WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the November 2018 issue of *CERN Courier.*

Explaining the strong interaction was one of the great challenges facing theoretical physicists in the 1960s. Though the correct solution, quantum chromodynamics, would not turn up until early the next decade, previous attempts had at least two major unintended consequences. One is electroweak theory, elucidated by Steven Weinberg in 1967 when he realised that the massless rho meson of his proposed SU(2)xSU(2) gauge theory was the photon of electromagnetism. Another, unleashed in July 1968 by Gabriele Veneziano, is string theory. Veneziano, a 26-year-old visitor in the CERN theory division at the time, was trying "hopelessly" to copy the successful model of quantum electrodynamics to the strong force when he came across the idea – via a formula called the Euler beta function – that hadrons could be described in terms of strings. Though not immediately appreciated, his 1968 paper marked the beginning of string theory, which, as Veneziano describes 50 years later, continues to beguile physicists. This issue of *CERN Courier* also explores an equally beguiling idea, quantum computing, in addition to a PET scanner for clinical and fundamental-physics applications, the internationally renowned Beamline for Schools competition, and the growing links between high-power lasers (the subject of the 2018 Nobel Prize in Physics) and particle physics.

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CERNCOURIER

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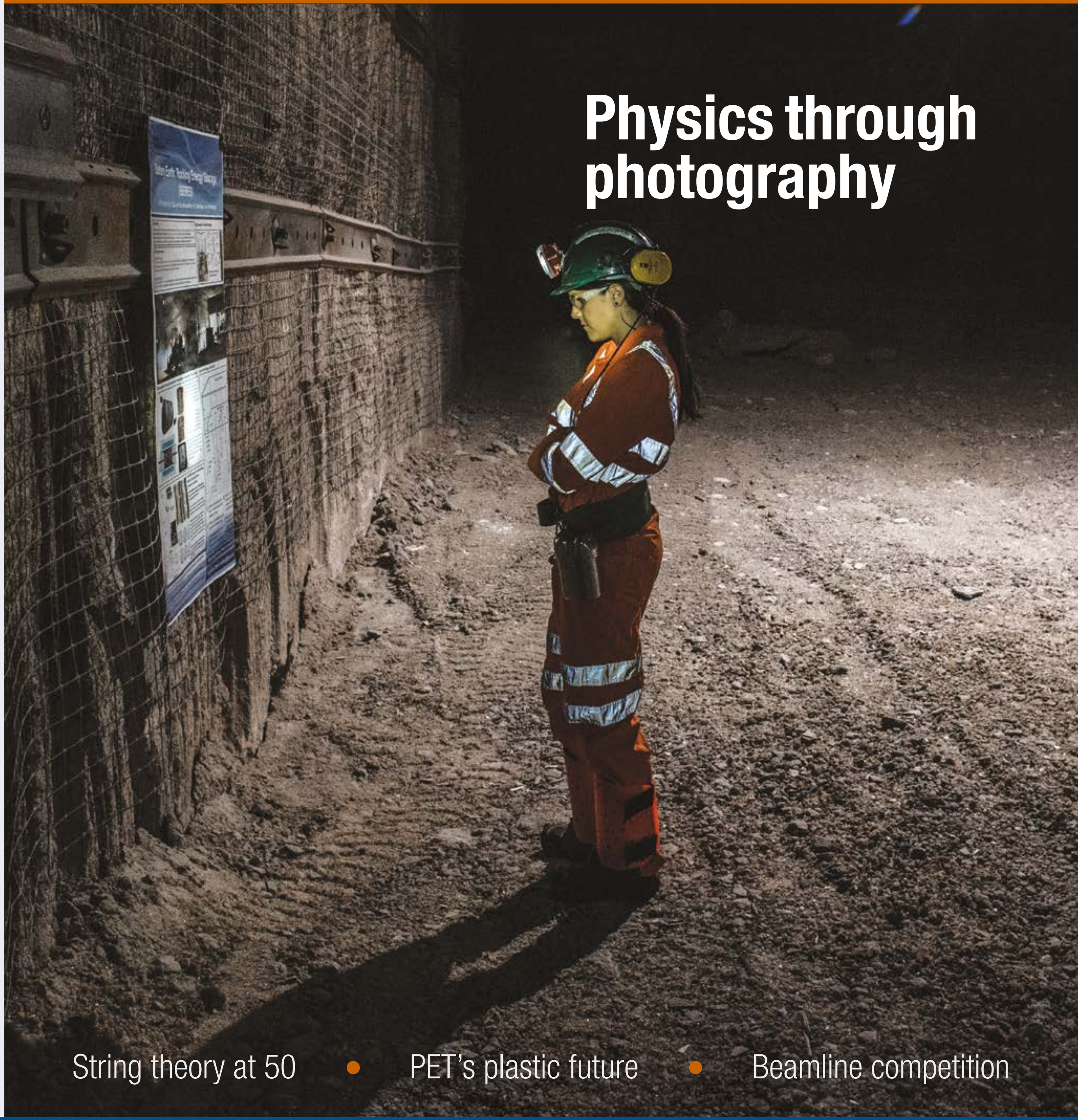

Contents

Covering current developments in high-energy physics and related fields worldwide

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VOLUME 58 NUMBER 9 NOVEMBER 2018

5 **VIEWPOINT**

7 **NEWS**
● *Nobel work shines a light on particle physics* ● *Beam tests bring ProtoDUNE to life* ● *First beam at IOTA for accelerator research* ● *Satellite premieres in CERN irradiation facility* ● *LHCb discovers two new baryons* ● *Search for new quarks addresses unnaturalness* ● *Suppression of the Λ(1520) resonance in Pb–Pb collisions* ● *CMS detects first production of top quark and photon*

15 **ASTROWATCH**

FEATURES

17 **J-PET's plastic revolution**
A PET detector based on plastic scintillators offers whole-body imaging in addition to precision tests of fundamental symmetries.

21 **The roots and fruits of string theory**
Gabriele Veneziano discusses his famous 1968 paper, which marked the beginnings of string theory.

26 **Deep physics brought to life through photography**
The winning entries of the 2018 Global Physics Photowalk competition.

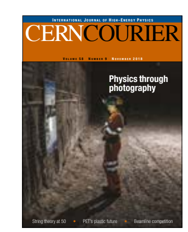
31 **Hands-on education at the frontiers of science**
Founded in 2014, CERN's Beamline for Schools competition inspires high-school physics students.

35 **FACES & PLACES**

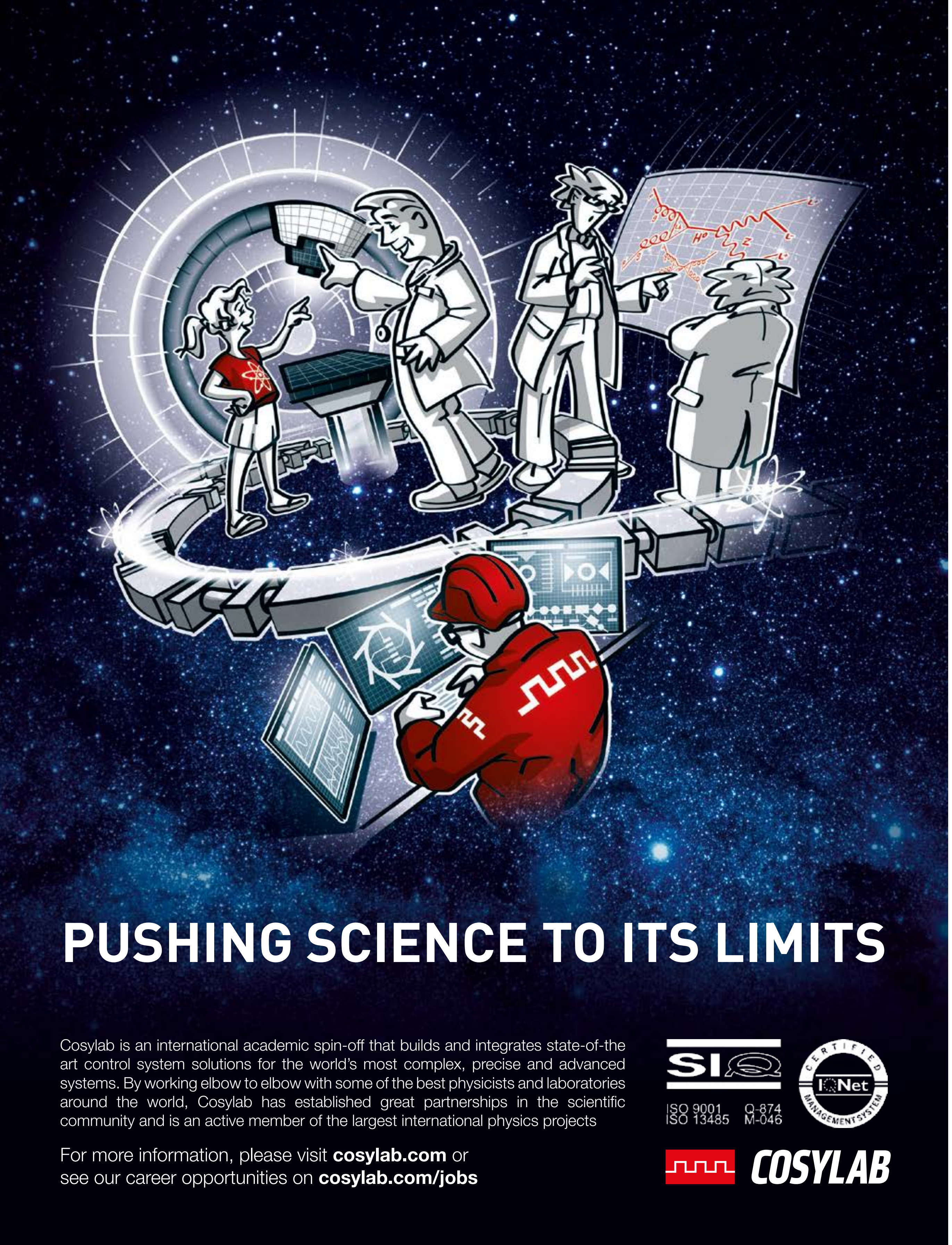
43 **BOOKSHELF**

46 **RECRUITMENT**

50 **ARCHIVE**



On the cover: The winning entry of the 2018 Global Physics Photowalk, picturing Tamara Leitan (of the UK Science and Technology Facilities Council) in the Boulby Underground Laboratory, p26. (Image credit: Simon Wright.)

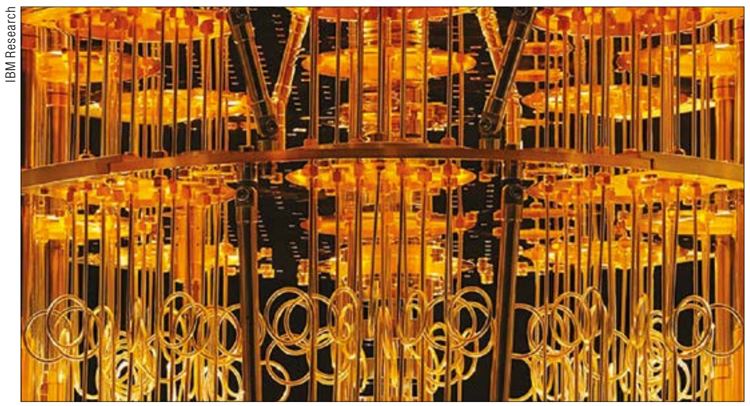


Viewpoint

Quantum thinking required

Particle physicists need to start thinking about tomorrow's computing technology today.

IBM Research



Cooling technology for a prototype quantum processor developed by IBM, one of several companies working to develop quantum-computing technologies.

By Federico Carminati

The High-Luminosity Large Hadron Collider (HL-LHC), due to operate in around 2026, will require a computing capacity 50–100 times greater than currently exists. The big uncertainty in this number is largely due to the difficulty in knowing how well the code used in high-energy physics (HEP) can benefit from new, hyper-parallel computing architectures as they become available. Up to now, code modernisation is an area in which the HEP community has generally not fared too well.

We need to think differently to address the vast increase in computing requirements ahead. Before the Large Electron–Positron collider was launched in the 1980s, its computing challenges also seemed daunting; early predictions underestimated them by a factor of 100 or more. Fortunately, new consumer technology arrived and made scientific computing, hitherto dominated by expensive mainframes, suddenly more democratic and cheaper.

A similar story unfolded with the LHC, for which the predicted computing requirements were so large that IT planners offering their expert view were accused of sabotaging the project! This time, the technology that made it possible to meet these requirements was grid computing, conceived at the turn of the millennium and driven largely by the ingenuity of the HEP community.

Looking forward to the HL-LHC era, we again need to make sure the community is ready to exploit further revolutions in computing. Quantum computing is certainly one such technology on the horizon. Thanks to the visionary ideas of Feynman and others, the concept of quantum computing was popularised in the early 1980s. Since then, theorists have explored its mind-blowing possibilities, while engineers have struggled to produce reliable hardware to turn these ideas into reality.

Qubits are the basic units of quantum computing: thanks to quantum entanglement, n qubits can represent 2^n different states on which the same calculation can be performed simultaneously. A quantum computer with 79 entangled qubits has an Avogadro number of states (about 10^{23}); with 263 qubits, such a machine could represent as many concurrent states as there are protons in the universe; while an upgrade to 400 qubits could contain all the information encoded in the universe.

However, the road to unlocking this potential – even partially – is long and arduous. Measuring the quantum states that result from a computation can prove difficult, offsetting some of the potential gains. Also, since classical logic operations tend to destroy the entangled state, quantum computers require special reversible gates. The hunt has been on for almost 30 years for algorithms that could outperform their classical counterparts. Some have been found, but it seems clear that there will be no universal quantum computer on which we will be able to compile our C++ code and then magically run it faster. Instead, we will have to recast our algorithms and computing models for this brave new quantum world.

In terms of hardware, progress is steady but the prizes are still a long way off. The qubit entanglement in existing prototypes, even when cooled to the level of millikelvins, is easily lost and the qubit error rate is still painfully high. Nevertheless, a breakthrough in hardware could be achieved at any moment.

A few pioneers are already experimenting with HEP algorithms and simulations on quantum computers, with significant quantum-computing initiatives having been announced recently in both Europe and the US. In CERN openlab, we are now exploring these opportunities in collaboration with companies working in the quantum-computing field – kicking things off with a workshop at CERN in November (see below).

The HEP community has a proud tradition of being at the forefront of computing. It is therefore well placed to make significant contributions to the development of quantum computing – and stands to benefit greatly, if and when its enormous potential finally begins to be realised.

● A workshop on quantum computing will take place at CERN on 5–6 November, with technology updates from companies including NVIDIA, Intel, IBM, Strangeworks, D-Wave, Microsoft, Rigetti and Google: https://indico.cern.ch/e/QC18.

Federico Carminati is the chief innovation officer for CERN openlab, a unique public–private partnership that works to tackle tomorrow's ICT challenges. (Image credit: CERN-PHOTO-201805-119-4.)

News

ACCELERATORS

Nobel work shines a light on particle physics

This year's Nobel Prize in Physics was shared between three researchers for groundbreaking inventions in laser physics. Half the prize went to Arthur Ashkin of Bell Laboratories in the US for his work on optical tweezers, while the other half was awarded jointly to Gérard Mourou of the École Polytechnique in Palaiseau, France, and Donna Strickland of the University of Waterloo in Canada "for their method of generating high-intensity, ultra-short optical pulses".

Mourou and Strickland's technique, called chirped-pulse amplification (CPA), opens new perspectives in particle physics. Proposed in 1985, and forming the foundation of Strickland's doctoral thesis, CPA uses a strongly dispersive medium to temporally stretch ("chirp") laser pulses to reduce their peak power, then amplifies and, finally, compresses them – boosting the intensity of the output pulse dramatically without damaging the optical medium. The technique underpins today's high-power lasers and is used worldwide for applications such as eye surgery and micro-machining.


LLNL

Chirped-pulse amplification gives extreme lasers sufficient peak power to accelerate electrons up to multi-GeV beams, such as the High-Repetition-Rate Advanced Petawatt Laser System (HAPLS) recently installed at the Extreme Light Infrastructure facility in the Czech Republic.

Surfing the waves

But CPA's potential for particle physics was clear from the beginning. In particular, high-power ultra-short laser pulses can drive advanced plasma-wakefield accelerators in which charged particles are brought to high energies over very short distances by surfing longitudinal plasma waves.

"After we invented laser-wakefield acceleration back in 1979, I was acutely aware that the laser community at that time did not have the specifications that we needed to drive wakefields, which needed ultrafast and ultra-intense pulses," explains Toshi Tajima of the University of California at Irvine, a long-time collaborator of Mourou. Tajima became aware of CPA in 1989 and first met Mourou in 1993 at a workshop at the University of Texas at Austin devoted to the future of accelerator physics upon the demise of the Superconducting Super Collider. "Ever since then, Gérard and I have formed a strong scientific and personal bond to promote ultra-intense lasers and their applications to accelerators and other important societal applications such as medical accelerators, transmutation and intense X-rays," he says.

Today, acceleration gradients two-to-three orders of magnitude higher than existing radio-frequency (RF) techniques are possible at state-of-the-art laser-driven plasma-wakefield experiments, promising more compact and potentially cheaper particle accelerators. Though not yet able to match the quality and reliability of conventional acceleration techniques, plasma accelerators might one day be able to overcome the limitations of today's RF technology, thinks Constantin Haefner, program director for advanced photon technologies at Lawrence Livermore National Laboratory in the US. "The race has started," he says. "The ability to amplify lasers to extreme powers enabled the discovery of new physics, and even more exciting, some of the early envisioned applications such as laser plasma accelerators are on the verge of moving from proof-of-principle to real machines."

Electrons can also be used to drive plasma accelerators, as is being explored at SLAC and in European labs such as LNF in Italy and DESY in Germany. Meanwhile, the AWAKE experiment at CERN has recently demonstrated the first proton-driven plasma-wakefield acceleration (*CERN Courier* October 2018 p7). Although AWAKE does not use a laser to drive the plasma, it employs a high-power laser to generate the plasma from a gas, at the same time seeding the proton self-modulation process that allows charged particles to be accelerated. CERN is also a partner in a recent project called the International Coherent Amplification Network, led by Mourou and funded by the European Union, to explore advanced wakefield drivers based on the coherent combination of multiple high-intensity fibre lasers that can run at high repetition rates and efficiencies.

"We have a long way to go, but plasma accelerators have game-changing ▷

Sommaire en français

Nobel 2018 : des travaux qui pourraient faire briller la physique des particules	7
Premiers essais de faisceau pour ProtoDUNE	8
Premier faisceau à IOTA, installation de recherche sur les accélérateurs	9
Un satellite pour étrenner l'installation d'essai CHARM	9
LHCb découvre deux nouveaux baryons	10
De nouveaux types de quarks pour élucider la hiérarchie des masses	11
Atténuation de la résonance Λ(1520) dans les collisions Pb–Pb	11
CMS détecte la première production d'un quark t et d'un photon	12
Les ondes gravitationnelles sondent les dimensions supplémentaires	15

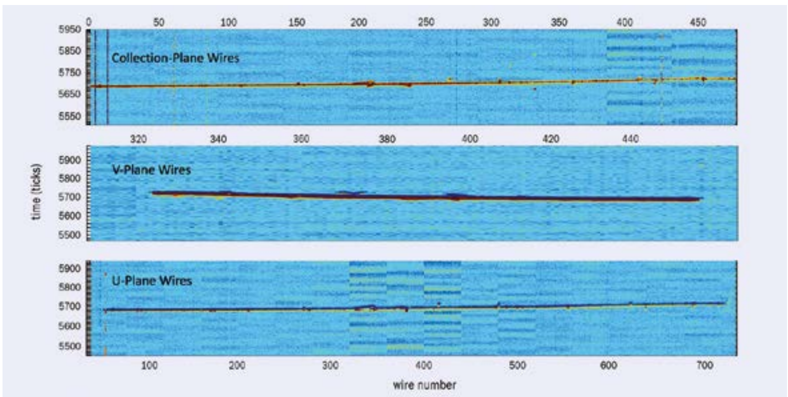
potential for high-energy physics," says Wim Leemans, director of the accelerator technology and applied physics division and Berkeley Lab Laser Accelerator Center (BELLA) at Lawrence Berkeley National Laboratory. "Other applications already being explored include free-electron lasers, a quasi-monoenergetic gamma-ray source for nonproliferation and nuclear security purposes, and a miniaturised method for brachytherapy, a cancer-treatment modality in which radiation is delivered directly to the site of a tumour."

Beyond accelerators, the enormous intensity of single-shot pulses enabled by CPA offer new types of experiments in high-energy physics. In 2005, Mourou initiated the Extreme Light Infrastructure (ELI), nearing completion in the Czech Republic, Hungary and Romania, to explore the use of high-power PW lasers such as Livermore Lab's HAPLS facility (see image on previous page). Going beyond ELI is the International Center for Zetta- and Exawatt Science and Technology (IZEST), established in France in 2011 to develop and build a community around the emerging field of laser-based particle physics. Under Mourou and Tajima's direction, IZEST will extend existing laser facilities (such as PETAL at the Megajoule Laser facility in France) to the exa- and zettawatt scale, opening studies including "searches for dark matter and energy and probes of the nonlinearity of the vacuum via zeptosecond dynamical spectroscopy."

DETECTORS

Beam tests bring ProtoDUNE to life

The world's largest liquid-argon neutrino detector has recorded its first particle tracks in tests at CERN, marking an important step towards the international Deep Underground Neutrino Experiment (DUNE) under preparation in the US. The enormous ProtoDUNE detector, designed and built at CERN's neutrino platform, is the first of two prototypes for what will be a much larger DUNE detector. Situated deep beneath the Sanford Underground Research Facility in South Dakota, four final DUNE detector modules (each 20 times larger than the current prototypes and containing a total of 70,000 tonnes of liquid argon) will record neutrinos sent from Fermilab's Long Baseline Neutrino Facility some 1300 km away.



DUNE collaboration

One of the first cosmic-muon tracks recorded by the ProtoDUNE detector at CERN during September. Three wire planes, each made up of thousands of individual wires, recorded the signal of a muon as it traveled approximately 3.8 m through the detector's liquid-argon volume.

DUNE's scientific targets include CP violation in the neutrino sector, studies of astrophysical neutrino sources, and searches for proton decay. When neutrinos enter the detector and strike argon nuclei they produce charged particles, which leave ionisation traces in the liquid from which a 3D event can be reconstructed. The first ProtoDUNE detector took two years to build and eight weeks to fill with 800 tonnes of liquid argon, which needs to be cooled to a temperature below –184 degrees. It adopts a single-phase architecture, which is an evolution from the 170 tonne MicroBooNE detector at Fermilab's short-baseline neutrino facility. The second ProtoDUNE module adopts a different, dual-phase, scheme with a second detection chamber.

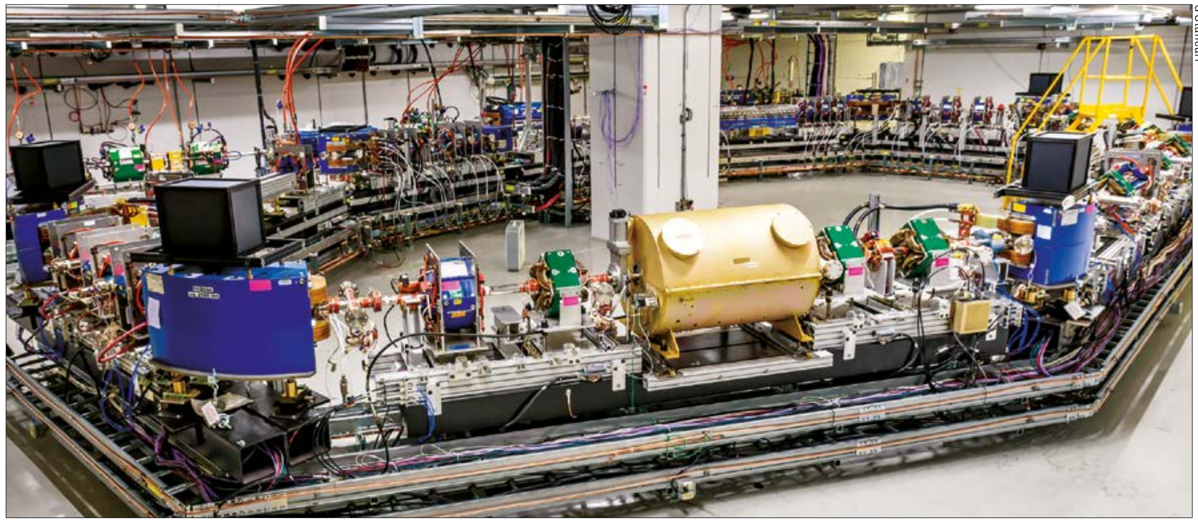
The construction and operation of ProtoDUNE will allow researchers to validate the membrane cryostat technology and associated cryogenics for the final detector, in addition to the networking and computing infrastructure. Now that the first tracks have been seen, from beam tests involving cosmic rays and charged-particle beams from CERN's SPS, ProtoDUNE's operation will be studied in greater depth. The charged-particle beam test enables critical calibration measurements necessary for precise calorimetry, and will also produce valuable data for optimising event-reconstruction algorithms. These and other measurements will help quantify and reduce systematic uncertainties for the DUNE far detector and significantly improve the physics reach of the experiment. "Seeing the first particle tracks is a major success for the entire DUNE collaboration," said DUNE co-spokesperson Stefan Soldner-Rembold of the University of Manchester, UK.

More than 1000 scientists and engineers from 32 countries in five continents are working on the development, design and construction of the DUNE detectors. For CERN, it is the first time the European lab has invested in infrastructure and detector development for a particle-physics project in the US. "Only two years ago we completed the new building at CERN to house two large-scale prototype detectors that form the building blocks for DUNE," said Marzio Nessi, head of the neutrino platform at CERN. "Now we have the first detector taking beautiful data, and the second detector, which uses a different approach to liquid-argon technology, will be online in a few months."

In July, the US Department of Energy also formally approved PIP-II, an accelerator upgrade project at Fermilab required to deliver the high-power neutrino beam required for DUNE. First data at DUNE is expected in 2026. Meanwhile, in Japan, an experiment with similar scientific goals and also with scientific links to the CERN neutrino platform – Hyper-Kamiokande – has recently been granted seed funding for construction to begin in 2020 (*CERN Courier* October 2018 p11). Together with several other experiments such as KATRIN in Germany, physicists are closing in on the neutrino's mysteries two decades after the discovery of neutrino oscillations (*CERN Courier* July/August 2018 p5).

ACCELERATORS

First beam at IOTA for accelerator research



G Stancari

Fermilab's 40 m-circumference Integrable Optics Test Accelerator.

In late August, a beam of electrons successfully circulated for the first time through a new particle accelerator at Fermilab in the US. The Integrable Optics Test Accelerator (IOTA), a 40 m-circumference storage ring, is one of only a handful of facilities worldwide dedicated to beam-physics studies. It forms the centrepiece of the Fermilab Accelerator Science and Technology (FAST) facility, and is the first research accelerator that will be able to switch between beams of electrons and protons.

Researchers will use IOTA to explore multiple accelerator technologies, including several that have been proposed but never tested, in particular targeting ultrahigh-intensity beams. More fundamentally it will allow precise control of a single electron – also opening the door to unique experiments in fundamental physics, such as understanding how the electron's quantum-mechanical nature blurs its position in space.

For accelerator physicists, IOTA's key focus is to test the concept of a nonlinear integrable focusing lattice in a realistic storage ring. Whereas contemporary accelerators are designed with linear focusing lattices, in reality machines always have nonlinearities, e.g. resulting from magnet imperfections, which lead to resonant behaviour and particle losses. A nonlinear integrable focusing lattice, proposed in 2010, is predicted to significantly suppress collective instabilities via Landau damping and thus could improve the performance of accelerators such as a Future Circular Collider. IOTA scientists will also capitalise on Fermilab's existing strengths in accelerator technologies, such as cooling, to make more orderly beams that are easier to manipulate and accelerate.

Over the next year, the Fermilab team will install the proton injector. Once it is in place, it will complete the trio of particle accelerators that make up Fermilab's FAST facility: the proton injector, the electron injector (completed in 2017) and the IOTA ring. FAST has already attracted 29 institutional partners, including European institutions, US universities, national laboratories and members from industry.

"IOTA is one of a kind – a particle storage ring designed and built specifically to host novel experiments with both electrons and protons, and to develop innovative concepts in accelerator science," says Fermilab physicist Alexander Valishev, head of the team that developed and constructed IOTA. "This facility offers a flexibility that can be useful to a wider community – above and beyond the needs of high-energy physics."

AEROSPACE

Satellite premieres in CERN irradiation facility

CHARM, a unique facility at CERN to test electronics in complex radiation environments, has been used to test its first full space system: a micro-satellite called CELESTA, developed by CERN in collaboration with the University of Montpellier and the European Space Agency. Built to monitor radiation levels in low-Earth orbit, CELESTA was successfully tested and qualified during July under a range of radiation conditions that it can be expected to encounter in space. It serves as an important validation of CHARM's potential value for aerospace applications.

CELESTA's main goal is to enable a space version of an existing CERN technology called RadMon, which was developed to monitor radiation levels in the Large Hadron Collider (LHC). RadMon also has potential applications in space missions that are sensitive to the radiation environment, ranging from telecom satellites to navigation and Earth-observation systems.

The CELESTA cubesat, a technological ▷

demonstrator and educational project made possible with funding from the CERN Knowledge Transfer fund, will play a key role in validating potential space applications by using RadMon sensors to measure radiation levels in low-Earth orbit. An additional goal of CELESTA is to demonstrate that the CHARM facility is capable of reproducing the low-Earth orbit radiation environment. "CHARM benefits from CERN's unique accelerator facilities and was originally created to answer a specific need for radiation testing of CERN's electronic equipment," explains Markus Brugger, deputy head of the engineering department and initiator of both the CHARM and CELESTA projects in the frame of the R2E (Radiation to Electronics) initiative. The radiation field at CHARM is generated through the interaction of a 24 GeV/c proton beam extracted from the Proton Synchrotron with a cylindrical copper or aluminium target. Different shielding configurations and testing positions allow


CERN-PHOTO-201807-181-3

CELESTA contains a space version of CERN's radiation-monitoring system RadMon, and is the first full satellite tested in the CHARM facility.

for controlled tests to account for desired particle types, energies and fluences.

It is the use of mixed fields that makes CHARM unique compared to other test facilities, which typically use mono-energetic particle beams or sources. For the latter, only one or a few discrete energies can be tested, which is usually not representative of the authentic and complex radiation environments encountered in aerospace missions. Most testing facilities also use focused beams, limiting tests to individual components, whereas CHARM has a homogenous field extending over an area of least one square metre, which allows complete and complex satellites and other systems to be tested.

CELESTA is now fully calibrated and will be launched as soon as a launch window is provided. When in orbit, in-flight data from CELESTA will be used to validate the CHARM test results for authentic space conditions. "This is a very important milestone for the CELESTA project, as well as an historical validation of the CHARM test facility for satellites," says Enrico Chesta, CERN's aerospace applications coordinator.

LHC Experiments

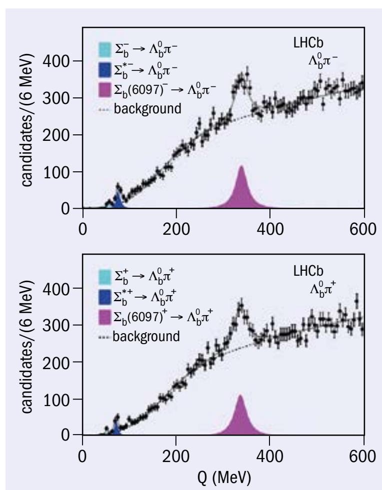
LHCb discovers two new baryons

Although the quark model of hadrons is highly successful in describing how the quarks combine to form baryons and mesons, the internal mechanisms governing the dynamics of the strong force that binds quarks inside those hadrons are far from fully understood. By studying new hadronic resonances and their excited states, light can be shed on these mechanisms.

LHCb physicists have recently observed, for the first time, two new baryons. These states, named $\Sigma_b(6097)^+$ and $\Sigma_b(6097)^-$, occur as resonances appearing in the two-body system $\Lambda_b^0\pi^\pm$, which consists of a neutral Λ_b^0 baryon and a charged π meson (see figure). The statistical significances of the observations are 12.7σ and 12.6σ, well above the threshold for discovery.

The new particles are members of the Σ_b family of baryons. Four of the six so-called ground states of this family, the Σ_b^+, Σ_b^-, Σ_b^{*+}, and Σ_b^{*-}, were previously discovered by the CDF collaboration at the Tevatron. LHCb also reports a study of the properties of these four ground states, measuring them with unprecedented statistics and improving the precision on their masses and widths by a factor of approximately five.

Establishing precisely how the new $\Sigma_b(6097)^+$ and $\Sigma_b(6097)^-$ states fit into this family is not straightforward. Theoretical predictions for a number of excited Σ_b states exist, including five $\Sigma_b(1P)$ states with expected masses close to the values seen by LHCb – though some of them may be difficult to observe experimentally. Since it's possible for different excited states to have similar masses, it can't be excluded that the newly observed mass peaks are actually superpositions of more than one state. Further input from theory, and future experimental studies with more data and in other final states, will help resolve this question.



Resonant structure in the $Q = m(\Lambda_b^0\pi^\pm) - m(\Lambda_b^0) - m(\pi^\pm)$ mass difference distribution. In the upper plot, showing $\Lambda_b^0\pi^-$, the new $\Sigma_b(6097)^-$ baryon is clearly seen over the background. The previously known Σ_b^- and Σ_b^{*-} resonances are also visible at low values of Q. In the lower plot, showing $\Lambda_b^0\pi^+$, a similar distribution is obtained in which the resonance $\Sigma_b(6097)^+$ is seen.

The meson sector is also capable of providing surprising results. Evidence for another new hadron has recently been reported by LHCb in a Dalitz plot analysis of B^0 decays to $\eta_c(1S)\,K^+\pi^-$. A structure, which could be a new resonance in the $\eta_c(1S)\,\pi^-$ system, was detected with a significance of more than three standard deviations. While this does not meet the threshold for discovery, it is an intriguing hint and will be pursued with more data. If confirmed, this new $Z_c(4100)^-$ resonance would be one of a small number of manifestly exotic mesons that cannot be described as a quark–anti-quark pair but must instead have a more complicated structure, such as being a tetraquark combination of two quarks and two antiquarks.

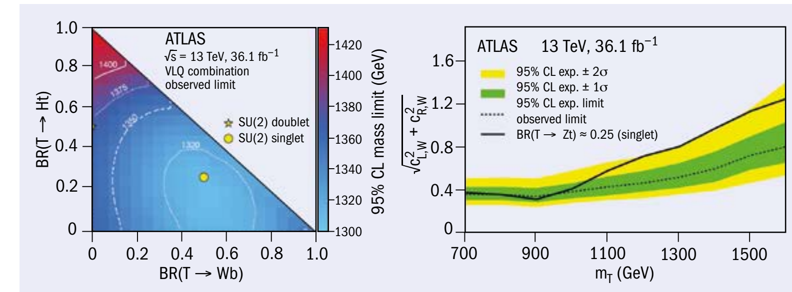
● **Further reading**

LHCb Collaboration 2018 arXiv:1809.07752.
LHCb Collaboration 2018 arXiv:1809.07416.

CERN Courier November 2018
News

Search for new quarks addresses unnaturalness

The Standard Model (SM) is a triumph of modern physics, with unprecedented success in explaining the subatomic world. The Higgs boson, discovered in 2012, was the capstone of this amazing theory, yet this newly known particle raises many questions. For example, interactions between the Higgs boson and the top quark should lead to huge quantum corrections to the Higgs boson mass, possibly as large as the Planck mass (>10^{18} GeV). Why, then, is the observed mass only 125 GeV? Finding a solution to this "hierarchy problem" is one of the top motivations of many new theories of particle physics.



Left: the lower limit on the mass of a vector-like top quark as a function of its branching ratio to Wb and Ht. Right: the upper limit on the coupling strength of the vector-like top quark as a function of the particle's mass.

A common feature in several of these theories is the existence of vector-like quarks – in particular, a vector-like top quark (T) that could naturally cancel the large quantum corrections caused by the SM top quark. Like other quarks, vector-like quarks are spin-½ particles that interact via the strong force and, like all spin-½ particles, they have left-handed and right-handed versions. The unique feature of vector-like quarks is their ambidexterity: while the weak force only interacts with left-handed SM particles, it would interact the same way with both the right- and left-handed versions of vector-like quarks. This also gives vector-like quarks more options in how they can decay. Unlike the Standard Model top quark, which almost always decays to a bottom quark and W boson (t→Wb), a vector-like top quark could decay three different ways: T→Wb, T→Zt, or T→Ht.

The search for vector-like quarks in ATLAS spans a wide range of dedicated analyses, each focusing on a particular experimental signature (possibly involving leptons, boosted objects or large missing transverse energy). The breadth of the programme allows ATLAS to be sensitive to most relevant decays of vector-like top quarks, and also those of vector-like bottom quarks, thus increasing the chances of discovery. The creation of particle–antiparticle pairs is the most probable production mechanism for vector-like quarks with mass around or below 1 TeV. For higher masses, single production of vector-like quarks may have a larger rate.

ATLAS recently performed a statistical combination of all the individual searches that looked for pair-production of vector-like quarks. While the individual analyses were designed to be sensitive to particular sets of decays, the combined results provide increased sensitivity to all considered decays of vector-like top quarks with masses up to 1.3 TeV. No vector-like top or bottom quarks were found. The combination allowed ATLAS to set the most stringent exclusion bounds on the mass of a vector-like top quark for arbitrary sets of branching ratios to the three decay modes (figure, left).

As the limits on vector-like quarks reach higher masses, the importance of searching for their single production rises. Such searches are also interesting from a theoretical perspective, since they allow one to constrain parameters of the production model (figure, right).

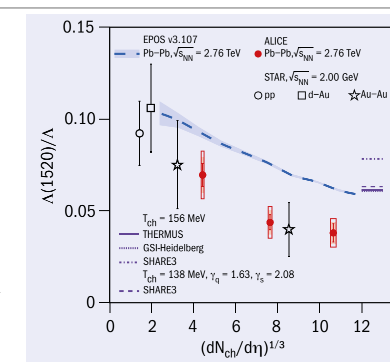
Given these new strong limits on vector-like quarks and the lack of evidence for supersymmetry, the theoretical case for a naturally light Higgs boson is not looking good! But nature probably still has a few tricks up her sleeve to get out of this conundrum.

● **Further reading**

ATLAS Collaboration 2018 arXiv:1808.02343.
ATLAS Collaboration 2018 arXiv:1806.10555.

Suppression of the Λ(1520) resonance in Pb–Pb collisions

The ALICE collaboration has recently reported the first measurement of the hadronic resonance Λ(1520) in heavy-ion collisions at the LHC. In such collisions, a deconfined plasma of quarks and gluons called quark–gluon plasma (QGP) is formed, which expands and cools. Eventually, the system undergoes a transition to a dense hadron gas (hadronisation), which further expands until all interactions among hadrons cease. Short-lived hadronic resonances are sensitive probes of the dynamics and properties of the medium formed after hadronisation. Due to their short lifetimes, they decay when the system is still dense and the decay products scatter in the hadron gas, reducing the observed number of decays.



The p_T-integrated ratio of Λ(1520)/Λ production as a function of charged-particle multiplicity, also showing predictions from several models.

The production yield of the Λ(1520) baryon resonance was measured at mid-rapidity in lead–lead (Pb–Pb) collisions at a centre of mass energy per nucleon–nucleon pair of 2.76 TeV. The resonance is reconstructed in the ▷

$\Lambda(1520) \rightarrow pK^-$ (and its charge-conjugate) hadronic decay channel and its production is measured as a function of the collision centrality. The ratio of the number of measured $\Lambda(1520)$ baryons to that of its stable counterpart, Λ, highlights the characteristics of resonance production directly related to the particle lifetime, since possible effects due to valence-quark composition (e.g. strangeness enhancement) cancel in the ratio. A gradual decrease of the $\Lambda(1520)/\Lambda$ yield ratio with increasing charged-particle multiplicity is observed from peripheral to central Pb–Pb collisions (see figure).

The result provides the first evidence for $\Lambda(1520)$ suppression in central heavy-ion collisions compared to peripheral collisions, achieving a 3.1σ confidence level once cancellations of correlated systematics are taken into account. An earlier measurement at lower collision energy by the STAR experiment at Brookhaven's Relativistic Heavy-Ion Collider showed a similar suppression, but with much larger uncertainties. The ratio of the $\Lambda(1520)$ resonance yield with respect to non-resonant Λ baryons reduces by about 45% in central collisions compared to peripheral collisions.

The EPOS3 model, which describes the full evolution of a heavy-ion collision and includes re-scattering in the hadronic phase, describes this suppression well, although it systematically overestimates the data. The relative decrease of the $\Lambda(1520)$ resonance yield is also slightly smaller in the EPOS3 model than observed in the data, suggesting a longer lifetime of the hadronic phase (about 8.5 fm/c in EPOS3), or that the description of the relevant hadronic cross-sections in the transport phase is imprecise. The mean transverse momentum is also shown to increase with increasing charged-particle multiplicity, hence with increasing collision centrality. The EPOS3 model can quantitatively describe this feature. It is noteworthy that the model does not describe the data when the microscopic transport stage responsible for the re-scattering effect inside the hadronic medium (as described by the UrQMD model), is disabled.

In summary, these measurements add further support to the formation of a dense hadronic phase in Pb–Pb collisions, highlighting its relevance and the importance of a microscopic description of the latest stages of the evolution of heavy-ion collisions.

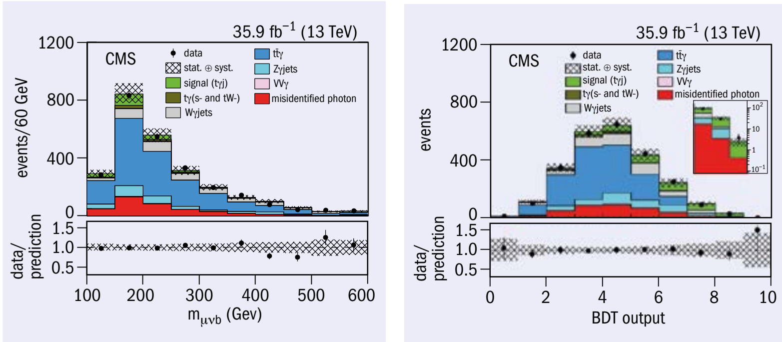
Further reading
ALICE Collaboration 2018 arXiv:1805.04361.

CMS detects first production of top quark and photon

It is well known that the top quark, the heaviest known elementary particle, plays an important role in electroweak-symmetry breaking, and is also one of the most promising particles to be investigated in the search for new physics. Numerous measurements of top-quark interactions have been performed at the Tevatron and LHC since the discovery of this particle at the Tevatron in 1995. The associated production of a top quark with a photon (tγj, where j indicates a jet) via electroweak interactions provides a powerful tool to probe the couplings of the top quark with the photon and the couplings of the W boson with the photon. The small production rate of the tγj process at the LHC makes its observation very challenging. However, any excess observed above the Standard Model (SM) rate would indicate new physics.

The CMS collaboration has released evidence for the tγj process using events with one isolated muon, a photon and jets in the final state. The results are based on proton–proton collision data recorded in 2016 at a centre-of-mass-energy of 13 TeV. The tγj process results in an interesting final state, which requires information from all sub-detectors of the CMS experiment, from the innermost tracker layers to the outermost muon systems.

The predicted cross section for tγj, including the branching fraction, is 81 fb, which corresponds to a few hundred events in the whole dataset. Therefore, a sophisticated method is needed to separate the signal events from the huge number of background events originating from several other SM processes. In addition, to achieve the highest signal-to-background ratio, a robust multivariate technique is used to estimate the contribution of the background in which a jet is misidentified as a photon. After these methods are employed, the largest background contribution comes from events that contain a top-quark pair associated with a photon.



Left: the reconstructed top-quark mass from a b-tagged jet, muon and missing energy. Right: the multivariate estimator for data and SM predictions after performing the fit. The inset presents a zoom of the last three bins plotted on log scale, while the hatched band shows the statistical and systematic uncertainties in the estimated signal and background yields, and the vertical bars on the points represent the statistical uncertainties of the data. The ratio of the data to the SM prediction is shown in the bottom panels.

CMS observed an excess of tγj events over the background-only hypothesis with a significance of 4.4 standard deviations, which corresponds to a p-value of 4.3×10^{-6}. The measured value of the signal cross section in the considered phase space is 115 ± 34 fb. The measurement is in agreement with the SM prediction within one standard deviation. This result is the first experimental evidence of the direct production of a top quark and a photon. Upcoming results, exploiting the full 13 TeV dataset, will further improve the precision of the measurement.

Further reading
CMS Collaboration 2018 arXiv:1808.02913.

Astrowatch

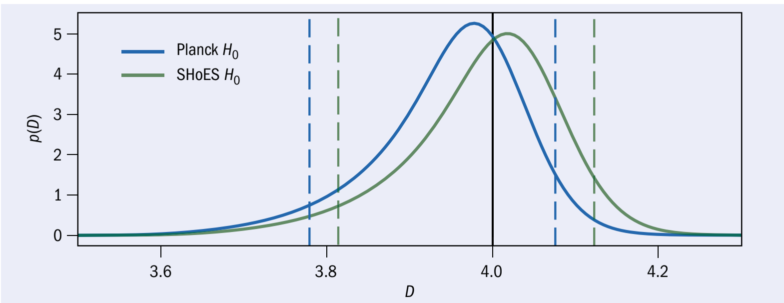
Compiled by Merlin Kole, Department of Particle Physics, University of Geneva

Gravitational hunt for extra dimensions

General relativity predicts very accurately how objects fall from a table and how planets move within the solar system. At larger scales, however, some issues arise. The most glaring is the theory's prediction of the motion of stars within a galaxy and of the acceleration of galaxies away from each other, both of which are at odds with observations. Models containing dark matter and dark energy can solve these two problems, respectively. Another potential solution is that space–time contains additional dimensions, modifying general relativity. Such additional dimensions are not observable with electromagnetic waves, but new information gleaned from gravitational waves (GWs) are allowing such models to be tested for the first time.

Some modifications of general relativity, such as the Dvali–Gabadadze–Porrati (DGP) model, involve the addition of extra dimensions accessible to gravity. If such extra dimensions are large, and thus not rolled up to a microscopic size as predicted by some beyond-Standard Model theories, part of the gravitational field would "leak" into the extra dimensions. Therefore, GWs arriving at detectors such as those of the LIGO and VIRGO observatories would be weaker than expected.

The first GWs detected, in September 2015, came from distant black-hole binaries. For such objects, there is no electromagnetic-wave counterpart, so the only information astronomers have about their distance from Earth is from the GWs themselves, making it impossible to check if some of the wave's intensity was lost. However, GW170817, the first observed merger of binary neutron stars, produced both GWs and electromagnetic radiation, which was measured by a wide range of instruments (*CERN Courier* December 2017 p16). As a result, we know in which galaxy the merger took place and therefore have a good measurement of the distance the GWs travelled. Using this distance measurement and the measured strength of the GW signal, one can test whether the signal follows general relativity or a model with additional dimensions.



The probability p *as a function of the number of spacetime dimensions* D *for two different values of the Hubble constant.*

Doing exactly this, a group led by Kris Pardo from Princeton University has found that the results are most compatible with the standard 3+1 space–time-dimensions picture. Assuming two values for the Hubble constant, as required due to a large discrepancy between values obtained by two different methods (*CERN Courier* May 2018 p17), the researchers show that, regardless of the value assumed, the results allow for a total of 4.0 ± 0.1 dimensions (see figure).

The authors also obtained an upper limit on the graviton's lifetime of 450 million years. As is the case with a potential leakage of gravity into extra dimensions, the decay of gravitons propagating towards Earth would also cause the strength of the GW signal to decrease.

These findings are just the beginning of the physics studies made possible by gravitational-wave astronomy. As the authors make clear in their paper, the results only affect theories with finite but large-scale extra dimensions. That may change, however, as more GWs are expected to be measured, with increased precision, in the future. One promising parameter capable of probing a larger set of models is the polarisation of the GWs. For the GW170817 system, polarisation information was not available at the time of observation owing to the limited number of GW detectors. Any higher-dimensional model allows for extra GW polarisation modes, which can be studied with the help of additional GW detectors such as the planned KAGRA and IndIGO facilities.

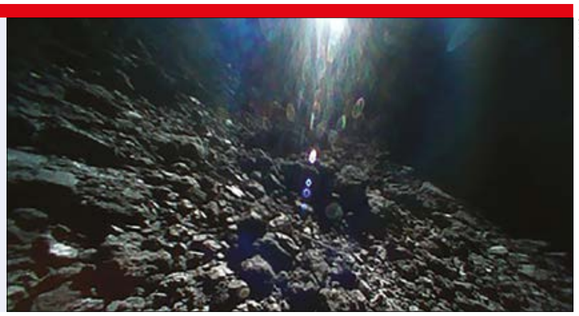
With a future global array of GW detectors, we can look forward to more studies in this field of physics which, until now, has been almost inaccessible.

Further reading

K Pardo *et al.* 2018 *J. Cosmol. Astropart. Phys.* **7** 48.

Picture of the month

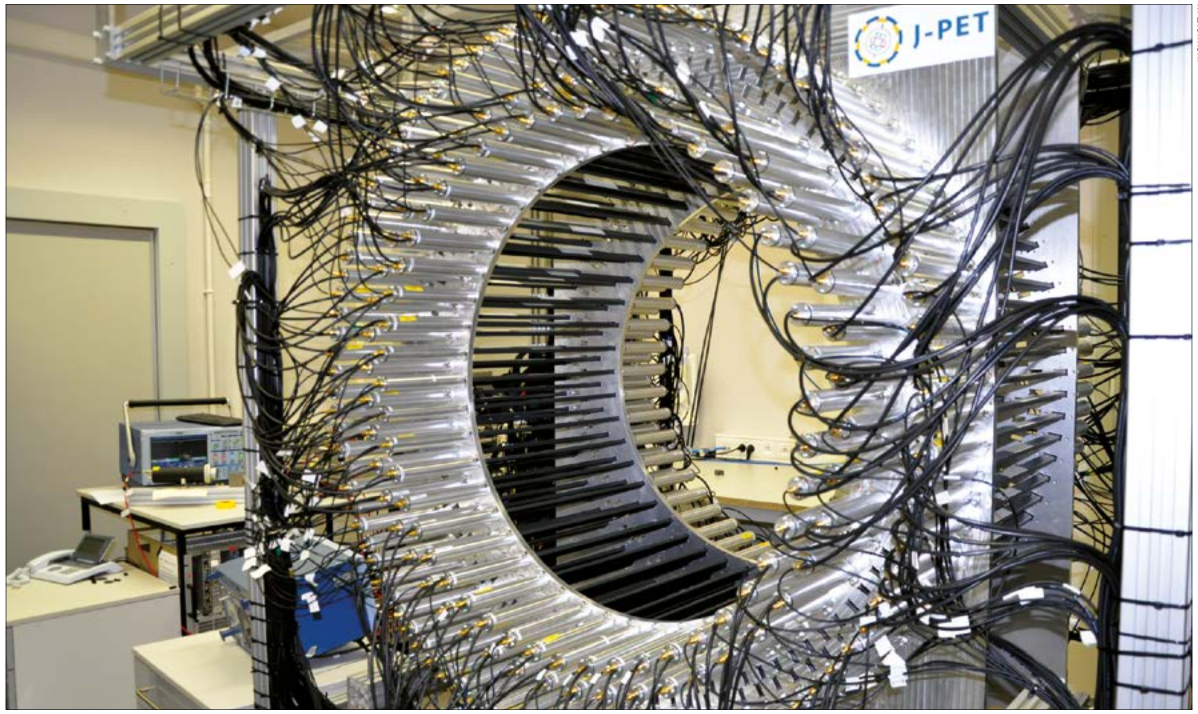
This slightly blurry distorted image of a rocky surface is more interesting than it might first appear. The small instrument responsible for the picture is the first of several robot "hoppers" to be deployed to an asteroid called Ryugu by the Japanese probe Hayabusa2, before the spacecraft itself will land on the asteroid surface to take samples back to Earth. The asteroid consists mainly of nickel, iron, cobalt, water, nitrogen, hydrogen and ammonia. It's slightly less than 1 km in diameter and weighs 450 million tonnes. The image was taken as the robot, which is about the size of a shoebox, jumped several metres high – a journey that, owing to a gravitational acceleration of just 0.0001 m s^{-2}, takes about 15 minutes.



JAXA

J-PET's plastic revolution

A recently developed detector based on inexpensive plastic scintillators paves the way for whole-body PET imaging and precision measurements of fundamental symmetries.



M Zieliński

The J-PET detector is made of three cylindrical layers of plastic scintillator strips (black) with photomultiplier tubes at each end.

It is some 60 years since the conception of positron emission tomography (PET), which revolutionised the imaging of physiological and biochemical processes. Today, PET scanners are used around the world, in particular providing quantitative and 3D images for early-stage cancer detection and for maximising the effectiveness of radiation therapies. Some of the first PET images were recorded at CERN in the late 1970s, when physicists Alan Jeavons and David Townsend used the technique to image a mouse. While the principle of PET already existed, the detectors and algorithms developed at CERN made a major contribution to its development. Techniques from high-energy physics could now be about to enable another leap in PET technology.

In a typical PET scan, a patient is administered with a radioactive solution that concentrates in malignant cancers. Positrons from β^+ decay annihilate with electrons from the body, resulting in the back-to-back emission of two 511 keV gamma rays that are registered in a crystal via the photoelectric effect. These signals are then used to reconstruct an image. Significant advances in PET imaging have taken place in the past few decades, and the vast majority of existing scanners use inorganic crystals – usually bismuth germanium oxide (BGO) or lutetium yttrium orthosilicate (LYSO) – organised in a ring to detect the emitted PET photons.

The main advantage of crystal detectors is their large stopping power, high probability of photoelectric conversion and good energy resolution. However, the use of inorganic crystals is expensive, limiting the number of medical facilities equipped with PET scanners. Moreover, conventional detectors are limited in their axial field of view: currently a distance of only about 20 cm along the body can be simultaneously examined from a single-bed position, meaning that several overlapping bed positions are needed to carry out a whole-body scan, and only 1% of quanta emitted from a patient's body are collected. Extension of the scanned region from around 20 to 200 cm would not only improve the sensitivity and signal-to-noise ratio, but also reduce the radiation dose

K Dulski

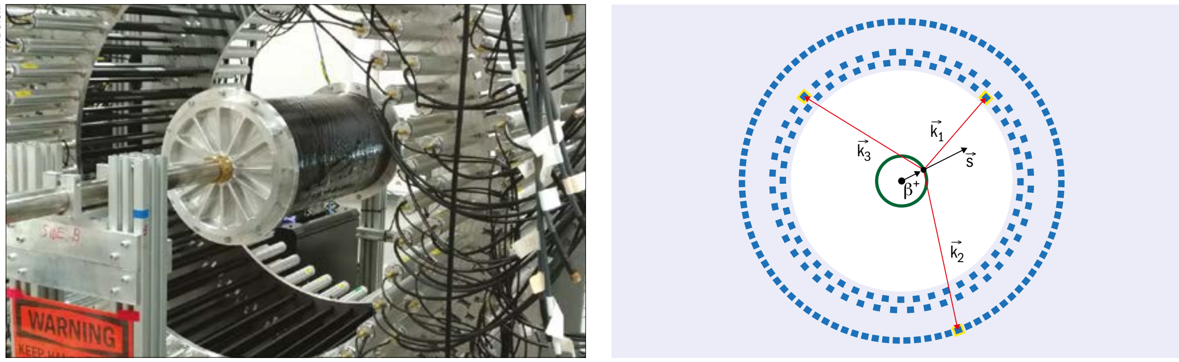


Fig. 1. (Left) The J-PET setup with a vacuum chamber installed in the centre for physics research. (Right) The position of a positronium annihilation event in the wall of a cylinder (green) can be reconstructed based on the position and time of the registered annihilation gamma quanta (k_1, k_2, k_3). Since the polarisation direction of a positron emitted from a beta source is mostly preserved during positronium formation, the positron spin direction (S) can also be obtained from the known positron emission point (centre) and the reconstructed e^+e^- annihilation point.

needed for a whole-body scan.

To address this challenge, several different designs for whole-body scanners have been introduced based on resistive-plate chambers, straw tubes and alternative crystal scintillators. In 2009, particle physicist Paweł Moskal of Jagiellonian University in Kraków, Poland, introduced a system that uses inexpensive plastic scintillators instead of inorganic ones for detecting photons in PET systems. Called the Jagiellonian PET (J-PET) detector, and based on technologies already employed in the ATLAS, LHCb, KLOE, COSY-11 and other particle-physics experiments, the aim is to allow cost effective whole-body PET imaging.

Whole-body imaging

The current J-PET setup comprises a ring of 192 detection modules axially arranged in three layers as a barrel-shaped detector and the construction is based on 17 patent-protected solutions. Each module consists of a $500 \times 19 \times 7\,\text{mm}^3$ scintillator strip made of a commercially available material called EJ-230, with a photomultiplier tube (PMT) connected at each side. Photons are registered via the Compton effect and each analog signal from the PMTs is sampled in the voltage domain at four thresholds by dedicated field-programmable gate arrays.

In addition to recording the location and time of the electron–positron annihilation, J-PET determines the energy deposited by annihilation photons. The 2D position of a hit is known from the scintillator position, while the third space component is calculated from the time difference of signals arriving at both ends of scintillator, enabling direct 3D image reconstruction. PMTs connected to both sides of the scintillator strips compensate for the low detection efficiency of plastic compared to crystal scintillators and enable multi-layer detection. A modular and relatively easy to transport PET scanner with a non-magnetic and low density central part can be used as a magnetic resonance imaging (MRI) or computed-tomography compatible insert. Furthermore, since plastic scintillators are produced in various shapes, the J-PET approach can be also introduced for positron emission mammography (PEM) and as a range monitor for hadron therapy.

J-PET can also build images from positronium (a bound state of electron and positron) that gets trapped in intermolecular voids. In about 40% of cases, positrons injected into the human body create positronium with a certain lifetime and other environmentally sensitive properties. Currently this information is neither recorded nor used for PET imaging, but recent J-PET measurements of the positronium lifetime in normal and cancer skin cells indicate that the properties of positronium may be used as diagnostic indicators for cancer therapy. Medical doctors are excited by the avenues opened by J-PET. These include a larger axial view (e.g. to check correlations between organs separated by more than 20 cm in the axial direction), the possibility of performing combined PET-MRI imaging at the same time and place, and the possibility of simultaneous PET and positronium (morphometric) imaging paving the way for *in vivo* determination of cancer malignancy.

Such a large detector is not only potentially useful for medical applications. It can also be used in materials science, where PALS enables the study of voids and defects in solids, while precise measurements of positronium atoms leads to morphometric imaging and physics studies. In this latter regard, the J-PET detector offers a powerful new tool to test fundamental symmetries.

Combinations of discrete symmetries (charge conjugation C, parity P, and time reversal T) play a key role in explaining the observed matter–antimatter asymmetry in the universe (CP violation) and are the starting point for all quantum field theories preserving Lorentz invariance, unitarity and locality (CPT symmetry). Positronium is a good system enabling a search for C, T, CP and CPT violation via angular correlations of annihilation quanta, while the positronium lifetime measurement can be used to separate the ortho- and para-positronium states (o-Ps and p-Ps). Such decays also offer the potential observation of gravitational quantum states, and are used to test Lorentz and CPT symmetry in the framework of the Standard Model Extension.

At J-PET, the following reaction chain is predominantly considered: $^{22}\text{Na} \rightarrow {}^{22}\text{Ne}^* e^+ \nu_e$, $^{22}\text{Ne}^* \rightarrow {}^{22}\text{Ne}\,\gamma$ and $e^+e^- \rightarrow$ o-Ps $\rightarrow 3\gamma$ annihilation. The detection of 1274 keV prompt γ emission from $^{22}\text{Ne}^*$ de-excitation is the start signal for the positronium-lifetime measurement. Currently, tests of discrete symmetries and quantum entanglement of photons originating from the decay of positronium atoms are the main physics topics investigated by the J-PET group. The first data taking was conducted in 2016 and six data-taking campaigns have concluded with almost 1 PB of data. Physics studies are based on data collected with a point-like source placed in the centre of the detector and covered by a porous polymer to increase the probability of positronium formation. A test measurement with a source surrounded by an aluminium cylinder was also performed. The use of a cylindrical target (figure 1, left) allows researchers to separate in space the positronium formation and annihilation (cylinder wall) from the positron emission (source). Most recently, measurements by J-PET were also performed with a cylinder with the inner wall covered by the porous material.

E Czerwiński

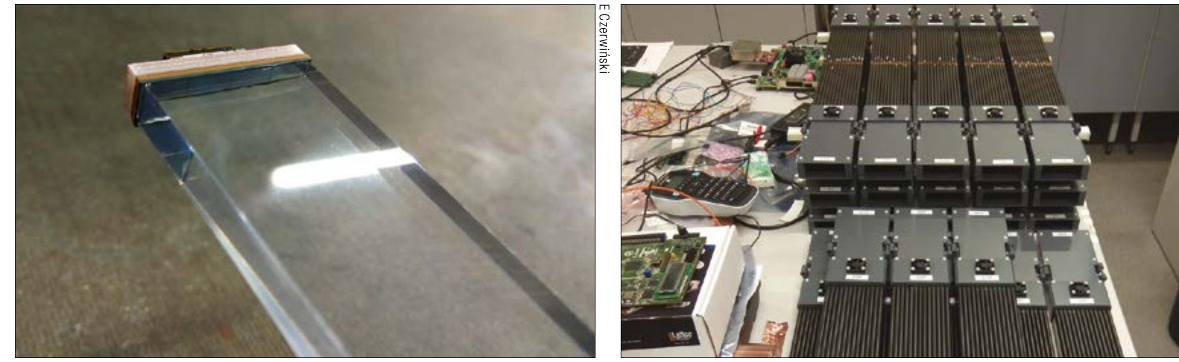


Fig. 2. Scintillator for a new J-PET layer with attached silicon photomultiplier (left), and modules consisting of 13 scintillators ready for implementation as a fourth J-PET layer (right).

The J-PET programme aims to beat the precision of previous measurements for C, CP and CPT symmetry tests in positronium, and to be the first to observe a potential T-symmetry violation. Tests of C symmetry, on the other hand, are conducted via searches for forbidden decays of the positronium triplet state (o-Ps) to 4γ and the singlet state (p-Ps) to 3γ. Tests of the other fundamental symmetries and their combinations will be performed by the measurement of the expectation values of symmetry-odd operators constructed using spin of o-Ps, momenta and polarisation vectors of photons originating from its annihilation (figure 1, right). The physical limit of such tests is expected at the level of about 10^{-9} due to photo–photon interaction, which is six orders of magnitude smaller than the present experimental limits (e.g. at the University of Tokyo and by the Gammasphere experiment).

Since J-PET is built of plastic scintillators, it provides an opportunity to determine the photon's polarisation through the registration of primary and secondary Compton scatterings in the detector. This, in turn, enables the study of multi-partite entanglement of photons originating from the decays of positronium atoms. The survival of particular entanglement properties in the mixing scenario may make it possible to extract quantum information in the form of distinct entanglement features, e.g. from metabolic processes in human bodies.

Currently a new, fourth J-PET layer is under construction (figure 2), with a single unit of the layer comprising 13 plastic-scintillator strips. With a mass of about 2 kg per single detection unit, it is easy to transport and to build on-site a portable tomographic chamber whose radius can be adjusted for different purposes by using a given number of such units.

The J-PET group is a collaboration between several Polish institutions – Jagiellonian University, the National Centre for Nuclear Research Świerk and Maria Curie-Skłodowska University – as well as the University of Vienna and the National Laboratory in Frascati. The research is funded by the Polish National Centre for Research and Development, by the Polish Ministry of Science and Higher Education and by the Foundation for Polish Science. Although the general interest in improved quality of medical diagnosis was the first step towards this new detector for positron annihilation, today the basic-research programme is equally advanced. The only open question at J-PET is whether a high-resolution full human body tomographic image will be presented before the most precise test of one of nature's fundamental symmetries.

Further reading

A Gajos *et al.* 2016 *Nucl. Instrum. Methods Phys. Res. A* **819** 54.
B Hiesmayr and P Moskal 2017 *Sci. Rep.* **7** 15349.
B Jasinska *et al.* 2017 *Acta Phys. Polon. B* **48** 1737.
D Kamińska *et al.* 2016 *Eur. Phys. J. C* **76** 445.
P Kowalski *et al.* 2018 *Phys. Med. Biol.* **63** 165008.
P Moskal *et al.* 2016 *Acta Phys. Polon.* B **47** 509.

Résumé

TEP : la révolution du plastique

La première image de tomographie par émission de positons (TEP), technique qui doit beaucoup aux détecteurs et aux algorithmes mis au point au CERN, a été enregistrée il y a 40 ans. Des techniques importées de la physique des hautes énergies pourraient être sur le point de produire un nouveau saut technologique en matière de TEP. Un nouveau détecteur appelé J-PET, utilisant des scintillateurs en plastique peu onéreux, ouvre la voie à l'imagerie haute résolution de tout le corps. Et ce n'est pas tout. Le détecteur permet aussi de réaliser des tests très précis de symétries fondamentales telles que celles relatives à la charge, à la parité et au temps.

Eryk Czerwiński, Jagiellonian University, Kraków, Poland.

The roots and fruits of string theory

In the summer of 1968, while a visitor in CERN's theory division, **Gabriele Veneziano** wrote a paper titled "Construction of a crossing-symmetric, Regge behaved amplitude for linearly-rising trajectories". He was trying to explain the strong interaction, but his paper wound up marking the beginning of string theory.

What led you to the 1968 paper for which you are most famous?

In the mid-1960s we theorists were stuck in trying to understand the strong interaction. We had an example of a relativistic quantum theory that worked: QED, the theory of interacting electrons and photons, but it looked hopeless to copy that framework for the strong interactions. One reason was the strength of the strong coupling compared to the electromagnetic one. But even more disturbing was that there were so many (and ever growing in number) different species of hadrons that we felt at a loss with field theory – how could we cope with so many different states in a QED-like framework? We now know how to do it and the solution is called quantum chromodynamics (QCD). But things weren't so clear back then. The highly non-trivial jump from QED to QCD meant having the guts to write a theory for entities (quarks) that nobody had ever seen experimentally.

No one was ready for such a logical jump, so we tried something else: an S-matrix approach. The S-matrix, which relates the initial and final states of a quantum-mechanical process, allows one to directly calculate the probabilities of scattering processes without solving a quantum field theory such as QED. This is why it looked more promising. It was also looking very conventional but, eventually, led to something even more revolutionary than QCD – the idea that hadrons are actually strings.

Veneziano, photographed at CERN in July, worked at CERN for more than 30 years and led the theory division between 1994 and 1997. (Image credit: CERN-PHOTO-201807-183-1.)

Is it true that your "eureka" moment was when you came across the Euler beta function in a textbook?

Not at all! I was taking a bottom-up approach to understand the strong interaction. The basic idea was to impose on the S-matrix a property now known as Dolen–Horn–Schmid (DHS) duality. It relates two apparently distinct processes contributing to an elementary reaction, say a+b → c+d. In one process, a+b fuse to form a metastable state (a resonance) which, after a characteristic lifetime, decays into c+d. In the other process the pair a+c exchanges a virtual particle with the pair b+d. In QED these two processes have to be added because they correspond to two distinct Feynman diagrams, while, according to DHS duality, each one provides, for strong interactions, the whole story. I'd heard about DHS duality from Murray Gell-Mann at the Erice summer school in 1967, where he said that DHS would lead to a "cheap bootstrap" for the strong interaction. Hearing this being said by a great physicist motivated me enormously. I was in the middle of my PhD studies at the Weizmann Institute in Israel. Back there in the fall, a collaboration of four people was formed. It consisted of Marco Ademollo, on leave at Harvard from Florence, and of Hector Rubinstein, Miguel Virasoro and myself at the Weizmann Institute. We worked intensively for a period of eight-to-nine months trying to solve the (apparently not so) cheap bootstrap for a particularly convenient reaction. We got very encouraging results hinting, I was feeling, for the existence of a simple exact solution. That solution turned out to be the Euler beta function.

But the 1968 paper was authored by you alone?

Indeed. The preparatory work done by the four of us had a crucial role, but the discovery that the Euler beta function was an exact realisation of DHS duality was just my own. It was around mid-June 1968, just days before I had to take a boat from Haifa to Venice and then continue to CERN where I would spend the month of July. By that time the group of four was already dispersing (Rubinstein on his way to NYU, Virasoro to Madison, Wisconsin via Argentina, Ademollo back to Florence before a second year at Harvard). I kept working on it by myself, first on the boat, then at CERN until the end of July when, encouraged by Sergio Fubini, I decided to send the preprint to the journal *Il Nuovo Cimento*.

Was the significance of the result already clear?

Well, the formula had many desirable features, but the reaction of the physics community came to me as a shock. As soon as I had submitted the paper I went on vacation for about four weeks in Italy and did not think much about it. At the end of August 1968, I attended the Vienna conference – one of the biennial Rochester-conference series – and found out, to my surprise, that the paper was already widely known and got mentioned in several summary talks. I had sent the preprint as a contribution and was invited to give a parallel-session talk about it. Curiously, I have no recollection of that event, but my wife remembers me telling her about it. There was even a witness, the late David Olive, who wrote that listening to my talk changed his life. It was an instant hit, because the model answered several questions at once, but it was not at all apparent then that it had anything to do with strings, not to mention quantum gravity.

When was the link to "string theory" made?

The first hints that a physical model for hadrons could underlie my mathematical proposal came after the latter had been properly generalised (to processes involving an arbitrary number of colliding particles) and the whole spectrum of hadrons it implied was unraveled (by Fubini and myself and, independently, by Korkut Bardakci and Stanley Mandelstam). It came out, surprisingly, to closely resemble the exponentially growing (with mass) spectrum postulated almost a decade earlier by CERN theorist Rolf Hagedorn and, at least naively, it implied an absolute upper limit on temperature (the so-called Hagedorn temperature).

The spectrum coincides with that of an infinite set of harmonic oscillators and thus resembles the spectrum of a quantised vibrating string with its infinite number of higher harmonics. Holger Nielsen and Lenny Susskind independently suggested a string (or a rubber-band) picture. But, as usual, the devil was in the details. Around the end of the decade Yoichiro Nambu (and independently Goto) gave the first correct definition of a classical relativistic string, but it took until 1973 for Goddard, Goldstone, Rebbi and Thorn to prove that the correct application of quantum mechanics to the Nambu–Goto string reproduced exactly the above-mentioned generalisation of my original work. This also included certain consistency conditions that had already been found, most notably the existence of a massless spin-1 state (by Virasoro) and the need for extra spatial dimensions (from Lovelace's work). At that point it became clear that the original model had a clear physical interpretation of hadrons being quantised strings. Some details were obviously wrong: one of the most striking features of strong interactions is their short-range nature, while a massless state produces long-range interactions. The model being inconsistent for three spatial dimensions (our world!) was also embarrassing, but people kept hoping.

When people say string theory can't be proved, it is unfair.

So string theory was discovered by accident?

Not really. Qualitatively speaking, however, having found that hadrons are strings was no small achievement for those days. It was not precisely the string we now associate with quark confinement in QCD. Indeed the latter is so complicated that only the most powerful computers could shed some light on it many decades later. *A posteriori*, the fact that by looking at hadronic phenomena we were driven into discovering string theory was neither a coincidence nor an accident.

When was it clear that strings offer a consistent quantum-gravity theory?

This very bold idea came as early as 1974 from a paper by Joel Scherk and John Schwarz. Confronted with the fact that the massless spin-1 string state refused to become massive (there is no Brout–Englert–Higgs mechanism at hand in string theory!) and that even a massless spin-2 string had to be part of the string spectrum, they argued that those states should be identified with the photon and the graviton, i.e. with the carriers of electromagnetic and gravitational interactions, respectively. Other spin-1 particles could be associated with the gluons of QCD or with the W and Z bosons of the weak interaction. String theory would then become a theory of all interactions, at a deeper, more microscopic level. The characteristic scale of the hadronic string (~10^{-13} cm) had to be reduced by 20 orders of magnitude (~10^{-33} cm, the famous Planck-length) to describe the quarks themselves, the electron, the muon and the neutrinos, in fact every elementary particle, as a string.

In addition, it turned out that a serious shortcoming of the old string (namely its "softness", meaning that string–string collisions cannot produce events with large deflection angles) was a big plus for the Scherk–Schwarz proposal. While the data were showing that hard hadron collisions were occurring at substantial rates, in agreement with QCD predictions, the softness of string theory could free quantum gravity from its problematic ultraviolet divergences – the main obstacle to formulating a consistent quantum-gravity theory.

Did you then divert your attention to string theory?

Not immediately. I was still interested in understanding the strong interactions and worked on several aspects of perturbative and non-perturbative QCD and their supersymmetric generalisations. Most people stayed away from string theory during the 1974–1984 decade. Remember that the Standard Model had just come to life and there was so much to do in order to extract its predictions and test it. I returned to string theory after the Green–Schwarz revolution in 1984. They had discovered a way to reconcile string theory with another fact of nature: the parity violation of weak interactions. This breakthrough put string theory in the hotspot again and since then the number of string-theory aficionados has been steadily growing, particularly within the younger part of the theory community. Several revolutions have followed since then, associated with the names of Witten, Polchinski, Maldacena and many others. It would take too long to do justice to all these beautiful developments. Personally, and very early on, I got interested in applying the new string theory to primordial cosmology.

Was your 1991 paper the first to link string theory with cosmology?

I think there was at least one already, a model by Brandenberger and Vafa trying to explain why our universe has only three large spatial dimensions, but it was certainly among the very first. In 1991, I (and independently Arkadi Tseytlin) realised that the string-cosmology equations, unlike Einstein's, admit a symmetry (also called, alas, duality!) that connects a decelerating expansion to an accelerating one. That, I thought, could be a natural way to get an inflationary cosmology, which was already known since the 1980s, in string theory without invoking an ad-hoc "inflaton" particle.

The problem was that the decelerating solution had, superficially, a Big Bang singularity in its past, while the (dual) accelerating solution had a singularity in the future. But this was only the case if one neglected effects related to the finite size of the string. Many hints, including the already mentioned upper limit on temperature, suggested that Big Bang-like singularities are not really there in string theory. If so, the two duality-related solutions could be smoothly connected to provide what I dubbed a "pre-Big Bang scenario" characterised by the lack of a beginning of time. I think that the model (further developed with Maurizio Gasperini and by many others) is still alive, at least as long as a primordial B-mode polarisation is not discovered in the cosmic microwave background, since it is predicted to be insignificant in this cosmology.

I just followed my nose and took risks that eventually paid off.

Did you study other aspects of the new incarnation of string theory?

A second line of string-related research, which I have followed since 1987, concerns the study of thought experiments to understand what string theory can teach us about quantum gravity in the spirit of what people did in the early days of quantum mechanics. In particular, with Daniele Amati and Marcello Ciafaloni first, and then also with many others, I have studied string collisions at trans-Planckian energies (> 10^{19} GeV) that cannot be reached in human-made accelerators but could have existed in the early universe. I am still working on it. One outcome of that study, which became quite popular, is a generalisation of Heisenberg's uncertainty principle implying a minimal value of Δx of the order of the string size.

50 years on, is the theory any closer to describing reality?

People say that string theory doesn't make predictions, but that's simply not true. It predicts the dimensionality of space, which is the only theory so far to do so, and it also predicts, at tree level (the lowest level of approximation for a quantum-relativistic theory), a whole lot of massless scalars that threaten the equivalence principle (the universality of free-fall), which is by now very well tested. If we could trust this tree-level prediction, string theory would be already falsified. But the same would be true of QCD, since at tree level it implies the existence of free quarks. In other words: the new string theory, just like the old one, can be falsified by large-distance experiments provided we can trust the level of approximation at which it is solved. On the other hand, in order to test string theory at short distance, the best way is through cosmology. Around (i.e. at, before, or soon after) the Big Bang, string theory may have left its imprint on the early universe and its subsequent expansion can bring those to macroscopic scales today.

What do you make of the ongoing debate on the scientific viability of the landscape, or "swamp", of string-theory solutions?

I am not an expert on this subject but I recently heard (at the Strings 2018 conference in Okinawa, Japan) a talk on the subject by Cumrun Vafa claiming that the KKLT solution [which seeks to account for the anomalously small value of the vacuum energy, as proposed in 2003 by Kallosh, Kachru, Linde and Trivedi] is in the swampland, meaning it's not viable at a fundamental quantum-gravity level. It was followed by a heated discussion and I cannot judge who is right. I can only add that the absence of a metastable de-Sitter vacuum would favour quintessence models of the kind I investigated with Thibault Damour several years ago and that could imply interestingly small (but perhaps detectable) violations of the equivalence principle.

What's the perception of strings from outside the community?

Some of the popular coverage of string theory in recent years has been rather superficial. When people say string theory can't be proved, it is unfair. The usual argument is that you need unconceivably high energies. But, as I have already said, the new incarnation of string theory can be falsified just like its predecessor was; it soon became very clear that QCD was a better theory. Perhaps the same will happen to today's string theory, but I don't think there are serious alternatives at the moment. Clearly the enthusiasm of young people is still there. The field is atypically young – the average age of attendees of a string-theory conference is much lower than that for, say, a QCD or electroweak physics conference. What is motivating young theorists? Perhaps the mathematical beauty of string theory, or perhaps the possibility of carrying out many different calculations, publishing them and getting lots of citations.

What advice do you offer young theorists entering the field?

I myself regret that most young string theorists do not address the outstanding physics questions with quantum gravity, such as what's the fate of the initial singularity of classical cosmology in string theory. These are very hard problems and young people these days cannot afford to spend a couple of years on one such problem without getting out a few papers. When I was young I didn't care about fashions, I just followed my nose and took risks that eventually paid off. Today it is much harder to do so.

How has theoretical particle physics changed since 1968?

In 1968 we had a lot of data to explain and no good theory for the weak and strong interactions. There was a lot to do and within a few years the Standard Model was built. Today we still have essentially the same Standard Model and we are still waiting for some crisis to come out of the beautiful experiments at CERN and elsewhere. Steven Weinberg used to say that physics thrives on crises. The crises today are more in the domain of cosmology (dark matter, dark energy), the quantum mechanics of black holes and really unifying our understanding of physics at all scales, from the Planck length to our cosmological horizon, two scales that are 60 orders of magnitude apart. Understanding such a hierarchy (together with the much smaller one of the Standard Model) represents, in my opinion, the biggest theoretical challenge for 21st century physics.

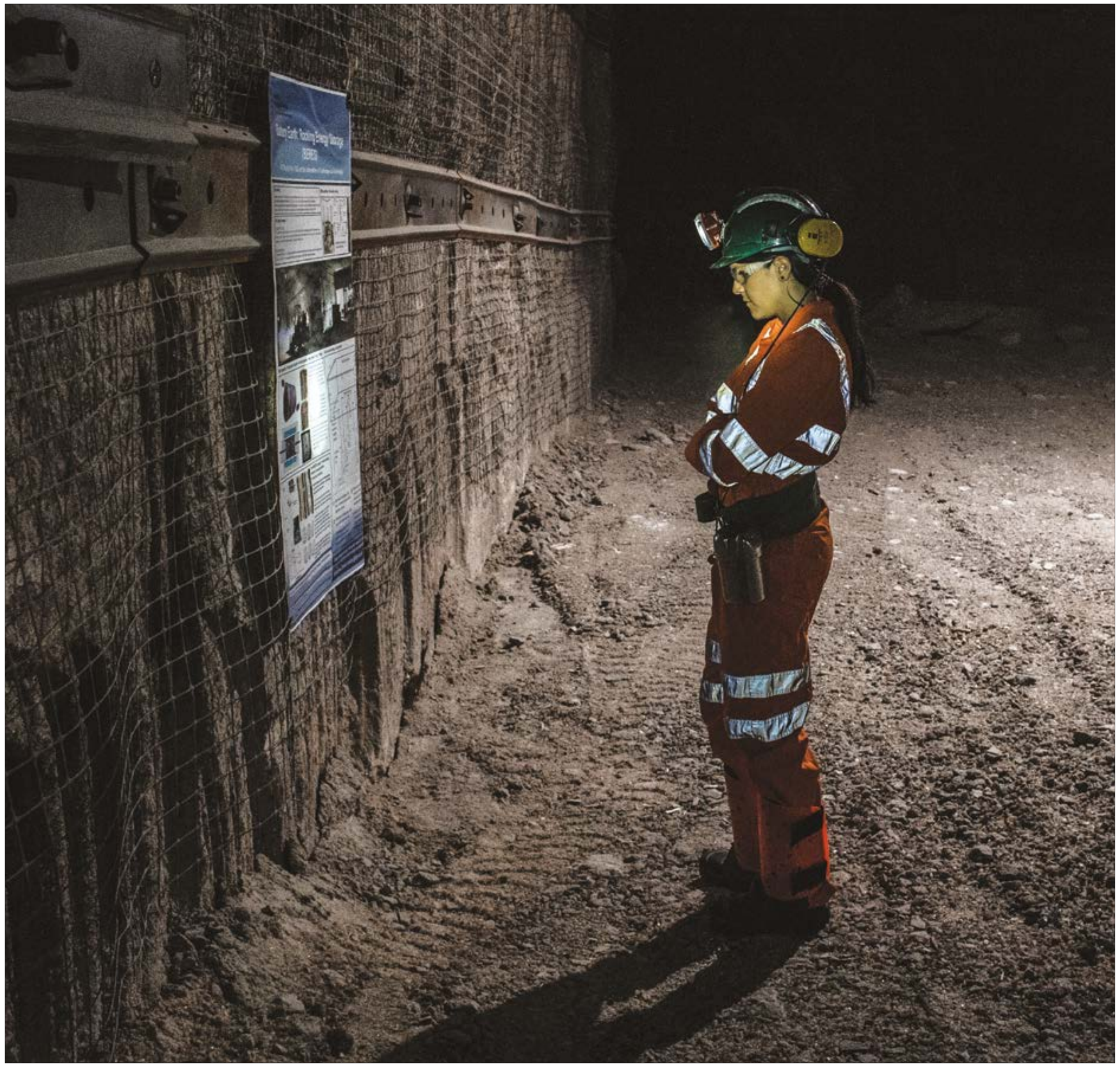
Matthew Chalmers, editor *CERN Courier.*

Photowalk

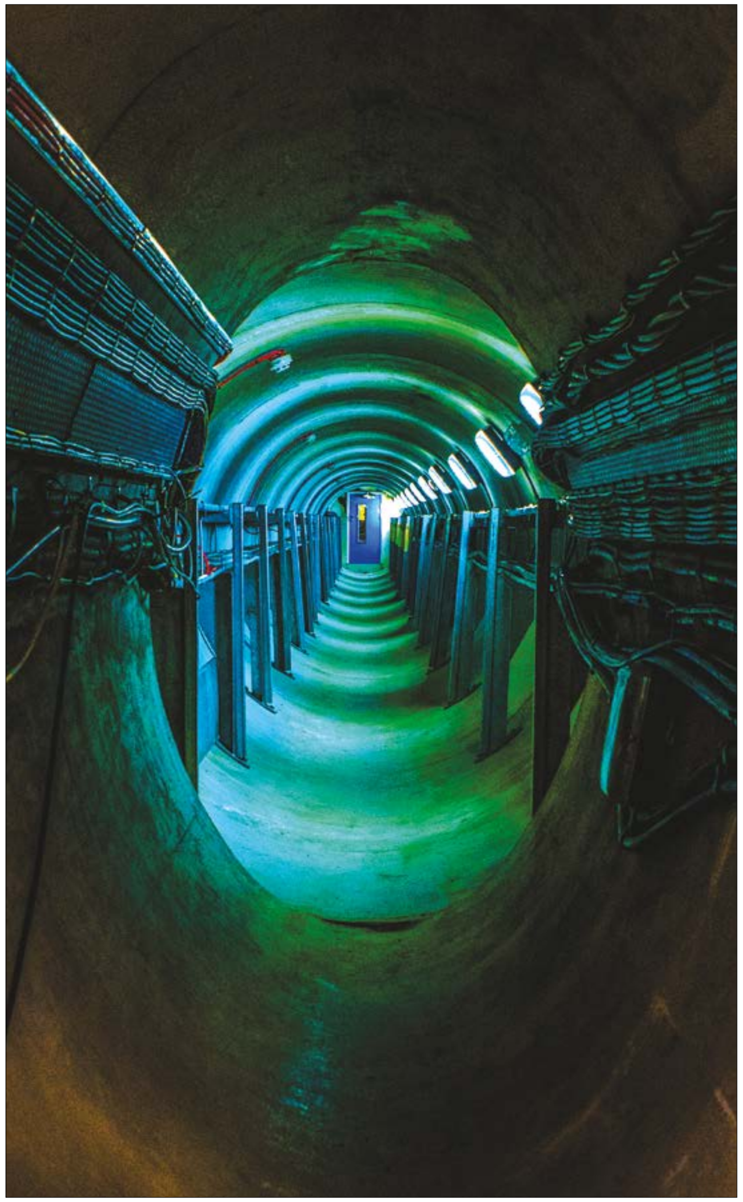
Deep physics brought to life through photography

The winning entries in the 2018 Global Physics Photowalk competition have been revealed.

The 2018 Global Physics Photowalk brought hundreds of amateur and professional photographers to 18 laboratories around the world, including CERN, to capture their scientific facilities and workforce. The science of the participating labs ranges from exploring the origins of the cosmos to understanding our planet's climate, and from improving human and animal health to helping deliver secure and sustainable food and energy supplies for the future. Following local competitions, each lab submitted its top three images to the global competition. A public online vote chose the top three from those images, and a jury of expert photographers and scientists also picked their three favourites. The photowalk was organised by the Interactions collaboration, and was supported by the Royal Photographic Society and Association of Science-Technology Centers (ASTC). The winning entries, shown here, were announced on 30 September at the ASTC annual conference in Hartford, Connecticut.



Simon Wright bagged first place in the expert jury's choice with this shot taken at the UK's STFC Boulby Underground Laboratory, which is located 1.1 km underground in Europe's deepest operating mine and contributes to the search for dark matter. The photograph captures STFC's Tamara Leitan as she scanned an information board at the lab. To highlight Leitan's face, Wright used a miner's lamp instead of a flash to minimise interference with light reflected from the safety equipment that workers must wear at the mine.

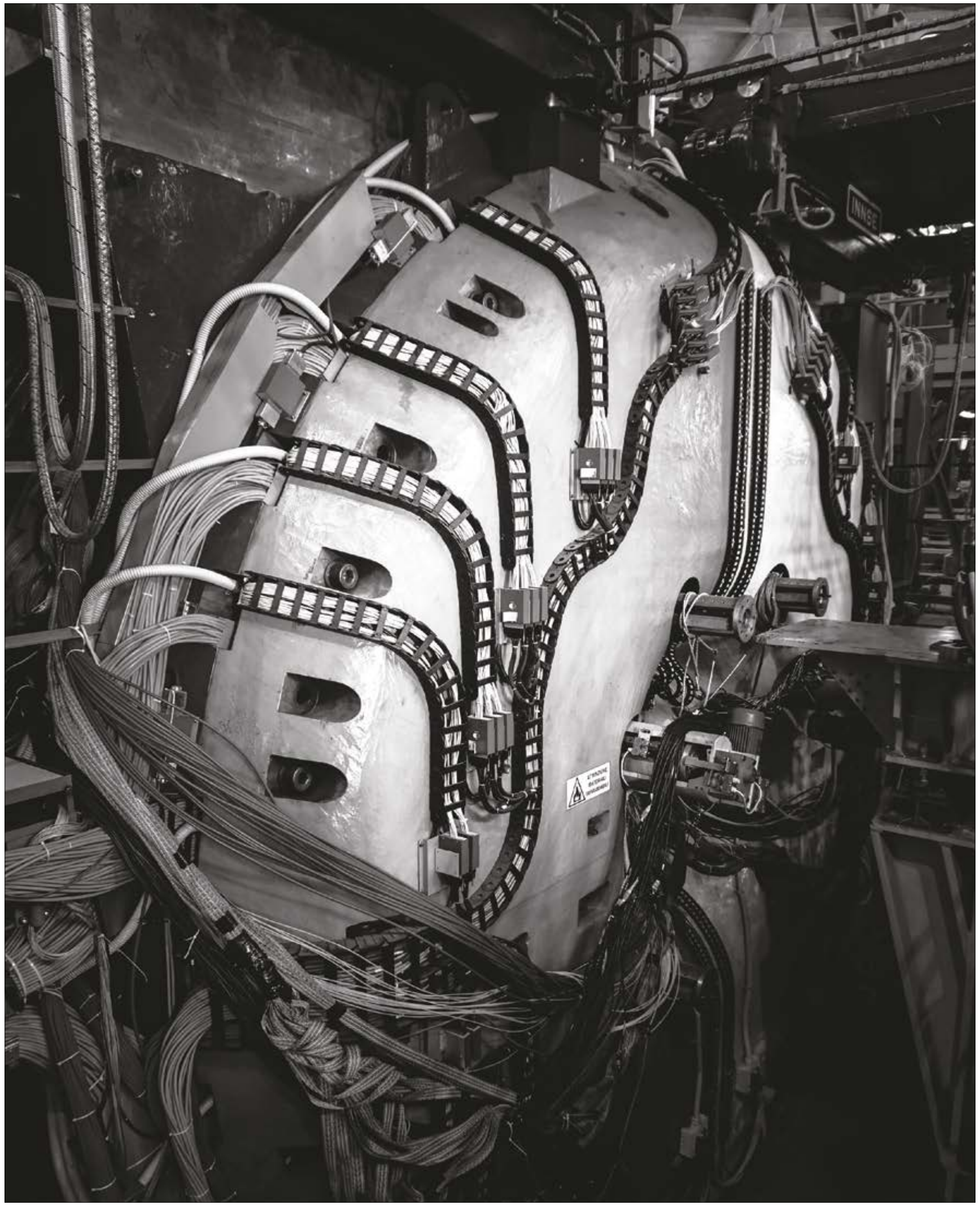


Simon Wright received another award, this time third prize in the people's choice category, for this image of green fluorescent lighting at an underground tunnel at the UK's STFC Chibolton Observatory, which is home to a wide range of science facilities.

Jon McRae took third place in the expert jury's selection, as well as second place in the people's choice, for this photo of the DESCANT neutron detector at Canada's TRIUMF laboratory. The detector can be mounted on the TIGRESS and GRIFFIN experiments to study nuclear structure. Holding a small, spherical lens between the camera and the detector array, McRae recreated a miniature simulacrum of DESCANT in the crystal-clear glass ball.

Stefano Ruzzini won the expert jury's second prize for this photograph of a silicon-strip particle detector, which was first used in CERN's NA50 experiment but is now at Italy's INFN Frascati National Laboratories. The photo was praised by the judges for portraying the three-dimensional aspect of the detector.

This picture from Gianluca Micheletti was also awarded third place in the expert jury's selection. It shows a researcher observing the XENON1T dark-matter experiment at Italy's INFN Gran Sasso National Laboratories. The judges commended Micheletti's composition of the image in evoking the sense of curiosity at the heart of physics.



Luca Riccioni snapped a picture of the KLOE-2 experiment at Italy's INFN Frascati National Laboratories, which recently concluded its data-taking campaign at the DAΦNE electron–positron collider. The photograph was awarded first place in the people's choice category.

CERN-PHOTO-201809-239-44

Hands-on education at the frontiers of science

Founded in 2014 at the time of CERN's 60th birthday, the Beamline for Schools competition inspires and trains the youngest researchers in science.

Is it fun to learn physics from a textbook? According to many teenage participants in CERN's Beamline for Schools (BL4S) programme, physics lessons at school are much too theoretical. Students from some countries do not even have physics lessons at all, let alone any contact with current science.

Many years back, in 2011, experimental particle physicist Christoph Rembser of CERN had an idea to get high-school students engaged with particle physics by offering them the chance to carry out their own experiment on a CERN beamline. Three years later, the 60th anniversary of CERN in 2014 offered an opportunity for what was meant to be a one-off worldwide science competition: BL4S was born. With the help of media attention in CERN around the time of the anniversary, teams of high-school students and their teachers were invited to propose an experiment at CERN. The response was overwhelming: almost 300 teams involving more than 3000 students from 50 countries submitted a proposal.

When the first two teams came to CERN in September 2014, it was clear that BL4S would not be a one-off event. Clearly the competition had the potential to attract large numbers of high-school students every year to get deeply involved with physics at the crucial stage in their education, two years before leaving school to take up further study. Ashish Tutakne, a member of the 2018 winning team from the Philippines, sums this up: "I believe the experience holds significant weight as it is not only a chance to collaborate with some of the smartest people in the world on a scientific project, it is also a taste of what conducting research is actually like. It is this experience that I believe that will in fact prove valuable to me … throughout the rest [of] my life."

CERN and society

Thanks to the huge success of the first edition, institutes and foundations around the world also recognised the potential of the competition. Through the CERN & Society Foundation, an independent charitable organisation supported by private donors, BL4S has since been provided with the financial help without which it would not have been possible to turn the competition into an annual event. The CERN & Society Foundation has the aim of spreading CERN's spirit of scientific curiosity for the benefit of

Image above: winning students from 2018.

Year	Team name	Origin	Experiment
2014	Odysseus Comrades Dominicuscollege	Greece Netherlands	Decay of pions into muons or electrons Characterisation of a self-made calorimeter
2015	Accelerating Africa LEO-4G	South Africa Italy	Production of channelling radiation in a doped, artificial diamond Using a webcam for particle detection
2016	Relatively Special Pyramid hunters	UK Poland	Measurement of the Lorentz factor Muon radiography of pyramids
2017	Charging Cavaliers TCO-ASA	Canada Italy	Search for exotic particles with a fractional charge Characterisation of a self-made Cherenkov detector
2018	Cryptic Ontics Beamcats	India Philippines	Deflection of relativistic particles in a magnetic field Measurement of the Bragg peak of hadrons

The winning teams of BL4S so far and the projects they undertook at CERN.

society, and supports young talent through high-quality, hands-on training. This year, for example, in addition to the BL4S initiative, the foundation has helped more than 80 educators participate in CERN's national teacher programme and granted more than 60 Summer Student scholarships.

So far, more than 900 teams with almost 8500 students from 76 countries have taken part in the BL4S competition, with one third of these students being female. While in the first edition in 2014 about 70% of the teams came from member states of CERN, this year roughly two-thirds of the participating teams were from associate and non-member states. This emphasises the international character of the competition and its global appeal.

The announcement of each edition of BL4S is usually made during the summer the year before, with a deadline for submitting a proposal of up to 1000 words and a one-minute video by 31 March. After about two months of evaluation, involving more than 50 volunteer physicists, the two winning teams and up to 30 shortlisted teams are announced in June. Besides certificates, which every participant receives, the shortlisted teams win special prizes such as BL4S T-shirts for every team member. The two winning teams are finally invited to CERN in September/October for a period of about 12 days to carry out their experiments.

Of course they are not doing this alone, but are guided by two professional scientists. These scientists, typically young PhD students in physics, make the largest contribution to the success of BL4S. They are not only responsible for the fine-tuning and implementation of the experiments of the winning teams but have, in collaboration with the CERN detector workshops, also developed bespoke devices for use in the BL4S experiments. Even though these support scientists were only involved with the project for less than a year, it offered them the opportunity to carry out a complete physics experiment from the beginning to the end; the skills that they acquired helped several of them to find interesting postdoc positions.

Beamline specifics

From the beginning, BL4S attracted a lot of CERN staff members as well as users and even retired staff to make voluntary contributions to the organisation of the event. This involves answering questions from the student teams, evaluating proposals, developing detectors and software, helping the winners with the analysis of the data, and many other things. These volunteers have become a crucial part of the competition.

CERN's accelerator complex is vast, and is in constant use by thousands of physicists worldwide. Since the first edition, the BL4S experiments have taken place at the T9 beamline of the Proton Synchrotron fixed-target area in the "East Hall" on the main CERN site. This beamline offers a secondary beam with a momentum of 0.5–10 GeV/c and a mixture of electrons, pions, kaons, protons and some muons. Regarding detectors, CERN provides a range of technologies: scintillators, Cherenkov counters, delay wire chambers, multigap resistive plate chambers, micro-mesh gaseous structure detectors, lead-glass calorimeters and Timepix detectors. In addition, students are allowed to build their own detectors and bring them to CERN. For the triggering, NIM modules are used, while the data-acquisition system is based on the RCD-TDAQ system of the ATLAS experiment. The student teams are provided with a detailed document that describes all of these components.

The students are completely free with respect to the experiment and use of these materials as long as it does not raise any safety concerns. Quite often we are surprised by their creativity, and the ten winning proposals from the past five years illustrate the wide spectrum of their ideas (see table above). Besides these winning proposals, all of the proposals received show what captures the attention of curious teenagers. Just a few examples are: the shielding of spacecraft to protect astronauts from the dangers of cosmic radiation; the analysis of the atmosphere with respect to greenhouse gasses; the exploration of natural resources; the creation of artificial aurora borealis; and the artistic translation of signals of elementary particles into sights or sounds.

For a successful participation in BL4S, the role of teachers and other mentors is paramount. Many teachers do not feel confident enough and might not propose their students to take part in BL4S. Partly they feel not qualified enough for such a challenge or they do not get the support from their schools that is necessary to coach a team for many weeks if not months. After all, many teachers are severely limited in the time that they can devote to such activities. In some cases, the students go ahead without any mentors and complete their proposal in a self-directed way. In other cases, they contact physicists at local universities or at one of the national or regional contact points established in almost 30 individual countries. Usually, however, the main burden is on the teacher and we

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The BL4S beamline at CERN.

are very grateful to the many teachers who every year dedicate a substantial part of their free time to coach a team of students. Unfortunately, our surveys show that due to the high workload only a few teachers are able to participate several years in a row.

The effect that BL4S has on the many students that are not lucky enough to be invited to CERN is difficult to assess. We know, however, via feedback from several teachers, that BL4S is appreciated as a means of motivating their students. In addition, the students themselves often write that their participation was a great experience for them and many are even motivated to work on their proposals and improve them to take part again in the next edition.

The winning teams are encouraged to stay together after having been at CERN and to write a paper about their experiment. So far, three papers have been published in an international peer-reviewed journal, *Physics Education*, with the following titles: Building and testing a high school calorimeter at CERN; The secret chambers in the Chephren pyramid; and Testing the validity of the Lorentz factor (see further reading). Papers are typically published one to two years after the completion of the experiment. At least one further paper is currently in the pipeline. This is not a mandatory step for the teams, but it represents a unique opportunity to have authored a scientific publication before even starting at university.

"The most beneficial impact has been the strong team-working and communication skills I developed."

According to a recent survey among the previous winners, most take up studies of natural sciences, engineering or mathematics. Max Raven of the 2016 winning team "Relatively Special" from Colchester Royal Grammar School in the UK remarked: "The most beneficial impact of BL4S has been the strong team-working and communication skills I developed… This invaluable experience has been instrumental to developing my interpersonal skills, which are vital for a successful career in engineering." After taking part in the BL4S competition Raven was accepted to study engineering by the Massachusetts Institute of Technology.

Students and teachers alike are clearly very happy to be associated with the competition, and this also benefits CERN and its educational aims. Winning BL4S often creates a lot of media attention in the home region of the teams or even at the national level, and recently the two Italian teams that won BL4S in 2015 and 2017 were invited to the ministry of foreign affairs in Rome for a special ceremony. At the same time, BL4S makes a contribution to physics education by leading students into a field of physics rarely touched upon in school curricula. Being able to do hands-on physics with detectors and accelerators used also for other current experiments presents a huge motivation for students to learn even in their free time. Yash Karan, a member of the Philippine winning team in 2018, remarked: "I have learnt much more in the last two weeks at CERN than in the last six months in school!"

Next stop DESY

At the end of this year, CERN's accelerator complex will be shut down for a period of two years to make way for maintenance and upgrades, in particular for the High-Luminosity LHC. This opens a new chapter in the history of the BL4S competition. In close collaboration with the DESY laboratory in Germany, the competition will continue there in 2019. DESY will provide beam time at the DESY II facility, offering electron and positron beams, and employ a dedicated support scientist on a three-year staff contract. Other

Education

institutes such as INFN-Frascati in Italy and the Paul Scherrer Institut in Switzerland are also interested in hosting the competition in the future.

What remains is the never-ending challenge of spreading the word. Even though CERN has many traditional and modern channels of communication, making BL4S known to high-school students and teachers around the world takes the effort of a large number of people at all levels. In particular, volunteers are needed to spread the word in their region and through their available channels, where they play several roles: acting as additional regional contacts for candidate teams; providing coaching if no teacher is available; taking part in the evaluation of proposals; assisting the winning teams with their data analysis and writing of scientific papers; and, finally, finding additional sponsors. Anyone interested can contact the BL4S team via bl4s.team@cern.ch.

As this article went to press, the 2018 winners were completing their experiments, which were hugely successful. All students claimed to have gained an immense increase in knowledge and they admired the passion that surrounded them everywhere they went at CERN. Working together in mixed shift crews each day, the teams have also learned about one another's experiments, fostering cooperation and personal growth. Quotes such as "Beamline for Schools was a life-changing experience" are not uncommon, and many of this year's students have made up their minds that they would like to pursue a career in particle physics or engineering.

The registration and proposal-submission for BL4S 2019 are now open. Hopefully the next edition will attract even more students from all around the globe to participate in this unique opportunity.

• Further reading

http://beamline-for-schools.web.cern.ch.
L Biesot *et al.* 2016 *Phys. Educ.* **51** 064002.
H Broomfield *et al.* 2018 *Phys. Educ.* **53** 055011.
B Gutowski *et al.* 2018 *Phys. Educ.* **53** 045011.

Résumé

Des travaux pratiques aux frontières de la science.

Depuis sa création en 2014, à l'occasion du 60e anniversaire du CERN, le concours Ligne de faisceau pour les écoles *a vu concourir 900 équipes, représentant au total près de 8 500 élèves de 76 pays. Les dix équipes gagnantes au fil des années ont pu mener des expériences au CERN ; les thèmes de recherche étaient variées, allant des chambres secrètes de la pyramide de Khephren à la validité de l'invariance de Lorentz. Plusieurs de ces équipes ont publié leurs résultats dans une revue à comité de lecture. Grâce à l'enthousiasme des élèves, des enseignants, des équipes organisatrices et de nombreux volontaires, le concours connaît de plus en plus de succès.*

Sarah Aretz and **Markus Joos**, CERN.

Faces & Places

APPOINTMENTS

Bassler to be next president of CERN Council

The CERN Council announced on 28 September the election of Ursula Bassler, a delegate of the Council since 2015 and a former member of the Large Hadron Collider (LHC) committee, as its 23rd president, for a period of one year (renewable twice) starting on 1 January 2019. She is currently deputy director at France's National Institute for Nuclear and Particle Physics (IN2P3 - CNRS), where she was involved, in particular, in preparing the Institute's contribution to the detector upgrades for the High Luminosity LHC (HL-LHC) and in shaping France's involvement in the European Open Science Cloud. Previously, she headed the particle-physics division at the Institute of Research into the Fundamental Laws of the Universe at the French Alternative Energies and Atomic Energy Commission (CEA) in Saclay.

CERN-PHOTO-201809-247-1

President-elect, Ursula Bassler.

"CERN as an organisation is essential to make progress in particle physics, as we need continuous, long-term efforts," said Bassler. "During the upcoming update of the European Strategy for Particle Physics, it will be important to design the vision for the future infrastructures in our field and to start laying out a path for their realisation with the CERN Member States and the global particle-physics community. I'm looking forward to working as Council president, together with the CERN directorate, the European Strategy Group and all delegations, on this challenging endeavour."

Bassler will take over from Sijbrand de Jong, who concludes his three-year term at the end of December.

Zanderighi joins Max Planck Institute for Physics as director

Giulia Zanderighi, a professor of physics at the University of Oxford in the UK and a staff member in CERN's theory department, has been appointed director of the Department of Novel Computational Techniques in Particle Phenomenology at the Max Planck Institute for Physics (MPP) in Munich, Germany. Zanderighi is an expert in collider phenomenology, and has received several awards for her work, including the Bessel Research Award and an ERC Consolidator Grant endowed with €1.5 million. She specialises in high-precision theoretical calculations of particle collisions at the Large Hadron Collider (LHC), specifically on fixed-order perturbative quantum chromodynamics calculations for multi-particle processes.

Private

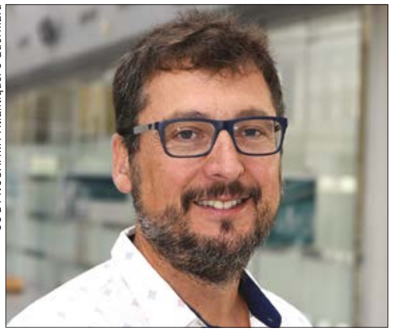
New MPP director Giulia Zanderighi.

Zanderighi will take up her post at MPP on 1 January 2019, where she will co-operate with Siegfried Bethke, director of experimental high-energy physics, in connection with the ATLAS detector at the LHC.

Martínez García to lead SUBATECH laboratory

Ginés Martínez García, a member of the ALICE collaboration at CERN and leader of the Nantes ALICE group, has been appointed director of the SUBATECH research laboratory, located in Nantes, France. He started the new post on 1 September.

SUBATECH's research activities focus on nuclear physics, radiochemistry and their applications. The unit is co-operated by the Institut Mines Telecom Atlantique (IMT-Atlantique), the French National Institute for Nuclear Physics and Particle Physics (IN2P3) of CNRS and the Université de Nantes.



CC BY NCSA/IMT Atlantique/C Quenniard

SUBATECH director Ginés Martínez García.

Martínez García has been working at SUBATECH for 20 years, leading the lab's plasma group first between 2002 and 2010 and then between 2013 and 2018. His research concerns heavy-ion physics. Martínez García worked in the PHENIX experiment at the Relativistic Heavy Ion Collider in Brookhaven between 1999 and 2004 and has been working in the ALICE experiment at CERN since 1998.

AWARDS

Bell Burnell to donate $3m Breakthrough Prize

Jocelyn Bell Burnell has been awarded a Special Breakthrough Prize in Fundamental Physics for her 1967 discovery of pulsars and a lifetime of inspiring leadership in the scientific community. Bell Burnell, currently a visiting professor of astrophysics at the University of Oxford and chancellor of the University of Dundee, will donate the $3m prize money to create a fund to support greater diversity for women and people from ethnic minorities. The money will be given to the UK Institute of Physics to support graduate students from under-represented groups.

A Special Breakthrough Prize in Fundamental Physics can be awarded by the selection committee at any time in recognition of an extraordinary scientific achievement, and in addition to the regular


D Harteis/Shutterstock

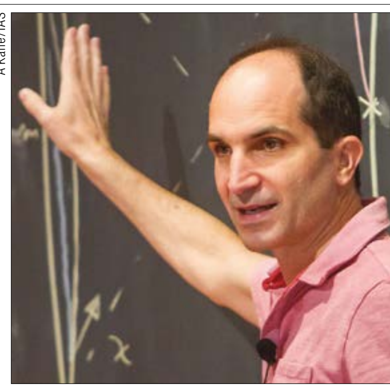
Prize winner Jocelyn Bell Burnell.

Breakthrough prizes awarded through the annual nomination process. "Jocelyn Bell Burnell's discovery of pulsars will always stand as one of the great surprises in the history of astronomy," said Edward Witten, the chair of the selection committee. "Until that moment, no one had any real idea how neutron stars could be observed, if indeed they existed. Suddenly it turned out that nature has provided an incredibly precise way to observe these objects, something that has led to many later advances."

Bell Burnell is the fourth to be awarded the special prize. Previous winners are the late Stephen Hawking, seven CERN scientists whose leadership led to the discovery of the Higgs boson, and the LIGO and Virgo collaborations for the detection of gravitational waves.

Prange award goes to Juan Maldacena

Juan Maldacena of the Institute for Advanced Study in Princeton, US, is the 2018 recipient of the Richard E Prange Prize and Lectureship in Condensed Matter Theory and Related Areas. Maldacena is recognised for his 1997 theoretical discovery of a deep connection between gauge theories and quantum gravity. Known as AdS/CFT duality, the connection is one of most important theoretical physics results of


A Kane/IAS

Prange award recipient Juan Maldacena.

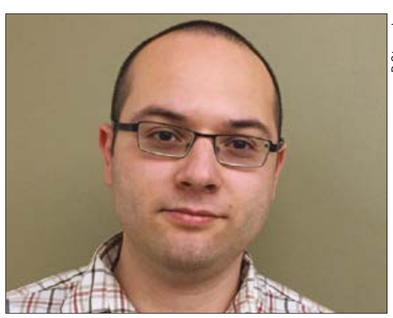
the past 30 years, and has remained a topic of great fundamental interest in particle physics, string theory, gravity, nuclear physics and condensed-matter physics. With more than 10,000 citations, the paper describing the result is among the most cited papers in all of science over the past 20 years.

Established by the University of Maryland (UMD), the prize, which carries a $10,000 honorarium, honours the late Richard E Prange, whose distinguished career at UMD spanned four decades. Previous winners include Philip W Anderson, David Gross and Frank Wilczek.

Global Neutrino Network dissertation prize announced

Gary Binder from the Colorado School of Mines and Lew Classen from the University of Münster have won the 2018 Global Neutrino Network (GNN) dissertation prize. The annual award distinguishes young researchers who have written an outstanding thesis and contributed significantly to GNN, an association of major neutrino telescopes such as IceCube dedicated to increasing communication between the experiments.

Primary criteria of the selection are the scientific quality, the didactics and the form of the thesis. Binder was recognised for his thesis "Measurements of the flavour composition and inelasticity distribution of high-energy neutrino interactions in IceCube", which he conducted at the


Colorado School of Mines


D Stransky

GNN award winners for 2018: Gary Binder (left) and Lew Classen (right).

University of California at Berkeley. Classen won with a thesis titled "The mDOM – a multi-PMT digital optical module for the IceCube-Gen2 neutrino telescope", which was completed at the University of Erlangen-Nürnberg.

CERN Courier November 2018

Faces & Places

Architecture prize for former artists in residence

Architects Matias del Campo and Sandra Manninger, who were artists in residence at CERN in 2016 through the Arts at CERN project with support from the Department of Arts of the Federal Chancellery of Austria, have received the prestigious 2018 Studio Prize by the American Institute of Architects (AIA). Del Campo, Manninger, along with thesis students of the Taubman College of Architecture + Urban Planning at the University of Michigan in the US, were recognised for their ideas for a new visitor centre at CERN for the proposed Future Circular Collider (FCC).

The AIA Studio Prize recognises thoughtful, innovative and ethical projects at accredited architecture schools in the US and Canada, and awards a cash sum of $25,000. Del Campo and colleagues' studio was selected by this year's jury as one of the most compelling studios in US architectural education today.

In one of the studio's ideas for the visitor centre (pictured), students Sung-Su Kim, Yongjoon Kim and Nathan Wesseldyk looked at pattern "as a means of understanding and conveying how multiple complex systems can be overlaid to find moments of interaction".

One of the ideas for a visitor centre for FCC. (Image credit: Sung-Su Kim, Yongjoon Kim, Nathan Wesseldyk, Taubman College of Architecture + Urban Planning.)

EVENTS

New entrance welcomes the world to CERN

On 28 September, CERN, the État de Genève and the Commune de Meyrin inaugurated the "Esplanade des Particules", an open space focused on welcoming visitors and the public to the European lab. This large public space, which connects CERN's reception building to the Globe of Science and Innovation, was designed with pedestrians and sustainable transport in mind. According to landscape architects Studio Paolo Bürgi of Ticino, "The esplanade puts everything on the same level, like a slab resting on the ground, with the aim of marking out a completely new space. A simple surface, enriched by brass inserts, evokes the vectorial shape of a magnetic field."

During the ceremony, the flags of CERN's 22 Member States were raised on the new esplanade for the first time. CERN's new official address is now 1 Esplanade des Particules.

"The Esplanade des Particules is the crowning achievement of the very fruitful collaboration between CERN, the État de Genève and the Commune de Meyrin, and symbolises CERN's desire to become ever more open to the world," said Fabiola Gianotti, CERN Director-General. "It will also form a magnificent setting for the construction of the Science Gateway, a new centre for communicating science to the general public and for encounters between CERN's scientists and visitors."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The newly inaugurated Esplanade des Particules.

Faces & Places

MEETINGS

Particle physics meets astrophysics and gravity


N Gulitsky

The ICNFP 2018 participants.

The 7th International Conference on New Frontiers in Physics (ICNFP 2018) took place on 4–12 July in Kolymbari, Crete, Greece, bringing together about 250 participants.

The opening talk was given by Slava Mukhanov and was dedicated to Stephen Hawking. To mention some of the five special sessions featured, the memorial session of Lev Lipatov, a leading figure worldwide in the high-energy behaviour of quantum field theory (see *CERN Courier* January/February 2018 p50), the session on quantum chromodynamics and the round table on the future of fundamental physics chaired by Albert de Roeck, saw a high number of attendees.

Alongside the main conference sessions, there were 10 workshops. Among these, the one on heavy neutral leptons highlighted novel mechanisms for producing sterile-neutrino dark matter and prospects for future searches of such dark matter with the next generation of space-based X-ray telescopes, including Spektr-RG, Hitomi and Athena+.

The workshop on instrumentation and methods in high-energy physics focused on the latest developments and the performance of complex detector systems, including triggering, data acquisition and signal-control systems, with an emphasis on large-scale facilities in nuclear physics, particle physics and astrophysics. This programme attracted many participants and led to the exchange of scientific information between different physics communities.

The workshop on new physics paradigms after the Higgs-boson and gravitational-wave discoveries provided an opportunity both to review results from searches for gravitational waves and to show plans for future precision measurements of Standard Model parameters at the LHC.

The workshop also featured several theory talks covering a wide range of subjects, including the implementation of supersymmetry breaking in string theory, new developments in early-universe cosmology and beyond-Standard Model physics. ICNFP 2018 also saw the first workshop on frontiers in gravitation, astrophysics and cosmology, which strengthened the Asian presence at ICNFP, gathering many participants from the Asia Pacific region.

For the second time in the ICNFP series, a workshop on quantum information and quantum foundations took place, with the aim of promoting discussions and collaborations between theorists and experimentalists working on these topics.

Yakir Aharonov gave a keynote lecture on novel conceptual and practical applications of so-called weak values and weak measurements, showing that they lead to many interesting hitherto-unnoticed phenomena. The latter include, for instance, a "separation" of a particle from its physical variables (such as its spin), emergent correlations between remote parties defying fundamental classical concepts, and a completely top-down hierarchical structure in quantum mechanics, which stands in contrast to the concept of reductionism. As exemplified in the talk of Avshalom Elitzur, the latter could be explained using self-cancelling pairs of positive and negative weak values.

Sandu Popescu, Pawel Horodecki, Marek Czachor and Eliahu Cohen presented many new phenomena involving quantum nonlocality in space and time, which open new avenues for extensive research. Ebrahim Karimi discussed various applications of structured quantum waves carrying orbital angular momentum (either photons or massive particles) and also discussed how to manipulate the topology of optical polarisation knots. Onur Hosten emphasised the importance of cold atoms for quantum metrology.

The workshop also featured many excellent talks discussing the intriguing relations between quantum information and condensed-matter physics or quantum optics. Some connections with quantum gravity, based on entanglement, complexity and quantum thermodynamics, were also discussed. Another topic presented was the comparison between the role of spin and polarisation in high-energy physics and quantum optics. In both of these fields, one should consider the total angular momentum, not the spin alone, and helicity is a very helpful concept in both, too.

Future accelerator facilities such as the low-energy heavy-ion accelerator centres FAIR in Darmstadt, Germany, and NICA at the Joint Institute for Nuclear Research in Dubna, Russia, were also discussed, particularly in the workshop on physics at FAIR-NICA-SPS-BES/RHIC accelerator facilities. Here new ideas as well as overview talks on current and future experiments on the formation and exploration of baryon-rich matter in heavy-ion collisions were presented.

The MoEDAL collaboration at CERN, which searches for highly ionising messengers of new physics such as magnetic monopoles, organised a mini-workshop on highly ionising avatars of new physics. The workshop provided a forum for experimentalists and phenomenologists to meet, discuss and expand this discovery frontier. The latest results from the ATLAS, CMS, MoEDAL and IceCube experiments were presented, and some important developments in theory and phenomenology were introduced for the first time. Highlights of the workshop included monopole production via photon fusion at colliders, searches for heavy neutral leptons and other long-lived particles at the LHC, regularised Kalb–Ramond monopoles with finite energy, and monopole detection techniques using solid-state and Timepix detectors.

Finally, on the education and outreach front, Despina Hatzifotiadou gave LHC "masterclasses" in collaboration with EKFE (the laboratory centre for physical sciences) to 30 high-school students and teachers, who had the opportunity to analyse data from the ALICE experiment and "observe" strangeness enhancement in relativistic heavy-ion collisions.

The next ICNFP conference will take place on 21–30 August 2019 in Kolymbari, Crete, Greece.

● *Larissa Bravina, Dmitry Gorbunov and Sonia Kabana.*

Faces & Places

ROOT's renovation takes centre stage at Sarajevo meeting


F Rademakers

The participants of the ROOT workshop held in Bosnia and Herzegovina.

The 11th ROOT Users' Workshop was held on 10–13 September in Sarajevo, Bosnia and Herzegovina, at the Academy of Science and Arts: an exceptional setting that also provided an opportunity to involve Bosnia and Herzegovina in CERN's activities.

The SoFTware Development for Experiments group in the experimental physics department at CERN drives the development of ROOT, a modular software toolkit for processing, analysing and visualising scientific data. ROOT is also a means to read and write data: LHC experiments alone produced about 1 exabyte of data stored in the ROOT file format.

Thousands of high-energy physicists use ROOT daily to produce scientific results. For the ROOT team, this is a big responsibility, especially considering the challenges Run 3 at the LHC and the High Luminosity LHC (HL-LHC) pose to all of us. Luckily, we can rely on a lively user community, whose contribution is so useful that, periodically, a ROOT users' workshop is organised. The event's objective is to gather together the ROOT community of users and developers to collect criticism, praise and suggestions: a unique occasion to shape the future of the ROOT project.

More than 100 people attended this year's workshop, a 30% increase from 2015, making the event a success. What's more, the diversity of the attendees – students, analysis physicists, software experts and framework developers – brought different levels of expertise to the event. The workshop featured 69 contributions as well as engaging discussions. Software companies participated, with three invited contributions: Peter Müßig from SAP presented OpenUI5, the core of the SAP javascript framework that will be used for ROOT's graphical user interface; Chandler Carruth from Google discussed ways to make large-scale software projects written in C++, the language for number-crunching code in high-energy and nuclear physics (HENP), simpler, faster and safer; and Sylvain Corlay from Quantstack showed novel ways to tackle numerical analysis with multidimensional array expressions. These speakers said they enjoyed the workshop and plan to come to CERN to extend the collaboration.

ROOT's renovation was the workshop's main theme. To be at the bleeding edge of software technology, ROOT – which has been the cornerstone of virtually all HENP software stacks for two decades – is undergoing an intense upgrade of its key components. This effort represents an exciting time for physicists and software developers. In the event, ROOT users expressed their appreciation of the effort to make it easier to use and faster on modern computer architectures, with the sole objective of reducing the time interval between data delivery and the presentation of plots.

In particular, the spotlight was on the modernisation of the I/O subsystem, crucial for the future LHC physics programme; ROOT's parallelisation, a prerequisite to face Run 3 and HL-LHC analyses; as well as on new graphics, multivariate tools and an interface to the Python language, which are all elements of prime importance for scientists' everyday work.

The participants' feedback was enthusiastic, the atmosphere was positive, and the criticism received was constructive and fruitful for the ROOT team. We thank the participating physicists and computer scientists: we appreciated your engagement and are looking forward to organising the next ROOT workshop.

● *Danilo Piparo for the ROOT team.*

Obituaries

Burton Richter 1931–2018

Burton Richter, a major figure in particle physics who shared the Nobel Prize for the co-discovery of the J/ψ meson, passed away on 18 July in Palo Alto, California, at the age of 87.

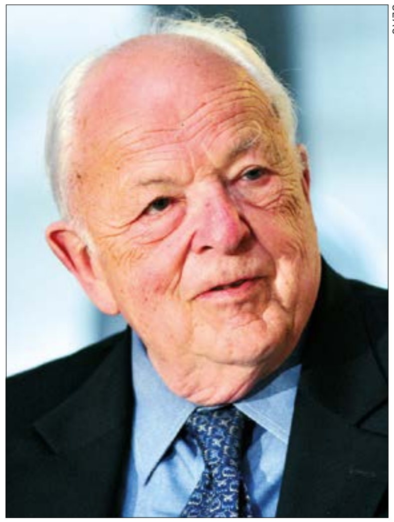
Born in Brooklyn, New York, in 1931, Richter's love of science began with the nightly blackouts during World War II, which revealed an unparalleled view of the night sky.

He studied physics at the Massachusetts Institute of Technology (MIT), where he was introduced to the electron–positron system by Martin Deutsch, who was conducting classical positronium experiments. He wrote his thesis on the quadratic Zeeman effect in hydrogen and completed his PhD in 1956 on the photoproduction of pi-mesons from hydrogen.

That year, Richter moved to Stanford University's high-energy physics laboratory as a research associate. In 1960, he became an assistant professor of physics, then associate professor in 1963 and professor in 1967. During this time, Richter married his wife, Laurose, and had two children, Elizabeth and Matthew. By 1970, Richter's talents in experimental particle physics and accelerator physics led to the Stanford Positron-Electron Asymmetric Ring (SPEAR) at the Stanford Linear Accelerator Center (SLAC). It included a groundbreaking type of general-purpose detector that has been used in particle colliders ever since, and it would eventually produce his biggest discovery.

After Richter secured funding for SPEAR in 1970, it took him just 27 months to build the accelerator, at a cost of $6 million. Experiments commenced in 1973 and, famously, in November 1974, SPEAR flushed out what the SLAC team dubbed the "psi" meson – a bound state of two charm quarks. Simultaneously, at Brookhaven National Laboratory on the other side of the continent, Sam Ting and his group had spotted the same resonance, which they christened the "J". Just two years later, Richter and Ting shared the 1976 Nobel Prize in Physics for their pioneering discovery of the J/ψ, which proved the existence of a fourth type of quark (charm). It was a major step towards the establishment of the Standard Model of particle physics.

Before he received the Nobel Prize, in 1975 Richter began a sabbatical year at CERN, during which he pursued an experiment at CERN's Intersecting Storage Rings (ISR) – the world's first hadron collider. He was hosted by Pierre Darriulat and worked on adding a muon spectrometer arm to the R702 experiment. Richter also worked out the general energy-scaling laws for high-energy electron–positron colliding-beam storage rings, looking specifically at the parameters of a collider with a centre-of-mass energy in the range 100–200 GeV, arguing that such a machine would be required to better understand the relationship between the weak and electromagnetic interactions: "That study turned into the first-order design of the 27 km-circumference LEP project at CERN that was so brilliantly brought into being by the CERN staff in the 1980s," he wrote in his Nobel biography.



Richter was an expert in accelerator and experimental physics.

SLAC

His influential paper "Very High Energy Electron–Positron Colliding Beams for the Study of the Weak Interactions" (*Nucl. Instrum. Methods* **136** 47) was followed by two detailed studies: one concerning the physics, published in November 1976 as CERN Yellow Report 76-18, of which Burt was a co-author, and an accelerator study headed by Kjell Johnsen. "Burt's paper and his personal advocacy of high-energy electron–positron collision triggered interest at CERN, and had a powerful impact on the development of the Laboratory, also paving the way for the LHC and the discovery of the Higgs boson," says CERN's John Ellis.

In 1978, along with others at SLAC, Richter began to investigate the possibility of turning the 3.2 km linear accelerator at SLAC into a linear electron–positron collider. Construction of the SLAC Linear Collider (SLC) began in 1983, and Richter became director of SLAC the following year, until stepping down in 1999. During that time, he oversaw the construction of the SLC, the only linear electron–positron collider yet to be built, and led the way to other machines for photon science. While SLAC director, Richter also initiated interregional collaborations with DESY in Germany and KEK in Japan, and was a proponent of bringing into existence a high-energy linear collider as a global collaboration.

"Perhaps his greatest contribution as director was, in the 1990s, designing a future for SLAC that would look very different from the past," said Stanford Provost Persis Drell, who served as SLAC director from 2007 to 2012. "He recognised that pursuing an X-ray free-electron laser at SLAC could be used to provide a revolutionary science opportunity to the photon science community, who use X-rays as their tool for discovery. This vision became the Linac Coherent Light Source. Burt recognised that outstanding science needed to drive the future of the institution, and he did not flinch from designing that future."

When he stepped down as SLAC director, Richter focused on public policy issues in science and energy, for which he received the prestigious 2007 Philip Hauge Abelson Prize from the American Association for the Advancement of Science. In 2010, he published *Beyond Smoke and Mirrors: Climate Change and Energy in the 21st Century*, an apolitical layperson's exploration of the facts of climate and energy. Among his many accolades, Richter received the US National Medal of Science, the nation's highest scientific honour, in 2014; the Enrico Fermi Award in 2012; and the Ernest Orlando Lawrence Award in 1976.

"In my career I have met no one who has made more fundamental contributions in electron–positron and electron–electron colliders, in the precision instrumentation used in colliders and in experimental physics," says Ting. "After we received the Nobel Prize together in 1976, I met him many times and we became good friends. My wife, Susan, and I are going to miss him deeply."

● *His friends and colleagues at CERN, with additional input from Stanford News Service.*

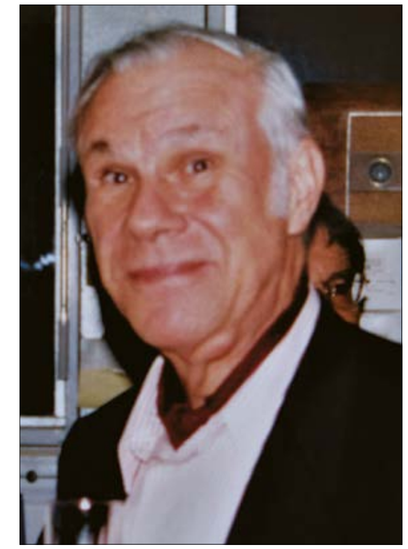
Georges Dôme 1928–2018

Georges Dôme, who had a long, productive and distinguished career at CERN dedicated to the study of accelerating radio-frequency (RF) structures and their interaction with particle beams, passed away on 27 June.

A physicist and mathematician, Dôme arrived at CERN in the early 1960s from the École Royale Militaire, Brussels, via the SLAC National Accelerator Laboratory in the US, where for 18 months he attacked the problems that would be his lifelong interest. His initial work at CERN concerned the theoretical studies of accelerating RF structures for the 300 GeV linac project, in the process contributing to the development of numerical computations of magnetic-field distributions.

With the advent of the Super Proton Synchrotron (SPS) project, he joined the team of Clemens Zettler, who was responsible for building the accelerating systems of the new machine. Georges derived the formulae to describe and use the accelerating structures, which are still the workhorse of the SPS machine today. He was in charge of the detailed measurements of the structures, specified the precision machining of the many drift tubes to fix the central operating frequency of the structures, and also identified and measured the higher-order frequency modes whose impedance can destroy the particle beams. Different antennas and probes were then designed to render these modes harmless.

Georges also designed the structure of the SPS higher-harmonic cavity, another component necessary in the struggle to stabilise the beams of ever increasing intensity. His work has been essential in ensuring that the high-intensity beams for the LHC and the SPS fixed-target experimental programme are available and that the future LHC Injectors Upgrade (LIU) project is possible.



Physicist and mathematician Georges Dôme had a distinguished career at CERN.

The SPS is a very versatile machine and its RF group has had to study and solve many varied problems to follow the different requirements. Georges made important contributions on many occasions, for example to the studies of particle diffusion due to RF noise, which was critical for beam lifetime in the proton–antiproton collider.

In the 1990s, Georges was asked by Vittorio Vaccaro from the University of Naples in Italy to review a paper on the coupling impedance of a circular iris, a subject that had long interested Georges. This triggered 20 pages of Georges' closely spaced, small-character calculations and a fruitful collaboration on wakefields and impedance with members of the University of Naples.

Georges studied a subject in depth and was a precise and meticulous mathematician with a strong love for Bessel functions. He was always willing to go over a piece of work for his colleagues, but this could be a daunting prospect. It would come back annotated in blue pencil, every inherent inaccuracy revealed by his rigorous, uncompromising approach. This, of course, was splendid – you knew it was now perfect – and his unfailing good humour and willingness to help made this process very easy.

Georges was a fine mentor, looking after his students and both his younger, and older, colleagues. His body of work, supplemented by the excellent RF lectures he gave at the CERN accelerator schools, is a reference for accelerator physicists, and he continued this work for many years after his retirement. He was also a lifelong friend of and supporter of the CERN library.

Georges was in every way a gentleman, quiet and courteous, always interesting to talk to – a good person to find at a gathering. We will miss him.

● *His friends and colleagues.*

Hans Paar 1944–2018

Hans Paar, emeritus professor of physics at the University of California, San Diego (UCSD), passed away on 17 June after a short illness. Paar was initially trained at Delft University of Technology in his native country of the Netherlands. This engineering background served him well throughout his career, allowing him to take on important tasks in the design, construction and testing of equipment in all the particle-physics experiments he participated in.

Paar started his particle-physics career at Columbia University in the US, where he worked with Leon Lederman on one of the first experiments at Fermilab (E70). After completing his PhD thesis on this project, he relocated to Europe to work as a CERN fellow with another Nobel Laureate, Jack Steinberger, on WA1, the first experiment with the high-energy neutrino beam of the newly commissioned Super Proton Synchrotron (SPS).

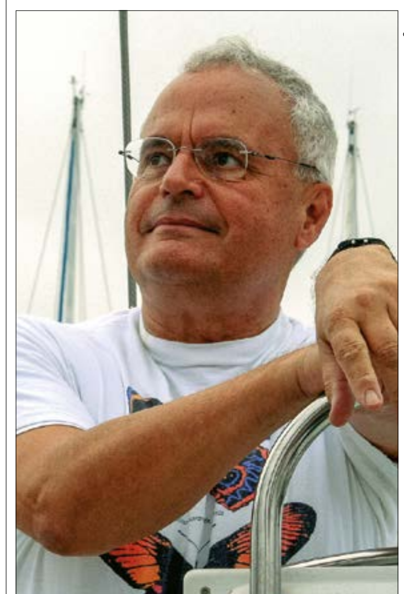
In 1978, Paar joined a team at NIKHEF, the Dutch National Institute for Subatomic Physics, that worked on the TPC/2γ experiment at the SLAC National Accelerator Laboratory in the US, and he quickly became one of the leaders of the collaboration that carried out this experiment. His visibility at SLAC led to an offer from the UCSD, which he then joined as a faculty member in 1986 and where he remained for the rest of his career.

Paar was an internationally recognised

physicist. He studied the properties of the bottom quark at electron–positron colliders since the early 1990s, first as a member of the CLEO collaboration (Cornell) and later the BaBar collaboration (SLAC). He also made essential contributions to the design and construction of novel types of calorimeters, in the context of the SPACAL and DREAM projects at CERN.

Later in Paar's career, his research interests included observational cosmology. Paar and his colleagues set out to detect the B-mode polarisation of the cosmic microwave background radiation to address one of the most fundamental problems in astrophysics – the inflation of the early universe. Paar made crucial contributions to the realisation of this project, named POLARBEAR, which is carried out at high altitude in the Atacama Desert in Chile. Not only did he provide expert leadership, design and analysis skills, he also secured a $600,000 private donation, which helped enable the fabrication of the telescope.

Paar cared deeply about education and creating a nurturing, motivating environment for students. He was instrumental in modernising the UCSD's



K SignoretPaar

Emeritus professor Hans Paar.

curriculum on quantum mechanics at all levels and authored the textbook *An Introduction to Advanced Quantum Physics*. As part of the UCSD Research Experience for Undergraduates programme, he gave a "Physics of Sailing" course consisting of lectures on the physics of the sport, followed by a full day of sailing on San Diego Bay.

Hans had many interests outside of physics. He was also a devoted husband, (step)father and a very good friend to many. He was a gifted piano player and a serious model-train enthusiast. He helped to create an atmosphere of creative thought and friendliness within every group he was part of. Our thoughts go to his wife Kim, his daughter Suzanne and his stepsons Eric and Alain. We all owe Hans for many happy memories.

● *His friends and colleagues.*

Bookshelf

Compiled by Virginia Greco, CERN

Strange Glow: The Story of Radiation

By Timothy J Jorgensen

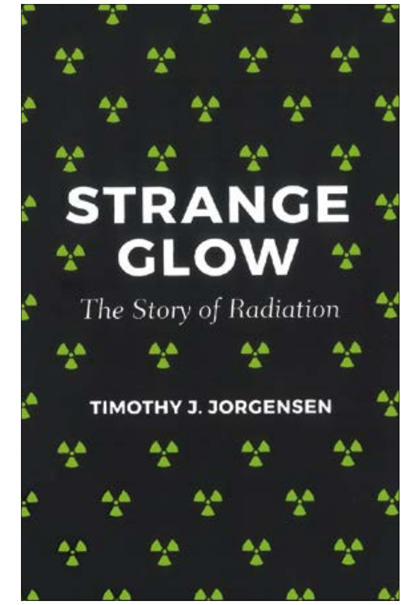
Princeton University Press

In this book, Timothy Jorgensen, a professor of radiation medicine at Georgetown University in the US, recounts the story of the discovery of radioactivity and how mankind has been transformed by it, with the aim of sweeping away some of the mystery and misunderstanding that surrounds radiation.

The book is structured in three parts. The first is devoted to the discovery of ionising radiation in the late 19th century and its rapid application, notably in the field of medical imaging. The author establishes a vivid parallel with the discovery and exploitation of radio waves, a non-ionising counterpart of higher energy X rays. A dynamic narrative, peppered with personal anecdotes by key actors, succeeds in transmitting the decisive scientific and societal impact of radiation and related discoveries. The interleaving of the history of the discovery with aspects of the lives of inspirational figures such as Ernest Rutherford and Enrico Fermi is certainly very relevant, attractive and illustrative.

In the second part, the author focuses on the impact of ionising radiation on human health, mostly through occupational exposure in different working sectors. A strong focus is on the case of the "radium girls" – female factory workers who were poisoned by radiation from painting watch dials with self-luminous paint. This section also depicts the progress in radiation-protection techniques and the challenges related to quantifying the effects of radiation and establishing limits for the exposure to it. The text succeeds in outlining the difficulties of linking physical quantities of radiation with its impact on human health.

The risk assessment related to radiation exposure and its impact on human health is further covered in the third part of the book. Here, Jorgensen aims to provide quantitative tools for the public to be able to evaluate the benefits and risks associated with radiation exposure. Despite his effort to offer a combination of complementary statistical approaches, readers are left with an impression that many aspects of the impact of radiation on human health are not fully understood. On the contrary, the large number of radiation-exposure cases in the Hiroshima and Nagasaki nuclear bombings, after which it was possible to correlate the absorbed dose with the location of the



various victims at the time of the explosion, provides a scientifically valuable sample to study both deterministic and stochastic effects of radiation on human health.

In part three, the book also digresses at length about the role of nuclear weapons in the US defence and geopolitical strategy. This topic seems somewhat misplaced with respect to the more technical and scientific content of the rest of the text. Moreover, it is highly US-centric, often neglecting the analogous role of such weapons in other countries.

It is noteworthy that the book does not cover radiation in space and its crucial impact on human spaceflight. Likewise, the discovery of cosmic radiation through Hess' balloon experiment in 1911–1912, while constituting an essential finding in addition to the already discovered radioactivity from elements on the Earth's surface, is completely overlooked.

Despite the lack of space-radiation coverage and the somewhat uncorrelated US defence considerations, this book is definitely a very good read that will satisfy the reader's curiosity and interest with respect to radiation and its impact on humans. In addition, it provides insight into the more general progress of physics, especially in the first half of the 19th century, in a highly dynamic and entertaining manner.

● *Rubén García Alía, CERN.*

The Great Silence – The Science and Philosophy of Fermi's Paradox

By Milan Cirkovic

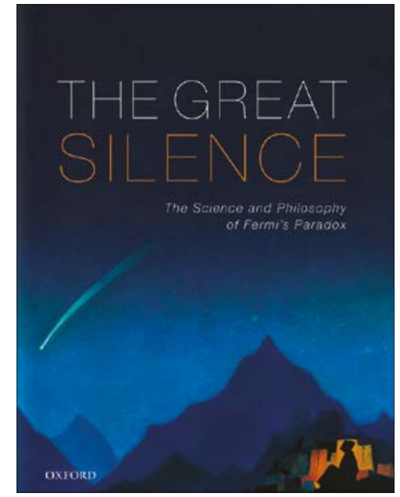
Oxford University Press

Enrico Fermi formulated his eponymous paradox during a casual lunchtime chat with colleagues in Los Alamos: the great physicist argued that, probabilistically, intelligent extraterrestrial lifeforms had time to develop countless times in the Milky Way, and even to travel across our galaxy multiple times; but if so, where are they?

The author of this book, Milan Cirkovic, claims that, with the wealth of scientific knowledge accumulated in the many decades since then, the paradox is now even more severe. Space travel is not speculative anymore, and we know that planetary systems are common – including Earth-like planets – suggesting that life on our planet started very early and that our solar system is a relative late-comer on the cosmic scene; hence, we should expect many civilisations to have evolved way beyond our current stage. Given the huge numbers involved, Cirkovic remarks, the paradox would not even be completely solved by the discovery of another civilisation: we would still have to figure out where all others are!

The Great Silence aims at an exhaustive review of the solutions proposed to this paradox in the literature (where "literature" is to be understood in the broadest sense, ranging from scholarly astrobiology papers to popular-science essays to science-fiction novels), following a rigorous taxonomic approach. Cirkovic's taxonomy is built from the analysis of which philosophical assumptions create the paradox in the first place. Relaxing the assumptions of realism, Copernicanism, and gradualism leads, respectively, to the families of solutions that Cirkovic labels "solipsist", "rare Earth", and "neocatastrophic". His fourth and most heterogeneous category of solutions, labelled "logistic", arises from considering possible universal limitations of physical, economic or metabolic nature.

The book starts by setting a rigorous foundation for discussion, summarising the scientific knowledge and dissecting the philosophical assumptions. Cirkovic does not seem interested in captivating the reader from the start: the preface and the first three chapters are definitely scholarly in their intentions, and assume that the reader already knows a great deal about Fermi's paradox. As a particularly egregious example, Kardashev's speculative classification of civilisations, based on the scale of their energy consumption, plays a



very important role in this book; one would have therefore expected a discussion about that, somewhere at the beginning. Instead, the interested reader has to resort to a footnote for a succinct definition of the three types of civilisation (Type I: exploiting planetary resources; Type II: using stellar system resources; Type III: using galactic resources).

However, after these introductory chapters, Cirkovic's writing becomes very pleasant and engaging, and his reasoning unfolds clearly. Chapters four to seven are the core of the book, each of them devoted to the solutions allowed by negating one assumption. Every chapter starts with an analogy with a masterpiece in cinema or literature, followed by a rigorous philosophical definition. Then, the consequent solutions to Fermi's paradox are reviewed and, finally, a résumé of take-home messages is provided.

This parade of solutions gives a strange feeling: each of them sounds either crazy, or incredibly unlikely, or insufficient to solve the paradox (at least in isolation). Still, once we accept Cirkovic's premise that Fermi's paradox means that some deeply rooted assumption cannot be valid, we are compelled to take seriously some outlandish hypothesis. The reader is invited to ponder, for example, how the solution to the paradox might depend on the politics of the Milky Way in the last few billion years: extraterrestrial civilisations may have all converged to a Paranoid Style in Galactic Politics, or we might unknowingly be under the jurisdiction of an Introvert Big Brother (Cirkovic has a talent for catchy titles). Some Great Old Ones might be temporarily asleep, or we (and any conceivable biological intelligence) might be limited in our evolution by some Galactic Stomach-Ache. A large class of very gloomy hypotheses assumes that all our predecessors were wiped out before reaching very high Kardashev's scores, and Cirkovic seems particularly fond of the idea of swarms of Deadly Probes that may still be roaming around, ready to point at us as soon as they notice our loudness. Unless we reach the aforementioned state of galactic paranoia, which makes for a very nice synergy between two distinct solutions of the paradox.

The author not only classifies the proposed solutions, but also rates them by how fully they would solve this paradox. The concluding chapter elaborates on several philosophical challenges posed by Fermi's paradox, in particular to Copernicanism, and on the link between it and the future of humanity.

Cirkovic is a vocal (and almost aggressive) critic of most of the SETI-related literature, claiming that it relies on excessive assumptions which strongly limits SETI searches. In his words, the failure of SETI so far has mostly occurred on philosophical and methodological levels. He quotes Kardashev in saying that extraterrestrial civilisations have not been found because they have not really been searched for. Hence Cirkovic's insistence on a generalisation of targets and search methods.

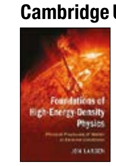
An underlying theme in this book is the relevance of philosophy for the advancement of science, in particular when a science is in its infancy, as he argues to be the case for astrobiology. Cirkovic draws an analogy with early 20th century cosmology, including a similitude between Fermi's and Olmert's paradoxes (the latter being: how can the night sky be dark, if we are reachable by the light of an infinite number of stars in an infinitely old universe?).

I warmly recommend *The Great Silence* to any curious reader, in spite of its apparent disinterest for a broad readership. In it, Cirkovic makes a convincing case that Fermi's paradox is a fabulously complex and rich intellectual problem.

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

Books received

Foundations of High-Energy-Density Physics: Physical Processes of Matter at Extreme Conditions
By Jon Larsen
Cambridge University Press



This book provides a comprehensive overview of high-energy-density physics (HEDP), which concerns the dynamics of matter at extreme temperatures and densities. Such matter is present in stars, active galaxies and planetary interiors, while on Earth it is not found in normal conditions, but only in the explosion of nuclear weapons and in laboratories using high-powered lasers or pulsed-power machines.

After introducing, in the first three chapters, many fundamental physics concepts necessary to the understanding of the rest of the book, the author delves into the subject, covering many key aspects: gas dynamics, ionisation, the equation-of-state description, hydrodynamics, thermal energy transport, radiative transfer and electromagnetic wave–material interactions.

The author is an expert in radiation-hydrodynamics simulations and is known for developing the HYADES code, which is largely used among the HEDP community. This book can be a resource for research scientists and graduate students in physics and astrophysics.

Quantized Detector Networks: The Theory of Observation
By George Jaroszkiewicz
Cambridge University Press

Quantised Detector Networks (QDN) theory was invented to reduce the level of metaphysics in the application of quantum mechanics (QM), moving the focus from the system under observation to the observer and the measurement apparatuses. This approach is based on the consideration that "labstates", i.e. the states of the apparatus that we use for observing, are the only things we can actually deal with, while we have no means to prove that the objects under study "exist" independently of observers or observations.

In this view, QM is not a theory describing objects *per se*, but a theory of entitlement, which means that it provides physicists with a set of rules defining what an observer is entitled to say in any particular context.

The book is organized in four parts: Basics, Applications, Prospects, and Appendices. The author provides, first of all, the formalism of QDN and then applies it to a number of experiments that show how it differs from standard quantum formalism. In the third part, the prospects for future applications of QDN are discussed, as well as the possibility of constructing a generalised theory of observation. Finally, the appendices collect collateral material referred to at various places in the book.

The aim of the author is to push the readers to look in a different way at the world they live in, to show them the cognitive traps caused by realism – i.e. the assumption that what we observe has an existence independent of our observation – and alerting them that various speculative concepts and theories discussed by some scientists do not actually have empirical basis. In other words, they cannot be experimentally tested.

Recruitment

For advertising enquiries, contact *CERN Courier* recruitment/classified, IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK.
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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.

Applications for postdoctoral research positions with LIGO Laboratory should indicate which of the LIGO sites (Caltech, MIT, Hanford, or Livingston), if any, are preferred by the applicant, and which (if any) are likely to be unworkable. Applications should be sent to HR@ligo.caltech.edu (Electronic Portable Document Format (PDF) submittals are preferred) and information provided is subject to the LIGO GDPR Policy – https://www.ligo.caltech.edu/page/gdpr-policy.

Caltech and MIT are Affirmative Action/Equal Opportunity employers. Women, minorities, veterans, and disabled persons are encouraged to apply.

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 will begin December 15, 2018 and will continue until all positions have been filled.

Caltech and MIT are Affirmative Action/Equal Opportunity Employers
Women, Minorities, Veterans, and Disabled Persons are encouraged to apply

More information about LIGO available at www.ligo.caltech.edu

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

In our team we therefore have the following positions available:

- **Junior Scientist**
- **Senior Scientist**
- **Laser Physicist**
- **Junior Engineer**
- **Senior Engineer**
- **Vacuum Technician**
- **Mechanical Designer**
- **Control System Specialist**
- **Safety Engineer**
- **Optical Engineer**
- **X-ray Scientist**
- **Opto-mechanics**

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

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MINISTRY OF EDUCATION, YOUTH AND SPORTS

EUROPEAN UNION
European Structural and Investing Funds
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PROFESSOR
ULTRAFAST SCIENCE (AP 18-08)
INSTITUT NATIONAL DE LA RECHERCHE SCIENTIFIQUE (tenure-track position)

CONTEXT AND SUMMARY

The Institut national de la recherche scientifique (INRS) is the only academic institution in Québec (Canada) dedicated exclusively to research and training at the graduate level. The influence of our faculty, researchers, and students extends worldwide. In partnership with the scientific community and the private sector, we are proud to contribute to societal development through our discoveries and through the training of young scientists.

INRS – Énergie Matériaux Télécommunications (EMT) Research Centre would like to hire a new faculty in the area of ***Ultrafast Science*** aiming at the transfer of knowledge and technologies to sectors such as photonics, advanced materials, energy, and healthcare. The areas of expertise of interest include: high-power femtosecond lasers for probing, imaging, and controlling the dynamics of ultrafast phenomena in matter, applied to atomic and molecular optical physics, and condensed matter physics. Other related areas may also be considered.

The Centre hosts the unique major research Infrastructure of Nanostructures and Femtoscience (http://lmn.emt.inrs.ca/EN/inf.htm), which comprises the Advanced Laser Light Source, the Laboratory of Micro and Nanofabrication, and the Infrastructure for Advanced Imaging.

This new position is intended to build a critical mass of expertise around a major *$13.9M* addition, the Advanced infrastructure for dynamic imaging and control of complex systems – ALLS+, awarded by the Canada Foundation for Innovation (CFI) in the 2016 competition. ALLS + includes high average power Ytterbium lasers to derive a continuum of sources from the THz to the X-ray spectral range. Combined with "Angular Resolved Photoelectron Spectroscopy" (ARPES) and other techniques, these sources will be used to investigate ultrafast phenomena. ALLS + adds to the current ALLS facility. The new faculty will work in an environment where about forty professors-researchers undertake leading-edge research and training in diverse areas of sustainable energy, advanced materials, ultrafast photonics, telecommunication systems and nanobiotechnology.

MAIN DUTIES AND RESPONSIBILITIES

- Develop an original and innovative program, capitalizing on the ALLS infrastructure.
- Secure external funding from a variety of granting agencies, also involving various partners from the public and private sectors whenever needed/pertinent.
- Establish collaborations with research teams already in place, while developing or maintaining partnerships with groups outside the EMT research center. The ability to develop partnerships with the private sector is particularly valuable.
- Participate in teaching and training at the graduate level (both M.Sc. and Ph.D. students), as well as supervising post-doctoral fellows and research personnel.

REQUIREMENTS

- A doctoral degree in a relevant discipline (physics, chemistry, engineering, materials science).
- An outstanding record of research accomplishments that will enable her/him to successfully develop a strong independent research program.
- Academic and technical expertise that are complementary to the existing faculty at EMT (http://www.emt.inrs.ca/les-professeurs/mosaique/6)
- The aptitude for teaching and supervising graduate students and other trainees.
- The ability to work in a multidisciplinary team and within research networks.
- The ability to collaborate with industrial partners.

WORKING LANGUAGE

French is the official language at INRS. Fluency in English is required. Candidates whose native language is not French are encouraged to apply. The Centre will provide them with all the resources necessary to facilitate their learning of the French language.

WORKPLACE

Institut national de la recherche scientifique (INRS)
Centre Énergie Matériaux Télécommunications
1650, boulevard Lionel-Boulet, Varennes (Québec) J3X 1S2 CANADA
Varennes is located on the South Shore of Montreal.

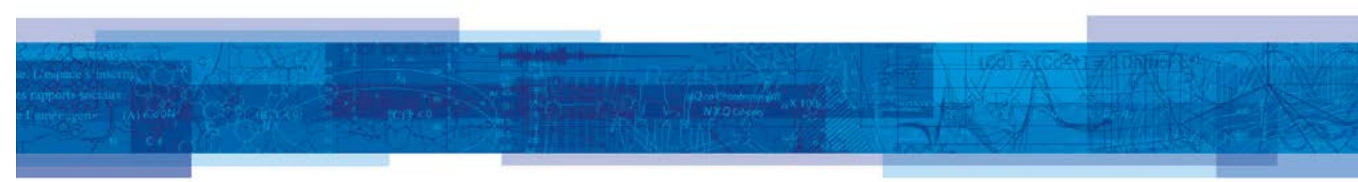
SALARY

Salary and benefits are in accordance with the current collective agreement at INRS.

HOW TO APPLY

Interested applicants should submit their application including a complete curriculum vitae, a copy of their three most significant publications, a three page summary of their research interests, a two page statement of teaching experience and philosophy, and the names and contact information of three referees, before **November 15th 2018** indicating position number AP 18-08 by e-mail at **concours@emt.inrs.ca** or by mail to:

Director
Institut national de la recherche scientifique (INRS)
Centre Énergie Matériaux Télécommunications
1650, boulevard Lionel-Boulet, Varennes (Québec) J3X 1S2 CANADA
concours@emt.inrs.ca



INRS subscribes to an equal access employment program and an equity employment program.
The Institute invites women, visible minorities, ethnic minorities, natives and people with disabilities to apply.
Priority will be given to candidates with Canadian citizenship or permanent resident.

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UNIVERSITÉ DE RECHERCHE
A RESEARCH UNIVERSITY

CERN Courier Archive: 1975

A look back to CERN Courier vol. 15, November 1975, compiled by Peggie Rimmer

CERN News

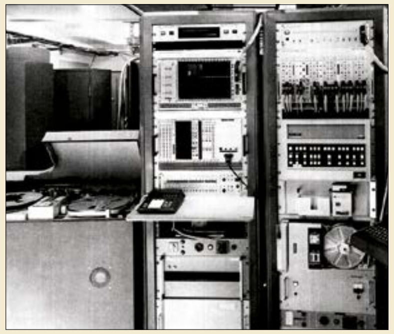
Storing data on videotape

One of the problems in high-energy physics experiments is the handling and storage of large volumes of data. It is not unusual for an experiment to need a thousand magnetic tapes. Conventional magnetic tapes can now hold 1600 bits per inch, and tape units are being marketed with improved techniques for writing and reading data at 6250 bits per inch.

For a much more radical improvement, in 1972 C Rubbia initiated a pioneering project to adapt videotape technology for digital data collection. This summer, a data handling system incorporating a video recorder has been used at the Intersecting Storage Rings. The IVC MMR-1 recorder is linked to the experiment via a small HP 2100 A computer and CAMAC. Data are written at 10^6 bits per square inch at rates of up to 1 Mbyte/s. One reel holds 9 Gigabytes, as much as about 250 conventional 1600 bits per inch tapes, making the need for tape changing very infrequent, once every few days.

The software was written by S Cittolin and the engineering development has been the responsibility of B G Taylor. The system has run for over 2500 hours and is performing well. No other high-energy physics laboratory has yet attacked the on-line data storage problem in this way.

CERN 289.9.75



The video tape data recording system recently used by a CERN/Harvard/Munich/Riverside/Northwestern collaboration. The tape unit is on the left alongside the minicomputer and CAMAC electronics.

● Compiled from text on pp344–345.

Spotting 3000 new galaxies

The 1 m Schmidt telescope of the European Southern Observatory, ESO, on the La Silla mountain in Chile has photographed an impressive number of new objects in the Southern sky. The analysis of 150 photographic plates, in collaboration with the Uppsala Observatory, has revealed more than 4000 interesting galaxies, including some 3000 which have never been observed before.

Since August, ESO astronomers have been making a spectroscopic study of these objects with the 1.5 m telescope at La Silla. So far, seven galaxies exhibit fairly strong emission lines in their spectrum, and calculated recession velocities attain 48,000 km/s. According to Hubble's empirical law, this corresponds to distances of three thousand million light-years. These observations whet the appetite for the use of the ESO 3.6 m telescope now being built in collaboration with CERN.

On 5 November a new comet was discovered at the ESO Sky Atlas Laboratory at CERN. Named Comet West after its discoverer, R M West, it is anticipated that the comet will pass within 30 million kilometres of the Sun on 26 February 1976. Presently a very faint object in the southern constellation of Sagittarius, it may become visible to the naked eye next year.

● Compiled from text on pp346–347.

Physics Nobel Prize 1975

Before 1949 every physicist knew that the atomic nucleus does not rotate. A quantum-mechanical rotator with moment of inertia J can take up various energy levels with rotational energies proportional to spin and inversely proportional to J. If the nucleus is considered as a rigid body, J is very large and the rotational energies correspondingly very small. Consequently, states of high spin and low excitation energy would exist and isomers would decay rapidly via these states. But isomers exist, so it seemed that the nucleus does not rotate.

In 1950, J Rainwater pointed out, in a brief contribution to *Physical Review*, that the observed large nuclear quadruple moments could be accounted for by unifying the Mayer–Jensen nuclear shell model and the Niels Bohr liquid drop model into a picture which has since been elaborated considerably by A Bohr and B Mottelson.

Keystone Press, Photopress

Nobel Prize winners, left to right, A Bohr, B Mottelson and J Rainwater.

Bohr, Mottelson and Rainwater received the 1975 Nobel Prize in Physics for this work. All three have repeatedly opened new doors, Bohr and Mottelson staying mainly in nuclear physics while Rainwater has moved to higher energies.

● Compiled from text on p343.

Compiler's note

Comet West was indeed one of the brightest objects passing through the inner solar system in 1976, bright enough to be observed in full daylight for a few days. Stargazing has bewitched modern human beings ever since we appeared on Earth some 300,000 years ago. Today, a profusion of telescopes invariably steals the show with the kind of glorious images that regularly feature on the *CERN Courier* Astrowatch pages. Thanks to these superb instruments, the observable universe is now thought to contain between 100 and 200 billion galaxies. The oldest one presently known is GN-z11 in the constellation of Ursa Major, found in 2016 by the Hubble Space Telescope. It has an estimated age of about 13.4 billion years, having formed just 400 million years after the Big Bang, when the infant universe had 3% of its present age and distances were about 1/12 their present size.