Special Report

If There Is a Nobel Prize for the Higgs Boson, Who Will Get It?

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Abstract

With the discovery of the "Massive Scalar Boson" (a.k.a The Higgs) seeming to be imminent, physicists are jostling for position to take the credit. There are at least seven living physicists who played key roles in the prediction of its existence fifty years ago and many more experimentalists and phenomenologists who worked more recently on its likely discovery at the LHC with supporting evidence from the Tevatron. It seems that at least one Nobel must be up for grabs for the theoretical work in the 1960s and possibly another for the experimental side, but the rules only allow for three laureates to share a prize, so who will the Nobel committee choose?

Key Words: Higgs Boson, discovery, credit, Nobel Prize.

On May 17, 2012 Peter Higgs presented his standard talk "My Life as a Boson" at Bristol in a CERN webcast seminar. It could be a good moment to continue the running debate about who is worthy of the inevitable Nobel prize for the Higgs Boson that has already featured on other blogs (see NEW, Resanaances, TRF).

With the discovery of the "Massive Scalar Boson" (a.k.a The Higgs) now seeming imminent, physicists are jostling for position to take the credit. There are at least seven living physicists who played key roles in the prediction of its existence fifty years ago and many more experimentalists and phenomenologists who worked more recently on its likely discovery at the LHC with supporting evidence from the Tevatron. It seems that at least one Nobel must be up for grabs for the theoretical work in the 1960s and possibly another for the experimental side, but the rules only allow for three laureates to share a prize, so who will the Nobel committee choose?

It is not just the prize money that is at stake. There is fervent national pride to play for. The prize for the Higgs boson is building to become the most widely anticipated Nobel Prize in history. Already we are seeing campaigns to support the various candidates in the form of people naming the particle in honour of their colleagues as a way of supporting their cause. Controversy started mounting at the Higgs Hunting conference in 2010 in Paris. The organisers decided that the sought after boson should actually be called the Brout-Englert-Higgs boson to recognise the contributions of 1964 Robert Brout and Francois Englert who submitted the first complete paper on the symmetry breaking mechanism a few weeks before Higgs. This ignited a raging controversy set alight by supporters of Tom Kibble, Gerald Guralnik and Carl Hagen, three physicists who submitted an independent account of the mechanism just as the work of the other

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three was appearing in print. Later in 2010 the Sakurai Prize was awarded to all six making the Anglo-French campaign to support only three seem especially chilling.

In 2011 Robert Brout died. The Nobel cannot be awarded posthumously. If Brout, Englert and Higgs has been the leading contenders to take the prize before then Brout's death opens up the way for a third Laureate to be recognised, who if anyone will it be? One possibility would be to include Kibble as a representative of the third group and also because of his extra work on the non-Abelian version of the mechanism that proved important when Weinberg and Salam developed the full theory by applying the symmetry breaking theory to Glashow's Electroweak Gauge theory. Another strong contender is Philip Anderson who took an influential step towards the discovery with a non-relativistic model inspired by condensed matter theories. Other possibilities might be Goldstone whose theoretical work on symmetry breaking that paved the way for the discovery has been overlooked by the Nobel committee. Perhaps even a phenomenologist such as John Ellis who did so much to develop the theory leading to its discovery could be honoured.

Getting to the bottom of it all is not easy. The final form of the Higgs mechanism was put in place by Steven Weinberg and independently Abdus Salam as the standard model Electro-Weak unification, but that work has already been rewarded, so the question is about which precursors are worthy of an extra Nobel for the Higgs. Was the prediction of the particle itself the essential element or was it the mechanism what counts? Only Higgs himself emphasised the importance of the massive Higgs boson in his early work. Does it matter if the first account was non-relativistic or was a full model for the boson required? Will they take into account that a potential winner already has one Nobel Prize? These are questions that only the Nobel committee can answer. One thing for sure is that the controversy can only get stronger. At a recent conference in La Thuille Englert was invited to open the session about the Higgs Boson's near discovery with a talk about its theory. This time it was the American Tevatron teams who used the BEH label while ATLAS and CMS opted for the "SM Scalar Boson".

For the record let me state my opinion for what it is worth. If I were able to nominate for the Nobel Prize for the theory my choice would be Higgs, Englert and Goldstone. Higgs deserves it for highlighting the experimental prediction of the massive scalar boson while Englert in collaboration with Brout was the first to publish a description of the symmetry breaking mechanism. Goldstone is added for realising the importance of the Mexican hat potential and its consequences as well as the understanding he provided for the strong force. The work of Anderson was important but it was too incomplete and he is already a Laureate. Kibble, Guralnik and Hagen offered important explanatory details for how the mechanism overcomes the Goldstone theorem but their contribution was too late to be considered part of the original discovery. However, if Goldstone were replaced by either Anderson or Kibble in the list it would still look very reasonable. The prize committee may set their own criteria or just be influenced by how many nominations each physicist gets.

If choosing the winners of the theory prize is hard enough, the allocation of the prize for its experimental discovery is even harder. No small set of individuals among the thousands who have worked in collaboration can take enough of the credit to single them out. In a few past cases the Nobel committee has given the award to the head of the lab concerned, but the Tevatron and LHC have been developed and run over many years and the directors have changed several times. My guess is that no Nobel will be given for its experimental discovery, just as none has been given for finding the top quark.

For those who want to investigate further I have compiled a convenient list of many of the key papers and contributions that led to the prediction of the Higgs boson, or followed it. Unfortunately all of these are locked behind paywalls so I don't have access to them and can only base my comments on what others have reported. Most of the protagonists have also posted their own historical accounts which provide valuable if highly biased background:

- Anderson: Interview by Alexei Kojevnikov
- Brout and Englert: Spontaneous Symmetry Breaking in Gauge Theories: a Historical Survey
- Higgs: My Life as a Boson
- Guralnik: The Beginnings of Spontaneous Symmetry Breaking in Particle Physics

Heisenberg 1928
W. Heisenberg, Z. Phys. 49 (1928) 619, A description of ferromagnetism as spontaneous symmetry breaking.

Stueckelberg 1938
Stueckelberg, Helvetica Physica Acta Vol.11, 1938, p.299, 312.

In an early precursor to the Higgs mechanism, Ernst Stueckelberg proposed a model of massive quantum electrodynamics with a coupled scalar field to spontaneously break the symmetry. This was different from the Abelian version of the Higgs mechanism in that it used an affine representation of the group rather than a linear one. Like much of his work this was ahead of its time and did not receive much credit during Stueckelberg's lifetime.

Ginzburg-Landau 1950
V. L. Ginzburg and L. D. Landau, On the theory of superconductivity, Zh. Eksp. Teor. Fiz. 20 (1950) 1064.

Ginzburg and Landau used a macroscopic thermodynamic theory to show how spontaneous symmetry breaking can make the photon massive and explain superconductivity. The symmetry breaking is induced by an electrically charged Bose condensate. This made use of an idea introduced by Landau where a W shaped potential spontaneously breaks the symmetry. It can be regarded as a thermodynamical precursor to the idea of the Mexican hat shaped Higgs potential that breaks the gauge symmetry in the standard model. Landau was awarded a Nobel prize in 1962 for work on superfluids. Ginzburg also received the prize in 2003 for superconductivity and superfluids.

Yang-Mills 1954
Yang, C. N.; Mills, R. (1954). "Conservation of Isotopic Spin and Isotopic Gauge Invariance", Physical Review 96 (1): 191–195.

Based on unpublished ideas of Wolfgang Pauli, Chen Ning Yang and Robert Mills developed a generalisation of the abelian gauge theories of quantum electrodynamics to non-abelian gauge groups. The theory was initially regarded as a failure due to its prediction of massless gauge bosons whereas the relevant nuclear interactions required massive intermediaries to explain the short range nature of their force. Despite its eventual spectacular success in the Standard Model, no Nobel was ever awarded for Yang-Mills theory although Pauli and Yang were physics laureates for other work.

Bardeen-Cooper-Schrieffer 1957

L. N. Cooper, Phys. Rev. 104 (1956) 1189; J. Bardeen, L. N. Cooper and J. R. Schrieffer, Microscopic theory of superconductivity, Phys. Rev. 106 (1957) 162.

This research described the first microscopic model that realised the theory of Ginsburg-Landau to explain low temperature superconductivity. Electrons form Cooper pairs which act like bosons and produce the charged Bose condensate as described by Ginzburg and Landau. The model breaks the electrodynamic gauge symmetry giving the photon an effective mass. This later became the inspiration for the Higgs mechanism where the bosonic field is fundamental. The three physicists were awarded the physics Nobel Prize in 1972 for this work.

Nambu 1960

Nambu, Y (1960), “Quasiparticles and Gauge Invariance in the Theory of Superconductivity”. Physical Review 117: 648–663; Y. Nambu, Axial vector current conservation in weak interactions, Phys. Rev. Lett. 4 (1960) 380.

Nambu investigated the effects of symmetry breaking in the context of superconductivity and found that it led to a massless particle. He then considered the idea that a similar mechanism may be relevant to particle physics where the pion is nearly massless. This is due to spontaneous breaking of approximate chiral symmetry leading to a light pseudo-Nambu-Golsytone boson.

Goldstone 1960

Goldstone, J (1961), “Field Theories with Superconductor Solutions”. Nuovo Cimento 19: 154–164.

Following Nambu, Jeffrey Goldstone showed that there would be massless particles when a continuous symmetry is broken. These particles are now called Nambu-Goldstone bosons. This was regarded as a problem for any attempt to use spontaneous symmetry breaking where no massless particles are known. This discovery was important in the theory of the string interactions where the pion can be regarded as a pseudo-Nambu-Goldstone boson. Goldstone also used elementary scalar fields with mexican hat potentials that became a crucial element of the Higgs mechanism. Nambu won a Nobel Prize for spontaneous symmetry breaking in sub-atomic physics but Goldstone has never been awarded the prize.

Nambu, Jona-Lasino 1961
Y. Nambu, G. Jona-Lasinio (1961), "Dynamical Model of Elementary Particles Based on an Analogy with Superconductivity". Physical Review 122: 345–358.

Y. Nambu and G. Jona-Lasinio described a four fermion model in which chiral symmetry is spontaneously broken and a zero mass boson is generated.

Glashow 1961
Gauge unification of electromagnetic with weak force, but no Higgs mechanism or other form of symmetry breaking so gauge bosons would be massless contrary to known physics.

Goldstone, Salam, Weinberg 1962
J. Goldstone, A. Salam, S. Weinberg (1962), "Broken Symmetries". Physical Review 127 (3): 965

A proof was given that a zero mass boson appears when symmetry is spontaneously broken. This was a disappointment because such a zero mass particle should be easily observable so it seemed to rule out the use of symmetry breaking. The development of the Higgs mechanism came about as a realisation that the conditions of the theorem did not apply to gauge theories.

Schwinger 1962
Schwinger, Julian (1962), Gauge Invariance and Mass. II. Physical Review, Volume 128. pp. 2425.

Julian Schwinger studied a model of quantum electrodynamics in 2 dimensions with a Dirac fermion. The Schwinger model can be solved analytically. It is found to exhibit spontaneous symmetry breaking of the U(1) symmetry making the photon massive. There are different views on how well this is related to the Higgs mechanism but it was certainly an influence in guiding people towards the idea that symmetry breaking could provide massive gauge bosons. Schwinger won a Noble Prize for his co-discovery of renormalisability of QED

Anderson 1962
P. W. Anderson (1962), "Plasmons, Gauge Invariance, and Mass".*Physical Review* **130** (1): 439–442.

Motivated by his work in condensed matter physics, Philip Anderson showed that spontaneous symmetry breaking of gauge symmetry can give mass to the gauge bosons. His mechanism was essentially a nonrelativistic precursor to the Higgs Mechanism. The work was published in Physics Review rather than a condensed matter journal because Anderson thought it relevant to particle physics. The crucial observation was that the troublesome massless Goldstone boson mode is absorbed into the gauge boson field transforming it from the component field of a massless particle to the three component field of a massive one. He did not point out that a massive scalar boson would also be important.

Anderson was overlooked when the 2010 Sakurai prize was given to Higgs, Brout, Englert, Kibble, Guralnik and Hagen for the Higgs mechanism. Some people justify this by pointing out that the relativistic extension of his idea is non-trivial and an important part of the theory. Others say that there is bias against him from particle physicists because he is condensed-matter physicist and argued against funding the American SSC hadron collider. It is a difficult call, he certainly had some of the key elements, but the Nobel Prize is usually only given for more complete theories. In the form presented by Anderson the idea was described by Higgs as crucial but just speculation. At least Higgs cited Anderson's paper. Brout, Englert, Guralnik, Hagen and Kibble all left the reference out despite being well aware of the prior work. Anderson has the Nobel Prize from 1977 for work on superconductivity

Klein-Lee 1964

A. Klein, B.W. Lee (1964), "Does Spontaneous Breakdown of Symmetry Imply Zero-Mass Particles?", Physical Review Letters 12 (10): 266.

Abraham Klein and Ben Lee pointed out that the relativistic case of Anderson's idea would be harder because Lorentz invariance and the lack of a referred reference frame restricted the terms that could be used. They thought that it might still be possible.

Gilbert 1964

W. Gilbert, Broken symmetries and massless particles, Phys. Rev. Lett. 12 (1964) 713.

In response to Klein and Lee, Walter Gilbert showed that under certain assumptions it was not possible to extend Andersons idea to the relativistic case. This perhaps demonstrates best of all that the subsequent steps were not a trivial development of Anderson's non-relativistic version of the theory. Gilbert later switched to biology and was awarded a Nobel Prize in chemistry. He was also a thesis advisor to Guralnik.

Brout-Englert 1964

F. Englert, R. Brout (1964), "Broken Symmetry and the Mass of Gauge Vector Mesons". Physical Review Letters 13 (9): 321–323.

On 26 June 1964 Robert Brout and Francois Englert submitted the first paper that describes the relativistic Higgs mechanism. It was published in Physics Review Letters on 31st August 1964. The paper showed how gauge symmetry can be broken by scalar fields to give rise to massive gauge bosons as required by the weak nuclear force. They did not mention the existence of a scalar boson. The work covered both Abelian and non-Abelian gauge theories and also considered the possibility that a condensate of fermions could be behind the symmetry breaking mechanism (this would mean a composite Higgs boson but they did not elucidate it in those terms). The paper mentioned both Abelian and non-Abelian gauge theories.

Higgs 1964

P. Higgs (1964), "Broken Symmetries, Massless Particles and Gauge Fields". Physics Letters 12 (2): 132; P. Higgs (1964), "Broken Symmetries and the Masses of Gauge Bosons". Physical Review Letters 13 (16): 508.

When Higgs saw Gilbert's paper it soon occurred to him that Schwinger's model already provided a counterexample to the claim that a relativistic theory of symmetry breaking without massless bosons was not possible. He quickly wrote a note for Physics Letters that was submitted on 24th July and was later accepted. A second paper describing the model in detail was submitted a week later. This contained a complete model of the Higgs mechanism for abelian gauge theories. It was a hybrid of Goldstones scalar theory with Maxwell's equations.

This second paper was rejected. It has been said that the referee who rejected the paper was Nambu and that he suggested the paper needed to have more about the experimental implications of the model. It has even been said that he highlighted the massive scalar boson in the spectrum. Higgs does not mention this influence in his account and says that he revised the paper himself along such lines. It was sent to Physical Review Letters at the end of August and was accepted. Higgs says that Nambu was the referee of this second paper for PRL not PL and that he drew his attention to the work of Brout and Englert which had just been published, with the result that Higgs added a citation to their paper.

Guralnik, Hagen and Kibble 1964

G.S. Guralnik, C.R. Hagen and T.W.B. Kibble (1964). "Global Conservation Laws and Massless Particles". Physical Review Letters 13 (20): 585.

The GHK paper on the symmetry breaking mechanism came later than BEH so it would have to add some crucial piece of the picture to be regarded as prize worthy. It is often regarded as the most comprehensive treatment of the time and showed how the massless mode is avoided in more explicit terms. It did not recognise the massive scalar boson but it is not obvious that this would have increased its worthiness if it had. The real question is just whether the extra contributions they made entitle the authors to be recognised as original pioneers of the Higgs mechanism. The authors were included in the award of the Sakurai prize in 2010, but there is no room for them to be included in the Nobel Prize. At best they can hope for one of them to be included.

Englert, Brout, Thiry 1966

F. Englert, R.Brout and M. Thiry, Il Nuovo Cimento 43A (1966) 244. This work reasoned that a gauge theory using the Higgs Mechanism could be renormalizable.

Higgs 1966

P. W. Higgs, Phys. Rev. 145 (1966) 1156. This was a more detailed paper about the Higgs Mechanism and its experimental consequences.

Kibble 1967

T. W. B. Kibble, Phys. Rev. 155, 1554 (1967). Details of the non-Abelian version of the Higgs Model

Weinberg 1967
S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264. Steven Weinberg married together the gauge theory of Glashow and the Higgs mechanism to form the completed model of Electroweak theory.

Salam 1968
A. Salam, in the Proceedings of 8th Nobel Symposium, Lerum, Sweden, 19-25 May, 1968, pp 367-377. Abdus Salam independently provided his formulation of the Electroweak theory.

Guralnik, Hagen and Kibble 1968
G.S. Guralnik, C.R. Hagen, T.W.B. Kibble (1968). “Broken Symmetries and the Goldstone Theorem”. In R. L. Cool, R. E. Marshak. Advances in Particle Physics. 2. Interscience Publishers. pp. 567–708.

‘t Hooft, Veltman 1971
G. ’t Hooft, “Renormalizable Lagrangians for massive Yang-Mills fields” Nucl. Phys. B35 (1971) 167. Proof that the standard model is renormalisable. It was not until this paper was published that acceptance of the Electroweak theory became widespread.

Ellis-Gaillard-Nanopoulos
J. R. Ellis, M. K. Gaillard and D. V. Nanopoulos, Nucl. Phys. B 106 (1976) 292. In this paper the authors started to look at how the Higgs might be observed in accelerators and alerted experimentalists to the possibility.

References

1. http://blog.vixra.org/2012/05/17/3632/