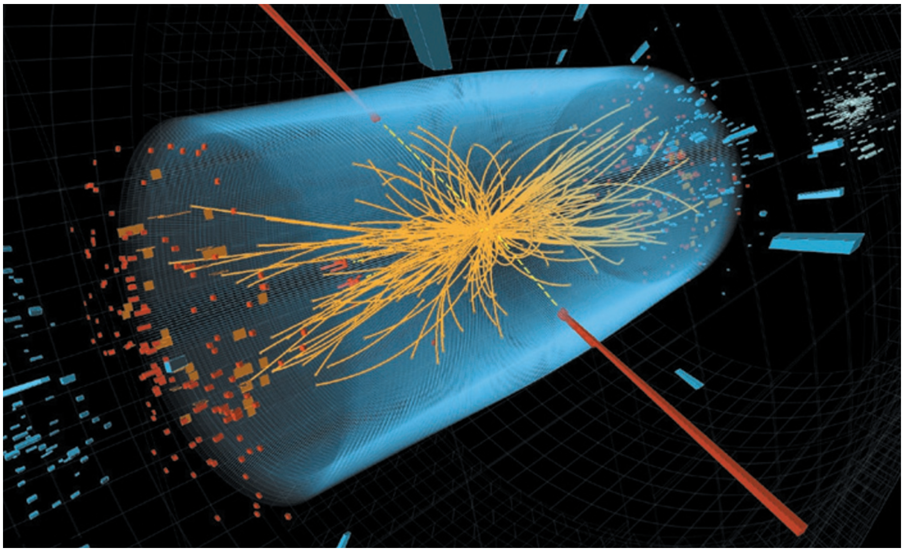

Hint of the Higgs: photons (red) and particles (yellow) result from a proton–proton collision at CERN.

The need for new physics

Regardless of whether the Higgs detection is confirmed, the standard model is incomplete, says **John Ellis**.

At the time of writing, physicists are excited by the possible detection of a Higgs boson. After analysing data from the Large Hadron Collider (LHC) at CERN, Europe's high-energy physics lab near Geneva, Switzerland, signals of the particle — thought to give other particles mass — have been seen in the region of 125 gigaelectronvolts (GeV).

It is too early to say whether these promising hints will be confirmed, but if they are, many people would take this to be a validation of the standard model of particle physics. There have been previous indirect signs from other data that the Higgs boson probably weighs less than 150 GeV, and CERN's possible observation would be in line with that. But I am a contrarian. I argue that whether or not the Higgs boson exists, we already know that there must be physics beyond the standard model. Let us consider the possibilities.

AVERTING COLLAPSE

One option is that the evidence from the LHC will be confirmed, and a standard-model Higgs boson exists in the low-mass range below 130 GeV. Experimentalists would say that this is where theorists were telling them to look all along, which is true. But there is a catch. Within the standard model, it is possible to calculate the lowest energy state of the Universe. If the Higgs is light, this calculation predicts a lowest energy state totally unlike our current Universe. It implies that our Universe is in some other, unstable state that will eventually flip over to its lowest energy condition — next week, or in a few billion years, we could go down the cosmological tubes. Some physicists say that this unsettling conclusion is the result of taking theory too seriously, and that we should simply find the Higgs and cross this bridge when we come to it. But it is worrying. The only way to produce a more stable model would be to add new particles to the standard model, in this case making it look as predicted by theories of supersymmetry.

AVERTING A BLOW-UP

What if the LHC evidence is not confirmed? In principle, there are other options. For example, there is another range of possible Higgs mass, above 600 GeV, where CERN has yet to look. In this case, we must go beyond the standard model for two reasons. First, physicists have found and measured the masses and other properties of W and Z bosons, which mediate the fundamental weak nuclear forces. The theoretical interpretation of these measurements is what hints that the Higgs should weigh less than 150 GeV. If the Higgs is actually much heavier, then this can be reconciled only by adding a host of new interactions between the known particles. Second, the interactions between heavy Higgs bosons become seemingly infinite at high energies. Clearly this blow-up must be averted, but understanding how also lies beyond the standard model.

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Could there be a lighter Higgs boson, hidden between 130 GeV and 600 GeV? The LHC has excluded a standard Higgs boson in this region, but it is still possible that the Higgs lurks there, if its interactions with other particles are not as the standard model predicts. One possibility might be that it has some additional, invisible mode of decaying into particles, such as via pairs of weakly interacting particles of dark matter. Another possibility is that its decays are normal, but the rate at which other particles collide to produce Higgs bosons is suppressed. Make such an adjustment, however, and the standard model is no longer a calculable theory; and the whole point of the Higgs is to make the standard model calculable. The only way to fix this would be to add new particles to the mix, such as massive spin-one particles, to finish the job that the Higgs was supposed to do.

These problems would be particularly severe in the absence of a Higgs boson. Physicists would have to explain, in a way that is both calculable and consistent with existing measurements, how and why the symmetry between different species of standard-model particles is broken — only some particles in the standard model have mass. The Higgs is assumed to be what forces the symmetric standard-model equations to have these asymmetric solutions. Breaking the intrinsic symmetry of the equations themselves would be inadvisable, because it is not known how to calculate sensible results in such a case.

Alternatively, one could break the symmetry of the solutions to the standard-model equations by setting specific boundary conditions. Just as a physicist's description of how a washing line hangs between two walls is dependent not just on the properties of the line, but also on its attachment to the walls, so too a description of bosons depends in part on their behaviour at the edges of the Universe. Our current description of a four-dimensional Universe doesn't have edges in this sense, but additional dimensions, presumably curled up into tiny spaces so that no experiment has yet been able to detect them, might provide suitable boundaries: physics beyond the standard model indeed.

Regardless of whether and where the Higgs boson is found, new physics is needed. ■

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