Nobel Prize in Physics 2013

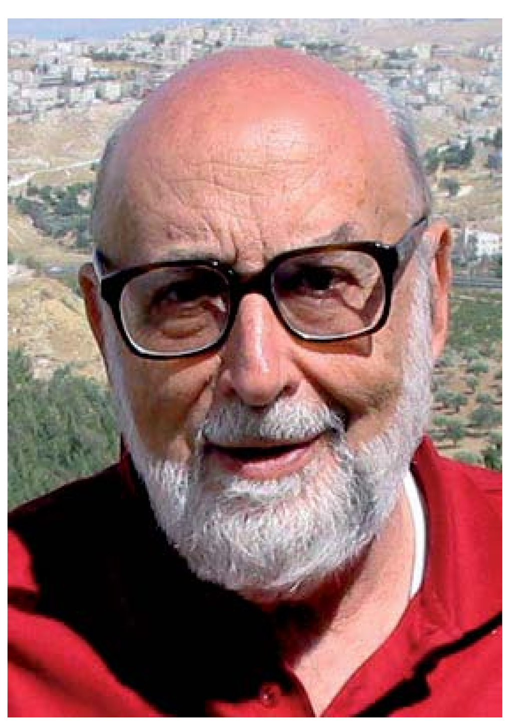
1. The Nobel Prize in Physics 2013

The Royal Swedish Academy Of Sciences has decided to award the Nobel Prize in Physics for 2013 to

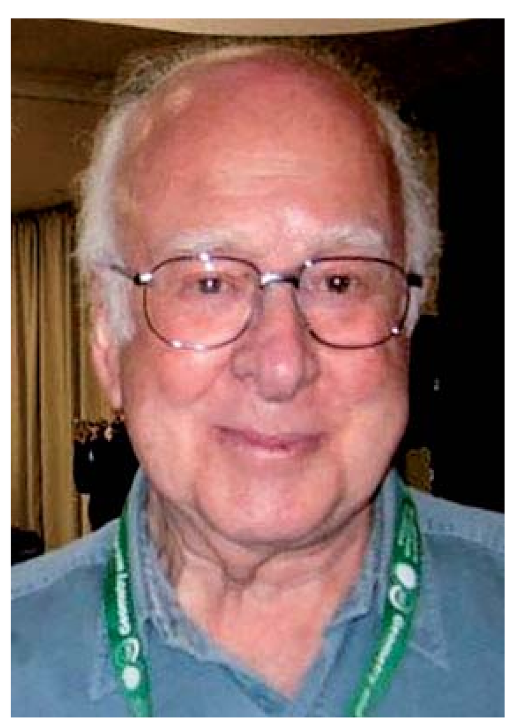
François Englert and Peter W. Higgs

for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider.

—Nobel Prize announcement by the Royal Swedish Academy of Sciences, October 8, 2013



François Englert



Peter Higgs

François Englert, Belgian citizen. Born 1932 in Etterbeek, Belgium. Ph.D. 1959 from Université Libre de Bruxelles, Brussels, Belgium. Professor Emeritus at Université Libre de Bruxelles, Brussels, Belgium.

Peter W. Higgs, UK citizen. Born 1929 in Newcastle upon Tyne, UK. Ph.D. 1954 from Kings College, University of London, UK. Professor emeritus at University of Edinburgh, UK.

2. From the press release by the Royal Swedish Academy of Sciences

François Englert and Peter W. Higgs are jointly awarded the Nobel Prize in Physics 2013 for the theory of how particles acquire mass. In 1964, they proposed the theory independently of each other (Englert together with his now deceased colleague Robert Brout). In 2012, their ideas were confirmed by the discovery of a so called Higgs particle at the CERN laboratory outside Geneva in Switzerland.

The awarded theory is a central part of the Standard Model of particle physics that describes how the world is constructed. According to the Standard Model, everything, from flowers and people to stars and planets, consists of just a few building blocks: matter particles. These particles are governed by forces mediated by force particles that make sure everything works as it should.

The entire Standard Model also rests on the existence of a special kind of particle: the Higgs particle. This particle originates from an invisible field that fills up all space. Even when the universe seems empty this field is there. Without it, we would not exist, because it is from contact with the field that particles acquire mass. The theory proposed by Englert and Higgs describes this process.

3. Higgs mechanism in the Standard Model

Prior to the work of Englert and Brout [2] and Higgs [3, 4] the existing theory for the unified description of the electroweak interactions was not in a good shape. In 1961 Sheldon Glashow had constructed a **Non-abelian chiral gauge theory** based on the group **SU(2)×U(1)** that could nicely incorporate all known quarks and leptonic particles and provided a **unified theory for the weak and electromagnetic interactions**. However, since gauge theories have massless gauge bosons, the theory was incomplete since the weak $W^{\pm}$ and Z vector bosons, the force carriers of the weak interactions, were known to be very heavy ($m_W = 80.39$ GeV, $m_Z = 91.188$ GeV). Giving the weak gauge bosons mass by hand would break the symmetry and make the theory meaningless. A possible way out was provided by the idea of **spontaneous symmetry breaking** which is based on a vacuum (ground) state that breaks the symmetry and then provides the gauge bosons with an effective mass, while the theory itself is still fully symmetric. This could lead to a consistent theory for massive gauge bosons, but appeared to unavoidably predict the existence of several massless (Nambu-Goldstone) scalar particles, which were, however, never seen in experiment.

Picking up an idea by Goldstone to realize spontaneous symmetry breaking with a self-interacting complex scalar field that has a non-zero vacuum expectation value—see fig. 1—Englert and Brout as well as Higgs worked out an explicit toy example of an Abelian gauge theory with a complex scalar field.

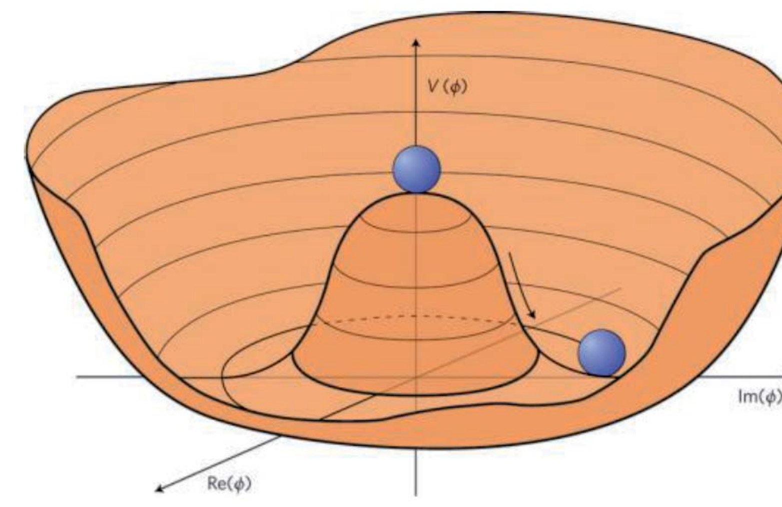


Figure 1: *"Mexican hat" potential for a complex scalar field which realizes spontaneous symmetry breaking. When the field falls to the state of lowest energy ("vacuum state") its absolute value—the so-called vacuum expectation value—becomes non-zero.*

After spontaneous symmetry breaking, the complex scalar field splits into two real scalar fields, one of which is the massless Nambu-Goldstone boson and the other one is a massive neutral scalar. They demonstrated that while the massive real scalar field describes a physical neutral scalar boson, the massless Nambu-Goldstone boson is not describing an observable massless scalar boson. In fact it provides the third of the three spin degrees of freedom of the massive gauge boson, which is important because massless gauge bosons in the unbroken theory only have two spin degrees of freedom. The Nambu-Goldstone boson is **"eaten up"** by the massive gauge boson.

Implemented into the SU(2)×U(1) gauge theory the idea of a complex scalar field that breaks the symmetry spontaneously (**"Higgs mechanism"**) finally provided a theory of the electroweak interactions, the **Standard Model of Elementary Particle Physics**. The Standard Model is fully consistent theoretically and describes essentially all known experimental observations in elementary particle physics. However, as for the Abelian models studied by Englert and Brout and Higgs, the Standard Model also predicts a neutral massive scalar particle, called **Higgs boson**. Because of its mass, which cannot be fixed precisely from the physics contained in the Standard Model, it could simply have escaped detection. However, the discovery of the Higgs boson was essential to fully show that the Standard Model really is the correct theory of electroweak interactions and that the Higgs boson is not just a theoretically useful concept.

4. The experimental discovery of the Higgs boson

Through its effects in **quantum corrections** the Higgs boson was very important (and in fact needed by consistency) in theoretical Standard Model calculations. So the mass of the Higgs boson could be constrained quite well indirectly from precise measurements of electroweak observables. The confirmation that the Higgs boson also existed as a real particle was finally provided by the **Large Hadron Collider (LHC)**. The LHC has sufficient energy and statistics to produce Higgs bosons in sufficiently large numbers to confirm its existence experimentally. The work required is tedious since only one out of 10^{12} events taking place at the LHC can be attributed to a produced Higgs boson.

In July 2012 the **ATLAS and CMS experiments** at the LHC could finally claim discovery of a new particle with properties consistent with the Standard Model Higgs boson and a mass of approximately 125 GeV.

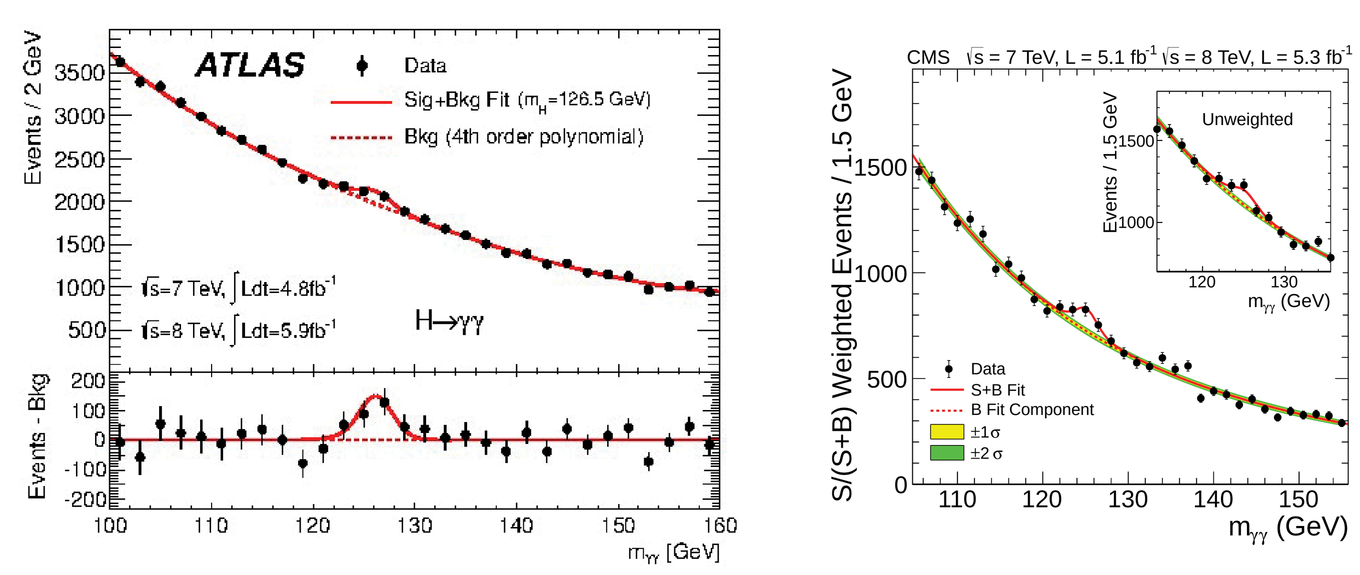


Figure 2: *Observed excess in the diphoton invariant mass at around 125 GeV observed by the Atlas Collaboration [5] (left plot) and the CMS Collaboration [6] (right plot) at the LHC.*

References

[1] The text of sections 1 and 2 is taken from the official press release by the Royal Swedish Academy of Sciences; www.nobelprize.org (8.10.2013).

[2] F. Englert and R. Brout, *Broken symmetry and the mass of gauge vector mesons*, Phys. Rev. Lett. **13** (1964) 321.

[3] P.W. Higgs, *Broken symmetries, massless particles and gauge fields*, Phys. Lett. **12** (1964) 132.

[4] P.W. Higgs, *Broken symmetries and the masses of gauge bosons*, Phys. Rev. Lett. **13** (1964) 508.

[5] G. Aad *et al.* [ATLAS Collaboration], *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. B **716** (2012) 1 [arXiv:1207.7214 [hep-ex]].

[6] S. Chatrchyan *et al.* [CMS Collaboration], *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys. Lett. B **716** (2012) 30 [arXiv:1207.7235 [hep-ex]].

Sources

Sources of the used pictures in order of appearance:

Nobel medal: http://en.wikipedia.org/wiki/Nobel_prize (9.10.2013); Photograph: Jonathunder; Medal: Erik Lindberg (1873-1966).

Photograph of François Englert: Pnicolet via Wikimedia Commons; as shown on www.nobelprize.org (8.10.2013).

Photograph of Peter Higgs: G-M Greuel via Wikimedia Commons; as shown on www.nobelprize.org (8.10.2013).

Mexican hat potential (fig. 1) copied from "*Scientific Background on the Nobel Prize in Physics 2013: The BEH-Mechanism, Interactions with Short Range Forces and Scalar Particles* (Compiled by the Class for Physics of the Royal Swedish Academy of Sciences)"; www.nobelprize.org (8.10.2013).

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