SPECIAL ISSU ON THE RECENT EXPLOIT OF HIGGS BOSON BY CERN

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[2] M. Barnes, "Stresses in Solenoids", *J. Appl. Phys.*, 48(5) (2001) 2000–2008.
[3] J. Jones, "Contact Mechanics", Cambridge University Press (Cambridge, UK) (2000), Ch.6, p.56.
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[5] M. Hashish, "Waterjet Technology Development", High Pressure Technology, PVP-Vol. 406 (2000), 135-140.
[6] D.W. Watson, "Thermodynamic Analysis", ASME Paper No. 97-GT-288 (1997).
[7] C.Y. Tung, "Evaporative Heat Transfer in the Contact Line of a Mixture", Ph.D. thesis, Rensselaer Polytechnic Institute, Troy, NY (1982).

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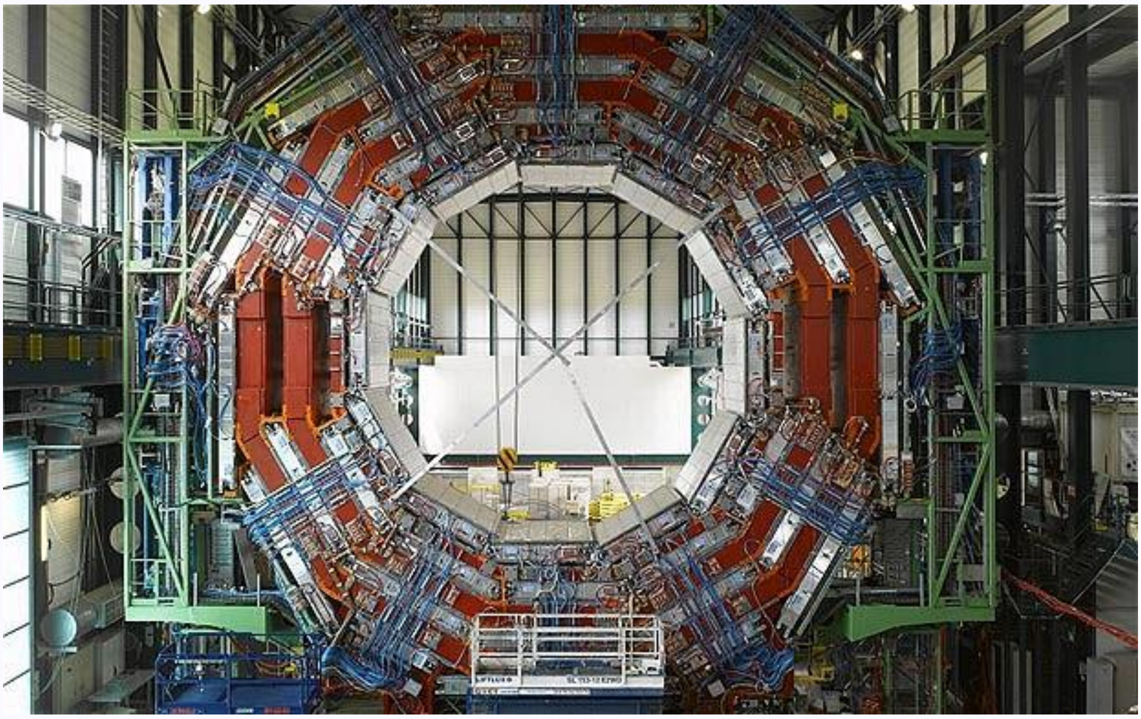
The Most Important Exploit in "Physics"

Introduced by
Oday A. Hamadi
Managing Editor
IJAP, July 2012

Entrance

More than 50 years ago Peter Higgs and five other theoretical physicists proposed that an invisible field lying across the Universe gives particles their mass, allowing them to clump together to form stars and planets.



What is the Higgs boson and the Higgs field?

The Higgs field has been described as a kind of cosmic "treacle" spread through the universe.

According to Professor Higgs's 1964 theory, the field interacts with the tiny particles that make up atoms, and weighs them down so that they do not simply whizz around space at the speed of light.

But in the half-century following the theory, produced independently by the six scientists within a few months of each other, nobody has been able to prove that the Higgs Field really exists.

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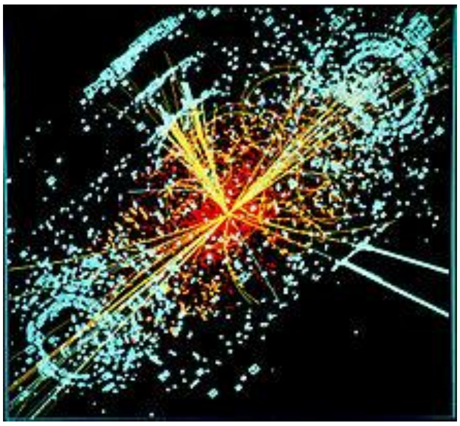
HIGGS BOSON



One possible signature of a Higgs boson from a simulated proton–proton collision. It decays almost immediately into two jets of hadrons and two electrons, visible as lines.[Note 1]

Composition
Elementary particle

Statistics
Bosonic

Status
Tentatively observed – a boson "consistent with" the Higgs boson has been observed, but as of July 2012, scientists have not conclusively identified it as the Higgs boson.[1]

Symbol
H^0

Theorised
R. Brout, F. Englert, P. Higgs, G. S. Guralnik, C. R. Hagen, and T. W. B. Kibble (1964)

Discovered a compatible particle has been observed by ATLAS and CMS (2012)

Types
1 in the Standard Model;
5 or more in supersymmetric models

Mass
125.3 0.6 GeV/c^2,[2] ~126 GeV/c^2[3]

Electric charge
0

Spin
0

The **Higgs boson** or **Higgs particle** is a proposed elementary particle in the Standard Model of particle physics. The Higgs boson is named after Peter Higgs who, along with others, proposed the mechanism that suggested such a particle in 1964.[4][5][6] The existence of the Higgs boson and the associated Higgs field would be the simplest known method to explain why certain other elementary particles in the standard model have their mass. In this theory, an unseen field permeates space; this field has a non-zero value everywhere, even in its lowest energy state, and various other elementary particles obtain mass by interacting with this field. The Higgs boson—the smallest possible excitation of this field—is predicted to exist by the same theory, and has been the target of a long search in particle physics. One of the primary design goals of the Large Hadron Collider ("LHC") at CERN in Geneva, Switzerland—one of the most complicated scientific instruments ever built—was to test the existence of the Higgs boson and measure its properties, which would allow physicists to confirm this cornerstone of modern theory.

Because of its role in a fundamental property of elementary particles, the Higgs boson has been referred to as the "God particle" in popular culture, although virtually all scientists regard this as a hyperbole. According to the Standard Model, the Higgs particle is a boson, a type of particle that allows multiple identical particles to exist in the same place in the same quantum state. Furthermore, the model posits that the particle has no intrinsic spin, no electric charge, and no colour charge. It is also very unstable, decaying almost immediately after its creation. If the Higgs boson were shown not to exist, other "Higgsless" models would be considered.

By 2011 a number of these experiments had gradually and consistently highlighted a range of energies around 125 GeV (a unit of mass for particles). On 4 July 2012, the CMS and the ATLAS experimental teams at the Large Hadron Collider independently announced that they confirmed the formal discovery of a previously unknown boson of mass between 125–127 GeV, whose behaviour so far was "consistent with" a Higgs boson, noting that further data and analysis were needed before positively identifying the particle beyond doubt.

Overview

The existence of the Higgs boson was predicted in 1964 to explain the Higgs mechanism (sometimes termed in the literature the Brout–Englert–Higgs, BEH or Brout–Englert–Higgs–Hagen–Guralnik–Kibble mechanism after its original proposers[7])—the mechanism by which elementary particles are given mass.[Note 2] While the Higgs mechanism is considered confirmed to exist, the boson itself—a cornerstone of the leading theory—had not been observed and its existence was unconfirmed. Its tentative discovery in July 2012 may validate the Standard Model as essentially correct, as it is the final elementary particle predicted and required by the Standard Model which had not yet been observed via particle physics experiments.[8] Alternative sources of the Higgs mechanism that do not need the Higgs boson also are possible and would be considered if the existence of the Higgs boson were to be ruled out. They are known as Higgsless models.

The Higgs boson is named after Peter Higgs, who in 1964 wrote one of three ground-breaking papers alongside the work of Robert Brout and François Englert and Tom Kibble, C. R. Hagen and Gerald Guralnik covering what is now known as the Higgs mechanism and described the related Higgs field and boson.

Technically, it is the quantum excitation of the Higgs field, and the non-zero value of the ground state of this field, that give mass to the other elementary particles, such as quarks and electrons. The Standard Model completely fixes the properties of the Higgs boson, except for its mass. It is expected to have no spin and no electric or colour charge, and it interacts with other particles through the weak interaction and Yukawa-type interactions between the various fermions and the Higgs field.

Because the Higgs boson is a very massive particle and decays almost immediately when created, only a very high-energy particle accelerator can observe and record it. Experiments to confirm and determine the nature of the Higgs boson using the Large Hadron Collider (LHC) at CERN began in early 2010, and were performed at Fermilab's Tevatron until its close in late 2011. Mathematical consistency of the Standard Model requires that any mechanism capable of generating the masses of elementary particles become visible at energies above 1.4 TeV;[9] therefore, the LHC (designed to collide two 7 TeV proton beams, but currently running at 4 TeV each) was built to answer the question of whether or not the Higgs boson exists.[10]

On 4 July 2012, the two main experiments at the LHC (ATLAS and CMS) both reported independently the confirmed existence of a previously unknown particle with a mass of about 125 GeV/c^2 (about 133 proton masses, on the order of $10^{\text{À}25}$ kg), which is "consistent with the Higgs boson" and widely believed to be the Higgs boson. They cautioned that further work would be needed to confirm that it is indeed the Higgs boson (meaning that it has the theoretically predicted properties of the Higgs boson and is not some other previously unknown particle) and, if so, to determine which version of the Standard Model it best supports.[1][2][3][11][12]

General description

In particle physics, elementary particles and forces give rise to the world around us. Physicists explain the behaviours of these particles and how they interact using the Standard Model—a widely accepted framework believed to explain most of the world we see around us.[13] Initially, when these models were being developed and tested, it seemed that the mathematics behind those models, which were satisfactory in areas already tested, would also forbid elementary particles from having any mass, which showed clearly that these initial models were incomplete. In 1964 three groups of physicists almost simultaneously released papers describing how masses could be given to these particles, using approaches known as symmetry breaking. This approach allowed the particles to obtain a mass, without breaking other parts of particle physics theory that were already believed reasonably correct. This idea became known as the Higgs mechanism (not the same as the boson), and later experiments confirmed that such a mechanism does exist—but they could not show exactly *how* it happens.

The leading and simplest theory for how this effect takes place in nature was that if a particular kind of "field" (known as a Higgs field) happened to permeate space, and if it could interact with fundamental particles in a particular way, then this would give rise to a Higgs mechanism in nature, and would therefore create around us the phenomenon we call "mass". During the 1960s and 1970s the Standard Model of physics was developed on this basis, and it included a prediction and requirement that for these things to be true, there had to be an undiscovered boson—one of the fundamental particles—as the counterpart of this field. This would be the Higgs boson. If the Higgs boson were confirmed to exist, as the Standard Model suggested, then scientists could be satisfied that the Standard Model was fundamentally correct. If the Higgs boson were proved not to exist, then other theories would be considered as candidates instead.

The Standard Model also made clear that the Higgs boson would be very difficult to demonstrate. It exists for only a tiny fraction of a second before breaking up into other particles—so quickly that it cannot be directly detected—and can be detected only by identifying the results of its immediate decay and analysing them to show they were probably created from a Higgs boson and not some other source. The Higgs boson requires so

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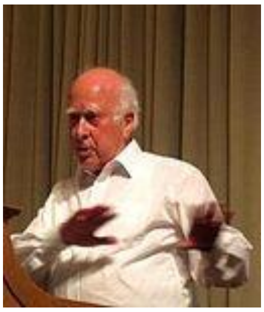
much energy to create (compared to many other fundamental particles) that it also requires a massive particle accelerator to create collisions energetic enough to create it and record the traces of its decay. Given a suitable accelerator and appropriate detectors, scientists can record trillions of particles colliding, analyse the data for collisions likely to be a Higgs boson, and then perform further analysis to test how likely it is that the results combined show a Higgs boson does exist, and that the results are not just due to chance.

Experiments to try to show whether the Higgs boson did or did not exist began in the 1980s, but until the 2000s it could only be said that certain areas were plausible, or ruled out. In 2008 the Large Hadron Collider (LHC) was inaugurated, being the most powerful particle accelerator ever built. It was designed especially for this experiment, and other very-high-energy tests of the Standard Model. In 2010 it began its primary research role: to prove whether or not the Higgs boson exists.

In late 2011 two of the LHC's experiments independently began to suggest "hints" of a Higgs boson detection around 125 GeV. In July 2012 CERN announced[1] evidence of discovery of a boson with an energy level and other properties consistent with those expected in a Higgs boson. Further work is necessary for the evidence to be considered conclusive (or disproved). If the newly discovered particle is indeed the Higgs boson, attention will turn to considering whether its characteristics match one of the extant versions of the Standard Model. The CERN data include clues that additional bosons or similar-mass particles may have been discovered as well as, or instead of, the Higgs itself. If a different boson were confirmed, it would allow and require the development of new theories to supplant the current Standard Model.

History



The six authors of the 1964 PRL papers, who received the 2010 J. J. Sakurai Prize for their work. From left to right: Kibble, Guralnik, Hagen, Englert, Brout. *Right:* Higgs.

Particle physicists study matter made from fundamental particles whose interactions are mediated by exchange particles known as force carriers. At the beginning of the 1960s a number of these particles had been discovered or proposed, along with theories suggesting how they relate to each other; however, even accepted versions such as the Unified field theory were known to be incomplete. One omission was that they could not explain the origins of mass as a property of matter. Goldstone's theorem, relating to continuous symmetries within some theories, also appeared to rule out many obvious solutions.[14]

The Higgs mechanism is a process by which vector bosons can get rest mass without explicitly breaking gauge invariance. The proposal for such a spontaneous symmetry breaking mechanism originally was suggested in 1962 by Philip Warren Anderson[15] and developed into a full relativistic model, independently and almost simultaneously, by three groups of physicists: by François Englert and Robert Brout in August 1964;[16] by Peter Higgs in October 1964;[17] and by Gerald Guralnik, C. R. Hagen, and Tom Kibble (GHK) in November 1964.[18] Properties of the model were further considered by Guralnik in 1965 [19] and by Higgs in 1966.[20] The papers showed that when a gauge theory is combined with an additional field that spontaneously breaks the symmetry group, the gauge bosons can consistently acquire a finite mass. In 1967, Steven Weinberg and Abdus Salam were the first to apply the Higgs mechanism to the breaking of the electroweak symmetry, and showed how a Higgs mechanism could be incorporated into Sheldon Glashow's electroweak theory,[21][22][23] in what became the Standard Model of particle physics.

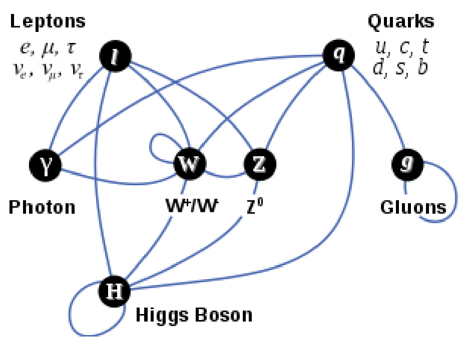
The three papers written in 1964 were each recognised as milestone papers during *Physical Review Letters*'s 50th anniversary celebration.[24] Their six authors were also awarded the 2010 J. J. Sakurai Prize for Theoretical Particle

Physics for this work.[25] (A dispute also arose the same year; in the event of a Nobel Prize up to three scientists would be eligible, with six authors credited for the papers.[26]) Two of the three PRL papers (by Higgs and by GHK) contained equations for the hypothetical field that eventually would become known as the Higgs field and its hypothetical quantum, the Higgs boson. Higgs's subsequent 1966 paper showed the decay mechanism of the boson; only a massive boson can decay and the decays can prove the mechanism.

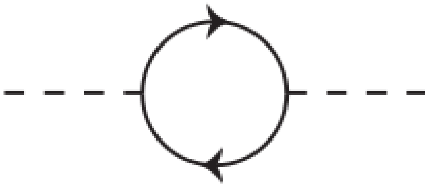
In the paper by Higgs the boson is massive, and in a closing sentence Higgs writes that "an essential feature" of the theory "is the prediction of incomplete multiplets of scalar and vector bosons". In the paper by GHK the boson is massless and decoupled from the massive states. In reviews dated 2009 and 2011, Guralnik states that in the GHK model the boson is massless only in a lowest-order approximation, but it is not subject to any constraint and acquires mass at higher orders, and adds that the GHK paper was the only one to show that there are no massless Goldstone bosons in the model and to give a complete analysis of the general Higgs mechanism.[27][28]

In addition to explaining how mass is acquired by vector bosons, the Higgs mechanism also predicts the ratio between the W boson and Z boson masses as well as their couplings with each other and with the Standard Model quarks and leptons. Subsequently, many of these predictions have been verified by precise measurements performed at the LEP and the SLC colliders, thus overwhelmingly confirming that some kind of Higgs mechanism does take place in nature,[29] but the exact manner by which it happens has not yet been discovered. The results of searching for the Higgs boson are expected to provide evidence about how this is realized in nature.

Theoretical properties



Summary of interactions between particles described by the Standard Model



A one-loop Feynman diagram of the first-order correction to the Higgs mass. The Higgs boson couples strongly to the top quark so it may, if heavy enough, decay into top–anti-top quark pairs

The Standard Model predicts the existence of a field, called the Higgs field, which has a non-zero amplitude in its ground state; i.e. a non-zero vacuum expectation value. The existence of this non-zero vacuum expectation spontaneously breaks electroweak gauge symmetry which in turn gives rise to the Higgs mechanism. It is the simplest process capable of giving mass to the gauge bosons while remaining compatible with gauge theories.[citation needed] The field can be pictured as a pool of molasses that "sticks" to the otherwise massless fundamental particles that travel through the field, converting them into particles with mass that form (for example) the components of atoms. Its quantum would be a scalar boson, known as the Higgs boson.[citation needed]

In the Standard Model, the Higgs field consists of two neutral and two charged component fields. Both of the charged components and one of the neutral fields are Goldstone bosons, which act as the longitudinal third-polarization components of the massive W^+, W^-, and Z bosons.[citation needed] The quantum of the remaining neutral component corresponds to (and is theoretically realised as) the massive Higgs boson. Since the Higgs field is a scalar field, the Higgs boson has no spin. The Higgs boson is also its own antiparticle and is CP-even, and has zero electric and colour charge.[30]

The Minimal Standard Model does not predict the mass of the Higgs boson.[31] If that mass is between 115 and 180 GeV/c^2, then the Standard Model can be valid at energy scales all the way up to the Planck scale (10^{16} TeV).[citation needed] Many theorists expect new physics beyond the Standard Model to emerge at the TeV-scale, based on unsatisfactory properties of the Standard Model.[citation needed] The highest possible mass scale allowed for the Higgs boson (or some other electroweak symmetry breaking mechanism) is 1.4 TeV; beyond this point, the Standard Model becomes inconsistent without such a mechanism, because unitarity is violated in certain scattering processes.[citation needed]

In theory, the mass of the Higgs boson may be estimated indirectly. In the Standard Model, the Higgs boson has a number of indirect effects; most notably, Higgs loops result in tiny corrections to masses of W and Z bosons. Precision measurements of electroweak parameters, such as the Fermi constant and masses of W/Z bosons, can be used to constrain the mass of the Higgs. As of July 2011, the precision electroweak measurements tell us that the mass of the Higgs boson is lower than about 161 GeV/c^2 at 95% confidence level (CL). This upper bound increases to 185 GeV/c^2 when including the LEP-2 direct search lower bound of 114.4 GeV/c^2.[29] These indirect constraints rely on the assumption that the Standard Model is correct. It may still be possible to discover a Higgs boson above 185 GeV/c^2 if it is accompanied by other particles beyond those predicted by the Standard Model.[citation needed]

The Minimal Standard Model as described above contains only one complex isospin Higgs doublet, however, it also is possible to have an extended Higgs sector with additional doublets or triplets. The non-minimal Higgs sector favoured by theory are the two-Higgs-doublet models (2HDM), which predict the existence of a quintet of scalar particles: two CP-even neutral Higgs bosons h^0 and H^0, a CP-odd neutral Higgs boson A^0, and two charged Higgs particles H . The key method to distinguish different variations of the 2HDM models and the minimal SM involves their coupling and the branching ratios of the Higgs decays. The so called Type-I model has one Higgs doublet coupling to up and down quarks, while the second doublet does not couple to quarks. This model has two interesting limits, in which the lightest Higgs doesn't couple to either fermions (fermiophobic) or gauge bosons (gauge-phobic). In the 2HDM of Type-II, one Higgs doublet only couples to up-type quarks, while the other only couples to down-type quarks.

Many extensions to the Standard Model, including supersymmetry (SUSY), often contain an extended Higgs sector. Many supersymmetric models predict that the lightest Higgs boson will have a mass only slightly above the current experimental limits, at around 120 GeV/c^2 or less.[citation needed] The heavily researched Minimal Supersymmetric Standard Model (MSSM) belongs to the class of models with a Type-II two-Higgs-doublet sector and could be ruled out by the observation of a Higgs belonging to a Type-I 2HDM.

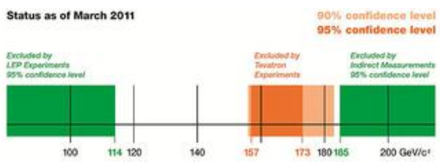
Alternative mechanisms for electroweak symmetry breaking

In the years since the Higgs field and boson were proposed, several alternative models have been proposed by which the Higgs mechanism might be realised. The Higgs boson exists in some, but not all, theories. For example, it exists in the Standard Model and extensions such as the Minimal Supersymmetric Standard Model yet is not expected to exist in alternative models such as Technicolor. Models which do not include a Higgs field or a Higgs boson are known as Higgsless models. In these models, strongly interacting dynamics rather than an additional (Higgs) field produce the non-zero vacuum expectation value that breaks electroweak symmetry. A partial list of these alternative mechanisms are:

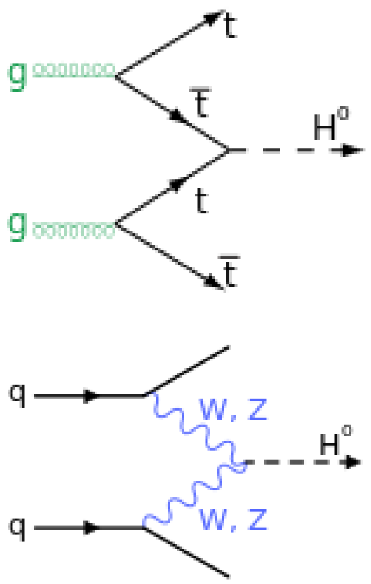
- Technicolor,[32] a class of models that attempts to mimic the dynamics of the strong force as a way of breaking electroweak symmetry.
- Extra dimensional Higgsless models where the role of the Higgs field is played by the fifth component of the gauge field.[33]
- Abbott-Farhi models of composite W and Z vector bosons.[34]
- Top quark condensate theory in which a fundamental scalar Higgs field is replaced by a composite field composed of the top quark and its antiquark.
- The braid model of Standard Model particles by Sundance Bilson-Thompson, compatible with loop quantum gravity and similar theories.[35]

A goal of the LHC and Tevatron experiments is to distinguish between these models and determine if the Higgs boson exists or not.

Experimental search



Status as of March 2011.[citation needed] Coloured sections have been ruled out to the stated confidence intervals either by indirect measurements and LEP experiments (green) or by Tevatron experiments (orange).



Feynman diagrams showing two ways the Higgs boson might be produced at the LHC. *Left:* two gluons convert to top/anti-top quark pairs, which combine. *Right:* two quarks emit W or Z bosons, which combine.

Like other massive particles (e.g. the top quark and W and Z bosons), Higgs bosons created in particle accelerators decay long before they reach any of the detectors. However, the Standard Model precisely predicts the possible modes of decay and their probabilities. This allows the creation of a Higgs boson to be shown by careful examination of the decay products of collisions. The experimental search therefore commenced in the 1980s with the opening of particle accelerators sufficiently powerful to provide evidence related to the Higgs boson.

Prior to the year 2000, data gathered at the Large Electron–Positron Collider (LEP) at CERN had allowed an experimental lower bound to be set for the mass of the Standard Model Higgs boson of 114.4 GeV/c^2 at the 95% confidence level (CL). The same experiment has produced a small number of events that could be interpreted as resulting from Higgs bosons with a mass just above this cut off—around 115 GeV—but the number of events was insufficient to draw definite conclusions.[36] The LEP was shut down in 2000 due to construction of its successor, the Large Hadron Collider (LHC).

Full operation at the LHC was delayed for 14 months from its initial successful tests on 10 September 2008, until mid-November 2009,[37][38] following a magnet quench event nine days after its inaugural tests that damaged over 50 superconducting magnets and contaminated the vacuum system.[39] The quench was traced to a faulty electrical connection and repairs took several months;[40][41] electrical fault detection and rapid quench-handling systems were also upgraded.

At the Fermilab Tevatron, there were also ongoing experiments searching for the Higgs boson. As of July 2010, combined data from CDF and DØ experiments at the Tevatron were sufficient to exclude the Higgs boson in the range 158-175 GeV/c^2 at 95% CL.[42][43] Preliminary results as of July 2011 extended the excluded region to the range 156-177 GeV/c^2 at 95% CL.[44]

Data collection and analysis in search of Higgs intensified from 30 March 2010 when the LHC began operating at 3.5 TeV.[45] Preliminary results from the ATLAS and CMS experiments at the LHC as of July 2011 excluded a Standard Model Higgs boson in the mass range 155-190 GeV/c^2[46] and 149-206 GeV/c^2,[47] respectively, at 95% CL. All of the above confidence intervals were derived using the CLs method.

As of December 2011 the search had narrowed to the approximate region 115–130 GeV, with a specific focus around 125 GeV, where both the ATLAS and CMS experiments had independently reported an excess of events,[48][49] meaning that a higher than expected number of particle patterns compatible with the decay of a Higgs boson were detected in this energy range. The data was insufficient to show whether or not these excesses were due to background fluctuations (i.e. random chance or other causes), and its statistical significance was not large enough to draw conclusions yet or even formally to count as an "observation", but the fact that two independent experiments had both shown excesses at around the same mass led to considerable excitement in the particle physics community.[50]

On 22 December 2011, the DØ collaboration also reported limitations on the Higgs boson within the Minimal Supersymmetric Standard Model, an extension to the Standard Model. Proton-antiproton (pp) collisions with a centre-of-mass energy of 1.96 TeV had allowed them to set an upper limit for Higgs boson production within MSSM ranging from 90 to 300 GeV, and excluding $\tan\beta > 20–30$ for masses of the Higgs boson below 180 GeV ($\tan\beta$ is the ratio of the two Higgs doublet vacuum expectation values).[51]

At the end of December 2011, it was therefore widely expected that the LHC would provide sufficient data to either exclude or confirm the existence of the Standard Model Higgs boson by the end of 2012, when their 2012 collision data (at energies of 8 TeV) had been examined.[52]

Updates from the two LHC teams continued during the first part of 2012, with the tentative December 2011 data largely being confirmed and developed further. Updates were also available from the team analysing the final data from the Tevatron. All of these continued to highlight and narrow down the 125 GeV region as showing interesting features.

On 2 July 2012, the ATLAS collaboration published additional analyses of their 2011 data, excluding boson mass ranges of 111.4 GeV to 116.6 GeV, 119.4 GeV to 122.1 GeV, and 129.2 GeV to 541 GeV. They observed an excess of events corresponding to the Higgs boson mass hypotheses around 126 GeV with a local significance of 2.9 sigma.[53] On the same date, the DØ and CDF collaborations announced further analysis that increased their confidence. The significance of the excesses at energies between 115–140 GeV was now quantified as 2.9 standard deviations, corresponding to a 1 in 550 probability of being due to a statistical fluctuation. However, this still fell short of the 5 sigma confidence, therefore the results of the LHC experiments were necessary to establish a discovery. They excluded Higgs mass ranges at 100–103 and 147–180 GeV.[54][55]

On 22 June 2012 CERN announced an upcoming seminar covering tentative findings for 2012,[56][57] and shortly afterwards rumours began to spread in the media that this would include a major announcement, but it was unclear whether this would be a stronger signal or a formal discovery.[58][59] On 4 July 2012 CMS announced the discovery of a boson with mass 125.3 0.6 GeV/c^2[2] and ATLAS of a boson with mass 126.5 GeV/c^2[3] – both experiments reached a local significance of 5 sigma. (The analysis of additional channels brought the CMS significance to 4.9 sigma.[2]) This meets the formal level required to announce a new particle which is "consistent with" the Higgs boson, but scientists have not positively identified it as being the Higgs boson, pending further data collection and analysis.[1]

Timeline of experimental evidence

All results refer to the Standard Model Higgs boson, unless otherwise stated.

- 2000–2004 – using data collected before 2000, in 2003–2004 Large Electron–Positron Collider experiments published papers which set a lower bound for the Higgs boson of 114.4 GeV/c^2 at the 95% confidence level (CL), with a small number of events around 115 GeV.[36]
- July 2010 – data from CDF (Fermilab) and DØ (Tevatron) experiments exclude the Higgs boson in the range 158–175 GeV/c^2 at 95% CL.[42][43]
- 24 April 2011 – media reports "rumors" of a find;[60] these were debunked by May 2011.[61] They had not been a hoax, but were based on unofficial, unreviewed results.[62]
- 24 July 2011 – the LHC reported possible signs of the particle, the ATLAS Note concluding: "In the low mass range (c. 120–140 GeV) an excess of events with a significance of approximately 2.8 sigma above the background expectation is observed" and the BBC reporting that "interesting particle events at a mass of between 140 and 145 GeV" were found.[63][64] These findings were repeated shortly thereafter by researchers at the Tevatron with a spokesman stating that: "There are some intriguing things going on around a mass of 140GeV."[63] On 22 August 2011 it was reported that these anomalous results had become insignificant on the inclusion of more data from ATLAS and CMS and that the non-existence of the particle had been confirmed by LHC collisions to 95% certainty between 145–466 GeV (except for a few small islands around 250 GeV).[65]
- 23–24 July 2011 – Preliminary LHC results exclude the ranges 155–190 GeV/c^2 (ATLAS)[46] and 149–206 GeV/c^2 (CMS)[47] at 95% CL.
- 27 July 2011 – preliminary CDF/DØ results extend the excluded range to 156–177 GeV/c^2 at 95% CL.[44]
- 18 November 2011 – a combined analysis of ATLAS and CMS data further narrowed the window for the allowed values of the Higgs boson mass to 114–141 GeV.[66]
- 13 December 2011 – experimental results were announced from the ATLAS and CMS experiments, indicating that if the Higgs boson exists, its mass is limited to the range 116–130 GeV (ATLAS) or 115–127 GeV (CMS), with other masses excluded at 95% CL. Observed excesses of events at around 124 GeV (CMS) and 125–126 GeV (ATLAS) are consistent with the presence of a Higgs boson signal, but also consistent with fluctuations in the background. The global statistical significances of the excesses are 1.9 sigma (CMS) and 2.6 sigma (ATLAS) after correction for the look elsewhere effect.[48][49]
- 22 December 2011 – the DØ collaboration also sets limits on Higgs boson masses

within the Minimal Supersymmetric Standard Model (an extension of the Standard Model), with an upper limit for production ranging from 90 to 300 GeV, and excluding tanβ>20–30 for Higgs boson masses below 180 GeV at 95% CL.[51]

- 7 February 2012 – updating the December results, the ATLAS and CMS experiments constrain the Standard Model Higgs boson, if it exists, to the range 116–131 GeV and 115–127 GeV, respectively, with the same statistical significance as before.[67][68][69]
- 7 March 2012 – the DØ and CDF collaborations announced that they found excesses that might be interpreted as coming from a Higgs boson with a mass in the region of 115 to 135 GeV/c^2 in the full sample of data from Tevatron. The significance of the excesses is quantified as 2.2 standard deviations, corresponding to a 1 in 250 probability of being due to a statistical fluctuation. This is a lower significance, but consistent with and independent of the ATLAS and CMS data at the LHC.[70][71] This new result also extends the range of Higgs-mass values excluded by the Tevatron experiments at 95% CL, which becomes 147-179 GeV/c^2.[72][73]
- 2 July 2012 – the ATLAS collaboration further analysed their 2011 data, excluding Higgs mass ranges of 111.4 GeV to 116.6 GeV, 119.4 GeV to 122.1 GeV, and 129.2 GeV to 541 GeV. Higgs bosons are probably located at 126 GeV with significance of 2.9 sigma.[53] On the same day, the DØ and CDF collaborations also announced further analysis, increasing their confidence that the data between 115–140 GeV is corresponding to a Higgs boson to 2.9 sigma, excluding mass ranges at 100–103 and 147–180 GeV.[54][55]
- 4 July 2012 – the CMS collaboration "announces the discovery of a boson with mass 125.3 0.6 GeV/c^2 within 4.9 σ (sigma)" and the ATLAS collaboration announced that "we observe in our data clear signs of a new particle, at the level of 5 sigma, in the mass region around 126 GeV." These findings meet the formal level required to announce a new particle which is "consistent with" the Higgs boson, but scientists have not positively identified it as being the Higgs boson, pending further analysis.[1]

"God particle"

The Higgs boson is often referred to as the "God particle" by individuals outside the scientific community,[74] after the title of Leon Lederman's popular science book on particle physics, *The God Particle: If the Universe Is the Answer, What Is the Question?*[75][76] While use of this term may have contributed to increased media interest,[76] many scientists dislike it, since it is sensational and overstates the particle's importance. Its discovery would still leave unanswered questions about the unification of quantum chromodynamics, the electroweak interaction, and gravity, as well as the ultimate origin of the universe.[74][77] Higgs, an atheist himself, is displeased that the Higgs particle is nicknamed the "God particle",[78] because the term "might offend people who are religious".[79]

Lederman said he gave it a nickname because the particle is "so central to the state of physics today, so crucial to our understanding of the structure of matter, yet so elusive,"[74][75][80] and added that he chose "the God particle" because "the publisher wouldn't let us call it the Goddamn Particle, though that might be a more appropriate title, given its villainous nature and the expense it is causing."[75]

A renaming competition conducted by the science correspondent for the British *Guardian* newspaper chose the name "the champagne bottle boson" as the best from among their submissions: "The bottom of a champagne bottle is in the shape of the Higgs potential and is often used as an illustration in physics lectures. So it's not an embarrassingly grandiose name, it is memorable, and [it] has some physics connection too."[81]

Notes

1. ^ Note that such events also occur due to other processes. Detection involves a statistically significant excess of such events at specific energies.
2. ^ Only 1% of the mass of composite particles, such as the proton and neutron, is due to the Higgs mechanism acting to produce the mass of quarks. The other 99% is due to the mass added by the kinetic energies of quarks and the energies of (massless) gluons of the

Introduction to the Higgs Boson Papers

John A. Gowan

Abstract

Although I had heard about, read about, and wondered about the "Higgs boson" for years, I simply couldn't get a "feel" for this particle, mostly because I was unable to place it within any overall, coherent scheme of physical phenomena. I didn't want to believe in its reality, but I hadn't wanted to believe in the reality of the "W" and "Z" IVBs, either. Having eaten a large serving of humble pie with the discovery of these particles in the early 1980s at CERN, I was not eager for second helpings from the Higgs, so I kept searching for its conservation role. What finally broke the impasse for me was the article by Gordon Kane in *Scientific American* (and there is much else in this article I don't agree with), which mentioned there could be more than one Higgs boson. (See: "The Mysteries of Mass" by Gordon Kane, *Scientific American* , July 2005, pp. 41-48.) That idea allowed me almost immediately to "do my thing", which is the construction of General Systems hierarchies, using the "phase transition" energy levels, or force- unification symmetric energy states, as benchmarks for the four sequential steps of a weak force decay "cascade" from the "Multiverse" to "ground state" atomic matter in our universe, with one step allotted to each of the four forces as they joined (or separated from) the unification hierarchy, and one Higgs boson identifying each unified-force energy plateau.

Part I

Introduction

I had been blocked from understanding the Higgs role and mechanism through thinking there was only one Higgs boson; the dam burst when I realized there could be more than one Higgs. Suddenly I saw how the various Higgs bosons could serve as a selection mechanism to define, organize, and "gauge" the energy levels or symmetric energy states of several other processes I had known about for some time, such as the compression of the quarks by the "X" IVBs to produce "proton decay", and the creation of leptoquarks by an even higher energy process involving the splitting of primordial charged leptons by "Y" IVBs to produce both electrically charged and neutral leptoquarks. It all fell into place once my mind was opened to the possibility of multiple Higgs bosons, one each to "gauge" or scale the stages of the decay sequences of the cascade. Here was the natural conservation role for the Higgs I was seeking. The quantization of the Higgs and IVBs is necessary to ensure the invariance of the *single* elementary particles they produce. No matter if this was not the exact same role posited for the Higgs in other sources; given the ambiguity in the technical jargon and explanations I had encountered, it was close enough to satisfy.

A common interpretation (in the popular literature) of the Higgs boson's role is that it is responsible for the inertial mass (mass measured as resistance to acceleration, as distinct from the "rest mass") of elementary particles - see Kane's article, above. This interpretation and distinction I have never understood and still do not agree with. I do agree that the Higgs is responsible for the Einstein "rest mass" of a particle (E = mcc), in that the Higgs scales, regulates, or "gauges" the creation, destruction, and transformation of elementary particles, determining their mass (at second hand) by setting and quantizing the IVB energy level at which these processes occur. But this is not how most authors seem to interpret the action of the Higgs. Instead, they argue that the Higgs acts like a spacetime field (something like the old "ether") which resists the motion of (accelerating) elementary particles (and only elementary particles, not compound particles such as baryons, whose mass consists mostly of binding energy). The objectionable feature of this idea is that it gives us several different kinds of inertial mass, and therefore compromises (it seems to me) a fundamental principle of Einstein's, the Equivalence Principle between rest mass, inertial mass, and gravitational mass ("weight"). Furthermore, in this interpretation, the Higgs is being thrust into a role which is already filled by the spacetime metric.

In my view, the inertial mass of a particle (the mass due to a particle's resistance to acceleration) is a consequence of the interference between the particle's gravitational field (which exactly measures its rest mass or bound energy content - Gm) and the spacetime metric. This latter interpretation satisfies Einstein's Equivalence Principle, the identity between inertial mass, rest mass, and gravitational "weight", and also explains why the accelerated motion of particles affects their dimensional and mass parameters (because of feedback between the metric fields of spacetime and gravitation). It also frees the Higgs boson for a more satisfactory role in the conservation economy of Nature as simply the scalar of elementary particle mass during the creation of "singlets" by the weak force. This also explains why light, which has no mass and produces no gravitational field, has no inertial resistance to acceleration.

Charge Invariance

The unified field theory, as developed in various papers on this website, rests upon 4 fundamental conservation principles of physical law: 1) the Conservation of Energy (1st law of thermodynamics); 2) Entropy (2nd law of thermodynamics); 3) the Conservation of Symmetry (Noether's Theorem); 4) Causality (law of cause and effect).

In writing the "Higgs Boson" series of papers referred to in the title, I have found it necessary to invoke a corollary, a natural adjunct of the symmetry conservation principle: *charge invariance* (including the invariance of other associated energetic and quantum-mechanical physical parameters of elementary charge-carrying particles, such as "rest mass" and spin). The magnitude of charge/mass/spin must remain invariant over time, despite the effects of entropy, the expansion of the Universe, the effects of relative motion, or any other factor which might either inflate or deflate the original value/magnitude of charge and other conserved physical parameters. Obviously, symmetry conservation over time and space depends upon charge invariance, which is implied in any notion of charge conservation. Charge conservation and charge invariance in the "particle" forces (including rest mass and spin), the invariance of "velocity c", Einstein's "Interval", "Lorentz Invariance", causality, and inertia in the "spacetime" forces, are the heart and soul of Noether's Theorem regarding symmetry conservation. *"The charges of matter are the symmetry debts of light".* Because of the firm connection between energy and symmetry conservation (as formalized in "Noether's Theorem"), physical parameters are typically conserved by both principles, if they are conserved by either.

While the principle of charge invariance has major consequences for charged particles in relative motion (magnetism, for example), it also has major consequences for the creation, destruction, and transformation of "singlet" or unpaired elementary particles over the course of history (the elaborate weak force transformation mechanism, including the massive weak force Higgs boson and IVBs, for example).

The central fact of our Universe is that it is "asymmetric", composed of matter only, not a symmetric mix of matter and antimatter. Nevertheless, the Cosmos apparently was born in a state of massless, chargeless symmetry, originally composed of equal parts matter and antimatter, and subsequently devolved to its current "ground state" of asymmetry (involving mass, charge, gravitation, and time - the asymmetric "gang of four"). Getting from the symmetric "Big Bang" origin of our Universe to its present asymmetric "ground state" is an evolutionary journey that imposes many constraints upon any intuitive mythology or rational hypothesis that attempts to reconstruct it. Among these constraints are the "global vs local gauge symmetry" dualities in the structure of spacetime and the field vectors of the forces (such as the electro/magnetic force), necessary to accommodate the relative motion of matter and charged particles vs the (much simpler) absolute motion of light. The massive Higgs boson and the weak force IVBs are likewise necessary for the creation, transformation, and decay of "singlet" or isolated elementary particles of matter, vs the (much simpler) electromagnetic creation and annihilation of particle-antiparticle pairs.

If the central fact of our Universe is its asymmetric content of matter, then the central force of the Universe must be the weak force, whose role is the creation/destruction/transformation of "singlet" elementary particles, isolated elementary particles of matter rather than particle-antiparticle pairs (as produced by the electromagnetic force).

Not only does the weak force create isolated particles of matter during the Big Bang (by virtue of its asymmetric reactions with matter vs antimatter), the weak force also creates and transforms isolated particles of matter (and sometimes antimatter) at later times, including today (radioactive decay, astrophysical processes, etc.) The weak force provides a "lawful" pathway of decay ("lawful" in that the decay pathway, driven by entropy, obeys the conservation laws) from the high energy, high mass particles created during the earliest moments of the "Big Bang" (leptoquarks, hyperons), to the low energy, low mass particles of "ground state" atomic matter (protons, electrons). The mechanism of particle creation, transformation, and decay involves both the massive Higgs boson and the weak force field vectors, or "Intermediate Vector Bosons" (IVBs) (so-called because in contrast to most massless bosons (such as the photon, graviton, and gluon), IVBs are very massive). The decay cascade is driven by

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positive entropy, regulated by the weak force, with an evolutionary "rebound" driven by symmetry conservation, time, and the negative entropy of gravitation.

The Higgs Cascade

The Higgs boson is a quantized scalar particle, reflecting and identifying the energy density or energy scale at which the "phase transitions" of force unification or symmetric energy states occur, "gauging", "scaling", or regulating the mass of the IVBs which perform elementary particle transformations within those energy boundaries and symmetry states. These are very specific energy levels determined by the "phase transition" boundaries or symmetry states of the four forces - the energy density or temperature at which the four forces merge into (or separate from) one another. These phase transitions are symmetry stages, levels, or steps in a hierarchy of energetic unification regimes beginning with the lowest electromagnetic (EM) "ground state" (cold atomic matter), and ending with the highest (the "Creation Event", "Big Bang", or separation of our universe from the "Multiverse").

The quantization of the (several) Higgs scalar bosons reflects the fact that these phase transitions are distinct and definite, always taking place at the same energy level, and therefore the IVBs gauged and selected by the Higgs always access the same energy level, producing elementary particles of the same charge, mass, and energy, no matter when or where in the Cosmos such weak force transitions happen to occur. The quantized Higgs boson is an obvious concession to charge and mass invariance in the service of energy, symmetry, and charge conservation. The quantized Higgs ensures that the IVB it gauges is in the correct symmetry state, unification regime, or energy level to perform the desired transformation, which will occur as a natural matter of course if the energy level and symmetric energy state is properly gauged or selected.

We can think of the Higgs boson as a scalar property necessary to distinguish between several force-unification energy levels or symmetric energy states, a property that converts a representative portion of the symmetry state into a quantized particle - the IVB peculiar to each specific force-unity state. The scalar is necessary not only to create the specific IVB particle, but to ensure the invariance of the IVB's mass, energy, and consequently its product, regardless of its relative motion, entropy, when or where it operates, or any other factor that could affect the invariance of the elementary particles the IVB produces. The IVB itself is necessary to provide a "lawful" pathway or mechanism of decay for the "singlet" bound energy forms of one symmetry state to the "singlet" bound energy forms of another state with greater (total system) entropy and less bound energy. Note that the mass of the Higgs, the IVBs, or the elementary particles they produce is not affected by the entropic expansion of the universe - a fact which allows quantized bound energy rest-mass to be used as a time-invariant scalar or gauge.

The enormous mass of the "W" IVB family - about 80-90 proton masses - which would seem to be much more massive than necessary to effect the transformations it produces (such as the creation of a single electron) - is due to the great energy density of the force-unification symmetric energy state which the IVB represents (the electroweak (EW) force-unification symmetric energy state in the case of the "W" IVB "family"). The IVBs work their transformations indirectly, by occupying the original force unification symmetry state in which these transformations first occurred during the exceedingly high temperatures and energy densities of the "Big Bang". Once the IVB is in this original energy-density state, the transformations which are the natural consequences of the symmetries native to that state occur as a matter of course. (For example, the lepton and quark "species" of our ground state EM level, exist in a unified "generic" state at the EW energy level - the lepton "genus" and the hadron "genus".) This strategy is necessary to ensure that the *single* elementary particles the IVBs create will always be the same, whether they were created during the "Big Bang" or billions of years later, in very different environments, times, and circumstances. Energy and charge conservation obviously demand that the elementary particle created today be exactly the same as that created yesterday, tomorrow, or in the "Big Bang". This is why the creation of "singlet" elementary particles of matter, particles that are unpaired with antimatter annihilation partners, is fraught with so much difficulty, and requires the extremely elaborate and conservative weak force Higgs and IVB mechanism which reprises the original mode and "Big Bang" environment of particle creation. The mass of the Higgs boson is the universal weak force constant which scales or "gauges" the weak force IVBs, and through the IVBs, the latter-day creation of single and invariant elementary particles. The invariant Higgs mass is the analog of the invariant "velocity c": the latter scales the dimensions of spacetime and the intrinsic motion of the photon, in the low-energy domain of our electromagnetic ground state; the former scales the mass of the IVBs and the elementary particles they produce from the EW symmetric energy state. IVBs belong to the EW realm, not to our EM realm, which is why they appear so massive, ephemeral, and strange to us.

Three Energy Levels of Higgs Bosons and Weak Force IVBs

The transformation mechanism of the IVBs is relatively simple. The IVBs are "metric" particles, quantized examples of the energy-dense metric at which a particular force-unification symmetric phase transition, or joining of forces, takes place. There are (presumably) three separate and discreet IVB energy levels with a distinct and separate Higgs scalar boson associated with (and definitively distinguishing) each level. The first (lowest) Higgs level is the "W" IVB "genus" level, consisting of the W+, W-, and W neutral (or Z neutral) IVBs. This (Hyperon Era) energy level (about 80 proton masses or 80 GEVs for the W+ and W-, and about 91 GEVs for the Z neutral) corresponds to the energy density at which the electric and weak forces join (the photon becomes part of the "W" IVB group). The symmetry of this phase transition consists not only in the merger of the photon with the "W" IVBs, but also in the joining of the three quark family members with each other, and likewise, the joining of the three lepton family members with each other (but quarks remain distinct from leptons). This is a more symmetric state because the lepton species are not distinguished among themselves, nor are the quark species distinguished among themselves, nor are photons distinguished from the "W" IVBs. Consequently, transitions among the six quark species and transitions among the six lepton species take place with complete facility at this energy level. In the (perhaps) more familiar terms of a biological taxonomic hierarchy, this is a symmetry realized at the "generic" (EW) level, unifying quark or lepton "species" collected from the EM level.

Because the "W" IVBs are essentially examples of (quantized portions of) the H1 energy density or electroweak force-unification symmetric energy state (which is why they are so massive), they can perform any transformation that normally characterizes this symmetric level of force unification. This level is experimentally verified with regard to the "W" family of IVBs, but the race continues to discover the level 1 (H1) Higgs boson. On this H1 level we find the production of alternative charge carriers (leptons, neutrinos, and mesons), the transformations of hyperons and baryons, and the creation and destruction of mesons, quarks, and unpaired lepton "singlets". (The creation and destruction of baryon "singlets" is a higher (H2) energy level process.) H1 is the familiar energy level of weak-force nuclear transformations, including radioactivity, fission, and element-building in stars, accessible only through the "W" IVBs if "singlet", isolated, elementary particles are created, destroyed, or transformed (such as electrons, neutrinos, or changes in quark "flavors" involving electrical charge).

"Alternative charge carriers" (leptons, neutrinos, mesons) balance the charges of other particles (notably baryons) in the absence of antimatter charge partners. Importantly, alternative charge carriers avoid annihilation reactions and are therefore crucial for the creation of "singlets" or isolated particles of matter. The electron-proton pair is our most familiar example, but the electron-electron antineutrino pair is equally important - as is the (hypothetical) proton - leptoquark antineutrino pair.

In a similar mode, the next higher step in the force-unification hierarchy is that between the strong force and the electroweak force, the so-called GUT unified force level or Grand Unified Theory. (This second energy level (Leptoquark Era) of IVBs and Higgs (H2) remains hypothetical, having not been experimentally verified.) Here the quark families and lepton families are unified, in hybrid particles called "leptoquarks". The IVBs of this "H2" level are designated "X" IVBs (X+, X-, X neutral), and are simply heavier versions of the "W" IVBs. Matter is created at this level (during the Big Bang) through the asymmetric weak force decay of electrically neutral leptoquarks vs antileptoquarks, with the emission of leptoquark antineutrinos. The H2 level hosts the creation and destruction of baryons as "singlets" or unpaired, isolated particles (including "proton decay"). It is here that the asymmetric creation of matter occurs during the "Big Bang", with the "X" IVBs destroying more (electrically neutral) antileptoquarks than leptoquarks. The leptoquark antineutrinos produced in these reactions are "dark matter" candidates. It is possible that this energy level occurs today inside black holes, where "proton decay" may be commonplace.

The final IVB level (also hypothetical) is the H3 energy state (Planck Era), designated the TOE (Theory of Everything) or quantum gravity energy level (this is the level of Gamow's primordial electromagnetic substance or "Ylem"). We will name the IVBs of this level the "Y" IVB family, presumably also a triplet of Y+, Y-, and Y neutral "metric" particles. ("Metric" particles are composed of a bound form of

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compacted, possibly convoluted, energy-dense spacetime metric. Their mass is composed not of quark or leptonic matter, but simply of the energy required to bind and maintain the spacetime metric into their particular form, density, and configuration.) The symmetric "phase transition" of the H3 energy level is the final joining of forces, the joining of gravity with the strong and electroweak forces. This is the level of the creation of mass or bound electromagnetic energy in the form of leptoquarks, produced by the "Y" IVBs, probably by splitting primordial charged leptons into three roughly equal parts. Like the "X", the "Y" IVB is also a super-heavy version of the "W" IVB. Unlike the "X", the "Y" is special in that it gets some extra help in its role from gravity (although the "X" may also get some help from gravity, as when it (presumably) produces proton decay in black holes). The "Y" IVBs of the "Ylem" create both electrically charged and neutral leptoquarks, but only the neutrals survive long enough to enter the H2 energy level, where they may undergo weak force decays via the "X" IVBs. (Electrically charged leptoquarks are immediately annihilated by their anti-mates in the H3 level.)

Leptoquarks are conceived as the most massive members of the leptonic spectrum; in fact, they may be so massive that they are unstable under the repulsive forces of their own electric charge, and undergo a sort of "decay" or reorganization (orchestrated by the "Y" IVBs) to a more stable three-part subdivision of both their mass and electric charge (quarks). Leptoquarks are created by the combined efforts of all the forces at the H3 energy level. Leptoquarks are composed of a highly compressed portion of the spacetime metric, and this metric contains (at least potentially) both quarks and leptons - the quarks representing subdivisions of leptonic elementary charges, which latter represent temporal forms of symmetry debts. We know this because today's metric still retains the ability to produce both quarks (mesons) and leptons as virtual particle-antiparticle pairs when appropriately energized. Symmetry conservation as applied to leptonic unit charges creates the confining strong force "color" charge, mediated by an eight-part "gluon" field, which prevents these fractional quark charges from ever leading an independent existence, in which they could not be canceled, neutralized, balanced, or annihilated by ordinary whole-value leptonic elementary charges. The great significance of quarks is that some combinations of their partial leptonic charges are electrically neutral, and it is these long-lived combinations which are susceptible to the asymmetric decays of the "X" IVBs of level H2 - creating the matter-only universe we inhabit. The "leptoquark" concept provides the missing link between the hadrons and leptons, and clarifies the relationship between the electromagnetic and strong forces - including the origin of the latter as the symmetry debt of whole-unit quantum charge.

The various Higgs bosons and their associated IVBs must be considered as normal members of the three force unification or symmetric energy states (EW, GUT, TOE), representing in their mass a sort of materialized summation of the various particles and charges capable of carrying the several conserved parameters of energy, symmetry, entropy, and causality requisite for their own particular unified-force symmetric energy state (such as leptoquarks, hyperons, baryons, mesons, quarks, leptons, neutrinos, etc.). Hence we have the highest (TOE) force unification level with the Higgs 3 boson, the "Y" IVB family and the primordial charged leptons and charged and neutral leptoquarks (Planck Era, fermions and bosons joined, "Ylem"); the intermediate (GUT) force-unification level with the Higgs 2 boson, the "X" IVB family, and (electrically neutral) leptoquarks and leptoquark neutrinos (Leptoquark Era, fermions combined among themselves, but not with bosons); the next lower (EW) force unification level with the Higgs 1 boson, the "W" IVB family (Hyperon Era), with leptons and hadrons combined within themselves as separate "genera"; still below all these we find the final ground state electromagnetic (EM) realm of light (Atomic-Chemical Era), expanded and cold spatial dimensions, time and history; gravity, galaxies, stars, and planets; ground state hadron and lepton species (separate and distinct); atomic matter, chemical information systems, and life.

One way to understand the Higgs and its associated IVBs is by analogy with the "ground state" electromagnetic force and its associated photon. "Velocity c", the electromagnetic force constant, is the "gauge" or scalar of the spacetime metric, and the photon is its force carrier ("field vector"). "Velocity c" gauges a symmetric energy state of the spacetime metric in which the photon is non-local, and time and distance (x, t) are banished. Leptons and quarks are stable at this ground state energy level, and can only be transformed, created, or destroyed at the next higher energy level or symmetric energy state (H1, the EW force-unity state).

In an analogous fashion, the mass of the Higgs boson is the weak force gauge constant, scaling a "particle metric", and the "W" IVB is its force carrier. The Higgs boson mass "gauges" a symmetric energy state of force-unity and particle identity (the electroweak force unified particle "metric" or regime), in which the IVB is "non-local" in the sense that it has no specific identity. Instead, the "W" IVB has many potential quark and lepton identities (the alternative charge carriers it produces - leptons, neutrinos, mesons), while the independent existence of the elementary leptonic and quark species is banished. Baryons may be transformed but not created or destroyed at the H1 energy level (due to the conserved color charge of their quarks). The creation and destruction of baryons becomes possible only with the merger of the hadron and lepton "genera" into the "family" of fermions and leptoquarks at the next higher GUT or H2 energy level.

Most curiously, we see astrophysical, gravitationally bound states tracking or reprising (approximately) the four stages of the "Higgs Cascade" and force unity states. The planets in stage 1, the electromagnetic ground state; stars in stage 2, the electroweak state of lepton and quark transformations; black holes in stage 3, the GUT state (where proton decay is thought to be commonplace); and finally the Big Crunch in stage 4, where gravity, spacetime, light, and particles are all fused together in the ultimate mixture of matter and antimatter, positive and negative energy.

Gravity and Mass - "Metric" Particles

All the IVB families work by compression, differing mainly in the intensity of the pressure they can apply, according to their mass and specific Higgs energy density level. The "Y" IVB is seen only during the initial moment of the "Big Bang", or the final moment of the "Big Crunch". Perhaps the most interesting feature of the H3 level is that this is the energy level at which gravity joins the other forces in a final full symmetry. But like the IVBs, gravity also works by metric compression or contraction; the IVBs are compressive metric particles and gravity is a contractile metric force. Clearly, in the joining of gravity with the "Y" IVBs of the H3 energy density level, we have the phenomenon of quantum gravity, a "metric particle" of enormous density. Gravity and the "Y" IVB make common cause: gravity, the metric, and particles are all joined in the final full symmetry of quantum gravity at the H3 Planck energy density level. It is at this H3 level that: 1) the primordial elementary leptoquarks are created/composed with three subunits (the quarks) by the "Y" IVBs (perhaps by splitting primordial charged leptons, and/or by assembly from the ambient "quark soup"); 2) particles acquire mass or bound energy (from the doubly compressed metric); 3) the metric and particles impress their characteristics upon one another. This is why the baryon looks like a miniature 3-dimensional cosmos, complete with internal "sticky light" composed of a massless boson field traveling at velocity c (the gluons). This may also be why we have 3 spatial dimensions and three energy tiers of quarks and leptons.

This H3 level primordial "Ylem" is an extremely peculiar state of energy, unlike anything we are even remotely familiar with, because the gravitational field, which contains negative energy exactly balancing the positive electromagnetic energy of particle "rest mass", is fully contained within the particle itself, not dispersed throughout a spacetime external to the massive particle (since none yet exists). Therefore, the particle contains equal amounts of positive and negative energy within itself, which separates into two components only as H3 decays to H2. During the decay to the H2 symmetry state, the positive component of energy condenses as the particle’s rest mass, while the negative component of energy becomes the particle’s external gravitational field. The quarks are formed before this separation between particle and gravitational metric takes place, and the particles and quarks are simultaneously imbrued with mass by the enormous compressive forces of the combined "Y" IVBs and the gravitational metric. The unification of gravity with the "Y" IVB is the realization of the union of Quantum Mechanics and General Relativity - "quantum gravity". The decay from the H3 to the H2 energy level (the separation of the gravitational metric field from the leptoquark particle field) may also include the "inflationary" era (?) of expansion envisioned by the theories of Guth and Linde.

The "Y" IVBs create electrically neutral leptoquarks as well as electrically charged leptoquarks, much as a "W" IVB can create a neutron from a proton, producing leptoquark neutrinos as well as other alternative charge carriers in the process. (Leptoquark neutrinos are not produced unless a single leptoquark is actually destroyed.) The "quark soup" of the H3 level provides the necessary mesons and quark flavors for this transformation. The neutral leptoquarks are "sent down" to the H2 level, where, due to their (relatively) long life, they are susceptible to the asymmetric weak force decays of the "X" IVBs, producing the baryons of our matter-only universe. It is in these decays that leptoquark antineutrinos are produced, balancing the "hidden" number charge of the baryons.

All three families of IVBs are simply representative samples of the dense metric of the Cosmos at a particular force-unification level or symmetric energy state of the unfolding, evolving, and cooling (entropy driven) "Big Bang", and each is enabled to perform its particular transformation role by virtue of that fact - it performs whatever transformations are typical of its force unification state or symmetry level - as gauged by the Higgs scalar bosons. The role of the Higgs is to ensure the uniformity of the IVBs and their products, identifying and quantifying the proper energy level for each family of IVB, such that all elementary particles produced by the IVBs have the same mass whenever and wherever they may be created in the Cosmos. The role of the IVB is to perform transformations appropriate to its specific energy density level or force-unification symmetric energy level. The role of the Higgs boson is to ensure that the IVB is at the proper energy level, or in the correct symmetry state or unification realm for the transformation/creation task at hand. It is because of these careful, quantized, methodical steps that we find ourselves in a conserved material Universe whose components work together - all its parts are in a seamless harmony of interaction and communication - despite its asymmetric condition, consisting only of matter with no corresponding antimatter component.

Rationale for the Weak Force

Why is all this weak force mechanism and hierarchy necessary? Only because the Universe and the weak force is producing asymmetric "singlets" of matter, that is, isolated baryons and leptons of matter that have no antimatter partners with which they can annihilate, cancel their charges, and return to the perfect symmetry of the light which created them. In the absence of antimatter annihilation partners, the complex and quantized weak force "machinery" is necessary so that energy and symmetry conservation may be fulfilled in an asymmetric Universe composed only of matter. *"The charges of matter are the symmetry debts of light",* and not until the last charge has been canceled will the Universe cease in its relentless quest for symmetry conservation and the fulfillment of Noether's Theorem.

Electrons (or any elementary particle) created today must be exactly the same as elementary particles created yesterday, tomorrow, or eons ago during the Big Bang. The weak force ensures this necessary uniformity by revisiting, via the Higgs scalar and the "W" IVBs, the energy density or symmetric energy state in which electrons and certain other elementary particles were first created, and where their identities are merged. In this regard, the "W" IVBs are "time machines", reprising the high density metric of the "Big Bang" era in which elementary particles originated.

The highest level of symmetry and force unification involves the entire Cosmos, as it is unified with the "Multiverse". The "Multiverse" is here conceived as the collection of all possible Universes, and our particular life-friendly Universe is but one subset of these manifold possibilities. It is in the initial distinguishing act, the separation of our Universe from the Multiverse, that the arbitrary values of the physical constants of our life-friendly Universe are determined. These values include such physical parameters as c (the electromagnetic constant), G (the gravitational constant), e (the value of electric charge), and h (Planck's energy constant), among others (including the magnitudes of the several Higgs boson masses and the weak force asymmetry parameter). There is no explanation for the life-friendly values of these physical constants. They are simply arbitrary, random values of one special (life-friendly) universe among the infinitely (?) many possibilities available to the creative energies of the "Multiverse". The "Anthropic Principle" determines the life-friendly values of the physical constants of our universe, because obviously we could live in, experience, and wonder about no other.

The only restriction I can imagine upon the creation of Universes by the energy and activity of the "Multiverse" is that, as in our case, a Universe initially requires no net energy or charge for its creation, and must be able to conserve whatever energy subsequently emerges, if, as in our case, the components should separate into positive and negative halves (positive electromagnetic energy vs negative gravitational energy).

We should finally note that the three energy levels of (hypothetical) Higgs bosons and IVB families are mirrored by the three energy levels of (demonstrated) quark and lepton families. Thus there is "precedent" in the other particle families for this structural and mass hierarchy in the "metric" particle families, even though the "precedent" is itself without explanation. Possibly the "precedent" is related to the 3 dimensions of space either as some sort of fractal resonance, or as a direct reflection of metric structure impressed upon particles at the H3 level of force unification. However, we do have an explanation for the three energy levels of the Higgs and IVBs in the "phase transition" symmetry levels of a hierarchy of force unifications, progressing from "ground state" atomic matter upward to the final symmetry of the "Multiverse". Curiously, as noted earlier, these force-unification symmetric energy states are also reprised in a "rebound" series or parallel hierarchy of gravitationally bound astrophysical states: planets, stars, black holes, and the "Big Crunch". It is because these force-unification symmetric energy states occur at a specific, invariant energy density that they can be represented and accessed by a quantized particle of specific mass-energy such as the Higgs or IVB.

Part II
The Birth of the Cosmos

The only way our Universe can be born as a quantum fluctuation from the Multiverse is if its total energy = zero, and its total charge = zero. These criteria can be met through the negative energy of gravitation, and the balancing charges of matter vs antimatter.

Initially, when our Universe separated from the Multiverse, it was composed of equal parts matter and antimatter, and the negative energy present as gravitation was equal to the positive energy contained in all the particles and other forms of electromagnetic energy. Presumably, our Universe in this primordial symmetry state differed from the "Multiverse" only in the specific "life-friendly" values of its physical constants. This is the perfect symmetric energy state of H3, the conjoining of gravity and the spacetime metric with the "Y" IVB family and the other forces and particles. The decay of the H3 state we attribute to "spontaneous symmetry-breaking", or an entropic instability, perhaps the consequence of a quantum fluctuation. In any case, the "Y" IVBs, aided by gravity, create primordial charged and neutral leptonic elementary particles with three subdivisions ("leptoquarks"). Particles acquire "metric mass" or "bound electromagnetic energy mass" at this critical transition, when gravity, the spacetime metric, the "Y" IVBs, and the leptonic primordial particles (with their nascent quarks) are all fused into a single substance (Gamow's "Ylem").

Because the particles and the gravitational spacetime metric are conjoined when the quarks are formed, particles and the metric share some characteristics. This is why the baryons: 1) appear to be fractured leptons, with partial charges that exactly add up to leptonic charges; 2) appear to be miniature universes, with an internally contained massless field of "sticky light" moving at velocity c - the gluons. In addition, the three families of quarks and leptons may also be a fractal reflection of the 3 spatial dimensions (the physical result of the fusing of the metric with particles during the H3 full-symmetry Planck Era). Finally, the quark "triplet" may be the consequence of the primordial leptonic subdivisions fracturing, aligning with, or otherwise organizing themselves along the "cleavage planes" of the three spatial dimensions (with the help of the "Y" IVBs).

Following the creation of the primordial leptoquarks - and perhaps because of it - the gravitational metric separates from the particles, in the sense that it becomes external to the particles, rather than wholly contained within them. The gravitational metric field remains centered on particles, however, as the gravitational metric must have a central focus (where the field sums to zero) to balance its own energy accounts. In this separation, all the positive energy remains with the electromagnetic energy forms, and all the negative energy remains with the gravitational metric, but the two remain exactly balanced in magnitude, despite their physical separation. This separation of field and particles and "spontaneous" decay from H3 to H2 energy levels may correspond to the "inflationary" era of Guth and Linde, as noted earlier.

In the subsequent H2 state (the Leptoquark Era), we find the "X" IVBs mediating the asymmetric decay of electrically neutral antileptoquarks, while their leptoquark partners escape to become hyperons (heavy baryons), as their quarks expand to reveal their conserved and stabilizing color charge (leptoquark antineutrinos produced in these reactions are candidates for "dark matter"). Only electrically neutral particles could undergo such an asymmetric weak force decay, which is the reason why the quarks have to be formed in the beginning if matter is to be produced in the end. The partial charges of quarks can be arranged to produce electrically neutral composite leptoquarks and baryons (such as the familiar neutron), whereas the elementary leptonic spectrum, the electron, muon, and tau, are all electrically charged. Can a super-heavy lepton exist higher in the energy profile of the leptonic particle spectrum? Yes - it is precisely the leptoquark, produced by the combined action of all the forces and the "Y" IVB, in both electrically charged and neutral forms. The origin of the asymmetry in these neutral "X" IVB decays is unknown. It is evidently a property of the "X" IVBs (similar asymmetries are known in the "W" IVBs), but I have also seen the opinion that it is a consequence of the 3-family structure of the elementary particles. During the annihilation reactions between leptoquarks and antileptoquarks, all are destroyed and converted to photons except for one surviving (neutral) leptoquark per ten billion matter-antimatter particle pairs.

The "Accelerating" Universe

As the Universe evolves, its content of matter is slowly converted to light by various processes, especially in the stars and quasars. Photons are perfectly symmetric energy forms and have no associated gravitational field. Moving at velocity c, photons are "non-local", and as such cannot provide the necessary center for a gravitational field. Consequently, the total gravitational field of the Cosmos is slowly diminished, producing the impression that the Universe is actually expanding at an accelerating rate. If "dark matter" exists, and also is slowly being converted to light in accordance with the universal symmetry conservation laws, this will only add to the total effect. The "repulsive drive" of the so-called "dark energy" of the Cosmos is therefore here interpreted as simply the "rebound" of spacetime as its total gravitational field is diminished by the universal conversion of bound to free energy.

A potential problem with this explanation is this: if gravity is a form of energy, then by energy conservation it should not be possible for gravity (or gravitational "negative energy") to simply vanish. However, we are treating gravity as a form of charge, a symmetry debt acknowledging the non-local distributional symmetry of light's energy, which is obviously broken by the local concentrations of energy in immobile, undistributed, bound forms of electromagnetic energy (atomic matter). Symmetry debts and charges can indeed vanish, when they are paid in full. The gravitational charge or symmetry debt is satisfied, paid, or discharged when bound energy (mass/matter) is completely converted to free energy (light). This is the fundamental reason why the negative energy of gravity is so strange and unlike other forms of positive energy: gravitational negative energy is the binding energy of a charge, expressed in metric, dimensional, or inertial terms.

The Miracle of Mass

When we think about the fact that we find in nature two different paths for the creation of the same particles, one symmetric and due to the operation of the electromagnetic force (the creation of particle-antiparticle pairs), and one asymmetric through the weak force, we can readily appreciate that these two forces might be joined in the "electroweak unification", and additionally, that the world we live in is apparently of a very special type. For if we can explain the creation of particles by the weak force, then we cannot understand how the electromagnetic force also manages the same feat - excepting for a most remarkable "given" characteristic of the spacetime metric - its ability to create particles from light or pure energy. This latter must be the more primitive condition, from which the weak force acquires its ability to create invariant, single particles.

We can understand that the weak force operates in special circumstances, because it only creates "singlets", isolated particles without antiparticle "mates", and so must recreate the original conditions of energy density in which such particles were first made during the "Big Bang". The constraint of universal mass invariance among elementary particles whenever and wherever they may be created is the reason why the massive Higgs boson and IVBs of the weak force are necessary, even to create the lowly electron and its neutrino. We can also appreciate that the mass of the "W" IVBs, which we think of as highly condensed and bound spacetime metric (in fact, as a representative sample of the original symmetric energy state of the primordial electroweak force unification era), may be necessary to create and hold invariant even the tiny mass of the electron. But we also see that electrons (and quarks in mesons) are readily created in particle-antiparticle pairs by the electromagnetic force without the help of the massive IVBs. So apparently the IVBs (and the Higgs) are necessary not to create particle mass, but only to *ensure the invariance* of elementary particle mass, due to the special circumstances of "singlet" creation, in which particles cannot be balanced and referenced against antiparticles.

However, both the weak and electromagnetic forces create particles from a common source, the spacetime "vacuum" or Heisenberg-Dirac metric "zoo" of particle-antiparticle pairs. We must credit this common source of "virtual particles" - the universal "vacuum" metric of spacetime - as the reason why these two different forces can create identical particles from different pathways. Thus when all forces combine to produce leptoquarks at the H3 energy level, the capacity to produce both leptons and quarks is already contained within the compressed metric structure. It is this structural potential (whose ultimate purpose is energy and symmetry conservation in both spatial and temporal realms) that is organized by the "Y" IVBs into charged and neutral leptoquarks.

We understand charge as a temporal solution to the problem of symmetry conservation (during the conversion of spatial light (free electromagnetic energy) to temporal matter (bound electromagnetic energy)), and mass as a solution to the problem of energy conservation during the same conversion/transformation. Gravitation is likewise the solution to the problem of entropy conservation/conversion, transforming the intrinsic motion of light (the spatial entropy drive of free energy) to the intrinsic motion of time (the historical entropy drive of bound energy). All three processes are obviously linked during the conversion of massless, chargeless, timeless, non-local and gravity-free light with intrinsic (entropic) spatial motion "c", to massive, charged, local, gravitating bound energy with intrinsic (entropic) historical motion "T".

We can understand the creation of charges (and spin) in particle-antiparticle pairs readily enough, because charges are always created in self-canceling or balancing pairs that sum to zero. But the creation of mass is not so readily comprehended, because there is no "antimass": both particle and antiparticle carry positive quantities of mass. Nevertheless, matter and antimatter will annihilate each other completely due to their opposite charges, restoring the metric and "non-local" distributional symmetry of the light which created them. *The charges of matter are the symmetry debts of light* - Noether's Theorem.

But what is mass and how is it created? It seems that mass, in most cases (including such exotic particles as the IVBs of the weak force), is just a bound form of light or electromagnetic energy mixed with the spacetime metric, usually associated with some form of symmetry-conserving charge and spin. When the "W" IVBs create "singlet" particles they are, through their mass, recreating a primordial condition or symmetric energy state of the spacetime metric (the electroweak force unification era), and when the electromagnetic force creates massive particle-antiparticle pairs, it does so in the current spacetime metric of the ground state electromagnetic force unification era. The spacetime metric is always involved in one way or another or one form or another in the creation of massive particles, and quite obviously no massive particle has ever been created outside the boundary or regulating presence of spacetime.

While we can invoke plausible rationales and roles for the IVBs and the Higgs particle in the case of "singlet" particle creation (the necessity for universal invariance in the mass/energy parameters of elementary particles), in the case of the creation of particle-antiparticle pairs by the electromagnetic force (or its derivative, the strong force), we can only invoke the special properties of spacetime itself. Spacetime has the ability, and indeed the propensity, to convert free forms of electromagnetic energy (light) into bound, massive forms (particles), carrying various charges, spin, time, and gravitation as the several conserved forms of the energy, symmetry, and entropy of light. It is simply one of the "given" ("anthropic") special properties of our universe, that its spacetime metric will assume both free (spatial) and bound (temporal) (wave and particle) forms of electromagnetic energy. Time and gravitation are part of the special entropic properties of our dimensionality (part of its conservation mechanism) which permits the existence and ready creation of massive, quantized, particulate, temporal, and conserved forms of electromagnetic energy from spatial, free forms of electromagnetic energy. It is this fundamental duality in the expression of its electromagnetic energy forms by our Cosmos which permits our material existence and experience - light and its temporally conserved form, matter.

Of course the ability to form particle-antiparticle pairs is not unique to the electromagnetic ground state energy level, but exists at all energy levels of the force unification hierarchy (because the metric exists in some form at all energy levels). In the ground state, this ability has been reduced to a "virtual" residue or potential, a fleeting reminder of past glories, which nevertheless may be called upon or awakened at any time by a sufficient application and concentration of energy. The creation of particles or bound energy forms by the interaction of light (free electromagnetic energy) with the spacetime metric or Heisenberg/Dirac "vacuum" remains the single greatest miracle of nature, a "given" or "anthropic" property of our Universe which may remain forever unexplained. (Possibly there is some sort of dimensional or topological entanglement or "knotting" between electromagnetic energy and the spacetime metric - as in the theory of "strings".)

Direct interaction between our electromagnetic ground state and the electroweak force unification energy level occurs in radioactive decay and element-building in stars, through the participation of virtual particle-antiparticle pairs in the nuclear transformations which characterize both processes. Because of our dependence upon solar energy, we have a special connection to the electroweak energy level through daily experience, a familiarity we do not enjoy with processes typical of the higher Higgs energy levels (such as proton decay or the creation of quarks). (The weak force is crucial to element-building in stars because protons must be converted to neutrons (via the "W" IVB) before strong force fusion can take place.)

The role of virtual particle-antiparticle pairs in the transformation of atomic nuclei via the "W"

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IVB family level is a fine example of the practical effect of electroweak unification. Our electromagnetic ground state maintains contact with higher force-unification energy levels via its retention of the ability to create any particle-antiparticle pair or weak force boson of any Higgs level, given a sufficient input of energy. Thus the importance of the presence of virtual particle-antiparticle pairs in the electromagnetic ground state Heisenberg/Dirac "vacuum" of spacetime can hardly be overestimated. Without them the Sun itself would be extinguished and element building in stars would cease. Contact between the electromagnetic ground state and higher force-unification energy levels would be limited to gravitational interactions, such as in and surrounding black holes.

It must be understood that the Sun is not itself an example of the electroweak force unification era or energy level. However, the "W" IVBs are such examples, and because the Sun (and other stars) provide a superabundant locus for "W" IVB activity (due to element-building and the transformation of nucleons in their cores), stars can at least be seen as connections to, if not gateways between, our electromagnetic ground state and the next higher symmetry realm or energy level of electroweak unity (the "W" itself is such a gateway). The same can be said for the radioactive elements and minerals. Interestingly, whereas the lodestone's mysterious "lines of force" provided clues to the electromagnetic unification, radioactive minerals' mysterious "rays" provided clues to the electroweak unification. Indeed, the electromagnetic and electroweak eras are well connected, as the transformation of nucleons involves the crucial participation by particle-antiparticle pairs from our electromagnetic ground state "vacuum", as well as the massive IVBs and Higgs of the electroweak energy level.

Our Sun represents a closed symmetry circuit, but only at the electroweak energy level, which means the Sun is limited to the creation and destruction of leptonic matter (although it can also transform quarks and baryons). Hence a neutron star is the (macroscopic) end state of this electroweak conversion or symmetry conservation circuit. To go further, we must climb to the next energy level at which baryons themselves can be created or destroyed, the GUT or leptoquark force unification energy level, represented in our ground state spacetime by black holes and proton decay (in the same sense that the Sun and radioactivity represent contact with the electroweak era). Proton decay (in my view) is commonplace inside black holes, converting quarks, baryons, and the internal mass of black holes to gravitationally bound light. Outside black holes, in the phenomenon of "Hawking radiation", we once again find that particle-antiparticle virtual pairs of our electromagnetic ground state vacuum are crucially involved in another higher level "gateway" to, or connection between, the several force unification energy levels (or symmetry eras) of the Cosmos. Hence while the Sun radiates at the gateway to the electroweak unification era, the black hole radiates (quasars, supernovas, Hawking's "quantum radiance") at the threshold to the GUT unification domain, and the Big Bang radiates (now seen as the 2.7K cosmic background radiation) at the entrance to the TOE and Multiverse unification realm. Our Cosmos is a fully connected whole, even with respect to its evolutionary history. We live indeed within a "Uni-verse".

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The biggest machine in the world

At 8.32 am on the 10th September this year (2011), the biggest machine in the world was switched on for the first time. The Large Hadron Collider at Cern is 100m below ground and lies inside a 27km circular tunnel which straddles the border between France and Switzerland. Scientists from all over the world are hoping to use it to unravel the secrets of the universe.

The LHC is the world's most powerful particle collider. When it is working at full power it will smash together subatomic particles with enough energy to re-create the intense conditions which existed in the universe immediately after the big bang and physicists hope that this will help them to explain how the forces of nature became what they are today. Tejinder Virdee, in charge of one of the LHC's detectors, said: "With the LHC, we will be able to look deeper into matter and further back in time than ever before." However, the scientists will first need to spend months testing and fine-tuning the machine and its four huge detectors. When Cern tested their last collider in 1996, they were surprised to find two beer bottles inside.

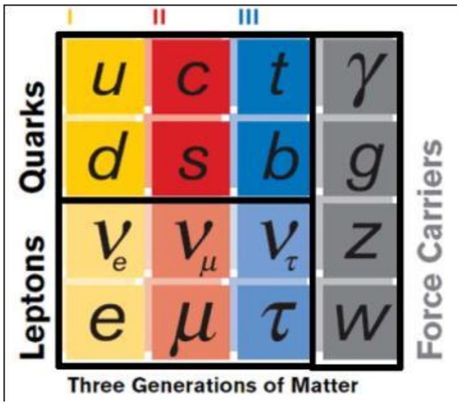
Scientists have a good idea of what they might find during their experiments though. From mini black holes to antimatter and extra dimensions, the LHC has the potential to make a whole host of amazing discoveries. Physicists are almost certain that they will detect the elusive Higgs boson particle which is crucial to understanding the origin of mass. It is thought that shortly after the big bang many particles weighed nothing and only became heavy later thanks to the Higgs boson. It may take a year or more to accumulate enough data to prove its existence though. One finding which may come from the very first collisions at the LHC could be the discovery of the nature of dark matter, the mysterious and invisible stuff that makes up 25% of the cosmos.

But will these experiments affect the man in the street? The answer is yes. Tim Berners-Lee was working at Cern in 1989 and needed a way of managing the huge number of documents that were being produced. His hypertext system went on to become the World Wide Web. And already the LHC is showing us how to manipulate vast amounts of data, providing us with processes that will shape the way computing is done in the future.

Not everyone in the scientific community is so enthusiastic though. German biochemist Otto Rössler believes that any micro black holes created in the LHC could grow and destroy the planet and has filed a lawsuit in the European Court of Human Rights claiming that Cern poses a grave risk for the 27 member states of the European Union and their citizens.

Introduction to Particle Physics and the LHC

The standard model:



This table displays all the fundamental particles known to particle physicists today. Fundamental means that these particles cannot be broken down into anything smaller.

Quarks are what make up hadrons, such as the proton and neutron. The lightest two are the up and down quarks. There are three generations of quarks, the second being the heavier charm and strange; and the third, even heavier top and bottom.

Hadrons can be split up into two kinds:

- mesons which are made of a quark and anti-quark (example, pions),
- baryons which are made of 3 quarks (example, neutrons and protons).

Electrons, muons and tau are charged particles known as leptons, each one of these particles has a corresponding neutrino particle. As in quark generations, the mass of the lepton increases with generations, the muon being approximately 200 times heavier than the electron and the tau being 3900 times heavier. Neutrinos have no charge and almost no mass. Both quarks and Leptons have corresponding anti-particles, of the same mass but opposite charge. It is still unsure, but it is possible that neutrinos may be their own anti-particle.

The force carriers are known as gauge bosons which are associated with force fields. These kinds of particles are always exchanged between particles.

- Gluons mediating the strong interactions,
- Photons mediating the electromagnetic interactions,
- W and Z bosons mediating the weak interactions

Weak interaction

The weak force is caused by the exchange of W and Z bosons between hadrons and leptons.

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It is extremely weak because Z and W bosons are very massive and therefore, have a lot of energy (80GeV for the W bosons and 92GeV for the Z boson).

Real W and Z bosons can be created if enough energy is available in the collider, then it's lifetime affects how far it typically travels. To detect a W or Z bosons in collisions we must look for their decay products.

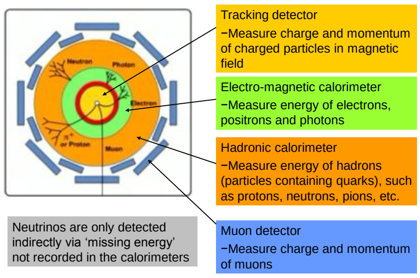
LHC

Real W and Z bosons were observed in 1983 at CERN. W and Z physics was studied in detail at LEP in the 1990s. At the LHC, W and Z boson production will be used as "benchmark " processes to calibrate various searches for the Higgs boson, SUSY (SUper SYmmetri), and other "new physics" processes.

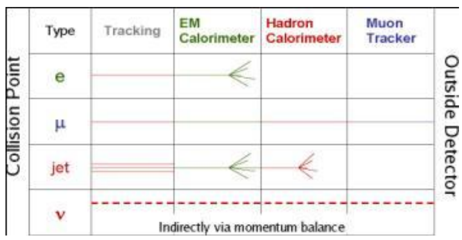
The LHC consists of two beams of subatomic particles called hadrons (either protons or lead ions) that will travel in opposite directions inside a circular accelerator, gaining energy with every lap. When the two beams collide it will recreate the conditions just after the big bang!

How to detect particles in a detector

Charged particles, such as an electron, are detected by ionizing matter in the tracking chamber. Then the tracking device sends electrical signals that can then be reconstructed into the track of the particle. Electrons also lose energy as they pass through a magnetic field they are accelerated. Accelerated charges radiate by releasing a bremsstrahlung photon. The photon can then create an electronpositron pair. As a result this creates EM showers. The total number of particles in the shower corresponds to the energy of the original particle. EM showers lose all their energy in the EM calorimeter.



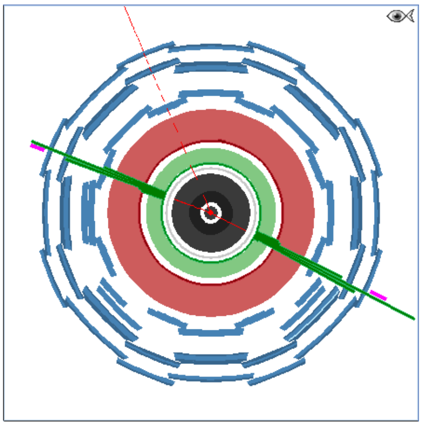
How to interpret collisions in the detector



- All **charged** particles leave tracks in the tracking chamber.
- **Electrons** are small charged particles. The electromagnetic, EM calorimeter stops these particles and the deposited energy is measured.
- **Muons** pass through all detector layers. Muons leave tracks and are the only particle that deposits a tiny amount of energy in all layers of the detector.
- **Neutral** particles can deposit energy in calorimeters, but leave no tracks in the tracking chamber.
- If there is no electron or muon, for this study, events will be called **background.** Sometimes collisions just produce particles usually hadrons which are made of quarks. These usually deposit energy in the hadron calorimeter.
- **Neutrinos** are neutral and very tiny particles of almost no mass, therefore, these particles pass through the detector without detection.

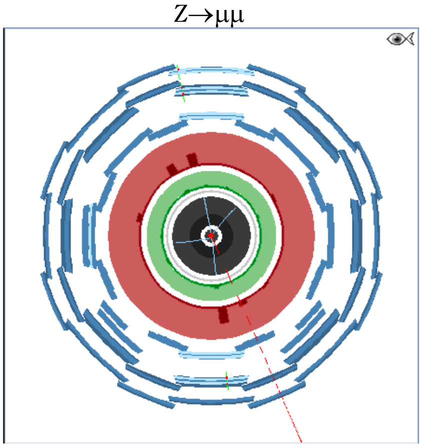
Characteristics of the different event types

$Z \rightarrow ee$



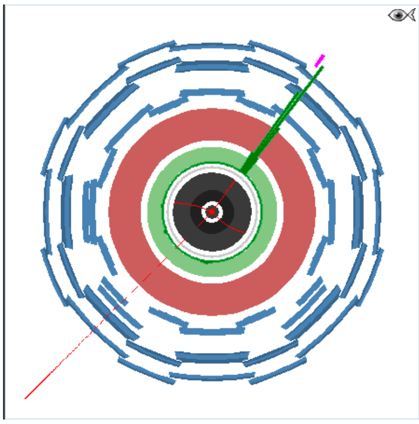
- 2 electrons with high pT

$Z \rightarrow \mu\mu$



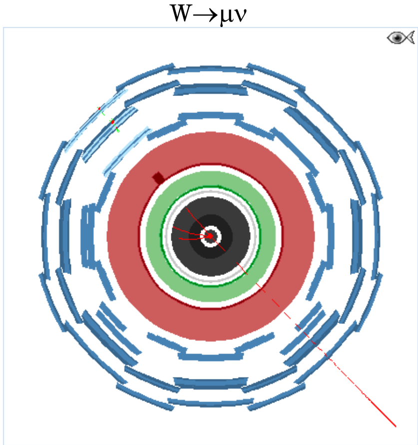
- 2 muons with high pT (>10GeV)

$W \rightarrow e\nu$



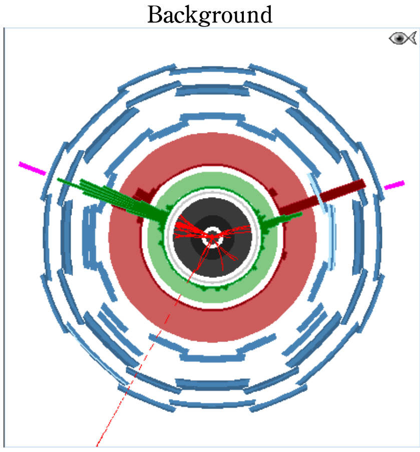
- one electron with high pT
- large missing ET (>10GeV)

$W \rightarrow \mu\nu$



- one muon with high pT
- large missing ET (>10 GeV)

Background



- mainly jets (particle bunch)
- only occasionally an electron or muon

THE MYTHICAL HIGGS BOSON

It has finally been proclaimed by the Bishops and Archbishops at CERN that the Higgs boson does not exist after all and that we have all been conned out of billions. A couple of weeks before this the Director at CERN issued many proclamations from his pulpit that the god particle would be with us in time for Christmas. This episode illustrates the complete lack of integrity in organized pseudoscience and is a tremendous insult to the intelligence of real working scientists. Many scientists think that chasing the god particle makes a mockery out of science and society. In my capacity as a Civil List Pensioner I wrote the Prime Minister in London warning him of such a debacle, but on two occasions my letter was intercepted by a bureaucrat and was sent to the same people at CERN who have wasted so many billions on rubbish science. So the Prime Minister was over-ruled and meekly left government to zealots. I was told to be interested in exciting CERN.

Also blandly evicted with the Higgs boson were sypersymmetry, superstrings, dark matter, spontaneous symmetry breaking, electroweak theory, and the whole lot. Only false authority remains. Any hypercomplexity that depended on the ego particle has evaporated. So again, claims of precision prediction are pure hogwash. The truth is that the standard model contains about twenty five loose parameters, enough to fit the Book of Kells. Now we are expected as ignorant peasants to add more billions in the search for superduperstrings and the particle to end all particles, the moron that is said to exist in so many dimensions that no one has thought up a funding application plan as yet. We at AIAS predicted this atrocious hypocrisy some time ago, and did so with no public funding. We predict other quite different things, dry petrol stations and the entire surface of the earth and sea covered with flailing ghosts of Don Quixote.

In 2010 Horst Eckardt and I showed clearly and simply that the basics of twentieth century particle physics are incorrect in many ways. This was done by anathema, in other words by simple theory that everyone can understand. This was pointed out to Downing Street and they told me that I must be excited about going beyond the standard model. They could not understand that there is nothing left from which to go beyond. Soon there will be nothing left of the Cameron Government, to be replaced by yet more unknown prime ministers. The answer to this monstrous degradation is the answer provided by Francis Bacon, contemplate nature and describe it with reason.

The mythical boson of Higgs was supposed to be the mechanism by which mass could be plucked out of nothingness, but after the LSD shambles we are left again with common sense, mass is inherent in any particle. If the photon be a particle it also has mass and this idea is inherent in the bending of light by gravitation. NASA has measured the bending with accuracy, but it has nothing to do with the standard model of physics, the completely defunct Einsteinian general relativity (EGR). Recently Bruchholz and Eckardt have produced a classical theory of diffraction that dispels Copenhagen and its wave particle dualism. Things are rapidly changing, ghosts and nightmares are vanishing. Early in 2011 Eckardt and I produced a series of papers showing the errors in indeterminacy from a reassessment of the Dirac equation. There are many gross idiocies in indeterminacy, even the name is confused with uncertainty. It was shown in 2011 that according to all that things exist and do not exist at the same time. That is a dose of LSD.

In the face of its proudly self proclaimed and total failure, false authority studiously ignores nature and those scientist that study nature. Otherwise it would lose its funding. False authority may as well be the Ministry of Truth. When the petrol finally runs dry there will be no more morons. Some of us think that that might be a good thing. Billions would be useful to try to stop the petrol running out in the first place. There are tens of thousands of pages of defunct junk now floating in the air, journal pages on the Higgs boson. All were supposedly refereed, all were supposedly cited, all were rubbish. The best citation system is the real time system used by AIAS to monitor the huge amount of interest in its work, probably the only real science around.

Elusive particle maybe near

GENEVA (AP) Physicists are closing in on an elusive subatomic particle that, if found, would confirm a long-held understanding about why matter has mass and how the universe's fundamental building blocks behave.

Few people outside physics can fully comprehend the search for the Higgs boson, which was first hypothesized 40 years ago. But proving that the 'God particle' actually exists would be 'a vindication of the equations we've been using all these years,' said one Nobel laureate.
Scientists announced Tuesday that they had found hints but no definitive proof of the particle that is believed to be a basic component of the universe.
They hope to determine whether it exists by next year.
It's hard to find, not because it is especially tiny, but because it is hard to create, said physicist Howard Gordon of the Brookhaven National Laboratory in Upton, New York.
He works with the ATLAS experiment, one of two independent teams looking for the Higgs boson at CERN, the European Organization for Nuclear Research near Geneva.
CERN runs the Large Hadron Collider under the Swiss-French border, a 17-mile tunnel where high-energy beams of protons are sent crashing into each other at incredible speeds.
A fraction of those collisions could produce the Higgs particle, assuming it exists.
Researchers said Tuesday that they had defined a range of likely masses for the Higgs.
CERN's director-general, Rolf Heuer, said 'the window for the Higgs mass gets smaller and smaller' as scientists learn more.
'But be careful it's intriguing hints,' he said. 'We have not found it yet. We have not excluded it yet.' Tuesday's revelations were highly anticipated by thousands of researchers, but the ideas behind the Higgs boson date back to the 1960s.
British physicist Peter Higgs and others theorized its existence to explain why the fundamental particles in matter have mass.
Those particles, such as electrons, are the building blocks of the universe.
Mass is a trait that combines with gravity to give an object weight.

Finding the Smallest Unifying Particle in the Human Universe:
An Artistic Theory of Everything

By Eric Booth

We human beings have a long history of proposing theories to unify disparate truths. This yearning to find a transcendent meaning for separate bodies of evidence may be one of our distinguishing traits. You have probably noticed this impulse in your own life: a series of experiences prompts the sense that something is hidden in the bundle of them. Your inner smarts work on the challenge— rationally, via various unconscious processes, and even while sleeping. The "Aha!" moment of identifying the deeper pattern in the evidence is satisfying and joyful; it launches a whole new set of possibilities for you as a person, as an artist.
I see the separate disciplines and fields within the arts and arts learning in that light because, although they seem to comprise disparate bodies of truth, my gut tells me that meaningful, unifying, common truths await, hidden in plain sight. Truths, that when embraced, can change the status quo.
You would be hard pressed to argue that we are a unified field. Practitioners of different art forms just don't think of themselves as part of a larger functional entity. Even though multidisciplinary performances and presentations are increasingly common, the various artistic tribes compete more often than they cooperate, believing that the concerns they share are less significant than the ones they face on their own. A regional theater company looks at a choral ensemble and does not see much resemblance; a string quartet looks at a small dance ensemble or a struggling art gallery and does not see itself mirrored there.
Likewise, the divisions within arts education never seem to resolve. We waste energy on the same familial tiffs we have had for decades: disciplinary instruction vs. arts integration, arts education for art's sake vs. arts education to produce other benefits, certified arts instructors

vs. teaching artists, in-school learning vs. all the learning that happens outside of school—and what about the granny who plays the ukulele? These old hostilities, prejudices, and cross-purposes persist within a culture of scarcity, eroding the expansive, inclusive impulses that got us into arts-learning in the first place.

As a consultant, I have had many opportunities to try to build local arts partnerships and consortia; the usual strategy is to identify common goals and thereby foster a joint commitment to actions that will lift all the organizational boats together. Sometimes progress is made, and there are inspiring examples of success in a few cities; more often, the separateness of the participants is palpable and pervasive, caution and distrust remain entrenched, and the proposed partners have no shared language. This last point takes a while to surface, and is hard to admit—each doesn't really know what the other is talking about, or the separate fields don't agree on some fundamental point. You don't believe me? Try discussing with an artist from another discipline what you think creativity really is.

The current painful economic constriction may be the catalyst we need to change our habits of thinking and jump us out of our ruts. As Rahm Emmanuel said when he was appointed White House Chief of Staff: "A crisis is too good an opportunity to waste."

What Good Is a Unifying Theory, Anyway?

Newton's theory of universal gravitation (1687) provided a unifying explanation for separate bodies of evidence on tidal patterns, Galileo's theory of Earth's gravity, and Kepler's laws of planetary influence. Adopted by scientists, and then by Western culture at large, Newton's theory erased the truth as it was known, writing the new understanding of reality and sparking an explosion of inquiry into forces of attraction in physics.

Two and a half centuries later, the term Unified Field Theory (also known colloquially as the Theory of Everything) was coined by Einstein and captures the drive of his mature years to find a deep, unifying truth beneath persistently separate but related bodies of evidence. Einstein sought to explain the distinct forces of relativity, electromagnetism and gravity by discovering the fundamental particles that interact in all.

That ongoing search by physicists later led to quantum mechanics, the formulation of string theory, and—now—searches for the theoretical Higgs boson. Particle physicists know of five fundamental kinds of bosons—the term for the smallest particles in the universe that carries force. Four of the five types have been observed experimentally; these are called gauge bosons. The Higgs boson is hypothesized yet still unseen; but the drive to find it is not theoretical—you may have heard news reports of the recently completed construction of the Large Hadron Collider by the European scientific consortium called CERN. It is an underground, 17-mile-circumference atom smasher near Geneva Switzerland, and the most expensive construction project in human history. At this point, it is the greatest technological hope to provide evidence of the Higgs boson and how it works.

If we come to know how it works, the Higgs boson may unify the currently separate force fields of gravitation, electromagnetism, strong and weak nuclear forces. Some physicists believe that the discovery will explain such ultimate mysteries as why matter becomes mass and why there is something instead of nothing. No wonder that the Higgs boson is sometimes called the God particle.

For those outside of particle physics, the search for a unified field theory can be seen as quixotic and pointlessly conceptual, the work of eggheads who can't boil an egg. We live in an aggressively anti-intellectual culture, particularly unfriendly to meta-headed endeavors, but even that bias can't deflect the truth that the impulse to find unity underneath seemingly disparate phenomena has led to some of the greatest breakthroughs in human understanding.

How Does It Apply to Us?

I believe the time has come for arts educators and others in the arts to grapple with their own unified field theory. We have lived and struggled separately and sometimes fear we may die separately; yet I see an emerging belief that we have much in common and that we enhance the visibility and viability of all if we identify and act on our common ground. Dozens of cities and regions are trying to build a local arts and/or arts education community to better their collective future. Information about this very impulse in Dallas, Richmond, Portland, Philadelphia, New Orleans, Providence and New York came across my desk in various forms in just one day, yesterday. Last summer's National Performing Arts Conference in Denver is another case in point. It was the largest such gathering ever, explicitly dedicated to building a more unified field; and the thousands of participants voted on common steps to build a national community.

Jim Collins, keynote speaker at the Denver conference, made a couple of points that went right at the heart of our challenge. Collins is a highly influential and credible business "guru"—the author, consultant, and leader of the bestselling "good to great" research on what makes businesses excel. I confess I was none too thrilled that a business leader was positioned as the keynoter for this historic arts gathering; part of me cringed that we would be asked to use a business model to come together as a field. But Collins has studied nonprofit organizations extensively, is an expert on what organizations must do in turbulent times (yes, that's now), and he's passionate about the arts—so I listened with an open mind. Lucky thing, too, because he made two points that I found essential to the consideration of a Unified Arts Field Theory.

Re-thinking the "Mission Statement."

Collins's first point—not controversial—was that in turbulent times, an organization must get the right people "on the bus," refocus on its primary mission, and experiment boldly to fulfill that mission. But his second point was a follow-up so challenging that many people didn't take it in. He said that most of us in the arts have a completely wrong-headed idea of our true mission (or core values or beliefs, but let's not get stuck in semantics). Collins argues that we mistakenly assume our mission is to present our particular and beloved artistic canon, the greatest artworks, old and new. He suggests our core values are exactly *not* that, that our favorite artworks are the *means* by which we have try to fulfill the core values of art, and according to his research, that is exactly where we must experiment. To rediscover our purpose, to live long and prosper, we must let go of our focus on programming favorite artworks, old and new, and instead boldly experiment with engaging people in artistic experiences. We must reconnect with the human art instinct.

The excellent new book *The Art Instinct* by Denis Dutton (Bloomsbury USA, 2008) argues compellingly that art is a universal human evolutionary advantage that goes back to our Stone Age roots.

The arts have been around since at least Day Two of human history (ornamental jewelry goes back 80,000 years, painting almost as far—and that's not mentioning our impulses to create dance, music and to tell stories, which undoubtedly are even more ancient). Artistic expression is not just the province of artists; it appears spontaneously, irrepressibly, throughout each of our lives, mostly in forms and venues not identified with Art with a capital A. So, how have we let the identity of art get quarantined as an occasional pricey event in a special building?

Art appears in every endeavor raised to its highest level of expression, and more commonly in our conversations, hobbies, homes, as we dance at parties … anywhere people slip into the work and play of art. The core value for those of us in the arts professions—engaging people in the richness of the artistic experience—is to prompt that universal sense of meaning, richness, "specialness," and satisfaction. It feels good—really good—the kind of good feeling that is hard to find in our overstimulated, materialistic, multitasking lives.

In order to unify our disparate arts, we need to find the quintessential elements of that human experience. We need to identify the fundamental particle or particles at the basis of the attraction, a Higgs boson for the human movement toward the artistic experience. And if we can agree around that unifying principle, I believe we can begin to answer the Jim Collins challenge in a powerful way, by experimenting boldly to bring people into the common, universal, highly-valued human experience of art. Not just those who already value the arts, but also those who aren't in the club and don't think about or care about the arts, yet yearn for fullness in their lives. We need to move the experience of art to the center of our intention, and reclaim *Homo sapiens'* cultural birthright of artistic engagement.

What happens in gospel-choir-and-audience singing that can fill the recital hall and stir the soul? What is the element that turns a good conversation into a great conversation that can be delivered in every theater? How is it that an encounter with a violinist in a fifth-grade classroom can spark a kid to be more curious about social studies? What is the *sine qua non,* the irreducible core, of all the different ways in which the artistic impulse has expressed itself in human history?

Identifying Our Own Higgs Boson.

Our field needs the debate as much as we need an answer. To get us started, let me posit my own hypothetical answer to spark further answers from others. Get mad at my opinion, please, to fuel the sharing of your own.

I think the fundamental act is the spark of connection. The spark may be literal, as the firing of a new synaptic link in the brain; and it is also metaphoric for making something new. The etymology of the word *art* means *to put things together*. The Higgs boson of art is the individual's act of creation, of putting together things that matter to that individual.

This makes us human and makes us feel human, feel alive, feel connected to others. Making a connection, look at the idiom: creating something that bridges a gap of separateness.

This fundamental act of art occurs when we find the right word in a poem or the dance move that captures what we know and cannot say. We spark the arts connection when we enter a "world" made by someone else (a work of art, a spoken image, a story, an eloquent gesture) and find a personally relevant connection inside it. We fire the art connection when we pick just the right song to play for a suffering friend and when we listen deeply to a friend's story and connect to its unspoken core. We slip into the physics of art when we resonate inside with the note just played, when we experience a sense of eternity under a night sky.

The power of the moment is not just "understanding" the world of a work of art, or "appreciating" it or even "enjoying" it. The boson is the creative act of making a new connection inside it. The fundamental power of an artwork is tapped not only by completing its construction, but also by making any meaningful new connection of your own.

Fundamental particles don't just exist; they influence each other in ways that manifest as electromagnetism and gravity, creating matter. Similarly, artistic bosons do not passively exist, but accrue force that manifests as human affinities such as: intrinsic motivation (doing things from your personal energy and yearning, as opposed to *ex*trinsic motivation, which drives all the other ways things happen in the world), curiosity, playfulness, satisfaction and gratitude (they seem linked in my experience), the recognition of beauty, the experience of love, and the cohesion of groups and communities. No wonder the arts have sustained since the beginning of human history—this is the list of the best parts of being alive. They provide unity, attraction, and the reason there is something to being a human instead of being nothing.

The unified field theory then challenges us to answer: What can we do, as believers in the power of the fundamental act of creation, to align our actions, our creations, our organizations, our intentions and interactions with everyone inside and outside the arts to maximize that power? How can we create environments that effectively, irresistibly support and nurture that power? What events can we devise that are dedicated to that power, not merely to the presentation of artworks that we hope will contain it for those few who pay to attend?

Are you whining, "Why can't we just play the heck out of Haydn quartets and be done with it? Why should we bother with all this?" Because fewer and fewer people are able to feel the spark of connection inside the canon of artworks we love, no matter how well you play the Haydn. If you are content with being part of the slow demise you complain about, fine. Our culture is not losing the art instinct, but turning it away from the fields that we believe are its most fertile ground. If you want to help the arts thrive and reclaim their ancient human birthright, start experimenting, boldly, with the clarity and care of a physicist, to find out how you can spark that act of creation in everyone you meet.

And the more important reason to grapple with the awkwardness of this challenge is that it recharges us as artists, in our most important cultural roles, as the voice of human truth, as re-creators of human relevance amid the dehumanizing forces of society, as fierce warriors for the human birthright of artistry in our brief time together. Our field does not have expensive new machinery to produce the evidence that will unify our field, but we can collide with each other in dialogue to find the evidence that guides us to experiment boldly, brilliantly, effectively, as artists do, to tap our most fundamental human force and channel it into artistic encounters.

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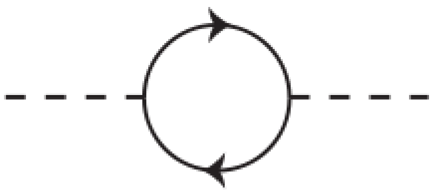
IN POPULAR CULTURE

The **Higgs boson** is a hypothetical massive scalar elementary particle predicted to exist by the Standard Model in particle physics. At present there are no known fundamental scalar particles in nature. The existence of the particle is postulated as a means of resolving inconsistencies in current theoretical physics, and attempts are being made to confirm the existence of the particle by experimentation, using the Large Hadron Collider. Other theories exist which do not anticipate the Higgs Boson, described elsewhere as the Higgsless model.

The Higgs boson is the only Standard Model particle that has not been observed. Experimental detection of the Higgs boson would help explain the origin of mass in the universe. The Higgs boson would explain the difference between the massless photon, which mediates electromagnetism, and the massive W and Z bosons, which mediate the weak force. If the Higgs boson exists, it is an integral and pervasive component of the material world.

The Large Hadron Collider (LHC) at CERN, which became fully operational on November 20, 2009, is expected to provide experimental evidence of the existence or non-existence of the Higgs boson. Experiments at Fermilab also continue previous attempts at detection, albeit hindered by the lower energy of the Fermilab Tevatron accelerator. Fermilab physicists have been reported to have suggested that the odds of Tevatron detecting the Higgs boson are between 50% and 96%, depending on its mass.

Theoretical overview



A one-loop Feynman diagram of the first-order correction to the Higgs mass. The Higgs boson couples strongly to the top quark so it may decay into top anti-top quark pairs.

The Higgs boson particle is one quantum component of the theoretical Higgs field. In empty space, the Higgs field has an amplitude different from zero; i.e., a non-zero vacuum expectation value. The existence of this non-zero vacuum expectation plays a fundamental role: it gives mass to every elementary particle which has mass, including the Higgs boson itself. In particular, the acquisition of a non-zero vacuum expectation value spontaneously breaks electroweak gauge symmetry, which scientists often refer to as the Higgs mechanism. This is the simplest mechanism capable of giving mass to the gauge bosons while remaining compatible with gauge theories. In essence, this field is analogous to a pool of molasses that "sticks" to the otherwise massless fundamental particles which travel through the field, converting them into particles with mass which form, for example, the components of atoms. Prof. David J. Miller of University College London provides a simple explanation of the Higgs Boson, he won a prize for this lucid explanation of the Higgs Boson.

In the Standard Model, the Higgs field consists of two neutral and two charged component fields. Both of the charged components and one of the neutral fields are Goldstone bosons, which act as the longitudinal third-polarization components of the massive W+, W–, and Z bosons. The quantum of the remaining neutral component corresponds to the massive Higgs boson. Since the Higgs field is a scalar field, the Higgs boson has no spin, hence no intrinsic angular momentum. The Higgs boson is also its own antiparticle and is CP-even.

The Standard Model does not predict the mass of the Higgs boson. If that mass is between 115 and 180 GeV/c2, then the Standard Model can be valid at energy scales all the way up to the Planck scale (1016 TeV). Many theorists expect new physics beyond the Standard Model to emerge at the TeV-scale, based on unsatisfactory properties of the Standard Model. The highest possible mass scale allowed for the Higgs boson (or some other electroweak symmetry breaking mechanism) is 1.4 TeV; beyond this point, the Standard Model becomes inconsistent without such a mechanism, because unitarity is violated in certain scattering processes. Many models of supersymmetry predict that the lightest Higgs boson (of several) will have a mass only slightly above the current experimental limits, at around 120 GeV or less.

Supersymmetric extensions of the Standard Model (so called SUSY) predict the existence of whole families of Higgs bosons, as opposed to a single Higgs particle of the Standard Model. Among the SUSY models, in the Minimal Supersymmetric extension (MSSM) the Higgs mechanism yields the smallest number of Higgs bosons: there are two Higgs doublets, leading to the existence of a quintet of scalar particles: two CP-even neutral Higgs bosons h and H, a CP-odd neutral Higgs boson A, and two charged Higgs particles H .

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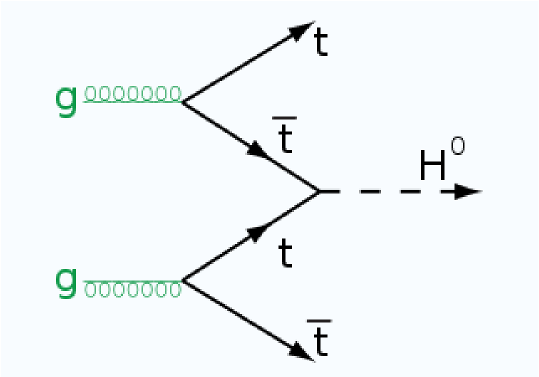
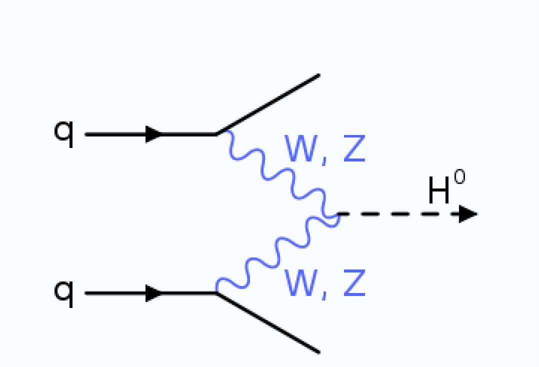


A Feynman diagram of one way the Higgs boson may be produced at the LHC. Here, two gluons decay into a top/anti-top pair which then combine to make a neutral Higgs.



A Feynman diagram of another way the Higgs boson may be produced at the LHC. Here, two quarks each emit a W or Z boson, which combine to make a neutral Higgs.

Experimental search

As of December 2009, the Higgs boson has yet to be observed experimentally, despite large efforts invested in accelerator experiments at CERN and Fermilab. The data gathered at the LEP collider at CERN allowed an experimental lower bound to be set for the mass of the Standard Model Higgs boson of 114.4 GeV/c2 at 95% confidence level. The same experiment has produced a small number of events that could be interpreted as resulting from Higgs bosons with mass just above said cutoff—around 115 GeV—but the number of events was insufficient to draw definite conclusions. The LEP was shut down in 2000 due to construction of its successor, the Large Hadron Collider which is expected to be able to confirm or reject the existence of the Higgs boson. Full operational mode was delayed until mid-November 2009, because of a serious fault discovered with a number of magnets during the calibration and startup phase.

At the Fermilab Tevatron, there are ongoing experiments searching for the Higgs boson. As of March 2009, combined data from CDF and DØ experiments at the Tevatron were sufficient to exclude the Higgs boson in the range between 160 GeV/c2 and 170 GeV/c2 at the 95% confidence level. Continued data collection is aimed at raising this lower bound.

Spotting a lighter Higgs would be much trickier. Fewer of them are expected to be produced and there are many more lookalike processes to worry about.

In a recent preprint, arXiv:0912.0004 , it has even been suggested (and commented as "important physical news" by several websites, e.g. under the headline Higgs could reveal itself in Dark-Matter collisions by "physicsworld", a website supported by the british Institute of Physics) that the Higgs Boson might not only interact with the above-mentioned particles of the Standard model of particle physics, but also with the mysterious WIMPs ("weakly interacting massive particles") of the Dark matter, playing a most-important role in recent astrophysics. In this case, it is natural to augment the above Feynman diagrams by terms representing such an interaction.

In principle, a relation between the Higgs particle and the Dark matter would be "not unexpected", since, (i), the Higgs field does not directly couple to the quanta of light (i.e. the photons), while at the same time, (ii), it generates mass.

Alternatives for electroweak symmetry breaking

In the years since the Higgs boson was proposed, several alternatives to the Higgs mechanism have been proposed. All of the alternative mechanisms use strongly interacting dynamics to produce a vacuum expectation value that breaks electroweak symmetry. A partial list of these alternative mechanisms are:

1. Technicolor is a class of models that attempts to mimic the dynamics of the strong force as a way of breaking electroweak symmetry.
2. Extra dimensional Higgsless models where the role of the Higgs field is played by the fifth component of the gauge field.
3. Abbott-Farhi models of composite W and Z vector bosons.
4. Top quark condensate.

The Higgs boson is often referred to as "the God particle" by the media, after the title of Leon Lederman's book, The God Particle: If the Universe Is the Answer, What Is the Question?. While use of this term may have contributed to increased media interest in particle physics and the Large Hadron Collider, it is disliked by scientists as overstating the importance of the particle. In a renaming competition, a jury of physicists chose the name "the champagne bottle boson" as the best popular name.

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