WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the November/December 2019 issue of *CERN Courier*.

The Extremely Large Telescope, adorning the cover of this issue, is due to record first light in 2025 and will outperform existing telescopes by orders of magnitude. It is one of several large instruments to look forward to in the decade ahead, which will also see the start of high-luminosity LHC operations. As the 2020s gets under way, the *Courier* will be reviewing the LHC's 10-year physics programme so far, as well as charting progress in other domains. In the meantime, enjoy news of KATRIN's first limit on the neutrino mass (p7), a summary of the recently published European strategy briefing book (p8), the genesis of a hadron-therapy centre in Southeast Europe (p9), and dispatches from the most interesting recent conferences (pp19—23). CLIC's status and future (p41), the abstract world of gauge–gravity duality (p44), France's particle-physics origins (p37) and CERN's open days (p32) are other highlights from this last issue of the decade. Enjoy!

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EDITOR: MATTHEW CHALMERS, CERN
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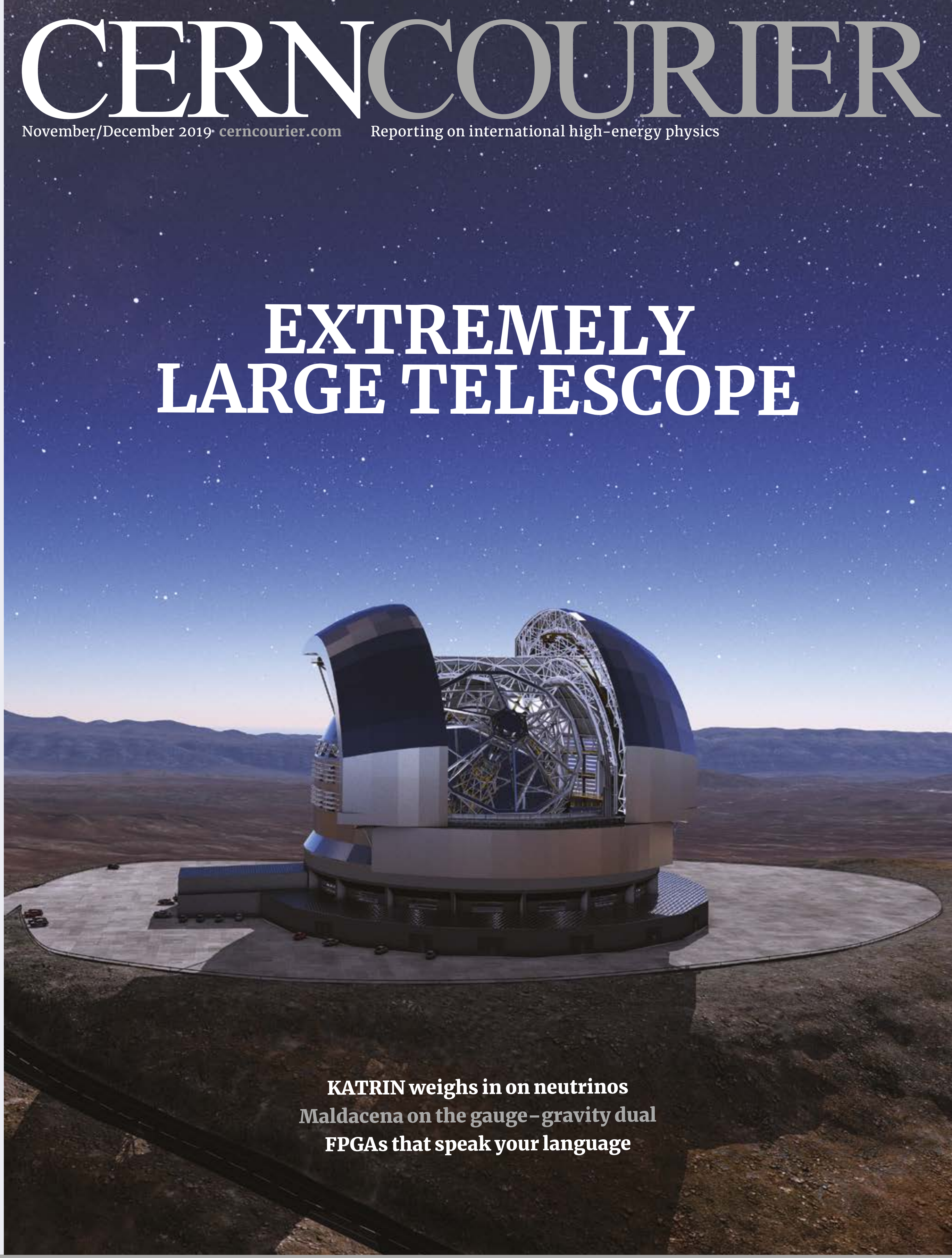

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November/December 2019 cerncourier.com Reporting on international high-energy physics

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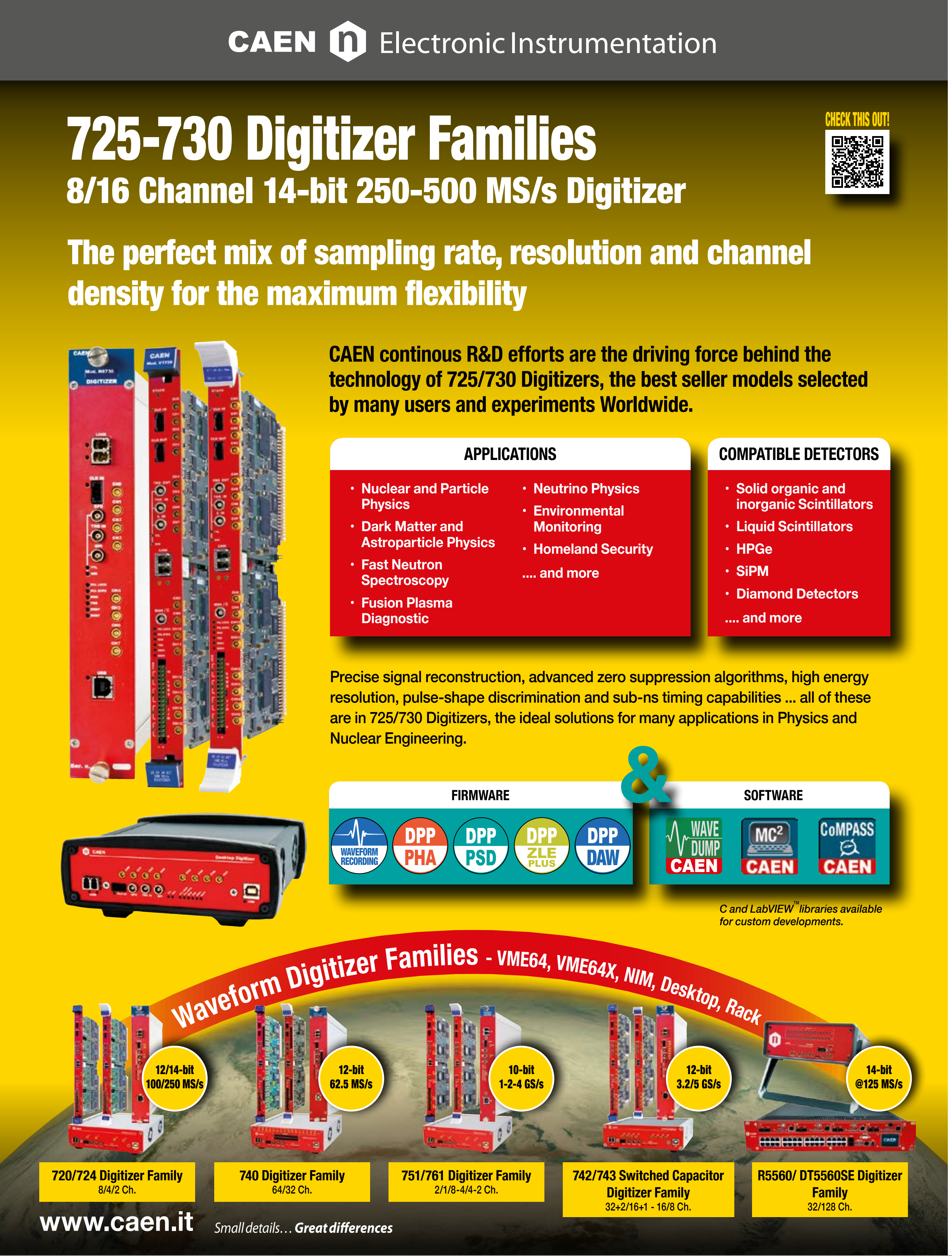
Maldacena on the gauge–gravity dual
FPGAs that speak your language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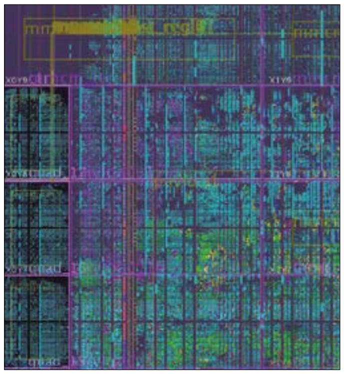
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FROM THE EDITOR

Tooling up for the next decade

Matthew Chalmers
Editor

The 2010s saw two great discoveries in fundamental physics: the Higgs boson in 2012 and gravitational waves in 2016. Both were the product of unique instruments at the limits of technology, built and operated by thousands of people from numerous countries over many years, and both provide rich physics programmes throughout the 2020s. What else lies in store for the decade ahead?

The Extremely Large Telescope, adorning the cover of this issue, is one of several large instruments to look forward to. The product of the 16 member-state European Southern Observatory, it is due to record first light in 2025 and will outperform existing telescopes by orders of magnitude (p25). Other facilities to come online in the 2020s include the Deep Underground Neutrino Experiment (DUNE), the European Spallation Source in Sweden, the Facility for Antiproton and Ion Research, the Square Kilometre Array, Cherenkov Telescope Array and ITER. The fate of an Electron-Ion Collider in the US, Hyper-Kamiokande in Japan and new third-generation gravitational-wave detectors will be sealed, while other projects, such as a post-Planck cosmic-microwave-background detector, gain momentum.

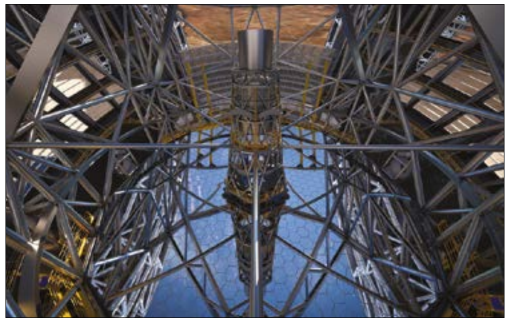
Dramatic landscape

Ten years ago, on 30 November 2009, having recovered from a major repair, the LHC accelerated its twin beams of protons to an energy of 1.18 TeV and became the world's highest energy accelerator. Its results dominated particle physics in the 2010s based on only a fraction of its expected total dataset and, from 2026, its high-luminosity upgrade is due to bring an avalanche of new data. One of the biggest decisions ahead is which collider should follow the LHC, for which the outcomes of the European strategy for particle physics, due in May, are eagerly awaited in Europe and beyond (p8).

The 2020s will also be make-or-break time for a clutch of anomalies

The landscape of possible physics beyond the Standard Model has changed dramatically during the past decade, and it is clear that new experimental strategies and theoretical insights are needed. The 2020s will see WIMP dark matter meet its ultimate test in upgraded and next-generation detectors, including XENONnT, LZ, DarkSide-20k, SuperCDMS and DARWIN, while a variety of novel experiments to search for axion-like and feebly-interacting particles will come online. In addition to DUNE and Hyper-K, neutrino physicists have KM3NeT and JUNO to look forward to, along with upgrades of the IceCube observatory and deeper searches for neutrinoless double-beta decay, while SuperKEKB's flavour-physics programme will get into full stride. These are just a taste of the numerous experiments, large and small, on the horizon. The 2020s will also be make-or-break time for a clutch of anomalies – including those in the flavour sector, cosmic rays and precision measurements of the muon's magnetic moment – along with developments in theory.

This year, the *Courier* has celebrated its 60th anniversary with a new design and website, and with a series of retrospective articles that are available online under the section "In focus". Next year, as the new decade gets under way, we will be reviewing the LHC's physics programme in full, as well as charting progress in other domains. In the meantime, enjoy news of KATRIN's first limit on the neutrino mass (p7), a hadron-therapy centre in Southeast Europe (p9), CLIC's status and future (p41), the abstract world of gauge-gravity duality (p44), France's particle-physics origins (p37), CERN's open days (p32), and much more.



ESO/L Calçada/ACe Consortium

Top of its class *Artist's rendering of the main mirror of the ELT, one of several major facilities to come online during the 2020s.*

Reporting on international high-energy physics

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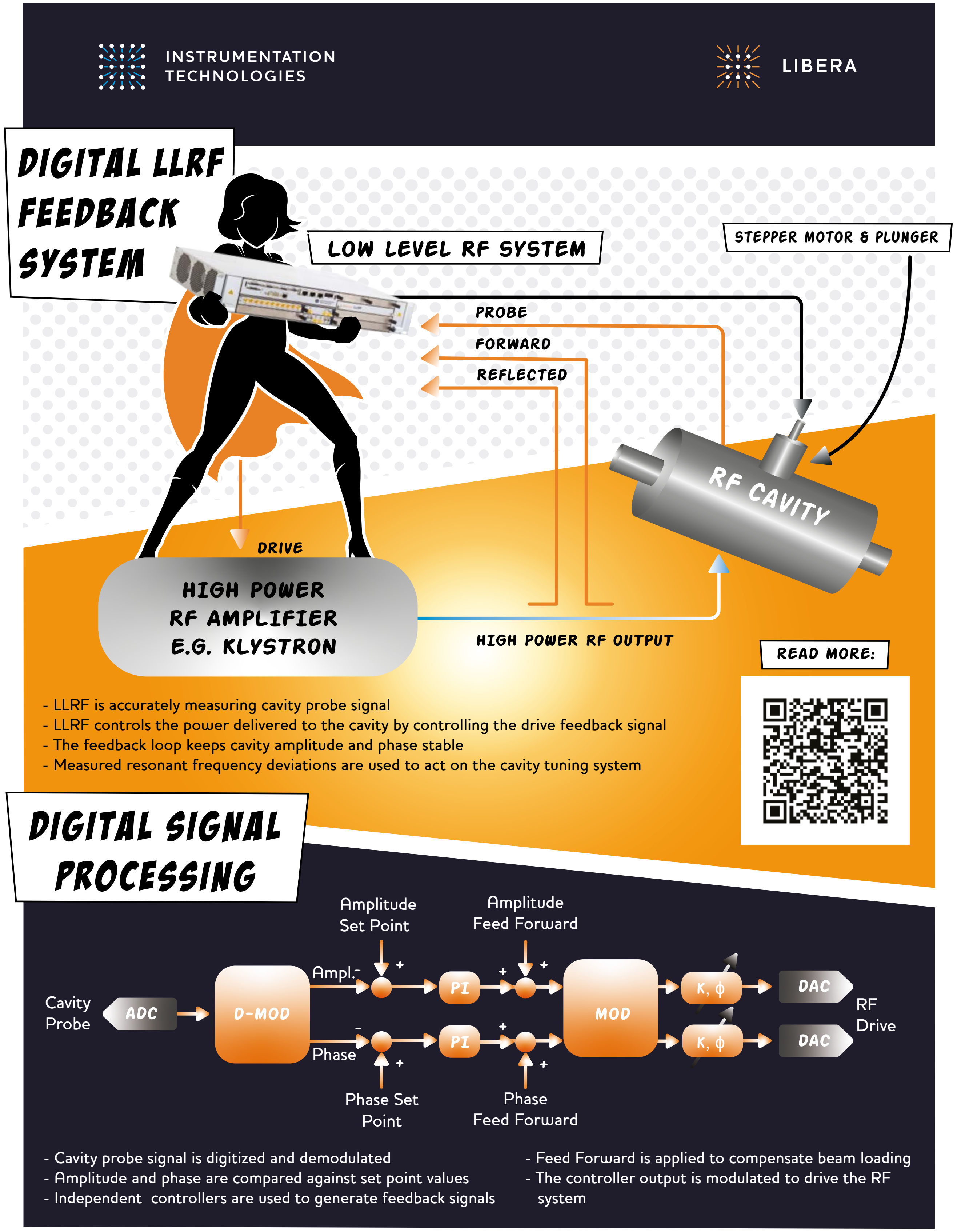


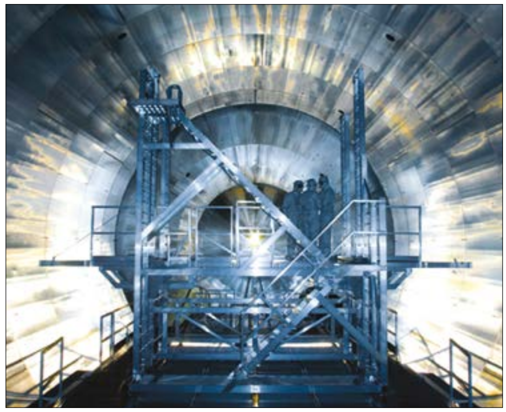
NEWS ANALYSIS

NEUTRINOS

KATRIN sets new limit on neutrino mass

Based on its first four weeks of running, researchers at the Karlsruhe Tritium Neutrino (KATRIN) experiment in Germany have set a new model-independent bound on the mass of the neutrino. First presented at the international TAUP conference in Toyama, Japan on 13 September (see p21), the collaboration reported an upper limit on the electron-antineutrino mass of 1.1 eV at 90% confidence, almost halving the previous bound.

Neutrinos are among the least well understood particles in the Standard Model. Their three known mass eigenstates do not match up with the better-known flavour eigenstates, electron, muon and tau, but mix according to the Pontecorvo–Maki–Nakagawa–Sakata matrix, resulting in the flavour transmutations seen by neutrino-oscillation experiments. Despite their success in constraining neutrino mixing, such experiments are sensitive only to squared mass differences between the eigenstates, and not to the neutrino masses themselves.


KATRIN

Weight watchers *Inside the KATRIN spectrometer at the Karlsruhe Institute of Technology.*

Direct approach

Physicists have pursued direct mass measurements since Reines and Cowan observed electron antineutrinos in inverse beta decays in 1956. The direct mass-measurement method hinges on precisely measuring the energy spectrum of beta-decay electrons, and is considered model independent as the extracted neutrino mass depends only on the kinematics of the decay. KATRIN is now the most precise experiment of this kind. It builds on the invention of gaseous molecular tritium sources and spectrometers based on the principle of magnetic adiabatic collimation with electrostatic filtering. The combination of these methods culminated in the previous best limits of 2.3 eV at 95% confidence in 2005, and 2.05 eV at 95% confidence in 2011, by physicists working in Mainz, Germany and Troitsk, Russia, respectively. The KATRIN analysis improves on these experimental results with systematic uncertainties reduced by a factor of six and statistical uncertainties reduced by a factor of two.

"These are exciting times for the collaboration," says KATRIN co-spokesperson Guido Drexlin of Karlsruhe Institute for Technology. "The great science potential of KATRIN in the future is highlighted by the fact that the result of the first measurement campaign is based on four weeks of data taking at reduced source activity, equivalent to five days at nominal activity." To reach its final sensitivity, KATRIN will collect data for 1000 days and systematic errors will be reduced. "This will allow us to probe neutrino masses down to 0.2 eV," continued Drexlin, "as well as many other interesting searches for beyond-the-Standard-Model physics, such as for admixtures of sterile neutrinos from the eV up to the keV scale."

The tightest limit on neutrino masses currently comes from cosmology

Conceived almost two decades ago, KATRIN operates using a high-resolution, large-acceptance and low-background measurement of the decay spectrum of tritium $^3\mathrm{H} \rightarrow {}^3\mathrm{He}\, e^- \bar{\nu}_e$. Electrons are transported to the spectrometer via a beamline that was completed in autumn 2016, allowing experimenters to search for distortions in the tail of the electron energy distribution that depend on the absolute mass of the neutrino. The KATRIN collaboration has more than 150 members in addition to collaborations with national and international institutes, including CERN.

"The CERN vacuum group helped us in designing the vacuum system of the KATRIN main spectrometer, which is the largest ultra-high-vacuum vessel in the world – seven times larger than the LHC beam-tube system," explains KATRIN co-spokesperson Christian Weinheimer of the University of Münster. "In the area of superconducting magnet expertise, we profited a lot from the know-how of retired CERN experts acting as consultants, while CERN's ISOLDE facility also assisted with the production of radioactive isotopes."

KATRIN collaborators are now in the midst of a two-month measurement campaign to increase the size of their sample. It will feature a signal-to-background ratio that is expected to be about one order of magnitude better than the initial measurement, due to an increase in source activity and a decrease in background due to hardware upgrades. The goal is to achieve an activity of 10^{11} beta-decay electrons per second, while reducing the current background level by about a factor of two.

Complementary limits

Direct measurements are not the only handle on neutrino masses available to physicists, though they are certainly the most model-independent. Experiments searching for neutrinoless double-beta decay offer a complementary limit, but must assume that the neutrino is a Majorana fermion.

The tightest limit on neutrino masses currently comes from cosmology. Comparing data from the Planck satellite with simulations of the development of structure in the early universe yields an upper limit on the sum of all three neutrino masses of 0.17 eV at 95% confidence.

"The Planck limit is fairly robust, and one would have to go to great lengths to avoid it – but it's not impossible to do so," says CERN theorist Joachim Kopp. For example, it would be invalidated by a scenario where as-yet-undiscovered right-handed neutrinos couple to a new scalar field with a vacuum expectation value that evolves over cosmological timescales. "Planck data tell us what neutrinos were like in the early universe," says Kopp. "The value of KATRIN lies in testing neutrinos now."

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POLICY

Briefing book sets stage for strategy update


CERN

Future focus *The European Strategy Group is due to submit its recommendations in May 2020.*

Physicists in Europe have published a 250-page "briefing book" to help map out the next major paths in fundamental exploration. Compiled by an expert physics-preparatory group set up by the CERN Council as part of the 2020 update of the European strategy for particle physics, the document captures the status and prospects for experiment, theory, accelerators, computing and other vital high-energy physics machinery.

Last year, the European Strategy Group (ESG) – which includes scientific delegates from CERN's member and associate-member states, directors and representatives of major European laboratories and organisations, and invitees from outside Europe – was tasked with formulating the latest European strategy for particle physics (*CERN Courier* April 2018 p7). Following a call for input in September 2018, which attracted 160 submissions, an open symposium was held in Granada, Spain, on 13–16 May, at which more than 600 delegates discussed the potential merits and challenges of the proposed research programmes (*CERN Courier* July/August 2019 p7). The ESG briefing book distills input from the working groups, the Granada symposium and subsequent inputs to provide a scientific summary.

"This document is the result of months of work by hundreds of people, and every effort has been made to objectively analyse the submitted inputs," says ESG chair Halina Abramowicz of Tel Aviv University. "It does not take a position on the strategy process itself, or on individual projects, but rather is intended to represent the forward thinking of the community and be the main input to the drafting session in Germany in January."

Next collider

A key element of the strategy update is to consider which major collider should follow the LHC. The Granada symposium revealed that there is clear support for an electron–positron collider to study the Higgs boson in greater detail, but four possible options exist: an International Linear Collider (ILC) in Japan, a Compact Linear Collider (CLIC) or Future Circular Collider (FCC-ee) at CERN, and a Circular Electron Positron Collider (CEPC) in China. As Higgs factories, the report finds all four to have similar reach, albeit with different time schedules and with differing potentials for the study of physics topics at other energies. Also considered in depth are design studies in Europe for high-energy colliders, including a 3 TeV CLIC (see p41) and a 100 TeV circular hadron collider (FCC-hh). The briefing book details the estimated timescales to develop some of these technologies, observing that the development of 16 T dipole magnets for FCC-hh will take a comparable time (about 20 years) to that projected for novel acceleration technologies such as plasma-wakefield techniques to reach conceptual designs.

"The Granada symposium and the briefing book mention the urgent need for intensifying accelerator R&D, including that for muon colliders," says Lenny Rivkin of the Paul Scherrer Institute, who shared responsibility for the chapter on accelerator science and technology. "Another important aspect of the strategy update is to recognise the potential impact of the development of accelerator and associated technology on the progress in other branches of science, such as astroparticle physics, cosmology and nuclear physics."

The bulk of the briefing book details the current physics landscape and prospects for progress, with chapters devoted to electroweak physics, strong interactions, flavour physics, neutrinos, cosmic messengers, physics beyond the Standard Model, and dark-sector exploration. A preceding theory chapter argues that theoretical research in fundamental physics should be kept "free and diverse" and not only limited to the goals of ongoing experimental projects. It points to historical success stories such as Peter Higgs' celebrated 1964 paper, which had the purely theoretical aim of showing that Gilbert's theorem is invalid for gauge theories at a time when applications to electroweak interactions were well beyond the horizon.

"While an amazing amount of progress has been made in the past seven years since the Higgs-boson discovery, our knowledge of the couplings of the Higgs to the W and Z and to third-generation charged fermions is quite imprecise, and the couplings of the Higgs boson to the other charged fermions and to itself are unmeasured," says Beate Heinemann of DESY, who co-convened the report's electroweak chapter. "The imperative to study this unique particle further derives from its special properties and the special role it might play in resolving some of the current puzzles of the universe, for example dark matter, the matter–antimatter asymmetry or the hierarchy problem."

The briefing book lists outstanding puzzles that can also be investigated by smaller scale experiments at lower energies

One vision

The briefing book lists outstanding puzzles – including the reason for the pattern of quark and lepton masses and the neutrinos' nature – that can also be investigated by smaller scale experiments at lower energies, for example by CERN's dedicated Physics Beyond Colliders initiative. Finally, in addressing the vital roles of detector and accelerator development, computing and instrumentation, the report acknowledges both the growing importance of energy efficiency and the risks posed by "the limited amount of success in attracting, developing and retaining instrumentation and computing experts", urging that such activities be better recognised. Strong support in computing and infrastructure is also key to the success of the high-luminosity LHC, which the report states will see a dynamic programme occupying a large fraction of the community during the next two decades – including a determination of the couplings between the Higgs boson and Standard Model particles at the percent level.

Following a drafting session in Bad Honnef, Germany, on 20–24 January, the ESG is due to submit its recommendations for the approval of the CERN Council in May 2020 in Budapest, Hungary.

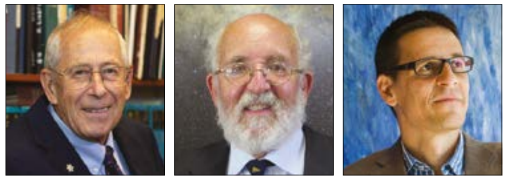
"Now comes the most challenging part: how to turn the exciting and well-motivated scientific proposals of the community into a viable and coherent strategy that will ensure progress and a bright future for particle physics in Europe," says Abramowicz. "Its importance cannot be overestimated, coming at a time when the field faces several crossroads and decisions about how best to maintain progress in fundamental exploration, potentially for generations to come."

Further reading

R K Ellis *et al.* 2019 CERN-ESU-004.

AWARD

2019 Nobel Prize in Physics for cosmic perspectives


Profound view *Left to right: Laureates James Peebles, Michel Mayor and Didier Queloz. (Credits: D Applewhite/Princeton; Inamori Foundation/ESO; BBVA Foundation.)*

The Nobel Prize in Physics for 2019 has recognised two independent bodies of work that have transformed our view of the universe and humanity's place in it. One half of the SEK 9 million prize, announced on 8 October in Stockholm, was granted to James Peebles of Princeton University for theoretical discoveries in physical cosmology, while the other was shared between Michel Mayor of the University of Geneva and Didier Queloz of the universities of Geneva and Cambridge for the discovery of an exoplanet orbiting a Sun-like star.

Peebles was instrumental in turning cosmology into the precision science it is today, with its ever closer links to collider and particle physics in general. Following the unexpected discovery of the cosmic microwave background (CMB) in 1965, he and others at Princeton used it to support the idea that the universe began in a hot, dense state. While the idea of a "big bang" was already many years old, Peebles paired it with concrete physics processes such as nucleosynthesis and described the role of temperature and density in the formation of structure. With others, he arrived at a model accounting for the density fluctuations in the CMB showing a series of acoustic peaks, which would demonstrate that the universe is geometrically flat and that ordinary matter constitutes just 5% of its total matter and energy content. In the early 1980s, Peebles was the first to consider non-relativistic "cold" dark matter and its effect on structure formation, and he went on to reintroduce Einstein's forsaken cosmological constant – work that underpins today's Lambda Cold Dark Matter model of cosmology.

Mayor and Queloz's discovery of an exoplanet orbiting a solar-type star in the Milky Way opened a new field of study. 51 Pegasi b lies 50 light years from Earth and takes just four days to complete its orbit. It was spotted by tracking how it and its star orbit around their common centre of gravity: a subtle wobbling seen from Earth whose speed can be measured from the starlight via the Doppler effect. The problem is that the radial velocities are extremely low. Mayor mounted his first spectrograph on a telescope at the Haute-Provence Observatory near Marseille in 1977, but it was only sensitive to velocities above 300 ms^{-1} – too high to see a planet pulling on its star. It took almost two decades of work by him and his group to strike success, with doctoral student Queloz tasked with developing new methods to increase the machine's light sensitivity. Today, more than 4000 exoplanets with a vast variety of forms, sizes and orbits have been discovered in our galaxy using the radial-velocity method and the newer technique of transit photometry, challenging ideas about planetary formation.

FACILITIES

Hadron therapy makes headway in Southeast Europe

gov.me/B Ćupić

Political support *Montenegro prime minister Duško Marković marks the start of the SEEIIST design phase on 18 September.*

A state-of-the-art facility for hadron therapy in Southeast Europe has moved from its conceptual to design phase, following financial support from the European Commission. At a kick-off meeting held on 18 September in Budva, Montenegro, more than 120 people met to discuss the future South East European International Institute for Sustainable Technologies (SEEIIST) – a facility for tumour therapy and biomedical research that follows the founding principles of CERN (*CERN Courier* March 2018 p5).

"The International Institute for Sustainable Technologies is an urgent need of our region," said Montenegro prime minister Duško Marković during the opening address. "I am confident that the political support for this project is obvious and indisputable. The memorandum of understanding was signed by six prime ministers in July this year in Poznan. I believe that other countries in the region will formally join the initiative."

The idea for SEEIIST germinated three years ago at a meeting of trustees of the World Academy of Art and Science in Dubrovnik, Croatia, promoted by former CERN Director-General Herwig Schopper and benefitting from a political push from Montenegro minister of science Sanja Damjanović, who is also a physicist who works at CERN and GSI-FAIR in Darmstadt, Germany. SEEIIST aims to create a platform for internationally competitive research in the spirit of the CERN model "science for peace", stimulating the education of young scientists, building scientific capacity and fostering greater cooperation and mobility in the region.

In January 2018, at a forum at the International Centre for Theoretical Physics in Italy held under the auspices of UNESCO, the International Atomic Energy Agency and the European Physical Society, two possibilities for a large international institute were presented: a synchrotron X-ray facility and a hadron-therapy centre. The 10 participating parties of SEEIIST's newly formed intergovernmental steering committee chose the latter.

SEEIIST aims to create a platform for internationally competitive research in the spirit of the CERN model "science for peace"

Europe has played a major role in the development of hadron therapy, with numerous centres offering proton therapy and four facilities offering proton and more advanced carbon-ion treatments. But no such facility yet exists in Southeast Europe.

SEEIIST will conceptually follow the "PIMMS" accelerator design started at CERN two decades ago (*CERN Courier* January/February 2018 p25), profiting from the experience at the dual proton–ion centres CNAO in Italy and MedAustron in Austria, and also centres at GSI and in Heidelberg. It will be a unique facility that splits its beam time 50:50 between treating patients and performing research with a wide range of different ions for radiobiology, imaging and treatment planning. The latter will include studies into the feasibility of heavier ions such as oxygen, making SEEIIST distinct in this rapidly growing field.

The next steps are to prepare a definite technical design for the facility and to define the conditions for the site selection. Says Damjanović: "If all goes well, construction is expected to start in 2023, with first patient treatment in 2028."

Policy

Particle physicists challenge EC rebranding

Change afoot *More than 13,000 scientists have objected to changes in the representation of education and research in the European Commission.*

An open letter addressed to the presidents of the European Parliament and the European Commission (EC) demanding better recognition for education and research has attracted more than 13,000 signatures. Prepared by a group of eight prominent particle physicists in Europe – Siegfried Bethke (MPI for Physics), Nora Brambilla (TU-München), Aldo Deandrea (U-Lyon 1), Carlo Guaraldo (INFN Frascati), Luciano Maiani (U-Roma La Sapienza), Antonio Pich (U-València), Alexander Rothkopf (U-Stavanger) and Johanna Stachel (U-Heidelberg) – the letter follows the announcement of a new EC organisational structure on 10 September in which former EC directorates for education, culture, sports and youth, as well as that for research, science and innovation, have been subsumed under a single commissioner with the titular brief "innovation and youth".

"Words are important," says Maiani, who was CERN Director-General from 1999–2003. "Omitting 'research' from the logo of the EC is reason for concern. The response we received, including from prestigious personalities, reassured us that this concern is widely shared."

The letter, which closes on 22 November and has also been signed by European, French and German physical societies, demands that the EC revises the title to "Education, Research, Innovation and Youth". It states: "We, as members of the scientific community of Europe, wish to address this situation early on and emphasise both to the general public, as well as to relevant politicians on the national and European Union level, that without dedication to education and research there will neither exist a sound basis for innovation in Europe, nor can we fulfill the promise of a high standard of living for the citizens of Europe in a fierce global competition." (www.futureofresearch.eu).

Acknowledging receipt of the letter on 8 October, former president of the European Parliament, Antonio Tajani, stressed that the parliament is seeking a 50% increase in budget dedicated to Horizon Europe compared to the €80 billion allocated for the Horizon 2020 programme.

"The fact that our open letter attracted such wide and prominent response so quickly shows how deeply the scientific community cares about the standing of research and education within Europe," says Rothkopf.

CERN

Croatia becomes an associate member of CERN

J Ordan/CERN

Strong partners *Vesna Batistic Kos, ambassador of Croatia to the United Nations in Geneva (left), and CERN Director-General Fabiola Gianotti exchanged signed agreements on 10 October.*

On 10 October CERN welcomed the Republic of Croatia as an Associate Member State, following receipt of official notification that Croatia has completed its internal approval procedures in respect of an agreement signed on 28 February.

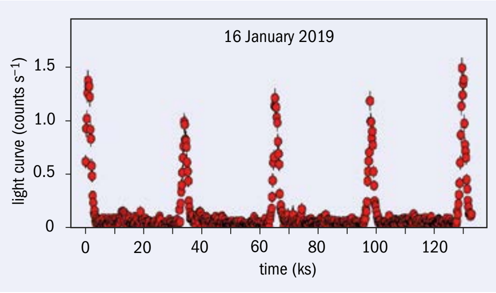
"It is a great pleasure to welcome Croatia into the CERN family as an associate member. Croatian scientists have made important contributions to a large variety of experiments at CERN for almost four decades, and as an associate member, new opportunities open up for Croatia in scientific collaboration, technological development, education and training," said CERN Director-General Fabiola Gianotti.

Researchers from Croatia have contributed to many experiments at CERN, and a cooperation agreement concluded in 2001 increased the country's participation in CERN's research and educational programmes. As an Associate Member State, Croatia will be represented at the CERN Council and be entitled to attend meetings of the finance committee and the scientific policy committee. Nationals of Croatia will be eligible to apply for limited-duration positions as staff members and fellows, while firms offering goods and services originating from Croatia will be entitled to bid for CERN contracts, creating opportunities for industrial collaboration in advanced technologies.

Croatia joins India, Lithuania, Pakistan, Turkey and Ukraine as Associate Member States, while Cyprus and Slovenia are Associate Member States in the pre-stage to membership.

Astrowatch

The galaxy that feeds three times per day



Nature **573** 381

Cyclic emission *The XMM-Newton satellite data showing a burst every nine hours.*

All galaxies are thought to contain a super-massive black hole (SMBH) at their centre, one of which was famously pictured for the first time by the Event Horizon Telescope only a few months ago (*CERN Courier* May/June 2019 p10). Both the sizes and activities of such SMBHs differ significantly from galaxy to galaxy: some galaxies contain an almost dormant black hole at their centre, while in others the SMBH accumulates surrounding matter at a vast rate, resulting in bright emissions with energies ranging from the radio to the X-ray regime.

While solar-mass black holes can show dramatic variations in their emission on the time scale of days or even hours, such time scales increase with size, meaning that for an SMBH one would not expect much change during years or even centuries. However, observations during the past decade have revealed sudden increases. In 2010 the X-ray emission from a galaxy called GSN 069, which has a relatively small SMBH (400,000 solar masses), became 240 times brighter compared to observations in 1989 – turning it into an active galaxy. In such objects the matter falling into the central SMBH releases radiation when it approaches the event horizon (the boundary beyond which nothing can escape the black hole's gravitational field).

The brightness of emissions typically varies randomly on short time scales as the SMBH feeds on the surrounding disk of matter, a result of changes in the accretion rate and turbulence in the disk. But subsequent observations with the European Space Agency's X-ray satellite XMM-Newton in 2018 revealed never-before-seen behaviour. The object emitted strong bursts of X-rays lasting about one hour. Even more surprising was that the bursts occurred at very consistent intervals of nine hours. Follow-up observations in 2019 with both XMM-Newton and NASA's Chandra X-ray telescope have now confirmed this picture. While simultaneous observations at radio wavelengths showed no variability, the intensity of the bursts at X-ray wavelengths decreased. An extrapolation of this decrease indicates that, by now, the bursts should have fully disappeared, although further observations are needed to confirm this.

The team behind the latest observations, published in *Nature*, has no clear explanation of what causes such extreme periodic behaviour in such a massive object. One possibility, the paper claims, is that it is the result of a second SMBH orbiting the main one: each time it crosses the disk of matter a burst would be expected. However, the associated variation would be expected to be smoother than is observed. Furthermore, no such bursts were seen in the 2010 observations, making this theory implausible. Another explanation is that a semi-destroyed star is currently orbiting the SMBH, disturbing the accretion rate. The last and most probable hypothesis is that the quasi-periodic explosions are a result of complex oscillations in the disk of hot matter surrounding the SMBH, which are induced by instabilities. The authors make it clear, however, that deeper studies are required to fully explain this new phenomenon.

The team has no clear explanation of what causes such extreme periodic behaviour

Although only observed in GSN 069, it could very well be that other galaxies exhibit a similar behaviour. In particular, SMBHs with masses many orders of magnitude larger could exhibit the same periodic burst but on time scales of months or years, explaining why no one has ever noticed them. So while it could be that GSN 069 is simply a strange galaxy, these findings could have large implications for galaxies in general.

Further reading

G Miniutti *et al.* 2019 *Nature* **573** 381.

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NEWS DIGEST

KAGRA

One of four mirrors for the KAGRA gravitational-wave observatory.

KAGRA complete

The construction of Japan's first gravitational-wave (GW) detector, KAGRA, was finished on 4 October. Following agreement with the LIGO and Virgo collaborations, KAGRA will now participate in their third joint observation run, which began in April. The detector, which was built by the University of Tokyo, the National Astronomical Observatory of Japan and KEK, is the world's fourth major GW detector, alongside LIGO in Washington state and Louisiana and Virgo in Italy. One of a suite of detectors in the Kamioka Observatory in northern Japan, KAGRA is also the first GW detector to operate at cryogenic temperatures, improving sensitivity at frequencies around 100 Hz – an important feature for proposed third-generation detectors such as the Einstein Telescope in Europe and the Cosmic Explorer in the US.

NA62 doubles down

The NA62 experiment at CERN has reported a new measurement of the extremely rare decay $K^+ \to \pi^+\nu\bar{\nu}$. Announcing the results at KAON2019 in Perugia, the collaboration found a branching fraction of $4.7^{+7.2}_{-4.7} \times 10^{-11}$, in agreement with the Standard Model prediction of $8.4 \pm 1.0 \times 10^{-11}$. The NA62 result, derived from data taken in 2017 using a secondary K^+ beam at CERN's Super Proton Synchrotron, adds two signal events to the single candidate found in their 10-times smaller 2016 data set. The previous best measurement of $17.3^{+11.5}_{-10.5} \times 10^{-11}$, based on all seven events observed prior to NA62, was made by the E787 and E949 collaborations at Brookhaven. If the SM prediction is correct, NA62 will collect ~50 events by Long Shutdown 3, yielding a 20% measurement of the branching ratio and constraining a range of new-physics models.

CERN-PHOTO-201509-239

A panorama of NA62's 120 m-long vacuum tank.

BESIII α_- anomaly confirmed

David Ireland of the University of Glasgow and colleagues at George Washington University, the University of Bonn and Forschungszentrum Jülich have used kaon-photoproduction data from the CLAS collaboration at Jefferson Laboratory to measure α_- – a parameter that describes the interference between parity-conserving and parity-violating amplitudes in the decay $\Lambda \to p\pi^-$ (*PRL* **123** 182301). Their new value, 0.721 ± 0.006 (stat) ± 0.005 (syst), confirms the recent value from the BESIII collaboration of 0.750 ± 0.009 (stat) ± 0.004 (syst) (*Nat. Phys.* **15** 631), which is significantly above the current PDG value of 0.642 ± 0.013 – a listing that has remained unchanged since 1978.

Energy recovery achieved

Accelerator physicists at Cornell and Brookhaven have announced that their prototype energy-recovery linac (ERL) has achieved full energy recovery for the first time. The Cornell–Brookhaven ERL Test Accelerator (CBETA) is a prototype technology that could be used in the proposed Electron-Ion Collider in the US (*CERN Courier* March 2018 p19). ERLs allow the energy of particle bunches to be recouped when they are decelerated, and then redeployed to accelerate subsequent bunches, greatly reducing power expenditure. When completed, CBETA will accelerate particles through four turns of the ring, before recovering this energy as the beams are decelerated, making it the world's first multi-turn superconducting radio-frequency ERL.

Greener FCC-ee

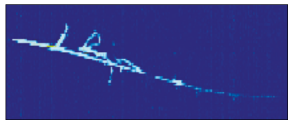
The synchrotron-radiation energy losses of the electron and positron beams of CERN's proposed Future Circular Collider (FCC-ee) could be reduced from 100 to 10 MW, according to accelerator physicists in the US (arXiv:1909.04437). After high-energy collisions have been accomplished, the novel scheme would employ energy-recovery linacs to decelerate the beams down to 2 GeV, at which point they would be cooled, before reacceleration to operational energies. The frequent cooling of the beams achieves a high luminosity with relatively low beam currents, and therefore low synchrotron-radiation losses. The design would also extend FCC-ee's energy reach from the top-antitop threshold to double-Higgs production at 500 GeV, says the team.

Non-Abelian Aharonov–Bohm

Physicists in the US have demonstrated the non-Abelian Aharonov–Bohm effect, proposed by Tai-Tsun Wu and Chen-Ning Yang in 1975, wherein time-reversal symmetry is broken (*Science* **365** 1021). Yi Yang (MIT), and colleagues, created synthetic non-Abelian gauge fields in fibre-optic systems using several non-reciprocal optical elements– in one case by passing light through a terbium-gallium garnet crystal in an external magnetic field. They found that the gauge fields produced different interference patterns depending on the direction of travel of the light. Such systems may prove useful for studying complex photonic topologies as they can be tuned to be either Abelian (commutative) or increasingly non-Abelian in nature. The Abelian Aharonov–Bohm effect was proposed in 1959 and confirmed experimentally by Robert Chambers in 1960 by observing a phase difference between electrons passing either side of a long solenoid.

First tracks for dual-phase DUNE

Researchers at CERN have recorded the first tracks in a novel prototype detector for the international Deep Underground Neutrino Experiment (DUNE) in the US. If successful, the "dual-phase" technology will be used alongside more traditional single-phase detectors to significantly amplify the faint signals created by neutrinos interacting in large volumes of liquid argon (LAr). Unlike the single-phase DUNE scheme demonstrated on a large scale at CERN in September 2018, in which wire planes and photosensors submerged in LAr detect ionisation signals caused by charged particles from neutrino interactions, dual-phase technology uses an additional layer of gaseous argon above the LAr target. This amplifies the signals before they arrive at the sensors, lowering the energy threshold of the detector. Another advantage is easier access to the cryogenic front-end electronics. The eventual single- and dual-phase DUNE detector modules will have an active volume approximately 20 times greater than the CERN prototypes.



ProtoDUNE

A cosmic-ray muon encroaches from the left, near the anode, in this 90°-rotated event display.

Dark matter down under

The Australian government has announced A$35 million of funding to investigate dark matter. The newly formed Australian Research Council (ARC) Centre of Excellence for Dark Matter Particle Physics will be led by Elisabetta Barberio and based at the University of Melbourne. An underground laboratory will also be built at the Stawell Gold Mine in western Victoria – the only one of its kind in the southern hemisphere. The centre will construct direct-detection dark-matter experiments and contribute to collider-based searches at the LHC.

ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

ATLAS

Zooming in on top quarks

As the heaviest known particle, the top quark plays a unique role in the Standard Model (SM), making its presence felt in corrections to the masses of the W and Higgs bosons, and also, perhaps, in as-yet unseen physics beyond the SM. During Run 2 of the Large Hadron Collider (LHC), high-luminosity proton beams were collided at a centre-of-mass energy of 13 TeV. This allowed ATLAS to record and study an unprecedented number of collisions producing top–antitop pairs, providing ATLAS physicists with a unique opportunity to gain insights into the top quark's properties.

ATLAS has measured the top–antitop production cross-section using events where one top quark decays to an electron, a neutrino and a bottom quark, and the other to a muon, a neutrino and a bottom quark. The striking eμ signature gives a clean and almost background-free sample, leading to a result with an uncertainty of only 2.4%, which is the most precise top-quark pair-production measurement to date. The measurement provides information on the top quark's mass, and can be used to improve our knowledge of the parton distribution functions describing the internal structure of the proton. The kinematic distributions of the leptons produced in top-quark decays have also been precisely measured, providing a benchmark to test programs that model top-quark production and decay at the LHC (figure 1).

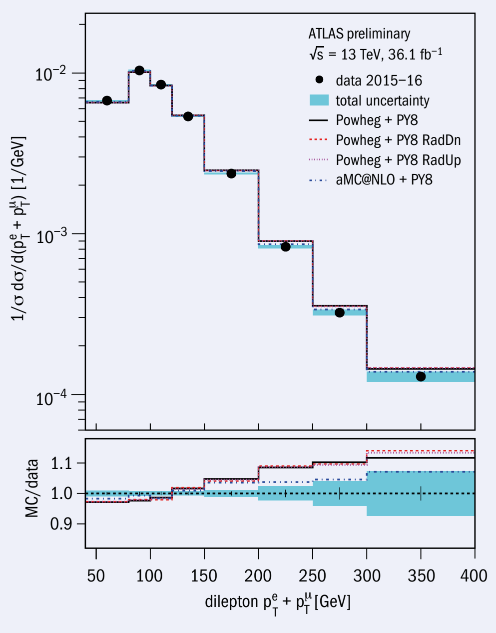


Fig. 1. *Measured $t\bar{t}$-production cross section versus the sum of the transverse momenta of the final-state leptons.*

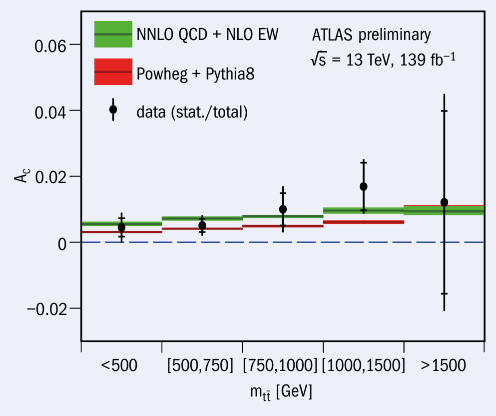


Fig. 2. *Measured value of the top-quark pair charge asymmetry (A_C) versus the reconstructed top–antitop mass, compared to a Monte Carlo prediction (red) and the latest SM calculation, which also includes NNLO QCD and NLO electroweak contributions (green).*

The striking eμ signature gives a clean and almost background-free sample

The mass of the top quark is a fundamental parameter of the SM, which impacts precision calculations of certain quantum corrections. It can be measured kinematically through the reconstruction of the top quark's decay products. The top quark decays via the weak interaction as a free particle, but the resulting bottom quark interacts with other particles produced in the collision and eventually emerges as a collimated "b-jet" of hadrons. Modelling this process and calibrating the jet measurement in the detector limits the precision in many top-quark mass measurements, however, 20% of the b-jets contain a muon that carries information relating to the parent bottom quark. By combining this muon with an isolated lepton from a W-boson originating from the same top-quark decay, ATLAS has made a new measurement of the top quark mass with a much-reduced dependence on jet modelling and calibration. The result is ATLAS's most precise individual top-quark mass measurement to date: 174.48 ± 0.78 GeV.

At the LHC, top and antitop quarks are not produced fully symmetrically with respect to the proton-beam direction, with top antiquarks produced slightly more often at large angles to the beam, and top quarks, which receive more momentum from the colliding proton, emerging closer to the axis. Higher order QCD diagrams translate this imbalance into the so-called charge asymmetry, which the SM predicts to be small (~0.6%), but which could be enhanced, or even suppressed, by new physics processes interfering with the known production modes. Using its full Run-2 data sample, ATLAS finds evidence of charge asymmetry in top-quark pair events with a significance of four standard deviations, confidently showing that the asymmetry is indeed non-zero. The measured charge asymmetry of 0.0060 ± 0.0015 is compatible with the latest SM predictions. ATLAS also measured the charge asymmetry versus the mass of the top–antitop system, further probing the SM (figure 2).

Further reading

ATLAS Collab. 2019 ATLAS-CONF-2019-026.
ATLAS Collab. 2019 ATLAS-CONF-2019-041.
ATLAS Collab. 2019 ATLAS-CONF-2019-046.

ALICE

Hypertriton lifetime puzzle nears resolution

Hypernuclei are bound states of nucleons and hyperons. Studying their properties is one of the best ways to investigate hyperon–nucleon interactions and offers insights into the high-density inner cores of neutron stars, which favour the creation of the exotic nuclear states. Constraining such astrophysical models requires detailed knowledge of hyperon–nucleon and three-body hyperon–nucleon–nucleon interactions. The strengths of these interactions can be determined in collider experiments by precisely measuring the lifetimes of hypernuclei.

Studying the properties of hypernuclei offers insights into the high-density inner cores of neutron stars

Hypernuclei are produced in significant quantities in heavy-ion collisions at LHC energies. The lightest, the hypertriton, is a bound state of a proton, a neutron and a Λ. With a Λ-separation energy of only ~130 keV, the average distance between the Λ and the deuteron core is 10.6 fm. This relatively large separation implies only a small perturbation to the Λ wavefunction inside the hypernucleus, and therefore a hypertriton lifetime close to that of a free Λ, 263.2 ± 2.0 ps. Most calculations predict the hypertriton lifetime to be in the range 213 to 256 ps.

The first measurements of the hypertriton lifetime were performed in the 1960s and 1970s with imaging techniques such as photographic emulsions and bubble chambers, and were based on very small event samples, leading to large statistical uncertainties. In the last decade, however, measurements have been performed using the larger data samples of heavy-ion collisions. Though compatible with theory, the measured lifetimes were systematically below theoretical predictions: thus the so-called "lifetime puzzle".

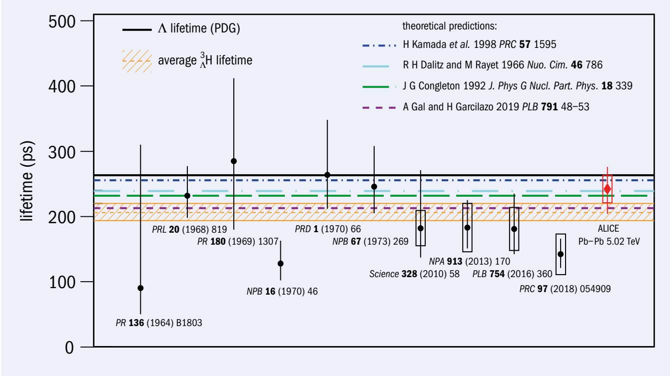


Fig. 1. *(Anti-)hypertriton lifetime measurements, including the latest from ALICE, using Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (red). The first six measurements were made using photographic emulsions and bubble chambers in the 1960s and 1970s. The remaining four are heavy-ion-collider measurements in the last decade. The orange band is the average of the lifetime values and the dashed lines represent theoretical predictions.*

The ALICE collaboration has recently reported a new measurement of the hypertriton lifetime using Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, which were collected in 2015. The lifetime of the (anti-)hypertriton is determined by reconstructing the two-body decay channel with a charged pion, namely ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^-$ (${}^{3}_{\bar{\Lambda}}\bar{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^+$). The branching ratio of this decay channel, taken from the theoretical calculations, is 25%. The measured lifetime is 242^{+34}_{-38} (stat) ± 17 (syst) ps. This result shows an improved statistical resolution and reduced systematic uncertainty compared to previous measurements and is currently the most precise measurement. It is also in agreement with both theoretical predictions and the free-Λ lifetime, even within the statistical uncertainty. Combining this ALICE result with previous measurements gives a weighted average of 206^{+15}_{-13} ps (figure 1).

This result represents an important step forward in solving the longstanding hypertriton lifetime puzzle, since it is the first measurement with a large data sample that is close to theoretical expectations. Larger and more precise data sets are expected to be collected during LHC Runs 3 and 4, following the ongoing major upgrade of ALICE. This will allow a significant improvement in the quality of the present lifetime measurement, and the determination of the Λ binding energy with high precision. The combination of these two measurements has the potential to constrain the branching ratio for this decay, which cannot be determined directly without access to the neutral and non-mesonic decay channels. This will be a crucial step towards understanding if the now partially confirmed theoretical description of the hypertriton is finally resolved.

Further reading

ALICE Collab. 2019 arXiv:1907.06906 (*Phys. Lett. B* **797** 134905).

LHCb

Rarest strange decay shrinks from sight

For every trillion K^0_S, only five are expected to decay to two muons. Like the better known $B_s \rightarrow \mu^+ \mu^-$ decay, which was first observed jointly by LHCb and CMS in 2013, the decay rate is very sensitive to possible contributions from yet-to-be discovered particles that are too heavy to be observed directly at the LHC, such as leptoquarks or supersymmetric partners. These particles could significantly enhance the decay rate, up to existing experimental limits, but could also suppress it via quantum interference with the Standard Model (SM) amplitude.

Despite the unprecedented K^0_S production rate at the LHC, searching for $K^0_S \rightarrow \mu^+\mu^-$ is challenging due to the low transverse momentum of the two muons, typically of a few hundred MeV/c. Though primarily designed for the study of heavy-flavour particles, LHCb's unique ability to select low transverse-momentum muons in real time makes the search feasible. According to SM predictions, just two signal events are expected in the Run-2 data, potentially making this the rarest decay ever recorded.

▷

The analysis uses two machine-learning tools: one to discriminate muons from pions, and another to discriminate signal candidates from the so-called combinatorial background that arises from coincidental decays. Additionally, a detailed and data-driven map of the detector material around the interaction point helps to reduce the "fixed-target" background caused by particles interacting with the detector material. A background of $K^0_S \rightarrow \pi^+\pi^-$ decays dominates the selection, and in the absence of a compelling signal, an upper limit to the branching fraction of 2.1×10^{-10} has been set at 90% confidence. This is approximately four times more stringent than the previous world-best limit, set by LHCb with Run-1 data. This result has implications for physics models with leptoquarks and some fine-tuned regions of the Minimal Supersymmetric SM.

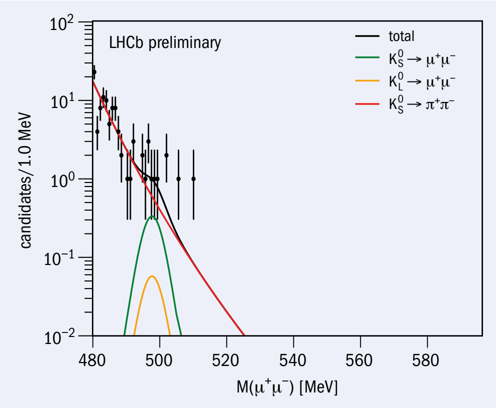


Fig. 1. *The invariant mass of $K^0_S \rightarrow \mu^+\mu^-$ candidates, and the fit to one of the most sensitive search regions. The $K^0_L \rightarrow \mu^+\mu^-$ background (orange) is suppressed with respect to K^0_S due to the longer distance of flight. The observed number of signal decays is consistent with zero.*

The upgraded LHCb detector, scheduled to begin operating in 2021 after the present long shutdown of the LHC, will offer excellent opportunities to improve the precision of this search and eventually find a signal. In addition to the increased luminosity, the LHCb upgrade will have a full software trigger, which is expected to significantly improve the signal efficiency for $K^0_S \rightarrow \mu^+\mu^-$ and other decays with very soft final-state particles.

Further reading

LHCb Collab. 2019 LHCb-CONF-2019-002.

CMS

CMS goes scouting for dark photons

One of the best strategies for searching for new physics in the TeV regime is to look for the decays of new particles. The CMS collaboration has searched in the dilepton channel for particles with masses above a few hundred GeV since the start of LHC data taking. Thanks to newly developed triggers, the searches are now being extended to the more difficult lower range of masses. A promising possible addition to the Standard Model (SM) that could exist in this mass range is the dark photon (Z_D). Its coupling with SM particles and production rate depend on the value of a kinetic mixing coefficient ε, and the resulting strength of the interaction of the Z_D with ordinary matter may be several orders of magnitude weaker than the electroweak interaction.

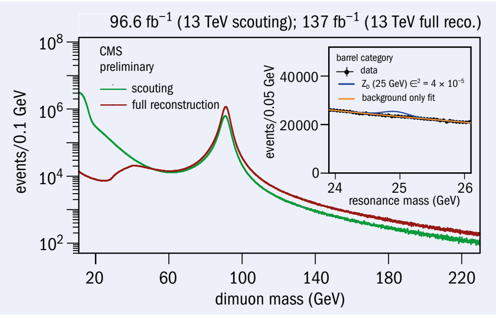


Fig. 1. *Dimuon invariant-mass distributions obtained from data collected by the standard dimuon triggers (red) and the dimuon scouting triggers (green).*

The CMS collaboration has recently presented results of a search for a narrow resonance decaying to a pair of muons in the mass range from 11.5 to 200 GeV. This search looks for a strikingly sharp peak on top of a smooth dimuon mass spectrum that arises mainly from the Drell–Yan process. At masses below approximately 40 GeV, conventional triggers are the main limitation for this analysis as the thresholds on the muon transverse momenta (p_T), which are applied online to reduce the rate of events saved for offline analysis, introduce a significant kinematic acceptance loss, as evident from the red curve in figure 1.

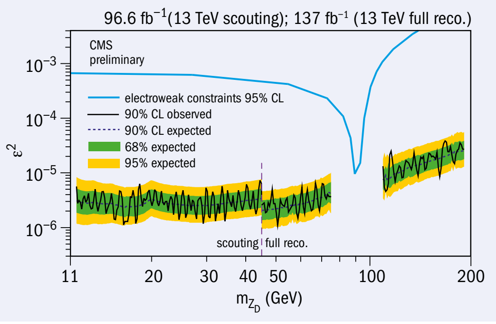


Fig. 2. *Upper limits on ϵ^2 as a function of the Z_D mass. Results obtained with data collected by the dimuon scouting triggers are to the left of the dashed line. Constraints from measurement of the electroweak observables are shown in light blue.*

A dedicated set of high-rate dimuon "scouting" triggers, with some additional kinematic constraints on the dimuon system and significantly lower muon p_T thresholds, was deployed during Run 2 to overcome this limitation. Only a minimal amount of high-level information from the online reconstruction is stored for the selected events. The reduced event size allows significantly higher trigger rates, up to two orders of magnitude higher than the standard muon triggers. The green curve in figure 1 shows the dimuon invariant mass distribution obtained from data collected with the scouting triggers. The increase in kinematic acceptance for low masses can be well appreciated.

The full data sets collected with the muon scouting and standard dimuon triggers during Run 2 are used to probe masses below 45 GeV, and between 45 and 200 GeV, respectively, excluding the mass range from 75 to 110 GeV where Z-boson production dominates. No significant resonant peaks are observed, and limits are set on ϵ^2 at 90% confidence as a function of the Z_D mass (figure 2). These are among the world's most stringent constraints on dark photons in this mass range.

Further reading

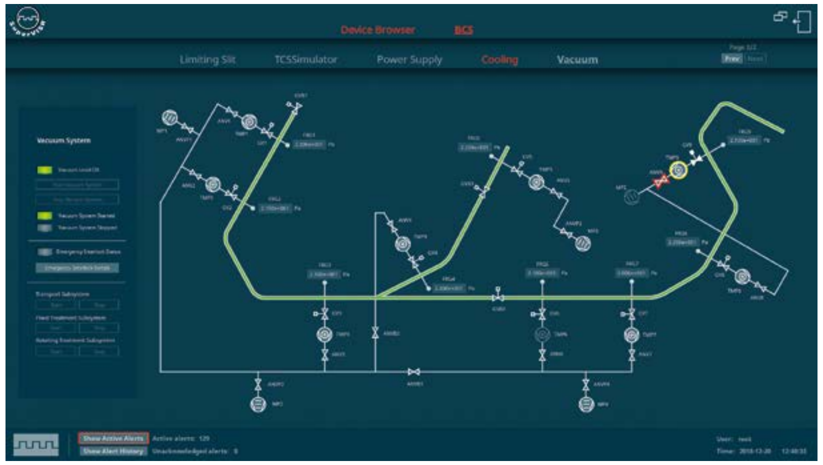
CMS Collab. 2019 CMS-PAS-EXO-19-018.

ADVERTISING FEATURE

When SCADA is the right solution

Throughout Cosylab's work in developing supervisory control and data acquisition (SCADA) solutions, we have often noticed that our customers have a lack of understanding of the role of SCADA in a system when we are asked to provide a solution. This poses a risk when it comes to whether or not our customers will find our solution useful for their work. As it is in our best interests to provide a useful resolution to our customers, and since this is also what we strive for, we would like to share what we see as the role of SCADA. In cases when SCADA really is the right solution for the given problem, then a number of questions must be asked in order to design a successful SCADA solution.

Our ultimate aim is to bring clarity to those thinking about whether they need SCADA or not.



Vacuum

What is a SCADA system?

SCADA systems are used all over the world for supervisory control and data acquisition. Understanding a useful SCADA and how to make it begins with an understanding about the role of SCADA in a system.

The need for SCADA evolved over time after agrarian and handicraft economies shifted rapidly to industrial and machine-manufacturing economies during the Industrial Revolution in the 18th century. Initially, machines were developed that could perform repeatable processes faster, with more consistency and with greater precision than people. Much of this was also about eliminating human error. While this first step in the Industrial Revolution replaced many people with machines for work that was previously done by hand, it opened up questions about whether it was possible to completely eliminate the human factor from the whole process, including the management of connecting all the different aspects of the manufacturing process, as well as the hands-on aspects.

For example, there was a time when mechanised processes were made of multiple machines operated by many people, including at least one who would be the supervisor of the whole process. The process supervisor was there to make sure that the system worked accurately, and to ensure that this happened the machine operators had to report any problems that could hinder the operation to the supervisor. As the supervisor had an overview of the whole process, they could make the most appropriate decisions to keep it running.

This is the purpose of SCADA. It centralises control, congregates and exposes data to other system components on higher levels, and attempts to minimise human interaction with process control.

Determining the right SCADA solution

Only after we have decided whether SCADA is the correct solution to a problem or not can we start asking ourselves what we want SCADA to do. This can be achieved through the following set of questions:

1. **What does the system need to be supervised and acted upon (by SCADA) to ensure that the process will do what we want it to do?**
   - What are the building blocks of the process that need supervision and what exactly does the supervision mean for every single building block?
   - What are the supervision tasks that are common for all the building blocks of the process?
2. **What are the possible events in the system that would negatively impact on what we want the system to do (e.g. machine failure, software bugs, human error) and which of these need be handled by SCADA?**
   - How can these events be handled to avoid negative impacts on the system?
   - Is it possible to detect these events?
   - How will SCADA receive notifications about these events?
   - Are there any preventative actions that we can take to prevent these events from happening?
3. **What supervisory information is required to enable improvements to the system?**
   - Here is where different types of SCADA statistics come in, including data mining and key performance indicators.
4. **Which parts of the work defined in the first three questions can be automated; which parts do we want to automate; and which parts require human intervention/supervision?**
   - In the case of a fully automated process, you would need a graphical user interface with a single start button.

In conclusion

The key to getting a useful SCADA starts with a conversation with the customer about what they need and a clear conceptual design, guided by the above questions. Only after this process has been completed does it make sense to choose a particular SCADA technology (for example, WinCC OA, EPICS or TANGO) that best fits the job.

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FIELD NOTES

Reports from events, conferences and meetings

INTERNATIONAL CONFERENCE ON RF SUPERCONDUCTIVITY

Superconductivity heats up in Dresden

Accelerator experts from around the world met from 30 June – 5 July in Dresden's historic city centre for six days of intense discussions on superconducting radio-frequency (SRF) science and technology. The Helmholtz-Zentrum Dresden-Rossendorf (HZDR) hosted the 19th conference in the biannual series, which demonstrated that SRF has matured to become the enabling technology for many applications. New SRF-based large-scale facilities throughout the world include the European XFEL in Germany, LCLS-II and FRIB in the US, ESS in Sweden, RAON in Korea, and SHINE in China.

The conference opened on Germany's hottest day of the year with a "young scientists" session comprising 40 posters. The following week featured a programme packed with 67 invited oral presentations, more than 300 posters and an industrial exhibition. Keynote lecturer Thomas Tschentscher (European XFEL) discussed applications of high-repetition-rate SRF-based X-ray sources, while Andreas Maier (University of Hamburg) reviewed rapidly advancing laser-plasma accelerators, emphasising their complementarity with SRF-based systems.

Much excitement in the community was generated by new, fundamental insights into power dissipation in RF superconductors. A better understanding of the role of magnetic flux trapping and impurities for RF losses has pushed state-of-the-art niobium to near its theoretical limit. However, recent advances with Nb_3Sn (*CERN Courier* July/August 2019 p9) have demonstrated performance levels commensurate with established niobium systems, but at a much higher operating temperature (≥ 4.2 K rather than ≤ 2 K). Such performance was unthinkable just a few years ago. Coupled with technological developments for tuners, digital control systems and cavity processing, turn-key high-field and continuous-wave operation at 4.2 K and above appears within reach. The potential benefit for both large-scale facilities as well as compact SRF-based accelerators in terms of cost and complexity is enormous.

The SRF conference traditionally plays an important role in attracting new, young researchers and engineers to the field, and provides them with a forum to present their results. In the three days leading up to the conference, HZDR hosted tutorials covering all aspects from superconductivity fundamentals to cryomodule design, which attracted 89 students and young scientists. During the conference, 18 young investigators were invited to give presentations. Bianca Giaccone (Fermilab) and Ryan Porter (Cornell University) received prizes for the best talks, alongside Guilherme Semione (DESY) for best poster.

The SRF conference rotates between Europe, Asia and the Americas. SRF 2021 will be hosted by Michigan State University/FRIB, while SRF 2023 moves on to Japan's Riken Nishina Center.

Jens Knobloch *Helmholtz-Zentrum Berlin and Universität Siegen.*

SRF2019

Dresden discussions *More than 300 delegates discussed new insights into RF power dissipation.*

RENCONTRES DU VIETNAM

Three neutrinos and beyond

Since 1993 the Rencontres du Vietnam have fostered exchanges between scientists in the Asia-Pacific region and colleagues from other parts of the world. The 15th edition, which brought together more than 50 physicists in Quy Nhon, Vietnam from 4–10 August, celebrated the 30th anniversary of the start of the Large Electron Positron collider (LEP) in 1989, which within a mere three weeks of running had established that the number of species of light active neutrinos is three (*CERN Courier* September/October 2019 p32). This was a great opportunity to emphasise the important role that colliders have played and will continue to play in neutrino physics. Before the three-neutrino measurement of LEP, the tau neutrino had been established in the years 1975–1986 by a combination of e^+e^--collider observations of tau decays, pp collisions (the $W \rightarrow \tau\nu_\tau$ decay was observed at CERN in 1985) and neutrino-beam experiments, where it was observed that taus are never produced by electron- or muon-neutrino beams (for example Fermilab's E531 experiment in 1986).

For a fortunate combination of parameters, this could lead to a spectacular signature

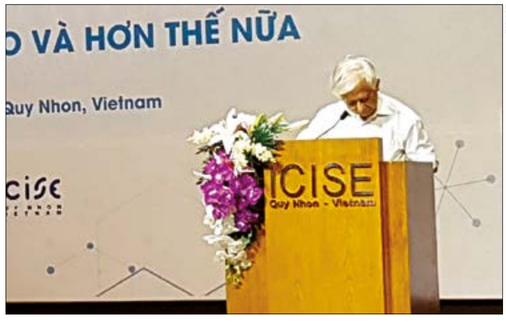
A neutrino-oscillation industry then sprang into being, following the discovery that neutrinos have mass. An abundance of recent results on oscillation parameters were presented from accelerator-neutrino beams, nuclear reactors, and atmospheric and astrophysical neutrinos. Interestingly, the data now seem to indicate at > 3σ that neutrinos follow the natural (rather than inverted) mass ordering, in which the most electron-like neutrino has a ▷

mass smaller than that of the muon and tau neutrinos. The next 10 years should see this question resolved, as well as a determination of the CP-violating phase of the neutrino-mixing matrix, with a precision of 5–10 degrees.

The fact that neutrinos have mass requires an addition to the Standard Model (SM), wherein neutrinos are massless by definition. There are several solutions, of which a minimal modification is to introduce right-handed neutrinos in addition to the normal ones, which have left-handed chirality. The properties of these heavy neutral leptons would be very well predicted were it not that their mass can lie anywhere from less than an eV to 10^{10} GeV or more. Being sterile they only couple to SM particles via mixing with normal neutrinos. Consequently, they should be very rare and have long lifetimes, perhaps allowing a spectacular observation in either fixed-target or high-luminosity colliders at the electroweak scale. One possible low-energy indication could be the existence of neutrinoless double-beta decay. Such decays, currently being searched for directly in dedicated experiments worldwide, violate lepton-number conservation in the case where neutrinos possess a Majorana mass term that transforms neutrinos into antineutrinos.

The meeting reviewed the status of all aspects of massive neutrinos, from direct mass measurements of the sort successfully executed shortly after the conference by the KATRIN experiment (see p7) to the search for heavy sterile neutrinos in ATLAS and CMS. A new feature of the field is the abundance of experimental projects searching for very weakly, or, to use the newly coined parlance, "feebly", interacting particles. These range from CERN's SHiP experiment to future LHC projects such as FASER and Mathusla (for masses from the pion to the B meson); proposed high-luminosity and high-energy colliders such as the Future Circular Collider would extend the search up to the Z mass for mixings between the heavy and light neutrinos down to 10^{-11}. Until recently classified as exotic, these experiments could yield the long-sought-after explanation for the matter–antimatter asymmetry of the universe by combining CP violation with an interaction that transforms particles into antiparticles. For a fortunate combination of parameters, this could lead to a spectacular signature: the production of a heavy neutrino in a W decay, tagged by an associated charged lepton, and followed by its transformation into its antineutrino, which could then be identified by its decay into a lepton of the same sign as that initially tagged (and possibly of a different flavour).

The meeting was thus concluded in continuity with its initial commemoration: could the physics of neutrinos be one of the highlights of future high-energy colliders?



Founding father *Jean Tran Thanh Van, founder of the Rencontres de Moriond and the Rencontres du Vietnam, welcomes delegates to the International Center for Interdisciplinary Science and Education .*

LPNHE

Alain Blondel *LPNHE Paris, CERN and University of Geneva.*

LEPTON–PHOTON 2019

Lepton–photon interactions in Toronto

The 29th International Symposium on Lepton–Photon Interactions at High Energies was held in Canada from 5–10 August at the Westin Harbour Castle hotel, right on the Lake Ontario waterfront in downtown Toronto. Almost 300 delegates provided a snapshot of the entire field of particle physics and, for the first time, parallel sessions were convened from abstracts submitted by collaborations and individuals.

The symposium opened with a welcome from Chief Laforme of the Mississauga First Nation. It was followed by highlights from the LHC experiments and updates on plans for the CERN accelerator complex, the CEPC project in China and the recently inaugurated Belle II programme in Japan. The Belle-II collaboration showed early results from their first 6.5 fb^{-1} of SuperKEKb data, including measurements of previously studied Standard Model (SM) phenomena and a new limit on dark-photon production near 10 GeV. Further plenary sessions covered dark-matter searches, multi-messenger astronomy, Higgs, electroweak and top-quark physics, heavy-ion physics, QCD, exotic-particle searches, flavour physics and neutrino physics.

The symposium ended with a progress report on the European strategy for particle physics and summaries on advances in particle detection and instrumentation, followed by a presentation on outreach and education initiatives from Kétévi Assamagan (Witwatersrand and BNL), and perspectives on future facilities. In the discussion on future flavour facilities, Tatsuya Nakada (EPFL) offered his views on flavour factories, emphasising their important role in guiding future experiments. He stressed the fact that yesterday's discoveries (most recently the Higgs boson) become today's workhorses, providing stringent tests of the SM. In the coming decades we are likely to have W and Higgs factories that will further illuminate the remaining shadows in the SM.

A packed public lecture by 2015 Nobel-Prize winner Art McDonald demonstrated the keen interest of the broader public in the continued developments in particle physics, including those in Canada at the SNOLAB underground laboratory, which now hosts several experiments engaged in neutrino physics and dark-matter searches, following the seminal results from the SNO experiment.

The puck stops here *Belle and Belle II collaborators at the Lepton–Photon conference gala.*

A M Rodriguez Vera

Hirohisa Tanaka *SLAC/University of Toronto and* **William Trischuk** *University of Toronto.*

TOPICS IN ASTROPARTICLE AND UNDERGROUND PHYSICS

TAUP tackles topical questions

The 16th International Conference on Topics in Astroparticle and Underground Physics (TAUP 2019) was held in Japan from 9–13 September, attracting a record 540 physicists from around 30 countries. The 2019 edition of the series, which covered recent experimental and theoretical developments in astroparticle physics, was hosted by the Institute for Cosmic Ray Research of the University of Tokyo, and held in Toyama – the gateway city to the Kamioka experimental site.

Discussions first focused on gravitational-wave observations. During their first two observing runs, reported Patricia Schmidt from Radboud University, LIGO and Virgo confidently detected gravitational waves from 10 binary black-hole coalescenses and one binary neutron star inspiral, seeing one gravitational-wave event every 15 days of observation. It was also reported that, during the ongoing third observing run, LIGO and Virgo have already observed 26 candidate events. Among them is the first signal from a black hole–neutron star merger.

The programme continued with presentations from various research fields, a highlight being a report on the first result of the KATRIN experiment (p7). Co-spokesperson Guido Drexlin revealed the first measurement results on the upper limit of the neutrino mass: < 1.1 eV at 90% confidence. This world-leading direct limit – which measures the neutrino mass by precisely measuring the kinematics of the electrons emitted from tritium beta decays – was obtained based on only four weeks of data. With the continuation of the experiment, it is expected that the limit will be reduced further, or even – if the neutrino mass is sufficiently large – the actual mass will be determined. Due to their oscillatory nature, it has been known since 1998 that neutrinos have tiny, but non-zero, masses. However, their absolute values have not yet been measured.

Diversity is a key feature of the TAUP conference. Topics discussed included cosmology, dark matter, neutrinos, underground laboratories, new technologies, gravitational waves, high-energy astrophysics and cosmic rays. Multi-messenger astronomy – which combines information from gravitational-wave observation, optical astronomy, neutrino detection and other electromagnetic signals – is quickly becoming established and is expected to play an even more important role in the future in gaining a deeper understanding of the universe.

The next TAUP conference will be held in Valencia, Spain, from 30 August to 3 September 2021.

Mass appeal *Guido Drexlin of the Karlsruhe Institute of Technology presents the first direct measurement of the neutrino mass by the KATRIN collaboration.*

TAUP 2019

Masafumi Kurachi, **Masayuki Nakahata** *and* **Masatake Ohashi** *ICRR, University of Tokyo.*

AUSTRIA–CERN ANNIVERSARY

Austria and CERN celebrate 60 years

Since joining in 1959, Austria has never stopped contributing to CERN. Associated in bygone days with the UA1 experiment at the SPS, where the W and Z bosons were discovered, and later with LEP's DELPHI experiment, which helped to put the Standard Model on a solid footing, today hundreds of Austrian scientists contribute to CERN's experimental programme, and its institutes participate in ALICE, ATLAS, CMS and in experiments at the Antiproton Decelerator. Two of the laboratory's directors, Willibald Jentschke and Victor Frederick Weisskopf, were born in Austria.

To celebrate the 60th anniversary of Austria's membership, the public were invited to "Meet the Universe" during a series of exhibitions and public events from 5–12 September, organised by the Institute of High Energy Physics (HEPHY) of the Austrian Academy of Sciences. CERN Director-General Fabiola Gianotti opened proceedings by discussing the role of particle colliders as tools for exploration. The following day, 2017 Nobel Prize winner Barry Barish presented his vision for gravitational-wave detectors and the dawn of multi-messenger astronomy. The programme continued with public lectures by Jon Butterworth of University College London, presenting the various experimental paths that could reveal hints for new physics, and Christoph Schwanda of HEPHY discussing the matter–antimatter asymmetry in the universe.

"We'd like to celebrate this important anniversary and continue to contribute to this long-term endeavour together with the other countries that participate in CERN's research programme," said Manfred Krammer, both of HEPHY and head of CERN's experimental physics department.

The long-standing relationship with CERN has offered broad benefits to the Austrian scientific community, a noticeable example being the Vienna Conference on Instrumentation, and since 1993 the Austrian doctoral programme, which has now trained more than 200 participants, has been fully integrated with CERN's PhD programme. Today, Austria's collaboration with CERN extends far beyond particle physics. Business incubation centres were launched in Austria in 2015, and the MedAustron advanced hadron-therapy centre (*CERN Courier* September/October 2019 p10), which was developed in collaboration with CERN, is among the world's leading medical research facilities.

"CERN is the place to push the frontiers, and scientists from Austria will contribute to make the next steps towards the unknown," said HEPHY director Jochen Schieck.

Diamond anniversary *Austrian physicists Manfred Krammer (left) and Jochen Schieck, both of HEPHY and CERN, flank CERN Director-General Fabiola Gianotti.*

Panos Charitos *CERN.*

HADRON 2019

Exotic hadrons take centre stage in Guilin

HADRON2019

The 18th International Conference on Hadron Spectroscopy and Structure, HADRON2019, took place in Guilin, China, from 16 to 21 August, co-hosted by the Guangxi Normal University and the Institute of Theoretical Physics of the Chinese Academy of Sciences. The conference brought together more than 330 experimental and theoretical physicists from more than 20 countries to discuss topics ranging from meson and baryon spectroscopy to nucleon structure and hypernuclei. The central issue was exotic hadrons: the strongly interacting particles that deviate from the textbook definitions of mesons and baryons. Searches for exotic hadrons and studies of their properties have been a focus for many high-energy physics experiments, and many fascinating results have been reported since 2003 when the first particles of this sort were discovered: the hidden-charm X(3872) and the open-charm $D^*_{s0}(2317)$ observed by Belle and BaBar, respectively. The most cited physics papers of Belle and BESIII and the second most cited of BaBar and LHCb are reports of the discoveries of exotic hadron candidates.

Pentaquark pushers
HADRON 2019 took place in Guilin, China.

The conference began with a report on LHCb measurements of the doubly charmed Ξ^{++}_{cc} baryon, and the discovery of pentaquark particles called P_c. The higher statistics of the LHC Run-2 data have resolved the $P_c(4450)$ reported by LHCb in 2015 into two narrower structures, $P_c(4440)$ and $P_c(4457)$. In addition, a third hidden-charm pentaquark, $P_c(4312)$, with a smaller mass, was observed for the first time. These P_c structures are very likely exotic baryons consisting of at least five quarks, including a charm quark–antiquark pair. Many theorists believe that these pentaquarks can be described as hadronic molecules of a charmed meson and a charmed baryon, analogous to the deuteron, which is a bound state of a neutron and a proton. A series of parallel talks described theoretical predictions that will be useful in motivating further measurements, such as searches for the decay to a charmed baryon and a charmed meson, and searches for the various new pentaquarks predicted by theoretical models.

Illustrating the difficulty of understanding the inner structure of hadrons, the X(3872) discovered by Belle 16 years ago is still the subject of intensive investigations. Its mass is extremely close to the sum of the masses of two charmed mesons, D^0 and $\bar{D}^{*0}$, and its decay width (< 1.2 MeV) is anomalously small for a hadron of such a mass. New results on its decays into lighter particles were reported by BESIII. Alongside proposals for precise measurements of its mass, width and polarisation at Belle-II, PANDA and the LHC experiments, a deeper understanding of the X(3872) may be just around the corner.

A close collaboration between experimentalists and theorists is required, and this conference provided a valuable opportunity to exchange ideas. Interesting discussions will continue at the next HADRON conference, to be held in Mexico in 2021.

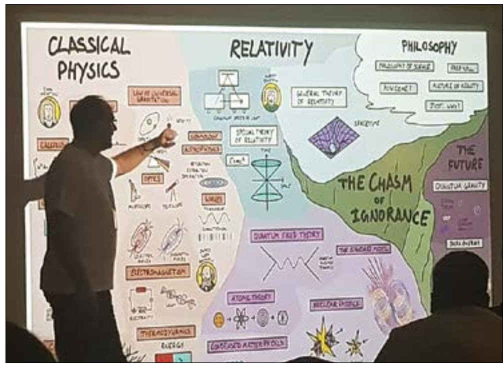
Feng-Kun Guo *Institute of Theoretical Physics, Chinese Academy of Sciences, and* **Simon Eidelman** *Budker Institute of Nuclear Physics and Novosibirsk State University.*

New Trends in High Energy Physics

Odessa conference surveys new trends

The 2019 edition of New Trends in High Energy Physics took place in Odessa, Ukraine, from 12 to 18 May, with 84 participants attending from 21 countries. Initiated by the Bogolyubov Institute for Theoretical Physics at the National Academy of Sciences in the Ukraine and the Joint Institute for Nuclear Research (JINR) in Dubna, the series focuses on new ideas and hot problems in theory and experiment. The series started in 1992 in Kiev under the name HADRONS, changed its title to "New Trends in High-Energy Physics" at the turn of the millennium, took place for a decade in the Crimea, then moved to Natal (Brazil) and Becici (Montenegro), before coming back to Ukraine this year.

This year's conference had an emphasis on heavy-ion physics and strong interactions, with aspects of the QCD phase diagram such as signatures of the transition from quark–gluon plasma to hadrons highlighted in several talks. The interpretation of recent experimental results on collectivity (the bulk motion of nuclear matter at high temperatures) in terms of the formation of a "perfect liquid" was also discussed.



A Burgazli

Into the abyss
Maciej Trzebinski (PAN Cracow) describes the perilous journey from classical physics to the future.

Future searches for glueballs and other exotic hadronic states will contribute to an improved understanding of non-perturbative aspects of QCD.

Parallel to the quest for the highest possible energies, many problems of low- and intermediate-energy physics are still unresolved, such as the critical behaviour of excited baryonic matter, the nature of exotic resonances and puzzles relating to spin. The construction of new facilities will help answer these questions, with high-luminosity collisions of particles ranging from polarised protons to gold ions at JINR–Dubna's NICA facility, complemented by fixed-target antiproton and ion studies with unprecedented collision rates at FAIR, the new international accelerator complex at GSI Darmstadt.

Talks on general relativity and cosmology, dark matter and black holes explored the many facets of modern astrophysical observations. Future multi-messenger observations, combining the measurements of the electromagnetic radiation spectrum and neutrinos with gravitational wave signals, are expected to contribute significantly to an improved understanding of the dynamics of binary black-hole and neutron-star mergers. Such measurements are of great significance for a variety of open issues, for example, nuclear physics at densities far beyond the regime accessible in laboratory experiments.

The next edition of the conference will be held in Kiev from 27 June to 3 July 2021.

Jamal Jalilian-Marian *CUNY,*
Richard Lednicky *JINR-Dubna and*
Rainer Schicker *Heidelberg.*

COOL19

Cooling experts head to Siberia

Accelerators of unstable or non-naturally occurring particles, such as the proton–antiproton colliders with which the W, Z and top quark were discovered, famously rely on "beam-cooling" techniques, which reduce the beam's phase-space volume in order to achieve sufficient interaction rates. Cooling techniques continue to improve, enhancing current and future experiments using low-energy antiprotons, heavy ions and molecular beams, and enabling future muon colliders. The community of scientists and engineers developing and applying beam cooling has been meeting to exchange ideas for more than 20 years at the COOL workshops.

It was gratifying to see the proliferation and progress of beam-cooling technologies at the 12th biennial international workshop on beam cooling and related topics, held from 23–27 September at the Budker Institute of Nuclear Physics in Novosibirsk (BINP), Russia.

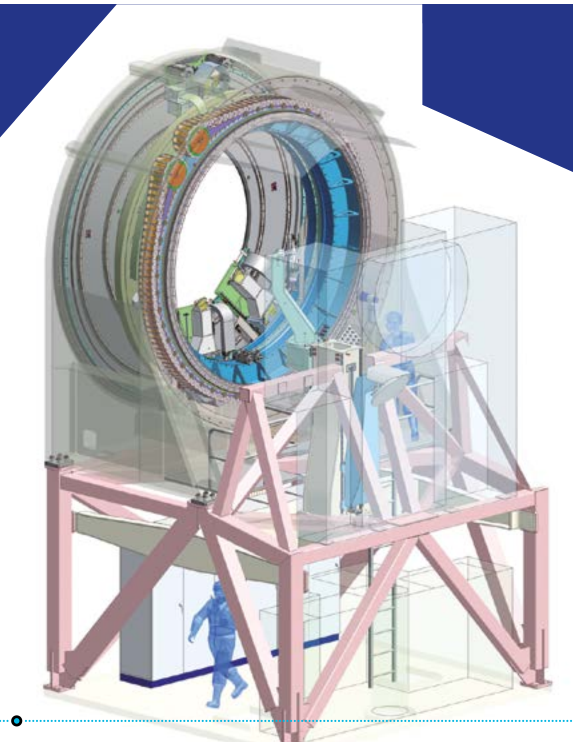
BINP

Fighting phase space
Beam-cooling experts met in Novosibirsk in September.

Electron-cooling R&D platforms were represented in profusion, including in the US (RHIC at Brookhaven and the planned EIC at Brookhaven and JLab), Germany (COSY at the Forschungszentrum Jülich, the CSR at MPI-K Heidelberg, and R&D at HIM Mainz), China (EICC and HIAF at IMP Lanzhou), CERN (the AD and ELENA), and Russia (NICA at JINR Dubna). Most of these are joint efforts with BINP, which continues to be the primary source for high-voltage, electron-gun and solenoid systems for such coolers. Also represented were stochastic cooling installations, tests of coherent electron cooling, and, at long last, results from the Muon Ionisation Cooling Experiment – notably, the first observation of muon ionisation cooling (first conceived at BINP almost 50 years ago), and a measurement of multiple scattering in a lithium-hydride energy absorber. Results with liquid hydrogen, and a wedge-shaped plastic absorber designed to demonstrate emittance exchange between the transverse and longitudinal planes, are expected soon.

Another highlight of the workshop was the report from Brookhaven, "Cooling commissioning results of the first RF-based electron cooler LEReC," which was delivered remotely by Alexei Fedotov. It was unfortunate that no one from a US national laboratory was able to travel to Novosibirsk in person – apparently a casualty of anti-Russia sanctions. Even at the height of the Cold War, US–USSR scientific contacts in particle and accelerator physics were successfully pursued. The argument that by cutting off such contacts one is shooting oneself in the foot seems quite plausible – after all, we go in order to learn.

Daniel M Kaplan *Illinois Institute of Technology.*



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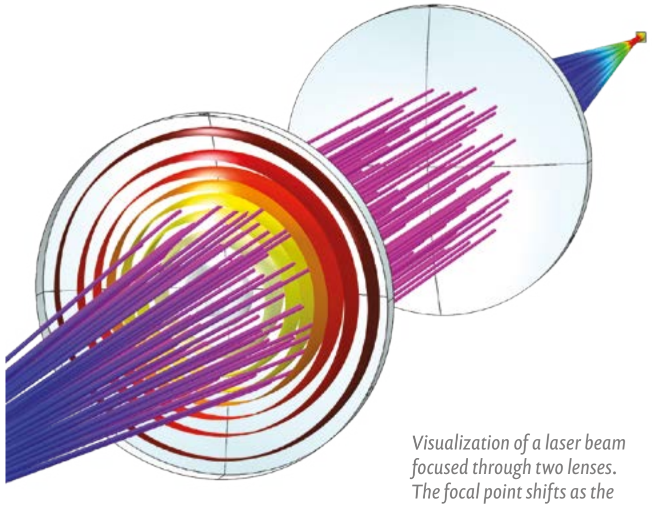

Analyze laser-material interaction with simulation.

Laser-material interaction, and the subsequent heating, is often studied with simulation using one of several modeling techniques. To select the most suitable approach, you can use information such as the material's optical properties, the relative sizes of the objects to be heated, and the laser wavelength and beam characteristics as a guide. For the simulation, you can use COMSOL Multiphysics®.

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Visualization of a laser beam focused through two lenses. The focal point shifts as the lenses heat up due to the high-intensity laser light.

COMSOL

ASTRONOMERS SCALE NEW SUMMIT

The world's largest optical/near-infrared telescope, the Extremely Large Telescope, under construction in Chile, will bring mysteries such as dark energy into focus.

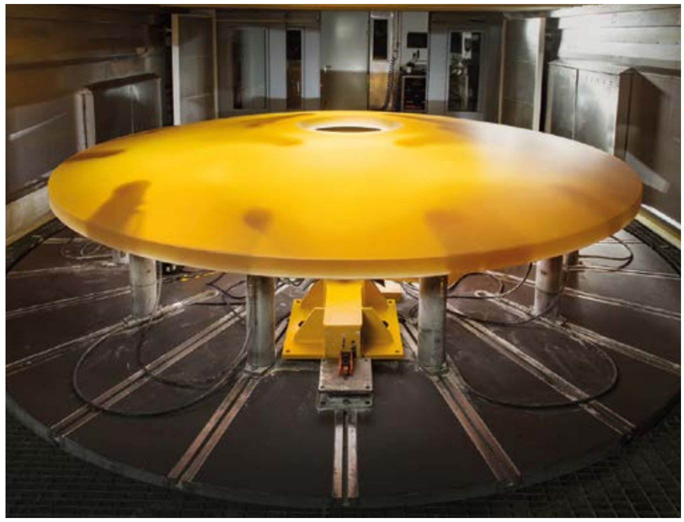
Peak construction *The foundations of ESO's Extremely Large Telescope atop Cerro Armazones in Chile, photographed in October 2018.*

G Hüdepohl/ESO

The 3 km-high summit of Cerro Armazones, located in the Atacama desert of Northern Chile, is a construction site for one of most ambitious projects ever mounted by astronomers: the Extremely Large Telescope (ELT). Scheduled for first light in 2025, the ELT is centred around a 39 m-diameter main mirror that will gather 250 times more light than the Hubble Space Telescope and use advanced corrective optics to obtain exceptional image quality. It is the latest major facility of the European Southern Observatory (ESO), which has been surveying the southern skies for almost 60 years.

The science goals of the ELT are vast and diverse. Its sheer size will enable the observation of distant objects that are currently beyond reach, allowing astronomers to better understand the formation of the first stars, galaxies and even black holes. The sharpness of its images will also enable a deeper study of extrasolar planets, possibly even the characterisation of their atmospheres. "One new direction may become possible through very high precision spectroscopy – direct detection of the expansion rate of the universe, which would be an amazing feat," explains Pat Roche of the University of Oxford and former president of the ESO council. "But almost certainly the most exciting results will be from unexpected discoveries."


ESO


SCHOTT

Ahead of the curve *Top: architectural concept drawing of the 80 m-high ELT at work. Bottom: the three-tonne "blank" for the ELT's secondary mirror, machined from a slab of the low-expansion ceramic ZERODUR, in January 2019.*

Technical challenges

Approved in 2006, civil engineering for the ELT began in 2014. Construction of the 74 m-high, 86 m-diameter dome and the 3400-tonne main structure began in 2019. In January 2018 the first segments of the main mirror were successfully cast, marking the first step of a challenging five-mirror system that goes beyond the traditional two-mirror "Gregorian" design. The introduction of a third powered mirror delivers a focal plane that remains un-aberrated at all field locations, while a fourth and a fifth mirror correct distortions in real-time due to the Earth's atmosphere or other external factors. This novel arrangement, combined with the sheer size of the ELT, makes almost every aspect of the design particularly challenging.

The main mirror is itself a monumental enterprise; it consists of 798 hexagonal segments, each measuring approximately 1.4 m across and 50 mm thick. To keep the surface unchanged by external factors such as temperature or wind, each segment has edge sensors measuring its location within a few nanometres – the most accurate ever used in a telescope. The construction and polishing of the segments, as well as the edge sensors, is a demanding task and only possible thanks to the collaboration with industry; at least seven private companies are working on the main mirror alone. The size of the mirror was originally 42 m, but it was later reduced to 39 m, mainly for costs reasons, but still allowing the ELT to fulfill its main scientific goals. "The ELT is ESO's largest project and we have to ensure that it can be constructed and operated within the available budget," says Roche. "A great deal of careful planning and design, most of it with input from industry, was undertaken to understand the costs and the cost drivers, and the choice of primary mirror diameter emerged from these analyses."

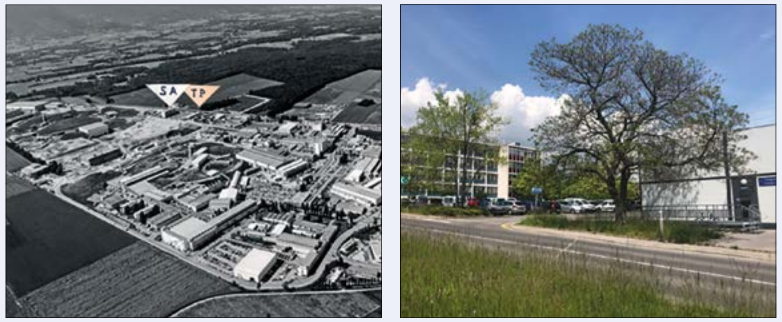
Currently, 28 companies are actively collaborating on different parts of the ELT design, mostly from Europe

The task is not much easier for the other mirrors. The secondary mirror, measuring 4 m across, is highly convex and will be the largest secondary mirror ever employed on a telescope and the largest convex mirror ever produced. The ELT's tertiary mirror also has a curved surface, contrary to more traditional designs. The fourth mirror will be the largest adaptive mirror ever made, supported by more than 5000 actuators that will deform and adjust its shape in real-time to achieve a factor-500 improvement in resolution.

European Southern Observatory's particle-physics roots

The ELT's success lies in ESO's vast experience in the construction of innovative telescopes. The idea for ESO, a 16-nation intergovernmental organisation for research in ground-based astronomy, was conceived in 1954 with the aim of creating a European observatory dedicated to observations of the southern sky. At the time, the largest such facilities had an aperture of about 2 m; more than 50 years later, ESO is responsible for a variety of observatories, including its first telescope at La Silla, not far from Cerro Armazones (home of the ELT).

Like CERN, ESO was born in the aftermath of the war to allow European countries to develop scientific projects that nations were unable to do on their own. The similarities are by no means a mere coincidence. From the beginning, CERN served as a model regarding important administrative aspects of the organisation, such as the council delegate structure, the finance base or personnel regulations. A stronger collaboration ensued in 1969, when ESO approached CERN to assist with the powerful and sophisticated instrumentation of its 3.6 m telescope and other challenges ESO was facing, both administrative and technological. This collaboration saw ESO facilities established at CERN: the Telescope Project Division and, a few years later, ESO's Sky Atlas Laboratory. A similar collaboration has since been organised for EMBL and, more recently for a new hadron-therapy facility in Southeast Europe.



Changed days *The location of ESO's Telescope Project Division (TP) and Sky Atlas Laboratory (SA) in the 1970s on the main CERN site (left), near what is now the language centre (right).*

Currently 28 companies are actively collaborating on different parts of the ELT design; most of these companies are European, but also include contracts with the Chilean companies ICAFAL, for the road and platform construction, and Abengoa for the ELT technical facility. Among the European contracts, the construction of the telescope dome and main structure by the Italian ACe consortium of Astraldi and Cimolai is the largest in ESO's history. The total cost estimate for the baseline design of the ELT is €1.174 billion, while the running cost is estimated to be around €50 million per year. Since the approval of the ELT, ESO has increased its number of member states from 14 to 16, with Poland and Ireland incorporating in 2015 and 2018, respectively. Chile is a host state and Australia a strategic partner.

Unprecedented view

A telescope of this scale has never been attempted before in astronomy. Not only must the ELT be constructed and operated within the available budget, but it should not impact the operation of ESO's current flagship facilities (such as the VLT, the VLT interferometer and the ALMA observatory).

The amount of data produced by the ELT is estimated to be around 1–2 TB per night, including scientific observations plus calibration observations. The data will be analysed automatically, and users have the option to download the processed data or, if needed, download the original data and process it in their own research centres. To secure observation time with the facility, ESO makes a call for proposals once or twice a year, at which researchers propose desired observations according to their own fields. "A committee of astronomers then evaluates the proposals and ranks them according to their relevance and potential scientific impact, the highest ranked ones are then chosen to be followed," explains project scientist Miguel Pereira of the University of Oxford.

The amount of data produced by the ELT is estimated to be around 1–2 TB per night

In addition to its astronomical goals, the ELT will contribute to the growing confluence of cosmology and fundamental physics. Specifically, it will help elucidate the nature of dark energy by identifying distant type 1a supernovae, which serve as excellent markers of the universe's expansion history. The ELT will also measure the change in redshift with time of distant objects – a feat that is beyond the capabilities of current telescopes – to indicate the rate of expansion. Possible variations over time of fundamental physics constants, such as the fine-structure constant and the strong coupling constant, will also be targeted. Such measurements are very challenging because the strength of the constraint on the variability depends critically on the accuracy of the wavelength calibration. The ELT's ultra-stable high-resolution spectrograph aims to remove the systematic uncertainty currently present in the wavelength calibration measurements, offering the possibility to make an unambiguous detection of such variations.

The ELT construction is on schedule for completion, and first light is expected in 2025. "In the end, projects succeed because of the people who design, build and support them," Roche says, attributing the success of the ELT to rigorous attention to design and analysis across all aspects of the project. The road ahead is still challenging and full of obstacles, but, as the former director of the Paris observatory André Danjon wrote to his counterpart at the Leiden Observatory, Jan Oort, in 1962: "L'astronomie est bien l'ecole de la patience." No doubt the ELT will pay extraordinary scientific rewards. ●

THE AUTHOR

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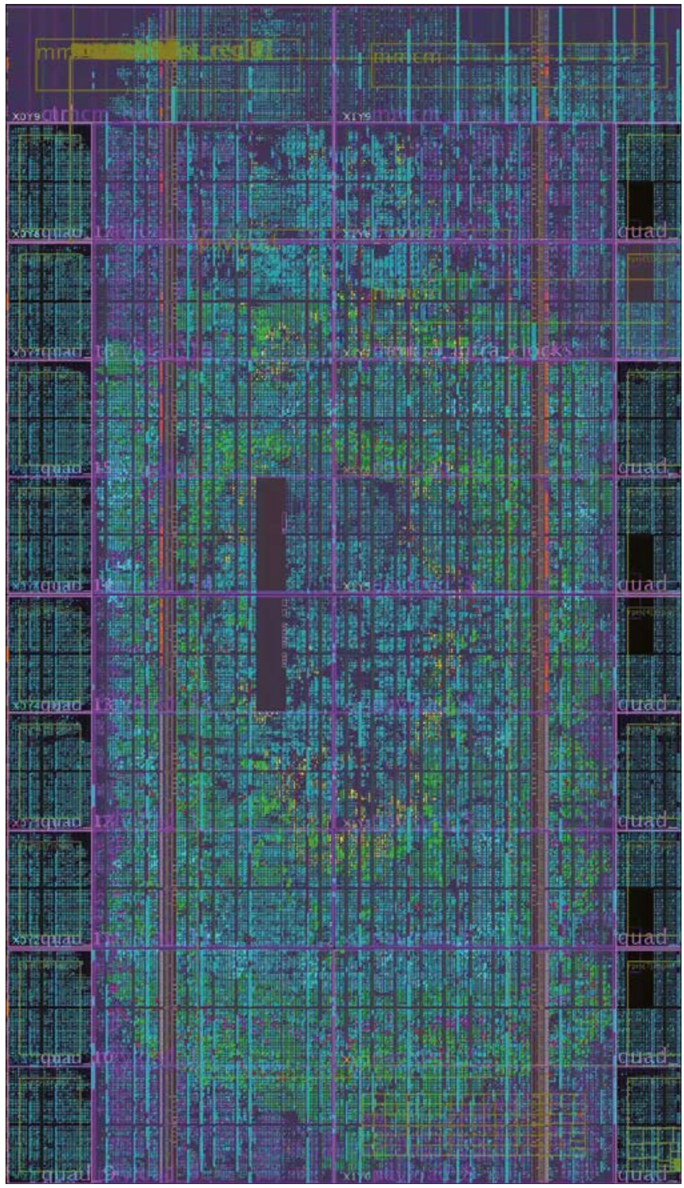
FPGAs THAT SPEAK YOUR LANGUAGE

Long the preserve of professional engineers coding in low-level languages, FPGAs can now be programmed in C++ and Java, bringing machine learning and complex algorithms within the scope of trigger-level analysis.

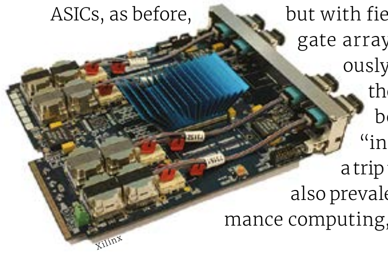


A Rose

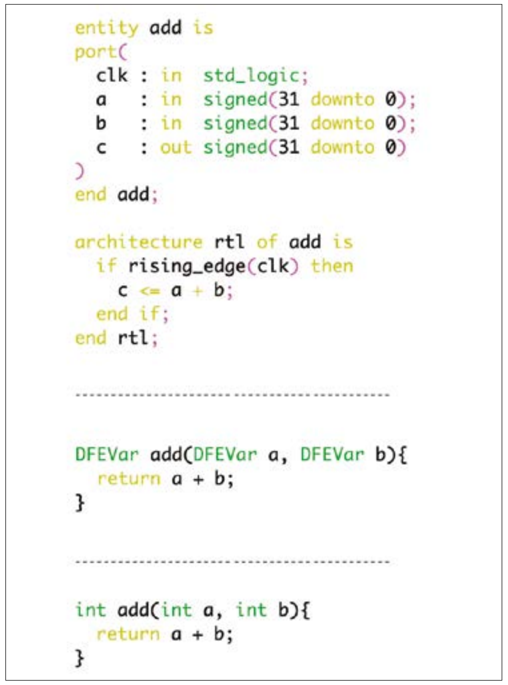
Purple rain *Visualisation of logic gates firing as an FPGA evaluates energies in the CMS calorimeter trigger.*

Teeming with radiation and data, the heart of a hadron collider is an inhospitable environment in which to make a tricky decision. Nevertheless, the LHC experiment detectors have only microseconds after each proton–proton collision to make their most critical analysis call: whether to read out the detector or reject the event forever. As a result of limitations in read-out bandwidth, only 0.002% of the terabits per second of data generated by the detectors can be saved for use in physics analyses. Boosts in energy and luminosity – and the accompanying surge in the complexity of the data from the high-luminosity LHC upgrade – mean that the technical challenge is growing rapidly. New techniques are therefore needed to ensure that decisions are made with speed, precision and flexibility so that the subsequent physics measurements are as sharp as possible.

The front-end and read-out systems of most collider detectors include many application-specific integrated circuits (ASICs). These custom-designed chips digitise signals at the interface between the detector and the outside world. The algorithms are baked into silicon at the foundries of some of the biggest companies in the world, with limited prospects for changing their functionality in the light of changing conditions or detector performance. Minor design changes require substantial time and money to fix, and the replacement chip must be fabricated from scratch. In the LHC era, the tricky trigger electronics are therefore not implemented with ASICs, as before, but with field-programmable gate arrays (FPGAs). Previously used to prototype the ASICs, FPGAs may be re-programmed "in the field", without a trip to the foundry. Now also prevalent in high-performance computing, with leading tech



Xilinx



```
entity add is
port(
  clk : in  std_logic;
  a   : in  signed(31 downto 0);
  b   : in  signed(31 downto 0);
  c   : out signed(31 downto 0)
)
end add;

architecture rtl of add is
  if rising_edge(clk) then
    c <= a + b;
  end if;
end rtl;
```

```
DFEVar add(DFEVar a, DFEVar b){
  return a + b;
}
```

```
int add(int a, int b){
  return a + b;
}
```

Fig. 1. *Code snippets illustrating the difficulty in writing even simple algorithms in VHDL (top), compared to implementations in Java-variant MaxJ (middle) and C++, as compiled by Vivado HLS (bottom).*

companies using them to accelerate critical processing in their data centres, FPGAs offer the benefits of task-specific customisation of the computing architecture without having to set the chip's functionality in stone – or in this case silicon.

Architecture of a chip

FPGAs can compete with other high-performance computing chips due to their massive capability for parallel processing and relatively low power consumption per operation. The devices contain many millions of programmable logic gates that can be configured and connected together to solve specific problems. Because of the vast numbers of tiny processing units, FPGAs can be programmed to work on many different parts of a task simultaneously, thereby achieving massive throughput and low latency – ideal for increasingly popular machine-learning applications. FPGAs can also support high bandwidth inputs and outputs of up to about 100 dedicated high-speed serial links, making them ideal workhorses to process the deluge of data that streams out of particle detectors (see *CERN Courier* September 2016 p21).

The difficulty is that programming FPGAs is traditionally the preserve of engineers coding low-level languages such as VHDL and Verilog, where even simple tasks can be tricky. For example, a function to sum two numbers together requires several lines of code in VHDL, with the designer even required to define when the operations happen relative to the processor clock (figure 1). Outsourcing the coding is impractical, given the imminent need to implement elaborate algorithms featuring machine learning in the trigger to quickly analyse data from high-granularity detectors in high-luminosity environments. During the past five years, however, tools have matured, allowing FPGAs to be programmed in variants of high-level languages such as C++ and Java, and bringing FPGA coding within the reach of physicists themselves.

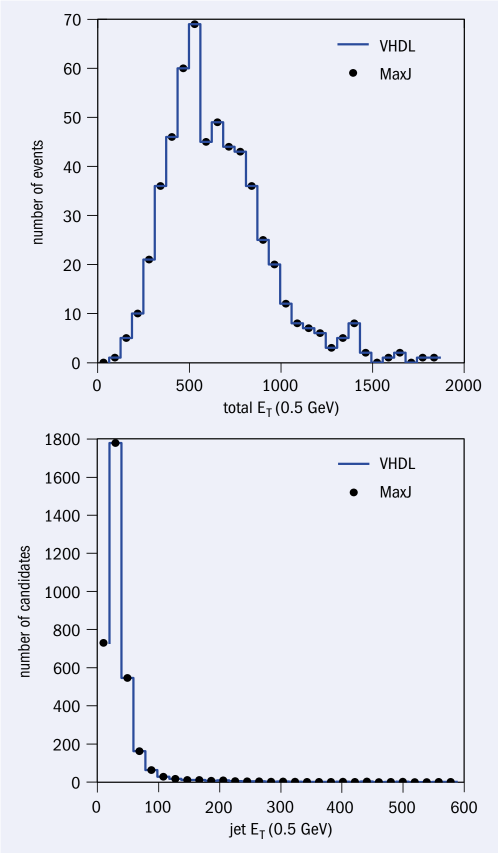


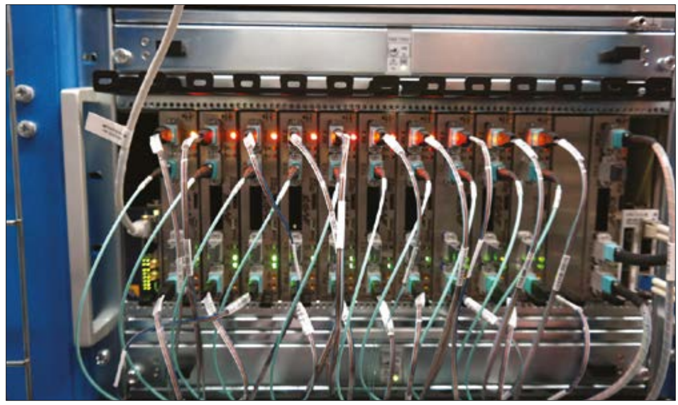
Fig. 2. *The official VHDL implementation of the CMS calorimeter trigger for missing transverse energy (top) and jet transverse energy (bottom) are consistent with high-level Java-based MaxJ code written by a doctoral student.*

FPGAs can compete due to their massive capability for parallel processing and relatively low power consumption per operation

But can high-level tools produce FPGA code with low-enough latency for trigger applications? And can their resource usage compete with professionally developed low-level code? During the past couple of years CMS physicists have trialled the use of a Java-based language, MaxJ, and tools from Maxeler Technologies, a leading company in accelerated computing and data-flow engines, who were partners in the studies. More recently the collaboration has also gained experience with the C++-based Vivado high-level synthesis (HLS) tool of the FPGA manufacturer Xilinx. The work has demonstrated the potential for ground-breaking new tools to be used in future triggers, without significantly increasing resource usage and latency.

Track and field-programmable

Tasked with finding hadronic jets and calculating missing transverse energy in a few microseconds, the trigger of the CMS calorimeter handles an information throughput of 6.5 terabits per second. Data are read out from the detector into the trigger-system FPGAs in the counting room in a cavern adjacent to CMS. The official FPGA code was implemented in VHDL over several months each of development, debugging and testing. To investigate whether high-level FPGA programming can be practical, the same algorithms were implemented in MaxJ by an inexperienced doctoral student (figure 2), with the low-level clocking and management of high-speed serial links still undertaken by the professionally developed code. The high-level code had comparable latency and resource usage with one exception: the hand-crafted VHDL was superior when it came to quickly sorting objects by their transverse momentum. With this caveat, the study suggests that using high-level development tools can dramatically lower the bar for developing FPGA firmware, to the extent that students and physicists can contribute to large parts of the development of labyrinthine electronics systems.



D Newbold

Workhorse *Nine calorimeter-trigger cards process CMS events in parallel, while a 10th receives their outputs. The 11th is spare. Each card has a Xilinx Virtex 7 FPGA (pictured on p29). The cards were installed at the beginning of LHC Run 2 and will be upgraded for high-luminosity running.*

Kalman filtering is an example of an algorithm that is conventionally used for offline track reconstruction on CPUs, away from the low-latency restrictions of the trigger. The mathematical aspects of the algorithm are difficult to implement in a low-level language, for example requiring trajectory fits to be iteratively optimised using sequential matrix algebra calculations. But the advantages of a high-level language could conceivably make Kalman filtering tractable in the trigger. To test this, the algorithm was implemented for the phase-II upgrade of the CMS tracker in MaxJ. The scheduler of Maxeler's tool, MaxCompiler, automatically pipelines the operations to achieve the best throughput, keeping the flow of data synchronised. This saves a significant amount of effort in the development of a complicated new algorithm compared to a low-level language, where this must be done by hand. Additionally, MaxCompiler's support for fixed-point arithmetic allows the developer to make full use of the capability of FPGAs to use custom data types. Tailoring the data representation to the problem at hand results in faster, more lightweight processing, which would be prohibitively labour-intensive in a low-level language. The result of the study was hundreds of simultaneous track fits in a single FPGA in just over a microsecond.

Ghost in the machine

Deep neural networks, which have become increasingly prevalent in offline analysis and event reconstruction thanks to their ability to exploit tangled relationships in data, are another obvious candidate for processing data more efficiently. To find out if such algorithms could be implemented in FPGAs, and executed within the tight latency constraints of the trigger, an example application was developed to identify fake tracks – the inevitable byproducts of overlapping particle trajectories – in the output of the MaxJ Kalman filter described above. Machine learning has the potential to distinguish such bogus tracks better than simple selection cuts, and a boosted decision tree (BDT) proved effective here, with the decision step, which employs many small and independent decision trees, implemented with MaxCompiler. A latency of a few hundredths of a microsecond – much shorter than the iterative Kalman filter as BDTs are inherently very parallelisable – was achieved using only a small percentage of the silicon area of the FPGA, so leaving room for other algorithms. Another tool capable of executing machine-learning models in tens of nanoseconds is the "hls4ml" FPGA inference engine for deep neural networks, built on the Vivado HLS compiler of Xilinx. With the use of such tools, non-FPGA experts can trade-off latency and resource usage – two critical metrics of performance, which would require significant extra effort to balance in collaboration with engineers writing low-level code.

Though requiring a little extra learning and some knowledge of the underlying technology, it is now possible for ordinary physicists to programme FPGAs in high-level languages, such as Maxeler's MaxJ and Xilinx's Vivado HLS. Development time can be cut significantly, while maintaining latency and resource usage at a similar level to hand-crafted FPGA code, with the fast development of mathematically intricate algorithms an especially promising use case. Opening up FPGA programming to physicists will allow offline approaches such as machine learning to be transferred to real-time detector electronics.

Novel approaches will be critical for all aspects of computing at the high-luminosity LHC. New levels of complexity and throughput will exceed the capability of CPUs alone, and require the extensive use of heterogenous accelerators such as FPGAs, graphics processing units (GPUs) and perhaps even tensor processing units (TPUs) in offline computing. Recent developments in FPGA interfaces are therefore most welcome as they will allow particle physicists to execute complex algorithms in the trigger, and make the critical initial selection more effective than ever before. ●

Further reading

R Aggleton *et al.* 2017 *JINST* **12** P12019.
J Duarte *et al.* 2018 *JINST* **13** P07027.
O Pell and V Averbukh 2012 *Comput. Sci. Eng.* **14** 98.
S Summers *et al.* 2019 *EPJ Web Conf* **214** 01003.
S Summers *et al.* 2017 *JINST* **12** C02015.

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PARTICLE PHYSICS INSPIRES ALL

Some 75,000 members of the public took part in the CERN Open Days on 14 and 15 September. Bathed in autumn sunshine, the lab offered visitors of all ages the opportunity to visit its underground and surface facilities, discover new technologies and engage with 150 activities at nine sites. Around 3000 staff and user volunteers, resplendent in bright-orange T-shirts, brought CERN's science and engineering to life. Here are a sample of shots and a smattering of visitor reactions captured by the *Courier* during CERN's biggest outreach event since the last Open Days in 2013.

CERN-PHOTO-201909-247-9

Director-General Fabiola Gianotti with visitors at LHC Point 4.

"It's a huge place full of ideas to try in case something revolutionary turns up."

CERN-PHOTO-201909-255-14

Sparking imagination in the power-converters lab.

"There is high-tech science going on. You're trying to make applications to real life, such as non-destructive testing."

CERN-PHOTO-201909-243-9

All smiles at LHC Point 6.

CERN-PHOTO-201909-254-8

Down under with ATLAS.

"We're not here for the science, we're here for the machines!"

CERN-PHOTO-201909-239-55

Awestruck by ALICE.

CERN-PHOTO-201909-249-9

John Ellis and Mónica Bello talk art and science.

"I thought it was all about programming, but you actually build things."

CERN-PHOTO-201909-248-13

New arrivals.

CERN-PHOTO-201909-251-6

Cool demonstrations in the cryogenics lab.

> **"CERN is here to test out how particles behave and exploring the limit of the universe, like matter (which we know) and antimatter (which we don't)."**

CMS-PHO-PUBLIC-2019-007-75

Marvelling at CMS.

CERN-PHOTO-201909-245-23

Virtual welding was a hit in the main workshop.

CERN-PHOTO-201909-239-47

The beauty of LHCb.

> **"If you understand materials and energy at the basic scale, you have a better chance of creating new energy sources and materials for the future."**

> **"I read an article recently that said this was all a waste of taxpayers' money, but now I am less sure because I have seen today that there are a lot of applications."**

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Physics fun in the superconductivity lab.

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- Embedded EPICS IOC, Channel Access

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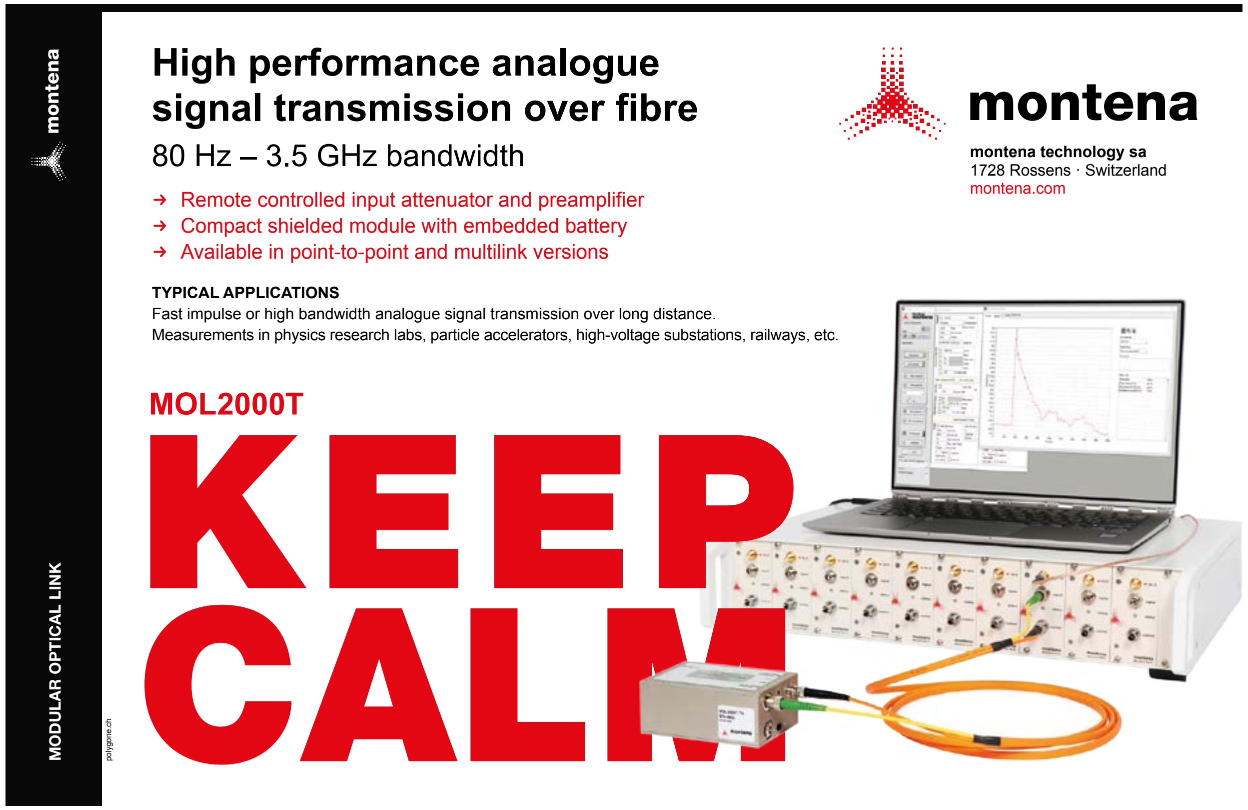
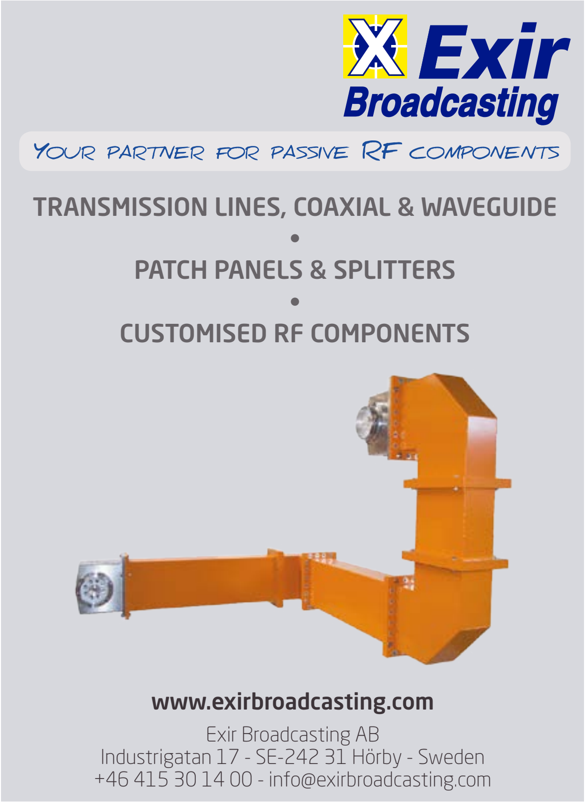




C Barué/GANIL–CNRS

Flourishing physics *The interior of a radio-frequency cavity used in a cyclotron at the GANIL (Grand Accélérateur National d'Ions Lourds) facility of the CEA and CNRS, showing regions that have been pulverised by the high-voltage electric arcs.*

THE RISE OF FRENCH PARTICLE PHYSICS

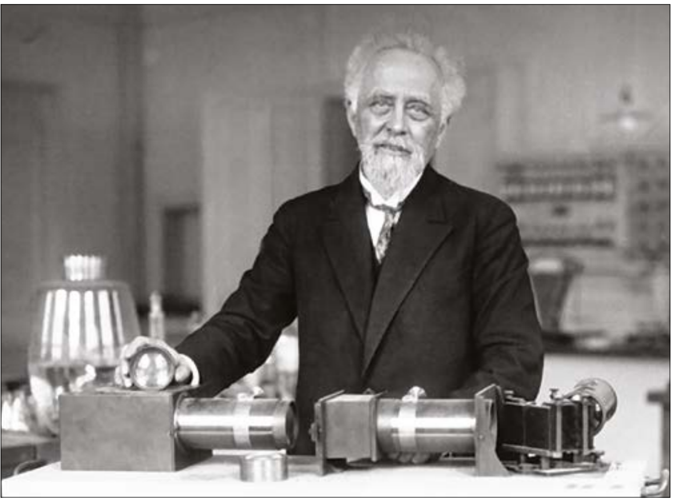
Founded 80 years ago, the French National Centre for Scientific Research (CNRS) is one of Europe's largest research institutions. Ursula Bassler and Denis Guthleben look back at its history and achievements in nuclear and high-energy physics.

Marie Curie once described the laboratory she shared with her husband Pierre as "just a clapboard hut with an asphalt floor and glass roof giving incomplete protection against the rain, without any amenities". Even her colleagues abroad were shocked by their paltry resources. German chemist Wilhelm Ostwald noted: "The laboratory was a cross between a stable and a potato shed, and if it hadn't been for the chemical apparatus, I would have thought it a practical joke." In the 1920s, newspapers showed the desperate situation the French laboratories were in. "There are some in attics, others in cellars, others in the open air..." the *Petit Journal* newspaper reported in 1921. Increasing research funding to elevate France to the level of countries like Germany became a rallying point for the nation.

In the inter-war years, Jean Perrin, winner of the 1926 Nobel Prize in Physics for his work showing the existence of atoms, championed the development of science and had the support of many other scientists. Thanks to financial support from the Rothschild Foundation, he founded the

THE AUTHORS

Ursula Bassler *CNRS National Institute of Nuclear and Particle Physics and president of the CERN Council; and* **Denis Guthleben** *scientific attaché to the committee for the history of CNRS.*


Agence de presse Meurisse

Founding father *CNRS founder Jean Perrin, winner of the 1926 Nobel Prize in Physics for his work on the discontinuous structure of matter, in his laboratory in 1927.*


Curie Archives

Marital bliss *Irène and Frédéric Joliot-Curie in 1935, the year they shared the Nobel Prize in Chemistry for the synthesis of new radioactive elements.*

Institute of Physico-Chemical Biology, the first place to employ researchers full-time. In 1935 he managed to get the National Scientific Research Fund set up to fund academic projects and research fellowships. One of its first fellows was the young Lew Kowarski in 1937, who had joined Frédéric Joliot-Curie's laboratory at the Collège de France. In May 1939, together with Hans von Halban, they filed patents via the fund that outlined the production of nuclear power and the principle of the atomic bomb.

A new government under Léon Blum took office in 1936, and with it came the appointment of France's first under-secretary of state for scientific research. Another first was the inclusion of three women in the government at a time when women still did not have the vote in France. Irène Joliot-Curie took up her post for three months in support of women's rights and scientific research. During this short period, she set out major objectives: an increase in research budgets, salaries and grants for research fellows.

After her resignation, Perrin took over. This sexagenarian with the appearance of a dishevelled scientist "immediately showed the ardour of a young man and the enthusiasm of a beginner, not for the prestige, but for the means of action the post provided", Jean Zay, the very young minister of national education at the time, noted in his memoirs. Over the next four years, his achievements included the opening of laboratories such as the Paris Institute of Astrophysics and culminated in the decree founding CNRS, published in October 1939. Six weeks after the outbreak of the Second World War, Perrin announced: "Science is not possible without freedom of thought, and freedom of thought cannot exist without freedom of conscience. You cannot require chemistry to be Marxist and expect to produce great chemists; you cannot require physics to be 100% Aryan and expect to keep the greatest physicists in your country... Each of us can die, but we want our ideals to live on."

The founding principle of the CNRS "to identify and conduct, alone or with its partners, every type of research in the interest of science and the technological, social and cultural advancement of the country" stands strong today. Around 32,000 people, including 11,000 academics and researchers, currently work at CNRS in collaboration with universities, private laboratories and other organisations. Most of the 1100 CNRS laboratories are co-directed with a partner institution and host CNRS personnel and, in the majority of cases, faculties and academics. These "mixed research units", which were introduced in 1966, form the backbone of French research and allow cutting-edge research to be done whilst being rooted in teaching and contact with students.

The evolution of nuclear and high-energy physics

Under the auspices of the national ministry of higher education, research and innovation, CNRS is France's largest research institution. With an annual budget of €3.4 billion, it covers the whole gamut of scientific disciplines, from the humanities to natural and life sciences, the science of matter and the universe, and from fundamental to applied research. The disciplines are organised thematically into 10 institutes, which manage the scientific programmes and a significant share of the investment in research infrastructure. CNRS plays a coordination role, particularly through its three national institutes, the National Institute of Nuclear and Particle Physics (IN2P3), together with the National Institute of Sciences of the Universe and the National Institute for Mathematical Sciences and their Interactions.

When CNRS was founded, French physicists were among the world-leading: Irène and Frédéric Joliot-Curie, Jean Perrin, Louis de Broglie and Pierre Auger are among the names that have entered the history books from this time. Frédéric Joliot-Curie's laboratory at the Collège de France played a crucial role thanks to its cyclotron, as did Irène Joliot-Curie's Radium Institute, Louis Leprince-Ringuet's laboratory at the École polytechnique and Jean Thibaud's in Lyon. The newly established CNRS put up the funds for facilities, research fellows, technical personnel and chairs of nuclear physics at universities and the elite Grandes Écoles. The war broke out the same year CNRS was founded, bringing everything to a halt: researchers either went into exile or tried to continue running their laboratories in inevitable isolation.

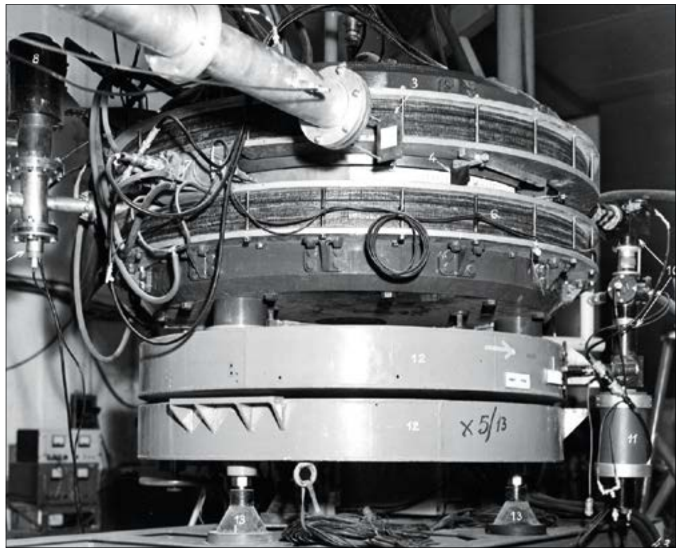
Frédéric Joliot-Curie, buoyed by his involvement in the Resistance, took up the reins of CNRS in August 1944 and strove to help France catch up again after the war, particularly in nuclear physics. After atomic bombs were dropped on Hiroshima and Nagasaki, General de Gaulle asked Frédéric Joliot-Curie and Raoul Dautry, who was minister for reconstruction and urbanism, to set up the Commissariat à l'Energie Atomique (CEA). Frédéric Joliot-Curie saw this organisation as a means of bringing together and coordinating all fundamental research in nuclear physics, including research undertaken in university laboratories. From 1946, all the big names – Auger, Joliot-Curie, Perrin and Kowarski – joined CEA. CNRS was therefore not greatly involved in this area. In 1947 the decision was taken to build a facility in Saclay combining fundamental and applied research. André Berthelot was the director of the nuclear physics division at Saclay and installed several accelerators there.

Founding CERN

In the 1950s French physicists played a key role in the establishment of CERN: Louis de Broglie, the first well-known scientist to call for the creation of a multinational laboratory; Auger, who was director of the department of exact and natural sciences at UNESCO; Dautry, director-general of CEA; Perrin, the high commissioner; and Kowarski, one of CERN's first staff members who later became director of scientific and technical services. He is credited with the construction of the first bubble chamber at CERN and the introduction of computers. Joliot-Curie, relieved of his duties at CEA owing to his political beliefs, was very upset not to be appointed to the CERN Council – unlike Perrin, who succeeded him at CEA. Alive to CERN's potential, Louis Leprince-Ringuet shifted the focus of his teams' research from cosmic rays to accelerators. He became the first French chair of the scientific policy committee (SPC) in 1964 and his laboratory contributed greatly to the involvement of French physicists at CERN.

Another CNRS recruit of the post-war period who also made a name for himself at CERN was Georges Charpak. Securing a research position at CNRS in 1948, he wrote his thesis under the supervision of Frédéric Joliot-Curie, who had wanted to nudge Charpak towards nuclear physics. But he picked his own area: detectors. He was hired at CERN by Leon Lederman in 1963 and went on to develop the multiwire proportional chamber, which replaced bubble chambers and spark chambers by enabling digital processing of the data. The invention won him the 1992 Nobel Prize in Physics.

When he returned to the Collège de France, Frédéric Joliot-Curie joined forces with Irène to create the Orsay campus. Given the prospect of new facilities at CERN, they felt that France needed to develop its own infrastructure to enable French physicists to train and prepare their experiments for CERN. "Helping to create and sustain CERN whilst letting fundamental nuclear-physics research fizzle out in France would be to act against the interests of our country and those of science," Irène Joliot-Curie wrote in *Le Monde*. The government under Pierre Mendès France made research a priority and in 1954 granted funds for the construction of two accelerators, a synchrocyclotron at Irène Joliot-Curie's Radium Institute and a linear accelerator for Yves Rocard's Physics Laboratory at the École normale supérieure. Irène Joliot-Curie secured the plots required in Orsay for the construction of the Orsay Institute of Nuclear Physics (IPNO) and the Linear Accelerator Laboratory (LAL). Irène Joliot-Curie did not live to see the new laboratory, but Frédéric Joliot-Curie became the IPNO's first director, while Hans Halban was called back from England to manage LAL. These two emblematic institutes still play a major role in French contributions to CERN.

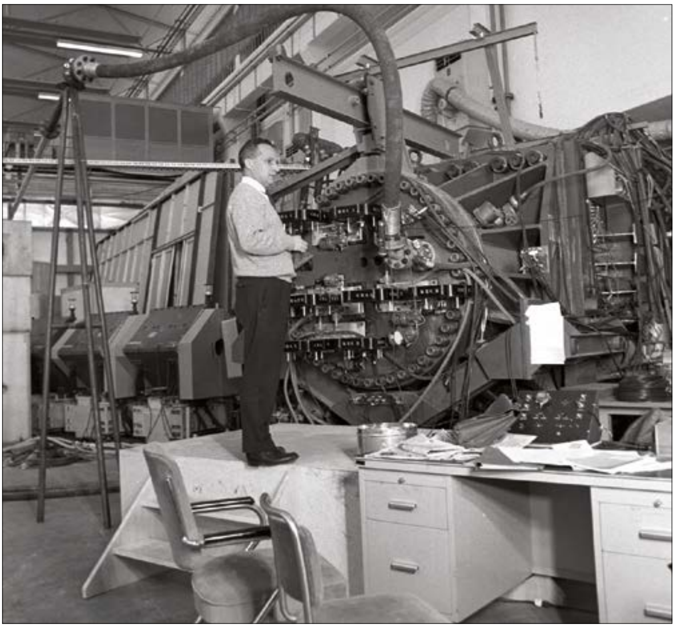

LAL

Big impact *The Italian AdA collider was installed at LAL in Orsay to take advantage of the linear accelerator's higher energies, giving rise to the first electron–positron collisions, before being returned to Frascati.*

From strength to strength

During the 1950s and 1960s CNRS went from strength to strength and set up more laboratories for high-energy and nuclear physics. A Cockroft-Walton accelerator, built in Strasbourg by the Germans during the war, was the seed that grew into the Nuclear Research Centre directed by Serge Gorodetsky. Maurice Scherer's chair in nuclear physics in Caen, created in 1947, evolved into the Corpuscular Physics Laboratory. One of its first doctoral students, Louis Avan, founded the eponymous laboratory in Clermont-Ferrand in 1959. Louis Néel laid the foundations for important physics research in Grenoble, and CEA set up a centre for nuclear studies there in 1956. The Franco-German research reactor was built at the "Institut Laue-Langevin" in Grenoble in 1967. In the same year, the Grenoble Nuclear Science Institute was established, hosting a cyclotron used in particular for the production of radioisotopes for medicine. Its director, Jean Yoccoz, later became a director of IN2P3. The Centre of Nuclear Studies of Bordeaux-Gradignan was established in a disused Bordeaux château in 1969.

The physicists at these laboratories played an active role in CERN experiments, thanks in particular to the flexible


CERN

High ambitions *André Lagarrigue in front of the Gargamelle bubble chamber at CERN.*

secondment policy at CNRS. Among them was Bernard Gregory, who worked at Leprince-Ringuet's laboratory and focused on the construction of a large, 81 cm liquid-hydrogen bubble chamber in Saclay in preparation for the impending commissioning of the Proton Synchrotron (PS) at CERN. It produced more than 10 million pictures of particle interactions, which were shared all over Europe. In 1965 Gregory became the Director-General of CERN. Five years later, he replaced Louis Leprince-Ringuet as the head of the École polytechnique laboratory, and then became director general of CNRS. He was elected President of the CERN Council in 1977.

Managing expansion

In the 1960s research facilities were becoming so large that the idea came about within CNRS to create national institutes to coordinate the laboratories' resources and programmes. LAL director André Blanc-Lapierre campaigned for a National Institute of Nuclear and Particle Physics, following the example of the Italian INFN founded in 1951. The aim was to organise the funding allocated to the various laboratories by CNRS, the universities and CEA. Discussions between the partners then began.

Around 32,000 people currently work at CNRS in collaboration with universities, private laboratories and other organisations

In parallel, French physicists were engaged in another debate. After the construction of the 3 GeV proton accelerator SATURNE at CEA in Saclay in 1958 and the 1.3 GeV electron linear accelerator at LAL in Orsay in 1962, as well as the later ACO collider at ALA in Orsay, opinions were divided about building a national machine that would complement CERN's experimental capabilities and strengthen the French scientific community. Two options were in the running: a proton machine and an electron machine. This decision was especially important since other machines were springing up elsewhere in Europe. In Italy, the electron–positron collider AdA was followed by ADONE in 1969. In Hamburg, Germany, the electron synchrotron DESY was commissioned in 1964.

France's priority, however, was construction at the European level with CERN, so neither of the two proposed projects ever got off the ground. Jean Teillac, who succeeded Frédéric Joliot-Curie as head of the IPNO, founded IN2P3 in 1971, federating the laboratories and the universities of CNRS. It was only later, in 1975, that CEA and IN2P3 decided to collaborate in building a national machine in Caen, the Large Heavy Ion National Accelerator ("Grand Accélérateur National d'Ions Lourds", GANIL), which specialised in nuclear physics. Despite the fact that the CEA laboratories involved were not part of IN2P3, the physicists of the two organisations collaborated extensively.

In this context, André Lagarrigue, who had been the director of LAL since 1969, proposed the construction of a new bubble chamber, Gargamelle, on a neutrino beam at CERN. The scientist had previously investigated the feasibility of bubble chambers containing heavy liquids that would favour interactions with neutrinos instead of hydrogen at the École polytechnique. After its construction at Saclay, the chamber filled with liquid freon was installed at CERN and detected neutral currents in 1973. This was a major discovery, which certainly would have won Lagarrigue a Nobel prize had he not died of a heart attack in 1975.

Then to now

Today, IN2P3 has around 20 laboratories and some 3200 staff, including 1000 academics and researchers in nuclear physics, particle physics, astroparticle physics and cosmology. The institute contributes to the development of accelerators, detectors and observation instruments and their applications to societal needs. Its data centre in Lyon plays an important role in processing and storing large volumes of data, as well as housing the digital infrastructure for other disciplines.

IN2P3 has had strong links with CERN through many projects and experiments. These include: the discovery of the W and Z bosons by UA1 and UA2; contributions to ALEPH, DELPHI and L3 at LEP; the discovery of the Higgs boson by ATLAS and CMS at the LHC; flavour studies at LHCb and heavy-ion physics at ALICE; neutrino physics; CP violation; antimatter experiments, as well as nuclear physics. These joint ventures also involve other CNRS institutes like the INP (Institute of Physics), with its specialists in quantum physics and lasers, as well as in strong magnetic fields.

Future CERN projects are currently being discussed in the update of the European strategy for particle physics. They offer the prospect of new collaborations between CERN and CNRS in high-energy physics, but also in engineering, computing, biomedical applications and even the humanities and social sciences. No doubt the synergy between these two organisations, with their exceptionally rich scientific knowledge, will continue to give birth to exciting new research. ●

● A French version of this article is available at cerncourier.com/a/lessor-de-la-physique-des-particules-en-france.

OPINION VIEWPOINT

Why CLIC?

Steinar Stapnes considers the past, present and future of CERN's proposed Compact Linear Collider.

Steinar Stapnes *is linear-collider study leader at CERN.*


CERN

Straight thinking *CLIC is one of several options being considered for a post-LHC collider.*

There is an increasing consensus that the next large accelerator after the LHC should be an electron–positron collider. Several proposals are on the table, circular and linear. Around 75 collaborating institutes worldwide are involved in the CERN-hosted studies for the Compact Linear Collider (CLIC), which offers a long-term and flexible physics programme that is able to react to discoveries and technological developments.

The 11 km-long initial stage of CLIC is proposed for operation at a centre-of-mass energy of 380 GeV, providing a rich programme of precision Higgs-boson and top-quark measurements that reach well beyond the projections for the high-luminosity LHC. From a technical point of view, operation of the initial stage by around 2035 is possible, with a cost of approximately 5.9 billion Swiss francs. This is similar to the cost of the LHC and of the proposed International Linear Collider in Japan, and considerably less than that of future circular lepton colliders.

Extensions beyond the initial CLIC energy into the multi-TeV regime allow much improved precision on Standard Model (SM) measurements and greater reach for physics beyond the SM, with upgrade costs of 5 (to 1.5 TeV) and 7 billion Swiss francs (to 3 TeV) for the two further stages. A key part of the CLIC study has been the physics and detector studies showing that beam-induced backgrounds can indeed be mitigated, compatible with the clean experimental conditions expected in electron–positron colliders.

The question of what follows after the initial stage of a linear electron–positron collider is premature to answer

The question of what follows after the initial stage of a linear electron–positron collider is premature to answer. It is crucial to choose the most flexible approach now, and to develop technically mature and affordable options, encouraging a broad and exciting R&D programme. The option of expanding CLIC from its initial phase is already built into its staging scheme. Novel acceleration technologies can potentially push linear colliders even further in energy, although significantly more work is needed on beam qualities and energy efficiency for such options. High-energy proton and muon colliders are also potential future directions that need to be developed. While for protons the challenges are related to magnet performance, collider size and costs, for muons the technical design concepts need to mature and the radiation and experimental conditions need to be better understood.

CLIC offers a unique combination of precision and energy reach, and has a long history dating back to around 1985. At that time, the LEP tunnel was under construction and the first LHC workshop had just taken place. The motivation then was to move well beyond the W- and Z-boson studies foreseen at LEP to search for and study the top quark, Higgs boson and possible supersymmetric particles in a mass range from hundreds of GeV to several TeV. After the top-quark discovery at Fermilab and Higgs-boson discovery at CERN, we know that CLIC can do exactly that – even though the search arena for new physics is much more open than considered at that time.

Successful formula

High-energy electron–positron collisions, together with proton–proton or proton–antiproton collisions, have been a successful formula for progress in particle physics for half a century. Increasing the energy and luminosity of such machines is challenging. CLIC's drive-beam concept was instrumental in providing a credible and scalable powering option at multi-TeV energies. A cost optimisation combined with the practical need of radio-frequency (RF) power units for R&D and testing led to the present normal-conducting 12 GHz "X-band" accelerating structures with an accelerating gradient of up to 100 MV/m. In parallel, CLIC's energy use at 380 GeV has been scrutinised to keep it well below CERN's annual consumption today, and less than 50% of the estimation for a future circular electron–positron collider.

The next steps needed for CLIC are clear. The project-implementation plan foresees a five-year preparation phase prior to construction, which is envisaged to start by 2026. The preparation phase would focus on further design optimisation and technical and industrial development of critical parts of the accelerator. System verification in free-electron-laser linacs and low-emittance rings will be increasingly important for performance studies, while civil engineering and infrastructure preparation will become progressively more detailed, in parallel with an environmental impact study. Detector preparation will need to be scaled up, too.

The increasing use of X-band technology – either as the main RF acceleration for CLIC or for compact test facilities, light sources, medical accelerators or low-energy particle physics studies – provides new collaborative opportunities towards a technical design report for the CLIC accelerator.

It is for the broader particle-physics community and CERN to decide whether CLIC proceeds. We are therefore eagerly looking forward to the conclusion of the European strategy process next year. For now, it is important to communicate how CLIC-380 can be implemented rapidly involving many collaborative partners, and at the same time provide unique and timely opportunities for R&D to keep future options open.

For mass flow rates > 0 kg/h

The world's smallest dual-tube Coriolis mass flow metre: high-precision measurements within 150 mm

Device in dual-tube design insensitive to pressure, impact and vibrations

For the measurement of very small flow rates, due to the weight influence of the sensor coils it is common practice to use single-tube Coriolis flow metres. The sensor coils of dual-tube Coriolis sensors are mounted onto one of two measuring tubes, and as the diameters of the tubes are very small, they have a significant weight influence on the tube on which they are mounted.

Therefore, the influence of the sensor coils on the measurement results increases with decreasing tube diameter. For this reason, single tubes are often favoured for the measurement of very small flow rates, where the coils are mounted onto the chassis and not on tube. However, with the use of just one measuring tube the influence of external interference increases dramatically. To reduce this sensitivity and at the same time deliver accurate measurements at very small flow rates, Heinrichs Messtechnik has developed the dual-tube Coriolis principle to a new level.

In this new state-of-the-art technology, the sensor coils are no longer mounted onto the tubes, but rather between them, thus freeing the measuring tubes from the influence of the coils' weight, and allowing for extremely small tube diameters in the dual-tube design.
The result is the world's smallest dual-tube Coriolis mass flow metre: the high-performance Coriolis (HPC). With an installation length of just 150 mm, it is now possible to achieve high-accuracy measurements with deviations of just ± 0.1%. Furthermore, the sensor shows insensitivity to temperatures of up to 180 °C, to pressures of up to 600 bar and to strong vibrations.

"Market observations have revealed an open gap in the measurement of small flow rates," explains Frank Schramm, managing director of Heinrichs Messtechnik GmbH. The current problem is that the state-of-the-art stipulates the use of dual-tube technology, where the magnets are mounted onto one tube, the exciter and sensor coils to the other. However, for very small flow rates this principle has a decisive limit. For example, where extremely small flow rates demand a tube diameter of just 1 mm, the vibrating behaviour of the weight of the coils can influence the measurement results significantly. "It is therefore common practice to use one tube system for these applications, in which the coils are mounted to the chassis of the sensor. This system has the decisive disadvantage in that the second tube, which also serves as a measurement reference, is omitted, requiring the sensor coils to be mounted onto the chassis of the enclosure, thus making the sensor more susceptible to vibrations and other disturbances.

Heinrichs Messtechnik GmbH have developed the smallest dual-tubed Coriolis mass flow metre in the world: the high-performance Coriolis (HPC). With an installation length of just 150 mm, high-accuracy measurements are achieved with deviations of just ±0.1%
Source: Heinrichs Messtechnik GmbH

For this reason, Heinrichs Messtechnik GmbH set an objective to develop a high-precision, shock-resistant Coriolis mass flow metre. Called the high-performance Coriolis (HPC), it has an installation length of just 150 mm, the smallest Coriolis mass flow metre in dual-tube design.

Instead of mounting the coils onto the tubes, the manufacturer chose to mount them onto a PCB situated between the measuring tubes. By simultaneously doubling the number of pick-up coils from two to four, the resolution is increased significantly.
Source: Heinrichs Messtechnik GmbH

Reducing the influence of disturbances by positioning the sensor coils between the measuring tubes

"Due to the sensitivity of single-tube Coriolis sensors, a costly mechanical decoupling is often required, rendering them inappropriate for many applications. Our quest was therefore to find a means of unifying a dual-tube design with very small diameter tubes," explains Schramm. Since the fundamental problem lies in the weight of the coils, which when compared with tube diameters of 1.5 mm or less presents a significant weight, Heinrichs Messtechnik adopted the following solution: a conventional approach of mounting the coils onto the tubes was abandoned in favour of their mounting on a printed circuit board placed between the tubes. This method also enables the use of four sensor coils instead of two, as is usually the case with a dual-tube Coriolis, providing a higher resolution.

On the measuring tubes themselves, only very light magnets are mounted, which, with a weight of only 0.08g, have little to no influence on the vibrating behaviour of the tubes. Instead of conventional brazing, the magnet holders are mounted onto the tubes using a special laser-welding technology. Utilising this method, Heinrichs Messtechnik aims to keep the production costs of the sensor to an absolute minimum, which not only allows for a stress free connection, but also eliminates the time-consuming and elaborate process of brazing in a vacuum oven.

With the exception of the laser-welded measuring tubes, the HPC essentially consists of a solid, drilled and tapped stainless-steel block. The result is an extremely robust device capable of withstanding temperatures and pressures of up to 180 °C and 600 bar, respectively. Source: Heinrichs Messtechnik GmbH

Insensitive to external influences

Using the dual-tube design, the new HPC displays extreme insensitivity towards external influences, allowing for precise measurements with a maximum deviation of ±0.1% of the mean value and a zero-point stability between 0.001 and 0.005, making a mechanical decoupling superfluous in most cases. Owing to the measuring tubes' high working frequency of over 200 Hz, the coupling of installation vibrations or similar oscillations into the measuring system is prevented, and so avoids fault signals. A further advantage in mounting the sensor coils on a motionless PCB is the elimination of open wiring within the sensor, as is the case in standard, commercially available devices. This wiring often presents a vulnerable weak point, since the wire and its point of connection must vibrate continuously with the frequency of the measuring tubes.

With the exception of the laser-welded measuring tubes, the HPC consists essentially of a solid drilled and tapped stainless-steel block. Furthermore, the HPC has been stripped of a splitter at the inflow of the tubes, instead possessing a reservoir – in which the process pressure distributes the fluid exactly into the measuring tubes, hence preventing the flow disturbances generally caused by splitters. This technique has the time-saving advantage of one less component to weld as well as one less potential material stress source. The result is an extremely robust device capable of withstanding temperatures and pressures of up to 180 °C and 600 bar, respectively. "In principle, the device may also be ordered with Hastelloy tubes and other alloys," adds Schramm.

Variable assembly concept

For flexible installations, different constructive variations of the HPC are available: besides the traditional inline version, which can be inserted directly into the process line, there are three further models that are suitable for either wall mounting, by means of wall brackets, or may simply be placed on a table. "For our table model there are two available options: with the measuring pipes pointing either downwards below the supply line or upwards above it. For the measurement of gas, upward-pointing tubes are recommended to prevent any issues with fluid collecting in the tubes. The same is also the case, vice versa, for the measurement of fluids," Schramm remarks.

Collectively, the devices are available in three measuring ranges: 0–20, 0–50 and 0–160 kg/h. On request, other adaptations can also be provided, for example, customer-specific enclosures, connectors or interfaces. In particular for the chemical and semiconductor industry, fully-welded stainless-steel enclosures are also available.

Rapid development success with high-end simulation

The whole of the development phase took a mere 1.5 years. To achieve this, Heinrichs Messtechnik utilised a state-of-the-art simulation technology. "By these means the required number of prototypes was drastically reduced, thus lowering the development costs significantly," Schramm says contentedly. Furthermore, with the aid of the simulation technology, customer-specific requirements can be captured and individual solutions presented in the shortest of time frames.

Providing a flexible installation concept, different versions of the HPC are available

Besides the traditional inline version, which can be inserted directly into the process line, there are three further models available, which are suitable for either wall or table mounting.

The HPC was presented for the first time at the Hannover trade fair from 23–27 April, which was simultaneously the official sales launch. Furthermore, ATEX and IECEx approvals are also planned, as well as a patent registration of the technology. Parallel to the sales launch, Heinrichs Messtechnik is also working on a new miniaturised transmitter with flexible interfaces, which is specially designed for compatibility with the HPC.

Further information can be found at:
www.heinrichs.eu

Founded in 1911 in Dusseldorf, Heinrichs Messtechnik has played a decisive role in the development and marketing of flow metres for over 100 years, one of its core target groups from the very beginning being the chemical and petrochemical industries. For this reason, the development of full-metal area flow metres was driven from the early 1960s onwards. In the mid-1980s Heinrichs was the first European company to develop and market a mass flow metre according to the Coriolis principle, systematically increasing its range of Coriolis metres in the following years.

Today, Heinrichs Messtechnik supplies customers in numerous industries such as chemical, oil/gas, energy, construction and mechanical engineering. In 2008 Heinrichs Messtechnik was integrated into the Kobold Group, providing it with immediate access to the group's substantial worldwide sales network. At present, a staff of 60 is employed at the company's main site in Cologne, where all products are developed and manufactured within its own premises.

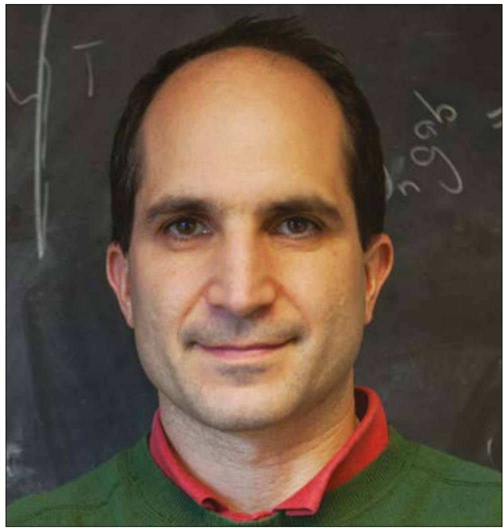
Gauge–gravity duality opens new horizons

In 1997, Juan Maldacena conjectured a deep relationship between gravity and quantum field theory that continues to offer insights into black holes and the search for quantum gravity.

What, in a nutshell, did you uncover in your famous 1997 work, which became the most cited in high-energy physics?
The paper conjectured a relation between certain quantum field theories and gravity theories. The idea was that a strongly coupled quantum system can generate complex quantum states that have an equivalent description in terms of a gravity theory (or a string theory) in a higher dimensional space. The paper considered special theories that have lots of symmetries, including scale invariance, conformal invariance and supersymmetry, and the fact that those symmetries were present on both sides of the relationship was one of the pieces of evidence for the conjecture. The main argument relating the two descriptions involved objects that appear in string theory called D-branes, which are a type of soliton. Polchinski had previously given a very precise description for the dynamics of D-branes. At low energies a soliton can be described by its centre-of-mass position: if you have N solitons you will have N positions. With D-branes it is the same, except that when they coincide there is a non-Abelian SU(N) gauge symmetry that relates these positions. So this low-energy theory resembles the theory of quantum chromodynamics, except that with N colours and special matter content.

On the other hand, these D-brane solitons also have a gravitational description, found earlier by Horowitz and Strominger, in which they look like "black branes" – objects similar to black holes but extended along certain spatial directions. The conjecture was simply that these two descriptions should be equivalent. The gravitational description becomes simple when N and the effective coupling are very large.

Did you stumble across the duality, or had you set out to find it?
It was based on previous work on the connection between D-branes and black holes. The first major result in this direction was the computation of Strominger and Vafa, who considered an extremal black hole and compared it to a collection of D-branes. By computing the number of states into which these D-branes can be arranged, they found that it matched the Bekenstein–Hawking black-hole entropy given in terms of the area of the horizon. Such black holes have zero temperature. By slightly exciting these black holes some of us were attempting to extend such results to non-zero temperatures, which allowed us to probe the dynamics of those nearly extremal black holes. Some computations gave similar answers, sometimes exactly, sometimes up to coefficients. It was clear that there was a deep relation between the two, but it was unclear what the concrete relation was. The gravity–gauge (AdS/CFT) conjecture clarified the relationship.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Lasting impact *Theorist Juan Maldacena of the Institute for Advanced Study in Princeton.*

One of the most interesting recent lessons is the important role that entanglement plays in constructing the geometry of spacetime

Are you surprised by its lasting impact?
Yes. At the time I thought that it was going to be interesting for people thinking about quantum gravity and black holes. But the applications that people found to other areas of physics continue to surprise me. It is important for understanding quantum aspects of black holes. It was also useful for understanding very strongly coupled quantum theories. Most of our intuition for quantum field theory is for weakly coupled theories, but interesting new phenomena can arise at strong coupling. These examples of strongly coupled theories can be viewed as useful calculable toy models. The art lies in extracting the right lessons from them. Some of the lessons include possible bounds on transport, a bound on chaos, etc. These applications involved a great deal of ingenuity since one has to extract the right lessons from the examples we have in order to apply them to real-world systems.

What does the gravity–gauge duality tell us about nature, given that it relates two pictures (e.g. involving different dimensionalities of space) that have not yet been shown to correspond to the physical world?
It suggests that the quantum description of spacetime can be in terms of degrees of freedom that are not localised in space. It also says that black holes are consistent with quantum mechanics, when we look at them from the outside. More recently, it was understood that when we try to describe the black-hole interior, then we find surprises. What we encounter in the interior of a black hole seems to depend on what the black hole is entangled with. At first this looks inconsistent with quantum mechanics, since we cannot influence a system through entanglement. But it is not. Standard quantum mechanics applies to the black hole as seen from the outside. But to explore the interior you have to jump in, and you cannot tell the outside observer what you encountered inside.

One of the most interesting recent lessons is the important role that entanglement plays in constructing the geometry of spacetime. This is particularly important for the black-hole interior.

I suspect that with the advent of quantum computers, it will become increasingly possible to simulate these complex quantum systems that have some features similar to gravity. This will likely lead to more surprises.

In what sense does AdS/CFT allow us to discuss the interior of a black hole?
It gives us directly a view of a black hole from the outside, more precisely a view of the black hole from very far away. In principle, from this description we should be able to understand what goes on in the interior. While there has been some progress on understanding some aspects of the interior, a full understanding is still lacking. It is important to understand that there are lots of weird possibilities for black-hole interiors. Those we get from gravitational collapse are relatively simple, but there are solutions, such as the full two-sided Schwarzschild solution, where the interior is shared between two black holes that are very far away. The full Schwarzschild solution can therefore be viewed as two entangled black holes in a particular state called the thermofield double, a suggestion made by Werner Israel in the 1970s. The idea is that by entangling two black holes we can create a geometric connection through their interiors: the black holes can be very far away, but the distance through the interior could be very short. However, the geometry is time-dependent and signals cannot go from one side to the other. The geometry inside is like a collapsing wormhole that closes off before a signal can go through. In fact, this is a necessary condition for the interpretation of these geometries as entangled states, since we cannot send signals using entanglement. Susskind and myself have emphasised this connection via the "ER=EPR" slogan. This says that EPR correlations (or entanglement) should generally give rise to some sort of "geometric" connection, or Einstein–Rosen bridge, between the two systems. The Einstein–Rosen bridge is the geometric connection between two black holes present in the full Schwarzschild solution.

One can find solutions of the Standard Model plus gravity that look like two microscopic magnetically charged black holes joined by a wormhole

Are there potential implications of this relationship for intergalactic travel?
Gao, Jafferis and Wall have shown that an interesting new feature appears when one brings two entangled black holes close to each other. Now there can be a direct interaction between the two black holes and the thermofield double state can be close to the ground state of the combined system. In this case, the geometry changes and the wormhole becomes traversable.

In fact, as shown by Milekhin, Popov and myself, one can find solutions of the Standard Model plus gravity that look like two microscopic magnetically charged black holes joined by a wormhole. We could construct a controllable solution only for small black holes because we needed to approximate the fermions as being massless.

If one wanted a big macroscopic wormhole where a human could travel, then it would be possible with suitable assumptions about the dark sector. We'd need a dark U(1) gauge field and a very large number of massless fermions charged under U(1). In that case, a pair of magnetically charged black holes would enable one to travel between distant places. There is one catch: the time it would take to travel, as seen by somebody who stays outside the system, would be longer than the time it takes light to go between the two mouths of the wormhole. This is good, since we expect that causality should be respected. On the other hand, due to the large warping of the spacetime in the wormhole, the time the traveller experiences could be much shorter. So it seems similar to what would be experienced by an observer that accelerates to a very high velocity and then decelerates. Here, however, the force of gravity within the wormhole is doing the acceleration and deceleration. So, in theory, you can travel with no energy cost.

How does AdS/CFT relate to broader ideas in quantum information theory and holography?
Quantum information has been playing an important role in understanding how holography (or AdS/CFT) works. One important development is a formula, due to Ryu and Takayanagi, for the fine-grained entropy of gravitational systems, such as a black hole. It is well known that the area of the horizon gives the coarse-grained, or thermodynamic, entropy of a black hole. The fine-grained entropy, by contrast, is the actual entropy of the full quantum density matrix describing the system. Surprisingly, this entropy can also be computed in terms of the area of the surface. But it is not the horizon, it is typically a surface that lies in the interior and has a minimal area.

If you could pick any experiment to be funded and built, what would it be?
Well, I would build a higher energy collider, of say 100 TeV, to understand better the nature of the Higgs potential and look for hints of new physics. As for smaller scale experiments, I am excited about the current prospects to manipulate quantum matter and create highly entangled states that would have some of the properties that black holes are supposed to have, such as being maximally chaotic and allowing the kind of traversable wormholes described earlier.

How close are we to a unified theory of nature's interactions?
String theory gives us a framework that can describe all the known interactions. It does not give a unique prediction, and the accommodation of a small cosmological constant is possible thanks to the large number of configurations that the internal dimensions can acquire. This whole framework is based on Kaluza–Klein compactifications of 10D string theories. It is possible that a deeper understanding of quantum gravity for cosmological solutions will give rise to a probability measure on this large set of solutions that will allow us to make more concrete predictions.

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

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OPINION LETTER

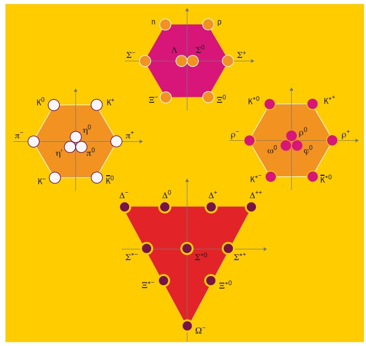
Quirks in the quark story

Your tributes to Murray Gell-Mann (*CERN Courier* July/August 2019 pp25–35) missed interesting details about the history of the quark model. During the 1950s, 1960s and early 1970s, Gell-Mann was indeed a dominant figure in theoretical particle physics, making many seminal contributions, particularly in the classification of particles and their symmetries. These included the proposal of the strangeness quantum number, the SU(3) symmetry of hadrons and the eightfold way, current algebra and quarks. Others also contributed to some of these ideas, such as Kazuhiko Nishijima and Abraham Pais for strangeness and Yuval Ne'eman for SU(3).

In recent years, the role of George Zweig in the quark story has been increasingly recognised. While a postdoc at CERN, on 17 January 1964, just a couple of weeks after Gell-Mann's paper on quarks was received by *Physics Letters* (4 January, though rumour says it had previously been considered by *Physical Review Letters*), Zweig wrote a paper proposing hadronic constituents that he called "aces", followed on 24 February by a more complete description of his model. Zweig's ideas were treated with scepticism by the CERN theoretical leadership of the day, and he was denied permission to submit his work to a US journal. His papers remained unpublished, which undoubtedly diminished their impact.

Less well known are the contributions of two other theorists. One was André Petermann of CERN, who proposed hadronic constituents in a paper that was submitted to *Nuclear Physics* on 30 December 1963, before Gell-Mann's *Physics Letters* submission. However, the impact of Petermann's work was reduced by the fact that he wrote his paper in French, and that publication was delayed until March 1965. Was this because of a sceptical referee, or perhaps Petermann's dilatory handling of the proofs? Additionally, there are no records of Petermann ever making any effort to publicise these ideas.

Digging deeper, according to Robert Serber (a professor at Columbia University at the time) in his book *Peace & War*, he came up with the idea of three constituents of hadrons in March 1963 while trying to understand representations of SU(3), and mentioned the idea to Gell-Mann over lunch when he came to give a colloquium at Columbia. Again, according to Serber, Gell-Mann immediately figured out that these constituents would have fractional charges, and said that their existence "would be a strange quirk of nature, and quirk was jokingly transformed into quark".



Strong architecture *Hadron multiplets.*

A Tovey

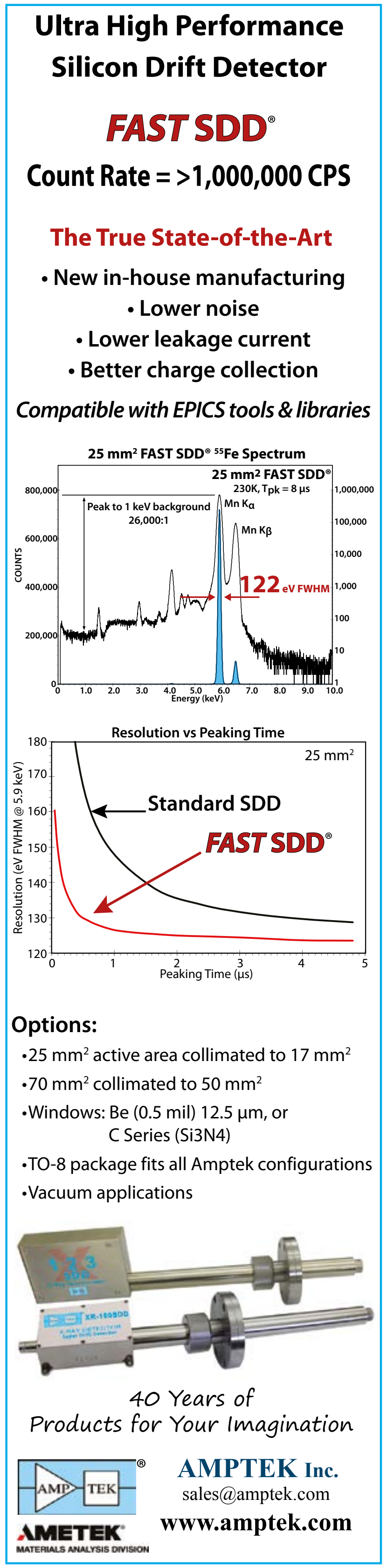
Serber also writes that he worked out shortly later that his model would make quite good predictions for the magnetic moments of the proton and neutron. However, Serber never published his idea, supposedly because he thought it must be familiar to the experts in the field. As a result, his claim to credit for the quark idea is weaker than that of Zweig or Petermann. However, Gell-Mann acknowledges him in his quark paper: "These ideas were developed … in March 1963; the author would like to thank Professor Robert Serber for stimulating them."

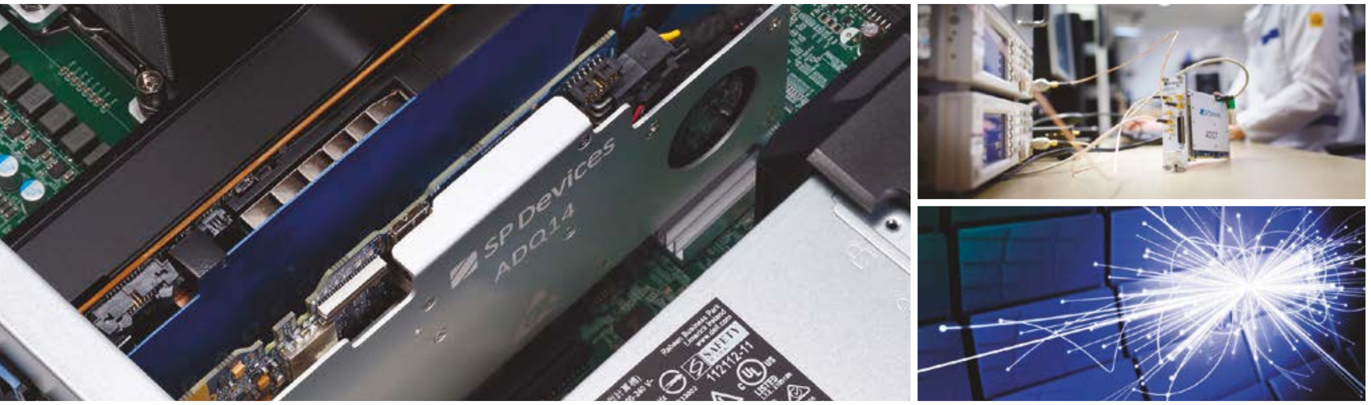
It took some time for the quark idea to gain wide acceptance, a contributing factor being Gell-Mann's insistence for some time that quarks should be regarded as "purely mathematical" entities. For several years, one of the principal proponents of the reality of quarks was Richard Dalitz of Oxford University, who led the way in showing that the quark model gives an excellent description of the spectrum of strongly interacting particles. But the quark model did not gain general acceptance until some time after the advent of deep-inelastic electron- and neutrino-hadron scattering. These results also provided the first tentative evidence for the physical reality of gluons, which Gell-Mann had also doubted.

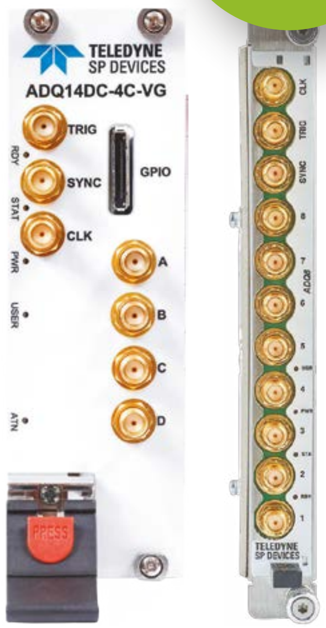
The proposal of a new underlying layer of strongly-interacting constituents required considerable temerity and met widespread doubts: perhaps it is not surprising that many of its proponents were so timorous?

John Ellis *King's College London.*

● Further details about the early history of quarks can be read in an article by CERN theorist Alvaro De Rujula (*CERN Courier* May 2014 p35) and on *cerncourier.com*.







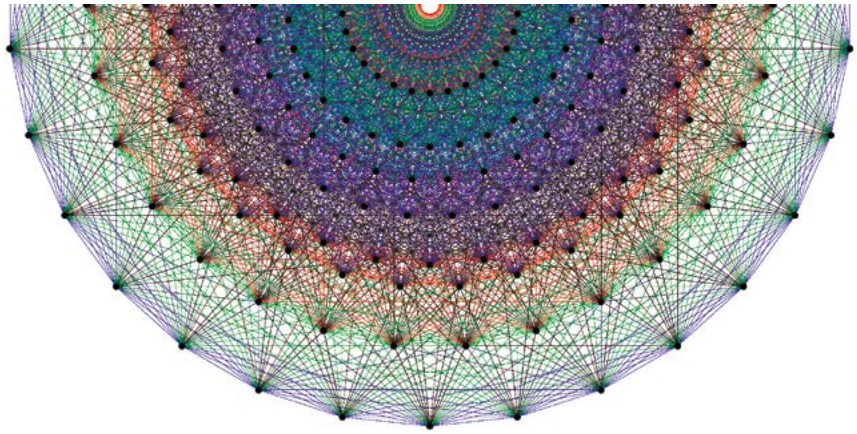
OPINION REVIEWS

Redeeming the role of mathematics

The Universe Speaks in Numbers: How Modern Math Reveals Nature's Deepest Secrets

By Graham Farmelo

Basic Books



Pieces of E_8 *With applications in supergravity and string theory, the Lie group represented here is an example of mathematical complexity in theoretical physics that is not yet grounded in experiment.*

Jgmoxness

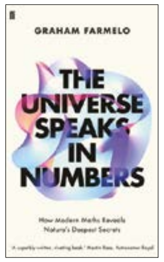
A currently popular sentiment in some quarters is that theoretical physics has dived too deeply into mathematics, and lost contact with the real world. Perhaps, it is surmised, the edifice of quantum gravity and string theory is in fact a contrived Rube–Goldberg machine, or a house of cards that is about to collapse – especially given that one of the supporting pillars, namely supersymmetry, has not been discovered at the LHC. Graham Farmelo's new book sheds light on this issue.

The universe speaks in numbers, reads Farmelo's title. With hindsight this allows a double interpretation: first, that it is primarily mathematical structure which underlies nature. On the other hand, one can read it as a caution that the universe speaks to us purely via measured numbers, and theorists should pay attention to that. The majority of physicists would likely support both interpretations, and agree that there is no real tension between them.

The author, who was a theoretical physicist before becoming an award-winning science writer, does not embark on a detailed scientific discussion of these matters, but provides a historical *tour de force* of the relationship between mathematics and physics, and their tightly correlated evolution. At the time of the ancient Greeks, there was no distinction between these fields, and it was only from about the 19th century onwards that they were viewed as separate. Evidently, a major factor was the growing role of experiments, which provided a firmer grounding in the physical world than what had previously been called natural philosophy.

The book follows the mutual fertilisation of mathematics and physics through the last few centuries as the disciplines gained momentum with Newton, and exploded in the 20th century. Along the way it peeks into the thinking of notable mathematicians and physicists, often with strong opinions. For example, Dirac, a favourite of the author, is quoted as reflecting both that "Einstein failed because his mathematical basis... was not broad enough" and that "theoretical physicists should not allow themselves to be distracted by every surprising experimental finding". The belief that mathematical structure is at the heart of physics and that experimental results ought to have secondary importance holds sway in this section of the book. Such thinking is perhaps the result of selection bias, however, as only scientists with successful theories are remembered.

The detailed exposition makes the reader vividly aware that the relationship between mathematics and physics is a roller coaster loaded with mutual admiration, contempt, misunderstandings, split-ups and re-marriages. Which brings us, towards the end of the book, to the current state of affairs in theoretical high-energy physics, which most of us in the profession would agree is characterised by extreme mathematical and intellectual sophistication, paired with a stunning lack of experimental support. After many decades of flourishing interplay, which provided, for example, the group-theoretical underpinning of the quark model, the geometry of gauge theories, the algebraic geometry of supersymmetric theories and finally strings, is there a new divorce ahead? It appears that some not only desire, but relish the lack of supporting experimental evidence. This concern is also expressed by the author, who criticises self-declared experts who "write with a confidence that belies the evident slightness of their understanding of the subject they are attacking."



The last part of the book is the least readable. Based on personal interactions with physicists, the exposition becomes too detailed to be of use to the casual, or lay reader. While there is nothing wrong with the content, which is exciting, it will only be meaningful to people who are already familiar with the subject. On the positive side, however, it gives a lively and accurate snapshot of today's sociology in theoretical particle physics, and of influential but less well known characters in the field.

The Universe Speaks in Numbers illuminates the role of mathematics in physics in an easy-to-grasp way, exhibiting in detail their interactive co-evolution until today. A worthwhile read for anybody, the book is best suited for particle physicists who are close to the field.

Wolfgang Lerche *CERN.*

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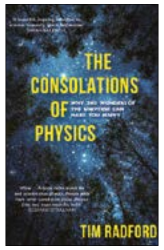
The Consolations of Physics: Why the Wonders of the Universe Can Make You Happy

By Tim Radford

Sceptre



As someone who lives and breathes physics every day, I have to confess that when I curl up with a book, it's rarely a popularisation of science. But when I saw that Tim Radford had written such a book, and that it was all about how physics can make you happy, it went straight to the top of my reading list.

Despite Radford's refusal to be pigeonholed as a science journalist, insisting instead that a good journalist moves from beat to beat, never colonising any individual space, he was science correspondent for *The Guardian* for a quarter of a century. Now retired, he remains one of the most respected science writers around.

The book is a joy to read. More a celebration of human curiosity than a popular science book, it's an antidote to the kind of narrow populism so prevalent in popular discourse today: a timely reminder of what we humans are capable of when we put differences aside and work together to achieve common goals.

The Voyager mission, along with LIGO and the LHC, serves as a guiding thread through Radford's vast and winding exploration of human curiosity. Right from the opening lines, the reader is taken on a breathtaking tour of the full spectrum of human inventiveness, from science to religion, and from art to philosophy. On the way, we encounter thinkers as diverse as St Augustine, Dante and H G Wells. Boethius, who took consolation in philosophy as he languished in a sixth-century jail is another recurring presence, the book's title being a nod to him.

We're treated to a concise and clear consideration of the roles of science and religion in human societies. "Religious devotion demands unquestioning faith," says Radford, whereas "science demands a state of mind that is always open to doubt". While many can enjoy both, he concludes that it may be easier to enjoy science because it represents truth in a way that can be tested.

No sooner have we dealt with religion than we find ourselves listening to echoes of the great Richard Feynman as Radford considers the beauty of a dew-laden cobweb on an English autumn morning. "Does it make it any less magical a sight to know that this web was spun from a protein inside the spider?", he asks, bringing to mind Feynman's wonderful monologue about the beauty of a flower in Christopher Sykes' equally wonderful 1981 documentary, The Pleasure of Finding Things Out. Both conclude that science can only enhance the aesthetic beauty of the natural world.

The overall effect is a bit like a roller-coaster ride in the dark: you're never quite sure when the next turn will come, or where it will take you. That's part of the joy of the book. There are few writers who could pull so many diverse threads together, spanning such a broad spectrum of time and subjects. Radford pulls it off brilliantly.

Someone expecting a popularisation of physics might be disappointed. Indeed, the physics is sometimes a little cursory. Yes, the LHC takes us back to the first unimaginably brief instants of the universe's life, and that's indeed something that catches the imagination. But that's just a part of what the LHC does – it's also about the here and now, and it's about the future as well. But to dwell on such things would be to miss the point of this book entirely.

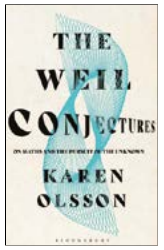
An elegant manifesto for physics is how the publisher describes this book, but it's more than that. It's a celebration of the best in humanity, built around the successes of CERN, LIGO and most of all the Voyager mission. What such projects bring us may be intangible and uncertain, but their results are available to all, and they enrich anyone who cares to look. Like any good roller coaster, when you get off, you just want to get right back on again, because if there's something else that can make you happy, it's Tim Radford's writing.

James Gillies *CERN.*

The Weil Conjectures

By Karen Olsson

Bloomsbury



"I am less interested in mathematics than in mathematicians," wrote Simone Weil to her brother André, a world-class mathematician who was imprisoned in Rouen at the time. The same might be said about US novelist and onetime mathematics student Karen Olsson. Despite the title, her new book, *The Weil Conjectures*, stars the extraordinary siblings at the expense of André's mathematical creation.

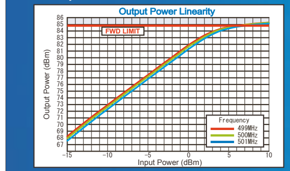
First conceived by André in prison, and finally proven three decades later by Pierre Deligne in 1974, the Weil conjectures are foundational pillars of algebraic geometry. Linking the continuous and the discrete, and the realms of topology and number theory, they are pertinent to efforts to unite gravity with the quantum theories of the other forces. Frustratingly, though, mathematical hobbyists hoping for insights into the conjectures will be disappointed by this book, which instead zeroes in on the people in orbit around the maths.

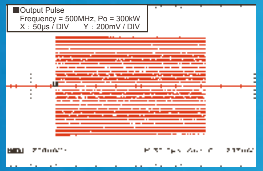
Olsson is particularly fascinated by Simone Weil. An iconoclastic public intellectual in France, and possessed by an intensely authentic humanity that the author presents as quite alien to André, Simone was nevertheless envious of her brother's mathematical insight, writing that she "preferred to die than to live without that truth". Olsson is clearly empathetic, and so, one would suspect, will be most readers in a profession where intellect is all. Whether one is a grad student or a foremost expert in the field, there is always someone smarter, whose insights seem inaccessible.

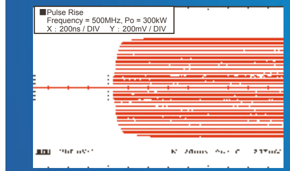
Physicists may also detect echoes of the current existential crisis in theoretical physics (see Redeeming the role of mathematics, p49) in Simone's thinking. While she feels that "unless one has exercised one's mind at the gymnastics of mathematics, one is incapable of precise thought, which amounts to saying that one is good for nothing," she criticises "the absolute dominion that is exercised over science by the most abstract forms of mathematics."

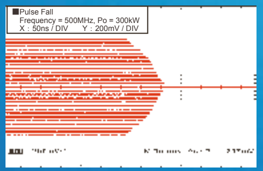
Peppered with anecdotes about other mathematicians – Girolamo Cardano is described as a "total dick" – and more a succession of scenes than a biography, the book is as much about Olsson herself as the Weils. The prose zig-zags between vignettes from the author's own life and the Weils without warning, leaving the reader to search for connections. Facts are unsourced, and readers are left to guess what is historical and what is the author's impressionistic character portrait. Charming and quirky, the text transforms dusty perceptions of the meetings of the secret Bourbaki society of French mathematicians into scenes of lakeside debauchery and translucent camisoles that are almost reminiscent of *Pride and Prejudice*. Olsson even takes us into Simone's dreams, with the conjectures only cropping up at the end of the book. If you limit your reading to the maths and the Weils, the resulting slim volume is a page turner.

Mark Rayner *CERN.*









Flying high after the Higgs

Eleni Mountricha describes her transition from ATLAS physicist to data scientist in a satellite communications firm.

AGB/Inmarsat

New plains *Eleni Mountricha in Inmarsat's offices.*

In 2018, Eleni Mountricha's career in particle physics was taking off. Having completed a master's thesis at the National Technical University of Athens (NTUA), a PhD jointly with NTUA and Université Paris-Sud, and a postdoc with Brookhaven National Laboratory, she had just secured a fellowship at CERN and was about to select a research topic. A few weeks later, she ditched physics for a career in industry. Having been based at CERN for more than a decade, and as a member of the ATLAS team working on the Higgs boson at the time of its discovery in 2012, leaving academia was one of the toughest decisions she has faced.

"On the one hand I was looking for a more permanent position, which looked quite hard to achieve in research, and on the other, in the years after the Higgs-boson discovery, my excitement and expectation about more new physics had started to fade," she says. "There was always the hope of staying in academia, conducting research and exploring new fields of physics. But when the idea of possibly leaving kicked in, I decided that I should explore the potential of all alternatives."

Mountricha had just completed initial discussions about her CERN research project when she received an offer of a permanent contract at Inmarsat – a provider of mobile satellite communications based in the nearby Swiss town of Nyon. It was unexpected, given how few positions she had applied for. "I felt a mixture of happiness and satisfaction at having succeeded in something that I didn't expect I had many chances for, and frustration at the prospect of leaving something that I had spent many years on with a lot of dedication," she explains. "What made it even harder was the discussions with other CERN experiments during the first month of the fellowship, which sparked my physics excitement again."

> **People should not feel disappointed for having to move outside physics**

New pastures

Mountricha's idea to leave physics first formed after attending, out of curiosity, a career networking event for LHC-experiment physicists in November 2017. "The main benefit I got out of the event was a feeling that, even if I left, this would not be the end of the world; and that, if I searched enough, I could always find exciting things to do." The networking event now takes place annually.

The Inmarsat job was brought to Mountricha's attention by a fellow CERN alumnus and it was the only job that she had applied for outside physics. "I believe that I was lucky but I also had invested a lot of personal time to polish my skills, prepare for the interview and, in the end, it all came together," she says.

Today, Mountricha's official job title is "aero-service performance manager". She works in the data-science team of the company's aviation department collecting and reporting on data about aircraft connectivity and usage. This involves the use of Python to develop custom applications, analysing data using Python and SQL, and developing reporting and monitoring tools such as web applications. Her daily tasks vary from data analysis to developing new products. "Much of the work that I do, I had no clue about in the past and I had to learn. Some other pieces of work, like the data analytics, I used to do in a research context. However, the level at which I was doing it at CERN was much more sophisticated and complex. Many people in my team are physicists, all of them from CERN. Besides the technical aspects though, it is really at CERN that I learned how to collaborate, discuss with people, bring and collect ideas, solve problems, present arguments, and all those soft skills that are very important in my current job."

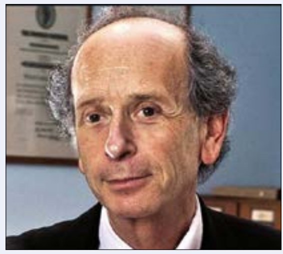
As for advice to others who are considering taking the leap, Mountricha thinks that people should not feel disappointed for having to move outside physics. "Fundamental research is a lot of fun and does equip us with much sought-after skills and experience. On the other hand, there are many exciting projects out there, where we can apply everything that we have learned and develop much further."

Higgs nostalgia

While happy to be on a new career path at the age of 37, working on the search for the Higgs boson will take some beating. "The announcement of the discovery was made in July, the papers were published in August and I defended my PhD thesis in September, so there was much pressure to finalise my work for all of those deadlines," recalls Mountricha. "Even the times when I was sleeping on top of my PC, exhausted, I still remember them with love and nostalgia. In particular, I remember the day of the announcement of the discovery, there were people sleeping outside the main auditorium the night before in order to make it to the presentation. As a result, I ended up watching it remotely from building 40 together with the whole analysis team. I was slightly disappointed not to be physically present in the packed auditorium, but this nevertheless remains such an important moment of my life."

Orestis Galanis *and*
Matthew Chalmers *CERN.*

Appointments and awards


M Brice/CERN

Spiro appointed IUPAP president
Prominent French particle physicist Michel Spiro has been appointed president of the International Union of Pure and Applied Physics (IUPAP), replacing theorist Kennedy Reed of Lawrence Livermore National Laboratory. IUPAP, which aims to stimulate and promote international cooperation in physics, was established in 1922 with 13 member countries and now has close to 60 members. Spiro, who participated in the UA1 experiment, the GALLEX solar-neutrino experiment and the EROS microlensing dark-matter search, among other experiments, has held senior positions in the French CNRS and CEA, and was president of the CERN Council from 2010 to 2013.

Breakthrough Prize for black-hole image

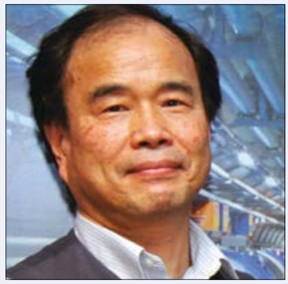

EHT collaboration

The first direct image of a black hole, obtained by the Event Horizon Telescope (EHT, a network of eight radio dishes that creates an Earth-sized interferometer) earlier this year, has been recognised by the 2020 Breakthrough Prize in Fundamental Physics. The $3 million prize will be shared equally between 347 researchers who were co-authors of the six papers published by the EHT collaboration on 10 April. Also announced were six New Horizons Prizes worth $100,000 each, which recognise early-career achievements. In physics, Jo Dunkley (Princeton), Samaya Nissanke (University of Amsterdam) and Kendrick Smith (Perimeter Institute) were rewarded for the development of novel techniques to extract fundamental physics from astronomical data. Simon Caron-Huot (McGill University) and Pedro Vieira (Perimeter Institute) were recognised for their "profound contributions to the understanding of quantum field theory".

Giorgi and Nakada share Fermi Prize


INFN

Marcello Giorgi (above) of the University of Pisa and Tatsuya Nakada (below) of the Swiss Federal Institute of Technology in Lausanne (EPFL) have been awarded the Enrico Fermi Prize from the Italian Physical Society for their outstanding contributions to the experimental evidence of CP violation in the heavy-quark sector. Giorgi is cited "for his leading role in experimental high-energy particle physics with particular regard to the BaBar experiment and the discovery of CP symmetry violation in the B meson systems with beauty quarks", while Nakada is recognised for his conception and crucial leading role in the realisation of the LHCb experiment that led earlier this year to the discovery of CP violation in D mesons with charm quarks. The prize was presented on 23 September during the opening ceremony of the 105th national congress of the Italian Physical Society in L'Aquila, Italy.


CERN

Brightness Award for ion source
Anatoli Zelenski (below) of Brookhaven National Laboratory is the recipient of the 2019 Brightness Award, presented at the International Conference on Ion Sources (ICIS) held in September in Lanzhou, China. Granted since 2003 at the biennial ICIS conferences, the award recognises significant recent achievements in ion-source physics and technology. Zelenski was recognised for his outstanding work in the development of high-current optically pumped polarised ion sources. By replacing Brookhaven's usual electron cyclotron resonance (ECR) proton source with a hydrogen injector and helium-ioniser cell inside a new 5 T superconducting solenoid, he increased the polarised H$^-$ output of the optically pumped polarised ion source by three orders of magnitude – leading to a reduction in polarisation losses at the Relativistic Heavy Ion Collider.


ICIS2019


CMS collaboration

Prize theses in CMS
Young researchers Thomas James (above), Joosep Pata (middle) and Daniel Salerno (bottom) have won the CMS prize for best thesis defended in 2018. James received his PhD from Imperial College, London, for his crucial work towards the upgrade of the CMS tracker. Pata and Salerno, who received their PhDs from ETH Zurich and the University of Zurich, respectively, focused on two different channels in the successful search for Higgs bosons produced in association with top quarks. The award committee recognises one (and in special cases, more than one) PhD thesis that stands out in terms of the quality of content, originality, clarity of writing, and impact within and outside of CMS.


CMS collaboration


CMS collaboration

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

LIGO Laser Interferometer Gravitational-Wave Observatory
Supported by the National Science Foundation
Operated by Caltech and MIT

Postdoctoral Research Positions LIGO Laboratory

The Laser Interferometer Gravitational-Wave Observatory (LIGO) has as its goal the development of gravitational wave physics and astronomy. The LIGO Laboratory is managed by Caltech and MIT, and is funded by the National Science Foundation. It operates observatory sites equipped with laser interferometric detectors at Hanford, Washington and Livingston, Louisiana, which recently made the first confirmed detection of gravitational waves. A vigorous LIGO Laboratory R&D program supports the development of enhancements to the LIGO detector as well as astrophysical data analysis, and development of future detectors and detector technologies.

The LIGO Laboratory anticipates having one or possibly more postdoctoral research positions at one or more of the LIGO sites – Caltech, MIT and at the two LIGO Observatories in Hanford, WA and Livingston, LA – beginning in Fall 2019. Hires will be made based on the availability of funding. Successful applicants will be involved in the operation of LIGO itself, analysis of LIGO data, both for diagnostic purposes and astrophysics searches, and/or the R&D program for future detector improvements. We seek candidates across a broad range of disciplines. Expertise related to astrophysics, modeling, data analysis, electronics, laser and quantum optics, vibration isolation and control systems is desirable. Most importantly, candidates should be broadly trained scientists, willing to learn new experimental and analytical techniques, and ready to share in the excitement of building, operating and observing with a gravitational-wave observatory. Appointments at the post-doctoral level will initially be for one-year with the possibility of renewal for up to two subsequent years.

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Applications should include curriculum vitae, list of publications (with refereed articles noted), and the names, addresses, email addresses and telephone numbers of three or more references. Please attach a cover letter describing past experience and current and future research interests. Applicants should request that three or more letters of recommendations be sent directly to HR@ligo.caltech.edu (Electronic Portable Document Format (PDF) submittals are preferred). Consideration of applications is ongoing.

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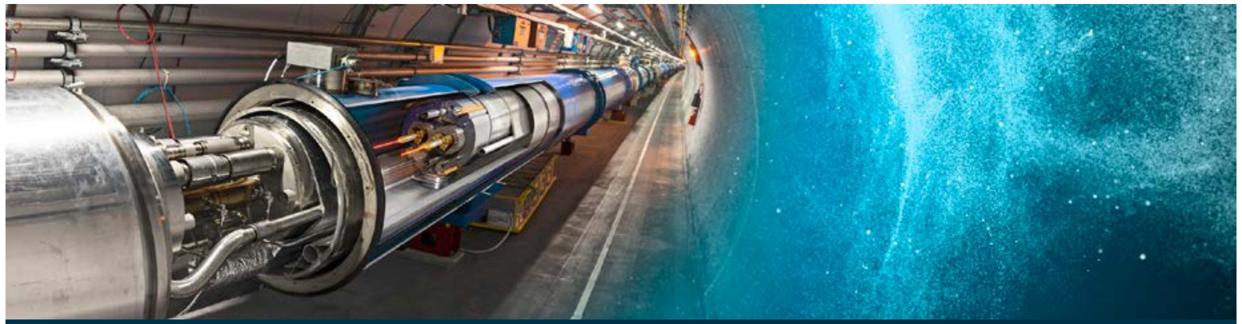

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- An excellent transport infrastructure with the opportunity to obtain a discounted employee ticket for public transportation (VRS) or to use assigned affordable parking.

The University of Bonn is committed to diversity and equal opportunity. It is certified as a family-friendly university and aims to increase the proportion of women employed in areas where women are underrepresented and to promote their careers. To that end, it urges women with relevant qualifications to apply. Applications will be handled in accordance with the Landesgleichstellungsgesetz (State Equality Act). Applications from suitable candidates with a certified disability or equivalent status are particularly welcome.

Complete applications (consisting of a CV, certificates, list of publications, and a letter of motivation) should be submitted until 30th of November 2019 via email as a single PDF file to **sprecher@ftd.uni-bonn.de** with the application code 12/19/331.

For further information please contact Prof. Dr. J. Dingfelder (Tel.: 0228 / 73 3532) or Prof. Dr. B. Ketzer (Tel.: 0228 / 73 2539).

ETH zürich

Professor or Assistant Professor (Tenure Track) of Theoretical Cosmology

→ The Department of Physics (www.phys.ethz.ch) at ETH Zurich invites applications for the above-mentioned position.

→ Successful candidates are outstanding scientists in the field of theoretical cosmology and will perform pioneering theoretical research in the exploration of the fundamental laws of nature. The new professor will i) aim to formulate new realistic theories which extend the known fundamental laws of physics and pursue the deep questions about the origin and evolution of the universe, ii) profit from the fast paced progress which is anticipated in observational cosmology and from future advances in other related fields such as experimental or theoretical particle physics, and iii) identify the important future milestones in the general field of cosmology and offer theoretical guidance for their accomplishment by the wider scientific community. He or she is expected to provide inspiration and leadership in research, to be an effective and enthusiastic teacher, and to develop and teach theoretical physics courses at the bachelor (in German or English) and master (in English) level. The Department of Physics offers a stimulating environment in mathematical, theoretical, and computational physics, as well as in experimental high-energy physics, condensed matter physics, astrophysics and observational cosmology, quantum optics, and neuroinformatics.

→ Assistant professorships have been established to promote the careers of younger scientists. ETH Zurich implements a tenure track system equivalent to other top international universities. The level of the appointment will depend on the successful candidate's qualifications.

→ **Please apply online: www.facultyaffairs.ethz.ch**

→ Applications should include a curriculum vitae, a list of publications, a statement of future research and teaching interests, a description of the three most important achievements, and the names of five references. The letter of application should be addressed **to the President of ETH Zurich, Prof. Dr. Joël Mesot. Submissions will be reviewed starting on 15 December 2019, but applications are welcome until the position is filled.** ETH Zurich is an equal opportunity and family friendly employer, strives to increase the number of women professors, and is responsive to the needs of dual career couples.

PEOPLE OBITUARIES

GASPAR BARREIRA 1940–2019

A leader with a grand vision

Experimental particle physicist Gaspar Barreira, co-founder of the Portuguese Laboratory for Instrumentation and Experimental Particle Physics (LIP), passed away on 1 June. He was the Portuguese delegate to the CERN Council and to the SESAME Council, and was a strong proponent of international cooperation.

Gaspar's life proceeded in cycles, each lived intensely with great energy and focus. He had a vision to foster progress, to change the world here and now. Each time, despite arriving as an outsider, he was able to make great impact thanks to his intelligence and capability to transmit enthusiasm. He always chose grand objectives: let's build something that doesn't exist at all in the country; let's do something that was never done before. He was not afraid of dreaming, nor of obstacles.


P Gomes

Gaspar Barreira was a strong believer in international cooperation.

Born in Braga, in the north of Portugal, Gaspar arrived in Lisbon at the age of 18 to study physics and mathematics. He fought against the dictatorship of Salazar, which gagged Portugal for more than 40 years until the Carnation Revolution of 25 April 1974, and was imprisoned more than once. In the early 1970s he taught himself electronics, and soon found himself at the Nuclear Physics Centre in Lisbon, saving the day for many colleagues with his ability to fix the scarce equipment or assemble non-existing parts. He also entered into pioneering collaborations with archaeologists to date ancient artefacts – a path that in 1980 led him to the International Centre for Theoretical Physics in Trieste, Italy, where he soon become director of the microprocessors laboratory.

In 1985 Gaspar retuned to Portugal to get involved in the county's accession to CERN, founding LIP with José Mariano Gago and Armando Policarpo, and building LIP's instrumentation division. NA38 at the SPS was the first experiment in which LIP participated as an institution. He greatly contributed to establish LIP as a reference laboratory in particle and astroparticle physics, instrumentation, technology and computing.

Gaspar was a strong believer in CERN and international cooperation. He had a fundamental role in bringing Portugal into the DELPHI experiment at LEP, and was a strong supporter of the LHC from the early days. He was a strong advocate of distributed computing, and did not spare efforts to have Portugal and LIP in the main projects in this area, at CERN and at a European level. Gaspar was responsible for the creation of the Portuguese Tier-2 in the CERN Worldwide LHC Computing Grid, and was active in several related initiatives.

From the turn of the century, Gaspar was fully involved in science policy. He was the Portuguese representative to a variety of international organisations and boards, and coordinated the Portuguese participation in the Alpha Magnetic Spectrometer for its shuttle flight in 1998. Gaspar was always particularly concerned with knowledge-transfer to society. He co-coordinated the training programmes for young Portuguese engineers at CERN, ESA and ESO, and the creation of the Portuguese language teachers programme.

Before and after the revolution of 1974, Gaspar worked towards the construction of a world where knowledge, freedom and rationality were decisive. We have lost a great friend of CERN, LIP and physics, an excellent scientist and a truly unique personality. Though departed, Gaspar leaves us an immense legacy of vision, endurance and resilience. His last big project, the installation in Portugal of a treatment and research centre for cancer therapy with protons, is not yet accomplished. For this we will strive.

His friends and colleagues *at LIP.*

GIOVANNI MURATORI 1924–2019

Remembering a superb engineer

Giovanni Muratori received a double degree in naval and mechanical engineering at the University of Genoa in 1949, after which he worked at ENI-AGIP on the construction of instruments for oil exploration. He started at CERN in August 1959 in the PS division, where he worked on the heavy-liquid bubble chamber designed to study neutrino physics. Giovanni oversaw the design of the cameras – not an easy task in view of the strong magnetic field that precluded the use of electric motors – and, after some initial setbacks, the chamber was ready for data-taking in early 1961. Finding the event rate to be insufficient, a crash programme was set in motion to improve the beam (using van der Meer's magnetic horn) and to increase the total mass of detectors (by adding spark chambers downstream). Giovanni embarked on the design of the mechanics and optics for these spark chambers, which were operational in 1963.

At the end of 1961 he was transferred to the nuclear physics division and in April 1966 was appointed leader of the technical assistance ▷

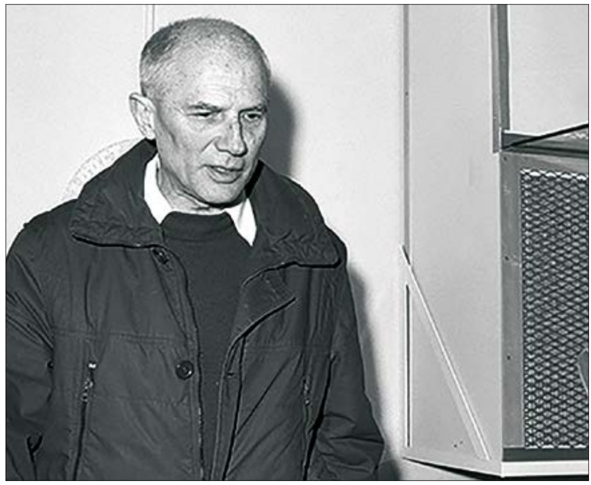
group, which was involved in the design and construction of optical and mechanical equipment. The group developed and constructed a wide variety of detectors and associated equipment, including the R-108 experiment at the ISR where the group built a set of novel cylindrical drift chambers allowing track positions along the wire to be measured using the difference of arrival times of the signal at the ends of each wire. For NA31 the group built drift chambers installed in a helium-filled tank as well as a lightweight Kevlar window separating the helium from a vacuum tank.

Early-on, the group designed and constructed an automatic machine for winding large wire spark chambers and soon became specialised in the construction of arrays for the new multiwire proportional chambers. Led by Giovanni, the group developed equipment and facilities for Cherenkov detectors, including a dry lab for handling lithium foil and methods of producing precision glass spherical mirrors coated with highly reflecting aluminium coatings. Mirrors made using these techniques were later used in the RICH detector at LEP's DELPHI experiment.

Towards the end of his CERN career he worked on the initial designs of the TPC detector for another LEP detector, ALEPH. He also started a collaboration with a group searching for the existence of a "fifth force" and designed and built a rotor that generated a dynamic gravitational field at around 450 Hz, which was used in the first absolute calibration of the gravitational wave detector EXPLORER at CERN.

Giovanni remained at CERN for several years after his retirement in 1986, during which time he worked on several problems including the initial design of a prototype liquid argon chamber for use in underground experiments at Gran Sasso. He was a superb engineer. His work was highly appreciated and his opinions respected. He participated actively in the design of equipment with innovative and ingenious ideas. He also loved solving machining and manufacturing problems, whether on a large or Swiss-watch scale. With his common-sense attitude and his warm and generous spirit, his advice was often sought on personal matters. Giovanni will be remembered with respect and affection by all.

His friends and colleagues.



Giovanni Muratori's analyses of technical problems were invariably correct.

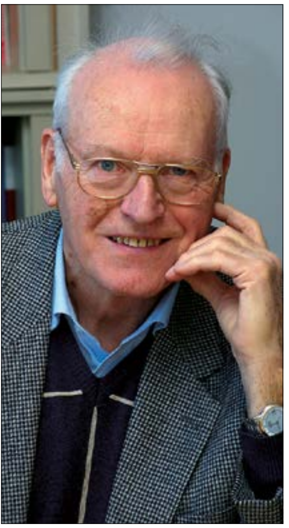
Family photograph

Ernst-Wilhelm Otten 1934–2019

Breadth and eminence across disciplines

Ernst-Wilhelm Otten received his doctorate in 1962 at the University of Heidelberg under the supervision of atomic and nuclear physicist Hans Kopfermann. From 1972 until his retirement in 2002, he headed the department of experimental atomic and nuclear physics (EXAKT) at the University of Mainz. Ernst spent numerous research stays abroad, including at CERN and at the Ecole Normale Supérieure in Paris. After his retirement Ernst continued his research activities, especially for the KATRIN neutrino experiment. The hallmark of his work was the extraordinary breadth across almost all disciplines of physics, which earned him a large number of distinctions and prizes.

In Heidelberg, Ernst developed the method of optical pumping for polarising the nuclear spins of radioactive isotopes to determine their nuclear moments. He also recognised, from its start-up in the late 1960s, the opportunities offered by the on-line isotope separator ISOLDE at CERN. He became a pioneer of optical spectroscopy with accelerators. The discovery of unexpected nuclear-shape coexistence and nuclear-size changes in neutron-deficient mercury isotopes is one of the most outstanding results obtained at ISOLDE, as early as 1972. In Mainz, his group developed the high-resolution method of collinear laser spectroscopy – now a workhorse at ISOLDE for the determination of nuclear ground-state properties of short-lived nuclei – and with his collaborators initiated laser-based trace analysis for the detection of radionuclides in the environment.



Ernst Otten initiated the KATRIN neutrino experiment, among many other achievements.

University of Mainz

The electron accelerators at Mainz enabled spectacular experiments: the test of parity non-conservation by neutral currents in polarised-electron nucleon scattering, and the determination of the neutron electric form factor using polarised ^{3}He targets at high density. With hyperpolarised ^{3}He gas, Ernst performed lung diagnostics by magnetic resonance imaging in collaboration with the German Cancer Research Centre in Heidelberg and the department of radiology at the University of Mainz.

In the 1980s, when a group reported a 30 eV mass of the antineutrino, Ernst developed a novel high-resolution beta spectrometer at Mainz to determine the neutrino mass very precisely from tritium decay. Together with his team he succeeded in setting an upper limit of 2 eV. After the discovery of neutrino oscillations in 1998, proving the existence of finite neutrino masses, Ernst initiated the KATRIN experiment at the Karlsruhe Institute of Technology to measure the neutrino mass. The construction of this technically extremely difficult spectrometer started in 2001, and Ernst was very actively involved until his death on 8 July. As such, he was able to witness the first successful result: the setting of a new upper limit on the neutrino mass of 1 eV (see p7).

Ernst leaves deep traces in science and in the physics community. We will remember him as a great scientist, teacher, mentor and friend.

Gerda Neyens *for the ISOLDE collaboration.*

Gaurang Bhaskar Yodh 1928–2019

From the ground to the skies

Gaurang Yodh, a passionate particle and cosmic-ray physicist and musician, passed away on 3 June at age 90. He was born in Ahmedabad in India. After graduating from the University of Bombay in 1948, he was recruited by the University of Chicago to join the group of Enrico Fermi and Herb Anderson. After Fermi's death in 1954, he finished his PhD with Anderson in 1955, after which he moved to Stanford where he worked with Wolfgang Panofsky.

He and his wife returned to Bombay (Mumbai) in 1956, where he started accelerator physics programmes at the Tata Institute of Fundamental Research, but he was lured back to the US and took a physics faculty job at the Carnegie Institute of Technology (later Carnegie Mellon University). In 1961 he joined the physics and astronomy department at the University of Maryland and stayed there until 1988, when he moved to the University of California at Irvine, where he finished his career.

Gaurang Yodh was also an accomplished sitar player.

J Goodman

Gaurang's PhD research work at Chicago with Anderson and Fermi studied the interactions of pions with protons and neutrons. With Panofsky he studied electron–nucleon scattering. He continued this work until the late 1960s when his interests shifted from accelerators to cosmic rays. In 1972, with Yash Pal and James Trefil, he showed that the proton–proton cross section increased with energy – a finding later confirmed at CERN.

Prominent work followed with the development of transition radiation detectors for particle identification. His 1975 paper "Practical theory of the multilayered transition radiation detector" is still a standard reference in high-energy and cosmic-ray physics. In the 1980s, Gaurang's interests shifted again, in this case to study high-energy gamma rays from space. His ideas led to the development of ground-based water Cherenkov telescopes for the study of gamma rays and searches for sources of cosmic rays. In the 1990s and 2000s, Gaurang and collaborators pursued these detection techniques, and their high-altitude offspring, in two major collaborations – MILAGRO and HAWC – and at UC Irvine Gaurang was a contributor to the IceCube collaboration. He was also a strong advocate for the ARIANNA project, which is developing radio techniques to look for astrophysical neutrinos. Throughout his career, Gaurang mentored many PhD students and post-docs who went on to successful careers.

Gaurang was a renowned sitar player who gave concerts at universities and physics conferences, and in 1956 recorded one of the very first albums of Indian music in the US: *Music of India* (volumes 1 & 2). He was a gentle and caring man with an infectious optimism and a joy for life. His friends enjoyed his good humour, charm and enthusiasm. He is survived by his three children, eight grandchildren and his sister.

Jordan Goodman, colleagues and friends *University of Maryland.*

BACKGROUND

Notes and observations from the high-energy physics community

Doomsayers decried

Railing against the notion that the world is sinking into chaos, hatred and irrationality, cognitive psychologist Steven Pinker of Harvard University brought rapid-fire feel-good factoids to the CERN auditorium on 14 October. His colloquium "Enlightenment now: the case for reason, science, humanism, and progress", after his 2018 book of the same name, saw the bestselling and sometimes controversial academic flash numerous plots suggesting a relentless upward trend in human progress, which he attributes to enlightenment values. Life expectancy has risen from 35 to 80 in 250 years, child mortality is down by a factor 100, and there has been a 75% reduction in extreme poverty in the last 30 years alone. Homosexuality is now legal in the vast majority of the world, and the death penalty abolished – along with witch-hunts and duelling. We've never enjoyed such levels of freedom, democracy, literacy, safety and happiness, he claimed. Even deaths from lightning strikes are plummeting.

Met with resolute scepticism, Pinker's rejoinder was that the news we consume is strongly biased towards the negative. "Progress is something intellectuals don't like," he said. "But it is an empirical issue."

42,280

Number of people, across 170 countries, who took part in the LHC's first mass-participation citizen science project "Higgs Hunters", initiated by physicists at the University of Oxford.

Brexit bites science

On 16 October the UK's The Royal Society published a report stating that, due to Brexit uncertainty, the UK is becoming a less attractive destination for top international science talent. Despite government underwrites in the event of a no-deal Brexit, it finds the UK's annual share of EU research funding has fallen by €0.5 billion since 2015, with almost a 40% drop in applications to Horizon 2020 and some 35% fewer scientists arriving via Marie Skłodowska-Curie fellowships.

UK research rebranded

UKRI Science and Technology Facilities Council

On 10 October UK Research and Innovation (UKRI) – a recently created body to direct government funding via the UK's major research councils – announced new branding "to support its vision and ambition as a world-class funder". The logo for UKRI's Science and Technology Facilities Council (STFC), which deals with high-energy physics (pictured), will soon replace existing ones that have been taking root across STFC's sites since 2007 when STFC was created. "UKRI has an important role to play and an important story to tell. The unified brand will help us to communicate this story nationally and internationally," said UKRI chief executive Mark Walport.

From the archive: November/December 1976

Prowess and prizes

CERN 217.8.76

Wim Klein (right), the human computer, has retired after 18 years in the Theory Division. His phenomenal abilities at mental arithmetic are legendary. Not many people understand the complication of extracting, for example, the 37th root of a 220 digit number. Wim marked his departure with a "Farewell Show" in the CERN Auditorium on 10 December.

The 1976 physics Nobel Prize was shared equally between Burt Richter, SLAC, and Sam Ting, MIT, who led the teams which found the J/ψ just two years ago, cited as "a heavy elementary particle of a new kind". This rapid recognition reflects the dramatic effect of the J/ψ on the world of high-energy physics – so dramatic that since the events of 1974, we talk of "the new physics".

- Compiled from text on p440 and p384 of *CERN Courier* November and December 1976.

Compiler's note

Probably few millennial readers will have heard of Willem Klein, an idiosyncratic Dutchman of prodigious mathematical acuity. Wim led a colourful though not always happy life, between science and circus. At CERN he filled a techno-gap, outpacing mechanical desk calculators but sadly becoming redundant when electronic computers took over. On 27 August 1976 Wim calculated the 73rd root of a 500-digit number in 2 minutes and 43 seconds, delighting the CERN audience and earning a place in the Guinness World Records.

Media corner

"Salam was the first Pakistani to win a Nobel, and his victory should have been a historic moment for the country. But instead, 40 years on, his story has largely been forgotten by the country in which he was born – in part because of the religious identity he held so dear."

BBC Online (15 October) reviews a new film about Abdus Salam titled *The First ****** Nobel Laureate*.

"Why jump ship if the vessel's still going strong, even though we don't fully understand how it functions?"

Philosopher of science ***Michela Massimi*** referring to the Standard Model in an article about model independence in the September issue of *Physics World*.

"According to the UK Public Attitudes to Science Survey, 79% of those surveyed agree that even if it brings no immediate benefits, research that advances knowledge should be publicly funded."

President of the British Academy ***David Cannadine*** on the historical importance of blue-sky research (*New Scientist*, 12 October).

"Concentric rings of gold and candy-apple red detectors encircle the proton beam tubes at its center. Lime-green supports help hold the electronics in place. Shimmering metal that looks like aluminum foil catches the industrial lights. It could be a space station. Or a half-billion-dollar piece of art."

Journalist ***Richard Morin*** experiences CMS during the CERN open days (*Washington Post*, 20 September).

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