Higgs Higgs hooray

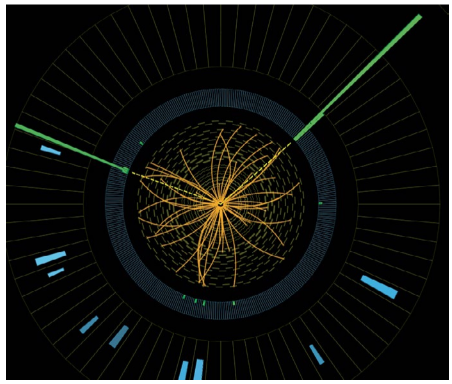
We celebrate the ten-year anniversary of the discovery of the Higgs boson — a whopping 48 years after its prediction.

Out of all elementary particles, the Higgs boson holds the record for the longest time between its prediction and discovery. This milestone is often referred to as finding the last piece of the standard model of particle physics.

During the development of the standard model, one essential question revolved around the mechanism that gave mass to the carriers of the weak force, the *W* and *Z* bosons, while leaving the photon massless and the gauge symmetry of quantum electrodynamics intact. The answer combines the concept of spontaneous symmetry breaking from the Bardeen–Cooper–Schrieffer theory of superconductivity with a scalar field, known now as the Brout–Englert–Higgs field. At a critical temperature — believed to have been reached around a picosecond after the Big Bang — electroweak symmetry breaking occurs and the Brout–Englert–Higgs field acquires a high vacuum expectation value and thus permeates the entire Universe.

In their papers published in 1964, Robert Brout and François Englert[1] and — separately — Peter Higgs[2] showed that spontaneous symmetry breaking does not imply the existence of additional massless particles in gauge theories, such as quantum electrodynamics. Instead, by interacting with the Brout–Englert–Higgs field, the *W* and *Z* bosons become massive whereas the photon remains massless. But the framework suggests that there exists one additional degree of freedom — the Higgs boson.

The mass of this scalar boson, however, could not be predicted. John Ellis, Mary Gaillard and Dimitri Nanopoulos ended a discussion of Higgs boson phenomenology in a wide range of possible masses with[3]: "We apologize to experimentalists for having no idea what is the mass of the Higgs boson […] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up."



Credit: CMS Collaboration; Mc Cauley, Thomas; Taylor, Lucas

When the massive *W* and *Z* bosons were discovered in 1983, the hunt for the Higgs boson began. Although its mass range was narrowed down over the years, it would take until 2012 to observe the Higgs boson. Rolf-Dieter Heuer, Director-General of CERN at that time, reminisces about the search for and eventual discovery of the particle by the ATLAS and CMS collaborations at the Large Hadron Collider in a Comment in this issue.

In a special CERN seminar on 4 July (ref. [4]), the two collaborations reported signs of a new particle with a mass around 125 GeV (refs. [5,6]). The decay into a pair of photons indicated that the observed particle had an integer spin different from one. Overall, it was compatible with the production and decay of the long-sought-after Higgs boson[7] predicted in the standard model.

But to establish that the particle observed by the ATLAS and CMS collaborations was indeed the one and only standard model Higgs boson, further studies were needed. In the years following the discovery, every property of this new particle was investigated: its mass was measured to increasing precision, its scalar nature confirmed and more and more production and decay mechanisms were studied. At the same time, all attempts to unmask this particle as an imposter of the standard model Higgs boson were unsuccessful.

Although the collective measurements suggest that the particle announced on 4 July 2012 is indeed the predicted one, this is certainly not the end of the story. Several models for physics beyond the standard model predict the existence of a variety of Higgs-like bosons — including composite and charged Higgs bosons. By continuing to perform high-precision measurements of the Higgs boson and processes sensitive to it, these models can be scrutinized further.

Some properties of the Higgs boson can be determined only with larger datasets or at future particle colliders. One example is the measurement of the potential self-coupling of the Higgs boson, where one Higgs boson could decay into two or maybe three Higgs bosons. Such a measurement could test the shape of the Brout–Englert–Higgs potential, which resembles a sombrero, near its minimum.

Looking back at the past ten years and peering into the future, we — together with colleagues from *Nature* and *Nature Reviews Physics* — have curated a collection (https://www.nature.com/collections/gbfhieacie) of research papers and other content to celebrate the ten-year anniversary of the discovery of the Higgs boson. Higgs Higgs hooray indeed! ❐

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References

1. Englert, F. & Brout, R. *Phys. Rev. Lett.* **13**, 321–323 (1964).
2. Higgs, P. W. *Phys. Rev. Lett.* **13**, 508–509 (1964).
3. Ellis, J., Gaillard, M. K. & Nanopoulos, D. V. *Nucl. Phys. B* **106**, 292–340 (1976).
4. Update on the Higgs Boson Searches at the LHC (CERN, 2012); https://doi.org/10.17181/cds.1459513
5. ATLAS Collaboration. *Phys. Lett. B* **716**, 1–29 (2012).
6. CMS Collaboration. *Phys. Lett. B* **716**, 30–61 (2012).
7. *Higgs*10 (CERN, 2022); https://home.web.cern.ch/news/series/higgs10/