UNIVERSITY OF CAMBRIDGE

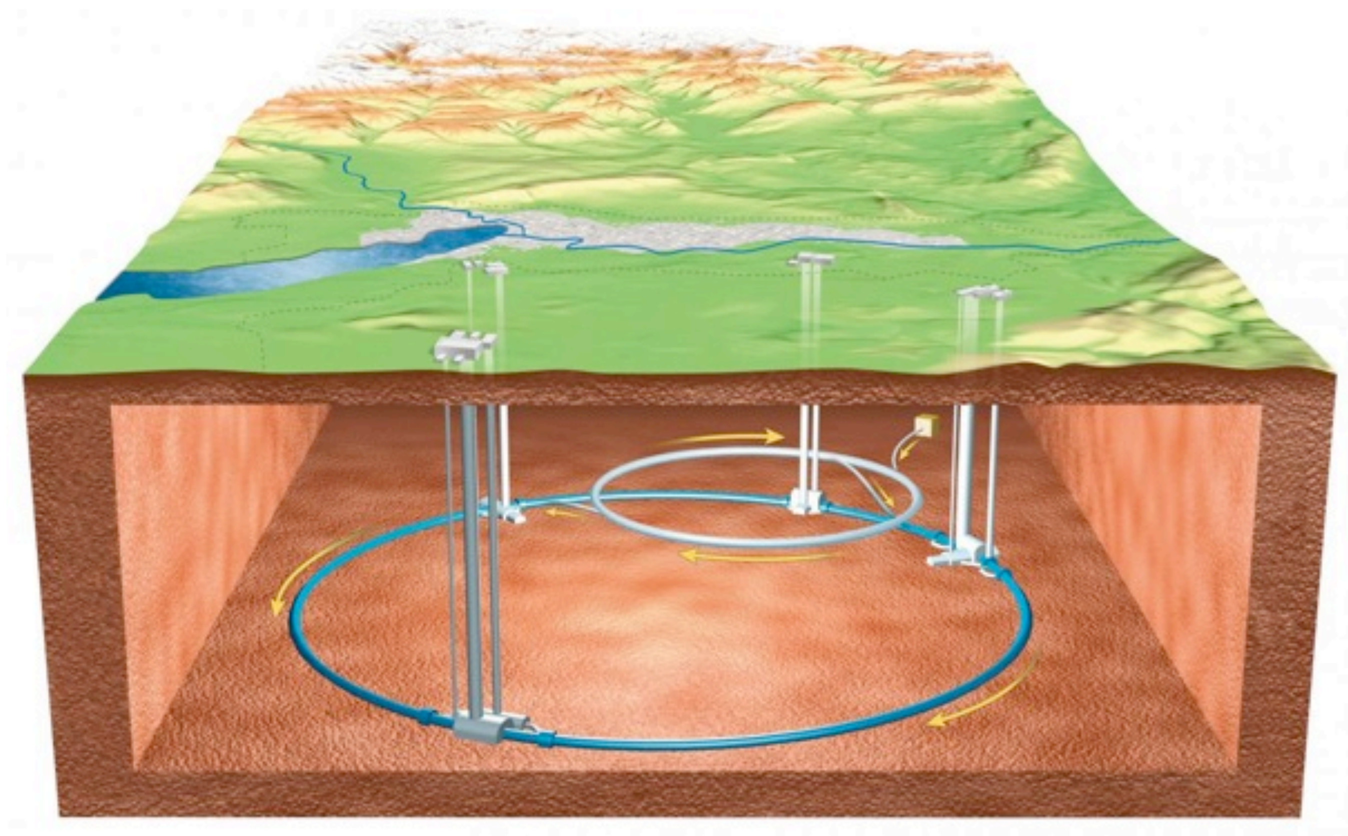
The search for Higgs

In July 2012 scientists at CERN announced the most exciting discovery in modern physics: the Higgs boson. But what exactly is this little particle, how did they know it was there and how did they find it?

The standard model of particle physics

Smashing bits of matter together has helped physicists to compile a list of 12 fundamental particles that seem to make up matter. The list includes electrons, and particles called *quarks, leptons* and *bosons*. The particles interact through four fundamental forces, gravity, electromagnetism, the strong nuclear force and the weak nuclear force. The physical description of the fundamental particles, together with a mathematical description of how they behave, is known as *the standard model of particle physics*.

When matter particles "feel a force" what is really happening on small distances is that particles are bumping into each other. The electrostatic repulsive force between two electrons, for instance, arises because one electron emits a photon, which then bumps into the other electron. This makes the electrons fly apart a little. Taking into account that this process happens many times per second, it appears as if the electrons feel the smooth form of repulsion that is familiar from physics in school. The standard model describes all known forces except gravity (which remains something of a mystery) in terms of the exchange of such particles.



The standard model has proved amazingly accurate, but the original theory contained a little flaw: physicists knew that some fundamental particles have mass, but the mathematics underlying the standard model predicts that they should be massless. A theoretical resolution to this puzzle came from a mechanism proposed in the 1960s by the physicist Peter Higgs (and others).

Electron Jelly

We usually think of a particle as a tiny billiard ball. But it turns out that particles, for example electrons, are better thought of as a weird sort of quantum jelly, which fills space. Like any liquid, the jelly can be calm like the surface of an undisturbed lake, or it can ripple. In the parts of space where the jelly is calm, we measure a vacuum. But where there are ripples in the jelly, we measure an electron.

The Higgs Boson

Higgs resolved the mass conundrum by considering the Universe right after the Big Bang, when it was hot and dense. He conjectured that at this early time all particle jellies were runny, just like water. But as the Universe cooled down, one particular jelly, known as the Higgs field, started to condense and become more viscous. Other particles (or particle jellies), when interacting with the Higgs field, are dragged back, just as a person walking through custard would be. Particles which experience this drag effect are experiencing inertia — one has to push them with a force to get them to move. According to Newton, any particle with inertia also has mass. Thus, Higgs' mechanism tells us how the particles of the standard model may have acquired non-zero masses. The amount of mass each particle feels is proportional to the strength with which it feels the effect of the Higgs jelly.

The Higgs jelly, just like other particle jellies, can ripple, and a ripple would look like a particle in experiments — this particle is the notorious Higgs boson. So producing and measuring it would finally verify Higgs' hypothetical mechanism.

Physicists could not hope, however, to see the Higgs boson directly, as it decays into other particles immediately. It is the properties and behaviour of the particles it decays into that could be detected by the Large Hadron Collider (LHC) at CERN. Using the standard model, which doesn't include the Higgs boson, it is possible to predict what the data collected by the LHC should look like as a result of the behaviour of all the other particles in the standard model. And if the actual data looks different from the predicted background data in the right way (if it agrees with the predictions of the standard model plus the Higgs) then that counts as evidence that the Higgs does exist.

Hooray for Higgs!

On 4th July 2012 the CERN team announced that they had indeed seen the right kind of discrepancies in their data. Such indirect observations do not give 100% certainty of course, but the team calculated that the chance of observing what they observed without there being a Higgs (or at least Higgs-like) particle is only about 1 in 3.5 million. In physics this level of certainty counts as a discovery.

This poster is based on the articles "Particle hunting at the LHC" by Professor Ben Allanach, and 'The Higgs boson: a massive discovery' by Rachel Thomas, published in Plus (plus.maths.org), a free online magazine opening a door to the fascinating world of mathematics.