WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the July/August 2019 issue of *CERN Courier*.

When CERN was just five years old, and the Proton Synchrotron was preparing for beams, Director-General Cornelis Bakker founded a new periodical to inform staff what was going on. It was eight-pages long with a print run of 1000, but already a section called "Other people's atoms" carried news from other labs and regions. Sixty years and almost 600 *Couriers* later, high-energy physicists are plotting a new path into the unknown, with the update of the European Strategy bringing into focus how much traditional thinking is shifting, with new ideas and strong opinions in abundance.

The first mention of quarks in the *Courier* was in March 1964, a few months after they were dreamt up almost simultaneously on either side of the Atlantic by George Zweig and Murray Gell-Mann, who passed away in May, and whose wide-ranging legacy is explored in this issue. Back then, the idea of fractionally charged, sub-nucleonic entities seemed preposterous. It's a reminder of how difficult it is to know what will be the next big thing in the fundamental-exploration business. On other pages, LHCb unfolds a ground-breaking analysis of CP violation in three-body B^+ decays, nonagenarian former CERN Director-General Herwig Schopper reflects on lessons from LEP, and Nick Mavromatos and Jim Pinfold report on the cut and thrust of a Royal Society meeting on topologically non-trivial solutions of quantum field theory.

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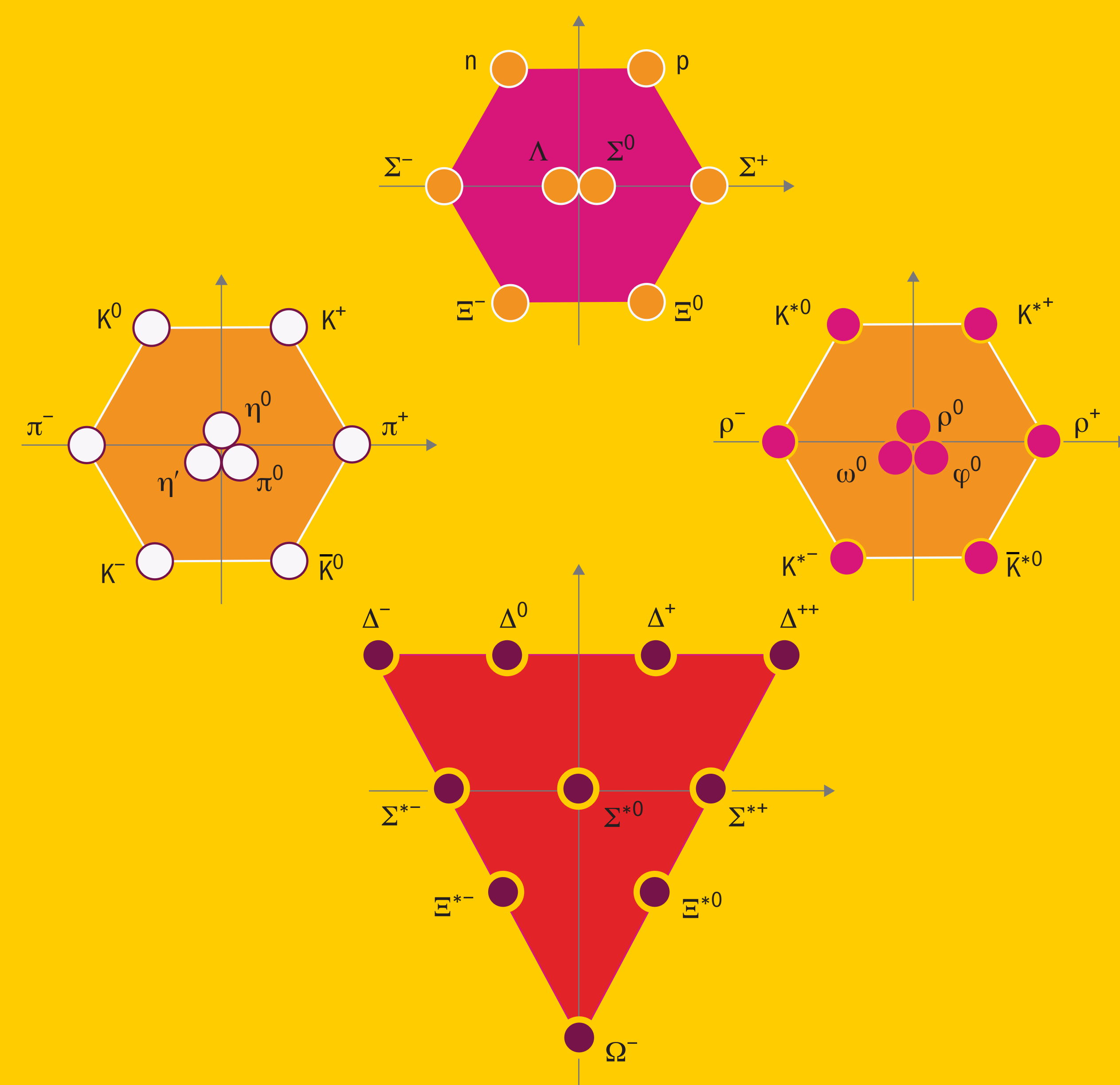
CERN COURIER
July/August 2019 cerncourier.com
Reporting on international high-energy physics

GELL-MANN'S COLOURFUL LEGACY



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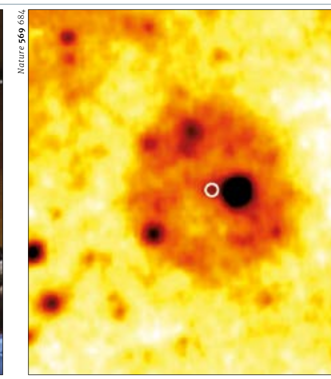
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FROM THE EDITOR

Fighting fit for a seventh decade

Matthew Chalmers
Editor

When CERN was just five years old, and the Proton Synchrotron was preparing for beams, Director-General Cornelis Bakker founded a new periodical to inform staff of what was going on. The first issue of *CERN Courier* (right) appeared in August 1959. It was eight-pages long with a print run of 1000, but already a section called "Other people's atoms" carried news from other labs and regions. Six years later, when CERN launched a weekly bulletin for staff, the *Courier* formally became an international publication. Today the magazine carries around 40 editorial pages plus 20 in advertisements, its 22,000 print copies and website reaching a global readership of more than 100,000.

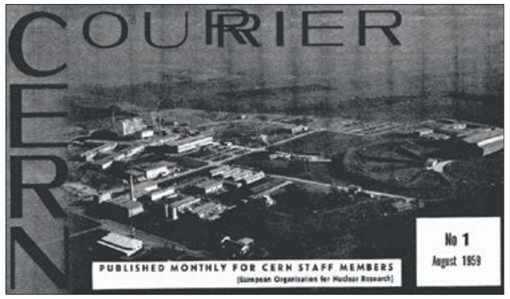
Several transformations have taken place in its 60-year history, most recently a print redesign. Very soon, the *Courier* will have a brand new website, too. It's the beginning of a new online publishing model whereby stories will appear on cerncourier.com in a timely manner, while offering greater variety and flexibility in the volume and types of content that we can publish.

Now is an opportune moment for the high-energy physics community to have a new communication tool at its disposal. The update of the European strategy (p7 and 37) is bringing into focus how much the traditional thinking in particular physics and cosmology is shifting, with new ideas and strong opinions in abundance. Flipping through almost 600 issues of *Couriers* past, it is striking both how much has changed in just over half a century, yet how some things remain familiar. Bask in hindsight comparing past and present on p30, and be reassured that it was no easier in times gone by to get next-generation accelerators such as LEP off the ground (p39).

60 years 1959–2019

Strong perspective

The first mention of the word "quark" in the *Courier* appeared in March 1964 – the year of their invention by Murray Gell-Mann, who passed away in May and is the cover theme of this issue (p25, 28 and 34). Back then, the idea of fractionally charged, sub-nucleonic entities seemed preposterous, and the *Courier* wrote of "open revolt" concerning their names – which included George Zweig's "aces" arranged into "deuces" (mesons) and "treys" (baryons). It's a reminder of how difficult it is to know what will be the next big thing in the fundamental-exploration business.



Number one *The cover image of the first issue of* CERN Courier.

Readers sometimes ask how articles get into the *Courier*. We encourage anyone who has a topic they're passionate about, an opinion they want to share or a result or a project that the community should know about to get in touch without hesitation. Those who do so almost always find the experience rewarding, and *Courier* feature authors often say that it has benefited their project or career in some way. This issue also includes a revived letters-to-the-editor section (p43). No suggestion is too weak or self-interested, and no comment too harsh for us to take on board. "Editors are – and should be – rugged people…", wrote inaugural editor Roger Anthoine in August 1959 in an address to readers. I would only add that a dose of fearlessness also benefits those who want to break into communication.

● Further articles marking the *Courier*'s 60th anniversary, including special focus issues on detectors and vacuum technology, can be found at cerncourier.com.

Reporting on international high-energy physics

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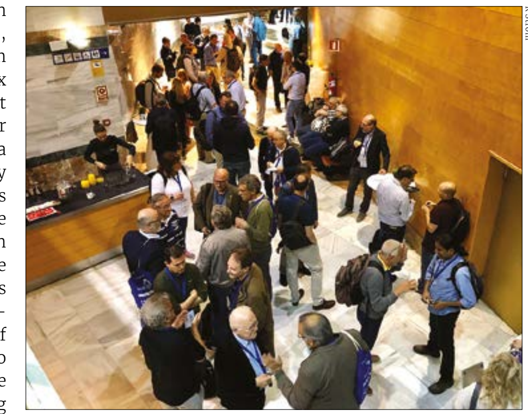
NEWS ANALYSIS

European Strategy

Granada symposium thinks big

The open symposium of the European Strategy for Particle Physics (ESPP), which took place in Granada, Spain, from 13–16 May, revealed a vibrant field in flux as it grapples with how to attack the next big questions. Opening the event, chair of the ESPP strategy secretariat, Halina Abramowicz, remarked: "This is a very strange symposium. Normally we discuss results at conferences, but here we are discussing future results." More than 10 different future-collider modes were under discussion, and the 130 or so talks and discussion sessions showed that elementary particle physics – in the wake of the discovery of the Higgs boson but so far no evidence of particles beyond the Standard Model (SM) – is transitioning into a new and less well-mapped realm of fundamental exploration.



R Strom

Long view *Discussions during a morning coffee break at the ESPP update.*

Plain weird

Theorist Pilar Hernández of the University of Valencia described the SM as plain "weird". The model's success in describing elementary particles and their interactions is beyond doubt, but as an all-encompassing theory of nature it falls short. Why are the fermions arranged into three neat families? Why do neutrinos have an almost imperceptibly small mass? Why does the discovered Higgs boson fit the simplest "toy model" of itself? And what lies beneath the SM's numerous free parameters? Similar puzzles persist about the universe at large: the mechanism of inflation; the matter–antimatter asymmetry; and the nature of dark energy and dark matter.

While initial results from the LHC severely constrain the most natural parameter spaces for new physics, said Hernández, the 10–100 TeV region is an interesting scale to explore. At the same time, she argued, there is a shift to more "bottom-up, rather than top-down", approaches to beyond-SM (BSM) physics. The new quarries includes axion-like and long-lived particles, and searches for hidden, dark and feebly-interacting sectors – in addition to studying the Higgs boson, which has deep connections to many puzzles in the SM, with much greater precision. "Particle physics could be heading to crisis or revolution," said Hernández.

Normally we discuss results at conferences, but here we are discussing future results

The accelerator, detector and computing technology needed for future fundamental exploration are varied and challenging. Reviewing Higgs-factory programmes, Vladimir Shiltsev, head of Fermilab's Accelerator Physics Center, weighed up the pros and cons of linear versus circular machines. The former includes the International Linear Collider (ILC) and the Compact Linear Collider (CLIC); the latter a future circular electron–positron collider at CERN (FCCee) and the Circular Electron Positron Collider in China (CEPC). Linear colliders, said Shiltsev, are based on mature designs and organisation, are expandable to higher energies, and draw a wall-plug power similar to that of the LHC. On the other hand, they face challenges including their luminosity and number of interaction points. Circular Higgs factories offer a higher luminosity and more interaction points than linear options but require R&D into high-efficiency RF sources and superconducting cavities, said Shiltsev.

For hadron colliders, the three current options – CERN's FCC-hh (100 TeV), China's SppC (75 TeV) and a high-energy LHC (27 TeV) – demand next-generation superconducting dipole magnets. Akira Yamamoto of CERN/KEK said that while a lepton collider could begin construction in the next few years, the dipoles necessary for a hadron collider might take 10 to 15 years of R&D before construction could start.

The symposium also saw much discussion about muon colliders, which offer an energy-frontier lepton collider but for which it was widely acknowledged the technology is not yet ready. Concerning more futuristic acceleration technologies based on plasma wakefields, impressive results at facilities such as BELLA at Berkeley and AWAKE at CERN were on show.

Thinking ahead

From colliders to fixed-target to astrophysics experiments, said Francesco Forti of INFN and the University of Pisa, detectors face a huge variety of operating conditions and employ technologies deeply entwined with developments in industry. Another difficulty, he said, is how to handle non-standard physics signals, such as long-lived particles and monopoles. Like accelerators, detectors require long time scales – it was the very early 1990s when the first conceptual design reports for the LHC detectors were written.

In terms of data processing, the challenges ahead are immense, said Simone Campana of CERN and the HEP software foundation. The high-luminosity LHC (HL-LHC) presents a particular challenge, but DUNE, FAIR, BELLE II and other experiments will also create unprecedented data samples, plus there is the need to generate ever-more Monte Carlo samples. At the same time, noted Campana, the rate of advance in hardware performance has slowed in recent years, forcing the community to towards graphics processing units, high-performance computing and commercial cloud services. Forti and Campana both argued for better career opportunities and greater recognition for physicists who devote their time to detector and computing efforts.

The symposium also showed that the strategic importance of communications, education and outreach is becoming increasingly recognised.

Discussions in Granada revealed a community united in its desire for a post-LHC collider, but not in its choice of ▷

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that collider's form. Stimulating some heated exchanges, the ESPP saw proposals for future machines pitted against each other and against expectations from the HL-LHC in terms of their potential physics reach for key targets such as the Higgs boson.

Big questions

Gian Giudice, head of CERN's Theory Department, said that the remaining BSM-physics space is "huge", and pointed to four big questions for colliders: to what extent can we tell whether the Higgs is fundamental or composite? Are there new interactions or new particles around or above the electroweak scale? What cases of thermal relic WIMPs are still unprobed and can be fully covered by future collider searches? And to what extent can current or future accelerators probe feebly interacting sectors?

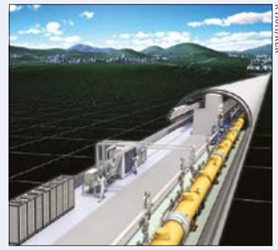
Though colliders dominated discussions, the enormous progress in neutrino physics since the previous ESPP was clear from numerous presentations. The open-symposium audience was reminded that neutrino masses, as established by neutrino oscillations, are the first particle-physics evidence for BSM phenomena. A vibrant programme is under way to fully measure the neutrino mixing matrix and in particular the neutrino mass ordering and CP violation phase, while other experiments are probing the neutrino's absolute mass scale and testing whether they are of a Dirac or Majorana nature.

Around a fifth of the 160 input documents to the ESPP were linked to flavour physics, which is crucial for new-physics searches because it is potentially sensitive to effects at scales as high as 10^5 TeV, said Antonio Zoccoli of INFN. Summarising dark-matter and dark-sector physics, Shoji Asai of the University of Tokyo said that a shift was taking place from the old view, where dark-matter solutions arose as a byproduct of beyond-SM approaches such as supersymmetry, to a new paradigm where dark matter needs an explanation of its own. Asai called for more coordination and support between accelerator-based direct detection and indirect detection dark-sector searches, as exemplified by the new European Center for Astro-Particle Theory.

Jorgen D'Hondt of Vrije Universiteit Brussel listed the many dedicated experiments in the strong-physics arena and the open questions, including: how to reach an adequate precision of perturbative and non-perturbative QCD predictions at the highest energies? And how to probe the quark–gluon plasma equation of state and to establish whether there is a first-order phase transition at high baryon density?

New working group to address ILC concerns

On 17 May in Granada, following the open symposium of the European Strategy for Particle Physics, the first meeting of a new international working group on the International Linear Collider (ILC) took place. The ILC is the most technologically mature of all current future-collider options, and was at the centre of discussions at the previous strategy update in 2013. Although its technology and costs have been revised since then, there is still no firm decision on the project's location, governance or funding model. The new working group was set up by Japan's KEK laboratory in response to a recent statement on the ILC from Japan's Ministry of Education, Sports, Culture, Science and Technology (MEXT) that called for further discussions on these thorny issues. Comprising two members from Europe, two from North America and three from Asia (including Japan), the group will investigate and update several points, including: cost sharing for construction and operation; organisation and governance of the ILC; and the international sharing of the remaining technical preparations. The working group will submit a report to KEK by the end of September 2019 and the final report will be used by MEXT for discussions with other governments.



R Hori/KEK

An illustration of the ILC in Japan.

Of all the scientific themes of the week, electroweak physics generated the liveliest discussions, especially concerning how well the Higgs boson's couplings to fermions, gauge bosons and to itself can be probed at current and future colliders. Summary speaker Beate Heinemann of DESY cautioned that such quantitative estimates are extremely difficult to make, though a few things stand out. One is the impressive estimated performance from the HL-LHC in the next 15 years or so; another is that a long-term physics programme based on successive machines in a 100 km-circumference tunnel offers the largest overall physics reach on the Higgs boson and other key parameters. There is broad agreement, however, that the next major collider immediately after the LHC should collide electrons and positrons to fully explore the Higgs and make precision measurements of other electroweak parameters.

The big picture

The closer involvement of particle physics with astroparticle physics, in particular following the discovery of gravitational waves, was a running theme. It was argued that, in terms of technology, next-generation gravitational-wave detectors such as the Einstein Telescope are essentially "accelerators without beams" and that CERN's expertise in vacuum and cryogenics would help to make such facilities a reality. Inputs from the astroparticle- and nuclear-physics communities, in addition to dedicated perspectives from Asia and the Americas, brought into sharp focus the global nature of modern high-energy physics and the need for greater coordination at all levels.

The closer involvement of particle physics with astroparticle physics was a running theme of the symposium

The open symposium of the ESPP update was a moment for physicists to take stock of the field's status and future. The community rose to the occasion, aware that the decisions ahead will impact generations of physicists yet to be born. A week of high-quality presentations and focused discussions proved how far things have moved on since the previous strategy update concluded in 2013. Discussions illuminated both the immensity of efforts to evaluate the physics reach of the HL-LHC and future colliders, and the major task faced by the European Strategy Group (ESG) in plotting a path to the future. It is clear that new thinking, from basic theory to instrumentation, computing, analysis and global organisation, is required to sustain progress in the field.

No decisions were taken in Granada, stresses Abramowicz. "During the open symposium we mainly discussed the science. Now comes the time to assess the capacity of the community to realise the proposed scientific goals," she says. "The Physics Preparatory Group is preparing the briefing book, which will summarise the scientific aspirations of the community, including the physics case for them."

The briefing book is expected to be completed in September. The ESG drafting session will take place on 20–24 January 2020 in Bad Honnef, Germany, and the update of the ESPP is due to be completed and approved by CERN Council in May 2020.

Accelerators

Niobium–tin cavities for smaller accelerators

A team at Cornell University in the US has demonstrated that high-frequency superconducting radio-frequency (SRF) cavities made from niobium–tin alloy can be operated more efficiently than conventional niobium designs, representing a step towards smaller and more economical particle accelerators.

SRF cavities are the gold standard for the acceleration of charged-particle beams and are used, for example, in the LHC at CERN and the upcoming LCLS-II free-electron-laser X-ray source at SLAC. Currently, the material of choice for the best accelerating cavities is niobium, which frequently has to be operated at a temperature of around 2 K and requires costly cryogenic equipment to cool the cavity in a bath of superfluid liquid helium. The technology is only heavily used at large-scale accelerators, and not at smaller institutions or in industry due to its complexity and costs.

Researchers around the world are striving to remove some of the barriers prohibiting broader uptake of SRF technology. Two major obstacles still need to be overcome to make this possible: the temperature of operation, and the size of the cavity.

Cornell University

Downsizing *Cornell student Ryan Porter with a standard 1.3 GHz cavity (left) and the highly efficient and compact 2.6 GHz triniobium-tin cavity.*

Earlier this year, a team at Cornell led by Matthias Liepe demonstrated that small, high-frequency triniobium-tin (Nb_3Sn) cavities can be operated very efficiently at a temperature of 4.2 K. While seemingly only slightly warmer than the 2 K required by niobium cavities, this small rise in temperature omits the need for superfluid-helium refrigeration.

The size of the cavity is inversely related to the frequency of the oscillating radio-frequency electromagnetic field within it: as the frequency doubles, the necessary transverse size of the cavity is halved. A smaller cavity with a higher frequency also demands a smaller cryomodule; what was once 1 m in diameter, the typical size of an accelerating SRF cryomodule, can now be roughly half that size.

The vast majority of SRF cavities currently in use operate at frequencies of 1.5 GHz and below – a region favoured because RF power losses in a superconductor rapidly decrease at lower frequency. But this results in large SRF accelerating structures. Cornell graduate student Ryan Porter successfully made and tested a considerably smaller proof-of-principle Nb_3Sn cavity at 2.6 GHz with promising results. "Niobium cannot operate efficiently at 2.6 GHz and 4.2 K," Porter explains. "But the performance of this 2.6 GHz Nb_3Sn cavity was just as good as the 1.3 GHz performance. Compared to a niobium cavity at the same temperature and frequency, it was 50 times more efficient."

"This is really the first step that shows that you can get good 4.2 K performance at high frequency, and it is quite promising," adds Liepe. "The dream is to have an SRF accelerator that can fit on top of the table."

Innovation

Europe seed-funds 170 technologies

ATTRACT

Winners *The kick-off meeting for successful ATTRACT projects took place in May.*

An event held at CERN on 20–21 May revealed 170 projects that have been granted €100,000 of European Union (EU) funding to develop disruptive detection and imaging technologies. The successful projects, drawn from more than 1200 proposals from researchers in scientific and industrial organisations across the world, now have one year to prove the scientific merit and innovation potential of their ideas.

The 170 funded projects are part of the Horizon 2020 ATTRACT project funded by the EU and a consortium of nine partners, including CERN, the European Southern Observatory (ESO), European Synchrotron Radiation Facility (ESRF), European XFEL and Institut Laue-Langevin. The successful projects are grouped into four broad categories: data acquisition systems and computing; front-end and back-end electronics; sensors; and software and integration.

CERN researchers are involved in 19 of the projects, in areas from magnets and cryogenics to electronics and informatics. Several of the selected projects involve the design of sensors or signal-transmission systems that operate at very low temperatures or in the presence of radiation, and many target applications in medical imaging and treatment or in the aerospace sector. Others seek industrial applications, such as 3D printing of systems equipped with sensors, the inspection of operating cryostats or applications in environmental monitoring.

Ideas were selected based on scientific merit, innovation readiness and potential societal impact

ESO's astronomical technology and expertise will be applied to an imaging spectrograph suitable for clinical cancer studies and to single-photon visible-light imagers for adaptive optics systems and low-light-level spectroscopic and imaging applications. Among other projects connected with Europe's major research infrastructures, four projects at the ESRF concern adaptive algebraic speckle tomography for clinical studies of osteoarticular diseases, a novel readout concept for 2D pixelated detectors, the transferral of indium-gallium-nitride epilayers onto substrates for full-spectrum LEDs, and artificial intelligence for the automatic segmentation of volumetric microtomography images.

"170 breakthrough ideas were selected based on a combination of scientific merit, innovation readiness and potential societal impact," explained Sergio Bertolucci, chair of ATTRACT's independent research, development and innovation committee. "The idea is to speed up the process of developing breakthrough technologies and applying them to address society's key challenges."

The outcomes of the ATTRACT seed-funding will be presented in Brussels in autumn 2020, and the most promising projects will receive further funding.

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Computing

Computing boost for Lebanon and Nepal

In the heart of Beirut in a five-storey house owned by the Lebanese national telecommunication company, floors are about to be coated to make them anti-static, walls and ceilings will be insulated, and cabling systems installed so wires don't become tangled. These and other details are set to be complete by mid-2020, when approximately 3000 processor cores, donated by CERN, will arrive.

The High-Performance Computing for Lebanon (HPC4L) project is part of efforts by Lebanese scientists to boost the nation's research capabilities. Like many other countries that have been through conflict and seen their highly-skilled graduates leave to seek better opportunities, Lebanon is trying to stem its brain-drain. Though the new facility will not be the only HPC centre in the country, it is different because it involves both public and private institutions and has the full support of the government. "There are a few small-scale HPC facilities in different universities here, but they suffer from being isolated and underused, and hence are quickly outdated and underused," says physicist Haitham Zaraket of Lebanese University in Beirut. "This HPC project puts together the main players in the realm of HPC in Lebanon."

Having joined the LHC's CMS experiment in 2016, Lebanese physicists want to develop the new facility into a CMS Tier-2 computing centre. High-speed internet will connect it to universities around the world and HPC4L has a mandate to ensure operation, maintenance, and user-interfacing for smooth and effective running of the facility. "We've been working with the government, private and public partners to prepare not just the infrastructure but also the team," explains HPC4L project coordinator Martin Gastal of CERN. "CERN/CMS's expertise and knowledge will help set up the facility and train users, but the team in Lebanon will run it themselves." The Lebanese facility will also be used for computational biology, oil and gas discovery, financial forecasting, genome analysis and the social sciences.

D Bista

Racking up *The HPC Nepal team in the new computing centre.*

Nepal is another country striving for greater digital storage and computing power. In 2017 Nepal signed a cooperation agreement with CERN. The following year, around 2500 cores from CERN enabled an HPC facility to be established at the government-run IT Park, with experts from Kathmandu University forming its core team. Rajendra Adhikari, project leader of Nepal's HPC centre (pictured, second from right), also won an award from NVIDIA for the latest graphics card worth USD 3000 and added it to the system. Nepal has never had computing on such a scale before, says Adhikari. "With this facility, we can train our students and conduct research that requires high-performance computing and data storage, from climate modelling, earthquake simulations to medical imaging and basic research."

The Nepal facility is planning to store health data from hospitals, which is often deleted because of lack of storage space, and tests are being carried out to process drone images taken to map topography for hydropower feasibility studies. Even in the initial phases of the new centre, says Adhikari, computing tasks that used to take 45 days can now be processed in just 12 hours.

The SESAME light source in Jordan, which itself received 576 cores from CERN in 2017, is also using its experience to assist neighbouring regions in setting up and maintaining HPC facilities. "High-performance computing is a strong enabler of research capacity building in regions challenged by limited financial resources and talent exodus," says Gastal. "By supporting the set up of efficient data processing and storage facilites, CERN, together with affiliated institutes, can assist fellow researchers in investing in the scientific potential of their own countries."

SI units

Kilogram joins the ranks of reproducible units

On 20 May, 144 years after the signing of the Metre Convention in 1875, the kilogram was given a new definition based on Planck's constant, *h*. Long tied to the International Prototype of the Kilogram (IPK) – a platinum-iridium cylinder in Paris – the kilogram is the last SI base unit to be redefined based on fundamental constants or atomic properties rather than a human-made artefact.

The dimensions of *h* are $m^2\,kg\,s^{-1}$. Since the second and the metre are defined in terms of a hyperfine transition in caesium-133 and the speed of light, knowledge of *h* allows the kilogram to be set without reference to the IPK.

C Suplee/NIST

Weighing in *The NIST-4 Kibble balance contributed to an international effort to define all base units in terms of fundamental constants.*

Measuring *h* to a suitably high precision of 10 parts per billion required decades of work by international teams across continents. In 1975 British physicist Bryan Kibble proposed a device, then known as a watt balance and now renamed the Kibble balance in his honour, which linked *h* to the unit of mass. A coil is placed inside a precisely calibrated magnetic field and a current driven through it such that an electromagnetic force on the coil counterbalances the force of gravity. The experiment is then repeated thousands of times over a ▷

period of months in multiple locations. The precision required is such that the strength of the gravitational field, which varies across the laboratory, must be measured before each trial.

Once the required precision was achieved, the value of *h* could be fixed and the definitions inverted, removing the kilogram's dependence on the IPK. Following several years of deliberations, the new definition was formally adopted at the 26th General Conference on Weights and Measures in November last year. The 2019 redefinition of the SI base units came into force in May, and also sees the ampere, kelvin and mole redefined by fixing the numerical values for the elementary electric charge, the Boltzmann constant and the Avogadro constant, respectively.

The vacuum magnetic permeability becomes an unfixed parameter to be measured experimentally

"The revised SI future-proofs our measurement system so that we are ready for all future technological and scientific advances such as 5G networks, quantum technologies and other innovations that we are yet to imagine," says Richard Brown, head of metrology at the UK's National Physical Laboratory.

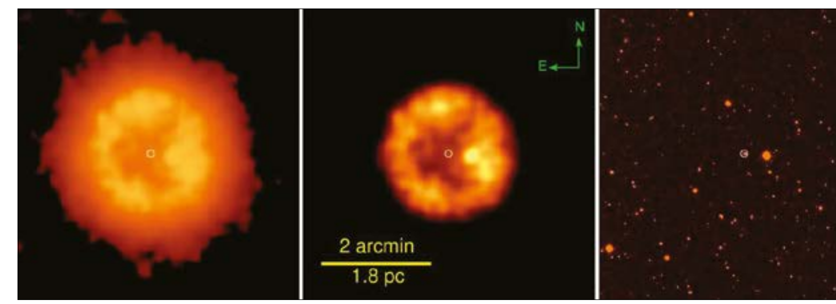
But the SI changes are controversial in some quarters. While heralding the new definition of the kilogram as "huge progress", CNRS research director Pierre Fayet warns of possible pitfalls of fixing the value of the elementary charge: the vacuum magnetic permeability (μ_0) then becomes an unfixed parameter to be measured experimentally, with the electrical units becoming dependent on the fine structure constant. "It appears to me as a conceptual weakness of the new definitions of electrical units, even if it does not have consequences for their practical use," says Fayet.

One way out of this, he suggests, is to embed the new SI system within a larger framework in which $c = h = \mu_0 = \varepsilon_0 = 1$, thereby fixing the vacuum magnetic permeability and other characteristics of the vacuum (*C. R. Physique* **20** 33). This would allow all the units to be expressed in terms of the second, with the metre and joule identified as fixed numbers of seconds and reciprocal seconds, respectively. While likely attractive to high-energy physicists, however, Fayet accepts that it may be some time before such a proposal could be accepted.

Astrowatch: White-dwarf merger

Clocking the merger of two white dwarfs

A never-before-seen object with a cataclysmic past has been spotted in the constellation Cassiopeia, about 10,000 light years away. The star-like object has a temperature of 200,000 K, shines 40,000 times brighter than the Sun and is ejecting matter with velocities up to $16{,}000\ \text{km s}^{-1}$. In combination with the chemical composition of the surrounding nebula, the data indicate that it is the result of the merger of two dead stars.



V Gvaramadze/Moscow University

Rejuvenated star *Infrared images show the result of the merger of two white dwarfs.*

Astronomers from the University of Bonn and Moscow detected the unusual object while searching for circumstellar nebulae in data from NASA's Wide-Field Infrared Survey Explorer satellite. Memorably named J005311, and measuring about five light years across, it barely emits any optical light and radiates almost exclusively in the infrared. Additionally, the matter it emits consists mostly of oxygen and does not have any signs of hydrogen or helium, the two most abundant materials in the universe. All this makes it unlike a normal massive star and more in line with a white dwarf.

White dwarfs are "dead stars" that remain when typical stars have used up all of their hydrogen and helium fuel, at which point the oxygen- and carbon-rich star collapses into itself to form a high-mass Earth-sized object. The white dwarf is kept from further collapse into a neutron star only by the electron degeneracy pressure of the elements in its core, and its temperature is too low to enable further fusion. However, if the mass of the white dwarf increases, for example if it accretes matter from a nearby companion star, it can become hot enough to restart the fusion of carbon into heavier elements. This process is so violent that the radiation pressure it produces blows the star apart. Such "type 1A" supernovae are observed frequently and, since they are unleashed when a white dwarf reaches a very specific mass, they have a standard brightness that can be used to measure cosmic distances.

Despite having the chemical signature of a white dwarf, such an object cannot possibly burn as bright as J005311. By comparing the characteristics of J005311 with models of what happens when two white dwarfs merge, however, the explanation falls into place. As two white dwarfs, likely produced billions of years ago, orbited one another they slowly lost momentum through the emission of gravitational waves. Over time, the objects came so close to each other that they merged. This would commonly be expected to produce a type 1A supernova, but there are also models in which carbon is ignited in a more subtle way during the merging process, allowing it to start fusing without blowing the newly formed object apart. J005311's detection appears to indicate that those models are correct, marking the first observation of a white-dwarf merger.

The rejuvenated star is, however, not expected to live for long. Based on the models it will burn through its remaining fuel within 10,000 years or so, forming a core of iron that is set to collapse into a neutron star through a violent event accompanied by a flash of neutrinos and possibly a gamma-ray burst. Using the speed of the ejected material and the distance it has reached from the star by now, it can be calculated that the merger took place about 16,000 years ago, meaning that its final collapse is not far away.

Further reading

V Gvaramadze *et al.* 2019 *Nature* **569** 684.

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NEWS DIGEST


M Brice/CERN-PHOTO-201611-278-2

The NA64 experiment.

Through a beam dump darkly

The NA64 collaboration at CERN has published world-best limits on dark photons below a mass of 200 MeV, excluding mixing strengths down to 10^{-3}, and below 10^{-5} for masses of the order of 1 MeV (arXiv:1906.00176). Hypothetical dark-sector physics could have an equally rich structure as the Standard Model, and the dark-photon vector field is one possible extension that could mix with the photon. A fixed-target experiment at CERN's SPS, NA64 (image above) looks for missing energy in the interaction of 100 GeV electrons in an active beam dump.

Circular reasoning

Following the European Strategy Update in Granada (see p7), proponents of a 100 km future circular collider in the vicinity of CERN have released a "Frequently Asked Questions"-style document, which will be regularly updated as the community debates the post-LHC future (arXiv:1906.02693). Focused on the first "FCC-ee" phase, the document currently addresses 24 questions, including "Why do we need at least 5×10^{12} Z decays?", "Why do we want FCC in Europe?" and quite simply "Are there better ways to 100 TeV than FCC-ee?"

Dø nabs $Z_c^{\pm}(3900)$

Following first observations of the charmonium-like state $Z_c^{\pm}(3900)$ at e^+e^- colliders in 2013, the Dø collaboration has published 5.4σ evidence for its presence in the decay chain of b-quarks in $p\bar{p}$ collisions (arXiv:1905.13704). Meanwhile, the BESIII e^+e^- experiment in Beijing has published 3.9σ evidence for its decay to $\rho^{\pm}\eta_c$ (arXiv:1906.00831). The Z_c resonance's quark configuration is still unknown, with models to describe its inner structure including loosely bound molecules of charm-meson pairs, compact tetraquarks, and hadro-quarkonium.

Strange neutron stars

Researchers working on the STAR detector at BNL's Relativistic Heavy-Ion Collider have measured the binding energy of hypertriton – a hypernucleus consisting of a proton, neutron and Λ hyperon. They found a higher value than the accepted 1973 measurement, calling weakly-bound Λ-deuteron models of the particle into question (arXiv:1904.10520). The team has also provided new constraints on neutron-star interiors (see also p16) and reported the first test of matter–antimatter symmetry pertaining to the binding of strange quarks in a nucleus.

Hawking's maths vindicated

Following the first observation of Hawking radiation in 2016 (*Nature Phys.* **12** 959), researchers at the Israeli Institute of Technology have now quantitatively confirmed the thermality of its spectrum and measured its temperature using an analogue black hole (BH) consisting of a flowing Bose–Einstein condensate (*Nature* **569** 688). The flow is supersonic within the analogue BH and subsonic without: the event horizon at the boundary excites the quantum vacuum and gives rise to the emission of quanta, known as Hawking radiation. The group now plans to study the time evolution of the analogue BH.


Technion

Jeff Steinhauer's group has measured the Hawking temperature.

In pursuit of Majorana

Researchers working on EXO-200 – a prototype liquid-xenon TPC in Carlsbad, New Mexico – are stepping up their pursuit of neutrinoless double beta decay ($0\nu\beta\beta$): the most sensitive probe for the postulated Majorana nature of neutrinos, whereby a neutrino is its own antiparticle. The full EXO-200 data set allowed a 90% confidence limit on the half life of $0\nu\beta\beta$ in ^{136}Xe of 3.5×10^{25} years (arXiv:1906.02723), approaching the world-best limit of 10.7×10^{25} years set by KamLand-Zen in 2016. Comparable limits in other isotopes where single-beta decay is suppressed have been set for ^{76}Ge (8.0×10^{25} years, GERDA) and ^{130}Te (1.5×10^{25} years, CUORE). Attention is now turning to nEXO, a planned tonne-scale successor that will push the sensitivity up by two orders of magnitude to ~10^{28} years.

The rarest decay

The XENON1T experiment, located 1.4 km below the Gran Sasso massif in northern Italy, has observed the rarest decay process ever seen, with a half-life a trillion times longer than the age of the universe: the two-neutrino double-electron capture of ^{124}Xe (*Nature* **568** 532). The measurement is a step towards the search for neutrinoless double-electron capture, which, like neutrinoless double-beta decay, would establish the Majorana nature of the neutrino and give access to the absolute neutrino mass. The detector's active mass is now being trebled to boost its primary dark-matter search.

Got an axion to grind?

Researchers are turning to creative proposals to search for axions – cold dark-matter candidates originally postulated to resolve the strong CP problem in QCD. Berkeley theorists propose employing superconducting RF cavities: axions would be converted to photons in the magnetic field of a gapped toroid inspired by the ABRACADABRA and DM Radio experiments (arXiv:1904.0724). Meanwhile, cosmologist Lawrence Krauss proposes to use atomic clocks to look for the effect of an axion background on photon propagation in the vacuum (arXiv:1905.10014). Similarly inventive proposals published recently seek to extend the search for generic low-mass dark matter downwards, for example using nuclear recoils in lab-grown diamond crystals (*Phys Rev D* **99** 123005).

EDM search goes pear-shaped

Permanent electric dipole moments (EDMs) of particles are excellent testbeds for the Standard Model. Nonzero EDMs imply that both P and T, and by implication CP, are violated. Nuclear physicists have thus been seeking to measure atomic EDMs since the 1980s, with pear-shaped nuclei the most promising candidates. More correctly termed a static octupole distortion, the pear shape was first seen at CERN's ISOLDE facility in radium-isotope ^{224}Ra in 2013 (*Nature* **497** 199). However, Peter Butler of the University of Liverpool and coworkers, using beams from the upgraded HIE-ISOLDE, have now established that radon-isotopes ^{224}Rn and ^{226}Rn do not possess static pear shapes in their ground states, and are thus not promising candidates to have measurable atomic EDMs (*Nat. Commun.* **10** 2473), inducing the team to switch focus to other isotopes.

Nuclei with octupole distortions may bear fruit in EDM searches.

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ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

LHCb

Three-body B^+ decays violate CP

New sources of CP violation (CPV) are needed to explain the absence of antimatter in our matter-dominated universe. The LHCb collaboration has reported new results describing CPV in $B^+ \to \pi^+K^+K^-$ and $B^+ \to \pi^+\pi^+\pi^-$ decays. Until very recently, all observations of CPV in B mesons were made in two-body and quasi-two-body decays; however, it has long been conjectured that the complex dynamics of multi-body decays could give rise to other manifestations. For CPV to occur in B decays, competing decay amplitudes with different weak phases (which change sign under CP) and strong phases (which do not) are required. The weak phase differences are tied to fundamental parameters of the Standard Model (SM), but the strong phase difference can arise from loop-diagram contributions, final-state re-scattering effects, and phases associated with intermediate resonant structure.

The three-body B decays under study proceed mainly via various intermediate resonances – effectively, a cascade of two-body decays – but also include contributions from non-resonant three-body interactions. The phase space is two-dimensional (it can be fully described by two kinematic variables) and its size allows a rich tapestry of resonant structures to emerge, bringing quantum-mechanical interference into play. Much as in Young's double-slit experiment, the total amplitude comprises the sum of all possible decay paths. The interference pattern and its phase variation could contribute to CPV in regions where resonances overlap.

One of the most intriguing LHCb results was the 2014 observation of large CPV effects in certain phase-space regions of $B^+ \to \pi^+K^+K^-$ and $B^+ \to \pi^+\pi^+\pi^-$ decays. In the new analysis, these effects are described with explicit amplitude models for the first time (figure 1). A crucial step in the phenomenological description of these amplitudes is to include unitarity-conserving couplings between final states, most notably ππ and KK. Accounting for these is essential to accurately model the complex S-wave component of the decays, which is the configuration where there is no relative angular momentum between a pair of oppositely-charged final-state particles, and which contains broad resonances that are difficult to model. Three complementary approaches were deployed to describe the complicated spin-0 S-wave component of the $B^+ \to \pi^+\pi^+\pi^-$ decay: the classical isobar model, which explicitly associates a line-shape with a clear physical interpretation to each contribution in the phase space; the K-matrix method, which takes data from scattering experiments as an input; and finally a quasi-model-independent approach, in which the S-wave magnitude and phase are extracted directly from the data.

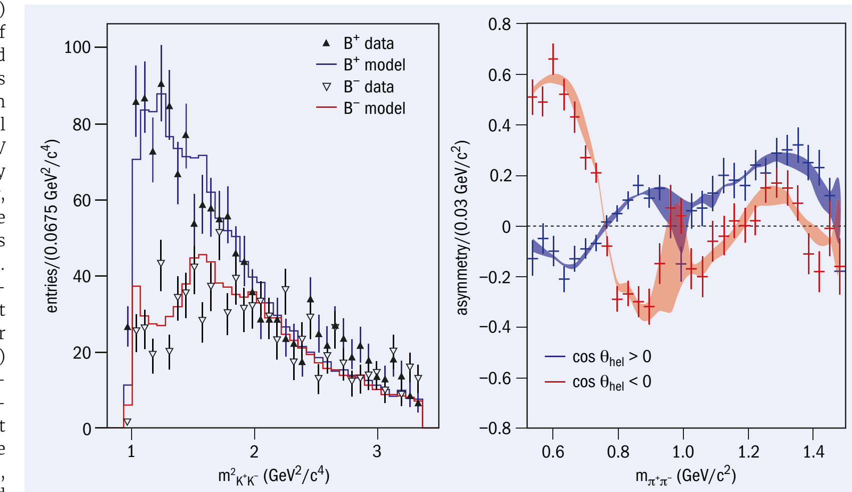

Fig. 1. *Left: yields of $B^+ \to \pi^+K^+K^-$ and $B^- \to \pi^-K^-K^+$ showing a clear asymmetry in the region of phase space dominated by re-scattering effects. Right: the CP asymmetry between $B^+ \to \pi^+\pi^+\pi^-$ and $B^- \to \pi^-\pi^-\pi^+$ decays in a region of phase space including the $\rho(770)^0$ and $f_2(1270)$, divided according to whether the cosine of the helicity angle is positive (blue) or negative (red). ($\cos\theta_{hel} > 0$ if, in the rest frame of the B, the pion with the same charge as the B has higher momentum than its oppositely charged counterpart.) The bands indicate the full spread of the isobar, K-matrix and quasi-model-independent models used to describe the decays.*

This is the first observation of CP violation in the interference between intermediate states

LHCb's amplitude analyses of these decays are based on data from Run 1 of the LHC and contain several ground-breaking results, including the largest CP asymmetry in a single component of an amplitude analysis, found in the $\pi\pi \leftrightarrow KK$ re-scattering amplitude; the first observation of CPV in the interference between intermediate states, seen in the overlap between the dominant spin-1 $\rho(770)^0$ resonance and the $\pi^+\pi^+$ S-wave; and the first observation of CPV involving a spin-2 resonance of any kind, found in the decay $B^+ \to f_2(1270)\pi^+$. These results provide significant new insights into how CPV in the SM manifests in practice, and motivate further study, particularly into the strong-phase-generating QCD processes that govern CP violation.

Further reading

LHCb Collaboration 2014 *Phys. Rev. D* **90** 112004.
LHCb Collaboration 2018 LHCb-PAPER-2018-051.
LHCb Collaboration 2019 LHCb-PAPER-2019-017.
LHCb Collaboration 2019 LHCb-PAPER-2019-018.

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ALICE

Studying neutron stars in the laboratory

Neutron stars consist of extremely dense nuclear matter. Their maximum size and mass are determined by their equation of state, which in turn depends on the interaction potentials between nucleons. Due to the high density, not only neutrons but also heavier strange baryons may play a role.

The main experimental information on the interaction potentials between nucleons and strange baryons comes from bubble-chamber scattering experiments with strange-hadron beams undertaken at CERN in the 1960s, and is limited in precision due to the short lifetimes (< 200 ps) of the hadrons. The ALICE collaboration is now using the scattering between particles produced in collisions at the LHC to constrain interaction potentials in a new way. So far, pK$^-$, pΛ, pΣ^0, pΞ$^-$ and pΩ$^-$ interactions have been investigated. Recent data have already yielded the first evidence for a strong attractive interaction between the proton and the Ξ$^-$ baryon.

Strong final-state interactions between pairs of particles make their momenta more parallel to each other in the case of an attractive interaction, and increase the opening angle between them in the case of a repulsive interaction. The attractive potential of the p–Ξ$^-$ interaction was observed by measuring the correlation of pairs of protons and Ξ$^-$ particles as a function of their relative momentum (the correlation function) and comparing it with theoretical calculations based on different interaction potentials. This technique is referred to as "femtoscopy" since it simultaneously measures the size of the region in which particles are produced and the interaction potential between them.

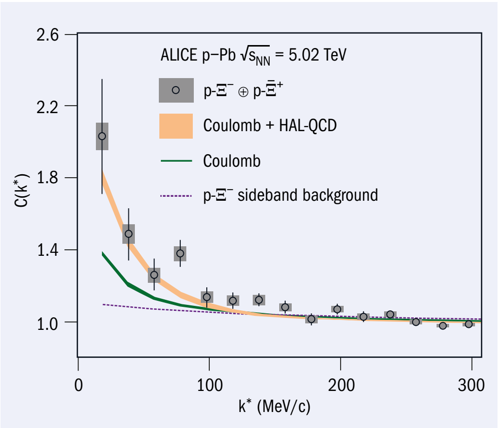

Fig. 1. *p–Ξ$^-$ correlation as a function of the relative momentum of the proton and Ξ$^-$, and the expected background contribution. The models show theoretical predictions, including only the Coulomb interaction, and both the Coulomb and strong interaction, as computed within the lattice–QCD framework of the HAL-QCD collaboration.*

Data from proton–lead collisions at a centre-of-mass energy per nucleon pair of 5.02 TeV show that p–Ξ$^-$ pairs are produced at very small distances (~1.4 fm); the measured correlation is therefore sensitive to the short-range strong interaction. The measured p–Ξ$^-$ correlations were found to be stronger than theoretical correlation functions with only a Coulomb interaction, whereas the prediction obtained by including both the Coulomb and strong interactions (as calculated by the HAL-QCD collaboration) agrees with the data (figure 1).

As a first step towards evaluating the impact of these results on models of neutron-star matter, the HAL-QCD interaction potential was used to compute the single-particle potential of Ξ$^-$ within neutron-rich matter. A slightly repulsive interaction was inferred (of the order of 6 MeV, compared to the 1322 MeV mass of the Ξ$^-$), leading to better constraints on the equation of state for dense hadronic systems that contain Ξ$^-$ particles. This is an important step towards determining the equation of state for dense and cold nuclear matter with strange hadrons.

Further reading

ALICE Collaboration 2019 arXiv:1904.12198.

CMS

New constraints on charm–quark hadronisation

One of the most useful ways to understand the properties of the quark–gluon plasma (QGP) formed in relativistic heavy-ion collisions is to study how various probes interact when propagating though it. Heavier quarks, such as charm, can provide unique insights as they are produced early in the collisions, and their interactions with the QGP differ from their lighter cousins. One important input to these studies is a detailed understanding of hadronisation, by which quarks form experimentally detectable mesons and baryons.

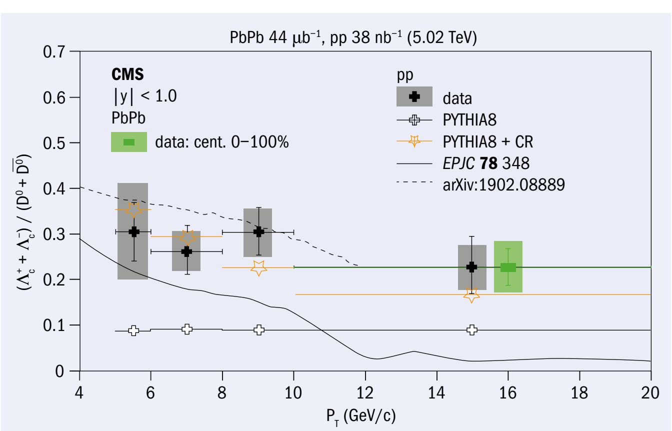

Fig. 1. *The Λ_c^+/D^0 production cross-section ratio versus transverse momentum for pp and PbPb collisions, with predictions from various pp-collision models.*

The lightest charm baryon and meson are the Λ_c^+ (udc) and the D^0 ($c\bar{u}$). In proton–proton (pp) collisions, charm hadrons are formed by fragmentation, in which charm quarks and antiquarks move away from each other and combine with newly generated quarks. In heavy-ion collisions, hadron production can also occur via "coalescence", whereby charm quarks combine with other quarks while traversing the QGP. The contribution of coalescence depends strongly on the transverse momentum (p_T) of the hadrons, and is expected to be much more significant for charm baryons than for charm mesons, as they contain more quarks.

The CMS experiment has recently determined the Λ_c^+/D^0 yield ratio over a broad range of p_T using the $\Lambda_c^+ \to pK^-\pi^+$ and $D^0 \to K^-\pi^+$ decay channels in both pp and lead–lead (PbPb) collisions, at a nucleon–nucleon centre-of-mass energy of 5.02 TeV. Comparing the behaviour of the Λ_c^+/D^0 ratio in different collision systems allows physicists to study the relative contributions of fragmentation and coalescence.

The measured Λ_c^+/D^0-production cross-section ratio in pp-collisions (figure 1) is found to be significantly larger than that calculated in the standard version of the popular Monte-Carlo event generator PYTHIA, while the inclusion of an improved description of the fragmentation ("PYTHIA8+CR") can better describe the CMS data. The data can also be reasonably described by a different model that includes Λ_c^+ baryons produced by the decays of excited charm baryons (dashed line). However, an attempt to incorporate the coalescence process characteristic of hadron production in heavy-ion collisions (solid line) fails to reproduce the pp-collision measurements.

The results highlight the lack of understanding of charm–quark hadronisation in proton–proton collisions

The CMS collaboration also measured Λ_c^+ production in PbPb collisions. The Λ_c^+/D^0-production ratio for p_T > 10 GeV/c is found to be consistent with that from pp collisions. This similarity suggests that the coalescence process does not contribute significantly to charm hadron production in this p_T range for PbPb collisions. These are the first measurements of the ratios at high p_T for both the pp and PbPb systems at a nucleon–nucleon centre-of-mass energy of 5.02 TeV.

In late 2018, CMS collected data corresponding to about 10 times more PbPb collisions than were used in the current measurement. These will shed new light on the interplay between the different processes in charm–quark hadronisation in heavy-ion collisions. In the meantime, the current results highlight the lack of understanding of charm–quark hadronisation in pp collisions, a subject that requires further experimental measurements and theoretical studies.

Further reading

CMS Collaboration 2019 arXiv:1906.03322.

ATLAS

How many protons collided in ATLAS in Run 2?

The large amount of Run-2 data (collected in 2015–2018) allows the LHC experiments to probe previously unexplored rare processes, search for new physics and improve Standard Model measurements. The amount of data collected in Run 2 can be quantified by the integrated luminosity – a number which, when multiplied by the cross section for a process, yields the expected number of interactions of that type. It is a crucial figure. The uncertainty of several ATLAS Run-1 cross-section measurements, particularly of W and Z production, was dominated by systematic uncertainty on the integrated luminosity. To minimise this, ATLAS performs precise absolute and relative calibrations of several luminosity-sensitive detector systems in a three-step procedure.

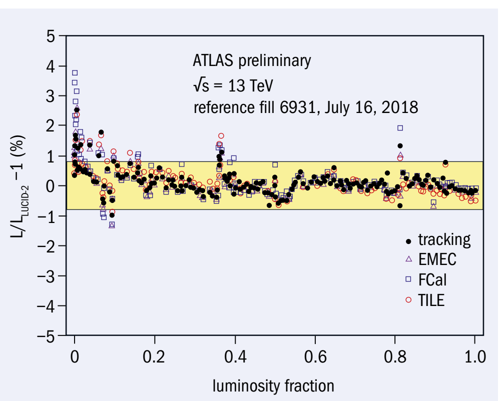

Fig. 1. *Fractional difference in the luminosity estimates of LUCID-2 compared with track counting, and the ATLAS electromagnetic end-cap (EMEC), forward (FCal) and hadronic tile (TILE) calorimeters in 2018. This long-term behaviour is used to quantify the uncertainty in the LUCID-2 calibration stability over time, indicated by the yellow band.*

The first step is an absolute calibration of the luminosity using a van-der-Meer beam-separation scan under specialised beam conditions. By displacing the beams horizontally and vertically and scanning them through each other, it is possible to measure the combined size of the colliding proton bunches. Determining in addition the total number of protons in each colliding bunch from the measurement of the beam currents, the absolute luminosity of each colliding bunch pair can be derived. Relating this to the mean number of interactions observed in the LUCID-2 detector – a set of photomultiplier tubes located 17 m in either direction along the beam pipe that detect the Cherenkov light of particles which come from the interaction – the scale for the absolute luminosity measurement of LUCID-2 is set.

The uncertainty of several Run-1 measurements was dominated by the luminosity

The second step is to extrapolate this calibration to LHC physics conditions, where the number of interactions increases from fewer than one to around 20–50 interactions per crossing, and the pattern of proton bunches changes from isolated bunches to trains of consecutive bunches with 25 ns spacing. The LUCID-2 response is sensitive to these differences. It is corrected with the help of a track counting algorithm, which relates the number of interactions to the number of tracks reconstructed in ATLAS's inner detector.

The final step is to monitor the stability of the LUCID-2 calibration over time. This is evaluated by comparing the luminosity estimate of LUCID-2 to those from track counting in the inner detector and various ATLAS calorimeters over the course of the data-taking year (figure 1). The agreement between detectors quantifies the stability of the LUCID-2 response.

Using this three-step method and taking into account correlations between years, ATLAS has obtained a preliminary uncertainty on the luminosity estimate for the combined Run-2 data of 1.7%, improving slightly on the Run-1 precisions of 1.8% at 7 TeV and 1.9% at 8 TeV. The full 13 TeV Run-2 data sample corresponds to an integrated luminosity of 139 fb^{-1} – about 1.1 × 10^{16} proton collisions.

Further reading

ATLAS Collaboration 2019 ATLAS-CONF-2019-021.

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FIELD NOTES

Reports from events, conferences and meetings

ROYAL SOCIETY HOOKE MEETING

Topological avatars of new physics

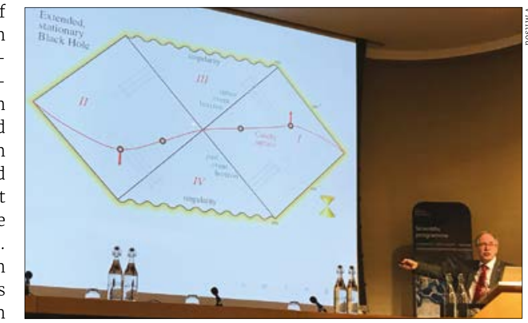
Topologically non-trivial solutions of quantum field theory have always been a theoretically "elegant" subject, covering all sorts of interesting and physically relevant field configurations, such as magnetic monopoles, sphalerons and black holes. These objects have played an important role in shaping quantum field theories and have provided important physical insights into cosmology, particle colliders and condensed-matter physics.

In layman's terms, a field configuration is topologically non-trivial if it exhibits the topology of a "mathematical knot" in some space, real or otherwise. A mathematical knot (or a higher-dimensional generalisation such as a Möbius strip) is not like a regular knot in a piece of string: it has no ends and cannot be continuously deformed into a topologically trivial configuration like a circle or a sphere.

One of the most conceptually simple non-trivial configurations arises in the classification of solitons, which are finite-energy extended configurations of a scalar field behaving like the Higgs field. Among the various finite-energy classical solutions for the Higgs field, there are some that cannot be continuously deformed into the vacuum without an infinite cost in energy, and are therefore "stable". For finite-energy configurations that are spherically symmetric, the Higgs field must map smoothly onto its vacuum solution at the boundary of space.

The 't Hooft–Polyakov monopole, which is predicted to exist in grand unified theories, is one such finite-energy topologically non-trivial solitonic configuration. The black hole is an example from general relativity of a singular space–time configuration with a non-trivial space–time topology. The curvature of space–time blows up in the singularity at the centre, and this cannot be removed either by continuous deformations or by coordinate changes: its nature is topological.

Such configurations constituted the main theme of a recent Royal Society Hooke meeting "Topological avatars of new physics", which took place in London from 4–5 March. The meeting focused on theoretical modelling and experimental searches for topologically important solutions of relativistic quantum field theories in particle physics, general relativity and cosmology, and quantum gravity. Of particular interest were topological objects that could potentially be detectable at the Large Hadron Collider (LHC), or at future colliders.



V Mitsou

Spatial awareness *Gerard 't Hooft grapples with the quantum mechanics of black holes.*

Black holes and sphalerons

Gerard 't Hooft opened the scientific proceedings with an inspiring talk on formulating a black hole in a way consistent with quantum mechanics and time-reversal symmetry, before Steven Giddings described his equally interesting proposal. Another highlight was Nicholas Manton's talk on the inevitability of topological non-trivial unstable configurations of the Higgs field – "sphalerons" – in the Standard Model. Henry Tye said sphalerons can in principle be produced at the (upgraded) LHC or future linear colliders. A contradictory view was taken by Sergei Demidov, who predicted that their production will be strongly suppressed at colliders.

A major part of the workshop was devoted to monopoles. The theoretical framework of light monopoles within the Standard Model, possibly producible at the LHC, was presented by Yong Min Cho. These "electroweak" monopoles have twice the magnetic charge of Dirac monopoles. Like the 't Hooft–Polyakov monopole, but unlike the Dirac monopole, they are solitonic structures, with the Higgs field playing a crucial role. Arttu Rajantie considered relatively unsuppressed thermal production of generic monopole–antimonopole pairs in the presence of the extreme high temperatures and strong magnetic fields of heavy-ion collisions at the LHC. David Tong discussed the ambiguities on the gauge group of the Standard Model, and how these could affect monopoles that are admissible solutions of such gauge field theories. Importantly, such solutions give rise to potentially observable phenomena at the LHC and at future colliders. Anna Achucaro and Tanmay Vachaspati reported on fascinating computer simulations of monopole scattering, as well as numerical studies of cosmic strings and other topologically non-trivial defects of relevance to cosmology.

One of the exemplars of topological physics receiving significant experimental attention is the magnetic monopole

One of the exemplars of topological physics currently receiving significant experimental attention is the magnetic monopole. The MoEDAL experiment at the LHC has reported world-leading limits on multiply magnetically charged monopoles, and Albert de Roeck gave a wide-ranging report on the search for the monopole and other highly-ionising particles, with Laura Patrizii and Adrian Bevan also reporting on these searches and the machine-learning techniques employed in them.

Supersymmetric scenarios can consistently accommodate all the aforementioned topologically non-trivial field theory configurations. Doubtless, as John Ellis described, the story of the search for this beautiful – but as yet hypothetical – new symmetry of nature, is a long way from being over. Last but not least, were two inspiring talks by Juan Garcia Bellido and Marc Kamionkowski on the role of primordial black holes as dark matter, and their potential detection by means of gravitational waves.

The workshop ended with a vivid round-table discussion of the importance of a new ~100 TeV collider. The aim of this machine is to explore beyond the historic watershed represented by the discovery of the Higgs boson, and to move us closer to understanding the origin of elementary particles, and indeed space–time itself. This Hooke workshop clearly demonstrated the importance of topological avatars of new physics to such a project.

Nick Mavromatos *King's College London* and **James Pinfold** *University of Alberta.*

IPAC 2019

Accelerator community comes together in Melbourne

More than 1100 accelerator professionals gathered in Melbourne, Australia, from 19 to 24 May 2019 for the 10th International Particle Accelerator Conference, IPAC'19. The superb Melbourne Convention and Exhibition Centre could easily cater for the 85 scientific talks, 72 industrial exhibitors and sponsors, 1444 poster presentations and several social functions throughout the week. Record levels of diversity at IPAC'19 saw 42 countries represented from six continents, and a relatively high gender balance for the field, with a quarter of speakers identifying as women.

In the wake of the update of the European Strategy for Particle Physics in Granada in May, accelerator designs that advance the energy and intensity range of a next-generation discovery machine were discussed, but there is no clear statement as to which is best. It will be up to the particle-physics community to decide which capability is needed to reach the most interesting physics. Reports on mature hadron facilities such as Japan's J-PARC and the LHC were balanced by the photon sources and electron accelerators that are becoming an increasingly robust presence at IPAC, and which comprised a fifth of contributions in 2019. Presentations on the most recently commissioned accelerators were a particular highlight, with Japan's SuperKEKB collider, Korea's PAL-XFEL free-electron laser and Sweden's MAX IV light source taking centre stage.

N Harrison

Australian expertise *Suzie Sheehy sizes up future challenges at the opening of IPAC'19.*

Exciting progress in the field of plasma- wakefield accelerators was also reported. In particular, Europe's EuPRAXIA collaboration is aiming to create a laser wakefield accelerator to drive a free-electron laser facility for users in the next few years. The scientific programme was bookended by local Australian-grown talent. Suzie Sheehy from the University of Melbourne described the successes of particle accelerators and some of the future challenges, while Henry Chapman, a director of the Center for Free-Electron Laser Science at DESY and the University of Hamburg, gave the closing plenary on how particle accelerators have enabled groundbreaking work in coherent X-ray science.

"In Unity" was chosen as the theme for IPAC'19 and art was commissioned from Torres Strait islander Kelly Saylor to symbolise this coming together of the particle-accelerator community. The success of IPAC'19 demonstrates the ongoing need for face-to-face meetings to share and communicate ideas and collaborate on pressing scientific problems. In a pioneering effort for the IPAC series, the opening and closing sessions were live-streamed to the world. The aim is to broaden the impact of the conference and highlight the importance of particle accelerators to many fields of science, industry and medical applications.

Student poster prizes were won by Nazanin Samadi, an Iranian PhD student at the University of Saskatchewan, Canada, and Daniel Bafia of Fermilab and IIT. Among other awards, the Xie Jialin Prize went to Vittorio Vaccaro of the University of Naples, the Nishikawa Tetsuji Prize was won by Vladimir Shiltsev of Fermilab, the Hogil Kim Prize went to Xueqing Yan of Peking University, and the Mark Oliphant Prize was taken by Stanford PhD student James MacArthur.

IPAC takes place annually and alternates between Asia, Europe and the Americas. Next year it will move to Caen in France, and then to Brazil in 2021.

Mark Boland *University of Melbourne.*

SUPERCONDUCTIVITY WORKSHOP

FuSuMaTech initiative levels up

On 1 April more than 90 delegates gathered at CERN to discuss perspectives on superconducting magnet technology. The workshop marked the completion of phase 1 of the Future Superconducting Magnet Technology (FuSuMaTech) Initiative, launched in October 2017.

FuSuMaTech is a Horizon 2020 Future Emerging Technologies project co-funded by the European Commission, with the support of industrial partners ASG, Oxford Instruments, TESLA, SIGMAPHI, ELLYT Energy and BILFINGER, and academia partners CERN, CEA, STFC, KIT, PSI and CNRS. It aims to strengthen the field of superconductivity for projects such as the High-Luminosity LHC and Future Circular Collider, while demonstrating the benefits of this investment to society at large.

"The need to develop higher performing magnets for future accelerators is certain, and cooperation will be essential," said Han Dols of CERN's knowledge transfer group. "The workshop helps reiterate common areas of interest between academia and industry, and how they might benefit from each other's know-how. And just as importantly," continued Dols, "FuSuMaTech is seeking to demonstrate the benefits of this investment by setting up demonstrator projects."

The successful preparation of 10 project proposals for both R&D actions and industrial applications is one of the main achievements of FuSuMaTech Phase-1, noted project coordinator Antoine Dael. These projects include new designs for MRI gradient coils, the design of 14 and 16 T MRI magnets, and a conceptual design for new mammography magnets. New developments are also included in the proposals, with the design for a hybrid low–high temperature superconductor magnet, an e-infrastructure to collect material properties and a pulsed-heat-pipe cooling system.

CERN

Phase transition *Han Dols (left) and Antoine Dael look to the future.*

In phase 2 of FuSuMaTech, launched with the signing of a declaration of intention between the FuSuMaTech partners on April 1, the 10 project proposals prepared during phase 1 will evolve into independent projects and make use of other European Union programmes. "We were really impressed with the interest we got from organisations outside of the project," said Dael. "We currently have six industrial partners, two more have already contacted us today, and we expect others."

Daniela Antonio *CERN.*

CERN–LATIN-AMERICAN SCHOOL OF HIGH-ENERGY PHYSICS

High-energy physics flourishes in Latin America

The 10th edition of the CERN–Latin-American School of High-Energy Physics (CLASHEP) hosted 75 students from 13 to 26 March in Villa General Belgrano in the Argentinian province of Cordoba. CLASHEP is a biennial series that takes place in different Latin-American locations. Since the first school in 2001, there has been a dramatic increase in the involvement of Latin-American groups in experimental HEP, including collaboration in the ALICE, ATLAS, CMS and LHCb experiments at CERN. The schools have played an important role in fostering this increased interest and participation in HEP in the region, as well as reinforcing existing activities and training young scientists.

M Mulders

Tree level *A discussion session at the 10th CLASHEP school taking place out in the open.*

The first schools in 2001 and 2003 took place in Brazil and Mexico, two countries in Latin America that already had substantial involvement in experimental HEP, followed by Argentina in 2005. María Teresa Dova of the Universidad Nacional de La Plata (UNLP) recalled that this first Argentinian school was a "strong catalyst" for Latin-American groups joining the LHC experimental programme. In due course, both UNLP and the Universidad de Buenos Aires formally joined ATLAS with support from the national funding agencies ANPCyT and CONICET.

The fourth school in Chile in 2007 gave unprecedented visibility for CERN and the LHC in a country which, until then, had no experimental HEP activity. Claudio Dib, the local director of the school, remarked that this was a key event in reaching agreements for the inclusion of Chile in the ATLAS experiment, and CERN and ATLAS representatives who were present were personally introduced to the authorities of the universities and the national funding agency, Conicyt. Following the fifth event in Colombia, in 2009, where there were also constructive meetings with the national funding agency and universities, the school returned to Brazil for a second time in 2011.

The Pontificia Universidad Católica del Perú celebrated the seventh school in Peru in 2013 with a special supplement of the university magazine dedicated to the work of local school director Alberto Gago's group, which participates in the ALICE experiment and in neutrino experiments at Fermilab. Gago commented that the impact of the school had been "impressive and far beyond [his] expectations". Similarly, discussions connected with the eighth school in Ecuador in 2015 were very important in stimulating interest in HEP within the universities and government agencies. This advanced the plans for the Escuela Politécnica Nacional and the Universidad San Francisco de Quito (USFQ) to join the CMS collaboration, supported by the national funding agency, Senescyt. USFQ's rector Carlos Montúfar Freile described the school as a milestone for physics in Ecuador. In 2017 the school returned to Mexico for a second time, with strong interest and encouragement from the national funding agency, CONACyT.

There has been a dramatic increase in the involvement of Latin-American groups in experimental HEP

Diversity

The 75 students attending this year's school were of 17 different nationalities and more than 30% were women. Most came from universities in Latin America, while 15 were from European institutes. Lectures on HEP theory and experiment were given by leading scientists from both sides of the Atlantic, with special lectures on gravitational waves and cosmological collider physics by prominent Argentinian physicists Gabriela González (spokesperson of LIGO when gravitational waves were discovered in 2016) and Juan Martín Maldacena (winner of the 2012 Breakthrough Prize in Fundamental Physics). In addition to 50 hours reserved for plenary lectures, parallel group discussions were held for 90 minutes most afternoons. CERN Director-General Fabiola Gianotti took part in a lively Q&A session by video link.

The school also received visits from senior representatives of the Universidad Nacional de Córdoba (UNC), including Gustavo Monti, who is president of the Argentinean Physical Society, and Francisco Tamarit, a director of the national research council CONICET.

Building on the tradition of the last few schools in the series, outreach activities were organised at UNC in the city of Cordoba. María Teresa Dova from UNLP, again the local director of the school, explained experimental particle physics to a general audience, and Juan Martín Maldacena, who was awarded an honorary doctorate, talked about black holes and the structure of space–time.

The next CLASHEP is set to take place in 2021.

Nick Ellis *and* **Martijn Mulders** *CERN.*

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NEW PHYSICS IN HEAVY-ION COLLISIONS

Heavy ions and hidden sectors

The first dedicated workshop on searches for new physics in heavy-ion collisions took place at the Université Catholique de Louvain, Belgium, on 4–5 December 2018. The meeting was inspired by several recent proposals to take advantage of the unique environment of heavy-ion collisions at the LHC to search for new phenomena. A key topic was the exploration of "hidden" or "dark" sectors that couple only feebly to ordinary matter and could explain the dark-matter puzzle, neutrino masses or the matter–antimatter asymmetry of the universe. This is currently a hot topic in the search for physics beyond the Standard Model that has gained increasing interest in the heavy-ion community. The purpose of this workshop was to spark ideas and initiate exchanges between theorists, experimentalists and accelerator physicists.

Discussions at the workshop first focused on particle production mechanisms unique to heavy-ion collisions. Simon Knapen from the IAS at Princeton University and Oliver Gould of the University of Helsinki emphasised the strongly enhanced production cross-sections for axion-like particles and magnetic monopoles in ultra-peripheral heavy-ion collisions compared to proton–proton collisions. This enhancement is due to the collective action of up to 82 charges (for lead ions), thereby generating the strongest electromagnetic fields ever produced in the laboratory, as the heavy ions pass each other at ultra-relativistic energies. David d'Enterria of CERN discussed the experimental potential to exploit such unique opportunities in searches for new physics by using the LHC as a "photon–photon collider". In contrast to these studies of ultra-peripheral collisions, Glennys Farrar of New York University motivated interest in head-on collisions: thermal production in the quark–gluon plasma could be used to search for non-conventional dark-matter candidates such as "sexaquarks".

Jan Hajer of the Université Catholique de Louvain stressed that not only the production mechanisms but also the backgrounds are qualitatively different in heavy-ion collisions. This can, for example, allow searches for long-lived particles in parameter regions that are hard to probe in proton collisions due to limitations related to the high pile-up during future LHC runs.

A key question that emerged from the workshop was how to optimise the choice of ions and the beam parameters for new-physics searches without compromising the study of the quark–gluon plasma. The discussion was extremely helpful for elucidating the hard engineering restrictions within which any novel proposals must fit, such as the capacity of the injectors and the beam lifetime.

The workshop was very successful and triggered many discussions, including the proposal to submit an input for the update of the European Strategy for Particle Physics and for a follow-up event in 2020. The topic is still young, and we are very much looking forward to input from the wider community.

Further reading

R Bruce *et al.* 2019 arXiv:1812.07688.

Marco Drewes *Université Catholique de Louvain.*

LARGE HADRON COLLIDER PHYSICS CONFERENCE

Mexico hosts dynamic LHCP week

The seventh edition of the Large Hadron Collider Physics (LHCP) conference took place in Puebla, Mexico, from 20 to 25 May, hosted by the Benemérita Universidad Autónoma de Puebla (BUAP). With almost 400 participants, the week involved dynamic discussions between experimentalists and theorists on an assortment of topics related to LHC research. These ranged from heavy-ion physics to precision measurements of the Standard Model (SM), including Higgs-sector constraints and searches for hints of physics beyond the SM such as supersymmetry and model-independent high-mass resonance searches.

Results from the wealth of LHC data collected at 13 TeV during Run 2 (from 2015–2018) are beginning to be published. The ATLAS and CMS collaborations presented new results in the search for supersymmetry, setting new limits on supersymmetric parameters. The latest CMS search for top squarks in events with two tau leptons in the final state excludes top-squark masses above 1 TeV for nearly massless neutralinos. The first ATLAS Run 2 measurement for the production of tau sleptons was also presented, excluding masses between 120 and 390 GeV for a massless neutralino. Both of these challenging analyses contain a high amount of missing momentum, originating from the lightest supersymmetric particle and the neutrinos from the tau decays.


BUAP

Mexican standoff *LHCP delegates gather to interrogate the Standard Model.*

Studies involving unusual signatures were popular at the Mexico conference. Disappearing tracks, emerging jets, displaced vertices and out-of-time decays, which would each be indications of new processes or particles being present in the event, were all discussed. These signatures also provide a challenge for detector and algorithm designs, especially at the high-luminosity LHC (HL-LHC).

The recent observation of CP violation in charm quarks (*CERN Courier* May/June p7) published by the LHCb Collaboration in March was presented. "Long awaited, finally observed!" was the statement from LHCb-spokesperson Giovanni Passaleva. This result, which shows the different decay rates of charm quarks and charm anti-quarks, opens up new avenues of investigation for testing the SM.

The final two days of the conference featured open discussions on recent progress in the upgrades of the LHC and the detectors for the HL-LHC, and on various proposals and design challenges for future colliders. The HL-LHC will be a very challenging environment in which to distinguish particles of interest, as the average number of proton–proton collisions will increase from around 50 to about 200 each time the bunches in the LHC beams cross. For future colliders, circular and linear, delegates agreed that the community must better communicate the motivations and goals for such future machines with governments and the public.

The next edition of the conference will take place in Paris in 2020. Though also taking place during the current long shutdown, many new results with the full LHC Run-2 statistics will be presented, as well as progress on preparing the detectors and the accelerator for Run 3.

Clara Nellist *University of Göttingen.*

ADDITIVE MANUFACTURING WORKSHOP

Tricky component? Use 3D printing…

Some 120 physicists gathered in Orsay on 13–14 December 2018 for a workshop on additive manufacturing – popularly called 3D printing – with metals. The goal was to review the work being done in Europe (particularly at CERN, CEA and CNRS) on the application of the technique to high-energy physics and astrophysics.

3D printing makes possible novel and optimised designs that would be difficult to create with conventional methods. Embedded radio-frequency (RF) cavities such as those featured in spiral-shaped cooling channels are one example. Another comes from detector design: mesh structures, as required for many gas-filled ionisation tracking detectors, are often difficult to manufacture with traditional methods as the removal of material in one part of the mesh may destroy another part of it; but these are easy to build with additive manufacturing.

LAL

3D printing *Physicists met up in Orsay for the additive manufacturing workshop.*

Despite the remaining challenges, which relate to ultra-high-vacuum properties, mechanical strength, electrical conductivity, new alloys and post-processing, the technique is beginning to be used for working accelerator components. Participants of the Orsay event heard about the beam test at an accelerator (LAL's photoinjector PHIL), of a beam position monitor and about the performances of RF antennas designed at Université de Rennes for future space missions. Plans for employing additive manufacturing at future accelerators and HEP experiments were also discussed.

Although metal additive manufacturing is currently limited to a few applications, the workshop, which was the first of its kind, showed that there is strong potential for it to play a larger role in the coming years.

Nicolas Delerue *Laboratoire de l'Accélérateur Linéaire, CNRS/IN2P3 and Université Paris-Sud.*

GELL-MANN'S MULTI-DIMENSIONAL GENIUS

Murray Gell-Mann was one of the great geniuses of the 20th century, says Lars Brink, and stands out among other Nobel laureates.

One of the 20th century's most amazing brains has stopped working. Nobel laureate Murray Gell-Mann died on 24 May at the age of 89. It is impossible to write a complete obituary of him, since he had so many dimensions that some will always be forgotten or neglected.

Murray was the leading particle theorist in the 1950s and 1960s in a field that had attracted the brightest young stars of the post-war generation. But he was also a polyglot who could tell you any noun in at least 25 languages, a walking encyclopaedia, a nature lover and a protector of endangered species, who knew all the flowers and birds. He was an early environmentalist, but he was so much more. It has been one of the biggest privileges in my life to have worked with him and to have been a close friend of his.

Murray Gell-Mann was born into a Jewish immigrant family in New York six weeks before the stock-market crash of October 1929. He was a trailing child, with a brother who was nine years older and relatively aged parents. He used to joke that he had been born by accident. His father had failed his studies and, after Murray's birth, worked as a guard in a bank vault. Murray was never particularly close to father, but often talked about him

WEF/M Wuertenberg

A giant of theoretical physics *Murray Gell-Mann photographed at the annual meeting of the World Economic Forum in 2012.*

Child prodigy

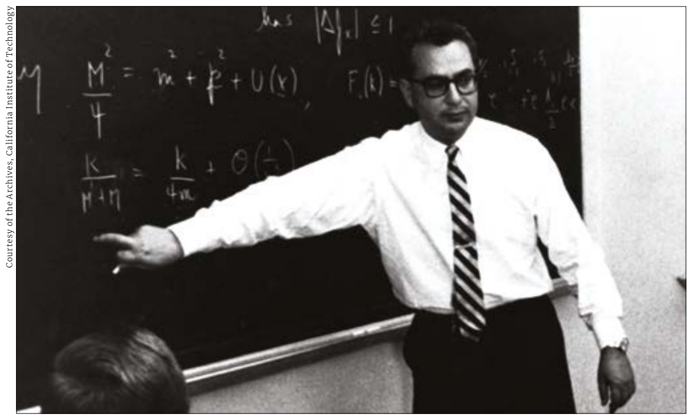
According to family legend, the first words that Murray spoke were "The lights of Babylon", when he was looking at the night sky over New York at the age of two. At three, he could read and multiply large numbers in his head. At five he could correct older people about their language and in discussions. His interest for numismatics had already begun: when a friend of the family showed him what he claimed was a coin from Emperor Tiberius' time, Murray corrected the pronunciation and said it was not from that time. At the age of seven, he participated in – and won – a major annual spelling competition in New York for students up to the age of 12. The last word that only he could spell and explain was "subpoena", also citing its Latin origins and correcting the pronunciation of the moderator.

By the age of nine he had essentially memorised the *Encyclopaedia Britannica*. The task sounds impossible, but some of us did a test behind his back once in the 1970s. The late Myron Bander had learnt and studied an incomprehensible word and steered the discussion on to it over lunch. Of course Murray knew what the word was. He even recalled the previous and subsequent entries on the page.

Murray's parents didn't know what to do with him, but his piano teacher (music was not his strong side) made them apply for a scholarship so that he could start at a good private school. He was three years younger than his classmates, yet they always looked to him to see if he approved of what the teachers said. His tests were faultless, except for the odd exception. Once he came home and had scored "only" 97%, to which his father said: How could you miss this? His brother, who was more "normal", was a great nature lover and became a nature photographer and later a journalist. He taught Murray about birds and plants, which would become a lifelong passion.

THE AUTHOR
Lars Brink
Chalmers Institute of Technology, Sweden.

Courtesy of the Santa Fe Institute



Courtesy of the Archives, California Institute of Technology

Passion for knowledge
Gell-Mann as a boy, a young man and a Caltech professor.

Sometimes there are people born with all the neurons in the right place

At the age of 15, he finished high school and went to Yale. He did not know which subject he would choose as a major, since he was interested in so many subjects. It became physics, partly to please his father who had insisted on engineering such that he could get a good job. He then went to MIT for his doctoral studies, receiving the legendary Victor "Viki" Weisskopf as his advisor. Murray wanted to do something pioneering, but he didn't succeed. He tried for a whole semester and at the same time studied Chinese and learnt enough characters to read texts. He finally decided to present a thesis in nuclear physics, which was approved but that he never wanted to talk about. When Weisskopf, later in life, was asked what his biggest contribution to physics was, he answered: "Murray Gell-Mann".

At the age of 21 Murray was ready to fly and went to the Institute for Advanced Study (IAS) as one of Robert Oppenheimer's young geniuses. In the next year he went to the University of Chicago under Enrico Fermi, first as an instructor and in a few years became an associate professor. Even though he had not yet produced outstanding work, when he came to Chicago he was branded as a genius. At the IAS he had started to work on particle physics. He collaborated with Francis Low on renormalisation and realised that the coupling constant in a renormalisable quantum field theory runs with energy. As would happen so often, he procrastinated with the publication until 1954, by which time Petermann and Stückelberg had published this result.

This was during the aftermath of QED and Gell-Mann wanted to attack the strong interactions. He started his odyssey to classify all the new particles and introduced the concept of "strangeness" to specify the kaons and the corresponding baryons. This was also done independently by Kazuhiko Nishijima. When he was back at the IAS in 1955, Murray solved the problem with K_L and K_S, the two decay modes of the neutral kaons in modern language (better known as the τ–θ puzzle). According to him, he showed this to Abraham Pais who said, "Why don't we publish it?", which they did. They were never friends after that. Murray also once told me that this was the hardest problem that he had solved.

A cavalcade of results

Aged 26, he lectured at Caltech on his renormalisation and kaon work. Richard Feynman, who was the greatest physicist at the time, said that he thought he knew everything, but these things he did not know. Feynman immediately said that Murray had to come to Caltech and dragged him to the dean. A few weeks later, he was a full professor. A large cavalcade of new results began to come out. Because he had difficulty relinquishing his works, they numbered just a few a year. But they were like cathedrals, with so many new details that he came to dominate modern particle physics.

After the ground-breaking work of T D Lee and C N Yang on parity violation in the weak interactions, Gell-Mann started to work on a dynamical theory – as did Feynman. In the end the dean of the faculty forced them to publish together, and the V–A theory was born. George Sudarshan and Robert Marshak also published the same result, and there was a long-lasting fight about who had told who before. Murray's part of the paper, which is the second half, is also a first sketch of the Standard Model, and every sentence is worth reading carefully. It takes students of exegetics to unveil all the glory of Murray's texts. Murray was to physics writing what Joseph Conrad was to novel writing!

Murray then turned back to the strong interactions and, with Maurice Lévy, developed the non-linear sigma model for pion physics to formulate the partially conserved axial vector current (PCAC). This was published within days of Yoichiro Nambu's ground-breaking paper where he understood pion physics and PCAC in terms of spontaneous breaking of the chiral symmetry. In a note added to the proof they introduced a "funny" angle to describe the decay of ^{14}O, which a few years later became the Cabibbo angle in Nicola Cabibbo's universal treatment of the weak interactions.

Gell-Mann then made the great breakthrough when he classified the strongly interacting particles in terms of families of SU(3), a discovery also made by Yuval Ne'eman. The paper was never published in a journal and he used to joke that one day he would find out who rejected it. With this scheme he could predict the existence of the triply strange Ω^- baryon, which was discovered in 1964 right where he predicted it would be. It paved the way for Gell-Mann's suggestion in 1963 that all the baryons were made up of three fundamental particles, which in the published form he came to call quarks, after a line in James Joyce's *Finnegans Wake*, "three quarks for Muster Mark". The same idea was also put forward by George Zweig who called them "aces". It was a very difficult thing for Murray to propose such a wild idea, and he formulated it extremely carefully to leave all doors open. Again, his father's approval loomed in the background.

With the introduction of current algebra he had laid the ground for the explosion in particle theory during the 1970s. In 1966, Weisskopf's 60th birthday was celebrated, and somehow Murray failed to show up. When he later received the proceedings, he was so ashamed that he did not open it. Had he done so, he would have found Nambu's suggestion of a non-abelian gauge field theory with coloured quarks for the strong interactions. Nambu did not like fractional charges so he had given the quarks integer charges. Murray later said that, had he read this paper, he would have been able to formulate QCD rather quickly.

Legacy

When, at the age of 40 in 1969, he received the Nobel Prize in Physics as the sole recipient, he had been a heavily nominated candidate for the previous decade. Next year the Nobel archives for this period will be open, and scholars can study the material leading up to the prize. Unfortunately, his father had died a few weeks before the prize announcement. Murray once said to me, "If my father had lived two weeks longer, my life would have been different."

During the 1950s and 1960s Gell-Mann had often been described in the press as the world's most intelligent man. With a Nobel Prize in his pocket, the attraction to sit on various boards and committees became too strong to resist. His commitment to conserving endangered species also took up more of his time. Murray had also become a great collector of pre-Columbian artefacts and these were often expensive and difficult to obtain.

In the 1970s, he was displaced from the throne by people from the next generation. Murray was still the one invited to give the closing lectures at major conferences, but his own research started to suffer somewhat. In the mid-1970s, I came to Caltech as a young postdoctoral fellow. I had met him in a group before, but trembled like an aspen leaf when I first met him there. He had, of course, found out from where in Sweden I came and pronounced my name just right, and demanded that everyone else in the group do so. Pierre Ramond also arrived as a postdoc at that time, having been convinced by Murray to leave his position at Yale. After a few months we started to work together on supergravity. We did the long calculations, since Murray was often away. But he always contributed and could spot any weak links in our work immediately. Once, when we were in the middle of solving a problem after a period of several days, he came in and looked at what we did and wrote the answer on the board. Two days later we came to exactly that result. John Schwarz, who was a world champion in such calculations, was impressed and humbled.

When I left Caltech I got a carte blanche from Murray to return as often as I wanted, during which I worked with Schwarz and Michael Green developing string theory. Murray was always very positive about our work, which few others were. It was entirely thanks to him that we could develop the theory. Eventually, I couldn't go to the US quite as often. Murray had also lost his wife in the early 1980s and never really recovered from this. In the mid-1980s he got the chance to set up a new institute in Santa Fe, which became completely interdisciplinary. He loved nature in New Mexico and here he could work on the issues that he now preferred, such as linguistics and large-scale order in nature. He dropped particle physics but was always interested in what happened in the field. Edward Witten had taken over the leadership of fundamental physics and Murray could not compete there.

Courtesy of the Santa Fe Institute

Cultivated
Gell-Mann in his office at the Santa Fe Institute.

Being considered the world's most intelligent person did not make Murray very happy. He had trouble finding real friends among his peers. They were simply afraid of him. I often saw people looking away. The post-war research world is a single great world championship. For us who were younger, it was so obvious that he was intellectually superior to us that we were not disturbed by it. All the time, though, the shadow of his father was sitting on his shoulder, which led him too often to show off when he did not need to.

Sometimes people are born with all the neurons in the right place. We sometimes hear about the telephone-directory geniuses or people who know railway schedules by heart, but who otherwise are intellectually normal, if not rather weak. The fact that a few of them every century also get the neurons to make them intellectually superior is amazing. Among all Nobel laureates in physics, Murray Gell-Mann stands out. Others have perhaps done just as much in their research in physics and may be remembered longer, but I do not think that anyone had such a breadth in their knowledge. John von Neumann, the Hungarian–American mathematician who, among other things, was the first to construct a computer was another such universal genius. He could show off knowing Goethe by heart and on his death bed he cited the first sentence on each page of *Faust* for his brother. Murray was certainly a pain for American linguists, as he could say so many words in so many languages that he could always gain control over a discussion.

There are so many more stories that I could tell. Once he told me "Just think what I could have done if I had worked more with physics." His almost crazy interest in so many areas took a lot of time away from physics. But he will still be remembered, I hope, as one of the great geniuses of the 20th century. ●

Gell-Mann was often described in the press as the world's most intelligent man

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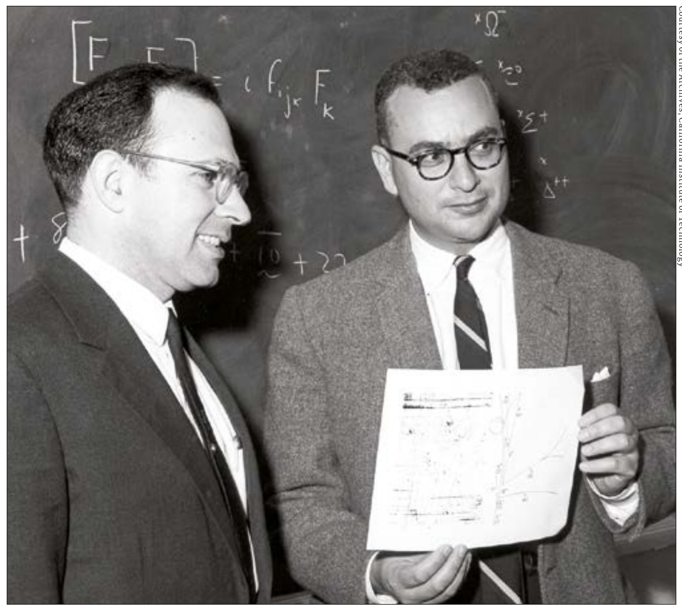
STRONG INTERACTIONS

Harald Fritzsch, who collaborated with Gell-Mann in the early 1970s, describes the steps that led to a full understanding of strong interactions.

Murray Gell-Mann's scientific career began at the age of 15, when he received a scholarship from Yale University that allowed him to study physics. Afterwards he went to the Massachusetts Institute of Technology and worked under Victor Weisskopf. He completed his PhD in 1951, at the age of 21, and became a postdoc at the Institute for Advanced Study in Princeton.

The following year, Gell-Mann joined the research group of Enrico Fermi at the University of Chicago. He was particularly interested in the new particles that had been discovered in cosmic rays, such as the six hyperons and the four K-mesons. Nobody understood why these particles were created easily in collisions of nucleons, yet decayed rather slowly. To understand the peculiar properties of the new hadrons, Gell-Mann introduced a quantum number, which he called strangeness (S): nucleons were assigned S = 0; the Λ hyperon and the three Σ hyperons were assigned S = (–1); the two Ξ hyperons had S = (–2); and the negatively charged K-meson had S = (–1).



Courtesy of the Archives, California Institute of Technology

Triply strange *Yuval Ne'eman (left) and Gell-Mann in March 1964, holding a copy of the event display that proved the existence of the Ω^- baryon that was predicted by Gell-Mann's "eightfold way".*

Strange assumptions

Gell-Mann assumed that the strangeness quantum number is conserved in the strong and electromagnetic interactions, but violated in the weak interactions. The decays of the strange particles into particles without strangeness could only proceed via the weak interaction.

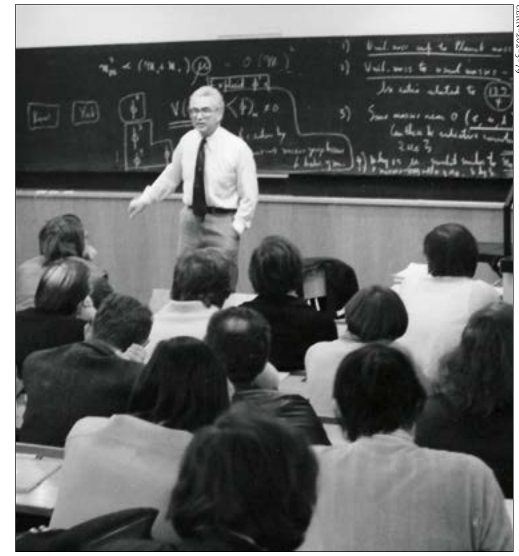
The idea of strangeness thus explained, in a simple way, the production and decay rates of the newly discovered hadrons. A new particle with S = (–1) could be produced by the strong interaction together with a particle with S = (+1) – e.g. a negatively charged Σ can be produced together with a positively charged K meson. However, a positively charged Σ could not be produced together with a negatively charged K meson, since both particles have S = (–1).

In 1954 Gell-Mann and Francis Low published details of the renormalisation of quantum electrodynamics (QED). They had introduced a new method called the renormalisation group, which Kenneth Wilson (a former student of Gell-Mann) later used to describe the phase transitions in condensed-matter physics. Specifically, Gell-Mann and Low calculated the energy dependence of the renormalised coupling constant. In QED the effective coupling constant increases with the energy. This was measured at the LEP collider at CERN, and found to agree with the theoretical prediction.

In 1955 Gell-Mann went to Caltech in Pasadena, on the invitation of Richard Feynman, and was quickly promoted to full professor – the youngest in Caltech's history. In 1957, Gell-Mann started to work with Feynman on a new theory of the weak interaction in terms of a universal Fermi interaction given by the product of two currents and the Fermi constant. These currents were both vector currents and axial-vector currents, and the lepton current is a product of a charged lepton field and an antineutrino field. The "V–A" theory showed that since the electrons emitted in a beta-decay are left-handed, the emitted antineutrinos are right-handed – thus parity is not a conserved quantum number. Some experiments were in disagreement with the new theory. Feynman and Gell-Mann suggested in their paper that these experiments were wrong, and it turned out that this was the case.

The quark model was not considered seriously by many physicists

In 1960 Gell-Mann invented a new symmetry to describe the new baryons and mesons found in cosmic rays and in various accelerator experiments. He used the unitary group SU(3), which is an extension of the isospin symmetry based on the group SU(2). The two nucleons and the six hyperons are described by an octet representation of SU(3), as are the eight mesons. Gell-Mann often described the SU(3)-symmetry as the "eightfold way" in reference to the eightfold path of Buddhism. At that time, it was known that there exist four Δ resonances, three Σ resonances and two χ resonances. There is no SU(3)-representation with nine members, but there is a decuplet representation with 10 members. Gell-Mann predicted the existence and the mass of a negatively charged 10th particle with strangeness S = (–3), which he called the Ω particle.



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Commanding figure *Gell-Mann lecturing on grand unification in CERN's theory conference room in 1979.*

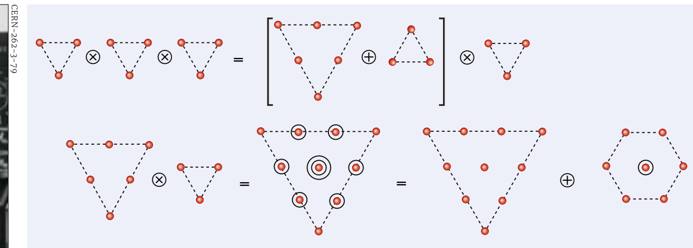
The Ω is unique in the decuplet: due to its strangeness it could only decay by the weak interaction, and so would have a relatively long lifetime. This particle was discovered in 1964 by Nicholas Samios and his group at Brookhaven National Laboratory, at the mass Gell-Mann had predicted. The SU(3) symmetry was very successful and in 1969 Gell-Mann received the Nobel Prize in Physics "for his contributions and discoveries concerning the classification of elementary particles and their interactions."

In 1962 Gell-Mann proposed the algebra of currents, which led to many sum rules for cross sections, such as the Adler sum rule. Current algebra was the main topic of research in the following years and Gell-Mann wrote several papers with his colleague Roger Dashen on the topic.

Quark days

In 1964 Gell-Mann discussed the triplets of SU(3), which he called "quarks". He proposed that quarks were the constituents of baryons and mesons, with fractional electric charges, and published his results in *Physics Letters*. Feynman's former PhD student George Zweig, who was working at CERN, independently made the same proposal. But the quark model was not considered seriously by many physicists. For example, the Ω is a bound state of three strange quarks placed symmetrically in an s-wave, which violated the Pauli principle since it was not anti-symmetric. In 1968, quarks were found indirectly in deep-inelastic electron–proton experiments performed at SLAC.

By then it had been proposed, by Oscar Greenberg and by



Adapted from M Thomson Modern Particle Physics (Cambridge 2013)

Fig. 1. *qqq multiplets in SU(3) symmetry broken down into the 6⊗3 part (second row), yielding a totally symmetric baryon decuplet and a mixed-symmetry baryon octet. The remaining 3⊗3̄ part (not shown) yields a mixed-symmetry octet and a totally antisymmetric singlet state.*

Moo-Young Han and Yoichiro Nambu, that quarks possess additional properties that keep the Pauli principle intact. By imagining the quarks in three "colours" – which later came to be called red, green and blue – hadrons could be considered as colour singlets, the simplest being the bound states of a quark and an antiquark (meson) or of three quarks (baryon). Since baryon wave functions are antisymmetric in the colour index, there is no problem with the Pauli principle. Taking the colour quantum number as a gauge quantum number, like the electric charge in QED, yields a gauge theory of the strong interactions: colour symmetry is an exact symmetry and the gauge bosons are massless gluons, which transform as an octet of the colour group. Nambu and Han had essentially arrived at quantum chromodynamics (QCD), but in their model the quarks carried integer electrical charges.

I was introduced to Gell-Mann by Ken Wilson in 1970 at the Aspen Center of Physics, and we worked together for a period. In 1972 we wrote down a model in which the quarks had fractional charges, proposing that, since only colour singlets occur in the spectrum, fractionally charged quarks remain unobserved. The discovery in 1973 by David Gross, David Politzer and Frank Wilczek that the self-interaction of the gluons leads to asymptotic freedom – whereby the gauge coupling constant of QCD decreases if the energy is increased – showed that quarks are forever confined. It was rewarded with the 2004 Nobel Prize in Physics, although a rigorous proof of quark confinement is still missing.

Gell-Mann did not just contribute to the physics of strong interactions. In 1979, along with Pierre Ramond and Richard Slansky, he wrote a paper discussing details of the "seesaw mechanism" – a theoretical proposal to account for the very small values of the neutrino masses introduced a couple of years earlier. After 1980 he also became interested in string theory. His wide-ranging interests in languages, and other areas beyond physics are also well documented.

I enjoyed working with Murray Gell-Mann. We had similar interests in physics, and we worked together until 1976 when I left Caltech and went to CERN. He visited often. In May 2019, during a trip to Los Alamos Laboratory, I was fortunate to have had the chance to visit Murray at his house in Santa Fe one last time. •

• Further memories of Gell-Mann can be found online at cerncourier.com.

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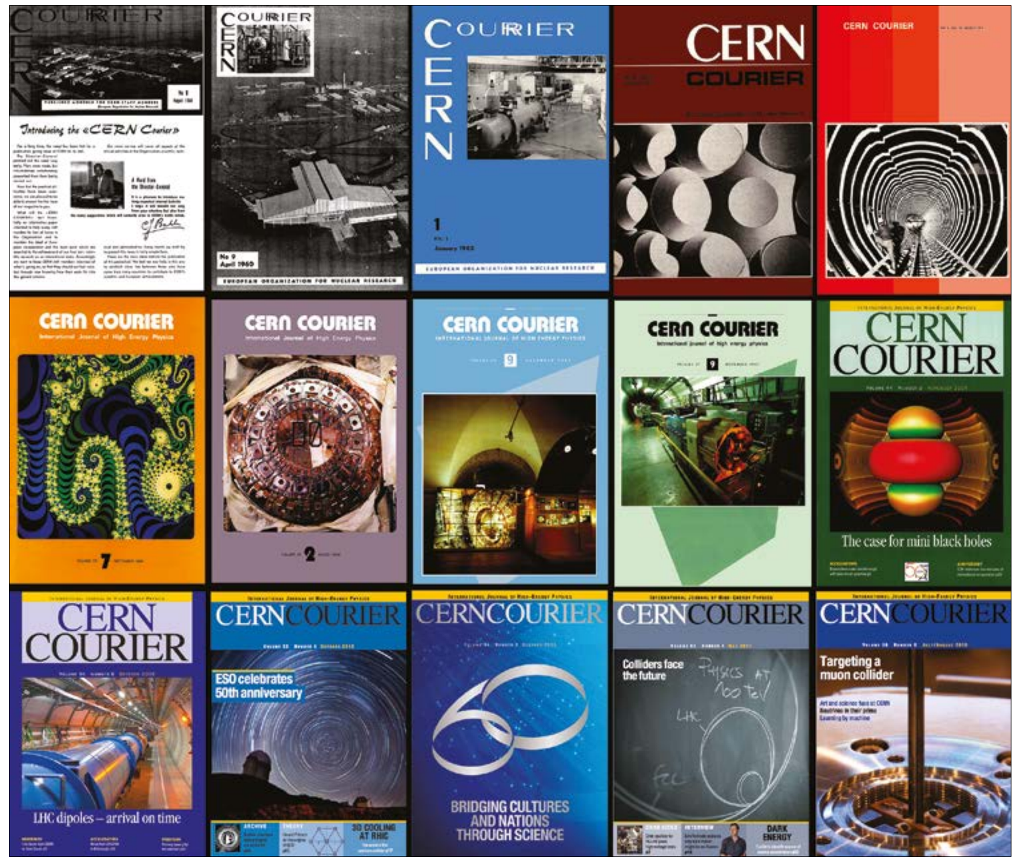
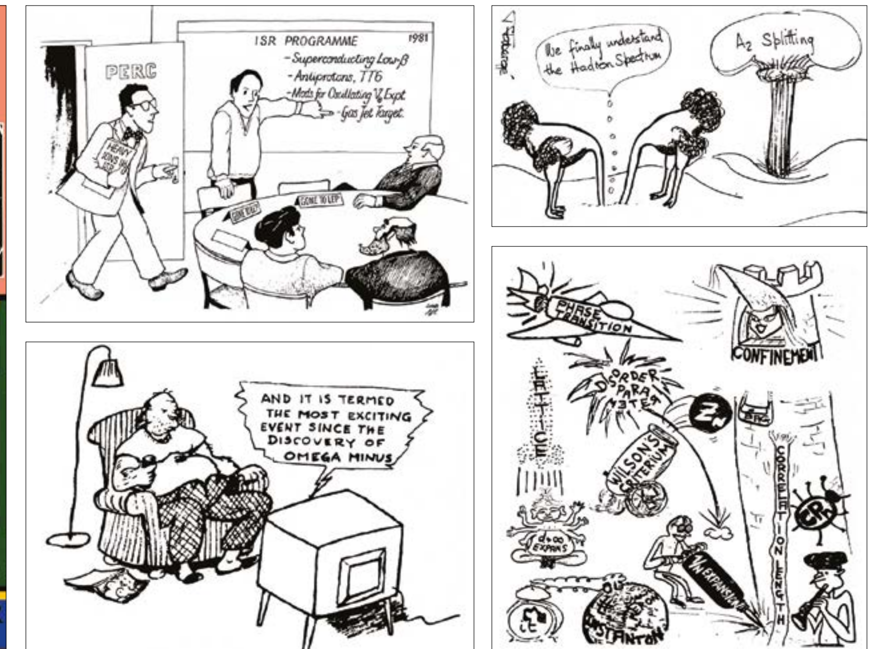
WE'VE BEEN HERE BEFORE…

Tales of colliders contained in 60 illustrious years of *CERN Courier* offer a rich perspective on the strategic decisions facing the field today.





Lost humour *Top left: in April 1984 Phil Bryant highlighted the closure of the ISR with the intended message: "Gentlemen, this is definitely the last project before we close the ISR!". Top right: this cartoon from the August 1969 issue was titled "Where we stand – 1969" and illustrated the troublesome time that theory was having in trying to accommodate the discovery of the splitting of the A2 meson. Bottom left: the November 1976 issue carried this cartoon by Bob Gould of SLAC, depicting the reaction of the "man in the street" at a time when high-energy physicists were in a state of euphoria over the discovery of the J/ψ, captioned: "Salutary reminder to all who attempt to popularise science". Bottom right: the October 1979 issue carried Alvaro De Rújula's view of the current scene in particle theory: "Who will succeed in rescuing the quark damsel confined in her tower?"*

In April 1960, Prince Philip, husband of Queen Elizabeth II, piloted his Heron airplane to Geneva for an informal visit to CERN. Having toured the laboratory's brand new "25 GeV" Proton Synchrotron (PS), he turned to his host, president of the CERN Council François de Rose, and struck at the heart of fundamental exploration: "What have you got in mind for the future? Having built this machine, what next?" he asked. De Rose replied that this was a big problem for the field: "We do not really know whether we are going to discover anything new by going beyond 25 GeV," he said. Unbeknown to de Rose and everyone else at that time, the weak gauge bosons and other phenomena that would transform particle physics were lying not too far above the energy of the PS.

This is a story repeated in elementary particle physics, and which *CERN Courier*, celebrating its 60th anniversary this summer, offers a bite-sized glimpse of.

The first issue of the *Courier* was published in August 1959, just a few months before the PS switched on, at a time when accelerators were taking off. The PS was the first major European machine, quickly reaching an energy of 28 GeV, only to be surpassed the following year by Brookhaven's Alternating Gradient Synchrotron. The March 1960 issue of the *Courier* described a meeting at CERN where 245 scientists from 28 countries had discussed "a dozen machines now being designed or constructed". Even plasma-based acceleration techniques – including a "plasma betatron" at CERN – were on the table.

A time gone by

The picture is not so different today (see p7), though admittedly thinner on projects under construction. Some things remain eerily pertinent: swap "25 GeV" for "13 TeV" in de Rose's response to Prince Philip, and his answer still stands with respect to what lies beyond the LHC's energy. Other things are of a time gone by. The third issue of the *Courier*, in October 1959, proudly declared that "elementary particles number 32" (by 1966 that number had grown to more than 50 – see "Not so elementary" on p32). Another early issue likened the 120 million Swiss Franc cost of the PS to "10 cigarettes for each of the 220 million inhabitants of CERN's 12 Member States".

The general situation of elementary particle physics back then, argued the August 1962 issue, could be likened to atomic physics in 1924 before the development of quantum mechanics. Summarising the 1962 ICHEP conference held at CERN, which attracted an impressive 450 physicists from 158 labs in 39 countries, the leader of the CERN theory division Léon Van Hove wrote: "The very fact that the variety of unexpected findings is so puzzling is a promise that new fundamental discoveries may well be in store at the end of a long process of elucidation." Van Hove was right, and the 1960s brought the quark model and electroweak theory, laying a path to the Standard Model. Not that this paradigm shift is much apparent when flicking through issues of the *Courier* from the period; only hindsight can produce the neat logical history that most physics students learn.

Within a few years of PS operations, attention soon turned to a machine for the 1970s. A report on the 24th session of the CERN Council in the July 1963 issue noted ECFA's recommendation that high priority be given to the construction in Europe of two projects: a pair of intersecting storage rings (ISR, which would become the world's first hadron collider) and a new proton accelerator of a very high energy "probably around 300 GeV", which would be 10 times the size of the PS (and eventually renamed the Super Proton Synchrotron, SPS). Mervyn Hine of the CERN directorate for applied physics outlined in the August 1964 issue how this so-called "Summit program" should be financed. He estimated the total annual cost (including that of the assumed national programmes) to be about 1100 million Swiss Francs by 1973, concluding that this was in step with a minimum growth for total European science. He wrote boldly: "The scientific case for Europe's continuing forcefully in high-energy physics is overwhelming; the equipment needed is technically feasible; the scientific manpower needed will be available; the money is trivial. Only conservatism or timidity will stop it."

The development of science

Similar sentiments exist now in view of a post-LHC collider. There is also nothing new, as the field grows ever larger in scale, in attacks on high-energy physics from outside. In an open letter published in the *Courier* in April 1964, nuclear physicist Alvin Weinberg argued that the field had become "remote" and that few other branches of science were "waiting breathlessly" for insights from high-energy physics without which they

…the money is trivial. Only conservatism or timidity will stop it

THE AUTHOR

Matthew Chalmers *editor.*

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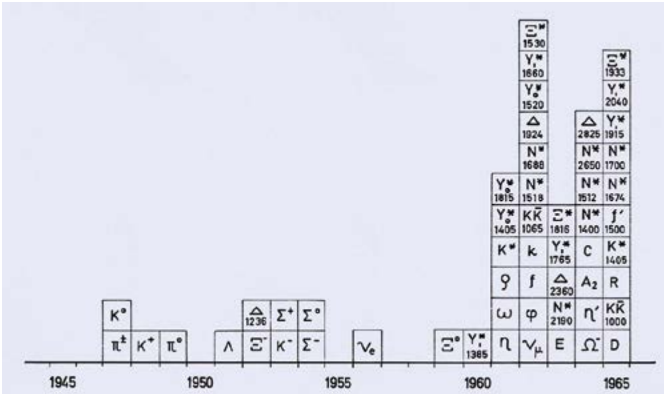
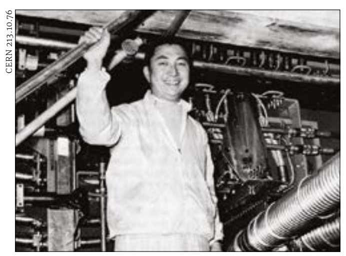


Not so elementary *This figure, reprinted from the December 1966 issue, shows the date of the discovery of what were then thought to be elementary particles. Altogether about 100 different particles were known, not counting their corresponding antiparticles. Most of the discoveries before 1955 were made in cosmic-ray experiments, while the large number found after 1960 were produced and investigated mainly with the proton synchrotrons at Berkeley, Brookhaven and CERN.*

J Sharp

CERN 213.10.76



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Faces and places *Top left: the "seraphic contentment" of Hildred Blewett when full energy had been achieved at the PS on 25 November 1959. Top right: a smiling November 1976 Sam Ting at his experiment at the ISR "where he continues the search for leptons which has dominated his research life". Bottom left: John Ellis snapped in an article about cosmology in the July/August 1983 issue. Bottom right: the* CERN Courier *team featured in the October 1979 issue, resplendent in CERN 25th anniversary T-shirts (left to right: Henri-Luc Felder, Monika Wilson, Brian Southworth (editor), Micheline Falciola and Gordon Fraser. Those were the days!).*

could not progress. Director-General Viki Weisskopf, writing in April 1965, concluded that the development of science had arrived at a critical stage: "We are facing today a situation where it is threatened that all this promising research will be slowed down by constrained financial support of high-energy physics."

Deciding where to build the next collider and getting international partners on board was also no easier in the past, if the SPS was any guide. The September 1970 issue wrote that the "present impasse in the 300 GeV project" is due to the difficulty of selecting a site and: "At the same time it is disturbing to the traditional unity of CERN that only half the Member States (Austria, Belgium, Federal Republic of Germany, France, Italy and Switzerland) have so far adopted a positive attitude towards the project." That half-a-century later, the SPS, soon afterwards chosen to be built at CERN, would be feeding protons into a 27 km-circumference hadron collider with a centre-of-mass energy of 13 TeV was unthinkable.

A giant LEP for mankind

An editorial in the January/February 1990 issue of the *Courier* titled "Diary of a dramatic decade" summed up a crucial period that had the Large Electron Positron (LEP) collider at its centre: Back in 1980, it said, the US was the "mecca" of high-energy physics. "But at CERN, the vision of Carlo Rubbia, the invention of new beam 'cooling' techniques by Simon van der Meer, and bold decisions under the joint Director-Generalship of John Adams and Léon Van Hove had led to preparations for a totally new research assault – a high-energy proton–antiproton collider." The 1983 discoveries of the W and Z bosons had, it continued, "nudged the centroid of particle physics towards Europe," and, with LEP and also HERA at DESY operating, Europe was "casting off the final shackles of its war-torn past".

Despite involving what at that time was Europe's largest civil-engineering project, LEP didn't appear to attract much public attention. It was planned to be built within a constant CERN budget, but there were doubts as to whether this was possible (see p39). The September 1983 issue reported on an ECFA statement noting that reductions in CERN's budget had put is research programme under "severe stress", impairing the lab's ability to capitalise on its successful proton–antiproton programme. "The European Laboratories have demonstrated their capacity to lead the world in this field, but the downward trend of support both for CERN and in the Member States puts this at serious risk," it concluded. At the same time, following a famous meeting in Lausanne, the ECFA report noted that proton–proton collision energies of the order of 20 TeV could be reached with superconducting magnets in the LEP tunnel and "recommends that this possibility be investigated".

Physicists were surprisingly optimistic about the possibility of such a large hadron collider. In the October 1981 issue, Abdus Salam wrote: "In the next decade, one may envisage the possible installation of a $p\bar{p}$ collider in the LEP tunnel and the construction of a supertevatron… But what will happen to the subject 25 years from now?" he asked. "Accelerators may become as extinct as dinosaurs unless our community takes heed now and invests efforts on new designs." Almost 40 years later, the laser-based acceleration schemes that Salam wrote of, and others, such as muon colliders, are still being discussed.

Accelerator physicist Lee Teng, in an eight-page long report about the 11th International Conference on High Energy Accelerators in the September 1980 issue, pointed out that seven decades in energy had been mastered in 50 years of accelerator construction. Extrapolating to the 21st century, he envisaged "a 20 TeV proton synchrotron and 350 GeV electron–positron linear colliders". On CERN's

CERN COURIER's crystal ball

A new simulation computer program, OMEN (On-going Multiparticle Event Number-cruncher) is being developed to aid the long-term planning of particle physics experiments. Although the program is not yet available for general release, we were fortunate enough to obtain a prototype version, and used input data culled from the pages of the 1977 COURIER to obtain this unique glimpse of what could be in store in 1978.

JANUARY
Twenty new high mass particles discovered in lepton pair experiments. Theorists propose periodic table of quarks. Copies printed and distributed to schools. IBM announces a new computer to handle the world's neutrino data.

FEBRUARY
Fractional electronic charges detected on a television screen in Memphis, Tennessee. Five muons seen coming from a neutrino interaction. Weinberg Salam angle remains unchanged. US Supreme Court rules that jets must no longer be produced in hadronic reactions.

MARCH
Leptons get heavier and heavier. Very high energy cosmic ray event recorded in South America. Government overthrown. The A1 meson disappears from view. Medical applications of charmed quarks demonstrated. Six muons seen coming from neutrino interaction.

APRIL
Analysis of cosmic ray event reveals ten free quarks, a tachyon, four Higgs particles, two magnetic monopoles, three superheavy nuclei and an intermediate vector boson (the charged kind). Weinberg-Salam angle remains unchanged but accelerator building stops throughout the world.

MAY
Particle Data Group publishes special quark souvenir issue. Land prices in the Andes soar as USA physicists rush to install particle detectors. European physicists hold Workshops to decide which cosmic rays to observe. Muon production in neutrino interactions included as event in Olympic games.

JUNE
The Big Shut Down starts. Accelerator sites used as car parks. BEBC is resited for cosmic ray experiments on the summit of Mont-Blanc. g-2 experiment reconstructed to measure the Weinberg-Salam angle to one part per million. South American governments introduce import tariffs on multiwire proportional chambers.

JULY
Photograph of cosmic ray event hung in Louvre. IBM (South America) reanalyses world's neutrino data. World record of 256 muons seen coming from a neutrino interaction is not ratified because of following wind and physicists taking anabolic steroids. Weinberg-Salam angle unchanged. Physicists read 'Finnegan's Wake' to learn significance of quarks.

AUGUST
CERN COURIER reports naked bottom seen on Copacabana beach. International high energy physics conference hurriedly convened in Rio de Janeiro. High energy physics football team wins final of World Cup in Argentina.

SEPTEMBER
South American cosmic ray event shown to be a hoax. Land prices in Andes plummet as physicists return to machines. Owners reluctant to remove their cars from accelerator sites. Parity experiment discovers violation of atomic physics. IBM analyses 'Finnegan's Wake'.

OCTOBER
IPCFA (Inter Planetary Committee for Future Accelerators) holds first meeting. Although next generation of machines envisaged to be built on a regional basis, plans to construct a Cosmic Ray Storage Ring in ten years' time as a World Machine are put forward. The A1 reappears. Five million physicists now using synchrotron radiation facilities.

NOVEMBER
IBM computer wins Nobel prizes for physics and literature. IPCFA proposes Energy Doubler for the Cosmic Ray Storage Ring. Mohammed Ali says 'I can knock muons out of anything!' Accelerator building stops again.

DECEMBER
Bug found in OMEN.

Oh well.

Search for the naked bottom *The December 1977 issue looked back over an exciting year that saw the discovery of the upsilon particle: "a new type of quark most frequently interpreted as consisting of a quark–antiquark pair of a new type". The postulated new quark, wrote the* Courier, *"has been assigned names like 'beauty', 'top' or 'bottom'. Just as the J/ψ provoked the search for naked charm, so the upsilon now offers physicists the exciting prospect in 1978 of looking for naked bottom." The issue closed with this satirical look (left) at what the next year might hold.*

50th anniversary in September 2004, former Director-General Luciano Maiani predicted what the post-2020 future might look like, asserting that "a big circular tunnel, such as that required by a Very Large Hadron Collider, would have to go below Lake Geneva or below the Jura (or both). Either option would be simply too expensive to consider. This is why a 3–5 TeV Compact Linear Collider (CLIC) would be the project of choice for the CERN site." It is the kind of decision that the current CERN management is weighing up today, 15 years later.

Driving success

This collider-centric view of 60 years of *CERN Courier* does little justice to the rest of the magazine's coverage of fixed-target physics, neutrino physics, cosmology and astrophysics, detector and accelerator physics, computing, applications, and broader trends in the field. It is striking how much the field has advanced and specialised. Equally, it is heartening to find so many parallels with today. Some are sociological: in October 1995 a report on an ECFA study noted "much dissatisfaction" with long author lists and practical concerns about the size of the even bigger LHC-experiment collaborations over the horizon. Others are more strategic.

It is remarkable to read through back issues of the *Courier* from the mid-1970s to find predictions for the masses of the W and Z bosons that turned out to be correct to within 15%. This drove the success of the Sp$\bar{p}$S and LEP programmes and led naturally to the LHC – the collider to hunt down the final piece of the electroweak jigsaw, the "so-called Higgs mesons" as a 1977 issue of the *Courier* put it. Following the extraordinary episode that was the development and completion of the Standard Model, we find ourselves in a similar position as we were in the PS days regarding what lies over the energy frontier. Looking back at six decades of fundamental exploration as seen through the imperfect lens of this magazine, it would take a bold soul to claim that it isn't worth a look.

Further reading

The full *Courier* archive can be browsed at https://cds.cern.ch.

MEMORIES FROM CALTECH

Stephen Wolfram reflects on Gell-Mann's complex character and his rivalry with Richard Feynman.

Talented rivals *Murray Gell-Mann (left) with Richard Feynman at Caltech in 1959.*

In the mid-1970s, particle physics was hot. Quarks were in. Group theory was in. Field theory was in. And so much progress was being made that it seemed like the fundamental theory of physics might be close at hand. Right in the middle of all this was Murray Gell-Mann – responsible for not one, but most, of the leaps of intuition that had brought particle physics to where it was. There'd been other theories, but Murray's, with their somewhat elaborate and abstract mathematics, were always the ones that seemed to carry the day.

It was the spring of 1978 and I was 18 years old. I'd been publishing papers on particle physics for a few years. I was in England, but planned to soon go to graduate school in the US, and was choosing between Caltech and Princeton. One weekend afternoon, the phone rang. "This is Murray Gell-Mann", the caller said, then launched into a monologue about why Caltech was the centre of the universe for particle physics at the time. Perhaps not as star-struck as I should have been, I asked a few practical questions, which Murray dismissed. The call ended with something like, "Well, we'd like to have you at Caltech".

I remember the evening I arrived, wandering around the empty fourth floor of Lauritsen Lab – the centre of Caltech theoretical particle physics. There were all sorts of names I recognised on office doors, and there were two offices that were obviously the largest: "M. Gell-Mann" and "R. Feynman". In between them was a small office labelled "H. Tuck", which by the next day I'd realised was occupied by the older but very lively departmental assistant.

I never worked directly with Murray but I interacted with him frequently while I was at Caltech. He was a strange mixture of gracious and gregarious, together with austere and combative. He had an expressive face, which would wrinkle up if he didn't approve of what was being said. Murray always grouped people and things he approved of, and those he didn't – to which he would often give disparaging nicknames. (He would always refer to solid-state physics as "squalid-state physics".) Sometimes he would pretend that things he did not like simply did not exist. I remember once talking to him about something in quantum field theory called the beta function. His face showed no recognition of what I was talking about, and I was getting slightly exasperated. Eventually I blurted out, "But, Murray, didn't you invent this?" "Oh", he said, suddenly much more charming, "You mean g times the psi function. Why didn't you just say that? Now I understand."

I could never quite figure out what it was that made Murray impressed by some people and not others. He would routinely disparage physicists who were destined for great success, and would vigorously promote ones who didn't seem so promising, and didn't in fact do well. So when he promoted me, I was on the one hand flattered, but on the other hand concerned about what his endorsement might really mean.

Both would make surprisingly childish comments about the other

Feynman interactions

The interaction between Murray Gell-Mann and Richard Feynman was an interesting thing to behold. Both came from New York, but Feynman relished his "working class" New York accent while Gell-Mann affected the best pronunciation of words from any language. Both would make surprisingly childish comments about the other. I remember Feynman insisting on telling me the story of the origin of the word "quark". He said he'd been talking to Murray one Friday about these hypothetical particles, and in their conversation they'd needed a name for them. Feynman told me he said (no doubt in his characteristic accent), "Let's call them 'quacks'". The next Monday, he said, Murray came to him very excited and said he'd found the word "quark" in a novel by James Joyce. In telling this to me, Feynman then went into a long diatribe about how Murray always seemed to think the names for things were so important. "Having a name for something doesn't tell you a damned thing," Feynman said. Feynman went on, mocking Murray's concern for things like what different birds are called. (Murray was an avid bird watcher.) Meanwhile, Feynman had worked on particles that seemed (and turned out to be) related to quarks. Feynman had called them "partons". Murray insisted on always referring to them as "put-ons".

Even though in terms of longstanding contributions to particle physics, Murray was the clear winner, he always seemed to feel as if he was in the shadow of Feynman, particularly with Feynman's showmanship. When Feynman died, Murray wrote a rather snarky obituary, saying of Feynman: "He surrounded himself with a cloud of myth, and he spent a great deal of time and energy generating anecdotes about himself." I never quite understood why Murray – who could have gone to any university in the world – chose to work at Caltech for 33 years in an office two doors down from Feynman.

Murray cared a lot about what people thought of him, but wasn't particularly good at reading other people. Yet, alongside the brush-offs and the strangeness, he could be personally very gracious. I remember him inviting me several times to his house. He also did me quite a few favours in my career. I don't know if I would call Murray a friend, though, for example, after his wife Margaret died, he and I would sometimes have dinner together, at random restaurants around Pasadena. It wasn't so much that I felt of a different generation from him (which of course I was). It was more that he exuded a certain aloof tension, that made one not feel very sure about what the relationship really was.

Murray Gell-Mann had an amazing run. For 20 years he had made a series of bold conjectures about how nature might work – strangeness, V–A theory, SU(3), quarks, QCD – and in each case he had been correct, while others had been wrong. He had one of the more remarkable records of repeated correct intuition in the whole history of science.

He tried to go on. He talked about "grand unification being in the air", and (along with many other physicists) discussed the possibility that QCD and the theory of weak interactions might be unified in models based on groups such as SU(5) and SO(10). He considered supersymmetry. But quick validations of these theories didn't work out, though even now it's still conceivable that some version of them might be correct.

I have often used Murray as an example of the challenges of managing the arc of a great career. From his twenties to his forties, Murray had the golden touch. His particular way of thinking had success after success, and in many ways he defined physics for a generation. By the time I knew him, the easy successes were over. Perhaps it was Murray; more likely, it was just that the easy pickings from his approach were now gone. He so wanted to succeed as he had before, not just in physics but in other fields and endeavours. But he never found a way to do it – and always bore the burden of his early success.

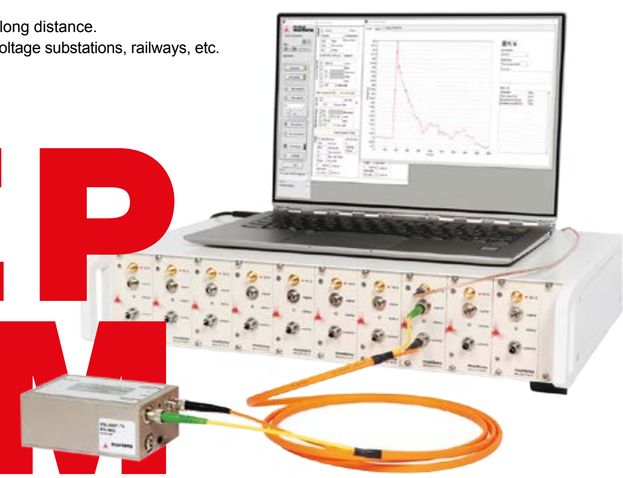
Though Murray is now gone, the physics he discovered will live on, defining an important chapter in the quest for our understanding of the fundamental structure of our universe. ●

He was a strange mixture of gracious and gregarious

● This article draws on a longer tribute published on www.stephenwolfram.com.

THE AUTHOR

Stephen Wolfram *founder and CEO of Wolfram Research.*



OPINION VIEWPOINT

Reflections on Granada

The open symposium of the European Strategy for Particle Physics stimulated much lively discussion about the future of particle physics and the central role of CERN, writes Eckhard Elsen.

CERN

Eckhard Elsen *is CERN director for research and computing.*

Sandbox Studio, Chicago, courtesy of Symmetry magazine

Multifaceted *The European Strategy Group faces a monumental challenge in plotting a course for the future of high-energy physics.*

Nearly 70 years ago, before CERN was established, two models for European collaboration in fundamental physics were on the table: one envisaged opening up national facilities to researchers from across the continent, the other the creation of a new, international research centre with world-leading facilities. Discussions were lively, until one delegate pointed out that researchers would go to wherever the best facilities were.

From that moment on, CERN became an accelerator laboratory aspiring to be at the forefront of technology to enable the best science. It was a wise decision, and one that I was reminded of while listening to the presentations at the open symposium of the European Strategy for Particle Physics in Granada, Spain, in May. Because among the conclusions of this very lively meeting was the view that providing world-leading accelerator and experimental facilities is precisely the role the community needs CERN to play today.

There was huge interest in the symposium, as witnessed by the 600-plus participants, including many from the nuclear and astroparticle physics communities. The vibrancy of the field was fully on display, with future hadron colliders offering the biggest leap in energy reach for direct searches for new physics. Precision electroweak studies at the few per cent level, particularly for the Higgs particle, will obtain sensitivities for similar mass scales. The LHC, and soon the High-Luminosity LHC, will go a long way towards achieving that goal of precision. Indeed, it's remarkable how far the LHC experiments have come in overturning the old adage that hadrons are for discovery and leptons for precision – the LHC has established itself as a precision tool, and this is shaping the debate as to what kind of future we can expect.

CERN needs to remain true to its founding vision of being a world-leading centre for accelerator technology

Nevertheless, however precise proton–proton physics becomes, it will still fall short in some areas. To fully understand the absolute width of the Higgs, for example, a lepton machine will be needed, and no fewer than four implementations were discussed. So, one key conclusion is that if we are to cover all bases, no single facility will suffice. One way forward was presented by the chair of the Asian Committee for Future Accelerators Geoff Taylor, who advocated a lepton machine for Asia while Europe would focus on advancing the hadron frontier.

Interest in muon colliders was rekindled, not least because of some recent reconsiderations in muon cooling (*CERN Courier* July/August 2018 p19). The great and recent progress of plasma-wakefield accelerators, including AWAKE at CERN, calls for further research in this field so as to render the technology usable for particle physics. Methods of dark-matter searches abound and are an important element of the discussion on physics beyond colliders, using single beams at CERN.

The Granada meeting was a town meeting on physics. Yet, it is clear to all that we can't make plans solely on the basis of the available technology and a strong physics case, but must also consider factors such as cost and societal impact in any future strategy for European particle physics. With all the available technology options and open questions in physics, there's no doubt that the future should be bright. The European Strategy Group, however, has a monumental challenge in plotting an affordable course to propose to the CERN Council in March next year.

There were calls for CERN to diversify and lend its expertise to other areas of research, such as gravitational waves: one speaker even likened interferometers to accelerators without beams. In terms of the technologies involved, that statement stands up well to scrutiny, and it is true that technology developed for particle physics at CERN can help the advancement of other fields. CERN already formally collaborates with organisations like ITER and the ESS, sharing our innovation and expertise. However, for me, the strongest message from Granada is that it is CERN's focus on remaining at the forefront of particle physics that has enabled the Organization to contribute to a diverse range of fields. CERN needs to remain true to that founding vision of being a world-leading centre for accelerator technology. That is the starting point. From it, all else follows.

● This article was originally published in the *CERN Bulletin*.

OPINION INTERVIEW

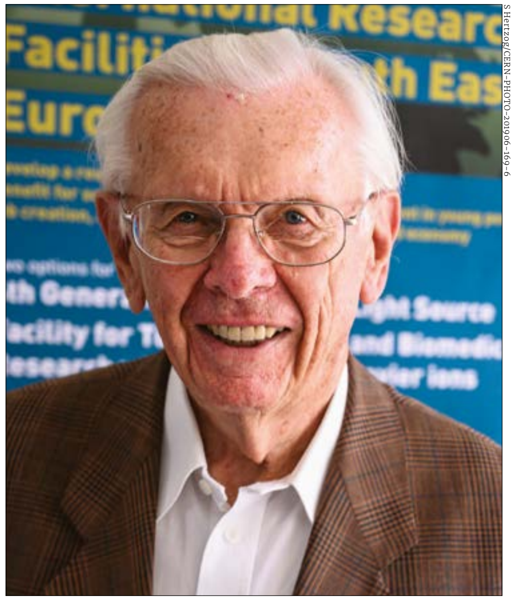
Lessons from LEP

The Large Electron Positron collider (LEP) changed particle physics, and CERN, forever. Former Director-General Herwig Schopper describes what it took to make LEP happen.

When was the first LEP proposal made, and by whom?
Discussions on how to organise a "world accelerator" took place at a pre-ICFA committee in New Orleans in the early 1970s. The talks went on for a long time, but nothing much came out of them. In 1978 John Adams and Leon Van Hove – the two CERN Director-Generals (DGs) at the time – agreed to build an electron–positron collider at CERN. There was worldwide support, but then there came competition from the US, worried that they might lose the edge in high-energy physics. Formal discussions about a Superconducting Supercollider (SSC) had already begun. While it was open to international contribution, Ronald Reagan's "join it or not" approach to the SSC, and other reasons, put other countries off the project.

Was there scientific consensus for a collider four times bigger than anything before it?
Yes. The W and Z bosons hadn't yet been discovered, but there were already strong indications that they were there. Measuring the electroweak bosons in detail was the guiding force for LEP. There was also the hunt for the Higgs and the top quark, yet there was no guidance on the masses of these particles. LEP was proposed in two phases, first to sit at the Z pole and then the WW threshold. We made the straight sections as long as possible so we could increase the energy during the LEP2 phase.

What about political consensus?
The first proposal for LEP was initially refused by the CERN Council because it had a 30 km circumference and cost 1.4 billion Swiss Francs. When I was appointed DG in February 1979, they asked me to sit down with both current DGs and make a common proposal, which we did. This was the proposal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Looking forward *Herwig Schopper believes that the next machine has to be a world facility.*

with the idea to make it 22 km in circumference. At that time CERN had a "basic" programme (which all Member States had to pay for) and a "special" programme whereby additional funds were sought. The latter was how the Intersecting Storage Rings (ISR) and the Super Proton Synchrotron (SPS) were built. But the cost of LEP made some Member States hesitate because they were worried that it would eat too much into the resources of CERN and national projects.

How was the situation resolved?
After long discussions, Council said: yes, you build it, but do so within a constant budget. It seemed like an impossible task because the CERN budget had peaked before I took over and it was already in decline. I was

I was advised by some senior colleagues to resign because it was not possible to build LEP on a constant budget

advised by some senior colleagues to resign because it was not possible to build LEP on a constant budget. So we found another idea: make advance payments and create debts. Council said we can't make debts with a bank, so we raided the CERN pension fund instead. They agreed happily since I had to guarantee them 6% interest, and as soon as LEP was built we started to pay it back. With the LHC, Carlo Rubbia had to do the same (the only difference was that Council said he could go to a bank). CERN is still operating within essentially the same constant budget today (apart from compensation for inflation), with the number of users having more than doubled – a remarkable achievement! To get LEP approved, I also had to say to Council that CERN would fund the machine and others would fund the experiments. Before LEP, it was usual for CERN to pay for experiments. We also had to stop several activities like the ISR and the BEBC bubble chamber. So LEP changed CERN completely.

How do LEP's findings compare with what was expected?
It was wonderful to see the W and Z discovered at the SPS while LEP was being built. Of course, we were disappointed that the Higgs and the top were not discovered. But, look, these things just weren't known then. When I was at DESY, we spent 5 million Deutsche Marks to increase the radio-frequency power of the PETRA collider because theorists had guaranteed that the top quark would be lighter than 25 GeV! At LEP2 it was completely unknown what it would find.

What is LEP's physics legacy?
These days, there is a climate where everything that is not a peak is not a discovery. People often say "not much came out from LEP". That is

completely wrong. What people forget is that LEP changed high-energy physics from a 10% to a 1% science. Apart from establishing the existence of three neutrino flavours, the LEP experiments enabled predictions of the top-quark mass that were confirmed at Fermilab's Tevatron. This is because LEP was measuring the radiative corrections – the essential element that shows the Standard Model is a renormalisable theory, as shown theoretically by 't Hooft and Veltman. It also showed that the strong coupling constant, α_s, runs with energy and allowed the coupling constants of all the gauge forces to be extrapolated to the Planck mass – where they do not meet. To my mind, this is the most concrete experimental evidence that the Standard Model doesn't work, that there is something beyond it.

How did the idea come about to put a proton collider in the LEP tunnel?
When LEP was conceived, the Higgs was far in the future and nobody was really talking about it. When the LEP tunnel was discussed, it was only the competition with SSC. The question was: who would win the race to go to higher energy? It was clear in the long run that the proton machine would win, so we had the famous workshop in Lausanne in 1983 where we discussed the possibility of putting a proton collider in the LEP tunnel. It was foreseen then to put it on top of LEP and to have them running at the same time. With the LHC, we couldn't compete in energy with the SSC so we went for higher luminosities. But when we looked into this, we realised we had to make the tunnel bigger. The original proposal, as approved by Council in October 1981, had a tunnel size of 22 km and making it bigger was a big problem because of the geology – basically we couldn't go too far under the Jura mountains. Nevertheless, I decided to go to 27 km against the advice of most colleagues and some advisory committees, a decision that delayed LEP by about a year because of the water in the tunnel. But it is almost forgotten that the LEP tunnel size was only chosen in view of the LHC.

Are there parallels with CERN today concerning what comes next after the LHC?
Yes and no. One of the big differences compared to the LEP days is that, back then, the population around CERN did not know what we were doing – the policy of management was *not* to explain what we are doing because it is "too complicated"! I was very surprised to learn this when I arrived as DG, so we had many hundreds of meetings with the local community. There was a misunderstanding about the word "nuclear" in CERN's name – they thought we were involved in generating nuclear power. That fortunately has completely changed and CERN is accepted in the area.

What is different concerns the physics. We are in a situation more similar to the 1970s before the famous J/ψ discovery when we had no indications from theory where to go. People were talking about all sorts of completely new ideas back then. Whatever one builds now is penetrating into unknown territory. One cannot be sure we will find something because there are no predictions of any thresholds.

What people forget is that LEP changed high-energy physics from a 10% to a 1% science

What wisdom can today's decision-makers take from the LEP experience?
In the end I think that the next machine has to be a world facility. The strange thing is that CERN formally is still a European lab. There are associates and countries who contribute in kind, which allows them to participate, but the boring things like staff salaries and electricity have to be paid for by the Member States. One therefore has to find out whether the next collider can be built under a constant budget or whether one has to change the constitutional model of CERN. In the end I think the next collider has to be a proton machine. Maybe the LEP approach of beginning with an electron–positron collider in a new tunnel would work. I wouldn't exclude it. I don't believe that an electron–positron linear collider would satisfy requests for a world machine as its energy will be lower than for a proton collider, and because it has just one interaction point. Whatever the next project is, it should be based on new technology such as higher field superconducting magnets, and not be just a bigger version of the LHC. Costs have gone up and I think the next collider will not fly without new technologies.

You were born before the Schrödinger equation and retired when LEP switched on in 1989. What have been the highs and lows of your remarkable career?
I was lucky in my career to be able to go through the whole of physics. My PhD was in optics and solid-state physics, then I later moved to nuclear and particle physics. So I've had this fantastic privilege. I still believe in the unity of physics in spite of all the specialisation that exists today. I am glad to have seen all of the highlights. Witnessing the discovery of parity violation while I was working in nuclear physics was one.

How do you see the future of curiosity-driven research, and of CERN?
The future of high-energy physics is to combine with astrophysics, because the real big questions now are things like dark matter and dark energy. This has already been done in a sense. Originally the idea in particle physics was to investigate the micro-cosmos; now we find out that measuring the micro-cosmos means investigating matter under conditions that existed nanoseconds after the Big Bang. Of course, many questions remain in particle physics itself, like neutrinos, matter–antimatter inequality and the real unification of the forces.

With LEP and the LHC, the number of outside users who build and operate the experiments increased drastically, so the physics competence now rests to a large extent with them. CERN's competence is mainly new technology, both for experiments and accelerators. At LEP, cheap "concrete" instead of iron magnets were used to save on investment, and coupled RF cavities to use power more efficiently were invented, and later complemented by superconducting cavities. New detector technologies following the CERN tradition of Charpak turned the LEP experiments into precision ones. This line was followed by the LHC, with the first large-scale use of high-field superconducting magnets and superfluid-helium cooling technology. Whatever happens in elementary particle physics, technology will remain one of CERN's key competences. Above and beyond elementary particle physics, CERN has become such a symbol and big success for Europe, and a model for worldwide international cooperation, that it is worth a large political effort to guarantee its long-term future.

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

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OPINION LETTERS

Completing the proton picture

Your article "The proton laid bare" (*CERN Courier* May/June 2019 p38) covered beautifully and to a large extent the subject under the given heading. For completeness, we in the COMPASS collaboration at CERN wish to add the following additional information.

A state-of-the-art description of the field should address the structure of the proton also in terms of its transverse degrees of freedom. These enter with the same relevance as the described longitudinal structure, and complete the 3D picture of the nucleon.

COMPASS has a world-leading role in this field. During the past 20 years it contributed numerous results on the study of helicity distributions, the gluon contribution to the spin of the proton, and the 3D proton structure using polarised Drell–Yan and hard semi-inclusive or exclusive processes, as well as transversity and transverse-momentum-dependent PDFs.

Finally, in terms of addressing "The proton spin crisis" (May/June, p40), the currently operational COMPASS experiment is certainly to be mentioned alongside work at Jefferson Laboratory.

Oleg Denisov *INFN and* **Jan Friedrich** *TUM, COMPASS spokespersons.*

Proton radius still puzzles

Your article "Solving the proton-radius puzzle" (*CERN Courier* May/June 2019 p42) mentioned some recent extractions of the proton charge radius from electronic hydrogen spectroscopy. These are more consistent with the value extracted from muonic hydrogen, 0.8409(4) fm, than the most recent CODATA value of 0.8751(61) fm.

Unfortunately, another recent extraction from electronic hydrogen spectroscopy by Fleurbaey *et al.* (*Phys. Rev. Lett.* **120** 183001) was omitted in the article; the value they find is 0.877(13) fm, which is more consistent with CODATA than muonic hydrogen.

Even more exciting, we now have two different groups, one in Paris and one in Garching, that have measured the same 1S–3S transition but extract different values of the proton charge radius. Thus, the proton-radius puzzle still stands.

Gil Paz *Wayne State University, Michigan, US.*

Adjusting cosmic-ray origins

I recently read your very nice article on IceCube from last year (*CERN Courier* September 2018 p7), but found the title "IceCube neutrino points to origin of cosmic rays" to be very misleading. By far, the majority of cosmic rays that we detect on Earth are from our own galaxy, and are much lower energy than those that IceCube is sensitive to. There are many things that we don't understand about the origin of cosmic rays in our own galaxy, for example whether the heaviest r-process cosmic rays originate in supernovae or in binary neutron star mergers, and these results do not address those. This does not in any sense diminish the importance of the IceCube and gamma-ray results. But in the future it would be better to qualify it by saying "extra-galactic" cosmic rays.

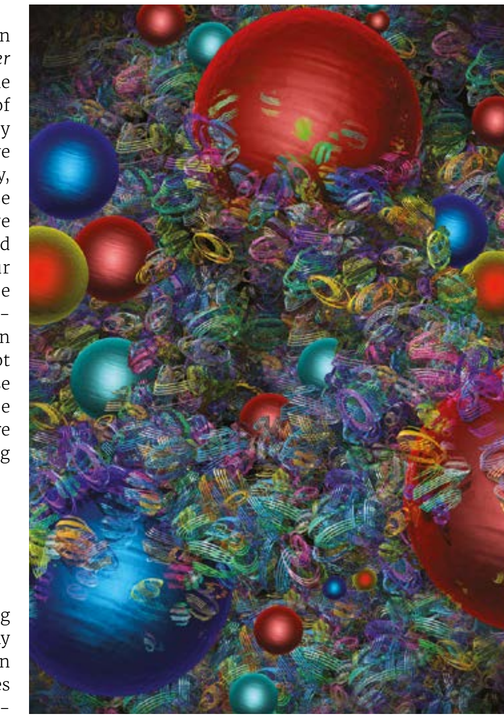
Robert Binns *Washington University in St. Louis, US.*

The music of physics

In an obituary of Nobel prize-winning chemist Manfred Eigen published recently in *Nature*, we learned that he remained an impressive amateur pianist, "sometimes playing Mozart's concertos after scientific meetings." It reminded me of Werner Heisenberg's piano proficiency described in this magazine (*CERN Courier* Jan/Feb 2005 p41). To celebrate Heisenberg's 60th birthday, a small orchestra was brought together to accompany him in performing Mozart's Piano Concerto, K488.

Former CERN Director-General Victor Weisskopf could even act as a conductor, as he did during his retirement celebration at MIT in 1974. For Weisskopf, music and physics served as sanctuary: "When life is hard, there are two things which make it worth living: Mozart and quantum mechanics". Reflecting on the phenomenon in an essay, Weisskopf wrote: True enough, music is "irrational" in the sense there is no "objective" way to prove what musical passage is right or wrong. But the structure of music is related to structure in science, especially in mathematics. I refer to symmetry, repetition of a passage in a different key, inversions of tunes and many other topological features. No wonder scientists are attracted by the fugues of Bach.

Min-Liang *National Chung Hsing University, Taiwan.*



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Colourful complexity *An artist's impression of the proton's innards.*

Too much particle physics?

I noticed that the Sciencewatch section has disappeared from the *CERN Courier*. I have read about all the changes that are being introduced in the magazine (*CERN Courier* December 2018 p56), but I am still left wondering about this decision. I think it was an interesting and enriching section. Without it, while still remaining very interesting, the magazine feels more "arid" to me. Does it all have to be particle physics 100%, even for the *Courier*?

Alexandre Sole *The Open University.*

Editor's reply

You are not alone in questioning Sciencewatch's retirement. As another reader put it: "There's something wonderful in reading about the subtleties of electroweak symmetry breaking one minute, then turning the page to find a story about the sex lives of lizards." What can we say? Only that all feedback is taken on board as we strive to keep *CERN Courier* relevant for a seventh decade and beyond.

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OPINION REVIEWS

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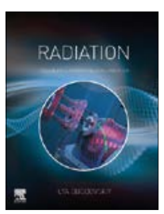
Handle with care *Radiation measurement tools and samples.*

Radio-euphoria rebooted?

Radiation: Fundamentals, Applications, Risks and Safety

By Ilya Obodovskiy

Elsevier



Ilya Obodovskiy's new book is the most detailed and fundamental survey of the subject of radiation safety that I have ever read.

The author assumes that while none of his readers will ever be exposed to large doses of radiation, all of them, irrespective of gender, age, financial situation, profession and habits, will be exposed to low doses throughout their lives. Therefore, he reasons, if it is not possible to get rid of radiation in small doses, it is necessary to study its effect on humans.

Obodovskiy adopts a broad approach. Addressing the problem of the narrowing of specialisations, which, he says, leads to poor mutual understanding between the different fields of science and industry, the author uses inclusive vocabulary, simultaneously quoting different units of measurement, and collecting information from atomic, molecular and nuclear physics, and biochemistry and biology. I would first, however, like to draw attention to the rather novel section 'Quantum laws and a living cell'.

Quite a long time after the discovery of X-rays and radioactivity, the public was overwhelmed by "X-ray-mania and radio-euphoria". But after World War II – and particularly after the Japanese vessel Fukuryū-Maru experienced the radioactive fallout from a thermonuclear explosion at Bikini Atoll – humanity got scared. The resulting radio-phobia determined today's commonly negative attitudes towards radiation, radiation technologies and nuclear energy. In this book Obodovskiy shows that radio-phobia causes far greater harm to public health and economic development than the radiation itself.

The risks of ionising radiation can only be clarified experimentally. The author is quite right when he declares that medical experiments on human beings are ethically evil. Nevertheless, a large group of people have received small doses. An analysis of the effect of radiation on these groups can offer basic information, and the author asserts that in most cases results show that low-dose irradiation does not affect human health.

It is understandable that the greater part of the book, as for any textbook, is a kind of compilation, however, it does discuss several quite original issues. Here I will point out just one. To my knowledge, Obodovskiy is the first to draw attention to the fact that deep in the seas, oceans and lakes, the radiation background is two to four orders of magnitude lower than elsewhere on Earth. The author posits that one of the reasons for the substantially higher complexity and diversity of living organisms on land could be the higher levels of ionising radiation.

In the last chapter the author gives a detailed comparison of the various sources of danger that threaten people, such as accidents on transport, smoking, alcohol, drugs, fires, chemicals, terror and medical errors. Obodovskiy shows that the direct danger to human health from all nuclear applications in industry, power production, medicine and research is significantly lower than health hazards from every non-nuclear source of danger.

Vladislav Grigoriev *Moscow Engineering Physics Institute.*

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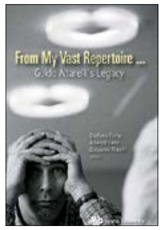
From My Vast Repertoire ... Guido Altarelli's Legacy

By Stefano Forte, Aharon Levy and Giovanni Ridolfi (editors)

World Scientific



"From my vast repertoire ..." is a rather peculiar opening to a seminar or a lecture. The late CERN theorist Guido Altarelli probably intended it ironically, but his repertoire was indeed vast, and it spanned the whole of the "famous triumph of quantum field theory," as Sidney Coleman puts it in his classic monograph *Aspects of Symmetry*. There can be little doubt that a conspicuous part of this triumph must be ascribed to the depth and breadth of Altarelli's contributions: the HERA programme at DESY, the LEP and LHC programmes at CERN, and indeed the current paradigms of the strong and electroweak interactions themselves, bear the unmistakable marks of Guido's criticism and inspiration.

From My Vast Repertoire ... is a memorial volume that encompasses the scientific and human legacies of Guido. The book consists of 18 well-assorted contributions that cover his entire scientific trajectory. His wide interests, and even his fear of an untimely death, are described with care and respect. For these reasons the efforts of the authors and editors will be appreciated not only by his friends, collaborators and fellow practitioners in the field, but also by younger scientists, who will find a timely introduction to the current trends in particle physics, from the high-energy scales of collider physics to the low-energy frontier of the neutrino masses. The various private pictures, which include a selection from his family and friends, make the presence of Guido ubiquitous even though his personality emerges more vividly in some contributions than others. Guido's readiness to debate the relevant physics issues of his time is one of the recurring themes of this volume; the interpretation of monojets at the SPS, precision tests of the Standard Model at LEP, the determination of the strong coupling constant, and even the notion of naturalness, are just a few examples.

While lecturing at CERN in 2005, Nobel prize-winning theorist David Gross outlined some future perspectives on physics, and warned about the risk of a progressive balkanisation. The legacy of Guido stands out among the powerful antidotes against a never-ending fission into smaller subfields. He understood which problems are ripe to study and which are not, and that is why he was able to contribute to so many conceptually different areas, as this monograph clearly shows. The lesson we must draw from Guido's achievements and his passion for science is that fundamental physics must be inclusive and diverse. Lasting progress does not come by looking along a single line of sight, but by looking all around where there are mature phenomena to be scrutinised at the appropriate moment.

Massimo Giovannini *CERN and INFN Milano-Bicocca, Italy.*

Signatures of the Artist

By Steven Vigdor

Oxford University Press

MC Escher's 1941 woodcut *Plane-Filling Motif with Reptiles* depicts two tessellating tetrapods, one black and one white, with intertwined legs and feet on the adjacent sides. Reflect the image horizontally and vertically, and the result is a photo negative: maximal parity violation. A black–white transformation – charge conjugation in the metaphor that inspired Steven Vigdor's book – and, as in nature, we return to the original. Well, almost. We can tell the difference from the position and colouration of Escher's stylised initials in the corner. The only imperfection is the signature of the artist.

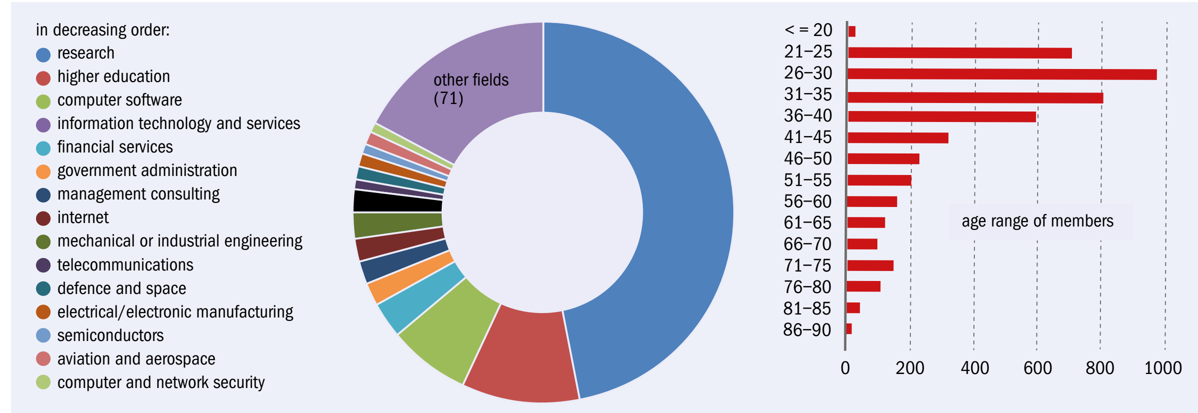
Vigdor's idea is that such deviations from perfect symmetry are not in fact "bugs", but are beautiful and essential. In the case of CP violation – an essential ingredient in Sakharov's baryogenesis recipe – the artist's signature is indispensable to our very existence, and the subject of a glut of searches for physics beyond the Standard Model.

Taking no position on the existence of a creator artist per se, Vigdor's aim is rather to complement books that speculate on new theories with an exposition of the "painstaking and innovative" efforts of generations of experimentalists to establish the weird and wonderful physics we know. His book is a romp from quantum mixing to the apparent metastability of the vacuum (given current measurements of the Higgs and top masses), with excursions into cosmology, biology and metaphysics. The intended audience is university students. As they cut their way through a jungle of mathematical drills in 19th-century physics, many lose sight of the destination. Cheerful and down to earth, this book offers an invigorating glimpse through the foliage.

Mark Rayner *CERN.*

High-energy networking

Two years since it was established, the CERN Alumni Network is proving a valuable careers resource, especially for young physicists who move out of academia, write Laure Esteveny and Rachel Bray.



Variety *CERN alumni by employment sector (left) and the age range of members (right).*

CERN has 65 years of history and more than 13,000 international users. The CERN Alumni Network, launched in June 2017 as a strategic objective of the CERN management, now has around 4600 members spanning all parts of the world. Alumni pursue careers across many fields, including industry, economics, information technology, medicine and finance. Several have gone on to launch successful start-ups, some of them directly applying CERN-inspired technologies.

So far, around 350 job opportunities, posted by alumni or companies aware of the skills and profiles developed at CERN, have been published on the alumni.cern platform. Approximately 25% of the jobs posted are for software developer/engineer positions, 16% for data science and 15% for IT engineering positions. Several members have already been successful in finding employment through the network.

Another objective of the alumni programme is to help early-career physicists make the transition from academia to industry if they choose to do so. Three highly successful "Moving out of academia" events have been held at CERN with the themes finance, big data and industrial engineering. Each involved inviting a panel of alumni working in a specific field to give candid and pragmatic advice, and was very well attended by soon-to-be CERN alumni, with more than 100 people at each event. In January the alumni network took part in an academia/industry event titled "Beyond the Lab – Astronomy and Particle Physics in Business" at the newly inaugurated Higgs Innovation Centre at the University of Edinburgh.

The data challenge

The network is still in its early days but has the potential to expand much further. Improving the number of alumni who have provided data (currently 37%) is an important aim for the coming years. Knowing where our alumni are located and their current professional activity allows us to reach out to them with relevant information, proposals or requests. Recently, to help demonstrate the impact of experience gained at CERN, we launched a campaign to invite those who have already signed up to update their profiles concerning their professional and educational experience. Increasing alumni interactions, engagement and empowerment is one of the most challenging objectives at this stage, as we are competing with many other communities and with mobile apps such as Facebook, WhatsApp and LinkedIn.

One very effective means for empowering local alumni communities are regional groups. At their own initiative, members have created seven of them (in Texas, New York, London, Eindhoven, Swiss Romandie, Boston and Athens) and two more are in the pipeline (Vienna and Zurich). Their main activities are to hold events ranging from a simple drink to getting to know each other at more formal events, for example as speakers in STEM-related fields.

One of the most rewarding aspects of running the network has been getting to know alumni and hearing their varied stories. "It's great that CERN values the network of physicists past and present who've passed through or been based at the lab. The network has already led to some very useful contacts for me," writes former summer student Matin Durrani, now editor of *Physics World* magazine. "Best wishes from Guyancourt (first office) as well as from Valenciennes (second office) and of course Stręgoborzyce (my family home). Let's grow and grow and show where we are after our experience with CERN," writes former technical student Wojciech Jasonek, now a mechanical engineering consultant.

After two years of existence we can say that the network is firmly taking root and that the CERN Office of Alumni Relations has seen engagement and interactions between alumni growing. Anyone who has been (or still is) a user, associate, fellow, staff or student at CERN, is eligible to join the network via alumni.cern.

Laure Esteveny *and* **Rachel Bray** *CERN Office of Alumni Relations.*

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Appointments and awards


ANL

New head for Oak Ridge physics
The Department of Energy's Oak Ridge National Laboratory has named Marcel Demarteau (above) as director of its physics division. Demarteau was previously at Argonne National Laboratory, where he directed the high-energy physics division with a programme ranging from studies at the LHC to investigations using the South Pole Telescope in Antarctica. He was previously at Fermilab for nearly 20 years, where he conducted detector R&D and served in leadership roles for the Dø experiment and worked on the CMS experiment at the LHC. Demarteau succeeds David Dean.

EPS prizes galore
The European Physical Society (EPS) has awarded the CDF and Dø collaborations at Fermilab with the 2019 High Energy and Particle Physics Prize for the discovery of the top quark and the detailed measurement of its properties. The EPS awards the prize every two years for an outstanding contribution in an experimental, theoretical or technological area.

The 2019 Giuseppe and Vanna Cocconi Prize for an outstanding contribution to particle astrophysics and cosmology went to the WMAP and Planck collaborations for their high-precision measurements of the cosmic microwave background temperature and polarisation anisotropies.

The Gribov Medal for outstanding work by a young researcher in theoretical particle physics was awarded to Douglas Stanford of the Institute for Advanced Study in Princeton (below) "for his pioneering


L A Cicero

work on quantum chaos and its relation to the near-horizon dynamics of black holes". The Young Experimental Physicist Prize for outstanding work of early-career researchers was awarded to Josh Bendavid of CERN "for outstanding and innovative contributions to detector operations, software development, data analysis and detector upgrades of the CMS experiment" and Lesya Shchutska of EPFL Lausanne


EPFL

(above) "for outstanding contributions to experimental activities in particle physics, from the design and simulation of novel experiments, test-beam operations and analyses, to data analyses and their final theoretical interpretations".

Finally, the 2019 EPS HEP Outreach Prize was awarded to


R Appleby

Rob Appleby of the University of Manchester (above), Chris Edmonds of the University of Liverpool (below) and Robyn Watson of Bolton Sensory Support Service for their project "Tactile


T Palin

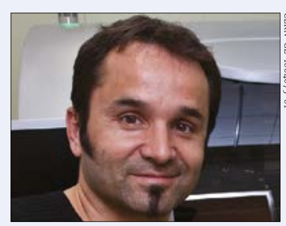
Collider", which brings particle physics to blind and visually impaired schoolchildren through touch and sound. The project has run at many sites across the UK and will be visiting CERN in the autumn of 2019.

Gomis wins Canadian award
Jaume Gomis of the Perimeter Institute in Canada (top right) has been awarded this year's Prize for Theoretical and Mathematical Physics by the Canadian Association of


PI

Physicists and the Centre de recherches mathématiques. The prize recognizes Gomis "for his broad range of important contributions to string theory and strongly coupled gauge theories, including the pioneering use of non-local observables, the exact computation of physical quantities in quantum field theory, and the unravelling of the non-perturbative dynamics of gauge theories."

Innovative spirit recognised
The inaugural Oed prize, established by the Institut Laue-Langevin in Grenoble, has been awarded to Rui de Oliveira of CERN (below) for his major contribution in the development of micro-pattern gas detectors. The prize aims to promote an innovative spirit and the ability to solve technical challenges, which were at the origin of the micro-strip gas chamber invented by Anton Oed in the late 1980s (see p57).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RECRUITMENT

Universidad de los Andes Colombia

UNIVERSIDAD DE LOS ANDES - BOGOTA, COLOMBIA
PHYSICS DEPARTMENT

ANNOUNCEMENT
FACULTY POSITION IN EXPERIMENTAL HIGH ENERGY PHYSICS

Deadline: August 30th, 2019

The Department of Physics at Universidad de los Andes (Uniandes), Bogotá, is seeking to fill a tenure-track faculty position in experimental High Energy Physics. Uniandes is a private university, which strives for excellence in both teaching and research. According with the QS academic ranking, Uniandes is positioned in the top ten universities in Latin America. Applicants should have a Ph.D. degree in this field of research with postdoctoral experience in hardware and software development and implementation.

All professors in our Department are required to participate in teaching a variety of undergraduate and graduate courses in physics, including physics major requirements, and elective courses related to the research activities of the professors. The new faculty member will be expected to participate in institutional development activities in our Department and at the University level, outreach and international collaborations.

The selected candidate is invited to join the High Energy Physics group at Universidad de los Andes. The group collaborates with the CMS experiment at the LHC, and has an intensive research program in particle physics phenomenology and interdisciplinary detector applications. It is preferable if the new faculty member can contribute in more than one of these areas. Also, the group is open to new research lines and projects in experimental high energy physics that the new faculty member may bring. Our institution is interested in highly motivated professors with an interdisciplinary research approach and commitment to teaching. More information about the department research lines and experimental and computing facilities can be found at: **http://fisica.uniandes.edu.co**

Interested applicants should fill out their personal information and submit the following documents:
a) curriculum vitae including a list of publications, b) an independent and viable research plan document, and a c) teaching plan document through the following link **http://fisicaconvocatoriasp.uniandes.edu.co**

Additionally, the applicant should provide the contact information of three references. Referees will be contacted by the Department of Physics to submit their reference letters through the online platform.

The selection process will begin August 30th, 2019, giving priority to applicants that apply by that date. However, applications will continue to be received beyond that date until the position is filled.

For further information, please contact:

Dr. Chad Leidy
e-mail: **director-fisica@uniandes.edu.co**
Head, Physics Department, Universidad de los Andes
A.A. 4976, Bogotá, Colombia, Phone (57-1)-339-4949 ext. 2730

CERNCOURIER.COM

ELI Beamlines research centre in Dolní Břežany is part of pan-European infrastructure ELI (Extreme Light Infrastructure) representing a unique tool of support of scientific excellence in Europe by making available its capacities to the best scientific teams across the world. The aim of ELI Beamlines is to establish the most intensive laser system in the world and to operate it on a long-term basis. Due to ultra-high performances of 10 PW (1 petawatt = 1,000,000,000,000,000 watts) and concentrated intensities of up to 1024 W/cm2, we can offer our users a unique source of radiation and beams of accelerated particles. The so called beamlines will enable groundbraking research in the area of physics and science dealing with materials, but also in biomedicine and laboratory astrophysics and many other fields. ELI Beamlines is part of the Institute of Physics of the Czech Academy of Sciences, and it was open in 2015.

The Institute of Physics of the Czech Academy of Sciences is a holder of the HR Excellence in Research Award. It is awarded by the European Commission to institutions which put significant effort into improving their HR strategy and ensuring professional and ethical working conditions.

Scientific Data Management Specialist (Software Engineer)

Job description: Your main mission will be to implement solutions for cataloging experimental data and metadata and integrating them into PaNOSC and EOSC. You will collaborate with multiple teams at ELI as well as within PaNOSC project to bring data from their acquisition to publicly accessible web services based on FAIR Data Principles (Findable, Accessible, Interoperable, Reusable).

Required skills: university degree in Computer Science, Engineering, Science, or related field • experience with working with scientific data and metadata • experience with setting up and managing databases • experience with development of APIs • experience with programming in Python • good knowledge of Linux/Unix programming environment • proficiency in English

Desired skills: experience with machine learning for big data processing • experience with control systems like TANGO • experience in European projects and international collaborations

We offer: the opportunity to participate in this unique scientific project • competitive and motivating salary • flexible working hours • nice working environment • career growth • lunch vouchers, pension contribution and 5 sick days • support of leisure time activities

Applications, containing CV, cover letter, contacts of references, and any other material the candidate considers relevant, should be sent to Mrs. Jana Ženíšková, HR specialist (jana.zeniskova@eli-beams.eu, +420 - 601560322).

Information regarding the personal data processing and access to the personal data at the Institute of Physics of the Czech Academy of Sciences can be found on: **https://www.fzu.cz/en/processing-of-personal-data**

eli beamlines — FZU — MŠMT Ministry of Education, Youth and Sports — European Union

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Accelerators | Photon Science | Particle Physics
Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

For our location in Hamburg we are seeking:

Scientist (f/m/diverse) CMS Experiment

DESY

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

The particle physics programme of DESY consists of strong contributions to the LHC experiments ATLAS and CMS, the Belle-II Experiment in Japan and to the preparation of future experiments. The experimental programme is enhanced by collaboration with a strong theory group. DESY is seeking an outstanding researcher to fill a scientist position working on the CMS experiment. The successful candidate is expected to take a leading role in the upgrade program of the CMS experiment for the high-luminosity LHC.

The position

- Active role in the CMS experiment
- Engagement in the upgrade of the CMS tracker for the HL-LHC
- Involvement in generic detector R&D activities
- Participation in the supervision of students and postdocs

Requirements

- Ph.D. in Experimental Particle Physics
- Extensive knowledge and experience with experiments in HEP
- Profound experience in detector development, in particular silicon tracking devices
- Outstanding teamwork abilities, good communication skills and knowledge of English

For further information please contact Dr. Guenter Eckerlin, +49 40 8998 2582 (guenter.eckerlin@desy.de) or Prof. Dr. Elisabetta Gallo, +49-40-8998-4849 (elisabetta.gallo@desy.de).

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

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

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

Deutsches Elektronen-Synchrotron DESY
Human Resources Department I Code: FHMA018/2019
Notkestraße 85 I 22607 Hamburg I 22607 Hamburg Germany
Phone: +49 40 8998-3392
http://www.desy.de/career

Deadline for applications: 2019/07/14

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

UNIVERSITÉ DE GENÈVE

The Faculty of Science of the University of Geneva invites applications for a position as

FULL PROFESSOR
in astroparticle physics

INSTITUTE: The Department of Nuclear and Particle Physics of the Science Faculty of the University of Geneva offers a dynamic scientific environment with world-renowned academics in the domain of particle, astroparticle and neutrino physics, as well as modern infrastructures. The Department is actively involved in several major international experiments and has a strong link with CERN since its foundation.

ASSIGNMENT: The Department opens a full-time position which includes teaching physics at bachelor, master and postgraduate level as well as supervising master and doctoral theses.

The candidate will develop original research at an international level in the field of space-borne experimental astroparticle physics and secure external funding. He/she will also take on organizational and administrative duties at department, section and faculty level.

We are seeking a candidate with a proven international scientific reputation, with a wide range of skills and knowledge, including an excellent understanding of astroparticle physics, a solid experience in data analysis and interpretation as well as a very good knowledge of complex satellite or space-station based detectors and their functioning, the ability to coordinate an important research group, the pedagogical aptitude, creativity and enthusiasm necessary for the management of students during their doctoral or master studies, and the ability to initiate communication and outreach programs for the University.

REQUIRED QUALIFICATIONS:

- PhD in physics or equivalent.
- Strong track record in research and experience in the management of research groups and in teaching.
- Publications in high-ranked international journals.

STARTING DATE: 01.08.2020 or upon mutual agreement

Applications including a cover letter, detailed CV and a list of publications, copy of the highest degree/diploma, research and teaching statement and a list of referees who can later be contacted directly by the search committee must be submitted before August 31st, 2019 (0:00, Geneva time) EXCLUSIVELY by clicking on the Postuler/Apply now button **https://jobs.unige.ch/www/wd_portal.show_job?p_web_site_id=1&p_web_page_id=41161**

APPLICATIONS SENT BY EMAIL SHALL NOT BE ACCEPTED.

In a perspective of parity, applications by women are particularly encouraged and welcome.

Complementary information may be obtained at the following e-mail address: **scienceopenings@unige.ch.**

JINR DUBNA

JINR Distinguished Postdoctoral Research Fellowship Programme

Call for applications

Missions

The Joint Institute for Nuclear Research is seeking for outstanding postdoctoral fellows and announces a call for applications for a number of vacant scientific research positions. The new positions are opened within a special Programme aimed at reinforcing the scientific personnel involved in realization of the JINR top-priority projects in the fields of theoretical and experimental physics of elementary particles, relativistic heavy-ion physics, nuclear physics, condensed matter physics, and radiobiology.

The Programme facilitates an opportunity for early-stage researchers pursuing science and engineering topics to be exposed and get involved in the forefront international projects in science and technical advancements at JINR Dubna. Detailed information about the Institute can be found at the JINR web site www.jinr.ru.

Skills

The successful applicant is expected to have experience and a solid background in nuclear or particle physics, or in a closely related field (including a recent PhD degree).

The successful applicant should be able to work well in an international environment, such as large multinational collaborations. The applicant will also be expected to take on responsibilities with the experiments and the analysis work and should be able to work, when needed, independently.

The original appointment will be for up to three years. The stipend will be commensurate with qualifications and experience.

Activities and Work Context

The Programme will allow maximizing the benefit by exploiting at best the research and training opportunities created by the JINR projects. This includes a broad range of topics such as neutrino and nuclear physics, biophysics, material research (including nano), high-performance computing, accelerator technology, superconducting magnets, theory.

Closing Date

The review of applications will begin on 01.09.2019 and will continue until the opportunities are filled.

Please circulate this information to any colleagues you may feel could be interested.

Further details for applications are made via the employment platforms of JINR Laboratories for respective vacancies:

Vacant positions within the Programme

NICA relativistic heavy-ion physics – 2 positions
http://lhe.jinr.ru

Accelerator physics and technologies – 3 positions
http://lhe.jinr.ru

Spin physics with polarized ion beams @ NICA – 1 position
http://lhe.jinr.ru

Radiobiology – 1 position
http://lrb.jinr.ru

Neutron physics – 3 positions
http://flnph.jinr.ru

Neutrino physics – 3 positions
http://dlnp.jinr.ru

FAIR GSI

GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt operates one of the leading particle accelerators for science. In the next few years, the new FAIR (**F**acility for **A**nti-proton and **I**on **R**esearch) one of the world's largest research projects, will be built in international cooperation. GSI and FAIR offer the opportunity to work together in this international environment with a team of employees committed to enabling world-class science.

The department **"System Design"** within the subproject "SIS100/SIS18" is responsible for design and development as well as control of the heavy ion synchrotrons in the GSI and FAIR facilities. For this department we are seeking as early as possible an

Accelerator Physicist with Experience at Circular Accelerators (m/f/d)

Posting ID: 6330-19.80

Responsibilities:

- Perform beam dynamics simulations aimed at design and development, optimization of operation, and the provision of data for the control of the synchrotrons.
- Plan, execute, and analyse machine experiments to optimize high intensity operation of the synchrotrons by improving the machine models used to control them.
- Develop and test algorithms for software-assisted measurement and feedback systems for beam-based monitoring, adjustment, and optimization of the synchrotrons.

Qualifications and Skills:

- PhD in physics or a related field, considerable knowledge in accelerator physics and years of demonstrated experience with simulation and operation of circular accelerators.
- Ideally, experience with ion optical simulation of non-linear effects, especially slow extraction, and practical experience with optimization of space charge dominated circular accelerators with respect to beam loss.
- Structured work habit, excellent team working, business fluent English and the willingness to learn German.

The position is initially limited to a duration of 5 years. GSI supports the vocational development of women. Therefore, women are especially encouraged to apply for the position. Handicapped persons will be preferentially considered when equally qualified.

Please send your application stating the **posting-ID** at the latest until **9 August 2019** to:

GSI Helmholtzzentrum für Schwerionenforschung GmbH
Abteilung Personal
Planckstraße 1
64291 Darmstadt
Germany
or by email to: **bewerbung@gsi.de**

PEOPLE OBITUARIES

Olga Borisovna Igonkina 1973–2019

A talent and a love for physics

Nikhef particle physicist and prominent member of the ATLAS experiment at CERN, Olga Igonkina, passed away on 19 May in Amsterdam at the age of 45.

Olya, as she was known to most of us, was born in 1973 in Moscow. Her father was an engineer, her mother a biological scientist. At age 14 she went to a special school for children talented in mathematics and in 1991 started her studies in physics at the Moscow Institute for Physics and Technology. Two years later Olya moved to the ITEP institute to specialise in particle physics, working at the ARGUS experiment and later the HERA-B experiment at DESY.

Olya wrote her dissertation about J/ψ production in HERA-B, with Mikhail Danilov as her supervisor. In 2002 she moved to BaBar at SLAC as a postdoc with the University of Oregon in the group of Jim Brau, where she worked on searches for lepton-flavour-violating tau decays and became convener of the BaBar tau working group. In 2006 she moved to CERN to spearhead Oregon's new ATLAS group. Her work in ATLAS concentrated on the trigger, where she contributed to many activities with great ideas and enthusiasm, in particular as the trigger-menu coordinator during the startup of the LHC, and later on physics with tau leptons. She began her appointment at Nikhef in 2008 and in 2015 became a professor at Radboud University in Nijmegen.

Olya was an expert in tau physics.

For her efforts on the ATLAS trigger, Olya was given an ATLAS outstanding achievement award in 2018. Physics-wise, her passion was lepton flavour violation, in particular in tau decays. Intrigued by the hints of lepton-flavour violation in B decays reported by the LHCb experiment and B factories, and always on the lookout for a niche in a large collaboration, in 2018 Olya moved some of her efforts from tau to B physics. She took responsibility for the B-hadron triggers with the aim of collecting an even larger sample of B decays in ATLAS for the final year of Run 2. She was working on preparations for an R_K measurement until her very last days.

Besides being a talented scientist, Olya was a dedicated teacher. She supervised an impressive number of PhD students and was very successful in obtaining research grants. She was also very active in outreach activities, with masterclasses and open days at Nikhef, and in community building at ATLAS. Recently she organised the 15th International Workshop on Tau Lepton Physics conference in Amsterdam.

Olya was a passionate physicist who was bursting with ideas. Among several tributes from her colleagues, Olya was described as a future experiment leader. She had a memorably strong work ethos, and until the very last moment refused to let her illness affect her work. She was always cheerful and always positive. Her attitude to work and life will remain a source of inspiration to many of us.

Olya leaves behind her husband, Wouter Hulsbergen of Nikhef, and two children.

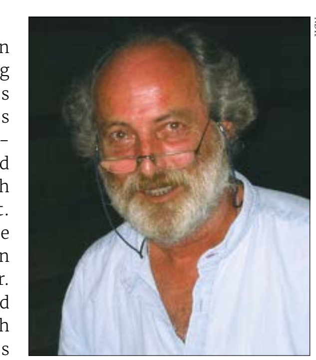
Her colleagues and friends.

Dieter Renker 1944–2019

A curious physicist with detector expertise

Dieter Renker, who made some key contributions to the design and construction of the CMS experiment at the LHC, passed away on 16 March after a short illness. Dieter was born in Bavaria and studied physics in Munich and Berlin. He obtained his PhD from the Ludwig Maximilian University in Munich, based on experiments performed at SIN, now the Paul Scherrer Institute (PSI), in Villigen, Switzerland. In 1982 he joined SIN as a staff physicist, where he remained until his retirement at the end of 2009.

At SIN/PSI he participated in many experiments, providing excellent technical support, as well as designing new beamlines at the accelerator there. His technical aptitude in due course turned to detector development, which led to his greatest achievement. In the early days of CMS there were various ideas for the design of the electromagnetic calorimeter. Among these was the use of lead tungstate crystals, which although having many suitable properties



Renker's pioneering measurements led to lead-tungstate crystals being adopted by the CMS calorimeter.

for operation at the LHC, have a relatively small scintillation-light yield. Dieter contributed the key measurements which showed that avalanche photodiodes (APDs), with their key properties of internal gain and insensitivity to shower leakage, could be used to read out the crystals. This led to lead-tungstate crystals being adopted by CMS for the design of ▷

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the calorimeter. Not only did they provide superb energy resolution for electrons and photons, enabling key discoveries such as the Higgs boson in 2012, but they also enabled a more compact detector with significantly reduced overall cost.

The development of the final APD was carried out over a period of many years by Hamamatsu Photonics (Japan), but under the close guidance of Dieter. Nearly 100 different APD prototypes were tested before the technology was deemed fit to be used in CMS. The size, capacitance, speed and, above all, radiation tolerance were the key parameters that needed to be improved, and the final choice was made very close to the deadline for commencing construction of the calorimeter. A complex multi-step screening process involving gamma irradiation and annealing also needed to be developed to ensure that the APDs installed met the demanding reliability requirements of CMS. Until now there has been no recorded failure of any of the 122,000 APDs installed in CMS.

Later, Dieter turned his attention to Geiger-mode APDs, which are now widely used in particle and astroparticle physics, as well as in PET scanners. Together with researchers at ETH Zurich, he started the development of the first camera based on these novel photo sensors for Cherenkov telescopes to measure very high-energy gamma rays from astrophysical sources. This camera was installed at the FACT telescope, located in La Palma, Spain, where the HEGRA experiment had also been operated with Dieter's active participation. The FACT telescope has now been operating successfully for more than seven years, without any sensor-related problems.

He had a very open mind, and was willing to advise and assist colleagues with great patience and good humour

After his retirement Dieter returned to his spiritual home, Munich, where he continued his work at the Technical University.

Dieter was a curious physicist with an exceptional talent for novel detector concepts. He pursued new ideas with a strong focus on achieving his goals. He had a very open mind, and was willing to advise and assist colleagues with great patience and good humour. In his free time his interests included classical music and cooking as well as searching the woods for unusual edible mushrooms. Many colleagues and visitors have fond memories of invitations to his home, embellished with fine cooking.

His sudden illness was a shock to many. Dieter leaves behind his partner, Ulrike.

Quentin Ingram *Paul Scherrer Institute and* **friends of Dieter**.

Anton Oed 1933–2018

An inspirational inventor

Anton Oed, a passionate inventor and a source of inspiration for many of us today, passed away on 30 September 2018. His introduction of micro-strip gas chambers (MSGCs) at the Institut Laue-Langevin (ILL) in 1988 was a decisive breakthrough in the field of radiation detectors. It demonstrated a significant gain in spatial resolution and counting rate, and the invention immediately stimulated the development of a new class of micro-pattern gas detectors (MPGDs).

Anton was born 1933 in Ulm, Germany, and studied physics at the University of Tübingen. For his diploma thesis on "The double resonance spectrum of ^{23}Na", he received the prize of the Faculty of Mathematics and Natural Sciences of the University of Tübingen. In his doctoral thesis, again in atomic physics, he studied the double-quanta decay of the hydrogen 2S level.

Anton arrived at the ILL in Grenoble in 1979, and set about developing the detector of the "Cosi Fan Tutte" spectrometer to measure the mass, charge and kinetic energy of fission fragments. The results obtained with this detector were so precise that it has been taken as a reference for several nuclear instruments in other institutes. Anton later started developing the MSGC technique to upgrade detectors of neutron diffractometers. Several ILL instruments are now equipped with MSGCs that have been in operation for more than 10 years.

The development of MSGCs for high-energy physics started at the beginning of the 1990s. Encouraging results were obtained by the RD28 collaboration at CERN but the relative fragility of MSGCs under harsh irradiation conditions motivated the development of new detectors with improved robustness. Among these, Micromegas and gas electron multipliers (GEMs) have become very successful and are currently being implemented in various upgrades to the LHC experiments. MSGC detectors are also used to detect X-rays on ESA's INTEGRAL telescope.


Artechnique/ILL

Anton Oed with a micro-strip plate.

In 1997 Anton received the R W Pohl medal from the Deutsche Physikalische Gesellschaft for the invention of the MSGC. To honour his memory, the ILL has established a prize promoting his innovative spirit and the ability to solve technical challenges in the field of micro-pattern gas detectors.

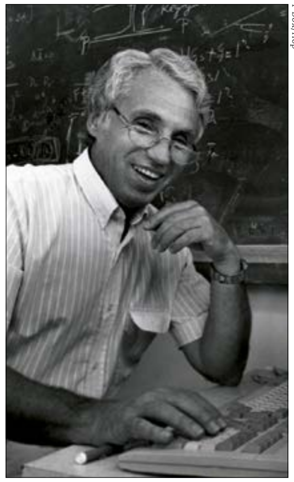
Memories of the technology's development and of Anton's personality were shared during a special session at the MPGD 2019 conference held in La Rochelle from 5–10 May. He has always been of great inspiration to many of the collaborators working with him. We will remember him as a very friendly and enthusiastic person, as well as for his kindness towards everybody.

Bruno Guérard *Institut Laue-Langevin.*

Jacques Soffer 1940–2019

Prolific theorist and polarisation pioneer

Jacques Soffer, a prolific theorist and phenomenologist with nearly 300 articles in journals or conference proceedings to his name, was born in 1940 in Marseille. During the war, he and his family were sheltered in a farm in the Alps. Afterwards, Jacques came back to Marseille, studied there, and obtained his doctoral degree under the supervision of A Visconti. He spent most of his career at the Centre de Physique Théorique in Marseille, serving as director from 1986 to 1993. He enjoyed sabbaticals at Maryland, Cambridge, CERN, the Weizmann Institute and Lausanne University, and after his retirement he became adjunct-professor at Temple University in the US.


P Box/Hop

Soffer showed how to extract physics from polarised proton beams.

Jacques played a big part in persuading the elementary particle community of the importance of polarisation-type measurements, which provide a probe of dynamical theories far sharper than tests involving just differential and total cross-sections. He is renowned in the community for predicting, together with Claude Bourrely and Tai Wu in 1984, the dramatic phenomenology of the growth with energy of the proton–proton cross-section. This prediction still holds when compared with experimental data after a 100-fold increase in collision energy – up to and including LHC energies. In 1999 Jacques contributed to a paper showing how to make an absolute measurement of the degree of polarisation of a proton beam – which was essential to the success of the Brookhaven spin programme.

In recent years, Jacques showed how positivity sets bounds on spin observables, with important applications to the extraction and determination of the polarised parton structure functions and to low-energy hadron–hadron scattering. His various achievements culminated in three major reviews in *Physics Reports*.

Jacques always cooperated closely and fruitfully with experimentalists. Entire programmes, such as the polarised proton–proton collisions at Brookhaven's Relativistic Heavy-Ion Collider, were inspired by his work and carried out with his guidance. Along his career, Jacques organised or co-organised several workshops and conferences on spin physics, and in more recent years was often giving the summary talk.

Throughout his pioneering work in particle physics, Jacques always got to the central issues very quickly, guided by an uncanny feeling for the new physics that roused the amazement and admiration of his collaborators. His colleagues and collaborators, and especially his thesis students, benefited from his advice and his broad knowledge of theory tools and experimental facts. They unanimously praised his warm friendship and hospitality, his sense of humour and his widespread interests in the arts, literature and technology.

Jacques is survived by his wife, Danielle, their three children and nine grandchildren.

His friends and colleagues.

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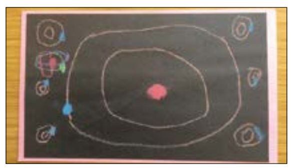
BACKGROUND

Notes and observations from the high-energy physics community

Designs on Higgs at 90

As part of a series of celebrations to mark Peter Higgs' 90th birthday, the University of Edinburgh launched a competition for primary-school children in Scotland to design a birthday card. Hundreds of entries were received, and the winning cards in each age group (ranging from age 4–12) were presented to Higgs at an official birthday dinner on 29 May. While these and the runners-up designs are indeed inspired (see below), we can't help but feel that the students missed a trick by not riffing on the famous pre-Higgs discovery "blue-band" plot, in which a global χ^2 fit of electroweak parameters had a minimum at a Higgs mass of around 90 GeV/c^2.



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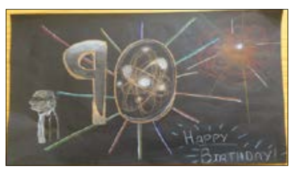


Media corner

"We will look at this possibility and will continue to maintain contacts with you on that matter."

Russian prime minister **Dmitry Medvedev**, who visited CERN on 10 June, quoted by Russian news agency TASS on the topic of Russia becoming a CERN Member State.

"The discovery doesn't radically change our perspective on physics yet because it matches theoretical predictions – and it certainly isn't a warp engine."

Theorist **Chanda Prescod-Weinstein** on the discovery of CP violation in charm mesons and its connection to *Star Trek* propulsion systems (*New Scientist* 15 June).

"It is not intended to be used as a verification tool for a specific theory but as a means of paving multiple experimental paths for the future."

Grigoris Panoutsopoulos and **Frank Zimmermann** writing in *Scientific American* (17 June) about the Future Circular Collider and whether theory or experiment should come first.

"Our new buildings do have photovoltaics on the roofs and a lot of insulation, but if I have one or two million Euros to spend, obviously it is better to inject it into the 90% of energy consumption [used by the machines, detectors and computing] rather than the 10% [the buildings use]."

Frédérick Bordry, CERN director of accelerators and technology, discussing the environmental credentials of large laboratories in the June issue of *Physics World*.

"Particle accelerators can be seen as analogues to Anton Chekhov's gun: if there's one shown in the first act, it must be fired in the third."

From a review of *Particle Panic! How Popular Media and Popularized Science Feed Public Fears of Particle Accelerator Experiments* (Springer 2019) in *Cosmos* magazine, 15 June.

From the archive: July/August 1976

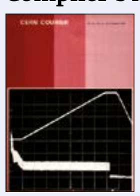
Tbilisi under the spell of Charm

The four quarks — Up, Down, Strange, Charm — sketched by rapporteur A de Rujula.

About 800 physicists from many parts of the world attended the 18th International Conference on High Energy Physics, one of the biennial Rochester Conferences, in July 1976 in Tbilisi, the capital of the Georgian Soviet Socialist Republic. With events found at CERN, Fermilab, DESY and SPEAR, the consensus clearly was that particles bearing the new quantum number, charm, have been found. And the charm was not 'hidden', as in the J/ψ and ψ', but unashamedly 'naked', with characteristic decays involving leptons and strange particles and 'exotic' relationships between electric charge and strangeness. The discovery of charm confirms one of the more striking aspects of a theory developed over several years by many authors. One version, sometimes called the 'standard model', is based on the work of Weinberg and Salam and of Glashow, Iliopoulos and Maiani. The theory is proving powerful in predicting phenomena such as neutral currents, and the understanding brought about by its unification of electric and weak forces has been compared to that achieved by Maxwell in unifying electricity and magnetism.

● Compiled from text on p252 of *CERN Courier* July/August 1976.

Compiler's note



With the second generation of quarks complete, the search was on for a third pair, predicted by Kobayashi and Maskawa in 1973 and named "top" and "bottom" by Haim Hartari. Lederman's team at Fermilab found the bottom in 1977, but it took another 18 years before the 173 GeV/c^2 top was finally discovered in 1995, also at Fermilab, 86,500 times heavier than the lightest up quark.

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Cabling in the SPS tunnel.

1996 km

Total length of optical fibres and copper cables that will be installed or removed during the current two-year shutdown of CERN's accelerator complex

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