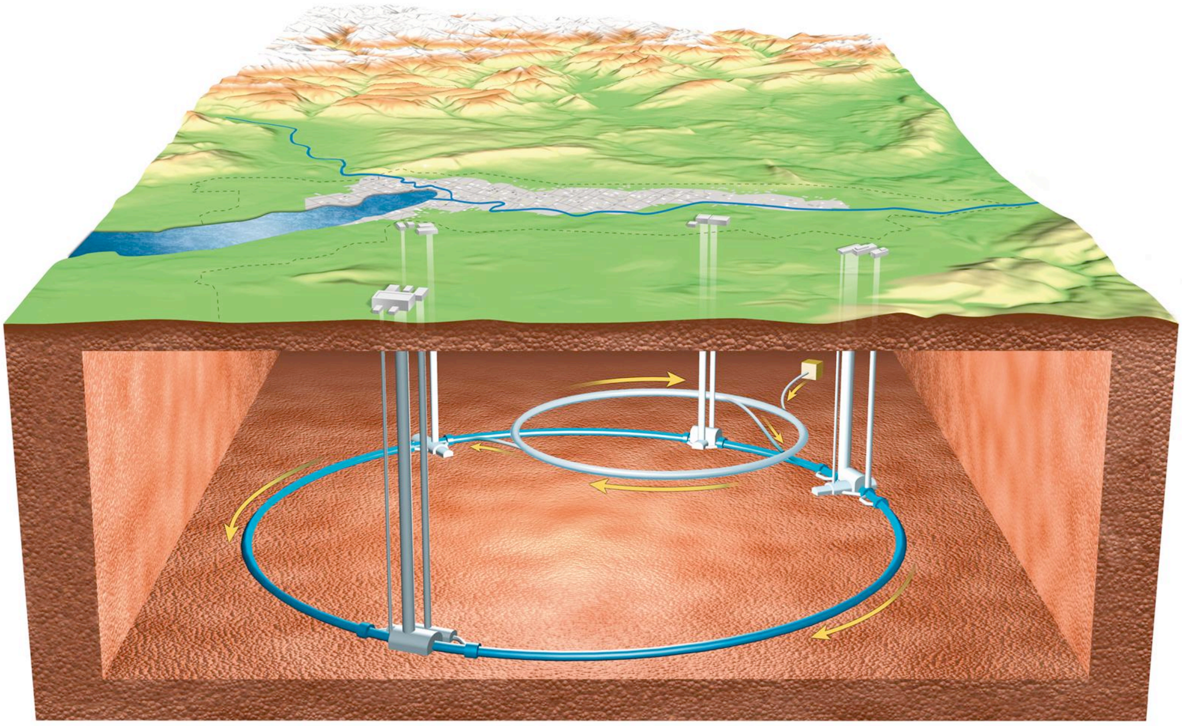
Belgian researchers at the Large Hadron Collider at CERN

Scientists and engineers from around the world finalized in 2008 the last construction stage of the largest and most complex scientific experiment ever. The Large Hadron Collider at CERN involves diverse frontline technologies applied for the first time. It is a circular particle collider of 27 km circumference built about 100 m underground on the French-Swiss border near Geneva. The first particle beams circulate since 2009 at about the speed of light, and collide protons reaching the highest temperatures ever equal to those in existence a fraction of a second after the Big Bang. Teams from several Belgian universities are contributing to the installation of a gigantic detector to study the physics phenomena occurring in these collisions. The data accumulated with the Compact Muon Solenoid detector provide the possibility to make important steps in our understanding of Nature on both the scale of the smallest particles and the largest scales in our Universe. The data from this facility should lead to a final conclusion on the existence of a yet undiscovered particle scientists believe to be responsible for the mass of the particles in our Universe. The discovery of this particle could result in a Nobel Prize for the three scientists, amongst whom two Belgians Robert Brout (deceased 2011) and François Englert, who first postulated its existence. The data will also provide insight into 96% of the content of the Universe, which we cannot understand today, the so-called dark matter and dark energy.

Belgian universities involved:

Université Catholique de Louvain
Université de Mons-Hainaut
Université Libre de Bruxelles
Universiteit Antwerpen
Universiteit Gent
Vrije Universiteit Brussel

Scheme of the Large Hadron Collider at CERN



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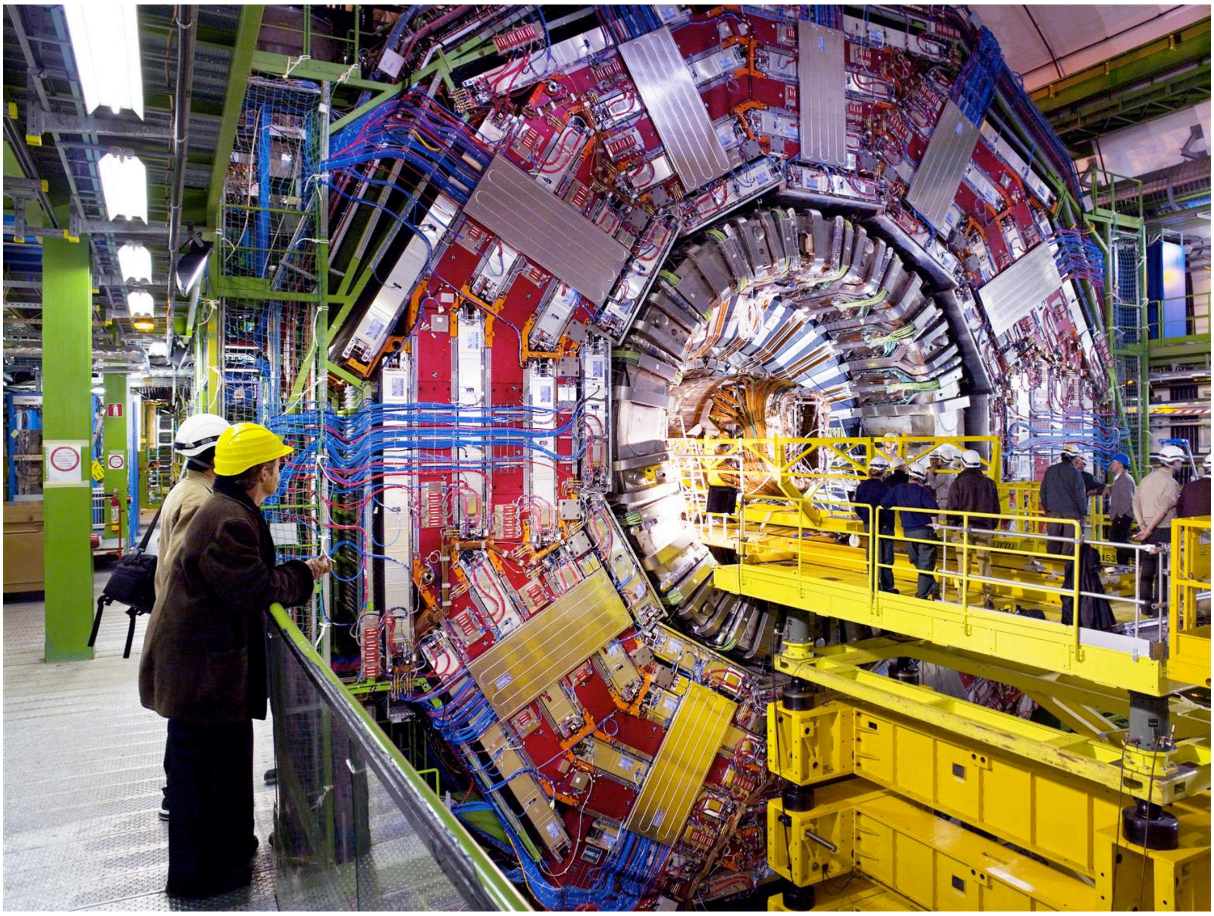
Picture of the installation of the Compact Muon Solenoid detector



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1. Context of the project in physics research

Particle physicists seek answers to questions about the content and the origin of the Universe. The experimental and theoretical achievements over the last half century made possible the creation of the Standard Model of particle physics. After a long series of experimental tests this theoretical model still holds, and therefore reveals part of Nature's story about its smallest building blocks. Despite this tremendous success, many fundamental questions are not answered by this model. The theoretical quest to create a new model beyond the Standard Model, incorporating new phenomena to address these open problems, led over the last decades to a number of possible models. These models predict particular observations in the high energy particle collisions physicists study at particle colliders. The start-up of the Large Hadron Collider represented a new milestone in our quest, because for the first time we reached an energy and intensity domain several times larger than in previous experiments. For the first time we test precisely the predictions of the proposed new models. The observations in this highest energy domain ever help us to solve the puzzle of the micro-cosmos and lead us to a deeper understanding of the origin and evolution of the Universe.

2. Presentation of the Large Hadron Collider (LHC) at CERN

CERN, the European Organization for Nuclear Research, was founded in 1954. It has become a prime example of international collaboration with currently 20 Member States including Belgium from the start. It is the biggest particle physics laboratory in the world, and sits astride the Franco-Swiss border near Geneva. CERN is a laboratory where scientists unite to study the building blocks of matter and the forces that hold them together. The new Large Hadron Collider will collide protons up to energies of 14 000 billion ElectronVolts (equivalent to the temperature 10^{-12} seconds after the Big Bang) and at a rate of several billion collisions a second. It is a unique machine constructed by taking great steps across the frontiers of technology and engineering. The accelerator, which has a circumference of about 27 km, is positioned about 100 m underground and uses superconducting magnets at about 1,9 degrees above absolute zero to guide the protons on their circular path while they are being accelerated and collided. The total amount of energy stored in the beams of these small particles is corresponding to the kinetic energy of a large high speed train.

CERN brochure: http://cdsweb.cern.ch/record/1097379/files/CERN-Brochure-2008-002-Eng.pdf
CERN's brochure of the LHC: http://cdsweb.cern.ch/record/1106546/files/CERN-Brochure-2007-006-Eng.pdf

3. Presentation of the Compact Muon Solenoid detector (CMS)

The proton collisions are studied by two general-purpose particle detectors, ATLAS and CMS, while two other detectors are used for specific physics purposes, ALICE and LHC-b. These detectors are gigantic compared to the scale of the elementary particles to be studied. Their complexity exceeds that of previous detectors to accomplish the goal of measuring the particles with great precision. International collaborations of thousands of physicists and engineers have worked for about 15 years from the original design to the final construction of these experiments. The

Belgian laboratories mentioned on the front page participate in the construction of the CMS detector and perform the analyses of the collision data observed by this instrument. Belgium has joined the CMS collaboration from the start with a team of about 80 people today. The complete CMS detector is a large cylinder, 21 m long, 15 m in diameter and weighs approximately 12 500 tons. One of the main components of the CMS detector is the world's largest superconducting magnet. It is 6 m in diameter and 13 m in length producing a uniform magnetic field of 3.8 Tesla, which is about 100 000 times the magnetic field of the Earth.

Main public CMS website: http://cms.cern.ch/
CMS outreach page: http://cmsinfo.cern.ch/outreach/
CMS brochure: http://doc.cern.ch//archive/electronic/cern/others/multimedia/brochure/brochure-2006-007-eng.pdf

4. Expected results of the project

Today there is no experimentally confirmed description of how elementary particles receive a mass. This is however very important to explain Nature as most of these particles do indeed have a non-zero mass. A mechanism created by P.Higgs and Belgian ULB scientists R.Brout and F.Englert in the sixties predicts the existence of a new as yet unobserved particle field to interact with the elementary particles and give them the masses they have. The LHC is built to give a final answer on the existence of this particle, either by its discovery or a firm conclusion that it does not exist. The existence of this particle is however crucial in our quest to unravel Nature and forms the basis of most theories. Therefore a discovery of this particle may result in a Nobel Prize for Belgian physicists.

Another as yet unobserved phenomenon, namely that Nature could be supersymmetric, would help us to explain for example the dark matter content in the Universe. If Nature is supersymmetric we should discover new particles related to this symmetry in the proton collisions at the LHC. These particles could be the main cause of the large amount of non-interacting matter (dark matter) in the Universe and therefore a discovery would bring us closer to an understanding of the origin and evolution of the Universe we live in.

Research on other phenomena, like the observation of extra space dimensions and black holes, will bring us closer to the "Theory of Everything".

If we do not observe the above phenomena, it would cause a revolution in particle physics. Our way of thinking would change dramatically. Therefore the outcome of the LHC project itself will define the future of particle physics research.

5. Timeline of the project (including important events)

The first ideas of the project were already discussed at workshops 25 years ago, followed by in depth research and development on the design of the collider and detectors. The construction period of accelerator and detectors spanned nearly two decades. By the year 2009, all pieces were brought together ready to start exploiting the facility and to explore the new energy frontier. Also the strategies to analyse these complex particle collisions and the computing infrastructure are in place and their performance tested. After the 2009-2010 commissioning period the machine was fully operational in 2011. The search for new phenomena started therefore at a tremendous speed this year with studies leading to a thorough understanding of our Universe.

6. Contributions from Belgian scientists

In total there are about 80 physicists and engineers involved from the Belgian institutes mentioned in the CMS experiment to take collision data at the LHC. From the start Belgium was involved in the design and construction of the main tracking device of the CMS detector. Belgium physicists are now taking a leading role in the commissioning, the data acquisition and the trigger system of the CMS experiment. Belgian groups are also involved in the design of the strategies to analyze the collision data, in particular in the context of Higgs and exotic particle searches, top quark and forward physics. Recently Belgian groups extended our activities to the design and construction of the forward muon detectors and forward calorimeter detectors, and the performance studies of the tracker. Two Belgian computing centers which are part of an international GRID network of computers and host about 2000 computing cores and has more then a Petabytes of disk space, has been set-up to analyze the collisions observed by the CMS experiment. This device, unique in Belgium, is crucial for our exploration of the collisions data.

8. Applications

Particle physics research is a driving force for the development of very sophisticated instruments using technologies that often exceed the available industrial know-how. Many of these technologies have made our daily lives more efficient, practical and comfortable. Examples are the development of the World Wide Web, improved PET scanners, large superconductive magnets, distributed computing networks, and many more. The collaborating universities and CERN provide a unique education and training ground for the next generation of scientists in an international setting.

CERN website: http://technologytransfer.web.cern.ch/TechnologyTransfer/

9. Relevant links

Main website for CERN activities: http://public.web.cern.ch/Public/Welcome.html
Main website for CERN's press office: http://press.web.cern.ch/press/
Main public website of the CMS experiment: http://cms.cern.ch/
Links to LHC related websites in other countries:

- UK: http://www.lhc.ac.uk/
- France: http://www.lhc-france.fr/
- Germany: http://www.weltderphysik.de/de/351.php
- US: http://www.uslhc.us/

Website on general particle physics topics: http://particleadventure.org/

For high resolution images:
Multimedia gallery of CERN: http://multimedia-gallery.web.cern.ch/multimedia-gallery

10. Detailed contact information

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Particle physics in Belgium

As a founding member state of CERN, Belgium has made numerous and important contributions to experimental particle physics projects over the last fifty years, thanks to the support of its universities, and of the National Fund for Scientific Research (FNRS/NFWO) and its associated Interuniversity Institute for Nuclear Science (IISN/IIKW). Belgian teams have been involved in major experiments using all the accelerators and colliders which, over this period of time, have been made available at CERN. They have also been present on other fronts in foreign laboratories, such as DESY (Germany) and Fermilab (USA).

The Brussels contributions to the Gargamelle neutrino experiment at the CERN proton synchrotron, leading to the discovery of the neutral currents should be underlined. On the theoretical and mathematical physics side, various groups have been active during the same period in all the universities of the country, covering many subjects. If only one development is to be singled out, it is the mechanism of spontaneous symmetry breaking proposed by Brout and Englert in Brussels, and by Higgs in Edinburgh, leading to the prediction of a scalar boson.

More recently, the efforts of the experimentalists of Antwerp (UA), Brussels (IIHE, ULB-VUB), Gent (UGent), Louvain-la-Neuve (UCL) and Mons (UMH), have concentrated on the following lines of research:

•Experiments using neutrino beams: successively CHARM-II, CHORUS and, today, OPERA. Contributions to experiments like HARP and to the development of ß-beams which should lead to the design of neutrino factories.

•Experiments at the electron-positron collider LEP: DELPHI and, to a lesser extent, ALEPH and OPAL whose analyses are still under way.

•Experiments on the deep-inelastic interaction of electrons or positrons on protons at the HERA collider: study of diffractive processes with H1, of the spin structure of the nucleon with HERMES and of W production with ZEUS.

•Preparation of the CMS experiment at the Large Hadron Collider at CERN, where the Belgian contributions range from the construction of the forward silicon tracker to the design of the trigger for the experiment and the optimization of the analysis schemes.

•Observation of ultra high energy neutrinos at the South pole with the AMANDA and IceCube detectors.

Belgian physicists have contributed to all phases of these projects: the design of the experiment, the construction of the apparatus, the collection of the data and their analysis.

Since 2002, collaboration between most physicists, theoreticians as well as experimentalists, doing research in the physics of particles and fields has been enhanced within a network supported by the federal government and called the "Interuniversity Attraction Pole (IAP) in fundamental interactions". Training, information exchange and outreach are also among the objectives of this network, which should be soon extended to encompass all teams active the field.

The participation of Belgium in a world wide computing Grid is actively being prepared through various initiatives taken at regional and national levels.