# Large Hadron Collider

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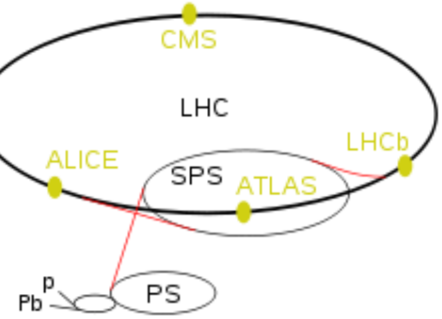
(Redirected from Lhc)

Coordinates: 46°14′ N 06°03′ E

**Large Hadron Collider (LHC)**




**LHC experiments**

| | |
|---|---|
| **ATLAS** | A Toroidal LHC Apparatus |
| **CMS** | Compact Muon Solenoid |
| **LHCb** | LHC-beauty |
| **ALICE** | A Large Ion Collider Experiment |
| **TOTEM** | Total Cross Section, Elastic Scattering and Diffraction Dissociation |
| **LHCf** | LHC-forward |

**LHC preaccelerators**

| | |
|---|---|
| **p and Pb** | Linear accelerators for protons (Linac 2) and Lead (Linac 3) |
| **(not marked)** | Proton Synchrotron Booster |
| **PS** | Proton Synchrotron |
| **SPS** | Super Proton Synchrotron |

The **Large Hadron Collider** (**LHC**) is the world's largest and highest-energy particle accelerator, intended to collide opposing particle beams of either protons at an energy of 7 TeV per particle, or lead nuclei at an energy of 574 TeV per nucleus. It is expected that it will address the most fundamental questions of physics, hopefully allowing progress in understanding the deepest laws of nature. The LHC lies in a tunnel 27 kilometres (17 mi) in circumference, as much as 175 metres (570 ft) beneath the Franco-Swiss border near Geneva, Switzerland.

| Hadron Colliders | |
|---|---|
| **Intersecting Storage Rings** | *CERN, 1971–1984* |
| **Super Proton Synchrotron** | *CERN, 1981–1984* |
| **ISABELLE** | *BNL, cancelled in 1983* |
| **Tevatron** | *Fermilab, 1987–present* |
| **Relativistic Heavy Ion Collider** | *BNL, operational since 2000* |
| **Superconducting Super Collider** | *Cancelled in 1993* |
| **Large Hadron Collider** | *CERN, 2009–* |
| **Very Large Hadron Collider** | *Theoretical* |
| **Super Large Hadron Collider** | *Proposed* |

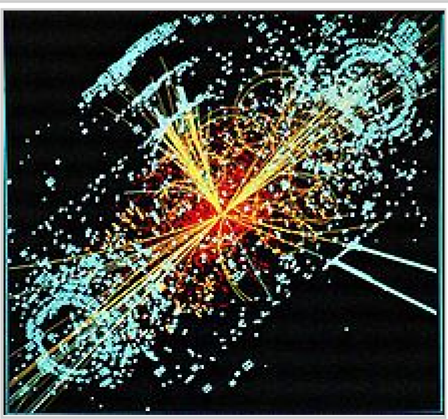
The Large Hadron Collider was built by the European Organization for Nuclear Research (CERN) with the intention of testing various predictions of high-energy physics, including the existence of the hypothesized Higgs boson[1] and of the large family of new particles predicted by supersymmetry.[2] It is funded by and built in collaboration with over 10,000 scientists and engineers from over 100 countries as well as hundreds of universities and laboratories.[3]

On 10 September 2008, the proton beams were successfully circulated in the main ring of the LHC for the first time.[4] On 19 September 2008, the operations were halted due to a serious fault between two superconducting bending magnets.[5] Repairing the resulting damage and installing additional safety features took over a year.[6][7] On 20 November 2009 the proton beams were successfully circulated again,[8] On 23 November 2009, the first proton–proton collisions were recorded, at the injection energy of 450 GeV per particle.[9] On 18 December 2009 the LHC was shut down after its initial commissioning run, which achieved proton collision energies of 2.36 TeV, with multiple bunches of protons circulating for several hours and data from over one million proton-proton collisions. The LHC resumed operations in February 2010, but it will operate at only half of the design collision energy. In 2012 it will be shut down for the repairs necessary to bring it to its full design energy, and then it will start up again in 2013.[10]

## Contents



# Purpose



A simulated event in the CMS detector, featuring the appearance of the Higgs boson.

Physicists hope that the LHC will help answer the most fundamental questions in physics, questions concerning the basic laws governing the interactions and forces among the elementary objects, the deep structure of space and time, especially regarding the intersection of quantum mechanics and general relativity, where current theories and knowledge are unclear or break down altogether. These issues include, at least:[11]

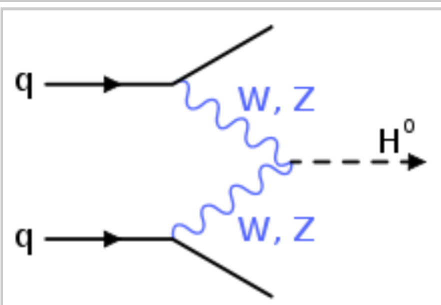
- Is the Higgs mechanism for generating elementary particle masses via electroweak symmetry breaking indeed realised in nature?[12] It is anticipated that the collider will either demonstrate (or rule out) the existence of the elusive Higgs boson(s), completing (or refuting) the Standard Model.[13][14][15]
- Is supersymmetry, an extension of the Standard Model and Poincaré symmetry, realised in nature, implying that all known particles have

supersymmetric partners?[16][17][18] These may clear up the mystery of dark matter.
- Are there extra dimensions,[19] as predicted by various models inspired by string theory, and can we detect them?

Other questions are:

- Are electromagnetism, the strong nuclear force and the weak nuclear force just different manifestations of a single unified force, as predicted by various Grand Unification Theories?
- Why is gravity so many orders of magnitude weaker than the other three fundamental forces? See also Hierarchy problem.
- Are there additional sources of quark flavours, beyond those already predicted within the Standard Model?
- Why are there apparent violations of the symmetry between matter and antimatter? See also CP violation.
- What was the nature of the quark-gluon plasma in the early universe? This will be investigated by ion collisions in ALICE.

# Design



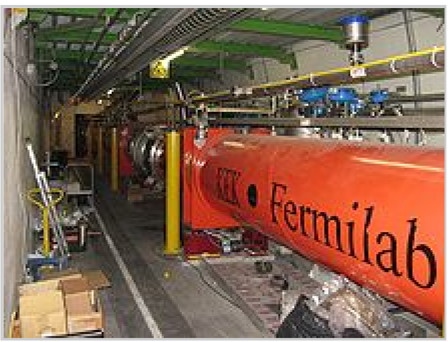
A Feynman diagram of one way the Higgs boson may be produced at the LHC. Here, two quarks each emit a W or Z boson, which combine to make a neutral Higgs.

The LHC is the world's largest and highest-energy particle accelerator.[20][21] The collider is contained in a circular tunnel, with a circumference of 27 kilometres (17 mi), at a depth ranging from 50 to 175 metres (160 to 570 ft) underground.


Map of the Large Hadron Collider at CERN

The 3.8-metre (12 ft) wide concrete-lined tunnel, constructed between 1983 and 1988, was formerly used to house the Large Electron–Positron Collider.[22] It crosses the border between Switzerland and France at four points, with most of it in France. Surface buildings hold ancillary equipment such as compressors, ventilation equipment, control electronics and refrigeration plants.

The collider tunnel contains two adjacent parallel beam pipes that intersect at four points, each containing a proton beam, which travel in opposite directions around the ring. Some 1,232 dipole magnets keep the beams on their circular path, while an additional 392 quadrupole magnets are used to keep the beams focused, in order to maximize the chances of interaction between the particles in the four intersection points, where the two beams will cross. In total, over 1,600 superconducting magnets are installed, with most weighing over 27 tonnes. Approximately 96 tonnes of liquid helium is needed to keep the magnets at their operating temperature of 1.9 K (−271.25 °C), making the LHC the largest cryogenic facility in the world at liquid helium temperature.

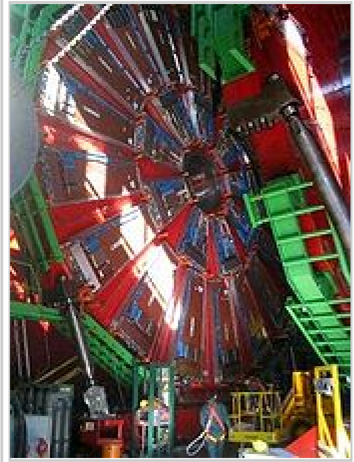


Superconducting quadrupole electromagnets are used to direct the beams to four intersection points, where interactions between accelerated protons will take place.

Once or twice a day, as the protons are accelerated from 450 GeV to 7 TeV, the field of the superconducting dipole magnets will be increased from 0.54 to 8.3 teslas (T). The protons will each have an energy of 7 TeV, giving a total collision energy of 14 TeV. At this energy the protons have a Lorentz factor of about 7,500 and move at about 99.9999991% of the speed of light.[23] It will take less than 90 microseconds (μs) for a proton to travel once around the main ring – a speed of about 11,000 revolutions per second. Rather than continuous beams, the protons will be bunched together, into 2,808 bunches, so that interactions between the two beams will take place at discrete intervals never shorter than 25 nanoseconds (ns) apart. However it will be operated with fewer bunches when it is first commissioned, giving it a bunch crossing interval of 75 ns.[24]

Prior to being injected into the main accelerator, the particles are prepared by a series of systems that successively increase their energy. The first system is the linear particle accelerator LINAC 2 generating 50-MeV protons, which feeds the Proton Synchrotron Booster (PSB). There the protons are accelerated to 1.4 GeV and injected into the Proton Synchrotron (PS), where they are accelerated to 26 GeV. Finally the Super Proton Synchrotron (SPS) is used to further increase their energy to 450 GeV before they are at last injected (over a period of 20 minutes) into the main ring. Here the proton bunches are accumulated, accelerated (over a period of 20 minutes) to their peak 7-TeV energy, and finally circulated for 10 to 24 hours while collisions occur at the four intersection points.[25]

The LHC physics program is mainly based on proton–proton collisions. However, shorter running periods, typically one month per year, with heavy-ion collisions are included in the program. While lighter ions are considered as well, the baseline scheme deals with lead ions[26] (see A Large Ion Collider Experiment). The lead ions will be first accelerated by the linear accelerator LINAC 3, and the Low-Energy Ion Ring (LEIR) will be used as an ion storage and cooler unit. The ions then will be further accelerated by the PS and SPS before being injected into LHC ring, where they will reach an energy of 2.76 TeV per nucleon (or 575 TeV per ion), higher than the energies reached by the Relativistic Heavy Ion Collider. The aim of the heavy-ion program is to investigate quark–gluon plasma, which existed in the early universe.



CMS detector for LHC

## Detectors

*See also: List of Large Hadron Collider experiments*

Six detectors have been constructed at the LHC, located underground in large caverns excavated at the LHC's intersection points. Two of them, the ATLAS experiment and the Compact Muon Solenoid (CMS), are large, general purpose particle detectors.[21] A Large Ion Collider Experiment (ALICE) and LHCb have more specific roles and the last two TOTEM and LHCf are very much smaller and are for very specialized research. The BBC's summary of the main detectors is:[27]

| Detector | Description |
|---|---|
| ATLAS | one of two general purpose detectors. ATLAS will be used to look for signs of new physics, including the origins of mass and extra dimensions. |
| CMS | the other general purpose detector will, like ATLAS, hunt for the Higgs boson and look for clues to the nature of dark matter. |
| ALICE | will study a "liquid" form of matter called quark–gluon plasma that existed shortly after the Big Bang. |
| LHCb | equal amounts of matter and antimatter were created in the Big Bang. LHCb will try to investigate what happened to the "missing" antimatter. |

# Test timeline

The first beam was circulated through the collider on the morning of 10 September 2008.[27] CERN successfully fired the protons around the tunnel in stages, three kilometres at a time. The particles were fired in a clockwise direction into the accelerator and successfully steered around it at 10:28 local time.[28] The LHC successfully completed its first major test: after a series of trial runs, two white dots flashed on a computer screen showing the protons travelled the full length of the collider. It took less than one hour to guide the stream of particles around its inaugural circuit.[29] CERN next successfully sent a beam of protons in a counterclockwise direction, taking slightly longer at one and a half hours due to a problem with the cryogenics, with the full circuit being completed at 14:59.

On 19 September 2008, a quench occurred in about 100 bending magnets in sectors 3 and 4, causing a loss of approximately six tonnes of liquid helium, which was vented into the tunnel, and a temperature rise of about 100 kelvin in some of the affected magnets. Vacuum conditions in the beam pipe were also lost.[30] Shortly after the incident CERN reported that the most likely cause of the problem was a faulty electrical connection between two magnets, and that – due to the time needed to warm up the affected sectors and then cool them back down to operating temperature – it would take at least two months to fix it.[31] Subsequently, CERN released a preliminary analysis of the incident on 16 October 2008,[32] and a more detailed one on 5 December 2008.[33] Both analyses confirmed that the incident was indeed initiated by a faulty electrical connection. A total of 53 magnets were damaged in the incident and were repaired or replaced during the winter shutdown.[34]

In the original timeline of the LHC commissioning, the first "modest" high-energy collisions at a center-of-mass energy of 900 GeV were expected to take place before the end of September 2008, and the LHC was expected to be operating at 10 TeV by the time of the official inauguration on 21 October 2008.[35] However, due to the delay caused by the above-mentioned incident, the collider was not operational until November 2009.[6] Despite the delay, LHC was officially inaugurated on 21 October 2008, in the presence of political leaders, science ministers from CERN's 20 Member States, CERN officials, and members of the worldwide scientific community.[36]

**Timeline**

| Date | Event |
|---|---|
| 10 Sep 2008 | CERN successfully fired the first protons around the entire tunnel circuit in stages. |
| 19 Sep 2008 | Magnetic quench occurred in about 100 bending magnets in sectors 3 and 4, causing a loss of approximately 6 tonnes of liquid helium. |
| 30 Sep 2008 | First "modest" high-energy collisions planned but postponed due to accident. |
| 16 Oct 2008 | CERN released a preliminary analysis of the incident. |
| 21 Oct 2008 | Official inauguration. |
| 5 Dec 2008 | CERN released detailed analysis. |
| 20 Nov 2009 | Low-energy beams circulated in the tunnel for the first time since the incident.[37] |
| 23 Nov 2009 | First particle collisions in all 4 detectors at 450 GeV.[9] |
| 30 Nov 2009 | LHC becomes the world's highest energy particle accelerator achieving 1.18 TeV per beam, beating the Tevatron's previous record of 0.98 TeV per beam held for 8 years.[38] |
| Late Feb 2010 | The LHC expected to continue operations ramping energies to run at 3.5TeV for 18 months to two years, after which it will be shut down to prepare for the 14 TeV collisions (7 TeV per beam).[39] |

### Expected results

CERN scientists estimate that if the Standard Model is correct, a single Higgs boson may be produced every few hours. At this rate, it may take about two to three years to collect enough data to discover the Higgs boson unambiguously. Similarly, it may take one year or more before sufficient results concerning supersymmetric particles have been gathered to draw meaningful conclusions.[20]

## Proposed upgrade

*Main article: Super Large Hadron Collider*

After some years of running, any particle physics experiment typically begins to suffer from diminishing returns: each additional year of operation discovers less than the year before. The way around the diminishing returns is to upgrade the experiment, either in energy or in luminosity. A luminosity upgrade of the LHC, called the Super LHC, has been proposed,[40] to be made after ten years of LHC operation.

The optimal path for the LHC luminosity upgrade includes an increase in the beam current (i.e., the number of protons in the beams) and the modification of the two high-luminosity interaction regions, ATLAS and CMS. To achieve these increases, the energy of the beams at the point that they are injected into the (Super) LHC should also be increased to 1 TeV. This will require an upgrade of the full pre-injector system, the needed changes in the Super Proton Synchrotron being the most expensive.

## Cost

With a budget of 9 billion US dollars (approx. €6300M or £5600M as of Jan 2010), the LHC is the most expensive scientific experiment in human history.[41] The total cost of the project is expected to be of the order of 4.6 billion Swiss francs (approx. $4400M, €3100M, or £2800M as of Jan 2010) for the accelerator and 1.16 billion francs (approx. $1100M, €800M, or £700M as of Jan 2010) for the CERN contribution to the experiments.[42]

The construction of LHC was approved in 1995 with a budget of 2.6 billion francs, with another 210 million francs towards the experiments. However, cost overruns, estimated in a major review in 2001 at around 480 million francs for the accelerator, and 50 million francs for the experiments, along with a reduction in CERN's budget, pushed the completion date from 2005 to April 2007.[43] The superconducting magnets were responsible for 180 million francs of the cost increase. There were also further costs and delays due to engineering difficulties encountered while building the underground cavern for the Compact Muon Solenoid,[44] and also due to faulty parts provided by Fermilab.[45]

Due to lower electricity costs during the summer, it is expected that the LHC will normally not operate over the winter months,[46] although an exception was being made to make up for the 2008 start-up delays over the 2009/10 winter.

# Computing resources

Data produced by LHC as well as LHC-related simulation will produce a total data output of 15 petabytes per year.[47] For comparison, every word spoken worldwide in one year, converted into text, would amount to 2–3 petabytes of data[*citation needed*].

The LHC Computing Grid is being constructed to handle the massive amounts of data produced. It incorporates both private fiber optic cable links and existing high-speed portions of the public Internet, enabling data transfer from CERN to academic institutions around the world.

The Open Science Grid is used as the primary infrastructure in the United States, and also as part of an interoperable federation with the LHC Computing Grid.

The distributed computing project LHC@home was started to support the construction and calibration of the LHC. The project uses the BOINC platform, enabling anybody with an internet connection to use their computer idle time to simulate how particles will travel in the tunnel. With this information, the scientists will be able to determine how the magnets should be calibrated to gain the most stable "orbit" of the beams in the ring.

# Safety of particle collisions

*Main article: Safety of particle collisions at the Large Hadron Collider*

The upcoming experiments at the Large Hadron Collider have sparked fears among the public that the LHC particle collisions might produce doomsday phenomena, involving the production of stable microscopic black holes or the creation of hypothetical particles called strangelets.[48] Two CERN-commissioned safety reviews have examined these concerns and concluded that the experiments at the LHC present no danger and that there is no reason for concern,[49][50][51] a conclusion expressly endorsed by the

American Physical Society.[52]

# Operational challenges

The size of the LHC constitutes an exceptional engineering challenge with unique operational issues on account of the huge energy stored in the magnets and the beams.[25][53] While operating, the total energy stored in the magnets is 10 GJ (equivalent to 2.4 tons of TNT) and the total energy carried by the two beams reaches 724 MJ (173 kilograms of TNT).[54]

Loss of only one ten-millionth part ($10^{-7}$) of the beam is sufficient to quench a superconducting magnet, while the beam dump must absorb 362 MJ (87 kilograms of TNT) for each of the two beams. These immense energies are even more impressive considering how little matter is carrying it: under nominal operating conditions (2,808 bunches per beam, $1.15\times10^{11}$ protons per bunch), the beam pipes contain $1.0\times10^{-9}$ gram of hydrogen, which, in standard conditions for temperature and pressure, would fill the volume of one grain of fine sand.

On 10 August 2008, computer hackers defaced a website at CERN, criticizing their computer security. There was no access to the control network of the collider.[55][56]

# Construction accidents and delays

- On 25 October 2005, a technician was killed in the LHC tunnel when a crane load was accidentally dropped.[57]
- On 27 March 2007 a cryogenic magnet support broke during a pressure test involving one of the LHC's inner triplet (focusing quadrupole) magnet assemblies, provided by Fermilab and KEK. No one was injured. Fermilab director Pier Oddone stated "In this case we are dumbfounded that we missed some very simple balance of forces". This fault had been present in the original design, and remained during four engineering reviews over the following years.[58] Analysis revealed that its design, made as thin as possible for better insulation, was not strong enough to withstand the forces generated during pressure testing. Details are available in a statement from Fermilab, with which CERN is in agreement.[59][60] Repairing the broken magnet and reinforcing the eight identical assemblies used by LHC delayed the startup date, then planned for November 2007.
- Problems occurred on 19 September 2008 during powering tests of the main dipole circuit, when an electrical fault in the bus between magnets caused a rupture and a leak of six tonnes of liquid helium. The operation

was delayed for several months.[61] It is currently believed that a faulty electrical connection between two magnets caused an arc, which compromised the liquid-helium containment. Once the cooling layer was broken, the helium flooded the surrounding vacuum layer with sufficient force to break 10-ton magnets from their mountings. The explosion also contaminated the proton tubes with soot.[33][62]
- Two vacuum leaks were identified in July 2009, and the start of operations was further postponed to mid-November, 2009.[63]

# Popular culture

The Large Hadron Collider has gained considerable attention from outside the scientific community and its progress is followed by most popular science media. The LHC has also sparked the imaginations of authors of works of fiction, such as novels, TV series, and video games, although descriptions of what it is, how it works, and projected outcomes of the experiments are often only vaguely accurate, occasionally causing concern among the general public.

The novel *Angels & Demons*, by Dan Brown, involves antimatter created at the LHC to be used in a weapon against the Vatican. In response CERN published a "Fact or Fiction?" page discussing the accuracy of the book's portrayal of the LHC, CERN, and particle physics in general.[64] The movie version of the book has footage filmed on-site at one of the experiments at the LHC; the director, Ron Howard, met with CERN experts in an effort to make the science in the story more accurate.[65]

The novel *FlashForward*, by Robert J. Sawyer, involves the search for the Higgs boson at the LHC. CERN published a "Science and Fiction" page interviewing Sawyer and physicists about the book and the TV series based on it.[66]

CERN employee Katherine McAlpine's "Large Hadron Rap" (http://www.youtube.com/watch?v=j50ZssEojtM) [67] surpassed 5 million YouTube views.[68][69]

# Notes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12. ^ "...in the public presentations of the aspiration of particle physics we hear too often that the goal of the LHC or a linear collider is to check off the last missing particle of the Standard Model, this year's Holy Grail of particle physics, the Higgs boson. *The truth is much less boring than that!* What we're trying to accomplish is much more exciting, and asking what the world would have been like without the Higgs mechanism is a way of getting at that excitement." – Chris Quigg (2005). "Nature's Greatest Puzzles". *arXiv:hep-ph/0502070 (http://www.arxiv.org/abs/hep-ph/0502070)* [hep-ph].
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# External links

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- Overview of the LHC at CERN's public webpage (http://public.web.cern.ch/public/en/LHC/LHC-en.html)
- CERN Courier magazine (http://www.cerncourier.com)
- CERN (http://twitter.com/cern) on Twitter
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physicists.
- Thirty collected pictures during commissioning and post- 19 September 2008 incident repair (http://www.boston.com/bigpicture/2009/11/large_hadron_collider_ready_to.html) , from Boston Globe.


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