WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the January/February 2019 issue of *CERN Courier.*

Particle physics rarely stands still, and the articles in this issue offer a snapshot of activities under way at CERN and elsewhere to secure the field into the next decade and beyond. Chief among these are the upgrades to the LHC experiments. Already exceeding its design luminosity, the LHC and its injector chain were shut down at the end of 2018 for two years of maintenance and upgrades, many of which are geared towards the High-Luminosity LHC (HL-LHC) scheduled to operate from 2026. To maximise the physics potential of this unique machine, the seven LHC experiments are using the current "long-shutdown two" to overhaul their detectors – a massive and complex effort that will continue during long-shutdown three beginning in 2024. HL-LHC promises a rich physics programme lasting into the 2030s at this curious time for the field, but strategic decisions need to be taken soon to ensure that there is minimal gap between the LHC and the next major collider. In recent months, China and Europe have launched design reports for a 100 km machine that would open a new era of exploration, while a decision is also imminent regarding a possible international linear collider in Japan. These and numerous other considerations will shape the upcoming update of the European Strategy for Particle Physics, more than 150 submissions for which were received by the deadline of 18 December.

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CERNCOURIER
January/February 2019 cerncourier.com Reporting on international high-energy physics

Coming to terms with naturalness
Individual recognition in particle physics
Twin bids for a 100 km collider

LHC EXPERIMENTS
REBORN

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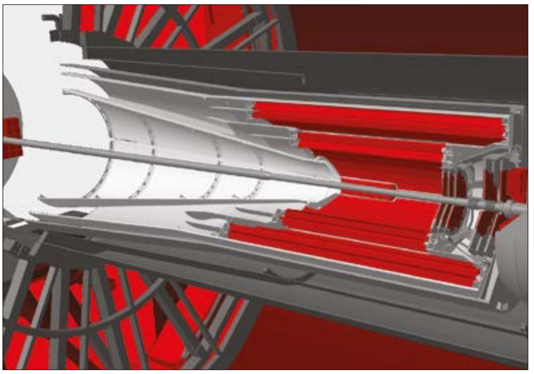
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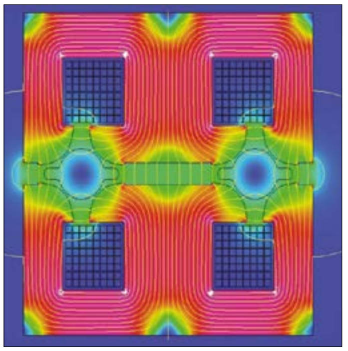
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FROM THE EDITOR

New-look CERN Courier captures a field in motion

Matthew Chalmers
Editor

Welcome to the redesigned first issue of 2019. Particle physics rarely stands still, and the articles in this issue offer a snapshot of activities under way at CERN and elsewhere to secure the field into the next decade and beyond. Chief among these are the upgrades to the LHC experiments to cope with the relentless performance of the machine so far and in the years ahead. Already exceeding its design luminosity, the LHC and its injector chain were shut down at the end of 2018 for two years of maintenance and upgrades, many of which are geared towards the High-Luminosity LHC (HL-LHC) scheduled to operate from 2026. To maximise the physics potential of this unique machine, the seven LHC experiments are using the current "long-shutdown two" to overhaul their detectors (p23–37) – a massive and complex effort that will continue during long-shutdown three beginning in 2024.

HL-LHC has been a priority of European particle physics and promises a rich physics programme lasting into the 2030s at this curious time (p19 and 45) for the field. To ensure that there is minimal gap between the LHC and the next major collider in particle physics, strategic decisions need to be taken soon. In recent months, China and Europe have launched design reports for a 100 km collider that would open a new era of exploration (p8 and 38). A decision is also imminent regarding a possible international linear collider in Japan, with potential ramifications for other proposals such as CERN's Compact Linear Collider. These and numerous other considerations will shape the upcoming update of the European Strategy for Particle Physics, more than 150 submissions for which were received by the deadline of 18 December (p9 and 43).

HL-LHC promises a rich physics programme at this curious time for the field

Introducing the new format

What better way to chronicle the exciting times ahead than a new incarnation of *CERN Courier*. The refreshed magazine design and structure are part of an overhaul that will see the print issue published six times per year and a dynamic new website launched in 2019. This transformation, informed by our recent reader survey (*CERN Courier* December 2018 p56) and expertly guided by Institute of Physics Publishing in the UK, takes full advantage of the modern publishing landscape to allow more efficient ways to communicate.

Celebrating its 60th anniversary this summer, the *Courier* looks forward to reporting on developments across international particle-physics in a timely manner, and to strengthening its role as a forum for the exchange and integration of knowledge and ideas. All feedback is welcome via the contacts below, and I wish you an enjoyable read.

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Maximising potential *The removal of the LHCb beam pipe in January as part of a major upgrade.*

Reporting on international high-energy physics

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NEWS DIGEST

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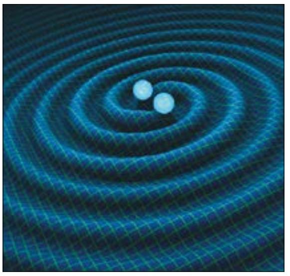

Artist's impression of a gravitational-wave event.

New gravitational-wave events

The LIGO and VIRGO collaborations have detected four new gravitational-wave events, bringing the total number of observed events since the first detection in 2015 to 11. Ten of these events are from black-hole mergers, and one is from a neutron-star merger. Of the black-hole events, the new event GW170729 is the most massive and distant gravitational-wave source ever observed – it converted almost five solar masses into gravitational radiation and took place about 5 billion years ago. The teams describe their results in a catalogue that comprises confirmed and candidate events (arXiv:1811.12907) and an analysis of the properties of the black-hole mergers (arXiv:1811.12940).

Open-science cloud launched

On 23 November, the European Commission launched the European Open Science Cloud (EOSC) – an open environment for researchers to store, analyse and re-use data for research, innovation and educational purposes. EOSC has emerged following extensive discussions with research infrastructures and scientists working across disciplines. For the astronomy and particle-physics fields, the ESCAPE project brings together the relevant research infrastructures, including CERN, to address their open-data science challenges and help build EOSC. Under the commission's Horizon 2020 programme, €600 million has been allocated to setting up EOSC by 2020.

New centre for particle physics

The German Research Foundation has established a new transregional centre to explore physics beyond the Standard Model with state-of-the-art theoretical methods and new search strategies. The centre, called Phenomenological Elementary Particle Physics after the Higgs Discovery, will be funded from January initially for four years with a total of around €12 million. It involves the Karlsruhe Institute of Technology (host institute), the University of Siegen and RWTH Aachen, in addition to researchers from the University of Heidelberg. The centre is one of 10 new collaborative research centres in Germany designed to enable researchers to pursue challenging, long-term research projects.

Most precise electron moment

The ACME collaboration at Harvard University's Jefferson Physical Laboratory in the US has performed the most precise measurement of the electric dipole moment (EDM) of the electron (*Nature* **562** 355), providing a powerful test of the Standard Model (SM). The SM predicts a non-zero but very small EDM, whereas extensions of the SM such as supersymmetry posit larger and potentially measurable EDMs, in the range 10^{-27}–10^{-30}. By measuring the electron spin precession in a superposition of quantum states of electrons subjected to a huge electric field, the ACME experiment (pictured) measured an upper limit for the electron's EDM of $1.1\times10^{-29}\,e$. cm – 8.6 times smaller than the best previous limit, also by ACME.

Harvard Univ.

The ACME experimental set-up.

SNO+ searches for nucleon decay

Many grand unified theories predict the existence of nucleon decay as a mechanism to allow baryon-number violation and potentially explain the matter–antimatter asymmetry in the universe. A new search for invisible nucleon decays has been conducted during the initial water phase of the SNO+ detector in Canada, before the detector runs with a scintillator (arXiv:1812.05552). Invisible nucleon decays could be detected through gamma rays emitted by the de-excitation of an excited daughter of the oxygen nucleus. The new SNO+ search for such gamma rays has resulted in limits of 2.5×10^{29} yr for the partial lifetime of the neutron, and 3.6×10^{29} yr for the partial lifetime of the proton, the latter being a 70% improvement over the previous limit from SNO.

Gluon revelation in the pion

Gluons contribute more to the total momentum of the pion – which is the lightest hadron – than previously thought. That's the conclusion of Patrick Barry of North Carolina State University and co-workers, who have published the first global QCD analysis of the parton distribution functions of the pion (*Phys. Rev. Lett.* **121** 152001). By using a Monte Carlo approach based on nested sampling, the analysis combined data from fixed-target and collider experiments to show that gluons contribute 30% of the total pion momentum – which is three times more than the previous estimate.

Physics resumes at RHIC

The 19th year of physics operations has commenced at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in the US. This year the collider is being reconfigured for a lower-energy run to look for signs of a critical point in the nuclear phase diagram at which the transition from ordinary matter to a quark–gluon plasma switches from abrupt to continuous.

Belle II vertex detector installed

The final piece has been inserted into the Belle II detector (pictured) at the SuperKEKB accelerator in Japan. When fully commissioned, Belle II – the "super-B factory" upgrade of the Belle detector – will detect events at the much higher rates provided by the 40-fold higher design luminosity of SuperKEKB compared to KEKB. This final component, the vertex detector, has two parts that now complete the overall detector: a two-layer pixel detector based on "DEPFET" technology, and a four-layer double-sided silicon-strip detector. The first layer lies just 14 mm from the interaction point to improve Belle II's vertex resolution significantly.

KEK

The vertex detector being incorporated into Belle II.

Metamaterial for acceleration

A team led by Richard Temkin at the Massachusetts Institute of Technology in the US has shown that an artificially engineered "metamaterial" could be an alternative to materials currently used in the emerging technology of wakefield acceleration. This type of acceleration relies on the intense electromagnetic field produced in the wake of an electron bunch that travels through a plasma or dielectric material to accelerate particles, and can reach higher accelerating gradients than conventional techniques. However, it has disadvantages such as limited tunability of the plasma (or dielectric) and a lower beam quality. Temkin and co-workers have engineered a metamaterial, made of steel and copper plates, that has both a high gradient and a high degree of tunability (*Phys. Rev. Lett.* **122** 014801).

NEWS
ANALYSIS

Big thinking *A visualisation of the 100 km circumference FCC tunnel and machine.*

ACCELERATORS

China and Europe bid for post-LHC collider

The discovery of the Higgs boson at the LHC in the summer of 2012 set particle physics on a new course of exploration. While the LHC experiments have determined many of the properties of the Higgs boson with a precision beyond expectations, and will continue to do so until the mid-2030s, physicists have long planned a successor to the LHC that can further explore the Higgs mechanism and other potential sources of new physics. Several proposals are on the table, the most ambitious and scientifically far-reaching involving circular colliders with a circumference of around 100 km.

On 18 December, the Future Circular Collider (FCC) study released its conceptual design report (CDR) for a 100 km collider based at CERN. A month earlier, the Institute of High Energy Physics (IHEP) in China officially presented a CDR for a similar project called the Circular Electron Positron Collider (CEPC). Both studies were launched shortly after the discovery of the Higgs boson (the FCC was a direct response to a request from the 2013 update of the European Strategy for Particle Physics to prepare a post-LHC machine, following preliminary proposals for a circular Higgs factory at CERN in 2011), and both envisage physics programmes extending deep into the 21st century. Documents concerning the FCC and CEPC proposals were also submitted as input to the latest update of the European Strategy for Particle Physics at the end of the year (see panel, right).

If a high-luminosity electron-positron Higgs factory were to drop out of the sky tomorrow, the line of users would be very long

"If a high-luminosity electron-positron Higgs factory were to drop out of the sky tomorrow, the line of users would be very long, while a very-high-energy hadron collider is a vessel of discovery and will help us study the role of the Higgs boson in taming the high-energy behaviour of longitudinal gauge-boson (WW) scattering," says theorist Chris Quigg of Fermilab in the US. "It is a very significant validation of the scientific promise opened by a 100 km ring for scientists of different regions to express the same judgment."

The four-volume FCC report demonstrates the project's technical feasibility and identifies the physics opportunities offered by the different collider options: a high-luminosity electron-positron collider (FCC-ee) with a centre-of-mass energy ranging from the Z pole (90 GeV) to the $t\bar{t}$ threshold (365 GeV); a 100 TeV proton-proton collider (FCC-hh); a future lepton-proton collider (FCC-eh); and, finally, a higher-energy hadron collider in the existing tunnel (HE-LHC). The FCC is a global collaboration of more than 140 universities, research institutes and industrial partners. During the past five years, with the support of the European Commission's Horizon 2020 programme, the FCC collaboration has made significant advances in high-field superconducting magnets, high-efficiency radio-frequency cavities, vacuum systems, large-scale cryogenic refrigeration and other enabling technologies (see p38).

According to the present proposal, ▷ an eight-year period for project preparation and administration is required before construction of FCC's underground areas can begin, potentially allowing the FCC-ee physics programme to start by 2039. The FCC-hh, installed in the same tunnel, could then start operations in the late 2050s. "Though the two machines can be built independently, a combined scenario profits from the extensive reuse of civil engineering and technical systems, and also from the additional time available for high-field magnet breakthroughs," says deputy leader of the FCC study Frank Zimmermann of CERN. "Timely preparation, early investment and diverse collaborations between researchers and industry are already yielding promising results and confirming the anticipated downward trend in the costs associated with operation."

Input received for European strategy update

The European Strategy for Particle Physics (ESPP) was initiated in 2006 to coordinate activities across a large, international and fast-moving community (*CERN Courier* April 2018 p7). 18 December 2018 was the deadline for the submission of materials for the second update of the ESPP, which will define the long-term priorities of the field to the mid-2020s and beyond. The European Strategy Group (ESG), which was established at the end of 2017 to coordinate the update process, received a total of 160 contributions – predominantly from Europe but including projects that extend beyond the continent (such as the CEPC proposal). Of these, about a quarter concern national road maps or are submissions from national organisations or funding agencies, another 20 or so concern large experiments or projects (about half of which, including the FCC and CLIC studies, target CERN as the host laboratory), and a similar number concern education, outreach and technology transfer. The rest are spread over the eight different themes that have been defined for the process: accelerator science and technology, beyond the Standard Model at colliders, dark matter and the dark sector, instrumentation and computing, electroweak physics, flavour physics, neutrino physics, and strong interactions. The proposals will be discussed at a public symposium in Granada, Spain, on 13–16 May, after which a "briefing book" will be prepared and submitted to the ESG for consideration in January 2020.

Asian ambition

CEPC is a putative 240 GeV circular electron-positron collider, the tunnel for which is foreseen to one day host a super proton-proton collider (SppC) that reaches energies beyond the LHC (*CERN Courier* June 2018 p21). The two-volume CEPC design report summarises the work accomplished in the past few years by thousands of scientists and engineers in China and abroad. IHEP states that construction of CEPC will begin as soon as 2022 – allowing time to build prototypes of key technical components and establish support for manufacturing – and be completed by 2030. According to the tentative operational plan, CEPC will run for seven years as a Higgs factory, followed by two years as a Z factory and one year at the WW threshold, potentially followed by the installation of the SppC. Although CEPC-SppC is a Chinese-proposed project to be built in China, it has an international advisory committee and more than 20 agreements have been signed with institutes and universities around the world.

"The Beijing Electron Positron Collider will stop running in the 2020s, and China's government is encouraging Chinese scientists to initiate and work towards large international science projects, so it is possible that CEPC may get a green light soon," explains deputy leader of the CEPC project Jie Gao of IHEP. "As for the site, many Chinese local governments showed strong interest to host CEPC with the support of the central government."

Cost is a key factor for both the Chinese and European projects, with the tunnel taking up a large fraction of the expense. CEPC's price tag is currently \$5 billion and FCC-ee is hovering at around twice this value, while, at present, a hadron collider on either continent would cost significantly more due to the cost of the required superconducting wire. Geoffrey Taylor of the University of Melbourne, who is chair of the International Committee for Future Accelerators, says that CERN has the major benefit of magnet expertise and high-energy collider development and operation, in addition to already having the multi-billion-dollar accelerator infrastructure required for the project. "The value of this infrastructure at CERN outweighs the cost of the tunnel; on the other hand, the Chinese proposal has a lower cost of tunneling but lacks the immense infrastructure and expertise necessary for the hadron collider."

Taylor says that whilst it is essential that CERN maintains its pre-eminent position, having competition from Asia with the potential for major investment would be beneficial for the field as a whole because Western investment in future machines may well remain at current levels. There are also broader cultural factors to be considered, says Quigg: "CERN has earned an exemplary reputation for inclusiveness and openness, which go hand in hand with scientific excellence. Any region, nation, and institution that aims to host a world-leading instrument must strive for a similar environment."

For theorist Gerard 't Hooft, who shared the 1999 Nobel Prize in Physics for elucidating the quantum structure of electroweak interactions, the physics target of a 100 km collider is far more important than its location. It is not obvious, in view of our present theoretical understanding, whether or not a 100 km accelerator will be able to enforce a breakthrough, he says. "Most theoreticians were hoping that the LHC might open up a new domain of our science, and this does not seem to be happening. I am just not sure whether things will be any different for a 100 km machine. It would be a shame to give up, but the question of whether spectacular new physical phenomena will be opened up and whether this outweighs the costs, I cannot answer. On the other hand, for us theoretical physicists the new machines will be important even if we can't impress the public with their results."

Having competition from Asia with the potential for major investment would be beneficial for the field as a whole

Profound discoveries

Experimentalist Joe Incandela of the University of California in Santa Barbara, who was spokesperson of the CMS experiment at the time of the Higgs-boson discovery, believes that a post-LHC collider is needed for closure – even if it does not yield new discoveries. "While such machines are not guaranteed to yield definitive evidence for new physics, they would nevertheless allow us to largely complete our exploration of the weak scale," he says. "This is important because it is the scale where our observable universe resides, where we live, and it should be fully charted before the energy frontier is shut down. Completing our study of the weak scale would cap a short but extraordinary 150 year-long period of profound experimental and theoretical discoveries that would stand for millennia among mankind's greatest achievements."

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PERIODIC TABLE

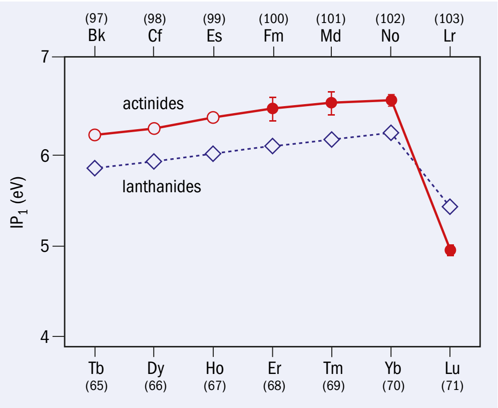
Actinide series shown to end with lawrencium

One hundred and fifty years since Dmitri Mendeleev revolutionised chemistry with the periodic table of the elements, an international team of researchers has resolved a longstanding question about one of its more mysterious regions – the actinide series (or actinoids, as adopted by the International Union of Pure and Applied Chemistry, IUPAC).

The periodic table's neat arrangement of rows, columns and groups is a consequence of the electronic structures of the chemical elements. The actinide series has long been identified as a group of heavy elements starting with atomic number Z = 89 (actinium) and extending up to Z = 103 (lawrencium), each of which is characterised by a stabilised $7s^2$ outer electron shell. But the electron configurations of the heaviest elements of this sequence, from Z = 100 (fermium) onwards, have been difficult to measure, preventing confirmation of the series. The reason for the difficulty is that elements heavier than fermium can be produced only one atom at a time in nuclear reactions at heavy-ion accelerators.

Confirmation

Now, Tetsuya Sato at the Japan Atomic Energy Agency (JAEA) and colleagues have used a surface ion source and isotope mass-separation technique at the tandem accelerator facility at JAEA in Tokai to show that the actinide series ends with lawrencium. "This result, which would confirm the present representation of the actinide series in the periodic table, is a serious input to the IUPAC working group, which is evaluating if lawrencium is indeed the last actinide," says team member Thierry Stora of CERN.



Source: Sato *et al.* 2018

Heavy elements *The first ionisation potential values of the heavy actinides and lanthanides, with closed circles representing the latest work.*

Using the same technique, Sato and co-workers measured the first ionisation potential of lawrencium back in 2015. Since this is the energy required to remove the most weakly bound electron from a neutral atom and is a fundamental property of every chemical element, it was a key step towards mapping lawrencium's electron configuration. The result suggested that lawrencium has the lowest first ionisation potential of all actinides, as expected owing to its weakly bound electron in the $7p_{1/2}$ valence orbital. But with only this value the team couldn't confirm the expected increase of the ionisation values of the heavy actinides up to nobelium (Z = 102). This occurs with the filling of the 5f electron shell in a manner similar to the filling of the 4f electron shell until ytterbium in the lanthanides.

In their latest study, Sato and colleagues have determined the successive first ionisation potentials from fermium to lawrencium, which is essential to confirm the filling of the 5f shell in the heavy actinides (see figure). The results agree well with those predicted by state-of-the-art relativistic calculations in the framework of QED and confirm that the ionisation values of the heavy actinides increase up to nobelium, while that of lawrencium is the lowest among the series.

The results demonstrate that the 5f orbital is fully filled at nobelium (with the [Rn] $5f^{14}$ $7s^2$ electron configuration, where [Rn] is the radon configuration) and that lawrencium has a weakly bound electron, confirming that the actinides end with lawrencium. The nobelium measurement also agrees well with laser spectroscopy measurements made at the GSI Helmholtz Center for Heavy Ion Research in Darmstadt, Germany.

"The experiments conducted by Sato *et al.* constitute an outstanding piece of work at the top level of science," says Andreas Türler, a chemist from the University of Bern, Switzerland. "As the authors state, these measurements provide unequivocal proof that the actinide series ends with lawrencium (Z = 103), as the filling of the 5f orbital proceeds in a very similar way to lanthanides, where the 4f orbital is filled. I am already eagerly looking forward to an experimental determination of the ionisation potential of rutherfordium (Z = 104) using the same experimental approach."

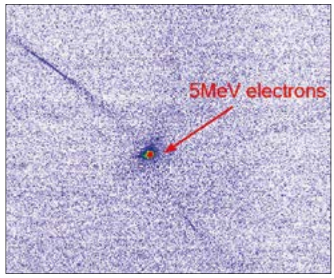
Further reading

T Sato *et al.* 2015 *Nature* **520** 209.
T Sato *et al.* 2018 *J. Am. Chem. Soc.* **140** 14609.
P Chhetri *et al.* 2018 *Phys. Rev. Lett.* **120** 263003.

ACCELERATORS

First beam at SLAC plasma facility

FACET-II, a new facility for accelerator research at SLAC National Accelerator Laboratory in California, has produced its first electrons. FACET-II is an upgrade to the Facility for Advanced Accelerator Experimental Tests (FACET), which operated from 2011 to 2016, and will produce high-quality electron beams to develop plasma-wakefield acceleration techniques. The $26 million project, recently approved by the US Department of Energy (DOE), will also operate as a federally sponsored research facility for advanced accelerator research that is open to scientists on a competitive, peer-reviewed basis.



SLAC

First beam *Photoelectrons produced at FACET-II on 20 September.*

"As a strategically important national user facility, FACET-II will allow us to explore the feasibility and applications of plasma-driven accelerator technology," said James Siegrist of the DOE Office of Science. "We're looking forward to seeing the groundbreaking science in this area that FACET-II promises, with the potential for a significant reduction in the size and cost of future accelerators, including free-electron lasers and medical accelerators."

Whereas conventional accelerators impart energy to charged particles via radiofrequency fields inside metal structures, plasma-wakefield accel- ▷

erators send a bunch of very energetic particles through a hot ionised gas to create a plasma wake on which a trailing bunch can "surf" and gain energy. This leads to acceleration gradients that are much higher and therefore potentially to smaller machines, but several crucial steps are required before plasma accelerators can become a reality. This is where FACET-II comes in, offering higher-quality beams than FACET, explains project scientist Mark Hogan. "We need to show that we're able to preserve the quality of the beam as it passes through plasma. High-quality beams are an absolute requirement for future applications in particle and X-ray laser physics."

SLAC has a rich history in developing such techniques, and the previous FACET facility enabled researchers to demonstrate electron-driven plasma acceleration for both electrons and positrons. FACET-II will use the middle third (corresponding to a length of 1 km) of SLAC's linear accelerator to generate a 10 GeV electron beam, kitted out with diagnostics and computational tools that will accurately measure and simulate the physics of the new facility's beams. The FACET-II design also allows for adding the capability to produce and accelerate positrons at a later stage, paving the way for plasma-based electron–positron colliders.

SLAC

Aerial view *SLAC's other major facilities, the Linac Coherent Light Source (LCLS) and Stanford Synchrotron Radiation Lightsource (SSRL).*

FACET-II has issued its first call for proposals for experiments that will run when the facility goes online in 2020. In mid-October, prospective users of FACET-II presented their ideas for a first round of experiments for evaluation, and the number of proposals is already larger than the number of experiments that can possibly be scheduled for the facility's first run.

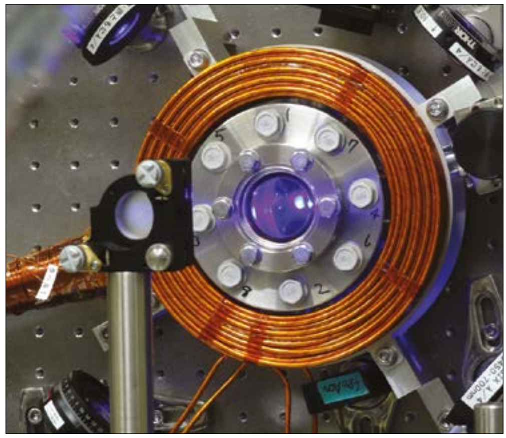
Last year, the AWAKE experiment at CERN demonstrated the first ever acceleration of a beam in a proton-driven plasma (*CERN Courier* October 2018 p7). Laser-driven plasma-wakefield acceleration is also receiving much attention thanks to advances in high-power lasers (*CERN Courier* November 2018 p7). "The FACET-II programme is very interesting, with many plasma-wakefield experiments," says technical coordinator and CERN project leader for AWAKE, Edda Gschwendtner, who is also chair of the FACET-II programme advisory committee.

PRECISION MEASUREMENT

German–Japanese centre to focus on precision physics

On 1 January a new virtual centre devoted to some of the most precise measurements in science was established by researchers in Germany and Japan. The Centre for Time, Constants and Fundamental Symmetries will offer access to ultra-sensitive equipment to allow experimental groups in atomic and nuclear physics, antimatter research, quantum optics and metrology to collaborate closely on fundamental measurements. Three partners – the Max Planck Institutes for nuclear physics (MPI-K) and for quantum optics (MPQ), the National Metrology Institute of Germany (PTB) and RIKEN in Japan – agreed to fund the centre in equal amounts with a total of around €7.5 million for five years, and scientific activities will be coordinated at MPI-K.

A major physics target of the German–Japanese centre is to investigate whether the fundamental constants really are constant or if they change in time by tiny amounts. Another goal concerns the subtle differences in the properties of matter and antimatter, namely C, P and T invariance, which have not yet shown up, even though such differences intrinsically must exist, otherwise the universe would consist of almost pure radiation. Closely related to these tests of fundamental symmetries is the search for physics beyond the Standard Model. The broad research portfolio also includes the development of novel optical clocks based on atoms, nuclei and highly charged ions.



H Katori

On time *A lattice clock at RIKEN, one of the partners of the new Centre for Time, Constants and Fundamental Symmetries.*

"It is fascinating that nowadays manageable laboratory experiments make it possible to investigate such fundamental questions in physics and cosmology by means of their high precision", says Klaus Blaum of MPI-K.

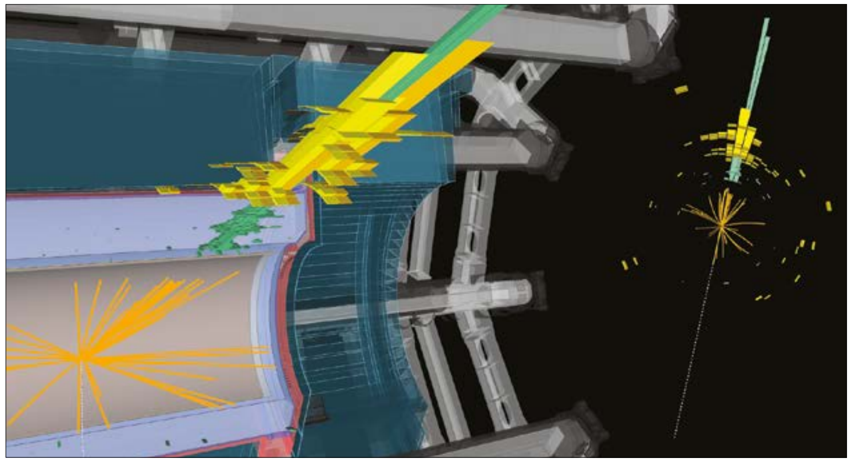
Stringent tests of fundamental interactions and symmetries using the protons and antiprotons available at the BASE experiment at CERN are another key aspect of the German–Japanese initiative, explains Stefan Ulmer, co-director of the centre, chief scientist at RIKEN, and spokesperson of the BASE experiment: "This centre will strongly promote fundamental physics in general, in addition to the research goals of BASE. Given this support we are developing new equipment to improve both the precision of the proton-to-antiproton charge-to-mass ratio as well as the proton/antiproton magnetic moment comparison by factors of 10 to 100."

To reach these goals, the researchers intend to develop novel experimental techniques – such as transportable antiproton traps, sympathetic cooling of antiprotons by laser-cooled beryllium ions, and optical clocks based on highly charged ions and thorium nuclei – which will outperform contemporary methods and enable measurements at even shorter time scales and with improved sensitivity. "The combined precision-physics expertise of the individual groups with their complementary approaches and different methods using traps and lasers has the potential for substantial progress," says Ulmer. "The low-energy, ultra-high-precision investigations for physics beyond the Standard Model will complement studies in particle physics."

Dark energy

Colliders join the hunt for dark energy

It is 20 years since the discovery that the expansion of the universe is accelerating, yet physicists still know precious little about the underlying cause. In a classical universe with no quantum effects, the cosmic acceleration can be explained by a constant that appears in Einstein's equations of general relativity, albeit one with a vanishingly small value. But clearly our universe obeys quantum mechanics, and the ability of particles to fluctuate in and out of existence at all points in space leads to a prediction for Einstein's cosmological constant that is 120 orders of magnitude larger than observed. "It implies that at least one, and likely both, of general relativity and quantum mechanics must be fundamentally modified," says Clare Burrage, a theorist at the University of Nottingham in the UK.


ATLAS

Dark analysis *Events such as this, showing the second highest* E_T^{miss} *monojet event recorded in the 2016 ATLAS data, were used to search for signs of dark energy.*

With no clear alternative theory available, all attempts to explain the cosmic acceleration introduce a new entity called dark energy (DE) that makes up 70% of the total mass-energy content of the universe. It is not clear whether DE is due to a new scalar particle or a modification of gravity, or whether it is constant or dynamic. It's not even clear whether it interacts with other fundamental particles or not, says Burrage. Since DE affects the expansion of space-time, however, its effects are imprinted on astronomical observables such as the cosmic microwave background and the growth rate of galaxies, and the main approach to detecting DE involves looking for possible deviations from general relativity on cosmological scales.

Unique environment

Collider experiments offer a unique environment in which to search for the direct production of DE particles, since they are sensitive to a multitude of signatures and therefore to a wider array of possible DE interactions with matter. Like other signals of new physics, DE (if accessible at small scales) could manifest itself in high-energy particle collisions either through direct production or via modifications of electroweak observables induced by virtual DE particles.

Last year, the ATLAS collaboration at the LHC carried out a first collider search for light scalar particles that could contribute to the accelerating expansion of the universe. The results demonstrate the ability of collider experiments to access new regions of parameter space and provide complementary information to cosmological probes.

Unlike dark matter, for which there exists many new-physics models to guide searches at collider experiments, few such frameworks exist that describe the interaction between DE and Standard Model (SM) particles. However, theorists have made progress by allowing the properties of the prospective DE particle and the strength of the force that it transmits to vary with the environment. This effective-field-theory approach integrates out the unknown microscopic dynamics of the DE interactions.

The new ATLAS search was motivated by a 2016 model by Philippe Brax of the Université Paris-Saclay, Burrage, Christoph Englert of the University of Glasgow, and Michael Spannowsky of Durham University. The model provides the most general framework for describing DE theories with a scalar field and contains as subsets many well-known specific DE models – such as quintessence, galileon, chameleon and symmetron. It extends the SM lagrangian with a set of higher dimensional operators encoding the different couplings between DE and SM particles. These operators are suppressed by a characteristic energy scale, and the goal of experiments is to pinpoint this energy for the different DE–SM couplings. Two representative operators predict that DE couples preferentially to either very massive particles like the top quark ("conformal" coupling) or to final states with high-momentum transfers, such as those involving high-energy jets ("disformal" coupling).

ATLAS has become the first experiment to probe all forms of matter in the observable universe

Signatures

"In a big class of these operators the DE particle cannot decay inside the detector, therefore leaving a missing energy signature," explains Spyridon Argyropoulos of the University of Iowa, who is a member of the ATLAS team that carried out the analysis. "Two possible signatures for the detection of DE are therefore the production of a pair of top-antitop quarks or the production of high-energy jets, associated with large missing energy. Such signatures are similar to the ones expected by the production of supersymmetric top quarks ("stops"), where the missing energy would be due to the neutralinos from the stop decays or from the production of SM particles in association with dark-matter particles, which also leave a missing energy signature in the detector."

The ATLAS analysis, which was based on 13 TeV LHC data corresponding to an integrated luminosity of 36.1 fb^{-1}, re-interprets the result of recent ATLAS searches for stop quarks and dark matter produced in association with jets. No significant excess over the predicted background was observed, setting the most stringent constraints on the suppression scale of conformal and disformal couplings of DE to normal matter in the context of an effective field theory of DE. The results show that the characteristic energy ▷ scale must be higher than approximately 300 GeV for the conformal coupling and above 1.2 TeV for the disformal coupling.

The search for DE at colliders is only at the beginning, says Argyropoulos. "The limits on the disformal coupling are several orders of magnitudes higher than the limits obtained from other laboratory experiments and cosmological probes, proving that colliders can provide crucial information for understanding the nature of DE. More experimental signatures and more types of coupling between DE and normal matter have to be explored and more optimal search strategies could be developed."

With this pioneering interpretation of a collider search in terms of dark-energy models, ATLAS has become the first experiment to probe all forms of matter in the observable universe, opening a new avenue of research at the interface of particle physics and cosmology. A complementary laboratory measurement is also being pursued by CERN's CAST experiment, which studies a particular incarnation of DE (chameleon) produced via interactions of DE with photons.

The search for dark energy at colliders is only at the beginning

But DE is not going to give up its secrets easily, cautions theoretical cosmologist Dragan Huterer at the University of Michigan in the US. "Dark energy is normally considered a very large-scale phenomenon, but you may justifiably ask how the study of small systems in a collider can say anything about DE. Perhaps it can, but in a fairly model-dependent way. If ATLAS finds a signal that departs from the SM prediction it would be very exciting. But linking it firmly to DE would require follow-up work and measurements – all of which would be very exciting to see happen."

Further reading

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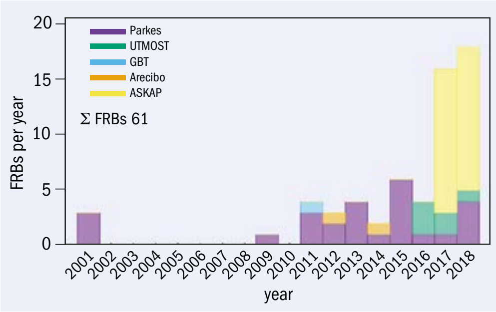
Astrowatch: Fast radio bursts

Solving the next mystery in astrophysics

In 2007, while studying archival data from the Parkes radio telescope in Australia, Duncan Lorimer and his student David Narkevic of West Virginia University in the US found a short, bright burst of radio waves. It turned out to be the first observation of a fast radio burst (FRB), and further studies revealed additional events in the Parkes data dating from 2001. The origin of several of these bursts, which were slightly different in nature, was later traced back to the microwave oven in the Parkes Observatory visitors centre. After discarding these events, however, a handful of real FRBs in the 2001 data remained, while more FRBs were being found in data from other radio telescopes.



Nat. Astron. **2** 865

Stellar stats *Number of detected FRBs up to July 2018.*

The cause of FRBs has puzzled astronomers for more than a decade. But dedicated searches under way at the Canadian Hydrogen Intensity Mapping Experiment (CHIME) and the Australian Square Kilometre Array Pathfinder (ASKAP), among other activities, are intensifying the search for their origin. Recently, while still in its pre-commissioning phase, CHIME detected no less than 13 new FRBs – one of them classed as a "repeater" on account of its regular radio output – setting the field up for an exciting period of discovery.

Dispersion

All FRBs have one thing in common: they last for a period of several milliseconds and have a relatively broad spectrum where the radio waves with the highest frequencies arrive first followed by those with lower frequencies. This dispersion feature is characteristic of radio waves travelling through a plasma in which free electrons delay lower frequencies more than the higher ones. Measuring the amount of dispersion thus gives an indication of the number of free electrons the pulse has traversed and therefore the distance it has travelled. In the case of FRBs, the measured delay cannot be explained by signals travelling within the Milky Way alone, strongly indicating an extragalactic origin.

The size of the emission region responsible for FRBs can be deduced from their duration. The most likely sources are compact km-sized objects such as neutron stars or black holes. Apart from their extragalactic origin and their size, not much more is known about the 70 or so FRBs that have been detected so far. Theories about their origin range from the mundane, such as pulsar or black-hole emission, to the spectacular – such as neutron stars travelling through asteroid belts or FRBs being messages from extraterrestrials.

For one particular FRB, however, its location was precisely measured and found to coincide with a faint unknown radio source within a dwarf galaxy. This shows clearly that the FRB was extragalactic. The reason this FRB could be localised is that it was one of several to come from the same source, allowing more detailed studies and long-term observations. For a while, it was the only FRB found to do so, earning it the title "The Repeater". But the recent detection by CHIME has now doubled the number of such sources. The detection of repeater FRBs could be seen as evidence that FRBs are not the result of a cataclysmic event, since the source must survive in order to repeat. However, another interpretation is that there are actually two classes of FRBs: those that repeat and those that come from cataclysmic events.

Until recently the number of theories on the origin of FRBs outnumbered the number of detected FRBs, showing how difficult it is to constrain theoretical models based on the available data. Looking at the experience of a similar field – that of gamma-ray burst (GRB) research, which aims to explain bright flashes of gamma rays discovered during the 1960s – an increase in the number of detections and searches for counterparts in other wavelengths or in gravitational waves will enable quick progress. As the number of detected GRBs started to go into the thousands, the number of theories (which initially also included those with extraterrestrial origins) decreased rapidly to a handful. The start of data taking by ASKAP and the increasing sensitivity of CHIME means we can look forward to an exponential growth of the number of detected FRBs, and an exponential decrease in the number of theories on their origin.

Further reading

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CHIME/FRB Collaboration 2019 *Nature* doi:10.1038/s41586-018-0864-x

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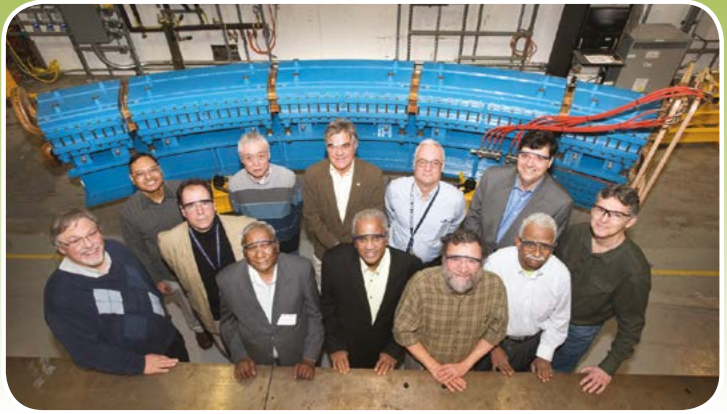
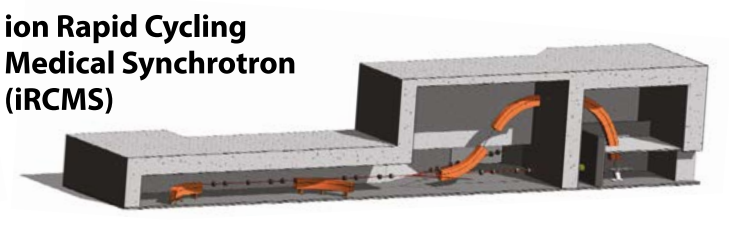
D Lorimer 2018 *Nat. Astron.* **2** 860.





ENERGY FRONTIERS

Reports from the LHC experiments

CMS

Exploring the spin of top-quark pairs

One of the most fascinating particles studied at the LHC is the top quark. As the heaviest elementary particle to date, the top quark lives for less than a trillionth of a trillionth of a second (10^{-24} s) and decays long before it can form hadrons. It is also the only quark that provides the possibility to study a bare quark. This allows physicists to explore its spin, which is related to the quark's intrinsic quantum angular momentum. The spin of the top quark can be inferred from the particles it decays into: a bottom quark and a W boson, which subsequently decays into leptons or quarks.

The CMS collaboration has analysed proton–proton collisions in which pairs of top quarks and antiquarks are produced. The Standard Model (SM) makes precise predictions for the frequency at which the spin of the top quark is aligned with (or correlated to) the spin of the top antiquark. A measure of this correlation is thus a highly sensitive test of the SM. If, for example, an exotic heavier Higgs boson were to exist in addition to the one discovered in 2012 at the LHC, it could decay into a pair of top quarks and antiquarks and change their spin correlation significantly. A high-precision measurement of the spin correlation therefore opens a window to explore physics beyond our current knowledge.

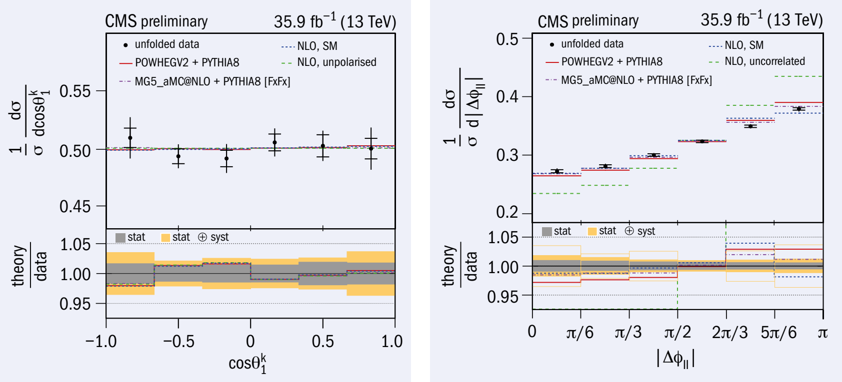


Fig. 1. *The unfolded distribution of the lepton angle with respect to the momentum of the top quark (left) as well as the azimuthal opening angle between two leptons (right). Good agreement with the NLO predictions is observed, as indicated by the dashed blue line.*

The CMS collaboration studied more than one million top-quark–antiquark pairs in dilepton final states recorded in 2016. To study all the spin and polarisation effects accessible in top-quark–antiquark pair production, nine event quantities sensitive to top-quark spin and correlations, and three quantities sensitive to the top-quark polarisation were measured. The measured observables were corrected for experimental effects ("unfolded") and directly compared to precise theoretical predictions.

The observables studied in this analysis show good agreement between data and theory, for example showing no angular dependence for unpolarised top quarks (see figure 1, left). A moderate discrepancy is seen in one of the measured distributions sensitive to spin (the azimuthal opening angle between two leptons), with respect to one of the Monte Carlo simulations (POWHEGv2+PYTHIA). This discrepancy is consistent with an observation made by the ATLAS collaboration last year, although CMS finds that other simulations ("MG5_aMC@NLO") and calculations that should give similar results agree with the data within the uncertainties.

A moderate discrepancy is seen in one of the measured distributions

In summary, a good agreement with the SM prediction is observed in CMS data, except for the case of one particular but commonly used observable, suggesting further input from theory calculations is probably necessary. The full Run-2 data set already recorded by CMS contains four times more top quarks than were used for this result. This larger sample will allow an even more precise measurement, increasing the chances for a first glimpse of new physics.

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ALICE

New measurements shine a light on the proton

The electromagnetic field of the highly charged lead ions in the LHC beams provides a very intense flux of high-energy quasi-real photons that can be used to probe the structure of the proton in lead–proton collisions. The exclusive photoproduction of a J/ψ vector meson is of special interest because it samples the gluon density in the proton. Previous measurements by ALICE have shown that this process could be measured in a wide range of centre-of-mass energies of the photon–proton system ($W_{\gamma p}$), enlarging the kinematic reach by more than a factor of two with respect to that of calculations performed at the former HERA collider.

Recently, the ALICE collaboration has performed a measurement of exclusive photoproduction of J/ψ mesons off protons in proton–lead collisions at a centre-of-mass energy of 5.02 TeV at the LHC using two new configurations. In both cases, the J/ψ meson is reconstructed from its decay into a lepton pair. In the first case, ▷

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CERN

the leptons are measured at mid-rapidity using ALICE's central-barrel detectors. The excellent particle-identification capabilities of these detectors allow the measurement of both the e^+e^- and $\mu^+\mu^-$ channels. The second configuration combines a muon measured with the central-barrel detectors with a second muon measured by the muon spectrometer located at forward rapidity. By this clever use of the detector configuration, we were able to significantly extend the coverage of the J/ψ measurement.

The energy of the photon–proton collisions, $W_{\gamma p}$, is determined by the rapidity (which is a function of the polar angle) of the produced J/ψ with respect to the beam axis. Since the direction of the proton and the lead beams was inverted halfway through the data-taking period, ALICE covers both backward and forward rapidities using a single-arm spectrometer.

These two configurations, plus the one used previously where both muons were measured in the muon spectrometer, allow ALICE to cover – in a continuous way – the range in $W_{\gamma p}$ from 20 to 700 GeV. The typical momentum at which the structure of the proton is probed is conventionally given as a fraction of the beam momentum, *x*, and the new measurements extend over three orders of magnitude in *x* from 2×10^{-2} to 2×10^{-5}. The measured cross section for this process as a function of $W_{\gamma p}$ is shown in figure 1 and compared with previous measurements and models based on different assumptions such as the validity of DGLAP evolution (JMRT), the vector-dominance model (STARlight), next-to-leading order BFKL, the colour-glass condensate (CGC), and the inclusion of fluctuating sub-nucleonic degrees-of-freedom (CCT). The last two models include the phenomenon of saturation, where nonlinear effects reduce the gluon density in the proton at small *x*.

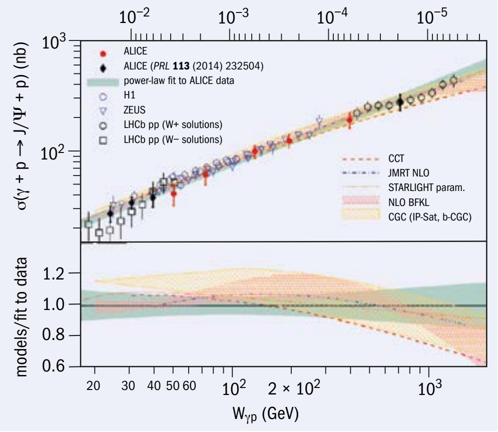

Fig. 1. *Exclusive J/ψ photoproduction off protons in proton–lead collisions at a centre-of-mass energy of 5.02 TeV, compared with previous measurements and model predictions.*

The new measurements are compatible with previous HERA data where available, and all models agree reasonably well with the data. Nonetheless, it is seen that at the largest energies, or equivalently the smallest *x*, some of the models predict a slower growth of the cross section with energy. This is being studied by ALICE with data taken in 2016 in p–Pb collisions at a centre-of-mass energy of 8.16 TeV, allowing exploration of the $W_{\gamma p}$ energy range up to 1.5 TeV, potentially shedding new light on the question of gluon saturation.

Further reading

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ATLAS

Report summarises dark-sector exploration

In our current understanding of the energy content of the universe, there are two major unknowns: the nature of a non-luminous component of matter (dark matter) and the origin of the accelerating expansion of the universe (dark energy). Both are supported by astrophysical and cosmological measurements but their nature remains unknown. This has motivated a myriad of theoretical models, most of which assume dark matter to be a weakly interacting massive particle (WIMP).

WIMPs may be produced in high-energy proton collisions at the LHC, and are therefore intensively searched for by the LHC experiments. Since dark matter is not expected to interact with the detectors, its production leaves a signature of missing transverse momentum (E_T^{miss}). It can be detected if the dark-matter particles recoil against a visible particle X, which could be a quark or gluon, a photon, or a W, Z or Higgs boson. These are commonly known as $X + E_T^{miss}$ signatures. To interpret these searches, a variety of simplified models are used that describe dark-matter production kinematics with a minimal number of free parameters. These models introduce new spin-0 or spin-1 mediator particles that propagate the interaction between the visible and the dark sectors. Because the mediators must couple to Standard Model (SM) particles in order to be produced in the proton–proton collisions, the mediators can also be directly searched for through their decays to jets, top-quark pairs and potentially even leptons. For certain model parameters, these direct searches can be more sensitive than the $X + E_T^{miss}$ ones.

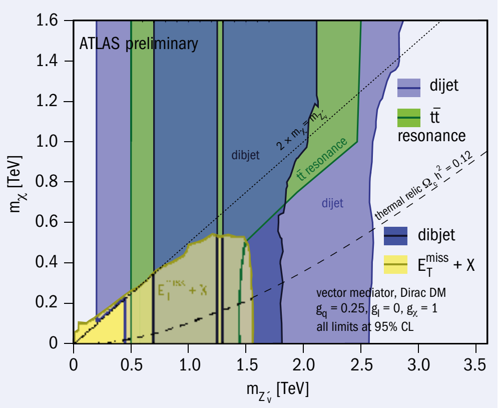


Fig. 1. *The regions in the mediator versus dark-matter mass plane excluded at 95% CL by dijet, di-b-jet, top and E_T^{miss} + X searches for vector-mediator simplified models.*

However, simplified models are not full theories like, for example, supersymmetry. Recent theoretical work has therefore focused on developing more complete, renormalisable models of dark matter, such as two-Higgs doublet models (2HDM) with an additional mediator particle. These models introduce a larger number of free parameters, allowing for a richer phenomenology.

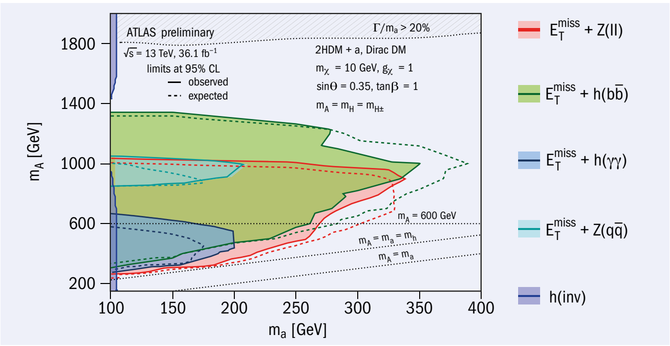
Similarly, for dark energy, effective field theory implementations may introduce a stable and non-interacting scalar field that universally couples to matter. This also leads to a characteristic E_T^{miss} signature at the LHC.

ATLAS has recently released a summary gathering the results from more than 20 experimental searches for dark matter and a first collider search for dark energy. The wide range of analyses gives good coverage for the different dark-matter models studied. For new models, such as 2HDM with an additional pseudoscalar mediator, multiple regions of the parameter space are explored to probe the interplay between the masses, mixing angles and vacuum expectation values. For the 2HDM with an additional vector mediator, the resulting exclusion limits are further improved by combining the E_T^{miss} + Higgs analyses where the Higgs boson decays to a pair of photons or b-quarks. For the dark-energy models, two operators at the lowest order effective Lagrangian allow for interactions between SM particles and the new scalar particles. These operators are proportional to the mass or momenta of the SM particles, making them most sensitive to the E_T^{miss} + top–antitop or the E_T^{miss} + jet final states.

▷

To date, no significant excess over the SM backgrounds has been observed in any of the ATLAS searches for dark matter or dark energy. Limits on the simplified models are set on the mediator-versus-dark-matter masses (figure 1), which can also be compared to those obtained by direct detection experiments. For the 2HDM with a pseudoscalar mediator, limits are placed on the heavy pseudoscalar versus the mediator masses, highlighting the complementarity of different channels in different regions of the parameter space (figure 2). Finally, collider limits on the scalar dark energy model (see p12) are also set and for the models studied improve over the limits obtained from astronomical observation and lab measurements by several orders of magnitude. With the full dataset of LHC collisions collected by ATLAS during Run 2, the sensitivity to these models will continue to improve.

Fig. 2. *Exclusion regions in the pseudoscalar Higgs versus mediator mass plane for an extended two-Higgs doublet model.*



The sensitivity to these models will continue to improve

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LHCb

Real-time triggering boosts heavy-flavour programme

Throughout LHC Run 2, LHCb has been flooded by b- and c-hadrons due to the large beauty and charm production cross-sections within the experiment's acceptance. To cope with this abundant flux of signal particles and to fully exploit them for LHCb's precision flavour-physics programme, the collaboration has recently implemented a unique real-time analysis strategy to select and classify, with high efficiency, a large number of b- and c-hadron decays. Key components of this strategy are a real-time alignment and calibration of the detector, allowing offline-quality event reconstruction within the software trigger, which runs on a dedicated computing farm. In addition, the collaboration took the novel step of only saving to tape interesting physics objects (for example, tracks, vertices and energy deposits), and discarding the rest of the event. Dubbed "selective persistence", this substantially reduced the average event size written from the online system without any loss in physics performance, thus permitting a higher trigger rate within the same output data rate (bandwidth). This has allowed the LHCb collaboration to maintain, and even expand, its broad programme throughout Run 2, despite limited computing resources.

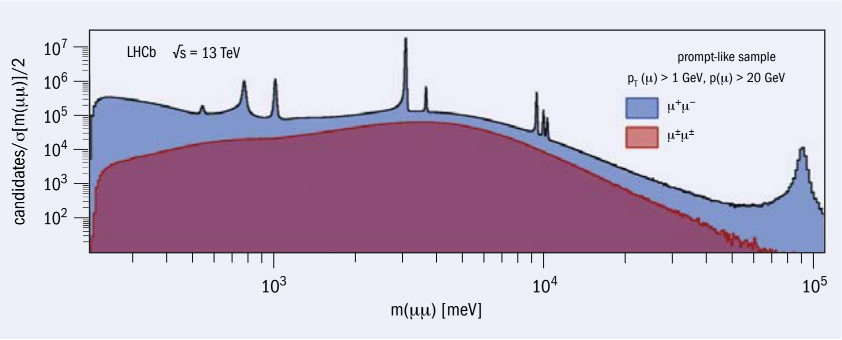

Fig. 1. *The mass spectrum of muon pairs arising from a common vertex, obtained directly from the real-time analysis trigger. No further offline processing was applied.*

The two-stage LHCb software trigger is able to select heavy flavoured hadrons with high purity, leaving event-size reduction as the handle to reduce trigger bandwidth. This is particularly true for the large charm trigger rate, where saving the full raw events would result in a prohibitively high bandwidth. Saving only the physics objects entering the trigger decision reduces the event size by a factor up to 20, allowing larger statistics to be collected at constant bandwidth. Several measurements of charm production and decay properties have been made so far using only this information. The sets of physics objects that must be saved for offline analysis can also be chosen "à la carte", opening the door for further bandwidth savings on inclusive analyses too.

For the LHCb upgrade (see p34), when the instantaneous luminosity increases by a factor of five, these new techniques will become standard. LHCb expects that more than 70% of the physics programme will use the reduced event format. The full software trigger, combined with real-time alignment and calibration, along with the selective persistence pioneered by LHCb, will likely become the standard for very high-luminosity experiments. The collaboration is therefore working hard to implement these new techniques and ensure that the current quality of physics data can be equalled or surpassed in Run 3.

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A Pearce 2016 *PoS (LHCP2018)* **226**.

FIELD NOTES

Reports from events, conferences and meetings

WUPPERTAL SUMMER SCHOOL

Interdisciplinary perspectives on particle physics

On 23–30 July 2018, physicists joined forces with researchers from the humanities to address historical, philosophical and sociological aspects of particle physics in Wuppertal, Germany. The event, the third in a series of spring and summer schools, was organised by the research unit The Epistemology of the Large Hadron Collider (ELHC), and was funded by the German Research Foundation and the Austrian Science Fund, with additional support by the University of Wuppertal. ELHC is an international collaboration between physicists, philosophers, historians and sociologists that aims for a comprehensive understanding of the goals and methods of LHC research. The unit has been active for approximately two years and follows the lead of three earlier projects at Wuppertal conducted between 2009 and 2015.


S Jarych

Bridging cultures *Physicists and humanities scholars join forces in Wuppertal.*

Discussions focussed on the theme "Particle physics at the crossroads": with no evidence of physics beyond the Standard Model from the LHC, where is particle physics headed? While these challenges are first and foremost being addressed by physicists, scholars from the humanities and social sciences can help identify the surrounding issues, such as the potential influences from social organisation. The talks at this year's summer school were all exemplars of how work in the humanities and social sciences has a bearing on current issues in high-energy physics.

Kent Staley, a philosopher from St. Louis University in the US, analysed the statistical reasoning involved in LHC research, arguing that pragmatic considerations can explain why the practice of high-energy physics relies more on frequentist statistical methods than on Bayesian ones. As an example, he contemplated what the repercussions of erroneous claims to the discovery of a Higgs boson would have been for the community, and argued that frequentist methods are better suited to avoid such claims.

Bringing together philosophy, history, sociology and particle physics proved fruitful

Friedrich Steinle, a historian of science from the Technical University Berlin, provided case studies of Newton and Faraday that demonstrated the fundamental role of concepts in physics, both in opening new vistas and providing long-term boundaries. For instance, Steinle argued that Newton's embedding of a *vis motrix* ("moving force") into a rich conceptual structure contributed to the success of Newtonian mechanics, and conjectured that a similarly deep conceptual change could open up new avenues in particle physics.

Hot debate

Rafaela Hillerbrand, a philosopher from Karlsruhe Institute of Technology, turned to another tool in LHC research – computer simulations. She proposed a classification of simulations depending on whether they provide information on abstract, laboratory or real-world systems, and discussed whether they should be seen as a theoretical or an experimental activity. This latter issue is hotly debated among philosophers, and LHC experiments, which rely on complex simulations, have attracted their attention.

Philosopher Chris Smeenk from Western University in Canada discussed a central topic in the philosophy of science: how can we ever claim even the approximate truth of a theory when the history of science shows that there were often alternative theories that had also been well confirmed empirically? Smeenk explored the extent to which this problem can be tamed by parameterising the space of alternative theories and using constraints to rule out some classes of theories. Giving an example, he explained that perturbative expansions around Minkowski space–time can be parameterised in such a way that possible alternatives to general relativity are fixed by the value ranges of these parameters.

Catherine Westfall, a science historian from Michigan State University, drew on the history of Fermilab during the 1960s and 1970s to highlight decision-making in the community. Even though in hindsight some of Fermilab's research strategies (such as its initial focus on smaller and inexpensive experiments) seem wrong-headed, she explained, the expectation of finding new phenomena at higher energies eventually paid off, for instance with the discovery of the bottom quark.

Anne Dippel from Jena University in Germany offered an anthropologist's perspective on the practice of particle physics. She emphasised that fierce competition, which is conducive to knowledge production at institutes such as CERN, manifests itself in many playful and even humorous elements in the daily work of researchers, such as the animal shelter for computer mice on the CERN campus. She also highlighted the creative potential of unforeseen incidents such as the incident at the LHC in September 2008 that temporarily forced the ▷ machine to close down.

Martina Merz, a scholar in science and technology studies at AAU Klagenfurt/Vienna, argued for the indispensability of images, such as event displays and plots of confidence limits, in reducing the complexity of the underlying data and establishing the existence of elementary particles such as the Higgs boson.

This programme was complemented by three inside views from physics. John Ellis from King's College London and CERN offered his view on future theoretical developments; former CERN Director-General Rolf-Dieter Heuer provided insights into the factors driving particle-physics research; and ATLAS member Christian Zeitnitz from Wuppertal University, as well as Margarete Mühlleitner from the Karlsruhe Institute of Technology, gave introductory lectures on experiment and theory, respectively.

At the end of the school, the discussions returned to the central theme of "particle physics at the crossroads", and found that the metaphor of a jungle, in which not even paths are clearly laid out, might be apt to characterise the current situation. One may feel reminded here of the situation in the 1960s where a "zoo" of particles was discovered without any hint, at least at first, of what theoretical structures underpinned them. However, the current situation is rather different because it is precisely such hopes for discovering particles beyond the current theory that have been dashed by the LHC so far.

Discussions focussed on the theme "Particle physics at the crossroads"

The participants agreed that bringing together philosophy, history, sociology and particle physics was fruitful and less hampered by controversy than one might have expected. As the so-called science wars of the 1990s showed, it requires an open mind on all sides to facilitate a fruitful discussion between the natural sciences, the social sciences and the humanities. The future of particle physics may be uncertain, but collaborative efforts such as the Wuppertal summer school will certainly contribute to a better assessment of the aims and relevance of this branch of fundamental physics research.

Florian Boge *RWTH Aachen University/IZWT Wuppertal and* **Adrian Wüthrich** *Technical University Berlin.*

DIS2018

The future of deep-inelastic scattering


H Hiramoto

All things hadron *Participants of the DIS workshop covered a vast range of physics.*

The most recent edition of the International Workshop on Deep Inelastic Scattering and Related Subjects (DIS2018) was held in Kobe, Japan, on 16–20 April 2018. The event continued in the style of a workshop, with almost 250 talks presenting new results on all things hadron physics: spin and 3D structure, structure functions and parton densities, and quantum chromodynamics (QCD) studies for high-sensitivity electroweak, Higgs and beyond-Standard Model measurements, to name a few.

The vast range of physics covered in DIS workshops cannot be easily integrated into a single theoretical framework, and there are slightly different views on hadronic interactions depending on the type and energy of the underlying collisions. One view, which applies to high-energy collisions, is a combination of fast-moving partons with little transverse momentum and a large amount of radiation in the initial and final states. Another is the parton and spin dynamics in hadrons and nuclei viewed "in 3D", where the transverse momentum and collective motions of partons play an important role in describing hadron behaviour.

Traditionally, these two views are discussed separately at DIS meetings, but the situation is gradually changing owing to projects for new lepton–hadron colliders. The proposed Electron Ion Collider (EIC) at the Brookhaven National Laboratory or Jefferson Lab in the US, at centre-of-mass energies of about 100 GeV (*CERN Courier* October 2018 p31), would offer not only a detailed tomographic view of the space and spin structure of quarks and gluons inside nucleons and nuclei, but also, thanks to its very high luminosity, high-precision probes of partons that carry a high-momentum fraction of the parent hadron.

Evolution

Meanwhile, the proposed Large Hadron electron Collider (LHeC) at CERN, bringing proton beams from the LHC into collision with electrons accelerated up to 60 GeV through a dedicated energy-recovery linac, would provide, in addition to precise measurements in the Higgs sector, more information on hadron structure through electron–proton and electron–ion collisions in regions of very low Bjorken-x and very high Q^2. LHeC would also allow researchers to see, through the behaviour of total and diffractive cross sections in the high-energy limit, if there is any saturation in the parton evolution inside nucleons and nuclei. Further down the line, the Future Circular Collider hadron–electron (FCC-he) project at CERN, as well the proposed very-high-energy electron–proton (VHEeP) collider with a 3 TeV electron beam accelerated by a proton-driven wakefield, also at CERN, could probe hadron structure in the high-energy limit too. These projects are intimately related, and call for a unified discussion of hadron physics across collision energies.

Given these developments, the 2018 DIS workshop comprised experimental and theory talks covering results from various energy regimes, as well as review talks on related subjects such as neutrino–nuclei scattering, parton fragmentation and exotic hadrons, to seek possible connections between traditional DIS studies and new ones. In addition, this year's event featured a special discussion session on future strategies for DIS studies and related subjects, following presentations by experimentalists from EIC, LHeC, VHEeP and FCC-he, and theorists working on QCD and heavy-ion physics. The responses of the participants were positive, noting the importance and complementarity of the projects. The outcome of the discussion has been summarised in a document that was submitted to the update of the European Strategy for Particle Physics.

The event also featured the award ceremony for the 2018 Guido Altarelli Award (*CERN Courier* July/August 2018 p36), which recognised the work of early-career scientists Jun Gao, on precision QCD theory, and Or Hen, on the "EMC effect" and the valence down- and up-quark ratio.

The next DIS workshop will take place in Turin, Italy, from 8 to 12 April 2019.

Yuji Yamazaki *Kobe University and chair of the DIS2018 organising committee.*

RUPAC2018

Russian accelerator science in focus

The 26th Russian Particle Accelerator Conference, RUPAC2018, was convened on 1–5 October 2018 in Protvino, Russia, at the Institute for High Energy Physics of the National Research Centre "Kurchatov Institute" (NRC KI–IHEP). This year the traditional biennial conference, which started in 1968, gathered some 170 participants from accelerator centres in Russia, Germany, Italy, Sweden, Romania, Canada and China to discuss the latest developments and results in accelerator science and engineering. The conference was organised by the Budker Institute of Nuclear Physics (BINP), the Joint Institute for Nuclear Research (JINR), and the NRC KI–IHEP under the auspices of the Russian Academy of Sciences.

The 54 oral talks and 135 poster contributions featured both national and international accelerator facilities, but attention was directed at Russia's domestic machines. BINP in Novosibirsk presented status reports on the VEPP-2000 and VEPP-4M electron–positron colliders, the operation of which has improved noticeably after the commissioning of a new positron injection chain. Talks from NRC KI–IHEP in Protvino reviewed the U70 proton synchrotron, which is now operated for 50–60 GeV fixed-target experimental physics, proton radiography studies and applied radiobiology research using carbon–nuclei beams.


NRC KI–IHEP

In step *Vladimir Petrov from the Institute for High Energy Physics, Protvino, speaking at RUPAC2018.*

The bulk of reports from JINR in Dubna were devoted to progress in the Nuclotron-based Ion Collider Facility (NICA) project at the nuclotron facility. Significant progress was also reported for the heavy-ion cyclotrons of the JINR's Flerov Laboratory of Nuclear Reactions (FLNR). The status of, and plans for, the other operational domestic machines – the high-intensity proton linear accelerator at INR (Troitsk), the synchrotron radiation (SR) source KSSR-2 at NRC KI (Moscow) and the 1 GeV synchrocyclotron SC-1000 at NRC KI–PNPI (Gatchina) – were also presented. Due attention was also given to two new SR projects: the Siberian Circular Photon Source (SKIF) and the fourth-generation Specialized Synchrotron Radiation Source-4.

It was fitting that the conference was held in a year of a few round-figure anniversaries for the Russian accelerator community: 75 years of the Kurchatov Institute (Moscow); 60 years of BINP (Novosibirsk) and 100 years of its founder and first director Gersh Budker; 55 years of IHEP (Protvino); and 50 years since the first national particle accelerator conference, the forerunner of the RUPAC series, was convened. The next meeting will be held in the autumn of 2020.

Sergey Ivanov *chair of the RUPAC2018 organising committee.*

LHCb WORKSHOP

Community talks heavy-flavour physics and more

On 17–19 October 2018, physicists from the LHCb collaboration and the theory community gathered at CERN to discuss the implications of LHCb's results and prospects for future studies. This was the eighth in a series of workshops that has become an annual tradition, attracting more than 200 physicists from all over the world, plus more participants connected remotely by video link.

LHCb is at the forefront of heavy-flavour physics research – as well as being active in heavy-ion and forward-electroweak physics – and the workshop was a welcome opportunity to discuss the latest developments, including some that were shown for the first time, and to consider what will be possible with LHCb's planned upgrades. The workshop was capped by a theory keynote talk by Antonio Pich from Valencia, which addressed current tensions between the Standard Model (SM) and recent results in flavour physics.

The physics content of the workshop was divided into four streams. The first was on mixing and CP violation in beauty and charm hadrons, looking at non-leptonic decays. A major focus was on extracting the γ parameter of the Cabibbo–Kobayashi–Maskawa quark-mixing matrix and the B^0 and B_s^0 mixing angles, with experimental updates presented. Measurements of B_s^0 mixing play an especially important role in constraining physics beyond the SM, and improved inputs from lattice quantum chromodynamics (QCD) calculations are crucial to this endeavour. Part of the session was dedicated to the decays of B mesons to multibody final states; the large CP asymmetries seen in these decays remain puzzling, and the community is eagerly waiting for experimental updates. The description of the final-state interactions in these decays is important but theoretically challenging. Many new, promising theoretical approaches, such as the use of triangle diagrams to describe the interactions, were discussed.

The workshop was a welcome opportunity to consider what will be possible with LHCb's planned upgrades

In the second stream, semileptonic decays, rare decays and tests of lepton flavour universality were covered. Discussions triggered by the tantalising hints of lepton-flavour-universality violation seen in tree-level and loop-suppressed decays – R_K and R_{K^*}, R(D) and R(D*), and the kinematic and angular distributions of $b \to s\,\mu^+\mu^-$ decays – were the highlight of this stream. After reviewing LHCb's experimental results, theory talks presented overviews of the status of SM calculations based on approaches such as non-perturbative lattice QCD simulations or QCD sum rules. Further new ideas were presented to improve SM predictions and address ▷ theory uncertainties, particularly those affecting predictions for $B \to D^*\ell\nu$ decays. Finally, the implications of the present anomalies were discussed from a model-building point of view, with special emphasis on models including leptoquarks, which could explain several of the current anomalies at once.

Unique potential

The third stream of the workshop covered the active experimental programme spanning electroweak physics, exotica, heavy flavour, heavy ions and central exclusive production. In the related theory talks, the unique potential of LHCb's forward acceptance to pin down the proton parton distribution functions in the unconstrained QCD regimes of low and high longitudinal momentum fraction (x) was discussed, as were a variety of models with the distinctive signature of displaced heavy neutral lepton decays that could explain neutrino oscillations and non-zero neutrino masses. Presentations also focused on the full multitude of charmonia ($c\bar{c}$ states) accessible to LHCb beyond the J/ψ, from the η_c to exotic X, Y and Z states. Future measurements of these states in a variety of collision systems will shed light on the low-x QCD regime, on nuclear structure and on the as-yet-unresolved puzzle of quarkonium production itself. Finally, progress on CODEX-b, a proposed additional detector to search for long-lived particles at LHCb, was presented: the background flux in the cavern has been measured, and simulation studies of potential backgrounds were shown.

The fourth physics stream was devoted to QCD spectroscopy. LHCb reported discoveries of several new baryons with heavy flavour, and theory talks discussed the impressive success of a semi-empirical approach to predict their masses. There were also new results from LHCb on exotic hadrons – those that defy interpretation as conventional mesons or baryons – and predictions from theory for related future discoveries. Several different quark models as well as lattice QCD agree in predicting a stable tetraquark with two bottom quarks and two light antiquarks. Experimental prospects for its discovery with the upgraded LHCb detector were discussed, and a new experimental method using B_c^+ mesons not originating at a primary vertex as a signature was proposed for identifying this and other hadrons with two bottom quarks.

Fresh results using data from LHC Run 2 were served up, but there was a strong appetite for more

Fresh results using data from LHC Run 2 were served up in all four streams, but there was a strong appetite for more. Key questions remain on the nature of the lepton flavour anomalies and on whether they will persist or fade as more data are added (*CERN Courier* April 2018 p23). Crucial questions also remain about the origin of the large local CP violation seen in multibody decays, the nature of exotic hadrons, and more. By the next workshop we will hopefully have some answers – and perhaps a few more questions. Preparations for the Run 3 physics programme will also be in full swing, ready for the big boost in statistics that will come from a complete overhaul of the detector and its readout system during the next two years (see p34). LHCb is also planning further upgrades, and the prospects for what we might learn with much more data – a factor 30 more than today – will surely be a hot topic.

Mat Charles *on behalf of the LHCb collaboration and theory contributors.*

CERN–SOUTH AFRICA

South Africa marks 10 years of CERN collaboration

An event commemorating the 10th anniversary of the CERN–South Africa programme took place at iThemba Laboratory for Accelerator-Based Sciences (iThemba LABS) in Cape Town from 19 to 21 November 2018, highlighting the importance of South African involvement in CERN and opportunities to further strengthen the partnership. The event was packed out, with the French and Swiss ambassadors to South Africa, the vice-chancellors of the universities of Cape Town and the Witwatersrand, internationally renowned physicists from CERN and South Africa, and many young students from South Africa and from other parts of Africa attending. The event also included impressive exhibitions and presentations from local industry.

Strengthening connections *Sibaliso Mhlanga (right) of iThemba LABS talking heavy-ion physics with CERN director for international relations Charlotte Warakaulle during a poster session.*

S Mouton

In terms of the number of participating scientists and engineers, South Africa is CERN's most important partner on the African continent. Researchers from several universities participate in the ALICE and ATLAS experiments as well as in ISOLDE, and are also visitors to CERN's theoretical physics department. The South African particle-physics community continues to grow and is expected to benefit from important synergies with the Square Kilometre Array (SKA) radio-telescope project, which South Africa will host jointly with Australia and which will require a massive computing infrastructure similar to the worldwide LHC computing grid. In fact, the SKA organisation signed an agreement with CERN in 2017 to address the challenges of such "exascale" computing and data storage (*CERN Courier* September 2017 p9).

The LHC has brought many opportunities for South Africa's science community, including contributions to major breakthroughs such as the discovery of the Higgs boson in 2012. In return, the CERN–South Africa partnership has helped to strengthen nuclear and particle physics efforts in South Africa. It has also accelerated technology development, enhancing both technological and social innovation and providing advanced scientific training for the next generation of South African scientists and engineers. It is expected and hoped that this valuable crossover of skills will continue long into the future.

Emmanuel Tsesmelis *CERN.*

ISOLDE WORKSHOP

Users highlight successful campaigns

K Johnston

Prize winners *The workshop organiser Gerda Neyens (second from right) with Victoria Araujo-Escalona and Natalia Sokolowska (two most left), who won for the best poster, and Tiago De Lemos Lima and Lisa Morrison (left and right of Neyens), who won for best young speaker.*

On 5–7 December 2018, the annual ISOLDE Workshop and Users meeting took place at CERN, attracting 153 participants. The programme consisted of 41 presentations, of which 22 were invited talks and 19 were oral contributions selected from 74 submitted abstracts.

ISOLDE, CERN's long-running nuclear research facility, directs a high-intensity proton beam from the Proton Synchrotron Booster (PSB) at a target station to produce a range of isotopes. Different devices are used to extract, ionise and separate the isotopes according to their mass, forming low-energy beams that are delivered to various experiments. These radioactive ion beams (RIBs) can also be re-accelerated using the REX/HIE-ISOLDE linear accelerators (linacs). An energy upgrade of the HIE-ISOLDE superconducting linac was completed this year, enabling RIBs with an energy up to about 10 MeV per nucleon.

A focus of the 2018 ISOLDE workshop concerned plans for upgrades and consolidation works during the second long shutdown of CERN's accelerator complex (LS2), including replacing 10-year-old equipment and adding more beam-monitoring systems. Five sessions were devoted to overviews from ISOLDE users on the outcome of physics campaigns at the different experimental set-ups, two sessions discussed progress at other RIB facilities in the world, and one session focused on applications in life sciences with an emphasis on the CERN MEDICIS programme.

The meeting began with an overview of successful experimental campaigns at the HIE-ISOLDE RIB accelerator, with operational set-ups achieved at all three beam lines. A total of 17 different RIBs were accelerated during July–November 2018. Beams of isotopes with an atomic mass from 7 to 228, with the radium-228 beam being the heaviest ever accelerated beam at ISOLDE, were delivered. The HIE-ISOLDE campaign began with seven experiments at the first beam line, with the MINIBALL detector array and its ancillary detectors. In October two experiments used the new ISOLDE solenoid spectrometer at the second beam line for the first time, with an inner detector lent from Argonne National Laboratory. For these, the full accelerator capacity was used for the first time. At the third beam line, used for "traveling experiments", three experiments used the scattering chamber – a large vacuum chamber that can hold several combinations of particle detectors brought by the users; one experiment used an optical time projection chamber to look for very rare proton decays from the halo nucleus beryllium-11.

The last experiment was performed in the scattering chamber, after protons stopped circulating in CERN's accelerator complex, by extracting long-lived beryllium-7 from an ISOLDE target that had been irradiated earlier. The first HIE-ISOLDE physics paper, accepted for publication in *Physical Review Letters*, was also highlighted. It provides the first direct proof that the very neutron-rich tin-132 nucleus, considered to be doubly magic, does indeed merit this special status.

Other sessions were dedicated to the rich low-energy experimental physics programme at ISOLDE. Overview talks were presented on recent achievements in high-precision mass studies, with indium-100 as a highlight; on collinear laser spectroscopy studies, with a long series of antimony isotopes and isomers; on decay-spectroscopy experiments; and on the solid-state physics programmes. Participants also heard about recent studies with antiprotons at the Antiproton Decelerator at CERN and about the extremely exotic isotopes produced at the Radioactive Isotope Beam Factory (RIBF) facility at RIKEN in Japan. The study of exotic isotopes using the VAMOS spectrometer at the French GANIL laboratory was discussed, as were new beam-production facilities at the Selective Production of Exotic Species (SPES) facility at Legnaro National Laboratory in Italy and the new neutron detector array NEULAND at the Facility for Antiprotons and Ions Research (FAIR) at GSI in Germany.

The meeting ended with the handing over of four prizes, sponsored by CAEN, for the best talks and posters presented by young researchers (see image). The 2018 ISOLDE users meeting was a great success, highlighting the important research being done at this unique facility.

Gerda Neyens *ISOLDE physics group leader.*

CERN–AUSTRIA

Silver celebration for student programme

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Student success *Celebrating the CERN–Austria PhD programme in November.*

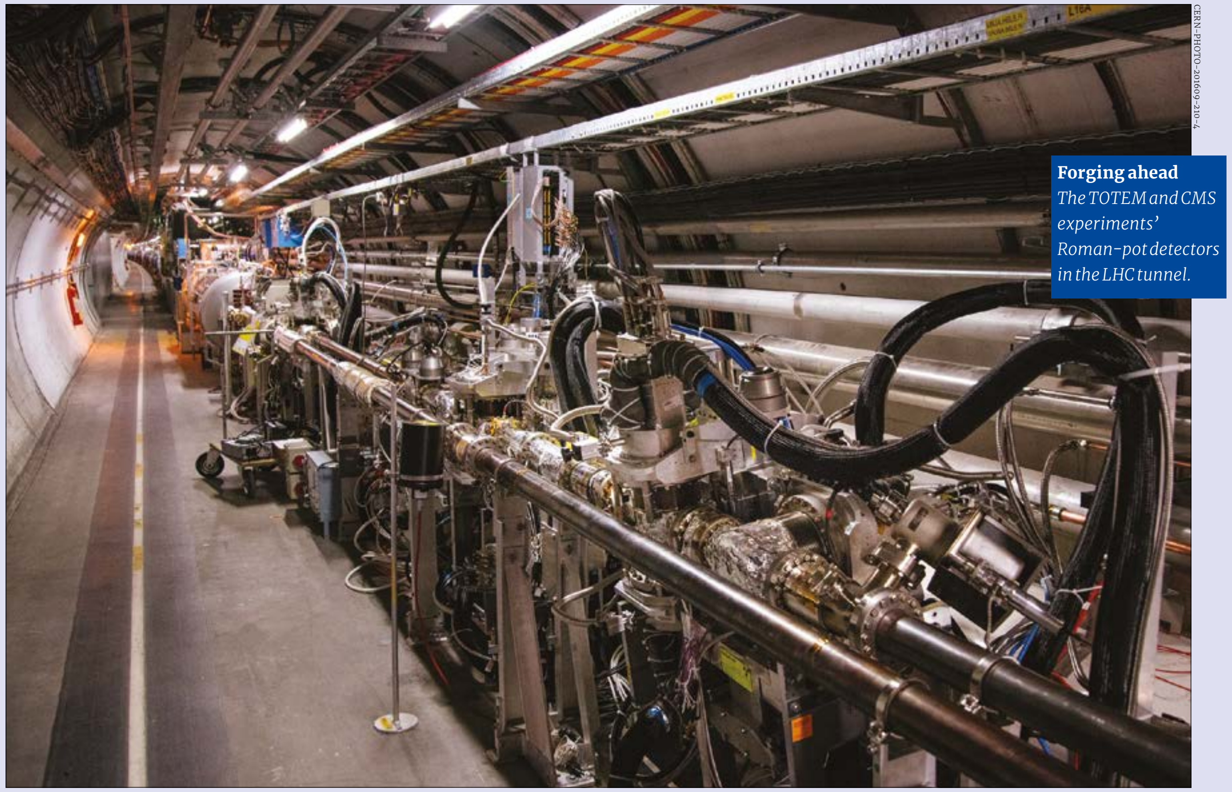
Young researchers from throughout the world came together at CERN on 30 November to celebrate the 25th anniversary of the CERN–Austrian doctoral student programme. Founded in 1993, following an agreement between CERN and the Austrian Ministry for Science and Research, the programme supports students from Austrian universities to pursue their PhD research at CERN in technology-related fields.

So far the programme has trained nearly 200 students in the stimulating environment offered by CERN. The bulk of these were in the fields of accelerator and detector research, with information technology and electronics also featuring large. Statistics from the programme show that, in the medium term, one third of all programme participants return to Austria, while much of the rest remain at CERN or work in other European countries.

Working in a cross-disciplinary and multicultural research environment such as CERN, participants learn how to collaborate in international networks, are exposed to leading-edge technologies and hone their language skills. The Austrian Ambassador, Elisabeth Tichy-Fisslberger, who participated in the celebration, underlined that the programme has also helped strengthen broader links between CERN and Austria, allowing significant technology transfer and networking with Austrian universities and high-tech industries.

The CERN–Austrian PhD programme serves as a model of efficient collaboration between CERN and its member states, and has inspired similar initiatives from other countries.

Michael Benedikt *CERN.*



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Forging ahead *The TOTEM and CMS experiments' Roman-pot detectors in the LHC tunnel.*

LARGE HADRON COLLIDER

THE EXPERIMENTS STRIKE BACK

The LHC lies dormant, its superconducting magnets drained of liquid helium to be brought back to room temperature. Along with the rest of CERN's accelerator complex, the LHC entered long-shutdown two (LS2) on 10 December.

The features in this first issue of 2019 bring you all the shutdown news from the seven LHC experiments, and what to expect when the souped-up detectors come back online in 2021.

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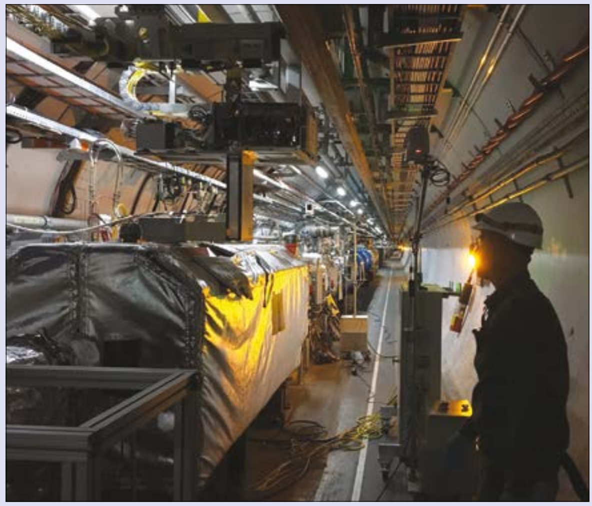
Wired *The MoEDAL (Monopole & Exotics Detector at the LHC) experiment in the LHCb cavern.*


L Bonechi/LHCf

Forward physics *The LHCf experiment located on either side of ATLAS simulates cosmic-ray interactions.*

During the next two years of long-shutdown two (LS2), the LHC and its injectors will be tuned up for high-luminosity operations: Linac2 will leave the floor to Linac4 to enable more intense beams; the Proton Synchrotron Booster will be equipped with completely new injection and acceleration systems; and the Super Proton Synchrotron will have new radio-frequency power. The LHC is also being tested for operation at its design energy of 14 TeV, while, in the background, civil-engineering works for the high-luminosity upgrade (HL-LHC), due to enter service in 2026, are proceeding apace.

The past three years of Run 2 at a proton–proton collision energy of 13 TeV have seen the LHC achieve record peak and integrated luminosities, forcing the detectors to operate at their limits. Now, the four main experiments ALICE, ATLAS, CMS and LHCb, and the three smaller experiments LHCf, MoEDAL and TOTEM, are gearing up for the extreme conditions of Run 3 and beyond.

At the limits

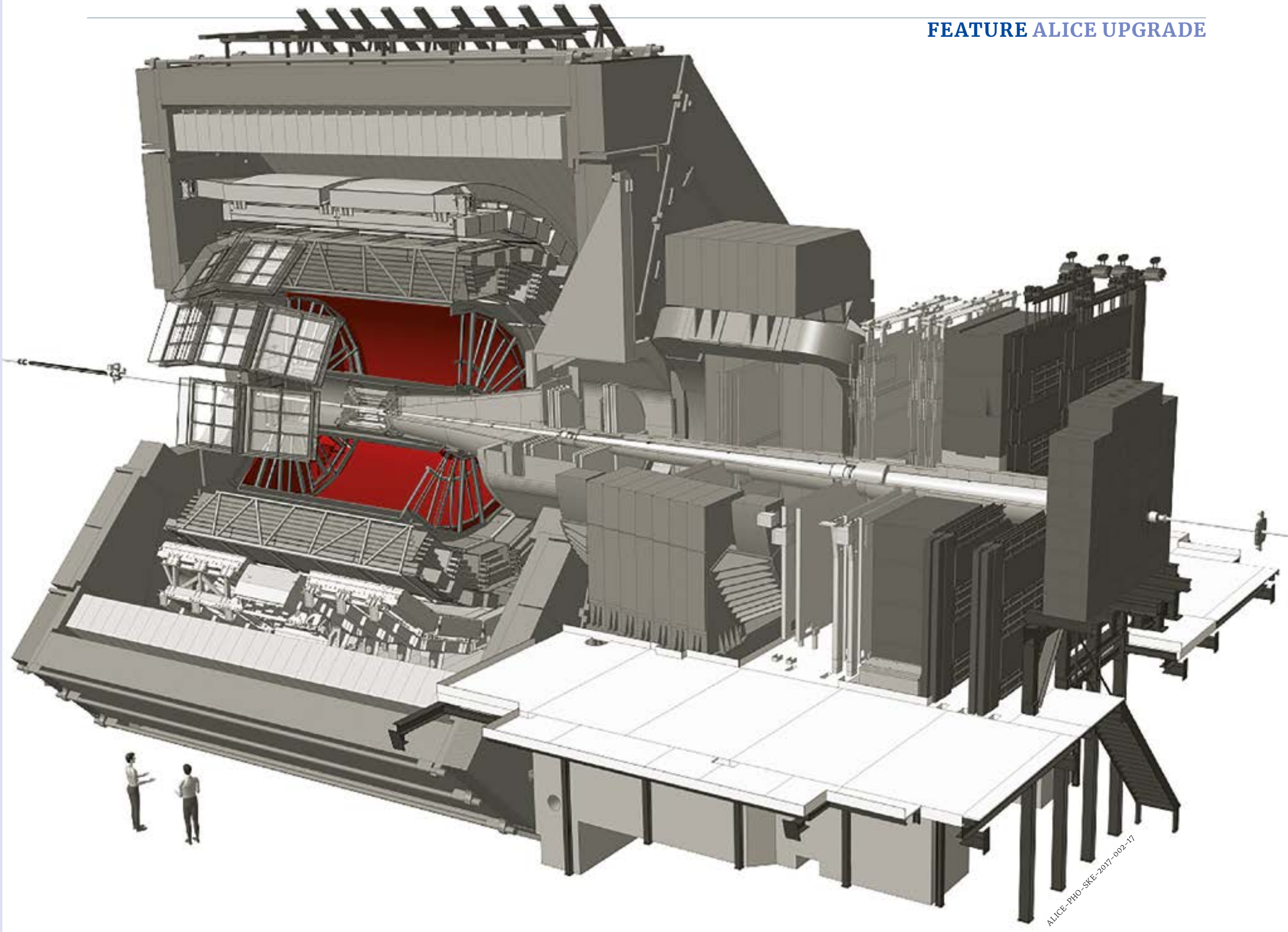
Since the beginning of the LHC programme, it was clear that the original detectors would last for approximately a decade due to radiation damage. That time has now come. Improvements, repairs and upgrades have been taking place in the LHC detectors throughout the past decade, but significant activities will take place during LS2 (and LS3, beginning 2024), capitalising on technology advances and the ingenuity of thousands of people over a period of several years. Combined, the technical design reports for the LHC experiment upgrades number some 20 volumes each containing hundreds of pages.

For LHCb, the term "upgrade" hardly does it justice, since large sections of the detector are to be completely replaced and a new trigger system is to be installed (p34). ALICE too is undergoing major interventions to its inner detectors during LS2 (p25), and both collaborations are installing new data centres to deal with the higher data rate from future LHC runs. ATLAS and CMS are upgrading numerous aspects of their detectors while at the same time preparing for major installations during LS3 for HL-LHC operations (p28 and 31). At the HL-LHC, one year of collisions is equivalent to 10 years of LHC operations in terms of radiation damage. Even more challenging, HL-LHC will deliver a mean event pileup of up to 200 interactions per beam crossing – 10 times greater than today – requiring totally new trigger and other capabilities.

In terms of radiation damage, one year of HL-LHC collisions is equivalent to 10 years of LHC operations

Three smaller experiments at the LHC are also taking advantage of LS2. TOTEM, which comprises two detectors located 220 m either side of CMS to measure elastic proton–proton collisions (see image on previous page), aims to perform total-cross-section measurements at maximal LHC energies. For this, the collaboration is building a new scintillator detector to be integrated in CMS, in addition to service work on its silicon-strip and spectrometer detectors. Another "forward" experiment called LHCf, made up of two detectors 140 m either side of ATLAS, uses forward particles produced by the LHC collisions to improve our knowledge about how cosmic-ray showers develop in Earth's atmosphere. Currently, the LHCf detectors are being prepared for 14 TeV proton–proton operations, higher luminosities and also for the possibility of colliding protons with light nuclei such as oxygen, requiring a completely renewed data-acquisition system. Finally, physicists at MoEDAL, a detector deployed around the same intersection region as LHCb to look for magnetic monopoles and other signs of new physics, are preparing a request to take data during Run 3. For this, among other improvements, a new sub-detector called MAPP will be installed to extend MoEDAL's physics reach to long-lived and fractionally charged particles.

The seven LHC experiments are also using LS2 to extend and deepen their analyses of the Run-2 data. Depending on what lies there, the collaborations could have more than just shiny new detectors on their hands by the time they come back online in the spring of 2021. ●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ALICE REVITALISED

The ALICE experiment is being tuned up to make even more precise measurements of the quark–gluon plasma and other extreme nuclear systems.

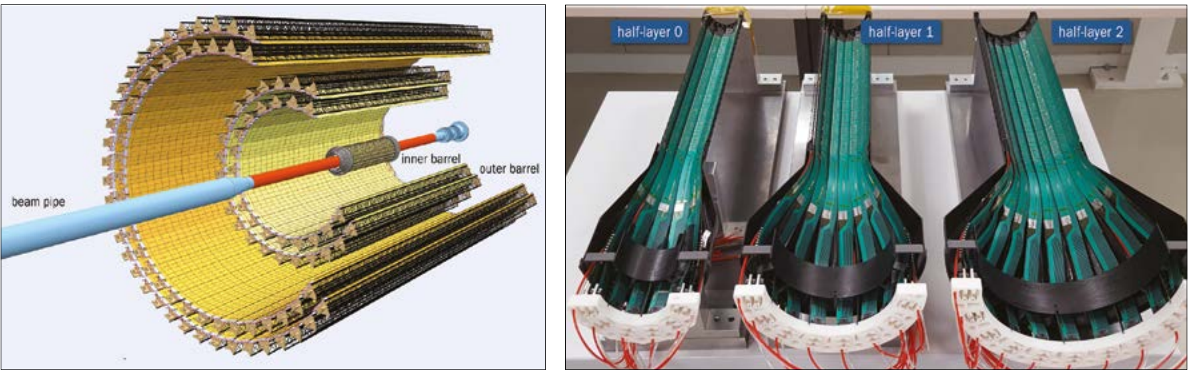
ALICE (A Large Ion Collider Experiment) will soon have enhanced physics capabilities thanks to a major upgrade of the detectors, data-taking and data-processing systems. These upgrades will improve the precision on measurements of the high-density, high-temperature phase of strongly interacting matter, the quark–gluon plasma (QGP), together with the exploration of new phenomena in quantum chromodynamics (QCD). Since the start of the LHC programme, ALICE has been participating in all data runs, with the main emphasis on heavy-ion collisions, such as lead–lead, proton–lead, and xenon–xenon collisions. The collaboration has been making major inroads into the understanding of the dynamics of the QGP – a state of matter that prevailed in the first instants of the universe and is recreated in droplets at the LHC.

THE AUTHORS

Tapan Nayak
is ALICE deputy spokesperson.

Virginia Greco
is communications officer for ALICE.

To perform precision measurements of strongly interacting matter, ALICE must focus on rare probes – such as heavy-flavour particles, quarkonium states, real and virtual photons, and low-mass dileptons – as well as the study of jet quenching and exotic nuclear states. Observing rare phenomena requires very large data samples, which is why ALICE is looking forward to the increased luminosity provided by the LHC in the coming years. The interaction rate of lead ions during the LHC Run 3 is foreseen to reach around 50 kHz, corresponding to an instantaneous luminosity of 6×10^{27} cm^{-2} s^{-1}. This will enable ALICE to accumulate 10 times more integrated luminosity (more than 10 nb^{-1}) and a data sample 100 times larger than what has been



C Gargiulo

A Junique

Inner tracker *Left: a schematic of the upgraded inner tracking system (ITS) showing the MAPS layers, carbon-fibre supports (black) and the narrower beampipe in the central region (orange). Right: photograph of the upgraded ITS inner half-layers.*

obtained so far. In addition, the upgraded detector system will have better efficiency for the detection of short-lived particles containing heavy-flavour quarks thanks to the improved precision of the tracking detectors.

During long-shutdown two (LS2), several major upgrades to the ALICE detector will take place. These include: a new inner tracking system (ITS) with a new high-resolution, low-material-budget silicon tracker, which extends to the forward rapidities with the new muon forward tracker (MFT); an upgraded time projection chamber (TPC) with gas electron multiplier (GEM) detectors, along with a new readout chip for faster readout; a new fast interaction trigger (FIT) detector and forward diffraction detector. New readout electronics will be installed in multiple subdetectors (the muon spectrometer, time-of-flight detector, transition radiation detector, electromagnetic calorimeter, photon spectrometer and zero-degree calorimeter) and an integrated online-offline (O^2) computing system will be installed to process and store the large data volumes.

Detector upgrades

A new all-pixel silicon inner tracker based on CMOS monolithic active pixel sensor (MAPS) technology will be installed covering the mid-rapidity ($|\eta| < 1.5$) region of the ITS as well as the forward rapidity ($-3.6 < \eta < -2.45$) of the MFT. In MAPS technology, both the sensor for charge collection and the readout circuit for digitisation are hosted in the same piece of silicon instead of being bump-bonded together. The chip developed by ALICE is called ALPIDE, and uses a 180 nm CMOS process provided by TowerJazz. With this chip, the silicon material budget per layer is reduced by a factor of seven compared to the present ITS. The ALPIDE chip is $15 \times 30\,\text{mm}^2$ in area and contains more than half a million pixels organised in 1024 columns and 512 rows. Its low power consumption ($< 40\,\text{mW/cm}^2$) and excellent spatial resolution ($\sim 5\,\mu\text{m}$) are perfect for the inner tracker of ALICE.

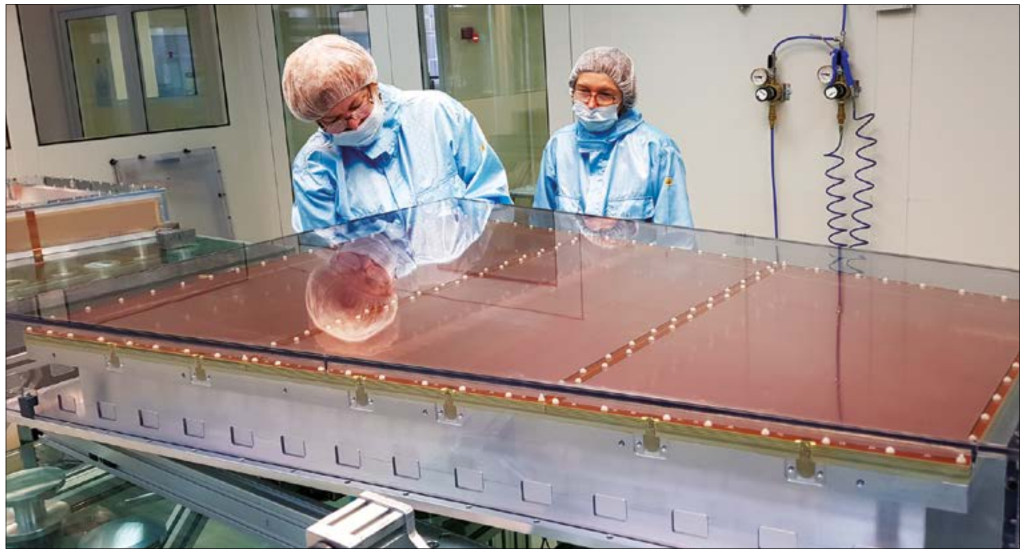
The ITS consists of seven cylindrical layers of ALPIDE chips, summing up to 12.5 billion pixels and a total area of $10\,\text{m}^2$. The pixel chips are installed on staves with radial distances 22–400 mm away from the interaction point (IP). The beam pipe has also been redesigned with a smaller outer radius of 19 mm, allowing the first detection layer to be placed closer to the IP at a radius of 22.4 mm compared to 39 mm at present. The brand-new ITS detector will improve the impact parameter resolution by a factor of three in the transverse plane and by a factor of five along the beam axis. It will extend the tracking capabilities to much lower p_T, allowing ALICE to perform measurements of heavy-flavour hadrons with unprecedented precision and down to zero p_T.

In the forward-rapidity region, ALICE detects muons using the muon spectrometer. The new MFT detector is designed to add vertexing capabilities to the muon spectrometer and will enable a number of new measurements that are currently beyond reach. As an example, it will allow us to distinguish J/ψ mesons that are produced directly in the collision from those that come from decays of mesons that contain a beauty quark. The MFT consists of five disks, each composed of two MAPS detection planes, placed perpendicular to the beam axis between the IP and the hadron absorber of the muon spectrometer.

The TPC is the main device for tracking and charged-particle identification in ALICE. The readout rate of the TPC in its present form is limited by its readout chambers, which are based on multi-wire proportional chambers. In order to avoid drift-field distortions produced by ions from the amplification region, the present readout chambers feature a charge gating scheme to collect back-drifting ions that lead to a limitation of the readout rate to 3.5 kHz. To overcome this limitation, new readout chambers employing a novel configuration of stacks of four GEMs have been developed during an extensive R&D programme. This arrangement allows for continuous readout at 50 kHz with lead–lead collisions, at no cost to detector performance. The production of the 72 inner (one GEM stack each) and outer (three GEM stacks each) chambers is now practically completed and certified. The replacement of the chambers in the TPC will take place in summer 2019, once the TPC is extracted from the experimental cavern and transported to the surface.

The new forward interaction trigger, FIT, comprises two arrays of Cherenkov radiators with MCP-PMT sensors and a single, large-size scintillator ring. The arrays will be placed on both sides of the IP. It will be the primary trigger, luminosity and collision time-measurement detector in ALICE. The detector will be capable of triggering at an interaction rate of 50 kHz, with a time resolution better than 30 ps, with 99% efficiency.

The newly designed ALICE readout system presents a change in approach, as all lead–lead collisions that are produced in the accelerator, at a rate of 50 kHz, will be read out in a continuous stream. However, triggered readout will be used by some detectors and for commissioning and calibration runs and the central trigger processor is being upgraded to accommodate the higher interaction rate. The readout of the TPC and muon chambers will be performed by SAMPA, a newly developed, 32-channel front-end analogue-to-digital converter with integrated digital signal processor.



ALICE-PHO-GEN-2019-001-45

Enhancements *Working on assembling one of the gas electron multiplier detectors in the cleanroom.*

ALICE will be ready to enter into a new era of high-precision measurements that will expand and deepen our understanding of the physics of hot and dense QCD matter

Performance boost

The significantly improved ALICE detector will allow the collaboration to collect 100 times more events during LHC Run 3 compared to Run 1 and Run 2, which requires the development and implementation of a completely new readout and computing system. The O^2 system is designed to combine all the computing functionalities needed in the experiment: detector readout, event building, data recording, detector calibration, data reconstruction, physics simulation and analysis. The total data volume produced by the front-end cards of the detectors will increase significantly, reaching a sustained data throughput of up to 3 TB/s. To minimise the requirements of the computing system for data processing and storage, the ALICE computing model is designed for a maximal reduction in the data volume read out from the detectors as early as possible during the data processing. This is achieved by online processing of the data, including detector calibration and reconstruction of events in several steps synchronously with data taking. At its peak, the estimated data throughput to mass storage is 90 GB/s.

A new computing facility for the O^2 system is being installed on the surface, near the experiment. It will have a data-storage system with a storage capacity large enough to accommodate a large fraction of data of a full year's data taking, and will provide the interface to permanent data storage at the tier-0 Grid computing centre at CERN, as well as other data centres.

ALICE upgrade activities are proceeding at a frenetic pace. Soon after the machine stopped in December, experts entered the cavern to open the massive doors of the magnet and started dismounting the detector in order to prepare for the upgrade. Detailed planning and organisation of the work are mandatory to stay on schedule, as Arturo Tauro, the deputy technical coordinator of ALICE explains: "Apart from the new detectors, which require dedicated infrastructure and procedures, we have to install a huge number of services (for example, cables and optical fibres) and perform regular maintenance of the existing apparatus. We have an ambitious plan and a tight schedule ahead of us."

When the ALICE detector emerges revitalised from the two busy and challenging years of work ahead, it will be ready to enter into a new era of high-precision measurements that will expand and deepen our understanding of the physics of hot and dense QCD matter and the quark–gluon plasma. ●

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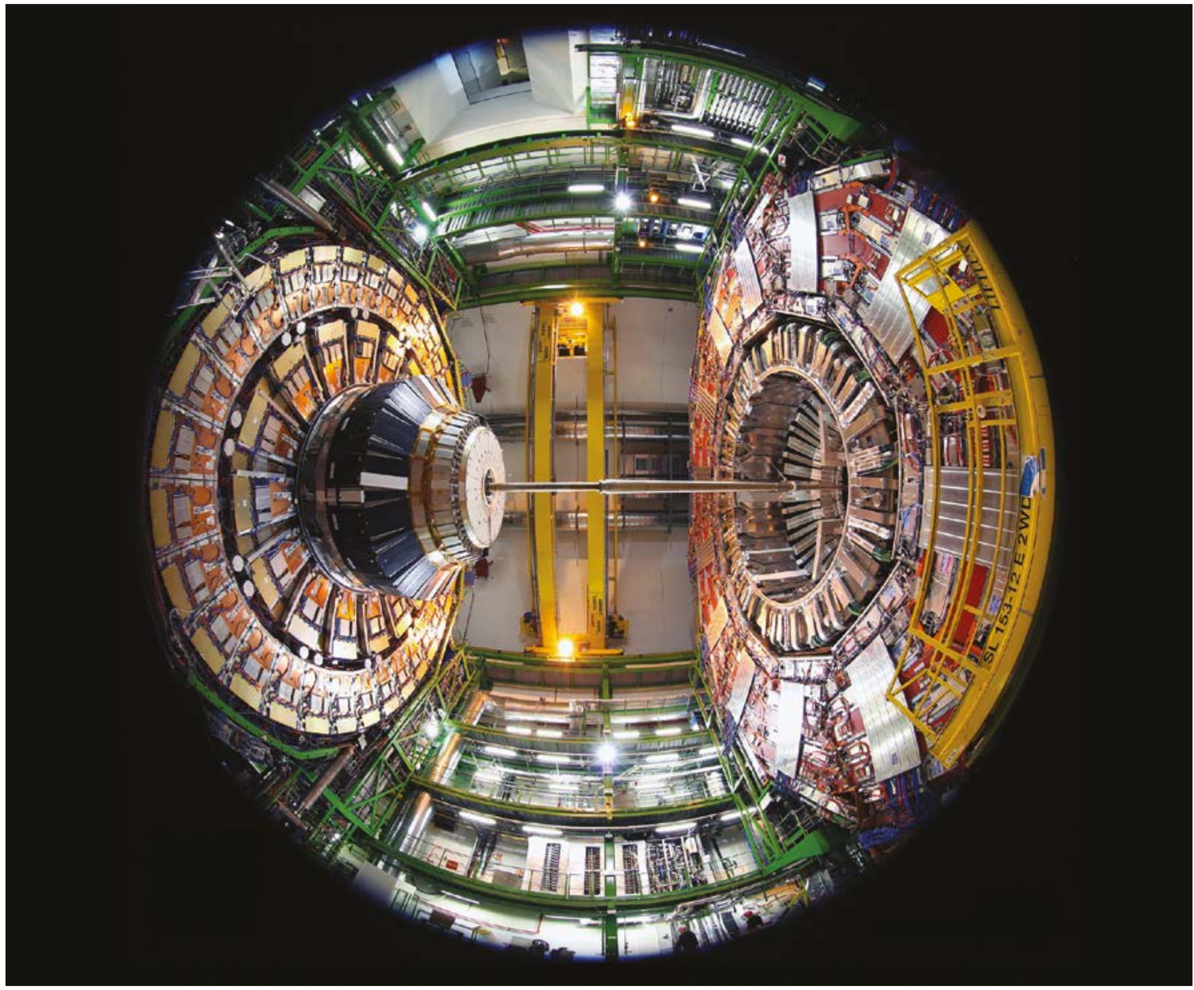


CMS-PHO-GEN-2013-012-5

Detector focus *The open detector from below, showing the beam pipe and endcap calorimeter "nose".*

CMS HAS HIGH LUMINOSITY IN SIGHT

One of the biggest challenges for the CMS collaboration during LS2 is to prepare its detector for the massive future installations necessary for the HL-LHC.

The CMS detector has performed better than what was thought possible when it was conceived. Combined with advances in analysis techniques, this has allowed the collaboration to make measurements – such as the coupling between the Higgs boson and bottom quarks – that were once deemed impossible. Indeed, together with its sister experiment ATLAS, CMS has turned the traditional view of hadron colliders as "hammers" rather than "scalpels" on its head.

In exploiting the LHC and its high-luminosity upgrade (HL-LHC) to maximum effect in the coming years, the CMS collaboration has to battle higher overall particle rates, higher "pileup" of superimposed proton–proton collision events per LHC bunch crossing, and higher instantaneous and integrated radiation doses to the detector elements. In the collaboration's arsenal to combat this assault are silicon sensors able to withstand the levels of irradiation expected, a new high-rate trigger, and detectors with higher granularity or precision timing capabilities to help disentangle piled-up events.

THE AUTHOR

Matthew Chalmers *editor.*

The majority of CMS detector upgrades for the HL-LHC will be installed and commissioned during long-shutdown three (LS3). However, the planned 30-month duration of LS3 imposes logistical constraints that result in a large part of the muon-system upgrade and many ancillary systems (such as cooling, power and environmental control) needing to be installed substantially beforehand. This makes the CMS work plan for LS2 extremely complex, dividing into three classes of activity: the five-yearly maintenance of the existing detectors and services, the completion of so called "phase 1" upgrades necessary for CMS to continue to operate until LS3, and the initial upgrades to detectors, infrastructure or ancillary systems necessary for HL-LHC. "The challenge of LS2 is to prepare CMS for Run 3 while not neglecting the work needed now to prepare for Run 4," says technical coordinator Austin Ball.

A dedicated CMS upgrade programme was planned since the LHC switched on in 2008

A dedicated CMS upgrade programme was planned since the LHC switched on in 2008. It is being carried out in two phases: the first, which started in 2014 during LS1, concerns improvements to deal with a factor-of-two increase over the design instantaneous luminosity delivered in Run 2; and the second relates to the upgrades necessary for the HL- LHC. The phase-1 upgrade is almost complete, thanks to works carried out during LS1 and regular end-of-year technical stops. This included the replacement of the three-layer barrel (two-disk forward) pixel detector with a four-layer barrel (three-disk forward) version, the replacement of photosensors and front-end electronics for some of the hadron calorimeters, and the introduction of a more powerful, FPGA-based, level-1 hardware trigger. LS2 will conclude phase-1 by upgrading photosensors (hybrid photodiodes) in the barrel hadron calorimeter with silicon photomultipliers and replacing the innermost pixel barrel layer.

Phase-2 activities

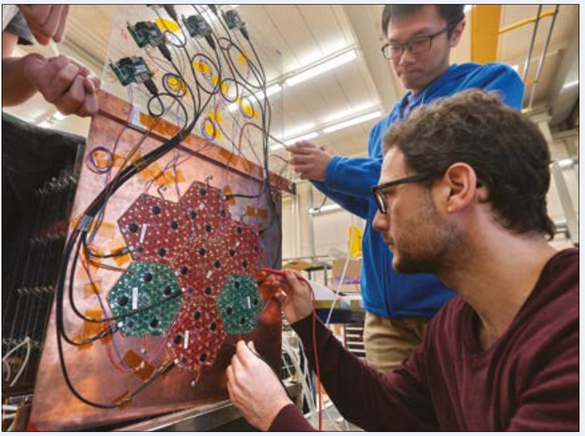
But LS2 also sees the start of the phase-2 CMS upgrade, the first step of which is a new beampipe. The collaboration already replaced the beampipe during LS1 with a narrower one to allow the phase-1 pixel detector to reach closer to the interaction point. Now, the plan is to extend the cylindrical section of the beampipe further to provide space for the phase-2 pixel detector with enlarged pseudo-rapidity coverage, to be installed in LS3. In addition,

A NEW ERA IN CALORIMETRY

The high-granularity calorimeter (HGCAL) is a major upgrade of CMS, and is necessary to maintain excellent calorimetric performance in the endcaps during HL-LHC operations. HGCAL is one of the most ambitious detector projects undertaken, due to the combination of extremely high readout and trigger granularity, coupled with the harsh radiation environment of the CMS endcaps during HL-LHC operation. Two radiation-tolerant materials have been selected: silicon in the high-radiation region and plastic scintillator tiles in the less harsh regions. To mitigate the effects of radiation damage, the silicon sensors must be cooled to about −30 °C, which also allows the use of on-tile silicon photomultipliers for the scintillator readout.

HGCAL has around 6.5 million detector channels, divided into 52 layers. The first 28 layers form the electromagnetic section, which is based on hexagonal silicon sensors (maximising the useable surface of 8″ circular silicon wafers) divided into hexagonal cells. The sensors are sandwiched between high-density copper-tungsten alloy baseplates on one side and printed circuit boards containing the front-end electronics on the other, and the resulting hexagonal modules are mounted on either side of CO_2-cooled copper plates. The following eight layers are similar, forming the front part of the hadronic section of HGCAL, but are single-sided and use a lighter baseplate, while the final 16 layers incorporate both silicon modules and scintillator tiles. The use of both detector technologies optimises the overall cost of the HGCAL whilst maintaining excellent long-term performance.

Prototype development began in 2016, and hexagonal silicon sensors have been built into modules to evaluate the feasibility of the overall design and to study the performance in beams at Fermilab, DESY and CERN. Results from these beam tests compare very well with simulations. Thanks to HGCAL's readout/triggering granularity and timing resolution for showers, the expected performance in terms of energy resolution, particle identification and triggering are all comparable to the present CMS endcap calorimeters – even in the presence of 200 pileup events and after the full radiation exposure expected at HL-LHC. The project has now moved to the final design and prototyping phase, with construction due to start in a couple of years.



CERN-PHOTO-201812-333-1

Prototype sensors *The assembly of prototype HGCAL detector planes, based on 6″ silicon modules, at CERN in October.*

CMS collaboration

Assembly *The production of the GEM chambers to be installed in the muon endcaps during LS2.*

CERN-PHOTO-201702-052-137

Pixel renewal *Replacing the CMS pixel detector in early 2017.*

for the muon detectors CMS will install a new gas electron multiplier (GEM), layer in the inner ring of the first endcap disk, upgrade the on-detector electronics of the cathode strip chambers, and lay services for a future GEM layer and improved resistive plate chambers. Several other preparations of the detector infrastructure and services will take place in LS2 to be ready for the major installations in LS3.

Work plan

Key elements of the LS2 work plan include: constructing major new surface facilities; modifying the internal structure of the underground cavern to accommodate new detector services (especially CO_2 cooling); replacing the beampipe for compatibility with the upgraded tracking system; and improving the powering system of the 3.8 T solenoid to increase its longevity through the HL-LHC era. In addition, the system for opening and closing the magnet yoke for detector access will be modified to accommodate future tolerance requirements and service volumes, and the shielding system protecting detectors from background radiation will be reinforced. Significant upgrades of electrical power, gas distribution and the cooling plant also have to take place during LS2.

The CMS LS2 schedule is now fully established, with a critical path starting with the pixel-detector and beampipe removal and extending through the muon system upgrade and maintenance, installation of the phase-2 beampipe plus the revised phase-1 pixel innermost layer, and, after closing the magnet yoke, re-commissioning of the magnet with the upgraded powering system. The other LS2 activities, including the barrel hadron calorimeter work, will take place in the shadow of this critical path.

"The timely completion of the intense LS2 programme, including the construction of the on-site surface infrastructures necessary for the construction, assembly or refurbishment activities of the phase-2 detectors, is critical for a successful CMS phase-2 upgrade," explains upgrade coordinator Frank Hartmann. "Although still far away, LS3 activities are already being planned in detail." The future LS3 shutdown will see the CMS tracker completely replaced with a new outer tracker that can provide tracks at 40 MHz to the upgraded level-1 trigger, and with a new inner tracker with extended pseudo-rapidity coverage. The 36 modules of the barrel electromagnetic calorimeter will be removed and their on-detector electronics upgraded to enable the high readout rate, while both current hadron and electromagnetic endcap calorimeters will be replaced with a brand-new system (see "A new era in calorimetry" box). The addition of timing detectors in the barrel and endcaps will allow a 4D reconstruction of collision vertices and, together with the other new and upgraded detectors, reduce the effective event pile-up at the HL-LHC to a level comparable to that already seen.

"The upgraded CMS detector will be even more powerful and able to make even more precise measurements of the properties of the Higgs boson as well as extending the searches for new physics in the unprecedented conditions of the HL-LHC," says CMS spokesperson Roberto Carlin. ●

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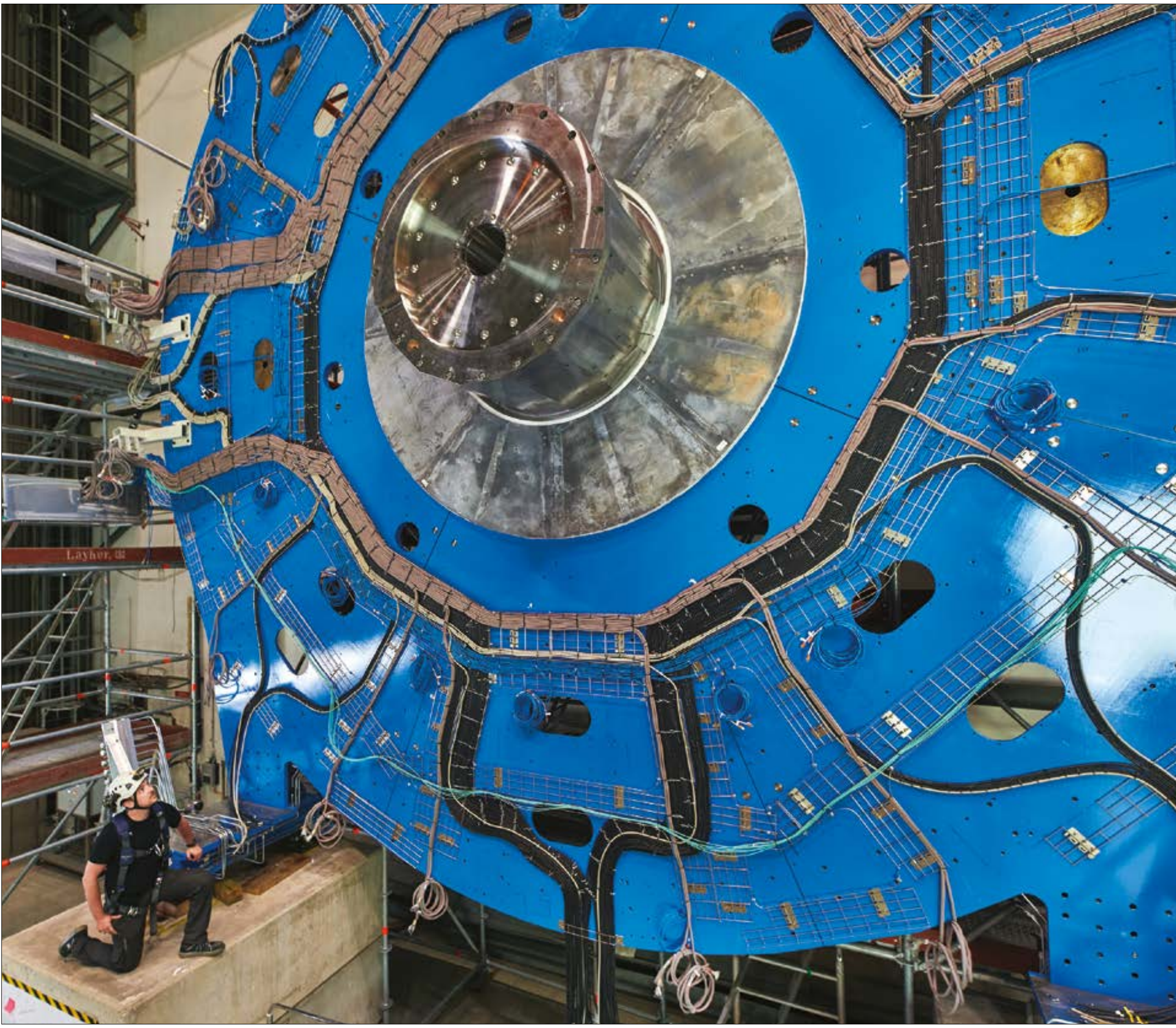


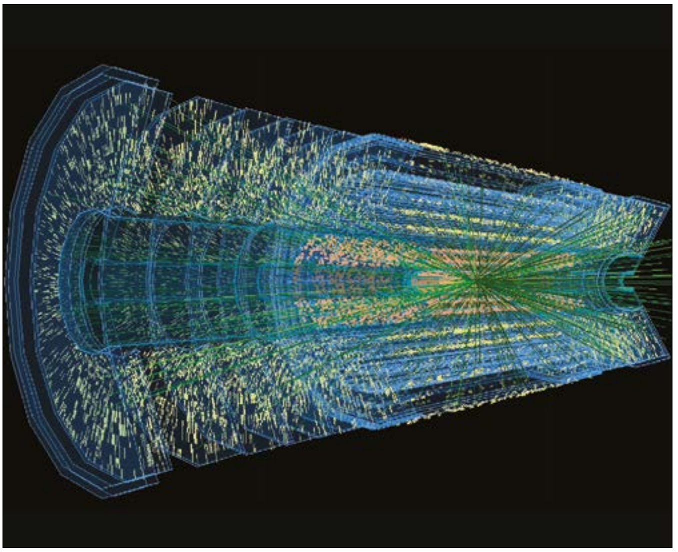
CERN-PHOTO-201806-175-1

Iron support *The mechanical structure of one of the new small wheels.*

ATLAS UPGRADES IN LS2

New wheel-shaped detectors that allow a better trigger and measurement capability for muons are among numerous transformations taking place to maintain the ATLAS physics programme into Run 3 and beyond.

To precisely study the Higgs boson and extend our sensitivity to new physics in the coming years of LHC operations, the ATLAS experiment has a clear upgrade plan in place. Ageing of the inner tracker due to radiation exposure, data volumes that would saturate the readout links, obsolescence of electronics, and a collision environment swamped by up to 200 interactions per bunch crossing are some of the headline



ATLAS

Extreme pile up *A simulated event at the HL-LHC, with a future inner tracker.*

ATLAS-PHOTO-2018-004-15

Endcap petals *Assembling cathode strip chambers during the end-of-year-shutdown in 2017/2018.*

challenges facing the 3000-strong collaboration. While many installations will take place during long-shutdown three (LS3), beginning in 2024, much activity is taking place during the current LS2 – including major interventions to the giant muon spectrometer at the outermost reaches of the detector.

The main ATLAS upgrade activities during LS2 are aimed at increasing the trigger efficiency for leptonic and hadronic signatures, especially for electrons and muons with a transverse momentum of at least 20 GeV. To improve the selectivity of the electron trigger, the amount of information used for the trigger decision will be drastically increased: until now, the very fine-grained information produced by the electromagnetic calorimeter is grouped in "trigger towers" to limit the number and hence cost of trigger channels, but advances in electronics and the use of optical fibres allows the transmission of a much larger amount of information at a reasonable cost. By replacing some of the components of the front-end electronics of the electromagnetic calorimeter, the level of segmentation available at the trigger level will be increased fourfold, improving the ability to reject jets and preserve electrons and photons. The ATLAS trigger and data-acquisition systems will also be upgraded during LS2 by introducing new electronics boards that can deal with the more granular trigger information coming from the detector.

New small wheels

Since 2013, ATLAS has been working on a replacement for its "small wheel" forward-muon endcap systems so that they can operate under the much harsher background conditions of the future LHC. The new small wheel (NSW) detectors employ two detector technologies: small-strip thin gap chambers (sTGC) and Micromegas (MM). Both technologies are able to withstand the higher flux of neutrons and photons expected in future LHC interactions, which will produce counting rates as high as 20 kHz cm^{-2} in the inner part of the NSW, while delivering information for the first-level trigger and muon measurement. The main aim of the NSW is to reduce the fake muon triggers in the forward region and improve the sharpness of the trigger threshold drastically, allowing the same selection power as the present high-level trigger.

The first NSW started to take shape at CERN last year. The iron shielding disks (see image on previous page), which serve as the support for the NSW detectors in addition to shielding the endcap muon chambers from hadrons, have been assembled, while the services team is installing numerous cables and pipes on the disks. Only a few millimetres of space is available between the disk and the chambers for the cables on one side, and between the disk and the calorimeter on the other side, and the task is made even more difficult by having to work from an elevated platform. In a nearby building, the sTGC chambers coming from the different construction sites are being integrated in full wedges and, soon this year, the Micromegas wedges will be integrated and tested at a separate integration site. The construction of the sTGC chambers is taking place in Canada, Chile, China, Israel and Russia, while the Micromegas are being constructed in France, Germany, Greece, Italy and Russia. On a daily basis, cables arrive to be assembled with connectors and tested; piping is cut to length, cleaned and protected until installation; and gas-leak and high-voltage test stations are employed for quality control. In the meantime, several smaller upgrades will be deployed during LS2, including the installation of 16 new muon chambers in the inner layer of the barrel spectrometer.

The organisation of LS2 activities is a complex exercise in which the maintenance needs of the detectors have to be addressed in parallel with installation schedules. After a first period devoted to the opening of the detector and the maintenance of the forward muon spectrometer, the first major non-standard operation (scheduled for January) will be to bring to the surface the first small wheel. Having the detector fully open on one side will also allow very important test for the installation of the new all-silicon inner tracker, which is scheduled to be installed during LS3. The upgrade of the electromagnetic-calorimeter electronics will start in February and continue for about one year, requiring all front-end boards to be dismounted from their crates, modifications to both the boards and the crates, and reinstallation of the modified boards in their original position. Maintenance of the ATLAS tile calorimeter and inner detector will take place in parallel, a very important aspect of which will be the search for leaks in the front-end cooling system.

Thousands of people around the world in more than 200 institutes are involved

Delicate operation

In August, the first small wheel will be lowered again, allowing the second small wheel to be brought to the surface to make space for the NSW installation foreseen in April 2020. In the same period, all the optical transmission boards of the pixel detector will have to be changed. Following these installations, there will be a long period of commissioning of all the upgraded detectors and the preparation for the installation of the second NSW in the autumn of 2020. At that moment the closing process will start and will last for about three months, including the bake-out of the beam pipe, which is a very delicate and dangerous operation for the pixel detectors of the inner tracker.

A coherent upgrade programme for ATLAS is now fully underway to enable the experiment to fully exploit the physics potential of the LHC in the coming years of high-luminosity operations. Thousands of people around the world in more than 200 institutes are involved, and the technical design reports alone for the upgrade so far number six volumes, each containing several hundred pages. At the end of LS2, ATLAS will be ready to take data in Run 3 with a renewed and better performing detector. ●

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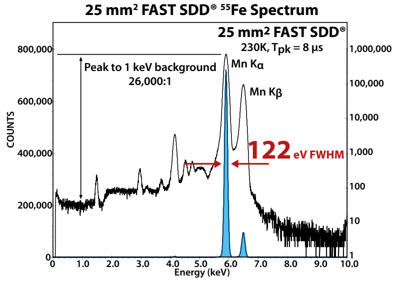
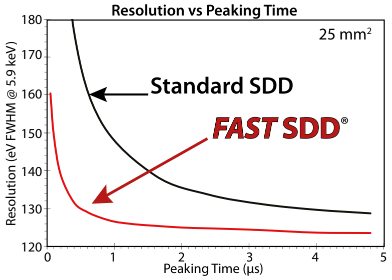
Ludovico Pontecorvo *is the ATLAS technical coordinator, CERN.*





LHCb'S MOMENTOUS METAMORPHOSIS

The LHCb detector is to be totally rebuilt in time for the restart of LHC operations.

In November 2018 the LHC brilliantly fulfilled its promise to the LHCb experiment, delivering a total integrated proton–proton luminosity of 10 fb^{-1} from Run 1 and Run 2 combined. This is what LHCb was designed for, and more than 450 physics papers have come from the adventure so far. Having recently finished swallowing these exquisite data, however, the LHCb detector is due some tender loving care.

In fact, during the next 24 months of long-shutdown two (LS2), the 4500 tonne detector will be almost entirely rebuilt. When it emerges from this metamorphosis, LHCb will be able to collect physics events at a rate 10 times higher than today. This will be achieved by installing new detectors capable of sustaining up to five times the instantaneous luminosity seen at Run 2, and by implementing a revolutionary software-only trigger that will enable LHCb to process signal data in an upgraded CPU farm at the frenetic rate of 40 MHz – a pioneering step among the LHC experiments.

LHCb is unique among the LHC experiments in that it is asymmetric, covering only one forward region. That reflects its physics focus: B mesons, which, rather than flying out uniformly in all directions, are preferentially produced at small angles (i.e. close to the beam direction) in the LHC's proton collisions. The detector stretches for 20 m along the beam pipe, with its sub-detectors stacked behind each other like books on a shelf, from the vertex locator (VELO) to a ring-imaging Cherenkov detector (RICH1), the silicon upstream tracker (UT), the scintillating fibre tracker (SciFi), a second RICH (RICH2), the calorimeters and, finally, the muon detector.

The LHCb upgrade was first outlined in 2008, proposed in 2011 and approved the following year at a cost of about 57 million Swiss francs. The collaboration started dismantling the current detector just before the end of 2018 and the first elements of the upgrade are about to be moved underground.

Physics boost

The LHCb collaboration has so far made numerous important measurements in the heavy-flavour sector, such as the first observation of the rare decay $B^0_s \to \mu^+\mu^-$, precise measurement of quark-mixing parameters and the observation of new baryonic and pentaquark states. However, many crucial measurements are currently statistically limited. The LHCb upgrade will boost the experiment's physics reach by allowing the software trigger to handle

CERN-PHOTO-201812-329-15

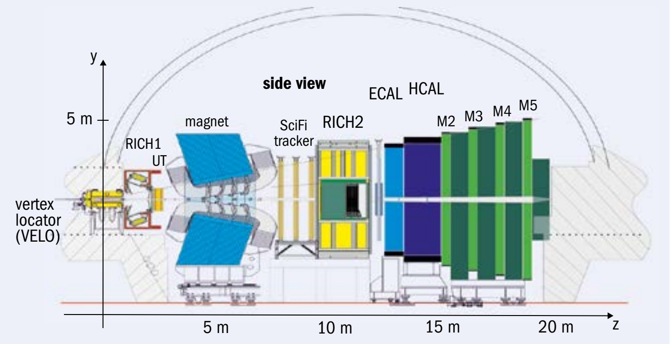
Tender loving care *The LHCb detector was opened up in December to make way for LS2 activities.*

THE AUTHORS

Massimiliano Ferro-Luzzi *LHCb detector upgrade coordinator, CERN.*

Rolf Lindner *LHCb technical coordinator, CERN.*

Giovanni Passaleva *LHCb spokesperson, CERN.*



LHCb

Subdetector structure *A cross-section showing the LHCb detector's main elements.*

CERN-PHOTO-201811-290-5

Under construction *Modules being lowered into place for LHCb's new data centre.*

S Jakobsen

Development *The SciFi tracker modules being assembled.*

an input rate around 30 times higher than before, bringing greater precision to theoretically clean observables.

Flowing at an immense rate of 4 TB/s, data will travel from the cavern, straight from the detector electronics via some 9000 300 m-long optical fibres, into front-end computers located in a brand-new data centre that is currently nearing completion. There, around 500 powerful custom-made boards will receive the data and transfer it to thousands of processing cores. Current trigger-hardware equipment will be removed and new front-end electronics have been designed for all the experiment's sub-detectors to cope with the substantially higher readout rates.

For the largest and heaviest LHCb devices, namely the calorimeters and muon stations, the detector elements will remain mostly in place. All the other LHCb detector systems are to be entirely replaced, apart from a few structural frames, the dipole magnet, shielding elements and gas or vacuum enclosures.

When it re-emerges, LHCb will be able to collect physics events at a rate 10 times higher than today

Subdetector activities

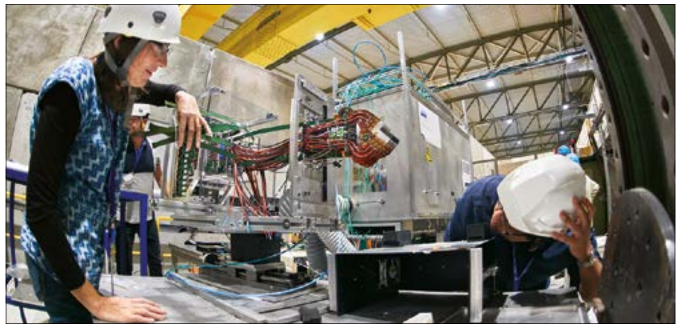
The VELO at the heart of LHCb, which allows precise measurements of primary and displaced vertices of short-lived particles, is one of the key detectors to be upgraded during LS2. Replacing the current system based on silicon microstrip modules, the new VELO consists of 26 tracking layers made from $55 \times 55\,\mu\text{m}^2$ pixel technology, which offers better hit resolution and simpler track reconstruction. The new VELO will also be closer to the beam axis, which poses significant design challenges. A new chip, the VELOPIX, capable of collecting signal hits from 256×256 pixels and sending data at a rate of up to 15 Gb/s, was developed for this purpose. Pixel modules include a cutting-edge cooling substrate based on an array of microchannels trenched out of a 260 µm-thick silicon wafer that carry liquid carbon dioxide to keep the silicon at a temperature of –20 °C. This is vital to prevent thermal run-away, since these sensors will receive the heaviest irradiation of all LHC detectors. Prototype modules have recently been assembled and characterised in tests with high-energy particles at the Super Proton Synchrotron.

The RICH detector will still be composed of two systems: RICH1, which discriminates kaons from pions in the low-momentum range, and RICH2, which performs this task in the high-momentum range. The RICH mirror system, which is required to deflect and focus Cherenkov photons onto photodetector planes, will be replaced with a new one that has been optimised for the much increased particle densities of future LHC runs. RICH detector columns are composed of six photodetector modules (PDMs), each containing four elementary cells hosting the multi-anode photomultiplier tubes. A full PDM was successfully operated during 2018, providing first particle signals.

Mounted just between RICH1 and the dipole magnet, the upstream tracker (UT) consists of four planes of silicon microstrip detectors. To counter the effects of irradiation, the detector is contained in a thermal enclosure and cooled to approximately –5 °C using a CO_2 evaporative cooling system. Lightweight staves, with a carbon foam back-plane and embedded cooling pipe, are dressed with flex cables and instrumented with 14 modules, each composed of a polymide hybrid circuit, a boron nitride stiffener and a silicon microstrip sensor.

Further downstream, nestled between the RICH2 and the magnet, will sit the SciFi – a new tracker based on scintillating fibres and silicon photomultiplier (SiPM) arrays, which replaces the drift straw detectors and silicon microstrip sensors used by the current three tracking stations. The SciFi represents a major challenge for the collaboration, not only due to its complexity, but also because the technology has never been used for such a large area in such a harsh radiation environment. More than 11,000 km of fibre was ordered, meticulously verified and even cured from a few rare and local imperfections. From this, about 1400 mats of fibre layers were recently fabricated in four institutes and assembled into 140 rigid $5 \times 0.5\,\text{m}^2$ modules. In parallel, SiPMs were assembled on flex cables and joined in groups of 16 with a 3D-printed titanium cooling tube to form sophisticated photodetection units for the modules, which will be operated at about –40 °C.

As this brief overview demonstrates, the LHCb detector is undergoing a complete overhaul during LS2 – with large parts being totally replaced – to allow this unique LHC experiment to deepen and broaden its exploration programme. CERN support teams and the LHCb technical crew are now busily working in the cavern, and many of the 79 institutes involved in the LHCb collaboration from around the world have shifted their focus to this herculean task. The entire installation will have to be ready for the commissioning of the new detector by mid-2020 so that it is ready for the start of Run 3 in 2021. ●



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VELO upgrade *Testing the new VELO modules at CERN.*

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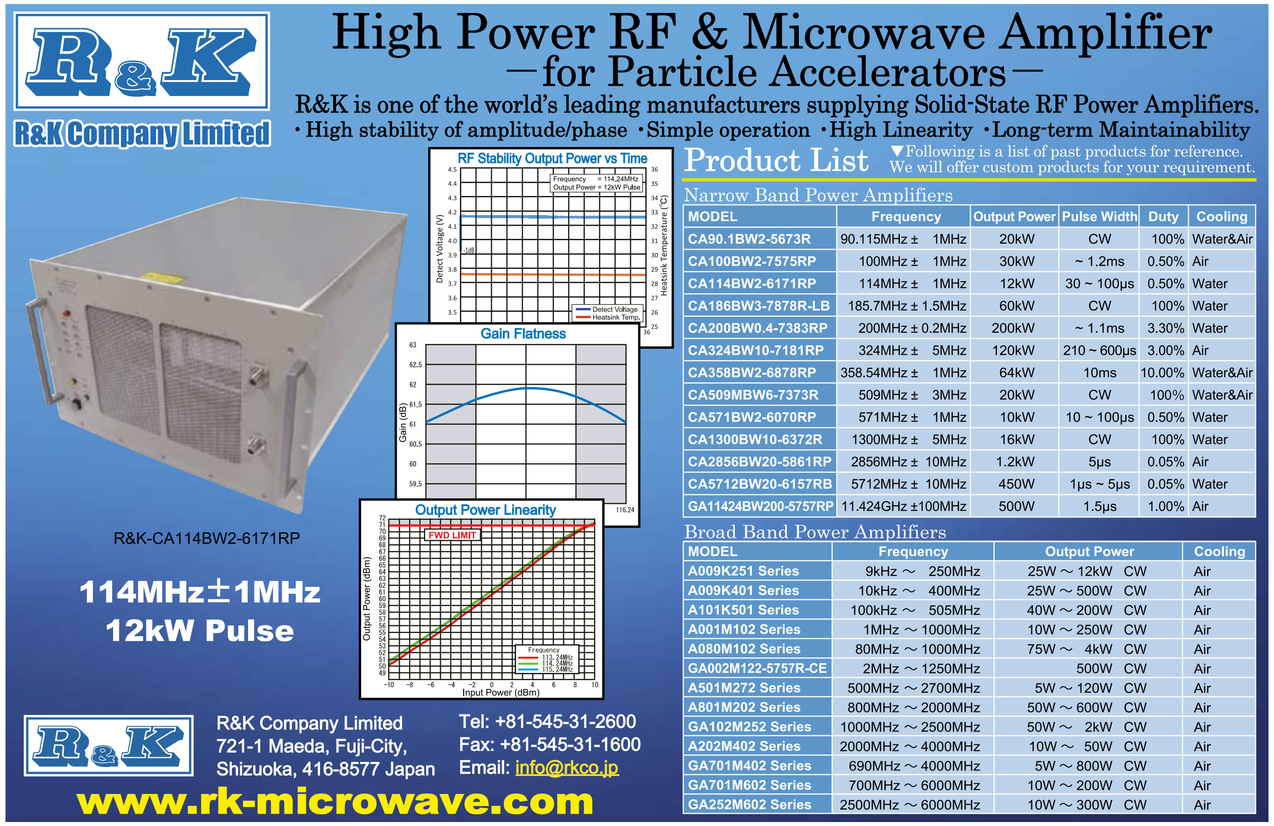
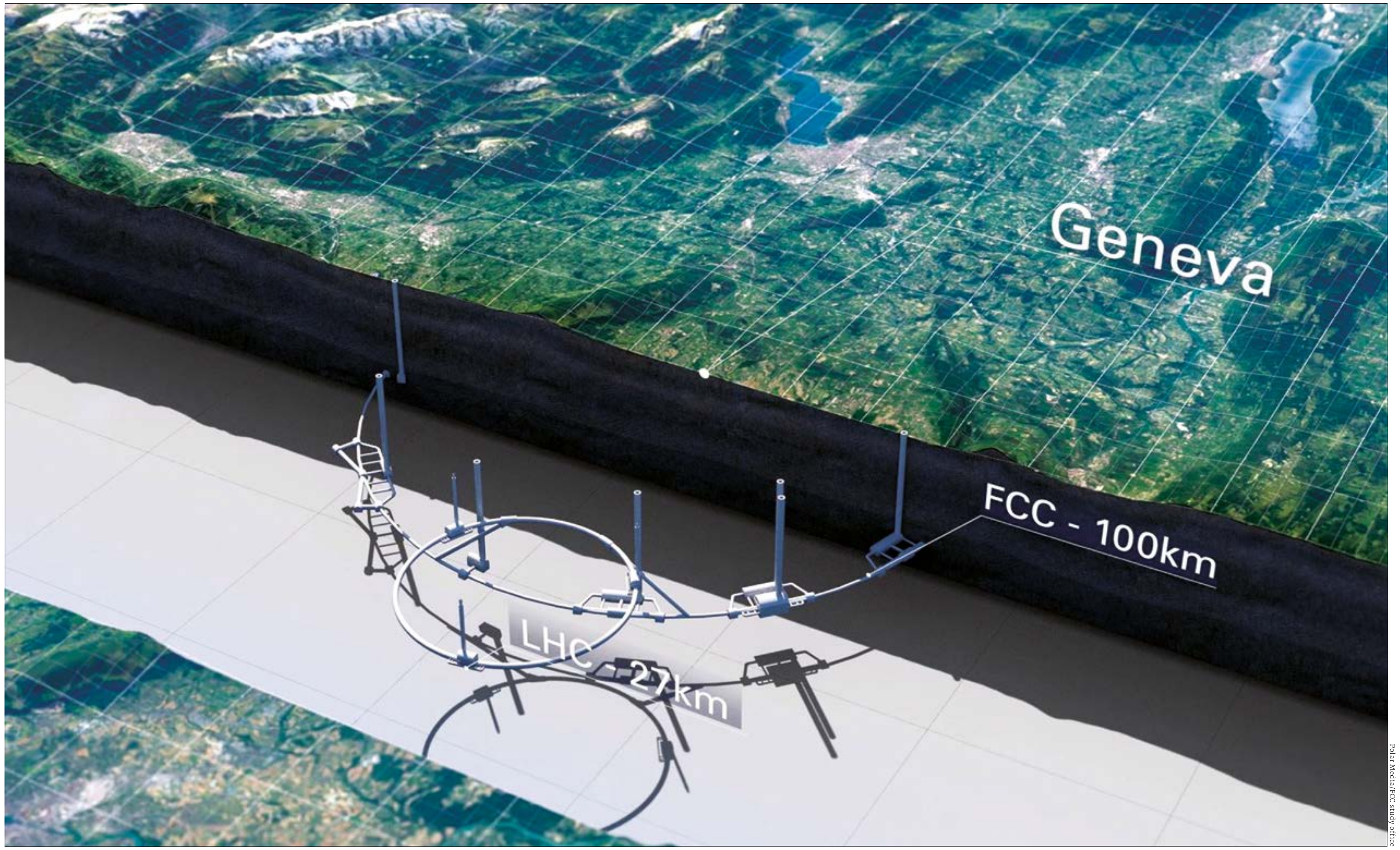
LHCb Collaboration 2011 CERN-LHCC-2011-001.
LHCb Collaboration 2012 CERN-LHCC-2012-007.



A GIANT LEAP FOR PHYSICS



Mind the gap
A schematic layout of the FCC in comparison with the current LHC.

Polar Media/FCC study office

Going from the LHC to a 100 km-circumference supercollider is a daunting challenge, but the community has made similar jumps in the past – and the future of fundamental exploration is at stake.

THE AUTHORS

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Particle physics has revolutionised our understanding of the universe. The experimental and theoretical tools developed in the 20th century delivered the Standard Model of particle physics, the particle content of which was completed in 2012 with the discovery of the Higgs boson at the LHC. And, yet, this hugely powerful theory leaves several observations unexplained. In solving mysteries such as the nature of dark matter, the origin of neutrino masses, the dominance of matter over antimatter on cosmological scales, and the low mass of the Higgs boson itself, physicists could open a completely new view of nature. Therefore, it is high time to start planning a new collider that maintains this rich course of exploration throughout the 21st century.

In late 2018 the Future Circular Collier (FCC) collaboration published a conceptual design report (CDR) addressing this need. A similar proposal is also under development in China (*CERN Courier* June 2018 p21). In more than 1000 pages distributed over four volumes, the FCC CDR covers all aspects of the project, including technologies, detector design, physics goals and civil-engineering considerations. But what changes when we move from a 27 km to a new 100 km-long tunnel, and what stays the same? The obstacles to new colliders pushing the current energy and intensity frontiers are many, yet the past five years have seen the international FCC study steadily break them down.

Lessons learned

The FCC design report shows that CERN's existing accelerator chain can serve as the foundation for a 100 km post-LHC machine, while also opening a rich fixed-target programme. The new 100 km infrastructure is indeed enormous, representing a four-fold increase in dimensions compared to the LHC. But, taking history as a guide, it should be possible: this jump in scale is identical to that adopted in the 1980s to move from the Super Proton Synchrotron (SPS) to the Large Electron Positron collider (LEP) and eventually to the LHC, allowing the completion of the Standard Model. Jumping to larger and more complex machines always comes with new challenges, but these translate precisely into opportunities for young researchers and industry (*CERN Courier* September 2018 p51).

A 100 km tunnel offers three main collider options. The most straightforward in terms of technological readiness is a luminosity-frontier lepton collider (FCC-ee) that will deliver unprecedented collision rates in a clean environment at specific energies corresponding to the Z pole (91 GeV), the WW threshold (161 GeV), Higgs production (240 GeV), and the top quark-antiquark threshold (350 to 365 GeV). By filling the FCC tunnel with new superconducting magnets twice the strength of the LHC's (16 T as opposed to 8 T), however, a hadron collider called FCC-hh can be built with a collision energy of 100 TeV – an order-of-magnitude higher than the LHC. The FCC study, which was formally launched in early 2014, also explores the option of a proton-electron collider (FCC-he) that could run in parallel with FCC-hh, and a high-energy LHC based on high-field magnets installed in the current LHC tunnel (*CERN Courier* June 2018 p15).

The cost of future colliders is a major issue, and concerted value-engineering of all aspects from individual components through sustainability to logistics is required. Cost estimates for FCC construction and operation are detailed in the CDR, although the range of collider modes, staging approaches and technology choices make it difficult to place a single figure on each machine. Construction on a site with an existing infrastructure, as offered by CERN, is a major cost advantage in terms of capital investment, sharing of infrastructure and breadth of the overall physics programme.

FCC-hh will produce a pile-up of up to 1000 events per bunch crossing

S Russenschuck, CERN

FCC-ee *Quadrupole test magnet at CERN's magnetic measurement laboratory.*

We are proposing an ambitious accelerator to push the boundaries of knowledge

The sequence of FCC-ee and FCC-hh would also resemble the successful staging of LEP and the LHC: a lepton–lepton machine followed by a hadron collider (both for protons and heavy ions). In the case of the FCC, possibly even a future muon collider could then follow as a third stage.

FCC-ee is a dream machine for precision measurements, taking the successful LEP scheme into entirely new territory (figure 1). Precise measurements of the properties of the Z, W and Higgs boson and the top quark, together with much improved measurements of other input parameters to the Standard Model such as the electromagnetic and strong coupling constants, would provide sensitivity to new particles with masses in the range 10–70 TeV.

Common lattice

The bulk of FCC-ee will comprise around 8000 normal-conducting low-power and cost-effective twin-aperture dipole magnets, 3000 focusing magnets and between 26 (Z pole) and 161 ($t\bar{t}$ threshold) four-cavity radio-frequency (RF) cryomodules, to compensate for the energy loss from synchrotron radiation and provide the required accelerating voltage. Currently, two interaction points are planned for high-luminosity FCC-ee operations, though up to four can be accommodated. A common FCC-ee lattice has been designed for all energy stages except for the highest energy $t\bar{t}$ threshold, where a small rearrangement of the beamline passing through the RF cavities will be needed. The basic cell of the FCC-ee lattice has been chosen for operation at a beam energy of 182.5 GeV and combines four dipole magnets and two main quadrupoles in a 50 m-long section. Moreover, to achieve the required high luminosities, the vertical beam size at the interaction points (called β^*_y) has to be very small (0.8 mm) at the Z pole, which is 50 times smaller than for LEP but about three times larger than for the SuperKEKB accelerator now being commissioned in Japan. The reduction in β^*_y is possible because of technological innovations during the past three decades (such as local chromatic correction of the final-quadrupole doublet and use of a crab-waist collision scheme) and thanks to the large size of the ring.

Indeed, achieving the unprecedented FCC-ee luminosity of up to 4×10^{36} cm^{-2}s^{-1} (the total for two experiments), while minimising the amount of synchrotron radiation near the detector, called for considerable effort in designing the final-focus system. Combined with a small crossing angle of 30 mrad, the minimum distance from the interaction point to the first quadrupole is 2 m, which is a compromise between beam dynamics and detector constraints. The present optics design has a momentum acceptance of around 2%, which is one of the most critical requirements of the FCC-ee design because it determines the beam lifetime.

A distinct feature of FCC-ee, in contrast to LEP, is the use of separate beam pipes for the two counter-rotating electron and positron beams, based on energy-efficient dual-aperture main magnets (pictured above). The two separate rings allow operation with a large number of bunches – up to around 16,000 at the Z pole – by avoiding parasitic collisions. This approach also allows for a well-centered orbit all around the ring and a nearly perfect mitigation of the energy "sawtooth" at the highest $t\bar{t}$ energies. A so-called tapering scheme is foreseen, which will enable the strengths of all the magnets to be scaled according to the local energy of the electron and positron beams, taking into account any differences in the energy loss due to synchrotron radiation. Also distinct from LEP, a top-up injection scheme has been designed for FCC-ee to maximise the integrated luminosity, whereby electrons and positrons are injected into the machine by a full-energy booster to maintain a constant high beam current.

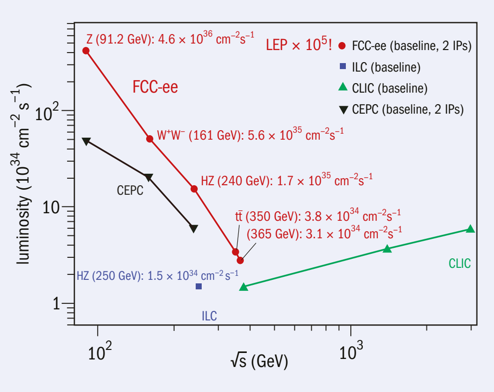
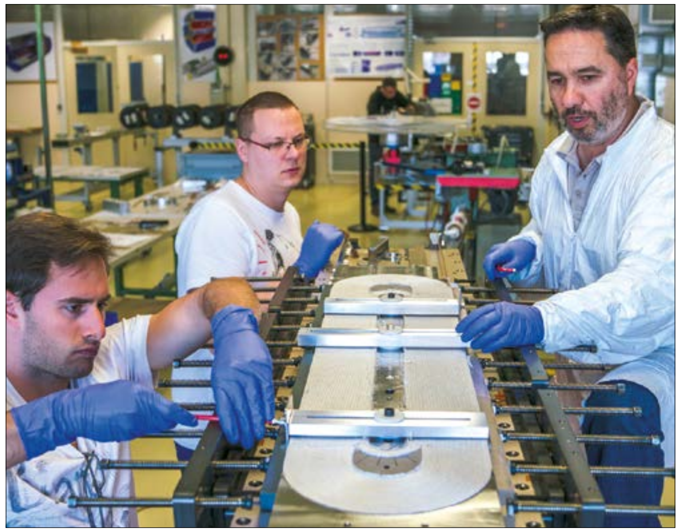


Fig. 1. *Lepton-collider luminosity as a function of centre-of-mass energy for different accelerator baseline projects and technologies, showing FCC-ee, the Circular Electron Positron Collider (CEPC), the Compact Linear Collider (CLIC) and the International Linear Collider (ILC).*



N Caraban/CERN

Racetrack coil *A model coil for 16 T FCC-hh dipole magnets with niobium-tin superconducting cable.*

Beating the fourth power

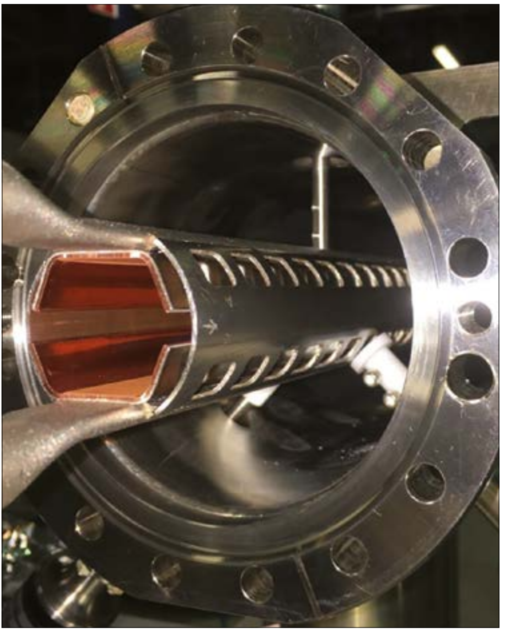
When moving to a larger radius and higher energies, one of the key obstacles for colliders is the synchrotron radiation emitted by the accelerated particles because the resulting energy loss increases with the fourth power of a charged particle's energy. Improving energy efficiency is critical for any future big accelerator, and the development of high-efficiency RF power sources, along with robust higher-gradient superconducting cavities, is at the core of the FCC programme. The cavities can be produced, for example, by applying a thin superconducting film on a copper substrate, as is currently being pursued by CERN in collaboration with global partners (*CERN Courier* May 2018 p26). To achieve a low power consumption and guarantee sustainable operation, a high conversion efficiency from wall-plug to RF power is critical. The FCC target RF operation efficiency is 65%, profiting from recent innovations in klystron design at CERN.

For FCC-ee to fulfil its promise of precision electroweak measurements, it is also vital that physicists can accurately determine its centre-of-mass energy so that the Z mass can be measured with a relative precision of 3×10^{-5}, the total Z width with a precision of 0.1 MeV and the W mass within 0.5 MeV. A strategy based on the resonant-depolarisation technique, as used at LEP, guarantees precise energy measurements every 15–20 minutes for both the electron and positron beam.

The design of the FCC-ee detectors is also described in the FCC design report. Due to the beam crossing angle, the detectors' solenoid magnetic field is limited to 2 T to confine their impact on the luminosity due to the synchrotron radiation emitted within the solenoid field. Two detector concepts have been optimised for the FCC-ee: CLD, a consolidated option based on the detector developed for CLIC, with a silicon tracker and a 3D-imaging highly-granular calorimeter; and IDEA, a bolder, possibly more cost-effective, design, with a short drift-wire chamber and a dual-readout calorimeter. However, specific detector-technology choices will be made at a later date.

Following the operation of FCC-ee, the same tunnel could host a 100 TeV proton collider, FCC-hh. A very large, circular hadron collider is the only feasible approach to reach significantly higher collision energies than the LHC (13–14 TeV) in the coming decades. A 100 TeV collider would offer access to new particles through direct production in the few-TeV to 30 TeV mass range, far beyond the LHC's reach. It would also provide much higher rates for phenomena in the sub-TeV mass range and therefore much greater precision on key measurements (*CERN Courier* May 2017 p34).

Within 25 years of operation, FCC-hh could accumulate an integrated luminosity of around 20 ab^{-1} in each of the two main experiments. FCC-hh also offers the possibility of colliding heavy ions with protons and heavy ions with heavy ions, adding to its physics opportunities. Reaching the physics goals of such a collider requires a machine availability of about 70%, which is comparable to what has been routinely reached with the LHC. Nevertheless, considering the increased machine complexity and the introduction of an additional machine in the injector chain in the FCC baseline scenario, achieving this target avail-



Beam screen *Prototype of the FCC-hh beam screen installed at the Karlsruhe Research Accelerator in Germany.*

Luis Antonio Gonzalez Gomez (CERN)

ability poses major challenges.

FCC-hh is envisioned to lie adjacent to the LHC and SPS, with two injection insertions so that protons can be injected from either the LHC or SPS tunnel. In the first case, the beam will be injected at an energy of 3.3 TeV from the LHC (which requires, in addition to new transfer lines and extraction systems, some modifications to allow the LHC to be ramped five times faster than today). In the second case, a new superconducting SPS – from which other experiments would also profit – could provide a beam at 1.3 TeV using fast ramping and cost-effective 6 T superconducting magnets. The FCC design report presents a complete lattice for FCC-hh that is consistent with this layout and the required energy reach. The arc lattice consists of around 500 cells each 200 m long and made up of two short, straight sections and 12 cryo-dipoles, comprising one 14 m-long dipole and one 0.11 m-long sextupole corrector. Integrated studies of the lattice performance are ongoing and will inform the final choice for the magnet design, along with considerations of power efficiency and cost.

Reducing costs

The biggest cost in reaching higher energies is that of the magnets. A primary goal of FCC-hh is to build 16 T superconducting magnets that are a factor of three to five times more cost-effective per TeV than those of the LHC. Achieving this goal would impact many accelerator applications outside physics, from medical treatments to food-quality monitoring and energy storage and distribution. The FCC study has recently launched a global conductor R&D programme involving collaborators from the US, Russia, Europe, Japan and Korea to improve the performance of the niobium-tin conductor and to reduce its cost.

The FCC-hh foresees two high-luminosity experiments, for which a key design challenge is to obtain the target values of β_y^* in the collision points while protecting the detectors and the magnets from the collision debris. Incredibly, FCC-hh will produce a pile-up of up to 1000 events per bunch crossing, compared to around 200 at HL-LHC. Another major challenge for FCC-hh is the beam-dump system to protect the machine components. Each of the two rings will have to reliably abort proton beams with stored energies of around 8 GJ, which is more than an order of magnitude higher than for HL-LHC. Beam extraction at the FCC has to be fast, and the first prototypes of new kicker generator and superconducting septum technologies are now being tested.

Synchrotron radiation is also an issue, since FCC-hh will emit about 5 MW at 100 TeV, and calls for a novel beam screen held at a temperature of 50 K (compared with 5–20 K at the LHC). The FCC-hh beam screen, a prototype of which is shown left, enables cost-effective heat removal and maintains the high quality vacuum while providing shielding from the beam. Finally, cooling the FCC-hh superconducting magnets poses entirely new challenges compared to the LHC. In addition to the higher synchrotron radiation, the cooling system (which, like the LHC will use liquid helium at 1.9 K) will have to cope with higher heat dissipated inside the cold magnets as well as from the cold bore itself. About 100 MW of total cooling power will be required to remove 5 MW of synchrotron radiation heat (see p8).

Coordinating the future

For almost 90 years, progress in particle physics has gone hand-in-hand with progress in accelerators. Today, capitalising on the great success of the LHC, the field faces pivotal decisions about what collider to build next. Advancing the enabling technologies for a future circular collider can only be done via a coordinated international effort between universities, research centres and industry. It also calls for smart solutions to ensure reliability and sustainability. The results of these efforts are documented in the four volumes of the FCC conceptual design report, which presents a clear route to a post-LHC machine and also serves as an input to the update of the European Strategy for Particle Physics.

The FCC offers great potential for curiosity-driven research with unimaginable consequences. Discoveries of new particles and forces not only alter our perspective of humankind's position in the universe, but also, either directly or via the technology that made them possible, lead to radical applications that improve our quality of life. In the present age of political turbulence and rapid change, we are proposing an ambitious future accelerator complex to push the boundaries of knowledge and to optimally prepare future generations for the challenges they are sure to face. ●

Further reading

M Benedikt *et al.* 2018 CERN-ACC-2018-0058.
M Benedikt *et al.* 2018 CERN-ACC-2018-0057.
M Michelangelo *et al.* 2018 CERN-ACC-2018-0056.
F Zimmermann *et al.* 2018 CERN-ACC-2018-0059.

OPINION
VIEWPOINT

Good strategy demands the right balance

As the second update of the European Strategy for Particle Physics gets under way, Tatsuya Nakada reflects on the experience of the previous update in 2013.

D Dominguez

Community call *Priorities for European particle physics will be formalised in the spring of 2020 following rigorous consultation at all levels.*

LHCb-PHO-PUBLIC-2010-002-2

Tatsuya Nakada *is a professor at the Swiss Federal Institute of Technology in Lausanne, and was scientific secretary and chairperson of the European Strategy Group for the 2013 European Strategy for Particle Physics Update.*

Strategy is a base that allows resources to be prioritised in the pursuit of important goals. No strategy would be needed if enough resources were available – we would just do what appears to be necessary.

Elementary particle physics generally requires large and expensive facilities, often on an international scale, which take a long time to develop and are heavy consumers of resources during operations. For this reason, in 2005 the CERN Council initiated a European Strategy for Particle Physics (ESPP), resulting in a document being adopted the following year. The strategy was updated in 2013 and the community is now working towards a second ESPP update (*CERN Courier* April 2018 p7).

The making of the ESPP has three elements: bottom-up activities driven by the scientific community through document submission and an open symposium (the latter to be held in Spain in May 2019); strategy drafting (to take place in Germany in January 2020) by scientists, who are mostly appointed by CERN member states; and the final discussion and approval by the CERN Council. Therefore, the final product should be an amalgamation of the wishes of the community and the political and financial constraints defined by state authorities. Experience of the previous ESPP update suggests that this is entirely achievable, but not without effort and compromise.

Discussions about the various ideas for the next big machine at CERN will be an important focus

Out of four high-priority items in the current ESPP, which concluded in 2013, three of them are well under way: the full exploitation of the LHC via a luminosity upgrade; R&D and design studies for a future energy-frontier machine at CERN; and establishing a platform at CERN for physicists to develop neutrino detectors for experiments around the world. The remaining item, relating to an initiative of the Japanese particle-physics community to host an international linear collider in Japan, has not made much progress.

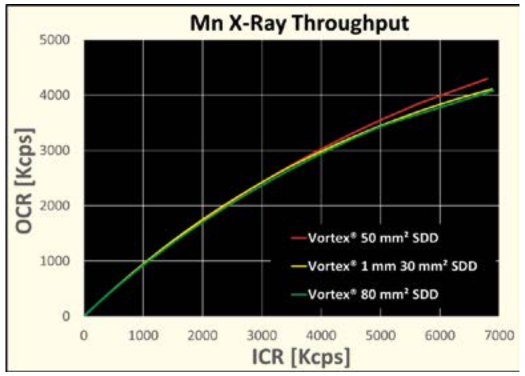
In physics, discussions about strategy usually start with a principled statement: "Science should drive the strategy". This is of course correct, but unfortunately not always sufficient in real life, since physics consideration alone does not provide a practical solution most of the time. In this context, it is worth recalling the discussion about long-baseline neutrino experiments that took place during the previous strategy exercises.

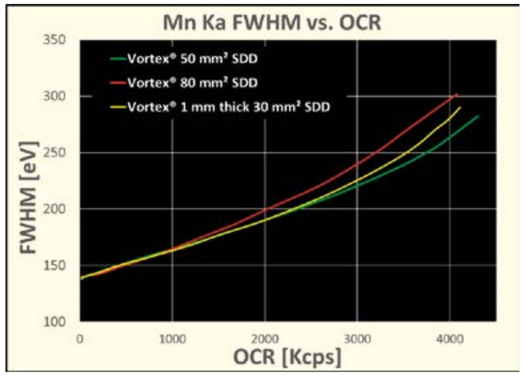
Optimal outcome

At the time of the first ESPP almost 15 years ago, so little was known about the neutrino mass-mixing parameters that several ambitious facilities were discussed so as to cover necessary parameter spaces. Some resources were directed into R&D, but most probably they were too little and not well prioritised. In the meantime, it became clear that a state-of-the-art neutrino beam based on conventional technology would be sufficient to make the next necessary step of measuring the neutrino CP-violation parameter and mass hierarchy. What should be done was therefore clear from a scientific point of view, but there simply were not enough resources in Europe to construct a long-baseline neutrino experiment together with a high performance beam line while fully exploiting the LHC at the same time. The optimal outcome was found by considering global opportunities and this was one of the key ingredients that drove the strategy.

The challenge facing the community now in updating the current ESPP is to steer the field into the mid-2020s and beyond. As such, discussions about the various ideas for the next big machine at CERN will be an important focus, but numerous other projects, including proposals for non-collider experiments, will be jostling for attention. Many brilliant people are working in our field with many excellent ideas, with different strengths and weaknesses. The real issue of the strategy update is how we can optimise the resources using time and location, and possibly synergies with other scientific fields.

The intention of the strategy is to achieve a scientific goal. We may already disagree about what this goal is, since it is people with different visions, tastes and habits who conduct research. But let us at least agree this to be "to understand the most fundamental laws of nature" for now. Also, depending on the time scales, the relative importance of elements in the decision-making might change and factors beyond Europe cannot be neglected. Strategy that cannot be implemented is not useful for anyone and the key is to make a judgement on the balance among many elements. Lastly, we should not forget that the most exciting scenario for the ESPP update will be the appearance of an unexpected result –then there would be a real paradigm shift in particle physics.





OPINION
INTERVIEW

Understanding naturalness

The last few years have seen an explosion of original ideas concerning whether the universe is "natural" or not, and the LHC has brought the issue into sharp focus. But we're only at the beginning of our understanding, says theorist Nathaniel Craig.

What is "naturalness"?

Colloquially, a theory is natural if its underlying parameters are all of the same size in appropriate units.

A more precise definition involves the notion of an effective field theory – the idea that a given quantum field theory might only describe nature at energies below a certain scale, or cutoff. The Standard Model (SM) is an effective field theory because it cannot be valid up to arbitrarily high energies even in the absence of gravity.

An effective field theory is natural if all of its parameters are of order unity in units of the cutoff. Without fine-tuning, a parameter can only be much smaller than this if setting it to zero increases the symmetry of the theory.

All couplings and scales in a quantum theory are connected by quantum effects unless symmetries distinguish them, making it generic for them to coincide.

When did naturalness become a guiding force in particle physics?

We typically trace it back to Eddington and Dirac, though it had precedents in the cosmologies of the Ancient Greeks. Dirac's discomfort with large dimensionless ratios in observed parameters – among others, the ratio of the gravitational and electromagnetic forces between protons and electrons, which amounts to the smallness of the proton mass in units of the Planck scale – led him to propose a radical cosmology in which Newton's constant varied with the age of the universe. Dirac's proposed solutions were readily falsified, but this was a predecessor of the more refined notion of naturalness that evolved with the development of quantum field theory, which drew on observations by Gell-Mann, 't Hooft, Veltman, Wilson, Weinberg, Susskind and other greats.

Nathaniel Craig *is an associate professor at the University of California Santa Barbara.*

N Craig

Does the concept appear in other disciplines?

There are notions of naturalness in essentially every scientific discipline, but physics, and particle physics in particular, is somewhat unique. This is perhaps not surprising, since one of the primary goals of particle physics is to infer the laws of nature at increasingly higher energies and shorter distances.

Isn't naturalness a matter of personal judgement?

One can certainly come up with frameworks in which naturalness is mathematically defined – for example, quantifying the sensitivity of some parameter in the theory to variations of the other parameters. However, what one does with that information is a matter of personal judgement: we don't know how nature computes fine-tuning (i.e. departure from naturalness), or what amount of fine-tuning is reasonable to expect. This is highlighted by the occasional abandonment of mathematically defined naturalness criteria in favour of the so-called Potter Stewart measure: "I know it when I see it." The element of judgement makes it unproductive to obsess over minor differences in fine-tuning, but large fine-tunings potentially signal that something is amiss. Also, one can't help but notice that the degree of fine-tuning that is considered acceptable has changed over time.

The element of judgement makes it unproductive to obsess over minor differences in fine-tuning

What evidence is there that nature is natural?

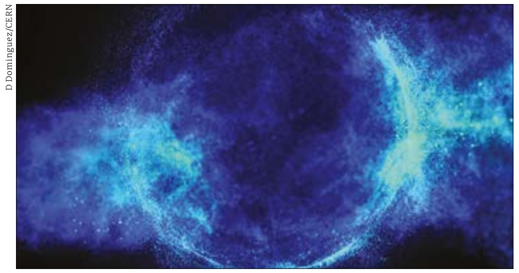
Dirac's puzzle, the smallness of the proton mass, is a great example: we understand it now as a consequence of the asymptotic freedom of the strong interaction. A natural (of order-unity) value of the QCD gauge coupling at high energies gives rise to an exponentially smaller mass scale on account of the logarithmic evolution of the gauge coupling.

Another excellent example, relevant to the electroweak hierarchy problem, is the mass splitting of the charged and neutral pions. From the perspective of an effective field theorist working at the energies of these pions, their mass splitting is only natural if the cutoff of the theory is around 800 MeV.

Lo and behold, going up in energy from the pions, the rho meson appears at 770 MeV, revealing the composite nature of the pions and changing the picture in precisely the right way to render the mass splitting natural.

Which is the most troublesome observation for naturalness today?

The cosmological-constant (CC) problem, which is the disagreement by 120 orders of magnitude between the observed and expected value of the vacuum energy density. We understand the SM to be a valid effective field theory for many decades above the energy scale of the observed CC, which makes it very hard to believe that the



D Dominguez/CERN

Unnatural? *Artistic illustration of the Higgs boson, for which quantum corrections lead to a naturalness or "hierarchy" problem.*

problem is solved in a conventional way without considerable fine-tuning. Contrast that with the SM hierarchy problem, which is a statement about the naturalness of the mass of the Higgs boson. Data so far show that the cutoff of the SM as an effective field theory might not be too far above the Higgs mass, bringing naturalness within reach of experiment. On the other hand, the CC is only a problem in the context of the SM coupled to gravity, so perhaps its resolution lies in yet-to-be-understood features of quantum gravity.

What about the tiny values of the neutrino masses?

Neutrino masses are not remotely troublesome for naturalness. A parameter can be much smaller than the natural expectation if setting it to zero increases the symmetry of the theory (we call such parameters "technically natural"). For the neutrino, as for any SM fermion, there is an enhanced symmetry when neutrino masses are set to zero. This means that your natural expectation for the neutrino masses is zero, and if they are non-zero, quantum corrections to neutrino masses are proportional to the masses themselves. Although the SM features many numerical hierarchies, the majority of them are technically-natural ones that could be explained by physics at inaccessibly high energies. The most urgent problems are the hierarchies that aren't technically natural, like the CC problem and the electroweak hierarchy problem.

Has applying the naturalness principle led directly to a discovery?

It's fair to say that Gaillard and Lee predicted the charm-quark mass by applying naturalness arguments to the mass-splitting of neutral kaons. Of course, the same arguments were also used to (incorrectly) predict a wildly different value of the weak scale! This is a reminder that naturalness principles can point to a problem in the existing theory, and a scale at which the theory should change, but they don't tell you precisely how the problem is resolved. The naturalness of the neutral kaon mass splitting, or the charged-neutral pion mass splitting, suggests to me that it is more useful to refer to naturalness as a strategy, rather than as a principle.

A slightly more flippant example is the observation of neutrinos from Supernova 1987A. This marked the beginning of neutrino astronomy and opened the door to unrelated surprises, yet the large water-Cherenkov detectors that detected these neutrinos were originally constructed to look for proton decay predicted by grand unified theories (which were themselves motivated by naturalness arguments).

> **It appears more useful to think of naturalness as a strategy, rather than as a principle**

While it would be great if naturalness-based arguments successfully predict new physics, it's also worthwhile if they ultimately serve only to draw experimental attention to new places.

What has been the impact of the LHC results so far on naturalness?

There have been two huge developments at the LHC. The first is the discovery of the Higgs boson, which sharpens the electroweak hierarchy problem: we seem to have found precisely the sort of particle whose mass, if natural, points to a significant departure from the SM around the TeV scale. The second is the non-observation of new particles predicted by the most popular solutions to the electroweak hierarchy problem, such as supersymmetry. While evidence for these solutions could lie right around the corner, its absence thus far has inspired both a great deal of uncertainty about the naturalness of the weak scale and a lively exploration of new approaches to the problem. The LHC null results teach us only about specific (and historically popular) models that were inspired by naturalness. It is therefore an ideal time to explore naturalness arguments more deeply. The last few years have seen an explosion of original ideas, but we're really only at the beginning of the process.

The situation is analogous to the search for dark matter, where gravitational evidence is accumulating at an impressive rate despite numerous null results in direct-detection experiments. These null results haven't ruled out dark matter itself; they've only disfavoured certain specific and historically popular models.

How can we settle the naturalness issue once and for all?

The discovery of new particles around the TeV scale whose properties suggest they are related to the top quark would very strongly suggest that nature is more or less natural. In the event of non-discovery, the question becomes thornier – it could be that the SM is unnatural; it could be that naturalness arguments are irrelevant; or it could be that there are signatures of naturalness that we haven't recognised yet. Kepler's symmetry-based explanation of the naturalness of planetary orbits in terms of platonic solids ultimately turned out to be a red herring, but only because we came to realise that the features of specific planetary orbits are not deeply related to fundamental laws.

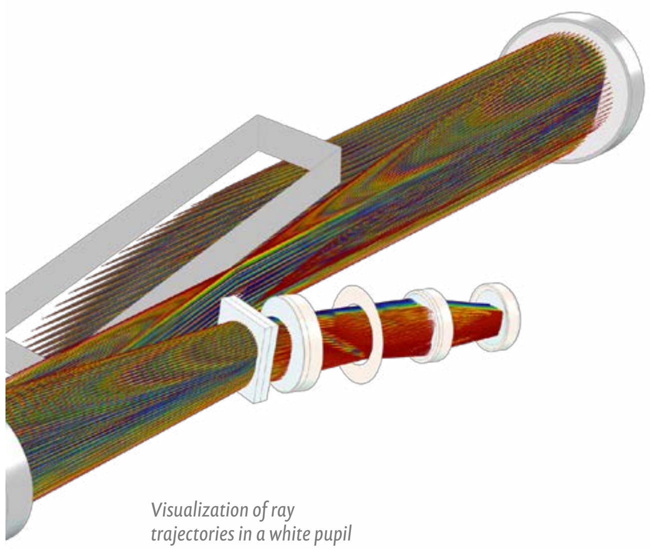
Without naturalness as a guide, how do theorists go beyond the SM?

Naturalness is but one of many hints at physics beyond the SM. There are some incredibly robust hints based on data – dark matter and neutrino masses, for example. There are also suggestive hints, such as the hierarchical structure of fermion masses, the preponderance of baryons over antibaryons and the apparent unification of gauge couplings. There is also a compelling argument for constructing new-physics models purely motivated by anomalous data. This sort of "ambulance chasing" does not have a stellar reputation, but it's an honest approach which recognises that the discovery of new physics may well come as another case of "Who ordered that?" rather than the answer to a theoretical problem.

What sociological or psychological aspects are at work?

If theoretical considerations are primarily shaping the advancement of a field, then sociology inevitably plays a central role in deciding what questions are most pressing. The good news is that the scales often tip, and data either clarify the situation or pose new questions. As a field we need to focus on lucidly articulating the case for (and against) naturalness as a guiding principle, and let the newer generations make up their minds for themselves.

Interview by **Matthew Chalmers** *editor.*



OPINION
REVIEWS

How beauty leads physics astray

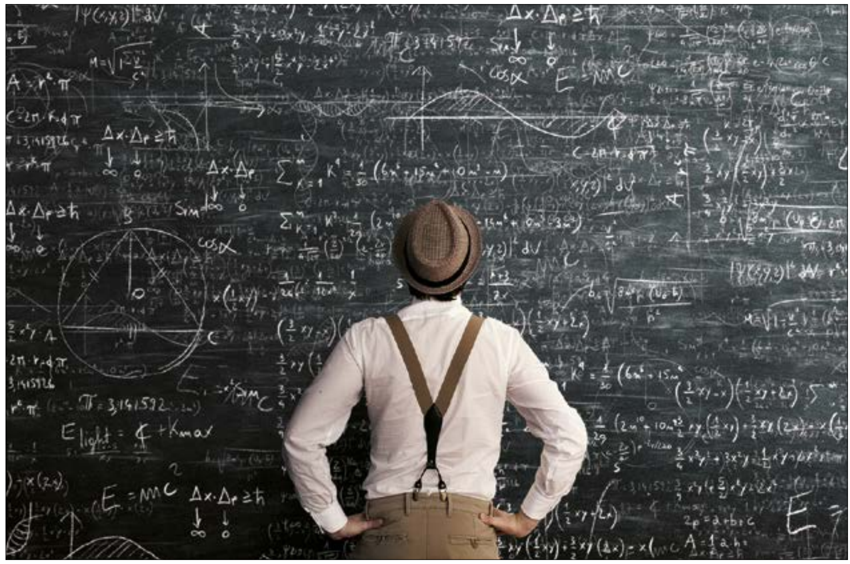
Lost in Math – How beauty leads physics astray

By Sabine Hossenfelder

Basic Books

In *Lost in Math*, theoretical physicist Sabine Hossenfelder embarks on a soul-searching journey across contemporary theoretical particle physics. She travels to various countries to interview some of the most influential figures of the field (but also some "outcasts") to challenge them, and be challenged, about the role of beauty in the investigation of nature's laws.

Colliding head-on with the lore of the field and with practically all popular-science literature, Hossenfelder argues that beauty is overrated. Some leading scientists say that their favourite theories are too beautiful not to be true, or possess such a rich mathematical structure that it would be a pity if nature did not abide by those rules. Hossenfelder retorts that physics is not mathematics, and names examples of extremely beautiful and rich maths that does not describe the world. She reminds us that physics is based on data. So, she wonders, what can be done when an entire field is starved of experimental breakthroughs?



iStock/francescoch

The eye of the beholder *Is the beauty of science overrated?*

Confirmation bias

Nobel laureate Steven Weinberg, interviewed for this book, argues that experts call "beauty" the experience-based feeling that a theory is on a good track. Hossenfelder is sceptical that this attitude really comes from experience. Maybe most of the people who chose to work in this field were attracted to it, in the first place, because they like mathematics and symmetries, and would not have worked in the field otherwise. We may be victims of confirmation bias: we choose to believe that aesthetic sense leads to correct theories; hence, we easily recall to memory all of the correct theories that possess some quality of beauty, while we do not pay equal attention to the counterexamples. Dirac and Einstein, among many, vocally affirmed beauty as a guiding principle, and achieved striking successes by following its guidance; however, they also had, as Hossenfelder points out, several spectacular failures that are less well known. Moreover, a theoretical sense of beauty is far from universal. Copernicus made a breakthrough because he sought a form of beauty that differed from those of his predecessors, making him think out of the box; and by today's taste, Kepler's solar system of platonic solids feels silly and repulsive.

Hossenfelder devotes attention to a concept that is particularly relevant to contemporary particle physics: the "naturalness principle" (see p45). Take the case of the Higgs mass: the textbook argument is that quantum corrections go wild for the Higgs boson, making any mass value between zero and the Planck mass *a priori* possible; however, its value happens to be closer to zero than to the Planck mass by a factor of 10^{17}. Hence, most particle physicists argue that there must be an almost perfect cancellation of corrections, a problem known as the "hierarchy problem". Hossenfelder points out that implicit in this simple argument is that all values between zero and the Planck mass should be equally likely. "Why," she asks, "are we assuming a flat probability, instead of a logarithmic (or whatever other function) one?" In general, we say that a new theory is necessary when a parameter value is unlikely, but she argues that we can estimate the likeliness of that value only when we have a prior likelihood function, for which we would need a new theory.

We choose to believe that aesthetic sense leads to correct theories

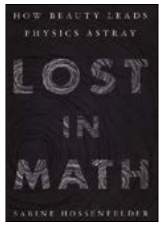
New angles

Hossenfelder illustrates various popular solutions to this naturalness problem, which in essence all try to make small values of the Higgs mass much more likely than large ones. She also discusses string theory, as well as multiverse hypotheses and anthropic solutions, exposing their shortcomings. Some of her criticisms may recall Lee Smolin's *The Trouble with Physics* and Peter Woit's *Not Even Wrong*, but Hossenfelder brings new angles to the discussion.

This book comes out at a time when more and more specialists are questioning the validity of naturalness-inspired predictions. Many popular theories inspired by the naturalness problem share an empirical consequence: either they manifest themselves soon in existing experiments, or they definitely fail in solving the problems that they were invented for.

Hossenfelder describes in derogatory terms the typical argumentative structure of contemporary theory papers that predict new particles "just around the corner", while explaining why we did not observe them yet. She finds the same attitude in what she calls the "di-photon diarrhoea", i.e., the prolific reaction of the same theoretical community to a statistical fluctuation at a mass of around 750 GeV in the earliest data from the LHC's Run 2.

The author explains complex matters at the cutting edge of theoretical physics research in a clear way, with original metaphors and appropriate illustrations. With this book, Hossenfelder not only reaches out to the public, but also invites it to join a discourse that she is clearly passionate about. The intended readership ranges from fellow scientists to the layperson, also including university administrators and science policy makers, as is made explicit in an appendix devoted to practical suggestions for various categories of readers.



While this book will mostly attract attention for its *pars destruens*, it also contains a *pars construens*. Hossenfelder argues for looking away from the lamppost, both theoretically and experimentally. Having painted naturalness arguments as a red herring that drives attention away from the real issues, and acknowledging throughout the book that when data offer no guidance there is no other choice than following some non-empirical assessment criteria, she advocates other criteria that deserve better prominence, such as the internal consistency of the theoretical foundations of particle physics.

As a non-theorist my opinion carries little weight, but my gut feeling is that this direction of investigation, although undeniably crucial, is not comparably "fertile". On the other hand, Hossenfelder makes it clear that she sees nothing scientific in this kind of fertility, and even argues that bibliometric obsessions played a big role in creating what she depicts as a gigantic bibliographical bubble. Inspired by that, Hossenfelder also advises learning how to recognise and mitigate biases, and building a culture of criticism both in the scientific arena and in response to policies that create short-term incentives, going against the idea of exploring less conventional ideas. Regardless of what one may think about the merits of naturalness or other non-empirical criteria, I believe that these suggestions are uncontroversially worthy of consideration.

Andrea Giammanco *UCLouvain, Louvain-la-Neuve, Belgium.*

Amaldi's last letter to Fermi: a monologue

Theatre, CERN Globe, 11 September 2018

On the occasion of the 110th anniversary of the birth of Italian physicist Edoardo Amaldi (1908–1989), CERN hosted a new production titled "Amaldi l'italiano, centodieci e lode!" The title is a play on words concerning the top score at an Italian university ("110 cum laude") and the production is a well-deserved recognition of a self-confessed "ideas shaker" who was one of the pioneers in the establishment of CERN, the European Space Agency (ESA) and the Italian National Institute for Nuclear Physics (INFN).

The nostalgic monologue opens with Amaldi, played by Corrado Calda, sitting at his desk and writing a letter to his mentor, Enrico Fermi. Set on the last day of Amaldi's life, the play retraces some of his scientific, personal and historical memories, which pass by while he writes.

It begins in 1938 when Amaldi is part of an enthusiastic group of young scientists, led by Fermi and nicknamed "Via Panisperna boys" (boys from Panisperna Road, the location of the Physics Institute of the University of Rome). Their discoveries on slow neutrons led to Fermi's Nobel Prize in Physics that year.

Then, suddenly, World War II begins and everything falls apart. Amaldi writes about his frustrations to his teacher, who had passed away but is still close to him. "While physicists were looking for physical laws, Europe sank into racial laws," he despairs. Indeed, most of his colleagues and friends, including Fermi who had a Jewish wife, moved to the US. Left alone in Italy, Amaldi decided to stop his studies on fission and focus on cosmic rays, a type of research that required less resources and was not related to military applications.

CERN-PHOTO-201809-217-34

Ideas shaker *Corrado Calda as Edoardo Amaldi.*

Out of the ruins

After World War II, while in Italy there was barely enough money to buy food, the US was building state-of-the-art particle-physics detectors. Amaldi described his strong temptation to cross the ocean, and re-join with Fermi. However, he decided to stay in war-torn Europe and help European science grow out of the ruins. He worked to achieve his dream of "a laboratory independent from military organisations, where scientists from all over the world could feel at home" – today know as CERN. He was general secretary of CERN between 1952 and 1954, before its official foundation in September 1954.

This beautiful monologue is interspersed by radio messages from the epoch, which announce salient historical facts. These create a factual atmosphere that becomes less and less tense as alerts about the Nazi's declarations and bombs are replaced by news about the first women's vote, the landing of the first person on the Moon, and disarmament movements.

Written and directed by Giusy Cafari Panico and Corrado Calda, the play was composed after consulting with Edoardo's son, Ugo Amaldi, who was present at the inaugural performance. The script is so rich in information that you leave the theatre feeling you now know a lot about scientific endeavours, mindsets and the general zeitgeist of the last century. Moreover, the play touches on some topics that are still very relevant today, including: brain drain, European identity, women in science and the use of science for military purposes.

The event was made possible thanks to the initiative of Ugo Amaldi, CERN's Lucio Rossi, the Edoardo Amaldi Association (Fondazione Piacenza e Vigevano, Italy), and several sponsors. The presentation was introduced by former CERN Director-General Luciano Maiani, who was Edoardo Amaldi's student, and current CERN Director-General Fabiola Gianotti, who expressed her gratitude for Amaldi's contribution in establishing CERN.

Letizia Diamante *CERN.*

Topological and Non-Topological Solitons in Scalar Field Theories

By Yakov M Shnir

Cambridge University Press

In the 19th century, the Scottish engineer John Scott Russell was the first to observe what he called a "wave of transition" while watching a boat drawn along a channel by a pair of horses. This phenomenon is now referred to as a soliton and described mathematically as a stable, non-dissipative wave packet that maintains its shape while propagating at a constant velocity.

Solitons emerge in various nonlinear physical systems, from nonlinear optics and condensed matter to nuclear physics, cosmology and supersymmetric theories.

Structured in three parts, this book provides a comprehensive introduction to the description and construction of solitons in various models. In the first two chapters of part one, the author discusses the properties of topological solitons in the completely integrable Sine-Gordon model and in the non-integrable models with polynomial potentials. Then, in chapter three, he introduces solitary wave solutions of the Korteweg-de Vries equation, which provide an example of non-topological solitons.

Part two deals with higher dimensional nonlinear theories. In particular, the properties of scalar soliton configurations are analysed in two 2+1 dimension systems: the $O(3)$ nonlinear sigma model and the baby Skyrme model. Part three focuses mainly on the solitons in three spatial dimensions. Here, the author covers stationary Q-balls and their properties. Then he discusses soliton configurations in the Skyrme model (called skyrmions) and the knotted solutions of the Faddev-Skyrme model (hopfions). The properties of the related deformed models, such as the Nicole and the Aratyn-Ferreira-Zimerman model, are also summarised.

Based on the author's lecture notes for a graduate-level course, this book is addressed at graduate students in theoretical physics and mathematics, as well as researchers interested in solitons.

Virginia Greco *CERN.*

Universal Themes of Bose-Einstein Condensation

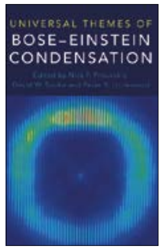
By Nick P Proukakis, David W Snoke and Peter B Littlewood

Cambridge University Press

The study of Bose-Einstein condensation (BEC) has undergone an incredible expansion during the last 25 years. Back then, the only experimentally realised Bose condensate was liquid helium-4, whereas today the phenomenon has been observed in a number of diverse atomic, optical and condensed-matter systems. The turning point for BEC came in 1995, when three different US groups reported the observation of BEC in trapped, weakly interacting atomic gases of rubidium-87, lithium-7 and sodium-23 within weeks of one another. These studies led to the 2001 Nobel Prize in Physics being jointly awarded to Eric Cornell, Wolfgang Ketterle and Carl Wieman.

This book is a collection of essays written by leading experts on various aspects and in different branches of BEC, which is now a broad and interdisciplinary area of modern physics. Composed of four parts, the volume starts with the history of the rapid development of this field and then takes the reader through the most important results.

The second part provides an extensive overview of various general themes related to universal features of Bose-Einstein condensates, such as the question of whether BEC involves spontaneous symmetry breaking, of how the ideal Bose gas condensation is modified by interactions between the particles, and the concept of universality and scale invariance in cold-atom systems. Part three focuses on active research topics in ultracold environments, including optical lattice experiments, the study of distinct sound velocities in ultracold atomic gases – which has shaped our current understanding of superfluid helium – and quantum turbulence in atomic condensates.



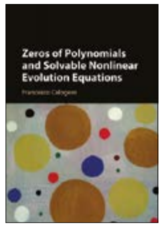
Part four is dedicated to the study of condensed-matter systems that exhibit various features of BEC, while in part five possible applications of the study of condensed matter and BEC to answer questions on astrophysical scales are discussed.

Virginia Greco *CERN.*

Zeros of Polynomials and Solvable Nonlinear Evolution Equations

By Francesco Calogero

Cambridge University Press

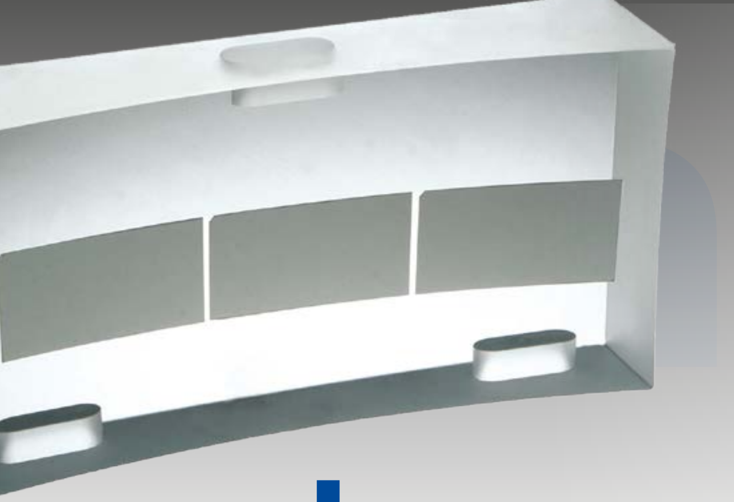


This concise book discusses the mathematical tools used to model complex phenomena via systems of nonlinear equations, which can be useful to describe many-body problems.

Starting from a well-established approach to solvable dynamical systems identification, the author proposes a novel algorithm that allows some of the restrictions of this approach to be eliminated and, thus, identifies more solvable/integrable N-body problems. After reporting this new differential algorithm to evaluate all the zeros of a generic polynomial of arbitrary degree, the book presents many examples to show its application and impact. The author first discusses systems of ordinary differential equations (ODEs), including second-order ODEs of Newtonian type, and then moves on to systems of partial differential equations and equations evolving in discrete time-steps.

This book is addressed to both applied mathematicians and theoretical physicists, and can be used as a basic text for a topical course for advanced undergraduates.

Virginia Greco *CERN.*



PEOPLE CAREERS

Standing out from the crowd

The European Committee for Future Accelerators is assessing individual recognition in large collaborations, not just for the benefit of early-career researchers but for the field as a whole.

CMS-PHO-PUBLIC-2017-004-3

Big physics *A portion of the CMS collaboration in 2017 on the occasion of the collaboration's 25th anniversary.*

Advances in particle physics are driven by well-defined innovations in accelerators, instrumentation, electronics, computing and data-analysis techniques. Yet our ability to innovate depends strongly on the talents of individuals, and on how we continue to attract and foster the best people. It is therefore vital that, within today's ever-growing collaborations, individual researchers feel that their contributions are recognised adequately within the scientific community at large.

Looking back to the time before large accelerators, individual recognition was not an issue in our field. Take Rutherford's revolutionary work on the nucleus or, more recently, Cowan and Reines' discovery of the neutrino – there were perhaps a couple of people working in a lab, at most with a technician, yet acknowledgement was at a global scale. There was no need for project management; individual recognition was spot-on and instinctive.

As high-energy physics progressed, the needs of experiments grew. During the 1980s, experiments such as UA1 and UA2 at the Super Proton Synchrotron (SPS) involved institutions from around five to eight countries, setting in motion a "natural evolution" of individual recognition. From those experiments, in which mentoring in family-sized groups played a big role, emerged spontaneous leaders, some of whom went on to head experimental physics groups, departments and laboratories. Moving into the 1990s, project management and individual recognition became even more pertinent. In the experiments at the Large Electron–Positron collider (LEP), the number of physicists, engineers and technicians working together rose by an order of magnitude compared to the SPS days, with up to 30 participating institutions and 20 countries involved in a given experiment.

Today, with the LHC experiments providing an even bigger jump in scale, we must ask ourselves: are we making our immense scientific progress at the expense of individual recognition?

Group goals

Large collaborations have been very successful, and the discovery of the Higgs boson at the LHC had a big impact in our community. Today there are more than 5000 physicists from institutions in more than 40 countries working on the main LHC experiments, and this mammoth scale demands a change in the way we nurture individual recognition and careers. In scientific collaborations with a collective mission, group goals are placed above personal ambition. For example, many of us spend hundreds of hours in the pit or carry out computing and software tasks to make sure our experiments deliver the best data, even though some of this collective work isn't always "visible". However, there are increasing challenges nowadays, particularly for young scientists who need to navigate the difficulties of balancing their aspirations. Larger collaborations mean there are many more PhD students and postdocs, while the number of permanent jobs has not increased equivalently; hence we also need to prepare early-career researchers for a non-academic career.

To fully exploit the potential of large collaborations, we need to bring every single person to maximum effectiveness by motivating and stimulating individual recognition and career choices. With this in mind, in spring 2018 the European Committee for Future Accelerators (ECFA) established a working group to investigate what the community thinks about individual recognition in large collaborations. Following an initial survey addressing leaders of several CERN and CERN-recognised experiments, a community-wide survey closed on 26 October with a total of 1347 responses.

Group goals are placed above personal ambition

Community survey

Participants expressed opinions on several statements related to how they perceive systems of recognition in their collaboration. More than 80% of the participants are involved in LHC experiments and researchers from most European countries were well represented. Just less than half (44%) were permanent staff members at their institute, with the rest comprising around 300 PhD students and 440 postdocs or junior staff. Participants were asked to indicate their level of agreement with a list of statements related to individual recognition. Each answer was quantified and the score distributions were compared between groups of participants, for instance according to career position, experiment, collaboration size, country, age, gender and discipline. Some initial findings are listed over the page, while the full breakdown of results – comprising hundreds of plots – is available at https://ecfa.web.cern.ch.

▷

- **Conferences:** *"The collaboration guidelines for speakers at conferences allow me to be creative and demonstrate my talents."* Overall, participants from the LHCb collaboration agree more with this statement compared to those from CMS and especially ATLAS. For younger participants this sentiment is more pronounced. Respondents affirmed that conference talks are an outstanding opportunity to demonstrate to the broader community their creativity and scientific insight, and are perceived to be one of the most important aspects of verifying the success of a scientist.

- **Publications:** *"For me it is important to be included as an author of all collaboration-wide papers."* Although the effect is less pronounced for participants from very large collaborations, they value being included as authors on collaboration-wide publications. The alphabetical listing of authors is also supported, and at all career stages. Participants had divided opinions when it came to alternatives.

- **Assigned responsibilities:** *"I perceive that profiles of positions with responsibility are well known outside the particle-physics community."* The further away from the collaboration, the more challenging it becomes to inform people about the role of a convener, yet the selection as a convenor is perceived to be very important in verifying the success of a scientist in our field. The majority of the participating early-career researchers are neutral or do not agree with the statement that the process of selecting conveners is sufficiently transparent and accessible.

- **Technical contributions:** *"I perceive that my technical contributions get adequate recognition in the particle-physics community."* Hardware and software technical work is at the core of particle-physics experiments, yet it remains challenging to recognise these contributions inside, but especially outside, the collaboration.

- **Scientific notes:** *"Scientific notes on analysis methods, detector and physics simulations, novel algorithms, software developments, etc, would be valuable for me as a new class of open publications to recognise individual contributions."* Although participants have very diverse opinions when it comes to making the internal collaboration notes public, they would value the opportunity to write down their novel and creative technical ideas in a new class of public notes.

Beyond disseminating the results of the survey, ECFA will reflect on how it can help to strengthen the recognition of individual achievements in large collaborations. The LHC experiments and other large collaborations have expressed openness to enter a dialogue on the topic, and will be invited by ECFA to join a pan-collaboration working group. This will help to relate observations from the survey to current practices in the collaborations, with the aim of keeping particle physics fit and healthy towards the next generation of experiments.

Archana Sharma *CERN and* **Jorgen D'Hondt** *Vrije Universiteit Brussel and ECFA chairperson.*

Life beyond CERN

Rocio Perez-Ochoa from Spain has a PhD in experimental particle physics and, following a stint in quantitative finance, now runs a company that distributes life-improving products in rural Kenya. Rocio is a member of the CERN Alumni Network: **https://alumni.cern.**

What's your academic background?
I was a technical student on the ALEPH experiment at CERN's LEP collider in the mid-1990s, and then continued with a PhD on OPAL. It was very much a flat organisation and, despite being just a student, I felt I was also making a valuable contribution. When I left in 1999, not only had I acquired analytical skills but I also discovered the importance of institutional culture.

Why did you leave the field?
I was looking for some stability, which I did not think I would find if I remained in academia. We didn't have social-media networks back then, so I relied on email and face-to-face networking to try and determine what I was going to do after CERN. I enrolled in an evening-class course on quantitative finance and found that the world of finance shares many similarities with physics – modelling and simulation for example. One thing I enjoyed is the sense of competition, although in the financial sector there is a lot more secrecy than in academia.

Did the course lead to a job offer?
Not directly, but I received lots of good advice, where to try my luck, which books to read, and how to highlight my own strengths. I worked in London from 2000–2007 as a quantitative analyst and hedge-fund manager in several organisations, including Merrill Lynch. Then, at the peak of the financial boom in the mid-2000s, I had what you might describe as a midlife-crisis. I started to think "what is the positive social outcome of what I'm doing?" So I enrolled for an MSc in environmental technology at Imperial College London, which led to a position as a policy analyst at the UK Department of Energy and Climate Change. I found the civil service quite strange in contrast to academia because it is extremely hierarchical and slow, and there is little freedom to implement what you think is best. But I gained valuable experience in understanding how government works and I enlarged my network.

How did you get into the world of start-ups?
I witnessed a huge amount of innovation in clean energies, especially in developing countries, so I started working as a freelance adviser, supporting green start-ups in emerging markets: a Colombian reforestation business, a clean-energy business in Sri Lanka and a manufacturer of solar systems for markets in Sub-Saharan Africa. Having participated in workshops, meetings and conferences, I had built up quite a network. In 2014, along with a friend who I'd met whilst studying for the MSc, I co-founded "Bidhaa Sasa" ("products now" in Swahili) based in rural Kenya. Bidhaa Sasa seeks to provide services to otherwise under-served communities, focussing on goods and services that will improve the quality of life for rural communities – particularly for women. What I bring to any table are my technical skills – anything that involves modelling, financial projections, building spreadsheets and developing the financial aspect of a business.

What is the most important thing you've learned so far?
There is a huge amount of value in the connections you make, which I did not realise when I started out. Do not feel shy when you reach out to people for advice, as you will be surprised by the kindness of strangers and the extent to which people are willing to help. Also take a course or attend a conference in an area of interest, speak to people and collect business cards. Use the power of the network!

Appointments

DESY chooses a new director
Wim Leemans (above) of Berkeley Lab in the US has been appointed director of DESY's accelerator division, effective from 1 February. A prominent leader in the development of plasma accelerators, Leemans was previously in charge of the accelerator technology and applied physics division at Berkeley, and head of the BELLA facility, which has achieved breakthrough results in advanced laser–plasma acceleration. Moving back to Europe after almost 30 years at Berkeley, he succeeds Reinhard Brinkmann, who has been director of the accelerator division since July 2007 and is now, at his own request, returning to DESY's accelerator research as a lead scientist.

Geddes to oversee UK labs
Experimental particle physicist Neil Geddes (above) has been named executive director for national laboratories science and technologies by the UK's Science and Technology Facilities Council (STFC). Taking up the position on 2 January, the new role comes with responsibility for the development of the UK's national labs and the exploitation of the technologies that underpin them. Geddes, who has spent periods at CERN and SLAC as a member of the OPAL and BaBar collaborations, has worked with the STFC for many years, spending time as the director for E-Science before becoming the director of STFC's technology department in 2012.

New comms chief for Fermilab
Fermilab in the US has appointed public-relations professional Chris Beard (right) as head of its office of communication, starting from 7 January. Beard has more than 20 years of experience in managing communications, brand reputation and stakeholder engagement for global corporations. Most recently he was senior director of corporate communications at Burson-Marsteller in Chicago, prior to which he was director of global reputation management for SC Johnson & Son. Fermilab's previous communications director, Katie Yurkewicz, moved to Argonne National Laboratory in 2018.

PEOPLE OBITUARIES

James Stirling 1953–2018

A key figure in the development of QCD

The eminent theoretical physicist James Stirling died on 9 November at his home in Durham, UK, after a short illness. He will be greatly missed, not only by his family but by his many friends and colleagues throughout the particle-physics community. His wide-ranging contributions to the development and application of quantum chromodynamics (QCD) were central in verifying QCD as the correct theory of strong interactions and in computing precise predictions for all types of processes at hadron colliders such as the LHC.


T Angus/Imperial College London

James Stirling's research always focused on confronting theory with experiment.

James was born in Belfast, Northern Ireland, and educated at Peterhouse at the University of Cambridge, where he obtained his PhD in 1979. After post-doc positions at the University of Washington in Seattle and at Cambridge, he went to CERN, first as a fellow and then as a staff member, leaving in 1986 for a faculty position at Durham University, where he remained until 2008. At Durham, he played a major role in the foundation of the university's Institute for Particle Physics Phenomenology in 2000, and served as its first director. He moved to Cambridge in 2008 to take up the Jacksonian Professorship of Natural Philosophy in the Cavendish Laboratory, becoming head of the department of physics in 2011. Then, in 2013, he was appointed to the newly created position of Provost, the chief academic officer, at Imperial College, London, from which he retired last August, moving back to Durham, where his retirement was tragically curtailed by illness.

James was a prolific and meticulous researcher, publishing more than 300 papers, including some of the most highly cited in particle physics. His research, always full of insight, focused on the confrontation of theoretical predictions with experimental results. Over the years, he performed frontier research on a vast range of phenomenological topics. During his graduate studies at Cambridge, in the early days of QCD, he clarified in detail the connection between deep-inelastic lepton–hadron scattering and hadron–hadron processes such as lepton pair production, which led to his later work on parton distribution functions at Durham. An example of his pioneering research is the first computation of the resummed transverse momentum distribution of W and Z bosons in hadron collisions at next-to-leading logarithmic order, performed with Christine Davies in 1984. Another is the development of the powerful helicity amplitude method, completed with Ronald Kleiss while they were at CERN. This enabled them to show that the "monojet" events seen at the CERN proton–antiproton collider, which had been thought to be a possible signal of new physics, could be explained by vector-boson plus jet production. The method has since facilitated the calculation of many other important Standard Model processes.

After moving to Durham in 1986, James formed a long-standing and successful research collaboration with Alan Martin, Dick Roberts and, later, Robert Thorne. Among other projects, they set the standard for determining the quark and gluon distributions in the proton, which led to the widely used MRS, MRST and MSTW parton distribution functions. Later, when James returned to Cambridge, he became interested in processes in which more than one parton from each colliding hadron participates (double parton scattering), bringing a new level of rigour to the analysis of such processes.

James had the gift of being able to explain complicated concepts and ideas simply. He was highly sought after as a plenary or summary speaker at the major international particle-physics conferences. His textbook *QCD and Collider Physics*, written with Keith Ellis and Bryan Webber, has been a standard reference for more than 20 years.

James was a humble and modest person but his intellectual brilliance, coupled with a very strong work ethic and exceptional organisational skills, meant that his advisory and administrative services were always in great demand. He was elected a Fellow of the Royal Society in 1999, and in 2006 he received the national honour CBE presented by the Queen for his services to science.

In addition to the great respect in which he was held as a scientist, James was much loved as a friend, colleague and mentor. He treated everyone with the same respect, courtesy and attention, whatever their status. His warmth, kindness and fundamental humanity made a deep impression on all who came into contact with him.

Alan Martin *Durham University and* **Bryan Webber** *University of Cambridge.*

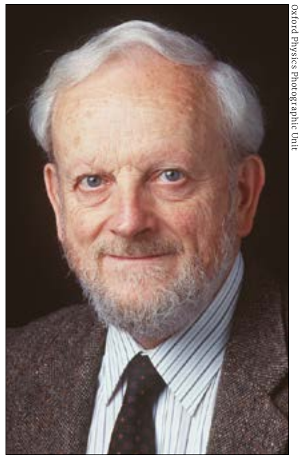
JOHN MULVEY 1929–2018

Promoting science in all its beauty

John Mulvey, one of the most enthusiastic supporters of European bubble-chamber physics in its heyday, died on 10 September.

John was brought up in Somerset in the UK, where he decided that he wanted to be a nuclear physicist. He graduated in physics from Bristol University in 1950, and went straight on to study for a PhD, during which he met his wife Denise while supervising her laboratory work as an undergraduate in chemistry. They married in 1955, the year after John submitted his thesis, and in 1956 went together to Los Angeles, where John spent two years as an assistant professor, making many lifelong friends. On their return to the UK, John began his 32 year-long career at the University of Oxford, where he led the Hydrogen Bubble Chamber Particle Physics Group.

John was always dedicated to his work and travelled frequently to help on experiments and attend meetings. In 1971 he took a six-month sabbatical in Hawaii, a memorable experience for the family. For three years, beginning in 1973, John was co-ordinator of the experimental programme at CERN.



Oxford Physics Photographic Unit

John Mulvey co-ordinated CERN's experimental programme in the mid-1970s.

A whole generation of students, who went on to lead great experiments of their own, refer with affection to Uncle John

An early success at CERN was his participation in the discovery of the $K^*(1420)$ resonance at the Proton Synchrotron. Back at Oxford, he set up the precision encoding and pattern recognition project, which measured tracks on bubble-chamber film with an online cathode-ray tube. With his collaborators in Hawaii, he pioneered an experiment at Berkeley to detect transition radiation from electrons passing through foils. His success encouraged Bill Willis to use the technique to detect J/ψ production at the ISR accelerator at CERN. Throughout his career, John encouraged new developments in detectors and accelerator physics at CERN and elsewhere.

During the 1980s he began to take a strong interest in UK science policy. He was frustrated by the cuts to science funding imposed by the Thatcher government and the idea, which was widely discussed, that the government should only fund research that had obvious economic benefits. He became a founding member of the Save British Science (SBS) society and spent much of his time lobbying politicians and businessmen. When he retired from the University of Oxford physics department in 1990, this became a full-time job; he set up an SBS office and ran it for eight years. (Later SBS became CaSE, the Campaign for Science and Engineering, as it is today.) In retirement, John worked on a book that sought to illustrate how research in pursuit of knowledge had frequently resulted in unforeseen benefits.

His life was celebrated at a memorial gathering at Wolfson College in Oxford on 6 October by his family and many friends, colleagues and former students. Speaking for those who had worked with him in particle physics, I recalled how John devoted his life to encouraging and enabling many people from far and wide to engage in unravelling particle science in all its beauty.

Discovery in our science is achieved neither by "prima donnas" working alone nor by groups directed from above, but by people working in dynamic teams held together through mutual respect and confidence – and that is where John made his greatest contribution.

Those who joined the Hydrogen Bubble Chamber Particle Physics Group at Oxford, those who worked with him at CERN, those who joined him to found SBS, and many others, all know how the trust that he engendered cemented international collaborations.

A whole generation of students, who went on to lead great experiments of their own, refer with affection to Uncle John. Indeed, his bright eyes and his smile were still shining when I last visited him.

In the physics department at Oxford there is a room that bears his name – an unusual honour that acknowledges his role in the achievements of the past 60 years and the affection that colleagues, staff and students had for him.

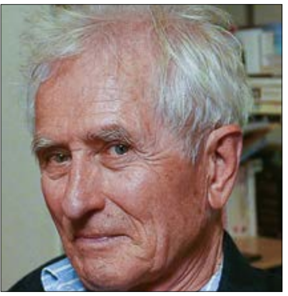
Wade Allison *Keble College, University of Oxford.*

PAUL BAILLON 1938–2018

Passion across disciplines

Paul Baillon, who was notable for the sheer variety of his output in particle physics and astrophysics, passed away on 2 October at the age of 80.

Paul was a pioneer in bubble-chamber physics. A graduate of École Normale Supérieure, he joined the École Polytechnique laboratory for his PhD. In 1961 and 1962 he participated in an experiment that recorded 750,000 antiproton annihilations at rest in liquid hydrogen at the 81 cm Saclay Bubble Chamber. His thesis, completed in 1965, presented a new determination of the mass and width of the K meson and described new resonances, in particular the first pseudoscalar meson in the 1400–1500 MeV mass region. Paul kept an interest in this subject because the meson could be interpreted as being made up of gluons (a "glueball"), and, 20 years after the data was recorded, he even carried out a new analysis looking for baryonium states.



Family collection

Paul Baillon was an eclectic physicist.

In 1966 Paul became a CERN staff member. From 1974 to 1982, he took part in experiments at the Proton Synchrotron that focused on the study of two-body hadronic reactions, and then spent a period of time at SLAC in the US, where he participated in the DELCO experiment at the PEP electron–positron collider, studying in particular the charm quark and the tau lepton.

Throughout his career, in parallel with his work at CERN, Paul managed to continue to collaborate with his French colleagues, often in his spare time. He was passionate about astrophysics and was one of the originators of gamma-ray astronomy in France through his involvement in the Themistocle experiment, carried out from 1988 to 1994. Later, he participated in the design of the CAT (Cherenkov Array at Themis) gamma-ray imaging telescope.

Paul was also involved in searches for dark matter based on the gravitational microlensing of background stars, contributing to the AGAPE and POINT-AGAPE searches conducted at the Pic du Midi and Las Palmas observatories in France and the Canary Islands.

Paul was as passionate about the construction of a detector as he was about abstract ideas in mathematical physics

Upon his return from the US, Paul again joined CERN's particle-physics programmes – first LEP and the DELPHI experiment, where he helped design and build the complex and innovative RICH Cherenkov detector. He then joined the CMS experiment at the LHC and made essential contributions to the design of the scintillating-crystal electromagnetic calorimeter, in particular the system that stabilises the crystal temperature to within a few hundredths of a degree.

With a solid foundation in classical physics and instrumentation, as well as in mathematics, Paul was as passionate about the construction of a detector as he was about abstract ideas in mathematical physics. Many still remember, for example, his highly informative class on the use of tensor calculus at the Herceg Novi school in 1968. In his retirement, he wrote a book entitled: *Differential Manifolds, A Basic Approach for Experimental Physicists*. He was writing a second on the basics of quantum field theory.

When faced with a problem, Paul had the knack of approaching it from an unexpected angle. It was a sign of brilliance, of true originality and even of a certain taste for the paradoxical, but it always produced results. Gifted and daring in his intellectual pursuits, he was also an accomplished skier and mountaineer. Beyond science and sport, Paul was interested in history and religion, and found time to get involved in politics and local affairs.

We will treasure the memories of our discussions with Paul, an exceptional scientist and person.

His colleagues and friends *at CERN and beyond.*

International Nuclear Physics Conference 2019

29 July – 2 August 2019, Scottish Event Campus, Glasgow, UK

The 27th International Nuclear Physics Conference (INPC 2019) will be held in Glasgow, UK, 29 July to 2 August, 2019. Held every three years, INPC is the biggest conference in the world for fundamental nuclear physics, and is overseen by the International Union of Pure and Applied Physics (IUPAP). The event in Glasgow follows conferences in Adelaide 2016, Florence 2013 and Vancouver 2010.

The programme will showcase the very latest work across the whole range of topic areas in nuclear physics, from the study of hadrons to the heaviest nuclei, and the role of nuclear physics in our understanding of the universe. It includes a world-class programme of plenary speakers, a range of parallel sessions with invited and contributed talks, poster sessions, outreach activities, including a public lecture delivered by Professor Jim Al-Khalili and a trade exhibition. There will also be social activities for informal networking.

Plenary speakers

- Professor Ani Aprahamian, Notre Dame University, USA
- Professor Michael Block, Johannes Gutenberg University Mainz, Germany
- Professor Dr Pierre Capel, Johannes Gutenberg University Mainz, Germany
- Dr Francesca Cavanna, National Institute for Nuclear Physics, Italy
- Professor Lola Cortina, University of Santiago de Compostela, Spain
- Professor Anna Frebel, MIT, USA
- Professor Alexandra Gade, Michigan State University, USA
- Professor Juan Jose Gomez Cadenas, Donostia International Physics Center, Spain
- Dr Kawtar Hafidi, Argonne National Laboratory, USA
- Dr Gaute Hagen, Oak Ridge National Laboratory, USA
- Dr Tetsuo Hatsuda, RIKEN, Japan
- Dr Arnau Rios Huguet, University of Surrey, UK
- Dr Ulli Köster, Institut Laue–Langevin, France
- Professor Oscar Naviliat-Cuncic, Michigan State University, USA
- Dr Alice Ohlson, University of Heidelberg, Germany
- Professor Joern Putschke, Wayne State, USA
- Professor Craig Roberts, Argonne National Laboratory, USA
- Professor Justin Stevens, College of William and Mary, USA
- Professor Toshimi Suda, Tohoku University, Japan
- Dr Peter Thirolf, Ludwig Maximilian University, Germany
- Professor Dr Jo Van den Brand, Dutch National Institute for Subatomic Physics and VU University Amsterdam, the Netherlands
- Dr Xiaofei Yang, Peking University, China

Key dates

Early registration deadline:	1 June 2019
Registration deadline:	19 July 2019

For further information, visit the conference website at **http://inpc2019.iopconfs.org**

IOP Institute of Physics

RECRUITMENT

For advertising enquiries, contact *CERN Courier* recruitment/classified, IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK.
Tel +44 (0)117 930 1264 E-mail sales@cerncourier.com.
Please contact us for information about rates, colour options, publication dates and deadlines.

A very happy new year from the CERN HR Talent Acquisition team!

2019 will see plenty of new opportunities opening up for students, graduates and experienced professionals, and **http://careers.cern** is the place to find them.

CERN: the place for a unique work experience.
A place like nowhere else on earth. **Take part!**

CERN | HR
Human Resources

ACCELERATORS AND CRYOGENIC SYSTEMS

Our company: Based at the heart of the Paris-Saclay Scientific Cluster, ACS (Accelerators and Cryogenic Systems) is positioned as a specialized engineering company on design and integration of accelerators and research instruments based on superconductivity and cryogenic techniques. We offer a wide range of engineering services, from technical studies and manufacturing monitoring, to prototyping tests on technology platforms.

R&D technical manager

- Master degree in Engineering (preferences on Electronics, Electrotechnics and Computer Sciences) and/or PhD on Physics.
- Good knowledge of fundamental and applied physics, and some experience on accelerator physics will be an advantage.

Job Description:

- Participation in R & D activities on major scientific equipments in projects related to the ACS activity, in collaboration with national and international research institutions.
- Management of the Engineers and Technicians of the company
- Interaction with our consultants and industrial partners
- Development of specifications and technical requirements of the company's contracts
- Definition of the technical strategy for computer simulations
- Definition of company strategy Computer and control technology solutions applied to scientific equipments
- Representation of ACS in instances and Identification of potential customers
- Participation in activities developed in connection with research institutions

Mail: Isabelle.doucot@acsfrance.com

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

The location Hamburg is seeking:

Scientist (f/m/diverse) ATLAS and future experiments

DESY

DESY is one of the world's leading research centres for photon science, particle and astroparticle physics as well as accelerator physics. More than 2400 employees work at our two locations Hamburg and Zeuthen in science, technology and administration.

The particle physics programme of DESY consists of strong contributions to the LHC experiments ATLAS and CMS, the Belle-II Experiment in Japan and to the preparation of future experiments. The experimental programme is enhanced by collaboration with a strong theory group. DESY is searching an experienced experimental physicist (f/m/diverse), who is interested in contributing to the ATLAS experiment at the LHC and to future particle physics projects at DESY.

The position

Leading role in ATLAS data analysis with focus on measurements Participation in ATLAS detector operation or upgrade Participation in the supervision of students and postdocs Engagement in Research and Design for Future Experiment(s)

Requirements

- PhD in experimental Particle Physics
- Experience in data analysis and software development
- Experience in detector operations and/or development
- Outstanding teamwork abilities and excellent communication skills and knowledge of English

For further information please contact Prof. Dr. Beate Heinemann (beate.heinemann@desy.de).

Please use our online application tool to submit your complete application (Motivation letter, a CV which also details your research accomplishments, a list of your publications, and a 2-3 page statement on future research plans) and please arrange for at least three letters of reference to be sent to the DESY human resource department (recruitment@desy.de), clearly stating your name and the position identifier.

Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. Handicapped persons will be given preference to other equally qualified applicants. DESY operates flexible work schemes. DESY is an equal opportunity, affirmative action employer and encourages applications from women. Vacant positions at DESY are in general open to part-time- work. During each application procedure DESY will assess whether the post can be filled with part-time employees.

We are looking forward to your application via our application system:
www.desy.de/onlineapplication

Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: FHMA051/2018 Notkestraße 85 |
22607 Hamburg | 22607 Hamburg Germany
Phone: +49 40 8998-3392
http://www.desy.de/career

Deadline for applications: 2019/01/31

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Karlsruhe Institute of Technology

Karlsruhe Institute of Technology (KIT) – The Research University in the Helmholtz Association creates and imparts knowledge for the society and the environment. It is our goal to make significant contributions to mastering the global challenges of mankind in the fields of energy, mobility, and information. For this, about 9300 employees of KIT cooperate in a broad range of disciplines in research, academic education and innovation.

The Department of Physics at KIT, as part of the Physics and Mathematics Division, invites applications for a

Professorship (W3) in Theoretical Particle Physics

at the Institute for Theoretical Physics (successor of Prof. Dr. Dieter Zeppenfeld).

KIT provides an excellent environment for research in particle physics. The Institute for Theoretical Physics is part of the KIT Center Elementary Particle and Astroparticle Physics (see www.kceta.edu for additional information). KIT hosts the Research Training Group "Particle Physics at Highest Energy and Precision" and the Karlsruhe School of Elementary Particle and Astroparticle Physics: Science and Technology (KSETA), which provides access to an excellent pool of Ph.D. students.

We are looking for an outstanding scientist working in the area of particle physics phenomenology, broadly defined. We are particularly interested in a scientist whose research focuses on collider physics, precision calculations, physics beyond the Standard Model or flavour physics. The successful applicant is expected to play an active role in the Collaborative Research Center"Particle Physics Phenomenology after the Higgs Discovery" and other coordinated research efforts at KIT.

The successful candidate will be part of a team of senior scientists who maintain and develop the research in particle physics at KIT.

The appointed professor is required to teach at all levels of the undergraduate and graduate curriculum (eventually in German) and to supervise bachelor, master and Ph.D. students.

A Habilitation degree or equivalent scientific and teaching qualifications are required. The employment conditions as outlined in Art. 47 LHG (Law of Baden-Württemberg on Universities and Colleges) shall apply.

KIT wishes to increase the proportion of female professors and hence, strongly encourages qualified women to apply. Handicapped applicants having the same qualification will be preferred.

Qualified candidates should submit before **January 28th, 2019** a curriculum vitae, list of publications, as well as research and teaching statements to: **Karlsruher Institut für Technologie (KIT), Dekan der KIT-Fakultät für Physik, 76128 Karlsruhe, Germany, preferably by email to dekanat@physik.kit.edu**.

For further information about this position please contact Prof. Dr. Margarete Mühlleitner, email: margarete.muehlleitner@kit.edu.

Since 2010, the KIT has been certified as a family-friendly university.

Zertifikat seit 2010 audit familiengerechte hochschule

KIT – The Research University in the Helmholtz Association

WWU MÜNSTER

Zertifikat seit 2008 audit familiengerechte hochschule

The DFG Research Training Group
Strong and Weak Interactions - from Hadrons to Dark Matter
at the University of Münster, Germany, invites applications for various

PhD Positions

(salary level TV-L E13, 75 %)

These fixed-term positions will start on April 1st, 2019 or later and are available for up to three years.

The structure of the DFG-funded Research Training Group (Graduiertenkolleg) is based on joint education and research of theorists and experimentalists in nuclear, particle and astroparticle physics as well as computer scientists and mathematicians (http://www.uni-muenster.de/Physik.GRK2149).

In strong interactions we aim at precision in experiments and theoretical predictions. Examples are the transition from the quark gluon plasma into bound hadrons, the parton distributions in cold nuclear matter or properties of mesons. In weak interactions we investigate more speculative questions beyond the Standard Model, especially those related to dark matter and neutrinos.

Applicants with a very good master's degree or diploma in physics are expected to submit the usual application documents (curriculum vitae, copies of transcripts and certificates) as well as two letters of reference and a letter explaining their motivation to join our Research Training Group and their research interests.

The University of Münster is an equal opportunity employer and is committed to increasing the proportion of women academics. Consequently, we actively encourage applications by women. Female candidates with equivalent qualifications and academic achievements will be preferentially considered within the framework of the legal possibilities. We also welcome applications from candidates with severe disabilities. Disabled candidates with equivalent qualifications will be preferentially considered.

Applications should be sent by **February 15th, 2019** to the spokesperson of the Research Training Group preferentially by email:

Prof. Dr. Christian Weinheimer
Institut für Kernphysik
Wilhelm-Klemm-Str. 9
D-48149 Münster
email: grk2149.info@uni-muenster.de

www.uni-muenster.de

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

For our location in Hamburg we are seeking:

Laser Development Scientist (f/m/diverse)

DESY

DESY is one of the world's leading research centres for photon science, particle and astroparticle physics as well as accelerator physics. More than 2400 employees work at our two locations Hamburg and Zeuthen in science, technology and administration.

DESY's laser science and technology group is responsible for research, development and operations of high power femtosecond and picosecond lasers for particle accelerators and free electron lasers (FEL). We are currently developing photocathode Laser systems for the European X-ray free electron Laser and are seeking to employ a self-driven highly motivated Laser scientist or Laser engineer (f/m/diverse) to strengthen our Team.

The position

- Develop, design and construct high power short pulse laser systems with high stability and reliability for photoelectron guns
- Develop nonlinear frequency conversion to the UV
- Develop concepts for spatial and temporal picosecond UV laser pulse diagnostics and pulse manipulation
- Interact with laser, controls and accelerator scientists and engineers

Requirements

- Master or equivalent in Physics, Electrical engineering or similar discipline, PhD is a plus
- Experience in ultra fast laser research and development with proven track record
- Skills in high-power, high-repetition rate fiber laser development beneficial
- Basic knowledge and experience in opto-mechanical engineering is a plus
- Working knowledge of electronics, controls and software Engineering
- Ability to work independent within a team of scientists and engineers
- Ability to communicate effectively in a multilingual, multi-disciplinary research environment

For further information please contact Dr. Ingmar Hartl (Ingmar.hartl@desy.de)

The position is limited to 2 years.
Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. Handicapped persons will be given preference to other equally qualified applicants. DESY operates flexible work schemes. DESY is an equal opportunity, affirmative action employer and encourages applications from women. Vacant positions at DESY are in general open to part-timework. During each application procedure DESY will assess whether the post can be filled with part-time employees.

We are looking forward to your application via our application system:
www.desy.de/onlineapplication

Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: FSMA079/2018
Notkestraße 85 | 22607 Hamburg | 22607 Hamburg Germany
Phone: +49 40 8998-3392
http://www.desy.de/career

Deadline for applications: 2019/02/12

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

The ELI (Extreme Light Infrastructure) Project is an integral part of the European plan to build the next generation of large research facilities. ELI-Beamlines as a cutting edge laser facility is currently being constructed near Pague, Czech Republic. ELI will be delivering ultra-short, ultra-intense laser pulses lasting typically a few tens of femtoseconds with peak power projected to reach 10 PW. It will make available time synchronized laser beams over a wide range of intensities for multi-disciplinary applications in physics, medicine, biology, material science etc. The high intensities of the laser pulse will be also used for generating secondary sources of e- and p+ and high-energy photons. Our research groups are expanding and recruiting physicists and engineers.

In our team we therefore have the following positions available:

- **Junior Researchers**
- **Postdoc/Senior Researchers**
- **Control Systems Specialist**
- **LabVIEW Software Developer**
- **Instrumental Scientist**

For more information see our website **www.eli-beams.eu** and send your application, please.

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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

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EUROPEAN
SPALLATION
SOURCE

Technical Director

The European Spallation Source (ESS) in Lund, Sweden, is a partnership of 13 European countries, hosted by Sweden and Denmark. Our vision is to build and operate the world's most powerful neutron source, addressing some of the most important societal challenges of our time.

ESS now invites applications for the position **Technical Director**.

- **ESS's Technical Directorate is responsible for delivery, commissioning and operations of the ESS Accelerator, Target and Integrated Control Systems. The Directorate is today also managing the ESS Engineering and Integration Support division. We are looking for an experienced leader providing inspirational Leadership and management of the ESS Technical Directorate as the organization transitions from construction to commissioning and operations.**

The Technical Director reports directly to the Director General. The Technical Director will be a member of the Executive Management Team that secures the success of ESS as a world leading research facility.

At ESS we offer people with talent and passion a unique opportunity to be involved in developing, building, and operating a world-leading facility for materials research. You will also enjoy being part of a company culture that promotes collaboration and achievement.

For more information regarding the ESS recruitment process, please look at https://europeanspallationsource.se/ess-recruitment-process

Submit your application as soon as possible, as we will review applications continuously, latest by **February 15th, 2019**

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rofin-sinar UK

Laser Engineer (Ref LE14)
The expansion of our product range and continuing growth of our company have created an opportunity for a self-motivated, innovative individual to join our Laser and Optics Group designing and developing Solid-State and CO2 lasers, and associated systems.

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- We're an innovative market leader in the development of world class industrial laser products
- We take pride in having a collaborative approach with all our customers and partners
- Our lasers drive future innovations in a range of industries

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Kingston upon Hull, HU13 0DG
or e-mail **jobs@rofin-sinar.uk**

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

IHEP RECRUITMENT OF OVERSEAS HIGH-LEVEL TALENTS

INSTITUTE OF HIGH ENERGY PHYSICS, CHINESE ACADEMY OF SCIENCES

The Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences (CAS) invites applications for permanent staff positions at all levels. IHEP is a comprehensive research laboratory for particle and astroparticle physics, accelerator physics and technology, radiation technologies and applications, as well as for nuclear analytical techniques and interdisciplinary research.

For More Information: **http://english.ihep.cas.cn/**

Recruitment Objectives:

Based on the needs of the research areas and the disciplines development of IHEP, we are now publicly recruiting overseas outstanding talents and scholars of relevant disciplines who possess research abilities and innovation awareness.

Programs:

1 National "Thousand Talents Program" (full time & part time programs) for established scientists
2 National "Thousand Young Talents Program" for outstanding junior scientists
3 Pioneer "Hundred Talents Program" of CAS for outstanding junior scientists, excellent junior detector or accelerator experts
4 "Outstanding Talents Program" of IHEP for scientific research or technical talents

Research Areas:

Experimental Particle and Nuclear Physics, Theoretical Physics, Astronomy and Astrophysics, Nuclear Technology, Accelerators, Neutron physics, Condensed matter physics, Chemistry, Biochemistry and Molecular Biology, Biophysics, Computing, Multidisciplinary Research.

Contact:

Office of Human Resources, Institute of High Energy Physics, Chinese Academy of Sciences
E-mail: lianggj@ihep.ac.cn **Tel:** (86)010-88233157 **Fax:** (86)010-88233102
Address: No. 19 (B), Yuquan Road, Shijingshan District, Beijing (Postcode: 100049)

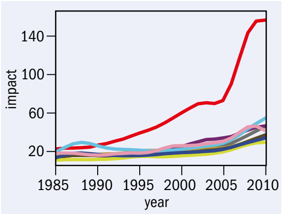
Applications should include a CV, an outline of academic accomplishments, description of current research and plan for future research, 3 – 5 published papers representative of your work, and a record of citations for your work. You should arrange for 3 letters of reference from experts in your field to be sent by post or email (established scientists are not requested).

For detailed information, please visit **http://english.ihep.cas.cn/doc/2649.html**

BACKGROUND

Notes and observations from the high-energy physics community

HEP comes out on top



High-energy physics (HEP) ranks top for productivity and impact, according to a study of the subfields of 135,877 physicists carried out by researchers at Central European University in Budapest. In HEP (red line) the average impact, defined as the number of citations per author within a five-year window, shows exceptional growth compared to other physics subfields such as condensed-matter (light blue) and "astro" (pink). Divide the number of paper citations by team size to capture the "fractional" impact, however, and HEP fares worse than most, displaying a downward trend during the past decade. Overall, concludes the team, the amount of knowledge produced per capita has decreased in all subfields despite the increase in the total number of physicists and physics papers (*Nat. Rev. Phys.* **1** 89).

Anomaly watch


LNGS-INFN

First there was the loose coaxial cable that led physicists to think neutrinos travel faster than light. Then there was the cosmic dust that duped researchers into thinking they had detected primordial B-modes, the smoking gun of inflation. Could the mundane be about to scupper a third major claim, this time concerning dark matter, before the decade is over?

The ultrapure sodium-iodide scintillators of the DAMA experiment at Gran Sasso National Laboratory (pictured) have long recorded highly significant seasonal variations in the event rate, consistent with Earth moving relative to a halo of dark matter surrounding the Milky Way. But Daniel Ferenc of the University of California Davis and co-workers reason that the probable cause of the DAMA anomaly is the migration of helium through photomultiplier tubes in the detectors. This, they say, could produce accidental coincidences of inflated "dark noise" waveforms that mimic scintillation events at just the right rate to explain the DAMA anomaly (arXiv:1901.02139).

From the archive: February 1976

People and things


CERN 348.10.71

Professor Werner Heisenberg died on 1 February 1976. One of the great figures in physics, he was amongst the most active and influential scientists who worked for the creation of CERN. Born in 1901, in his 20s Heisenberg participated in the glorious days of the evolution of quantum theory, his name immortally linked to the "Uncertainty Principle", formulated in 1926. It brought him the Nobel Prize for Physics in 1932.

Heisenberg's involvement in the affairs of CERN began as a delegate of the Federal Republic of Germany at the formative meeting in 1951; in 1952 he signed the Agreement establishing CERN in the name of the German government. He continued to give his time and abilities to CERN, as delegate to CERN Council (to 1963) and a member of the Scientific Policy Committee (to 1961). His last official appearance at CERN was in October 1971 when he inaugurated the Intersecting Storage Rings (photo above).

- Compiled from text on p59 of *CERN Courier* February 1976.

6%

Percentage of the LHC's total expected dataset collected so far

B physics goes south

Greig Cowan

The theme of the famous "penguin" diagram, responsible for rare flavour-changing processes and so-named by John Ellis in 1977 following a lost bet over a game of darts, was last year turned into a word cloud in which the size of each word represents the frequency of its appearance on the public LHCb web page – offering a guide as to what's, err, hot on the flavour-physics scene.

Media corner

"Just as it meant something beyond the world of particle physics when America cancelled its proposed giant SSC and CERN's LHC became the biggest game in town, so it would mean something if China took CERN's crown."

The Economist assesses China's scientific ambitions following the nation's landing of a craft on the Moon (print edition, 12 January).

"My advice is to try crazy ideas and innovative experiments. Something will come up."

Steven Weinberg on the challenges facing today's researchers in *APS Physics* (*Physics* **11** 134).

"Because the Standard Model has gone from success to success, and the quanta from which the Higgs condensate is made were at last detected, we are amply entitled to conclude that we live inside an exotic (electroweak) superconductor."

Frank Wilczek writing about the evolving unity of physics in the inaugural issue of *Nature Reviews Physics* (*Nat. Rev. Phys.* **1** 5).