

Box 1 The Standard Model

The Standard Model is the currently accepted theory of matter and energy, dealing with the fundamental particles of which matter is made, such as photons and gluons, which carry the forces of interaction. According to the Standard Model, there are two types of fundamental particle – leptons and quarks – which cannot be broken down into anything more basic.

- **Leptons** are lightweight particles (electrons and neutrinos).
- **Hadrons** are heavier particles, including protons and neutrons, and are not fundamental; they are made up of **quarks**.

The nucleus of a hydrogen atom is a single proton.

1 eV = 1 electron-volt; this is the energy gained by an electron when it is accelerated through a voltage of 1 V. 1 TeV = 10^{12} eV.

Accelerator action

Protons are the positively-charged particles which are found in the atomic nucleus. According to a theory called the Standard Model (see Box 1), protons belong to a family of particles called **hadrons** (meaning *heavy particles*, as opposed to the much lighter **leptons**, such as the electron).

To produce protons, a high voltage is used to strip electrons from hydrogen atoms. To produce the necessary beams of high-speed protons, the LHC has three accelerators which, in sequence, boost the energy of the protons before injecting them into the LHC ring. The protons eventually reach a speed of 99.999 9991% of the speed of light (see Box 2). Each proton will have an energy of 7 TeV (tera-electronvolts); 1 TeV is about the energy of a flying mosquito. This is small on a human scale, but it is exceedingly high on the scale of a particle as small as a proton.

Beam bending

Two beams of accelerated protons, travelling in opposite directions, enter the giant LHC ring. A force is needed to make these beams follow the curve of the tunnel; the force is provided by magnets (Figure 2).

A ring of large blue cylinders occupies the length of the tunnel. Each is a large electromagnet or solenoid – there are 1232 of them in total. Each of these is a coil of superconducting wire which must be cooled to 1.9 K, less than 2 degrees above absolute zero, using liquid helium. Only superconducting wires can carry

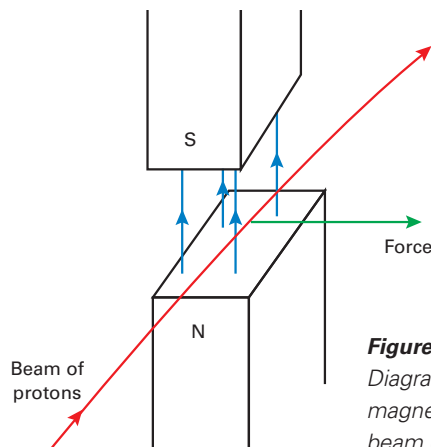


Figure 2
Diagram of magnet bending beam of protons

- Find out more about the parts of the ATLAS detector shown in Figure 3 at http://hands-on-cern.physto.se/ani/acc_lhc_atlas/endview.swf

Box 2 Approaching the speed of light

The LHC will accelerate protons to within a tiny fraction of the speed of light c . When a particle is accelerated, its mass increases as well as its speed. This effect is only noticeable at speeds approaching c . So the protons circulating in the LHC beams are not only very fast but they are also much more massive than when stationary. Hence their kinetic energy is enormous.

Einstein's equation $E = mc^2$ allows us to calculate the energy E which is released when a particle of mass m is converted entirely to energy.

the high current needed to produce a sufficiently strong magnetic field.

The proton beams travel parallel to one another, but in opposite directions, in two evacuated tubes inside the electromagnets. Each beam is in fact a series of 'bunches' of protons, each made up of about a billion particles. The bunches are separated by about 75 m in the tubes, or 25 nanoseconds (billionths of a second).

Collision control

Experiments have been set up at four points around the tunnel. At these points, the two beams can be directed so that they meet head on. In practice, only about 20 proton-proton collisions will occur from each bunch. This is because each beam is about 1 micrometre across, but a proton has a diameter of about 10^{-15} m. Hence, even with 10^9 protons in a bunch, head-on collisions are relatively infrequent.

The combined energy of two protons colliding is 14 TeV. This is enough to produce a shower of energetic particles and radiation, and these are detected as they emerge from the collision chamber. The detectors are enormous machines, built in layers capable of detecting the tracks of charged and

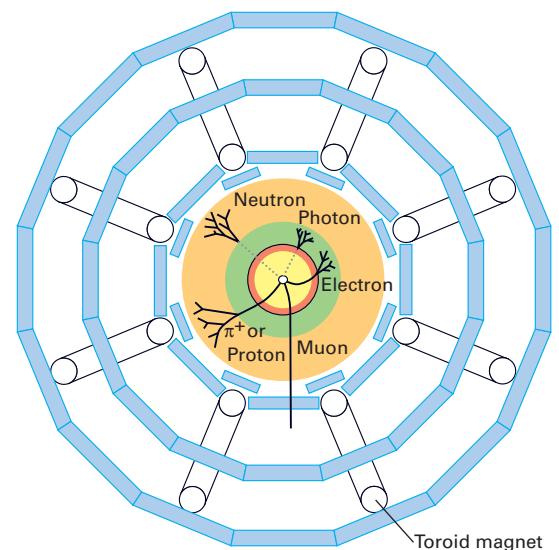


Figure 3 Cross-section of the ATLAS detector showing particle tracks



CERN copyright

A technician cycles to work in the LHC tunnel. This photograph was taken during the installation of the superconducting solenoids; two of the metal tubes will carry the proton beams

uncharged particles, as well as photons of electromagnetic radiation (Figure 3). As the spray of particles and radiation passes through the detectors, it is logged electronically and the path of each particle or photon is recorded. The length and curvature of each track reveals the charge and energy of the particle which produced it, and from this the researchers can deduce just what happened in the collision.

Demanding data

When it is up and running at full capacity, the LHC will produce 1 billion collisions per second. Of these, only 10 or 100 may be of serious scientific interest. So a system is needed to identify the collisions of interest. A lot of computing power is required for this. When an event of interest is identified, longer term recording is triggered and the less interesting data are wiped from the temporary store, to make way for more data flooding in. There will be some 4000 PCs linked in parallel at CERN to handle this data storage.

The scientists managing the project decided not to set up a single computer centre to analyse the LHC

data. Instead, they have established an international grid, the Worldwide LHC Computing Grid, or GridPP, linking over 6500 computers in 75 sites around the world. This is known as distributed computing (see back cover). All the data are available to each of the 5000 scientists who will be working on the different experiments, and the available computing power will be shared according to demand.

Possible outcomes

Why is it important to achieve high-energy collisions? Rutherford's experiment of 1910 used alpha particles to probe gold atoms, and this established the existence of the atomic nucleus. However, the alpha particles which bounced off the gold nuclei had an energy of less than 1 MeV, a millionth of that achievable by the LHC. To penetrate more closely, and to achieve much stronger interactions between particles, higher energies are needed.

Among the debris of the billions of proton-proton collisions that the LHC will produce, scientists hope to spot evidence of some exotic events. In particular, they would like to see evidence of a particle called the Higgs boson. This particle is believed to explain why matter has mass, but it has yet to be observed because it is only expected to appear in high-energy collisions with energies of 1 TeV or more. This is an important test of the Standard Model (see Box 1).

The fast-moving, highly-energetic protons in the LHC beams reproduce the conditions in the early history of the universe, shortly after the Big Bang. So the LHC can be thought of as a 'telescope' which allows us to see back in time, to within a fraction of a second of the emergence of our universe.

David Sang writes textbooks and is an editor of CATALYST.

● You can find out about visiting CERN on page 11.

One concern about the LHC is that it might result in the production of exotic forms of matter. For example, a tiny black hole might be created which would then suck in material from its surroundings, eventually engulfing the whole planet. However, this is thought to be extremely unlikely – such a black hole is predicted to evaporate in a fraction of a second.

Box 3 Useful websites

- The Large Hadron Collider homepage is at: <http://lhc.web.cern.ch/lhc>
 - View an animation of the accelerator in action and the ATLAS detector at: http://hands-on-cern.physto.se/ani/acc_lhc_atlas/lhc_atlas.swf
 - To find out more about the ATLAS experiment select *movie* at: www.atlas.ch/index.html
 - You can learn more about the detector at: www.atlas.ch/detector.html
- Click on *eTours* or *Detector Desc.*