The New Physics of the 21st century

Titanic Collider

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10 September brought the much-awaited launch of the world's most powerful accelerator, dubbed the LHC. It may perhaps manage to find the "God particle": the long sought-after Higgs boson

Elementary particle physics is nowadays governed by the Standard Model. It maintains that the basic elementary particles can be classified into carriers of the fundamental forces plus quarks and leptons. Of these, only the lightest few ordinarily occur, since heavier particles quickly decay into lighter ones. However, not everything in this Standard Model is completely clear. For instance, we do not know why the particles differ so greatly in terms of mass: the *t* quark is 350,000 times heavier than an electron, a γ photon has an intrinsic mass of zero, while the *W* and *Z* bozons have a mass of around 90 GeV. Physicists expect this riddle to be solved by the experimental discovery of the theoretically predicted Higgs particle, thought to give other particles mass. The hope is that the Large Hadron Collider (LHC), the world's most powerful particle accelerator, will help us confirm the Higgs particle's existence.

Very heavy particles can only be created when there are large energies involved. Such energies were present just after the Big Bang (i.e. within $t < 10^{-10}$ s after the beginning of the universe), but they also occur when particles of cosmic radiation collide with our atmosphere – albeit extremely rarely. If we had a detector covering an area of 10 km^2 trying to observe a Higgs particle resulting from such interactions, we would probably have to wait a billion years for a single incident!

These days we are able to build devices that impart incredible energies measured in teraelectronvolts (TeV) to trillions of particles

Andrzej Kotarba

Polish engineers and technicians have performed thousands of measurements to help smooth out irregularities at the LHC

(this is like imparting the amount of energy present in a flying mosquito to a single proton) which we can then set to collide with one another a billion times a second. Under such conditions, a Higgs particle could be created every 10 seconds - although its appearance still has to be recorded and identified among the huge quantities of other interactions. The same challenges apply to noticing other as yet unwitnessed phenomena we expect to occur in the LHC accelerator.

The LHC program

The Large Hadron Collider has been built inside an underground tunnel 27 km in circumference dug for the purposes of a previous accelerator, in stable bedrock some 100 m under the surface. The LHC is a ring accelerator, in which particles sped up to higher and higher energies move along circular orbits inside vacuum pipes, their trajectories guided by magnets - the greater the energy (momentum) of the particles, the greater the intensity of the magnetic fields is needed. This circular configuration simplifies the process of acceleration: particles repeatedly pass through the points where additional energy is imparted to them, and moreover collisions become more likely since they repeatedly cross the "intersections" (points where the particle orbits intersect). The total energy released in such head-on collisions is 14 TeV, but since that gets shared between the quarks and gluons making up the individual protons we can expect the resulting particles to have masses on the order of up to a few TeV "only."

Aside from the acceleration systems, magnets are key elements of the LHC accelerator - all told, the LHC has around 10,000 magnets of various types (for bending and correcting, etc.) positioned along the 27 km ring. The LHC uses superconducting magnets, with coils made of materials exhibiting zero resistance at low temperatures (such as niobium-titanium alloy). This solution helps keep electric power consumption on moderate levels - the LHC's launch will not greatly boost CERN's power requirements (now comparable to the needs of a medium-sized city).

Physicists hope the LHC will find the theoretically predicted Higgs particle, thought to give other particles mass

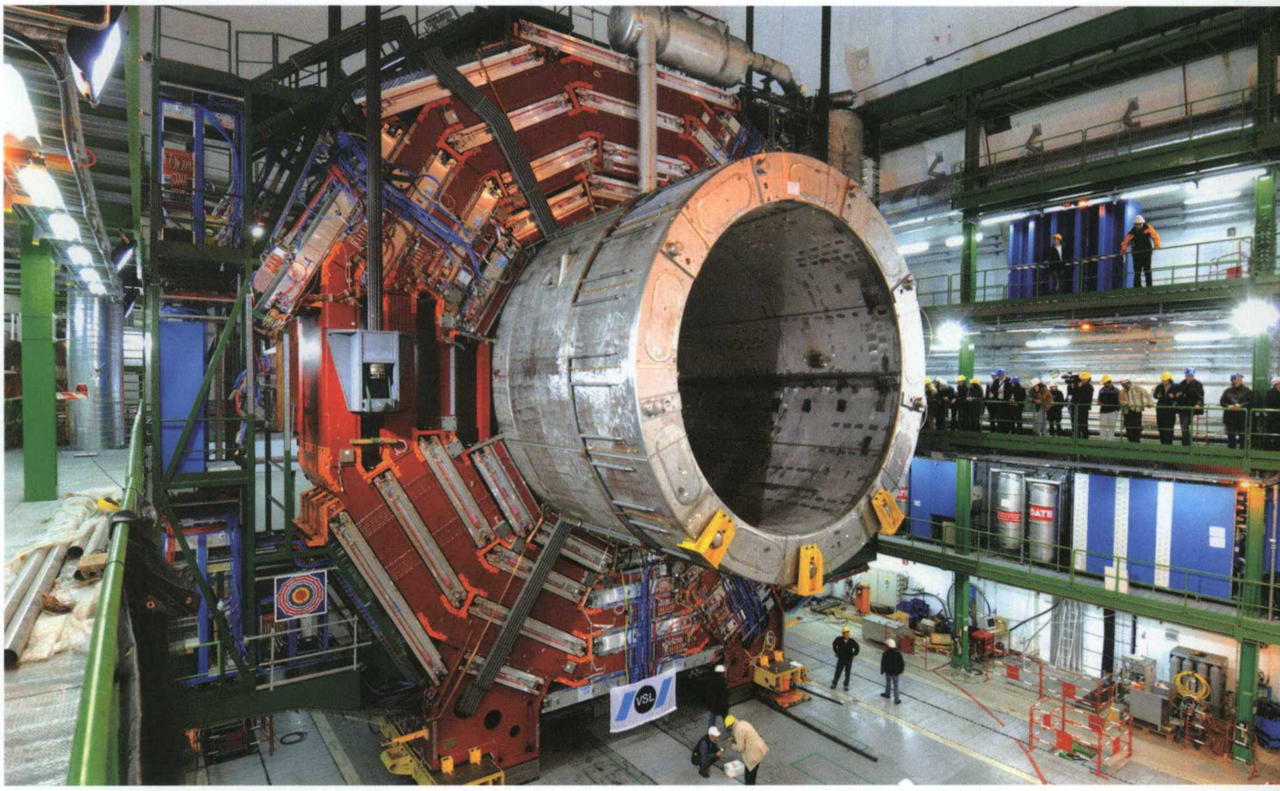
CERN archives

These supports, meant to bear the calorimeters of the ATLAS experiment (weighing 1800 tons), were made in Poland

120 tons of liquid helium is used to cool the magnets to temperatures close to absolute zero, making the LHC the world's largest helium installation. A sizable share of that helium comes from Poland (Odolanów). When brought down to a temperature of 1.9 degrees Kelvin (less than the temperature of outer space!) helium becomes superfluid and demonstrates extraordinary liquidity and thermal conductivity, enabling consistent temperatures to be maintained all along the accelerator's extensive circumference.

Inside the LHC magnets are two vacuum pipes 5 cm in diameter, surrounded by two independent coils generating opposing magnetic fields. Two independent streams of particles can therefore circulate in opposite directions within the same magnet. To ensure that the proton beams do not interact with any traces of gas, the vacuum maintained in the tunnels is lower than the vacuum present on the surface of the Moon, enabling the beams to circulate for 10 hours without any distinct loss in proton numbers. They will be brought to collide head-on at several chosen points along the accelerator's circumference, where spectrometers, the instruments for measuring the output of such collisions, are located. Because the vast energy contained in the accelerated proton beams is sufficient to melt several hundred kilograms of copper, the guidance system has to steer them with great precision to make sure none of the components of the accelerator itself get damaged.

CERN archives



A magnet of the CMS experiment, being installed in the subterranean experimental chamber

The beams which are no longer needed get defocused and directed into a special "beam dump," an energy absorber made of graphite, situated in a side branch of the tunnel.

Installation of all the LHC elements was completed in 2007. Several months of work on cooling individual sections of the machinery began in early 2008 (the full circle being divided into 8 sections), after which testing of the magnets commenced. In the summer of 2008 the vacuum pipes were closed, and on 10 September the first proton beams were sent around the accelerator's circumference. The first experimental collisions are now expected in 2009.

Experiments

Plans for four experimental projects recommended by the research committees were approved by CERN management back in 1994: the two general-purpose experiments ATLAS (A Toroidal LHC ApparatuS) and CMS (Compact Muon Solenoid), able to measure a whole range of reactions but especially geared towards seeking the Higgs particle and other new particles, plus ALICE, specially designed to study heavy ion interactions where thousands of secondary particles will be produced, and LHCb, concentrating on the decay of b-hadrons (heavy particles containing a bottom or "beauty" quark).

The first two experiments are colossal undertakings, unparalleled in the history of particle physics. The ATLAS apparatus takes the form of a cylinder 44 meters long, 24 meters in diameter, weighing some 7,000 tons - dimensions comparable to a six-storey building. CMS is somewhat smaller but heavier - its central magnet has an iron core, weighing more than the material used to build the Eiffel Tower.

All the experiments also require sensitive state-of-the-art electronics capable of pinpointing and recording interesting events. The crisscrossing beams of protons will produce many simultaneous collisions requiring the ATLAS and CMS spectrometers to record the paths and energies of more than 1000 particles at a time. 1-2 megabytes of information will be generated by each event (similar to the amount of information contained in a typical book). Because 40 million such events (or "books") will be generated every second, data will have to be preliminarily analyzed in real time so that only 100-200 of the most interesting events can be stored, then subsequently processed and analyzed to identify new particles and/or new phenomena. Even then, a huge amount of information will be generated as a result. Every year, each of the experiments will register several petabytes (10^{15} bytes) of data - akin to a vast "library" of a billion volumes, somewhere concealing magic rules that need to be found and deciphered.

Dealing with this incredible quantity of information itself poses a separate research problem, made all the more challenging by the fact that international teams strewn across countries and continents each need to have broad access to the data. The right solutions have only become available in recent years: very fast (and relatively cheap) network connections now make it possible to set up a powerful system of distributed computing. This system is called a "Grid," by analogy to an electric power network that can supply electricity from various power stations spread throughout the country.

Poland's contribution

The Polish contribution to the LHC program began back in the early 1990s and included involvement in R&D work, studying the feasibility of constructing the necessary detectors and sensor electronics, and striving to better understand the physical processes caused by very high energy particles. Polish physicists from Kraków and Warsaw, assisted by engineers and technicians, now play a part in all four LHC experiments: teams from AGH University of Science and Technology (ALICE, ATLAS, and LHCb), the Sołtan Institute for Nuclear Studies in Warsaw (ALICE, CMS, and LHCb), the Warsaw University of Technology (ALICE), and the University of Warsaw (CMS).

Polish involvement in the LHC research program would not be complete without being linked into the World LHC Computer Grid (WLCG). The first work has been launched at the networking centers in Kraków (ACK Cyfronet AGH), Poznań (PCSS) and Warsaw (ICM UW) in 2000. Involvement in the European projects CrossGrid (coordinated by the author) and EGEE offered an opportunity to become familiar with new grid technology, enabling Polish centers to become equal partners in the CERN project. At present, some 2% of all computation required by the LHC experiments is now being performed in Poland.

Does it all make sense?

Instead of an ordinary summary, we can conclude this overview by asking whether investing all of this effort and money really does make sense. Many people feel the answer is a resounding "yes," that the advancement of civilization is impossible without scientific research. The cost of the LHC program (at some 4 billion euro), although huge, would nevertheless represent just a tiny fraction of worldwide spending on weaponry and warfare, being comparable to the price of an F-16 squadron purchased by Poland. Yet what is even more important is mankind's constant drive to study and understand the world that surrounds us. Such curiosity is what has brought humanity to its current level of development, the comforts of which few would opt to do without. Columbus and other explorers set sail to learn about the Earth and its wonders. Faraday and Maxwell studied electricity at a time when most people, including many scientists, considered it something unpromising and impractical. Democritus and his successors, Bohr, Dirac and Fermi, wondered about the smallest bits that make up the world and what holds them together, leading to the discovery of nuclear power. In recent years physicists involved in the large CERN experiments "happened" to invent something that became known as the World Wide Web. Perhaps, therefore, research at the LHC will yield knowledge about new particles and forces that will prove very useful to civilization in the not-too-distant future. ■

Further reading:

http://www.fuw.edu.pl/~ajduk/Public/Welcome.html
http://www.cern.ch
http://www.przygodazczastkami.org

CERN archives

Prof. P.W. Higgs himself, visiting the gallery of the ATLAS experiment (4 April 2008)