

## The Large Hadron Collider ; bridge between two infinities

The theme of this symposium in memory of the fall of the Berlin wall is : breaking down walls and building bridges. In my contribution I would like to show you how the Large Hadron Collider (LHC) constitutes a bridge between the Micro- and Macro cosmos. After introducing the two infinities to which I refer I will show you the LHC proton-proton collider at CERN which is about to start the most ambitious research project that mankind has ever conceived.

Since the beginning of humanity, men have looked at the sky and asked themselves many questions like :

- How does the universe work, where does it come from and where does it go. In modern physics they translate into ;
- What are the ultimate building blocks of all matter, how do they move and what makes them move. These are exactly the questions that Particle or High Energy Physics addresses and that have guided Natural Philosophy throughout history.

The present visible universe extends over at least  $10^{26}$  meters, contains about  $10^{11}$  galaxies and about  $10^{21}$  stars. The most widely accepted hypothesis for its origin is the model of the Big Bang based on three fundamental observations :

- Edwin Hubble's observation of the evading galaxies.
- The abundance of light elements due to the primordial nucleosynthesis.

- The observation by Penzias and Wilson of the microwave background radiation at  $3^0$  K; later refined by the COBE and WMAP satellites.

In the macrocosm, Einstein's general relativity governs the behavior of matter at the large scales involved. However in the microcosm Quantum Mechanics rules the behavior of matter. Both these pillars of modern physics have been experimentally verified to unprecedented precision however as for now, both theories still seem in contradiction. In some extreme systems like the early universe or black holes (extremely small and heavy) both theories are required.

After slightly over one century of experimentation in particle physics, the "Standard Model" of particles and fields has emerged as an effective theory that describes well the physics of the microcosm at the dimensions and energies where experimentation has been possible. Four fundamental forces act between matter particles : the strong force through the exchange of "gluons", the electromagnetic force with the exchange of photons, the weak force where charged or neutral heavy bosons (W,Z) are exchanged and finally gravity with the exchange of the hypothetical "graviton". Gravity is far too weak to be of any importance at the scale of fundamental particles.

All matter is build up from three families of fundamental fermions : quarks and leptons.

All these fundamental particles of the Standard Model (SM) have been experimentally observed and studied however their masses are generated through their coupling to the hypothetical "Brout-Englert-Higgs" field generated by a still undiscovered boson; the missing piece of the SM theory. However the particle content of the SM only represents 4% of the mass in the universe. The remaining 96% are referred to as "dark matter and dark energy". It is therefore generally believed that the SM requires to be extended in order to describe correctly the behavior of the physical systems under study. Astronomers study the universe but can only look back to about 300000 years after the Big Bang when electrons were bound in atoms and light was set free. To study the universe at earlier instances particle colliders are used to reproduce similar energy density conditions as

those of the early universe. The most recent operational ones among them : LEP an  $e^+e^-$  collider at CERN (1989-2000) and the Tevatron proton-antiproton collider in the USA (1983-now). At the energy densities obtainable there, no contradiction with the numerous predictions of the SM has been observed; however the “Brout-Englert-Higgs” boson has remained undetected pushing its mass above  $114 \text{ GeV}/c^2$ . A new proton-proton collider LHC has recently started operating at the CERN laboratory near Geneva; its mass reach should attain the 1 TeV scale and it is expected that its research program will take particle physics beyond the Standard Model.

CERN (Conseil Européen pour la Recherche Nucléaire) is at present the largest laboratory for Particle Physics research in the world. It is situated near Geneva in Switzerland and has been founded in 1954 to stop the brain drain in Europe after World War II. Today the organization has 20 member states and more than 10000 users from all over the world. After the exploitation of the LEP  $e^+e^-$  collider until the year 2000, a new accelerator has been installed into the LEP underground tunnel of 27 km length : The Large Hadron Collider LHC. This fully superconducting proton-proton collider is a marvel of technology pushing many of the technologies used to new limits. Its aim is to provide proton-proton collisions at a centre of mass energy of 14 TeV at a luminosity of  $10^{34} \text{ cm}^{-2}\text{s}^{-1}$  i.e. a gain of a factor 7 in energy w.r.t. the Tevatron but more importantly a gain of a factor 100 in luminosity. The LHC will provide beam crossings at a rate of 40 MHz in order to look for extremely rare processes. To achieve its design goals the 1232 superconducting dipole magnets have to deliver a magnetic field of 8.5 Tesla requiring a current of 12000 Ampères to run through its superconducting coils. The entire machine is therefore cooled with super fluid Helium at a temperature of  $1.8^0 \text{ K}$ ; colder than interstellar space. The two counter rotating beams contain each 2835 bunches of  $10^{11}$  protons per bunch. They travel in a 27 km long vacuum pipe where the residual pressure is ten times less than on the moon to reach a speed of 99.9999991% that of light. No wonder this accelerator has put unprecedented challenges to the detectors that will record the collision data since they will have to dig out very rare events from the 800 million proton-proton collisions that occur per second; a selection of 1 in  $10^{13}$  typically. Four gigantic detectors have been conceived and built. ATLAS and CMS are multi purpose detectors designed to search for new physics. ALICE is con-

ceived for heavy ion collisions and LHCb for the study of the b-quark system. Six Belgian universities have pooled their resources to contribute to the design, construction and operation of the Compact Muon Solenoid experiment together with some 160 institutes from all over the world. Well over 2000 engineers and scientists collaborate in this huge scientific adventure. The key element of the CMS detector is the world's largest superconducting solenoid, about 7m in diameter and 13m long, delivering a magnetic field of 4 Tesla inside the coil. The surrounding modular iron yoke brings the CMS overall dimensions to 15m in diameter and 22m in length for a total weight of 12500 Ton. The magnetic spectrometer is equipped with millions of sensors to record and identify the particles produced in the collisions. Moving from the interaction point outwards one finds inside the coil : the pixel detectors, the silicon tracker, the electromagnetic calorimeter and the hadron calorimeter. Outside the coil the iron return yokes are instrumented with 4 stations of muon detectors. The pixel and silicon strip tracking elements will record the tracks of charged particles through the magnetic field and hence measure their momentum. Some 80000 Lead Tungstate crystals will measure the energy of electrons and photons in the electromagnetic calorimeter. The hadron calorimeter consists of a sandwich structure of metal plates interleaved with plastic scintillating tiles and measures the energy of hadrons. The penetrating muon particles will be recorded in the outer layers of this onion like structure. Also the ATLAS detector has a similar onion like structure of components to record and identify particles. Their muon magnet is however based on 8 superconducting toroid coils making the ATLAS detector even bigger : 25m in diameter and 46 m long. The remaining two detectors, ALICE and LHCb, are designed for their specific research program and I have no time to go into the details here.

During the last 6 weeks of the year 2009, the LHC has successfully been brought into operation reaching the world record collision energy of 2.36 TeV corresponding to 2000 Ampères of current in the dipole magnets. In 2010, the energy and intensity will rise to reach at least 7 TeV in the center of mass. The most ambitious scientific research program will then start. The fundamental questions that the LHC research program will address are paramount; among them :

- Does the Brout-Englert-Higgs boson exist and what is its mass?
- Is there a whole new class of particles to be discovered as predicted by the Supersymmetry (SUSY) theory. If so, this may solve the enigma of the missing mass in the universe.
- Do extra dimensions exist in nature?
- What is the origin of the matter-antimatter asymmetry that we observe in the universe?
- Does a new kind of fundamental matter exist where quarks and gluons would be set free to form a quark-gluon plasma?
- Do the elementary particles that we know today still exhibit substructure at higher energy levels?

But of course the experiments are also designed to discover unexpected phenomena that would lead the way beyond the Standard Model and improve our understanding of the origin and fate of our universe. The LHC research program really builds a bridge between two infinities.

