

Annual Report 2013





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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 21 Member States as of January 2014. 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, except:
Thomas Kubes (pp. 2–3),
Andrzej Zalewska (p. 4),
Iván Martínez/FPA (p. 7, upper),
Hasse Ferrold (p. 7, lower),
L P Gaffney et al. 2013 *Nature* **497** 199 (p. 12),
Planck Collaboration (p. 21),
Wigner RCP (p. 23).



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Message from the President of Council



“It was a great pleasure to welcome Israel as the first new Member State in 14 years.”

A notable highlight of 2013 — not only for CERN but for physics as a whole — was the award of the Nobel Prize in Physics to François Englert and Peter Higgs, for their work on the Brout–Englert–Higgs mechanism. This mechanism, which contributes to our understanding of the mass of fundamental particles, was confirmed through the discovery of a Higgs boson by the ATLAS and CMS experiments at the LHC. CERN Council was delighted by the award, which gives important recognition to the effort taken to build the LHC and its experiments by thousands of scientists and engineers in the Member States and many other countries.

The year also saw the accomplishment of the process to update the European Strategy for Particle Physics, initiated by Council in September 2011. The updated strategy document with 17 strategy statements was prepared by the European Strategy Group at its meeting in Erice in January. Council discussed the document at its session in March and then unanimously adopted it at its special session in Brussels on 30 May.

The session in Brussels, hosted by the European Commission, was accompanied by events that were a great success in communicating the contributions of particle physics to society. These included a CERN exhibition in the commission’s Berlaymont Building, a discussion panel on ‘What do we get from basic research’, an event in the European Parliament, and a presentation to the ministers of research and innovation at the meeting of the European Union’s Competitiveness Council.

In June, Council adopted the Medium Term Plan for CERN for the years 2014–2018, which takes into account the updated Strategy. In particular, it follows up on the statement that recognizes exploitation of the full potential of the LHC, including the high-luminosity upgrade, as a top priority for Europe.

The first extremely successful phase of the LHC operation came to a conclusion early in the year. Council congratulated the CERN Management and all those involved in the running of the LHC machine on the excellent results, and applauded the LHC collaborations and everyone involved in the Worldwide LHC Computing Grid on the remarkable physics analyses. Since then Council has been following the excellent progress being made with Long Shutdown 1.

Another remarkable event for 2013 was the unanimous adoption of a resolution at the December session of Council to admit Israel as the Organization’s 21st Member State. Israeli scientists have been involved in the CERN programme for many years, and it was a great pleasure for Council to welcome their country as the first new Member State in 14 years.

It has been an enormous privilege that my first year as President of CERN Council has been at such a momentous time. I look forward to 2014, which will be a particularly special year as the Organization celebrates its 60th anniversary.

Agnieszka Zalewska

Agnieszka Zalewska

Message from the Director-General



“The achievements that these prizes recognize were only possible because of the dedication of everyone involved”

The discovery of a Higgs boson in 2012 may have seemed a hard act to follow, but a number of events meant that 2013 was another exciting year for CERN. From the start of the major shutdown of the whole accelerator complex for refurbishment and upgrades, through the fascinating results from the LHC's first run and experiments elsewhere at CERN, to the Open Days in September — there was plenty happening throughout the year.

It was also a notable year for prizes. The award of the 2013 Nobel Prize in Physics to François Englert and Peter Higgs was met with jubilation not only at CERN, but among particle physicists everywhere. Honours that were bestowed on CERN included the Prince of Asturias Award and the UNESCO Niels Bohr Gold Medal.

All of these awards are a wonderful tribute to the hard work of the thousands of people who have been involved in building the LHC, its detectors and the necessary computing capacity since the collider was first formally proposed in the early 1980s. The achievements that these prizes recognize were only possible because of the dedication of everyone involved, at CERN and at many laboratories and universities around the world.

This work continues as the Laboratory prepares for the next chapter in the story of the LHC. Since the start of the first long shutdown, LS1, the whole accelerator complex has been undergoing the most extensive campaign of maintenance and renovation that it has ever had. Having progressed well in 2013, LS1 is on course for the accelerators to restart one by one from summer 2014 onwards — thanks to the efforts of all of the teams concerned, including many external groups.

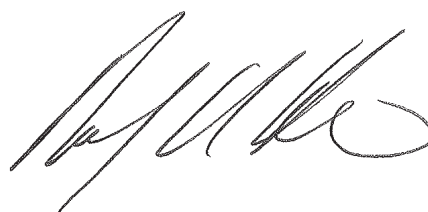
At the same time, projects to upgrade the LHC are already under way, in line with the priorities set during the year by the updated European Strategy for Particle Physics. Work has also begun

on new or improved facilities. These include, for example, the CERN MEDICIS project to produce radioisotopes for medical applications, the ELENA project at the Antiproton Decelerator, and a new experimental area for the neutron source, n_TOF.

The increasing recognition for particle physics and for CERN, as well as the continuing flow of results and innovative initiatives, has kept the Laboratory in the headlines. In 2013, thousands of visitors from the neighbouring area and beyond were able to benefit from LS1 to see underground, in particular during the Open Days. These were, once again, made possible through the commitment of the Organization's staff and the large community of 'users' who make up the CERN family.

All in all, it was a memorable year. In 2014, CERN celebrates its 60th anniversary, which promises to be another year to remember.

Rolf Heuer





A jubilant crowd at CERN watches the announcement of the award of the 2013 Nobel Prize in Physics live on the screen visible to the right.

A year at CERN

An end and a beginning

At 7.24 am on 14 February 2013, the shift crew in the CERN Control Centre extracted the beams from the Large Hadron Collider, bringing the machine's first three-year running period to a successful conclusion. The LHC exceeded all expectations during this first run, delivering significantly more data to the experiments than initially foreseen. This allowed major advances in physics: the consolidation of the current Standard Model of particle physics, including the first observation of some rare particle decays; the discovery of interesting properties in hot, dense matter; and the acclaimed discovery in 2012 of a particle that bears the hallmarks of a Higgs boson.

During the first weeks of 2013, the LHC had operated in a new mode, producing collisions between a beam of protons and a beam of lead ions as part of the programme to understand matter as it might have been just after the Big Bang. The data collected revealed intriguing new effects in all of the four large LHC experiments: ALICE, ATLAS, CMS and LHCb.

The end of the run marked the beginning of the first long shutdown, LS1, not only for the LHC but for all of CERN's accelerator complex, after three years of almost continuous running — unprecedented at CERN. Work started immediately on preparing the LHC for running at higher energy as well as on essential maintenance for other parts of the accelerator chain, including the Proton Synchrotron (PS) and the Super Proton Synchrotron (SPS). By the end of the year, the programme for LS1 was well on schedule thanks to the efforts of all involved, including many external groups. Maintenance and installation also involved the ISOLDE facility, the n_TOF neutron source and the Antiproton Decelerator (AD). At the same time, the analysis of data collected in 2012 at these facilities continued and produced fascinating results related to nuclei and to antiprotons.

The discovery continues

The new boson discovered in 2012 continued to be a major highlight in 2013, both at CERN and around the world. At the Moriond conference in March, the ATLAS and CMS collaborations



On 25 October, François Englert, left, and Peter Higgs, centre, received the Prince of Asturias Award together with CERN, for ‘the theoretical prediction and experimental detection of the Higgs boson’. The ceremony took place in Oviedo, in the presence of Her Majesty the Queen of Spain and the Prince and Princess of Asturias. CERN’s Director-General, Rolf Heuer, right, accepted the prize on behalf of the Laboratory.



At a ceremony on 5 December in Copenhagen, UNESCO awarded the Niels Bohr Gold Medal to CERN ‘in recognition of its outstanding global action in promoting scientific cooperation across borders’. The medal — first awarded in 1998 — is given to those who have made outstanding contributions to physics in research that has or could have a significant influence on the world.

presented results that further characterized the particle. Having analysed two and a half times more data than was available for the discovery announcement, they could say that it did indeed look very much like a Higgs boson — the particle linked to the Brout–Englert–Higgs mechanism that gives mass to elementary particles. It remains an open question whether it is the Higgs boson of the Standard Model of particle physics — a question that will take time to answer.

Several major awards reflected this growing understanding of the new particle. In May, the European Physical Society announced the award of its High-Energy and Particle-Physics Prize to the ATLAS and CMS collaborations, ‘for the discovery of a Higgs boson, as predicted by the Brout–Englert–Higgs mechanism’, and to Michel Della Negra, Peter Jenni and Tejinder Virdee, ‘for their pioneering and outstanding leadership roles in the making of the ATLAS and CMS experiments.’ The announcement of the most prestigious award — the 2013 Nobel Prize in Physics — was awaited with mounting excitement at CERN on 8 October.

Then the news came: François Englert and Peter Higgs had been honoured for ‘the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s Large Hadron Collider.’ (Sadly, Englert’s co-worker Robert Brout had passed away in 2011.)

These events all helped to keep CERN in the spotlight. There were 181 protocol and high-level national visits during the year, from countries varying from Austria to Australia, from Turkey to Thailand. More than 1200 journalists visited, many in a new programme of national visits. Moreover, at the end of September, CERN opened its doors to some 70 000 people, with the opportunity — allowed by the shutdown — for many to go underground (see p. 31).

International collaboration

At the end of May, at a special meeting hosted by the European Commission in Brussels, CERN Council formally adopted an update to the European Strategy for Particle Physics, taking into account the changing scene in particle physics not only in Europe but globally. The updated strategy emphasizes that Europe and the European particle-physics community should exploit the LHC to its full potential over many years via the series of planned upgrades, in particular the High Luminosity LHC (see p. 28). Another aim is to preserve and build on the European model for cross-border research. As part of the updated strategy, CERN — in close collaboration with research institutions in the Member States and under the guidance of Council — will participate in global engagement in particle physics.



Left to right: Eliezer Rabinovici, Chair of the Israeli Academy of Science's National Committee for High Energy Physics; Eviatar Manor, Israel's Ambassador to the UN in Geneva; CERN's Director-General, Rolf Heuer, and Giora Mikenberg of the Weizmann Institute.

A new Member State

At its 169th session on 12 December, Council unanimously adopted a resolution to admit Israel as CERN's 21st Member State.

Israel has a long-standing relationship with CERN in both theoretical and experimental physics. This was formalized in 1991, when the country was granted Observer status in recognition of the major involvement of Israeli institutions in the OPAL experiment at the Large Electron–Positron collider, accompanied by contributions to the running of the accelerator. Today, Israel is involved with the ATLAS, ALPHA and COMPASS experiments, as well as experiments at the ISOLDE facility, and continues to collaborate in theoretical physics. In addition, Israel contributes to the LHC and to the CLIC accelerator design study, and operates a Tier-2 centre of the Worldwide LHC Computing Grid.

Snapshots 2013



01/03

UN Secretary-General Ban Ki-moon, right, visited CERN for the first time since the Organization was granted observer status at the UN General Assembly in December 2012. He visited the ATLAS experiment with the new spokesperson, Dave Charlton, left.



05/04

Olga Golodets, Deputy Prime Minister of the Russian Federation, came to CERN on a visit that included a tour of the ATLAS underground experimental area and the LHC tunnel. She also met members of CERN's Russian community.



15/04

Androulla Vassiliou, centre left, European Commissioner for Education, Culture, Multilingualism, Sport, Media and Youth, visited CERN to meet young researchers supported by the EU Marie Curie Actions fellowship programme.



03/05

The inaugural TEDxCERN event took place in the Globe of Science and Innovation and was webcast live at participating institutes around the world. With the theme of ‘multiplying dimensions’, the event went beyond particle physics and speakers ranged from pioneers to young scientists.



04/06

Elio Di Rupo, the prime minister of Belgium, left, visited CERN accompanied by groups of Belgian school students. His tour included the CMS experimental area with future Nobel laureate François Englert, centre, and Joe Incandela, the spokesperson for the CMS collaboration.



11/06

The visit of the president of Austria, Heinz Fischer, second from right, with spouse Margit Fischer, centre, and the Austrian minister for science and research, Karlheinz Töchterle, right, included a tour of the AD with AEGIS spokesperson Michael Doser.



02/07

Approaching his 103rd birthday, former French ambassador and President of CERN Council, François de Rose, visited the ATLAS experiment and expressed pride in the Organization as a “great European achievement”.



10/07

American sound artist Bill Fontana began his artist residency at CERN, finding inspiration in the LHC tunnel.



28/10

Former US Vice President Al Gore, with Sergio Bertolucci, CERN's Director for Research and Scientific Computing, signs the guest book during his visit to CERN.



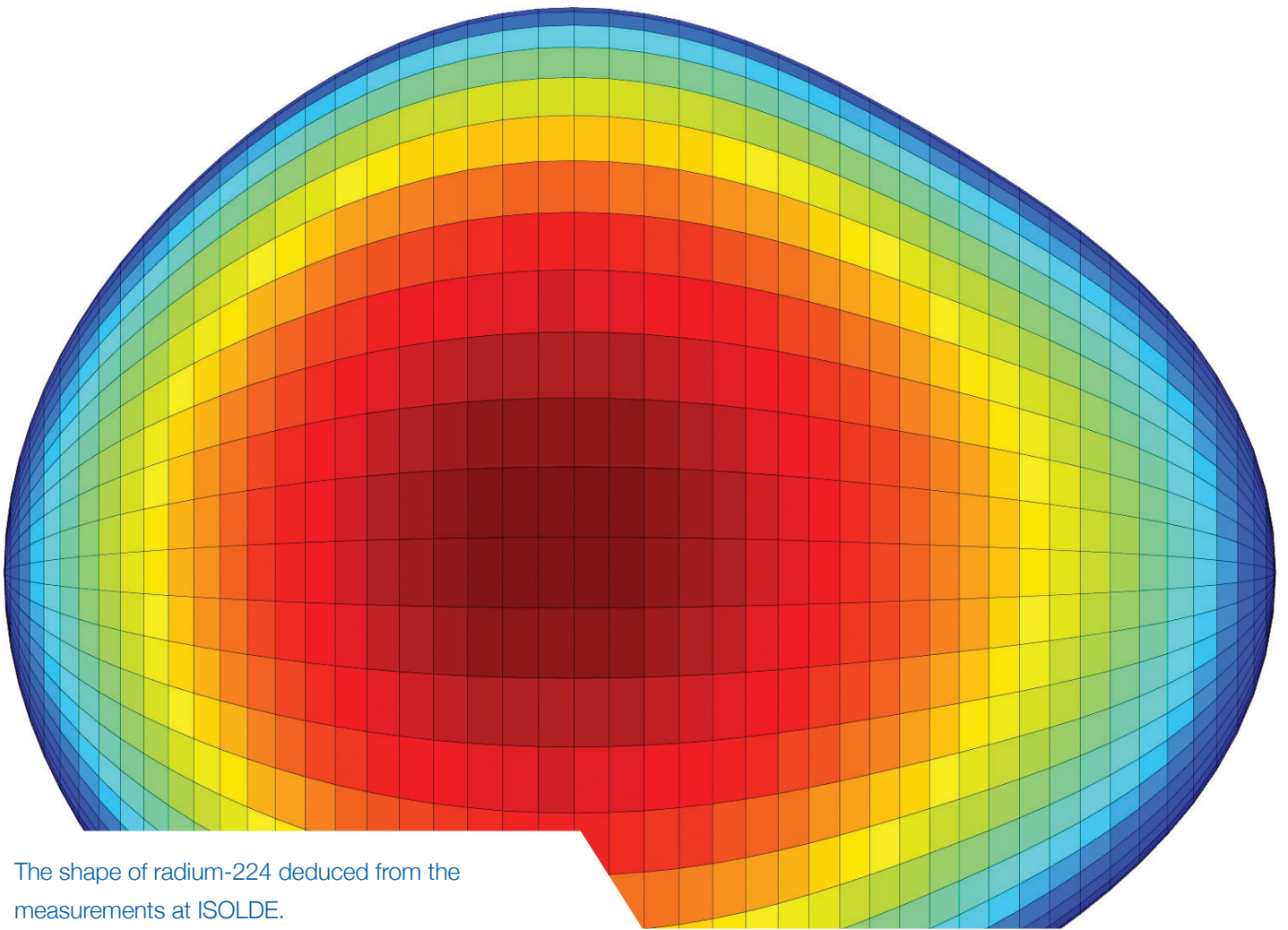
13/12

CERN celebrated Steve Myers' career with a colloquium at the end of his five-year mandate as Director of Accelerators and Technology.



20/12

CERN launched an online scavenger hunt with the challenge to find hidden LEGO characters in Google's Street View of the Computing Centre.



The shape of radium-224 deduced from the measurements at ISOLDE.

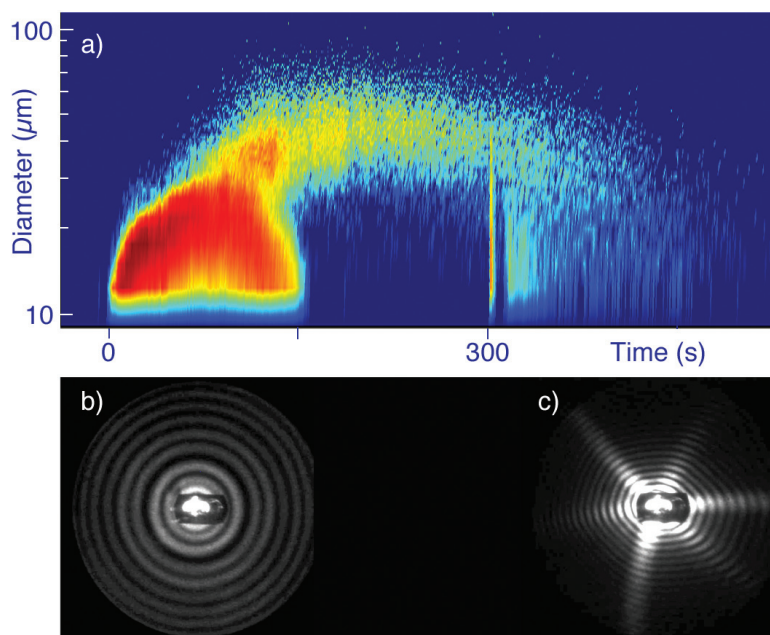
Physics and Experiments

The year started for the accelerator complex with the short proton-lead run at the LHC, before the long shutdown began for all of CERN's accelerators. This made 2013 a year for refurbishment and analysis, yielding fascinating results in experiments across the complex — from the lowest to the highest energies.

ISOLDE in the news

The ISOLDE facility, in operation since 1967, produces a broad range of radioactive beams for many different experiments in nuclear and atomic physics, condensed-matter physics and life sciences. While the facility underwent some reorganization during the long shutdown (see p. 30), 2013 nevertheless proved exciting for physics, with results from three different experiments appearing in *Nature* publications within the space of a few weeks.

Early in May, *Nature* published results from a detailed study of the spectrum of gamma-rays emitted from short-lived heavy atomic nuclei, revealing new information about their shape. Most nuclei are spherical or axially deformed but theory also predicts



A cloud in CLOUD. (a) shows the cloud particle size as a function of time during an adiabatic expansion in the CLOUD chamber (the colour scale indicates the concentration, red being denser). Liquid droplets start to form at time zero. About 100 seconds later, some droplets freeze and rapidly grow bigger. Then the remaining liquid droplets (everything smaller than $30\text{ }\mu\text{m}$) evaporate, leaving a pure ice cloud — exactly as happens when ice forms in natural clouds. At 300 seconds, air is re-injected into the chamber, terminating the cloud; (b) and (c) show optical diffraction images from this same cloud of a single liquid droplet (b) and hexagonal ice plate (c).

asymmetric shapes, such as octupole or ‘pear’ shapes. The new measurements, made with the MINIBALL apparatus, indicate that radium-224 presents a stable pear shape; in contrast, radon-220 vibrates about this shape but does not stabilize. The results help to discriminate between nuclear models and to identify which nuclei could have sizeable atomic electric-dipole moments — a measure of the separation of positive and negative electric charge — as predicted by theories that go beyond the Standard Model.

A few days later, a team working with the Resonant Ionization Laser Ion Source at ISOLDE published the first determination of the ionization potential of astatine in the online journal *Nature Communications*. Astatine is the rarest element on Earth and the value of this fundamental property is the last to be found for the naturally occurring elements. It is of particular interest because isotopes of astatine could be used in radiopharmaceuticals for cancer therapy. It will also help in predicting properties of the super-heavy element 117, astatine’s heaviest chemical homologue.

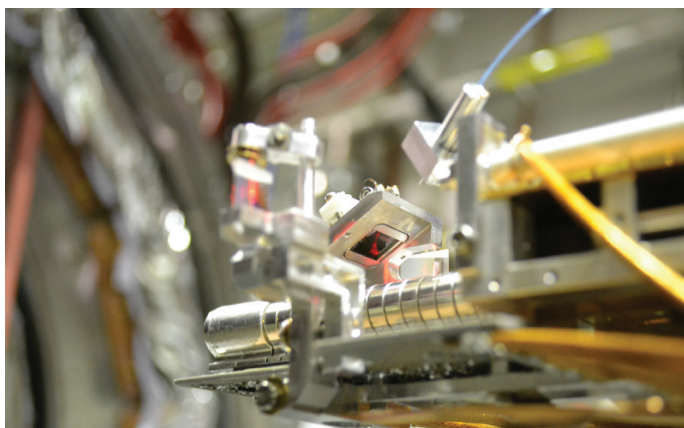
In June, it was the turn of the ISOLTRAP collaboration to publish in *Nature*. They had measured the masses of exotic calcium nuclei using an innovative electrostatic ‘mirror’ device. In the shell model of nuclei, the protons and neutrons arrange themselves in ‘shells’ similar to those of electrons in atoms; the so-called ‘magic’ numbers of protons or neutrons correspond to full shells, where the constituents are more tightly bound, leading to nuclei with higher stability. The results strengthen the evidence that 32 is a new magic number one of the few to be found since the shell model of the nucleus was proposed in the 1940s, and cast light on how nuclei can be described in terms of the fundamental strong force.

Beams from the PS

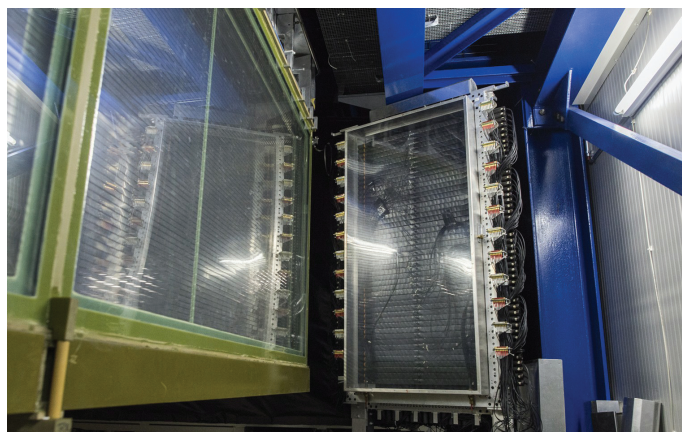
At the PS, the CLOUD experiment is investigating whether atmospheric aerosols and clouds are influenced by galactic cosmic rays. In a paper published in *Nature* in October, the collaboration reported that amine vapours, which are found in the atmosphere at extremely low concentrations of only a few molecules per trillion air molecules, can combine with sulphuric acid to form highly stable aerosol particles at rates similar to those observed in the lower atmosphere. This represents a major advance because it is the first time that atmospheric particle-formation has been reproduced with a complete knowledge of the participating molecules. During the shutdown of the accelerator complex, the collaboration continued to take data, using cosmic rays to study liquid and ice clouds inside the CLOUD chamber.

The DIRAC experiment, which ran at the PS during 2008–2012, studies unusual ‘atoms’ made of pions and kaons rather than electrons and protons, in order to check the low-energy predictions of quantum chromodynamics for light quarks. The analysis of the data for πK and $\pi^+\pi^-$ (pionium) atoms continued apace during 2013. To check highly precise theoretical predictions involving strange quarks, the experiment measured the lifetime of πK atoms. DIRAC may also have observed the first long-lived $\pi^+\pi^-$ atoms with a significance of 5 standard deviations (or sigma, σ) but this is still under scrutiny.

For the n_TOF facility, which uses protons from the PS to create a high-intensity neutron beam, 2013 has been a year of transition, with the construction of a new experimental area, EAR-2 (see p. 30). The collaboration also used the shutdown to finalize analyses and publish important results based on data from 2011–13. The triennial International Conference on



The antihydrogen production region of the AEGIS experiment.



Tracking chambers for the NA61/SHINE experiment.

Nuclear Data for Science and Technology provided the perfect opportunity to share the latest results, with a record number of 18 talks on nuclear experiments performed at CERN. Last but not least, the n_TOF family continues to grow, welcoming new collaborators from Japan, Russia and the UK.

Focus on antimatter

The collaborations investigating antimatter at the Antiproton Decelerator (AD) worked on their experimental set-ups during 2013, in order to be ready for beam in the second half of 2014. A major goal is to check if antiatoms behave in the same way as atoms of ordinary matter.

The ASACUSA collaboration greatly increased the number of trapped positrons, achieved better antiproton-trapping rates and worked towards demonstrating the feasibility of antihydrogen beams. Recent theoretical and technical improvements also opened the door to improved spectroscopy of antiprotonic helium.

The ATRAP collaboration published its new measurement of the antiproton's magnetic moment in *Physical Review Letters*. With an unprecedented uncertainty of 4.4 parts per million, the result is 680 times more precise than previous measurements. The team also progressed towards trapping and studying larger numbers of antihydrogen atoms.

A new arrival at the AD, the Baryon Antibaryon Symmetry Experiment (BASE), was approved in June to apply a different technique to the measurement of the magnetic moment of the proton and the antiproton. The collaboration, which aims to determine this fundamental property to one part per billion, started installation in September.

Elsewhere in the AD hall, the ALPHA collaboration commissioned components of an extended new apparatus, ALPHA-2. This

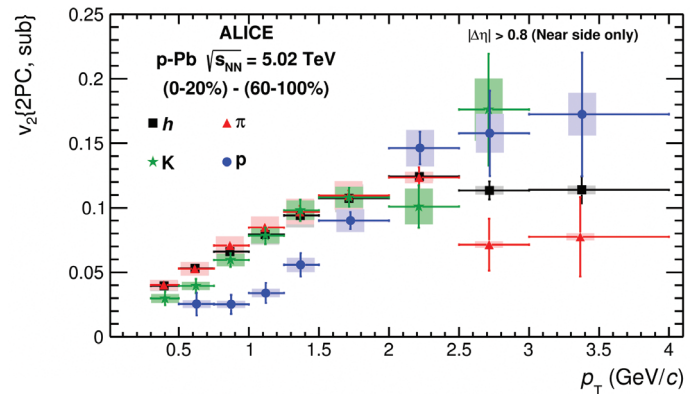
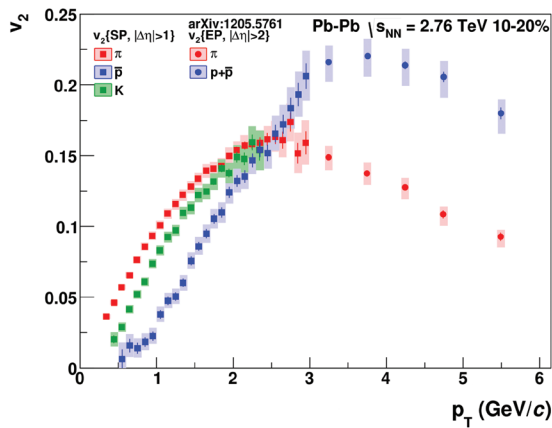
separates the process of trapping from that of studying antihydrogen, allowing improved access for lasers to probe the trapped antihydrogen atoms. The collaboration also made a novel investigation of how antimatter is affected by gravity. Using data from 2012, they searched for the free fall (or rise) of antihydrogen atoms released from the trap, and put the first very loose limits on the gravitational properties of antimatter in a paper published in *Nature Communications*.

Two experiments, AEGIS and GBAR, are designed specifically to measure the gravitational interaction of antimatter. The AEGIS apparatus was completed and improved in 2013, with the many components (traps, positron and positronium production, lasers, detectors) needed to form antihydrogen being commissioned. The GBAR experiment will take place at the future ELENA facility at the AD (see p. 30).

Beams from the SPS

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 experiment (NA58) implemented the complex hardware modifications needed for data taking in 2015 when a beam of pions will interact with polarized protons (p^\uparrow). The reaction $\pi p^\uparrow \rightarrow \mu^+ \mu^- X$ will be induced by a 190 GeV beam of pions impinging on a transversely polarized ammonia target. The goal is to measure for the first time how the polarization affects the production of pairs of muons ($\mu^+ \mu^-$). The whole beam line is being rearranged for this measurement. This entails moving the world's largest target of polarized protons and its superconducting magnets by 2 m in order to make room for the thick absorber of tungsten, alumina and concrete, which is necessary to stop all particles except muons (and neutrinos). Meanwhile, the collaboration continued to analyse the large amount of data recorded in 2008 and 2009 with pion and kaon beams. A search for exotic particle states has revealed a new,



The strength of elliptic flow, denoted v_2 , as measured by ALICE for various identified particles emerging from lead-lead (PbPb) collisions (left) and proton-lead (pPb) collisions (right) as a function of their momentum transverse to the beam. In both cases this behaviour depends in the same way on the mass of the emerging particles, where pions (π) are the lightest and protons (p) the heaviest.

narrow state with a mass of 1420 MeV. Its exact nature is still being assessed.

The NA61/SHINE experiment conducts heavy-ion studies to understand under what conditions and how the quarks and gluons that are normally confined inside protons and neutrons can form quark-gluon plasma, in which the quarks and gluons move freely. In 2013, the collaboration studied the collisions of a beam of beryllium — a light nucleus — from the SPS with a target, also of beryllium. The first results indicate that at high SPS energies the mechanism to produce hadrons — particles made of quarks and gluons — with beryllium nuclei is different from what NA61/SHINE previously observed with proton collisions. This suggests that a phase transition to a quark-gluon plasma may happen in collisions even of light nuclei, a phenomenon never observed before. NA61/SHINE also studies the properties of hadrons produced in proton-carbon interactions, a key measurement for the T2K neutrino-oscillation experiment in Japan. This fruitful association encouraged other physicists working with neutrino beams at Fermilab to collaborate with NA61/SHINE to obtain similar measurements tailored to their needs.

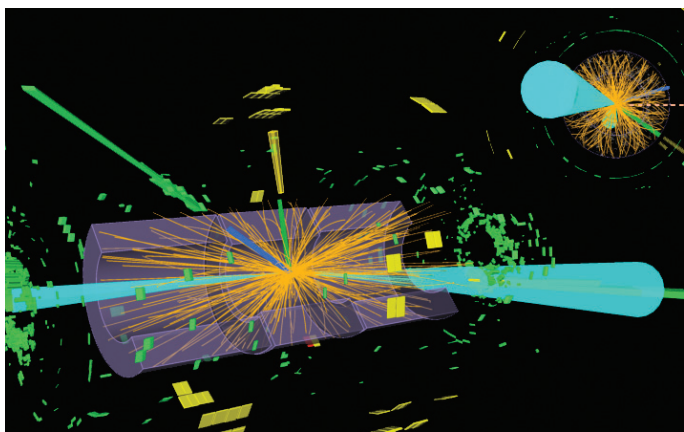
The NA62 experiment saw important milestones in 2013 for the upgrade of the complete set-up. The collaboration allocated all of the remaining large construction contracts, including those for the drift-chamber interfaces and the vessel for the ring-imaging Cherenkov detector. They also received the innovative TDCpix chip — a key element of the beam tracker — and launched the full production of the electronics for the liquid-krypton calorimeter, following a successful pre-production phase. At the same time the collaboration completed the analysis of data accumulated during a technical run performed at the end of 2012. The data indicate how best to operate the new detectors, beam and electronics.

The NA63 experiment studies quantum effects in electromagnetic interactions occurring when a beam of high-energy particles passes through thin amorphous targets. In 2013, the collaboration obtained results that considerably clarified the role of multiple scattering in the emission of radiation from targets made of light nuclei. They also measured the resonance pattern that arises when the formation length of the photon — the distance required to create a photon — exactly matches the distance between two closely spaced foils. Surprisingly, this length can be determined using foils placed 0.5 mm apart, even though the wavelength of the radiation is barely 10 femtometres, some 100 000 million times smaller.

The CERN Neutrinos to Gran Sasso project, which produced a beam of muon neutrinos at the SPS, came to an end in December 2012, having provided the ICARUS and OPERA experiments located in the Gran Sasso National Laboratory in central Italy with plenty of data. Neutrinos interact very feebly with matter, so the beam travelled easily through the Earth's crust, but there was a small probability that during the 730 km journey, the muon neutrinos could change into another type of neutrino. Such neutrino 'oscillations' cast light on the tiny masses of these particles. During continued analysis in 2013, the OPERA collaboration found a third event in which a muon neutrino changed into a tau neutrino, indicating that muon neutrinos do appear to oscillate to tau neutrinos. In complementary work, ICARUS studied oscillations of muon neutrinos to a third type, the electron neutrino. In 2013, the collaboration reported the detection of such oscillations, but with no indication of anomalous effects claimed for experiments elsewhere.

ALICE: the hottest matter

At the LHC, the ALICE experiment specializes in studying the hot, dense matter formed in the high-energy, head-on collisions between lead nuclei, which contain many nucleons (protons and neutrons) and hence large numbers of quarks (the constituents



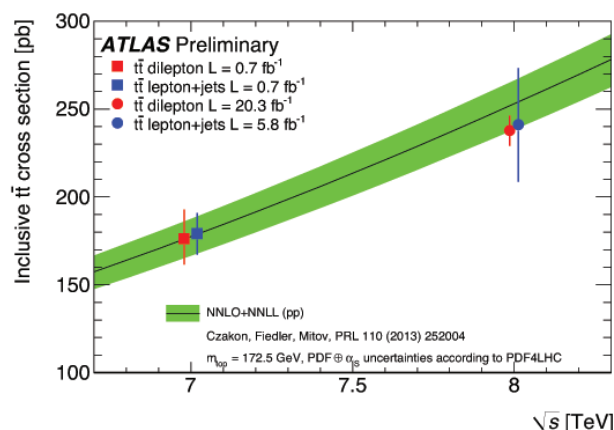
A candidate event in ATLAS, for the decay of a Higgs boson to two tau leptons, with one tau decaying to an electron (blue track) and the other to a hadron (green track). Two forward jets are also visible, suggesting production by W or Z fusion.

of nucleons) and gluons (which bind the quarks together). With the data collected in Run 1, ALICE has made progress in characterizing a new state of matter and has made unexpected observations by comparing the measurements for the lead–lead (PbPb) system with those for proton–lead (pPb) and proton–proton (pp) collisions.

The results from Run 1 consolidate the picture in which the PbPb collisions produce a state of matter with a high density of free colour charge — the ‘charge’ of the strong force associated with the quarks and gluons. This matter, known as quark–gluon plasma, has the properties of a perfect liquid and is opaque to strongly interacting particles (hadrons). The matter then undergoes a collective, hydrodynamic expansion, which leaves its imprint on the emerging hadrons in a way that depends on their mass and their transverse momentum. These dependencies can be described in terms of the radial expansion of the system and a temperature. Surprisingly, the correlation between these two parameters turns out to follow a very similar pattern in pp, pPb and PbPb collisions. While various hydrodynamic models have some success in describing these effects, no single model has so far proved capable of describing all of the data.

Further information comes from measuring how often baryons (made of three quarks) are produced in comparison with mesons (quark–antiquark pairs). For up, down and strange quarks at intermediate values of transverse momentum, this ratio is much higher in central (or head-on) PbPb collisions than in similar pp collisions. While such behaviour could result from a hydrodynamic expansion, it could also indicate a new way for hadrons to form from the quarks in the quark–gluon plasma. Again, surprisingly, the same behaviour was also observed in pPb collisions.

ALICE also made further studies of the intriguing ‘double-ridge’ pattern observed previously in high-multiplicity pPb collisions,



Measurements by ATLAS of the production cross-section (production rate) for pairs of top quarks as a function of centre-of-mass energy.

which was indicative of long-range angular correlations between pairs of particles. These correlations appear to have a dependence on mass similar to that observed in central PbPb collisions. In that case, the effect was interpreted in terms of the response of a frictionless medium to strong internal pressure gradients. For pPb collisions, there are several explanations. The most popular involve coherent effects in the initial state or collective effects in the final state.

In other studies, ALICE further investigated the phenomenon of ‘jet quenching’, in which jets of correlated particles produced in the collisions of the quarks and gluons are modified by the nuclear matter they traverse. The new studies made full analyses of jets down to values of transverse momenta as low as 40 GeV/c. While the results indicate a strong suppression of jets in central PbPb collisions, there is no evidence for much modification of their structure. In addition, the production of mesons containing charm quarks was measured in PbPb collisions and compared to results from pp scattering. These mesons turn out to be highly suppressed — just like those containing lighter quarks — which suggests that hard-scattered charm quarks are also reabsorbed by the medium.

In pPb collisions, however, there is no evidence of jet quenching. Here, the results can be explained in terms of the ‘shadowing’ effects in the quark–gluon structure of the nucleus, which ALICE could probe down to small values of the quark and gluon momenta. The key question now is how to interpret the pPb observations, which indicate similar collective behaviour to PbPb collisions, but show no evidence of jet quenching.

ATLAS: a rich harvest

After the intense activity of the first three-year long run of the LHC, 2013 brought the ATLAS collaboration the opportunity to take stock, consolidate and build upon the physics results already achieved — and to dig deeper into the vast treasure

Plenty to do in LS1 for ATLAS and CMS

During LS1, the ATLAS collaboration was busy with an intensive programme of detector maintenance, consolidation and upgrades. The pixel detector was removed to the surface, repaired and reinstalled, in readiness to receive the Insertable B-Layer. This will enhance the detector's capability to 'tag' heavy quarks in dense jets of particles. Preparations were made to run the whole detector at a rate of 100 kHz for the first-level trigger and significant extra selection-capabilities have been added to whole trigger system. Major improvements on the offline software were also under way to cope with the larger data rate that will be needed to exploit fully the increases in the performance of the LHC after LS1.

For CMS, LS1 started with the first opening of the experiment in three years. As planned, the upgrade programme was completed for half the detector by the end of 2013. This included preparations for the tracker operation at -20°C , the completion of the staged muon system in the endcap region, as well as the revision of electronics in the existing muon detector and the hadron calorimeter. In preparation for a new pixel tracker in 2016–17, a smaller diameter central beam pipe has been manufactured and prepared for installation. Finally, the trigger and data-acquisition systems were overhauled in hardware and software to enable the best exploitation of the increased data rates anticipated in Run 2.

is a pure pseudoscalar particle (zero spin, negative parity) is essentially excluded, as are simple spin-2 models. This confirms that the new particle really is a zero spin, positive parity boson.

In parallel, the couplings to the W and Z bosons have been updated, and remain in full accord with those of the Standard Model. CMS also found evidence of the Higgs decaying into two tau leptons. Combining this result with earlier searches in the b-quark pair final state, CMS obtained strong evidence of the fermionic decays of the Higgs. While these and other measurements are consistent with the values predicted for a Higgs boson in the Standard Model, they still fall short of the requisite precision to rule out more complex scenarios of physics beyond the Standard Model.

Beyond the Higgs, CMS continued its search for new particles related to models based on supersymmetry (SUSY) — specifically for the so-called 'natural' SUSY scenarios that require the supersymmetric analogues of the heavier quarks (the top and bottom 'squarks') to be relatively light. Numerous extensive analyses have yielded full agreement between the data and the Standard Model, so new stringent limits on the masses of the top and bottom squarks have been obtained. A large number of other searches for new phenomena, ranging from more exotic decays of the SUSY particles to dark matter and other new particles, have been carried out. In the absence of a signal, significant constraints have been placed on the masses and properties of these hypothesized particles.

With the full amount of data from Run 1, CMS also conducted several high-precision measurements of Standard Model processes, involving the W and Z bosons and the top quark. The figure on p. 17 gives an overall summary of all of the

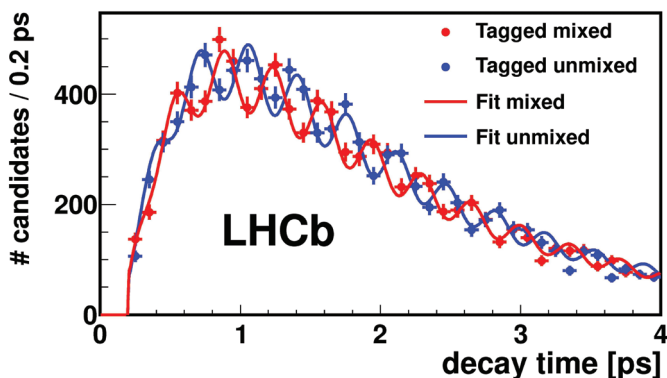
measurements of cross-sections achieved with this data set. Their values span almost six orders of magnitude. A notable example of a very rare process pinned down by CMS is the observation of the production of a top quark in association with a W boson. This is one of three production channels for single top quarks and completes a picture of production mechanisms first observed at Fermilab in the US.

One of the most prominent results was the observation of the rare decay of the B^0_s meson to two muons by both the CMS and the LHCb collaborations. The combination with LHCb gives a decay rate that is in good agreement with the predictions of the Standard Model.

At the same time, the CMS collaboration continued physics-performance studies for Phase 1 and Phase 2 of the LHC upgrades. The 'Snowmass' white paper on the discovery potential of CMS for the High Luminosity LHC was submitted for evaluation in the US, while earlier studies for future physics were summarized in the report of the ECFA HL-LHC workshop and in nine published benchmark analyses.

LHCb: rare beauty

The LHCb experiment makes precise studies of particles containing beauty (b) or charm (c) quarks. It focuses on rare decays and on CP violation — a difference in behaviour between particles and their antiparticles. These are phenomena that are sensitive to new physics through quantum effects. The continuing of analysis of data for proton–proton collisions accumulated during Run 1 of the LHC provided many new results in 2013, including some 'firsts'. Most of the results confirmed predictions of the Standard Model, but the data were under constant scrutiny for hints of new physics. The experiment also



Neutral mesons like the B_s (made of a beauty antiquark and a strange quark) can spontaneously transform into their antiparticle, the \bar{B}_s (made of a beauty quark and a strange antiquark), leading to oscillations between particle and antiparticle state. LHCb obtained the world's most precise measurement of the oscillation frequency.

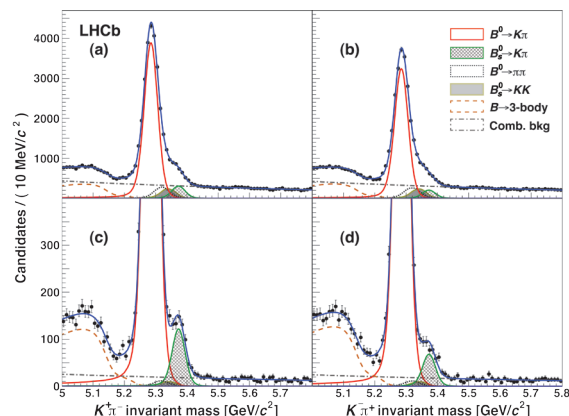
collected its first data with lead ions, during the run with protons and lead ions just before the start of LS1.

A notable rare decay is that of the B_s^0 meson to two muons, which is predicted to occur once in every few thousand million decays. After revealing the first evidence for this decay in 2012, the LHCb collaboration continued analysis of the full data set from Run 1, finding a branching fraction of $2.9 \pm 1.1 - 1.0 \times 10^{-9}$. The combination of LHCb's results with those from CMS exceeded the significance of 5 standard deviations (or sigma, σ) that is required to claim an observation, making this the rarest decay so far observed. The result is in good agreement with the expectations of the Standard Model.

Another breakthrough was the first observation of CP violation in decays of the B_s^0 meson to a negative kaon and a positive pion, with a significance of more than 5σ . This marked the first time that CP violation has been found in the decays of B_s^0 mesons and makes it the fourth type of particle in which the effect has now been seen.

In other studies, LHCb made the world's most precise measurement of the lifetime of the B_c^+ meson — a fascinating particle that has both beauty and charm. Using data collected in 2012, the collaboration extracted the largest sample of reconstructed B_c^+ decays ever reported and obtained a lifetime of 509 ± 15 fs.

The updated European strategy for particle physics highlighted the physics of 'flavour' — the physics mainly of beauty and charm — as one of the highest priorities. The approved upgrade for LHCb, to be installed during the second long shutdown of the LHC, will increase the experiment's data-taking capacity by an



The plots show the charge combination $K^+\pi^-$ (left column) and $K^-\pi^+$ (right), for B^0 mesons (in red, top row) and for B_s^0 (in green, bottom row). The height of the peaks seen in each plot is different, showing that the particles and their antiparticles decayed at different rates, a phenomenon called CP violation.

order of magnitude. During 2013 the collaboration approved the choice of technology for the upgrade of its Vertex Locator, giving the go-ahead for a new pixel detector to replace the current microstrip device.

LHCf and cosmic rays

The LHCf experiment aims to calibrate theoretical models that describe the interactions of extremely high-energy cosmic rays. In early 2013, the collaboration took data with proton-lead collisions at the LHC. These new data should provide information on the nuclear interactions that occur when cosmic rays arrive in the Earth's atmosphere. 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 and monopoles

MoEDAL, the Monopole and Exotics Detector At the LHC, is designed to search for highly ionizing manifestations of new physics such as magnetic monopoles and other exotic massive long-lived charged particles. In 2013, a team from Bologna analysed the 80 m² plastic Nuclear Track Detector (NTD) test-array, which had been exposed to LHC proton beams in 2012. In early 2013, new plastic NTDs were exposed to proton-lead collisions at the LHC and were then removed for analysis. MoEDAL also reported test results from its trapping detector array. The full MoEDAL detector will be installed in 2014 and start taking data in 2015.

TOTEM: the basics

The TOTEM experiment, which cohabits with CMS at Point 5 on the LHC, is optimized to make precise measurements of particles that emerge from collisions close to and along the

direction of the LHC beams. In particular, it can measure the total probability for proton collisions — the total proton–proton (pp) cross-section. TOTEM also studies inelastic ‘diffractive’ processes. These are important in studies in quantum chromodynamics — the theory of the strong force — in which the configuration of the gluons exchanged in the collision allows the protons to survive the collision without breaking apart.

In 2013, the collaboration released new measurements including the cross-section for double diffraction. Moreover, data taken with special settings of the LHC’s magnets allowed TOTEM to explore elastic scattering between protons in the region where the electrical Coulomb force matches the strength of the strong (hadronic) force. This led in 2013 to the collaboration’s report on the first evidence for Coulomb–hadronic interference in pp elastic scattering at 8 TeV.

Detectors for a linear collider

CERN participates in a worldwide effort to develop detectors for experiments at a future linear electron–positron collider. The Linear Collider Detector (LCD) project at CERN encompasses studies of the physics performance and detector optimization, as well as R&D on detector hardware.

One option for such a collider, pursued in the Compact Linear Collider (CLIC) study, would be capable of boosting the energy of each particle beam to 1.5 TeV, while the International Linear Collider design aims for beam energies of some 250 GeV. At the end of 2012 a new cooperative framework was set up for studies for experiments at CLIC. The CLIC Detector and Physics study, CLICdp, is hosted by CERN and by the end of 2013, 20 institutes from 16 countries had signed up.

During the year, much effort went into simulating Higgs measurements at CLIC for many different production and decay modes at a range of centre-of-mass energies. The studies confirmed the high precision that can be achieved in electron–positron collisions, in particular when combining data taken at several centre-of-mass energies.

There was good progress in pixel-detector development, with the production and testing of a fully functional readout-chip with pixels that are 25 μm square, designed with an advanced microelectronics technology. Several beam tests were carried out with sensors as thin as 50 μm . Other studies showed that power-pulsing to reduce heating effects can fulfil the requirement for sensors of low noise and low mass. Measurements in a new set-up are under way to examine cooling of the pixel environment simply by air-flow. Results were published from measurements in a test beam of a large fine-grained hadron calorimeter with

absorber plates of tungsten. These data provide unprecedented details of hadronic showers in tungsten and are ideal for the validation of the widely used Geant4 simulation software.

Astroparticle physics

The nature of the dark matter in the Universe remains one of the greatest mysteries in physics. The CAST and OSQAR experiments use powerful LHC dipole magnets to look for various low-mass hypothetical particles proposed as dark-matter candidates, such as axions or other weakly interacting slim particles (WISPs). OSQAR is a ‘light shining through a wall’ experiment. It searches for quantum oscillations between photons from a 15 W continuous laser and WISPs that could be induced by a strong transverse magnetic field. CAST tracks the Sun in search for solar-produced WISPs.

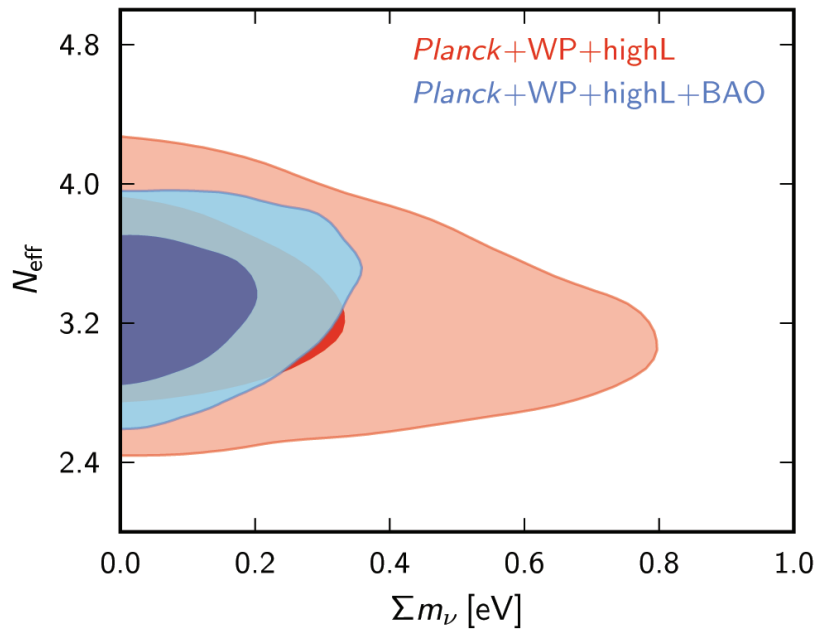
In 2013, CAST operated with vacuum in its magnet tubes and used ‘micromegas’ photon detectors with remarkably reduced backgrounds to improve the sensitivity to low-mass WISPs. The collaboration also installed a new silicon detector to search in the uncharted range of photon energies below 1 keV for particles called ‘chameleons’ — candidates to explain dark energy.

In theory

CERN’s Theory Unit (TH) carries out cutting-edge research across the spectrum of theoretical physics. This includes a key role in support of the LHC physics programme and the interpretation of its results, in cooperation with the experimental groups through the framework of the LHC Physics Centre at CERN (LPCC). On average the group published one article per day.

In 2013 there was an intense effort to understand the implications of the discovery of a Higgs boson and the measurements on the validity of the Standard Model and its extensions, including supersymmetry. LHC-related work also included studying constraints from direct searches and flavour-physics results, proposals for new searches and measurements, and the development of tools to predict and analyse the outcome of collisions.

Besides the physics of the Standard Model and beyond, the unit’s broad research programme covers astrophysics and cosmology, lattice field theory, heavy-ion physics and more formal theory, such as different aspects of string theory, supergravity and nonperturbative gauge dynamics as well as conformal field theory (CFT). In particular, members of TH made important progress in 2013 in understanding the subtleties of the evaporation of black holes within the context of the anti-de Sitter/CFT correspondence.

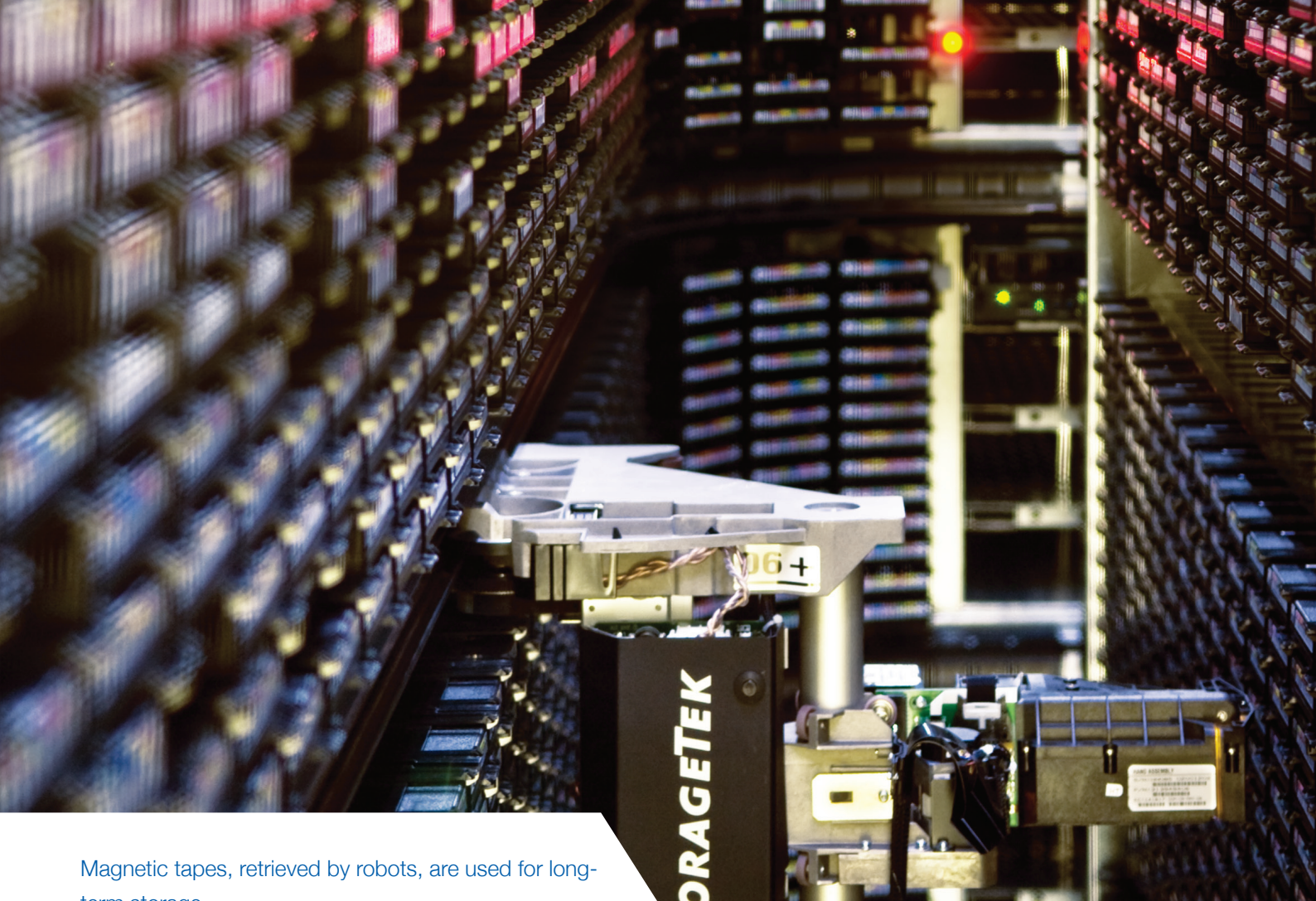


On the cosmology front, members of TH were closely involved with experiments on the European Space Agency's Planck spacecraft, playing an important role in the interpretation and analysis of the data acquired on the cosmic microwave background (CMB) radiation. A major data release in 2013 confirmed standard cosmological models, and constrained cosmological parameters with unprecedented accuracy.

The TH unit also serves as a centre of excellence for the international theoretical physics community. In 2013, it hosted 60 fellows, 41 doctorate students, 28 scientific associates, 3 guest professors of the Director-General and about 800 visitors, with support from 9 European grants related to research excellence. In addition, it contributed to outreach and training efforts at CERN and elsewhere, organizing two schools on site, several workshops and four theory institutes.

Finally, TH is an active contributor to community-wide efforts that help to guide the field. In 2013 areas of notable activity included studies of the physics potential of the High Luminosity LHC upgrade, the physics potential of CLIC and linear colliders, and the start of a multi-year effort to examine the physics opportunities associated with Future Circular Colliders (see p. 29).

This plot, from the Planck collaboration's data-release of March 2013, shows the joint confidence limits on the sum of neutrino masses, Σm_ν , and the density of very light or massless relic particles in the Universe, parameterized by N_{eff} . In the standard cosmological model N_{eff} is about 3, from the three neutrino families. The red contours show the limits inferred from Planck and from complementary CMB data. The blue contours additionally include astrophysical data on the scale of baryon acoustic oscillations (BAO). The figure shows that there is no evidence for extra light relics beyond the known neutrinos, while the upper limit on the sum of neutrino masses is moving closer to the lower bound of 0.06 eV set by neutrino oscillation experiments. Additional data sets, such as direct measurements of the Hubble parameter from supernovae, or the observations of CMB polarization by BICEP2, would favour slightly larger values of N_{eff} .



Magnetic tapes, retrieved by robots, are used for long-term storage.

Computing

The 100 PB milestone

By 14 February 2013 — the same day that the LHC's first three-year physics run ended — CERN's mass storage systems had surpassed the remarkable figure of 100 petabytes (PB), or 100 million gigabytes, of physics data. The storing of these 100 PB — the equivalent of 700 years of full HD-quality video — represents a major challenge. The bulk of the data is archived on more than 50 000 tapes while the rest is stored on a disk pool system for fast access by many concurrent users. To optimize storage space, the complete archive is regularly migrated to the latest high-capacity tapes. Disk-based systems are repopulated automatically after hard-disk failures from one of several concurrent copies and a scalable namespace enables fast, simultaneous access to millions of individual files.

Scaling up for the future

The CERN Data Centre and the Worldwide LHC Computing Grid (WLCG) were kept busy as the accelerator complex entered

its first long shutdown, not only with the analysis of the large amount of data already collected at the LHC but also with preparations for the higher flow of data expected when the LHC starts up again. The consolidation of the CERN Data Centre and the inauguration of its extension in Budapest are two major milestones in the upgrade plan achieved in 2013.

The main objective of the consolidation and upgrade of the Data Centre was to secure critical information technology (IT) systems. Such services can now keep running even in the event of a major power cut affecting CERN. The bulk of the work was completed during the first half of the year. This entailed the creation of a new 200 m² room equipped with 90 passive water-cooled racks to host the critical servers. The power supply for the whole Data Centre was also extended with the creation of new electrical-supply rooms containing uninterruptable power supply (UPS) systems equipped with 500 batteries. In case of a power cut, these batteries provide the data-centre operators with 10 minutes' worth of additional power, so that they can perform

From left to right: CERN's Director-General, Rolf Heuer, József Pálincás, President of the Hungarian Academy of Sciences, and Viktor Orbán, Prime Minister of Hungary, inaugurating the new facility at Wigner RCP, in the company of Péter József Lévai, far right, General Director of the Wigner RCP.



an orderly shut down of servers. Such extra time is essential to avoid data failure or corruption of major services, such as the WLCG, for which the CERN Data Centre is the Tier-0 site. Diesel generators provide further backup of the electrical supply for the critical systems. However, the consolidation not only secured the critical IT systems but also ensured important redundancy and increased the overall computing-power capacity of the IT centre from 2.9 MW to 3.5 MW.

On 13 June, CERN and the Wigner Research Centre for Physics (RCP) in Budapest inaugurated the Hungarian data centre that hosts the extension of the CERN Tier-0 Data Centre, adding up to 2.5 MW capacity to the facility on the Meyrin site. The dedicated and redundant 100 Gbit/s circuits connecting the two sites have been functional since February, and about 20 000 computing cores, 500 servers and 5.5 PB of storage were already

operational at the new facility at the time of its inauguration. This substantially extends the capabilities of the Tier-0 activities of the WLCG, while bolstering the continuity capabilities of CERN's business infrastructure. The capacity is remotely managed from CERN and will continue to scale up in future years.

The Meyrin data centre hosts 10 000 servers, which are renewed every 4–5 years as they become obsolete for the purposes of CERN's research. However they remain suitable for less demanding applications. In October, 196 of these servers and 10 routers were donated to Egypt and installed on the premises of the Academy of Scientific Research and Technology in Cairo, where they are used to analyse data from the ALICE and CMS experiments. Egypt is the fifth country to benefit from such donations after Morocco, Ghana, Bulgaria and Serbia.

In the cloud with OpenStack

OpenStack is an open-source project to deliver a massively scalable cloud operating system. Started in 2010 by Rackspace and NASA, it has grown to encompass 1300 developers from 200 companies, who contribute millions of lines of code licensed under Apache open-source conditions. This allows for flexible use by companies and researchers. CERN has made significant contributions to the project through code, outreach and governance and was in the top 10 contributing organizations to the Keystone component of OpenStack, which is used to authenticate users. As a cloud platform, OpenStack controls and automates pools of computing, storage, and networking resources to turn standard hardware into a powerful cloud computing environment. With cloud computing becoming more ubiquitous, an open source project such as OpenStack plays a vital role in enabling CERN to tailor its computing resources in a flexible way. Multiple OpenStack clouds at CERN now successfully run simulation and analysis for the CERN user community.

Fostering collaboration

The year 2013 saw the launch of a new online repository, created to make it easier for researchers to share and cite publications, the associated data and the software used to analyse them, thus facilitating open data and collaboration. The repository, called Zenodo, is powered by Invenio. It has been designed to help researchers based at institutions of all sizes to share results in a variety of formats across all fields of science. Zenodo was created through the OpenAIREplus project of the European Commission's 7th Framework Programme (FP7) and is hosted at CERN. OpenAIREplus started at the end of 2011 as a follow-on project to OpenAIRE, which was also funded through FP7.

CERN openlab — CERN's public-private partnership with leading companies in IT and computing — entered the second year of its fourth three-year phase in 2013. The framework hosted several joint initiatives with a new contributor, Rackspace, with a view to creating a reference architecture and operational model for federated cloud-services between Rackspace private cloud, Rackspace public cloud and CERN's OpenStack-powered clouds. The Russian search-provider Yandex became CERN openlab's first associate — a newly created sponsorship for activities requiring no presence on the CERN site. Yandex researchers worked on software technologies for indexing

collections of event data and filtering of events, in order to provide researchers at CERN with tools to increase the quality and speed of event analysis. The initial focus of these activities was on the LHCb experiment's data. Huawei, who joined as a contributor in 2012, became a full partner in 2013.

In February, the Intel-CERN European Doctorate Industrial Programme — ICE-DIP — was officially launched. This Marie Curie Actions project within FP7 builds on CERN's long-standing relationship with Intel in the CERN openlab project. It brings together CERN and two industrial partners — Intel and Xena Networks — to train five early-stage researchers. The researchers are funded by the EC and granted CERN fellowships while enrolled in doctoral programmes at partner universities, Dublin City University and the National University of Ireland Maynooth. During their three-year training programme, the researchers go on extended secondments to Intel Labs at locations across Europe and the US. The project aims to develop unparalleled capabilities in the domain of high-throughput, low-latency online data-acquisition, forming a solid foundation for future cutting-edge data-processing technologies of high interest to a broad range of industries. The research themes addressed by ICE-DIP are critical to the sustained forward momentum of European high-energy physics and numerous other disciplines of science and technology.

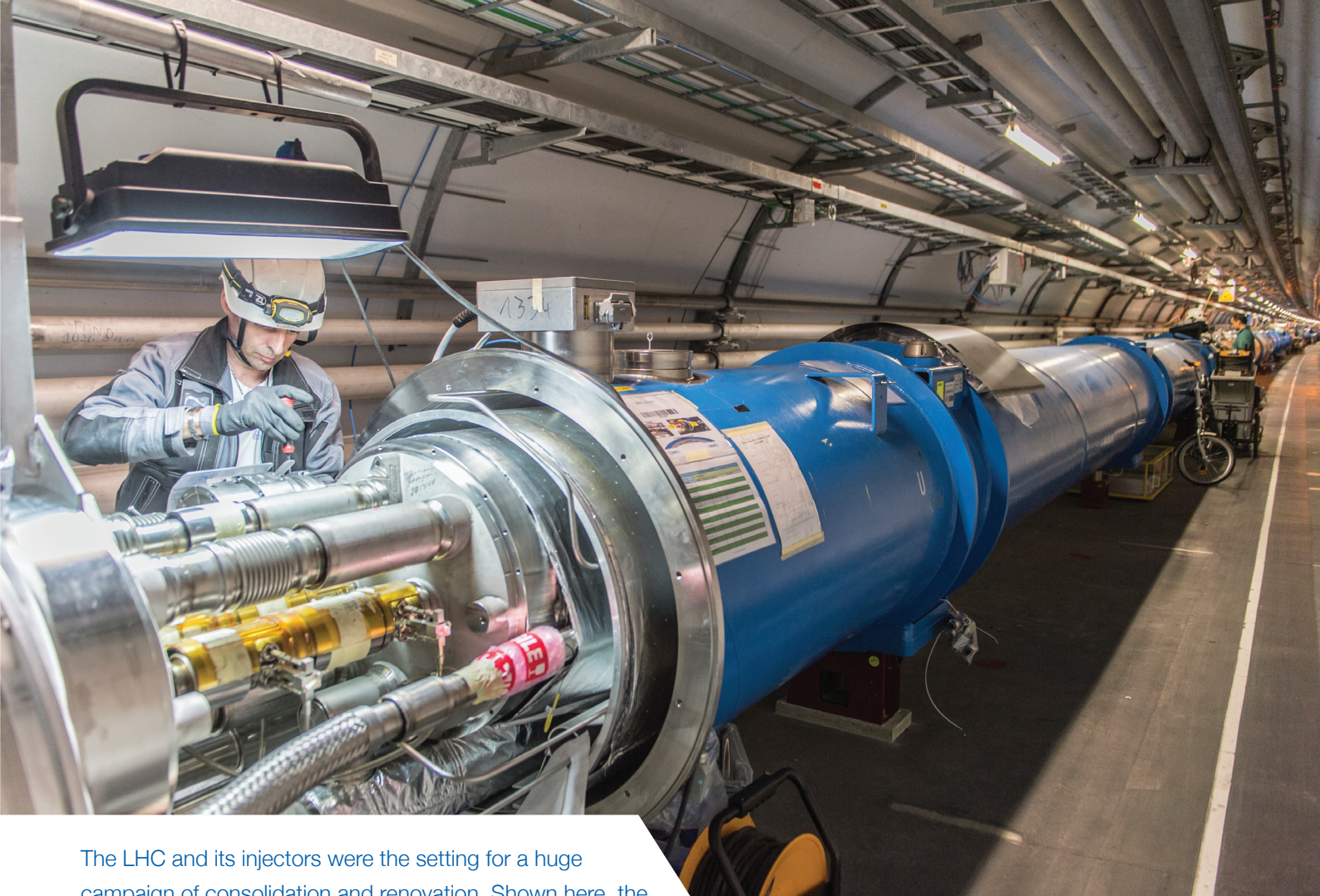
Satellite imagery analysis powered by CERN

The IT Department is the host to the United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme (UNOSAT), a UN entity. This partnership allows UNOSAT to benefit from CERN's IT infrastructure whenever the situation requires, allowing the UN to be at the forefront of satellite-analysis technology. Specialists in geographic information systems (GIS) and in the analysis of satellite data, supported by IT engineers and policy experts, ensure a dedicated service to the international humanitarian and development communities 24 hours a day, seven days a week.

UNOSAT benefited from computing resources at CERN to develop some of the first response maps for emergencies during 2013, such as typhoon Haiyan that hit the Philippines in November. The institute provides maps not only in response to emergencies, but also supports national and regional capacity-development, training initiatives and disaster risk-reduction, and provides technical assistance in Central America, Asia, and Africa.

The UN Secretary-General, Ban Ki-moon, visited UNOSAT in conjunction with a visit to CERN. He recalled how in various instances and crises the mapping and analysis work done by UNOSAT was valuable to the UN.





The LHC and its injectors were the setting for a huge campaign of consolidation and renovation. Shown here, the consolidation of one of the 10 170 electrical junctions between the magnets.

Accelerators

In the cold dawn of Thursday, 14 February, a handful of protons completed their last lap of the largest collider in the world. At 7.24 am, the protons ended their breathtaking journey and the curtain fell on three years of operation of the Large Hadron Collider (LHC). Four days earlier, the last collisions between lead ions and protons had been recorded by the LHC's detectors. Three weeks of this unprecedented mode of operation provided ALICE, ATLAS and CMS with 30 inverse femtobarns (fb^{-1}) of luminosity and LHCb with 2.1 fb^{-1} . This mode of operation had been tested briefly in 2012 and represented a huge challenge for those involved. Just after the Christmas shutdown, the accelerator complex was brought back into service in record time. The first stable beams were obtained on 20 January, with 13 bunches per beam, reaching 338 bunches per beam a few days later. Colliding lead ions and protons — particles with such different masses — requires complicated gymnastics with the radio-frequency system. The two beams are accelerated to different frequencies, then, at maximum energy, the frequencies are recalibrated in order to produce collisions in the experiments. The excellent performance of the injectors allowed

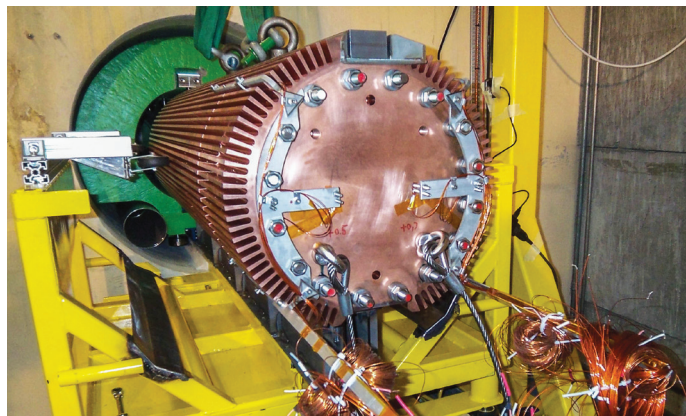
the production of bunches of ions with a higher intensity and brightness than originally forecast. At the same time, the SPS managed to deliver lead ions to the NA61/Shine experiment at extremely low energies of 29, 18 and 12 GeV per nucleon. At these energies, the lowest ever used in the SPS, the beams are difficult to control: it's a little like asking a champion cyclist to follow a snail.

A huge worksite

As the particles were leaving the stage, the teams were busy in the wings preparing for the first long shutdown of the LHC and its injectors, which for almost two years must undergo significant work in preparation for a collision energy of 14 TeV in the LHC. However, the LHC will restart in 2015 at a collision energy of 13 TeV, an increase from the maximum of 8 TeV so far, in order to allow for the 'training' phase of the magnets. Analysis of the commissioning of the magnets in 2014, followed by operation at 13 TeV in 2015, will allow a decision to be taken on an increase of the energy to 14 TeV.



Electrical quality assurance on one of the 10 170 reinforced connections.



The new PS Booster beam dump during installation.

The first long shutdown, a huge programme of maintenance, consolidation and improvement, took several years of preparation, which culminated in vacuum and electrical tests just after the accelerators were shut down. The extensive list of work had to be planned in minute detail and centralized by a team. These ‘conductors’ of the long shutdown ‘orchestra’ scheduled dozens of projects in parallel, involving up to 1600 people from CERN, institutes and contractors, working two or even three shifts per day.

Three major projects are progressing in parallel: the improvement of the LHC, including the important Superconducting Magnets and Circuits Consolidation (SMACC) programme, the maintenance and consolidation of the injectors, and work on protecting electronics against radiation (see p. 30).

Reinforced interconnections

An indispensable prerequisite for restarting the LHC at 13 TeV is the reinforcement of all of the electrical connections on the circuits supplying the superconducting magnets. Currents of around 12 000 A will flow through these circuits after the restart. To reach such intensities, the 10 170 electrical connections between the magnets must be fitted with copper shunts, which take away the current if there is a quench. No fewer than 27 000 shunts need to be installed. Very precise measurements of the resistance of the interconnections revealed that, in addition to these reinforcements, 3000 connections needed to be redone. Moreover, 5000 reinforced insulation units must be installed around each pair of connections. The SMACC team, who spent the second half of 2012 training on mock-ups, has now begun its assault on the worksite.

The team consists of veritable ‘trains’ of workers, with each ‘carriage’ on the train carrying out a sequence of work. The first carriage opens the interconnections, the second cuts the lines containing the electrical connections, the next few reconstruct

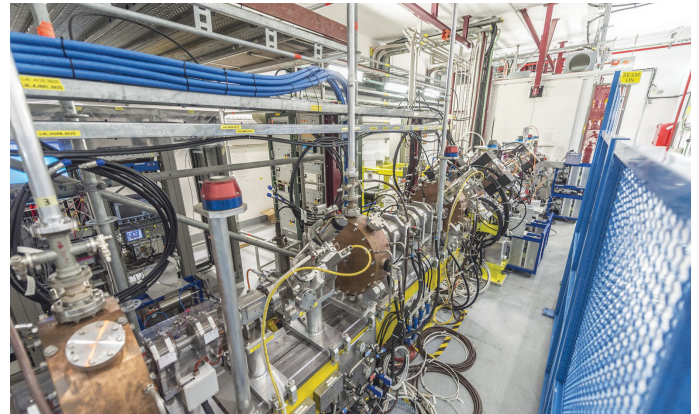
the connections, fit the shunts and insulation units and carry out welding, and the last few close the interconnections. This chain of operations is interspersed with many electrical, geometric, visual, sealing and other tests. Almost 300 people from CERN, outside companies and institutes have worked in two shifts to carry out the work. Even the operators of the LHC, who usually control the machine from the CERN Control Centre, have joined in, surveying the tunnel to carry out quality checks. By the end of 2013, 2500 connections had been redone, 19 000 shunts and 3400 insulation units installed, 5400 welds completed and more than 200 000 resistance measurements, 10 000 electrical quality assurance tests and 4500 leak tests carried out. In addition to the work done by the operations train, teams have replaced 18 magnets and installed 612 additional pressure safety valves. By the end of the year, one of the eight sectors of the accelerator had been closed, ready for testing. In addition, the SMACC project team started on the renovation of the electrical distribution units, the impressive devices that transfer the current from resistive cables to superconducting cables. Four of these units had been consolidated by the end of 2013.

The cryogenic installations of the LHC and its detectors have also undergone maintenance operations. Almost 100 compressors and their motors — essential components of the cryogenic stations — have been removed and sent to the suppliers for servicing: three-quarters of them were being reinstalled at the end of 2013. Inside the cryogenic distribution line, 16 out of more than 2000 compensators, which absorb thermal contraction and dilation, have been replaced. The difficulty of accessing the cryogenic line made this work particularly arduous.

The LHC protection system has been reinforced with new collimators: these devices consist of jaws that close around the beam and absorb stray particles. Twenty-three new collimators, incorporating beam-position monitors, have been developed to be installed on either side of the experiments and at Point 6 of



One of the new ventilation system stations for the PS is moved into the accelerator.



On 14 November, for the first time, a beam travelled along a section of the new Linac 4 accelerator installed in the tunnel.

the LHC, where the beam dump is located. With this integrated instrumentation, adjustment of the collimators will be optimized, reducing the time needed to fill the machine.

Rejuvenated injectors

The five accelerators that make up the LHC injector complex have also undergone significant renovation and improvement work, in the framework of the LHC Injectors Upgrade (LIU) project.

A delicate operation took place in the Proton Synchrotron's injector, the PS Booster. The old beam dump, installed in 1972, was replaced by a brand new beam dump in preparation for the increase in intensity and energy planned for the accelerator. The energy of the PS Booster, initially 800 MeV, is now 1.4 GeV. When the PS Booster is connected to the new linear accelerator, Linac 4, after the second long shutdown (see p. 29) its energy will increase further to 2 GeV. The delicate replacement operation in a radioactive environment took several weeks in summer 2013.

Additional modules were added to the accelerating cavity prototype using FineMet technology, which performs better at the energy level anticipated for the PS Booster. Beam tests of this technology, developed with the J-PARC laboratory in Japan, will continue during the next operating phase, with a view to replacing all of the cavities during the second long shutdown of the LHC and its injectors. New low-level beam control radio-frequency electronics have also been installed in the four rings of the accelerator.

A new lease of life

A few metres away, the oldest accelerator at CERN still in service, the PS, has also had a facelift. FineMet technology has been used here for a new beam-stabilization system, which will be installed before the restart. The PS ventilation system has been

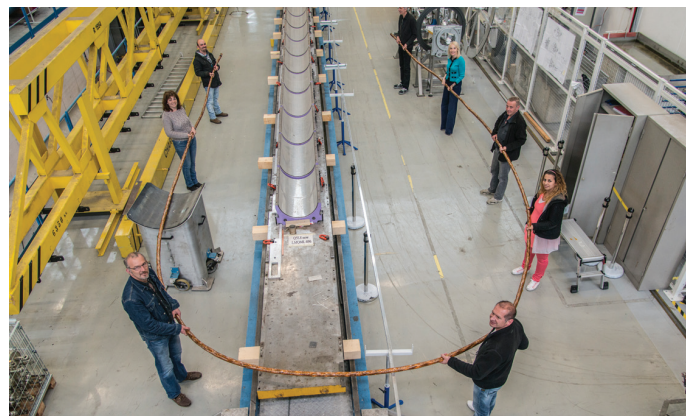
replaced with a completely new design. Both the dismantling of the old system, dating from 1957, and the installation of the new system were particularly delicate operations owing to the restricted space: it took three months to extract the 80 tonnes of equipment and more than six months to install the new system, formed of 22 units. The ventilation is controlled by a brand new electronic system, located in the centre of the ring of the venerable accelerator. The access system now comprises biometrically controlled airlocks, just like those at the LHC. Outside the accelerator, extensive civil engineering work has taken place to improve the shielding.

The clouds are lifting

At the Super Proton Synchrotron (SPS), an amorphous carbon coating has been applied to the interior walls of the vacuum chambers of 16 magnets. This operation is designed to reduce the phenomenon of electron clouds, which destabilize the beam. Electrons initially produced by the ionization of residual air molecules can generate other electrons when they hit the walls of the vacuum chamber. This phenomenon occurs if the material of the chamber has a high secondary-electron emission coefficient and it becomes faster and more intense the closer and denser the particle bunches. Amorphous carbon offers a solution as it has a very low secondary-emission coefficient; its long-term behaviour will be tested during the next operating period. A new prototype fast wire-scanner detector — a tool used to measure the transverse dimension of the beams — has been installed for testing with beams. Above ground, the structure of the cooling towers has been completely renovated and numerous valves in the cooling system have been replaced. Finally, the accelerator is being prepared for twice the radio-frequency power during the next long shutdown to double the intensity of the beam. The design of the amplifiers and other radio-frequency equipment has progressed and the construction of a new building for them has been approved.



Replacement of the electrical distribution network for the SPS accelerator.



The new high-temperature superconducting cable, able to carry 20 000 amps over a distance of 20 m.

Aside from these projects specific to each injector, work has been taking place across the whole accelerator chain. Many magnets have been replaced or renovated. In the accelerators, the control electronics have been rejuvenated by the replacement of the real-time control systems. These systems consist of electronic data-acquisition cards next to the machines and control all of the accelerator equipment. Almost 500 systems have been replaced in the injectors, as well as in the Antiproton Decelerator (AD) and the REX-ISOLDE nuclear physics installation. The control software platform has also been completely replaced.

In addition to the injectors, the renovation programme touched on the control and management systems of the whole infrastructure. The control systems for machine protection, vacuum, cryogenics, the experiment gas systems, cooling and ventilation have been renovated or updated. A new supervision, control and data-acquisition system for the electrical distribution network has been developed and installed.

A vital network

The large-scale electrical work that started in 2012 has continued, notably including the replacement of the 18 kV electrical distribution network at the SPS, which was 40 years old and consists of 90 km of cables. Two large electrical substations have also been constructed to improve the reliability of the CERN electrical network, in particular to provide a redundant supply for the CERN Control Centre, an emergency supply for the Prévessin site and a second supply for the Meyrin site. This new equipment has allowed the accelerator networks to be separated from the networks supplying general services on the Meyrin site. The uninterruptible power supply systems for the LHC have been completely replaced.

These huge projects have generated an unprecedented amount of cabling work, on both the copper and the fibre-optic cable networks. Over the years, the evolution of the accelerators has

resulted in an accumulation of cables, some of which are now surplus to requirements and need to be removed. On top of this, new cables need to be installed or moved, for example for the R2E project (see p. 30). The reliability of this complex network is vital to the operation of the machines. During the long shutdown, no fewer than 1000 km of copper and fibre-optic cables (about 10 000 connections) will either be installed or replaced, in the framework of 37 major campaigns of work. In 2013, the cabling teams replaced 100 km of irradiated cables in the SPS, for example. In the same accelerator a new fibre-optic network has been installed. The huge task of identifying all of the unused cables in the cluttered PS Booster has also begun.

Renovations have at the same time been ongoing at CERN's other accelerators. The target area of the ISOLDE nuclear physics installation is being renovated, and a new robot for replacing the targets is being installed.

Green light for high luminosity

Although most teams are focused on the restart in 2015, some are also thinking about the future of the accelerators. This future has been set out in the European Strategy for Particle Physics, the update of which was approved by the CERN Council in May. The document sets out the basis for a medium- and long-term programme up to 2035, and a much longer-term programme beyond 2035 (see p. 29). For the period 2015–2035, a programme for the LHC and its injectors was approved at the end of 2013, with operational phases of three years interspersed with long shutdowns. The main objective is to exploit the LHC to its full potential. As a result, the green light has been given to the High Luminosity LHC (HL-LHC) project, which aims to increase the number of collisions by a factor of 5 to 10 to reach a luminosity of 250 fb^{-1} per year after 2025.

Towards future accelerators

What will fundamental physics look like in 20 years? What tools will tomorrow's scientists use? These questions might appear speculative, but they are of interest to experts in the field who are looking into the distant future, following in the footsteps of the visionaries who dreamt up the LHC more than 25 years before it began operating. In May 2013, the European Strategy Session of CERN Council gave the green light to feasibility studies for two very long-term projects: the Compact Linear Collider (CLIC) study for a linear electron–positron collider and the Future Circular Colliders project, based on a hadron collider with a circumference of around 100 km able to reach an energy of 100 TeV. The latter study will also include the possibility of a lepton collider as an intermediate step as well as a lepton–hadron collider option.

The CLIC concept relies on an innovative new acceleration technology with two beams, the feasibility of which was documented in a conceptual design report in 2012. During 2013, the CLIC test facility at CERN made new measurements, confirming the principle of acceleration with two beams. In addition, an initial klystron test facility has been commissioned. Tests on beam alignment and emittance were carried out at the SLAC laboratory in the US, and the first complete acceleration module has been manufactured. New partner institutes have joined the collaboration, which now consists of 70 institutes in 30 countries, and cooperation with the International Linear Collider (ILC) study continues. Finally, CLIC is opening up to other applications: studies have examined the potential use of its acceleration techniques for compact accelerators for free-electron lasers, destined in particular for medical applications.

To mark this milestone, a kick-off meeting for the HL-LHC project, bringing together 160 scientists from all over the world, was organized as part of the annual meeting of the HiLumi LHC Design Study, which is partially financed by the 7th Framework Programme of the European Commission, and the LHC Accelerator Research Program (LARP), which is a collaboration between the US laboratories and CERN. The project is based around the development of new more powerful quadrupole magnets for the inner triplets (the magnets installed just before the collision points); shorter and more powerful dipole magnets — 11 Tesla (T) compared to 8 T for the current LHC magnets; ‘crab’ radio-frequency cavities to position the beam before collision; an improved collimation system and 300-m-long superconducting connections.

In 2013, several tests were carried out on prototype 11 T superconducting magnets, which use a new superconducting niobium-tin alloy. In the spring, a 1-m dipole magnet, developed with Fermilab, achieved a record field of 11.7 T. A short coil, developed to test the cable, reached a field of 13.5 T at CERN in the autumn. Research into superconducting ‘crab’ cavities has also progressed. Three cavities, with different designs, have been proposed. One, developed at the University of Lancaster and the Cockcroft Institute in the UK, has been tested at CERN. The two others have been developed and tested at the Jefferson Laboratory and the Brookhaven National Laboratory in the US. The three cavities have greatly exceeded the objective of an acceleration voltage of 3.4 MV, validating the feasibility of this technology.

With the increase in luminosity, certain radiation-sensitive power converters will need to be moved to the surface and connected to the accelerator by 300-m-long superconducting cables. CERN, in cooperation with industry, has developed high-temperature superconducting wires based on magnesium diboride (MgB_2). The first prototypes of cables manufactured with such wires have been tested: one cable was able to carry a current of 30 000 A over 2.5 m, but at 4.5 K (-268°C). Another cable, able to carry a current of 20 000 A over 20 m at 20 K (-253°C), has been manufactured for testing in 2014. Finally, collimators made from molybdenum graphite are being studied as this material interferes less with the beam than those currently used.

Baby beams

The injector chain must also be prepared for this bright future. An analysis of the different injector-upgrade scenarios was carried out in the autumn in order to optimize the choices based on cost and performance. A technical report describing all of the work planned in the framework of the LIU project will be published in 2014. The Linac 4 linear accelerator, which will take over from the current Linac 2 after the second long shutdown of the LHC, will be the first link in the renovated accelerator chain. Linac 4 is currently under construction and has already shown the first signs of life. A beam was accelerated in a section of the accelerator for the first time in a test zone in spring and then in the accelerator tunnel in the autumn. The first three components of the chain — the ion source, the radio-frequency quadrupole and the chopper line — were commissioned at an energy of 3 MeV. An improved ion source was finalized in December.

The radio-frequency acceleration structures that will bring the beam up to 100 MeV have been manufactured, and most have been tested. The pre-series models of the final accelerator structures, which will accelerate the beam to 160 MeV, have been delivered and the other structures are being manufactured. Linac 4 will start to be commissioned in 2015, then tested before being connected to the PS Booster during the second long shutdown of the accelerators.

To maintain the diversity of CERN's physics programme, other machines are being developed. Studies have progressed for the Extra Low ENergy Antiproton ring (ELENA), a project aimed at improving the efficiency of the Antiproton Decelerator (AD) by further slowing down the antiprotons destined for the antimatter experiments. Detailed studies have made progress and the machine has been presented to an international review board. The detailed design report will be published in spring 2014. The construction of a new annex connected to the AD building, and destined to rehouse equipment occupying the space intended for ELENA, started in June and has progressed well.

A few days earlier, the diggers had been at work on another site, the new experimental area (EAR-2) for n_TOF, CERN's neutron source. This new installation, which should receive its first beams in summer 2014, will increase the supply of neutrons for the scientific community. Reactions with neutrons are used for studies in numerous fields of fundamental and applied science, from astrophysics to medical applications and nuclear waste processing technology. With its improved capabilities, EAR-2 will

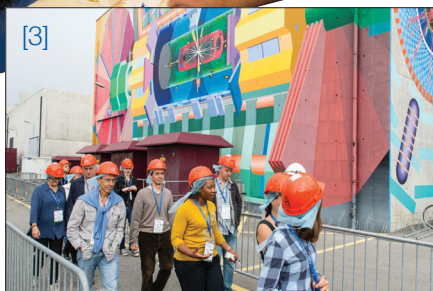
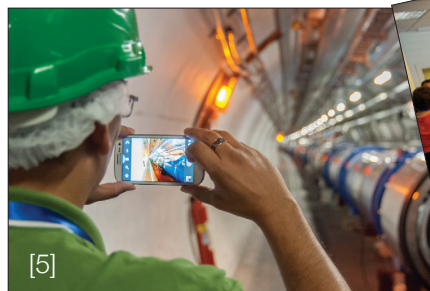
be used to study new processes and isotopes, with a precision never before achieved.

Also in the field of nuclear physics, development of the new superconducting linear accelerator High Intensity and High Energy (HIE-ISOLDE) is continuing. This 16-m-long accelerator will increase the energy of the beams in the ISOLDE installation from 3 to 10 MeV per nucleon and will quadruple their intensity. The ISOLDE hall has been partially transformed to house the new accelerator. Two accelerating cavities delivered performances in excess of their specifications. The manufacture of radio-frequency equipment, magnets, power convertors and instrumentation has begun. Finally, a clean room for the assembly of components has been set up.

The last new project to spin off from the LHC is the Advanced Wakefield Experiment (AWAKE), an accelerator R&D study approved in mid-2013, which is expected to be commissioned by the end of 2016. This experiment, which will receive beams from the SPS, will study the use of plasmas for acceleration (plasma wakefield acceleration). This principle has already been demonstrated by other laboratories with electron acceleration systems and lasers. AWAKE is aimed at demonstrating the principle with protons for the first time. The aim is to reach acceleration gradients of several gigavolts per metre, much greater than the gradients of around 100 MV/m reached with current radio-frequency cavities. Studies such as AWAKE open new opportunities in the accelerator field.

R2E: Electronics put up strong resistance

A lost particle in an accelerator is far from being a trivial matter. Isolated particles colliding with electronic boards have been the cause of many an accelerator shutdown. In 2011, around 70 electronic faults were attributed to these wandering particles, incidents referred to as 'single event effects' (SEE). The problem, which was identified several years ago, has resulted in a large-scale campaign of shielding and relocation of electronic equipment, and in the testing and development of boards that are more resistant to radiation. The first shielding and relocation campaign in 2011 led to a reduction in the number of faults by a factor of four. The aim is to reduce the incidents by a further factor of six so that they result in only one beam shutdown for every 2 fb^{-1} of data recorded. During the long shutdown, around a hundred electronic racks are being moved at five points of the machine and power convertors are being moved away from the beam lines as part of the Radiation to Electronics (R2E) project. At Point 7, for example, the control electronics for the vacuum, cryogenics, machine protection and the power convertors are being moved into the service tunnel, which has required significant civil engineering work. The shielding of four service caverns at Points 1 and 5 are being reinforced with thick iron walls, which are more effective than concrete. In parallel, new radiation monitors have been installed in the LHC, which now has almost 400 of these measuring devices, while the injector chain is also well-equipped in this regard. New electronic boards that are more resistant to radiation are being developed, particularly the power convertor control boards for which prototypes were developed in 2013. A new radiation test facility, CHARM, the only one of its kind in the world, will be commissioned in 2014 to test these electronic boards. It will also have other applications, such as testing electronics for aeronautical use, which are exposed to radiation from cosmic rays.



At the Open Days.

[1] In the 'Fun zone!' children played with science, technologies, robots and more, including constructing a miniature LHC. [2] A CERN volunteer demonstrates levitation with superconducting magnets cooled with liquid nitrogen. [3] Visitors pass the ATLAS mural on their way to the experiment cavern. [4] Visitors to the CMS cavern gaze

in wonder at the huge and complex detector. [5] A visitor takes a photo of the LHC tunnel with his smartphone. [6] There was also the chance to visit the CERN Control Centre, the control room for the accelerators and technical facilities. [7] The control room for the Open Days saw CERN's services working in harmony with French and Swiss authorities to ensure that the event ran smoothly.

Making an impact

CERN opens its doors

More than 70 000 people came to CERN's Open Days on the weekend of 28–29 September, with 20 000 of them able to see accelerators and detectors underground. A taskforce of 2300 volunteers acted as guides and helpers, both below ground and at more than 40 activities on the surface at both the Meyrin and Prévessin sites.

As well as the public open days, there were events before and after the weekend. On 27 September, CERN welcomed local officials and industrial contacts from throughout its Member States for exclusive tours of the Laboratory. On the same day, at a CERN 'tweetup', 12 citizen journalists shared a preview of the open days with the world via Twitter. In the evening — and to celebrate European Researchers' Night — CERN and the Istituto Nazionale di Astrofisica organized 'Origins 2013', an event that included simultaneous activities at CERN, Paris and Bologna,

with participation from UNESCO, ESA, ESO and INFN. The events culminated on 30 September with a celebration for CERN people — 'Bosons and More'.

During the year, CERN played host to numerous other events to engage the general public, from Passport to the Big Bang (see p. 33) and TEDxCERN (see p. 10) to Famelab and LHCComedy.

CERN's arts programme saw the first laureates from 2012 win the prestigious Hermès Foundation New Settings award for *Quantum*, a piece devised from both their residencies at CERN. With movement by choreographer Gilles Jobin, and light installation by Julius von Bismark, *Quantum* had its world premiere at the CMS experiment during the Open Days, in partnership with the Forum de Meyrin. Thanks to the Hermès award, it later began its international tour in Paris. Artists-in-residence for 2013 were sound artist Bill Fontana (see p. 11), winner of the Prix Ars Electronica Collide@CERN residency, and film-maker



The 'Origins 2013' event, co-funded by the European Commission's 7th Framework Programme, included participation from international organizations connected via webcast, and celebrated the scientific results of the satellite telescope Planck and of the LHC experiments.

Jan Peters, winner of the Collide@CERN Geneva residency. The year also marked the launch of an externally funded country-specific one-month research award — Accelerate@CERN — with the first call going out to Greek and Swiss artists.

Knowledge transfer and collaboration

The Knowledge Transfer (KT) group saw positive trends in the number of technology-transfer opportunities and agreements signed, thanks to initiatives such as the BE-KT day, which was organized in collaboration with the Beams Department in June to identify ideas with significant technology-transfer potential. CERN continues to re-invest part of the KT revenues into new projects via the KT Fund. Of the 14 proposals received, seven new projects received support in 2013, ranging from positron-emission tomography systems, through open-source software for the design of circuit boards, to additive manufacturing techniques (3D printing).

Following its launch in 2012, the STFC–CERN Business Incubation Centre (STFC CERN BIC) in the UK selected the first three companies to enter the incubator. Advanced discussions are now in progress to establish new BICs in other member states. The aim is to enable small high-tech businesses to access CERN's know how and technologies, so as to bridge the gap between basic science and industry. Additional business opportunities included the facilitating of a spin-off company based on Invenio, CERN's digital-library software, and the first EIROforum science and business Workshop on Advanced Materials and Surfaces, which was held at CERN in November.

In life sciences, the European Network for Light Ion Hadron Therapy — ENLIGHT — continues to help catalyse more interest in hadron therapy in Europe, with CERN playing a key role in its projects. In 2013, the European Commission (EC) chose the ENTERVISION project as 'a success story illustrating the good use of European Union (EU) funds for research' and as a



Participants in the High School Teacher Programme 2013. This in-depth course, held in English, gives more time for additional working groups and discussions with scientists to explore the research done at CERN more deeply.

'gold project' to promote the new Horizon 2020 programme. In addition, most of the young researchers from PARTNER, an EC-funded Marie Curie Initial Training Network that ended in 2012, are now working in medical facilities in many different countries.

December marked the end of the EU Framework Programme 7 (FP7), which had run since 2007. During FP7 CERN participated in 87 EU projects and coordinated 36, ranking the laboratory in the top 50 of more than 15 000 FP7, participants in terms of EC funding received. CERN is now turning its attention to proposals for the new framework programme, Horizon 2020, the largest-ever EU research-funding programme to tackle 'Excellent Science', 'Industrial Leadership' and 'Societal Challenges'.

Inspiration and education

In 2013, CERN welcomed about 90 000 visitors from 63 countries — 40% of them high-school students — on guided tours to many CERN sites, including the LHC detectors. Popular visit points, namely the cryogenic test facility (SM18), the CERN Control Centre and the Computer Centre, obtained state-of-the-art interactive exhibition facilities to improve the quality of the visits. The permanent exhibitions, Universe of Particles and Microcosm, attracted 65 000 visitors. CERN exhibitions were also shown in Spain, Greece, and Norway, while the large Accelerating Science exhibition travelled to the Kopernikus Science Centre in Warsaw, Poland. The year also saw the start of construction work for a new 'school laboratory' of hands-on experiments, to be completed in 2014.

CERN's courses for physics teachers, who play a key role in motivating and inspiring students to continue in science, technology and engineering, continued to be popular. More than 1000 teachers from 21 countries took part in 26 one-week courses, held in the native language of the teachers. In July 2013, the international three-week course had 51 participants from 30 countries. A highlight of the 2013 programme was a discussion

Passport to the Big Bang

On 2 June, in collaboration with Swiss and French communes, CERN inaugurated 'Passport to the Big Bang' — a new, permanent, scientific tourist trail, in which 54 km of sign-posted itineraries link ten exhibition platforms above ground around the ring of the LHC. The launch day included a bicycle rally and tours of some surface facilities, as well as numerous attractions for families.



with Peter Higgs (see p. 7). A collaboration with UNESCO and the Paul Allen Foundation allowed the participation of teachers from sub-Saharan Africa, while the Dominican Republic financed the participation of 20 teacher trainers.

In the year marking the 20th anniversary of the European School of High-Energy Physics (ESHEP), CERN continued to organize its 'schools of excellence' in physics and engineering. In addition to ESHEP, which was held in Hungary, these included CERN Accelerator Schools in Italy, Norway and Switzerland, the CERN Latin-American School of High-Energy Physics in Peru, and the CERN School of Computing in Cyprus.

Easy and open access

At the end of 2013, representatives from 24 countries signed Memoranda of Understanding, to allow the SCOAP³ Open

Access publishing initiative to start on 1 January 2014. A vast number of scientific articles in the field of high-energy physics will become Open Access in 10 leading journals at no cost for any author: everyone will be able to read them, authors will retain copyright, and generous licenses will enable wide re-use of the information.

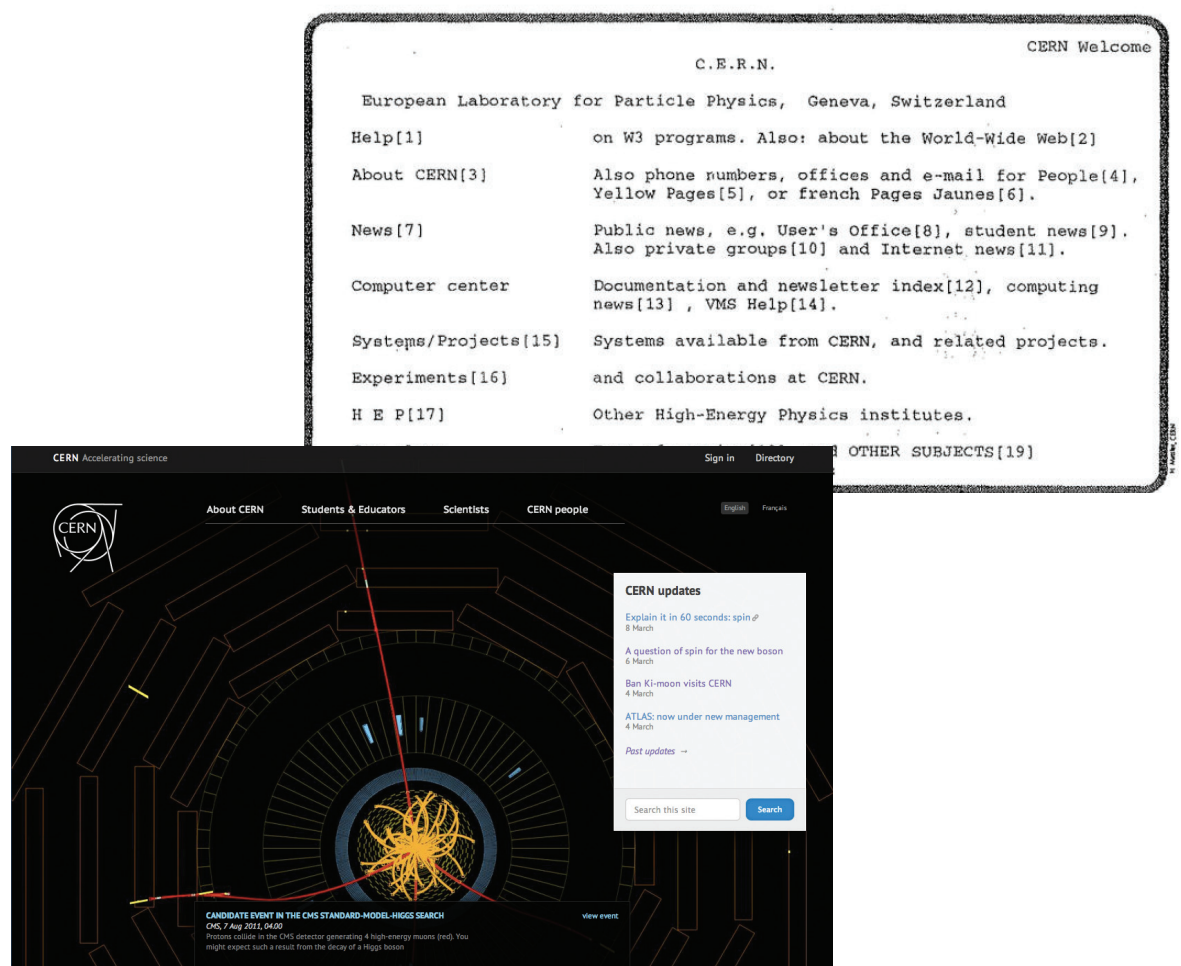
In a world where 'everything' can be downloaded from the web, library services still remain indispensable to scientists at CERN and even the reading rooms continue to be a popular facility. However, the emphasis is clearly shifting to digital services. With electronic books of classical titles in mathematics and physics now available, some 130 000 e-book chapters were consulted by users of the CERN library in 2013. INSPIRE, the database offering access to preprints and articles in high-energy physics, is queried twice a second around the clock by physicists around the world.

A web for all

In 1993, CERN published a statement making World Wide Web technology available on a royalty-free basis, allowing the web to flourish. To mark this 20th anniversary, CERN began a project to restore the first website — <http://info.cern.ch> — and preserve digital assets associated with the birth of the web, including the recreation of the line-mode browser.

The year also marked the launch of CERN's newly designed website, a multi-department project. The new website offers increased functionality and compatibility with mobile devices and attracts about 3 million unique visitors a year from around the world. CERN also made a first collection of photographs available under the Creative Commons licence (CC-BY-SA), allowing the images to be shared more widely and used more consistently, for example, in Wikipedia pages.

Crowdsourcing and citizen science were at the heart of a prototype 'app' developed for the AEGIS antimatter experiment (see p. 14). This app allows several hundred amateur physicists to analyse data from the experiment. In the LHC@home project, the Test4theory platform simulated the million millionth particle collision since its launch two years ago.



Top: A screenshot of the line-mode browser interface showing the CERN website from around 1993. Numbers in square brackets appear next to hyperlinks that can be followed by typing the number and hitting the Enter key. Bottom: CERN's newly designed website, launched in 2013.



The Service Desk handles some 400 requests a day and during 2013 reached a total of more than 300 000 since its launch.

A place to work

The CERN Laboratory extends over sites in both France and Switzerland with facilities that attract around 11 000 visiting researchers. To support its facilities, infrastructure and research, CERN employs some 2500 staff and welcomes more than 1200 fellows, associates, students and apprentices (see p. 44).

The General Infrastructure Services (GS) Department provides and maintains much of the necessary infrastructure across these sites, including technical and administrative information systems, as well as services to ensure the health and safety of anyone on site.

One of the keys to the smooth running of this large, distributed site with its many 'users' comes under the name of the CERN Service Portal and its human element, the Service Desk. Together they provide a 'one-stop shop' for queries about the many services provided at CERN — from cutting keys, to problems with email, to leaks in the roof. While the team behind the Service Desk can handle requests during working days, a web-based interface offers a 24-hour window on the Service Portal, providing information on a range of services. Implemented by the GS and IT Departments in 2011, the Service Portal uses commercial software in a new way to

provide a single window on all services. It has proved so successful that in 2013 representatives from several major companies and other research facilities visited CERN to find out more.

To maintain its position at the forefront of research after nearly 60 years of existence, CERN has to deal simultaneously with both renovation and new development. On the Meyrin site, work was finished on the consolidation of the facades of Building 30 and on the refurbishment of the IT auditorium, which features state-of-the-art technology. At the same time, work began on an extension to CERN's antimatter facility to house the ELENA project (see p. 30) and also progressed at Prévessin on the new building (774) to house the Beams Department's Controls Group.

On the accelerator complex itself, the project to upgrade the access and safety systems of the first links in the LHC accelerator chain neared completion during 2013. These systems provide personnel with automatic protection by limiting access to hazardous areas and by ensuring that no one is present when the relevant accelerator is in operation. Nineteen new access points were successfully installed and deployed across many areas including



On 28 February, a ceremony was held to lay the foundation stone of Building 774, attended by Stéphane Donnot, Sub-Prefect of Gex, Octavio Mestre and Francesco Soppelsa, the architects, and Sigurd Lettow, CERN's Director of Administration and General Infrastructure.

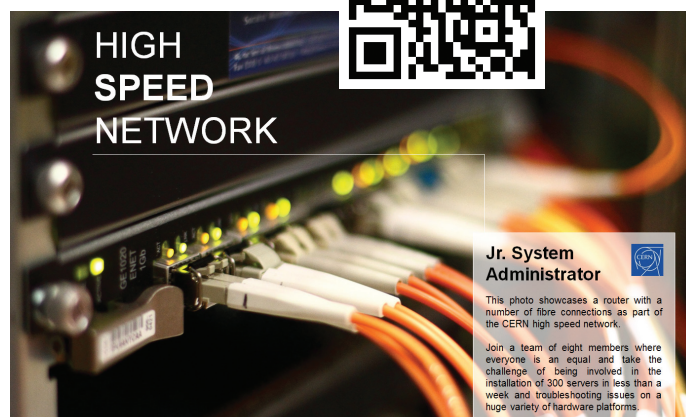
the LHC injectors — in particular the PS — and also at the AD, ISOLDE and n_TOF.

An inclusive culture

The Human Resources (HR) Department has responsibility for many aspects of the working life of personnel, from recruitment, training and development to social services and social security.

As a large accelerator laboratory, CERN offers a unique environment for training; indeed, the founding Convention recognized the important role that the Organization could play in training Europe's scientists and engineers. Taking into account challenges in recruiting high-calibre international technicians, in 2013 the HR Department set up a pilot programme to enable recently qualified technicians to apply to CERN for a first career-development experience. After initially making five appointments, the pilot was extended during the year to take on a total of 23 technicians from 7 Member States. More generally, recruitment efforts were enhanced with the launch of a new web site 'Careers at CERN', which makes full use of social media and aims to attract a broad range of applicants.

CERN's Diversity Office, which was established in 2012, focuses its attention across the three areas of recruitment, career development and work environment. The strategic objectives set include improving the distribution of under-represented nationalities, achieving gender distribution in recruitment for all professional categories, and the provision of an enabling work environment. A programme of events to raise awareness on diversity issues has been well attended and is proving to be a useful tool for addressing these issues at CERN. In 2013, events included several talks by invited speakers, covering areas of professional creativity, gender and disability. Actions taken at CERN to make the work place more enabling have seen the provision of disabled access in all new and renovated buildings. In addition, in September, a new crèche, managed by the Staff



Visually appealing advertisements on social media channels, often accompanied by Quick Response (QR) codes, top, are a new way to reach potential applicants.

Association, opened on site. It is fully integrated with the existing nursery school, which can now accept children aged from 3 months to 6 years.

Activities have also taken place away from the CERN site. During the year, as part of the effort to attract under-represented nationalities, CERN took part in career fairs and other events in Austria, Germany, the Netherlands, Norway and Switzerland. Members of the Organization also participated in events to promote the drive for more women in science. These included a panel discussion organized by UNESCO at the UN's Palais des Nations in Geneva, in which CERN's Director-General, Rolf Heuer, participated.

Regarding gender distribution, CERN has been implementing measures in the selection process since the Equal Opportunities policy was launched in 1996. With the creation of the Diversity Office, pro-active measures continue to be focused on the sourcing and pre-selection stages of recruitment, as well as selection practice. These measures have led to a positive trend in gender statistics for all professional categories, for example, reaching parity in the professional administrator category (rising from 18% in 1996 to 51% in 2012). There are also encouraging increases in the categories of research physicist, applied physicist, engineer and technician (rising from about 2% in 1996 to 10% in 2012).

Accountability

CERN's Internal Audit Service provides an independent, objective assurance and consulting activity designed to add value and improve the Organization's operations. The service reports to the Director-General, and the Head of Internal Audit is the Secretary of the Standing Advisory Committee on Audits. The service also provides support to the External Auditors who are appointed by CERN Council to certify the accounts of CERN and the CERN Pension Fund. The current External Auditors, appointed as of 1 January 2013, are representatives of the Supreme Audit Office of Poland, Najwyższa Izba Kontroli.



Fire-extinguisher training at the Safety Training Centre.

Safety and Environment

The assurance of safety at CERN requires several steps: prevention and emergency preparedness in case an accident occurs; rescue, recovery and improvement based on lessons learned from accidents that happen. A key part of prevention lies in raising awareness of safety issues, while being well prepared helps to lessen the consequences if accidents do occur. The recovery phase involves analysing incidents and feeding the lessons learned back into the effort of prevention and preparedness. Each year, measures to improve safety at CERN address one or more of these steps.

Raising awareness

Safety, quality, schedule: this is the motto for the LS1 shutdown, which started in February 2013 and became the dominant activity for the year at CERN. It marked the beginning of a

new era of shutdowns that will be 1–2 years long, instead of lasting only a few months. The aim from the start was to make LS1 a safe shutdown and this implied a new focus on raising awareness of safety and in turn an appropriate level of training. A significant increase in the budget for safety training allowed additional courses throughout the year for people working on the CERN site on maintenance and upgrade work, on the surface as well as underground. Indeed, LS1 triggered an increase in the number of requests for training, mainly from people required to carry out work on the LHC.

To cope with this increased level of activity and to continue to offer a high-quality service, the HSE Unit increased the number of both trainers and sessions. The courses include those that are obligatory for access to the underground areas, such as use of the self-rescue mask and radiation-protection courses relevant



Training in the use of the self-rescue mask in the new LHC mock-up.



One of the new terminals that automatically reads operational dosimeters.

to the radiation classification of the area to be accessed. Altogether, the safety training programme offers around 50 classroom courses and 17 e-learning courses. These include a new e-learning course developed to provide all those working on LS1 activities with accurate safety-oriented information. During 2013, 6800 people undertook classroom training, compared with 4500 in 2012, and some 10 000 sessions of e-learning were registered, with 4271 of those being on the new course for LS1.

At the same time, classroom training has become still more 'hands on' at the Safety Training Centre on the Prévessin site. In 2013 — thanks to in-kind contributions from the TE, GS, BE and EN Departments — the centre built a mock-up of the LHC, which simulates the work and safety conditions in the tunnel. The new facility has significantly improved the quality of the various training courses, for example, on the use of self-rescue masks. The centre has also been equipped with a new classroom specifically designed for courses in radiation protection, which opened on 16 October.

Being prepared

In 2012, the GS, IT and PH Departments worked together on the installation of a new digital radio-communication system known as TETRA. Designed to meet emergency communication needs, the system has been in use since January 2013 by the CERN Fire Brigade as well as by hundreds of CERN personnel and contractors' staff working in the tunnels. It has already proved its worth, particularly thanks to the DATI application — dispositif d'alarme pour travailleur isolé, or alarm device for isolated workers — which sends a signal to the Fire Brigade's control room whenever a person is horizontal for a long time or whenever the device detects a significant impact. In 2013 this allowed the Fire Brigade to help someone who had lost consciousness.

As part of the continual effort to ensure the highest standards in the field of radiation protection, 50 terminals that automatically

read operational dosimeters were installed around the accelerator complex by the Radiation Protection Group in March. Operational dosimeters, which complement 'passive' dosimeters, must be used whenever a person enters certain types of Controlled Radiation Area. Each request for access to these areas is made via the IMPACT software tool and submitted to the Radiation Protection Group, who set a dose threshold that depends on the job, the estimated dose and the worker's previous exposure. If this threshold is reached during the intervention, the dosimeter gives an alarm to warn the person to stop work and leave the area. In addition, as the exposure data are automatically recorded in a database, the information is rapidly available. With the link to the activities declared in IMPACT, it is also possible to analyse the doses more thoroughly and with more precise statistics.

As part of its continued commitment to operating a safe laboratory, CERN has developed a robust crisis management plan. To test it, the Laboratory held two meticulously planned and realistic emergency exercises on 11 October and 14 November, led by the specialists who had worked with the Crisis Management Team to develop the plan. The exercises involved staff across the Organization and were designed to check CERN's strategic response procedures in case of a crisis. The experience also allowed the people involved to get a feel for managing a real crisis situation. The intention is to hold a similar exercise every year.

We're all concerned!

On 18 April, the Safety Unit of the BE Department, the HSE Unit, the Medical Service and the Fire Brigade organized an event for World Day for Safety and Health at Work, for the third year running. Information stands on the themes of stress and back pain were set up in each of CERN's three restaurants, addressing stress self-evaluation, anti-stress techniques, and tips for avoiding and managing back pain. Cycling safety was



Helmets and reflective vests were a focus of the campaign on bike safety.



More than half of CERN's 650 hectares are fields, pasture and woodland – a natural environment that, thanks to a conservation-oriented policy, is characterized by a remarkable biodiversity including these fallow deer on the Prévessin site.

the focus of a campaign on 3–17 June, led by the HSE Unit, in collaboration with the Reception and Access Control Service from the GS Department. In exchange for vouchers distributed by the security guards, 195 people took part in a survey that contained questions on their cycling habits and level of knowledge on bike safety issues. They received a helmet and a reflective vest as well as documents on cycling safety issues. In December, with the first snows of the winter and prolonged period of freezing fog, the HSE Unit highlighted the risks of falling in wintry conditions.

Safety for all

CERN's paramount attention to safety extends not only to people using the facilities but to all of those who visit. Safety was an important item on the agenda in the organization of all of the activities for three big events in 2013 — Passport to the Big Bang, the Open Days and Bosons and More. This demanded thousands of hours of effort to inspect, secure and clear the relevant sites — as many as 40 sites for the Open Days. The result was an excellent safety record, thanks to all of the preventive safety work.

The Open Days also provided the opportunity to raise public awareness on aspects of environmental protection aspects and to show how CERN monitors the impact of its activities on the environment.



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Dr B. Jacobsen (Norway)

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Finance Committee

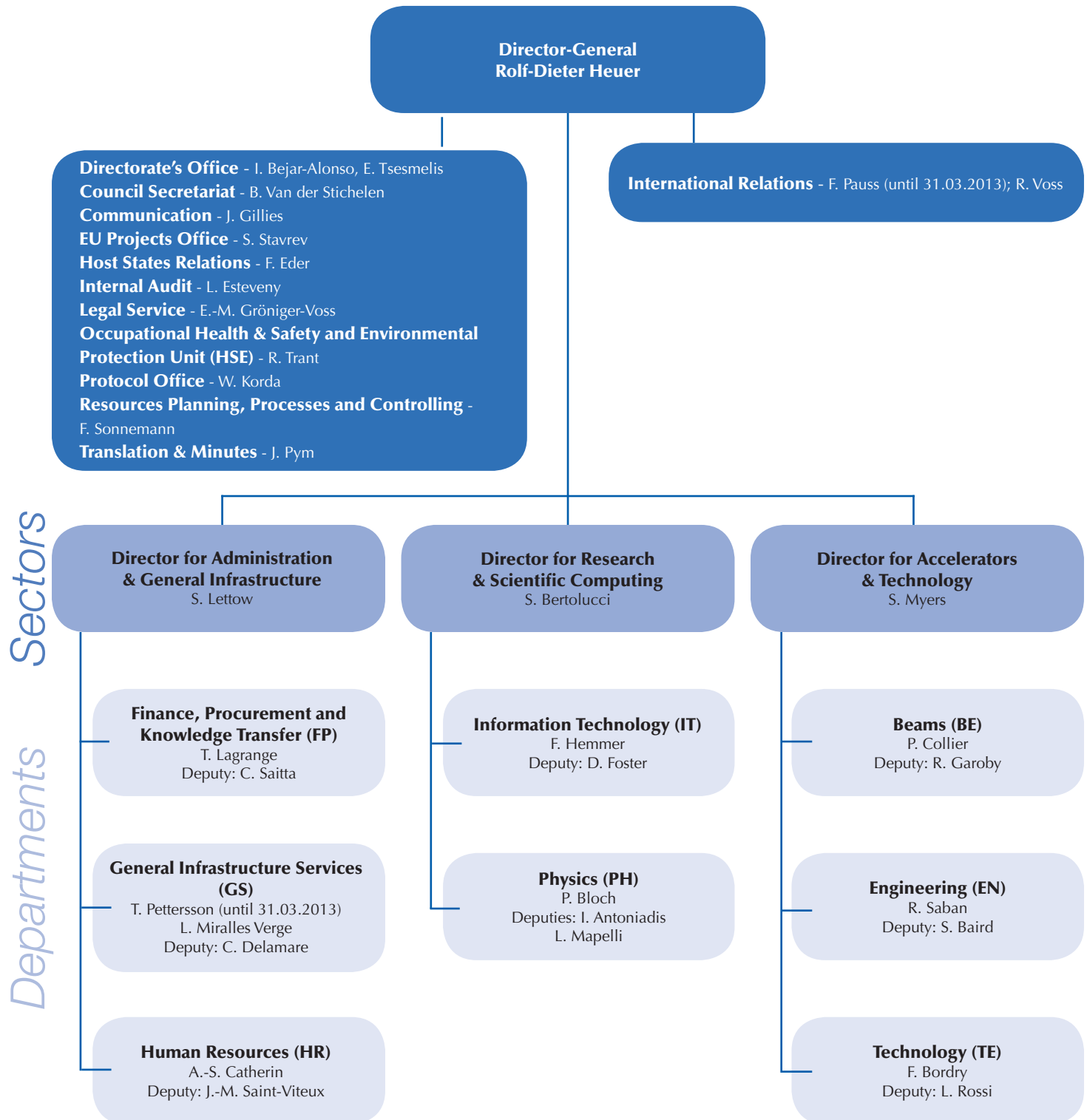
Chairman

Dr B. Jacobsen (Norway)

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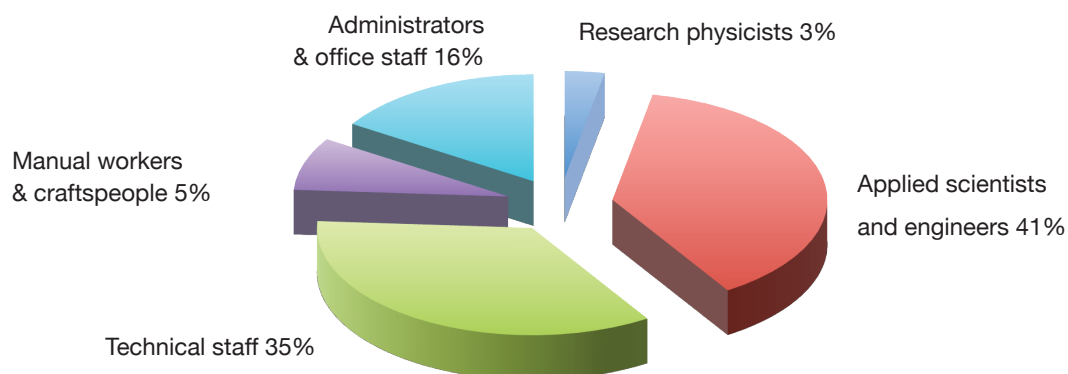


Departments & Groups

S DIR	Director-General Office Sector	HR	Human Resources Department	IT-SDC	Support for Distributed Computing
DG	Director-General	HR-CB	Compensation & Benefits	PH	Physics Department
DG-AS	Administrative Support	HR-DHO	Department Head Office	PH-ADE	ATLAS Detector Systems
DG-CO	Communication	HR-LD	Learning and Development	PH-ADO	ATLAS Detector Operation
DG-CS	Council Secretariat	HR-SA	Staff Association Secretariat (administratively attached to HR)	PH-ADP	ATLAS Data Processing
DG-DG	Office of the Director-General	HR-TA	Talent Acquisition	PH-ADT	ATLAS DAQ & Trigger
DG-DI	Directorate Office	S AT	Accelerator & Technology Sector	PH-AGS	Administration & General Services
DG-EU	EU Projects Office	BE	Beams Department	PH-AID	ALICE Detector & Systems
DG-IA	Internal Audit Service	BE-ABP	Accelerator & Beam Physics	PH-AIO	ALICE Management & Engineering Support
DG-IR	International Relations	BE-ASR	Administration, Safety & Resources	PH-AIP	ALICE Physics & Computing
DG-LS	Legal Service	BE-BI	Beam Instrumentation	PH-CMD	CMS DAQ & Trigger
DG-PRT	Protocol Office	BE-CO	Controls	PH-CMG	CMS Physics, Software & Computing
DG-RH	Relations with Host States	BE-HDO	Head of Department's Office	PH-CMO	CMS Organization
DG-RPC	Resources Planning, Processes and Controlling	BE-OP	Operation	PH-CMX	CMS Experiment Systems
DG-TM	Translation & Minutes	BE-RF	Radio Frequency	PH-DI	Office of the Department Leader
DGS	Occupational Health & Safety and Environmental Protection Unit	EN	Engineering Department	PH-DT	Detector Technology
DGS-DI	Head Office of the HSE Unit	EN-CV	Cooling & Ventilation	PH-EDU	Education & Visits
DGS-RP	Radiation Protection Group	EN-EL	Electrical Engineering	PH-ESE	Electronics Systems for Experiments
DGS-SEE	Safety Engineering & Environment Group	EN-GMS	General Management & Secretariats	PH-LBC	LHCb Computing
S AI	Administration and General Infrastructure Sector	EN-HDO	Head of Department's Office	PH-LBD	LHCb Detector
FP	Finance, Procurement & Knowledge Transfer Department	EN-HE	Handling Engineering	PH-LBO	LHCb Co-ordinators Office
FP-DI	Office of the Department Head	EN-ICE	Industrial Controls & Engineering	PH-LCD	Linear Collider Detector
FP-FAS	Financial & Accounting Services	EN-MEF	Machines & Experimental Facilities	PH-SFT	Software Design for Experiments
FP-KT	Knowledge Transfer	EN-MME	Mechanical & Materials Engineering	PH-SME	Small & Medium Experiments
FP-PI	Procurement & Industrial Services	EN-STI	Sources, Targets & Interactions	PH-TH	Theoretical Physics
GS	General Infrastructure Services Department	TE	Technology Department	PH-TOT	TOTEM Experiment
GS-AIS	Advanced Information Systems	TE-ABT	Accelerator Beam Transfer	PH-UAD	Antiproton Users
GS-ASE	Access, Safety & Engineering Tools	TE-CRG	Cryogenics	PH-UAI	ALICE Users
GS-DI	Head of Department's Office	TE-EPC	Electrical Power Converters	PH-UAT	ATLAS Users
GS-FB	Fire Brigade	TE-HDO	Head of Department's Office	PH-UC3	CTF3 Users
GS-IS	Integrated Services	TE-MPE	Machine Protection & Electrical Integrity	PH-UCM	CMS Users
GS-ME	Medical Service	TE-MSD	Magnets, Superconductors & Cryostats	PH-UFT	Fixed Target Users
GS-SE	Site Engineering	TE-RPA	Resources Planning & Administration	PH-UGC	General Collaboration Users
GS-SIS	Scientific Information Service	TE-VSC	Vacuum, Surfaces & Coatings	PH-UHC	Other LHC Users
GS-SMS	Service Management & Support	S RC	Research & Scientific Computing Sector	PH-UIS	ISOLDE Users
		IT	Information Technology Department	PH-ULB	LHCb Users
		IT-CF	Computing Facilities	PH-ULD	Linear Collider Detector Users
		IT-CIS	Collaboration and Information Services	PH-ULE	LEP Users
		IT-CS	Communication Systems	PH-UNT	n_TOF Users
		IT-DB	Database Services	PH-UOP	Other Physics Users
		IT-DI	Departmental Infrastructure	PH-URD	R&D Users
		IT-DSS	Data & Storage Services	PF	Pension Fund
		IT-OIS	Operating Systems & Infrastructure Services	PFMU	Pension Fund Management Unit
		IT-PES	Platform & Engineering Services	PF-BA	Benefits and Accounting
				PF-AAR	Asset Allocation and Risk Management
				PF-IPM	Internal Portfolio Management
				PF-MO	Middle Office
				PF-GMS	General Management Support

CERN in figures

CERN Staff



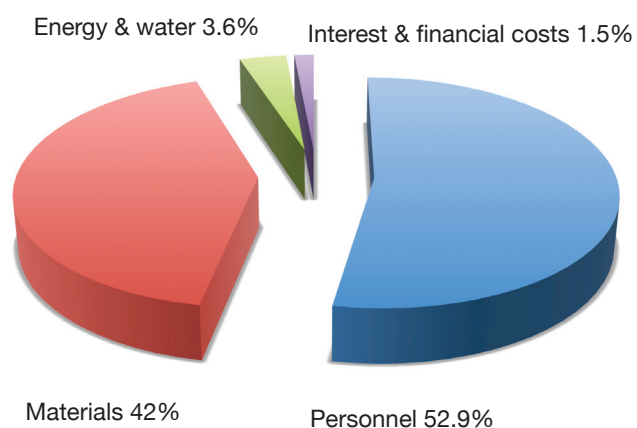
Evolution of Staff numbers *Including externally funded*

2010	2427
2011	2424
2012	2512
2013	2513

Evolution of Fellows, Associates, Students, Users & Apprentices *Trainees, Visiting Scientists & Guest Professors also included from 1 January 2013*

2010	11 025
2011	11 449
2012	12 080
2013	12 313

CERN Expenses



Total expenses 1139.7 MCHF

Personnel	603.2
Materials	479
Goods, consumables and supplies	248.6
Other materials expenses	230.4
Energy and water	40.9
Interest and financial costs	16.6

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.

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 uniting 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

The particle linked to the Brout-Englert-Higgs mechanism that gives mass to elementary particles.

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).

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.)

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.

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.)

n_TOF

A facility that uses protons from the PS to create a high-intensity neutron beam to study neutron-induced reactions over a broad range of energies.

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 the electron and electron neutrino, muon and muon neutrino, tau and tau neutrino. The quarks and leptons, which are all particles of matter, are referred to collectively as fermions. 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.

Positron

The antiparticle of the electron. (See also Antimatter.)

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 state of matter in which protons and neutrons 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.

Transfer line

Carries a beam of particles, e.g. protons, from one accelerator to another using magnets to guide the beam.

TeV

See Electronvolt.

Trigger

An electronic system for spotting potentially interesting collisions in a particle detector and triggering the detector's read-out system to record the data resulting from the collision.

Vacuum

A volume of space that is substantively empty of matter, so that gaseous pressure is much less than standard atmospheric pressure.

WLCG (Worldwide LHC Computing Grid)

The mission of the WLCG is to build and maintain a data-storage and analysis infrastructure for the entire high-energy physics community that will use the LHC.

