physics?

- Wigner:
  "the unreasonable effectiveness of mathematics"

- Weinberg:
  "the unreasonable ineffectiveness of philosophy"



Wrong expectation.

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THE EPISTEMOLOGY OF THE LARGE HADRON COLLIDER (LHC)

Epistemology = theory of knowledge

DFG

FWF Der Wissenschaftsfonds.

SOUTH CAROLINA

Current Job Advertisement

Junior Professor in Philosophy with a specialization in Philosophy of Physics

6 Postdoctoral and 5 Doctoral Student positions in the fields of philosophy of science, physics, history of science, and science studies

The idea and structure of the research unit

Epistemology of the LHC

- Robert Harlander
- Rafaela Hillerbrand
- Michael Krämer
- Dennis Lehmkuhl
- Holger Lyre
- Peter Mättig
- Martina Merz
- Gregor Schiemann
- Erhard Scholz
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physicists

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physicists
philosophers
historians

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- Friedrich Steinle
- Michael Stöltzner
- Adrian Wüthrich
- Christian Zeitnitz

physicists
philosophers
historians
sociologist

postdocs (so far):
Arianna Borrelli
Simon Friederich
Koray Karaca

Philosophy *for* physics

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Philosophy *of* physics

How does science work?

→ *phy*

- how …
  - co
  - rev
  - …
- how …
  - ex
  - the
  - …
- how do concepts emerge, how are they established?

all?

ATLAS

nitz

"The Strong and Weak Senses of Theory-Ladenness of Experimentation: Theory-Driven versus Exploratory Experiments in the History of High-Energy Particle Physics," *Science in Context*, 26(1): 93–136 (2013).

"Philosophical Reflections on Diagram Models and Diagrammatic Representations," *Journal of Experimental & Theoretical Artificial Intelligence*, in the Special Issue on "Epistemology of Modeling and Simulation," 24: 365–384 (2012).

"Representing Data Acquisition Procedures through Diagrams: The Case of the ATLAS Experiment," at *Studies in History and Philosophy of Modern Physics*.

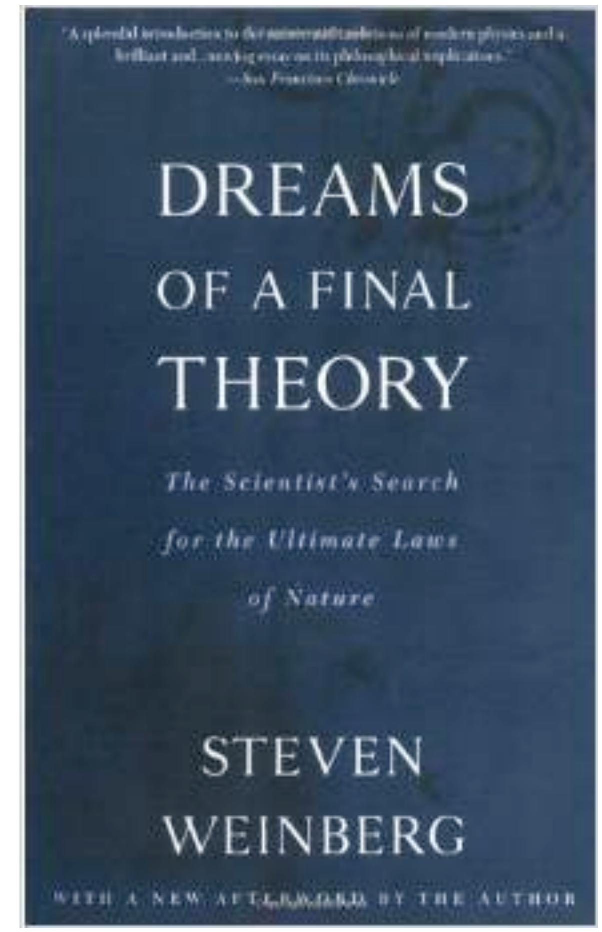
"A Study in the Philosophy of Experimental Exploration," invited contribution to the special issue of *Synthese* on the discovery of the Higgs boson.

"Lessons of Modeling from the Large Hadron Collider: Models of Data Acquisition," at Philosophy of Science.

Philosophy of physics

→ ***contact to history***

"[P]hilosophy of science […] at its best seems to me a pleasing gloss on the history and discoveries of science."



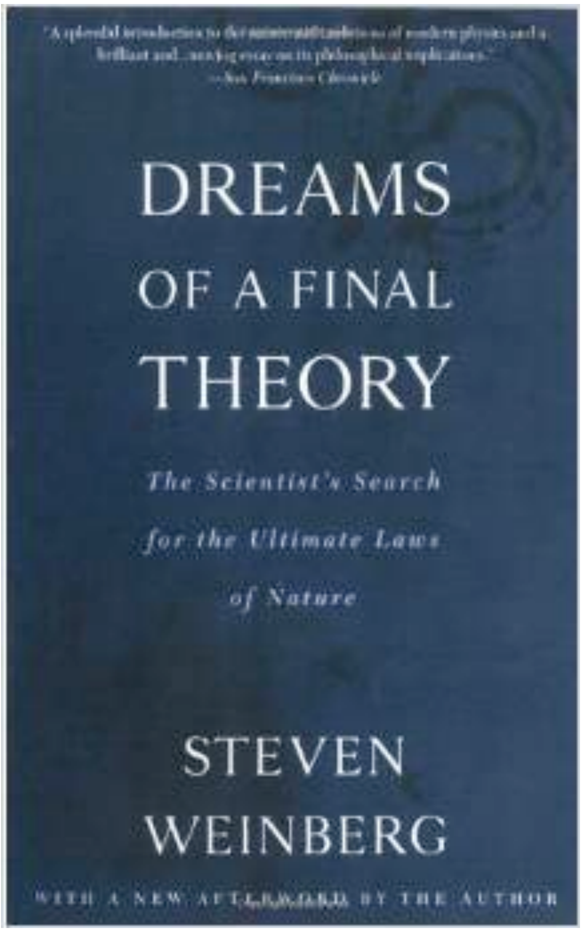
I think the reflective character is crucial.

Philosophy of physics

→ ***contact to sociology***

"It is simply a logical fallacy to go from the observation that science is a social process to the conclusion that the final product, our scientific theories, is what it is because of the social and historical forces acting in this process."

It depends on what you call the "final product"…



E.g., the "Leithammel" concept:
ancient: *Aristoteles, …*
modern: ’*t Hooft, Witten, Arcani-Hamed, …*

recent example:

$\Rightarrow$ NLO revolution!

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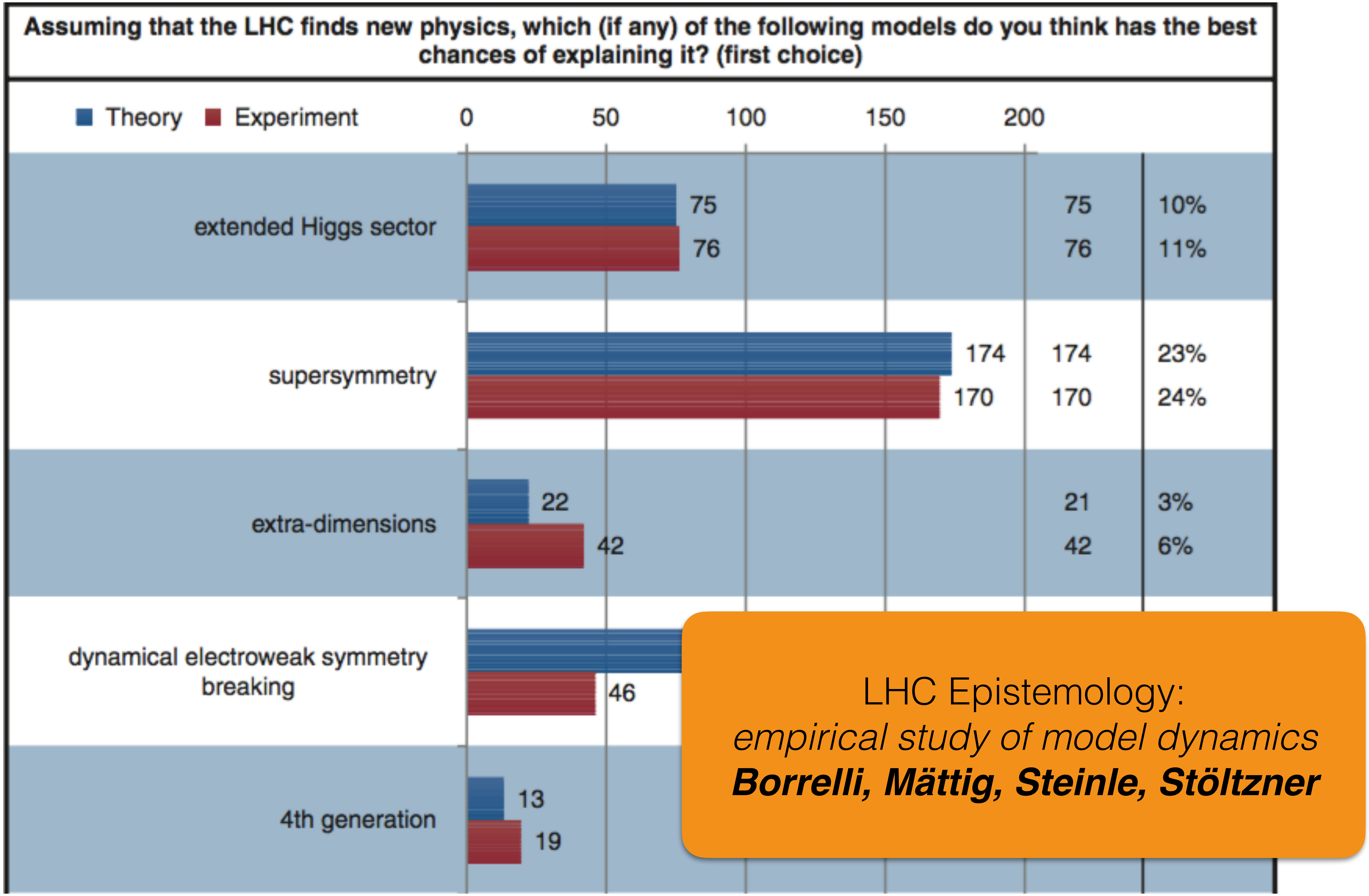
imagine…

Perturbative Gauge Theory As A String Theory In Twistor Space

Shavkat Mirziyoyev
University of Ubekibekistanstan

Perturbative scattering amplitudes in Yang-Mills theory have many unexpected properties, such as holomorphy of the maximally helicity violating amplitudes. To interpret these results, we Fourier transform the scattering amplitudes from momentum space to twistor space, and argue that the transformed amplitudes are supported on certain holomorphic curves. This in turn is apparently a consequence of an equivalence between the perturbative expansion of $\mathcal{N} = 4$ super Yang-Mills theory and the D-instanton expansion of a certain string theory, namely the topological B model whose target space is the Calabi-Yau supermanifold $\mathbb{CP}^{3|4}$.



September 2011

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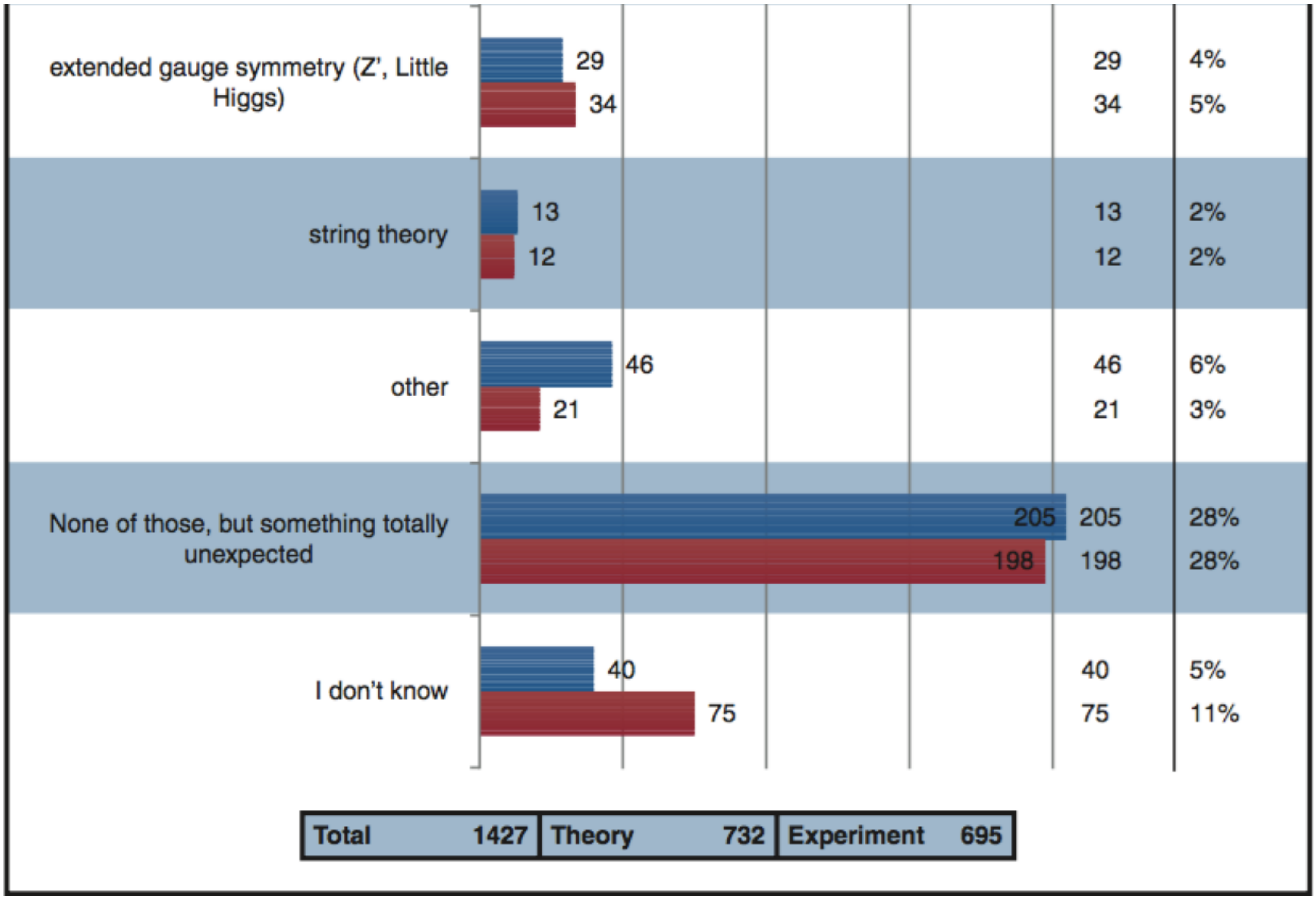

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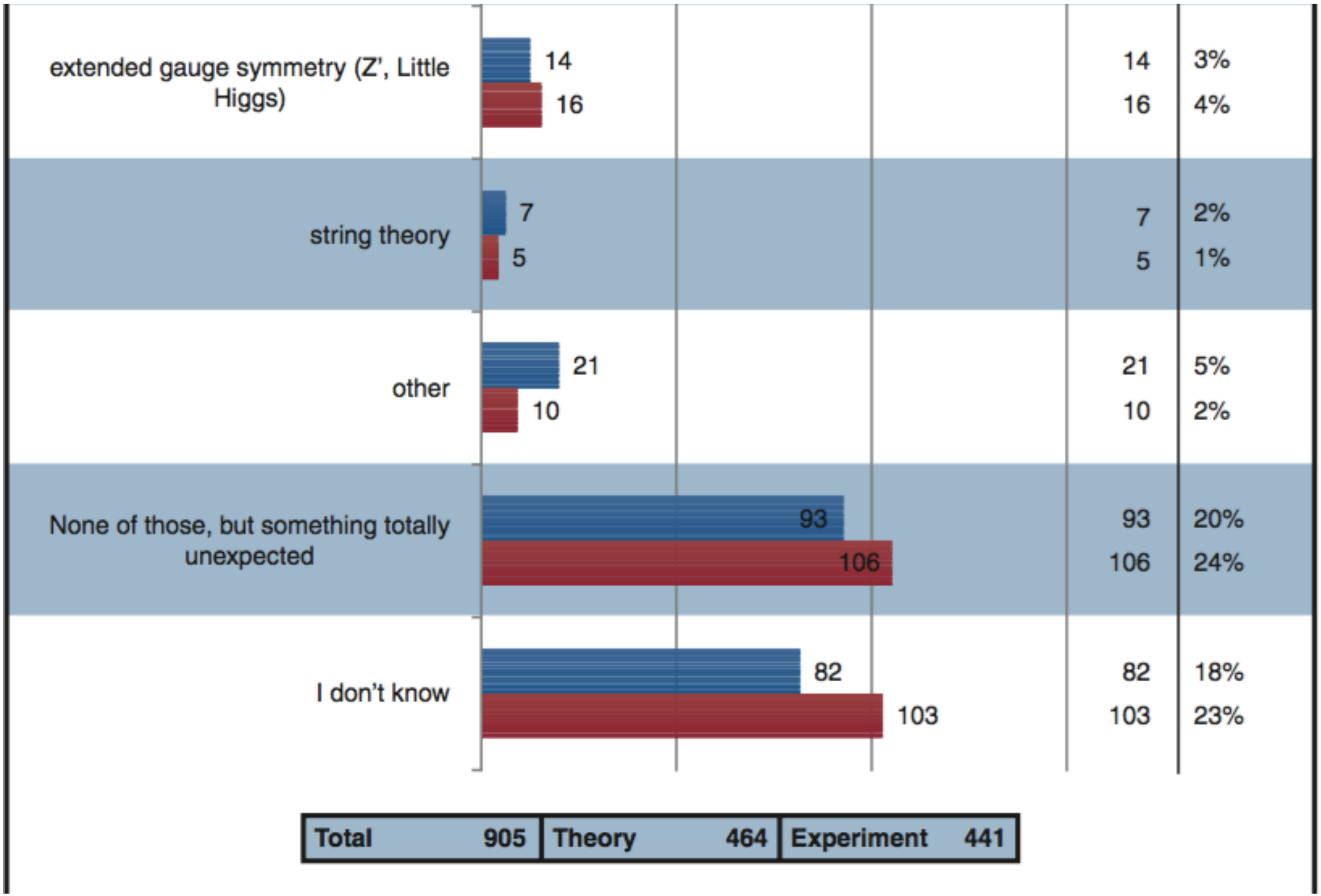


September 2012

Philosophy of physics

What is real?

What *is* "real"?

Ontology =
theory of being, reality

Is a chair real?
Is a quark real?
Is it as real as a chair?

LHC Epistomology:
ontology of the Higgs mechanism
Friederich, Harlander, Lyre

Is gauge symmetry real?
Is breaking of a gauge symmetry real?

Do the ingredients of a theory have to be observable?

Reality of gauge symmetries

Noether's theorem:
symmetry $\Rightarrow$ conserved quantity

examples:
classical mechanics:
translational symmetry $\Rightarrow$ momentum cons'n, etc.

field theory:
global U(1) $\Rightarrow$ electric charge conservation, etc.

$$\phi(x) \to e^{i\theta}\phi(x)$$

Invariante Variationsprobleme.

(F. Klein zum fünfzigjährigen Doktorjubiläum.)

Von

Emmy Noether in Göttingen.

Vorgelegt von F. *Klein* in der Sitzung vom 26. Juli 1918[1]).

wieder dem System angehören. Die Gruppe heißt eine *endliche kontinuierliche* $\mathfrak{G}_\varrho$, wenn ihre Transformationen enthalten sind in einer allgemeinsten, die analytisch von ϱ *wesentlichen* Parametern ε abhängt (d. h. die ϱ Parameter sollen sich nicht als ϱ Funktionen von weniger Parametern darstellen lassen). Entsprechend versteht man unter einer *unendlichen kontinuierlichen* $\mathfrak{G}_{\infty\varrho}$ eine Gruppe, deren allgemeinste Transformationen von ϱ wesentlichen willkürlichen Funktionen $p(x)$ und ihren Ableitungen analytisch oder wenigstens stetig und endlich oft stetig differentiierbar abhängen. Als Zwischenglied zwischen beiden steht die von unendlich vielen Parametern, aber nicht von willkürlichen deutig führt.

Es handelt sich nun im folgenden um die beiden Sätze:

I. Ist das Integral I invariant gegenüber einer $\mathfrak{G}_\varrho$, so werden ϱ linear-unabhängige Verbindungen der Lagrangeschen Ausdrücke zu Divergenzen — umgekehrt folgt daraus die Invarianz von I gegenüber einer $\mathfrak{G}_\varrho$. Der Satz gilt auch noch im Grenzfall von unendlich vielen Parametern.

$$\frac{\delta \mathcal{L}}{\delta \phi_i} - \partial_\mu \frac{\delta \mathcal{L}}{\delta(\partial_\mu \phi_i)} = \partial_\mu X^\mu$$

global symmetries: $$X^\mu = \sum_i \frac{\delta \mathcal{L}}{\delta(\partial_\mu \phi_i)} \frac{\partial \phi_i}{\partial \alpha} \equiv J^\mu$$

on-shell: $$\frac{\delta \mathcal{L}}{\delta \phi_i} - \partial_\mu \frac{\delta \mathcal{L}}{\delta(\partial_\mu \phi_i)} = 0 \quad \Rightarrow \quad \partial_\mu J^\mu = 0$$

global symmetry ⇒ $\partial_\mu J^\mu = 0$

⇒ conserved charge Q

⇒ quantum states can be labelled accordingly:

$$\ldots,\ |Q=-1\rangle\,,|Q=0\rangle\,,|Q=1\rangle\,,|Q=2\rangle\,,\ \ldots$$

II. Ist das Integral I invariant gegenüber einer $\mathfrak{G}_{\infty\varrho}$, in der die willkürlichen Funktionen bis zur σten Ableitung auftreten, so bestehen ϱ identische Relationen zwischen den Lagrangeschen Ausdrücken und ihren Ableitungen bis zur σten Ordnung; auch hier gilt die Umkehrung[1]).

$$\frac{\delta\mathcal{L}}{\delta\phi_i} - \partial_\mu \frac{\delta\mathcal{L}}{\delta(\partial_\mu\phi_i)} = \partial_\mu X^\mu$$

local symmetries: $$X^\mu = \frac{\delta\mathcal{L}}{\delta A_\mu} - \partial_\nu \frac{\delta\mathcal{L}}{\delta(\partial_\nu A_\mu)}$$

no new information (on-shell)!

puzzle:

global symmetry $\Leftrightarrow$ conserved charge

$\rightarrow$ measurable!

local symmetry $\Leftrightarrow$???

Is local symmetry a theoretical artefact?
If so, how can its breaking have physical consequences?

Elitzur's theorem: in gauge theories, $\langle\Phi\rangle$=0 *always*
(proven in lattice gauge theories)

Earman (2004):

As the semi-popular presentations put it, “Particles get their masses by eating the Higgs field.”
Readers of Scientific American can be satisfied with these just-so stories. But philosophers of science should not be. For a genuine property like mass cannot be gained by eating descriptive fluff, which is just what gauge is.

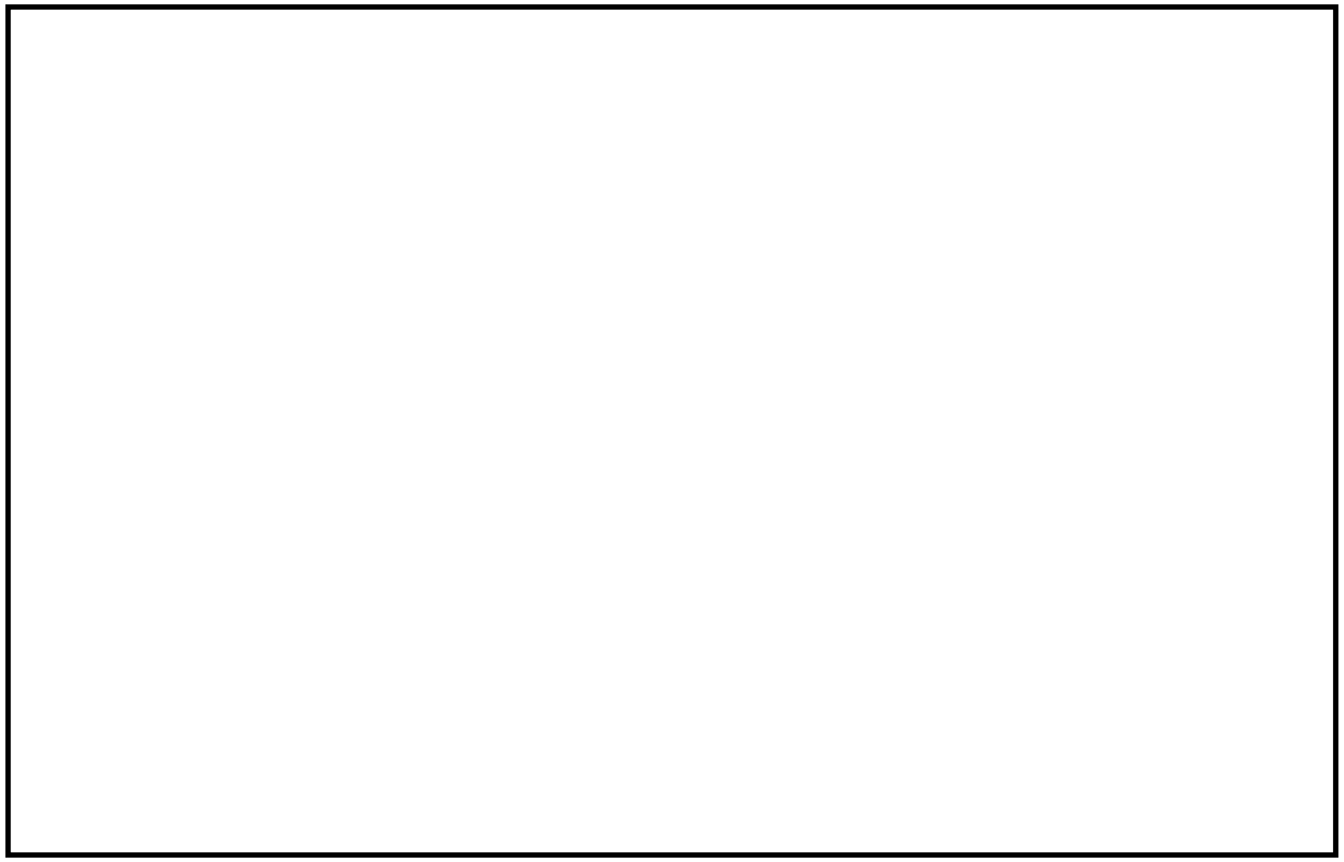
Philosophy of physics

disambiguition:

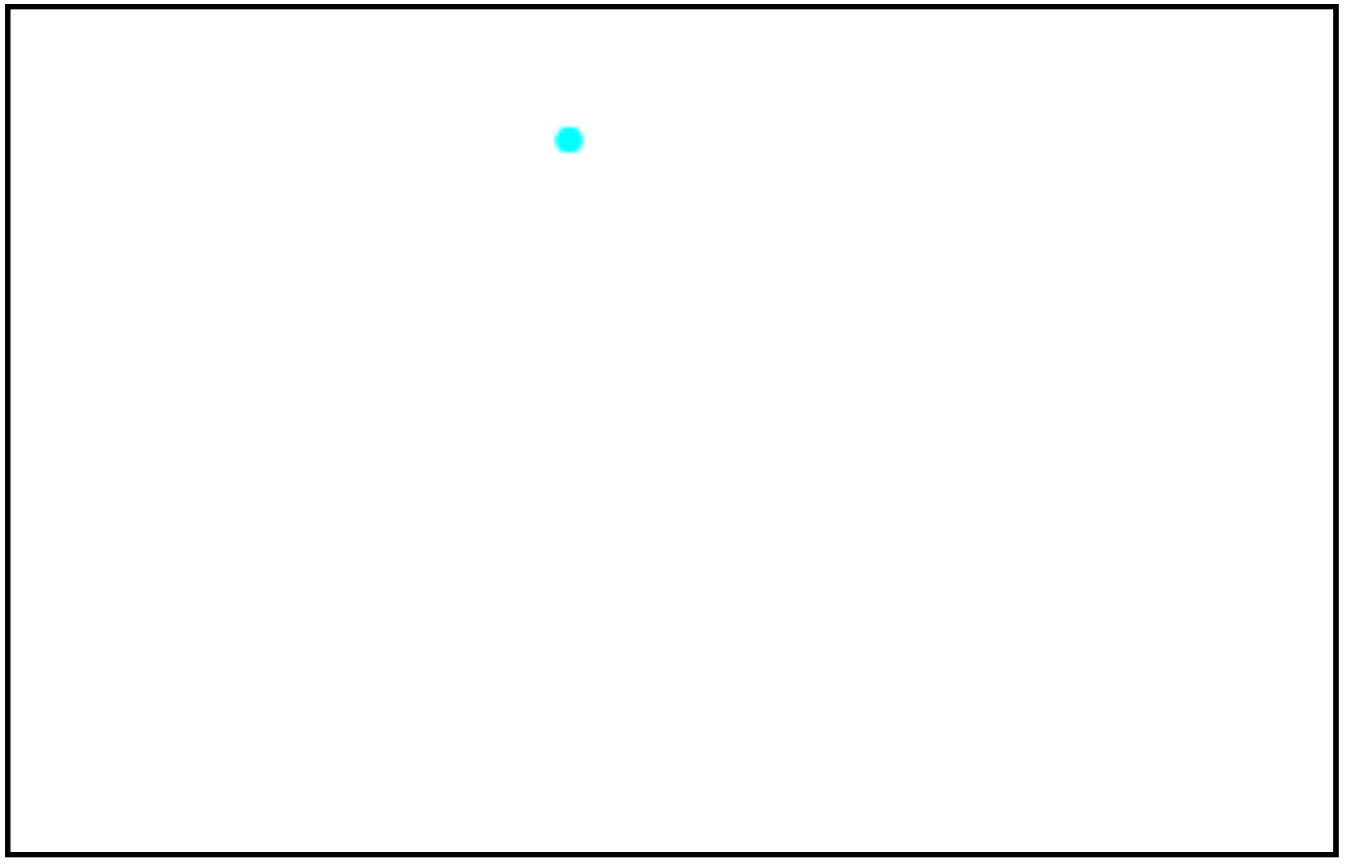
Identify and resolve ambiguities in physical jargon:

- symmetry breaking
- virtual particle
- particle
- mechanism
- explanation
- simplicity
- aesthetics
- ad hoc
- …

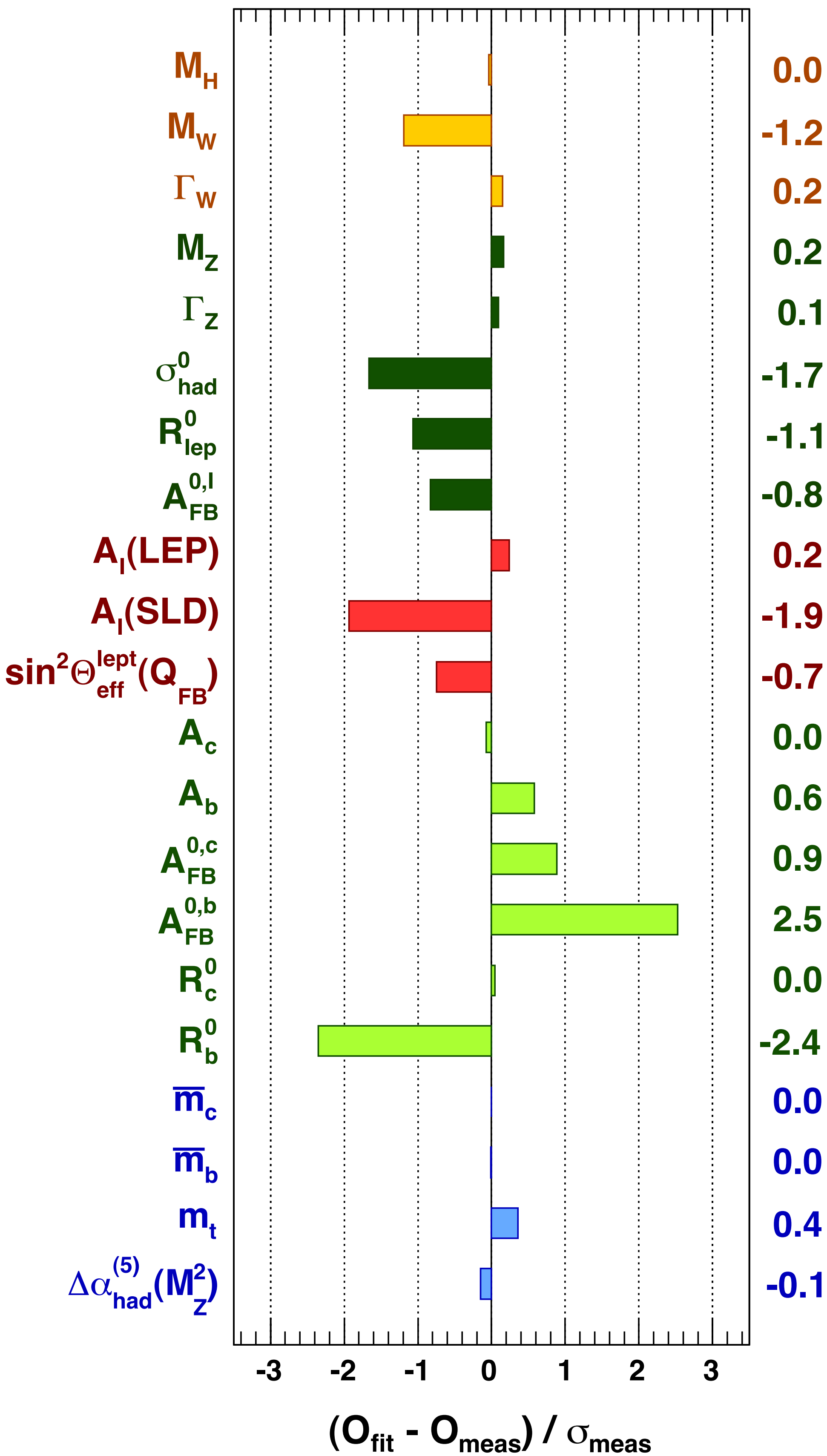
The vacuum



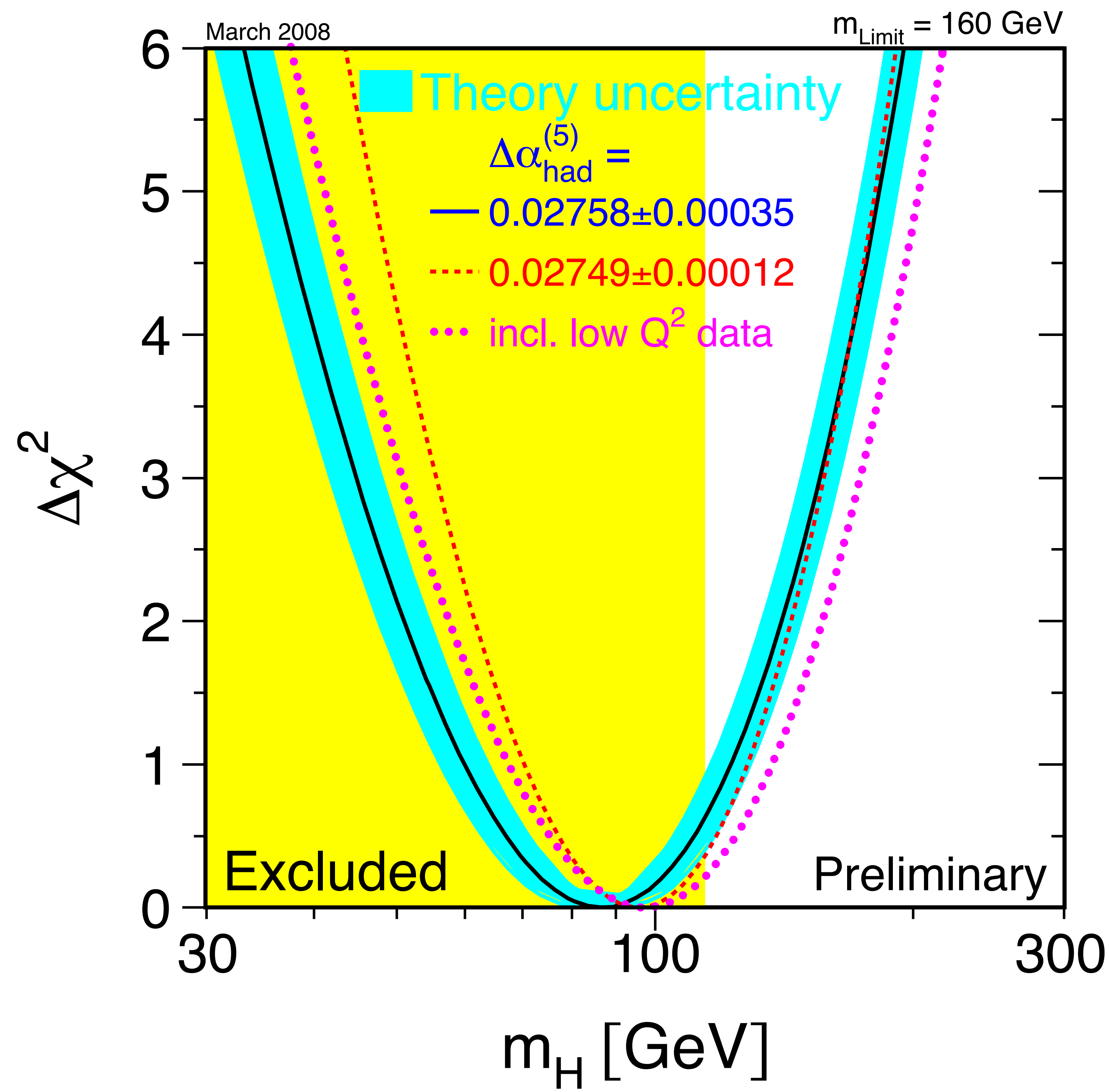
The quantum vacuum



$$\frac{g_2^2}{g_1^2+g_2^2} = \frac{M_W^2}{M_Z^2}\left(1+\delta\rho\left(m_t, M_H, \dots\right)\right)$$



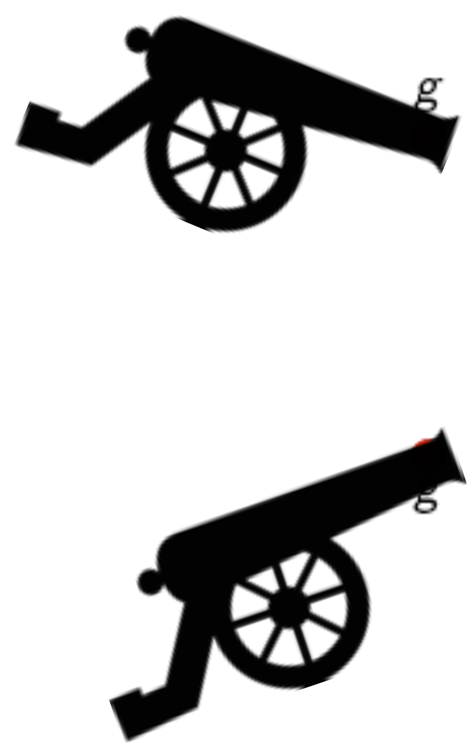
M_H 0.0
M_W -1.2
Γ_W 0.2
M_Z 0.2
Γ_Z 0.1
σ^0_{had} -1.7
R^0_{lep} -1.1
$A^{0,l}_{FB}$ -0.8
A_l(LEP) 0.2
A_l(SLD) -1.9
$\sin^2\Theta^{lept}_{eff}(Q_{FB})$ -0.7
A_c 0.0
A_b 0.6
$A^{0,c}_{FB}$ 0.9
$A^{0,b}_{FB}$ 2.5
R^0_c 0.0
R^0_b -2.4
$\overline{m}_c$ 0.0
$\overline{m}_b$ 0.0
m_t 0.4
$\Delta\alpha^{(5)}_{had}(M^2_Z)$ -0.1
-3 -2 -1 0 1 2 3
$(O_{fit} - O_{meas}) / \sigma_{meas}$



March 2008
m_{Limit} = 160 GeV
Theory uncertainty
$\Delta\alpha^{(5)}_{had}$ =
0.02758±0.00035
0.02749±0.00012
incl. low Q^2 data
$\Delta\chi^2$
0 1 2 3 4 5 6
Excluded
Preliminary
30 100 300
m_H [GeV]


g


g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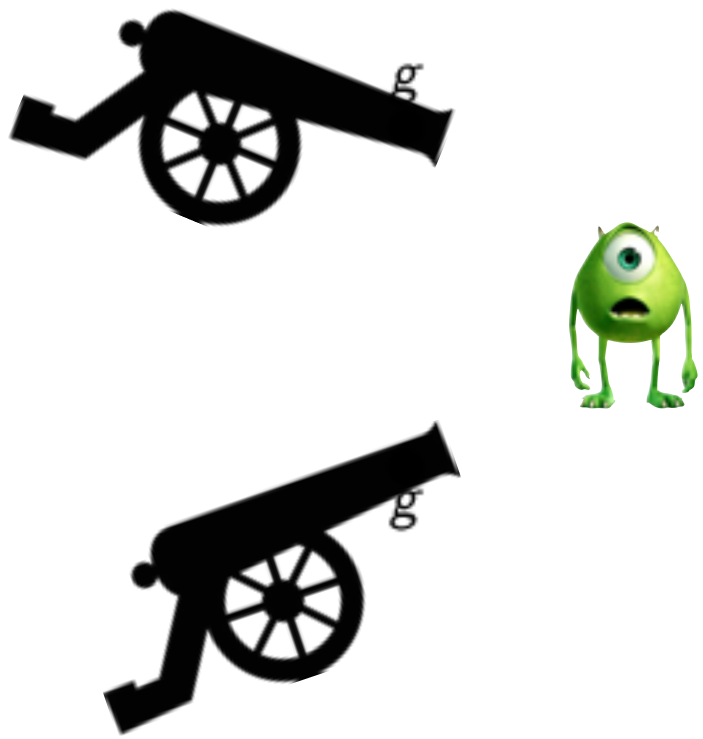
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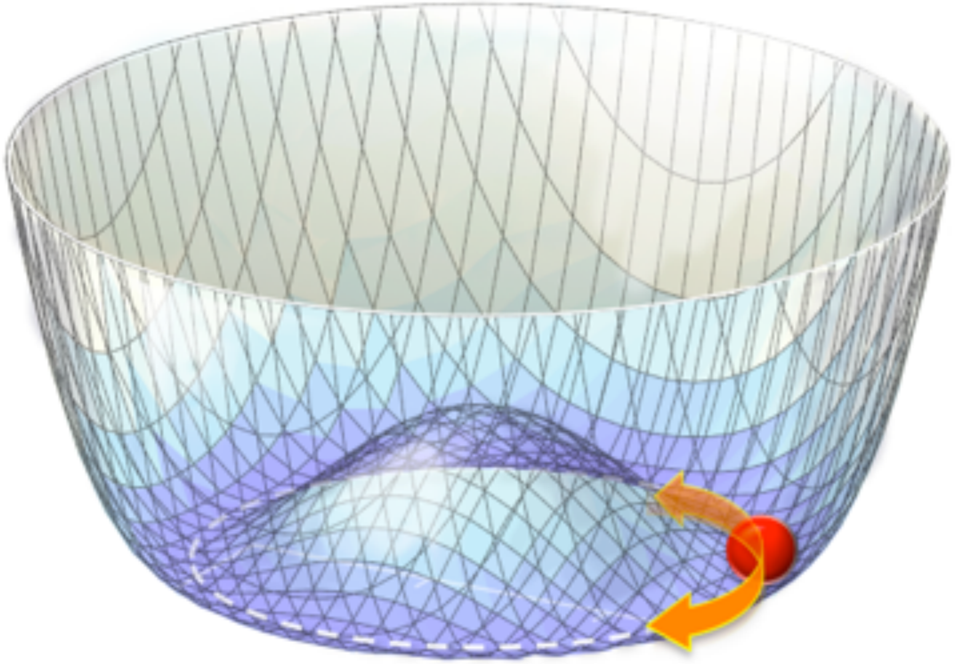

The Nobel Prize in Physics 2013

François Englert, Peter Higgs

The Nobel Prize in Physics 2013

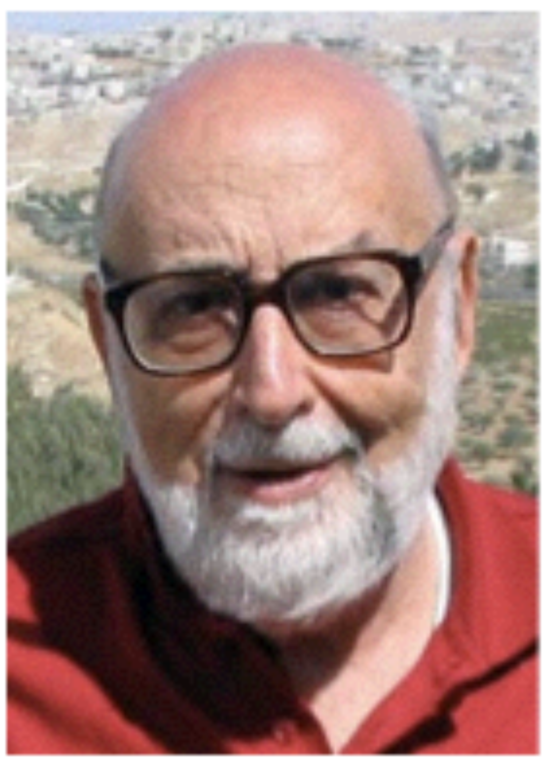

Photo: Pnicolet via Wikimedia Commons

François Englert

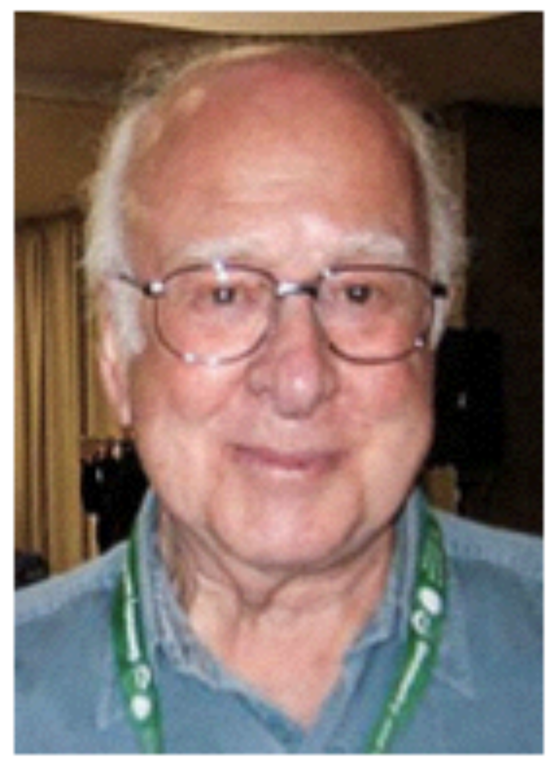

Photo: G-M Greuel via Wikimedia Commons

Peter W. Higgs

+ Brout

+ Guralnik, Hagen, Kibble

+ Anderson

+ ...

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field φ_1 has mass M_1 while φ_2 and φ^- have mass zero. But we can easily see that the Goldstone bosons represented by φ_2 and φ^- have no physical coupling. The Lagrangian is gauge invariant, so we can perform a combined isospin and hypercharge gauge transformation which eliminates φ^- and φ_2 everywhere[6] without changing anything else. We will see that G_e is very small, and in any case M_1 might be very large,[7] so the φ_1 couplings will also be disregarded in the following.

The effect of all this is just to replace φ everywhere by its vacuum expectation value

$$\langle\varphi\rangle = \lambda\binom{1}{0}. \tag{6}$$

The first four terms in $\mathcal{L}$ remain intact, while the rest of the Lagrangian becomes

$-\frac{1}{8}\lambda^2 g^2[$

and has mass

$$M_W = \tfrac{1}{2}\lambda g. \tag{9}$$

The neutral spin-1 fields of definite mass are

$$Z_\mu = (g^2+g'^2)^{-1/2}(gA_\mu{}^3 + g'B_\mu), \tag{10}$$

$$A_\mu = (g^2+g'^2)^{-1/2}(-g'A_\mu{}^3 + gB_\mu). \tag{11}$$

Their masses are

$$M_Z = \tfrac{1}{2}\lambda(g^2+g'^2)^{1/2}, \tag{12}$$

$$M_A = 0, \tag{13}$$

ied as the photon field.
en leptons and spin-1

er than $\frac{\alpha}{2}$. Of course our model has too many arbitrary features for these predictions to be taken very seriously, b

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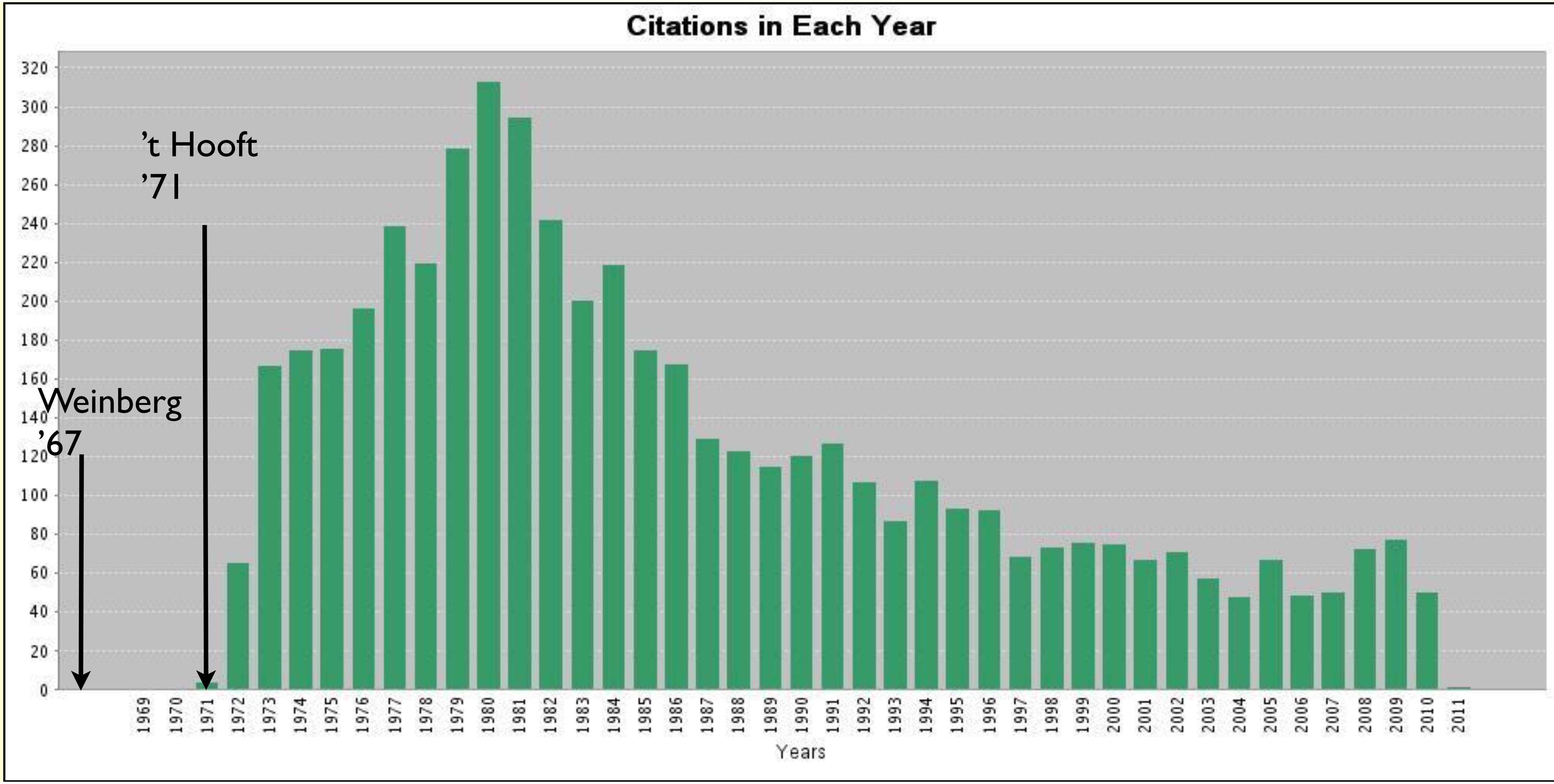
Citations to Weinberg's "Model of Leptons":



H. Kragh

7.A.1

Nuclear Physics B35 (1971) 167–188. North-Holland Publishing Company

RENORMALIZABLE LAGRANGIANS FOR MASSIVE YANG-MILLS FIELDS

G.'t HOOFT
Institute for Theoretical Physics, University of Utrecht

† The model of this section is due to Weinberg [13], who showed that it can describe weak interactions between leptons. His lepton model can be shown to be renormalizable.

studied in more detail, local SU(2) is broken in such a way that local U(1) remains as a symmetry. A renormalizable and unitary theory results, with photons, charged massive vector particles, and additional neutral scalar particles. It has three independent parameters.

Another model has local SU(2)$\otimes$U(1) as a symmetry and may serve as a renormalizable theory for ρ-mesons and photons.

In such models electromagnetic mass-differences are finite and can be calculated in perturbation theory.

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PHYSICAL REVIEW VOLUME 145, NUMBER 4 27 MAY 1966

Spontaneous Symmetry Breakdown without Massless Bosons*

PETER W. HIGGS†
Department of Physics, University of North Carolina, Chapel Hill, North Carolina
(Received 27 December 1965)

We examine a simple relativistic theory of two scalar fields, first discussed by Goldstone, in which as a result of spontaneous breakdown of $U(1)$ symmetry one of the scalar bosons is massless, in conformity with the Goldstone theorem. When the symmetry group of the Lagrangian is extended from global to local $U(1)$ transformations by the introduction of coupling with a vector gauge field, the Goldstone boson becomes the longitudinal state of a massive vector boson whose transverse states are the quanta of the transverse gauge field. A perturbativ… phenomena are present in zero orde… lowest order, and it is shown that … ich the original symmetry is no lo… invariant La-grangian, the other … ally conserved current which inter…

i. Decay of a Scalar Boson into Two Vector Bosons

The process occurs in first order (four of the five cubic vertices contribute), provided that $m_0 > 2m_1$. Let p be the incoming and k_1, k_2 the outgoing momenta. Then

$$M = i\{e[a^{*\mu}(k_1)(-ik_{2\mu})\phi^*(k_2) + a^{*\mu}(k_2)(-ik_{1\mu})\phi^*(k_1)] \\ - e(ip_\mu)[a^{*\mu}(k_1)\phi^*(k_2) + a^{*\mu}(k_2)\phi^*(k_1)] \\ - 2em_1 a_\mu^*(k_1)a^{*\mu}(k_2) - fm_0\phi^*(k_1)\phi^*(k_2)\}.$$

By using Eq. (15), conservation of momentum, and

Nuclear Physics B106 (1976) 292–340

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he

We sho … to ex-
perimental … ke the
case with … cles, except
that they are probably all very small. For these reasons we do not want to encourage
big experimental searches for the Higgs boson, but we do feel that people performing
experiments vulnerable to the Higgs boson should know how it may turn up.

Problems with the Higgs mechanism

- requires a fundamental scalar particle
  — *the only one!*
- naturalness: Higgs mass should be large

assume: $\mathcal{L} = \mathcal{L}_{\rm SM}(\hat{g}, \hat{m}_q, \hat{M}_W, \hat{M}_H, \ldots) + \mathcal{L}_\Lambda$

physics at E≪Λ:

$$\mathcal{L} \to \mathcal{L}_{\rm SM}(g, m_q, M_W, M_H, \ldots) + \mathcal{O}\left(1/\Lambda\right)$$

$$m(\mu) = \hat{m}(\mu)\left(1 + \mathcal{O}(\ln\mu/\Lambda)\right)$$
$$g(\mu) = \hat{g}(\mu)\left(1 + \mathcal{O}(\ln\mu/\Lambda)\right)$$
$$M_H^2 = \hat{M}_H^2 + \mathcal{O}(\Lambda^2)$$

$125^2 = 10^{32} - (10 + 0.0000000000000000000000000000488)^{32}$

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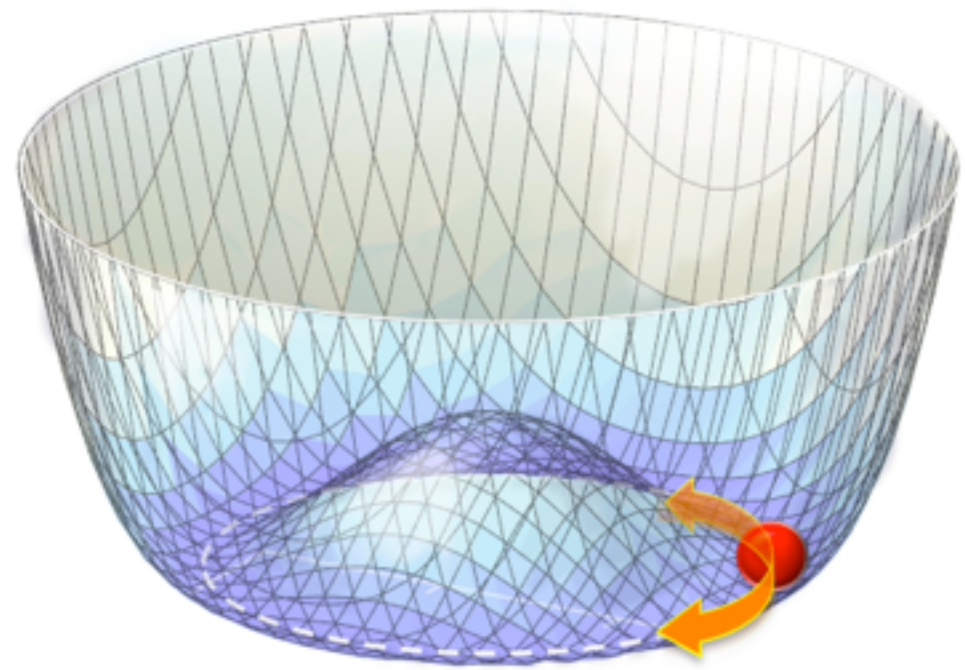
Problems with the Higgs mechanism

$$V(\phi) = -\mu^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2$$

↑

by hand



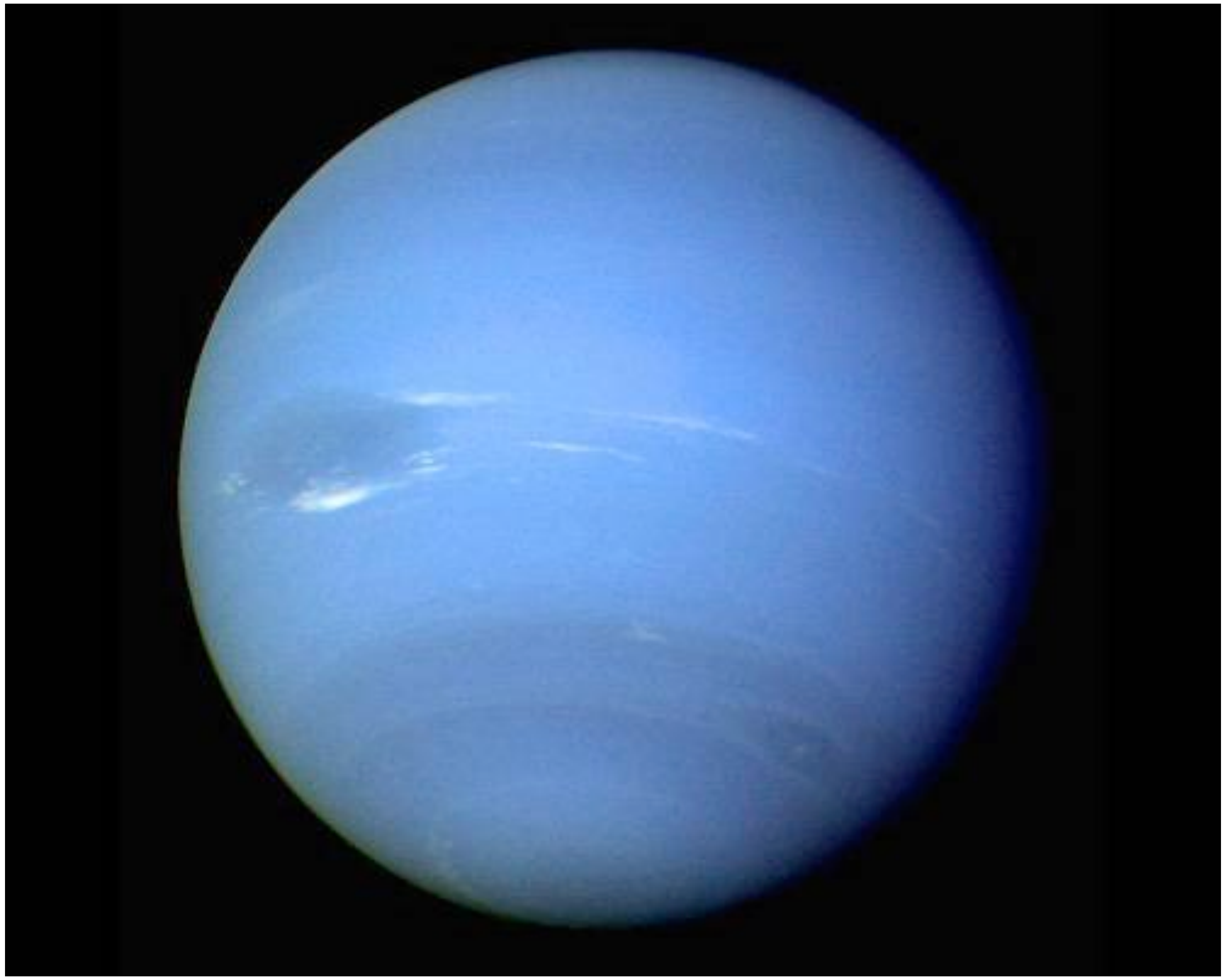
- no prediction of particle masses
- no prediction of CKM matrix
- …

> While the Weinberg-Salam model [i.e. the SM] is recognized to be a theoretical and experimental success, it is frequently believed that the Higgs mechanism [...] is an unsatisfactory feature of the theory. There is no experimental evidence for fundamental scalar fields, which are introduced in an ad hoc manner with ad hoc interactions solely to effect the symmetry breakdown. There is no other compelling theoretical reason for scalar fields. (Farhi and Jackiw 1982, p. 1.)

> Spontaneous symmetry breaking is adopted from many-body, condensed matter physics, where it is well understood: the dynamical basis for the instability of symmetric configurations can be derived from first principles. In the particle physics application, we have not found the dynamical reason for the instability. Rather, we have postulated that additional fields exist, which are destabilizing and accomplish the symmetry breaking. But this ad hoc extension introduces additional, a priori unknown parameters and yet-unseen particles, the Higgs mesons [i.e. Higgs bosons]. (Jackiw 1998, 12777)

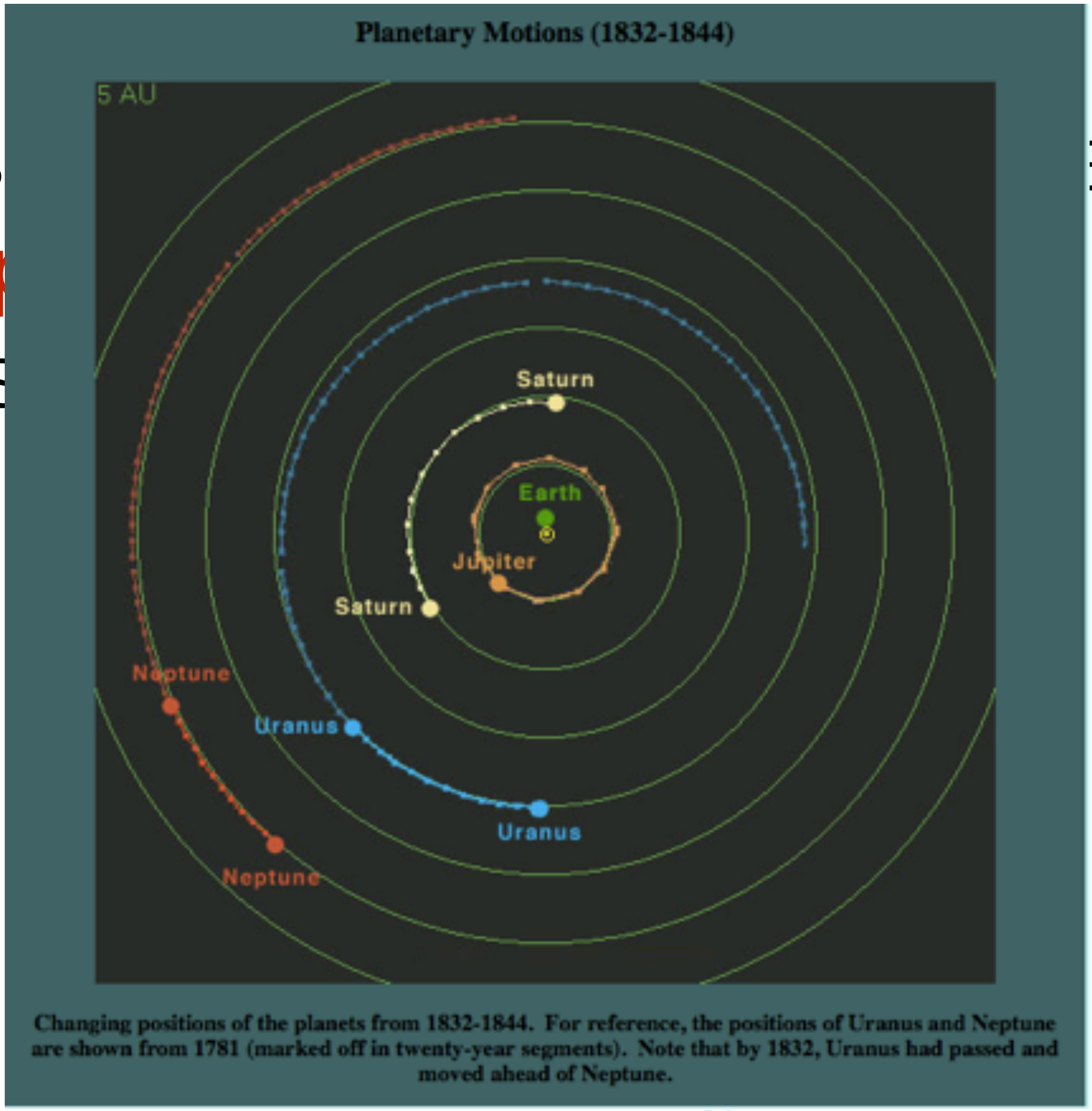
> Unlike the rest of the theory, the Higgs sector is rather arbitrary, and its form is not dictated by any deep fundamental principle. For this reason its structure looks frightfully ad hoc. [...] (Guidice 2009, p. 174)

> [While] the idea of spontaneous symmetry breaking to explain why each of the elementary particles we see in the world has different properties [...] is a beautiful idea, there is a certain ad hoc quality to how it is realized. To this date, no one has so far observed a Higgs particle and we have only a very imprecise idea of their actual properties. (Smolin 1999, p. 61.)



Neptune

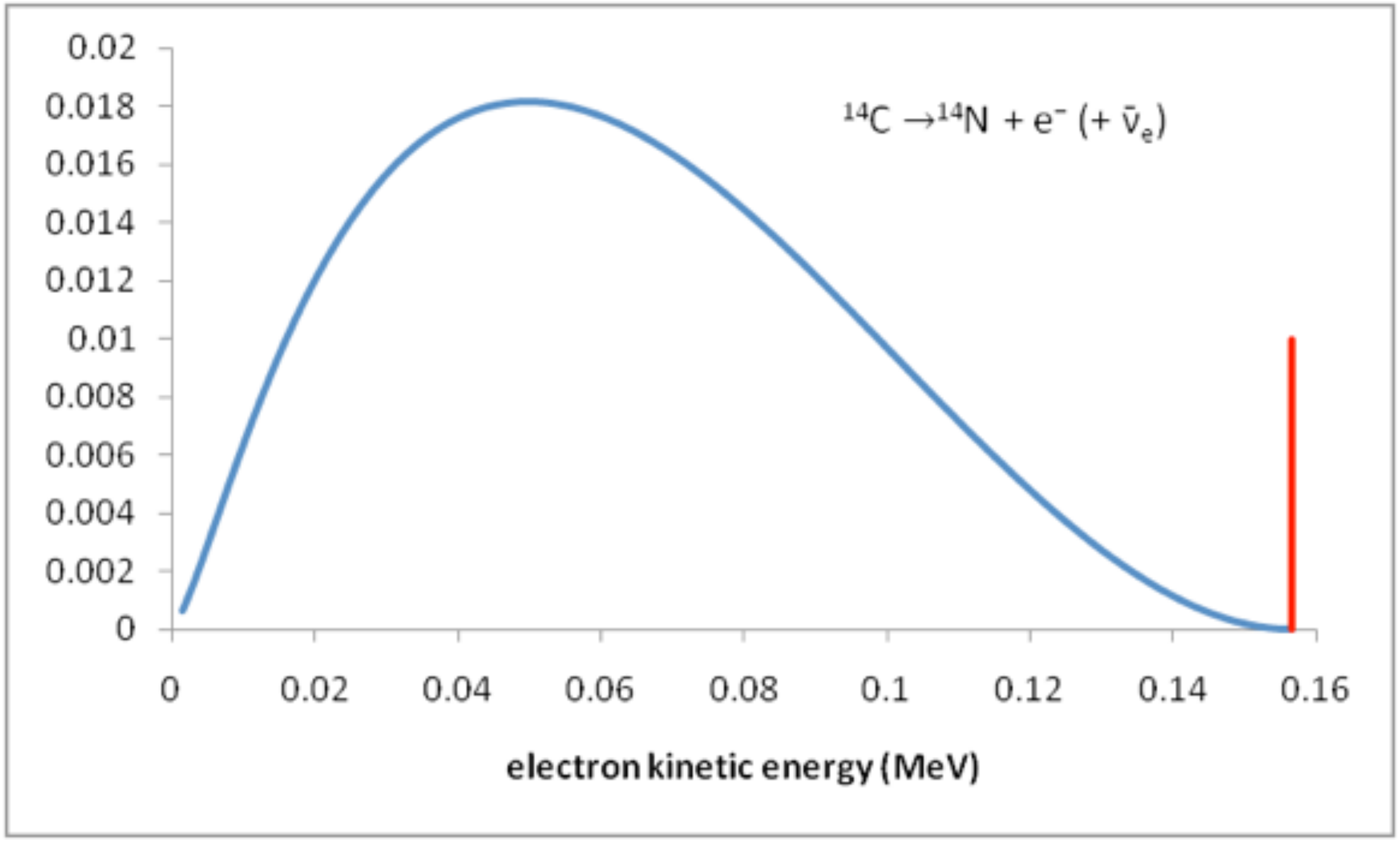
- 1781: Uranus discovered (W. Herschel)
- 1788: position deviates from prediction
- 1835: A. Bouvard suggests trans-Uranian planet
  → ad hoc?
- 1845: J.C. Adams ... e
  position of the Ne...
- 1846: Neptune dis...



Changing positions of the planets from 1832-1844. For reference, the positions of Uranus and Neptune are shown from 1781 (marked off in twenty-year segments). Note that by 1832, Uranus had passed and moved ahead of Neptune.

Neutrino

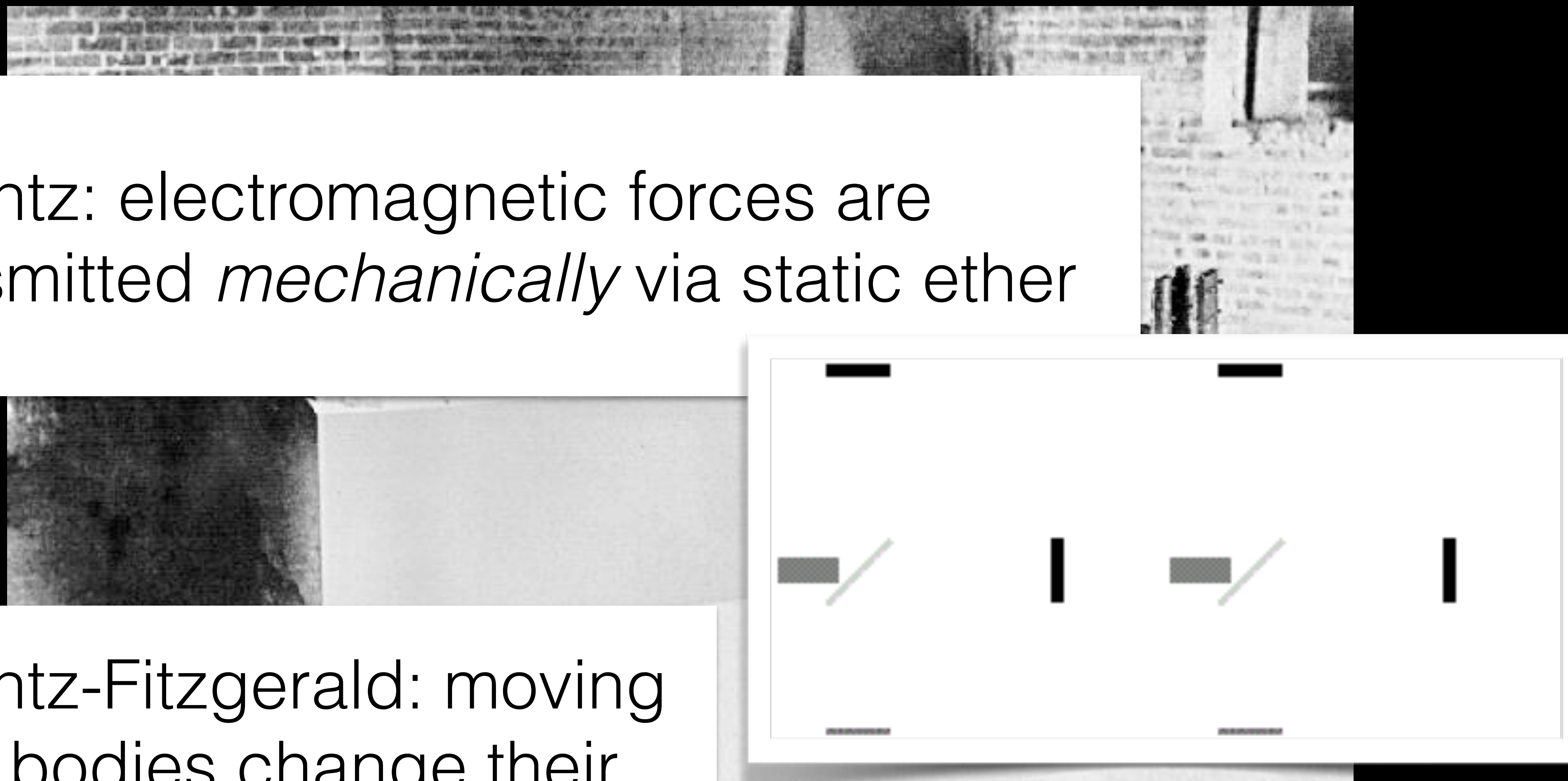
- apparent energy violation in β decay



- 1930: Pauli proposes a new particle: massless, electrically neutral → ad hoc?

Lorentz-Fitzgerald length contraction

Michelson-Morley 1887



Lorentz: electromagnetic forces are transmitted *mechanically* via static ether

Lorentz-Fitzgerald: moving rigid bodies change their size.

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What is ad hoc?

- 1934: Popper

“Some genuinely testable theories, when found to be false, are still upheld by their admirers - for example by introducing ad hoc some auxiliary assumption, or by re-interpreting the theory ad hoc in such a way that it escapes refutation. Such a procedure is always possible, but it rescues the theory from refutation only at the price of destroying, or at least lowering, its scientific status.”

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- 1975: Feyerabend

Ad-hoc-Hypothesen verschaffen…

"…neuen Theorien eine Atempause, und sie deuten die Richtung der zukünftigen Forschung an."

[ad-hoc hypotheses give new theories some breathing time; they indicate the direction of future research]

in other words: time to look for a better theory!

JARRETT LEPLIN

THE CONCEPT OF AN *AD HOC* HYPOTHESIS

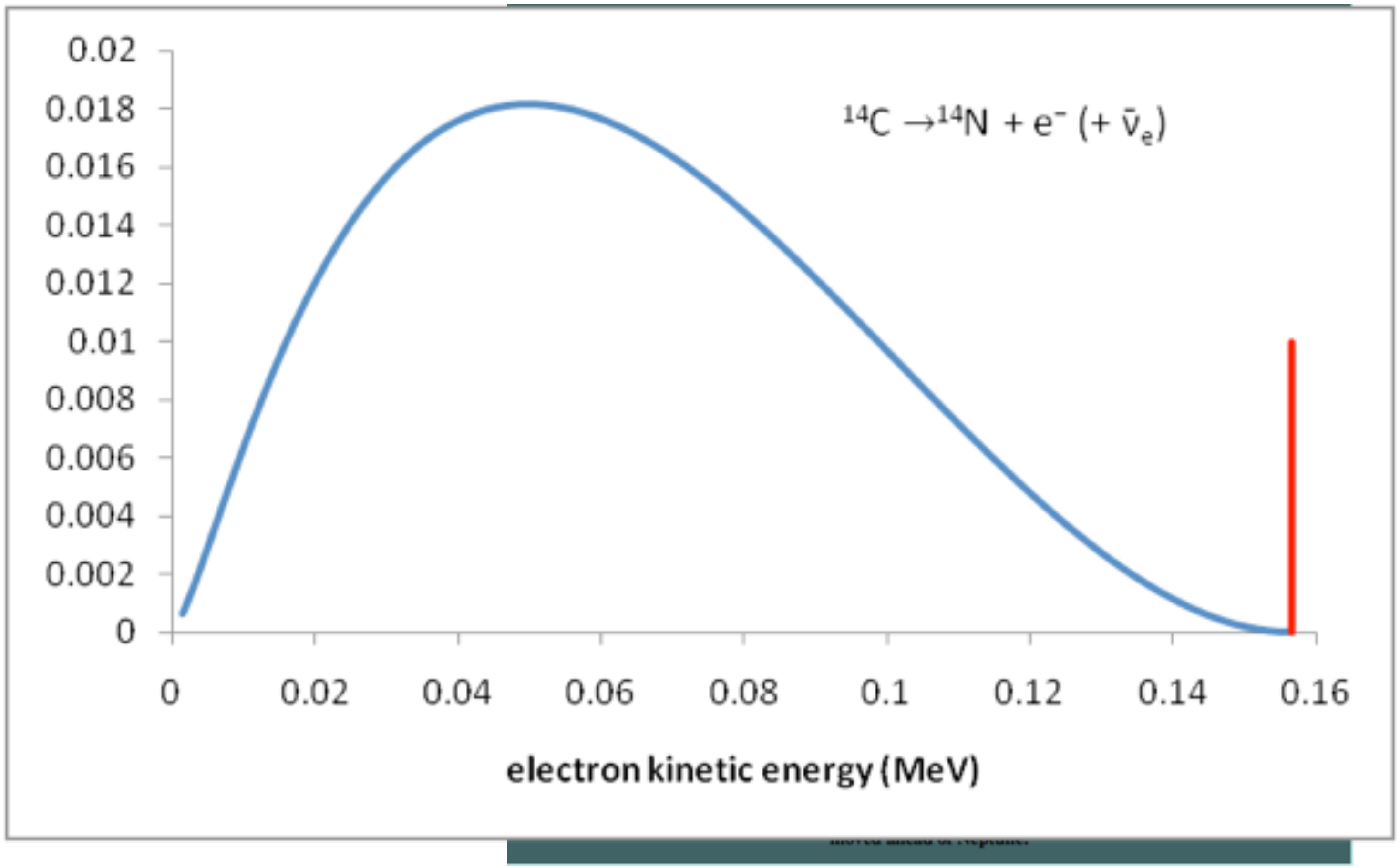
Introduction

RECENT work on the history of the Lorentz theory of electrons and its competition with the special theory of relativity poses a challenging philosophical problem. The acceptance of relativity in preference to the Lorentz theory is readily understandable from a contemporary perspective. But with what arguments could a physicist defend this decision during

1975

Condition of experimental anomaly
If an hypothesis H is introduced into a theory T in response to an experimental result E, then if H is *ad hoc*, E is anomalous for T but not for T as supplemented by H.

There is some "strange" result.



Condition of justification

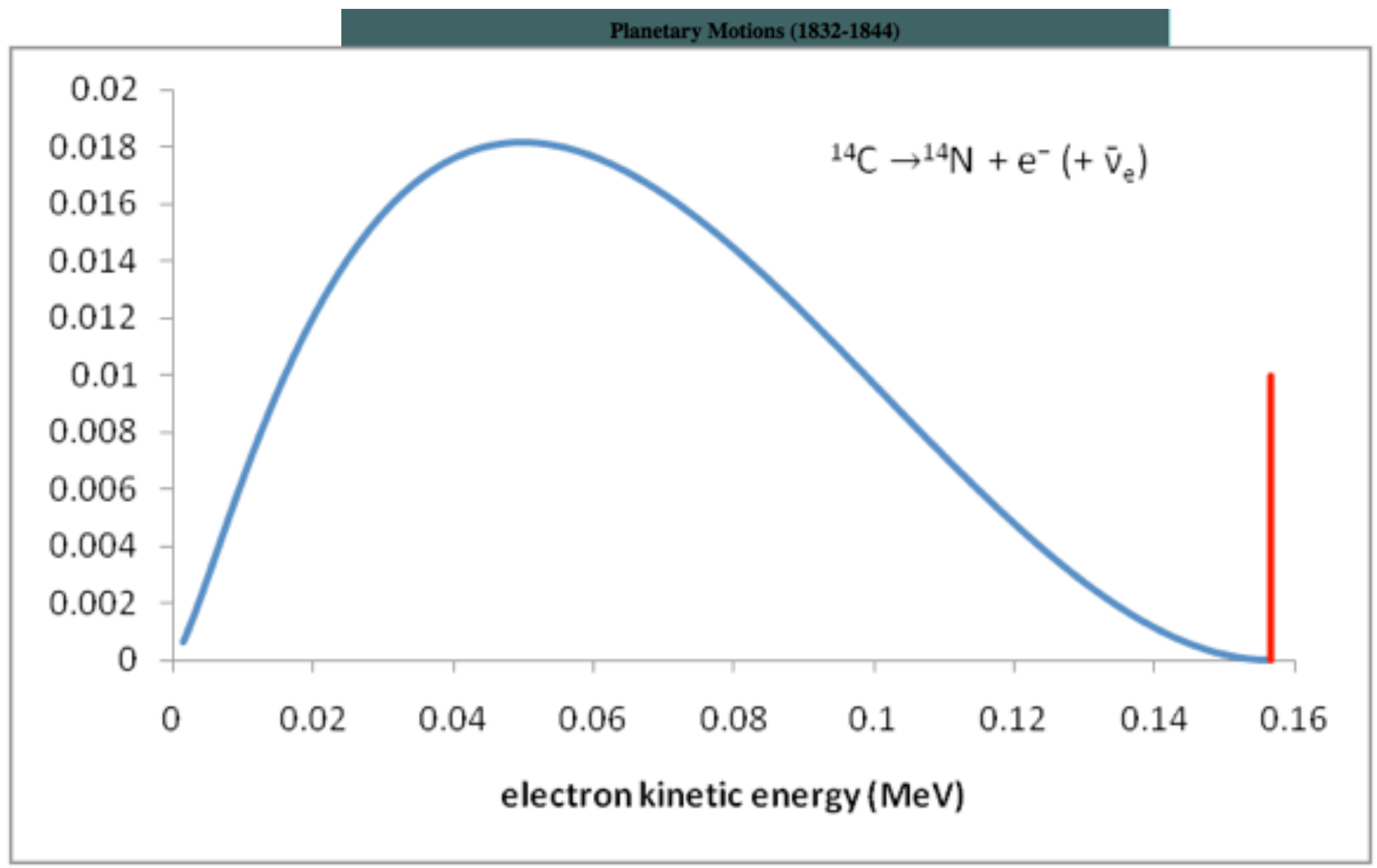
If an hypothesis *H* is introduced into a theory *T* in response to an experimental result *E*, then if *H* is *ad hoc*, *E* is evidence for *H* but:

1. No available experimental results other than *E* are evidence for *H*.
2. *H* has no application to the domain of *T* apart from *E*.
3. *H* has no independent theoretical support.

I have a solution! But…

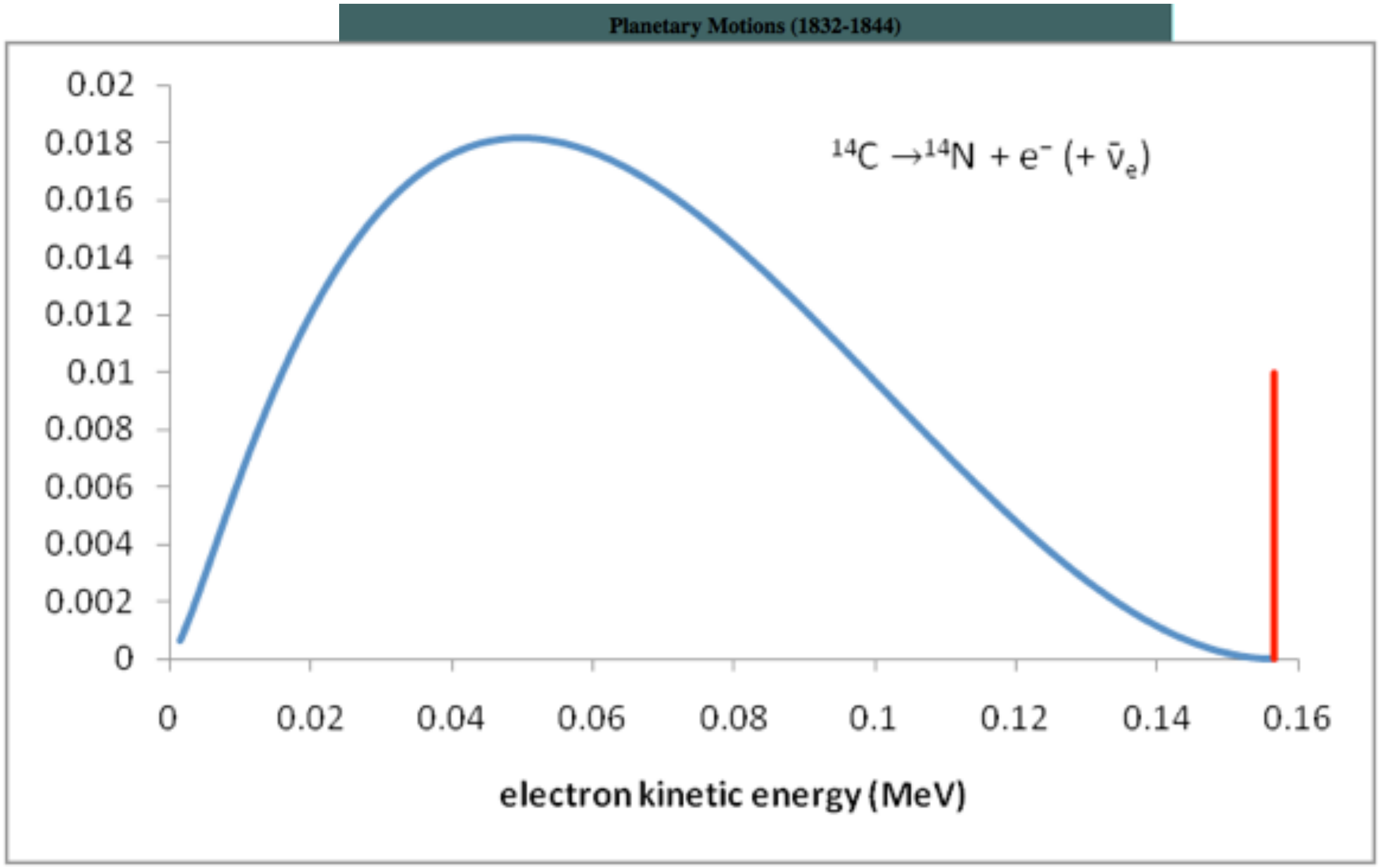
1. … it only solves *this one problem*
2. … I don't know any other application in this field
3. … I cannot explain it from anything we know

"independent support"



Consistency condition
If an hypothesis *H* introduced into a theory *T* is *ad hoc*, then *H* is consistent with accepted theory and with the essential propositions of *T*.

… at least my solution is not in contradiction with what we know.

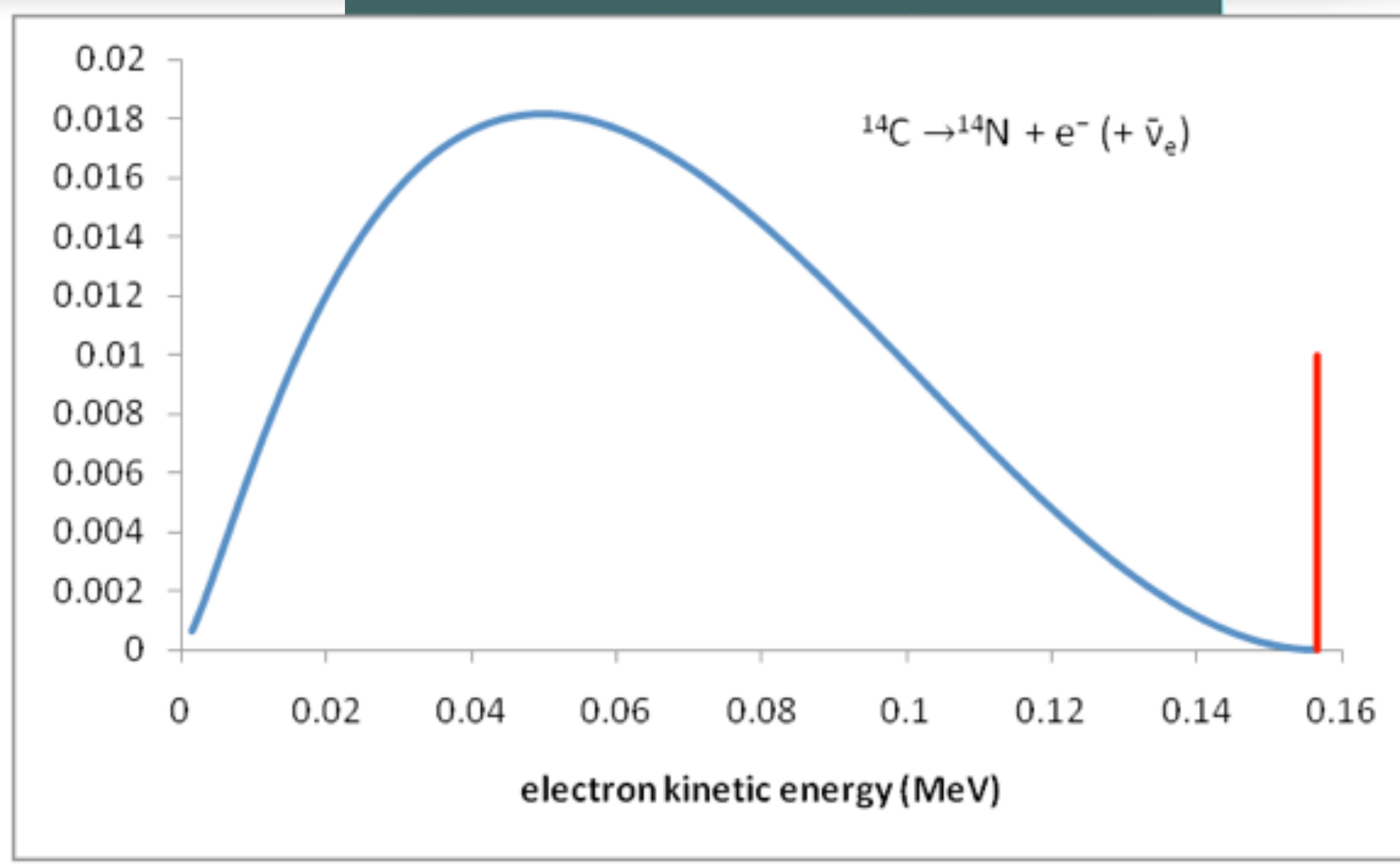


Condition of tentativeness

If an hypothesis *H* is *ad hoc*, then there are no sufficient grounds for holding that *H* is true and no sufficient grounds for holding that *H* is false.

Planetary Motions (1832-1844)

I cannot convince you that I'm right, but you cannot convince me that I'm wrong either.



Condition of non-fundamentality

If an hypothesis *H* introduced into a theory *T* in response to an experimental result *E* is *ad hoc*, then there are problems other than *E* confronting *T* which there is good reason to believe are connected with *E* in the following respects:

(*a*) These problems together with *E* indicate that *T* is non-fundamental.

(*b*) None of these problems including *E* can be satisfactorily solved unless this r

(*c*) A satis tribute to the soluti

In other words: if H is “true”, we’ll be in even deeper trouble.

I know, it feels like…

I REMOVE THE SYMPTOMS, BUT NOT THE CAUSE...

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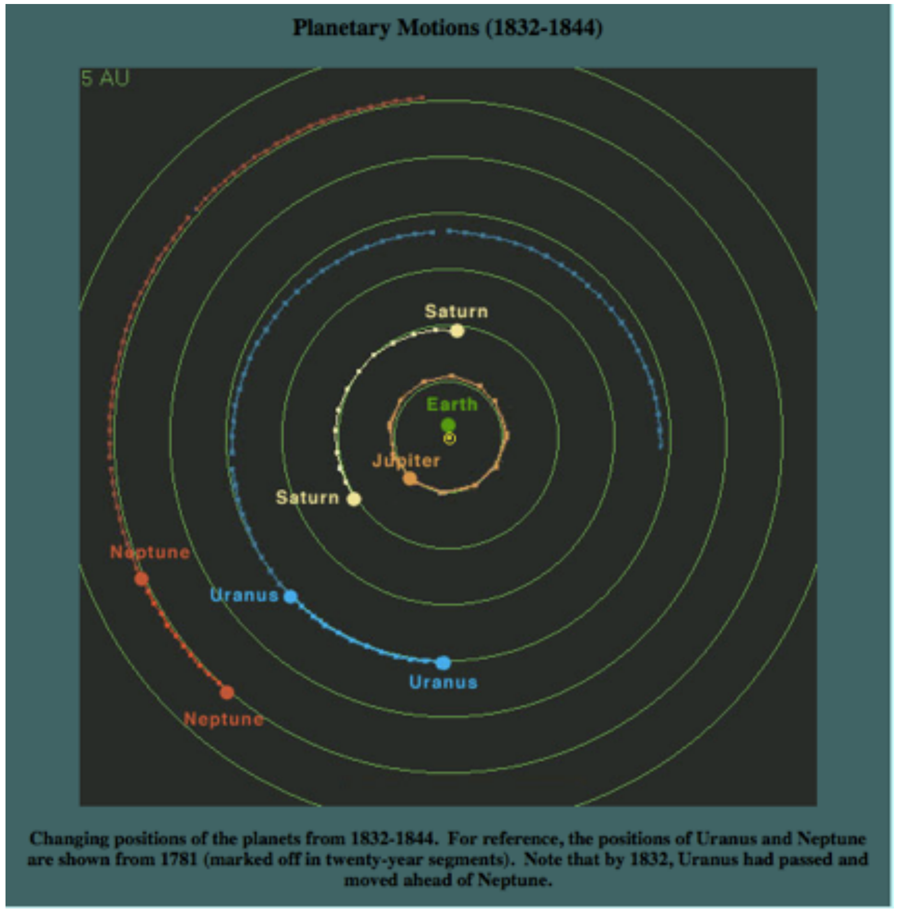
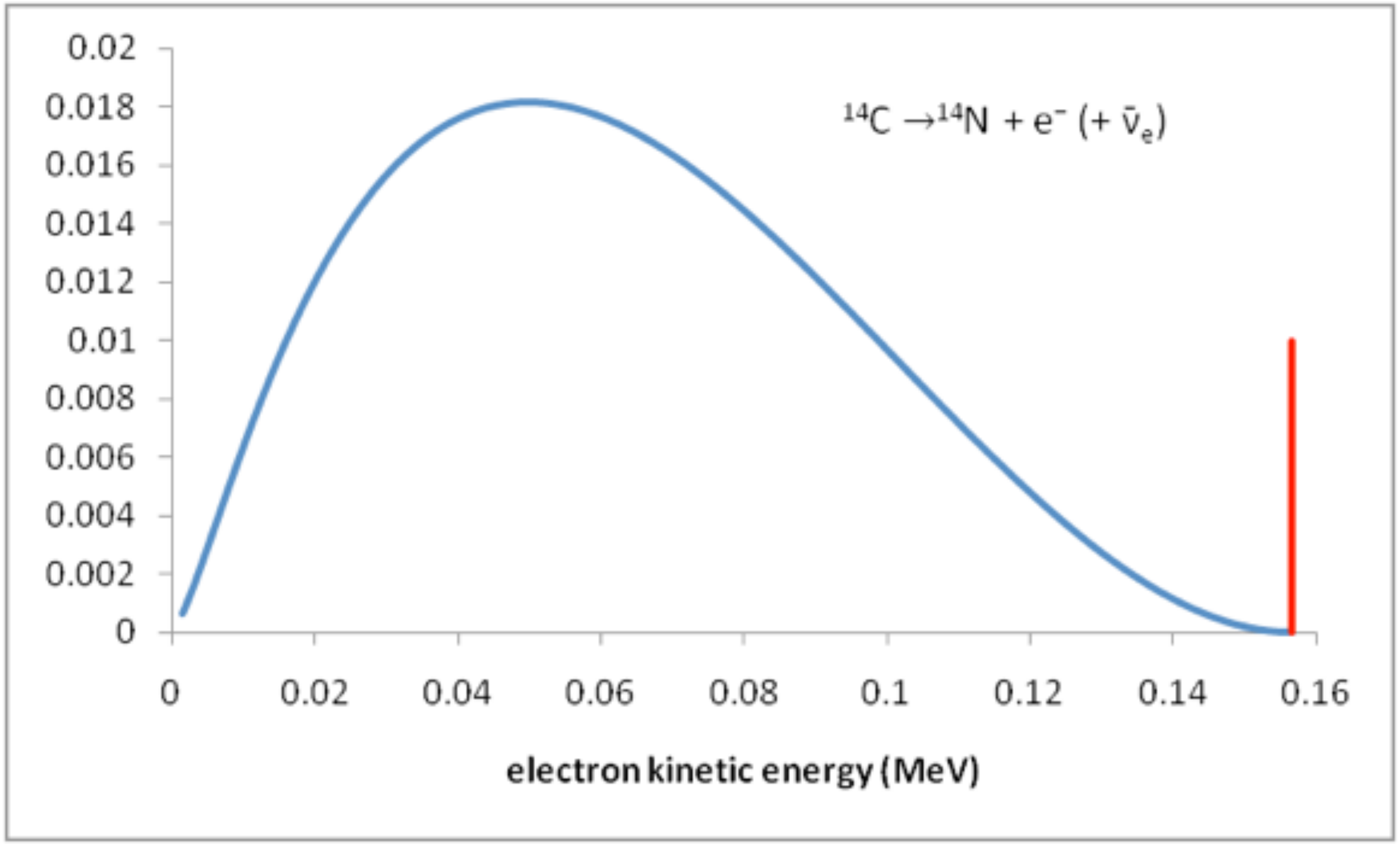
Do we think the underlying theory is fundamental?



gravity: definitely

Do we think the underlying theory is fundamental?



QFT: infinities!

"Maybe understanding the infinities will also resolve the energy-conservation problem?"

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Result:

- Neptune is not ad hoc
- Neutrino is ad hoc

(but it still turned out right!)

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Lorentz-Fitzgerald length contraction

- **Is there an experimental anomaly?**
  Sure: Michelson-Morley ✓
- **Is there independent support for length contraction?**
  No: there is only Michelson-Morley, and there is no theory behind it. ✓
- **Is it theoretically consistent?**
  Yes: Remember that the ether defines an absolute reference frame! ✓

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Lorentz-Fitzgerald length contraction

- **Can I convince you that it's right?**
  Definitely no. ✓
- **Can you convince me that it's wrong?**
  Definitely no: in the end, it sort of turned out right! ✓
- **Are there other problems with the ether theory?**
  Oh yes:
  - back reaction ether ⟷ matter
  - relativity (why is there a preferred frame?)
  - etc. ✓

definitely ad hoc!

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Higgs mechanism (Standard Model)

Standard Model:

$$SU(3)\otimes SU(2)\otimes U(1) \;=:\; SM_0$$

$$\oplus$$

Higgs mechanism

- **Is there an experimental anomaly w.r.t. SM_0?**
  yes: particle masses

was known *before* SM_0

$\Rightarrow$ requires slight modification of Leplin's conditions

$\Rightarrow$ (✓)

Higgs mechanism (Standard Model)

Standard Model:

$$SU(3)\otimes SU(2)\otimes U(1) \quad =: \quad SM_0$$

$$\oplus$$

Higgs mechanism

- **Is it theoretically consistent?**
  yes ✓

Higgs mechanism (Standard Model)

Standard Model:

$$SU(3)\otimes SU(2)\otimes U(1) \;=:\; SM_0$$

$$\oplus$$

Higgs mechanism

- **Is there independent support?**

  experimentally:

  - ρ-parameter? no
  - several particle masses? not really $\Rightarrow$ ✓
  - **Higgs boson? not before 2012!**

  theoretically: no (sign of μ^2 put by hand!)

Higgs mechanism (Standard Model)

Standard Model:

$$SU(3) \otimes SU(2) \otimes U(1) \;\; =: \;\; SM_0$$

$$\oplus$$

Higgs mechanism

- **Can you convince me that it's wrong?**

  no: after all, SM is renormalizable

$$\Rightarrow \checkmark$$

Higgs mechanism (Standard Model)

Standard Model:

$$SU(3) \otimes SU(2) \otimes U(1) \quad =: \quad SM_0$$

$$\oplus$$

Higgs mechanism

- **Can I convince you that it's right?**

  no:
  - naturalness problem
  - there are too many alternatives

  $\Rightarrow \checkmark$

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Higgs mechanism (Standard Model)

Standard Model:

$$SU(3)\otimes SU(2)\otimes U(1) \;=:\; SM_0$$

$$\oplus$$

Higgs mechanism

- **Is the Standard Model a fundamental theory?**

  I don't think so:
  - gravity?
  - pattern of CKM matrix?
  - pattern of particle masses?
  - number of generations?
  - …

→ all possibly related the the Higgs mechanism!

$\Rightarrow$ ✓

Higgs mechanism (Standard Model)

Standard Model:

$$SU(3) \otimes SU(2) \otimes U(1) \;\; =: \;\; SM_0$$

$$\oplus$$

Higgs mechanism

result:
before July 4, 2012: SM Higgs mechanism is ad hoc
after that: no longer ad hoc!

so what?

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A religious analogy

assume: there is no astronomy

1. Paradigm: *God is good* — theories are natural
2. Observation: *Craters* — particle masses
3. Ad-hoc hypothesis: *Meteorites* — Higgs mechanism
   → *could destroy us* → *conflict with paradigm*
4. Event: *Meteorite hits earth* — Higgs discovery
   → *hypothesis no longer ad hoc*
5. Possible conclusions:
   A. it's all part of a bigger plan — new physics to come
   B. God is not good — naturalness is a red herring
   C. there is no God — anthropic principle

pre-discovery: Higgs mechanism ad hoc

$\Rightarrow$ a reason to look for alternatives

post-discovery: no longer ad hoc

but problems remain real

$\Rightarrow$ time to think about the arguments used against it

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THE EPISTEMOLOGY OF THE LARGE HADRON COLLIDER (LHC)

Current Job Advertisement

Junior Professor in Philosophy with a specialization in Philosophy of Physics

6 Postdoctoral and 5 Doctoral Student positions in the fields of philosophy of science, physics, history of science, and science studies

The idea and structure of the research unit

THE EPISTEMOLOGY OF THE LARGE HADRON COLLIDER (LHC)

Thematic Cluster A: Change in the theoretical foundations of physics

As much as the Standard Model provides a stunningly precise description of all data in the energy range up to several hundred GeV, there are plenty of features that call for a more encompassing theory. The firm belief of the physics community in the existence of a better theory is, to a large extent, not determined by experimental observations contradicting the standard theoretical framework, but instead by conceptual arguments. Thematic Cluster A investigates concepts and methods shared by all extensions of the Standard Model, as well as different ways in which this model landscape can be partitioned according to different aims and principles. What these aims and principles have in common is the striving for simpler and more encompassing theories.

A1) THE FORMATION AND DEVELOPMENT OF THE CONCEPT OF VIRTUAL PARTICLES

A2) THE HIERARCHY, FINE-TUNING, AND NATURALNESS PROBLEM FROM A PHILOSOPHICAL PERSPECTIVE

A3) LHC AND GRAVITY

THE EPISTEMOLOGY OF THE LARGE HADRON COLLIDER (LHC)

Thematic Cluster B: The Complex Practice of Particle Physics

In the second thematic cluster the Research Unit will focus on the complexity of the conditions under which knowledge is produced at the LHC. In particular, it will turn to the use and role of computer simulation for the conduct of experiment, on theoretical model building, and on the social organisation of collaborations. As already mentioned, complexity manifests itself in distinct forms and assumes different meanings in each of the associated contexts. It is the principal aim of the Research Unit to progressively determine the notion of complexity in particle physics by comparing its diverse instantiations. Amongst other things, a distinction needs to be made between the logico-mathematical significance of complexity (which will not be discussed in the Research Unit), the definition that relates to the objects of physics, and the social and organisational meanings of the term. Complexity does not stand in the centre of attention for its own sake, but as a declared challenge for the actual research in particle physics. Three research projects zoom in on the practice of particle physics with an interest in specific dimensions of its complexity.

B1) THE IMPACT OF COMPUTER SIMULATIONS ON THE EPISTEMIC STATUS OF LHC DATA

B2) MODEL BUILDING AND DYNAMICS

B3) PRODUCING NOVELTY AND SECURING CREDIBILITY: LHC EXPERIMENTS IN STS-PERSPECTIVE

Conclusions

- interaction philosophy/physics is fun
  (most of the time…)
- immediate impact on philosophy » on physics
- possible back-reaction? ("spin-offs")
- interest among physicists unexpectedly large
  → Springschools
  → Workshop
  → etc.