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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CT-BOX:
- Upgrade central
- The ALICE inner detectors
- 25 On stage
- Edoardo Amaldi’s life

**Future collider**
Magnet design for an FCC-ee quadrupole

**On the cover:** ALICE being opened up in December.

**ALICE UPGRADE**
ALICE revitalised
The ALICE experiment is being upgraded to make even more precise measurements of extreme nuclear matter
- 25

**CMS UPGRADE**
CMS has high luminosity in sight
A challenge for CMS is to prepare the detector for future installations necessary for HL-LHC
- 28

**ATLAS UPGRADE**
ATLAS upgrades in LS2
New wheel-shaped detectors are among numerous transformations taking place
- 31

**VIEWPOINT**
Good strategy demands the right balance
Tatsuya Nakada reflects on the European Strategy for Particle Physics
- 43

**INTERVIEW**
Understanding naturalness
Theorist Nathaniel Craig discusses the pros and cons of naturalness in high-energy physics
- 45

**REVIEWS**
How beauty leads physics astray
Hossenfelder is Lost in Math • Performance celebrates Amaldi’s life • Short reviews
- 49

**DEPARTMENTS**
- FROM THE EDITOR
- NEWS DIGEST
- LIFE BEYOND CERN
- APPOINTMENTS
- RECRUITMENT
- BACKGROUND
New-look CERN Courier captures a field in motion

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 (p38). 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).

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 edition 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 interrogation of knowledge and ideas. All feedback is welcome via the contacts below, and I wish you an enjoyable read.

Maximising potential: The removal of the LHCb beam pipe in January as part of a major upgrade.
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**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 €1.2 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 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. The new result (Nature, 564, 395), providing a powerful test of the Standard Model (SM), will be used to refine the SM predictions of the EDM. The EDM is non-zero but small, on the order of 10^{-29} eÅ.

**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. The black-hole events, the new event GW171209 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 the results in a catalogue that comprises confirmed and candidate events (arXiv:1811.13907) 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 education 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 science challenges and help build EOSC. Under the commission’s Horizon 2020 programme, €1.6 million has been allocated to setting up EOSC by 2020.

**Physics resumes at RHIC**

The 19th year of physics operations at RHIC 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 low-energy run to look for signs of a critical point in the phase diagram at which the transition from ordinary matter to a quark-gluon plasma switches from abrupt to continuous.
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, a breakthroug...
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 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 7f electronic configuration. The electron configurations of the heavier elements of this sequence, from Z = 100 (fermium) onwards, have been difficult to measure, preventing confirmation of the series.

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 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 issue to the IUPAC working group, which is evaluating if lawrencium is indeed the last actinide," says team member Thierry Stora of CERN.

Confirmation

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 7f5 orbital "valence" electron. But with only this value the team couldn’t confirm the expected increase of the ionisation value of the heavy actinides up to nobelium (Z = 102). This is because with the filling of the 5f electron shell in a similar manner to the filling of the 4f electron shell until ytterbium in the lanthanides.

In their latest study, Sato and colleagues have last accessed the successive ionisation potentials from fermium to lawrencium, which is essential to confirm the filling of the 5f shell (heavy actinides, see figure). The results agree well with those predicted by state-of-the-art relativistic quantum-mechanical calculations and confirm that the ionisation valence electron of actinides increases up to nobelium, while that of lawrencium is the lowest among the series.

The results demonstrate that the 7f orbital is fully filled at nobelium (with the [Rn] 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 Türling, a chemist from the University of Bern, Switzerland. "As the authors state, these measurements provide unequivocal proof that the actinide electron configuration at lawrencium is indeed the last, and as such the filling of the 7f orbital proceeds in a very similar way to lanthanides, where the 5f 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


Aerial view SLAC/SLAC Photo by R. Berger

SLAC has a rich history in developing such techniques, and the previous FACET facility enabled researchers to demonstrate electron–light plasma acceleration for both electrons and positrons. FACET-II will use the mid-third resolution (corresponding to a length of 1 km) of SLAC’s linear accelerator to generate a 4.5 GeV electron beam, fitted 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 the development of new machines where additional steps are required before plasma accelerators can become a reality. This is the version of FACET-II that, in addition to higher–quality beams than FACET, explores – the so–called "MeV-gain". "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 recently approved a $26 million project, the latest work. "This result, which would confirm the actinide series ends with lawrencium, is indeed the last actinide," says team member Thierry Stora of CERN. "As the authors state, these measurements provide unequivocal proof that the actinide electron configuration at lawrencium is indeed the last, and as such the filling of the 7f orbital proceeds in a very similar way to lanthanides, where the 5f 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


First beam FACET-II on 20 September.

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 (FAEST), which operated from 1986 to 2010. FACET-II produces high–quality electron beams to develop plasma–waked field accelerators, which are now a promising way for future high–energy particle accelerators.

"The first beam was produced on 20 September and the next step is to see if the beams can be accelerated in a vacuum to high energies," says Uwe Krause of SLAC.

The team has published the results of the first electron beam, which was produced at a total energy of 4.5 GeV and with a brightness of 1.6 billion per milliradian. This is a factor of 25 more than existing electron beams at SLAC. "The beam will be further optimised during the next phase of the experiment, which will begin in early 2019," says Krause.

"It is fascinating that nowadays mankind has access to high–energy particle beams that are orders of magnitude more intense than the ones we used to produce up to now," says Krause.

"The FACET-II project design also allows for the capability to produce and accelerate positrons at a later stage, paving the way for plasma–based electron–positron colliders. FACET-II has issued its first call for proposals for experiments that will run the facility by 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–waked 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–waked experiments,” says technical coordinator and CERN project leader for AWAKE, Edda Gschwendtner, who is also chair of the FACET–II programme advisory committee.

"It is fascinating that nowadays mankind has access to high–energy particle beams that are orders of magnitude more intense than the ones we used to produce up to now," says Krause.

"The low–energy, ultra–high–precision investigations for physics beyond the standard model are an important complement studies in particle physics."
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 little precise about the underlying cause. In a classical universe with no quantum effects, the cosmic acceleration can be explained by a constant density of dark energy. However, in a universe with no quantum effects, the expansion of the universe is accelerating, as the universe itself in high-energy particle collisions. Like other signals of new physics, DE (if it exists) cannot be explained by interactions between DE and SM particles.

Signatures

“Any possible deviations from general relativity and the geometry of spacetime must be fundamentally modified,” says Clare Burrage, a theorist at the University of Nottingham in the UK. 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 could be the result of quantum effects. 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 radiation, the distribution 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 direct production of DE particles, since they are sensitive to a multitude of signatures and therefore in a wider array of possible DE interactions with matter. Like other signals of new physics, DE (if it exists) cannot be explained by interactions between DE and SM particles. 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 DE particle and the strength of the force that it couples to determine the couplings to the SM particles. 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 University of Paris–Saclay, Burrage, Christopher Englert of the University of Glasgow, and Michael Haehl (now of Durham University). The model provides the most general framework for describing DE theories with a scalar field and contains as subsets many well-established 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, the size of the emission region

The ATLAS analysis, which was based on 13.1 fb of LHC data corresponding to an integrated luminosity of 46.5 fb⁻¹, impepairs the result of recent ATLAS searches for stop-quark and dark matter produced in association with jets. No significant excess over the predicted background was observed, setting the most stringent limits on additional DE–SM couplings. Two representative operator predictions that DE couples preferentially to the almost 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).

Signatures

“In a big class of these operators the DE particle cannot decay inside the detector, therefore leaving a missing energy signature,” explains SpyridonArgyropoulos of the University of Iowa, who is a member of the ATLAS team that carried out the ATLAS 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 13.1 fb of LHC data corresponding to an integrated luminosity of 46.5 fb⁻¹, reinterprets 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 limits on additional DE–SM couplings. Two representative operator predictions that DE couples preferentially to the almost 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).

With this pioneering interpretation of collider searches in terms of dark-energy models, ATLAS has become the first experiment to probe all forms of matter and energy in the observable universe, opening a new avenue of research at the interface of particle physics and cosmology. A complementary laboratory measurement is also pursued by CERN’s CAST experiment, which aims to provide crucial information for understanding the nature of DE. CAST and the new ATLAS results contribute to the ability of DE and normal matter to be explored and more optimal search strategies could be developed.

The search for dark energy is only at the beginning

Colliders join the hunt for dark energy
CERN COURIER JANUARY/FEBRUARY 2019

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 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. For example, an exotic heavy Higgs boson would be detected in addition to the one discovered in 2012 at the LHC, it could decay into a pair of top–quarks and anti–quarks and align their spin correlation significantly. A high–precision measurement of the spin correlation therefore opens a window to explore physics beyond our current knowledge.

The CMS collaboration studied more than one million top–quark–antiquark pairs in dilepton final states recorded in 2016. To study all the spins 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 convoluted 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: left). Good agreement with the NLO predictions is observed, as indicated by the dashed blue line.

A moderate discrepancy is seen in one of the measured distributions

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.

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 photon production of J/ψ mesons 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 (Wγ) and kinematical reach of the J/ψ meson, enabling the possibility of reaching a factor of two with respect to the calculation performed at the former HERA collider.

Recently, the ALICE collaboration has performed a measurement of exclusive photon production 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,

Table 1 shows the production cross section for the production of J/ψ mesons in proton–lead collisions with 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,
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 $e$- and $\mu$- channels. The second configuration combines a muon measured with the central-barrel detectors with a second muon measured by the muon spectrometers located at forward rapidity. By this clever use of the detector configuration, we were able to significantly extend the coverage of the $J/\psi$ measurement.

The energy of the photon–proton collisions, $\sqrt{s}$, is determined by the rapidity (which is a function of the polar angle) of the produced $J/\psi$ with respect to the beam axis. Since the direction of the photon 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 a continuous way – the range of $W$ from 3 to 10 TeV! 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 $2 \times 10^{-3}$ to $2 \times 10^{-1}$. The measured cross section for this process as a function of $W$ is shown in figure 1 and compared with previous measurements and model predictions based on different assumptions such as the validity of DGLAP evolution (MRTB), the next-to-leading order BFKL, the colour-singlet (CoS) model, and the inclusion of linearly mixed $xg$ and $xg$ quark quark (CFT). The last two models include the decrease in gluon saturation, where nonlinear effects reduce the gluon density in the proton at small $x$. These ingredients are compatible with previous HERA data where available, but 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–p collisions at a centre-of-mass energy of 8 TeV, allowing exploration of the $W_{\gamma}$ energy range up to 1.5 TeV, potentially shedding new light on the question of gluon saturation.

Further reading
S.Klein and J.Nystrom and 2017 Physics Today 70 66

LHCb: Real-time triggering boosts heavy-flavour programme

Throughout LHC Run 2, LHCb has been flooded by $b$–$c$-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 $b$–$c$-hadron decay keys. 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 those interesting physics objects (for example, $J/\psi$ mesons) and, thus, 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.

The two-stage LHCb software trigger is able to select heavy-flavour 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. Selecting 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 therefore been made so far using only this information. The sets of physics objects that must be saved for offline analysis can also be chosen “a 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 75% of the physics programme will be used the reduced event format. The full software trigger, combined with real-time alignment and calibration, along with the high efficiency detailed in Run 2, 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 carried over into Run 3.

Further reading

Fig. 1. The cross-section for the process $e^{+}e^{-} \rightarrow J/\psi + X$, measured at the Tevatron (left) and the LHC (right). The full lines at the bottom show the theory predictions for the two sets of measurements.

Fig. 2. The sensitivity of the LHCb model to upcoming ATLAS and CMS searches.

Fig. 3. The regions in the mediator versus dark-matter mass plane excluded at 95% CL by dijet, di-b-jet, top and ETmiss signatures at the LHC.

Fig. 4. The two-stage LHCb software trigger.
On 23–30 July 2018, physicists joined forces in Wuppertal, Germany, to address historical, philosophical, and sociological aspects of particle physics in Wuppertal, Germany. The event, the third in a series of spring and summer workshops, 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 previous workshops conducted between 2016 and 2019.

Discussions focused on the theme “Particle physics at the crossroads,” with no evidence of physics beyond the standard model. Despite their focus on current issues in high-energy physics, the talks at this year’s summer school were all examples of work in both the humanities and social sciences that 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 behind different approaches to high-energy physics. He argued that statistical and scientific considerations can explain why the practice of high-energy physics has followed the most frequent statistical methods than on Bayesian ones. As a result, he noted, scientists have not only created their followed in the successful Fermilab, but also the future of the LHC since the late 1980s.

The most recent edition, the International Workshop on Deep Inelastic Scattering and Related Subjects (DIS2018) was held in Kobe, Japan, on 20–24 April 2018. The event continued in the style of past workshops, with no less than 150 talks presented. The main topic was the future of deep inelastic scattering, which relies on complex simulations and discussions whether they should be followed. In addition to precise measurements in the final and initial states. Another is that perturbative and spin dynamics in hadrons and nuclei, “in the midst of the quantum world, the motion and the dynamics of parts play an important role in describing hadron behaviour.” Traditionally, these topics have been discussed separately at DIS meetings, but the situation is gradually changing owing to long-term funding. The proposed Electron Ion Collider (EIC) at Jefferson Lab in the US, centre-of-mass energies of about 11 GeV (CERN) and LHC energies, would allow proton–nucleus scattering, parton fragmentation, 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 hadron 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 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 RHIC into collision with electrons accelerated up to 250 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 differential 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-ee) project at CERN, as well as the proposed very-high-energy electron–proton (VHEEeP) collider with a PWFA 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 description of proton and hadron physics across collision energies.

Given these developments, the 2018 workshop focused on the philosophy and particle physics of Higgs bosons and nuclei, including their very high luminosity, high-resolution probe of states that carry a high-momentum fraction of the parent hadron. Discussions focused on the theme “Particle physics at the crossroads,” with no evidence of physics beyond the standard model and the potential for new particles discovered so far. 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 certain, but collaborative efforts such as the Wuppertal Summer School can certainly contribute to a better assessment of the aims and relevance of this branch of fundamental physics research.
Russian accelerator science in focus

The 26th Russian Particle Accelerator Conference, RUPAC2018, was convened on 1–3 October 2018 at the Skolkovo Institute of Science and Technology, Moscow, Russia, at the Institute for High Energy Physics of the National Research Center “Kurchatov Institute” (BINP, Moscow). This year the traditional biennial conference, which started in 1968, gathered some 170 participants from accelerator centres in Russia, Germany, Italy, Sweden, Ukraine, 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 155 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 e+e− collider, the operation of which has improved noticeably after the commissioning of a new positron source. The high-intensity proton linear accelerator NRC KI–IHEP in Protvino reviewed the U43 proton synchrotron, which is now operated for 50–60 GeV fixed-target physics studies and applied radiobiology research using carbon–nuclei beams.

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 Nucleon-based Ion Collider Facility (NICA) project at the nucleon facility. Significant progress was also reported for the heavy-ion cyclotrons of the JINR’s Flavor Laboratory of Nuclear Reactions (FLNR). The status of, and plans for, the other operational domestic machines—the high-intensity proton linear accelerator of INR (Trieste), the synchrotron radiation (SR) source RSR-2 at NRC KI (Moscow) and the IAS synchrocyclotron SC-1000 at NRC KI–IHEP (Gatchina) —were also presented. Due attention was also given to two new SR projects: the Siberian Circular Photon Source (SIP) and the fourth-generation Specialized Synchronotron 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 ten years of its founder and first director Gersh Budker; 55 years of INR (Trieste); 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.

An event commemorating the 10th anniversary of the CERN–South Africa programme took place at iThemba LabS (<https://www.iThembaLabS.org>) in Cape Town from 19 to 21 November 2018, highlighting the importance of South African involvement in CERN and opportunities to further strengthen the collaboration. The event was packed, 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.

In terms of the number of participating scientists and engineers, South Africa is CERN’s most important partner in the African continent. Researchers from several universities participate in the ALICE collaboration and had the opportunity to present their research during the conference. At the time of the event, ALICE was able to address the challenges as in ISOLDE, and also visitors to CERN’s theoretical physics department. The South African particle-physical community continues to grow and is expected to benefit from the unique research opportunities in South Africa, with the Square Kilometre Array (SKA) radio–telescope project, which South Africa will host jointly with Australia and which will require massive computing infrastructure similar to that at the Worldwide LHC Computing grid. In fact, the SKA organisation is starting an agreement with CERN in 2017 to address the challenges of such “exascale” computing and data storage (CERN Courier September 2017 p3).

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 national and particle physics efforts in South Africa. It has also contributed to and 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 crossovers of skills will continue long into the future.

Emmanuel Twesmali CERN.
On 5-7 December 2018, the annual ISOLDE Workshop and Users meeting took place at CERN, attracting 192 participants. The programme consisted of 43 presentations, of which 32 were oral talks and 19 were oral contributions, selected from 74 submitted abstracts. ISOLDE, CERN’s long-running radioactive beam 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 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 30-year-old equipment and adding more beam-monitoring systems. Five sessions were devoted to overviews from ISOLDE on the outcome of physics campaigns at different experimental set-ups, two sessions discussed progress at other ISOLDE 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 288, with the cadmium-28 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 sole-fuelled 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 “travelling 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 nuclear beryllium—n.

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 in irradiation. 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—see as a highlight, on collinear laser spectroscopy studies, with a long series of antimatter 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 Antiproton and Ion 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.

Giedra Neyeys (ISOLDE physics group leader).

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.
LARGE HADRON COLLIDER: THE EXPERIMENTS STRIKE BACK

The moves towards the high-luminosity operation at the LHC (HL-LHC) are in fact proceeding apace, with ATLAS, CMS, and LHCb being the major beneficiaries of the extensive work to improve detector and data-processing systems for this next generation of LHC operations. ALICE, smaller experiments, and the LHCf (Forward Physics) and TOTEM (Forward Physics) experiments are also gearing up to be ready for the extreme conditions of HL-LHC.

The 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.

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

The experiment in the LHCb cavern.

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

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

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.

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.

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 6 × 10^{37} cm^{-2} s^{-1}. This will enable ALICE to accumulate 10 times more integrated luminosity (more than 10^{34} cm^{-2} s^{-1}) and a data sample 100 times larger than what has been measured so far.

The authors

Tapas Nayak, ALICE deputy spokesperson.
Virginia Greco, communications officer for ALICE.
A new all-pixel silicon inner tracker based on CMOS monolithic active pixel sensor (MAPS) technology will be installed in the same piece of silicon in place of the present ITS. The production of the 72 inner (one GEM stack each) and 24 outer (three GEM stacks each) MAPS detector planes, placed perpendicularly to the beam axis between the IP and the hadron absorber of the muon spectrometer.

The MAPS detector planes are based on multi-wire proportional chambers. In order to avoid drift-field distortions produced by ions from the beam, MAPS detector planes are placed with drift perpendicular to the beam axis between the IP and the hadron absorber. The MAPS detector planes will have intrinsic spatial resolution of about 5 μm, which is the best performance in the ALICE upgrade scheme. The MAPS detector planes are placed on both sides of the IP.

The beam pipe has also been redesigned with a smaller outer radius of 90 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 compared to the present ITS.

The forward-rapidity region, ITS 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 two mesons that are produced directly in the collision from those that come from decays of mesons that are produced in the accelerator, at a rate of 50 kHz, which 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 SAMPY, a newly developed, 32-channel front-end analog-to-digital converter with integrated digital signal processor.

Performance boost

The significantly improved ALICE detector will allow the collaboration to collect 500 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 O2 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 37 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 30TB/s.

A new computing facility for the O2 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 to 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 start dismantling the instrument 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.
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 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-the-fly silicon photomultipliers for the scintillator readout. HGCAL has around 6.5 million detector channels, divided into 52 layers. The first 28 layers consist of 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 CO2-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.

A NEW ERA IN CALORIMETRY

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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 LS3, 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-3 upgrade is almost complete, thanks to works carried out during LS3 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 photonsensors 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 the 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.

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 LS3 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,
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 CO2 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 LS3 activities, including the barrel hadron calorimeter work, will take place in the shadow of this critical path.

**Further reading**

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

Challenges facing the 30-fold strong coupling. 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 reachest 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 drastically increased: until now, the very fine-grained amount of information used for the trigger decision will be drastically increased, allowing the same selection power as the present high-level trigger.

The first LS2 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 encap thickness 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 tSOG 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 tSOG 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 and, modifications to both the boards and the crate, 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.

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 delicate and dangerous operation for the pixel detectors of the 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.

Further reading

Options:
- <25 mm² active area collimated to 17 mm²
- <70 mm² collimated to 50 mm²
- Windows: Be (0.5 mil) 12.5 µm, or C Series (SLN4)
- TO-8 package fits all Amptek configurations
- Vacuum applications

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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 20m 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 B⁰ → μ⁺μ⁻, 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

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LHCb spokesperson, CERN.
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 through some 1500 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 detectors and sub-detector systems are to be entirely replaced, apart from a few rare and local imperfections. From this, about 14,000 mats of fibre layers were recently fabricated in four institutes and assembled into 140 rigid 5 m × 5 m modules. In parallel, 58 fibre optic cables, each containing four elementary cells hosting the multianode photomultiplier tubes, were manufactured. A full PDM was recently assembled and characterised in tests with a rate of up to 15 Gb/s, was developed for this purpose. Pixel modules include a cutting-edge cooling substrate based on a 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 Spre Proton Synchrontron.

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 RICH 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 CO2 evaporative cooling system. Lightweight staves, with a carbon foam backing, are dressed with flex cables and instrumented with 14 modules, each composed of a polycrystalline copper beryllium wire 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 eventually cured from a few rare and local imperfections. From this, about 14,000 mats of fibre layers were recently fabricated in four institutes and assembled into 140 rigid 5 m × 5 m 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 photodetector 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 LHC 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.

Further reading

LHCb Collaboration 2008 CERN-LHCC-2008-007.
LHCb Collaboration 2012 CERN-LHCC-2012-007.

When it re-emerges, LHCb will be able to collect physics events at a rate 10 times higher than today.
A GIANT LEAP FOR PHYSICS

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.

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 Collider (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 100km 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 p51).

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.

THE AUTHORS
Michael Benedikt
FCC study leader, CERN.
Frank Zimmermann
FCC study deputy leader, CERN.
We are proposing an ambitious accelerator to push the boundaries of knowledge.

The success 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 an 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 (E pole) and 166 (E pole) 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 (5 TeV 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 jgos) has to be very small (0.8 mm) at the Z pole, which is 10 times smaller than for LEP but about three times larger than for the SuperKEKB accelerator now being commissioned in Japan. The reduction in β− 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 5 × 10^34 cm^–2s^–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 1 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 TeV 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.

Beating the fourth power

When moving to a larger radius and higher energies, one of the key choices 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 operational efficiency is 65%, profiling from recent innovations in klystron design at CERN.

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° 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 30°–dicing 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.

Ability poses major challenges. FCC-hh is envisioned to lie adjacent to the LHC and SPS, with two injection sets 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 5.3 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 7 TeV using fast ramping and cost-effective 6T 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 lattices 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 6T 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 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.

FCC-hh foresees two high-luminosity experiments, for which a key design challenge is to obtain the target values of βi in the collision points while protecting the detectors and the magnets from the collision debris. Incredibly, FCC-hh will produce a 1-σ up to 500 events per bunch crossing, compared to around 20 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 GeV, which is more than an order of magnitude higher than the HL-LHC beam extraction at the FCC. It has to be fast, and the first prototypes of new licicker generator and superconducting septum technologies are now being tested.

Synchrotron radiation is also an issue, since FCC-hh will emit about 5 MW at 10 TeV, and calls for a novel beam screen held at a temperature of 4 K (compared with 5-20 K at the LHC). The FCC-hh beam screen, a prototype of which is shown below, 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 pic).
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**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 symmetry distinguishes 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 Geiβ-Mann, Y. Hooft, Veltman, Wilson, Weinberg, Kauskind and other greats.

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 is connected by quantum mechanics 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 energy scale 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...
It appears more useful to think of naturalness as a strategy, rather than as a principle. 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). 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 big 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 be 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 disfavour 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: thencever – 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 unnaturalness 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 animalistic 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.
Looking beyond our solar system with ray tracing simulation...

Astronomers detected an Earth-like planet 11 light-years away from our solar system. How? Through data from an échelle spectrograph called HARPS, which finds exoplanets by detecting tiny wobbles in the motion of stars. Engineers looking to further the search for Earth-mass exoplanets can use ray tracing simulation to improve the sensitivity of échelle spectrographs.

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Visualization of ray trajectories in a white pupil échelle spectrograph.

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 is 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 favorite 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 math 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?

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 impossible; however, its value happens to be closer to zero than to the Planck mass by a factor of $10^{12}$. 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 the authors argue that we can estimate the likeliness of that value only when we have a priori likelihood functions, for which we would need a new theory.

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...
Amaldi’s last letter to Fermi: a monologue

Theatre, CERN Globe, 13 September 2018

On the occasion of the 110th anniversary of the birth of the Italian physicist Edoardo Amaldi (1906-1996), a new production titled “Amaldi l’italiano, centenario e lode” was presented. The play was composed after consulting with Edoardo Amaldi’s son, Ugo Amaldi, who was present at the theatre feeling you now know a lot about the theoretical foundation of the book.

As a non-theorist my opinion carries a different weight, and I am not a trained physicist, but I believe that the play is a valuable contribution to the understanding of the historical context of the physics community at the time.

The story of Bose-Einstein condensation (BEC) has undergone an incredible evolution since its discovery in 1924, and the play does an excellent job of capturing the excitement and intellectual debate surrounding this phenomenon.

The play begins in 1938 when Amaldi is part of an enthusiastic group of young scientists led by Fermi and nicknamed “Il Cervino”. The play retrace some of his scientific, personal, and historical significances, as well as the milestones he achieved in his career.

Amaldi was a true scientist, and the play highlights his passion for physics and his contributions to the field of quantum mechanics.

The play is a must-watch for anyone interested in the history of science, and it will surely inspire a new generation of thinkers and innovators.
BENT CRYSTAL MONOCHROMATOR APPLICATIONS
NOT JUST POSSIBLE, BUT PRACTICAL

Advances in particle physics are driven by well-defined innovations in accelerators, instruments, 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 recognized 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 revolution—very recently, Cowen and Reines’ discovery of the neutrino – there were perhaps a couple of people working in a lab, at most with a technician, and acknowledgment 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 1960s, 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 these 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 1980s, 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 150 and more collaborating institutions and 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? Each answer was quantitative in nature, and stimulating individual recognition became ever more pertinent.

Large collaborations mean that, within today’s ever-growing collaborations, individual recognition was spot-on and instinctive. As high-energy physics progressed, the needs of experiments grew. During the 1960s, 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 these 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 1980s, 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 150 and more collaborating institutions and countries involved in a given experiment.

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Big physics has been a part of the CERN collaboration for 25 years; the occasion of the collaboration’s 25th anniversary.

**Community survey**

Participants expressed opinions on several statements related to how they perceive systems of recognition in their collaboration. More than 90% of the participants are involved in LHC experiments and researchers from most European countries were well represented. Just less than half (47%) were permanent staff members at their institute, with the rest comprising around 300 PhD students and LHC 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.
What’s your academic background? I was a technical student on the ALSPH experiment at CERN’s LEP collider in the mid-1990s, and then continued with a PhD on QPL. 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 relying 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 in 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 advice, where to try my luck, which books to read, and how to make the most of 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 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 2011, 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-EU 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 2011, 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-unaccessed populations in rural communities, focusing 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 spreadsheet 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, 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, talk to people and collect business cards. Use the power of the network!
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.

James was born in Belfast, Northern Ireland, and educated at Petherton as 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 at the Cavendish Laboratory, becoming head of the department of physics in 2013. Then, in 2015, 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 confirmation 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 1986. 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 “monopole” 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, Dirk 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 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 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
Bryan Webber University of Cambridge
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 Somersét 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 Dorothy while supervising her laboratory work as an undergraduate in chemistry. They married in 1959, 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 in 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 1975, John was co-ordinator of the experimental programme at CERN. An early success at CERN was his participation in the discovery of the W±, Z0 boson and the proton synchrotron. Back at Oxford, he set up the precision encoding chamber physics programmes – first at SBS and later at Oxford – 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, as he set up an SBS office and ran it for eight years. (Later SBS became CAMEL, 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 led to unforeseen benefits.

His life was celebrated at a memorial gathering at Wolfson College, where he helped design and build the first 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 jet 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 founder 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, as he set up an SBS office and ran it for eight years. (Later SBS became CAMEL, 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 led to unforeseen benefits.

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

Paul Baillon was a graduate of École Normale Supérieure, he joined the École Polytechnique laboratory for his PhD. In 1965 and 1966 he participated in an experiment that recorded 750,000 antiproton annihilations at rest in liquid hydrogen at the 8 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 “gluonball”), and 20 years after the data was recorded, he even found particles that could be interpreted in this way.

In 1965 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 ILAC in the US, where he participated in the HERA experiment at the PEP electron-positron collider, studying in particular the charm quark and the tau lepton.

Throughout his career, in particular 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 THEMIS/GRO 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 POINTE-AGAPE searches conducted at the Pic-du-Midi and Las Palmas observatories in France and the Canary Islands.

Upon his return from the US, Paul again joined CERN’s particle-physics programmes – first at LEP and the DELPHI experiment, where he helped design and build the complex and innovative RHIC 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 hundreds of a degree.

With a solid foundation in classical physics and instrumentation, as well as in his mathematics, Paul was 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 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 driven by success in his intellectual pursuits, he was also an accomplished skier and mountaineer. Beyond science and sport, Paul was interested in 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 Anmau Rios Huguet, University of Surrey, UK
- Dr Ulli Kästner, Institut Laue–Langevin, France
- Professor Oscar Naviliat-Cuncic, Michigan State University, USA
- Dr Alice Ohlson, University of Heidelberg, Germany
- Professor Jeroen Puttschke, 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 Thirioff, 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](http://inpc2019.iopconfs.org)
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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.

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

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The future is in laser technologies
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 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 69).

**From the archive: February 1976**

**People and things**

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 1966). 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.

**Anomaly watch**

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 toscupper 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 (pictures) 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).

**B physics goes south**

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.
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