The Large Hadron Collider (LHC) is being built in a circular tunnel 27 km in circumference. The tunnel is buried around 50 to 175 m. underground. It straddles the Swiss and French borders on the outskirts of Geneva.

It planned to circulate the first beams in May 2008. First collisions at high energy are expected mid-2008 with the first results from the experiments soon after.

The LHC is designed to collide two counter rotating beams of protons or heavy ions. Proton-proton collisions are foreseen at an energy of 7 TeV per beam.

- The beams move around the LHC ring inside a continuous vacuum guided by magnets.
- The magnets are superconducting and are cooled by a huge cryogenics system. The cables conduct current without resistance in their superconducting state.
- The beams will be stored at high energy for hours. During this time collisions take place inside the four main LHC experiments.
The ATLAS Experiment
Mapping the Secrets of the Universe

ATLAS Detector Photos

The first interconnection of the LHC...
Engineers checking the electronics on...
Welding one of the final LHC...
First LHC magnet installed. The...

Download
Diagram of an LHC dipole magnet. Diagram showing the cross-section of an LHC dipole magnet with cold mass and vacuum chamber. June 1999
Photo #: 9906025_01
There are a large variety of magnets in the LHC. However the big ones are the main dipoles.

**Main Dipoles**

The main budget item and a serious technological challenge are the superconducting (1.9 K) dipoles which bend the beams around the 27 km circumference of the LHC. At 7 TeV these magnets have to produce a field of around 8.4 Tesla at a current of around 11,700 A. The magnets have two apertures, one for each of the counter-rotating beams. Each one is 14.3 metres long. A total of 1232 are needed.

- Vertical B field in the dipole bends the beam round via the Lorentz force
- Need very strong magnets to get the high energy beam around the circle. Superconducting (1.9 K) dipoles producing a field of 8.3 T - current 11,850 A
- 2-in-1 magnet design.
- Bending magnets (dipoles): 14.3 metres long. Cost: ~ 0.5 million CHF each. Need 1232 of them
- Quads etc to keep beam focused and the motion stable
- Stored magnetic energy up to 1.29 GJ per sector. Total stored energy in magnets = 11GJ
- One dipole weighs around 35 tonnes.

![Dipoles in the assembly hall](http://lhce-machine-outreach.web.cern.ch/lhc%2Dmachine%2D0...)

A quarter of a dipole aperture showing the 6 superconducting blocks and the magnetic field produced.

The manufacture of the coils, which contain the superconducting cable to provide the all-important 8.33 T magnetic field, represents 60% of the magnet production work. The niobium-titanium coils create the magnetic fields to guide the two counter-rotating proton beams in separate magnetic channels, but within the same physical structure. The coils are surrounded by non-magnetic "collars" of austenitic steel, a material that combines the required properties of good thermal contraction and magnetic permeability. The collars hold the coils in place against the strong magnetic forces that arise when the coils are at full field - the force loading 1 m of dipole is about 400 tonnes.
A popular quadrupole model designed for high gradients, low multipole content, and compact size. As with other RadiaBeam magnets, the pole tips are CNC machined to the ideal form rather than approximated by straight cuts.

A variety of bore sizes and coil packs are available to suit the demands of injector beamlines. The octagon quadrupoles are in operation in multiple laboratories worldwide, including LLNL, FNAL, DESY.
The quadrupole magnetic field magnitude increases linearly with distance from the center along the horizontal and vertical, or x and y, directions in the figure. If it converges charged particles to a focus in the x-direction it diverges them in the y-direction. But two quadrupoles spaced not too far apart will focus in both directions, as indicated below. If the first is diverging and the second converging, the focus is at the same point. So the pair works like a conventional focusing lens.
We aim to squeeze the beam size down as much as possible at the collision point to increase the chances of a collision.

Even so... protons are very small things.

So even though we squeeze our 100,000 million protons per bunch down to 64 microns (about the width of a human hair) at the interaction point. We get only around 20 collisions per crossing with nominal beam currents.

The bunches cross (every 25 ns.) so often we end up with around 600 million collisions per second - at the start of a fill with nominal current.

Most protons miss each other and carry on around the ring time after time. The beams are kept circulating for hours

Collision rate

By definition event rate = luminosity * cross section

The total proton-proton cross section at 7 TeV is approximately 110 mbarns. This total can be broken down in contributions from:

* inelastic (sin = 60 mbarn)
* single diffractive (ssd = 12 mbarn)
* elastic (sel = 40 mbarn)

The cross section from elastic scattering of the protons and diffractive events will not be seen by the detectors as it is only the inelastic scatterings that give rise to particles at sufficient high angles with respect to the beam axis.

Inelastic event rate at nominal luminosity therefore $10^{34} \times 60 \times 10^{-3} \times 10^{-24} = 600$ million/second per high luminosity experiment - around 19 inelastic events per crossing.

The bunch spacing in the LHC is 25 ns., however, there are bigger gaps (e.g. to allow dump kickers the time to get up etc.). A 25 ns. beam gives us a peak crossing rate of 40 MHz. Because of the gaps we get an average crossing rate = number of bunches * revolution frequency = 2808 * 11245 = 31.6 MHz. Times 19 events per crossing at nominal luminosity gives us our 600 million inelastic events per second.
Eight-month delay for LHC

Broken magnets put particle collider in limbo.

Geoff Brumfiel

Details of last month's accident at the Large Hadron Collider (LHC), the world's premier particle accelerator, are emerging — and confirm that the machine will not restart before late May or early June 2009.

Officials at CERN, Europe's particle-physics laboratory near Geneva, Switzerland, say that the time is needed to overhaul a sector of the 27-kilometre-long machine, after an electrical failure on 19 September caused some 6 tonnes of ultra-cold liquid helium to leak into its tunnel. A preliminary report issued on 16 October says that as many as 29 of the nearly 10,000 magnets used to guide the accelerator's proton beam will need to be replaced. Further magnets may need to be removed and inspected, and modifications must also be made to prevent future accidents. "It's a serious incident," says James Gillies, a spokesman for the laboratory.

Still, CERN is confident it has the resources to make the repairs. No more than 24 dipole magnets and 5 quadrupole magnets were damaged; CERN has 30 dipole magnets — each weighing 35 tonnes — in reserve, as well as sufficient quadrupoles, says Gillies. Replacement magnets are already being tested in a facility above the buried accelerator tunnel. Nevertheless, Gillies says that the damage will take all of CERN's winter shutdown period to repair. Not including labour and the spares, the work will cost an estimated 100,000 Swiss francs (US$90,000), he says.

The LHC's superconducting magnets generate enormous fields by circulating huge electrical currents with virtually no resistance. To work correctly, they must be immersed in liquid helium and kept at a temperature of just 1.9 kelvin. During the 19 September test, the accident report says, a weld in a superconducting wire connecting two magnets heated above its operating temperature. That in effect turned the wire into a resistor — causing a massive 8.7 kiloamps of power to arc through the liquid helium and puncture into the surrounding vacuum vessel.

"The amount of helium released was larger than the valves were designed to handle." In just milliseconds, the arc managed to vaporize a "significant fraction" of the nearly metre-long connection between the two magnets, says Jim Strait, an accelerator physicist at the Fermi National Accelerator Laboratory in Batavia, Illinois, who has been consulting on the accident investigation. The liquid helium flowed through the hole and into an insulating region of vacuum, which was meant to work as a thermos to keep the magnets cool. Relief valves designed to allow the helium to escape were overwhelmed and, within seconds, the pressure in the machine became powerful enough to wrench magnets off their concrete supports.

Strait says that the relief valves' tolerances were based on "incorrect assumptions" about how much helium might escape in an accident. "The total amount of helium released was larger than the valves were designed to handle," he says. "You could call it a design error."

Gillies says that "clearly something was wrong" with the models of how much helium could be released, but he adds that it is difficult to foresee every possible scenario. "This thing is its own prototype," he says.

The electrical arc also penetrated the beam pipes, allowing soot from the accident to contaminate the pipes. "It's a mess in the affected spots," Strait says.

CERN is looking at adding extra relief valves and developing new diagnostics to catch such a failure before it occurs. A late May or early June start-up seems ambitious to Strait, but he has faith in the team at CERN. "It looks very difficult to me, but I would not count them out," he says.

Those awaiting the start of the machine remain stoic. "We are a bit disappointed," says Peter Jenni, a spokesman for the ATLAS detector, which employs more than 2,500 physicists.