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CERN, the European Organization for Nuclear Research, operates the world’s leading laboratory for particle physics. Its business is fundamental physics, finding out what the Universe is made of and how it works. Founded in 1954, CERN has become a prime example of international collaboration, with currently 20 Member States. Additional nations from around the globe also contribute to and participate in the research programmes.

The CERN Laboratory sits astride the Franco–Swiss border near Geneva. Its flagship research facility, the Large Hadron Collider, is housed in a 27-kilometre tunnel under the plain between Lake Geneva and the Jura mountains. The photograph above is a view from Le Reculet in the Jura, showing the Laboratory in its setting north of Geneva with the Alps, including Mont Blanc, in the distance.

Photos:
CERN Photo Service,
Thomas Kubes (pp. 2–3),
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AEPSHEP (p.33, bottom),
Christoph Balle (p.35),
Octavio Mestre/Francesco Soppeisa Architectes (p.36, right).
Contents

Introductory messages  4
A year at CERN   6
Snapshots 2012   9
Physics & Experiments  12
Computing   22
Accelerators   25
Making an impact   31
A place to work   35
Safety & environment   37
Council & Committees  40
Internal organization   42
CERN in figures   44
Glossary   45
The discovery of a particle that bears many of the hallmarks of the Higgs boson, together with several record-breaking achievements by the teams that operate the LHC, made 2012 a historic year for CERN. These successes, which marked a major step forward in our understanding of the particles and forces of matter, are the result of a long-term strategy that has involved many players for some 40 years: the particle-physics community, in Europe and around the world; the Staff and Management at CERN; and the Member States, without whom CERN would not exist.

During the year, the process to enlarge CERN geographically continued well. In March, Serbia formally became an Associate Member State in the pre-stage to membership, joining Israel; they are to be followed by the Republic of Cyprus in 2013. In addition, Brazil, Russia and Ukraine have joined Turkey in applying for Associate Membership.

It is highly encouraging that new countries are keen to join CERN, even during the continuing global recession. Indeed, despite these well-known difficulties, most of the Member States have been able to meet their obligations and thereby keep CERN’s economic situation manageable.

At the same time, the situation of the CERN Pension Fund, which has seen structural problems, is encouraging. This is thanks not only to very good results from investments during 2012 but also to the continued support of the Member States.

The process to update the European Strategy for Particle Physics also made excellent progress in 2012. The Open Symposium held in Cracow in September was an important part of the consultation undertaken by the European Strategy Group, which will present a proposal for an updated strategy to Council in March 2013. With recent results in neutrino physics and continuing research at the high-energy frontier at the LHC, we can anticipate a bright future for the subject for the next 20 years.

My term of office as President of Council finished at the end of 2012, when I handed over to Agnieszka Zalewska. A professor at the H Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow, she has a long association with CERN.

I would like to thank the Member States, Management, Staff and all of CERN’s users for making my three years as president so remarkable. I wish my successor as excellent a term as I have had.

Michel Spiro
In 2012, particle physics became one of the biggest news stories around the world, when the ATLAS and CMS collaborations announced the discovery at the LHC of a particle that looked very much like the long-sought Higgs boson. I commented a year ago that obscure words such as ‘sigma’ were beginning to appear beyond the pages of science magazines. Following the announcement on 4 July, they were appearing in headline news on TV and radio, as well as in newspapers and magazines, in print and on the web.

It was a fantastic day for science, but also a great day for humanity, for it provided an outstanding symbol of what people can achieve when countries pool their resources and work together. CERN was founded on principles of fairness to its members and openness to the world. It gives an equal voice to all Member States, large and small, and allows them to contribute according to their means. Its research model welcomes scientists from around the world. Today, the Laboratory is the hub of a global community of scientists advancing the frontiers of knowledge.

Scientific success stories like this are more important now than ever. At a time when the world is suffering the worst economic crisis in decades, people, particularly the young, need to see and appreciate the benefits of basic science and collaboration across borders. Having the eyes and ears of the world on CERN’s science provided a vital opportunity to send out these messages to everyone, from the general public to the decision-makers who enable basic research to be done not only here, but in labs throughout the world.

Towards the end of year, CERN took another step in helping to promote the importance of basic science, when the UN General Assembly adopted a resolution to allow our Organization to participate in the work of the assembly and to attend its sessions as an observer. In particular, we will work together on the essential role that basic science can play in development.

The year proved extremely fruitful, with a prodigious amount of data-taking enabled by the excellent performance of the accelerator complex, the experiments and the Worldwide LHC Computing Grid. The next two years will be dominated by the consolidation and refurbishment of key components in all of these systems. This will allow us to advance still further in pushing back the frontiers of basic science — and in transmitting its importance to progress in the world at large.

Rolf Heuer
A day to remember
It’s 2 am in Chicago, 9 am in Geneva and 5 pm in Melbourne, on 4 July 2012. Around the world, particle physicists in labs, lecture theatres and homes, are full of anticipation. They are waiting to hear the latest update in the search for the Higgs boson at CERN’s flagship accelerator, the Large Hadron Collider (LHC). Everyone feels the excitement in the air. The seminar has been rapidly scheduled to align with the start of the 2012 International Conference on High-Energy Physics (ICHEP) in Melbourne, where 700 participants are ready to watch by video-conference.

In a packed Main auditorium at CERN on 4 July, the ATLAS and CMS collaborations announced that they had observed clear signs in proton–proton collisions at the LHC of a new particle consistent with being the long-sought Higgs boson (see box). It was a day that everyone associated with CERN will remember for years to come. The news immediately stretched beyond the physics community to reach millions of people across the globe, not only through the webcast of the seminar, but also through social media such as Twitter, as well as through news agencies, TV and the printed press. On the day, CERN hosted nearly 100 journalists and 20 TV companies, with video footage being used by more than 1000 TV stations and 5000 news programmes.

CERN was to receive many accolades for this scientific achievement by the end of the year, including ‘Newsmaker of the year’ in the science magazine Nature.

Not only the LHC
The LHC may have grabbed many headlines in 2012, but as a storage ring, it used only some of the protons produced at CERN during the year. While the Proton Synchrotron (PS) and the Super Proton Synchrotron (SPS) are vital elements in the chain that sends particles to the LHC, they also supply a range of experiments. In addition, beams are directed to the Antiproton Decelerator (AD), the n-ToF neutron source, the ISOLDE facility and the CERN Neutrinos to Gran Sasso (CNGS) project.
More than two hours before the seminar was due to start, long queues of people were waiting for the doors of CERN’s Main auditorium to open.

Four of the six people behind the seminal work of 1964 were able to attend the seminar and share the emotion. From left to right: François Englert and Peter Higgs, Carl Hagen and Gerald Guralnik.

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A long search

The search for the Higgs boson has its roots in the 1960s. Theoreticians Robert Brout, François Englert, Peter Higgs, Gerald Guralnik, Carl Hagen and Tom Kibble did seminal work that was to become a key piece of the Standard Model of the fundamental particles of matter and the forces that act upon them. They proposed a mechanism that gives mass to some of the particles when they interact with an invisible field. As with all fundamental fields, there is an associated particle, which became known as the Higgs boson. From the 1970s onwards, searches for the Higgs boson progressed as particle accelerators provided beams of increasingly high energy. Experiments at Fermilab’s Tevatron and CERN’s Large Electron–Positron collider provided the best limits, before the LHC entered the game in 2010. Englert, Higgs, Guralnik and Hagen were all in the audience at CERN to hear the news directly on 4 July. (Sadly Brout died in 2011 and Kibble was unable to attend.)
During 2012, the accelerator complex delivered record numbers of protons to several of these facilities. Together with a few non-accelerator experiments, they all make important contributions to the diverse programme of research that CERN supports (see pp. 12–21).

CERN continued to open to the world during 2012, in line with the Organization’s mission of bringing nations together through science. In January, the President of Serbia and CERN’s Director-General signed an agreement to admit Serbia as an Associate Member State in the pre-stage to membership of CERN. With ratification by the Serbian parliament completed in March, Serbia followed Israel, who had taken the same step in 2011. These two Associate Member States join CERN’s 20 Member States, 6 Observer States and 41 non-Member States, together with 1 Candidate for Accession to Membership.

Co-ordination of the future direction of the field of particle physics, not only at CERN but in Europe as a whole, is part of the Organization’s original remit. On 10–12 September, some 500 physicists attended an open symposium in Cracow for the purpose of updating the European Strategy for Particle Physics, which was adopted by CERN Council in 2006. The meeting provided an opportunity for the global particle-physics community to express views on scientific objectives in the light of developments over the past six years, including the discovery of the new boson at the LHC and important measurements on neutrinos in laboratories elsewhere.

Another of the Organization’s missions is to promote the essential role of basic science for the benefit of humankind. Here a new horizon opened as the year drew to a close. On 14 December the General Assembly of the United Nations (UN) adopted a resolution to allow CERN to participate in its work and to attend its sessions as an observer. As a result CERN will contribute actively to the UN’s efforts to promote science, in particular with the UN Educational, Scientific and Cultural Organization.
Snapshots 2012

23/01

Nobel laureate, Murray Gell-Mann, well known for proposing the quark model, toured CERN, including the ATLAS experiment.

28/02

Iveta Radičová, left, the Slovak Republic’s Prime Minister, came to CERN on a visit that included a tour of the ALICE experiment, with the ALICE spokesperson, Paolo Giubellino, centre right, and senior physicist Karel Safarik, right.

27–28/03

CERN’s Director-General, Rolf Heuer, centre, and Frédérick Bordry, Head of the Technology Department, centre right, explore some of the latest developments during the ‘France at CERN’ event.
Former CERN Fellow, Christer Fuglesang, right, presented a ‘neutralino’ to Sergio Bertolucci, Director for Research and Scientific Computing; the soft-toy particle from CERN had travelled with the ESA astronaut into space and back.

Shree Bose, the 2011 Google Science Fair winner, visited CERN. Her winning project had focused on discovering a way to improve ovarian cancer treatment by overcoming patients’ resistance to chemotherapy drugs.

The first laureate of the Collide@CERN–Geneva prize, and the Laboratory’s first choreographer-in-residence, was the acclaimed Swiss choreographer Gilles Jobin, seen here as a ‘Strangel’ in an intervention in the CERN library.

Astronauts (left to right) Andrew Feustel, Gregory Chamitoff, Gregory Johnson, Michael Fincke and Mark Kelly in the AMS Payload Operations Centre at CERN. This crew flew on the last voyage of the space shuttle Endeavor, which delivered the AMS detector to the International Space Station in May 2011.
Jean-Marc Ayrault, the Prime Minister of the French Republic, left, and Geneviève Fioraso, the Minister of Higher Education and Research, visited the LHC with the Director-General.

President of the Slovak Republic, Ivan Gašparovič, centre left, and First Lady, Silvia Gašparovičová, met with the Director-General and Karel Safarik, right, a senior Slovak physicist on ALICE, during a visit.

Edward Stone, left, project scientist for the Voyager probes since 1972, with Roberto Battiston, INFN and Perugia University, at the SpacePart12 conference held at CERN.

CERN hosted a symposium to mark the 70th birthday of Chris Llewellyn Smith, who was CERN’s Director-General 1994–98. Left to right: (back) Rolf Heuer, Peter Jenni, Lyn Evans, Chris Llewellyn Smith, Steve Cowley, Zehra Sayers, David Gross, Chris Allsopp, Robert Jaffe, Bikash Sinha; (front) Geoffrey West, Álvaro de Rújula, John Ellis.
Candidate events consistent with the decay of a Standard Model Higgs boson in ATLAS (top) and CMS (bottom).
An excellent year for CERN’s accelerator complex meant a productive year for many of the experiments, with several records being broken in terms of numbers of particles and collisions. At the LHC, the energy in proton–proton collisions increased to 8 TeV and by the end of the year the integrated luminosity — a measure of the amount of data collected by the experiments — had risen to four times the total for the previous year for ATLAS and CMS. This wealth of data led to the event for which 2012 will long be remembered: the discovery of a new particle consistent with the long-sought Higgs boson.

A new boson at the LHC

After the excitement of the first hints of a particle that could be a Higgs boson in 2011, expectations were high as 2012 began. Once data taking at 8 TeV had started at the LHC in early April, the ATLAS and CMS experiments began to record an integrated luminosity of up to 1 inverse femtobarn (fb⁻¹) each week. With each run, the data were recorded, calibrated, reconstructed, validated and delivered to the physics analysis teams on a regular basis. At first, the teams searching for Higgs bosons restricted their attention to signal-free ‘control regions’, aiming to prove to themselves and their colleagues that the new data were thoroughly understood. After a series of review meetings, with just a few weeks remaining before July’s ICHEP meeting in Melbourne, the go-ahead was given to ‘un-blind’ the data taken up to that point. This was a moment of great excitement tinged with anxiety.

The signal of something new with a mass around 125–126 GeV became increasingly visible as more data were added week-by-week and combined with the results from improved analyses of the 2011 data. It rapidly became clear to both collaborations, working independently, that they had a significant signal for the decay of a new particle both to two photons and to four leptons. The last two weeks before the announcement were particularly intense, with exhaustive crosschecks of the results and many discussions on exactly how to present and interpret what had been seen. With the inclusion of nearly 6 fb⁻¹ of data at 8 TeV, ATLAS had signals with significances of 4.5 standard deviations (or sigma, σ) in the two-photon channel and 3.4 σ in the four-lepton channel. CMS observed signals with significances of 4.0 σ and 2.5 σ in the two-photon and four-lepton channels, respectively. This allowed both collaborations to report the observation of a new particle with a combined significance of 5 σ for ATLAS and of 5 σ for CMS using two high-resolution decay channels at the special seminar held at CERN and broadcast to the world on 4 July.

At last it was clear: a new particle had been discovered and the decays to two photons proved that it must be a boson, a particle with integer spin. By the end of the year, CMS had results showing a combined significance of 6.9 σ while those for ATLAS combined to yield 5.9 σ.

While these results established beyond doubt the existence of a new boson, its exact identity remained uncertain. As early as July, the CMS collaboration showed new techniques to reveal its identity by measuring its spin and parity — properties of particles that relate to their angular momentum and their mirror images. Since then, both CMS and ATLAS have found that the new boson is much more likely to have zero spin and positive parity than other values. These are interesting results and necessary, though not sufficient, to claim that it is a Standard Model Higgs boson.

Looking for surprises

Both the ATLAS and CMS collaborations have developed sophisticated and creative techniques to search for further new particles. One example relates to the search for dark matter — invisible matter that seems to account for 26% of the content of the Universe. (Ordinary matter made of quarks and leptons amounts to only 4%.) One way to find out if this mysterious form...
of matter is produced in collisions at the LHC is to search for ‘unbalanced’ events, in which a single photon or jet of particles is produced recoiling against a pair of undetected particles that could be dark matter (since dark matter would be invisible to the detectors). Limits can then be set on how often weakly interacting massive particles (WIMPs) — hypothetical particles that could form dark matter — would interact with ordinary matter. A highlight in 2012 for the ATLAS collaboration was to use the full dataset for 2011 to set limits for WIMPs with masses up to around 1 TeV.

One promising idea that goes beyond the Standard Model and that could provide an explanation for dark matter is supersymmetry (SUSY) — a new symmetry in nature that requires that all particles have heavier ‘superpartners’. ATLAS and CMS have performed searches for many different types of supersymmetric particles, in particular those related to the b and t quarks, and to the tau neutrino, as they could be relatively light.

Just as with dark matter, many of these searches involve finding events in which weakly interacting particles escape the detectors unseen. This makes it essential to have detectors that are hermetic, fully operational and well understood, since even a slight malfunction could mimic a ‘missing’ particle. Both CMS and ATLAS achieved this goal, despite the challenge imposed by high ‘pile-up’, where on average 30 other collisions took place at the same time as the collision of interest.

ATLAS and CMS also looked for other new particles, such as heavier bosons that could decay into pairs of top quarks and antiquarks. They would show up as a bump at a given mass in the distribution of all events containing a top quark–antiquark pair. The complete 2011 dataset gives access to masses well beyond 1 TeV, but so far there is no sign of any excess. Analysis of the 2012 data will allow searches beyond this limit.

Beauty and charm
Specializing in particles with lower masses, the LHCb experiment focuses on particles containing beauty (b) quarks, such as B mesons, as well as those having lighter charm (c) quarks. Thanks to smooth operation and an integrated luminosity of 2.2 fb⁻¹, the experiment more than tripled its dataset. After only three years, LHCb has already achieved the precision reached by the “B factories” — electron–positron colliders tuned to produce pairs of B particles and their antiparticles — in measurements of the angle γ in a triangle that is related to matter–antimatter differences in B mesons.

This wealth of data allowed LHCb to find the first evidence for the decay of a Bs (composed of a beauty antiquark and a strange quark) into two muons, Bs → μ⁺μ⁻. With only three or four such events happening for every 1000 million Bs decays, this is one of the rarest decays ever seen. The number of events observed by LHCb agrees with predictions from the Standard Model. The collaboration also obtained the world’s most stringent limit for the decay of the B̄ to two muons. Taken together, these two results had a huge impact on various SUSY models, helping to guide theorists in the right direction.

LHCb illustrated its strength for charm physics by becoming the first experiment to observe mixing between the neutral charm particles, D⁰, and their antiparticles, with a significance exceeding 5σ. Previously this phenomenon had been established only by combining several measurements in different kinds of experiments at other laboratories.

ATLAS and CMS continued to exploit the large samples of hadrons containing b quarks that are produced at the LHC — in particular those with two-muon final states, which can be recorded at even the highest luminosities. Highlights for CMS included the discovery of the Ξ⁺ (xi-b-star), a new short-lived particle. Both ATLAS and CMS studied the details of CP-
violation in the decay $B_s \rightarrow J/\Psi \Phi$ ($B_s$ goes to $J/\psi$ and $\phi$), which was found to be in perfect agreement with the Standard Model, and made precise measurements of the mass and lifetime of the $\Lambda_b$ (lambda-b).

**Precision measurements**

The ATLAS, CMS and LHCb experiments put much effort into measuring known processes with the highest possible accuracy in order to characterize the Standard Model at the energy of the LHC. Finding a deviation from predictions could be a hint for new physics beyond the current theory.

The measurements of the production of pairs of bosons — WW, WZ, ZZ, Wγ and Zγ — allowed the ATLAS and CMS collaborations to place stringent constraints on anomalous couplings between these bosons at high energies. The results are also an essential ingredient in understanding the backgrounds to all of the searches for the Higgs boson and new physics alike.

The more energy an accelerator provides, the more massive the particles that can form in the collisions. At the LHC it is much easier to create the heaviest quark — the top quark, $t$ — than at any previous collider, thus providing an unprecedented amount of data for CMS and ATLAS. Particular highlights included, from CMS, an improved accuracy for the mass and production rate of the top quark, and from ATLAS, the measurement of the helicity (a spin characteristic) of the $W$ boson and spin correlation in pairs of top quarks and antiquarks. These are key ingredients to test the Standard Model, since all of these quantities are intricately correlated and must provide a coherent picture.

Reducing the error margins removes leeway in the model and should eventually reveal if new theories — and which ones — are needed.

**Hot matter**

Quark–gluon plasma (QGP) is a state of matter that probably existed just after the Big Bang, when the temperature was much too high for quarks to ‘condense’ into protons and neutrons, the building blocks of today’s matter. At the LHC, the head-on collisions of lead ions — atoms stripped of electrons — allow the study of such hot, dense matter. A specialty of the ALICE experiment, they are also an important part of the programmes for CMS and ATLAS. All three experiments pursued a broad range of heavy-ion physics based mainly on data from 2011, as there was no dedicated LHC run with lead–lead collisions in 2012.

As QGP cools down during the rapid expansion of the initial ‘fireball’ created in heavy-ion collisions, quarks become trapped inside hadrons (ordinary matter), which can then be detected. Measuring the global pattern of the emission of these hadrons, as well as their detailed composition, sheds light ultimately on the properties of the QGP.

Using the spectrum of photons escaping from the fireball created in collisions, the ALICE collaboration estimated the effective temperature reached in the lead–lead collisions at the LHC. The result, a value of $1.8 \times 10^{12}$ kelvin (K), is a million times higher than the temperature in the core of the Sun and high enough to form QGP. This is the highest temperature ever observed in a laboratory.

ALICE, ATLAS and CMS all study the dynamics and composition of QGP to learn about its thermodynamic properties and observe how ‘probe’ particles interact with the medium, in order to investigate its transport properties. In particular, ALICE can select probes containing different quarks, so the collaboration can study how the transportation of partons (quarks or gluons) inside QGP depends on their mass, their transverse momentum and their ‘colour’ — the ‘charge’ associated with the strong
The goal is to understand how objects carrying a colour charge propagate through a coloured medium. ATLAS and CMS investigated the production of photons and Z bosons, as well as jets of particles. The development of a new technique to subtract the background from the ‘underlying event’ in lead–lead collisions allowed the collaboration to make precise measurements of the energies of jets and to identify electrons and photons in the electromagnetic calorimeter. Because photons and Z bosons emerge from the nuclear collision ‘unscathed’, this opens the door to using the energy balance in photon–jet and Z–jet events to study the loss of energy from jets when they travel through QGP.

September saw the LHC’s only operation with lead ions in 2012, in a first test of collisions between protons and lead ions. Lead ions contain 208 protons and neutrons, so to improve the understanding of what happens when these composite objects collide, the collaborations decided to study proton–lead collisions. This should help to disentangle which effects come from free protons and which are associated with the many-body medium created in heavy-ion collisions. Data on proton–proton collisions already provide an important part of this disentanglement effort.

Using data from the test run, the ALICE collaboration soon published some key results. For example, by looking at the density of charged particles produced in the collisions, they could discriminate between theoretical models to determine which ones adequately describe the initial state of the lead ions.

An unexpected and still unexplained phenomenon originally observed in heavy-ion experiments at other laboratories concerns the ‘ridge’ effect — a clustering in space of pairs of particles produced with different momenta. CMS first observed the effect at the LHC in proton–proton collisions in 2010, then in lead–lead data in 2011, and most recently in the proton–lead test run, where the effect seems as strong as in the lead–lead data. Both ALICE and ATLAS confirmed this observation, but also discovered an even more surprising double-ridge structure. These results raise the question: can a QGP-like matter be formed in simple proton–lead collisions?

**A total result**

The TOTEM experiment, which cohabits the same interaction point as CMS, is optimized to make precise measurements of particles that emerge from collisions close to and along the direction of the LHC beams.

Using detectors inserted in special devices that take them close to the beam, it can register elastic collisions in which the protons are deflected only slightly after interacting with protons in the other beam. With additional detectors, the experiment also records inelastic collisions where the protons do not simply graze each other but interact fully, producing other types of particles.

Taken together, the rates for the two processes allow the TOTEM collaboration to calculate the total probability for proton collisions — the total proton–proton cross-section. While of interest in its own right, this is also a key ingredient needed by all of the LHC experiments to calibrate the rate of all types of interactions occurring at the LHC. In 2012, the collaboration released new measurements of both elastic and inelastic collisions at total energies of 7 TeV and 8 TeV. These include the first measurements of the total proton–proton cross-section that do not depend on knowledge of the LHC’s luminosity.

**Cosmic rays and monopoles**

The LHCf experiment aims to provide data to calibrate the theoretical models that describe the interactions of extremely high-energy cosmic rays. Results published in 2012, based on
earlier measurements of neutral particles (pions and photons) emitted close to the path of the beam in proton–proton collisions, are challenging existing models. During the year, the collaboration also constructed and tested a new calorimeter that will be less subject to radiation damage, in preparation for the restart of the LHC in 2015.

MoEDAL, the Monopole and Exotics Detector At the LHC, is designed to search for magnetic monopoles and other exotic, highly ionizing particles. In 2012, the collaboration approximately doubled in size, to total 40 physicists from 18 institutes. A main highlight was the testing of the Magnetic Monopole Trapping detector. This consists of an array of magnetic trapping volumes in which highly ionizing particles should slow down and be trapped. In December, the team removed the 80 m$^2$ test-array for processing and analysis at INFN Bologna. MoEDAL will deploy all of its detectors during the long shutdown and start taking data in 2015.

‘Firsts’ for ISOLDE
CERN’s ISOLDE facility attracts more than 450 researchers working on 90 experiments. Using protons from the PS Booster, it can produce ‘exotic’ isotopes of most chemical elements. These nuclei are used to study nuclear structure, nuclear astrophysics, fundamental symmetries, atomic and condensed-matter physics, and for applications in life sciences.

In a highly successful year for ISOLDE, beams were delivered to 50 of the experiments for a record-breaking 37 weeks, with more protons than ever hitting the targets. One of the biggest achievements was to probe a sample in liquid form for the first time at ISOLDE. This was far from easy, as a liquid cannot exist in the vacuum that is needed for the beams. The team at ISOLDE succeeded in catching polarized magnesium ions on a drop of liquid and then observing them using a sensitive technique known as ‘beta nuclear magnetic resonance’ (βNMR). This approach, which is available nowhere else in the world, holds great promise for biologically important studies of the interaction of metal ions with proteins and nucleic acids.

Another ‘first’ involved the extremely efficient selection of atoms that is achieved by lasers in the method known as collinear resonant ionization spectroscopy. This allowed measurements of a key magnetic property — the magnetic moment — of ions that are produced at a rate of only a few per second.

A new electrostatic ‘mirror’ device, which has been integrated into the ISOLTRAP experiment, can now separate ions with tiny mass-differences by bouncing them many times over distances comparable to the circumference of the LHC. The system offers mass separation with unprecedented speed and was used, for example, to isolate a few ions of zinc-82 from thousands of rubidium-82 ions in measurements that cast new light on the composition of the outer layers of neutron stars.

ISOLDE has also attracted new research teams and experimental set-ups from other institutes. One example is an optical time-projection chamber equipped with a digital camera for particle detection, which is being used to study helium-6 at extremely low energies.

Particles from the PS
The n-ToF facility makes use of protons from the PS to create a high-intensity neutron beam to study neutron-induced reactions over a broad range of energies. The facility performed extremely well in 2012, breaking all records in its 10 years of operation, both for beam intensity and the number of experiments performed. Thanks to an array of synthetic diamond detectors and other advanced detection systems, the n-ToF Collaboration succeeded with challenging measurements of reactions that are relevant to future nuclear reactors, astrophysics, medical physics and basic nuclear physics.
A new neutron beamline for the facility was approved in 2012. This will allow measurements of neutron-induced reactions that are inaccessible elsewhere and will greatly extend a-ToF’s scientific programme. Construction of the new vertical beamline and the experimental hall will start in the spring of 2013.

Also at the PS, the CLOUD experiment has completed its third year of operation. It is investigating how aerosols affect cloud formation, and whether they are influenced by galactic cosmic rays. The experiment has now studied a range of atmospheric vapours that are capable of condensing to form new aerosol particles — which may in turn grow large enough to seed cloud drops — and has measured the effects of ionizing particles on these processes. Work is under way to include the interactions of ions and aerosols with haze and clouds — processes that have never before been studied under controlled atmospheric conditions in a laboratory.

The DIRAC experiment studies unusual ‘atoms’ made of pions and kaons rather than electrons and protons. The aim is to check the low-energy predictions of quantum chromodynamics for light quarks. Data-taking in 2012 continued to investigate long-lived pionium (π⁺π⁻) atoms, following the earlier successful measurement of the lifetime of short-lived pionium. The collaboration installed an improved detector and a new radiation-resistant magnet near the target. With better means to identify the exotic atoms, the team expects to find a significant signal from long-lived pionium states from the 2012 data, together with preliminary results on kaonium (Kπ) atoms.

Antimatter in focus
At the AD, CERN’s antimatter facility, the ATRAP Collaboration took a big step forward in checking if antimatter behaves like the mirror image of matter. The team managed to improve the measurement of the antiproton’s magnetic moment by a factor of nearly a thousand. In addition, the ASACUSA Collaboration improved the measurement of the antiproton’s mass, using laser spectroscopy of antiprotonic helium — an ‘exotic’ atom in which an antiproton replaces an electron. ASACUSA also continued its work towards the production of antihydrogen beams and the observation of the first anti-nucleus annihilation in flight, both to be attempted after the long shutdown.

Having carried out a first spectroscopic measurement of antihydrogen (via microwaves) in 2011, the ALPHA Collaboration concentrated on constructing and commissioning a new apparatus (ALPHA-2) in 2012. This should provide much greater access to trapped antihydrogen atoms. The various components were successfully installed and tested with antiprotons during a few weeks towards the end of the year.

Another way to investigate antimatter, pursued by the AEgIS experiment, aims to measure its gravitational interaction. The first stage of this experiment went live in 2012 following installation in the smallest of the AD zones. The AEgIS team could then start to test the many items (antiprotons, positrons, lasers, detectors) needed to form antihydrogen.

Beams to the north
The SPS supports its own research programme with a variety of particle beams in the North Area (NA) at CERN’s Prévessin site.

The COMPASS Collaboration (NA58) changed its target area twice in 2012. One goal of the experiment is to see if a composite object, such as a pion (made of a quark and an antiquark), is deformed by the magnetic and electrical fields of a nucleus in the way that theory predicts. To do this, both pions and muons (particles with no sub-structure) were scattered off nuclei in a nickel target. The comparison will explore the expected deformation of composite particles with unprecedented precision. Following a second change of the target area, including the installation of new equipment, the team performed a pilot
run to prepare for the future COMPASS programme. Muons with energies of 160 GeV were directed onto a liquid-hydrogen target to produce scattered protons together with single high-energy photons. It was the first time that this reaction has been studied at the high energy allowed by the COMPASS beam. The goal is to investigate the correlations between a quark’s momentum and its transverse position inside a proton or a neutron.

A variety of beams, targets and energies have attracted 140 researchers to the SPS Heavy Ion and Neutrino Experiment (NA61/SHINE). The ultimate goal of the heavy-ion studies is to understand how the quarks and gluons that are normally confined inside nucleons (protons and neutrons) can start moving freely as a quark–gluon plasma following a highly energetic collision, rather like studying what happens to molecules when ice melts into water. To access both forms of matter, it is essential to vary the beam energy. The greatest achievement in 2012 was to bring the SPS energy to its lowest-ever value per nucleon, enabling the NA61 team to probe below the point where the transition to quark–gluon plasma occurs.

The NA63 experiment studies quantum effects in electromagnetic interactions, by investigating what happens when a beam of high-energy particles meets the strong electric fields within crystalline structures. In 2012, the collaboration announced results that considerably improve understanding of ‘beamstrahlung’. This is radiation that is emitted when beams encounter one another in particle colliders; particles in one beam radiate when they ‘see’ a strong electric field associated with the opposing beam. Using crystalline targets, NA63 was able to simulate the process with only a single beam. The team confirmed that there is an important quantum effect that diminishes the emission of beamstrahlung by some 50%. This has important implications for studies for a future linear electron–positron collider, such as CLIC (see p. 29).

**Neutrinos to the south**

One beam created at the SPS consists of muon neutrinos — particles that interact very feebly with other matter. In this case, they head south-east from the CNGS facility and pass unhindered through the Earth’s crust to the Gran Sasso National Laboratory in central Italy. There, after six years of running, in 2012 the OPERA experiment detected a second ‘candidate’ event indicating that one of the muon neutrinos had changed into a different kind of neutrino — a tau neutrino — during its 730 km journey. This follows a first candidate detected in 2010. OPERA was set up specifically to search for such neutrino ‘oscillations’, which cast light on the tiny mass of these particles. During 2012, OPERA and three other experiments — Borexino, ICARUS and LVD — also monitored the neutrino beam to determine precisely the particles’ time of flight to Gran Sasso. They all measured a time that is consistent with the speed of light.

**The low-energy frontier**

Dark matter is one of the greatest puzzles facing particle physicists and astrophysicists. Several theories attempt to provide new particles with the characteristics of this unknown form of matter. For the CAST and OSQAR experiments, the task is to build a highly specialized system to detect these particles, even though no one knows what they look like.

Dark matter could be some type of ‘weakly interacting slim particle’ (WISP). Reusing a prototype LHC dipole magnet, the CAST experiment tracks the Sun to search for hypothetical solar-produced WISPs. In 2012, the magnet tubes were filled with low-pressure helium-4 gas and kept at temperatures near absolute zero to push the sensitivity to the region of 0.4 eV for the particle mass. The OSQAR experiment also uses a prototype LHC magnet to explore this low-energy frontier, in this case by investigating the interaction of a powerful laser beam with a high magnetic field over an unprecedented length.
Detectors for a linear collider

CERN participates in a worldwide development effort for future detectors through the Linear Collider Detector (LCD) project, which targets physics at a future electron–positron collider. One option is being pursued in the Compact Linear Collider (CLIC) design study and February saw the publication of Physics and Detectors at CLIC, one of the three volumes of the CLIC Conceptual Design Report.

From the CLIC viewpoint, it is more efficient to start with a shorter machine and then expand it to reach full energy. Hence, work has focused on studies geared towards an optimal physics exploitation via a few main energy stages. Operating initially at around 400 GeV will allow precise measurements of most of the properties of the Higgs boson and the top quark. Then, 1 or 2 TeV would give access to possible new phenomena and could also yield pairs of Higgs bosons or the simultaneous production of Higgs bosons and top quarks, allowing a measurement of their coupling. The final energy stage at 3 TeV would bring the full potential for new physics and the possibility to measure rare decays of the Higgs boson into muons. All of these processes have been studied with detailed simulations to demonstrate the potential of the detectors.

The year saw good progress in the design of the pixel detector for a CLIC experiment and in the development of hardware. Teams carried out studies on the mechanical support structure, cooling and power pulsing. They also produced pixel assemblies based on ‘through-silicon-via interconnect’ technologies and designed a small-scale pixel chip in deep-submicron technology.
In theory

The Theory Unit (TH) carries out cutting-edge research on topics across the spectrum of theoretical physics, including physics of the Standard Model and beyond, astrophysics and cosmology, lattice field theory, heavy-ion physics and more formal theory, such as different aspects of string theory, supergravity and non-perturbative gauge dynamics. On average the group published one article per day during 2012.

The group plays a key role in supporting the LHC physics programme and interpreting its results in co-operation with the experimental groups, through the framework of the LHC Physics Centre at CERN. There was inevitably intense activity on Higgs physics in 2012, aimed at understanding the consistency of the experimental measurements with the Standard Model and its extensions, and possibly learning about the ultimate stability of the Universe (see figure above).

Other highlights included a landmark precision calculation of the cross-section for the production of top quarks, as well the first fully automated tool (aMC@NLO) for accurate, realistic simulations of the whole spectrum of physics processes at the LHC. TH’s impact on LHC physics was recognized through the award in 2012 of another European Research Council Advanced Grant, LHCTTheory. The group has also further strengthened its focus on the LHC with the recruitment of a new senior staff member.

On the cosmology front, the group was closely involved with the experiments of the European Space Agency’s Planck mission, which is mapping relic radiation from the Big Bang. Members have been particularly active on the subject of non-Gaussian signatures and aspects of cosmological inflation.

TH also serves as a centre of excellence for the international theoretical physics community. In 2012, it hosted 66 fellows, 63 doctorate students and about 800 visitors, with support from nine European grants related to research excellence. In addition, it contributed to training efforts at CERN and elsewhere, organizing two schools, several workshops and four theory Institutes. Last but not least, TH is an active contributor to community-wide efforts that help to guide research in particle physics, notably in 2012 in the preparation of the updated European Strategy for Particle Physics (see p. 8).
CERN’s Computer Centre houses servers and data-storage systems not only for Tier-0 of the WLCG, but also for systems critical to the daily functioning of the Laboratory.

Computing

Worldwide connections
With the vast amount of data from the LHC being distributed and analysed on a global scale, the Worldwide LHC Computing Grid (WLCG) successfully delivered the computing needed for the major announcement on 4 July. Initial planning estimated that the LHC would produce 15 petabytes (PB) of data per year. This was already achieved in 2010 but since then the total has grown to 23 PB in 2011 and 27 PB in 2012. Such increases reflect the excellent performance of the Grid infrastructure, and show the reliability and resilience of the whole system. Indeed, this distributed computing system constantly transmits, stores, processes and analyses data; the Grid never sleeps — even at midnight as 2012 ended, almost 250 000 jobs were running on the network.

On 4 July itself, the IT Department provided the audio-visual support for the ‘Higgs update seminar’ — a huge broadcasting achievement. The Main auditorium of CERN had been upgraded to HD-quality equipment just in time for the event and the broadcast reached an estimated 1 billion people. Almost 500 000 single IP connections were made to the live webcast and a record 60 500 IPs connected at once. CERN also provided an HD connection to 150 scientific institutes — with an estimated audience of 10 000 — and a two-way video conference with the 700 physicists present in Melbourne for the ICHEP conference.

Impressive connections were not only in Grid computing and webcasting: a new video conference system was also established at CERN in 2012. Within CERN, the GS, IT and PH Departments worked on a new digital radio-communication system, known as TETRA. The TETRA system was installed and tested in 2012 and will be used for emergency communications from January 2013 by the CERN Fire Brigade, as well as by hundreds of CERN personnel and contractors working in the tunnels. The installation of 1000 underground position indicators from 2013 onwards is under study to enable a geolocation system that will work even in the tunnels.
CERN’s Computer Centre extends to Hungary

In May 2012, CERN signed a contract with the Wigner Research Centre for Physics in Budapest for an extension of the CERN data centre, after a competitive call to tender. Under the new agreement, the Wigner Centre will substantially extend the capabilities of the LHC Computing Grid Tier-0 activities, increasing the processing power and disk data-storage at CERN by a further 20 000 cores and 5.5 petabytes (PB) of disk storage, and doubling this after three years. As well as additional equipment, this remote site helps to mitigate risks, such as possible power cuts at the CERN site, and therefore improves business continuity. State-of-the-art networking solutions are now in place to connect CERN and the Wigner Centre.

Towards the end of May, construction began at the Wigner Centre to convert an existing building into a data centre, enabling the first (of four) computer rooms to be fully operational by January 2013. This work concerned not only the computer room, but also the associated cooling and electrical distribution infrastructure, such as chillers, transformers, uninterruptible power-supply systems and electrical rooms. This was essentially achieved and during 2013 equipment will be shipped and installed for the centre to be fully operational by the end of the year.

Increasing the capacity

Amounts of data continue to grow and to this end, in 2012 three complementary ways were investigated to increase capacity. First the consolidation and upgrade of the computing centre; second, the hosting of CERN servers in a remote data centre in another Member State (see above); and third, cloud computing.

The CERN Computer Centre consists of three machine rooms with a combined surface of more than 2800 m², where there are 71 200 disks, 9200 systems, 15 500 processors and 73 000 cores. An upgrade has been under way to improve the electrical and cooling infrastructure of the centre to increase the availability of critical IT services needed for the Laboratory and to provide more floor space for servers in the area called “The Barn”. Ongoing consolidation work progressed significantly during the year and most of the major work was completed, including increasing the power from 2.9 MW to 3.5 MW; the project should be finalized by mid-2013.

Big science teams up with big business

The year 2012 saw the start of the ‘Helix Nebula — the Science Cloud’ project, a public–private partnership to create a cloud-computing platform supported by leading European IT providers. Cloud computing is not foreseen to replace Grid computing, but instead to complement it with additional computing capacity. Instead of procuring the hardware, which must be maintained and managed, CERN could procure the service from a commercial infrastructure-provider within the Helix Nebula partnership to provide network access, storage and CPU, with CERN paying only for the resources that are used.

The first two years of the project are a pilot phase, with CERN contributing ATLAS and CMS simulations to test performance, functionality and reliability. Results have so far been promising, but there are still subjects to be explored, including cost and applicable legislation in relation to the use of cloud services not managed by CERN. CERN and the other two international organizations involved — the European Molecular Biology
New life for retired CERN servers

As part of a regular cycle of equipment renewal, 2012 saw many out-of-warranty servers replaced with faster, more efficient alternatives. These four- to five-years-old servers, although retired from their cutting-edge use at CERN, prove to be very useful in less demanding environments. As a result, in 2012 servers were donated to Morocco, Ghana, Bulgaria and Serbia.

In March, 161 servers were loaded onto a lorry bound for Morocco — half going to build a Tier-2 Grid centre in Rabat, the other half being distributed to the Réseau Universitaire de Physique des Hautes Énergies of the four main high-energy physics institutes in the country. The shipment fulfilled a promise made by CERN back in May 2011 during the conference on ‘Sharing knowledge across the Mediterranean’.

In September, 220 servers and 30 routers were donated to the Kwame Nkrumah University of Science and Technology (KNUST) in Ghana, with 200 servers using Grid technology for research purposes and the remaining 20 units being used for new digital libraries (each with two servers) at 10 different interconnected universities and research centres in Ghana.

In October, 58 servers were donated to the Sofia University St. Kliment Ohridski in Bulgaria for computing support for the CMS experiment. Then in November, 130 servers were sent to two Serbian institutions. The Belgrade Institute of Physics received 92 servers to enhance the performance of the Serbian computing Grid. This enables them to process their own data more efficiently, in particular for active participation in the NA61 experiment at CERN. The additional 38 servers were delivered to the Petnica Science Centre, the largest non-profit organization for informal science education in South Eastern Europe.

Isaac K. Dontwi, Director of the National Institute for Mathematical Sciences at KNUST, joins CERN’s Director-General to watch the servers embark on their journey to Ghana.
Accelerators

Continuous improvements to the LHC’s radio-frequency cavities contributed to the exceptional performance of the machine in 2012.

It was a three-year marathon at the pace of a sprint, as the accelerators were put through their paces in the first LHC run. During 2012 — the last full year of operation before the first long shutdown — the accelerator complex pulled off some Olympic performances in terms of increased energy and record luminosity. The year ended with an unprecedented volume of data for the LHC experiments and excellent results at the other accelerators and facilities.

The LHC started operation with protons on 5 April, with the collision energy increased to 8 TeV from the 2011 level of 7 TeV. Less than two weeks later, the number of bunches per beam reached 1380, the target value for 2012. By June, the LHC had produced more data for the experiments than during the whole of 2011. Thanks to this quantity of data, which when added to those from 2011 gave a total of 12 fb$^{-1}$ of integrated luminosity, the experiments were able to identify a new particle consistent with the Higgs boson. Following the announcement of the discovery, CERN decided to extend the proton run by seven weeks in order to provide 20 fb$^{-1}$ of integrated luminosity to ATLAS and CMS. In the end, the stream of data exceeded all predictions: ATLAS and CMS each received more than 23 fb$^{-1}$ of data, with the total delivered to all experiments combined reaching 48 fb$^{-1}$.

In the last week of operation, the teams halved the spacing between bunches from 50 to 25 nanoseconds (ns), with fewer protons per bunch. This set-up is of more interest to the experiments as it reduces the pile-up of events. In parallel, it increases the volume of data accumulated, since the number of bunches is doubled. For the LHC, this mode of operation is delicate because the beams are more unstable, particularly because of the electron-cloud phenomenon, which increases as the number of bunches increases. The results of the test were therefore highly anticipated. The teams managed to reach a record number of 2748 bunches per beam, but at injection energy and without collisions. They then conducted a physics run with 396 bunches per beam, with spacing of 25 ns and at a collision energy of 8 TeV.
A shining example

The accelerator teams showed considerable perseverance and skill in increasing luminosity. In the LHC, the compression of the beams at the point of collision was increased, while in the injectors, efforts focused on the brightness of the beam, or to put it another way, the density of particles per unit of surface area. Constant optimization made it possible to increase the brightness of the proton bunches by a factor of three. To increase it further, a new operating mode, called BCMS (batch compression merging and splitting), was tested in the PS. In the LHC’s chain of four injectors, the PS is the accelerator that structures the beam, forming the bunches of particles. Until now, the PS made up 36 bunches of protons spaced at 50 ns from the 6 bunches coming from its injector, the PS Booster. The BCMS system allows the team to ‘play’ with the radio-frequency (RF) cavities to form 24 bunches from 8 bunches from the PS Booster. The bunches are therefore denser. These complicated gymnastics are tremendously effective. For bunches spaced at 50 ns, the brightness is increased by 30%, and it is doubled for bunches spaced at 25 ns. This new mode will be adopted when the LHC is restarted.

Unfortunately, increased brightness means increased instability. Important work was carried out in 2012 to stabilize the beams. In the PS, a damper system was tested successfully. The SPS now has a new, more stable operating point thanks to the replacement of the machine’s optics.

In addition to operation with protons, collisions between protons and lead ions were tested for a week to prepare for a run at the start of 2013. On 13 September, collisions between protons and the much heavier lead ions were produced for the first time. Accelerating and colliding particles with such different masses is a challenge for the RF system. The two beams are accelerated at different frequencies and the frequencies must then be readjusted to produce collisions inside the detectors.

Cold at the top

The remarkable operation in 2012 benefited from a faultless infrastructure for all of the accelerators. The electrical distribution, cooling and ventilation systems all functioned very well, which was quite a feat after three years without a long technical shutdown. The flawless infrastructure also helped the cryogenic systems, which accomplished a major feat in 2012. Cryogenics are crucial for the operation of the LHC, operating at a temperature of 1.9 kelvin (-271°C). The slightest fault can result in several hours without a beam, as the cryogenic system has a slow response time. In 2012, the system achieved 94% availability, compared to 87% in 2011. Taking into account the fact that the machine has eight independent cryogenic sectors, the availability of each sector exceeded 99% on average. This result was obtained, among other factors, thanks to constant improvements to the methods of operation, systematic analysis of faults and, of course, the reliability of the infrastructure systems. In addition, the amount of helium-loss was almost halved, from 40 tonnes to 21 tonnes out of a total of 136 tonnes of helium in the LHC.

For their part, the injectors displayed a remarkable level of availability, often exceeding 90%. Although the LHC is their most prominent customer, it uses fewer than 1 proton out of every 1000 produced by the accelerator chain. Indeed, the injectors supply many installations and experiments, providing a total of $1.81 \times 10^{20}$ protons in 2012. Although this seems like a huge number, it represents less than 1 milligram of matter.

The largest user of particles is ISOLDE, the nuclear physics installation, followed by the CERN Neutrinos to Gran Sasso project. Designed to study the oscillation of neutrinos, CNGS ended its operations with $3.9 \times 10^{20}$ protons received onto its target in 2012. This final run brought to an end five years of operation, during which the SPS delivered more than 80% of the agreed number. For n-ToF, the installation that provides
a pulsed neutron source, the 2012 target was exceeded with $1.9 \times 10^{19}$ protons delivered. Finally, the AD also had an excellent year, with 4500 hours of operation and 90% availability for the antimatter experiments.

Preparations for the long shutdown

While the accelerators were working at full capacity, teams were preparing for the first long shutdown. In 2013 and 2014, the accelerators will be turned off for a full makeover. The LHC will be improved so that it can operate at a higher energy. Among other work, around 10,000 high-current splices between the superconducting magnets will be reinforced, 600 valves will be installed and 700 km of cable replaced. In parallel, the injectors and infrastructure will undergo renovation and improvement work. For example, the entire ventilation system of the PS will be replaced. This major work was already being planned in 2012, as multiple activities were fully scheduled, orders were placed, teams were recruited and their training began. New systems to consolidate the LHC were tested: a reinforced LHC splice, like those that will form the interconnections between the magnets, was subjected to 20,000 operating cycles with a current of 13,000 amps (compared to 8000 amps at present). Some work even got underway in 2012, such as the consolidation and extension of the electrical distribution system. This ambitious 15-year plan is aimed at renovating and reinforcing the system to adapt it to CERN’s changing needs. The large-scale electrical work began at the SPS: eight transformers were replaced and the new supply network infrastructure was installed. In addition, a new building was built on the Prévessin site to house two electrical substations and the redundant power supplies for the servers and the accelerator control electronics. Renovation of the accelerator control systems also began, with several dozen embedded computers replaced. The Diamon software, a diagnostic tool used by the operators, continued to be deployed, and was installed on more than 1000 control computers.

Towards greater luminosity

In the longer term, after 2022, the High Luminosity LHC project is aimed at increasing the number of collisions by a factor of 5–10 to reach a luminosity of 250 fb$^{-1}$ per year. The studies are being financed partly by the European Commission’s 7th Framework Programme, as part of the HiLumi LHC Design Study, which brings together a large number of laboratories from CERN’s Member States (France, Germany, Italy, Spain, Switzerland and the UK), as well as from Russia, Japan and the US. Increasing luminosity requires more powerful focusing magnets and an improved collimation system, with collimators that will have to be integrated into the continuous cryostat of the LHC. In order to free-up space for the collimators, some of the existing dipole magnets will be replaced with shorter magnets with stronger 11-tesla (T) fields. These magnets have been developed in the framework of a collaboration between CERN and the Fermi National Laboratory (Fermilab) in the US, which has resulted in the construction of a 2-m prototype using niobium–tin superconducting cable. The magnet has been tested and has produced a field of 10.4 T.

In addition, the teams have opted to develop focusing magnets with a bigger aperture of 150 mm. This will allow stronger focusing to reduce the size of the beam at the collision point. Research into superconducting or ‘crab’ cavities, which direct the bunches before collision, has also advanced, with the completion of the conceptual design report. Tests on a prototype cavity made by the University of Lancaster and the Cockcroft Institute in the UK have begun at CERN, while two other prototypes are being manufactured in the US. Owing to the increase in luminosity, some power converters that are sensitive to radiation will need to be moved to the surface and connected to the accelerator with 300-m long superconducting cables. CERN, in cooperation with an Italian company, has developed high-temperature superconducting cables made from magnesium diboride; these are considerably cheaper than traditional high-temperature superconductors.
superconductors, and can operate at up to 25 K (-248°C). Tests on these cables have begun in a new test installation.

Two major meetings allowed experts in these innovative technologies from all over the world, from both institutes and industry, to review this research: the second annual HiLumi LHC-LARP meeting of 130 specialists was hosted by the Frascati National Laboratory, and the ‘Superconducting technologies for next-generation accelerators’ workshop drew 100 experts to CERN, including a large number of representatives of industry.

The injector chain will play an essential role in reaching this increased luminosity. The LHC Injectors Upgrade (LIU) project is coordinating the implementation of the necessary improvements to all of the injectors, from the source right through to injection into the LHC. At the very start of the chain, the future linear accelerator, Linac 4, is taking shape. Two vital components of this machine were completed in 2012: the new ion source and all of the associated equipment, as well as the RF quadrupole (RFQ), which gives the ions their initial acceleration. The source was designed to produce both H- ions, required by the PS Booster, and protons, for tests or to replace Linac 2 before the second long shutdown. The RFQ is the result of four years of joint development by CERN and the Commissariat à l’énergie atomique et aux énergies alternatives (CEA), and was entirely manufactured in CERN workshops.

Tests of these two components began in 2012. The other elements of the accelerator chain are in production or assembly. One hundred and fifty permanent quadrupole magnets, the prototype klystron and the modulators have been delivered and tested. Finally, the beam instrumentation has been developed, notably a new system for measuring the beam emittance. In a brand-new building, all of the infrastructure — electricity, ventilation and cooling — is in place. The RF equipment has been partially installed, as well as the first magnets. The tunnel is ready for the installation of Linac 4, which should be connected to the PS Booster in 2018. The PS Booster, the second link in the accelerator chain, celebrated its 40th birthday in 2012 with good prospects for improvements (see opposite).

Commissioned in 1959 and 1976 respectively, the PS and the SPS also need to be consolidated and upgraded to accelerate the beam that the PS Booster will provide from 2018. Beam studies in 2012 have improved knowledge of the current limits and have led to the implementation of some improvements. Thanks to these results, the specification and design of the new equipment, which is essential to reach the target level of performance, has advanced. Prototypes will be installed during the 2013–2014 shutdown and all of the modifications will be deployed during the second long shutdown of the LHC in 2018.

Some equipment for the High Luminosity LHC has already undergone testing on the new High Radiation to Materials (HiRadMat) installation. The installation, which is designed to test materials and components under high-intensity beams, carried out nine experiments in 2012, its first year of operation. Six of these experiments were for the LHC, the other three being devoted to research and development of materials for high-power targets within the EuCARD project. One experiment has enabled beam tests of six candidate materials for the new generation of LHC collimators. Bent crystals intended for use in the LHC’s collimation system also underwent testing in October.

Three other projects made progress in 2012. The ISOLDE nuclear physics installation will be reinforced in 2015 with a 16-m long superconducting linear accelerator. High-Intensity and Energy ISOLDE (HIE-ISOLDE) will increase the beam energy from 3 to 10 MeV per nucleon and increase the beam intensity fourfold. After four years of development, a low-energy superconducting cavity prototype has been tested successfully, producing an accelerator field of 6 MV/m. The copper cavities, manufactured
in the CERN workshops, are coated with a 1 micrometre thick superconducting film, for which CERN has unique expertise; their production will begin in 2013. The diagnostics box, which contains the beam instrumentation, has been completed and tested. In parallel, the buildings to house the new accelerator have also been completed.

Another development is the installation of a beam line on the Prévessin site, at the end of an extraction line from the SPS, to supply the new NA62 experiment (see p. 20). This line is 100 m long and extends into the detector for another 160 m. It includes about 30 magnets, a collimation and muon-sweeping system, as well as a particularly large vacuum chamber.

The study phase for the Extra Low ENErgy Antiproton ring (ELENA) has advanced considerably. Approved in 2011, this upgrade project for the AD is aimed at slowing down the antiprotons further in order to improve the effectiveness of their injection into the antimatter experiments. When extracted from the AD, the antiprotons will be decelerated in a 30-m ring from

5 to 0.1 MeV, with considerable efficiency thanks to cooling by electrons, in order to increase the number of antiprotons trapped by the experiments by a factor of 10 – 100. The machine’s lattice, i.e. the geometric layout of the components, was completed in 2012.

There has been progress with the design of equipment, particularly the magnets, which, because of the deceleration, will have to produce very low fields of excellent quality. The first prototypes are being developed. Studies have been carried out on the properties of the beam and the vacuum system, which is essential for limiting interactions with the residual gas. The design of the injection and the transfer lines to the experiments is almost complete. In June, a memorandum of understanding for the construction of ELENA was signed, with several institutions promising contributions to the project.

Successful first phase for CLIC

The results from the LHC in the search for the Higgs boson have given rise to new ideas about future accelerators (see p. 30). The CLIC project, which is studying the possibility of a high-energy electron–positron linear collider, is one option for a successor to the LHC. CLIC is based on an innovative two-beam acceleration design, in which a drive beam provides power to the electron and positron beams. In this way, the particles reach high energies over a shorter distance. This principle poses a challenge, however, in generating acceleration fields greater than 100 MV/m.

The PS Booster doubles its energy

Particle physics never stops turning old into new. On 26 May, the PS Booster, the second link in CERN’s accelerator chain, celebrated its 40th birthday. This remarkable machine, which has four acceleration stages, increases the energy of particles from Linac 2 from 50 MeV to 1.4 GeV before injecting them into the PS. The Booster also supplies the experiments of the ISOLDE nuclear physics installation, its only direct user. Initially designed to accelerate particles from the Linac up to 800 MeV, the PS Booster has been improved over the years to reach 1.4 GeV. In 2018, as part of the LIU project, the injection energy will be increased to 160 MeV, thanks to Linac 4, and the extraction energy will be brought up to 2 GeV.

The studies for this improvement progressed considerably in 2012. The design of the crucial injection equipment was completed with a view to producing prototypes in 2013. In addition, a pre-prototype RF cavity was tested. It was designed in collaboration with the J-PARC and KEK laboratories in Japan, using a special material that has stronger magnetic permeability than the traditional ferrite rings.

The PS Booster in 1972, the year it was commissioned.
Paths towards a Higgs factory

The announcement of a Higgs-like boson with a mass of around 125 GeV sent theorists back to their blackboards and accelerator physicists back to their drawing boards. If it is confirmed, this discovery will guide thoughts on future machines to study the particle in more detail. In November, a workshop attended by 70 experts from all over the world was held at Fermilab to discuss the subject of Higgs factories. Several meetings were also held as part of the European project EuCARD.

The High Luminosity LHC will already be a good Higgs factory (see p. 27). Further on the horizon are high-energy electron–positron colliders for precision studies. These include the CLIC project (see p. 29), which has adapted to the new situation by proposing construction in three stages. Physicists are also thinking about circular machines, such as a high-luminosity electron–positron collider, TLEP, whose energy would reach 350 GeV. The advantage would be the possibility to reuse the infrastructure for its successor, the Very High Energy LHC (VHE-LHC), a hadron collider.

Studies have also been carried out over the past three years on a hybrid machine that would collide electrons with protons, or electrons with ions. A preliminary design report was published in 2012 for this project, known as LHeC, which would make use of the LHC infrastructure. Leptons would be accelerated by an innovative linear accelerator, an energy recovery linac (ERL), or by a lepton ring in the LHC tunnel. The infrastructure could be reused for a novel photon–photon collider, such as that proposed by the SAPHIRE project, the advantage of which would be the use of a Higgs boson production channel at a lower energy. Finally, a Higgs at 125 GeV brings the idea of a lepton collider in the same tunnel as the LHC back into play. LEP3, an improved version of the original Large Electron Positron (LEP) collider that ran from 1989 to 2000, would boast an energy of 240 GeV and allow Higgs physics to be studied at a lower cost, but its construction would conflict with the High Luminosity LHC.

The next results from the LHC are needed before these different options can be taken further. In 2016 or 2017, the community will need to be ready to propose a large project to succeed the LHC.

In 2012, the feasibility studies were completed and included in a preliminary design report. The report includes conclusive results on the principle of acceleration with two beams and on the rates of acceleration, as well as details of performance studies on the physics and the detectors, technical studies on the accelerator complex and the stabilization and alignment of the machine, and simulations and prototypes. All of these tests were carried out on the CTF3 test installation at CERN and in several other installations belonging to the collaboration, which comprises 44 institutes around the world. The staged implementation, the costs, the scheduling and the power consumption were also studied and documented.

The creation of a full work plan for 2016–2017, notably including the technical implementation of the project, was approved by the collaboration. An update of the current data was initiated in parallel to optimize the development stages of the machine and its parameters to take account of recent results from the LHC. Several new institutes have joined the collaboration. Studies of the physics and the detectors began with 15 groups dedicated to this work.

Work is also in progress on future installations for research into neutrinos. In this framework, studies concerning a high-power superconducting linear accelerator (the High Power Superconducting Linac or HP-SPL) progressed in 2012. Solid niobium superconducting cavities are being developed at CERN and in industry in order to assemble an initial prototype cryomodule. Mastery of this technology is important not only for a future high-luminosity neutrino beam, but also for future renovation of the injector chain for the LHC or its successor.
Making an impact

CERN engages with students, educators, businesses and the general public in a huge variety of ways. Outreach initiatives and training programmes seek to inspire the scientists of tomorrow, while dynamic exchanges of knowledge help to transfer innovative technology developed for CERN’s state-of-the-art machines to academia, industry and even the arts.

Innovation through collaboration
In 2012, the Knowledge Transfer (KT) Group saw a significant increase in the number of identified CERN accelerator, detector and computing technologies that could be transferred to industry or other research laboratories (new technology transfer opportunities). The KT Fund, introduced in 2011, has proved a powerful tool to provide financial support for knowledge-transfer initiatives. The six projects selected in 2011 are advancing and are now joined by six new projects ranging from accelerator structures for proton therapy to humidity fibre-optic sensors.

An initiative called CERN Easy Access IP was launched in June 2012 (see p. 34). In addition, to trigger and support entrepreneurship initiatives, the KT Group is developing the CERN Business Ideas Accelerator concept (CERN-BIA). This concept, based on a pre-incubator managed by the KT Group, concerns a network of national incubators across the Member States and a network of entrepreneurship schools. In 2012, about 60 Norwegian students came to the Laboratory to work alongside inventors and technology-transfer officers to assess inventions selected from CERN’s technology portfolio. Collaborative R&D is also promoted through academia–industry matching events, organized by CERN often in collaboration with EU projects.

CERN continues its successful participation in the EU 7th Framework Programme (FP7) for research and technological development. Twelve EU projects with the participation of CERN were selected for funding in 2012, bringing the total number of projects since FP7 began in 2007 to 80. CERN co-ordinates five of these new projects: Helix Nebula on science cloud computing, EuCARD2 on accelerator research and development in Europe, EDUSAFE and ICE-DIP on training of young researchers and engineers in the fields of extreme environments and advanced IT
Building bridges between physics, medicine and biology
Bringing together experts in medicine, biology and physics for the advancement of hadron therapy has been one of the major achievements of the European Network for Light Ion Hadron Therapy (ENLIGHT), which celebrated its 10th anniversary in 2012. ENLIGHT, coordinated by CERN, counts some 400 participants from more than 20 countries across Europe. The network entered its second decade with four EC-funded projects under its umbrella: PARTNER, ULICE, ENVISION and ENTERVISION. All of these projects are directed towards the different aspects of developing, establishing and optimizing hadron therapy. PARTNER (Particle Training Network for European Radiotherapy) successfully completed its programme in September, having provided multidisciplinary training to 29 researchers and published an outstanding number of scientific papers.

In February, more than 600 medical doctors, physicists, biologists and engineers gathered at the ICTR-PHE 2012 Conference in Geneva — a merger of CERN’s Physics for Health in Europe (PHE) conference, first held in 2010, with the International Conference in Translational Research in Radio-Oncology (ICTR). Four months later, the proposal of a biomedical facility at CERN, born from the first PHE conference, was discussed by more than 200 multidisciplinary experts in a brainstorming meeting at CERN. The discussion focused on the need for research in the radiobiological and physics sectors using the Low-Energy Ion Ring, which produces high-density ion beams for the LHC and for fixed-target experiments at the SPS.

An important milestone for European hadron therapy facilities was reached on 13 November: the first patient was treated with carbon ions at the CNAO hadron-therapy facility in Pavia. The CNAO accelerator complex is based on the Proton Ion Medical Machine Study, a design study that took place at CERN from 1995 to 2000, adapted by the TERA foundation. CNAO, which started treating patients with proton beams in September 2011, is the second centre in Europe to provide carbon-ion beams for cancer therapy, after the Heidelberg Ion-Beam Therapy Centre began clinical trials in 2009. CERN also works closely with MedAustron, the advanced centre for Ion Beam Therapy and Research under construction in Wiener Neustadt, Austria, on the development and production of a synchrotron-based accelerator complex for light-ion therapy. With the accelerator development nearly completed in 2012, the focus of activities will shift to the operation site in Wiener Neustadt in 2013.

Inspiring future generations
In 2012, the Education and Outreach Group welcomed 85 200 visitors on guided tours to the CERN sites, of which about 40% were high-school students from more than 20 countries. The award-winning Universe of Particles exhibition, housed in the Globe of Science and Innovation, was seen by 63 000 visitors. Travelling exhibitions helped to extend CERN’s inspirational reach to Member States and beyond, with the Accelerating Science exhibition’s visit to Turkey and Ireland, and the mini-exhibition’s extended visit in Greece. When the mini-exhibition reached Serbia in October, it drew record numbers with more than 100 000 visitors.

CERN’s teacher programmes enable teachers to pass on the excitement of particle physics to new generations. In 2012, more than 1000 teachers from 35 countries attended 36 courses. These ranged from 3–5-day national programmes dedicated to Member States, with teaching materials, visits and recorded lectures provided in the teachers’ native languages, to the in-depth three-week international High School Teacher Programme, with 40 participants.
Local school children visit the CMS cavern as part of "Dans le peau d’un chercheur", organized from January to June by the Communication Group.

Schools of excellence

From humble beginnings with a week-long school in the Jura Mountains, 50 years ago, CERN now organizes numerous off-site ‘schools of excellence’ related to its research and technologies. Not only do participants learn from leading experts in the field, they can also interact with researchers from all over the world.

In 2012, CERN worked together with the Joint Institute of Nuclear Research in Russia and the CEA and IN2P3 in France to organize the European School of High-Energy Physics, in Anjou, France. Later in the year, CERN and Japanese institutes organized the first Asia–Europe–Pacific School of High-Energy Physics, in Fukuoka, Japan, which brought together students from 21 different countries for an intensive yet rewarding two weeks.

The year also marked the 35th CERN School of Computing, held in Uppsala, Sweden, co-organized by Uppsala University, and the third International School of Trigger and Data Acquisition, in Cracow, Poland, organized by CERN, Cracow University of Technology and the Institute of Nuclear Physics. A specialized CERN Accelerator School on ion sources was held in spring in Senec, Slovakia, and some months later an introductory school on accelerator physics took place in Granada, Spain.
Easy access for all

A new approach to knowledge transfer, CERN Easy Access IP, was adopted in June 2012. Under this label, CERN grants a free licence for selected technologies from its portfolio, making it easier for businesses and entrepreneurs to access intellectual property generated at the Laboratory.

In the same spirit of accessibility, CERN has kept its leading role in the Open Access movement for scientific publications. In 2012, all of the scientific results from the LHC — more than 300 articles — were made available at no cost to any reader, through partnerships with leading scientific publishers. The Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP³) was officially launched on 1 October and is co-ordinated by the Open Access team in the Scientific Information Service, with the support of the Procurement and Industrial Services Group and the Legal Service. It is breaking new ground in a transition of scientific publishing from a ‘content economy’ to a ‘service economy’. Open Hardware projects also saw success in 2012, with many reaching commercialization, including the White Rabbit project, originally developed for the synchronization requirements of CERN’s accelerators.

At the same time, accessibility improved online, with a pre-release of CERN’s new website and more efforts devoted to social media with regular posts on Twitter, Facebook, YouTube and Google+. Along with the first ‘Tweetup’, which gave social-media enthusiasts an exclusive tour of the Laboratory, virtual visits allowed remote audiences to see inside CERN via video-conferencing tools. Live video conferences on YouTube known as ‘Hangout with CERN’ started up, growing out of similar online events by the CMS and ATLAS outreach teams and the Education Group.

The ATLAS experiment’s “Virtual Visits” received the award of ‘Best Online Event’ at the Digital Communication Awards 2012. During a virtual visit, participants use web-based video-conferencing tools to talk with physicists, receive a tour of the control room, and get answers to their questions.
CERN is one of the world’s largest centres for scientific research. The Laboratory extends over sites in both France and Switzerland, and is host to around 11,000 visiting researchers who use the facilities.

To support its facilities, infrastructure and research, CERN employs around 2,500 staff, 500 fellows and about 20 apprentices. It also welcomes some 370 associates and more than 300 students through a variety of programmes. The Human Resources (HR) Department has responsibility for many aspects of the working life of personnel, from talent acquisition and performance appraisal to social welfare and settlement of internal disputes. The Department reviewed and simplified its activities in 2012 and also optimized its structure. The aim of the new structure is to provide a ‘service and delivery’ partnership that reflects modern common practice, relying on centres of expertise and an enhanced ‘frontline’ role.

Interest in working at CERN continued to grow, with more than 40,000 applications in 2012 — another record-breaking number. Here, the HR Department’s recruitment campaign on social media proved extremely fruitful. It also led to invitations to speak at events on innovation in recruitment, as well as to four awards to CERN from the recruitment industry.

Innovation in human resources had already resulted in the Saved Leave Scheme, developed to increase the Organization’s ability to attract and retain staff by allowing them to purchase leave beyond the standard entitlement. The scheme was further enhanced in 2012, so that leave can be purchased and saved for taking at the end of a staff-member’s career or contract. In October, the new Long-Term Saved Leave Scheme received a Swiss award for HR Innovation.

CERN attracts people with a highly diverse mix of talents. During the year, the HR Department launched a new diversity programme, aimed at strengthening the Laboratory’s tradition of
inclusiveness. Initiatives linked to this programme include events to raise awareness of the need to acknowledge and leverage the differences that people bring to the workplace, as well as to identify priority areas, such as gender role-models, work-life balance, inclusiveness and mutual respect.

The Organization’s social system — the CERN Pension Fund and the Health Insurance Scheme — are important to all those employed by the Organization. CERN Council took several important decisions in 2010 to restabilize these schemes financially. The resulting package of measures was completed in 2012, a year that also saw the Pension Fund honoured with two international awards, for innovation and for risk management.

Enhancing the infrastructure
The General Infrastructure Services (GS) Department provides and maintains the buildings and underground civil engineering as well as logistic services to ensure the health and safety of anyone on site. It also provides and supports technical and administrative information systems.

Among the highlights of 2012 for GS were the construction and renovation of several buildings at CERN. Building 30, which houses many accelerator-sector personnel, saw consolidation of its facades. Elsewhere on the Meyrin site, the cryo lab was completely renovated and the CERN computer centre upgrade went from strength to strength (see p. 23). Construction of a new building — 107 — began in July, to house the Technology (TE) Department’s new facility for surface finishing, electronic module design and micro-pattern gas detector development. As well as a 70-space car park on the roof, air extraction systems will use scrubbers to remove pollution while minimizing the induced noise.

Over on the Prévessin site, work began in September for a new building — 774 — to house the Beams (BE) Department’s Controls Group from the end of 2013. Situated opposite the CERN Control Centre (CCC), this new four-storey building incorporates sustainable development aspects. For example, part of the roof will be covered with vegetation to absorb rainwater and enhance insulation. In addition, it will be fitted with 300 m² of solar panels, designed on the basis of technology developed at CERN (see p. 32).

More than 1400 facility maintenance and works requests were treated in 2012, aided by the CERN Service Portal, set up by the GS and IT Departments in 2011. Improvements to the Hostel management software led to greater flexibility with reservations. The new PS access system also progressed well. The IMPACT system to control access-flow to the LHC allowed for 6880 coordinated activities in 2012.

A new look at CERN
Many aspects of the Laboratory have taken on a crisp new look thanks to CERN’s new graphic charter, which was launched officially in 2012. The logo and a uniform branding are slowly but surely appearing everywhere, from vehicles and signage to websites and letterheads. The charter is a living resource that will evolve along with the Organization.
Safety and Environment

Safety is a priority for CERN, with five key safety objectives outlined for 2012 in line with international best practices. Objective number one was to limit the number of incidents in the workplace. Achieving this meant systematically investigating and acting on every incident that involves work stoppage, as well as the most frequent workplace accidents: falls, trips and slips. The performance indicators — the percentages of investigations and follow-ups completed — have been improving year on year.

The second objective was to improve hazard control, with a focus in 2012 on chemical hazards. The third concerned the safety of equipment, focusing this year on machine tools. Limiting CERN’s environmental impact was the fourth objective, which addressed issues such as noise pollution and energy consumption. Best practice in matters of radiation protection was the fifth safety objective for 2012, with the aim of keeping individual doses to personnel to values not only below legal limits but ‘ALARA’ – as low as reasonably achievable.

The definition of these corporate objectives marked a new approach in the implementation of CERN’s Safety Policy. By setting priorities in the different safety domains and promoting action through measurable safety goals, the Director-General encouraged a proactive approach from CERN personnel. In 2012, a risk assessment form for occupational hazards, developed by the Occupational Health and Safety and Environmental Protection Unit (HSE) in collaboration with the General Services (GS) and the Human Resources (HR) Departments, was linked to the yearly appraisal process to encourage a joint analysis of working
conditions between supervisee and supervisor. Members of the Safety Inspections Services section of HSE continued to regularly scrutinize the infrastructure and equipment at the Laboratory’s many sites. Inspections consisted of a comprehensive analysis of all risks to ensure that, for example, a high-voltage electrical installation was properly earthed, a system under pressure had no weak points, safety valves operated at the correct pressure threshold or there were no risks of falling objects or any other hazardous situations.

Prevention is better than cure

Hands-on training has become a key way of passing safety messages to CERN personnel, through newly formulated training courses, such as working at height, using self-rescue masks and fire extinguishing, as well as demonstrations and events. On the World Day for Health and Safety at Work in April, the Beams Department and the HSE Unit, with the help of the Engineering and GS Departments, organized events focusing in particular on ergonomics and electrical risks. The Fire Brigade organized a cardiac-massage competition – the goal of which was to try and get as close to the natural heartbeat rate as possible — with no fewer than 80 participants, including the Director-General.

In June, the CMS safety team, in collaboration with the Fire Brigade and the Medical Service, demonstrated the recommended, potentially life-saving, response to cardiac arrest, including first aid and the correct use of a defibrillator. Ten defibrillators were installed in key CERN locations in 2010.

To provide the best care for personnel, reorganization and improvement of the emergency services on site is being carried out, through a mandate given to the Medical Service. In 2012, one of the Fire Brigade’s two ambulances was replaced by a state-of-the-art vehicle tailor-made to meet CERN’s unique requirements.

Sustainability on site

The year 2012 was designated the International Year of Sustainable Energy for All by the United Nations General Assembly. CERN appointed an Energy Issues Coordinator in 2011 to help optimize infrastructure to become more sustainable and eco-friendly, and is now exploring the use of solar panels on the roofs of new buildings (see p. 36).

To help reduce CERN’s impact on the environment, in 2011 the GS Department received its first bi-fuel vehicles capable of running with petrol or natural gas. In 2012, this fleet — the first of its type in French-speaking Switzerland — reached a total of 100 vehicles. An awareness campaign ‘Hit the gas: go green!’ was launched to highlight the environmental benefits of running on natural gas, namely that it contains 20% biogas, which is carbon-neutral, and reduces carbon dioxide emissions by some 40%. It is also entirely soot-free and produces 60 – 95% less pollution overall than ordinary petrol.

On the move

Cycling also took centre stage in 2012. In May, the HSE Unit ran a cycling safety campaign in collaboration with the Swiss Office of Accident Prevention and the Touring Club Suisse. Activity stands and competitions helped pass the messages of safe cycling. In June, the GS Department promoted the Swiss Bike to Work initiative as part of the ‘Move! & Eat Better’ campaign run by the Medical Service. With cars left locked in garages and feet placed firmly on pedals, 316 CERN participants took up the initiative, clocking up more than 58 000 kilometres in total during the month-long scheme. The ‘Move! & Eat Better’ campaign also introduced a new category of nordic walking into CERN’s yearly relay race, which in 2012 saw more than 100 teams taking part. The ‘Move! & Eat Better’ campaign emerged as a result of a gradual increase in the average body mass index (BMI) of CERN people towards unhealthy levels over recent years. In an era of increasingly busy lives with screen-based working environments,
At 4.6 m long, CERN’s new ambulance is much more spacious than its predecessors, providing plenty of room for patient, doctor and paramedic.

This increase in BMI is not unique to CERN, but it does not take much to reverse the trend. Presentations by sports doctors and dieticians coupled with demonstrations by the CERN fitness club contributed to campaign events.

The ‘Move! & Eat Better’ campaign was launched in May with no end date. Just half an hour of physical activity a day, even something as simple as walking, coupled with a moderate and balanced diet, can make all the difference.

CERN participants in the Swiss Bike to Work initiative in June.
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President of Council: Professor M. Spiro (France)
Vice Presidents: Professor D.O. Riska (Finland), Professor R. Wade (United Kingdom)

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Dr D. Weselka

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Professor B. Sitár

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Dr L. Ruiz

Sweden
Dr M. Johnsson
Professor B. Åsman

Switzerland
Mr B. Moor
Professor U. Straumann

United Kingdom of Great Britain & Northern Ireland
Professor R. Wade (until June 2012)
Professor J. Womersley (from June 2012)
Dr G. Reid

Candidate for Accession

Romania
Professor N. Zamfir
Professor I. Andrei

Associate Member State in the Pre-stage to Membership

Israel
H.E. Mr A. Leshno Yaar (until September 2012)
H.E. Mr E. Manor (from September 2012)
Professor E. Rabinovici

Serbia (from 15 March 2012)
H.E. Mr U. Zvekić
Professor D. Popović

Observers

India, Japan, Russian Federation, Turkey, USA, European Commission, UNESCO
... and its Committees 2012

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Professor F. Zwirner (Italy)

Members
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Professor K. Tokushuku
Professor D. Wark
Professor T. Wyatt

Ex-officio members
Chairman of the LHC Experiments Committee:
Professor E. Elsen

Chairman of the SPS and PS Experiments Committee:
Professor C. Vallee

Chairman of the ISOLDE and Neutron Time-of-Flight Experiments Committee:
Professor P. Butler

Chairman of the European Committee for Future Accelerators:
Professor M. Krammer

Also present
President of the Council:
Professor M. Spiro (France)

Chairman of the Finance Committee:
Dr B. Jacobsen (Norway)

Director-General:
Professor R.-D. Heuer

Finance Committee

Chairman
Dr B. Jacobsen (Norway)

Members
One or more Delegates from each Member State
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**Director-General**
Rolf-Dieter Heuer

**Directorate's Office** - I. Bejar-Alonso, E. Tsesmelis
**Council Secretariat** - B. Van der Stichelen
**Communication** - J. Gillies
**EU Projects Office** - S. Stavrev
**Host States Relations** - F. Eder
**Internal Audit** - L. Esteveny
**Legal Service** - E.-M. Gröniger-Voss
**Occupational Health & Safety and Environmental Protection Unit (HSE)** - R. Trant
**Resources Planning, Processes and Controlling** - F. Sonnemann
**Translation & Minutes** - J. Pym
**VIP Office** - W. Korda

**Director for Administration & General Infrastructure**
S. Lettow

- **Finance, Procurement and Knowledge Transfer (FP)**
  T. Lagrange
  Deputy: C. Saitta

- **General Infrastructure Services (GS)**
  T. Pettersson
  Deputy: C. Delamare

- **Human Resources (HR)**
  A.-S. Catherin
  Deputy: J.-M. Saint-Viteux

**Director for Research & Scientific Computing**
S. Bertolucci

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- **Physics (PH)**
  P. Bloch
  Deputies: I. Antoniadis, L. Mapelli

**Director for Accelerators & Technology**
S. Myers

- **Beams (BE)**
  P. Collier
  Deputy: R. Garoby

- **Engineering (EN)**
  R. Saban
  Deputy: S. Baird

- **Technology (TE)**
  F. Bordry
  Deputy: L. Rossi
## Departments & Groups

<table>
<thead>
<tr>
<th>S DIR</th>
<th>Director-General Office Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG</td>
<td>Director-General</td>
</tr>
<tr>
<td>DG-AS</td>
<td>Administrative Support</td>
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<tr>
<td>DG-CO</td>
<td>Communication</td>
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<td>DG-CS</td>
<td>Council Secretariat</td>
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<td>Director-General</td>
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<td>DG-DI</td>
<td>Directorate</td>
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<td>DG-EU</td>
<td>EU Projects Office</td>
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<td>DG-IA</td>
<td>Internal Audit Service</td>
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<tr>
<td>DG-IR</td>
<td>International Relations</td>
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<td>DG-LS</td>
<td>Legal Service</td>
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<tr>
<td>DG-RH</td>
<td>Relations with Host States</td>
</tr>
<tr>
<td>DG-RPC</td>
<td>Resources Planning &amp; Control</td>
</tr>
<tr>
<td>DG-TM</td>
<td>Translation &amp; Minutes</td>
</tr>
<tr>
<td>DG-VIP</td>
<td>VIP &amp; Protocol Office</td>
</tr>
</tbody>
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<thead>
<tr>
<th>DGS</th>
<th>Occupational Health &amp; Safety and Environmental Protection Unit</th>
</tr>
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<tbody>
<tr>
<td>DGS-DI</td>
<td>Head Office of the HSE Unit</td>
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<tr>
<td>DGS-RP</td>
<td>Radiation Protection</td>
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<td>DGS-SEE</td>
<td>Safety Engineering &amp; Environment Group</td>
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<th>S AI</th>
<th>Administration and General Infrastructure Sector</th>
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<th>FP</th>
<th>Finance, Procurement &amp; Knowledge Transfer Department</th>
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<tr>
<td>FP-DI</td>
<td>Office of the Department Head</td>
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<tr>
<td>FP-FAS</td>
<td>Financial &amp; Accounting Services</td>
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<td>FP-KT</td>
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<td>FP-PI</td>
<td>Procurement &amp; Industrial Services</td>
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<tr>
<th>GS</th>
<th>General Infrastructure Services Department</th>
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<tr>
<td>GS-AIS</td>
<td>Advanced Information Systems</td>
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<tr>
<td>GS-ASE</td>
<td>Access, Safety &amp; Engineering Tools</td>
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<td>Head of Department's Office</td>
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<td>Fire Brigade</td>
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<td>Integrated Services</td>
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<td>Medical Service</td>
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<td>Site Engineering</td>
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<td>GS-SMS</td>
<td>Service Management &amp; Support</td>
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<th>HR</th>
<th>Human Resources Department</th>
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<td>HR-CB</td>
<td>Compensation &amp; Benefits</td>
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<td>Talent Acquisition</td>
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<td>BE-CO Controls</td>
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<td>BE-RF Radio Frequency</td>
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<td>EN-GMS General Management &amp; Secretariats</td>
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<td>EN-MEF Machines &amp; Experimental Facilities</td>
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<td>EN-MME Mechanical &amp; Materials Engineering</td>
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<td>EN-STI Sources, Targets &amp; Interactions</td>
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<td>TE-EPC Electrical Power Converters</td>
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<td>TE-MSC Magnets, Superconductors &amp; Cryostats</td>
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<td>TE-RPA Resources Planning &amp; Administration</td>
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<td>TE-VSC Vacuum, Surfaces &amp; Coatings</td>
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<thead>
<tr>
<th>S RC Research &amp; Scientific Computing Sector</th>
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<tr>
<th>IT Information Technology Department</th>
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<tr>
<td>IT-CF Computing Facilities</td>
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<td>IT-OIS Collaboration and Information Services</td>
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<td>IT-CS Communication Systems</td>
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<td>IT-DB Database Services</td>
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<td>IT-DI Departmental Infrastructure</td>
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<td>IT-DSS Data &amp; Storage Services</td>
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<td>IT-ES Experiment Support</td>
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<td>IT-GT Grid Technology</td>
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<tr>
<td>IT-OIS Operating Systems &amp; Infrastructure Services</td>
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<td>IT-PES Platform &amp; Engineering Services</td>
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<th>PH Physics Department</th>
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<tr>
<td>PH-ADE ATLAS Detector Systems</td>
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<tr>
<td>PH-ADO ATLAS Detector Operation</td>
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<tr>
<td>PH-ADP ATLAS Data Processing</td>
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<tr>
<td>PH-ADT ATLAS DAQ &amp; Trigger</td>
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<tr>
<td>PH-AGS Administration &amp; General Services</td>
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<tr>
<td>PH-AID ALICE Detector &amp; Systems</td>
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<tr>
<td>PH-AIP ALICE Management &amp; Engineering Support</td>
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<tr>
<td>PH-CMD CMS DAQ &amp; Trigger</td>
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<tr>
<td>PH-CMG CMS Physics, Software &amp; Computing</td>
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<tr>
<td>PH-CMO CMS Organization</td>
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<td>PH-CMX CMS Experiment Systems</td>
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<td>PH-DI Office of the Department Leader</td>
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<tr>
<td>PH-DT Detector Technology</td>
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<td>PH-EDU Education &amp; Visits</td>
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<tr>
<td>PH-ESE Electronics Systems for Experiments</td>
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<td>PH-LBF LHCb Computing</td>
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<td>PH-LBD LHCb Detector</td>
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<td>PH-LBO LHCb Co-ordinators Office</td>
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<td>PH-LCD Linear Collider Detector</td>
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<tr>
<td>PH-SFT Software Design for Experiments</td>
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<td>PH-SME Small &amp; Medium Experiments</td>
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<td>PH-TH Theoretical Physics</td>
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<td>PH-TOT TOTEM Experiment</td>
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<td>PH-UAD Antiproton Users</td>
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<td>PH-UAJ ALICE Users</td>
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<td>PH-UC3 CTF3 Users</td>
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<td>PH-UCL CMS Users</td>
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<td>PH-UFT Fixed Target Users</td>
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<td>PH-UGC General Collaboration Users</td>
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<td>PH-UHC Other LHC Users</td>
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<td>PH-UJS ISOLDE Users</td>
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<td>PH-ULB LHCb Users</td>
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<td>PH-ULD Linear Collider Detector Users</td>
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<td>PH-ULE LEP Users</td>
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<td>PH-UOP Other Physics Users</td>
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<td>PH-URD R&amp;D Users</td>
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<thead>
<tr>
<th>PF Pension Fund</th>
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<tr>
<td>FPMU Pension Fund Management Unit</td>
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<tr>
<td>PF-DI Departmental Infrastructure</td>
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<tr>
<td>PF-INV Investments</td>
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<tr>
<td>PF-OPS Operations</td>
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CERN in figures 2012

CERN Staff

- Applied scientists and engineers 41%
- Technical staff 35%
- Manual workers & craftspeople 5%
- Administrators & office staff 16%
- Research physcists 3%

CERN Expenses

- Personnel 55.1%
- Materials 36.9%
- Energy & water 6.4%
- Interest & financial costs 1.6%

Total expenses 1078.6 MCHF
- Personnel 594.6
- Materials 397.5
- Goods, consumables and supplies 200
- Other materials expenses 197.5
- Energy and water 69.3
- Interest and financial costs 17.2

Evolution of Staff numbers*

<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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<tbody>
<tr>
<td>Workers</td>
<td>2378</td>
<td>2427</td>
<td>2424</td>
<td>2512</td>
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Evolution of Fellows, Associates, Students, Users & Apprentices

<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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<tbody>
<tr>
<td>Count</td>
<td>10,405</td>
<td>11,025</td>
<td>11,449</td>
<td>12,080</td>
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</tbody>
</table>

*Staff head count including externally funded, as of 31 December 2012.
Glossary

Accelerating cavity
Accelerating cavities produce the electric field that accelerates the particles inside particle accelerators. Because the electric field oscillates at radio frequency, these cavities are also referred to as radio-frequency cavities.

Accelerator
A machine in which beams of charged particles are accelerated to high energies. Electric fields are used to accelerate the particles while magnets steer and focus them. Beams can be made to collide with a static target or with each other.

- A collider is a special type of circular accelerator where beams travelling in opposite directions are accelerated and made to interact at designated collision points.
- A linear accelerator (or linac) is often used as the first stage in an accelerator chain.
- A synchrotron is an accelerator in which the magnetic field bending the orbits of the particles increases with the energy of the particles. This makes the particles move in a circular path.

AD
The Antiproton Decelerator, the CERN research facility that produces the low-energy antiprotons for the experiments ACE, AEGIS, ALPHA, ASACUSA and ATRAP.

ALICE (A Large Ion Collider Experiment)
One of the four large experiments studying the collisions at the LHC.

Antimatter
Every kind of matter particle has a corresponding antiparticle. Charged antiparticles have the opposite electric charge to their matter counterparts. Although antiparticles are extremely rare in the Universe today, matter and antimatter are believed to have been created in equal amounts at the time of the Big Bang.

ATLAS
One of the four large experiments studying the collisions at the LHC.

Beam
The particles in an accelerator are grouped together in a beam. Beams can contain billions of particles and can be divided into discrete portions called bunches. Each bunch is typically several centimetres long and just a few microns wide.

Boson
The collective name given to the particles that carry forces between particles of matter. (See also Particles.)

Calorimeter
An instrument for measuring the amount of energy carried by a particle. In particular, an electromagnetic calorimeter measures the energy of electrons and photons, whereas a hadronic calorimeter determines the energy of hadrons, that is, particles made of quarks, such as protons, neutrons, pions and kaons.

CLIC (Compact Linear Collider)
A site-independent feasibility study aiming at the development of a realistic technology at an affordable cost for an electron–positron linear collider for physics at multi-TeV energies.

CMS (Compact Muon Solenoid)
One of the four large experiments studying the collisions at the LHC.

CNGS (CERN Neutrinos to Gran Sasso)
A project that aims at the first observation of the tau neutrino by sending a beam of muon neutrinos from CERN to the Laboratori Nazionali del Gran Sasso in Italy.

Cosmic ray
A high-energy particle that strikes the Earth’s atmosphere from space, producing many secondary particles, also called cosmic rays.

CP violation
A subtle effect observed in the decays of certain particles that betrays Nature’s preference for matter over antimatter.

Cryostat
A refrigerator used to maintain extremely low temperatures.

Dark matter
Only 4% of the matter in the Universe is visible. The rest is of an unknown nature and is referred to as dark matter (26%) and dark energy (70%). Finding out what it consists of is a major question for modern science.

Detector
A device used to measure properties of particles. Some detectors measure the tracks left behind by particles, others measure energy. The term ‘detector’ is also used to describe the huge composite devices made up of many smaller detector elements. In the large detectors at the LHC each layer has a specific task.

Dipole
A magnet with two poles, like the north and south poles of a horseshoe magnet. Dipoles are used in particle accelerators to keep particles moving in a circular orbit. In the LHC there are 1232 dipoles, each 15 m long.

Electronvolt (eV)
A unit of energy or mass used in particle physics. One eV is extremely small, and units of a million electronvolts, MeV, or a thousand million electronvolts, GeV, are more common. The LHC will ultimately reach 7 million million electronvolts, or 7 TeV per beam. One TeV is about the energy of motion of a flying mosquito.

Event
A snapshot of a particle collision, as recorded by a detector.

Forces
There are four fundamental forces in nature. Gravity is the most familiar to us, but it is the weakest. Electromagnetism is the force responsible for thunderstorms and carrying electricity into our homes. The two other forces, weak and strong, are confined to the atomic nucleus. The strong force binds the nucleus together, whereas the weak force causes some nuclei to break up. The weak force is important in the energy-generating processes of stars, including the Sun. Physicists would like to find a theory that can explain all these forces. A big step forward was made in the 1960s when the electroweak theory unifying the electromagnetic and weak forces was proposed. This was later confirmed in a Nobel-prize-winning experiment at CERN.

GeV
See Electronvolt.

Hadron
A subatomic particle that contains quarks, antiquarks, and gluons, and so experiences the strong force. (See also Particles.)

Higgs boson
A particle predicted by theory. It is linked with the mechanism by which physicists think particles acquire mass.

Injector
System that supplies particles to an accelerator. The injector complex for the LHC consists of several accelerators acting in succession.

Ion
An ion is an atom with one or more electrons removed (positive ion) or added (negative ion).

Isotope
Slightly different versions of the same element, differing only in the number of neutrons in the atomic nucleus — the number of protons is the same.

ISOLDE
A radioactive ion beam facility that directs a beam of protons from the Proton-Synchrotron Booster onto special targets to produce more than 1000 different isotopes for a wide range
of research including life sciences. (See also Isotope.)

**Kelvin**
A unit of temperature. One kelvin is equal to one degree Celsius. The Kelvin scale begins at absolute zero, −273.15°C, the coldest temperature possible.

**Lepton**
A class of elementary particle that includes the electron. Leptons are particles of matter that do not feel the strong force. (See also Particles.)

**LHC**
The Large Hadron Collider, CERN’s biggest accelerator.

**LHCb (Large Hadron Collider beauty)**
One of the four large experiments studying the collisions at the LHC.

**Linac**
See Accelerator.

**Luminosity**
In particle physics, luminosity is a measure of how many particles pass through a given area in a certain amount of time. The higher the luminosity delivered by the LHC, the larger the number of collision events happening at each experiment. Hence, more luminosity means more precise results and an increased possibility to observe rare processes.

**Muon**
A particle similar to the electron, but some 200 times more massive. (See also Particles.)

**Muon chamber**
A device that identifies muons, and together with a magnetic system creates a muon spectrometer to measure momenta.

**Neutrino**
A neutral particle that hardly interacts at all. Neutrinos are very common and could hold the answers to many questions in physics. (See also Particles.)

**Nucleon**
The collective name for protons and neutrons.

**Particles**
There are two groups of elementary particles, quarks and leptons. The quarks are up and down, charm and strange, top and bottom (beauty). The leptons are electron and electron neutrino, muon and muon neutrino, tau and tau neutrino. There are four fundamental forces, or interactions, between particles, which are carried by special particles called bosons. Electromagnetism is carried by the photon, the weak force by the charged W and neutral Z bosons, the strong force by the gluon; gravity is probably carried by the graviton, which has not yet been discovered. Hadrons are particles that feel the strong force. They include mesons, which are composite particles made up of a quark–antiquark pair and baryons, which are particles containing three quarks. Pions and kaons are types of meson. Neutrons and protons (the constituents of ordinary matter) are baryons; neutrons contain one up and two down quarks; protons two up and one down quark.

**PS**
The Proton Synchrotron, backbone of CERN’s accelerator complex.

**Quadrupole**
A magnet with four poles, used to focus particle beams rather as glass lenses focus light. There are 392 main quadrupoles in the LHC.

**Quantum chromodynamics (QCD)**
The theory for the strong interaction, analogous to QED.

**Quantum electrodynamics (QED)**
The theory of the electromagnetic interaction.

**Quark–gluon plasma (QGP)**
A new kind of plasma in which protons and neutrons are believed to break up into their constituent parts. QGP is believed to have existed just after the Big Bang.

**Sextupole**
A magnet with six poles, used to apply corrections to particle beams. At the LHC, eight- and ten-pole magnets will also be used for this purpose.

**Sigma**
A representation of standard deviation — the error margin on a measurement — where 5 sigma is the probability that a measurement is 99.99994% correct.

**Spectrometer**
In particle physics, a detector system containing a magnetic field to measure momenta of particles.

**SPS**
The Super Proton Synchrotron. An accelerator that provides beams for experiments at CERN, as well as preparing beams for the LHC.

**Standard Model**
A collection of theories that embodies all of our current understanding about the behaviour of fundamental particles.

**Superconductivity**
A property of some materials, usually at very low temperatures, that allows them to carry electricity without resistance. If you start a current flowing in a superconductor, it will keep flowing for ever — as long as you keep it cold enough.

**Supersymmetry**
A theory that predicts the existence of heavy ‘superpartners’ to all known particles. It is being tested at the LHC.

**Technology transfer**
The promotion and dissemination to third parties of technologies developed, for example at CERN, for socio-economic and cultural benefits.
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