WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the November 2017 issue of *CERN Courier*.

Rarely has such a short paper sparked such a massive experimental campaign as Steven Weinberg's 50 year-old "Model of Leptons". CERN, along with SLAC in the US and others, has been at the centre of the action in verifying the model's predictions: it took Gargamelle to unearth neutral currents, the Super Proton Synchrotron to produce the W and Z bosons, the Large Electron–Positron collider to measure their properties in detail, and the Large Hadron Collider to flush out the Higgs boson. Unifying the electromagnetic and weak interactions, Weinberg's iconic 2.5 page-long and relatively straightforward manuscript brought a much needed moment of clarity to the field. But today, with all its bosons bagged, Weinberg says that the electroweak Standard Model has become a victim of its own success, with no obvious way to break through to a more fundamental picture. This month we also celebrate 60 years of the Particle Data Group, whose *Review of Particle Physics* has been at the side of physicists throughout the Standard Model's remarkable evolution.

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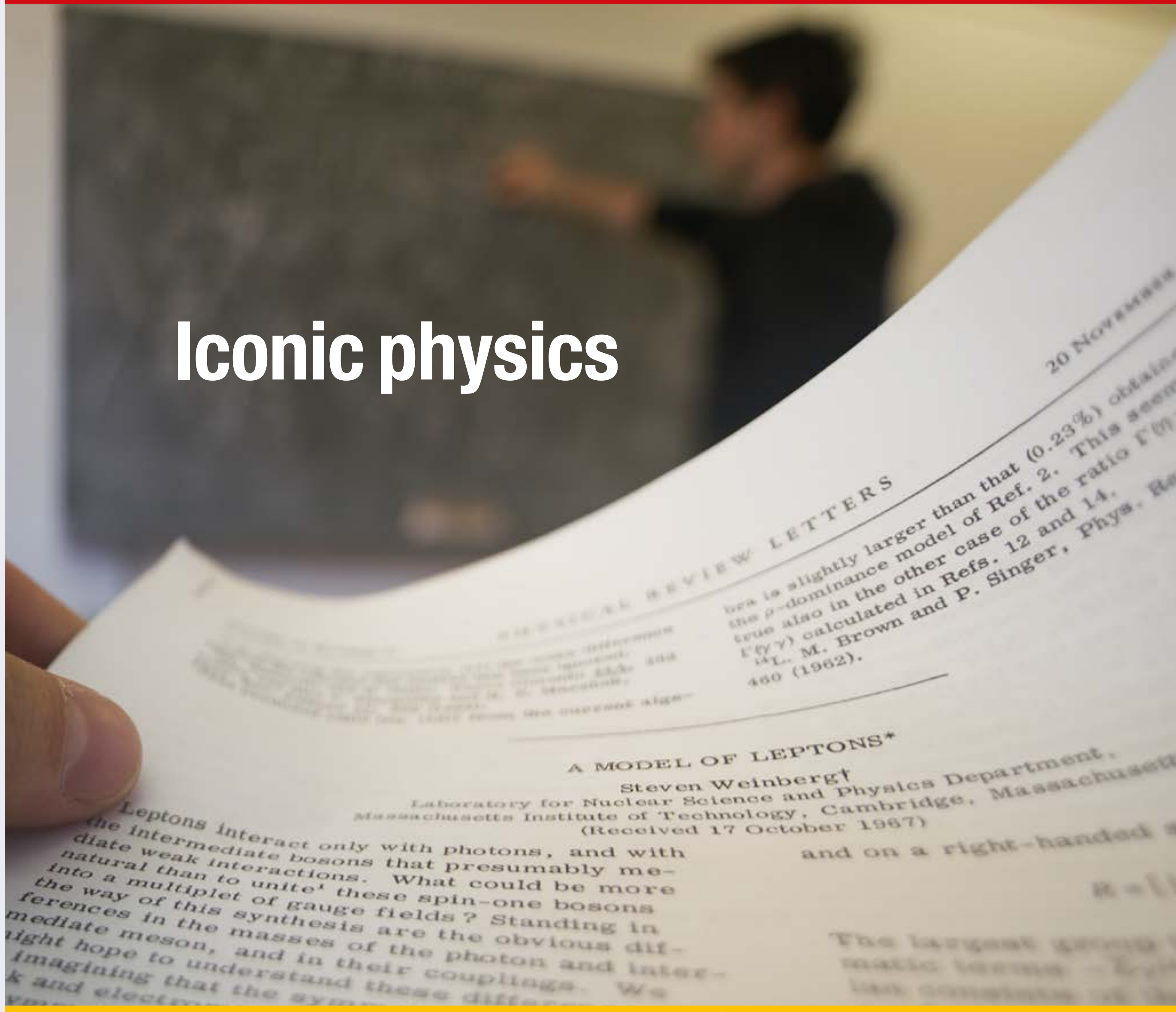
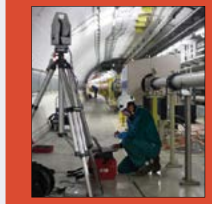
DIGITAL EDITION CREATED BY DESIGN STUDIO/IOP PUBLISHING, UK

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERN COURIER
VOLUME 57 NUMBER 9 NOVEMBER 2017





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

CERN Courier is distributed to member-state governments, institutes and laboratories affiliated with CERN, and to their personnel. It is published monthly, except for January and August. The views expressed are not necessarily those of the CERN management.

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Produced for CERN by IOP Publishing Ltd
IOP Publishing Ltd, Temple Circus, Temple Way,
Bristol BS1 6HG, UK
Tel +44 (0)117 929 7481

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General distribution Courrier Adressage, CERN, 1211 Geneva 23, Switzerland
E-mail: courrier-adressage@cern.ch
In certain countries, to request copies or to make address changes, contact:
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PO Box 918, Beijing 100049, People's Republic of China
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UK Sian Giles, Science and Technology Facilities Council, Polaris House,
North Star Avenue, Swindon, SN2 1SZ
E-mail: sian.giles@stfc.ac.uk
US/Canada Published by Cern Courier, 6N246 Willow Drive,
St Charles, IL 60175, US. Periodical postage paid in St Charles, IL, US
Fax 630 377 1569. E-mail: creative_mailing@att.net
POSTMASTER: send address changes to: Creative Mailing Services, PO Box 1147,
St Charles, IL 60174, US

Published by European Organization for Nuclear Research, CERN,
1211 Geneva 23, Switzerland
Tel +41 (0) 22 767 61 11. Telefax +41 (0) 22 767 65 55

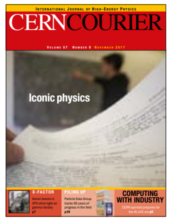
Printed by Warners (Midlands) plc, Bourne, Lincolnshire, UK

 ISSN 0304-288X

IOP Publishing

CERN COURIER

VOLUME 57 NUMBER 9 NOVEMBER 2017



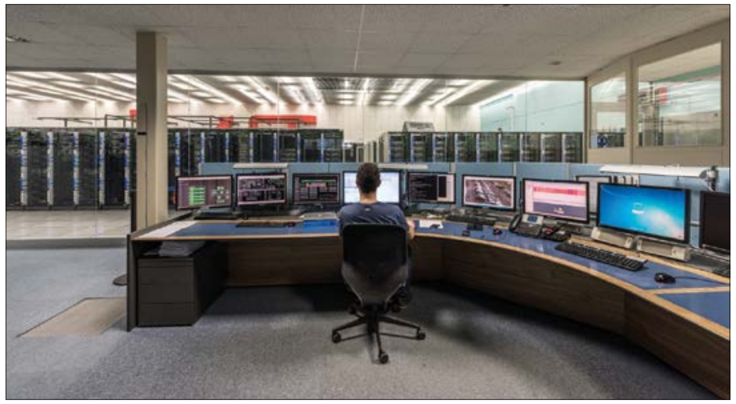
On the cover: A copy of Weinberg's 1967 paper photographed in the CERN theory department. (Image credit: M Brice & J Ordan/CERN.)

Viewpoint

Facing up to the exabyte era

CERN openlab works with industry to tackle the ICT challenges of the high-luminosity LHC.

S Bennett/CERN



An operator in the CERN data centre. The HL-LHC will demand 50–100 times more computing capacity than the LHC, as highlighted in a CERN openlab white paper published in September.

By Alberto Di Meglio

The high-luminosity Large Hadron Collider (HL-LHC) will dramatically increase the rate of particle collisions compared with today's machine, boosting the potential for discoveries. In addition to extensive work on CERN's accelerator complex and the LHC detectors, this second phase in the LHC's life will generate unprecedented data challenges.

The increased rate of collisions makes the task of reconstructing events (piecing together the underlying collisions from millions of electrical signals read out by the LHC detectors) significantly more complex. At the same time, the LHC experiments are planning to employ more flexible trigger systems that can collect a greater number of events. These factors will drive a huge increase in computing needs for the start of the HL-LHC era in around 2026. Using current software, hardware and analysis techniques, the required computing capacity is roughly 50–100 times higher than today, with data storage alone expected to enter the exabyte (10^{18} bytes) regime.

It is reasonable to expect that technology improvements over the next seven to 10 years will yield an improvement of around a factor 10 in both processing and storage capabilities for no extra cost. While this will go some way to address the HL-LHC's requirements, it will still leave a significant deficit. With budgets unlikely to increase, it will not be possible to solve the problem by simply increasing the total computing resources available. It is therefore vital to explore new technologies and methodologies in conjunction with the world's leading information and communication technology (ICT) companies.

CERN openlab, which was established by the CERN IT department in 2001, is a public–private partnership that enables CERN to collaborate with ICT companies to meet the demands of particle-physics research. Since the start of this year, CERN openlab has carried out an in-depth consultation to identify the main ICT challenges faced by the LHC research community over the coming years. Based on our findings, we published a white paper in September on future ICT challenges in scientific research.

The paper identifies 16 ICT challenge areas that need to be tackled in collaboration with industry, and these have been grouped into four overarching R&D topics. The first focuses on data-centre technologies to ensure that: data-centre architectures are flexible and cost effective; cloud-computing resources can be used in a scalable, hybrid manner; new technologies for solving storage-capacity issues are thoroughly investigated; and long-term data-storage systems are reliable and economically viable. The second major R&D topic relates to the modernisation of code, so that the maximum performance can be achieved on the new hardware platforms available. The third R&D topic focuses on machine learning, in particular its potentially large role in monitoring the accelerator chain and optimising the use of ICT resources.

The fourth R&D topic in the white paper identifies ICT challenges that are common across research disciplines. With ever more research fields such as astrophysics and biomedicine adopting big-data methodologies, it is vital that we share tools and learn from one another – in particular to ensure that leading ICT companies are producing solutions that meet our common needs.

In summary, CERN openlab has identified ICT challenges that must be tackled over the coming years to ensure that physicists worldwide can get the most from CERN's infrastructure and experiments. In addition, the white paper demonstrates the emergence of new technology paradigms, from pervasive ultra-fast networks of smart sensors in the "internet of things", to machine learning and "smart everything" paradigms. These technologies could revolutionise the way big science is done, particularly in terms of data analysis and the control of complex systems, and also have enormous potential for the benefit of wider society. CERN openlab, with its unique collaboration with several of the world's leading IT companies, is ideally positioned to help make this a reality.

● openlab.cern.

Alberto Di Meglio is head of CERN openlab and has 20 years' experience leading ICT projects across research and industry.

News

ACCELERATORS

Xenon beams light path to gamma factory

On 14 September, CERN injected a beam of partially ionised xenon atoms into the Super Proton Synchrotron (SPS) and kept it circulating for a short period. The successful demonstration, carried out by the SPS operations and radio-frequency teams, is the first of a series of experimental steps to explore the feasibility of a gamma-ray source with an intensity several orders of magnitude higher that those currently in operation.

Earlier this year, CERN's accelerator complex demonstrated its flexibility by producing a beam of fully ionised xenon atoms for the fixed-target experiment NA61, which studies the physics of strong interactions. Profiting from this achievement, the gamma-factory study group – which is part of CERN's Physics Beyond Colliders study – requested dedicated beam tests with partially ionised xenon atoms in the SPS. The beam was composed of xenon nuclei carrying 15 out of the 54 electrons present in the neutral atom, the missing 39 electrons having been stripped off before reaching the SPS.

The xenon beams injected into the SPS are the most fragile of any beam so far accelerated to, and stored at, ultra-relativistic energies at CERN. A loss of even a single electron changes the magnetic rigidity of the stored particles and leads to beam loss. The losses for the xenon-39 beam due to interactions of the beam with the residual gas in the SPS vacuum pipe were expected to be severe, and the tests confirmed that the beam lifetime is indeed short (of the order of one second). However, the lifetime is expected to be significantly higher for lead beams with only one or two attached electrons, which are the principal candidates to drive the high-energy gamma factory. Tests with lead atoms will be carried out next year in parasitic mode during the LHC's heavy-ion programme, when the CERN accelerator teams aim not only to inject partially ionised lead atoms into the SPS but also into the LHC.


M Brice/CERN

The SPS, pictured during a recent technical stop, was loaded with beams of partially ionised xenon atoms in September.

Light source

An eventual gamma factory would use beams of highly ionised atoms to drive a novel type of light source. The idea is to insert the ion beams into a storage ring and illuminate them with a laser that excites the electrons to a higher energy state, leading to spontaneous emission of secondary photons. In this scheme, the initial laser-photon frequency is boosted by a factor of up to $4\gamma_L^2$, where γ_L is the Lorentz factor of the ion beam. With the LHC as a storage ring, photons in the energy range 1–400 MeV would therefore be possible. Such a source of gamma rays would open many scientific opportunities, such as precision atomic electroweak physics with high-Z hydrogen-like atoms, dark-matter searches using photon beams, and neutron dipole moment and neutron–antineutron oscillations. It would also act as a test bed for a future neutrino factory or a TeV-scale muon collider, says the team.

Meanwhile, independent activities during machine-development periods this year will see xenon atoms injected and brought into collision in the LHC. "The beauty of the operation mode of the CERN accelerator complex is not only that the xenon-39 beam tests in the SPS could be done with no influence on the LHC pp operation, but that they could be done concurrently to injecting and accelerating other types of beam in the SPS – e.g. two cycles for the fixed-target programme and one parasitic cycle for xenon-39," says Witold Krasny of the gamma-factory study group.

CERN's Physics Beyond Colliders initiative was launched in 2016 to explore the opportunities offered by the CERN accelerator complex and infrastructure "to get new insights into some of today's outstanding questions in particle physics through projects complementary to high-energy colliders and other initiatives in the world" (*CERN Courier* November 2016 p28).

Sommaire en français

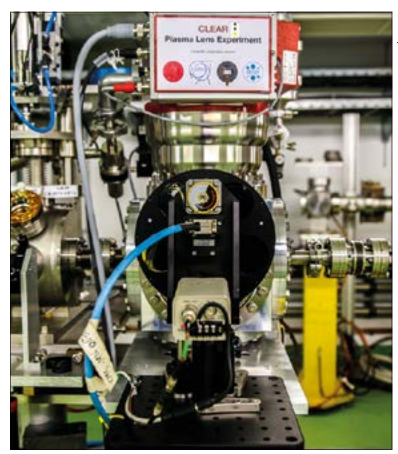
CLEAR prospects for accelerator research

A new user facility for accelerator R&D, the CERN Linear Electron Accelerator for Research (CLEAR), started operation in August and is ready to provide beam for experiments. CLEAR evolved from the former CTF3 test facility for the Compact Linear Collider (CLIC), which ended a successful programme in December 2016. Following approval of the CLEAR proposal, the necessary hardware modifications started in January and the facility is now able to host and test a broad range of ideas in the accelerator field.

CLEAR's primary goal is to enhance and complement the existing accelerator R&D programme at CERN, as well as offering a training infrastructure for future accelerator physicists and engineers. The focus is on general accelerator R&D and component studies for existing and possible future accelerator applications. This includes studies of high-gradient acceleration methods, such as CLIC X-band and plasma technologies, as well as prototyping and validation of accelerator components for the high-luminosity LHC upgrade.

The scientific programme for 2017 includes: a combined test of critical CLIC technologies, continuing previous tests performed at CTF3; measurements of radiation effects on electronic components to be installed on space missions in a Jovian environment and for dosimetry tests aimed at medical applications; beam instrumentation R&D; and the use of plasma for beam focusing. Further experiments, such as those exploring THz radiation for accelerator applications and direct impedance measurements of equipment to be installed in CERN accelerators, are also planned.

The experimental programme for 2018 and beyond is still open to new and challenging proposals. An international scientific committee is currently being formed to prioritise proposals, and a user request form is available at the CLEAR website: cern.ch/clear.



M Volpi

CLEAR's plasma-lens experiment will test ways to drive strong currents through a plasma for particle-beam transverse focusing.

Facilities

China neutron source sees first beam

IHEP

An aerial view of the CSNS facility in August this year.

In late August, the China Spallation Neutron Source (CSNS) produced its first neutron beam, representing an important milestone for the $280 million project. The world's fourth pulsed spallation neutron source, following ISIS in the UK, SNS in the US and J-PARC in Japan, CSNS is located in the city of Dongguan in Guangdong province and is expected to become an important base for research and innovation in China and the surrounding region. CSNS entered construction in 2011 and is being built and operated by the Institute of High Energy Physics in collaboration with the Institute of Physics, both part of the Chinese Academy of Sciences.

A spallation neutron source uses intense pulses of protons to strike a target, producing a beam of neutrons that have been knocked out of the target nuclei. CSNS is driven by a 80 MeV H$^-$ linac and a 1.6 GeV rapid cycling synchrotron, providing a 100 kW proton beam. The protons strike a solid tungsten target and the emerging neutrons are slowed using three moderators, before being delivered to the instrumentation facilities. A second phase of the project, upgrading the linac to 250 MeV and the proton beam power to 500 kW, is planned for the near future.

At 10.56 a.m. on 28 August, a proton beam pulse from the accelerator collided with the tungsten target for the first time. Neutron detectors located at two of the facility's 20 beamlines measured the neutron spectrum, showing that the neutron beam had been successfully produced. The spectrum was consistent with the prediction from Monte Carlo simulations, with a higher neutron yield than expected.

Construction of the first three neutron spectrometers is also complete. A general-purpose powder diffractometer will be used to study crystal and magnetic structures of materials, while a small-angle neutron-scattering instrument will probe structures such as polymers at the level of 1–100 nm. A third instrument, a multipurpose reflectometer, will analyse neutrons reflected from a sample to study the surface and interface structure of materials.

These and other instruments will soon be available to users from around the world for research in materials science and technology, life sciences, physics, the chemical industry, environment, energy and other fields. Commissioning of the spectrometers is under way, on track for the facility to open to users in the spring of 2018.

M Brice/CERN

On 12 September, 56 servers left CERN bound for the SESAME light-source facility in Jordan. "These servers are a very valuable addition to the SESAME data centre," said Salman Matalgah, head of IT at SESAME. "They will help ensure that we're able to provide first-class computing support to our users." Speaking for CERN, Charlotte Warakaulle, director for international relations, said: "After many other successful donations, it's great that we can extend the list of beneficiaries to include SESAME: a truly inspiring project showcasing and building on scientific capacity in the Middle East and neighbouring regions." Pictured are CERN's head of IT Frédéric Hemmer (left), Charlotte Warakaulle and president of SESAME Council Rolf Heuer, with the servers packed and ready to go.

Funding

UK neutrino investment steps up

The UK is to invest £65 million (€74 million) in the Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) in the US, announced UK science minister Jo Johnson on 20 September. Currently under construction at Fermilab and Sanford Underground Research Laboratory, LBNF/DUNE will investigate crucial questions about neutrinos such as their mass ordering and CP-violating properties.

The latest investment makes the UK, already a major scientific contributor with 14 universities and two Science and Technology Facilities Council laboratories providing expertise and components, the largest country in the LBNF/DUNE project outside of the US.

"We have been working towards this for a long time and it is important both for the UK and for DUNE overall," says co-spokesperson of the DUNE collaboration Mark Thomson of the University of Cambridge. "Specifically, the investment will allow the UK to play a major role in the construction of the DUNE far detector (read-out TPC wire planes and DAQ system) and in the neutrino beamline (super-conducting RF for the PIP-II LINAC and the LBNF neutrino target)."

M Brice and J Ordan/CERN

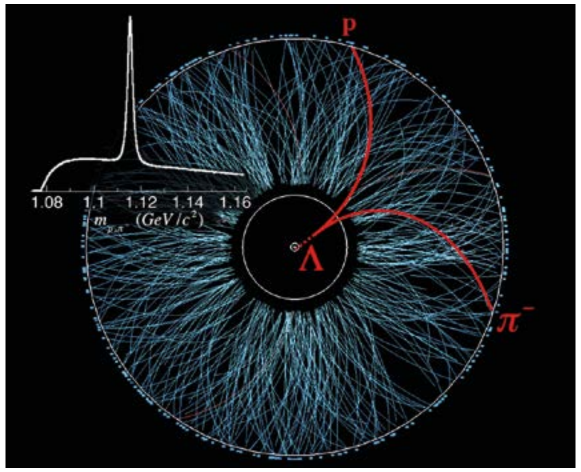
Prototype liquid-argon detectors for the international DUNE project are currently being built at CERN.

LBNF/DUNE is the first major project to be addressed by a broader UK–US science and technology agreement, the first between the two countries, signed in January to strengthen UK–US co-operation.

CERN is an important partner in LBNF/DUNE and is developing prototype liquid-argon detectors for the project as part of its dedicated neutrino platform.

HEAVY IONS

Fastest spinning fluid clocked by RHIC



Charged particles from a gold–gold nuclei collision in the STAR detector. Measurements of the alignment between the global angular momentum of non-central collisions and the spin of emitted particles reveal that the QGP is the most vortical system so far observed.

Experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory have found that droplets of quark–gluon plasma (QGP) can spin faster than any other fluid. The immensely hot and fast-expanding QGP is already known to behave as a near "perfect" liquid, exhibiting a viscosity lower than any other. Now, researchers on RHIC's STAR experiment report that the vorticity (or curl) of the fluid produced in RHIC's relativistic heavy-ion collisions is about $9\times10^{21}\,s^{-1}$. That exceeds the rotation of a super-cell tornado by a factor 10^{20} and is 14 orders of magnitude higher than any fluid ever observed, beating the previous spin record held by nano-droplets of superfluid helium. The results will aid descriptions of quark–gluon plasma and, with more data, offer a way to measure the strength of the plasma's magnetic field.

The past decade has seen major advances in our understanding of the quark–gluon plasma, with RHIC experiments also reporting recently that the extreme state might even form in collisions involving very light nuclei such as deuterium – in line with recent observations by the LHC experiments of proton-collision systems.

● **Further reading**
STAR Collaboration 2017 *Nature* **548** 62.

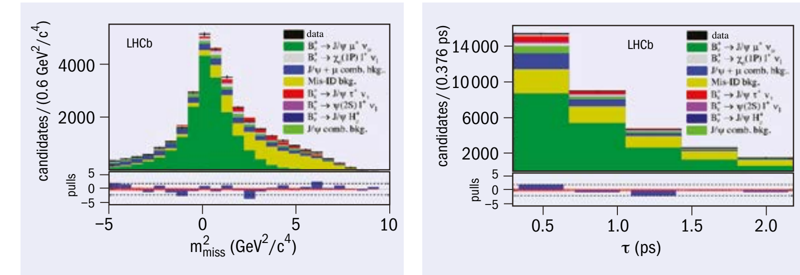
LHC EXPERIMENTS

LHCb digs deeper into lepton-flavour universality

The LHCb collaboration has released yet another result in its campaign to test lepton-flavour universality. Following anomalies already detected in the rate that B mesons decay into muons compared to electrons or tau leptons, the latest result concerns the charmed B meson, B_c^+.

Using data recorded at collision energies of 7 and 8 TeV during LHC Run 1, LHCb reports evidence for the semi-tauonic decay $B_c^+\rightarrow J/\psi\,\tau^+\nu_\tau$ and has performed a measurement of the ratio $R(J/\psi) = Br(B_c^+\rightarrow J/\psi\,\tau^+\nu_\tau)/Br(B_c^+\rightarrow J/\psi\,\mu^+\nu_\mu)$. The ratio is found to be $0.71\pm0.17\pm0.18$, which is within 2σ of the expected Standard Model (SM) range of 0.25–0.28. The SM prediction of $R(J/\psi)$ deviates from unity only due to the large mass difference between the tau and the muon.

Both the semi-muonic decay, $B_c^+\rightarrow J/\psi\,\mu^+\nu_\mu$, and the semi-tauonic decay, $B_c^+\rightarrow J/\psi\,\tau^+\nu_\tau$, with $J/\psi\rightarrow\mu^+\mu^-$ and $\tau^+\rightarrow\mu^+\nu_\mu\bar{\nu}_\tau$, lead to a three-muon final state with the two channels distinguished by their decay kinematics. Despite the distinct signature, however, the analysis must overcome several major challenges. For example, since B_c mesons account for less than 0.1% of the b hadrons produced at the LHC energies, light b hadrons are a major source of background when one or more particles in their final states are misidentified in the detector. Fortunately, the presence of two heavy quarks in the B_c means it decays nearly three times faster than its lighter cousins, providing a powerful handle for statistically separating their respective contributions.



1D projections of the 3D fit to the data in two of the fit variables: the invariant-mass squared of the neutrino system (left) and the decay time of the selected B_c candidates (right).

The latest LHCb result adds to the intriguing picture emerging from the measurements of semi-tauonic decays of b-flavoured hadrons. Previous studies of the ratios of branching fractions between $B\rightarrow D^{(*)}\tau^+\nu_\tau$ and $B\rightarrow D^{(*)}\mu^+\nu_\mu$ at LHCb, BaBar and Belle have shown hints of departure from lepton-flavour universality. The combined effect is now almost at the level of 4σ with respect to the SM prediction. In addition, previous LHCb analyses of $B\rightarrow K^{(*)}\mu^+\mu^-$ and $B\rightarrow K^{(*)}e^+e^-$ decays also deviate from the SM by about 2.5σ.

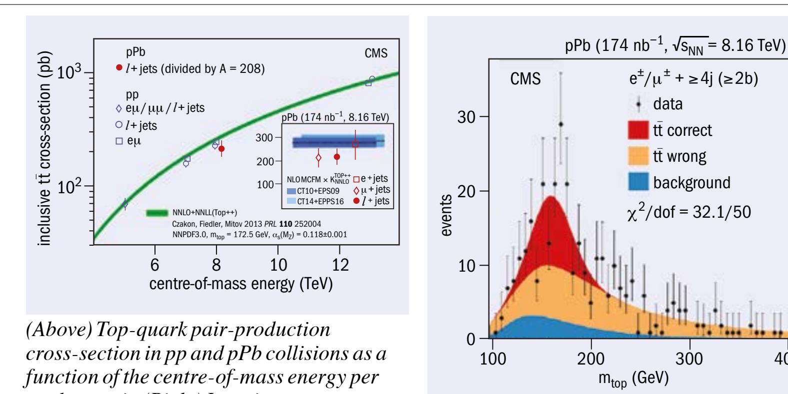
There is much more to come from LHCb on tests of lepton-flavour universality, which remains one of the most enduring hints of deviation from the SM. This includes updates of the results with Run-2 data and measurements from other b-hadron species.

● **Further reading**
LHCb Collaboration 2017 LHCb-PAPER-2017-035.
LHCb Collaboration 2017 arXiv:1708.08856.
LHCb Collaboration 2015 *Phys. Rev. Lett.* **115** 111803.

CMS observes top quarks in proton–nucleus collisions

The top quark, the heaviest elementary particle in the Standard Model, has been the subject of numerous detailed studies in proton–antiproton and proton–proton collisions at the Tevatron and LHC since its discovery at Fermilab in 1995. Until recently, however, studies of top-quark production in nuclear collisions remained out of reach due to the small integrated luminosities of the first heavy-ion runs at the LHC and the low nucleon–nucleon (NN) centre-of-mass energies ($\sqrt{s_{NN}}$) available at other colliders such as RHIC in the US.

Proton–lead runs at $\sqrt{s_{NN}} = 8.16$ TeV performed in 2016 at the LHC have allowed the CMS collaboration to perform the first-ever study of top-quark production in nuclear collisions.



(Above) Top-quark pair-production cross-section in pp and pPb collisions as a function of the centre-of-mass energy per nucleon pair. (Right) Invariant mass distribution of the hadronic top-quark candidates in selected events with two b-tagged jets.

Top-quark cross-sections at the LHC can be computed with great accuracy via perturbative quantum chromodynamics (pQCD) methods, thus making this quark a "standard candle" and a tool for further investigations. In proton–nucleus collisions, in particular, the top quark is a novel probe of the nuclear gluon density at high virtualities in the unexplored high Bjorken-x region. In addition, a good understanding of top-quark production in proton–nucleus collisions is crucial for studies of the space–time ▷

structure of the quark–gluon plasma formed in nucleus–nucleus collisions.

Once produced, each top quark decays promptly into a W boson plus a bottom quark, with the W boson further decaying into either a charged lepton and a neutrino or a pair of light quarks. To identify pair-produced top quarks, CMS therefore selected events containing one isolated electron or muon, two "b-tagged" jets, and two jets that fail b tagging. The amount of signal in the selected sample is inferred by a fit to the invariant mass of the two untagged jets, interpreted as W boson decay products ($W \to qq'$). The amount of non-top background is constrained by two complementary event samples, with zero or one b-tagged jets, also included in the fit. In this way, the background behaviour in this (so far unexplored) phase-space region and the b-tagging efficiency are evaluated *in situ* with only minimal assumptions, independent of prior inputs. As a validation, the outcome of the fit is used to model the signal and background invariant mass distributions of the top-quark candidate in the hadronic decay channel ($t \to Wb \to qq'b$), which are in agreement with the data (see figure).

The excess of events with respect to the background-only hypothesis corresponds to a significance of more than 5σ, even under the most conservative assumptions. The measured top-pair cross-section is consistent with the expectations from scaled proton–proton collision data as well as pQCD predictions at next-to-next-to-leading order with next-to-next-to-leading-log accuracy (figure, right). This result paves the way towards future studies of top-quark production in the hot and dense matter created in nucleus–nucleus collisions.

Further reading

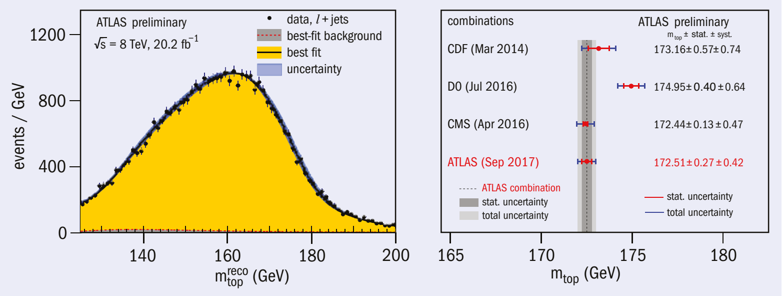
CMS Collaboration 2017 arXiv:1709.07411.

ATLAS experiment makes precision measurement of top-quark mass

The top quark is copiously produced at the LHC, allowing for very precise measurements of its properties. The mass of the top quark, m_{top}, plays a special role in the Standard Model (SM) of particle physics. It is a key part of the mechanism of electroweak symmetry breaking and one of the parameters governing the stability of the universe in the SM.

Following years of meticulous work, ATLAS presented a new measurement of m_{top} at the 10th International Workshop on Top Quark Physics held in Braga, Portugal, in late September. The measurement was performed using around 100,000 proton–proton collision events at an energy of 8 TeV, each containing a top-quark pair reconstructed in the single-lepton final state. In this channel, each top quark immediately decays to a W boson and a bottom quark, and one W boson decays to an electron or muon and a neutrino, while the second W boson decays to two light quarks.

A simultaneous measurement of m_{top} together with a global jet-energy scale factor and a relative bottom-to-light jet-energy scale factor was performed. The inclusion of these scale factors strongly reduces systematic uncertainties. The precision of the measurement is further improved by differentiating between correctly reconstructed top-quark events and events where the final-state objects are incorrectly assigned to the two top quarks. While only retaining 40% of the events, the total uncertainty is improved by 19%, leading to a top-quark mass of 172.08±0.91 GeV.



(Left) The reconstructed top-quark mass recorded at 8 TeV together with the best-fit template. (Right) the new ATLAS combined result compared to those from other experiments.

The power of this measurement, which is the second most precise individual top-quark mass measurement made by ATLAS to date, is revealed when combined with previous ATLAS measurements in the single-lepton channel at 7 TeV and the dilepton channel at 8 TeV. This combination relies on a careful evaluation of the correlation between measurements for all sources of systematic uncertainty. In both channels at 8 TeV, the analysis optimisation trades reduced systematic against increased statistical uncertainty, thereby reducing the correlation among the measurements. The combined result thus has a 41% smaller uncertainty than the single most precise measurement. The current combined value is 172.51±0.50 GeV with a relative precision of 0.29%, which is mainly limited by the calibration of the jet-energy scales and is similar to that of the leading single-experiment combined measurements.

The current precision on m_{top} represents a significant achievement that demonstrates the precise understanding of all the relevant aspects of the ATLAS detector. The measurement will allow further and deeper tests of the consistency of the SM.

Further reading

ATLAS Collaboration 2017 ATLAS-CONF-2017-071.

Les physiciens des particules du monde entier sont invités à apporter leurs contributions au CERN Courier, en français ou en anglais. Les articles retenus seront publiés dans la langue d'origine. Si vous souhaitez proposer un article, faites part de vos suggestions à la rédaction à l'adresse cern.courier@cern.ch.

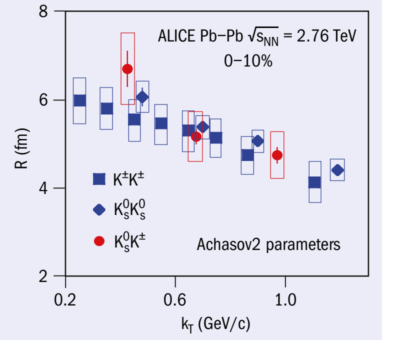
CERN Courier welcomes contributions from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

ALICE studies possible light tetraquark

The a_0(980) resonance is formally classified by the Particle Data Group as a light diquark (quark + antiquark) meson similar to the pion. However, it has long been considered as a candidate tetraquark state made up of two quarks and two antiquarks. Existing experimental evidence based on the radiative decay of the ϕ meson has not been convincing, so the ALICE collaboration took a different approach to study the a_0 by measuring K^0_S–$K^\pm$ correlations in lead–lead collisions at the LHC. Since the kaons are not identical there is no Hanbury–Brown–Twiss interferometry enhancement, and since the K^0_S is uncharged there is no Coulomb effect. Nevertheless, because the rest masses of the two kaons reach the threshold to produce the a_0 it is expected that there is a strong final-state interaction between the two kaons through the a_0 resonant channel.

Using the data from central lead–lead collisions with a nucleon–nucleon energy of 2.76 TeV, ALICE fitted the experimental two-kaon yield to extract the radius and emission strength of the kaon source assuming only a final-state interaction through the a_0 (see figure).

Both the radii and the emission strength from the K^0_S–$K^\pm$ analysis agree with the identical kaon results, suggesting that the final-state interaction between the K^0_S and $K^\pm$ goes solely through the a_0 resonance without any competing non-resonant channels. A tetraquark a_0 is expected to couple more strongly to the two kaons, since it has the same quark content, while the formation of a diquark state requires the annihilation of the strange quarks, which is suppressed due to geometric effects and a selection rule. Although there are no quantitative predictions for the magnitude of this suppression that would result for a diquark form of a_0, the qualitative expectation is that this would open up non-resonant channels that would compete with the a_0 final-state interaction, making it smaller than the identical-kaon values. The ALICE result of the final-state interaction going solely via the a_0 thus favours the interpretation of the a_0 as a tetraquark state.



Radius parameters versus average transverse kaon-pair momentum determined from K^0_S–$K^\pm$ correlations and identical-kaon correlations in central ALICE lead–lead collisions.

Further reading

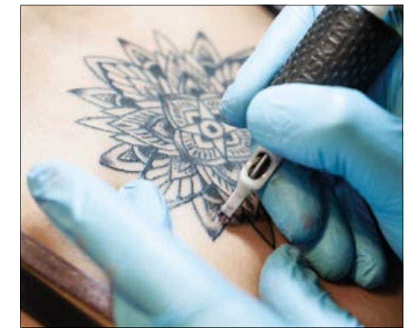
ALICE Collaboration 2017 *Phys. Lett. B* **774** 64.

Sciencewatch

Compiled by John Swain, Northeastern University

Tattoo ink travels in body

The inks in tattoos are supposed to remain confined to the skin, but a recent study by Andreas Luch of the German Federal Institute for Risk Assessment in Berlin and colleagues shows that elements within inks are transported in micro- and nanoparticle forms from the skin to regional lymph nodes. The team used synchrotron X-ray fluorescence at the European Synchrotron in Grenoble, France, to track the presence of various elements *ex vivo* in tattooed tissues. The results revealed the first evidence for the transport of various organic and inorganic pigments and toxic-element impurities, such as heavy metals and titanium dioxide. Fourier-transform infrared spectroscopy also revealed ultrastructural changes in tissue next to tattoo particles and elevated lipid contents, which may contribute to inflammation and other problems associated with tattooing.



The hazards that potentially derive from tattoos had previously only been investigated by chemical analysis of the inks and their degradation products in vitro.

Further reading

I Schreiver *et al.* 2017 *Sci. Rep.* **7** 11395.

Three hundred kinds of ice

Ice is commonly thought to have a hexagonal crystal structure, as reflected in the symmetry of snowflakes. Along with cubic ice, which is found in the upper atmosphere, these are the only crystalline forms of ice found in nature so far. Now, Takahiro Matsui and colleagues at Okayama University in Japan suggest that this is merely the tip of the iceberg. Using classical molecular dynamics simulations, the team found over 300 new kinds of porous ice structures derived from zeolite frameworks and space fullerenes. Despite being a vast increase over the 17 ice polymorphs found experimentally so far, they only exist at very low – even negative – pressures and temperatures near absolute zero.

Further reading

T Matsui *et al.* 2017 *J. Chem. Phys.* **147** 091101.

Climate and leaf size

The sizes of leaves vary by more than five orders of magnitude among plant species worldwide, yet the reason why has remained mysterious. Ian Wright of Macquarie University in Australia and colleagues have now characterised the patterns of leaf sizes for 7670 plant species together with climatic data from 682 sites worldwide, and report consistent patterns that explain why earlier predictions had limited success. The results also provide a quantitative explanation for leaf-size variation with latitude: for much of the world, a key factor limiting leaf size turns out to be night temperature and the associated risk of frost damage.

Further reading

I Wright *et al.* 2017 *Science* **357** 917.

Plants outside of tropical climes have smaller leaves that are more robust against cold.

Helicity dynamics in water

Vortices are an interesting feature of fluid motion. William Irvine of the University of Chicago and colleagues have now shown that the helicity of vortices, which is a measure of the degree to which vortex lines wind around each other, can remain constant even in viscous fluids. Helicity is conserved in the absence of viscosity, but can be dissipated in real (viscous) fluids. Observing the twisting, linking and writhing of hydrofoils in water, the team shows that twisting dissipates vortex tubes while writhing and linking conserve them. The result could allow helicity to be manipulated in real fluid flows, with implications for atmospheric flows ranging from turbulence to the formation of tornados.

Further reading

M Scheeler *et al.* 2017 *Science* **357** 487.

Rat nightmares

Nightmares are familiar to humans, but it now seems rats can have them too. Gabrielle Girardeau and colleagues at New York University put rats in a maze and blasted them in the face with an unpleasant, yet harmless, burst of compressed air. As the rats slept later, patterns of activity arose in their hippocampi corresponding to their mental map of the maze, but activity in the amygdala, a region involved in emotion, also showed up whenever the blast of air was activated.

Further reading

G Girardeau *et al.* 2017 *Nat. Neurosci.* doi:10.1038/nn.4637.

Farewell to Cassini

On 15 September, having expended the last of its rocket propellant, NASA's Cassini probe was deliberately crashed into Saturn following an epic two-decade-long journey of exploration. The mission has revolutionised our understanding of the complex Saturn system, in particular its moons and rings, and broadened our knowledge about life in the solar system. The first spacecraft to orbit Saturn, Cassini has led to hundreds of scientific papers and shaped the future of planetary exploration.

Further reading

saturn.jpl.nasa.gov.

Astrowatch

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

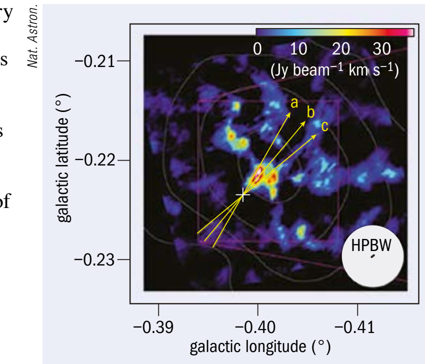
First intermediate black-hole candidate

Since the prediction of black holes a century ago, numerous black-hole candidates have been found. These consist of both low-mass black holes, which have several times the mass of the Sun, and supermassive black holes (SMBHs), which are billions of times heavier. While many candidates exist for stellar-mass black holes and SMBHs, the latter being thought to occupy the centres of galaxies, candidates for black holes in the intermediate mass range were lacking.

A group of researchers from Keio University in Japan has now shown strong evidence for the existence of an intermediate-mass black hole (IMBH) within the Milky Way, which could shed light on the formation of black holes and of our galaxy.

While there is a consensus that stellar-mass black holes form when massive stars die, the source of SMBHs – one of which is thought to be at the centre of the Milky Way – is not well known. It is believed that large galaxies such as the Milky Way grew to their current size by cannibalising smaller dwarf galaxies containing IMBHs at their centres. Finding a candidate IMBH would provide evidence for this theory.

First, using the Nobeyama radio telescope, the team detected a gas cloud in the Milky Way with a peculiar velocity profile, hinting that an IMBH exists near the centre of our galaxy. This then prompted a more precise observation of the area using the Atacama Submillimeter Telescope Experiment (ASTE) and Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. The cloud, named CO-0.40-0.22, was found to consist of one dense cloud in the centre with a large velocity profile, surrounded by 20 smaller clouds, the velocity profiles of which are aligned. Since the probability of these clouds being aligned by chance is less than one part in 10^8, it suggests there is some other object close to the cloud interacting with it. Within the gas cloud the data also revealed a point source emitting weak electromagnetic radiation at submillimetre wavelengths and none at higher wavelengths, ruling out a massive star cluster.



Integrated emission from the gas cloud, where the cross marks the black hole and the arrows indicate the measured velocity directions. The white filled circle and black filled ellipse show the beam sizes of ASTE and ALMA, respectively.

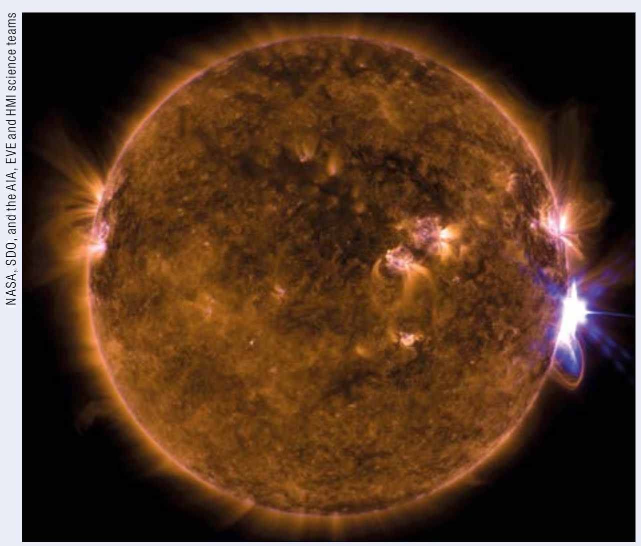
Based on these striking observations, the group simulated the gravitational interactions of the cluster and found that the measured velocity profiles are consistent with a gravitational kick by a dense object of 10^5 solar masses. Combined with the lack of high-energy emission and the spectrum of the object measured in radio wavelengths, the object matches all the characteristics of an IMBH – the first one ever observed. Two further IMBHs are now under study. The finding opens a new research avenue in understanding both massive and supermassive black holes, and strengthens the hypothesis that our galaxy grew by cannibalising smaller ones.

Further reading

T Oka *et al.* 2017 *Nat. Astron.* **1** 709.

Picture of the month

This image of the Sun shows a large solar flare (on the right side of the picture) coming from a giant active region called AR2673 just as the region is about to disappear behind the solar horizon. Since 6 September, AR2673 has been responsible for several flares including the largest seen in more than a decade. The large flare shown here, captured in ultraviolet by the Atmospheric Imaging Assembly on the Solar Dynamics Observatory mission, was followed by a large coronal mass ejection (CME) on 10 September. While solar flares are responsible for emission in the ultraviolet and X-ray regions, gamma-rays with an energy of several GeV have been measured in the past by the Fermi-LAT satellite. CMEs, which often follow solar flares, are responsible for the ejection of high-energy electrons and protons into the solar system resulting in the Northern Lights. Although the CMEs coming from this region resulted in spectacular Northern Lights, much stronger CMEs have occurred in the past. In 1859 a CME was strong enough to cause auroras to be visible at latitudes as low as Cuba, while the results of a very strong solar event in the year 775 are thought to be responsible for a large carbon-14 surplus found in tree rings around the world.



NASA, SDO, and the AIA, EVE and HMI science teams

The physicist's guide to the universe

First issued in 1957, the *Review of Particle Physics* has become the number-one reference in high-energy physics, detailing more than 38,000 measurements and counting.

The latest (2016) PDG Review of Particle Physics *leaning against all previous editions, with the oldest issues at the bottom.*

Lawrence Berkeley National Laboratory

Teasing out the intricate measurements that separate the smallest components of matter in the universe often involves monumental machines and huge international scientific collaborations. So it's important that particle physicists are on the same page – or, rather, pages – when it comes to particle-physics results. For the past 60 years, the definitive collection of particle-physics evaluations and reviews has been bound up in a weighty print volume called the *Review of Particle Physics*, which is published every other year. The latest (2016) edition of what is sometimes referred to as the "bible of particle physics" contains 1808 pages in the complete version published online, and features 117 review articles on topics ranging from the Higgs boson to the Big Bang, statistics and particle detectors. Its Particle Listings include evaluations of 3062 new measurements from 721 papers, in addition to 35,436 measurements from 9843 papers published in earlier editions. The staff behind it carefully evaluate data on around 8000 different quantities to provide averages, fits and best limits.

The *Review* is the all-time most highly cited publication in particle physics, with recent editions eventually reaching more than 6000 citations. It also has a companion 344 page booklet that is the descendant of "wallet cards" first issued in 1957, with a summary of particle data from the main *Review*. The PDG website (pdg.lbl.gov) features the complete content of the book as both PDF files and in an interactive version, with downloadable figures and tables, as well as educational materials. The *Review* continues to grow as we learn more about the basic constituents of matter, and its history reflects a field that is continuously evolving.

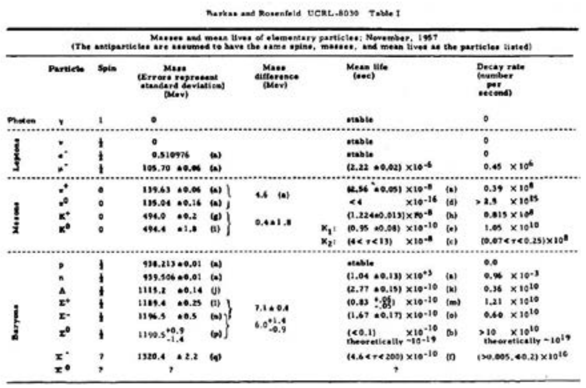
Berkeley beginnings

The *Review of Particle Physics* and its associated publications and website are the products of the international Particle Data Group (PDG), which since its beginnings has been headquartered at the University of California Radiation Laboratory, now the Lawrence Berkeley National Laboratory (Berkeley Lab), in California. More than 200 authors around the globe currently contribute to the contents of the *Review*, including 3.5 full-time-equivalent physicists in the PDG group at Berkeley Lab who also co-ordinate the effort.

The story began towards the end of 1957 with a paper in the *Annual Review of Nuclear Science* authored by the late Arthur "Art" Rosenfeld and Murray Gell-Mann. The tables of particle masses and lifetimes associated with that article, which Rosenfeld prepared with Walter Barkas in an unpublished report, "Data for Elementary-Particle Physics," are credited with PDG's inception. "The damn thing just grew," Rosenfeld said of the wallet-card summary of that first report, which now fills a spiral-bound booklet.

The *Review* is the all-time most highly cited publication in particle physics.

Rosenfeld said in 1975 that the motivation for the original 1957 report was to provide particle data for early computer programs that were used to process the data from new particle-physics experiments, including bubble-chamber ▷


Barkas and Rosenfeld UCRL-8030 Table I

Masses and mean lives of elementary particles; November, 1957
(The antiparticles are assumed to have the same spins, masses, and mean lives as the particles listed)

	Particle	Spin	Mass (Errors represent standard deviation) (Mev)	Mass difference (Mev)	Mean life (sec)	Decay rate (number per second)
Photon	γ	1	0		stable	0
Leptons	ν	½	0		stable	0
	e^-	½	0.510976 (a)		stable	0
	μ^-	½	105.70 ±0.06 (a)		(2.22 ±0.02) ×10⁻⁶	0.45 ×10⁶
Mesons	π^+	0	139.63 ±0.06 (a)	4.6 (a)	(2.56 ±0.05) ×10⁻⁸ (a)	0.39 ×10⁸
	π^0	0	135.04 ±0.16 (a)		<4 ×10⁻¹⁶ (d)	>2.5 ×10¹⁵
	K^+	0	494.0 ±0.2 (g)	0.4±1.8	(1.224±0.013)×10⁻⁸ (h)	0.815 ×10⁸
	K^0	0	494.4 ±1.8 (i)		K_1: (0.95 ±0.08) ×10⁻¹⁰ (e)	1.05 ×10¹⁰
					K_2: (4<τ<13) ×10⁻⁸ (c)	(0.07<τ<0.25)×10⁸
Baryons	p	½	938.213 ±0.01 (a)		stable	0.0
	n	½	939.506 ±0.01 (a)		(1.04 ±0.13) ×10⁺³ (a)	0.96 ×10⁻³
	Λ	½	1115.2 ±0.14 (j)		(2.77 ±0.15) ×10⁻¹⁰ (k)	0.36 ×10¹⁰
	Σ^+	½	1189.4 ±0.25 (l)	7.1±0.4	(0.83 +.06/−.05) ×10⁻¹⁰ (m)	1.21 ×10¹⁰
	Σ^-	½	1196.5 ±0.5 (n)	$6.0^{+1.4}_{-0.9}$	(1.67 ±0.17) ×10⁻¹⁰ (o)	0.60 ×10¹⁰
	Σ^0	½	$1190.5^{+0.9}_{-1.4}$ (p)		(<0.1) ×10⁻¹⁰ (b) theoretically ~10⁻¹⁹	>10 ×10¹⁰ theoretically ~10¹⁹
	Ξ^-	?	1320.4 ±2.2 (q)		(4.6<τ<200) ×10⁻¹⁰ (f)	(>0.005, <0.2) ×10¹⁰
	Ξ^0	?	?		?	

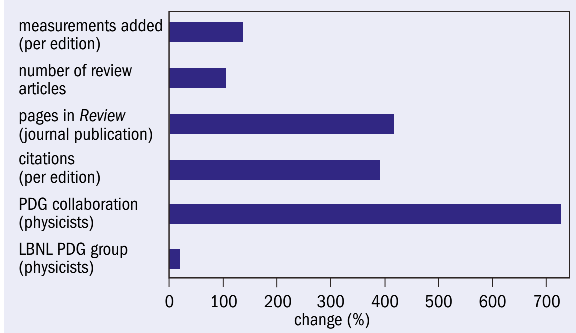
Masses and mean lifetimes of elementary particles, as shown in Table I of the first wallet card issued in 1957. (Image credit: Barkas and Rosenfeld, UCRL-8030.)

experiments. The following year the report was revised. The report was next revised in 1961, and during these first few years of the *Review* Rosenfeld and his colleagues intermittently distributed updates of the report to the particle-physics community, along with the updated wallet cards.

New discoveries in the field led to a growing need for particle-data resources, and Rosenfeld was clear that the 1963 edition should be the last attempted without the help of a computer. A separate effort by Finnish physicist Matts Roos called "Tables of Elementary Particles and Resonant States" also illustrated that it was no longer possible for a single person to compile data critically, reckoned Rosenfeld. So the two separate efforts joined forces, with five Berkeley authors and Roos publishing "Data on Elementary Particles and Resonant States" in 1964. This article, which appeared in the *Reviews of Modern Physics* journal, comprised 27 pages plus three wallet cards.

The group branded itself as the Particle Data Group in 1968 and published its first data booklet that year. By 1974 the report, by then called *Review of Particle Properties*, had grown to 200 pages and had 13 authors, several of them based in Europe. An escalation of discoveries in the field during the mid-1970s provided the cornerstones for the Standard Model of particle physics, which described the family of known and theorised particles and their properties. The heavy crush of particle data flowing into PDG during this period led the staff to implement a new media format for distributing some data and additional quality-control measures. In 1973 a microfiche with references and backup material was included in an envelope at the back of the book.

Since then, the population of particle physicists worldwide has exploded and the print version of the *Review* and related booklets are currently distributed to thousands of physicists. INSPIRE, an information system that tracks published materials and experiments in the field of high-energy physics, now counts more than 1100 active experiments in the field, compared to about 300 in 1975, and the number of particle physicists has also increased from about 7000 in 1975 to an estimated 20,000 today. The print book was getting so big – growing at a rate of about 10% per year – that



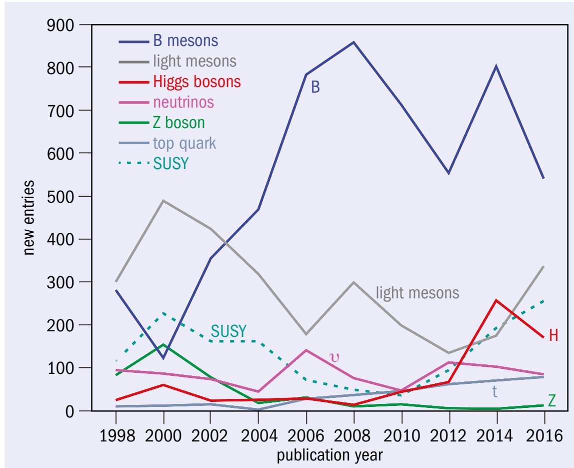


Fig. 1. Changes between the 1986 and 2016 editions of the Review *(top) and the number of measurements of selected particles added to the* Review *as a function of the year of the edition (above).*

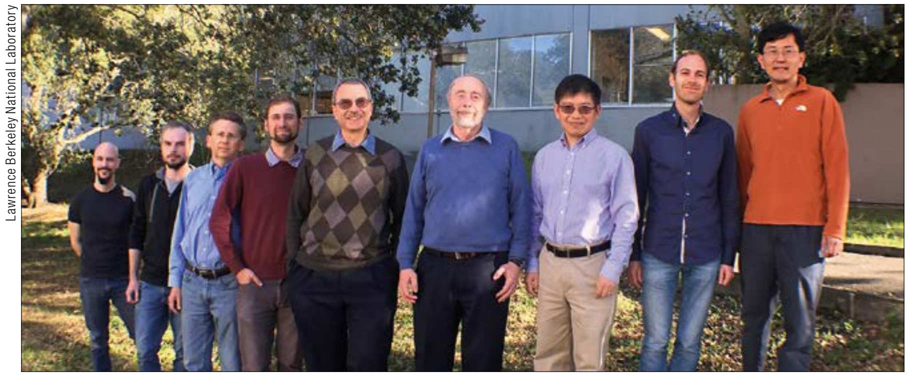
Image credits: Lawrence Berkeley National Laboratory

the PDG dropped its Listings from the print edition in 2016.

"We would have had to print two volumes if we continued to include the Listings. Given that there is likely no single person who wants to read through a major fraction of the Listings, this wasn't justified," recalls Juerg Beringer of Berkeley Lab, who became leader of the PDG in 2016. "Looking up data from the Listings online is anyway far more convenient." The Listings are still available on the PDG website and included in the online journal publication.

Review articles

Many sections in the Listings are accompanied by review articles that provide further information on the data presented. Other review articles summarise major topics in particle physics or cosmology. Review articles can vary from about a page to tens of pages in length, and roughly two-thirds of review articles require updates in each edition. The first PDG review article on the Higgs boson, which appeared in 1988, was two pages long. Today, five years after the Higgs was discovered, the review is about 50 pages long and is the most viewed review on the website, with more than 50,000 downloads each year. PDG even delayed publication in 2012 to


Lawrence Berkeley National Laboratory

Members of Berkeley Lab's PDG group in 2016. From left to right: Paul Schaffner (graphics/web designer), Kirill Lugovsky (software developer), Piotr Zyla (editor), Dan Dwyer (staff scientist), Juerg Beringer (group leader), Michael Barnett (past group leader), Wei-Ming Yao (staff scientist), Simone Pagan Griso (staff scientist) and Cheng-Ju Lin (staff scientist).

accommodate the Higgs boson's discovery, with staff scrambling to add the Higgs addendum to the *Review* within eight days of the discovery's announcement on 4 July 2012.

The scope and importance of PDG has grown substantially, especially during the past 30 years (figure 1 opposite). While the size of the PDG group at Berkeley Lab has remained essentially the same, a large number of physicists worldwide were recruited to keep up with the flood of publications in particle physics and write the many PDG review articles that now cover almost every aspect of particle physics. There are now 223 authors who contribute to the review articles or Listings and each will typically write a single review article or handle one Listings section. Collaborators outside Berkeley Lab are volunteers who usually spend only a small fraction of their time on the *Review*, while PDG group members at Berkeley Lab typically spend half of their time working on the PDG (image above). There is also a European-based PDG "meson team" of about a dozen members, which holds meetings twice a year at CERN, while another PDG sub-group called the baryon team is responsible for the data on baryon resonances.

Michael Barnett, a Berkeley Lab physicist and previous head of PDG having been in the role for 25 years, recalled his first experience working with the *Review* production when he joined Berkeley Lab in 1984. "It was barely 300 pages long and still put together by hand," Barnett said. "We used 20 rolls of Scotch Tape to stick pieces together for the camera-ready copy. The section on B mesons was a single page. These days the B-meson section alone is over 120 pages." In earlier days, the data for the publications were stored on computer punch cards. The print data back then appeared as only uppercase letters, with no mathematical symbols, because the punch cards couldn't accommodate them. Under Barnett's watch the design and layout became more reader-friendly. Particle categories multiplied, with properties listed in detail. Many new reviews were added to help explain the content of Listings sections.

Computing era

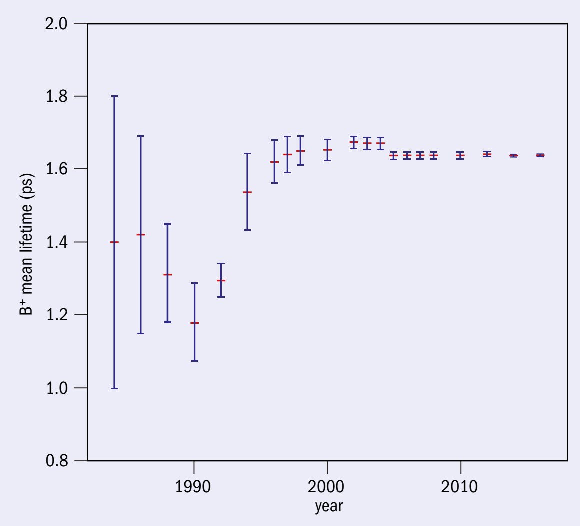
In the late 1980s a then-modern computing system was developed that served the PDG well for two decades. But a major upgrade eventually became inevitable, and the COMPAS group from the Institute of High Energy Physics in Protvino, Russia, which had been a PDG collaborator for many years, began working on prototypes for a new computing system. Working with COMPAS and experts from Berkeley Lab's Computational Research Division, Beringer led the development of a new web-based computing platform that was supported by a special grant from the US Department of Energy (DOE). As a result, each collaborator can now directly add data to the PDG database rather than channelling it all through the PDG editor. This platform has made *Review* updates far more manageable. "The new system allows collaborators to see changes immediately, without waiting for the editor to go through thousands of e-mails with instructions on what to change," says Piotr Zyla, who succeeded Betty Armstrong as PDG editor in 2003.

As with any large-scale, data-intensive publishing endeavour, there have been a few notable glitches. The 1994 booklet had a ruler with centimetre marks that were shrunk by the publisher so that each centimetre was actually 0.97 of a centimetre. The error was discovered too late to fix, but not too late to insert a disclaimer citing fictitious and comical explanations for why the centimetres fell a bit short: "The PDG feels it has the right to redefine anything it wants"; "The booklets were returned from the printer at 0.25 times the speed of light"; and "A theorist is in charge of the PDG."

Barnett and his colleagues had considered publishing the *Review* on the internet since the early days of the World Wide Web – which, of course, was created at CERN in 1989 to more easily share research data around the world. The entire contents of the *Review* were available on the web in 1995 and its interactive version, pdgLive, appeared with the 2006 edition. An increasingly sophisticated PDG web presence has been influenced by membership surveys asking readers whether in the digital age a printed book is essential, useful, or altogether unnecessary. The first survey, in 2000, got about 2450 responses, half of which found the print version useful and well over a third found it essential. By 2014 the number of responses had tripled. While there was a clear trend in favour of online publications, many respondents still emphasised the importance of the printed book. As one respondent stated in the 2000 survey, "I could live without my right arm, but I don't want to."

We used 20 rolls of Scotch Tape to stick pieces together for the camera-ready copy.

"We expected older physicists to be the ones who valued the book and the younger ones, ▷



Particle Data Group 2016 *Chin. Phys. C* **40** 100001

Fig. 2. History of the PDG value of the charged B-meson mean lifetime as quoted in the Review of Particle Physics. *By and large, history plots show a progression toward greater precision at central values quite consistent with the first data points shown.*

	m_{1957} (MeV)	m_{2016} (MeV)	$\frac{m_{1957}-m_{2016}}{\sqrt{\sigma^2_{1957}+\sigma^2_{2016}}}$	$\frac{\sigma_{(1957)}}{\sigma_{(2016)}}$
e^-	0.510976	0.5109989461±0.0000000031		
μ^-	105.70±0.06	105.6583745±0.0000024	0.7	25000
π^+	139.63±0.06	139.57018±0.00035	1.0	171
π^0	135.04±0.16	134.9766±0.0006	0.4	267
K^+	494.0±0.2	493.677±0.016	1.6	13
K^0	494.4±1.8	497.611±0.013	−1.8	138
p	938.213±0.01	938.272081±0.000006	−5.9	1667
n	939.506±0.01	939.565413±0.000006	−5.9	1667
Λ	1115.2±0.14	1115.683±0.006	−3.4	23
Σ^+	1189.4±0.25	1189.37±0.07	0.1	4
Σ^0	$1190.5^{+0.9}_{-1.4}$	1192.642±0.024	−2.4	38
Σ^-	1196.5±0.5	1197.449±0.030	−1.9	17
Ξ^-	1320.4±2.2	1321.71±0.07	−0.6	31

Lawrence Berkeley National Laboratory

Table comparing several PDG masses in 1957 and in 2016. Also shown are the discrepancies between these values and the improvement in the accuracy of the measurements.

who grew up with the internet, not to care," says Barnett. "We got it backwards. Everybody used the web, but more grad students and postdocs found the printed book essential." Their comments told why: to those entering physics, the book was not merely a reference but an introduction to the unexplored dimensions of their field. The distribution scheme for the print publications has become fairly sophisticated to minimise shipping costs. There are now four separate distribution channels: in Switzerland, Japan, China and the US. Receiving the print materials is not automatic and recipients must specifically request each new edition. The audience is largely physicists, teachers, students and physics fans, with most mailings going out to high-energy physics centres and academic institutions.

The bulk of the funding for PDG comes from the Office of Science of the DOE and supports the co-ordination and production activities at Berkeley Lab. Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) contributes to these efforts via a US–Japan agreement on co-operative research and development. CERN supports the meson team, and in recent years CERN and the Institute of High Energy Physics of the Chinese Academy of Sciences have paid for most of the printing and shipping costs of books and booklets. Funding agencies in multiple countries, including INFN in Italy, MINECO in Spain, and IHEP in Russia provide travel and other support to PDG collaborators in their countries.

Until recently, the PDG group at Berkeley Lab was able to handle most of the PDG co-ordination tasks. But with the growth of PDG in recent years, combined with a challenging funding environment, even this has become increasingly difficult. Thankfully, INFN recently agreed to help Berkeley Lab in this area. A recent effort to streamline and automate many aspects of PDG's operations is also providing necessary relief.

Contributing knowledge

The published results collected in the Listings provide best values and limits for a wide range of particle properties. The data can also be used to study how knowledge in particle physics evolves, for example by plotting the evolution of PDG best values over time (figure 2 and table).

Over the decades there have been occasional disputes and discrepancies for PDG staff to resolve. In one instance, discussions escalated to a threatened lawsuit over PDG's refusal to include one researcher's particle data in the *Review*'s Summary Tables. There was also a case in which the experimental measurements of the mass squared of one particle (the electron neutrino) appeared as a negative number in the data: since this is mathematically impossible, the PDG editors adjusted the error margins to account for the problem. Another unusual episode concerned claims of discoveries of pentaquarks about a decade ago and later experiments discounting those earlier claims. These ups and downs, including the latest measurements from the LHCb experiment, were covered in the reviews to keep readers up to date.

When various data are in substantial conflict, PDG sets error bars that range across the whole span of results, or, in some cases, provides no average at all. Also, about 20 years ago, the PDG instituted a new naming scheme that more logically renamed many particles. All of them stuck except for one – there was an international campaign against that name-change, so the PDG staff deferred in this one instance.

When you see your data appearing, you feel like you are a particle physicist.

Only a subset of data collected by PDG is available in a downloadable format suitable for further processing. There is a demand for such access from researchers running Monte Carlo programs and others who want to, for example, investigate the statistical properties of the agreement between multiple measurements of the same quantity. "Making all PDG data available in a machine-readable format is a very high priority. We've wanted to do this for a long time as there are many uses and a lot of interest from the community. But we can barely keep up with the ongoing updates of the *Review*, and so the implementation of such new features takes much more time than we would like," Beringer says.

Rosenfeld, in the conclusion of his 1975 paper assessing the work of PDG, noted challenges even then in supporting the data needs of the scientific community: "As we write this review we wonder if we have not been too modest in our requests for support…we feel that PDG is doing an effective job, but if we could spend, each year, one-fifth of the typical experiment [in those days the typical experiment cost about $3 million], it could provide broader and more timely services."

The gradual transition from print to primarily online distribution is expected to continue, in line with the overall shift of publishers toward online publication but also, in part, because of the high cost of printing and mailing the books. Nevertheless, as long as there is continuing demand and adequate resources, PDG hopes to continue the printed book. "Producing and updating the *Review of Particle Physics* in modern formats will remain PDG's core mission," says Beringer.

Online access to PDG's increasingly mobile-friendly web pages, or a PDG smartphone app with the complete contents of the *Review* in a mobile-friendly format, could in principle replace the PDG booklet. But especially for students, the PDG book and booklet also carry substantial symbolic value, and the booklets are often distributed in introductory particle-physics classes. "It is a landmark thing for some of the graduate students and postdocs," Barnett remarks. "When you get your first book, and when you see your data appearing, you feel like you are a particle physicist."

• Further reading

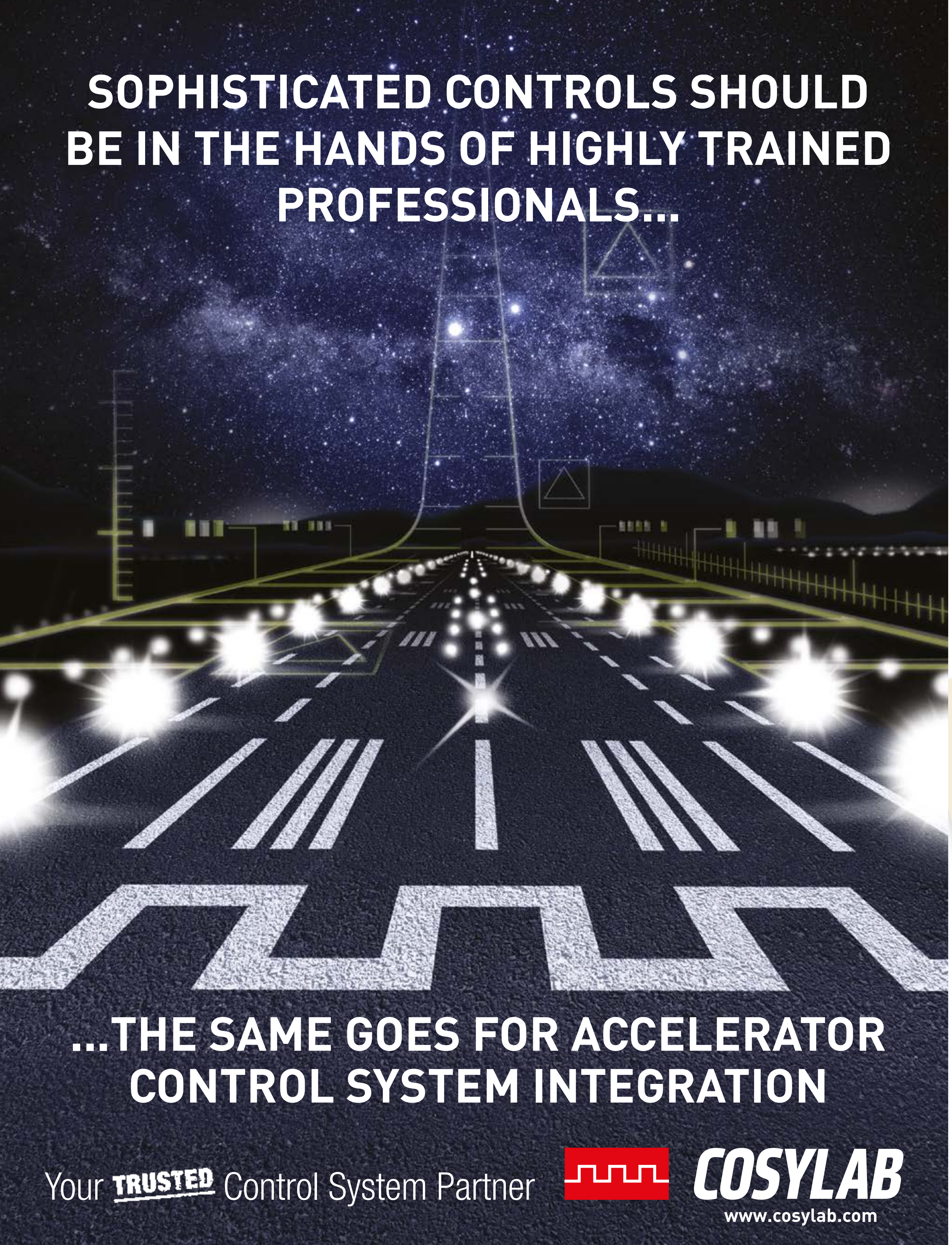
pdg.lbl.gov.
M Gell-Mann and A Rosenfeld 1957 *Annual Review of Nuclear Science* **7** 407.
Particle Data Group 2016 *Chin. Phys. C* **40** 100001.
A Rosenfeld 1975 *Annual Review of Nuclear Science* **25** 555.

Résumé

Le guide de l'Univers du physicien

Depuis 60 ans, les progrès en physique des particules sont compilés dans un volume, Review of Particle Physics. *Il s'agit de la publication la plus citée en physique des particules. La dernière édition de cet ouvrage, parfois appelé la « bible de la physique des particules », contient 117 articles de synthèse. Sa section «* Particle Listings *» comprend des évaluations de 3 062 nouvelles mesures, provenant de 721 articles s'ajout aux 35 436 mesures des éditions précédentes. Ses rédacteurs évaluent soigneusement des données portant sur environ 8 000 quantités différentes afin de fournir des moyennes, des ajustements et les meilleures limites existantes. Cet ouvrage continue de s'étoffer et son histoire est le reflet d'un domaine en constante évolution.*

Glenn Roberts Jr., Lawrence Berkeley National Laboratory, with contributions by **Paul Preuss**.



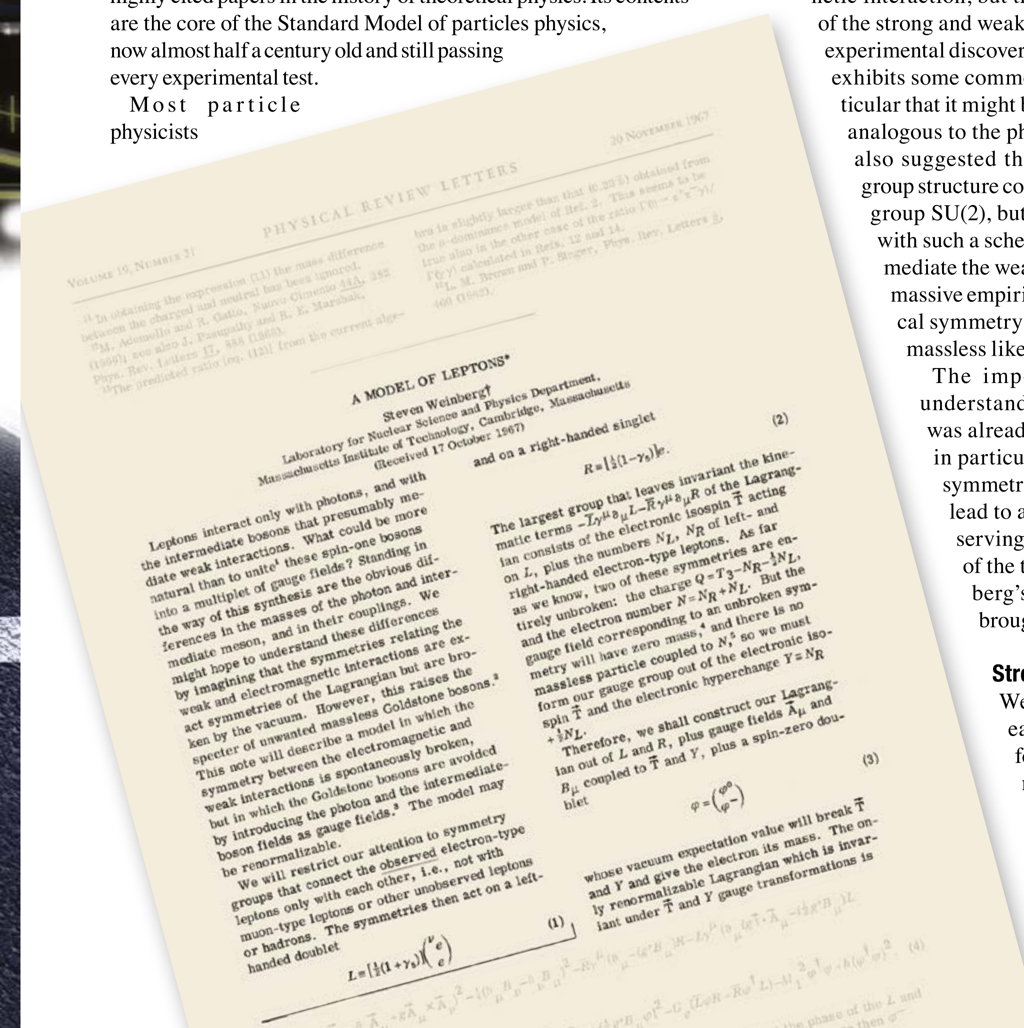
Birth of a symmetry

Half a century ago, Steven Weinberg spent the summer at Cape Cod, working on a new theory of the strong interaction of pions. By October 1967, the idea had morphed into a theory of the weak and electromagnetic interactions, and the following month he published a paper that would revolutionise our understanding of the fundamental forces.

Weinberg's paper "A Model of Leptons", published in *Physical Review Letters* (PRL) on 20 November 1967, determined the direction of high-energy particle physics through the final decades of the 20th century. Just two and a half pages long, it is one of the most highly cited papers in the history of theoretical physics. Its contents are the core of the Standard Model of particles physics, now almost half a century old and still passing every experimental test.

Most particle physicists today have grown up with the Standard Model's orderly account of the fundamental particles and interactions, but things were very different in the 1960s. Quantum electrodynamics (QED) had been well established as the description of the electromagnetic interaction, but there were no mature theories of the strong and weak nuclear forces. By the 1960s, experimental discoveries showed that the weak force exhibits some common features with QED, in particular that it might be mediated by a vector boson analogous to the photon. Theoretical arguments also suggested that QED's underlying "U(1)" group structure could be generalised to the larger group SU(2), but there was a serious problem with such a scheme: the W boson suspected to mediate the weak force would have to be very massive empirically, whereas the mathematical symmetry of the theory required it to be massless like the photon.

The importance of symmetries in understanding the fundamental forces was already becoming clear at the time, in particular how nature might hide its symmetries. Could "hidden symmetry" lead to a massive W boson while preserving the mathematical consistency of the theory? It was arguably Weinberg's developments, in 1967, that brought this concept to life.


A MODEL OF LEPTONS*

Steven Weinberg†

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(Received 17 October 1967)

Leptons interact only with photons, and with the intermediate bosons that presumably mediate weak interactions. What could be more natural than to unite[1] these spin-one bosons into a multiplet of gauge fields? Standing in the way of this synthesis are the obvious differences in the masses of the photon and intermediate meson, and in their couplings. We might hope to understand these differences by imagining that the symmetries relating the weak and electromagnetic interactions are exact symmetries of the Lagrangian but are broken by the vacuum. However, this raises the specter of unwanted massless Goldstone bosons.[2] This note will describe a model in which the symmetry between the electromagnetic and weak interactions is spontaneously broken, but in which the Goldstone bosons are avoided by introducing the photon and the intermediate-boson fields as gauge fields.[3] The model may be renormalizable.

We will restrict our attention to symmetry groups that connect the observed electron-type leptons only with each other, i.e., not with muon-type leptons or other unobserved leptons or hadrons. The symmetries then act on a left-handed doublet

$$L=[\tfrac{1}{2}(1+\gamma_5)]\binom{\nu_e}{e} \quad (1)$$

and on a right-handed singlet

$$R=[\tfrac{1}{2}(1-\gamma_5)]e. \quad (2)$$

The largest group that leaves invariant the kinematic terms $-\bar{L}\gamma^\mu\partial_\mu L-\bar{R}\gamma^\mu\partial_\mu R$ of the Lagrangian consists of the electronic isospin $\vec{T}$ acting on L, plus the numbers N_L, N_R of left- and right-handed electron-type leptons. As far as we know, two of these symmetries are entirely unbroken: the charge $Q=T_3-N_R-\frac{1}{2}N_L$, and the electron number $N=N_R+N_L$. But the gauge field corresponding to an unbroken symmetry will have zero mass,[4] and there is no massless particle coupled to N,[5] so we must form our gauge group out of the electronic isospin $\vec{T}$ and the electronic hyperchange $Y\equiv N_R+\frac{1}{2}N_L$.

Therefore, we shall construct our Lagrangian out of L and R, plus gauge fields $\vec{A}_\mu$ and B_μ coupled to $\vec{T}$ and Y, plus a spin-zero doublet

$$\varphi=\binom{\varphi^0}{\varphi^-} \quad (3)$$

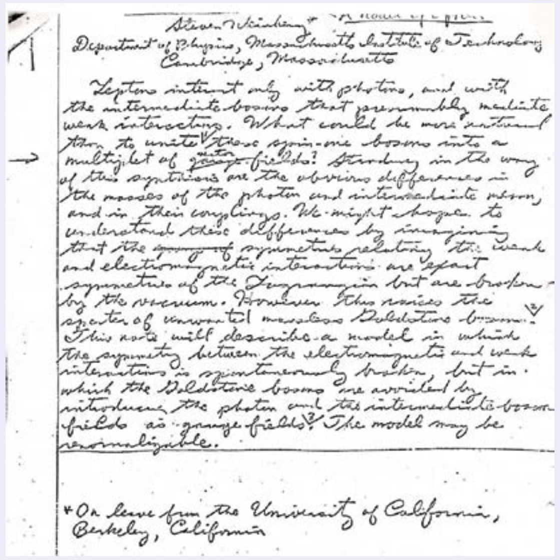
whose vacuum expectation value will break $\vec{T}$ and Y and give the electron its mass. The only renormalizable Lagrangian which is invariant under $\vec{T}$ and Y gauge transformations is

The first page of Weinberg's 1967 paper "A Model of Leptons", published in Physical Review Letters.

Strong inspiration

Weinberg's inspiration was an earlier idea of Nambu in which fermions – such as the proton or neutron – can behave like a ▷

S Weinberg and M Veltman



Steven Weinberg*

Department of Physics, Massachusetts Institute of Technology
Cambridge, Massachusetts

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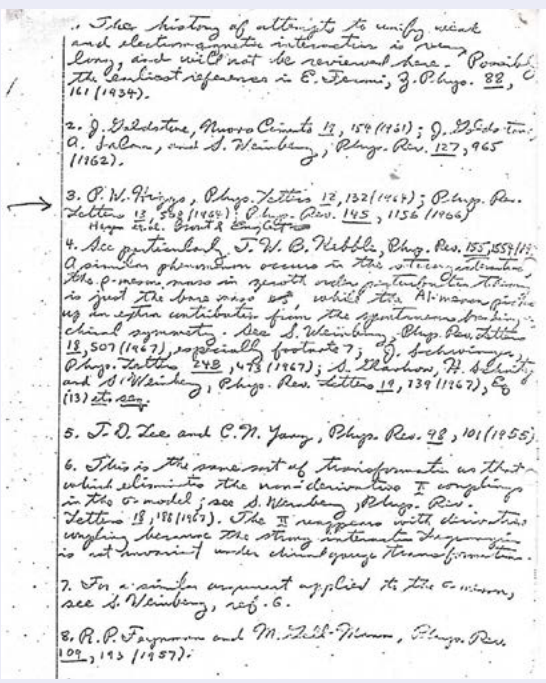
*On leave from the University of California, Berkeley, California



1. The history of attempts to unify weak and electromagnetic interactions is very long, and will not be reviewed here. Possibly the earliest reference is E. Fermi, Z. Phys. 88, 161 (1934).

2. J. Goldstone, Nuovo Cimento 19, 154 (1961); J. Goldstone, A. Salam, and S. Weinberg, Phys. Rev. 127, 965 (1962).

3. P. W. Higgs, Phys. Letters 12, 132 (1964); Phys. Rev. Letters 13, 508 (1964); Phys. Rev. 145, 1156 (1966)
Higgs et al. Brout & Englert

4. See particularly T. W. B. Kibble, Phys. Rev. 155, 1554 (1967). A similar phenomenon occurs in the strong interactions; the ρ-meson mass in zeroth order perturbation theory is just the bare mass m_0, while the A1-meson picks up an extra contribution from the spontaneous breaking of chiral symmetry. See S. Weinberg, Phys. Rev. Letters 18, 507 (1967), especially footnote 7; J. Schwinger, Phys. Letters 24B, 473 (1967); S. Glashow, H. Schnitzer and S. Weinberg, Phys. Rev. Letters 19, 139 (1967), Eq. (13) et seq.

5. T. D. Lee and C. N. Yang, Phys. Rev. 98, 101 (1955).

6. This is the same sort of transformation as that which eliminates the non-derivative π couplings in the σ-model; see S. Weinberg, Phys. Rev. Letters 18, 188 (1967). The π reappears with derivative coupling because the strong interaction Lagrangian is not invariant under chiral gauge transformation.

7. For a similar argument applied to the σ meson, see S. Weinberg, ref. 6.

8. R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1957).

The cover page (top) and references (above) of Weinberg's original manuscript, as given to H P Durr at the time of the 1967 Solvay conference, may be compared with the paper in published form. The origin of the arrow on the manuscript adjacent to reference three is unknown, but may be a reminder to complete that reference: the citations of Brout and Englert and to "Hagen et al.*" (Guralnik Hagen and Kibble) have been added later, possibly following discussions at that meeting.*

left- or right-handed screw as they move. If mass is ignored, these two "chiral" states act independently and the theory leads to the existence of a particle with properties similar to those of the pion – specifically a pseudoscalar, which means that it has no spin and its wavefunction changes sign under mirror symmetry. Nambu's original investigations, however, had not examined how the three versions of the pion, with positive, negative or zero charge, shared their common "pion-ness" when interacting with one another. This commonality, or symmetry, is mathematically expressed by the group SU(2), which had been known in nuclear physics since the 1930s and in mathematics for much longer.

It was this symmetry that Weinberg used as his point of departure in building a theory of the strong force, where nucleons interact with pions of all charges and the proton and neutron themselves form two "faces" of the underlying SU(2) structure. Empirical observations of the interactions between pions and nucleons showed that the underlying symmetry of SU(2) tended to act on the left- or right-handed chiral possibilities independently. The mathematical structure of the resulting equations to describe this behaviour, as Weinberg discovered, is called SU(2)×SU(2).

However, in nature this symmetry is not perfect because nucleons have mass. Had they been massless, they would have travelled at the speed of light, the left- and right-handed possibilities acting truly independently of one another and the symmetry left intact. That nucleons have a mass, so that the left and right states get mixed up when perceived by observers in different inertial frames, breaks the chiral symmetry. Nambu had investigated this effect as far back as 1959, but without the added richness of the SU(2)×SU(2) mathematical structure that Weinberg brought to the problem. Weinberg had been investigating this more sophisticated theory in around 1965, initially with considerable success. He derived theorems that explained the observed interactions of pions and nucleons at low energies, such as in nuclear physics. He was able to predict how pions behaved when they scattered from one another and, with a few well-defined assumptions, paved the way for a whole theory of hadronic physics at low energies.

Meanwhile, in 1964, Brout and Englert, Higgs, Kibble, Guralnik and Hagen had demonstrated that the vector bosons of a Yang–Mills theory (one that is like QED but where attributes such as electric charge can be exchanged by the vector bosons themselves) put forward a decade earlier could become massive without spoiling the fundamental gauge symmetry. This "mass-generating mechanism" suggested that a complete Yang–Mills theory of the strong interaction might be possible. In addition to the well-known pion, examples of massive vector particles that feel the strong force had already been found, notably the rho-meson. Like the pion, this too occurs in three charged varieties: positive, negative and zero. Superficially these rho-mesons had the hallmarks of being the gauge bosons of the strong interactions, but they also have mass. Was the strong interaction the theatre for applying the mass-generating mechanism?

Despite at first seeming so promising, the idea failed to fit the data. For some phenomena, the SU(2)×SU(2) symmetry empirically is broken, but for others where spin didn't matter it works perfectly. When these patterns were incorporated into the maths, the rho-meson stubbornly remained massless, contrary to reality.

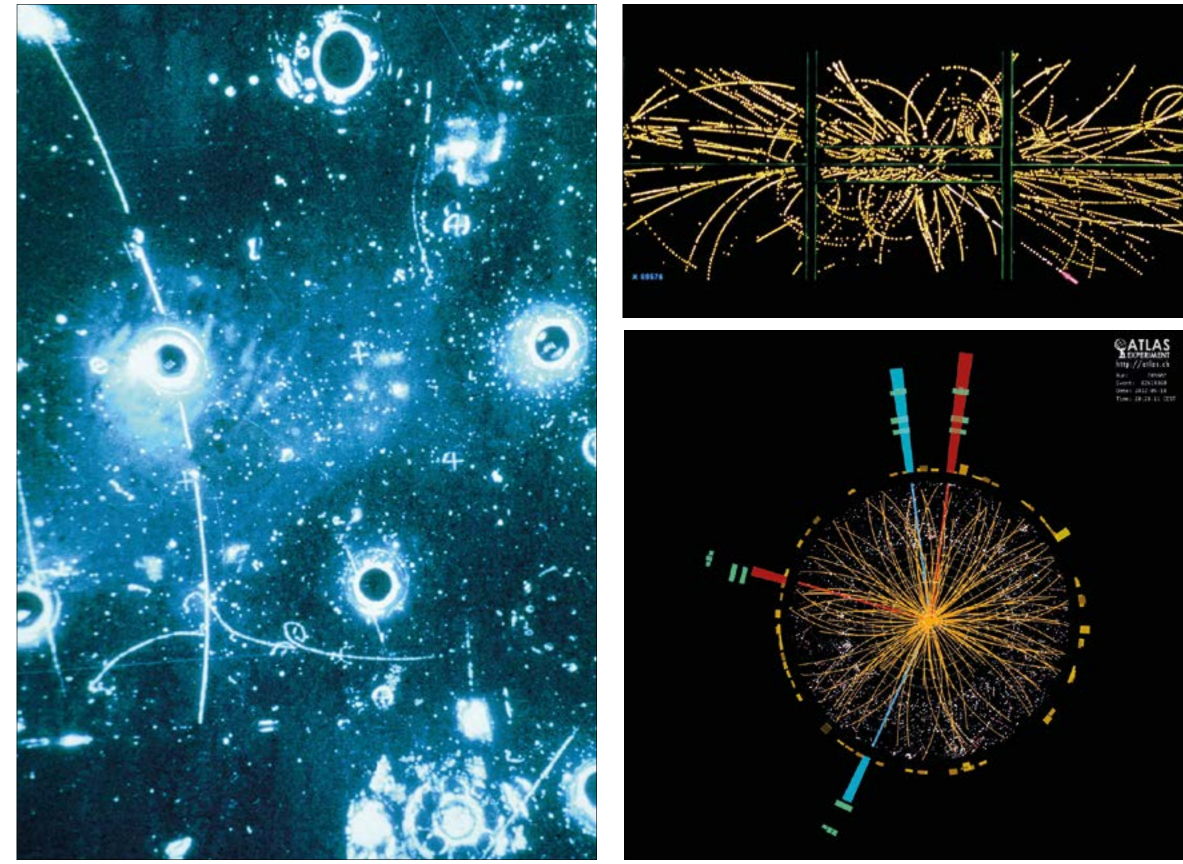


Image credits: CERN

CERN has been instrumental in proving the validity of Weinberg's model of leptons. (Left) The first evidence for the weak neutral current, recorded by the Gargamelle bubble-chamber experiment in July 1973, in which an incoming antineutrino knocks an electron forwards (towards the left) to create a characteristic electronic shower with electron–positron pairs. (Top right) Direct production for the first time of the W boson in the UA1 detector in late 1982, producing a high transverse energy electron (arrow). (Bottom right) An event display from the ATLAS experiment showing a candidate event for a Higgs boson decaying into four electrons, recorded a few weeks before the official Higgs discovery was announced on 4 July 2012.

Epiphany on the road

In the middle of September 1967, while driving his red Camaro to work at MIT, Weinberg realised that he had been applying the right ideas to the wrong problem. Instead of the strong interactions, for which the SU(2)×SU(2) idea refused to work, the massless photon and the hypothetical massive W boson of the electromagnetic and weak interactions fitted perfectly with this picture. To call this possibility "hypothetical" hardly does justice to the time: the W boson was not discovered until 1984, and in 1967 was so disregarded as to receive at best a passing mention, if any, in textbooks.

Weinberg needed a concrete model to illustrate his general idea. The numerous strongly interacting hadrons that had been discovered in the 1950s and 1960s were, for him, a quagmire, so he restricted his attention to the electron and neutrino. Here too it is worth recalling the state of knowledge at the time. The constituent quark model with three flavours – up, down and strange – had been formulated in 1964, but was widely disregarded. The experiments at SLAC that would help establish these constituents were a year away from announcing their results, and Bjorken's ideas of a quark model, articulated at conferences that summer, were not yet widely accepted either. Finally, with only three flavours of quark, Weinberg's ideas would lead to empirically unwanted "strangeness-changing neutral currents". All these problems would eventually be solved, but in 1967 Weinberg made a wise choice to focus on leptons and leave quarks well alone.

Following the discovery of parity violation in the 1950s, it was clear that the electron can spin like a left- or right-handed screw, whereas the massless neutrino is only left-handed. The left–right symmetry, which had been a feature of the strong interaction, was gone. Instead of two SU(2), the mathematics now only needed one, the second being replaced by the unitary group U(1). So Weinberg set up the equations of SU(2)×U(1) – the same structure that, unknown to him, had been proposed by Sheldon Glashow in 1961 and by Abdus Salam and John Ward in 1964 in attempts to marry the electromagnetic and weak interactions. His theory, like ▷

Private collection

Weinberg in Stockholm in 1979 receiving the Nobel Prize in Physics from the king of Sweden. The prize was shared between him, Sheldon Glashow and Abdus Salam "for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, *the prediction of the weak neutral current".*

theirs, required two massive electrically charged bosons – the W^+ and W^- carriers of the weak force – and two neutral bosons: the massless photon and a massive Z^0. If correct, it would show that the electromagnetic and weak forces are unified, taking physics a step closer to the goal of a single theory of all fundamental interactions.

"The history of attempts to unify weak and electromagnetic interactions is very long, and will not be reviewed here." So began the first footnote in Steven Weinberg's seminal November 1967 paper, which led to him being awarded the 1979 Nobel Prize in Physics with Salam and Glashow. Weinberg's footnote mentioned Fermi's primitive idea for unification in 1934, and also the model that Glashow proposed in 1961.

Clarity of thought

Weinberg started his paper by articulating the challenge of unifying the electroweak forces as both an opportunity and a threat. He focused on the leptons – those fermions, such as the electron and neutrino, which do not feel the strong force. "Leptons interact only with photons, and with the [weak] bosons that presumably mediate weak interactions. What could be more natural than to unite these spin-one bosons [the photon and the weak bosons] into a multiplet," he pondered. That was the opportunity. The threat was that "standing in the way of this synthesis are the obvious differences in the masses of the photon and [weak] boson."

Weinberg then suggests a solution: perhaps "the symmetries relating the weak and electromagnetic interactions are exact [at a fundamental level] but are [hidden in practice]". He then draws attention to the ideas of Higgs, Brout, Englert, Guralnik, Hagen and Kibble, and uses these to give masses to the W and Z in his model. In a further important insight, Weinberg shows how this symmetry-breaking mechanism leaves the photon massless.

His opening paragraph ended with the prescient observation that: "The model may be renormalisable." The argument upon which this remark is based appears at the very end of the paper, although with somewhat less confidence than the promise hinted at the beginning. He begins the final paragraph with a question: "Is this model renormalisable?" The extent of his intuition is revealed in his argument: although the presence of a massive vector boson hitherto had been a scourge, the theory with which he had begun had no such mass and, as such, was "probably renormalisable". So, he pondered: "The question is whether this renormalisablity is lost [by the spontaneous breaking of the symmetry]." And the conclusion: "If this model is renormalisable, what happens when we extend it…to the hadrons?"

By speculating that his model may be renormalisable, Weinberg was hugely prescient, as 't Hooft and Veltman would prove four years later. And perhaps it was a chance encounter at the Solvay Congress in Belgium two weeks before his paper was submitted that helped convince Weinberg that he was on the right track.

Solvay secrets

By the end of September 1967, Weinberg had his ideas in place as he set off to Belgium to attend the 14th Solvay Congress on Fundamental Problems in Elementary Particle Physics, held in Brussels from 2 to 7 October. He did not speak about his forthcoming paper, but did make some remarks after other talks, in particular following a presentation by Hans Peter Durr about a theorem of Jeffrey Goldstone and spontaneous symmetry breaking. During a general discussion session following Durr's talk, Weinberg mused: "This raises a question I can't answer: are such models renormalisable?" He continued with a similar argument to that which later appeared in his paper, ending with: "I hope someone will be able to find out whether or not [this] is a renormalisable theory of weak and electromagnetic interactions."

There was remarkably little reaction to Weinberg's remarks, and he himself has recalled "a general lack of interest". The only recorded statement came from François Englert, who insisted that the theory is renormalisable; then, remarkably, there is no further discussion. Englert and Robert Brout, then relatively junior scientists, had both attended the same Brussels meeting.

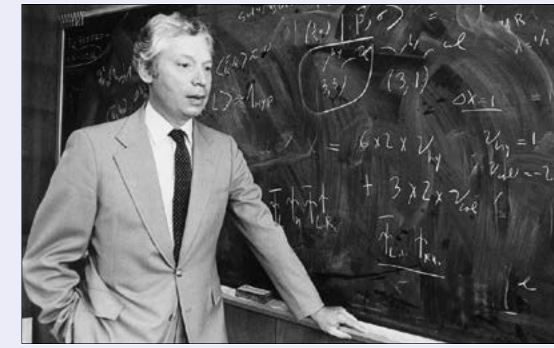
At some point during the Solvay conference, Weinberg presented a hand-written draft of his paper to Durr, and 40 years later I obtained a copy by a roundabout route. Weinberg himself had not seen it in all that time, and thought that all record of his Nobel-winning manuscript had been lost. The original manuscript is notable for there being no sign of second thoughts, or editing, which suggests that it was a provisional final draft of an idea that had been worked through in the preceding days. The only hint of modification after the first draft had been written is a memo squeezed in at the end of a reference to Higgs, to include references to Brout and Englert, and to Guralnik, Hagen and Kibble, for the idea of spontaneous symmetry breaking, on which the paper was based. Weinberg's intuition about the renormalisability of the model is already present in this manuscript, and is identical to what appears in his PRL paper. There is no mention of Glashow's SU(2)×U(1) model in the draft, but this is included in the version that was published in PRL the following month. This is the only substantial difference. This manuscript was submitted to the editors of PRL on Weinberg's return to the US, and received by them on 17 October. It appeared in print on 20 November.

Private collection

Symmetries, groups and massive insight led to electroweak unification

Weinberg's 1967 achievement is rooted in the notation of group theory, which is the mathematical language describing the symmetries of a system, and built upon many earlier successes including that of quantum electrodynamics (QED). QED is perhaps the simplest example of a general class of "non-abelian gauge theories". Since the all-important electric charge in QED is a single number, it can be described mathematically in terms of the first unitary group, U(1). In the 1950s Yang and Mills constructed generalisations of QED in which the U(1) number was replaced by matrices, such as in the groups SU(2) or SU(3). The weak force exhibited tantalising hints that a SU(2) generalisation of QED might be involved, but there was a serious problem: a "W boson" – the analogue of QED's photon – would have to be very massive empirically, whereas the mathematical symmetry of the theory required it to be massless – like the photon. The only way to give the W and Z particles mass yet leave the photon massless was if nature contained "hidden symmetries" that were somehow broken.

In 1961 Goldstone discovered a theorem suggesting, *inter alia*, that a theory of the weak force involving hidden symmetry is impossible. However, in 1963, condensed-matter theorist Philip Anderson pointed out that superconductivity manages to evade Goldstone's theorem, and demonstrated this mathematically in a theory without relativity. The following year several theorists, including Peter Higgs, generalised Anderson's insights to include relativity. Among the implications were that a theory involving fermions with no mass – with so-called chiral symmetry – could hide this property in empirically consistent ways when particles become massive; that there should be a massive boson without spin (the Higgs boson); and that the W boson could also gain mass while preserving the underlying mathematical symmetry of the theory. It was Weinberg's 1967 paper that brought all of these pieces together, and today we know that nature follows this path, with the weak and electromagnetic interactions described by a single SU(2)×U(1) structure. At the time, however, the breakthrough was hardly noticed.



Weinberg at his blackboard.

Lasting impact

Weinberg's genius was to assemble together the various pieces of a jigsaw and display the whole picture. The basic idea of mass generation was due to the assorted theorists mentioned above, in the summer of 1964. However, a crucial feature of Weinberg's model was the trick of being able to give masses to the W and Z while leaving the photon massless. This extension of the mass-generating mechanism was due to Tom Kibble, in 1967, which Weinberg recognises and credits.

As was the case with his comments in Brussels the previous month, Weinberg's paper appeared in November 1967 to a deafening silence. "Rarely has so great an accomplishment been so widely ignored," wrote Sidney Coleman in *Science* in 1979. Today, Weinberg's paper has been cited more than 10,000 times. Having been cited but twice in the four years from 1967 to 1971, suddenly it became so important that researchers have cited it three times every week throughout half a century. There is no parallel for this in the history of particle physics. The reason is that in 1971 an event took place that has defined the direction of the field ever since: Gerard 't Hooft made his debut, and he and Martinus Veltman demonstrated the renormalisability of spontaneously broken Yang–Mills theories. A decade later the W and Z bosons were discovered by experiments at CERN's Super Proton Synchrotron. A further 30 years were to pass before the discovery of the Higgs boson at the Large Hadron Collider completed the electroweak menu. And in the meantime, completing the Standard Model, quantum chromodynamics was established as the theory of the strong interactions, based on the group SU(3).

This episode in particle physics is not only one of the seminal breakthroughs in our understanding of the physical world, but touches on the profound link between mathematics and nature. On one hand it shows how it is easier to be Beethoven or Shakespeare than to be Steven Weinberg: change a few notes in a symphony or a phrase in a play, and you can still have a wonderful work of art; change a few symbols in Weinberg's equations and the edifice falls apart – for if nature does not read your creation, however beautiful it might be, its use for science is diminished. Like all great theorists, Weinberg revealed a new aspect of reality by writing symbols on a sheet of paper and manipulating them according to the logic of mathematics. It took decades of technological progress to enable the discoveries of W and Higgs bosons and other entities that were already "known" to mathematics 50 years ago.

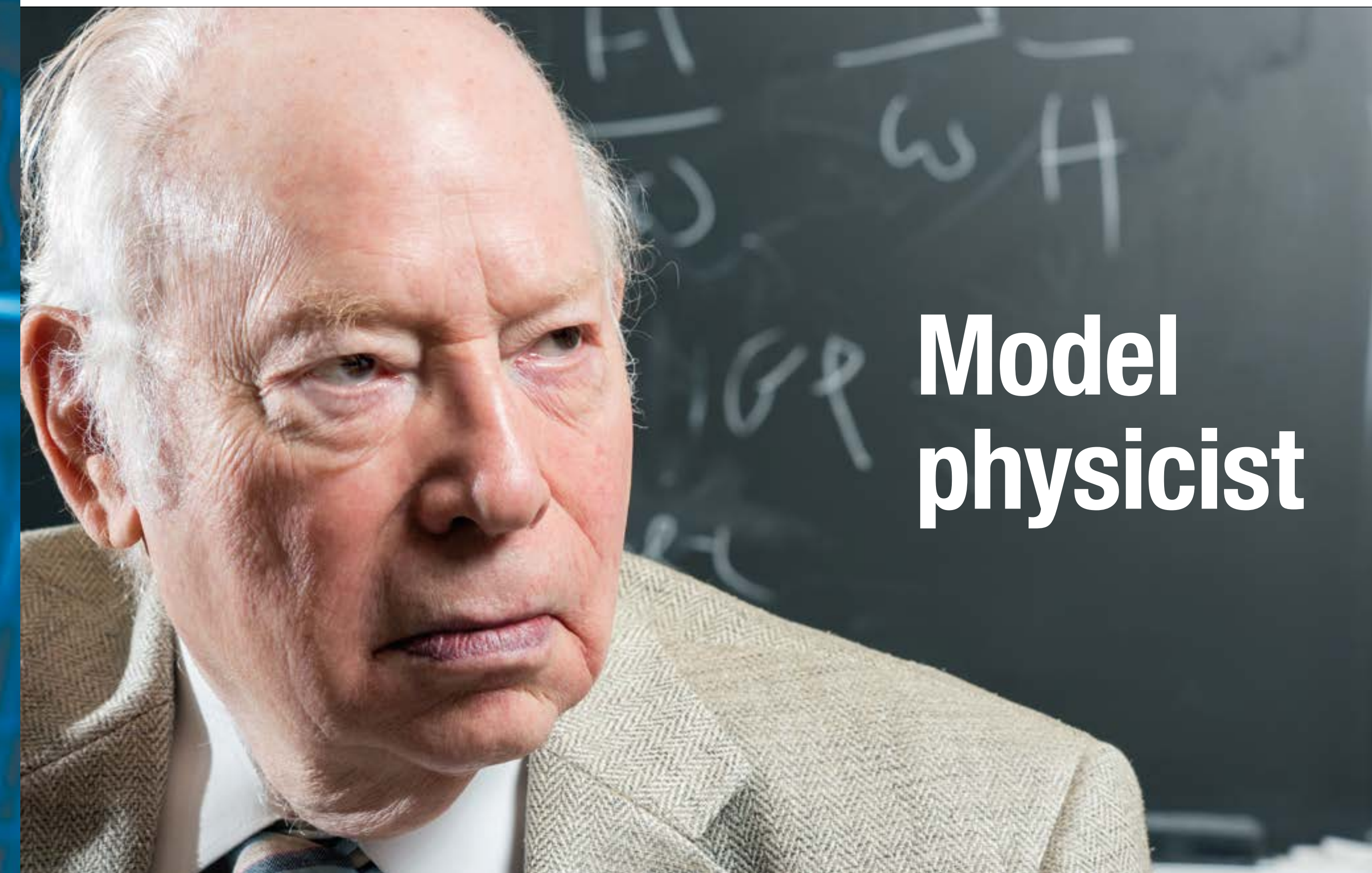
● *This article draws on material from Frank Close's history of the path to discovery of the Higgs boson:* The Infinity Puzzle *(Oxford University Press).*

Résumé

Naissance d'une symétrie

Il y a un demi-siècle, Steven Weinberg, lors d'un été à Cape Cod, travaillait sur une nouvelle thérie de l'interaction forte des pions. En octobre 1967, l'idée devient une théorie des interactions faible et électromagnétique, et le mois suivant il publie un article qui allait révolutionner notre connaissance des forces fondamentales.

Frank Close, University of Oxford.



Model physicist

Theorist Steven Weinberg talks about his seminal 1967 work and reflects on the status of the field now that all the particles on the electroweak menu have been discovered.

Steven Weinberg was 34 when he produced his iconic "Model of Leptons". The paper marked a moment of clarity in the history of particle physics and gave rise to the electroweak Standard Model, but it was also exceptional in inspiring one of the biggest experimental programmes science has ever seen. Flushing out and measuring its predicted W, Z and Higgs bosons took a multi-billion Swiss-franc effort in Europe that spanned four major projects – Gargamelle, the SPS, LEP and the LHC – and defined CERN's research programme, keeping experimentalists in gainful employment for at least four decades. Not bad for a theory that, as Weinberg wrote at the time, "has too many arbitrary features for [its] predictions to be taken very seriously".

Needless to say, Weinberg is delighted to have been able to witness the validation of the Standard Model (SM) over the decades. "I mean, it's what keeps you going as a theoretical physicist to hope that one of your squiggles will turn out to describe reality," he says. "I wouldn't have been surprised or even very chagrined that, although the general idea was right, this particular model didn't describe nature."

Today, 50 years after his 1967 insight, Weinberg protests the notion that he is retired. The US has laws against discrimination on the basis of age, he says dryly. "I tell the people here that I plan to retire shortly after I die." He is currently teaching a course in astrophysics at the University of Texas at Austin, his base for the past 35 years, and has two books and a new cosmology paper in the pipeline. Weinberg spoke to the *Courier* by phone in September from his home, reflecting on the state of high-energy physics following the Higgs boson discovery and on where the best hopes for new physics might lie. He began by recounting the thought processes that led him to his seminal 1967 work – many of which took place in children's playgrounds. ▷

Steven Weinberg photographed at the University of Texas at Austin in late September 2017. (All image credits: Matt Valentine.)

Park-bench physics

"It was a complicated time of my life because my family had moved to Cambridge from Berkeley while my wife was studying at Harvard for her law degree. I had all the responsibility of taking care of our four-year old daughter, including taking her to nursery school, and a lot of my thinking was done while sitting on park benches and watching my daughter play," he says.

Weinberg did not set out to unify the forces. He had been applying his ideas about symmetries, specifically the structure SU(2)×SU(2), to the strong interaction but it implied that the rho meson would be massless, contrary to experiment. "When I had the idea that the massless rho meson might really be the photon, it became natural to me that the rest of this gauge theory, suitably modified, could only be a theory of weak forces." The work went quickly once he realised what he was doing. "You take the left-handed electron plus neutrino doublet and right-handed electron and ask what the most general possible symmetry group is, which turns out to be SU(2)×U(1)×U(1). Then you throw one U(1) away because if that was an unbroken gauge symmetry, you would have long-range forces among electrons which you don't observe. So you're led almost inevitably towards SU(2)×U(1). Indeed, though at first I didn't know it, the same group had been used in a different way earlier by Glashow and by Salam and Ward."

The paper was published without fanfare in *Physical Review Letters* on 20 November within a month of its submission. Weinberg doesn't recall any talk he gave before the publication. He mentioned it in a side comment at the Solvay conference around that time (see p25), but it didn't arouse tremendous excitement.

In many ways, the paper was uncharacteristic of Weinberg. His tendency was to write general papers without worrying too much about their specific realisation in nature, he says, but in this one he was more specific. "Of course, experimentalists don't test general ideas, so I was delighted when they showed that my theory was the right one. And then, after the neutral-currents discovery, the W and Z were discovered directly at CERN 10 years later and measured in detail at LEP and SLAC."

It was not the specific model of leptons that excited him, though. Since his graduate days at Princeton, Weinberg has been hooked on the possibility of having a deductive basis for a physical theory following from the principles of symmetry and, in particular, renormalisability. "Symmetry is not enough by itself. In electromagnetism, for example, if you write down all the symmetries we know, such as Lorentz invariance and gauge invariance, you don't get a unique theory that predicts the magnetic moment of the electron. The only way to do that is to add the principle of renormalisability – which dictates a high degree of simplicity in the theory and excludes these additional terms that would have changed the magnetic moment of the electron from the value Schwinger calculated in 1948."

Science is not the experience of just one scientist but of the whole community extending back to antiquity.

Renormalisability was the technique that connected quantum field theory to reality, offering a scientifically sound way to deal with the infinities that arise in calculations. Back when his paper was published, however, Weinberg did not know if his theory was renormalisable. That was probably why nobody took much notice of it, he says. "Remember: when we're talking about renormalisability, it's not just something theorists do to get rid of infinities. It was a criterion that was the sort you look for in theoretical physics, that defines a certain type of simplicity in your theories which otherwise would be arbitrary. We're talking about whether we can have a theory of the weak interaction in which we can calculate beyond the lowest order in perturbation theory." Weinberg strongly suspected his might be such a theory because before spontaneous symmetry breaking is taken into account, it has the same form as QED and it had already been proved that non-spontaneously broken Yang–Mills theories were renormalisable. "Salam and I weren't sure but we didn't think spontaneous symmetry breaking would affect the renormalisability because if you go to very high energies (much larger than the W or Z mass), the fact the symmetry is broken is no longer significant." Had he not thought the model renormalisable, he might not have published. "The prospect of issuing an erratum was too much!"

In 1971, Weinberg began to realise that his paper was "hot stuff", following the critical breakthrough by 't Hooft and Veltman proving that the theory was renormalisable, although whether or not his particular model of leptons was correct was a still matter for experiment. The same year, he also tried to extend his ideas to the strong interactions using the quark model, in which there was little confidence at the time. The reality of quarks became clear with the discovery by Gross and Wilczek and Politzer in 1973 of the asymptotic freedom of some gauge theories, and the subsequent development of quantum chromodynamics, to which Weinberg, along with Gross and Wilczek, contributed the idea that it is impossible to isolate coloured particles such as quarks and gluons.

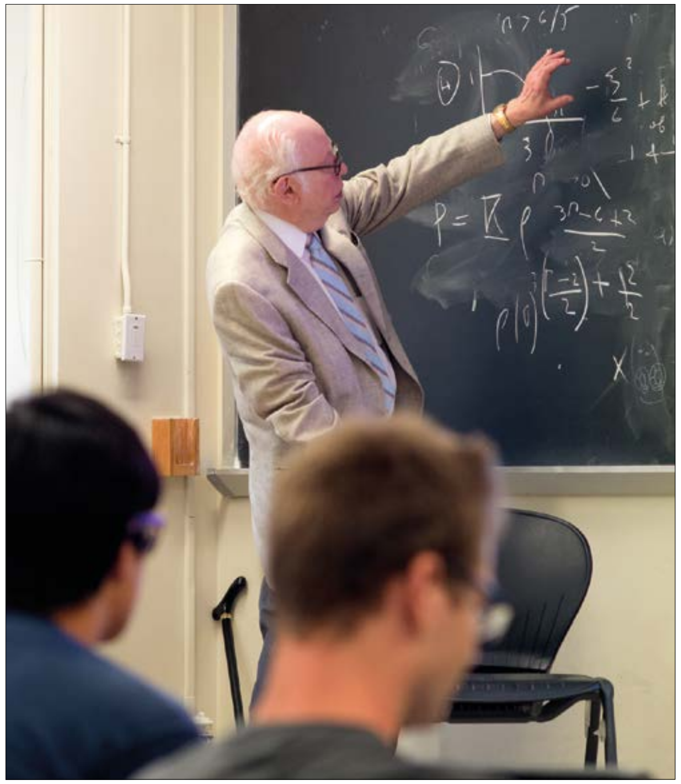
"It's funny you know, people look back at the 1970s as one of the most miserable peacetime decades in the 20th century, as there was lots of unemployment and high inflation, in the US at least," he muses. "But for us physicists it was a great time: everything was coming together, and experimentalists and theorists were talking to each other in lots of ways. Things are much harder today."

The Higgs nightmare

The discovery of the Higgs boson by the ATLAS and CMS experiments at CERN five years ago was the capstone in Weinberg's model. Until then, no one knew for sure how the electroweak symmetry gets broken to give elementary particles their masses – it was still possible that the Higgs mechanism was correct but that it does not involve a Higgs boson, for instance, or that the "Higgs" is a composite particle bound by new strong forces that lead to a dynamical breakdown of the symmetry. Precisely such a model, called technicolour, was proposed by Weinberg and Susskind in 1979. Back in 1967, though, Weinberg took the simplest possibility: a doublet of scalars. It was the only kind of elementary field that could not only give mass to the W and the Z but the electron, he reasoned, and it would lead to the necessary existence of a leftover scalar particle that was not eliminated by the Higgs mechanism and became known as the

CERN Courier November 2017

Interview: Steven Weinberg



Higgs boson. "The discovery of the Higgs boson was very important because it confirmed the very simple early picture of spontaneous symmetry breaking, which we couldn't have known was correct because there were alternatives," he says.

So did Weinberg's 1967 paper also predict the Higgs boson? "It depends, as Bill Clinton might say, what is meant by the word 'the'," he laughs. "Is it *the* Higgs boson? Well, the existence of these particles in the general class of spontaneously broken gauge theories was predicted by Higgs and so on, and if you included theories that are non-gauge invariant then even earlier by Goldstone. But if by 'the' you mean the particle discovered, then that was predicted in my paper. The first paper that made a specific prediction of a single neutral particle whose coupling to leptons and later also to quarks was proportional to their masses was the 1967 model of leptons. The others also had a scalar particle but they were not developing a theory of weak interactions, they were considering several classes of theories with leftover scalars with unknown properties."

Weinberg thinks the Nobel-prize committee made an "excellent job" in deciding who would share in the 2013 prize for the discovery (François Englert and Peter Higgs). "It isn't a prize for predicting the Higgs boson, it is a prize for the theoretical discovery of the Higgs mechanism, which is exactly right because that is what was proposed by those 1964 papers. I rediscovered it in 1967 because I was working on spontaneously broken SU(2)×SU(2) gauge theory for the strong interaction, but I take no credit for it because it was already in the literature for three years. The actual Higgs boson, I think that was an experimental achievement."

Unlike many particle physicists on the day of the Higgs announcement on 4 July 2012, Weinberg doesn't recall exactly what he was doing when he heard the news. What he is sure of is that we are entering what he described several years ago as the "nightmare scenario" of having found a SM Higgs boson and nothing else. He says we've gotten ourselves into a rather unfortunate situation because the SM describes all the physics that can be addressed experimentally except things outside the SM like gravity and the neutrino masses. "It's nobody's fault. It is not an intellectual failure. It's just a fix we've got into." He doesn't hold out too much hope in mainstream theoretical arguments for the existence of physics beyond the SM at the energies currently being probed at the LHC – i.e. that new heavy particles must exist to cancel out quantum contributions to the Higgs mass that would cause it to spiral to infinity. The fact that we now know that an elementary Higgs scalar exists makes this "hierarchy problem" somewhat harder, Weinberg concedes, but he points out that we've been living with the problem already for 40 years. So far the LHC has not found evidence for physics beyond the SM, including the most popular solution to shield the Higgs from getting additional mass: supersymmetry (SUSY). "Worse, there isn't any one completely satisfactory SUSY model. Every SUSY model has things in it that are troublesome," says Weinberg.

He thinks we might have to find other explanations for this and other absurdly fine-tuned parameters in the universe, such as the very small value of the vacuum energy or cosmological constant, or even abandon traditional explanations altogether.

"No one has come up with a plausible suggestion there except for the somewhat desperate suggestion that it is anthropic – that you have a multiverse and by accident there are occasional sub-universes where the vacuum energy is small and it's only those in which galaxies can form – and people have suggested similar anthropic arguments for the smallness of the Higgs mass and the quark-mass hierarchy," says Weinberg, who himself used anthropic reasoning in the 1980s to estimate, correctly, the approximate value of the cosmological constant a decade before it was inferred observationally from the velocities of distant supernovae. It's a depressing kind of solution to the problem, he accepts. "But as I've said: there are many conditions that we impose on the laws of nature such as logical consistency, but we don't have the right to impose the condition that the laws should be such that they make us happy!"

Weinberg's outlook on the field today is pretty much as it was in 1979 when he gave his Nobel-prize lecture. The only big difference would be string theory, he says, which hadn't yet come along as a possible theory of everything. "Apart from that, I said about the future beyond the SM that I think it's unfortunate that there isn't a clear idea to break into it." Even the discovery of neutrino masses, inferred from the observation of neutrino oscillations 20 years ago, does not threaten the SM, he says. On the contrary: neutrino masses are what you expect.

Neutrinos and new physics

By the time Weinberg received his Nobel prize in late 1979, he had arrived at a more nuanced interpretation of field theory and described it in a paper titled "Phenomenological Lagrangians". Building on the work of others, such as Schwinger, it presented the ▷

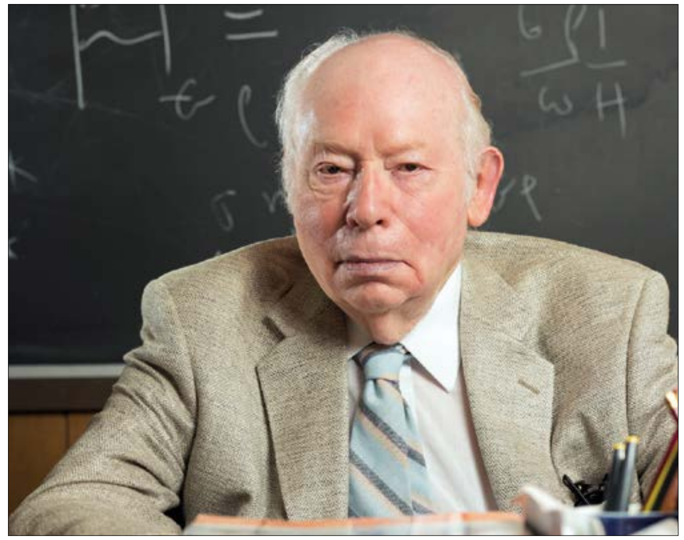
SM as the leading term in an "effective" field theory that is merely a low-energy manifestation of a deeper microscopic theory that we are yet to uncover. In this more modern view, field theories don't have to be renormalisable to be logically consistent but can contain, in addition to the renormalisable terms, a slew of non-renormalisable terms that are suppressed by negative powers of some very large mass (corresponding to the scale at which the true theory applies).

For neutrinos, treating the SM as an effective field theory has major implications. Whereas simply inserting neutrino masses into the theory would violate the SU(2)×U(1) symmetry, Weinberg realised that there is an interaction between leptons and the Higgs doublet that avoids this. Crucially, since the interaction is non-renormalisable, it is suppressed by a very large-mass denominator – explaining both the existence of neutrino masses and their smallnesses and giving rise to what is more generally called the seesaw mechanism.

"In a sense it is beyond the SM, but I would rather say it is beyond the leading terms – the renormalisable, unsuppressed part of the SM," says Weinberg. "But hell – so is gravity! The symmetries of general relativity don't allow any renormalisable interactions of massless spin-2 particles called gravitons. We know about gravity even though it's incredibly strongly suppressed only because it has this property of adding up: every atom in the Earth attracts a falling body, always pulling in the same direction. If it wasn't for that fact, we wouldn't know about its existence from experiments – certainly not at experiments at the LHC." Of course, neutrinos were still thought massless back in 1979. Weinberg does not take credit for predicting neutrino masses, but he thinks it's the right interpretation. What's more, he says, the non-renormalisable interaction that produces the neutrino masses is probably also accompanied with non-renormalisable interactions that produce proton decay and other things that haven't been observed, such as violation of baryon-number conservations. "We don't know anything about the details of those terms, but I'll swear they are there."

As to what is the true high-energy theory of elementary particles, Weinberg says string theory is still the best hope we have. "I am glad people are working on string theory and trying to explore it, although I notice that the smart guys such as Witten seem to have turned their attention to solid-state physics lately. Maybe that's a sign that they are giving up, but I hope not." Weinberg worked on strings himself in the late 1980s, writing a couple of papers "of stunning unimportance", but decided not to devote his career to it. As is documented in his 1992 book *Dreams of a Final Theory*, and much earlier in his Nobel lecture, he has his own hunch about an ultimate microscopic theory of nature, rooted in an idea called "asymptotic safety". Weinberg also still holds hope that one day a paper posted in the arXiv preprint server by some previously unknown graduate student will turn the SM on its head – a 21st century model of particles "that incorporates dark matter and dark energy and has all the hallmarks of being a correct theory, using ideas no one had thought of before".

Until that day comes, particle physicists have to be content with scouring the TeV energy scale at the LHC for new particles and with subjecting the SM to increasingly precise tests – not just at the LHC but at numerous other experiments at CERN and beyond. The field also faces a critical decision in the next few years as to what the



next big-ticket collider experiment should be: an electron–positron collider, which potentially comes in straight or circular varieties, or a more energetic hadron collider. Most of the options on the table have precision measurements of the Higgs boson as part of their physics cases.

Next steps for the field

Weinberg says he doesn't have an educated opinion on which machine should come next. "It hinges partly on what the experimentalists can actually accomplish, and I'm not equipped to judge that. And it hinges also on what the new physics is, and I'm not equipped to judge that!" he says. "If I had a very specific proposal for beyond-the-SM then it might indicate in which of these directions we should go, but I don't know of any proposal that is attractive enough to go one way or the other." Although he would like to see the Higgs, the first scalar particle discovered, measured in more detail, he fears that it will just confirm the simplest picture of the Higgs mechanism. "Because that's what you get if you insist on a renormalisable theory, and I think it's correct to do so for reasons I was beginning to understand in 1979."

He is glad that CERN is continuing with the LHC, and that the US is doing neutrino-oscillation experiments, "which seems to now be the American style having given up on the SSC". Another topic he thinks should be pushed more is the search for baryon non-conservation (proton decay) on Earth. But the most promising arena for progress these days is astronomy, he says. After all, otherwise we wouldn't even dream of the existence of dark matter and dark energy, and it's an area where experiment is still very fruitful – as evidenced by the recent discovery of gravitational waves. "My goodness, that's the most exciting thing – studying gravitational radiation not just for its own sake but opening up a whole area of astronomy." Cosmology, along with the foundational issues of quantum mechanics, is the subject of Weinberg's own recent work, and he is currently putting together a paper with co-worker Raphael Flaugera on the effect of the intergalactic medium on gravitational waves from distance sources.

It is not an intellectual failure. It's just a fix we've got into.

Reflecting on physics

It is beyond doubt that Weinberg's 1967 paper was game-changing, but does he himself rate it as his most important contribution to physics? "Oh I don't know. I don't like praising my own papers. The 1967 paper was part of a programme of many decades – a concern with symmetries, especially broken ones – which went back to the early 1960s, at least to my paper with Goldstone and Salam raising the issue of massless Goldstone bosons, after which Higgs *et al*. showed us how to avoid them. I guess mine was a key paper in that department, but I had been working on broken symmetries in the context of strong interactions for a decade. Then there is the development of effective theories, which is not so much a theory but a point of view." What he prizes above all else, however, is not embodied in any single paper or certainly not in any single model: it is about changing the point of view of physicists.

"I prized the 1967 paper programmatically because it exemplified the need to look for a renormalisable theory based on symmetries that are spontaneously broken, and by god it turned out to be the right model!" From the start, he knew his model of leptons was the kind of theory that looked right, but it doesn't just take a certain mind to be able to see such truths, he explains. It takes a lot of minds over a long period. Weinberg illustrates the process with the example of chicken sexing. It is important in the poultry business to be able to determine the sex of newborn chicks, he says, and there was a school that taught the science of chicken sexing by giving people a newborn chick and asking them to say whether it was male of female: if they guessed wrong, they would receive some sort of punishment, while if they guessed right they got some kind of reward. After repeating the process hundreds of times, people began to guess correctly. "We've learned that, just as feeling the underside of a newborn chicken you might learn what distinguishes a male from a female, science is not the experience of just one scientist but of the whole community extending back to antiquity, which has gradually beaten into us which theory is beautiful and which is likely to be right."

Asked what single mystery, if he could choose, he would like to see solved in his lifetime, Weinberg doesn't have to think for long: he wants to be able to explain the observed pattern of quark and lepton masses. In the summer of 1972, when the SM was coming together, he set himself the task of figuring it out but couldn't come up with anything. "It was the worst summer of my life! I mean, obviously there are broader questions such as: why is there something rather than nothing? But if you ask for a very specific question, that's the one. And I'm no closer now to answering it than I was in the summer of 1972," he says, still audibly irritated. He also doesn't want to die without knowing what dark matter is. There are all kinds of frustrations, he says. "But how could it be otherwise? I am enjoying what I am doing and I have had a good run, and I have a few more years. We're having a total eclipse here in April 2024 and I look forward to seeing that."

Forty years after the publication of his famous book *The First Three Minutes*, which has been translated into 22 languages and for which he still receives royalty cheques, he intends to go on writing. He has a contract with Cambridge University Press to publish a new book called *Lectures on Astrophysics* based on his current teaching activities and is bringing out a third collection of popular essays with Harvard University Press, with a fourth planned.

The last three minutes

Steven Weinberg's career – from his undergraduate days at Cornell, graduate studies in Princeton, and subsequent positions at Columbia, Berkeley, Harvard, MIT and Texas – is one that any physicist would aspire to. His name will always be associated with our fundamental understanding of the universe, and you get the feeling that none of it ever felt much like "work" in the usual sense. "The physics career, quite apart from what you do in physics day to day, has given me the opportunity to know a lot of interesting people and to visit different countries not as a tourist but as a co-worker," he says. "It's such a delight to talk to fellow physicists and to work-up a paper based on a common understanding, and to at the same time transcend national boundaries. I like that so much." Not that he has collaborated that much: as with "A Model of Leptons", most of his 350 or so papers have been "one-man jobs".

Yet Weinberg is not your stereotypical lost-in-his-work genius who locks himself away for long periods to work on a problem. His best ideas don't come to him while he's working at all. He recalls one day he came out of the shower and exclaimed to his wife that he had figured out why the cosmological constant is so small (at a time before he had started thinking about anthropic explanations). "Then the next day I came out and I said [deep voice] 'no'! So ideas come to you all the time and most of them are no good, and every once in a while you find one that is good and you have fun working at your desk. Getting good ideas isn't something you get by trying hard, but by thinking a lot about what problems bother you. But that doesn't always work either – just think of my ruined summer in 1972!"

He never works in his office. His research work has always been done at home, where he and his wife have separate offices down the hall from one another and interrupt one another frequently. "I'm not hard to interrupt. I have a television set on my desk which I keep on while I work, typically watching an old movie, because I find work in theoretical physics so far removed from normal affairs." Doesn't it distract him? "But I need the distraction to keep at my desk because the actual work is so, well…it's so chillingly non-human. I need to feel that I am still part of the human race while I'm doing it."

Résumé

Le physicien et le Modèle

La découverte du boson de Higgs, en confirmant que la symétrie électrofaible est brisée de la manière la plus simple possible, a été une consécration pour la théorie proposée par S. Weinberg en 1967. Le Courier a pu s'entretenir par téléphone avec cet éminent physicien. Il nous a parlé des conséquences de la découverte du boson de Higgs et de ce que nous pouvons faire pour avancer encore dans notre connaissance des champs et des particules élémentaires.

Matthew Chalmers, CERN.

Faces & Places

Appointments

CERN Council elects European-strategy secretary

At the 186th session of CERN Council, which took place at CERN on 25–29 September, experimental particle physicist Halina Abramowicz of Tel Aviv University in Israel was appointed secretary of the European Strategy Group. This marks the official start of the next update of the European Strategy for Particle Physics, which will reach a conclusion in May 2020, with Abramowicz's first task being to develop the timeline and a detailed plan.

Abramowicz works on the ATLAS experiment, specialising in perturbative and non-perturbative QCD, and is also a member of the FCAL collaboration devoted to forward detectors for future linear colliders. She completed her undergraduate and postgraduate degrees at Warsaw University in Poland in the 1970s, and also worked on the former experiments ZEUS and CDHSW. "The strategy update is a very important task in preparing the future of our field," said CERN Director-General Fabiola Gianotti. "We need everybody's contribution to ensure that we have a strategy that truly reflects the wishes of the field."


A Levy
Experimentalist Halina Abramowicz, secretary of the European Strategy Group.

Awards

Nobel recognition for discovery of gravitational waves

The 2017 Nobel Prize in Physics has been awarded to Rainer Weiss, Barry Barish and Kip Thorne of the LIGO/Virgo collaboration "for decisive contributions to the LIGO detector and the observation of gravitational waves". Weiss, of MIT, shares half the SEK 9 million award, while his Caltech colleagues Barish and Thorne share the other half.

More than 40 years ago, Thorne and Weiss pioneered the idea that gravitational waves could be detected, in particular using large laser interferometers that would measure distortions in space–time induced by a passing gravitational wave. Together with Barish, who led the transformation of LIGO from a small R&D project, the trio ensured that the search for gravitational waves would end in success. A fourth key figure in the LIGO story, Ronald Drever, passed away in March this year. He had already shared, along with Weiss and Thorne, the 2016 Breakthrough prize, Gruber Cosmology Prize and the Kavli Prize in Astrophysics.

The recognition by the Nobel committee for physics comes less than two years after the LIGO/Virgo collaborations announced the first direct detection of gravitational waves in February 2016, followed by a second event a few months later and a third announced in June this year. A fourth gravitational-wave signal was revealed just last month. These and further events open a brand new view of the universe (*CERN Courier* January/February 2017 p34).


Rainer Weiss, Barry Barish and Kip Thorne brought to fruition a 40-year long research programme.

IEEE applied-superconductivity award

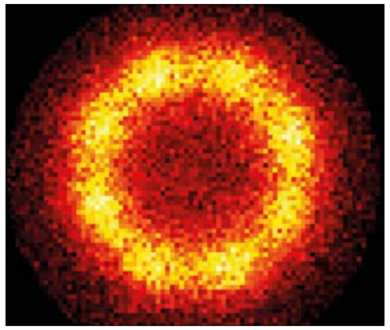
The IEEE Award for Continuing and Significant Contributions in the Field of Large Scale Applied Superconductivity was presented to CERN's Luca Bottura during the European Conference on Applied Superconductivity (EUCAS) on 18 September in Geneva, Switzerland. The award recognises outstanding technical contributions and achievements in the field of applied superconductivity and comprises a plaque, an inscribed medallion, and a cash award of US$5000.

Bottura, who is head of CERN's magnets, superconductors and cryostats group, was selected for developing computer models for the design and analysis of cable-in-conduit superconductors, measuring the field of the LHC's superconducting magnets and developing a parametric field model for the LHC operation, leading the development of advanced superconducting magnets for future accelerator projects, and promoting superconducting technology internationally through technical editorship, scientific networking, and the organisation of scientific events.


J Ordan/CERN
CERN's Luca Bottura receives his award.

DOE names top 40 breakthroughs

A 2010 paper from the ALPHA experiment at CERN's Antiproton Decelerator, which describes the successful trapping of 38 antihydrogen atoms, is one of 40 landmark papers selected by the US Department of Energy (DOE) to celebrate its 40th anniversary. The discovery of the Higgs boson by the LHC's ATLAS and CMS experiments was also selected. Other particle-physics results listed include: Fermilab's discoveries of the top and bottom quarks; the measurement of $\sin 2\beta$ with B^0 mesons at SLAC; the observation at Brookhaven Lab that free quarks and gluons make a perfect liquid; and the discovery of neutrino oscillations at SNO and elsewhere.



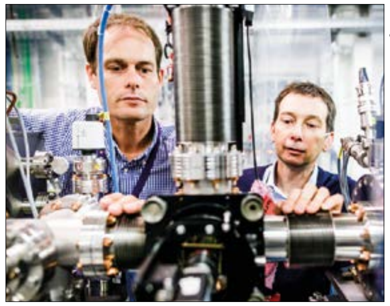
CERN

Untrapped antihydrogen atoms annihilating on the inner surface of the ALPHA trap.

Event

First users at European XFEL

Inaugurated on 1 September, the world's most powerful X-ray laser – the European XFEL in Hamburg, Germany – has now welcomed its first users. The culmination of a worldwide effort, the facility will eventually fire up to 27,000 pulses of intense X-rays per second to image electronic, chemical and biological processes in unprecedented detail. The first batch of users aimed to get a better understanding of the shape and function of biomolecules, using techniques such as femtosecond crystallography. In this first round of beamtime a total of 14 groups with up to 80 users each will conduct experiments until March 2018.



L Berg/DESY

DESY's Anton Barty (left) and Henry Chapman (right) were involved in the first user experiments.

Anniversary

Sibling celebrations at the LHC

In early October, the ATLAS and CMS collaborations celebrated their 25th birthdays. On 1 October 1992, the nascent collaborations each submitted a letter of intent for the construction of a detector to be installed at the proposed LHC, containing detailed specifications that were close to what exist in the final designs. The letters of intent for ALICE and LHCb, the LHC's two other large experiments, followed a few months later. Earlier in 1992, some 600 physicists and engineers from 250 institutes worldwide had met in Évian-les-Bains to discuss the physics and detectors of the LHC. Construction of the LHC was approved in December 1994.

CERN

A joint ATLAS and CMS cake.

J Ordan/CERN

*On 19 September, CERN Director-General Fabiola Gianotti delivered a public lecture at the University of Geneva titled "The Higgs boson in our lives", during which she described the Higgs boson discovery and how research into fundamental particles has implications beyond the laboratory. The lecture was part of a rich programme of outreach events associated with the 2017 European Conference on Applied Superconductivity (EUCAS) held in Geneva from 17 to 21 September and co-organised by CERN in collaboration with the University of Geneva and EPFL-SPC (*CERN Courier* *September 2017 p17).*

Meetings

CERN School of Computing marks 40th edition

The CERN School of Computing (CSC) aims to promote advanced learning and knowledge exchange in scientific computing among young scientists and engineers involved in particle physics or other sciences. The CSC, along with the CERN Schools of Physics and the CERN Accelerator School, are the three schools that CERN has set up to help train the next generation of researchers across the laboratory's main scientific and technical domains.

Since the first CSC in Italy in 1970, the school has visited 21 countries and been attended by more than 2600 students from five continents and 80 nationalities. Participants are young, come from many different backgrounds and all have a passion for computing and science. They work together for two weeks, not only to widen their skills but also to establish lifelong links that will be useful throughout their careers.

The 2017 CSC, which took place in Madrid from 27 August to 9 September, marked its 40th edition. Organised together with the Universidad Politécnica de Madrid (UPM), it welcomed 63 students from 37 different universities and institutes. Representing 26 nationalities, students were selected from a record number of 110 applicants. This year, the usual intensive academic programme (52 hours of lectures and exercises covering base technologies, physics computing and data technologies) was complemented by a rich social programme that included scientific visits to UPM's wind tunnel and biotechnology lab. At the end of the school, 59 students passed the optional exam – 14 of them with distinctions.

A Pace/CERN

Since 1970, the CERN School of Computing has trained more than 2600 participants from 80 nationalities in scientific computing.

Since 2002, the school has offered a CSC diploma upon successful completion of an optional exam. In addition, since 2008, the university hosting the CSC audits its academic programme and incorporates the CSC into its official teaching programme. As a result, a formal certificate of five or six ECTS (European Credit Transfer System) credit points are awarded by the hosting university and recognised across Europe for any doctoral and masters programme. Since 2005, CSC management has also organised an "inverted" CSC (iCSC) and, since 2013, a "thematic" CSC (tCSC). The idea behind the inverted school is to invite CSC alumni to become teachers themselves at a short school organised at CERN in the winter. The tCSC, on the other hand, is a one-week school that goes into more depth about a particular topic – this year's was efficient parallel processing of future scientific data.

Applications for CSC and tCSC 2018 will be open early next year. For more information, visit csc.web.cern.ch/.

Strong discussions in Montpellier

The 20th High-Energy Physics International Conference in Quantum Chromodynamics (QCD 17) took place in Montpellier, France, on 3–7 July, involving around 50 participants with a large number of young experimental and theoretical physicists present. The conference is unique in its coverage of all aspects of QCD, from the formal field-theory approach to confinement to its phenomenological facets, in addition to searches for physics beyond the Standard Model.

This year's event was divided into four main sessions. The first concerned the production of jets, photons, dibosons, top quarks and B and D mesons from various experiments – ATLAS, CMS and ALICE at the LHC, HERA and COMPASS – during which improved measurements of the QCD coupling constant, studies of fragmentation and parton distribution functions were presented. In the second session, the BESIII group presented experimental results for heavy molecules and four-quark states, in addition to ▷

properties of light hadrons. These results were complemented by theoretical talks on QCD spectral sum rules, potential models, holographic QCD and glueball searches.

The third session was dedicated to the more formal non-perturbative aspects of QCD, such as confinement, finite temperature and hydrodynamics, while the fourth session concerned low-energy precision tests of the electroweak Standard Model. The latter included recent measurements of lepton anomalous magnetic moments, where consistent results on the measurements of the cross-sections for $e^+e^- \rightarrow$ hadrons were presented by BABAR, BESSIII and CMD-3 and compared to different theoretical contributions (there is now good agreement among different experiments confirming a 3.6σ discrepancy with respect to theoretical predictions).

The conference ended with different precision measurements of the W, Z and Higgs boson masses and couplings, and with experimental searches for physics beyond the Standard Model by LHCb, ATLAS and CMS. Theoretical talks on current LHCb anomalies and on the discreteness origin of particle masses were presented, and the future performance of the ATLAS and CMS detectors was discussed.

With almost equal numbers of theorists and experimentalists present, the conference series is an opportunity for participants to interact in a relaxed atmosphere.

New results presented in this conference also have the advantage of appearing just before the larger EPS and ICHEP international conferences. QCD18 is expected to take place from 2 to 6 July 2018.

Photo Alizé

Participants at the 20th edition of the QCD conference, held in Montpellier in July.

Baikal school stays vibrant

Cold waters and hot scientific discussions were the main ingredients of the 17th international Baikal Summer School on high-energy physics and astrophysics, which was held from 13 to 20 July in the small Russian village of Bolshie Koty on the shore of Lake Baikal. More than 50 undergraduate and PhD students from Russia, Germany, Poland, Italy, India and Romania gathered at this remote and scenic location for a full week of Siberian-style scientific immersion, with an intense lecture programme set in magnificent wilderness.

The Baikal Summer School is organised annually by the Joint Institute for Nuclear Research (JINR), Dubna, and Irkutsk State University (ISU). Emerging in the early 2000s as a summer event for local physics students, it evolved into a dynamic, fully international scientific school, and one of the major annual particle-physics events in Siberia. This year, in addition to funding from JINR and ISU, the school received substantial financial support from the Russian Foundation for Basic Research and Russian energy firm En+ group, while the Traiektoria foundation provided books for student prizes.

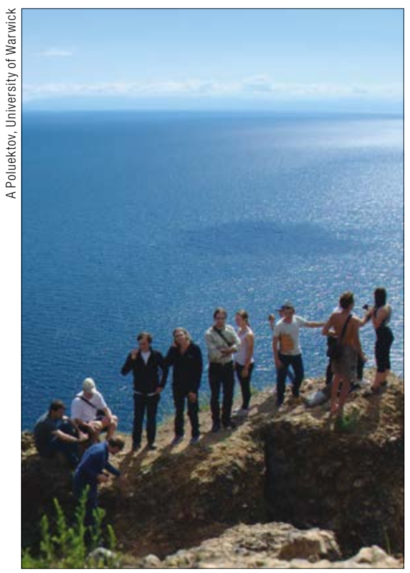
The lecture programme maintains a good balance between theory, experiment and astroparticle topics, covering the Standard Model, the basics of QCD and B physics, statistical methods and other topics. A selection of results by the ATLAS, CMS and LHCb collaborations were also given, covering Higgs physics, top-quark properties, supersymmetry and exotics searches, heavy hadron spectroscopy and B-meson decays. Students also enjoyed overviews of the vast field of experimental neutrino physics and neutrino-mass model building. The latter were so favoured by the students that the lecturer received an unexpected appreciation prize at the closing ceremony.

The astroparticle aspect of the Bailkal school was equally intense, with introductions to dark matter and its various candidate particles. IceCube's results on high-energy astrophysical neutrinos were presented, as was the status of high-energy cosmic-ray programmes by the Auger and TAIGA collaborations. TAIGA, located in the Tunka valley near Lake Baikal, and the Baikal-GVD neutrino detector working inside the lake are the two flagship astroparticle experiments in Russia, and many students working in or planning to join these collaborations participated in the school. The astroparticle lecture programme closed with lectures on LIGO's recent discovery of gravitational waves.

In addition to lectures, the students presented their own work and participated in regular discussion sessions in small groups. The school offered ample opportunities for students to talk to lecturers outside of normal office hours, and staff from Irkutsk Planetarium organised stargazing sessions under the spectacular Siberian skies.

Preparations for the 2018 school, which will be organised jointly with the European network of doctorate schools in astroparticle physics (ISAPP), are already proceeding at full speed. The ISAPP-Baikal Summer school 2018 will strengthen ties between Europe, JINR and the astroparticle experiments conducted at Baikal.

● astronu.jinr.ru/school/current.



A Poluektov, University of Warwick

Summer-school students enjoying the view over Lake Baikal.

Visits

Teruo Kishi, science and technology adviser to the minister for foreign affairs, Japan, came to CERN on 14 September. During his trip, Kishi, who is professor emeritus at the University of Tokyo, visited the ATLAS visitor centre and signed the guestbook with CERN director for international relations Charlotte Warakaulle and Director-General Fabiola Gianotti.

Deepak Dhital, ambassador of Nepal to the United Nations office in Geneva, came to CERN on 19 September, during which he signed an International Co-operation Agreement between the government of Nepal and CERN concerning scientific and technical co-operation in high-energy physics and related areas.

Māris Kučinskis, prime minister of the Republic of Latvia (furthest left), came to CERN on 20 September. Owing to a short machine stop, he was able to take a quick look at the LHC tunnel and CMS underground area. He also visited the Microcosm, S'Cool LAB and the CERN computer centre.

Image credits: (left) R Bergerie-Pagadoy & N Aitor; (middle and right) S Bennett/CERN

Obituaries

Dmitry Bardin 1945–2017

Our colleague Dmitry (Dima) Yurievich Bardin, an academic at Dzhelepov Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research (JINR), Dubna, Russia, left us on 30 June.

Dima graduated with honours from Moscow State University and started research work at JINR in 1968. He defended his PhD thesis under the guidance of Samoil Bilenky in 1974 based on studies of elastic pion–electron scattering and rare decays of pions and kaons. Since then, Dima's scientific work was devoted to the calculation of complete electroweak and QCD radiative corrections in the Standard Model. He had close interactions with many experimental collaborations at LEP, SPS, the LHC (CERN) and HERA (DESY).

From 1978 to 1986 Dima derived, with various collaborators, electroweak corrections to deep inelastic scattering and developed a pioneering approach to renormalisation in the unitary gauge. These two projects were the basis of many now-classical applications of radiative corrections in the Standard Model, performed in close co-operation with experiments at CERN and other research centres.

With the advent of LEP, Dima's scientific activity focused on precise calculation of the properties of the Z boson, in particular by developing the ZFITTER project. In 1989 he contributed substantially to the now-famous workshop Z Physics at LEP1, and in 1995 he was a convener of the working group for event generators for Standard Model processes at LEP2. During 1994–1995 he was a co-ordinator of the precision calculations working group at CERN. The CERN report *Precision Calculations for the Z Resonance* was the basis for the well-known "blue-band plot" of the LEP electroweak working group. ZFITTER was one of the main codes used for LEP1 and LEP2 data analyses, and was a central theoretical tool for predicting the masses of the top quark and the Higgs boson prior to their discoveries.


A Kalinovskaya

Dima Bardin developed ZFITTER and many other software projects.

Further software packages in which Dima was directly involved are: muela for polarised mu-e scattering, GENTLE for LEP2 data analysis and HECTOR for radiative corrections to ep scattering. Since 2000 Dima also led the software system SANC for calculations of radiative corrections for LHC processes, and together with Giampiero Passarino he authored the significant monograph *The Standard Model in the Making*.

Dima Bardin exemplified faithful and selfless service to fundamental science. It is impossible to overestimate his role in creating an atmosphere of high standards in scientific research. With broad knowledge, extensive experience and diligence, he was a true professional in his field. A severe, debilitating and prolonged illness brought a great deal of suffering and pain, but despite this he continued working until his last day.

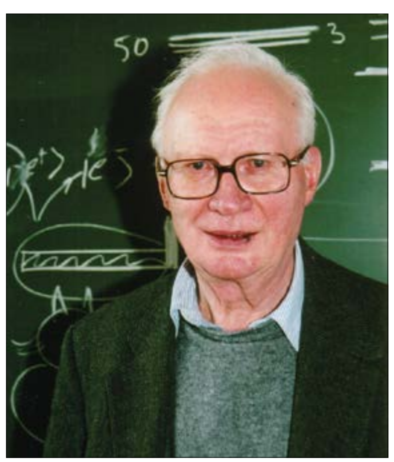
Dima was not only an outstanding scientist but also a reliable friend and colleague, and a wonderful family man. We feel a great loss, not only personally but also as a scientific community.

● *Andrej Arbuzov, Wolfgang Hollik, Lida Kalinovskaya and Tord Riemann, on behalf of his colleagues and friends.*

Wiesław Czyż 1927–2017

Outstanding theoretical physicist and former editor-in-chief of the journal *Acta Physica Polonica B*, Wiesław Czyż passed away on 8 April after a long illness. Wiesław was born on 2 May 1927 in Lublin, eastern Poland. His education was interrupted by the Second World War, during which he was active in the Polish resistance (the Home Army). After the war, he completed his master's degree in mathematics at the Maria Curie-Skłodowska University in Lublin.

His career in physics began in 1948, when he moved to Cracow to work at Jagiellonian University. He received his PhD in 1955 for a dissertation on spin interactions in nuclear matter. Soon after the establishment of the Institute of Nuclear Physics in Cracow, he created its theory department, which he headed for 34 years.


A Kobos

Wiesław Czyż made pioneering contributions to high-energy nuclear physics.

During his long research career, Wiesław was associated with many institutions. He spent two years (1957–1959) at the Niels Bohr Institute in Copenhagen, where he developed an interest in theoretical high-energy physics, his lifelong scientific passion. Then, in the early 1960s, he visited the Stanford Linear Accelerator Centre for one year, where he made significant contributions to our understanding of nuclear structure and composite-particle scattering.

In Poland, he kept in touch with the group of theoretical physicists at the Jagiellonian University, especially with Andrzej Białas, with whom he published many papers, including their most famous one, on the wounded nucleon model, completed in 1976.

Throughout his career Wiesław developed close relations with the community of theoretical physicists in the US, visiting different institutions in the late 1960s and early 1970s. He spent six months at Stanford University, the National Bureau of Standards, Stony Brook University and the University of Virginia in Charlottesville, and one year at the University of Illinois, Urbana-Champaign. He also visited for shorter periods the University of Washington in Seattle, CERN, Utrecht and Munich, and the University of Tel Aviv many times. In 1988, Wiesław returned to Jagiellonian University and produced a stream of work on high-energy scattering of nuclei, resulting in a number of pioneering contributions to the study of quark–gluon plasma, which was a mere hypothesis at the time.

In addition to being a great scientist, Wiesław was also an outstanding lecturer and teacher. He was involved in the organisation of the Cracow School of Theoretical Physics since its inception in 1961. Together with Andrzej Białas and their wives, Maria Czyż and Elżbieta Białas, he helped create a unique institution, which has attracted young scientists and senior lecturers for 57 years.

From 1972 to 1994, Wiesław was editor-in-chief of the leading Polish physics journal *Acta Physica Polonica B*, with Maria Czyż acting as the managing editor. It is impossible to talk about Wiesław without mentioning Maria, who was a true guardian angel for a large group of theoretical physicists at Jagiellonian University.

Wiesław was a member of the Polish Academy of Sciences and of the Polish Academy of Arts and Sciences. He was awarded the highest Polish distinctions, including the Commander Cross of the Order of Polonia Restituta.

His death is a great loss to his friends, colleagues and students, both in Cracow and around the world. We will all miss this extraordinary scientist and human being, who shared with us the fruits of his talent with exceptional modesty – his most characteristic virtue. We will miss his inimitable sense of humour and simple kindness, so much needed in today's world.

● *Michał Praszałowicz, Jagiellonian University.*

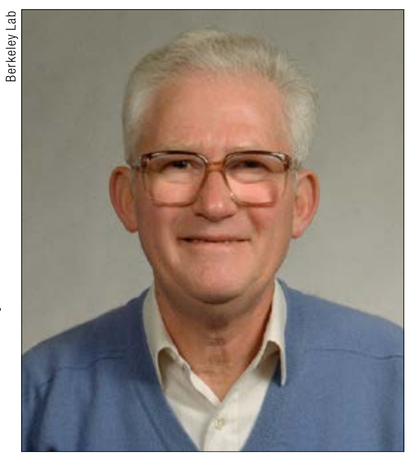
Alper Garren 1925–2017

Alper Abdy Garren was born on 30 April 1925 in Oakland, California, and died peacefully on 25 June in the same place.

Al attended the US Naval Reserve Midshipmen's School at the University of Notre Dame in 1945 and served as a commissioned lieutenant in the US Naval Reserve through 1947. By 1950 he had received undergraduate and masters degrees from the University of California, Berkeley, and in 1955 he completed his PhD at the Carnegie Institute of Technology.

A career particle physicist at Berkeley Lab, located on the hill above the UC Berkeley campus, Al wrote his first paper for what was then the Radiation Laboratory in 1949. He wrote his final paper in 1991 at what had become the Lawrence Berkeley National Laboratory (LBL).

Al was a brilliant scientist who designed the accelerator lattice for the Superconducting Super Collider (SSC), in particular inventing the "diamond bypass" to allow two beams to be injected and aborted from just one straight section. His career also included work on the Tevatron, the asymmetric B-Factory at SLAC's PEP-II accelerator and SYNCH – a computational tool used extensively at particle-physics labs around the world and for which he held a patent. He contributed to the design and orbit theory of the following machines: the Bevatron, Magnetic Mirror Fusion Reactors, 88-inch Cyclotron, Advanced Light Source (ALS), Fermilab Proton Synchrotron, the Large Proton–Proton Storage Rings LSR (CERN), ISABELLE (BNL), and the High Energy Heavy Ion Facility SUMATRAN (Japan).


Berkeley Lab

Alper Garren designed the lattice for the SSC.

Al was a sweet, kind, generous man who made friends easily and kept them for life. He loved to travel and was especially drawn to the culture and people of Asia. He loved the performing arts and was a patron of the San Francisco Opera, the San Francisco Symphony and the Philharmonia Baroque Orchestra. He was a dedicated philanthropist, supporting some 200 environmental, human-rights and performing-arts organisations in his later years.

Physicist, teacher, mentor, world traveller, sailor, philanthropist and above all a dear friend, Al enriched many lives during his 92 years.

● *Based on text published in the* San Francisco Chronicle *by Jon Eisenberg and Marilee Bailey.*

Maryam Mirzakhani 1977–2017

Maryam Mirzakhani, mathematics professor at Stanford University and Fields Medalist in 2014, passed away on 14 July aged just 40. She was the first woman and first Iranian citizen to win a Fields Medal.

Born in Teheran, at high-school age Maryam participated in two International Mathematics Olympiads, winning gold medals both times – once with a perfect score. After undergraduate studies at Sharif University, she moved to the US to enroll in a PhD course at Harvard University, under the supervision of Fields Medalist Curtis McMullen. Before joining Stanford in 2008 she was a fellow of the Clay Mathematics Institute in Cambridge (MA) and a professor at Princeton University.

Since her early career as a ▷

mathematician, Maryam obtained fundamental results on moduli spaces of Riemann surfaces and inhomogeneous space dynamics – topics at the intersections between mathematics and physics. One of her first major results was a counting theorem on closed geodesics that unexpectedly led to a new proof of Witten's conjecture, related to the partition function of two-dimensional quantum gravity.

As Harvard string theorist Cumrun Vafa recalled in his speech at a memorial event held in August, results of Maryam's work and the techniques she applied in her proofs might be applied to solve problems in string theory. Riemann surfaces are natural ingredients in string theory, where they appear both as 2D world-sheets of strings dynamically evolving in space–time, as well as 2D internal manifolds on which the theory is compactified to reduce its original 10 or 11 dimensions to a more familiar 4D scenario.

Both applications of Riemann surfaces are of great interest to theoretical physicists. Ongoing research in CERN's theory department directly investigates string world-sheet and scattering amplitudes, as well as supersymmetric field theories, which are constructed through geometric engineering of branes wrapping Riemann surfaces. Maryam's approach to moduli spaces provided powerful tools that, in the future, could lead to major advances in theoretical physics.

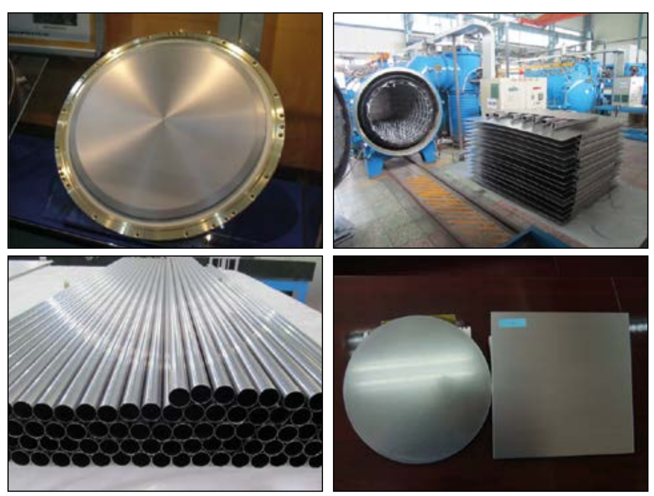
The premature departure of Maryam Mirzakhani represents a huge loss for the scientific community, not just for her scientific excellence. Winning a Fields Medal not only highlights the academic achievement of the recipient but, as Terrence Tao (Fields Medalist, UCLA) wrote in a note about Maryam Mirzakhani, it also promotes the recipient to a role model. In the case of Maryam Mirzakhani this was definitely true: as a female mathematician and the first woman to win a Fields Medal, she will remain a reference figure for future generations of female scientists.

In addition to an extraordinary scientific career, particularly noticeable were her generosity and humble personality.

● *Alessandra Gnecchi and colleagues from the CERN theory department.*

Stanford News Service

Mirzakhani, who was the first woman to be awarded a Fields Medal, worked at the intersection between mathematics and physics.



Recruitment

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Experimental High-Energy Physics

at the Ecole polytechnique fédérale de Lausanne (EPFL)

The School of Basic Sciences of the Ecole Polytechnique Fédérale de Lausanne (EPFL) seeks to appoint a tenure-track assistant professor of experimental high-energy physics in the Institute of Physics.

The Laboratory for High-Energy Physics is strongly involved in the LHCb experiment at CERN's Large Hadron Collider from the time of its conception, and is currently making a major contribution to the detector upgrade, with a view to enhance data-taking capability to extend the science reach from 2021 onwards. The position offers the opportunity to capitalize on this investment while also developing ideas for the longer-term future, in an environment providing strong technical support in detector development.

A PhD degree in particle physics as well as a strong and growing track record in research and scientific leadership are required. The appointed professor is expected to initiate a creative experimental program, and engage in physics teaching at undergraduate and graduate levels.

Significant start-up resources, research budget and state-of-the-art research infrastructure are available. Salaries and benefits are internationally competitive.

Applications should include a motivation letter, a curriculum vitae with a list of research outputs, a statement of research (max. 3 pages) and teaching interests (max. 1 page), as well as the names and addresses (including e-mail) of at least three references.

Application files should be submitted in PDF format and uploaded by **December 15th, 2017** to
https://facultyrecruiting.epfl.ch/position/6848513

Enquiries may be addressed to:
Prof. Harald Brune
Chairman of the Search Committee
E-mail: iphysdirector@epfl.ch

For additional information, please consult www.epfl.ch, sb.epfl.ch, iphys.epfl.ch

EPFL is committed to increasing the diversity of its faculty, and strongly encourages women to apply.

CERN Courier November 2017

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 2018. 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). 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, 2017 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

eli beamlines

Institute of Physics ASCR, v. v. i., Na Slovance 2, 182 21 Praha 8
info@eli-beams.eu | www.eli-beams.eu

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 is a cutting-edge laser facility that is currently being constructed in Dolní Břežany (on the southern border of Prague); its commissioning is scheduled for end of 2017. ELI will be delivering ultra-short, ultra-intense laser pulses lasting typically a few tens of femtoseconds (up to 150 fs) 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 laser electric field intensities of the laser pulse will be also used for generating secondary sources of e- and p+ and high-energy photons.

The research group RP3 is expanding and recruiting physicists in relevant fields for the design/development of the facility and for preparation of future experimental activities.

In our team we therefore have the following position available:

Junior/Senior Engineer/Experimental Physicist (ELI-RP3 ELIMAIA)

The candidate is supposed to work predominantly on the following topics:

- Implementation of various optical devices (mirrors, focusing optics, cameras, microscope objectives, and laser diagnostics) in vacuum chambers where initial commissioning RP3 experiments (particle acceleration by lasers) will be carried out with 100-TW class lasers (and later PW-class).
- Operation of laser alignment and diagnostic systems, including data acquisition and transfer to local control systems

Requirements:

- University degree in optical engineering or experimental physics
- Experience in high power laser laboratories
- Engineering skills concerning alignment of optics and targets, as well as vacuum and electrical installations.
- Knowledge in the use of codes for optical simulations is a plus.
- Fluent in English for speaking and writing; knowledge of Czech is a plus
- Ability to work in a team as well as independently

Job conditions:

- The opportunity to participate in this unique scientific project
- Career growth, professional education
- 5 weeks of holiday and other employee benefits
- Pleasant work environment

Applications, containing CV, cover letter, contacts of references, and any other material the candidate considers relevant, should be sent to Mrs. Jana Ženíšková (jana.zeniskova@eli-beams.eu, +420 601 560 322).
Please include the following text in your cover letter, to allow us to process your personal details:

I agree that, according to the decree 101/2000 coll. (Czech Republic), my personal details sent to FZU AVCR, v.v.i, Na Slovance 2, 18221 Praha 8, Czech Republic can be used for the purpose of obtaining employment and management of database of employment candidates. This permission is given for the period of one year and can be at any time withdrawn by giving a notice in writing.

TEXAS TECH UNIVERSITY
Department *of* Physics & Astronomy

The Department of Physics and Astronomy at Texas Tech University, as part of its strategic growth plan, invites applications for a tenure-track position in experimental particle physics at the assistant professor level; exceptional candidates at a more senior level may be considered.

The starting date is September 2018. The members of the experimental particle physics group at Texas Tech (Akchurin, Kunori, Lee, Volobouev, and Wigmans) actively participate in the CMS experiment at CERN and maintain a rigorous R&D program in advanced detector physics. In addition to the ongoing beyond Standard Model searches, we share significant responsibilities for the upgrade of the CMS calorimeters for the high luminosity LHC. The group enjoys strong infrastructure support: the Advanced Particle Detector Laboratory is well-suited for R&D and production of detectors based on scintillator and silicon systems, and the High Performance Computing Center allocates substantial resources in support of the group's analysis work. The university has recently been ranked in the Highest Research Activity category by the Carnegie Foundation.

We expect the new experimental faculty member to strengthen and complement the ongoing research in CMS, particularly in detector upgrade effort, or to initiate a new and significant research program in any area of experimental particle physics. Candidate must have a Ph.D. in physics and at least two years of post-doctoral experience, possess an outstanding research record, and show promise of excellent teaching at both undergraduate and graduate levels. Candidate is expected to garner extramural funding to support his/her research. Service to the department, college, and university is also expected.

Applicants should submit a vita, list of publications, statement of research interests and plans, teaching philosophy, and contact information for at least three references. Applications should be submitted online jobs.texastech.edu using requisition ID 11830. Inquiries should be sent to Professor Nural Akchurin (nural.akchurin@ttu.edu). Applications will be reviewed starting December 1st 2017 and will continue until the position is filled.

As an Equal Employment Opportunity/Affirmative Action employer, Texas Tech University is dedicated to the goal of building a culturally diverse faculty committed to teaching and working in a multicultural environment. We actively encourage applications from all those who can contribute, through their research, teaching, and/or service, to the diversity and excellence of the academic community at Texas Tech University. The university does not discriminate on the basis of an applicant's race, ethnicity, color, religion, sex, sexual orientation, gender identity, national origin, age, disability, genetic information or status as a protected veteran. Texas Tech welcomes consideration of dual career and professional couple accommodations.

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People at CERN are driven by a shared goal, a single purpose. They want to achieve the impossible, to do what's never been done before. Everyone here strives to be the best they can be, true specialists and industry "firsts" are created regularly –not just in the world of physics. The engineering and technical skills needed to make the experiments succeed are as world-class as the science behind them.

If you're looking for a new challenge in engineering & technical fields, check out the diverse opportunities CERN has to offer on:
cern.ch/jobs. Take part!

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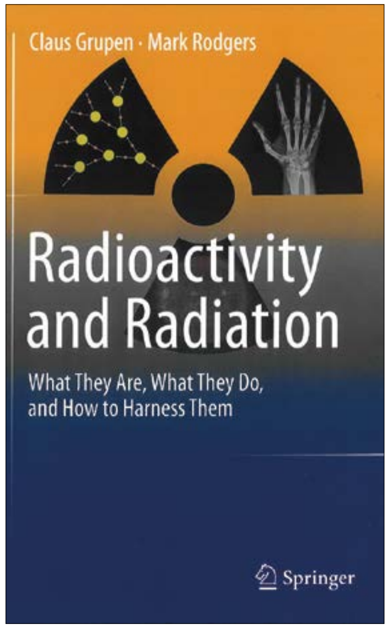
Bookshelf

Compiled by Virginia Greco, CERN



Radioactivity and Radiation: What They Are, What They Do, and How to Harness Them

By Claus Grupen and Mark Rodgers
Springer International Publishing

Have you ever thought that batteries capable of providing energy over very long periods could be made with radioisotopes? Did you know that the bacterium *deinococcus radiodurans* can survive enormous radiation doses and, thanks to its ability to chemically alter highly radioactive waste, it could be potentially employed to clean up radioactively contaminated areas? And do you believe that cockroaches have an extremely high radiation tolerance? Apparently, the latter is a myth. These are a few of the curiosities contained in this "all that you always wanted to know about radioactivity" book from Grupen and Rodgers. It gives a comprehensive overview of the world of radioactivity and radiation, from its history to its risks for humans.

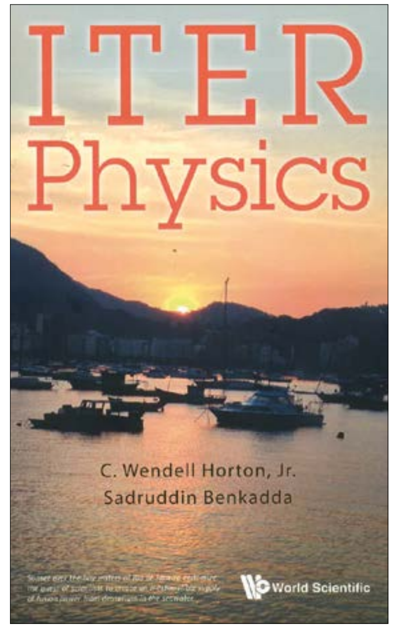
The book begins by laying the groundwork with essential, but quite detailed (similar to a school textbook), information about the structure of matter, how radiation is generated, how it interacts with matter and how it can be measured. In the following chapters, the book explores the substantial benefits of radioactivity through its many applications (not only positive, but also negative and sometimes questionable) and the possible risks associated with its use. The authors deal mainly with ionising radiation; however, in view of the public debate about other kinds of radiation (such as mobile-phone and microwave signals), they include a brief chapter on non-ionising radiation. Also interesting are the final sections, provided as appendices, which summarise the main technologies of radiation detectors as well as the fundamental principles of radiation protection. In the latter, the rationale behind current international rules and regulations, put in place to avoid excessive radiation exposure for radiation workers and the general public, is clearly explained.

This extensive topic is covered using easily understood terms and only elementary mathematics is employed to describe the essentials of complex nuclear-physics phenomena. This makes for pleasant reading intended for the general public interested in radioactivity and radiation, but also for science enthusiasts and inquisitive minds. As a bonus, the book is illustrated with eye-catching cartoons, most of them drawn by one of the authors.

The book emphasises that radiation is everywhere and that almost everything around us is radioactive to some degree: there is natural radiation in our homes, in the food that we eat and the air that we breathe. Radiation from the natural environment does not present a hazard; however, radiation levels higher than the naturally occurring background can be harmful to both people and the environment. These artificially increased radiation levels are mainly due to the nuclear industry and have therefore risen substantially since the beginning of the civil-nuclear age in the 1950s. This approach helps readers to put things in perspective and allows them to compare the numbers and specific measurement quantities that are used in the radiation-protection area. These quantities are the same used by the media, for instance, to address the general public when a radiation incident occurs.

Not only will this book enrich the reader's knowledge about radioactivity and radiation, it will also provide them with tools to better understand many of the related scientific issues. Such comprehension is crucial for anyone who is willing to develop their own point of view and be active in public debates on the topic.

● *Federico Ravotti, CERN.*



ITER Physics

By C Wendell Horton Jr and Sadruddin Benkadda
World Scientific

This 235 page book is dedicated to the ITER tokamak, the deuterium–tritium fusion reactor under construction in France, which aims to investigate the feasibility of fusion power. The book provides a concise overview of the state-of-the-art plasma physics involved in nuclear-fusion processes. Definitely not an introductory book – not even for a plasma-physics graduate student – it would be useful as a reference text for experts. Across 10 chapters, the authors describe the physics learned from previous tokamak projects around the world and the application of that experience to ITER.

After an introduction to the ITER project, the conventional magneto-hydrodynamic description of plasma physics is discussed, with strong emphasis on the geometry of the divertor (located at the bottom of the vacuum vessel to extract heat and reduce contamination of the plasma from impurities). Chapter 3 deals with the problem of alpha-particle distribution, which is a source of Alfven and cyclotron instabilities. Edge localised mode (ELM) instabilities associated with the divertor's magnetic separatrix are also discussed. Conditions of turbulent transport are assumed throughout, so chapter 4 provides a general review of our (mainly experimental) knowledge of the topic. Chapters 5 and 6 are specific to the ITER design because they describe the ELM instabilities in the ITER tokamak and the solutions adopted for their control. Concluding the part dedicated to the fusion-reactor transient phase, steady-state operations and plasma diagnostics techniques are described in chapters 7 and 8, respectively.

The tokamak's complex magnetic field is able to confine charged particles in the fusion plasma but not neutral particles. Neutron bombardment of surfaces can be viewed as an inconvenience, making it necessary to ensure the walls are radiation hard, or an advantage, turning the surfaces into a breeding blanket to generate further tritium fuel. Radiation hardness of the tokamak walls is discussed in chapter 9, while chapter 10 explains how ITER will transmute a lithium blanket into tritium via bombardment with fusion neutrons. The IFMIF (International Fusion Materials Irradiation Facility) project, conceived for fusion-material tests and still in its final design phase, is also briefly presented. The book closes with some predictions about the expectations to be fulfilled by ITER, before proceeding to the design of DEMO – a future tokamak for electrical-energy production.

In summary, *ITER Physics* is a book for expert scientists who are looking for a compact overview of the latest advances in tokamak physics. I appreciated the exhaustive set of references at the end of each chapter, since it provides a way to go deeper into concepts not exhaustively explained in the book. Plasma-fusion physics is complex, not only because it is a many-body problem but also because our knowledge in this field is limited, as the authors stress. I would have appreciated more graphic material in some parts: in order to fully understand how a fusion reactor works, one has to think in 3D, so schematics are always helpful.

● *Rogelio Palomo, University of Seville, Spain*

Books received

Relativistic Kinetic Theory, with Applications in Astrophysics and Cosmology

By Gregory V Vereshchagin and Alexey G Aksenov
Cambridge University Press

This book provides an overview of relativistic kinetic theory, from its theoretical foundations to its applications, passing through the various numerical methods used when analytical solutions of complex equations cannot be obtained.

Kinematic theory (KT) was born in the 19th century and aims to derive the properties of macroscopic matter from the properties of its constituent microscopic particles. The formulation of KT within special relativity was completed in the 1960s.

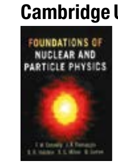
Relativistic KT has traditional applications in astrophysics and cosmology, two fields that tend to rely on observations rather than experiments. But it is now becoming more accessible to direct tests due to recent progress in ultra-intense lasers and inertial fusion, generating growing interest in KT in recent years.

The book has three parts. The first deals with the fundamental equations and methods of the theory, starting with the evolution of the basic concept of KT from nonrelativistic to special and general relativistic frameworks. The second part gives an introduction to computational physics and describes the main numerical methods used in relativistic KT. In the third part, a range of applications of relativistic KT are presented, including wave dispersion and thermalisation of relativistic plasma, kinetics of self-gravitating systems, cosmological structure formation, and neutrino emission during gravitational collapse.

Written by two experts in the field, the book is intended for students who are already familiar with both special and general relativity and with quantum electrodynamics.

Foundations of Nuclear and Particle Physics

By T W Donnelly, J A Formaggio, B R Holstein, R G Milner and B Surrow
Cambridge University Press



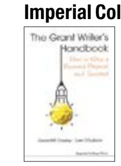
This textbook aims to present the foundations of both nuclear and particle physics in a single volume in a balanced way, and to highlight the interconnections between them. The material is organised from a "bottom-up" point of view, moving from the fundamental particles of the Standard Model to hadrons and finally to few- and many-body nuclei built from these hadronic constituents.

The first group of chapters introduces the symmetries of the Standard Model. The structure of the proton, neutron and nuclei in terms of fundamental quarks and gluons is then presented. A lot of space is devoted to the processes used experimentally to unravel the structure of hadrons and to probe quantum chromodynamics, with particular focus on lepton scattering. Following the treatment of two-nucleon systems and few-body nuclei, which have mass numbers below five, the authors discuss the properties of many-body nuclei, and also extend the treatment of lepton scattering to include the weak interactions of leptons with nucleons and nuclei. The last group of chapters is dedicated to relativistic heavy-ion physics and nuclear and particle astrophysics. A brief perspective on physics beyond the Standard Model is also provided.

The volume includes approximately 120 exercises and is completed by two appendices collecting values of important constants, useful equations and a brief summary of quantum theory.

The Grant Writer's Handbook: How to Write a Research Proposal and Succeed

By Gerard M Crawley and Eoin O'Sullivan
Imperial College Press



This book is designed as a "how to" guide to writing grant proposals for competitive peer review. Nowadays researchers are often required to apply to funding agencies to secure a budget for their work, but being a good researcher does not necessarily imply being able to write a successful grant proposal. Typically, the additional skills and insights needed are learnt through experience.

This timely book aims to guide researchers through the whole process, from conceiving the initial research idea, defining a project and drafting a proposal, through to the review process and responding to reviewers' comments. Drawing on their own experience as reviewers in a number of different countries, the authors provide many important tips to help researchers communicate both the quality of their research and their ability to carry it out and manage a grant. The authors illustrate their guidelines with the help of many examples of both successful and unsuccessful grant applications, and emphasise key messages with quotes from reviewers.

The book also contains valuable advice for primary investigators on how to set up their research budget, manage people and lead their project. Two appendices at the end of the volume provide website addresses and references, as well as an outline of how to organise a grant competition.

Aimed primarily at early career researchers applying for their first grant, the book will also be beneficial to more experienced scientists, to the administrators of universities and institutions that support their researchers during the submission process, and to the staff of recently established funding organisations, who may have little experience in organising peer-review competitions.

CERN Courier Archive: 1974

A look back to CERN Courier vol. 14, November 1974, compiled by Peggie Rimmer

Brookhaven

Present and future programmes

The Brookhaven National Laboratory [established in 1947] for many years enjoyed a pre-eminent reputation among high-energy physics research centres. In its heyday, many of the major discoveries fell to the 33 GeV Alternating Gradient Synchrotron, AGS, which was the highest energy machine in the world. The inevitable leap-frogging has since taken place and facilities at Serpukhov, CERN and the FermiLab have extended the fields of research beyond the reach of the BNL machine. There is therefore the keenest interest in BNL's project for the future – the very high-energy collider ISABELLE.

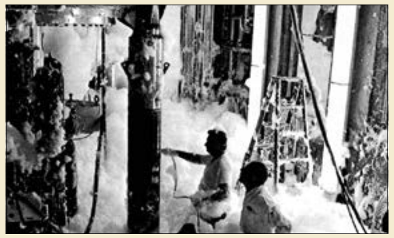
Of course, the major activities remain centred on the high energy physics programme and the operation and development of the AGS. The experimental programme has been fed by beams from an internal target, by two fast ejected beams to the 80-inch and 7-foot bubble chambers, and by a slow ejected beam to a variety of counter experiments.

Financial restrictions forced the close down of the 80-inch chamber at the end of September. The chamber came into action in 1963, collecting some 12 million photographs for seventy experiments. Its particular moment of glory came in 1964, with the identification of the omega minus [three strange quarks] in the experiment led by N P Samios. The bubble chamber burden is now taken up by the 7-foot chamber sitting in the North Experimental area, where it is fed by a neutrino beam.

In the East Experimental Area an internal target provides a neutral kaon beam, a separated 3 GeV/c negative kaon beam and test beams. The slow ejected beam, via two splitting stations and a bending station, can give protons onto four targets. An experiment fed by target A is by a MIT/Brookhaven team led by S C C Ting, to continue the study of the electromagnetic properties of the nucleon by measuring electron pairs emerging from proton–proton collisions.*

**Fascinating news from this experiment at the beginning of November: they believe they have seen a new particle (baptised the J particle) of mass 3.1 GeV which decays into an electron–positron pair. The electron–positron ring SPEAR at Stanford also has seen it. Another tantalising contribution to the hadron/lepton relationship.*

● Compiled from texts on pp388–391.



Several months ago the foam fire protection system for the 7-foot bubble chamber came on automatically because of an electrical design fault in the manufacturer's circuit. The incident provided a vivid demonstration of the system's ability to flood the entire building with extinguishing foam very quickly. Clean-up was completed in about a day and left the bubble chamber whiter than white.

Dubna/Orsay

Collaborative look at the nucleus

Dubna's Laboratory of Nuclear Reactions under G N Flerov got together this year with the Orsay mass spectroscopy group of R Klapisch to bring their combined talents to bear on the study of the nucleus.

The Laboratory has one of the world's finest heavy ion machines – a 3-m cyclotron capable of accelerating ions to energies of 8 MeV per nucleon with intensities up to 200 μA. The Orsay group has a high reputation in nuclear and mass spectroscopy. The team has done notable work at the CERN proton synchrotron particularly on a series of sodium and lithium isotopes. Their spectrometer is a mobile instrument that could be readily transported to the cyclotron.

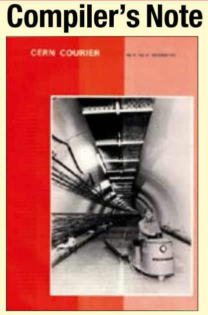
An agreement was reached between Dubna and the Institut National de Physique Nucléaire et de Physique des Particules for 500 hours of beam time. The experiments began in June and were completed at the end of August.

The collaboration has been fruitful for both parties and it is likely that they will get together again, perhaps when the 4-m cyclotron, now under construction, comes into action and opens the door to a new range of nuclear studies.

● Compiled from texts on pp391–392.

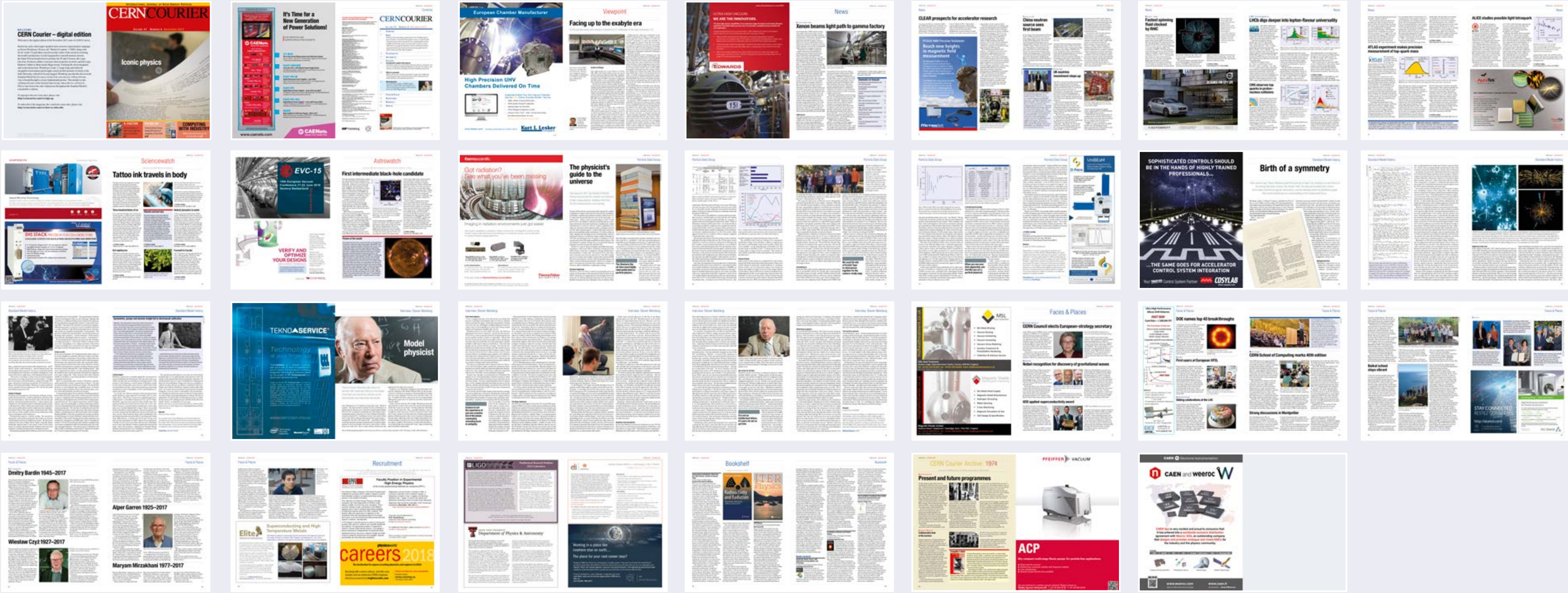
The Orsay mass spectrometer swings into the air outside the Laboratory of Nuclear Reactions at Dubna.

Compiler's Note



The fascinating footnote of course concerned the J/ψ meson (charm–anticharm), named J at BNL, ψ at Stanford. Sam Ting and Burton Richter shared the 1976 Nobel prize for this discovery that sparked the 1974 November Revolution in particle physics and furthered acceptance of the Standard Model. Additional evidence had come in 1975 when a charmed Λ baryon (comprising an up, down and charm quark) was recorded in the BNL 7-foot bubble chamber. This clinched arguments for the existence of a second generation of matter.

Unfortunately, the ISABELLE 200+200 GeV proton collider was dropped in 1963, unfinished. However, parts of its tunnel, experimental hall and magnet infrastructure were salvaged and reused for BNL's Relativistic Heavy Ion Collider (RHIC), approved in 1991 and operational in 2000. This was the first heavy-ion collider and is still the only spin-polarised proton collider. RHIC produces like-on-like collisions of copper, gold and uranium ions, as well as colliding protons, deuterons, helium-3 and copper on gold.



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VOLUME 57 NUMBER 9 NOVEMBER 2017

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