Welcome to the digital edition of the March 2016 issue of CERN Courier.

This month we have been captivated by the wonderful images of the Very Large Telescope, ESO’s breathtaking installation, which made the cover, and the article is as inspiring as the accompanying photographs. We also collect a series of “firsts” in this issue. The first Viewpoint by CERN’s new Director-General, Fabiola Gianotti, as well as the first article about the newly proposed SHiP facility, designed to explore the hidden world. And the idea that two researchers had to use the sonification technique (well known in particle physics) to develop novel investigation methods to study the body motor also comes under the “first” label. In addition to a great collection of features, we have a rich body of news articles, with new information published on antimatter and nuclear physics.

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All new smart High vacuum pumps and systems
Charting the future of CERN

The coming years will be crucial for the long-term future of particle physics.

By Fabiola Gianotti

Over the next five years, key events shaping the future of particle physics will unfold. We will have results from the second run of the LHC, and from other particle and astroparticle physics projects around the world. These will help us to chart the future scientific landscape of our field. The international collaboration that is forming around the US neutrino programme will crystallise, bringing a new dimension to global collaboration in particle physics. And initiatives to host major high-energy colliders in Asia should become clear. All of this will play a role in shaping the next round of the European Strategic Physics programme, which will in turn shape the future of our field in Europe and at CERN.

CERN is first and foremost an accelerator laboratory. It is there that we have our greatest experience and concentration of expertise, and it is there that we have known our greatest successes. I believe that it is also there that CERN’s future lies. Whether or not new physics emerges at the LHC, and whether or not a new collider is built in Asia, CERN should aim to maintain its pre-eminence as an accelerator lab exploring fundamental physics. CERN should aim to maintain its pre-eminence as an accelerator lab exploring fundamental physics.

CERN's top priority for the next five years is ensuring a successful LHC Run 2, and securing the financial and technical development and readiness of the High-Luminosity LHC project. This does not mean that CERN should compromise its scientific diversity. Quite the opposite: our diversity underpins our strength. CERN’s programme today is vibrant, with unique facilities such as the Antiproton Decelerator and ISOLDE, and experiments studying topics ranging from kaons to axions. This is vital to our intellectual life, and it is a programme that will evolve and develop as physics needs dictate. Furthermore, with the new neutrino platform, CERN is contributing to projects hosted outside of Europe, notably the exciting neutrino programme underway at Fermilab.

If CERN is to retain its position as a focal point for accelerator-based physics in the decades to come, we must continue to play a leading role in global efforts to develop technologies to serve a range of possible physics scenarios. These include R&D on superconducting high-field magnets, high-gradient, high-efficiency accelerating structures, and novel acceleration technologies. In this context, AWAKE is a unique project using CERN’s high-energy, high-intensity proton beams to investigate the potential of proton-driven plasma wakefield acceleration for the very-long-term future. In parallel, CERN is playing a leading role in international design studies for future high-energy colliders that could succeed the LHC in the medium-to-long term. Circular options, with colliding electron–positron and proton–proton beams, are covered by the Future Circular Collider (FCC) study, while the Compact Linear Collider (CLIC) study offers potential technology for a linear electron–positron option reaching the multi-TeV range. To ensure a future programme that is compelling, and scientifically diverse, we are putting in place a study group that will investigate future opportunities other than high-energy colliders, making full use of the unique capabilities of CERN’s rich accelerator complex, while being complementary to other endeavours around the world. Along with the developments I mention above, these studies will also provide valuable input into the next update of the European Strategy, towards the end of this decade.

Global planning in particle physics has advanced greatly over recent years, with European, US and Japanese strategies broadly aligning, and the processes that drive them becoming ever more closely linked. For particle physics to secure its long-term future, we need to continue to promote strong worldwide collaborations, develop synergies, and bring new and emerging players, for example in Asia, into the fold.

Within that broad picture, CERN should steer a course towards a future based on accelerators. Any future accelerator facility will be an ambitious undertaking, but that should not deter us. We should not abandon our exploratory spirit just because the technical and financial challenges are intimidating. Instead, we should rise to the challenge, and develop the innovative technologies needed to make our projects technically and financially feasible.
Providing Positioning Solutions

Queensgate, a brand of Elektron Technology UK Ltd, specialise in offering nano-positioning and nano-measuring solutions to meet individual customer requirements. Queensgate pioneered the use of capacitive micrometry in nano-positioning. The capacitive sensors deliver high resolution, low noise and high linearity of movement with positional repeatability of less than 1nm.

Tip mechanisms – these offer a single accuracy of positioning.

• Tip mechanisms – these offer a single accuracy of positioning.

sensors delivers unparalleled speed and technology, doubles the bandwidth that can be achieved using traditional PID & notch filter control for a given resonant frequency. This coupled with the capacitive positioning sensors delivers unparalleled speed and accuracy of positioning.

• Tip mechanisms – these offer a single accuracy of positioning.

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in very-low-angle elastic scattering. The worst effects were observed in Run 1, when two beams. Designed to be radiation stable to 10^6 Gy, UHV compatible to 10^6 °¹, the gold plated ceramic sensors are designed so they can be used from -273 to +150 Degrees C and operate in a high magnetic field.

The NCG-1-AL-UHV Nanosensor ™ was designed to measure over an 11mm range with 80nm (typical) resolution to provide accurate positioning of two parallel magnetic beams. Designed to be radiation stable to 10^6 Gy, UHV compatible to 10^6 °¹, the gold plated ceramic sensors are designed so they can be used from -273 to +150 Degrees C and operate in a high magnetic field.

The Queensgate NPS-Z-500A-UHV was developed as an extra-long range flexure guided piezo actuator offering over a times the range of standard actuators to operate in UHV for crystal bending applications. Its companion NPS-Z-15L-UHV was developed to sustain loads of up to 60kg with a high resonant frequency, and it has a blocking force of 35,000N.

The Queensgate NPS-Z-15L-UHV was developed to sustain loads of up to 60kg with a high resonant frequency, and it has a blocking force of 35,000N.

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The DPT-0 and DPT-E range of actuators are designed with capacitive feedback control to give precise positioning. They are capable of moving loads of up to 60 kg over the full travel range with low electronic noise and high linearity. This gives confidence that the actuator is positioned with precision, speed and accuracy. High thermal stability super invar construction gives super high global position stability.

Beamline Insertion Device

The NCG-1-AL-UHV Nanosensor ™ was developed to measure over an 11mm range with 80nm (typical) resolution to provide accurate positioning of two parallel magnetic beams. Designed to be radiation stable to 10^6 Gy, UHV compatible to 10^6 °¹, the gold plated ceramic sensors are designed so they can be used from -273 to +150 Degrees C and operate in a high magnetic field.

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Beamline Insertion Device

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beam dump, an extensive campaign of impregnation measuring, and the development of electron-cloud reduction measures. The upgrade programme also targets ions as they plans improve to Linac3 and LEIR, and looks at implementing new techniques to produce a higher number of intense ions on target. Here, plans have been base-lined to the RF and collimation systems are also as a way of tackling the electron cloud in the laser-engineered surface structures (LESS) of its stable isotopes are magic in both shape, mass, excitation energy and stability, which makes them very difficult to spherical, and present a very high degree of nucleons, namely 2, 8, 20, 28, 50 and 82, are were awarded the Nobel prize in 1963. M Goeppert-Mayer and J D Jensen, who protons or neutrons completely fill a shell. The calcium-isotopic chain (\(N = 32\)) was obtained in 2013 (Wienholtz et al. 2013 Nature 498 346). Therefore, to determine the radius beyond of note is major work in the much-solicited PbPs and SPS experimental areas. Of the charge radii for \(40–52 \text{Ca}\) isotopes were obtained by high-resolution bunched-beam collinear laser spectroscopy in the COLLAPS installation at ISOLDE, CERN. The charge radii for \(40–52 \text{Ca}\) isotopes were observed to be slightly smaller than the neutron separation energy. In addition, the measured charge radii for \(40–52 \text{Ca}\) isotopes are in good agreement with the nuclear-model calculations, which suggest that the charge radii for \(40–52 \text{Ca}\) isotopes are close to their absolute limits. An in-depth survey of the potential performance limitations of the HL-LHC and means to mitigate or circumvent them were discussed. Although it is clear that the electron cloud will remain an issue, the experts gathered at Chamonix proposed a number of measures including in-situ amorphous carbon (a-C) coating and in-situ laser-engineered surface structures (LESS) as a way of tackling the electron cloud in the magnets at the insertion regions. Besides the complete re-working of the high-luminosity insertions, key upgrades to the RF and collimation systems are also required. Here, plans have been base-lined and work is in progress to develop and produce the required hardware. An important novel contribution from RF is the production of crab cavities, which are designed to mitigate the effect of the large crossing angle at the high-luminosity interaction points. The preparation for the installation of test crab cavities in the SPS is well under way. Ions will be an integral part of the HL-LHC programme and the plans to deliver the required beams and luminosity are taking shape. The recent successful Pb–Pb run at 5.02 TeV centre-of-mass energy per colliding nucleon pair and the quench tests performed during this run have provided very useful input. Although it will only start in 2019, planning for LS2 is already under way, and a dedicated session looked at the considerable amount of work foreseen for the next two-year step of the accelerator complex. A major part of the effort will be devoted to the deployment of the LIU injector upgrade discussed previously. Looking at the experiments, ALICE and LHCb will perform major upgrades to their detectors and read-out systems. An impressive amount of consolidation work is also foreseen.

**Exploring the nature of the proposed magic number \(N = 32\)**

Magic numbers appear in nuclei in which protons or neutrons completely fill a shell. The existence of magic numbers can explain certain regularities observed in nuclei was discovered in 1949 independently by McGeoch and Mayer and D. Jensen, who were awarded the Nobel prize in 1963. Nuclei containing a magic number of nucleons, namely 2, 8, 20, 28, 50 and 82, are spherical, and present a very high degree of stability, which makes them very difficult to excite. The degree of “magicity” of a nucleus can be determined by precisely determining its shape. Mass, excitation energy and electromagnetic observables—properties that can be precisely studied with dedicated experiments at SIS-DE. The calcium-isotopic chain (\(Z = 20\), magic proton number) is a unique nuclear system to study how protons and neutrons interact inside of the atomic nucleus: two of its stable isotopes are magic in both their proton and neutron number (\(^{40}\)Ca with \(N = 20\) and \(^{48}\)Ca with \(N = 28\)). Despite an excess of eight neutrons, \(^{40}\)Ca exhibits the striking feature that it has an identical mean square charge radius as \(^{40}\)Ca. In addition, experimental evidence of doubly magic features in a short-lived calcium isotope, \(^{48}\)Ca (\(N = 32\), was obtained in 2013 (Wienholtz et al. 2013 Nature 498 346). Therefore, to determine the radius beyond \(^{48}\)Ca was crucial from an experimental and theoretical point of view. The new determination of the nuclear radius is now challenging the magicity of the \(^{40}\)Ca isotope. The measurements were performed by using high-resolution bunched-beam collinear laser spectroscopy in the COLLAPS installation at ISOLDE, CERN. The charge radii for \(^{40–52}\)Ca isotopes were obtained from the optical isotope shifts extracted from the fit of the hyperfine experimental spectra. Indeed, although the average distance between the electrons and the nucleus in an atom is about 5000 times larger than the nuclear radius, the size of the nuclear-charge distribution is manifested as a perturbation of the atomic energy levels. A strong signature in optical isotope shifts gives rise to a shift of the atomic hyperfine structure (hfs) levels. This shift is larger than the separation between two isotopes, one million times smaller than the absolute transition frequency, commonly known as the isotope shift, includes a part that is proportional to the change in the nuclear mean-square charge radius. Measurement of such a tiny change is only possible by using ultra-high-resolution techniques. With a production yield of only a few hundred ions per second, the measurement on \(^{40}\)Ca represents one of the highest purity ever reached using fluorescence-detection techniques. The collinear laser spectroscopy technique developed at ISOLDE has been established as a unique method to reach such high resolution, and has been applied with different detection schemes to study a variety of nuclear chains.

**Antimatter**

**New ALPHA measurement of the charge of antihydrogen**

The ALPHA collaboration has just published a new measurement of the charge of the antihydrogen atom. Although the Standard Model predicts that antihydrogen must be strictly neutral, only a few experiments have been performed so far to test this conjecture. A glance at the Particle Data Book reveals that, according to the latest measurements, the antiproton charge can differ from the charge of the electron by at most \(10^{-10}\) times the fundamental charge. The comparable number for the positron is somewhat larger, at \(4 \times 10^{-8}\). Note that studies with atoms of normal matter show that they are neutral to within one part in \(10^{10}\). We are, therefore, unsurprisingly, way behind in our ability to study antimatter. Given that we still do not understand the baryon asymmetry, it is generally a good idea to take a hard look at antimatter, if you can get your hands on some. Antihydrogen is unique in the laboratory in that it should be neutral, stable antimatter. Indeed, an exact Coulomb symmetry requires antihydrogen to have the same properties as hydrogen, including charge. Antihydrogen, we can produce antihydrogen atoms and catch them in a trap formed by superconducting magnets, and we can hold them for at least 1000 s. The current article in Nature results from experiments in the recently commissioned ALPHA-2 machine, and uses a new technique proposed by ALPHA member Joel Foord at UC Berkeley. The new method, known as stochastic acceleration, involves subjecting the trapped antihydrogen atoms to electric-field pulses at various time intervals. If the antihydrogen is not really neutral, it will be “heated” by the repeated pulses until it finally escapes the trap and annihilates. Comparing the results of trials with and without the pulsed field, we can derive a limit on how “charged” antihydrogen might be. The answer so far: antihydrogen is neutral to \(0.7 \text{ ppb}\) (one standard deviation) of the fundamental charge. This is a factor of 20 improvement over our previous limit, set by using static electric fields to try to deflect antihydrogen when it is released from the trap. If we take another approach and assume that antihydrogen is indeed neutral, we can combine this result with ASACUSA’s measurement of the antiproton charge anomaly to improve the limit on the positron charge anomaly by a factor of about 2.5. Of course, we are looking for signs of new physics in the antihydrogen system—it is probably best not to assume anything.

**Further reading**


CERN Courier welcomes contributions from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

CERN Courrier March 2016
searches looked for such a signature, with different selections depending on the number of jets, b-tagged jets and leptons, to be sensitive to different production and decay modes. Six different searches found event rates in good agreement with the Standard Model prediction, and placed new limits on squark and gluino masses. For a gluino decaying to two b quarks and a neutralino LSP, for a light neutralino, the Run 1 limit of 1300 GeV on the gluino mass has been extended to 1780 GeV by the new result.

The seventh search looked for events with a Z boson, jets and missing transverse momentum, a final state where a 3 jet meson is produced in association with a Z boson, jets and missing transverse momentum. In this channel, the Run 1 limit of 1300 GeV on the gluino mass has been extended to 1780 GeV by the new result. The search was sensitive to the gluino mass in the range of 300–1780 GeV. The LHCb experiment, in contrast to the case of the case of the Higgs boson, has studied the decay of the gluino into a Z boson and two light quarks, which is a very clean channel for the gluino.

The search was performed using 2.76 fb⁻¹ of pp collision data taken at s = 2.76 TeV, at the LHC Run 1. The analysis was based on an improved reconstruction algorithm for the detection of jets, which was used for the first time in the Run 1 data. The algorithm was designed to be more sensitive to the presence of jets in the final state of the gluino decay, which is expected to be typically a 3 jet meson.

CMS preliminary

Jet measurements in high-energy physics are crucial for understanding the fundamental properties of particles and their interactions. The jet energy loss is an important observable that can provide information about the energy and momentum distribution of particles produced in the collision. The jet energy loss is induced by the absorption of energy by the medium created in the collision, which changes the momentum distribution of the particles. This loss is particularly important in heavy-ion collisions, where the medium created is known as the quark-gluon plasma (QGP).

Jet measurements have been extensively studied in both the Tevatron and the LHC experiments. The data from these experiments have been used to test the predictions of perturbative QCD and to study various aspects of the QGP. The LHCb experiment has conducted several searches for new particles beyond the Standard Model, including the search for the gluino, which is a candidate for supersymmetric physics. The search was performed using 2.76 fb⁻¹ of pp collision data taken at s = 2.76 TeV, at the LHC Run 1. The analysis was based on an improved reconstruction algorithm for the detection of jets, which was used for the first time in the Run 1 data. The algorithm was designed to be more sensitive to the presence of jets in the final state of the gluino decay, which is expected to be typically a 3 jet meson.
New facilities and delivery of components for the new heavy-ion synchrotron SIS100 at FAIR has begun

The international Facility for Antiproton and Ion Research (FAIR) is a superconducting accelerator complex that will deliver antiprotons and heavy ions of unprecedented intensities and qualities to perform heavy-ion and antimatter research. The driver accelerator of FAIR is a fast-ramping, superconducting synchrotron, SIS100, which allows the acceleration of high-intensity beams of stable elements from protons (29 GeV) to uranium (11 GeV/u). SIS100 will be installed in an underground tunnel and all of the services will be installed in a parallel supply tunnel. The delivery of components for SIS100 commenced at the end of 2015. On 21 December, AUdION in Siegenstadt delivered the first of nine magnetic-alloy bunch-compression cavities. In a combined site/factory acceptance test at GSI, approval for series production is now in preparation. As the first Polish in-kind contribution, the first piece of cryogenic-bypass line, made at the Wroclaw University of Technology, was delivered in February. After delivery, the bypass line will undergo acceptance tests at GSI. The site acceptance test of the first of a series of fast-ramped, dipole magnets is in its final stage (see figure). The results available so far indicate high mechanical precision and excellent performance of the superconducting coil. Following successful results, series production has started, and the first devices are expected to be delivered by the middle of 2016. The series devices will be tested at the new test facility at GSI, which has been set up for cold testing of FAIR magnets. In accordance with the contracts, many other SIS100 components will be delivered in 2016, including the first of a series of superconducting quadrupoles from JINR (Dubna, Russia), resonance sextupole magnets, acceleration cavities, magnet chambers, cryo-catcher and cryo-adsorption pumps, and many others.

The realisation phase of the SIS100 project is fully under way, and the work is proceeding according to schedule. The production of accelerator components is expected to take a maximum of four years.

 NEWS & FACILITIES

Construction of KM3NeT, a next-generation neutrino telescope, has begun

In the early morning of 3 December, scientists and engineers started the installation of KM3NeT (CERN Courier July/August 2012 p.31). Once completed, it will be the largest detector of neutrinos in the Northern Hemisphere. Located in the depths of the Mediterranean Sea, the infrastructure will be used to study the fundamental properties of neutrinos and to map the high-energy cosmic neutrinos emanating from extreme cataclysmic events in space.

Neutrinos are the most elusive of elementary particles and their detection requires the instrumentation of enormous volumes: the KM3NeT neutrino telescope will occupy more than a cubic kilometre of seawater. It comprises a network of several hundred vertical detection strings, anchored to the seabed and kept taut by a submerged buoy. Each string hosts 18 light-sensor modules, equally spaced along its length. In the darkness of the abyss, the sensor modules register the faint flashes of light emanating from extreme cataclysmic events.

Neutrino detectors in KM3NeT are neutrino telescopes. A neutrino telescope is a large-scale detector array that uses the effect of charged-particle production in a dense medium to observe and measure the direction of neutrino interactions. The KM3NeT neutrino telescope can detect neutrinos with energies of more than 100 GeV and, with its improvements in sensitivity, it will detect the first high-energy neutrinos observed in the Northern Hemisphere. KM3NeT represents a major milestone in neutrino astronomy.

Further reading

Underground Laboratories

LUNA observes a rare nuclear reaction that occurs in giant red stars

In December, the Laboratory for Underground Nuclear Astrophysics (LUNA) (CERN Courier October 2004 p.35) reported the first direct observation of sodium production in giant red stars. The first reaction was the Ne(p,α) reaction, which is a key process in the nuclear network that explains the origin of the elements of the universe.

LUNA is a compact linear accelerator for light ions (maximum energy 400 keV). A unique facility, it is installed in a deep underground laboratory and shielded from cosmic rays. The experiment aims to study the nuclear reactions that take place inside stars, where elements that make up matter are formed and then driven out by giant explosions and scattered as cosmic dust. For the first time, LUNA has observed three low-energy resonances in the neon-sodium cycle, the Ne(p,α)23Na reaction, responsible for sodium production in red giants and energy generation. LUNA recreates the energy ranges of nuclear reactions and, with its accelerator, goes back in time to one hundred million years after the Big Bang, when the first stars formed and the processes that gave rise to the huge variety of elements in the universe started.

This result is an important piece in the puzzle of the origin of the elements in the universe, which LUNA has been studying for 25 years. Stars assemble atoms through a complex system of nuclear reactions. A very small fraction of these reactions have been studied at the energies existing inside of the stars, and a large part of those few cases have been observed using LUNA.

A high-purity germanium detector with relative efficiency up to 100% was used for this particular experiment, together with a windowless gas target filled with enriched gas. The rock surrounding the underground facility at the Gran Sasso National Laboratory and additional passive shielding protected the experiment from cosmic rays and ambient radiation, making the direct observation of such a rare process possible.

Further reading

Neutrino Physics

Invariant mass spectra for $D^\pm \rightarrow K^\pm K^\mp$ (left) and $D^\pm \rightarrow \pi^\pm \pi^\mp$ (right), showing the high-statistics sample of cleanly reconstructed decays in these suppressed modes. This brings charm physics to the frontier of experimental knowledge. The experiment plans to collect an integrated luminosity of 50 inverse femtobarn, owing to an upgraded detector, in about 10 years from now. This will improve the precision of these results by an order of magnitude.

Further reading

Manufacturing and delivery of components for the new heavy-ion synchrotron SIS100 at FAIR has begun

The international Facility for Antiproton and Ion Research (FAIR) is a superconducting accelerator complex that will deliver antiprotons and heavy ions of unprecedented intensities and qualities to perform heavy-ion and antimatter research. The driver accelerator of FAIR is a fast-ramping, superconducting synchrotron, SIS100, which allows the acceleration of high-intensity beams of stable elements from protons (29 GeV) to uranium (11 GeV/u). SIS100 will be installed in an underground tunnel and all of the services will be installed in a parallel supply tunnel. The delivery of components for SIS100 commenced at the end of 2015. On 21 December, AUdION in Siegenstadt delivered the first of nine magnetic-alloy bunch-compression cavities. In a combined site/factory acceptance test at GSI, approval for series production is now in preparation. As the first Polish in-kind contribution, the first piece of cryogenic-bypass line, made at the Wroclaw University of Technology, was delivered in February. After delivery, the bypass line will undergo acceptance tests at GSI. The site acceptance test of the first of a series of fast-ramped, dipole magnets is in its final stage (see figure). The results available so far indicate high mechanical precision and excellent performance of the superconducting coil. Following successful results, series production has started, and the first devices are expected to be delivered by the middle of 2016. The series devices will be tested at the new test facility at GSI, which has been set up for cold testing of FAIR magnets. In accordance with the contracts, many other SIS100 components will be delivered in 2016, including the first of a series of superconducting quadrupoles from JINR (Dubna, Russia), resonance sextupole magnets, acceleration cavities, magnet chambers, cryo-catcher and cryo-adsorption pumps, and many others.

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**News**

**Astroparticles**

**DAMPE joins the search for dark matter in space**

On 17 December, the Chinese Academy of Sciences (CAS) successfully launched the Dark Matter Particle Explorer (DAMPE) satellite from the Jiuquan Satellite Launch Center in northwest China, marking the entrance of a new player in the global hunt for dark matter.

The nature of dark matter is one of the most fundamental questions of modern science, and many experiments have been set up to unravel this mystery, using either large underground detectors or at colliders (for example at the LHC), or with space missions (for example, AMS, CERN Courier November 2014 p6, or CALET, CERN Courier November 2015 p3). DAMPE is the first science satellite launched by CAS. Built with advanced particle-detection technologies, DAMPE will extend the dark-matter search in space into the multi-TeV region. It will measure electrons and photons in the 5 GeV–10 TeV range with unprecedented energy resolution (1.5% at 100 GeV), to find dark-matter annihilation in various types of particles, with energy raging from 1 to 400 GeV.

Three days after the launch, on 20 December, the STK was powered on, and four days later, the high voltage of the calorimeter was also turned on. To the satisfaction of the collaboration, all of the detector sub-systems functioned very well, and in-orbit commissioning is now well under way to tune the detector to optimal condition for the three-year observation period. A great deal of data collection, process and analysis lie ahead, but thanks to CERN, we can look forward to a well-calibrated DAMPE detector to produce exciting new measurements in the very near future.

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Low-cost diamonds?

A novel, new form of carbon, dubbed “Q-carbon”, is harder than diamond. The new phase, discovered by Jagdish Narayan and Anagha Bhamurk of North Carolina State University in Raleigh, US, results from the rapid quenching of liquid carbon produced by high-power nanosecond laser pulses on amorphous carbon. The material can be a semiconductor or metallic, depending on temperature. It is ferromagnetic and, depending on the cooling rate, can be formed with tiny diamonds. The process takes place under normal temperatures and pressures and is inexpensive, making bulk, low-cost diamond production look very feasible, in addition to there now being a very interesting new form of carbon.

Chameleon tongues

Chameleons are able to lash out with their sticky tongues that extend more than twice their body lengths, and achieve incredible accelerations of 25490 m/s² or 264 g, corresponding to peak power outputs of more than 14,000 W/kg, outperforming any other amniotes. Christopher V Anderson of Brown University in Rhode Island, US, has tracked the mechanism back to stretching elastic tissues, similar to the stretching of a bow. This energy can then be released rapidly – much more so than muscles could provide directly.

Seventh-row complete

Four new elements have been discovered, completing the seventh row of the periodic table. The RIKEN collaboration in Japan takes the credit for element 113 (ununtrium, Uut), and they will be invited to propose a more interesting name. For elements 115, 117 and 118 (ununpentium, Uup; ununseptium, Uus; and ununoctium, Uuo), credit goes to JINR in Dubna, LLNL in California and ORNL in Tennessee. New names and two letter symbols will also be proposed for these. Now it’s time to try for the eighth row.

Further reading


Multicellular life from a single accident

Early life was unicellular, and we now know that it took just one random but crucial mutation, 600 million years ago, which changed the function of one key protein, to make multicellular life possible. In multicellular organisms, adjoining cells have to co-ordinate, and key to this at division is the orientation of the mitotic spindle, which segregates chromosomes into daughter cells. Using a technique called ancestral protein reconstruction, which is based on gene sequencing and computer modelling, Kenneth Prehoda of the University of Oregon, US, and colleagues tracked things back to a mutation in the GK protein-interaction domain (GKPID). Even more remarkable, the reason that a single mutation could have such a huge effect is a lucky resemblance between two seemingly unrelated molecules – so we’re lucky to be here at all.

Further reading

C V Anderson 2016 Scientific Reports 6 18625 and video at news.brown.edu/articles/2016/01/chameleon.

Bell loophole closed

Tests of local realism based on Bell’s inequality have, up to now, always had a small loophole, but that has now been closed. Lynden K Shalm of NIST in Boulder, Colorado, US, and colleagues looked at entangled photon pairs, ensuring that the events used were space-like separated and using fast random-number generators and high-speed polarisation measurements. The result: local realism is rejected with a p value of 5.9 x 10⁻¹⁰. Bell’s inequality is dead.

Further reading

Is there a ‘ninth planet’ after all?

Pluto was considered to be the ninth planet of the solar system, until it was relegated to a “dwarf planet” by the International Astronomical Union (IAU) in 2006. It was judged to be too small among many other trans-Neptunian objects to be considered a real planet. Almost 10 years later, two astronomers have now found indications of the presence of a very distant heavy planet orbiting the Sun. While it is still to be detected, it is already causing a great deal of excitement in the scientific community and beyond.

Pluto was discovered in 1930 by a young American astronomer, Clyde Tombaugh, who tediously looked at innumerable photographic plates to detect an elusive planet moving relative to background stars. With the progressive discovery – since the 1990s – of hundreds of objects orbiting beyond Neptune, Pluto is no longer alone in the outer solar system. It even lost its status of the heaviest trans-Neptunian object with the discovery of Eris in 2003. This forced the IAU to rethink the definition of a planet and led to the exclusion of Pluto from the strict circle of eight planets.

Eris is not the only massive trans-Neptunian object found by Mike Brown, an astronomer of the California Institute of Technology (Caltech), US, and colleagues. There are also Quaoar (2002), Sedna (2003), Haumea (2004) and Makemake (2005), all only slightly smaller than Pluto and Eris. Despite these discoveries, almost nobody during recent years would have thought that there could still be a much bigger real planet in the outskirts of our solar system. But this is what happened in 2015 by a young American astronomer, Clyde Tombaugh, who tediously looked at innumerable photographic plates to detect an elusive planet moving relative to background stars. With the progressive discovery – since the 1990s – of hundreds of objects orbiting beyond Neptune, Pluto is no longer alone in the outer solar system. It even lost its status of the heaviest trans-Neptunian object with the discovery of Eris in 2003. This forced the IAU to rethink the definition of a planet and led to the exclusion of Pluto from the strict circle of eight planets.

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Mike Brown and one of his colleagues, the theorist Konstantin Batygin, now propose. The two astronomers deduced the existence of a ninth planet through mathematical modeling and computer simulations, but have not yet observed the object directly. The evidence comes from an unexpected clustering of perihelion positions and orbital planes of a group of objects just outside of the orbit of Neptune, in the so-called Kuiper belt. All six objects with the most elongated orbits – with semi-major axes greater than 250 AU – share similar perihelion positions and pole orientations.

The combined statistical significance of this clustering is 3.8, assuming that Sedna and the five other peculiar planetoids have the same observational bias as other known Kuiper-belt objects.

Batygin and Brown then show that a planet with more than about 10 times the mass of the Earth in a distant eccentric orbit anti-aligned with the six objects would maintain the peculiar configuration of their orbits. This possible ninth planet would rotate around the Sun about 20 times further out than Neptune, therefore completing one full orbit only approximately once every 10,000 years. Batygin’s simulations of the effect of this new planet further predict the existence of a population of small planetoids in orbits perpendicular to the plane of the main planets. When Brown realised that such peculiar objects exist and have indeed already been identified, he became convinced about the existence of Planet Nine.

Observers now know along which orbit they should look for Planet Nine. If it happens to be found, this would be a major discovery: the third planet to be discovered since ancient times after Uranus and Neptune and, as with the latter, it would have been first predicted to exist via calculations.

Further reading


Diagram of the orbit around the Sun of the predicted ninth planet (orange), maintaining the orbits of the six most distant Kuiper-belt objects on the opposite side (pink), and also forcing five known objects into elongated perpendicular orbits (blue). The diagram was created using WorldWide Telescope.
Several challenges lie ahead for CERN during the years 2016–2020. With the winter technical stop of the accelerators coming to an end in March, the voyage of true post-Higgs physics exploration can start at the LHC. In the meantime, all of the other accelerators and experiments will continue to ensure that the scientific programme of the laboratory remains as diverse and compelling as it has always been.

For CERN, this means ensuring that the High-Luminosity LHC project and injector upgrades remain technically on track and financially secure, for both the accelerators and the experiments. The rich programme of collaboration with the worldwide scientific community will be enhanced through studies and projects like the FCC study, CLIC and AWAKE. Beyond the lab, CERN will contribute to neutrino research outside of Europe through the CERN neutrino platform.

In the words of the Director-General, these years will be crucial “to start building the long-term future of particle physics”.

Fabiola Gianotti took the reins on 1 January, alongside several incoming directors who complete the new structure of the laboratory.

Fabiola Gianotti – Director-General

A member of the CERN community since 1994, Fabiola Gianotti is the first female Director-General of CERN. Gianotti has been a research physicist in the Physics Department of CERN since 1994 – when she joined as a fellow – and since then has been involved in several CERN experiments, detector R&D and construction, as well as software development and data analysis. From 2009 to 2013, she held the elected position of spokesperson for the ATLAS experiment, and was honoured to announce the discovery of the Higgs boson in a seminar at CERN on 4 July 2012.

During her career she has also been a member of several international committees, such as the Scientific Council of the CNRS (France), the Physics Advisory Committee of the Fermilab Laboratory (USA), the Council of the European Physical Society, the Scientific Council of the DESY Laboratory (Germany), and the Scientific Advisory Committee of NIKHEF (Netherlands). She is also a member of the Scientific Advisory Board of the UN secretary-general, Mr Ban Ki-Moon, and of both the US National and the Italian Academy of Sciences (Accademia Nazionale dei Lincei).
Martin Steinacher – Director for Finance and Human Resources

Martin Steinacher has held high-level roles in the ESO and ESRF Councils and in the CERN Finance Committee.

Then he continued as a civil servant at the Foreign Ministry, where he acted as a delegate for Switzerland and was responsible for planning the Swiss financial contribution to the European Space Agency (ESA), European Southern Observatory (ESO) and other international organisations.

These skills led to Steinacher being appointed the scientific adviser for the Federal Office for Education and Science, before being appointed the deputy head of international co-operation at the State Secretariat for Education and Research.

In his role as chairman of the CERN Finance Committee, Steinacher worked closely with CERN member states, which led to the unanimous approval of a new method to calculate the annual scale of contribution.

In 2013, Steinacher was promoted to head of the International Research Organisations Unit, giving him high-level roles as senior scientific administrator in the ESO and ESRF Councils. His achievements while in this position include helping to negotiate Poland’s accession to ESO and also securing a funding agreement for the Swiss participation in the European Spallation Source project, until 2026.

Charlotte Lindberg Warakaule – Director for International Relations

Charlotte Warakaule has held a variety of posts at the United Nations, and was a key focal point for relations between CERN and the UN Office at Geneva.

She was also a linchpin in the preparations for CERN obtaining observer status with the General Assembly at the United Nations in 2012.

Most recently, she took on the position of chief of the United Nations Library in Geneva, where she was responsible for library services, knowledge management, cultural diplomacy and intellectual outreach.

Prior to her work with the United Nations, Warakaule held a Cambridge visiting research fellowship at Lucy Cavendish College at the University of Cambridge from 1998 to 2001. During her time at the University of Cambridge, she also served as editor-in-chief of the Cambridge Review of International Affairs, a peer-reviewed international affairs journal published by the Centre of International Studies at the University of Cambridge.

She gained her MPhil in international relations at the University of Cambridge (Pembroke College), and also holds an MA in history (cand.mag.) from the University of Copenhagen, as well as an MA in history (coursework) from the University of Sydney and a BA in History from the University of Copenhagen.

Since 2001, Charlotte Warakaule has held a variety of posts at the United Nations, from associate speechwriter to chief of the Political Affairs and Partnerships Section of the United Nations Office at Geneva. During her time in this post, she was a key focal point for relations between CERN and the United Nations Office at Geneva, and was closely involved in the first-ever UN-UNOD CERN Co-operation Agreement, signed in 2011.

Frédérick Bordry – Director for Accelerators and Technology

In 1979, Frédérick Bordry graduated with a PhD in electrical engineering from the Institut National Polytechnique in Toulouse, and went on to gain his higher doctorate in science from the same institute in 1985.

Bordry’s early career was spent teaching and conducting energy conversion research. Then he moved to Brazil, where he spent two years as a professor at the Federal University of Santa Catarina (Florianópolis). In 1981, he was appointed senior lecturer at the Institut National Polytechnique in Toulouse.

Since 2009, Bordry was promoted to head of the CERN Technology Department – responsible for technologies specific to existing particle accelerators, facilities and future projects – where he has remained until 2013.

From 2014, he acted as the director for accelerators and technology, where he is responsible for the operation and exploitation of the whole CERN accelerator complex, with particular emphasis on the LHC and for the development of new projects and technologies. He was re-appointed CERN’s Director for Accelerators and Technology.

Eckhard Elsen – Director for Research and Computing

Particle physicist Eckhard Elsen has held many committee positions, including chairing the LHC experiments committee from 2011 to 2014.

made contact with CERN as a member of the OPAL collaboration.

In 1990, Elsen was promoted to senior scientist for the Deutsches Elektronen-Synchrotron (DESY), in Germany. During this time, he became the spokesperson for the H1 experiment (an international collaboration that developed and built the H1 detector at the ep-collider HERA at DESY), and later – after a sabbatical at the Ballarat experiment at Stanford – project manager for the International Linear Collider (ILC) project team at DESY, when Elsen continued his relationship with CERN.

In 2006, Elsen was made a professor at Hamburg University, where he taught both general physics courses and accelerator physics, and supervised students.

Elsen has co-authored two books (the most recent on the physics harvest of the LHC Run 1), worked on more than 450 publications in various fields of particle physics, and participated in many scientific committees – including chairing the LHC experiments committee from 2011 to 2014.

Eckhard Elsen obtained his PhD in particle physics from Hamburg University in 1981.

Elsen’s research focused initially on e+ e- collider particle physics and led to prominent postdoctoral positions at Hamburg University, SLAC National Accelerator Laboratory, and Heidelberg University, where he first

Since 2012, Gianotti has been bestowed with several awards, including the Special Fundamental Physics Prize of the Milner Foundation (2012), the Enrico Fermi Prize of the Italian Physical Society (2013) and the Medal of Honour of the Niels Bohr Institute of Copenhagen (2013). She was also awarded the honour of “Cavaliere di Gran Croce dell’ordine al merito della Repubblica” by the Italian President.

Gianotti’s influence and success have also led to her being ranked 5th in Time magazine’s “Personality of the Year 2012”, included in the Guardian’s 2011 “Top 100 most inspirational women” and Forbes magazine’s 2013 “Top 100 most inspirational women” lists, and is considered one of the “Leading Global Thinkers of 2013” by Foreign Policy magazine (USA, 2013).

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SHiP sets a new course in intensity-frontier exploration

SHiP (Search for Hidden Particles) is a newly proposed experiment for CERN’s Super Proton Synchrotron accelerator. Its challenging goals include the direct search for hidden non-Standard Model particles.

A Golutvin, Imperial College London/CERN, and R Jacobsson, CERN, on behalf of SHiP.

SHiP is an experiment aimed at exploring the domain of very weakly interacting particles and studying the properties of tau neutrinos. It is designed to be installed downstream of a new beam-dump facility at the Super Proton Synchrotron (SPS). The CERN SPS and PS experiments Committee (SPSC) has recently completed a review of the SHiP Technical and Physics Proposal, and it recommended that the SHiP collaboration proceed towards preparing a Comprehensive Design Report, which will provide input into the next update of the European Strategy for Particle Physics, in 2018/2019.

We have now observed all the particles of the Standard Model, however it is clear that it is not the ultimate theory. Some yet unknown particles or interactions are required to explain a number of observed phenomena in particle physics, astrophysics and cosmology, the so-called beyond-the-Standard Model (BSM) problems, such as dark matter, neutrino masses and oscillations, baryon asymmetry, and the expansion of the universe.

While these phenomena are well-established observationally, they give no indication about the energy scale of the new physics. The analysis of new LHC data collected at \( \sqrt{s} = 13 \) TeV will soon have directly probed the TeV scale for new particles with couplings at O(%) level. The experimental effort in flavour physics, and searches for charged lepton flavour violation and electric dipole moments, will continue the quest for specific flavour symmetries to complement direct exploration of the TeV scale.

However, it is possible that we have not observed some of the particles responsible for the BSM problems due to their extremely feeble interactions, rather than due to their heavy masses. Even in the scenarios in which BSM physics is related to high-mass scales, many models contain degrees of freedom with suppressed couplings that stay relevant at much lower energies.

Given the small couplings and mixings, and hence typically long lifetimes, these hidden particles have not been significantly

\[ \text{Periodic Table of the Elements} \]

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Neutral lepton decaying to a muon and a pion. The SHiP Collaboration is a new type of intensity-frontier experiment motivated by the possibility to search for any type of neutral hidden particle with the unique potential to test lepton flavour universality by comparing interactions of muon and tau neutrinos. SHiP is designed to give access to a large class of interesting models. It has discovery potential for the major observational puzzles of modern particle physics and cosmology, and can explore some of the models down to their natural “bottom line”. SHiP also has the unique potential to test lepton flavour universality by comparing interactions of muon and tau neutrinos.

Global milestones and next steps

The SHiP experiment aims to start data-taking in 2026, as soon as the SPS resumes operation after Long Shutdown 3 (LS3). The 10 years consist, globally, of three years for the comprehensive design phase and then, following approval, a bit less than five years of civil engineering, starting in 2021, in parallel with four years for detector production and staged installation of the experimental facility, and two years to finish the detector installation and commissioning.

The key milestones during the upcoming comprehensive design phase are aimed at further optimising the layout of the experimental facility and the geometry of the detectors. This involves a detailed study of the muon-shield magnets and the geometry of the decay volume. It also comprises revisiting the neutrino background in the fiducial volume, together with the background detectors, to decide on the required type of technology for evacuating the decay volume. Many of the milestones related to the experimental facility are of general interest beyond SHiP, such as possible improvements to the SPS extraction, and the design of the target and the target complex. SHiP has already benefitted from seven weeks of beam time in test beams at the PS and SPS in 2015, for studies related to the Technical Proposal (TP). A similar amount of beam time has been requested for 2016, to complement the comprehensive design studies.

The SHiP collaboration currently consists of almost 250 members from 47 institutes in 15 countries. In only two years, the collaboration has formed and taken the experiment from a rough idea in the Expression of Interest to an already mature design in the TP. The CERN task force, consisting of key experts from CERN’s different departments, which was launched by the CERN management in 2014 to investigate the implementation of the experimental facility, brought a fundamental contribution to the TP. The SHiP physics case was demonstrated to be very strong by a collaboration of more than 80 theorists in the SHiP Physics Proposal.

The SHiP collaboration has just received the green light to prepare a Comprehensive Design Report for the proposed experiment and facility.

The intensity frontier greatly complements the search for new physics at the LHC. In accordance with the recommendations of the last update of the European Strategy for Particle Physics, a multi-range experimental programme is being actively developed all over the world. Major improvements and new results are expected during the next decade in neutrino and flavour physics, proton-decay experiments and measurements of the electric dipole moments. CERN will be well-positioned to make a unique contribution to exploration of the hidden-particle sector with the SHiP experiment at the SPS.

For further reading, see cds.cern.ch/record/2007512.

Résumé

SHiP ouvre une nouvelle voie pour explorer les frontières de l’intensité.

Conçu pour être installé en aval d’un nouveau dispositif d’arrêt de faisceau auprès du Supersynchrotron à protons (SPS), l’expérience SHiP (Search for Hidden Particles), récemment proposée, vise à explorer le territoire des particules interagissant très faiblement, ainsi qu’à étudier les propriétés des neutrinos tau.

Le Comité SPSC du CERN a recommandé à la collaboration SHiP de préparer un rapport de conception complet, lequel fournira des éléments d’informations pour la prochaine mise à jour de la stratégie européenne pour la physique des particules en 2018–2019.
The eye that looks at galaxies far, far away

The Very Large Telescope, ESO’s breathtaking installation, is the world’s largest optical instrument, and among the most productive in terms of scientific papers generated.

Paola Catapano, with photos and video by Mike Struik, CERN.

Night is falling over Cerro Paranal, a 2600 m peak within the mountain range running along Chile’s Pacific coastline. As our eyes gradually become accustomed to total obscurity and we start to catch a glimpse of the profile of the domes on top of the Cerro, we are overwhelmed by the breathtaking view of the starry sky we have ever seen. The centre of the Milky Way is hanging over our heads, together with the two Magellanic Clouds and the four stars of the Southern Cross. The galactic centre is so star-dense that it looks rather like a 3D object suspended in the sky.

As we enter the control room, I immediately feel a sense of déjà vu: a dozen busy and mostly young astronomers are drinking coffee, eating crisps and talking in at least three different languages, grouped around five islands of computer terminals. Welcome to the nerve centre of the most complex and advanced optical telescope in the world. From here, all of the instrumentation is remotely controlled through some 100 computers connected to the telescopes by bunches of optical fibres. Four islands are devoted to the operation of all of the components of the VLT telescopes, from their domes to the mirrors and the imaging detectors, and the fifth is entirely devoted to the controls of interferometry.

Highly specialised ESO astronomers take their night shifts in this room 300 nights per year, on average. Most observations are done in service mode (60–70% of the total time), with ESO staff doing observations for other astronomers within international projects that have gone through an evaluation process and have been approved. The service mode guarantees full flexibility to reschedule observations and match them with the most suitable atmospheric conditions. The rest of the time is “visitor mode”, with the astronomer in charge of the project leading the observations, which is particularly useful whenever any real-time decision is needed.

The shift leader tonight is an Italian from Padova. He swaps from one screen to the next, trying to ignore the television crew’s microphones and cameras, while giving verbal instructions to a young Australian student. He is activating one of the VLT’s adaptive-optics systems, hundreds of small pistons positioned under the mirrors to change their curvature up to thousands of times per second, to counteract any distortion caused by atmospheric turbulence. “Thanks to adaptive optics, the images obtained with the VLT are as sharp as if we were in space,” he explains briefly, before leaning back on one of the terminals.

Complex machinery

Adaptive optics is not the only astronomers’ dream come true at the VLT. The VLT’s four 8.2 m-diameter mirrors are the largest single-piece light-collecting surface in the world, and the best application of active optics – the trick ESO scientists use to correct for gravitationally induced deformations as the telescope changes its orientation and so maintain the optics of the vast surface. The telescope mirrors are controlled by an active support system powered by more than 250 computers, working in parallel and positioned locally in each structure, to apply the necessary force to the mirrors to maintain their alignment with one another. The correcting forces have a precision of 5 g and keep the mirror in the ideal position, changing it every 3 minutes with 10 nm precision. The forces are applied on the basis of the analysis of the image of a real star, taken during the observations, so that the telescope is self-adjusting. The weight of the whole structure is incredibly low for its size. The 8.2 m-diameter reflecting surface is only 17 cm thick, and the whole mirror weighs 22 tonnes; its supporting cell weighs only 10 tonnes. Another technological marvel is the secondary mirror, a single-piece lightweight hyperbolic mirror that can move in all directions along five degrees of freedom. With its 1.2 m diameter, it is the second largest object entirely made in beryllium, after the Space Shuttle doors.

But the secret of the VLT’s uniqueness lies in a tunnel under the platform. Optical interferometry is the winning idea that enables
The resolution obtained by the Very Large Telescope Interferometry (VLTI) is equivalent to the resolution of a 100 m-diameter single telescope, making the VLT the latest optical instrument in the world. Another revolution introduced by the VLT is the e-science. The amount of data generated by the new high-capacity VLTI science instruments drove the development of end-to-end models in astronomy, introducing electronic proposal submission and service observing with processed and raw science and engineering data fed back to everyone involved. The expansion of the data links in Latin America enabled the use of high-speed internet connections spanning continents, and ESO has been able to link its observatories to the data grid. “ESO practises an open-access policy (with regulated, but limited property rights for science proposers) and holds public-survey data as well. Indeed, it functions as a virtual observatory on its own,” says Claus Madsen, senior counsel for international relationships at ESO. Currently, up to 15% of refereed science papers based on ESO data are authored by researchers not involved in the original data generation (e.g. as proposers), and an additional 10% of the papers are partly based on archival data. Thanks also to this open-access policy, the VLT has become the most productive ground-based facility for astronomy operating at visible wavelengths, with only the Hubble Space Telescope generating more scientific papers.

Delivering science at a high rate

The resolution obtained by the Very Large Telescope Interferometer (VLTI – the name given to the telescopes when they function in this mode) is equivalent to the resolution of a 100 m-diameter mirror. Moreover, the Auxiliary Telescopes are mounted on tracks, and can move over the entire telescope platform, enabling the VLTI to obtain an even better final resolution. The combined images of the 4+4 telescopes allow the same light collection capacity as a much larger individual mirror, therefore making the VLT the largest optical instrument in the world.

Another revolution introduced by the VLTI has to do with e-science. The amount of data generated by the new high-capacity VLTI science instruments drove the development of end-to-end models in astronomy, introducing electronic proposal submission and service observing with processed and raw science and engineering data fed back to everyone involved. The expansion of the data links in Latin America enabled the use of high-speed internet connections spanning continents, and ESO has been able to link its observatories to the data grid. “ESO practises an open-access policy (with regulated, but limited property rights for science proposers) and holds public-survey data as well. Indeed, it functions as a virtual observatory on its own,” says Claus Madsen, senior counsel for international relationships at ESO. Currently, up to 15% of refereed science papers based on ESO data are authored by researchers not involved in the original data generation (e.g. as proposers), and an additional 10% of the papers are partly based on archival data. Thanks also to this open-access policy, the VLT has become the most productive ground-based facility for astronomy operating at visible wavelengths, with only the Hubble Space Telescope generating more scientific papers.

Le Très Grand Télescope (VLT, Very Large Telescope) est le plus grand instrument optique du monde. Ce qui le rend unique se cache dans le tunnel situé sous la plate-forme. Le recours à l’interférométrie optique est en effet l’idée lumineuse qui permet au VLT d’atteindre une résolution d’image inégalée ; cette technique combine en effet la lumière recueillie par les télescopes de l’unité principale et celle reçue par les télescopes auxiliaires. Le VLT est aujourd’hui l’un des centres d’astronomie les plus productifs en termes d’articles scientifiques publiés. Lance-vous dans une visite virtuelle pour découvrir tous les secrets de cette installation extraordinaire.

Watch the video at https://cds.cern.ch/record/2128425.

Résumé

En all ouvrant sur des galaxies très, très lointaines

Le Très Grand Télescope (VLT, Very Large Telescope) est le plus grand instrument optique du monde. Ce qui le rend unique se cache dans le tunnel situé sous la plate-forme. Le recours à l’interférométrie optique est en effet l’idée lumineuse qui permet au VLT d’atteindre une résolution d’image inégalée ; cette technique combine en effet la lumière recueillie par les télescopes de l’unité principale et celle reçue par les télescopes auxiliaires. Le VLT est aujourd’hui l’un des centres d’astronomie les plus productifs en termes d’articles scientifiques publiés. Lance-vous dans une visite virtuelle pour découvrir tous les secrets de cette installation extraordinaire.

Striking night skies are not unusual at the VLT’s experimental site.
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Data sonification enters the biomedical field

Music and life sciences share an incredibly strong link: both are dependent on the idea of cycles, periodicity, fluctuations, transitions and, in a fascinating sense, harmony.

Resonances, periodicity, patterns and spectra are well-known notions that play crucial roles in particle physics, and that have always been at the junction between sound/music analysis and scientific exploration. Detecting the shape of a particular energy spectrum, studying the stability of a particle beam in a synchrotron, and separating signals from a noisy background are just a few examples where the connection with sound can be very strong, all sharing the same concepts of oscillations, cycles and frequency.

In 1619, Johannes Kepler published his Harmonices Mundi (the “harmonies of the world”), a monumental treatise linking music, geometry and astronomy. It was one of the first times that music, an artistic form, was presented as a global language able to describe relations between time, speed, repetitions and cycles.

The research we are conducting is based on the same ideas and principles: music is a structured language that enables us to examine and communicate periodicity, fluctuations, patterns and relations. Almost every notion in life sciences is linked with the idea of cycles, periodicity, fluctuations and transitions. These properties are naturally related to musical concepts such as pitch, timbre and modulation. In particular, vibrations and oscillations play a crucial role, both in life sciences and in music. Take, for example, the regulation of glucose in the body. Insulin is produced from the pancreas, creating a periodic oscillation in blood insulin that is thought to stop the down-regulation of insulin receptors in target cells. Indeed, these oscillations in the metabolic process are so key that constant inputs of insulin can jeopardise the system.

Oscillations are also the most crucial concept in music. What we call “sound” is the perceived result of regular mechanical vibrations happening at characteristic frequencies (between 20 and 20,000 times per second). Our ears are naturally trained to recognise the shape of these oscillations, their stability or variability, the way they combine and their interactions. Concepts such as pitch, timbre, harmony, consonance and dissonance, so familiar to musicians, all have a formal description and characterisation that can be expressed in terms of oscillations and vibrations.

Many human movements are cyclic in nature. An important example is gait – the manner of walking or running. If we track the position of any point on the body in time, for example the shoulder or the knee, we would see it describing a regular, cyclic movement. If the gait is stable, as in walking at a constant speed, the frequency associated would be regular, with small variations due to the inherent variability of the system. By measuring, for example, the vertical displacement of the centre of each joint while walking or running, we would have a series of one-dimensional oscillating waveforms. The collection of these waveforms provides a representation of co-ordinated movement of the body. Studying their properties, such as phase relations, frequencies and amplitudes, then provides a way to investigate the order parameters that define modes of co-ordination.

Previous methods of examining the relation between components of the body have included statistical techniques such as statistics. These have been limited in their ability to capture the full complexity of the system. In contrast, data sonification allows us to express these oscillations as sound, enabling a new level of understanding and insight.

The research we are conducting is focused on developing new methods for sonifying biological data. By translating complex datasets into musical compositions, we can identify patterns, trends and anomalies that might not be apparent from traditional analysis methods. This approach is known as data sonification.

Examples of applications include:

- **Physiological signals:** Monitoring heart rate, blood pressure, and other physiological parameters can be translated into musical notes, providing an auditory representation of the data.
- **Neurological recordings:** EEG and fMRI data can be transformed into sound, allowing researchers to gain new insights into brain activity.
- **Musculoskeletal systems:** Joint movements and muscle activity can be sonified, revealing the dynamic interactions between different body parts.
- **Environmental monitoring:** Data from sensors measuring environmental conditions can be translated into sound, creating auditory representations of pollution levels or temperature changes.

By using data sonification, we can make complex biological information more accessible and understandable, facilitating new avenues for research and discovery.
The final result of this cancellation is a globally simpler dynamical system.

Sonograms to study body movements

Our approach is based on the idea of analysing the waveforms and their relations by translating them into audible signals and using the natural capability of the ear to distinguish, characterise and analyse waveform shapes, amplitudes and relations. This process is called data sonification, and one of the main tools to investigate the structure of the sound is the sonogram (sometimes also called a spectrogram). A sonogram is a visual representation of how the spectrum of a certain sound signal changes with time, and we can use sonograms to examine the phase relations between a large collection of variables without having to reduce the data. Spectral analysis is a particularly relevant tool in many scientific disciplines, for example in high-energy physics, where the interest lies in energy spectra, pattern and anomaly detections, and phase transitions.

Using a sonogram to examine the movement of multiple markers on the body in the frequency domain, we can obtain an individual and situation-specific representation of co-ordination between the major limbs. Because anti-phase frequencies cancel, in-phase frequencies enhance each other, and a certain degree of variability in the phase of the oscillation results in a band of frequencies, we are able to represent the co-ordination within the system through the resulting spectrogram.

In our study, we can see exactly this. A participant ran on a treadmill that was accelerating between speeds of 0 and 18 km/h for two minutes. A motion-analysis system was used to collect 3D kinematic data from 24 markers placed bilaterally on the head, neck, shoulders, elbows, wrists, hand, pelvis, knees, heels, ankles and toes of the participant (sampling frequency 100 Hz, trial length 120 s). Individual and combined sensor measurements were resampled to generate audible waveforms. Sonograms were then computed using moving-frequency Hanning analysis windows for each sensor (length 120 s). Individual and combined sensor measurements were resampled to generate audible waveforms. Sonograms were then computed using moving-frequency Hanning analysis windows for all of the sound signals computed for each marker and combination of markers.

Sonification of individual and combined markers is shown above right. Sonification of an individual marker placed on the left knee (top left in the figure) shows the frequencies underlying the marker movement on that particular joint-centre. By combining the markers, say of a whole limb such as the leg, we can examine the relations of single markers, through the cancellation and enhancement of frequencies involved. The result will show some spectral lines strengthening, others disappearing and others stretching to become bands (top right). The nature of the collective movements and associated oscillations that underpin the mechanics of an arm or a leg moving regularly during the gait can then be analysed through the sound generated by the superposition of the relative waveforms.

A particularly interesting case appears when we combine audifications of marker signals coming from opposing limbs, for example left leg/right arm or right leg/left arm. The sonogram bottom left in the figure is the representation of the frequency content of the oscillations related to the combined sensors on the left leg and the right arm (called additive synthesis, in audio engineering). If we compare the sonogram of the left leg alone (top right) and the combination with the opposing arm, we can see that some spectral lines disappear from the spectrum, because of the phase opposition between some of the markers, for example the left knee and the right elbow, the left ankle and the right hand.

The final result of this cancellation is a globally simpler dynamical system, described by a smaller number of frequencies. The frequencies themselves, their sharpness (variability) and the point of transition provide key information about the system. In addition, we are able to observe and hear the phase transition between the walking and running state, indicating that our technique is suitable for examining these order-parameter states. By examining movement in the frequency domain, we obtain an individual and situation-specific representation of co-ordination between the major limbs.

Sonification of movement as audio feedback

Sonification, as in the above example, does not require data reduction. It can provide us with unique ways of quantifying and perceiving co-ordination in human movement, contributing to our knowledge and understanding of motor control as a self-organised dynamical system that moves through stable and unstable states in response to changes in organismic, task and environmental constraints. For example, the specific measurement described above can increase our understanding of the adaptability of human motor control to something like a prosthetic limb. The application of this technique will aid diagnosis and tracking of pathological and perturbed gait, for example highlighting key changes in gait with ageing or leg surgeries.

In addition, we can also use sonification of movements as a novel form of audio feedback. Movement is key to healthy ageing and recovery from injuries or even pathologies. Physiotherapists and practitioners prescribe exercises that take the human body through certain movements, creating certain forces. The precise execution of these exercises is fundamental to the expected benefits, and while this is possible under the watchful eye of the physiotherapist, it can be difficult to achieve when alone at home.

In precisely executing exercises, there are three main challenges. First, there is the patient’s memory of what the correct movement of exercise should look like. Second, there is the ability of the patient to execute correctly the movement that they are required to do, working the right muscles to move the joints and limbs through the correct space, over the right amount of time or through an appropriate amount of force. Last, finding the motivation to perform sometimes painful, strenuous or boring exercises, sometimes many times a day, is a challenge.

Sonification can provide not only real-time audio feedback but also elements of feed-forward, which provides a quantitative reference for the correct execution of movements. This means that the patient has access to a map of the correct movements through real-time feedback, enabling them to perform correctly. And let’s not forget about motivation. Through sonification, in response to the movements, the patient can generate not only waveforms but also melodies and sounds that are pleasing.

Another possible application of generating melodies associated with movement is in the artistic domain. Accelerometers, vibration sensors and gyroscopes can turn gestures into melodics lines and harmonies. The demo organised during the public talk of the International Conference on Translational Research in Radio-Oncology – Physics (ICTR-PHE), on 16 February in Geneva, was based on that principle. Using accelerometers connected to the arm of a flute player, we could generate melodies related to the movements naturally occurring when playing, in a sort of duel between the flute and the flutist. Art and science and music and movement seem to be linked in a natural but profound way by a multitude of different threads, and technology keeps providing the right tools to continue the investigation just as Kepler did four centuries ago.

Résumé
La sonification des données fait son entrée dans le domaine biomédical.

La musique et les sciences de la vie ont beaucoup d’affinités : les deux disciplines font intervenir les concepts de cycles, de périodicité, de fluctuations, de transition et même, curieusement, d’harmonie. En utilisant la technique de la sonification, les scientifiques sont capables de percevoir et de quantifier la coordination des mouvements du corps humain, ce qui permet d’améliorer notre connaissance et notre compréhension du contrôle moteur en tant que système dynamique. De plus, l’application de cette méthode est un outil à la fois intuitif et révolutionnaire, instable en fonction de changements dans les contraintes s’exerçant au niveau de l’organisme, des tâches et de l’environnement.
FLIR A8300SC
THE FIRST “LOW COST” HD MWIR THERMAL CAMERA

The FLIR A8300sc is the first “Low Cost” HD thermal camera available for a budget below 100K€. This model incorporates a cooled FLIR Indium Antimonide InSb detector that operates in the 3.5 to 5 microns wavelength. It produces crisp 1,024 × 768 thermal images of 1280 x 736. Achieving a high thermal sensitivity with very low noise (typically 100 µK), the FLIR A8300sc can capture the finest image detail and is GigilVision-gen compliant.

The FLIR A8300sc camera works seamlessly with FLIR Reasearcher Max Software and is compatible with 3rd party software including MathWorks MATLAB Software.

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Interactions & Crossroads

FUTURE FACILITIES

Any hints for new physics?

The International Workshop on Future Potential of High Intensity Proton Accelerator for Particle and Nuclear Physics, HINT2015, was held from 13 to 15 October at the Japan Proton Accelerator Research Complex (J-PARC). The purpose of the workshop was to discuss future prospects for high-intensity proton accelerators and beams with megawatt (MW) beam power, and new frontiers in particle and nuclear physics enabled by the high-intensity beams. 129 scientists from 12 countries participated in the workshop. The workshop covered a broad range of topics, from technical challenges to the science potential of MW high-intensity proton accelerators to be used for neutrino, kaon, muon, hypernuclei, hadron and neutron physics.

In his welcome address, Naohito Saito, director of J-PARC since April, emphasised the importance of flavor physics as a guiding light in particle and nuclear physics. Following that, Ryusichi Kitano, a theorist from KIT, presented a grand picture of the precision/intensity frontier in particle physics, and Taku Yamanaka, an experimentalist from Osaka University, addressed the issues in designing new facilities for the intensity frontier.

In addition, the status and future of the Hadron Experimental Facility (HEF), the Hadron Experimental Facility 2 (HEF2), the Hadron Experimental Facility 3 (HEF3), the Main Ring (MR) and the Main Ring (MR) for neutrino experiments is 1.3 MW. The technical issues on ion sources, RF cavities, beam instrumentation, beamlines, beam windows, production targets, focusing devices and remote maintenance were overviewed and discussed by the experts. A variety of physics research topics were covered by theorists and experimentalists.

The T2K experiment presented the possibility to extend the measurement to accumulate up to 2 × 10²⁰ protons on target to find evidence of CP violation at > 3σ. The KOTO experiment for K⁻→π⁺νν decay will soon reach the sensitivity of the so-called Grossman-Nir bound, and start the search for new physics. The COMET experiment for μ→e conversion completed construction of the experimental hall and will continue the construction of the beamline and detector. The muon g-2 EDM experiment has completed the technical design report. Results from the hadron–nuclear experiments with high-intensity kaon beams are superseding the achievements at BNL-AGS and INFIN-DAΦNE in the past, and new experiments with the beams of primary protons and high-energy mesons will open up a new era of hadron physics.

The concluding remark were provided by Tsuyoshi Nakaya, an experimentalist from Kyoto University, who shared his memory with the late Yoji Totsuka, who contributed significantly on the construction of Super-Kamiokande and J-PARC. A poster session was held in the afternoon of the first day, and young scientists enjoyed discussions.

More details are available at j-parc.jp/pn/HINT2015.

Annual meeting takes the pulse of EuroCirCol

June 2015 saw the start of the EU-funded EuroCirCol project, a design study for a post-LHC hadron collider that is part of the wider Future Circular Collider (FCC) study. The study has received €3 million within the Horizon 2020 Research and Innovation Framework programme to produce a conceptual design of a 100 TeV hadron collider by 2019, in time for the next update of the European Strategy for Particle Physics.

The project is co-ordinated by CERN and brings together an international consortium of 36 beneficiary organisations. Five work packages have been established within EuroCirCol to deal with the huge challenge of designing a cost-effective 100 km-long energy frontier accelerator with high-luminosity experimental insertion regions. Moreover, EuroCirCol will study the development of a cryogenic beam vacuum system to cope with unprecedented synchrotron light power, and an innovative design for superconducting accelerator magnets, to achieve high-quality dipole fields up to 16 T.

On 19–20 November, a meeting was held at the Institute of Nuclear Physics in Orsay (France), gathering more than 50 EuroCirCol scientists and engineers to review the progress made in the first six months of the study in each of the work packages.

One of the priorities established in the kick-off meeting in June was to recruit the necessary highly qualified research staff. Most positions have been filled, but some are still available (https://fcc.web.cern.ch/Pages/Oportunities-For-Individuals.aspx).

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All of the work packages are advancing at a good pace. For the lattice design, many versions have been considered and tested in simulations, working in close collaboration with the team in charge of the experimental insertion-regions design.

Several options for the cryogenic beam vacuum system have also been studied, considering both 1.9 K and 4.5 K operation temperature of the magnets, and a beam-screen prototype will be tested at a later stage at the ANKA synchrotron in Karlsruhe. Regaing the 16 T superconducting magnets, design optimisation based on different coil geometries is ongoing and a review will take place in spring, to identify the preferred options. In parallel to the EuroCirCol design activity, a complementary FCC Magnets Technology programme has been set up at CERN, to launch the development of the required high-performance Nb3Sn superconducting wire with industry and to carry out magnet-prototyping work.

The discussion held during the meeting evidenced how much the EuroCirCol project is pushing the limits of technology and entering uncharted territory. They also demonstrated the strong interdependence of the characteristics of the different elements of the accelerator. Both aspects of the project define the enormous challenge that lies ahead in the FCC study.

An international FCC conference will be held in Rome from 11 to 15 April (fccw2016.web.cern.ch/fccw2016/), to follow up on the design progress and set the goals for the coming year. Dedicated technology R&D programmes will be presented, and an open poster session will provide a platform to showcase new concepts and technologies related to the FCC study.

The participation of industry and potential future partners is highly encouraged.

High-energy physicists have been doing data science without realising it. Over the last decade, the field of machine learning has developed outside of high-energy physics (HEP), thanks to key algorithmic developments and increased computing power, driven by the needs of industry. A workshop took place at CERN on 9–13 November, which brought together top data scientists and high-energy physicists to discuss possible synergies for data processing and analysis. The workshop was a great success in terms of the quality of talks, discussions and attendance (more than 200 participants), both in person and remotely. The programme was designed so that both communities could learn each other’s language.

Morning sessions were dedicated to plenary talks and were organised to introduce the fields of HEP and data science. Several optimisation methods and applications for the high-energy field were presented, including experience with the matrix element method. Renowned speakers lectured on the state-of-the-art in deep learning. Online-data processing at the LHC was presented and potential hardware solutions were discussed. Promising results from recent HEP machine learning projects were shown. Early-afternoon symposiums hosted speakers in other scientific domains that make use of promising data-science techniques. Applications in artificial intelligence (are we moving towards an artificial scientist?), urban science (what to do with a two-year-long time lapse of the New York skyline), astronomy (discovering hundreds of exoplanets) and genomics (deciphering the genome code with sparse data) were discussed. Late-afternoon tutorial sessions offered talks and hands-on session on tools and techniques from both fields. Notably, participants could gain practical experience in the latest improvements of multivariate analysis in the CERN TMVA ROOT package. A dense agenda on the matrix-element method guided the audience through the state-of-the-art of using theoretical calculations in HEP data analysis.

Three well-attended tutorials were dedicated to machine-learning analysis software: Caffe (a popular image recognition toolbox), pylearn (one of many deep-neural-network training software) and an analysis pipeline constructed in the scikit-learn python framework (widely used in the machine-learning community).

The workshop ended with a panel on open data and reproducibility. It was noted that the CERN experiments are fairly advanced on this matter compared with other domains of science. The paring vow was to hold a dedicated workshop on science reproducibility as HEP. The workshop was the first of a series of conferences that will alternate generic and topical events. The next topical event will take place in summer 2016, and then again in spring 2017.

● Talks and videos from the 2015 workshop are available at cern.ch/DataScience.HC2015.

MATERIALS SCIENCE
Magnet-technology conference features techniques for the FCC

The International Conference on Magnetic Technology took place in Seoul, Korea, from 18 to 23 October. CERN’s Amalia Ballarino gave a plenary talk on “Superconductors for future circular colliders”. After presenting the current status of the HiLumi LHC project, she explained the technical challenges generated by the Future Circular Collider (FCC) study, and the need for future R&D in superconducting materials that would allow reaching higher magnetic fields. She discussed both low-temperature superconducting (Nb-Sn) and high-temperature superconducting (HTS) materials. She outlined the ongoing studies on Nb-Sn that aim to increase the performance of the material to meet the need for 16 T fields, as well as to start production.

One of the techniques that can be used to tackle these challenges is the implementation of artificial pinning in materials, although this has today only been tried on a laboratory scale for short lengths of conductor. Ballarino explained that the HiLumi LHC exploits the performance of state-of-the-art high-field Nb-Sn, but a future FCC collider requires further improvements in the performance of the conductor and production of large quantities of affordable wire. More effort is needed from the perspective of both material science and magnet-conductor techniques, to understand how artificial pinning can be implemented to improve the in-field properties of this material.

In the framework of the FCC study, several collaborations involving industry and laboratories are being launched. The main focus is to establish a worldwide effort to develop and produce high-Nb-Sn conductors and involve industrial partners from Europe, Japan, Korea, Russia and the US. These are the countries where Nb-Sn industry exists, and large quantities of Nb-Sn were indeed produced for the ITER project. ITER today represents the first large-scale production (~500 tonnes) of Nb-Sn wire. The FCC will require thousands of tonnes, with far higher performance.

It is important to forge synergies between laboratories and industrial partners to promote collaboration and co-ordination of efforts at a global scale. Fundamental research can provide the necessary feedback to industry, which can in turn profit from industrial production of advanced materials. It is an interactive process, and the FCC study requirements extend the boundaries of our present knowledge.

● For more information, see www.mt24.org/index.php/userAgent=PC&.

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The Metrolab PT2026 sets a new standard for precision magnetometers. Leveraging 30 years of expertise building the world’s gold standard magnetometers, it takes magnetic field measurement to new heights: measuring higher fields with better resolution.

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CERN's Amalia Ballarino presented an overview of the current studies on superconducting materials for future circular colliders.
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“I want MDC to be the low cost, high quality, innovator in the vacuum business. We aim to delight our customers with technology and tools, expanding our capabilities and skill sets, and kicking off a global focus on continual innovation”.

Roger Cockroft, MDC’s CEO.

During the last 30 years, Rubbia has been devoted to promoting co-operation in science and technology between China and Europe. Particularly since 1989, when serving as Director-General of CERN, he promoted collaboration between CERN and the Institute of High Energy Physics, Chinese Academy of Sciences (IHEPCAS), helped to construct the experimental high-energy physics base in China, and supported IHEPCAS in accessing the internet.

Under his leadership, in 1993 CERN proposed free internet protocols and procedures, which had important significance for the development of the internet as well as its application in China. Moreover, he enhanced co-operation in the fields of energy and the environment between Italy and China, and supported China’s research in accelerator-driven systems, with significant achievements.

Rubbia, who was appointed a senator for life of the Italian Republic in 2013, is currently a president of the Chinese University of Mining and Technology’s Institute of Sustainable Energy. The institute’s main research focus is on zero-emission energy systems, energy-storage systems, and transmitting electric power over long distances using superconductors.

This work follows his recent research on finding solutions to the world’s energy crisis through renewable sources. As a result of this, Rubbia has held several positions on energy advisory boards, including the United Nations Economic Commission for Latin America. He is currently a professor at the Gran Sasso Science Institute (INFN) and spokesman of the ICARUS experiment (one of the three SBN experiments at Fermilab).

The prize — considered to be the top honour for foreign individuals — is awarded to several scientists each year for their contributions to China's social, technological and economic development.

CERN is extremely proud of this new recognition for Rubbia, whose contribution to the history of both particle physics and CERN itself has been critical.

Rubbia was presented with the award by president Xi Jinping and premier Li Keqiang in Beijing on 8 January.

## Awards

### Carlo Rubbia awarded China’s highest scientific prize

Carlo Rubbia, Nobel laureate for physics in 1984 and CERN’s Director-General from 1989 to 1994, has been awarded the International Scientific and Technological Co-operation Award by the People’s Republic of China.

The awards honour the significant contributions that Rubbia has made to China’s scientific development in the field of high-energy physics.

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## Appointments

### New director for Lawrence Berkeley National Laboratory

Michael Witherell, vice chancellor for research at the University of California Santa Barbara (UCSB), has been appointed the new director of the Lawrence Berkeley National Laboratory (Lawrence Berkeley National Lab), in the US.

Witherell is a leading particle physicist with a highly distinguished career in teaching, research and managing complex organisations. He has received numerous honours and recognitions for his scientific contributions and achievements.

Witherell is the former director of the Fermi National Accelerator Laboratory (Fermilab) and currently holds the presidential chair in physics at UCSB.

Michael Witherell.

2013 (p) and he was also a member of the CMS collaboration. Before that, he studied $e^+e^-$ collisions with the BaBar, CLEO and SLD detectors, and charm production in fixed-target experiments at Fermilab E-691, with a particular interest in heavy-quark physics.

Lawrence Berkeley National Lab, the internationally renowned institution whose scientific expertise has been recognised with 13 Nobel prizes, is managed by the University of California on behalf of the US Department of Energy (DOE) since it was founded in 1931.
New leadership structure accelerates TRIUMF

With a fresh leadership structure at TRIUMF, the laboratory’s new deputy director (DD), Reiner Krücken, will guide the realisation of TRIUMF’s scientific vision.

TRIUMF recently instituted changes to the laboratory’s management structure, as the organisation enters into its latest five-year plan (FYP, 2015–2020). Changes included renaming the Science Division to the Physical Sciences Division, and creating the Life Science Division, into which the current Nuclear Medicine Division will be integrated as a department. All divisions will be under the leadership of associate laboratory directors (ALDs, replacing division heads). Most significantly, a DD position was created, with Dr Reiner Krücken being appointed to the new role by director JonathanBagger. All changes were effective as of 1 October 2015.

The DD’s responsibilities include supporting the director in driving TRIUMF’s projects in the current FYP, such as the Advanced Rare Isotope Laboratory (ARIEL) and the upcoming Institute for Advanced Medical Isotopes (IAMI). The DD will work across TRIUMF’s divisions – accelerator, physical sciences, life sciences, and engineering – to realise the FYP in a safe and effective manner, as well as to develop the laboratory’s long-term science strategy.

Krücken is ready for the job. He developed a profound knowledge of TRIUMF’s research programme while leading the laboratory’s (now) Physical Sciences Division since 2011, co-editing TRIUMF’s 2010–2015 FYP, and creating the ARIEL science workshop series. Moreover, he founded the Isotopes for Science and Medicine (IsoSIM) programme, a joint venture between TRIUMF and the University of British Columbia under the Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Training Experience (CREATE) programme umbrella. IsoSIM will expose students and postdocs to the interdisciplinary nature and applications of isotope science, providing them with a unique training opportunity within UBC and TRIUMF’s diverse research programmes.

His broad scientific interests, which have evolved from experimental nuclear physics to applications of nuclear physics in medicine and other scientific fields, are particularly well suited for his role, interacting with all of the associate lab-directors.

As the new DD, Krücken declares his primary goal to be achieving TRIUMF’s FYP vision. He emphasises that ARIEL is a key priority upon which the laboratory’s future is based, because it will solidify TRIUMF’s position as a world-leading isotope-production facility for studies in particle physics, nuclear physics, materials science and nuclear medicine.

With both Bagger and Krücken at the helm, and a new management structure in place, TRIUMF is well poised to navigate the challenges facing the laboratory in the exciting times ahead.

C E L E B r a t i O n s

Aleksandr Skrinsky celebrates his 80th birthday

Aleksandr (Sasha) Skrinsky, currently the scientific leader of Budker Institute of Nuclear Physics (Russia), turned 80 on 15 January.

Skrinsky is well-known for his contribution to the development of colliding beams in storage rings. At the VEPP-1 and VEPP-2 colliders in Novosibirsk, Skrinsky and colleagues conducted a series of pioneering tests of quantum electrodynamics and studies of vector mesons. Studies on the beams in storage rings led to the discovery of the longitudinal and transverse coherent instabilities and, subsequently, to the development of methods for their suppression. Skrinsky was also the first to show the nonlinear nature of the beam–beam effects in circular accelerators. In particular, he showed the role of nonlinear resonances and stochastic instability in reducing the luminosity of colliders.

In the 1970s, Skrinsky played a leading role in the development of the theory of spin motion in circular accelerators, based on the invention of the periodic spin precession axis. Together with colleagues, he proposed a method for the precise measurement of elementary particle mass by resonant depolarisation of electron–positron beams. In 1974, Skrinsky and colleagues developed the theory of “electron cooling” (proposed by G I Budker in 1967), and confirmed it experimentally. The method has been widely used at many laboratories around the world, including CERN, GSI (Germany), and IMP (China).

During the past few years, Skrinsky has worked on the ionisation cooling of muons for muon colliders. Skrinsky is an expert on free-electron lasers (FELs), for which he proposed the optical klystron. Largely through his efforts, a number of Russian laboratories have been involved in the LHC programme.

Today, while he continues to ski and run regularly, Skrinsky participates in experiments at the VEPP-4M and VEPP-2000 colliders, and is involved in the design of the Super-tau-charm factory, one of the most ambitious scientific projects in the field of high-energy physics.
HV and RF Technology Innovations from L-3

L-3 Electron Devices is leading the technology revolution with powerful solutions like the 13 kW klystron for the 12 GeV Upgrade at the Thomas Jefferson National Accelerator Facility and the 96 kW IOT amplifier for Brookhaven National Lab’s NSLS-II Booster RF Transmitter System. For high-voltage switching or stable and reliable RF power, L-3’s thyatrons, klystrons, IOTs and TWTs are meeting the demanding requirements of many of the world’s major accelerator systems, and we are working to produce the next generation of devices for tomorrow’s new accelerators.

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What Powers your Accelerator?

JINR celebrates 90th birthday of academichian Alexander Baldin

On 26 February, the scientific community of the Joint Institute for Nuclear Research (JINR) celebrated Alexander Mikhailovich Baldin, who was born on the same day in 1926 in the Krasnaja Presnja district of Moscow.

Baldin’s youth and student years were lived during the Second World War and post-war reconstruction. In 1946, he was invited to continue his studies at the newly established Moscow Mechanics Institute of Ammunition – later named the Moscow Engineering Physics Institute (MEPhI) – from which he graduated in 1949.

Baldin’s first research work was on the theory of particle motion in a cyclic accelerator. These investigations allowed him to develop a method that was used to improve the performance of JINR’s Synchrophasotron, and it is still being widely used in calculations for the design of new accelerators. In the early 1950s, Baldin developed the theory of meson photoproduction off nucleons and nuclei, and in 1973 he was awarded the USSR State Prize for pioneering research in p–meson photoproduction.

In 1988, in his capacity as a scientific leader of JINR, Baldin set nuclear interactions at relativistic energies as a major research activity. Under his guidance, the Synchrophasotron was modified to become a specialised accelerator of relativistic and polarised nuclei, which led to the discovery of the nuclear cumulative effect predicted by Baldin. The results of the first period of studies with relativistic nuclei enabled Baldin to suggest the idea of a new, superconducting accelerator – the Nuclotron.

Baldin’s scientific and organisational activities were extremely versatile. He was president of the Council on Electromagnetic Interactions and a member of the Bureau of the Nuclear Physics Department of the Russian Academy of Sciences, editor-in-chief of the journals Physics of Elementary Particles and Atomic Nuclei and Physics of Particles and Nuclei Letters, as well as a member of the editorial boards of many scientific publications. Baldin was also very much appreciated for the effort he put into training younger scientists.

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ET Enterprises Ltd have introduced a compact 78mm active diameter curved window photomultiplier for use in multi-pmt optical modules for underwater and similar neutrino telescopes. The length of less than 100mm enables up to 31 pmts to be fitted into a standard 17 inch glass pressure sphere resulting in a significantly increased light collection area and directional sensitivity compared to single larger diameter pmts.

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**NETWORKING**

**CERN signs agreements with Lebanon, Palestine, the US, ESO and IRENA**

December was a good month for global collaboration in particle physics because it saw the signature of several agreements that will contribute to cementing CERN’s partnerships and create frameworks for fruitful co-operation.

On 3 December last year, CERN signed an International Co-operation Agreement (ICA) with the Lebanese National Council for Scientific Research, CNRNL, paving the way for future collaboration with Lebanese academia. Soon after, on 18 December, a second ICA was signed with Palestine, allowing CERN to forge stronger links with Palestinian universities.

Lebanese researchers have long had links with CERN’s theory group, and have recently expressed an interest in joining the LHC experiments. Three Lebanese doctoral students active on LHC experiments gave talks at the signing ceremony, held at the Lebanese University in Beirut, where Lebanon also expressed immediate interest in the heavy-ion programme at the LHC and in hardware upgrades on CMS. Links between CERN and Palestine have so far been more limited, with a number of individuals working on CERN programmes and Palestinian participation in CERN summer student programmes. However, this new agreement confirms the increasing interest in the LHC and opens the way for Palestinian researchers to join the ATLAS collaboration.

CERN has a high level of engagement in the Middle East and North Africa region, with ICAs already signed with Iran, Jordan, Saudi Arabia and the United Arab Emirates, and well-established contacts with Oman and Qatar. Moreover, CERN plays an important role in SESAME, the region’s first intergovernmental research organisation (CERN Courier July/August 2015 p19).

Also in December, CERN signed ICAs with the European Southern Observatory (ESO) and with the International Renewable Energy Agency (IRENA). The agreements address many areas, including scientific research, technology development and sharing, and big-data solutions, as well as education and public-outreach activities.

Collaboration between CERN and the US is nothing new: the US is a valued partner in the LHC, contributing to investment in the facility, to the running of LHC experiments and to the globally distributed computing infrastructure necessary to process the vast data volumes produced by the experiments. The most recent co-operation agreement was signed between CERN, the US Department of Energy and the US National Science Foundation at the White House on 7 May last year, marking both a renewal of a long-standing friendship and a commitment to take the partnership further.

The new protocols signed in December confirm the US’s commitment to the LHC project and its upgrade programme, the High-Luminosity LHC. For the first time, they set down in black and white European participation through CERN in pioneering neutrino research in the US. They are a significant step towards a fully connected trans-Atlantic research programme.

In this framework, CERN, which is no longer running its own neutrino beamlines, will serve as a platform for worldwide scientists engaged in neutrino-detector R&D, who will go on to work at neutrino experiments in the US and elsewhere.

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On 20 January, Her Excellency Dr Dalia Grybauskaitė, President of the Republic of Lithuania, visited CERN. Three days later, on 23 January, CMS welcomed Her Excellency Mr Muhammad Nawaz Sharif, Prime Minister of the Islamic Republic of Pakistan. The Lithuanian delegation had a busy morning, visiting several CERN facilities. The tour of the laboratory started at Point S (the CMS experiment), where the President and her delegation were welcomed by Director-General Fabiola Gianotti. In the afternoon, the delegation stopped off at the Computing Centre, where they heard a presentation on the worldwide LHC Computing Grid. At the end of the visit, the President took a moment to shake hands with members of the Lithuanian community at CERN, and also participated in a virtual visit by a high-school class connected remotely from Lithuania as part of the CERN Lab project. CMS also received a visit by Her Excellency Mr Muhammad Nawaz Sharif from Pakistan. The delegation was welcomed by the representative of France, Stéphane Donnot, sous-Préfet de Seine, CERN’s Director-General, and other members of the CERN directorate. It was the first visit by a head of government of Pakistan since the country became CERN’s latest associate member state in July 2015. The Prime Minister then had the opportunity to visit the CMS underground experimental area accompanied by the CMS spokesperson, Tiziano Camporesi, and the CMS collaboration’s national contact physicist for Pakistan, Hafeez Hoorani. At the end of his visit, the Prime Minister took the time to sign CERN’s guestbook and to meet with a number of Pakistanis collaborating with CERN. Picture on the left: The President of Lithuania, Dalia Grybauskaitė, observing a cloud-chamber experiment at the S-Cool Lab. Picture on the right: From left to right: Minister of Finance Mr Mohammad Ishaq Dar, Prime Minister of the Islamic Republic of Pakistan Muhammad Nawaz Sharif, CERN Director-General Fabiola Gianotti and CMS national contact physicist Hafeez Hoorani.
OBITUARY

Michael K Craddock 1936–2015

Michael K Craddock, UBC emeritus professor and retired TRIUMF research scientist, passed away in Vancouver, Canada, on 11 November, following a brief battle with cancer. One of TRIUMF’s founding fathers, he worked tirelessly on the cyclotron and other key projects for 50 years, including 33 years as TRIUMF’s head accelerator physicist, until his retirement in 2001. Mike Craddock was born on 15 April 1936 in the UK. He received his Bachelor’s and Master’s degrees in mathematics and physics at Oxford University in 1957 and 1961, respectively. He was a scientific officer at Rutherford Appleton Laboratory while pursuing a D.Phil in nuclear physics at Oxford, which he was awarded in 1964. Upon graduation, Mike joined the Physics Department at the University of British Columbia (UBC), where he remained throughout his career.

Originally hoping simply to conduct experiments at UBC’s Van de Graaf accelerator, he was thrust almost immediately into the department’s campaign to build a new accelerator on campus. Tasked with investigating options for a new machine, he recommended a modified version of the H- cyclotron design of Reg Richardson at UCLA. Mike managed the overall specification, which settled on a scaled-down 500 MeV, 20µA machine. In 1968, the TRIUMF proposal was approved by the Canadian government, and for the next 10 years, Mike was the beam-dynamics group leader. His most memorable challenge in that time was responsibility for determining the position and number of the magnetic shims installed during the massive cyclotron field-shaping campaign. Mike’s reward came when he was present at Reg Richardson’s shoulder as the first beam emerged on 15 December 1974.

Mike was TRIUMF’s leading beam physicist throughout his career, from joint head of the Beam Development Group from 1978 to 1981, then as Accelerator Research Division head from 1982 to 1988 and head of the Accelerator Division from 1989 to 1994, to group leader for accelerator physics from 1995 until his retirement in 2001. He was a chief architect of the KAON Factory project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary Project, where as deputy to project-leader Alan Astbury, he led a multidisciplinary

related to the Large Hadron Collider (LHC) accelerator injector chain at CERN, the success of which raised the lab’s profile worldwide. Remarkably, during all this time he supervised more than 14 graduate students, regularly taught undergraduate and graduate physics courses, and acted as TRIUMF’s correspondent for the CERN Courier for 29 years, until August 2004.

Retirement did little to tamper with Mike’s relentless energy. He joined the Accelerator Development Group and worked on several projects before settling on fixed-field alternating-gradient accelerators (FFAGs) from 2004 to 2012, where he participated in an international project to build a 20 MeV electron model (EMMA) at Daresbury, UK. He was a constant presence at the lab, organising conferences, and presenting introductory accelerator physics lectures to students at TRIUMF, UBC, and the University of Victoria, all while acting as TRIUMF’s unofficial historian.

During a career that spanned five indefatigable decades, Mike demonstrated exceptional leadership in the field of high-energy subatomic-particle physics, notably in particle-accelerator design and construction, and he was instrumental in fostering new generations of accelerator physicists in Canada and abroad. A testament to his outstanding character, before he passed away, Mike made a very generous gift to TRIUMF: establishing the Michael Craddock Fund for Accelerator students.

His passing has been felt worldwide and has left a gaping hole in the TRIUMF family. He will be sorely missed by all who knew him.

● His friends and colleagues.

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Extreme Light Infrastructure – Nuclear Physics (ELI-NP)

Extreme Light Infrastructure – Nuclear Physics (ELI-NP) will be a new Center for Scientific Research to be built by the
National Institute of Physics and Nuclear Engineering (IFIN-HH) in Bucharest-Magurele, Romania.

ELI-NP is a complex facility which will host two state-of-the-art machines of high performances:
- A very high intensity laser beams from two 10 PW lasers;
- A very intense, brilliant γ beam, very low bandwidth, with $Eγ > 19$ MeV, which is obtained by incoherent Compton
  back scattering of a laser light off an intense electron beam ($Ee > 7000$ MeV) produced by a warm linac.

The jobs description, the Candidate’s profiles and the Rules of Procedures of Selection can be found at

The applications shall be accompanied by the documents required in the Rules and Procedures of Selection for these positions

The applications shall be sent to the Human Resources Department at human.resources@eli-np.ro.

Full time academic position in experimental astroparticle physics

The physics department of the Université Libre de Bruxelles (ULB) seeks outstanding candidates in the field of astroparticle physics.

The experimental particle and astroparticle physics group is located within the Inter-university Institute for High Energies (IHE – ULB-IHE). This research group of 100 people has a long history at the forefront of experimental research with major contributions to detector construction and data analysis in accelerator experiments (DEtectors at LEP, H1 at DESY and CMS at LHC), in astroparticles (the large-scale South Pole neutrino observatories AMANDA, IceCube, and ARGO), in neutrino oscillation physics (OPERA at Gran Sasso, Solar at SK-INO), and in R&D on data acquisition systems for deployment at future accelerator and non-accelerator facilities, supported by university and private industries and technical personnel. The experimental astroparticle physics group maintains a close collaboration with colleagues in the ULB-ULB theory groups whose research interests include phenomenology, cosmology, astroparticle and astrophysics.

More details may be found on the institute’s web page: www.ihe.ac.be.

A successful candidate shall demonstrate a history of outstanding experimental or observational research and leadership in the field. Strong skills in the development of detector instrumentation are an asset. The candidate is invited to participate in the framework of the ongoing research projects but is also encouraged to begin to new research topics.

The official vacancy can be found on:
Application deadline: 15 Mar 2016

FULL-TIME POSTDOCTORAL WORKER

Junior group leader for antihydrogen research

The University of Glasgow, charity number SC004401

The University is committed to equality of opportunity in employment.

Junior group leader for antihydrogen research has been opened. The successful candidate is expected to contribute to existing activities on antihydrogen hyperfine spectroscopy and gravity measurements at the Anti-Protton Decelerator of CERN which are currently performed within the ASACUSA and AEGIS collaborations.

In addition to the junior group leader position (tenure track, initial appointment 5 years), funding for the equivalent of ten Ph.D. positions as well as funds for travel and investment are available. The candidate is expected to obtain additional external funding for his research activities.

Candidates are required to have a Ph.D. in experimental physics and low-energy atomic physics type experiments at particle accelerator laboratories. Previous involvement in antihydrogen experiments, or atom trapping, or particle detection will be of advantage.

Candidates need to provide a research plan together with the usual documents and submit them to
mrd@gla.ac.uk until March 15, 2016.

More information can be obtained from
http://www.gla.ac.uk/about/jobs/ or by email from mrd@gla.ac.uk
Patent Examiner Recruitment

Patents help companies benefit from their R&D and innovation by protecting new technology for both products and methods of manufacture. The Intellectual Property Office (IPO) is seeking to recruit 50 Patent Examiners to start in September 2016.

Patent Examiners help companies to innovate and grow by granting high quality, valid patents. They scrutinise both the technical and legal aspects of a patent application, comparing the new invention against those found in patent databases, before considering whether or not to grant a patent.

Patent examining offers an unusual opportunity to combine your scientific and technical knowledge with legal skills. We are seeking people with highly developed analytical and critical skills and the communication skills necessary to express complex technical and legal arguments along with strong oral communication skills to communicate effectively with colleagues and customers. We require candidates who are self-motivated and willing to take responsibility for their own decisions.

The office deals with a wide range of subject matter, from chemical compounds to smart phones; we endeavour for each examiner to work in areas appropriate to their qualifications and interests.

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8th Joint European Magnetic Symposia

22–26 August 2016

SECC: Scottish Exhibition and Conference Centre, Glasgow, UK

The Joint European Magnetic Symposia (JEMS) combine to form the most important and comprehensive conference on magnetism in Europe.

JEMS has evolved over the last 15 years into a premier scientific forum for presenting the latest cutting-edge developments in magnetism and magnetic materials research. The conference has a breadth of topics ranging from the fundamental to the applied, and exemplifies the diversity of approach inherent to the European context. Topics range across all areas of current interest and include strongly correlated systems, materials for energy and biomedical applications, spintronics, ultrafast optical switching, chiral spin materials and magnonics.

The structure of the conference ensures that all participants can enjoy plenary and semi-plenary speakers from around the world, representing leading efforts at the forefronts of topical areas. Attendees are encouraged to contribute to specialised symposia through talks and poster sessions devoted to their specific research topics. An exhibition will also be held alongside the conference, enabling delegates to connect with industry representatives.

Plenary speakers
- Vincent Cros (CNRS/Thales)
- Burkhard Hillebrands (TU Kaiserslautern)
- Jordan Katine (HGST)
- Hideo Ohta (Tohoku University)
- Nicola Spaldin (ETH Zurich)

Key dates

Abstract submission deadline: 18 March 2016
Early registration deadline: 10 July 2016
Registration deadline: 12 August 2016

http://jems2016.iopconfs.org
Controlling the formation and propagation of high-intensity laser fields in the laboratory and the Internet is a topic of great interest to many scientists. This is a field of ongoing research, and the literature on the subject is not yet comprehensive. This growing research field is so recent that the literature on the subject is not yet adequate; in this sense, this book partially fills the gap. It contains contributions from several Chinese groups, both experimental and theoretical, and reports on recent studies of bound electron and molecular nonlinearities. The content is organised over eight chapters and spans a broad range of topics of this specialist subject.

Strong-field tunnelling is a possible key to the ionisation of neutrals. It offers a sophisticated and imaginative probe of atomic and molecular quantum processes. In fact, the study of direct and rescattered (by the nucleus) electrons in the ionisation process is able to resolve orbitals; in this context, the systematic study of atomic and molecular strong- and field-approximation, and to evaluate the contribution of the long-range Coulomb field, either in a numerical solution of the time-dependent Schrödinger equation (TDSE) or in a more intuitive quantum-trajectories Monte Carlo method describing the formation mechanisms of the photoelectron angular distribution of above-threshold ionisation (chapter 2). Direct and rescattered electrons can be recorded together as a reference wave and a signal wave, respectively: the interstellar patterns constitute the analogue of optical holography, reconstructor the ionised objects. It is possible to integrate the influence of the long-range Coulomb field, either in a numerical solution of the time-dependent Schrödinger equation (TDSE) or in a more intuitive quantum-trajectories Monte Carlo method describing the formation mechanisms of the photoelectron angular distribution of above-threshold ionisation (chapter 2).

The theoretical discussion of double ionisation in a strong laser field is treated on the basis of a numerical analysis of the theoretically predicted and experimental results for a molecule interacting with a strong ultrashort laser pulse, it is necessary to start with the simplest systems — the hydrogen molecular ion H₂⁺. In chapter 3, on the basis of the Coulomb field, either in a numerical solution of the time-dependent Schrödinger equation (TDSE), the author suggests a pump–probe strategy to understand dissociation. The theoretical discussion of double ionisation in a strong laser field is treated on the basis of a numerical analysis of the strongly interacting systems of chemical reactions.

Nuclear Reactions: An Introduction
By Hans Paetz & gen. Schieck

The study of the structure of complex nuclei has experienced a revival in recent years, thanks to the availability of energetic radioactive beams. New facilities such as HE-ISOLDE at CERN are coming online. Nuclear reactions are exciting objects of study in their own right and are also indispensable tools to study the structure of nuclei. Therefore, one should expect a readaptation of nuclear-physics courses in graduate nuclear-physics curricula, and the aim of the present book is to provide the material for such courses.

The author is an experimentalist, and as a consequence, the test contains a refreshing mix of experimental facts and methods with basic theoretical knowledge. The book will convince the reader that nuclear physics is a lively and modern field. As examples of recent progress describe, recent experiments are exploiting the discovery of halo nuclei using high-energy reactions induced by radioactive beams (chapter 2), as well as the treatment of superheavy nuclei (chapter 15). It is, however, also satisfying to see some elegant traditional-physics manifestations, such as the prompt γ emissions, as well as the reaction of halo nuclei using high-energy reactions induced by radioactive beams (chapter 2).

Adventures of Atoms and Molecules in Strong Laser Fields
By Achintya Rao, CERN

Both in a single attosecond pulse and in a train of attosecond pulses, by a conversion of the light frequency from IR to the X-ray regime. This technique provides a tomographic image of molecular orbitals as an alternative to scanning tunneling microscopy or angle-resolved photoelectron spectroscopy. In this book, the author presents a new, intriguing way to visualise both atoms and molecules with femtosecond or ultrashort pulses. This technique has been used to generate detailed information about the reaction pathways for various chemical reactions.

The Handbook is an invaluable resource for researchers in the field of strong-field physics. It provides a comprehensive overview of the latest developments in this rapidly evolving field, making it an essential tool for students and researchers alike.
The book proposes a solid graduate curriculum on nuclear reactions and contains a clear presentation of the basic concepts necessary for undertaking a PhD in nuclear physics, illustrated by examples of modern discoveries and experiments that should motivate the reader. Its aim is not, however, to replace books that are indispensable to the practitioner, such as Direct Nuclear Reactions by G.R. Satchler. Let’s hope that this relatively modern and accessible course in nuclear reactions will encourage the teaching of the subject to a generation of nuclear scientists.

The book provides a comprehensive discussion of quantum confined semiconductors, based on the author’s long and extensive teaching experience in the field. It begins with a short, historical account of the birth and development of lasers in general, concerning the methods used to measure these experimental data are also presented.

In the second volume (Predictive Models), two chapters explain how to develop reliable models of metallic liquids, starting from the essential conditions for a model to be relevant. The use of a statistical approach is to determine the different models. On the basis of this assessment, the authors have compiled tables of predicted values for the thermophysical properties of metallic liquids, which are included in the book. A large amount of experimental data are also given.

The two books are particularly oriented to students of materials science and engineering, but also to research scientists and engineers engaged in liquid metallic processing. They collect a large amount of information in a readable way, therefore they are bound to become an essential reference for students and researchers involved in the field.

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February 19 was the second anniversary of the authorisation of construction of the Super Proton Synchrotron (SPS). It was celebrated by the start of tunnel boring by the “mole”. This conventional Robbins boring machine, built in Seattle, came by sea from the US Pacific Coast, through the Panama Canal to Rotterdam, up the Rhine to Basel, and then by lorry to Geneva. It arrived at the end of last year.

The SPS tunnel will be 4.8 m in diameter with a circumference of 6.9 km. A tunnelling scheme was selected (rather than the “cut-and-fill” method) to avoid changing the character of the countryside in a major way so that agricultural and forestry activities can continue much as previously. A second reason is the variation in altitude over the site. To retain a minimum Earth shield of 20 m for radiation protection, the tunnel will be 65 m below the highest point on the surface at an average depth of 40 m. A final point is that the mole’s bedrock is solid enough to allow the tunnel to be bored reasonably easily.

Survey problems at the SPS are different to those encountered in building the PS or the tunnel to be bored reasonably easily.

To solve these problems, the surveyors resorted to triangulation (angular measurement) and trilateration (distance measurement). Datum points are located on high buildings (ISR Laboratory, Laboratory 5, SB Building, etc.). It was impossible to use the top of the ISR water tower, the highest point at CERN, because it is subject to movements of up to 2 cm. Other points (monuments), some beyond the site, have been set in the ground at a height of about 1.5 m, one at a height of 8 m. The baseline is provided by two PS survey points. The results give an accuracy of 2 mm between all points.

In subterranean surveying, one of the most difficult problems is the dropping of a perpendicular line within a shaft to transfer surface co-ordinates to the tunnel level. Various methods were used for this operation.
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CERN sets accelerator objectives for 2016 • Exploring the nature of the proposed magic number $N = 32$ • New ALPHA measurement of the charge of antihydrogen • ATLAS searches for strong SUSY production at Run 2 • CMS bridges the gap in jet measurements • Jet measurements with ALICE • LHCb brings charm physics to the frontier of experimental knowledge • Construction of KM3NeT, a next-generation neutrino telescope, has begun • Manufacturing and delivery of components for the new heavy-ion synchrotron SIS100 at FAIR has begun • LUNA observes a rare nuclear reaction that occurs in giant red stars • DAMPE joins the search for dark matter in space

Data sonification enters the biomedical field
Sonograms can be used to better understand human motor control.