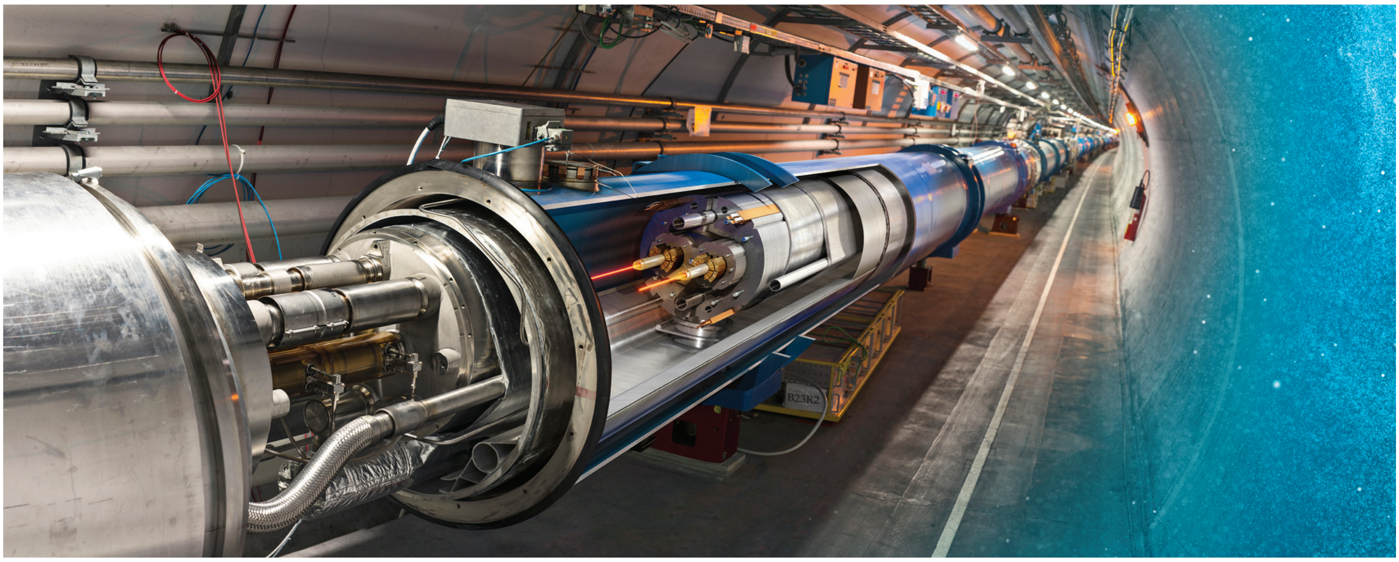
LHC Season 2
facts & figures

The Large Hadron Collider (LHC) is the most powerful particle accelerator ever built. The accelerator sits in a tunnel 100 metres underground at CERN, the European Organization for Nuclear Research, on the Franco-Swiss border near Geneva, Switzerland.



WHAT IS THE LHC?

The LHC is a particle accelerator that pushes protons or ions to near the speed of light. It consists of a 27-kilometre ring of superconducting magnets with a number of accelerating structures that boost the energy of the particles along the way.

WHY IS IT CALLED THE "LARGE HADRON COLLIDER"?

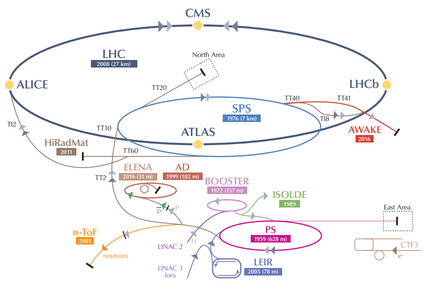
• "Large" refers to its size, approximately 27km in circumference.

• "Hadron" because it accelerates protons or ions, which belong to the group of particles called hadrons.

• "Collider" because the particles form two beams travelling in opposite directions, which are made to collide at four points around the machine.

HOW DOES THE LHC WORK?

• The CERN accelerator complex is a succession of machines with increasingly higher energies. Each machine accelerates a beam of particles to a given energy before injecting the beam into the next machine in the chain. This next machine brings the beam to an even higher energy and so on. The LHC is the last element of this chain, in which the beams reach their highest energies.



• Inside the LHC, two particle beams travel at close to the speed of light before they are made to collide. The beams travel in opposite directions in separate beam pipes – two tubes kept at ultrahigh vacuum. They are guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets. Below a certain characteristic temperature, some materials enter a superconducting state and offer no resistance to the passage of electrical current. The electromagnets in the LHC are therefore chilled to -271.3°C (1.9K) – a temperature colder than outer space – to take advantage of this effect. The accelerator is connected to a vast distribution system of liquid helium, which cools the magnets, as well as to other supply services.

WHAT ARE THE MAIN GOALS OF THE LHC?

The Standard Model of particle physics – a theory developed in the early 1970s that describes the fundamental particles and their interactions – has precisely predicted a wide variety of phenomena and so far successfully explained almost all experimental results in particle physics. But the Standard Model is incomplete. It leaves many questions open, which the LHC will help to answer.

• **What is the origin of mass?** The Standard Model does not explain the origins of mass, nor why some particles are very heavy while others have no mass at all. However, theorists Robert Brout, François Englert and Peter Higgs made a proposal that was to solve this problem. The Brout-Englert-Higgs mechanism gives a mass to particles when they interact with an invisible field, now called the "Higgs field", which pervades the universe. Particles that interact intensely with the Higgs field are heavy, while those that have feeble interactions are light. In the late 1980s, physicists started the search for the Higgs boson, the particle associated with the Higgs field. In July 2012, CERN announced the discovery of the Higgs boson, which confirmed the Brout-Englert-Higgs mechanism. However, finding it is not the end of the story, and researchers have to study the Higgs boson in detail to measure its properties and pin down its rarer decays.

• **Will we discover evidence for supersymmetry?** The Standard Model does not offer a unified description of all the fundamental forces, as it remains difficult to construct a theory of gravity similar to those for the other forces. Supersymmetry – a theory that hypothesises the existence of more massive partners of the standard particles we know – could facilitate the unification of fundamental forces.

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• **What are dark matter and dark energy?** The matter we know and that makes up all stars and galaxies only accounts for 4% of the content of the universe. The search is then still open for particles or phenomena responsible for dark matter (23%) and dark energy (73%).

• **Why is there far more matter than anti-matter in the universe?** Matter and antimatter must have been produced in the same amounts at the time of the Big Bang, but from what we have observed so far, our Universe is made only of matter.

• **How does the quark-gluon plasma give rise to the particles that constitute the matter of our Universe?** For part of each year, the LHC provides collisions between lead ions, recreating conditions similar to those just after the Big Bang. When heavy ions collide at high energies they form for an instant the quark-gluon plasma, a “fireball” of hot and dense matter that can be studied by the experiments.

HOW WAS THE LHC DESIGNED?
Scientists started thinking about the LHC in the early 1980s, when the previous accelerator, the LEP, was not yet running. In December 1994, CERN Council voted to approve the construction of the LHC and in October 1995, the LHC technical design report was published.
Contributions from Japan, the USA, India and other non-Member States accelerated the process and between 1996 and 1998, four experiments (ALICE, ATLAS, CMS and LHCb) received official approval and construction work

Quantity	Number
Circumference	26659 m
Dipole operating temperature	1.9 K (-271.3°C)
Number of magnets	9593
Number of main dipoles	1232
Number of main quadrupoles	392
Number of RF cavities	8 per beam
Nominal energy, protons	6.5 TeV
Nominal energy, ions	2.56 TeV/u (energy per nucleon)
Nominal energy, protons collisions	13 TeV
No. of bunches per proton beam	2808
No. of protons per bunch (at start)	1.2×10^{11}
Number of turns per second	11245
Number of collisions per second	1 billion

started on the four sites.

IMPORTANT FIGURES: THE ENERGY OF THE LHC FOR RUN 2

WHAT ARE THE DETECTORS AT THE LHC?
There are seven experiments installed at the LHC: ALICE, ATLAS, CMS, LHCb, LHCf, TOTEM and MoEDAL. They use detectors to analyse the myriad of particles produced by collisions in the accelerator. These experiments are run by collaborations of scientists from institutes all over the world. Each experiment is distinct, and characterized by its detectors.

WHAT IS THE DATA FLOW FROM THE LHC EXPERIMENTS?

The CERN Data Centre stores more than 30 petabytes of data per year from the LHC experiments, enough to fill about 1.2 million Blu-ray discs, i.e. 250 years of HD video.
Over 100 petabytes of data are permanently archived, on tape.

WHAT IS THE LHC POWER CONSUMPTION?
The total power consumption of the LHC (and experiments) is equivalent to 600 GWh per year, with a maximum of 650 GWh in 2012 when the LHC was running at 4 TeV. For Run 2, the estimated power consumption is 750 GWh per year.
The total CERN energy consumption is 1.3 TWh per year while the total electrical energy production in the world is around 20000 TWh, in the European Union 3400 TWh, in France around 500 TWh, and in Geneva canton 3 TWh.

WHAT ARE THE MAIN ACHIEVEMENTS OF THE LHC SO FAR?

• **10 September 2008:** LHC first beam

• **23 November 2009:** LHC first collisions

• **30 November 2009**: world record with beam energy of 1.18 TeV

• **16 December 2009:** world record with collisions at 2.36 TeV and significant quantities of data recorded

• **March 2010**: first beams at 3.5 TeV (19 March) and first high energy collisions at 7 TeV (30 March)

• **8 November 2010:** LHC first lead-ion beams
• **22 April 2011:** LHC sets new world record beam intensity

• **5 April 2012:** First collisions at 8 TeV

• **4 July 2012:** Announcement of the discovery of a Higgs-like particle at CERN

• **28 September 2012:** Tweet from CERN: "The LHC has reached its target for 2012 by delivering 15 fb-1 (around a million billion collisions) to ATLAS and CMS"

• **14 February 2013:** At 7.24 a.m, the last beams for physics were absorbed into the LHC, marking the end of Run 1 and the beginning of the Long Shutdown 1

• **8 October 2013:** Physics Nobel prize to François Englert and Peter Higgs for “the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s Large Hadron Collider”

WHAT ARE THE MAIN GOALS FOR THE SECOND RUN OF THE LHC?
The discovery of the Higgs boson was only the first chapter of the LHC story. Indeed, the restart of the machine this year marks the beginning of a new adventure, as it will operate at almost double the energy of its first run. Thanks to the work that has been done during the Long Shutdown 1, the LHC will now be able to produce 13 TeV collisions (6.5 TeV per beam), which will allow physicists to further explore the nature of our Universe.

HOW LONG WILL THE LHC RUN?
The LHC is planned to run over the next 20 years, with several stops scheduled for upgrades and maintenance work.

HOW MUCH DOES THE LHC COST?
• **Construction costs (MCHF)**

	Personnel	Materials	Total
LHC machine and areas*	1224	3756	4980
CERN share to detectors	869	493	1362
LHC computing (CERN share)	85	83	168
Total	2178	4332	6510

**Includes: Machine R&D and injectors, tests and pre-operation*

• **Costs for Run 1**
Exploitation costs of the LHC when running (direct and indirect costs) represent about 80% of the CERN annual budget for operation, maintenance, technical stops, repairs and consolidation work in personnel and materials (for machine, injectors, computing, experiments).
The directly allocated resources for the years 2009-2012 were about 1.1 billion CHF.

• **Costs for LS1**
The cost of the Long Shutdown 1 (22 months) is estimated at 150 Million CHF.
The maintenance and upgrade works represent about 100 MCHF for the LHC and 50 MCHF for the accelerator complex without the LHC.