Tantalizing evidence of the Higgs boson

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Physicists continue to pore through experimental data recorded by the Large Hadron Collider in Switzerland, the world’s largest particle accelerator, in search of the Higgs boson, the last remaining undiscovered particle predicted by particle physics. Tantalizing hints of its possible discovery have been reported in just the last two weeks, but full confirmation awaits several more months of patient work.

To detect and characterize the Higgs boson is to complete the effort of particle physics begun 40 years ago in systematizing the fundamental particles. The theoretical basis of this work has allowed physicists to probe deeper and deeper into the structure of matter with remarkable success. This synthesis is now known as the “Standard Model.”

Peter Higgs, along with five other physicists in 1964, first proposed the idea of what we know of today as the “Higgs boson.” The basic consideration is this: what fundamental particle accounts for the difference in masses seen in the Standard Model? This question is of the greatest significance. For example, why are protons 1836 times as massive as an electron? What in fact is the origin of this mass: why do particles behave with the properties of mass, and why are these properties constant? The confirmation of the existence of the Higgs boson will simultaneously confirm the operation of the Higgs *mechanism*, which is thought to answer this question, at least in part.

The search for the Higgs boson is full of suspense and interest, and stands in stark contrast to the last major particle to be discovered, the top quark, whose existence was confirmed in 1995 by Fermilab. The laboratory observation of the top quark was considered only a matter of time and effort. Textbooks existing before 1995 assumed its existence and proceeded from that vantage point, demonstrating how confident the particle physics community was that the top quark existed, as well as the various properties it held.

To understand the difficulty in finding the Higgs boson, it is necessary to consider the search for exotic new particles in general. The high-energy collisions between protons in the LHC fill an intensely small amount of space with an enormous amount of energy. Some of that energy can spontaneously convert to matter as pairs of particles and anti-particles, such that the mass of the particle pair equals the amount of energy removed, according to Einstein's famous equation E=mc2. However, such massive particles are incapable of existing for long. Almost immediately, they begin to decay into smaller and lighter particles. These particle decays have distinct signatures and that is what researchers look for. Experimental particle physics is essentially the study of the various ways massive particles decay into lighter particles and how to detect them.

The Large Hadron Collider studies the debris of the about half a billion collisions per second that occur in its counter-rotating beams. More than three hundred trillion such collisions have taken place at the facility this year. Two separate detector packages, known as CMS and ATLAS, independently look for different signatures of the decay of the Higgs particle.

Different particles decay very differently. In the search for the top quark, a very distinct and specific signature was expected. The only difficulty in finding it is that the top quark is much more massive than its nearest counterpart. Only with the construction of a new accelerator, the Tevatron at Fermilab, could the conditions necessary to its creation be manufactured. However, once generated, the top quark was relatively easy to spot, demonstrated both at Fermilab in 1995 and confirmed as part of ordinary operation of the LHC in 2010.

Finding the Higgs boson is much more problematic. Not only is the possible mass range of the Higgs boson less well known than that of the top quark at the time of its discovery, but it has a large number of potential decay chains that can be easily confused with other phenomena. To find it requires detailed analysis of a vast number of decays of collisions at extremely high energies. Only through statistical methods can the decays of the Higgs be distinguished from other particle decay chains and its signature isolated. This is one of the main reasons behind why the Large Hadron Collider was created, and it defined the engineering parameters for this particle accelerator.

Other accelerators have looked for signatures of the Higgs at lower energy ranges (and thus lower masses for the Higgs) during their operational lifetimes. Each previous accelerator has ruled out lower mass ranges for the Higgs, while other theoretical considerations have placed plausible upper limits on its mass. Another mass range was excluded by operation of the LHC at different collision energies in the first half of 2011. That has left only a narrow range of probable masses for the Higgs which the LHC is now investigating.

That is the reason why even initial data is being received with such excitement in the LHC's current season of operation. Both the CMS and ATLAS experiments, have shown independent weak statistical signatures for the existence of a Higgs boson, and in a cross-check, each signature indicates a Higgs possessing the same mass, about 133 times that of an ordinary proton.

Both signatures are weak: random chance would give a 1 percent chance of *both* being wrong. But every day of accumulating collisional data improves the statistics. A few months of additional experimental data will either affirm the signature of the Higgs boson, exclude it in this energy range, or find something inexplicable. Any of these results would be monumental for physics.

Beyond any new physics discoveries, the Large Hadron Collider is also a triumph of organized labor on a mass scale and at the highest technical level. It is the culmination of a century's worth of inquiries by humanity into the most fundamental nature of the universe at the smallest of scales and demonstrates mankind's great potential when labor is put to use for discovery, not destruction. All that stops physics from being taken even further is that such undertakings are currently bound by what nations gain international prestige and which contracting firms stand to profit. Social need—including the universal desire to understand nature—plays almost no role.

The discovery of the Higgs will simultaneously close one long and storied chapter in experimental physics and begin another. The Higgs will have to be characterized, not simply found, and its behavior related to that of other particles in the Standard Model. Even more fundamentally, many relations in the Standard Model are not explained by theory and simply exist as observed properties of the universe, leaving the inevitable question: why is this so? Physicists have no fear that the book on their science will be closed any time soon.

[1] https://cms-docdb.cern.ch/cgi-bin/PublicDocDB/RetrieveFile?docid=5709&version=1&filename=GUIDO_HIGGS_CERN_SEMINAR.pdf

[2] http://cdsweb.cern.ch/record/1406358/files/ATLAS-CONF-2011-163.pdf