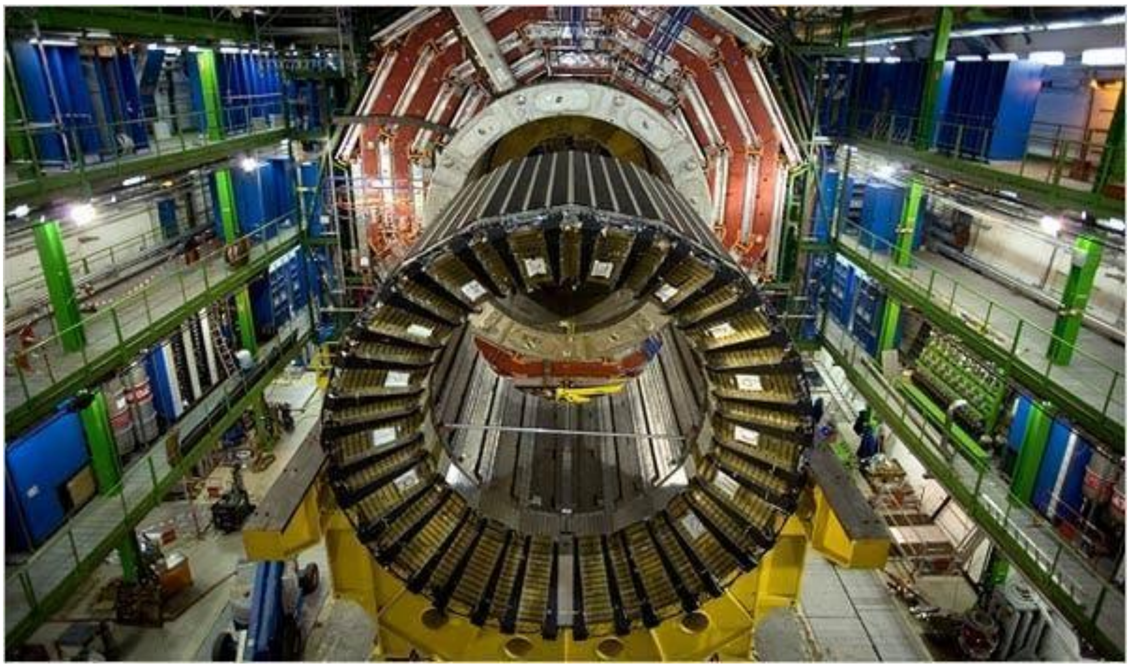
CERN AND LHC:

A STEP FORWARD IN OUR UNDERSTANDING OF THE UNIVERSE



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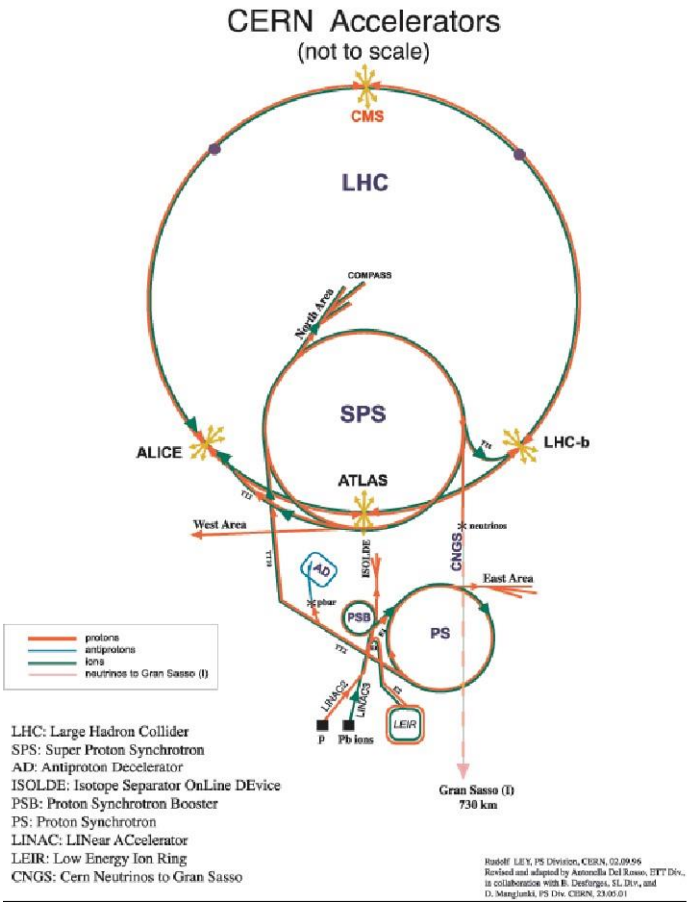
Our report aims at providing an overview of CERN and LHC, an institution and a research tool which are allowing scientists to shed light on new theories of particle physics beyond the Standard Model. After analyzing the general characteristics of CERN and LHC, we will focus on one of their most significant scientific achievements: the observation of the Higgs Boson. Finally, we will investigate two eminent personalities in the field of physics which have a link with CERN: the Belgian François Englert and the Italian Fabiola Gianotti.

What is CERN?

CERN – short for "European Organization for Nuclear Research" – is the world's largest physics laboratory. Based on the outskirts of Geneva, on the Franco-Swiss border, it presently has 23 member states, including Italy and Belgium and Israel, which is the only non-European country. Employing the world's most complex scientific instruments (several particle accelerators), CERN aims at studying the particles which make up everything around us and it therefore contributes to improve our understanding of the Universe.



What is the history of CERN?

At the end of the Second World War, when European science was no longer outstanding, a group of forward-looking scientists imagined creating a European atomic physics laboratory. Among these pioneers were Raoul Dautry, Pierre Auger and Lew Kowarski in France, Edoardo Amaldi in Italy and Niels Bohr in Denmark.

Such a laboratory would not only connect scientists from all across Europe, but also enable them to share the rising costs of nuclear physics installations. On September 1954, the convention establishing CERN was ratified by 12 states: Belgium, Denmark, France, the Federal Republic of Germany, Greece, Italy, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, and Yugoslavia. The CERN's first accelerator, the Synchrocyclotron (SC), was built in 1957 and it offered countless bundles for CERN's first experiments in particle and nuclear physics.

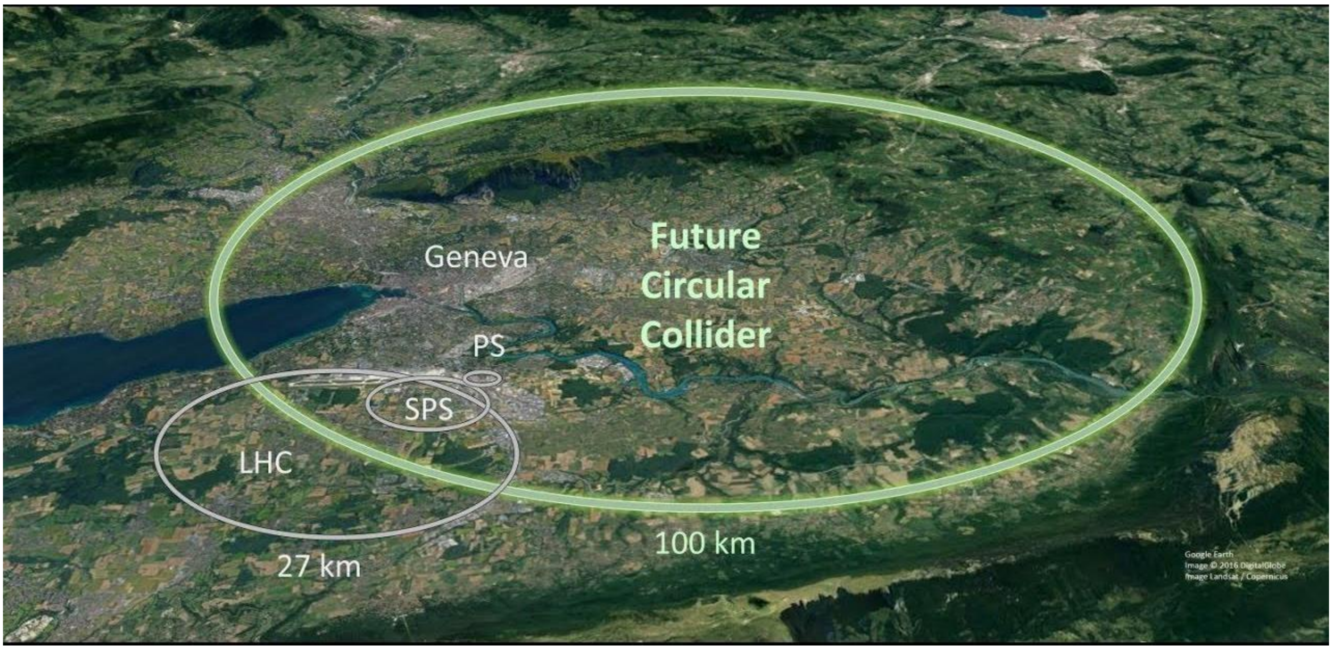
Picture 3: The voting in the canton of Geneva by the Danish, Dutch, Swiss and French governments

What is LHC?

LHC is the abbreviation of Large Hadron Collider:

- “Large” refers to the big size of this device: it’s 27 km long in circumference.
- “Hadron” because it accelerates protons or ions, which belong to the group of subatomic particles called hadrons.
- “Collider” because LHC is a research tool, an accelerator in which two beams of particles are made to collide.

LHC is not a common collider: it’s the largest and highest-energy particle collider in the world. It was built by CERN between 1998 and 2008.It is settled in a tunnel, that is 27 km long, and located 50-175 meters below ground. This collider has four crossing points, around which are positioned seven detectors, each designed for certain kinds of research. The LHC uses the collision of protons in its experiments.



Picture 4: A section of the LHC

Picture 5: A map of the current LHC, and the future circular collider

How does LHC work?

First of all, it must be said that LHC is connected to a succession of machines with increasing acceleration. Each machine accelerates a beam of particles to a given energy and then injects the beam into the next machine in the chain; this machine brings the beam to an even higher energy. The process continues until you reach the LHC. The LHC is the last element of this chain: beams reach their highest energies there.

Inside the LHC, two particle beams travel in opposite directions at an extremely elevate rate. They travel at such rate that they end up colliding with strong force; the collision generates countless new subatomic particles. They are guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets. The materials enter a superconducting state if the temperature is below a certain characteristic temperature, and as a consequence, they offer no resistance to the passage of electrical current. The electromagnets are very cold: their temperature reaches -271.3 °C. The magnets are connected to a vast distribution system of liquid helium, if they weren't, they would've overheated.

What is the purpose of LHC?

Many physicists hope that the Large Hadron Collider will help answer some fundamental questions, which were left open by the Standard Model of Particle Physics. The Standard Model explains how the basic building blocks of matter interact, governed by four fundamental forces: the strong force, the weak force, the electromagnetic force, and the gravitational force (The existence of the gravitational force has not been proven yet). Developed in the early 1970s, the Standard Model has achieved lots of significant results. However, it cannot provide an answer to some important questions: What is the origin of mass? What are dark matter and dark energy? Why is there far more matter than antimatter in the universe?

LHC, which studies elementary particles and the way they interact with each other, is conceived as a research tool to carry out experiments which can provide an adequate answer to these and other fundamental questions.

What experiments has LHC performed?

Scientists from institutes all over the world cooperate and run together experiments at the Large Hadron Collider.

The Large Hadron Collider has performed eight big experiments. Each of them requires particular detectors to analyze the multitude of particles which are produced in the accelerator.

Two of the experiments, ATLAS (A Toroidal LHC Apparatus) and CMS (Compact Muon Solenoid), use general-purpose detectors to investigate many aspects of particle production and decay.

Significant are also ALICE (A Large Ion-Collider Experiment) and LHCb (LHC b-Hadron Experiment): the first one focuses on heavy ion-collisions, the other mainly concerns the decays of hadrons containing the bottom quark, a quark with a charge of $-1/3$ e.

The smallest experiments on the LHC are TOTEM, LHCf and FADER.

A special mention goes, finally, to MOEDAL, an experiment searching for the magnetic monopole, a particle endowed with a magnetic charge which is, at present, only hypothetical.

Does LHC always work safe?

The presence of Framework (property, safety and security) does not exclude the possibility of damages at the machine. For example, on 19 September 2008 there was an incident at the LHC: during powering tests of the main dipole circuit, a fault in the electrical bus connection resulted in the release of helium from the magnet cold mass into the tunnel. Nonetheless, the safety systems performed as expected, and no-one was put at risk.

THE HIGGS BOSON AND ITS OBSERVATION AT CERN

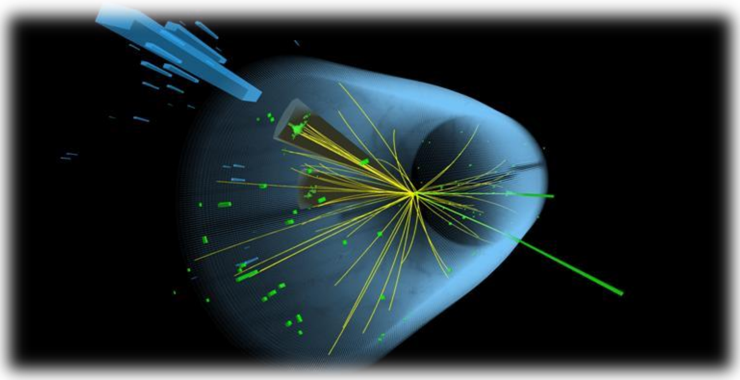
In the early 1960s, physicists developed a theory concerning the presence of very close link between two of the four fundamental forces: the weak force and the electromagnetic one. These can be described within the theory, which forms the basis of the Standard Model. That implies that certain phenomena, such as magnetism, are all manifestations of a single underlying force, the electroweak force. The equation of the theory correctly describes the electroweak force and its associated force-carrying particles, but all of them emerge without a mass.

In 1964, Peter Higgs proposed a solution: the Brout-Englert-Higgs (BEH) mechanism, so called because its development also implied the collaboration of the theorists François Englert and Robert Brout. It gives mass to W and Z bosons when they interact with an invisible field, the Higgs field, which pervades the universe.

Interaction and mass are directly proportional. Particles interacted with the Higgs field 10^{-12} seconds after the Big Bang.

Before it, all they were massless and travelled at the speed of light. After the universe expanded and cooled, particles interacted with the Higgs field and gained mass. The Higgs field has an associated particle: the Higgs boson, which can be seen as the visible manifestation of the Higgs field. A problem was that no experiments have observed the Higgs Boson to confirm the theory. The Higgs Boson was discovered on 4 July 2012.

On 8 October 2013, the Nobel Prize in Physics was jointly awarded to François Englert and Peter Higgs for the discovery, based on measurements of its decay into vector bosons, of Higgs' field fundamental particle. However, Brout did not receive the price, because the died in 2011. The mass, the last unknown parameter in the Standard Model, was one of the first parameters measured and it was found to be about 125 GeV (about 130 times larger than the mass of the proton). Subsequent studies by ATLAS and CMS found that the Higgs boson interacts with both bosons and fermions, confirming the prediction of the Standard Model that all elementary particles acquire mass via the all-pervading Higgs field.



Picture 6: A simulation of the hypothetical decay of a Higgsparticle.

Picture 7: The six authors of the 1964 PRL papers, who received the 2010 J.J. Sakurai Prize for their work; from left to right: Kibble, Guralnik, Hagen, Englert, Brout; right: Higgs.

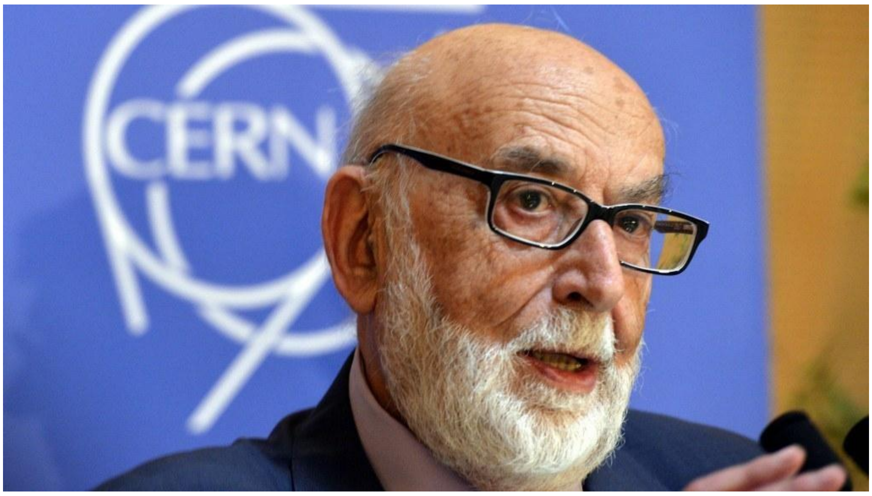
A LINK BETWEEN BELGIUM AND CERN: FRANÇOIS ENGLERT

Belgium is the birthplace of a theoretical physicist who shaped the world of modern physics: François Englert.
Englert has the merit of developing the BEH (Brout-Englert-Higgs) mechanism, which helps us understand how fundamental particles gain mass.
François Englert was born in Etterbeek, a small town close to Brussels, in 1932, from a family of Jewish origin.
During the German occupation of Belgium during the Second World War, he concealed his Jewish roots by hiding at different orphanages.
First educated as an electrical-mechanical engineer, he later chose the path of physics. He received a degree in physics in 1959 and a doctorate the following year.

The breakthrough in his career came in 1964, when Englert, together with another physicist, Robert Brout, wrote a paper proposing that particles can gain mass through the interaction with a particular field (later called the Higgs field). The particles gain mass from interaction with the Higgs field through the exchange of the Higgs boson.
The existence of a boson was hypothesized not by Englert, but by the British physicist Peter Higgs, who presented his theory in a paper wrote in 1965.

Englert, Higgs and Brout's theories were not unfounded: in 2012, scientists at the Large Hadron Collider at CERN obtained definitive confirmation of the existence of the Higgs boson. See ‘The Higgs boson and its observation at CERN.

Englert was told that his discovery “contributed to our understanding of the origin of the mass of subatomic particles”.



Picture 8: François Englert

ITALY AT CERN: FABIOLA GIANOTTI

Fabiola Gianotti (Rome, 29 October 1960) is an Italian physicist, since January 2016 director of CERN in Geneva.

She has her first acquaintance with physics after reading about Marie Curie's biography and Einstein's photoelectric effect experiment, she begins studying physics. She graduates in sub-nuclear physics in 1984; after only three years she joins CERN and begins working on various experiments.

In February 1992, she takes part in the ATLAS experiment, which involves collaboration with over 3 000 physicists from 38 countries around the world and is considered the largest scientific experiment ever made.

This experiment is based on the ATLAS detector.

The detector is shaped like a cylinder, has a diameter of 25 meters, weighs about 7,000 tons and consists of six different detecting subsystems wrapped concentrically in layers.

Beams of particles travelling at speeds up to 99.99% that of light collide at the center of the ATLAS detector and the violent collision gives origin to new particles which fly out in all directions.

A part of these particles is tracked and identified by the detector, which therefore allows physicists to investigate a wide range of phenomena: from the study of the Higgs boson and top quark to the search for particles that could make up dark matter, the possibilities which the ATLAS detector offers are countless.

The ATLAS collaboration has succeeded, for example, in presenting evidence in the LHC data for a particle consistent with the Higgs boson.

The observation such particle compatible with the Higgs boson was announced by Fabiola Gianotti on 4 July 2012.

Picture 9: Fabiola Gianotti

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Photo of LHC: from the official website of CERN:
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Picture showing an aerial view of CERN: from the official website of CERN:
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Picture showing CERN accelerators: from ResearchGate
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Representation of the Higgs boson:
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