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1. Kleinewietfeld, M. *et al. Nature* **496,** 518–522 (2013).
2. Wu, C. *et al. Nature* **496,** 513–517 (2013).
3. Weaver, C. T., Hatton, R. D., Mangan, P. R. & Harrington, L. E. *Annu. Rev. Immunol.* **25,** 821–852 (2007).
4. Stockinger, B., Veldhoen, M. & Martin, B. *Semin. Immunol.* **19,** 353–361 (2007).
5. Kolls, J. K. & Linden, A. *Immunity* **21,** 467–476 (2004).
6. Miossec, P. & Kolls, J. K. *Nature Rev. Drug Discov.* **11,** 763–776 (2012).
7. Cua, D. J. *et al. Nature* **421,** 744–748 (2003).
8. Sutton, C. E., Mielke, L. A. & Mills, K. H. G. *Eur. J. Immunol.* **42,** 2221–2231 (2012).
9. Bruhn, M. A., Pearson, R. B., Hannan, R. D. & Sheppard, K. E. *Growth Factors* **28,** 394–408 (2010).
10. Honda, K. & Littman, D. R. *Annu. Rev. Immunol.* **30,** 759–795 (2012).
11. Dong, C., Davis, R. J. & Flavell, R. A. *Annu. Rev. Immunol.* **20,** 55–72 (2002).
12. Wang, R. & Green, D. R. *Nature Immunol.* **13,** 907–915 (2012).
13. Stockinger, B., Hirota, K., Duarte, J. & Veldhoen, M. *Semin. Immunol.* **23,** 99–105 (2011).

PARTICLE PHYSICS

Minimalism triumphant

The discovery of a particle that looked like the Higgs boson marked a milestone for physics. Results reported since then are strikingly consistent with expectations for the Higgs particle of the minimal standard model of particle physics.

FRANK WILCZEK

Since the announcement last July that a new kind of particle had been discovered at the Large Hadron Collider (LHC) at CERN, Europe's particle-physics laboratory near Geneva in Switzerland, a much fuller portrait of that particle has emerged. The two main experimental collaborations, ATLAS and CMS, reported a host of measurements in papers and presentations at last month's Moriond conference in La Thuile, Italy[1,2]. So far, all results remain consistent with the interpretation that the new particle is the Higgs boson anticipated in the minimal implementation of electroweak symmetry breaking in the standard model of particle physics.

The Higgs particle is a rare and fleeting physical phenomenon. Even at the LHC, the particle is produced in less than one-billionth of the proton–proton collisions, and it is highly unstable — its lifetime is inferred to be about 10^{-22} seconds. To appreciate the significance of the Higgs particle, it is necessary to put it in its proper context — the Higgs mechanism.

A central assumption of the standard model, inferred from many experiments, is that the basic forces of nature — the strong, weak and electromagnetic forces, as well as gravity — are mediated by quantum fields of spin 1 or (for gravity) spin 2. It is challenging to accommodate that assumption theoretically, in consistent equations. Naive attempts founder because they predict the existence of violent (quantum) fluctuations in the fields at short distances, which lead to a plague of mathematical infinities in calculations of physical quantities. These difficulties can be avoided only in theories in which the fields have enormous symmetry, called gauge symmetry.

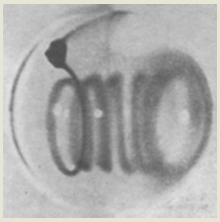
Gauge symmetry, however, seems to require that the most basic manifestations of the gauge fields, the minimal concentrations of energy or quanta of the fields, are particles with zero mass. That property holds true in many cases: the photons of electromagnetism, the colour gluons of the strong interaction and the graviton of gravity do seem to have zero mass. But W and Z bosons, the quanta of the fields that are responsible for the weak interaction, have substantial masses.

The Higgs mechanism provides a way out of this difficulty. The key observation is that gauge symmetry requires the W and Z bosons to have zero mass only in empty space. Material can slow them down, screen their influence and make them behave as if they have non-zero mass. If an appropriate material fills all space uniformly and stably, the W and Z bosons will never escape its influence — and they will always be observed to have non-zero mass. The hypothesis that such a material does, in fact, fill space is the essence of the Higgs mechanism. But does this material exist? And, if so, what is it made out of?

The triumph of the standard-model account of weak interactions, which relies on the Higgs mechanism, has long provided overwhelming, if circumstantial, evidence that the material exists. In recent months, we have learned what it is made out of. Among all the logical possibilities for the new material, the simplest and most economical proposal defines the 'minimal standard model'. In this model, the cosmic material is made from just one ingredient. The terminology in this subject is both confused and in flux, but here the term Higgs particle is used to refer to the unique particle that is introduced to

50 Years Ago

'Internal circulations within liquid drops' — It has long been recognized that under certain conditions some sort of axisymmetric flow is induced within liquid drops as they pass through a viscous medium … Although an internal circulation theory has been very attractive in considerations of meteorological phenomena, there appears to be little experimental evidence to substantiate such a theory … In this communication we discuss a technique which affords velocity measurements and at the same time outlines the vortical core … The streamlines within the drop are recorded photographically by means of dye trails. The figure indicates the streak-lines due to the motion within water drops moving through mineral oil … We have obtained a great deal of velocity data with this method.



From *Nature* 27 April 1963

100 Years Ago

The twinkling of stars may be imitated in the dark-room. If a small light be looked at in a dark-room, as, for instance, that coming through the smallest diaphragm of my colour perception lantern, … care being taken not to move the eye, the light will appear to twinkle like a star. It will be noticed that pale bluish-violet circles start at the periphery of the field of vision, and, gradually contracting, reach the centre. On reaching the centre the light brightens. If the circles stop the light disappears. The colour of the circle is the same for white light or any colour.

From *Nature* 24 April 1913