Particle physics is at a turning point

The discovery of the Higgs boson will complete the standard model — but it could also point the way to a deeper understanding, says **Gordon Kane**.

Let's tentatively agree that the Large Hadron Collider (LHC) detectors ATLAS and the Compact Muon Solenoid have discovered a Higgs boson, with a mass of about 125 gigaelectronvolts (GeV). Although standard statistical measures might not consider the situation settled, it seems very likely that there has indeed been a discovery at CERN, Europe's high-energy physics lab near Geneva, Switzerland, given that two quite different detectors both see a signal of some significance at about the same mass, and that both see the expected signals in two or more channels.

This is a profound turning point in the quest for a fundamental unified theory of the physical world. The properties and mass of the LHC's Higgs boson suggest that physicists will soon find superpartners for particles, and that we have begun to connect string theory to the real world.

The Higgs boson, an as-yet-unknown kind of matter thought to generate mass in other particles, is the final ingredient needed to complete and confirm the standard model of particle physics. This amazing theory describes the particles (quarks and leptons) and the strong, weak and electromagnetic forces that interact to make our world (with the addition of the theory of gravity). Quarks combine to make protons and neutrons; protons and neutrons to make nuclei; nuclei and electrons (a type of lepton) to make atoms, then molecules and chocolate and people and planets and stars and so on. The standard model has no puzzles or problems, and incorporates at a fundamental level everything from condensed-matter physics to astrophysics. It achieves the goals of four centuries of physics. The Higgs itself has been sought for decades: the main route through which its signal was reported at the LHC was the particle's decay into two photons. Collaborators and I first studied this signal in the mid 1980s, as a possible method for detecting the Higgs boson at the Superconducting Super Collider, which was to be built at Waxahachie in Texas but was cancelled in 1993.

Besides completing the standard model, the discovery of the Higgs tells us that a future, deeper underlying theory of the law(s) of nature must include and account for fundamental Higgs bosons. (Physicists have suggested alternative theories that include oddities such as composite Higgs bosons, but the CERN discovery essentially excludes them.) That will extend the standard model, and go beyond it to illuminate issues such as supersymmetry and the origin of dark matter.

A major and unexpected clue to the future offered by the CERN discovery is that the reported Higgs boson signal seems to behave as if it were a 'standard-model Higgs boson'. Under the standard model, this should not be possible, because relativistic quantum field theory shows that the Higgs' mass must experience quantum corrections that are much, much larger than the mass itself. Because the masses of quarks, leptons and the W and Z bosons that mediate the weak force are themselves dependent on the Higgs mass, the standard model predicts masses for them many orders of magnitude larger than what we observe.

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This can be fixed. When the standard model is extended to a supersymmetric theory, the nature of the predicted Higgs boson changes. Its mathematical behaviour improves and the resulting theory is realistic.

Physicists thought that a Higgs boson, when discovered, would take this supersymmetric form, so how have we discovered one so apparently identical to the impossible standard-model version? Working out how to interpret this could be a large step towards the underlying broader theory that will extend the standard model.

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One explanation could come from an unexpected source: string theory or its extension, M-theory. Contrary to what you may have heard, predictions about the real world can be made from string theory, although the 10- or 11-dimensional theory must first be 'compactified' to 4 dimensions (with 6 or 7 small dimensions left curled up). There has been considerable progress on that, as well as on how to stabilize the fields that describe the curled-up dimensions.

My collaborators and I have shown that in generic string and M-theories — consistent with constraints from cosmology and incorporating the Higgs mechanism for generating mass — the lightest Higgs boson behaves very much like the standard-model Higgs boson. And it has a mass of about 125 GeV, just as observed.

We first reported these results at the international String Phenomenology Conference in Madison, Wisconsin, in August; and just days before the CERN data were reported, we posted a paper containing a significantly more precise prediction (G. Kane *et al.* http://arXiv.org/abs/1112.1059; 2011).

The same string theory (actually M-theory) that predicts the Higgs mass correctly also predicts that a spectrum of superpartners and some of their associated signals should now be discovered at the LHC. Particles such as gluinos — superpartners to gluons, which mediate the strong force — have not yet been searched for explicitly in the decay modes predicted by the string theories, mainly decay to top and bottom quarks. They could be found in these modes by the middle of next year. If so, the discovery may have a lower profile than the news of the Higgs boson, but the implications could be even greater. String theory could have come of age at last. ■

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