WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the November/December 2023 issue of *CERN Courier*.

Welcome to a special issue of the *Courier* to celebrate the opening of CERN Science Gateway. In addition to lifting the lid on this new flagship facility for science education and outreach, we explore the broader issues surrounding education, communication and outreach in particle physics (p27). Delving into Science Gateway's exhibition spaces, experts reflect on four stunning art installations (p36), the secrets of success for an interactive exhibit (p31) and the power of objects (p39). Following a deep dive into the new educational labs (p41), learn about CERN's activities in physics-education research (p43), the impact of its hugely popular teacher programmes (p45), and how particle physics is integrated in school curricula (p47). From empowering children (p49) to taking physics to festivals (p50) and transcending physical and neurological boundaries (p51), three articles emphasise the importance of reaching out as far and wide as possible. Last but certainly not least, we consider the invaluable role played by physicists (p52 and 53) and weave the rich experiences of CERN guides throughout the pages.

It's business as usual in the rest of the issue – that is, if you consider the first measurement of the freefall of antimatter (p7), the first high-energy observation of entanglement (p15) or a 5σ discrepancy between theory and experiment (p8) business as usual. Other highlights include an interview with the incoming KEK director-general (p58), the latest conference reports (p19), careers (p62) and reviews (p60).

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EDITOR: MATTHEW CHALMERS, CERN
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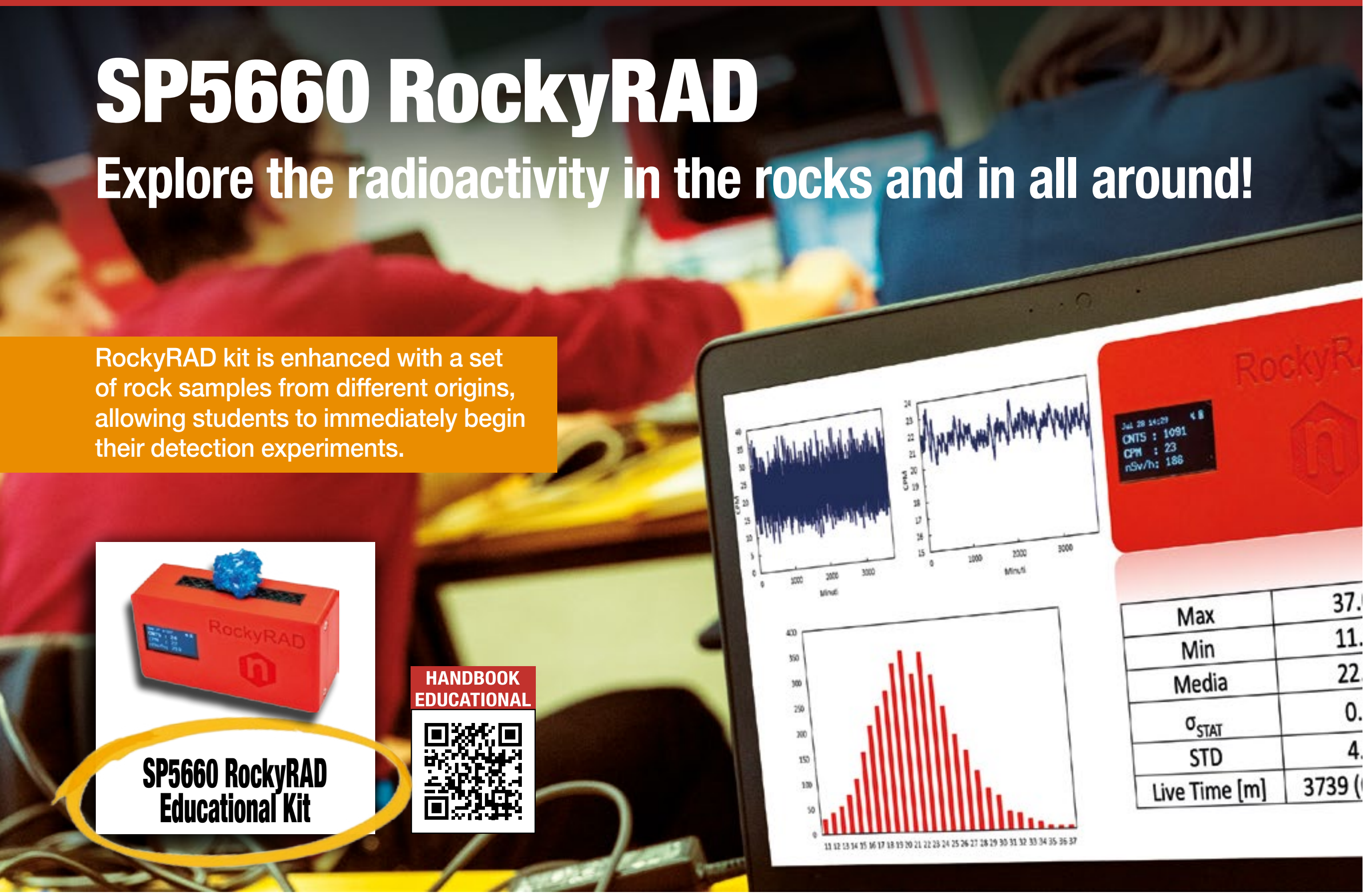

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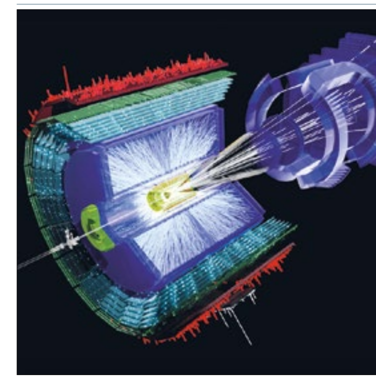

Back on track *Heavy-ion collisions return to the LHC.* **11**

Dark art *Artworks in CERN Science Gateway show physics in a new light.* **36**

Same wavelength *Formulating narratives for the future of the field.* **55**

FROM THE EDITOR

The importance of reaching out

Matthew Chalmers
Editor

With some exceptions – notably neutron-discoverer James Chadwick, who in 1908 attended the wrong interview at the University of Manchester and was too shy to explain his mistake – few people become physicists by chance. Whether it was a science-minded parent or friend of the family, an encouraging teacher, a visit to a lab or museum, a public figure, talk, book, film, ... something or someone awakened an innate curiosity.

CERN Science Gateway – a vision articulated by CERN Director-General Fabiola Gianotti in January 2017, funded through external donations, and now open to the public just three years after Geneva authorities gave the green light for construction – offers up to half a million people per year a chance to be infused with physics. This special issue goes behind the scenes of Science Gateway's content and explores broader aspects of education, communication and outreach in physics – including the vital role of physicists (p25).

The landscape of science communication has changed dramatically in recent decades. Gone are the days of the "deficit model" when an amorphous public was viewed as empty vessels to be filled with knowledge. Today, it's about dialogue, engagement, the scientific method, and simply allowing people to have enjoyable experiences in a science context regardless of the information they pick up. Another factor, fuelled by an explosion of graduate courses, is the rise of the professional science communicator. While such courses offer a grounding in models of communication and invite students of the natural sciences to take a healthy look at their field through the lenses of history, sociology, psychology and philosophy, there is no substitute for the authenticity of a practising scientist sharing their passion and subject knowledge. We need both.

It is easily forgotten that communication is not just about connecting with non-scientists but is the lifeblood of science itself

Particle physicists have a strong tradition of going direct to audiences. It is also encouraging that education, communication and outreach are being integrated into the agendas of major high-energy physics conferences. However, outreach is still too often viewed as an optional, non-serious activity that detracts from a researcher's core business, and more could be done to recognise such efforts in career structures.

CERN-PHOTO-202310-244-108

Guiding hand *Head of the CERN exhibitions team Emma Sanders interacting with the first Science Gateway visitors.*

It is easily forgotten that communication is not just about connecting with non-scientists but is the lifeblood of science itself, whether it be writing compelling papers and grant proposals or being an effective mentor and leader. Even when talking internally within the community, especially about the goals of a future collider, few physicists are immune to the motivational power of snappy formulations (p55).

The fascinating ideas and open questions in particle physics, and the scale of the machines and international effort behind it, offer powerful narratives of exploration and adventure. At the same time, the abstraction of particle physics from everyday experience and the increasing specialisation of subfields within high-energy physics can pose a challenge when communicating progress to others. Done poorly, or not enough, there is a risk of generating wrong perceptions, for example that the field is only about finding new particles.

Engaging in particle-physics outreach is not just about ensuring a bright future for the field. It is a duty to the hundreds of millions of people who pay for fundamental research. As the articles in this issue show, it is also highly rewarding personally and professionally. There is no need for all particle physicists to engage in outreach. But those who can, should.

Reporting on international high-energy physics

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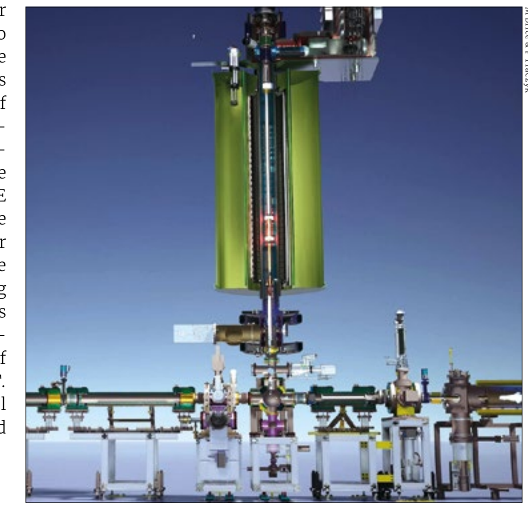
NEWS ANALYSIS

ANTIMATTER

ALPHA-g clocks the freefall of antihydrogen

Ever since the discovery of antimatter 90 years ago, physicists have striven to measure its properties in new and more precise ways. Experiments at CERN's Antimatter Factory represent the state of the art. In addition to enabling measurements of properties such as the antiproton charge-to-mass ratio with exquisite precision (recently shown by the BASE experiment to be equal to that of the proton within a remarkable 16 parts per trillion), the ability to trap and store large numbers of antihydrogen atoms for long periods by the ALPHA experiment has opened the era of antihydrogen spectroscopy. Such studies allow precise tests of fundamental symmetries such as CPT. Until now, however, the gravitational behaviour of antimatter has remained largely unknown.



M Brice & P Traczyk

Heavy stuff *Digital twin of the ALPHA-g apparatus at CERN's Antimatter Factory.*

Equivalence principle

Using a modified setup, the ALPHA collaboration recently clocked the freefall of antihydrogen, paving the way for precision studies of the magnitude of the gravitational acceleration between antiatoms and Earth. The goal is to test the weak equivalence principle of general relativity, which requires that all test masses must react identically to Earth's gravity. While models have been built that suggest differences could exist between the freefall rates of matter and antimatter (for example due to the existence of new, long-range forces), the theoretical consensus is clear: they should fall to Earth at the same rate. In physics, however, you don't really know something until you observe it, emphasises ALPHA spokesperson Jeffrey Hangst: "This is the first direct experiment to actually observe a gravitational effect on the motion of antimatter. It's a milestone in the study of antimatter, which still mystifies us due to its apparent absence in the universe."

The ALPHA collaboration creates antihydrogen by binding antiprotons produced and slowed down in the Antiproton Decelerator and ELENA rings with positrons accumulated from a sodium-22 source. It then confines the neutral, but slightly magnetic, antimatter atoms in a magnetic trap to prevent them from coming into contact with matter and annihilating. Until now, the team has concentrated on spectroscopic studies with the ALPHA-2 device. But it has also built an apparatus called ALPHA-g, which makes it possible to measure the vertical positions at which antihydrogen atoms annihilate with matter once the trap's magnetic field is switched off, allowing the antiatoms to escape.

This is the start of a new avenue of experimental exploration that pushes the development of trapping and other techniques

The ALPHA team trapped groups of about 100 antihydrogen atoms and then slowly released them over a period of 20 seconds by gradually ramping down the top and bottom magnets of the trap. Numerical simulations indicate that, for matter, this operation would result in about 20% of the atoms exiting through the top of the trap and 80% through the bottom – a difference caused by the downward force of gravity. By averaging the results of seven release trials, the ALPHA team found that the fractions of antiatoms exiting through the top and bottom were in line with simulations. Since vertical gradients in the magnetic field magnitude can mimic the effect of gravity, the team repeated the experiment several times for different values of an additional bias magnetic field, which could either enhance or counteract the force of gravity. By analysing the data from this bias scan, the team found that the local gravitational acceleration of antihydrogen is directed towards Earth and has magnitude $a_{\bar{g}} = [0.75 \pm 0.13$ (stat. + syst.) ± 0.16 (sim.)]g, which is consistent with the attractive gravitational force between matter and Earth.

The next step, says Hangst, is to increase the precision of the measurements via laser-cooling of the antiatoms, which was first demonstrated in ALPHA-2 and will be implemented in ALPHA-g in 2024. Two other experiments at CERN's Antimatter Factory, AEgIS and GBAR, are poised to measure $a_{\bar{g}}$ using complementary methods. AEgIS will measure the vertical deviation of a pulsed horizontal beam of cold antihydrogen atoms in an approximately 1 m-long flight tube, while GBAR will take advantage of new ion-cooling techniques to measure ultraslow antihydrogen atoms as they fall from a height of 20 cm. All three experiments are targeting a measurement of $a_{\bar{g}}$ at the 1% level in the coming years.

Even higher levels of precision will be needed to test models of new physics, say theorists. "The role of antimatter in the 'weight' of antihydrogen is very little, since practically all the mass of a nucleon or antinucleon comes from binding gluons, not antiquarks," says Diego Blas of Institut de Física d'Altes Energies and Universitat Autònoma de Barcelona. "Any new force that couples differently to matter and antimatter would therefore need to have a huge effect in antiquarks, which makes it difficult to build models that are consistent with existing observations and where the current measurements by ALPHA-g would be different." Things start to get interesting when the precision reaches about one part in 10 million, he says. "This is the start of a new avenue of experimental exploration that pushes the development of trapping and other techniques. If you compare the situation with the sensitivity of the first prototypes of gravitational-wave detectors 50 years ago, which had to be improved by six or seven orders of magnitude before a detection could be made, anything is possible in principle."

Further reading

E K Anderson *et al.* 2023 *Nature* **621** 716.

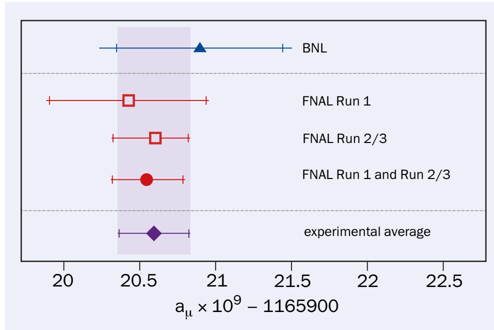
MUON G–2

Muon g–2 update sets up showdown with theory

On 10 August, the Muon g–2 collaboration at Fermilab presented its latest measurement of the anomalous magnetic moment of the muon a_μ. Combining data from Run 1 to Run 3, the collaboration found $a_\mu = 116\,592\,055\,(24) \times 10^{-11}$, representing a factor-of-two improvement on the precision of its initial 2021 result (*CERN Courier* May/June 2021 p7). The experimental world average for a_μ now stands more than 5σ above the Standard Model (SM) prediction published by the Muon g–2 Theory Initiative in 2020. However, calculations based on a different theoretical approach (lattice QCD) and a recent analysis of e^+e^- data that feeds into the prediction are in tension with the 2020 calculation, and more work is needed before the discrepancy is understood.

The anomalous magnetic moment of the muon $a_\mu = (g-2)/2$ (where g is the muon's gyromagnetic ratio) is the difference between the observed value of the muon's magnetic moment and the Dirac prediction (g = 2) due to contributions of virtual particles. This makes measurements of a_μ, which is one of the most precisely calculated and measured quantities in physics, an ideal testbed for physics beyond the SM. To measure it, a muon beam is sent into a superconducting storage ring reused from the former g–2 experiment at Brookhaven National Laboratory. Initially aligned, the muon spin axes precess as they interact with the magnetic field. Detectors located along the ring's inner circumference allow the precession rate and thus a_μ to be determined. Many improvements to the setup have been made since the first run, including better running conditions, more stable beams and an improved knowledge of the magnetic field.

The new result is based on data taken from 2019 and 2020, and has four times the statistics compared to the 2021 result. The collaboration also decreased the systematic uncertainty to levels beyond its initial goals. Currently, about 25% of the total data (Run 1–Run 6) has been analysed. The collaboration plans to publish its final results in 2025, targeting a precision of 0.14 ppm compared to the current 0.2 ppm. "We have moved the accuracy bar of this experiment one step further and now we are waiting for the theory to complete the calculations and cross-checks necessary to match the experimental accuracy," explains collaboration co-spokesperson Graziano Venanzoni of INFN Pisa and the University of Liverpool. "A huge experimental and theoretical effort is going on, which makes us confident that theory prediction will be in time for the final experimental result from FNAL in a few years from now."



A challenge to theory *At 0.2 ppm, the latest measurement from the Muon g–2 collaboration is twice as precise as the previous one.*

The theoretical picture is foggy. The SM prediction for the anomalous magnetic moment receives contributions from the electromagnetic, electroweak and strong interactions. While the former two can be computed to high precision in perturbation theory, it is only possible to compute the latter analytically in certain kinematic regimes. Contributions from hadronic vacuum polarisation and hadronic light-by-light scattering dominate the overall theoretical uncertainty on a_μ at 83% and 17%, respectively.

To date, the experimental results are confronted with two theory predictions: one by the Muon g–2 Theory Initiative based on the data-driven "R-ratio" method, which relies on hadronic cross-section measurements, and one by the Budapest–Marseille–Wuppertal (BMW) collaboration based on simulations of lattice QCD and QED (*CERN Courier* May/June 2021 p25). The latter significantly reduces the discrepancy between the theoretical and measured values. Adding a further puzzle, a recently published value of hadronic cross-section measurements by the CMD-3 collaboration that contrasts with all other experiments narrows the gap between the Muon g–2 Theory Initiative and the BMW predictions (see p19).

"This new result by the Fermilab Muon g–2 experiment is a true milestone in the precision study of the Standard Model," says lattice gauge theorist Andreas Jüttner of CERN and the University of Southampton. "This is really exciting – we are now faced with getting to the roots of various tensions between experimental and theoretical findings."

Further reading

Muon g–2 Collab. 2023 arXiv:2308.06230 (accepted by *Phys. Rev. Lett.*).
BMW Collab. 2021 *Nature* **593** 51.
Muon g–2 Theory Initiative 2020 *Phys. Rept.* **887** 1.

NORTH AREA

Pushing the intensity frontier at ECN3

Following a decision taken during the June session of the CERN Council to launch a technical design study for a new high-intensity physics programme at CERN's North Area, a recommendation for experiment(s) that can best take advantage of the intense proton beam on offer is expected to be made by the end of 2023.

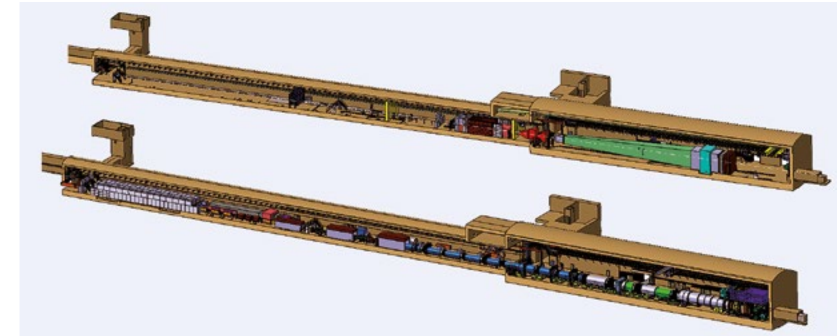
The design study concerns the extraction of a high-intensity beam from the Super Proton Synchrotron (SPS) to deliver up to a factor of approximately 20 more protons per year to ECN3 (Experimental Cavern North 3). It is an outcome of the Physics Beyond Colliders (PBC) initiative, which was launched in 2016 to explore ways to further diversify and expand the CERN scientific programme by covering kinematical domains that are complementary to those accessible to high-energy colliders, with a focus on programmes for the start of operations after Long Shutdown 3 towards the end of the decade.

To employ a high-intensity proton beam at a fixed-target experiment in the North Area and to effectively exploit the protons accelerated by the SPS, the beam must be extracted slowly. In contrast to fast extraction within a single turn of the synchrotron, which utilises kicker magnets to change the path of a passing proton bunch, slow extraction gradually shaves the beam over several hundred thousand turns to produce a continuous flow of protons over a period of several seconds. One important limitation to overcome concerns particle losses during the extraction, foremost on the thin electrostatic extraction septum of the SPS but also along the transfer line ▷

> **CERN is confident in reaching the beam intensities required for all experiments**

leading to the North Area target stations. An R&D study backed by the PBC initiative has shown that it is possible to deflect the protons away from the blade of the electrostatic septum using thin, bent crystals. "Based on the technical feasibility study carried out in the PBC Beam Delivery ECN3 task force, CERN is confident in reaching the beam intensities required for all experiments," says ECN3 project leader Matthew Fraser.

Currently, ECN3 hosts the NA62 experiment, which searches for ultra-rare kaon decays as well as for feebly-interacting particles (FIPs). Three experimental proposals that could exploit a high-intensity beam in ECN3 have been submitted to the SPS committee, and on 6 December the CERN research board is expected to decide which should be taken forward. The High-Intensity Kaon Experiment (HIKE), which requires an increase of the current beam intensity by a factor of between four and seven, aims to increase the precision on ultra-rare kaon decays to further constrain the Cabibbo–Kobayashi–Maskawa unitarity triangle and to search for decays of FIPs that may appear on the same axis as the dumped proton beam. Looking for off-axis FIP decays, the SHADOWS (Search for Hidden And Dark Objects With the SPS) programme could run alongside HIKE when operated in beam-dump mode. Alternatively, the SHiP (Search for Hidden Particles) experiment would investigate hidden sectors such as heavy neutral leptons in the GeV mass range and also enable access to muon- and tau-neutrino physics in a dedicated beam-dump facility installed in ECN3 (see figure).



Pending verdict *Technical drawing of the proposed experiments in the ECN3 hall (brown). The top drawing shows SHiP, and the bottom drawing shows SHADOWS (coral, left) and HIKE (blue and grey, right).*

The ambitious programme to provide and prepare the high-intensity ECN3 facility for the 2030s onwards is driven in synergy with the North Area consolidation project, which has been ongoing since Long Shutdown 2. Works are planned to be carried out without impacting the other beamlines and experiments in the North Area, with first beam commissioning of the new facility expected from 2030.

"Once the experimental decision has been made, things will move quickly and the experimental groups will be able to form strong collaborations around a new ECN3 physics facility, upgraded with the help of CERN's equipment and service groups," says Markus Brugger, co-chair of the PBC ECN3 task force.

Further reading

C Ahdida *et al.* 2023 CERN-PBC Report-2023-003.
J Jaeckel *et al.* 2020 *Nat. Phys.* **16** 393.
F Velotti *et al.* 2019 *Phys. Rev. Accel. Beams* **22** 093502.

CERN

CERN Science Gateway inaugurated

On 7 October, CERN Science Gateway – a new emblematic centre for science education and outreach targeting all ages – was inaugurated in the presence of 500 invited guests, including the president of the Swiss Confederation, ministers and other high-level authorities from CERN's member and associate member states, the project's donors, and other partners. The following day the centre opened to the public, welcoming about 1400 visitors.

Opening the inauguration ceremony in the new 900-seat auditorium, CERN Director-General Fabiola Gianotti stressed the value of education and outreach: "Sharing CERN's research and the beauty and utility of science with the public has always been a key objective and activity of CERN, and with Science Gateway we can expand significantly this component of our mission. We want to show the importance of fundamental research and its applications to society, infuse everyone who comes here with curiosity and a passion for science, and inspire young people to take up careers in science, technology, engineering and mathematics. Science Gateway will be a place where scientists and the public can interact daily. For me, personally, ▷

Joy all round *Left to right: president of the CERN Council Eliezer Rabinovici, president of the Swiss Confederation Alain Berset, CERN Director-General Fabiola Gianotti, chair of Stellantis John Elkann and chief architect Renzo Piano officially declare Science Gateway open.*

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High level *A roundtable discussion took place between visiting ministers, vice-ministers and senior officials on the role of scientific research infrastructures as platforms for talent development.*

First steps *Members of the public enjoying the immersive spaces of CERN Science Gateway the day after the inauguration.*

it is a dream that has become a reality and I am deeply grateful to all the people who have contributed, starting with our generous donors."

The overall cost of Science Gateway, about CHF 100 million, was funded exclusively through donations. Contributing CHF 45 million, the Stellantis Foundation is the largest single donor. The Fondation Hans Wilsdorf is also a major donor. The other donors are the LEGO Foundation, Loterie Romande, Ernst Göhner Stiftung, Rolex, Carla Fendi Foundation, Fondation Gelbert, Solvay, Fondation Meyrinoise du Casino and the town of Meyrin.

In his address, president of the Swiss Confederation Alain Berset said: "Those familiar with Venn diagrams will agree that this invisible circle puts CERN at the intersection between Switzerland, France and Europe, thus symbolising its commitment to shared scientific and political values. CERN truly is an exceptional facility and one that enables Switzerland and Geneva to shine on the world stage."

Throughout the day, guided by CERN scientists and children of CERN personnel, visitors were able to experience first-hand the range of Science Gateway's opportunities, from interactive exhibitions to laboratories for educational experiments and immersive spaces (see p25). The new centre, which is free of charge and open six days a week (it is closed on Mondays), is expected to host up to 500,000 visitors a year from across the world. While the full project was launched in 2018, construction of the Science Gateway campus – designed by renowned architect Renzo Piano – took just over two years, with the first stone of the building being laid on 21 June 2021.

The overall cost of Science Gateway was funded exclusively through donations

Speaking on behalf of CERN's member and associate-member states, president of the CERN Council Eliezer Rabinovici said: "Today we celebrate the courage and passion to innovate that CERN has always demonstrated and the commitment to share the fruits of its research with people from all countries and of all ages. May the science leaders of tomorrow come from among the curious children who will fill this wonderful place with joy in the coming years."

Open doors for open science

September saw another important inauguration at CERN: that of the refurbished CERN library. Following 12 months of renovation work, on 28 September the library and bookshop welcomed users of the new spaces with a two-day event packed with activities and entertainment.

The library renovation project had two main goals. One was to lower the library's carbon footprint using state-of-the-art cooling and ventilation, LED lights, the replacement of all windows and the renovation of the roof. The second aim was to improve the comfort of library users thanks to an optimised layout of the reading room, which is fitted out with modern, high-quality furniture and ergonomic workspaces. A first-stone ceremony was held in March during which a time capsule containing photos of the library through the years, personal messages from users and librarians, and a key holder that opened the old library desk, was sealed into the walls.

Designed by UK architects Bisset Adams, the new CERN library is accessible 24 hours a day, seven days a week. Sixty new workplaces await users, and more than 16,000 books are available in open stacks with many more available upon request or as e-books. The library desk and bookshop are open from 09:00 to 18:00 during weekdays, and books can be borrowed outside these hours by emailing library.desk@cern.ch.

House of knowledge *Inaugurating the all-new CERN library, in which the* Courier *takes pride of place (right).*

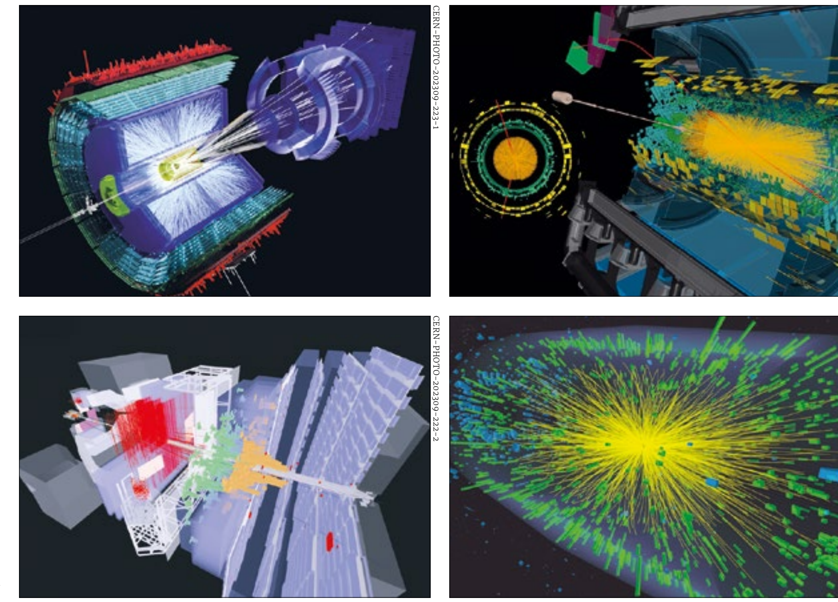
LHC

Heavy ions return in style

Following the successful repair in August of a small leak in the insulation vacuum of the LHC inner triplet assembly near Point 8, beams returned on 30 August for the first long heavy-ion run of Run 3. Stable beams were declared on 27 September with an energy of 5.36 TeV per nucleon pair (compared to 5.02 TeV during Run 2) and a collision rate increased by a factor of 10 since the last heavy-ion run in 2018.

The primary goal of the five-week-long run was to advance understanding of quark–gluon plasma, in which quarks and gluons move around freely for a split-second before the system expands and cools down, turning back into hadrons. In addition to the improved beam parameters, significant upgrades have taken place in the LHC experiments to maximise their physics harvest. ALICE is now using an entirely new mode of data processing, storing all collisions without selection, resulting in up to 100 times more collisions being recorded per second (*CERN Courier* September/October 2023 p39). In addition, its track reconstruction efficiency and precision have increased due to the installation of new subsystems and upgrades of existing ones. CMS and ATLAS have also upgraded their data acquisition, reconstruction and selection infrastructures to take advantage of the increased collision rates, while LHCb is preparing a unique programme of fixed-target collisions between lead nuclei and other types of nuclei using its SMOG2 apparatus.

The increased number of collisions is expected to allow measurements of the temperature of the quark–gluon plasma using thermal radiation in the form of photons and electron–positron pairs. Hydrodynamic properties of this near-perfect liquid state will also be measured in greater detail. In addition, the experiments will probe ultra-peripheral collisions of heavy ions in which one beam emits a high-energy photon that strikes the other beam. These collisions will be used to probe gluonic matter inside nuclei and to study rare phenomena such as light-by-light scattering and τ-lepton photoproduction.



Back on track *First event displays from the Run 3 heavy-ion run recorded by the (clockwise from top left) ALICE, ATLAS, CMS and LHCb experiments.*

ASTROWATCH

Supernovae probe neutrino self-interactions

Towards the end of the lifetime of a very massive ($>8\,M_\odot$) star, the nuclear fusion processes in its core are no longer sufficient to balance the constantly increasing pull of gravitational forces. This eventually causes the core to collapse, with the release of an enormous amount of matter and energy via shockwaves. Nearly 99% of such a core-collapse supernova's energy is released in the form of neutrinos, usually leaving behind a compact proto-neutron star with a mass of about $1.5\,M_\odot$ and a radius of about 10 km. For more massive remnant cores ($>3\,M_\odot$), a black hole is formed instead. The near-zero mass and electrical neutrality of neutrinos make their detection particularly challenging: when the famous 1987 supernova SN1987a occurred 168,000 light-years from Earth, the IMB observatory in the US detected just eight neutrinos, BNO in Russia detected 13 and Kamiokande II in Japan detected 11 (*CERN Courier* March/April 2021 p12).

The effects of neutrino self interactions on SN1987a are starting to become clearer

Besides telling us about the astrophysical processes inside a core-collapse supernova, such neutrino detections might also tell us more about the particles themselves. The Standard Model (SM) predicts feeble self-interactions among neutrinos (νSI), but probing them remains beyond the reach of present-day laboratories on Earth. As outlined in a white paper published earlier this year by Jeffrey Berryman and co-workers, νSI (mediated, for example, by a new scalar or vector boson) enter many beyond-the-SM theories that attempt to explain the generation of neutrino masses and the origin of dark matter. One of the probes that can be used to explore such interactions are core-collapse supernovae, since the extreme conditions in these catastrophic events make it more likely for νSI to occur and therefore affect the behaviour of the emitted neutrinos.

Recently, Po-Wen Chang and colleagues at Ohio State University explored this possibility by considering the formation of a tightly coupled neutrino fluid that expands under relativistic ▷

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hydrodynamics, thereby having an effect on neutrino pulses detected on Earth. The team derives solutions to relativistic hydrodynamic equations for two cases: a "burst outflow" and a "wind outflow". A burst outflow of a uniform neutrino fluid occurs when it undergoes free expansion in vacuum, while a wind outflow occurs when steady-state solutions to the hydrodynamics equations are looked for. In their current work, the authors focus on the former.

In a scenario without νSI, the neutrinos escape and form a shell of thickness about 10^5 times the radius of the proto-neutron star that freely travels away at the speed of light. On the other hand, in a scenario with νSI, the neutrinos don't move freely immediately after escaping the proto-neutron star and instead undergo increased neutrino elastic scattering. As a result, the neutrino shell continues expanding radially until it reaches the point where the density becomes low enough for the neutrinos to decouple and begin free-flowing. The thickness of the shell at this instant depends on the strength of the νSI interactions and is expected to be much larger than that in the no-νSI case. This, in turn, would translate to longer neutrino signals in detectors on Earth.


NASA/ESA/CSA

Super view *A detailed image of SN1987A captured by the James Webb Space Telescope's near-infrared camera.*

Data from SN1987a, where the neutrino signal lasted for about 10 s, broadly agree with the no-νSI scenario and were used to set limits on very strong νSI interactions. On the other hand, if νSI were to exist as a burst-outflow, the proposed model gives very robust results, with an estimated sensitivity of 3 s. Additionally, the authors argue that the steady-state wind-outflow case might be more likely to occur, a dedicated treatment of which has been left for future work.

For the first time since its observation 36 years ago, the effects of νSI on SN1987a are starting to become clearer. Further advances in this direction are much anticipated so that when the next supernovae occurs it could help clear the fog that surrounds our current understanding of neutrinos.

Further reading

J Berryman *et al.* 2023 *Phys. Dark Universe* **42** 101267.
P-W Chang *et al.* 2023 *Phys. Rev. Lett.* **131** 071002.

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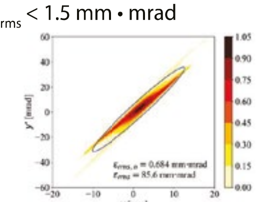

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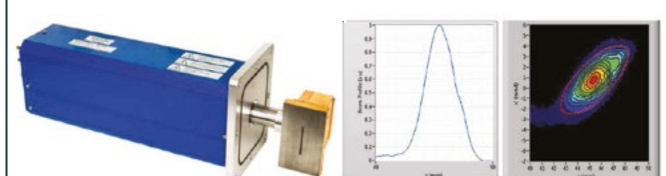

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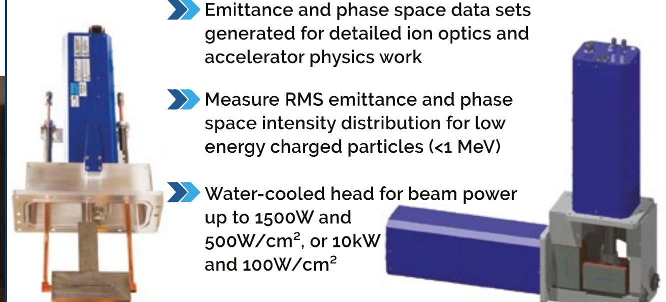

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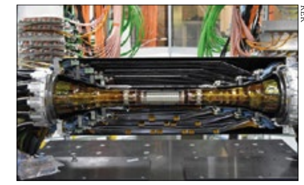

KEK

Undergoing installation at KEK.

Belle II pixels in place

On 3 August, the world's thinnest pixel vertex detector – roughly the size of a drinks can – was installed in the Belle II experiment at the SuperKEKB collider in Japan. Due to start collecting data in early 2024, the new detector, which consists of 20 75 µm-thick silicon wafers arranged in two concentric cylindrical layers, is located 1.4 cm from the collision point to allow accurate reconstruction of the decay points of short-lived particles. The detector, based on DEPFET technology developed at the Max Planck Semiconductor Laboratory in Munich and commissioned and tested at DESY, is designed to capture B decays at a rate of up to 50 kHz.

UK back on the Horizon

On 7 September, the European Commission and the UK reached a political agreement on the UK's participation in Horizon Europe, the EU's research and innovation programme, and Copernicus, the EU's Earth observation programme. The agreement ends several years of uncertainty following the UK's departure from the EU and means that UK researchers can now apply for grants and bid to take part in projects under the Horizon Europe programme, with certainty that the UK will be participating as a fully associated member for the remaining lifetime of the programme to 2027.

Exploring Run 3 for new physics

The CMS collaboration has reported its first search for new physics using data from LHC Run 3, recorded at a collision energy of 13.6 TeV and corresponding to an integrated luminosity of 36.7 fb^{-1}. The collaboration searched for a pair of oppositely-charged muons that originate from a common secondary vertex spatially separated from the proton–proton interaction point – a key signature of long-lived particles. The results, which mark a significant improvement over previous analyses thanks to improved triggers for displaced muons and offline analysis refinements, set new limits on two benchmark models: the hidden Abelian Higgs model, in which the Higgs boson decays into a pair of long-lived dark photons, and an R-parity violating supersymmetric model, in which long-lived neutralinos decay into a pair of muons and a neutrino (CMS-PAS-EXO-23-014).

Record precision on α_s

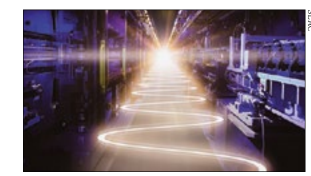
ATLAS researchers have made the most precise measurement to date of the strength of the strong force at the Z-boson mass, $\alpha_s(m_Z) = 0.1183 \pm 0.0009$, using 20.2 fb^{-1} of LHC data recorded in 2012 at a centre-of-mass energy of 8 TeV. The team studied Z-boson decays that involve two leptons and determined the Z boson's transverse momentum by examining its decay products, comparing the measurement with theoretical predictions to determine α_s. The result, which represents an uncertainty of just 0.8%, agrees with both the world average and state-of-the-art calculations (arXiv:2309.12986).

Hamburg backs PETRA IV

On 27 September, the Hamburg City Parliament agreed to provide 10% of the total funding required for PETRA IV, an upgrade of the existing PETRA III light source that aims to accelerate the development of technologies such as novel materials and drug development. The total cost will be €1.54 billion, of which DESY will use its own funds amounting to €170 million. Preparatory work on PETRA IV is envisaged to take place in 2024 and 2025, with central construction beginning in 2026 and commissioning scheduled in 2029. The PETRA storage ring was originally built as an e^+e^- collider for high-energy physics, after which it served as a pre-accelerator for the electron–proton collider HERA.

First light for LCLS-II

After more than a decade of work, the newly upgraded Linac Coherent Light Source (LCLS) at SLAC successfully produced its first X-rays on 18 September. Providing up to one million X-ray flashes per second (8000 times more than its predecessor),


SLAC

A depiction of LCLS-II.

LCLS-II will enable unprecedented studies of ultrafast atomic and molecular phenomena relevant to fields ranging from quantum materials to clean energy technologies and medicine. Central to LCLS-II's enhanced capabilities is a linac based on superconducting radio-frequency cavities developed and built in close collaboration with Fermilab and JLab, which will operate in parallel with the existing copper one to allowing observations over a wider energy range (*CERN Courier* September/October 2022 p39).

AION interference

Atom interferometry is a promising technique to provide sensitive probes of dark matter in the form of waves of ultralight bosons and gravitational waves in the mid-frequency band between that of operating and planned laser interferometers. On 24 July the AION consortium in the UK, one of several teams worldwide working towards such detectors, passed a milestone with the observation of atomic interference fringes in its laboratory at the University of Birmingham. Once the technique has been perfected and developed to scale, the consortium plans to use larger interferometers to search for changes in the fringes due to atomic interactions with ultra-light dark matter or the passage of gravitational waves, as proposed in the AION roadmap (*CERN Courier* March/April 2021 p10).

Shape-shifting gold

An intriguing property of nuclei is that their shape, usually spherical or nearly spherical, can change dramatically when single neutrons are removed. Neutron-deficient mercury and bismuth nuclei have already been observed to morph from spheres into rugby balls. Surprisingly, a study at ISOLDE has now revealed such behaviour in neutron-deficient gold nuclei at a lower neutron number, with a particularly strong radius change at N = 99. Fifty years after it was first observed, the phenomenon of shape staggering still poses a challenge to nuclear theory (accepted by *Phys. Rev. Lett.*).

Nuclear beam advance

On 28 July, physicists at the K500 Superconducting Cyclotron (SCC) facility at the Variable Energy Cyclotron Centre (VECC) in Kolkata, India, performed an experiment to characterise a $^{14}N^{4+}$ beam with an energy of 18 MeV/nucleon, marking a key step towards fundamental research into frontier areas of nuclear physics around the Fermi energy domain. Within VECC's sights are the nuclear equation of state and isospin degree of freedom, structures of exotic isotopes and resonances, as well as heavy-ion fusion leading to nuclei in the island of super-heavy elements. The team is also performing experiments with a $^{20}Ne^{6+}$ beam with an energy of 21 MeV/nucleon.

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ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

ATLAS

Highest-energy observation of entanglement

Entanglement is an extraordinary feature of quantum mechanics: if two particles are entangled, the state of one particle cannot be described independently from the other. It has been observed in a wide variety of systems, ranging from microscopic particles such as photons or atoms to macroscopic diamonds, and over distances ranging from the nanoscale to hundreds of kilometres. Until now, however, entanglement has remained largely unexplored at the high energies accessible at hadron colliders, such as the LHC.

At the TOP 2023 workshop, which took place in Michigan in September, the ATLAS collaboration reported a measurement of entanglement using top-quark pairs with one electron and one muon in the final state selected from proton–proton collision data collected during LHC Run 2 at a centre-of-mass energy of 13 TeV, opening new ways to test the fundamental properties of quantum mechanics.

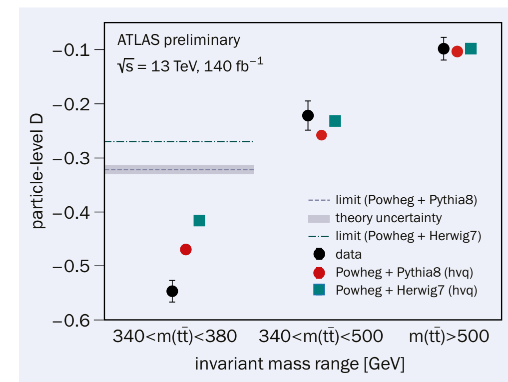

Fig. 1. *The observed and expected values of the entanglement witness D for different regions defined by $m_{t\bar{t}}$, compared to various Monte Carlo predictions. The value of the entanglement limit $D = -1/3$ at parton level is converted to particle level.*

Two-qubit system

The simplest system that gives rise to entanglement is a pair of qubits, as in the case of two spin-1/2 particles. Since top quarks are typically generated in top-antitop pairs ($t\bar{t}$) at the LHC, they represent a unique high-energy example of such a two-qubit system. The extremely short lifetime of the top (10^{-25} s, which is shorter than the timescale for hadronisation and spin decorrelation) means that its spin information is directly transferred to its decay products. Close to threshold, the $t\bar{t}$ pair produced through gluon fusion is almost in a spin-singlet state, maximally entangled. By measuring the angular distributions of the $t\bar{t}$ decay products close to threshold, one can therefore conclude whether the $t\bar{t}$ pair is in an entangled state.

For this purpose, a single observable can be used as an entanglement witness, D. This can be measured from the distribution of $\cos\varphi$, where φ is the angle between the charged lepton directions in each of the parent top and anti top rest frames, with $D = -3 \cdot \langle\cos\varphi\rangle$. The entanglement criterion is given by $D = \mathrm{tr}(\mathbf{C})/3 < -1/3$, where $\mathrm{tr}(\mathbf{C})$ is the sum of the diagonal elements of the spin-correlation matrix C of the $t\bar{t}$ pair before hadronisation effects occur. Intuitively, this criterion can be understood from the fact that $\mathrm{tr}(\mathbf{C})$ is the expectation value of the product of the spin polarisations, $\mathrm{tr}(\mathbf{C}) = \langle\sigma\cdot\bar{\sigma}\rangle$, with σ, $\bar{\sigma}$ being the $t,\bar{t}$ polarisations, respectively (classically $\mathrm{tr}(\mathbf{C}) \leq 1$, since spin polarisations are unit vectors). D is measured in a region where the invariant mass is approximately twice the mass of the top quark, $340 < m_{t\bar{t}} < 380$ GeV, and is performed at particle level, after hadronisation effects occur.

The shape of $\cos\varphi$ is distorted by detector and event-selection effects for which it has to be corrected. A calibration curve connecting the value of D before and after the event reconstruction is extracted from simulation and used to derive D from the corresponding measurement, which is then compared to predictions from state-of-the-art Monte Carlo simulations. The measured value $D = -0.547 \pm 0.002\,(\mathrm{stat.}) \pm 0.021\,(\mathrm{syst.})$ is well beyond five sigma from the non-entanglement hypothesis. This constitutes the first-ever observation of entanglement between a pair of quarks and the highest-energy measurement of entanglement.

Apart from the intrinsic interest of testing entanglement under unprecedented conditions, this measurement paves the way to use the LHC as a novel facility to study quantum information. Prime examples are quantum discord, which is the most basic form of quantum correlations; quantum steering, which is how one subsystem can steer the state of the other one; and tests of Bell's inequalities, which explore non-locality. Furthermore, borrowing concepts from quantum information theory inspires new approaches to search for physics beyond the Standard Model.

Further reading

ATLAS Collab. 2023 ATLAS-CONF-2023-069.
Y Afik and J de Nova 2021 *Eur. Phys. J. Plus* **136** 907.

LHCb

Antinuclei production in pp collisions

At the European Physical Society Conference on High Energy Physics, held in Hamburg in August, the LHCb collaboration announced first results on the production of antihelium and antihypertriton nuclei in proton–proton (pp) collisions at the LHC. These promising results open a new research field, that up to now has been pioneered by ground-breaking work from the ALICE collaboration on the central rapidity interval $|y| < 0.5$. By extending the measurements into the so-far unexplored forward region $1.0 < y < 4.0$, the LHCb results provide new experimental input to derive the production cross sections of antimatter particles formed in pp collisions, which are not calculable from first principles.

The helium identification method proves the feasibility of new research fields at LHCb

LHCb's newly developed helium-identification technique mainly exploits information from energy losses through ionisation in the silicon sensors upstream (VELO and TT stations) and downstream (Inner Tracker) of the LHCb magnet. The amplitude measurements from up to ~50 silicon layers are combined for each sub-detector into a log-likelihood estimator. In addition, timing information from the Outer Tracker and velocity measurements from the RICH detectors are used to ▷

improve the separation power between heavy helium nuclei (with charge Z = 2) and lighter, singly charged particles (mostly charged pions). With a signal efficiency of about 50%, a nearly background-free sample of 1.1×10^5 helium and antihelium nuclei is identified in the data collected during LHC Run 2 from 2016 to 2018 (see figure, inset).

As a first step towards a light-nuclei physics programme in LHCb, hypertritons are reconstructed via their two-body decay into a now-identified helium nucleus and a charged pion. Hypertriton (${}^3_\Lambda\mathrm{H}$) is a bound state of a proton, a neutron and a Λ hyperon that can be produced via coalescence in pp collisions. These states provide experimental access to the hyperon–nucleon interaction through the measurement of their lifetime and of their binding energy. Hyperon–nucleon interactions have significant implications for the understanding of astrophysical objects such as neutron stars. For example, the presence of hypernuclei in the dense inner core can significantly suppress the formation of high-mass neutron stars. As a result, there is some tension between the observation of neutron stars heavier than two solar masses and corresponding hypertriton results from the STAR collaboration at Brookhaven. ALICE seems to have resolved the tension between hypertriton measurements at colliders and neutron stars. An independent confirmation of the ALICE result has up to now been missing, and can be provided by LHCb.

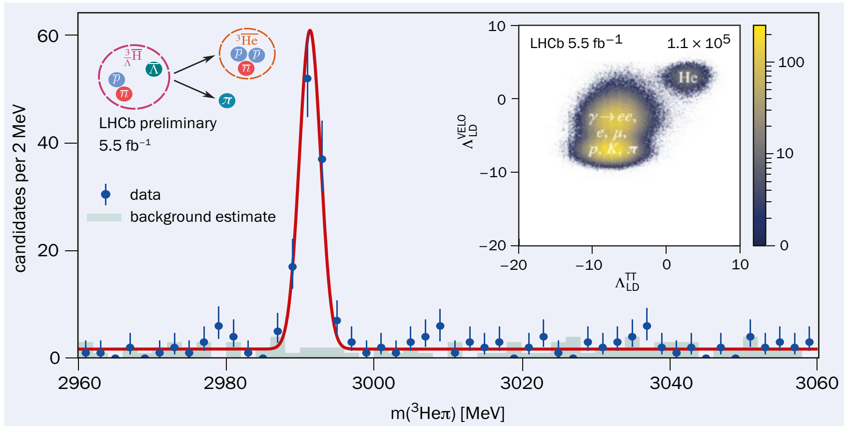

Fig. 1. *Invariant-mass distribution of hypertriton and antihypertriton candidates reconstructed using the hypertriton decay and its charge conjugate, where ^{3}He nuclei are identified using a novel LHCb technique. The separation power of this method is shown in the inset, where 1.1×10^5 helium tracks are isolated from Z = 1 particles.*

The invariant-mass distribution of hypertriton and antihypertriton candidates is shown in figure 1. More than 100 signal decays are reconstructed, with a statistical uncertainty on the mass of 0.16 MeV, similar to that of STAR. In a next step, corrections for efficiencies and acceptance obtained from simulation, as well as systematic uncertainties on the mass scale and lifetime measurement, will be derived.

The new helium identification method from LHCb summarised here proves the feasibility of a rich programme of measurements in QCD and astrophysics involving light antinuclei in the coming years. The collaboration also plans to apply the method to other LHCb Run 2 datasets, such as proton–ion, ion–ion and SMOG collision data.

Further reading

LHCb Collab. 2023 LHCb-CONF-2023-002.
LHCb Collab. 2023 LHCb-DP-2023-002.

ALICE

Collectivity in small systems produced at the LHC

High-energy heavy-ion collisions at the LHC exhibit strong collective flow effects in the azimuthal angle distribution of final-state particles. Since these effects are governed by the initial collision geometry of the two colliding nuclei and the hydrodynamic evolution of the collision, the study of anisotropic flow is a powerful way to characterise the production of the quark–gluon plasma (QGP) – an extreme state of matter expected to have existed in the early universe.

To their surprise, researchers on the ALICE experiment have now revealed similar flow signatures in small systems encompassing proton–proton (pp) and proton–lead (pPb) collisions, where QGP formation was previously assumed not to occur. The origin of the flow signals in small systems (and in particular whether the mechanisms behind these correlations in small systems share commonalities with heavy-ion collisions) are not yet fully understood. To better interpret these results, and thus to understand the limit of the system size that exhibits fluid-like behaviour, it is important to carefully single out possible scenarios that can mimic the effect of collective flow.

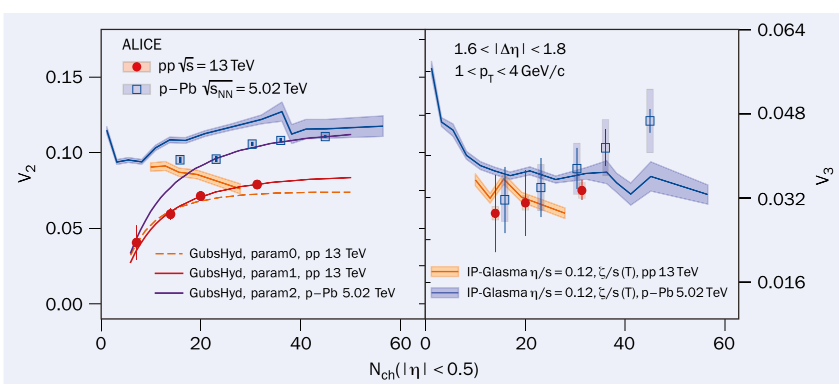

Fig. 1. *The measured and calculated evolution of elliptic (left) and triangular (right) flow in pp and pPb collisions as a function of charged-particle multiplicity at midrapidity. The measurements are compared to the state-of-the-art hydrodynamic calculations.*

Anisotropic-flow measurements ▷ become more difficult in small systems because non-flow effects, such as the presence of jets, become more dominant. Thus, it is important to examine methods where non-flow effects are properly subtracted first. One of the methods, the so-called low-multiplicity template fit, has been widely used in several experiments to determine and subtract the non-flow elements.

The origin of the flow signals in small systems is not yet fully understood

The ALICE collaboration studied long-range angular correlations for pairs of charged particles produced in pp and pPb collisions at centre-of-mass energies of 13 TeV and 5.02 TeV, respectively. Flow coefficients were extracted from these correlations using the template-fit method in samples of events with different charged-particle multiplicities. This method considers that the yield of jet fragments increases as a function of particle multiplicity and allows physicists to examine assumptions made in the low-multiplicity template fit for the first time – demonstrating their validity, including a possible jet-shape modification.

Figure 1 shows the measurement of two components of anisotropic flow – elliptic (v_2) and triangular (v_3) – as a function of charged-particle multiplicity at midrapidity (N_{ch}). The data show decreasing trends towards lower multiplicities. In pp collisions, the results suggest that the v_2 signal disappears below N_{ch} = 10. The results are then compared with hydrodynamic models. To accurately describe the data, especially for events with low multiplicities, a better understanding of initial conditions is needed.

These results can help to constrain the modelling of initial-state simulations, as the significance of initial-state effects increases for collisions resulting in low multiplicities. The measurements with larger statistics from Run 3 data will push down this multiplicity limit and reduce the associated uncertainties.

Further reading

ALICE Collab. 2023 arXiv: 2308.16591.

CMS

Measuring energy correlators inside jets

Quarks and gluons are the only known elementary particles that cannot be seen in isolation. Once produced, they immediately start a cascade of radiation (the parton shower), followed by confinement, when the partons bind into (colour-neutral) hadrons. These hadrons form the jets that we observe in detectors. The different phases of jet formation can help physicists understand various aspects of quantum chromodynamics (QCD), from parton interactions to hadron interactions – including the confinement transition leading to hadron formation, which is particularly difficult to model. However, jet formation cannot be directly observed. Recently, theorists proposed that the footprints of jet formation are encoded in the energy and angular correlations of the final particles, which can be probed through a set of observables called energy correlators. These observables record the largest angular distance between N particles within a jet (x_L), weighted by the product of their energy fractions.

The CMS collaboration recently reported a measurement of the energy correlators between two (E2C) and three (E3C) particles inside a jet, using jets with p_T in the 0.1–1.8 TeV range. Figure 1 (top) shows the measured E2C distribution. In each jet p_T range, three scaling regions can be seen, corresponding to three stages in jet-formation evolution: parton shower, colour confinement and free hadrons (from right to left). The opposite E2C trends in the low and high x_L regions indicate that the interactions between partons and those between hadrons are rather different; the intermediate region reflects the confinement transition from partons to hadrons.

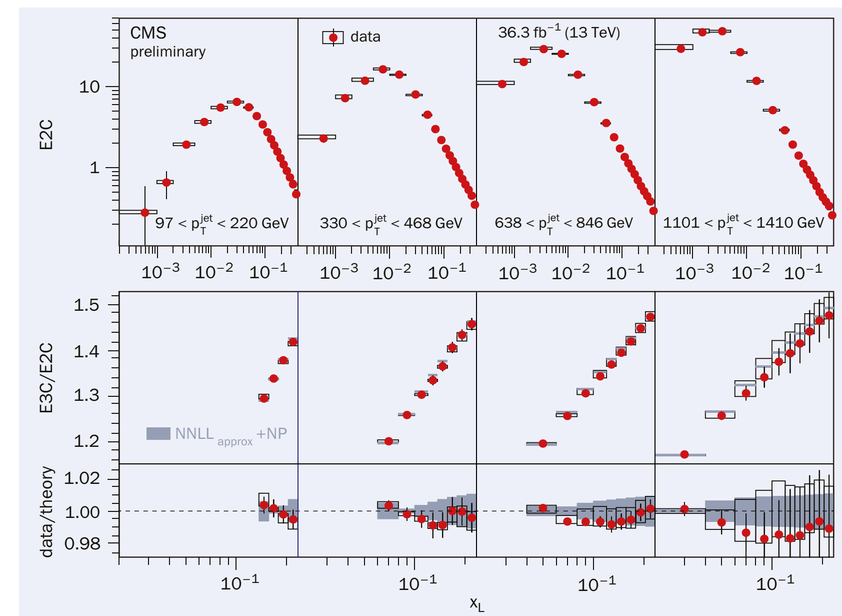

Fig. 1. *Top: the unfolded distribution of E2C, after subtracting backgrounds and removing detector effects, in four different jet p_T regions. Bottom: the E3C over E2C ratio as measured by CMS (red points) and as computed by theory (grey bars); the lower panels show the data over theory ratios.*

Theorists have recently calculated the dynamics of the parton shower with unprecedented precision. Given the high precision of the calculations and of the measurements, the CMS team used the E3C over E2C ratio, shown in figure 1 (bottom), to evaluate the strong coupling constant α_S. The ratio reduces the theoretical and experimental uncertainties, and therefore minimises the challenge of distinguishing the effects of α_S variations from those of changes in quark–gluon composition. Since α_S depends on the energy scale of the process under consideration, the measured value is given for the Z-boson mass: $\alpha_S = 0.1229$ with an uncertainty of 4%, dominated by theory uncertainties and by the jet-constituent energy-scale uncertainty. This value, which is consistent with the world average, represents the most precise measurement of α_S using a method based on jet evolution.

Further reading

CMS Collab. 2023 CMS-PAS-SMP-22-015.

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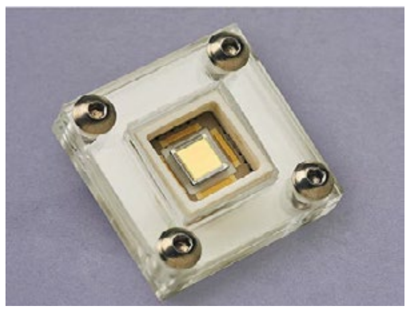
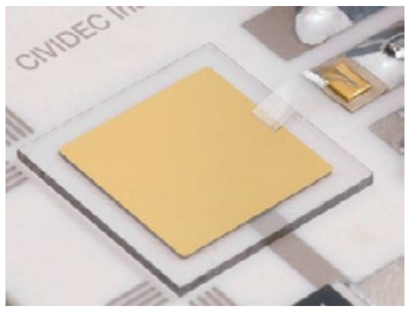

Neutron Diagnostics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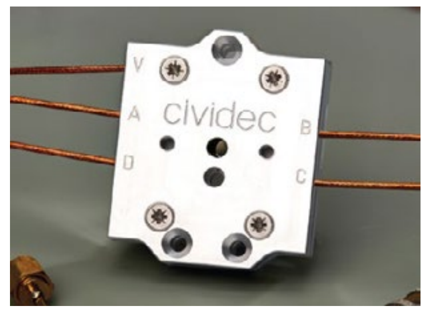
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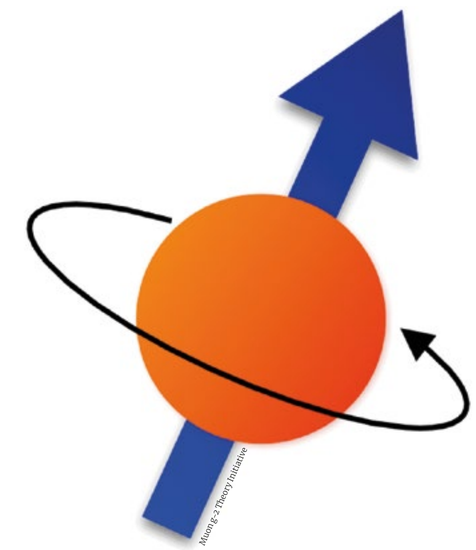
FIELD NOTES

Reports from events, conferences and meetings

Sixth Plenary Workshop of the Muon g-2 Theory Initiative

Getting to the bottom of muon g-2

About 90 physicists attended the sixth plenary workshop of the Muon g-2 Theory Initiative, held in Bern from 4 to 8 September, to discuss the status and strategies for future improvements of the Standard Model (SM) prediction for the anomalous magnetic moment of the muon. The meeting was particularly timely given the recent announcement of the results from runs two and three of the Fermilab g-2 experiment (p8), which reduced the uncertainty of the world average to 0.19 ppm, in dire need of a SM prediction at commensurate precision. The main topics of the workshop were the two hadronic contributions to g-2, hadronic vacuum polarisation (HVP) and hadronic light-by-light scattering (HLbL), evaluated either with a lattice-QCD or data-driven approach.



Hadronic vacuum polarisation

The first one-and-a-half days were devoted to the evaluation of HVP – the largest QCD contribution to g-2, whereby a virtual photon briefly transforms into a hadronic "blob" before being reabsorbed – from e^+e^- data. The session started with a talk from the CMD-3 collaboration at the VEPP-2000 collider, whose recent measurement of the $e^+e^- \to \pi^+\pi^-$ cross section generated shock waves earlier this year by disagreeing (at the level of 2.5–5σ) with all previous measurements used in the Theory Initiative's 2020 white paper. The programme also featured a comparison with results from the earlier CMD-2 experiment, and a report from seminars and panel discussions organised by the Theory Initiative in March and July on the details of the CMD-3 result. While concerns remain regarding the estimate of certain systematic effects, no major shortcomings could be identified.

Further presentations from BaBar, Belle II, BESIII, KLOE and SND detailed their plans for new measurements of the 2π channel, which in the case of BaBar and KLOE involve large data samples never analysed before for this measurement. Emphasis was put on the role of radiative corrections, including a recent paper by BaBar on additional radiation in initial-state-radiation events and, in general, the development of higher-order Monte Carlo generators. Intensive discussions reflected a broad programme to clarify the extent to which tensions among the experiments can be due to higher-order radiative effects and structure-dependent corrections. Finally, updated combined fits were presented for the 2π and 3π channels, for the former assessing the level of discrepancy among datasets, and for the latter showing improved determinations of isospin-breaking contributions.

Six lattice collaborations (BMW, ETMC, Fermilab/HPQCD/MILC, Mainz, RBC/UKQCD, RC*) presented updates on the status of their respective HVP programmes. For the intermediate-window quantity (the contribution of the region of Euclidean time between about 0.4–1.0 fm, making up about one third of the total), a consensus has emerged that differs from e^+e^--based evaluations (prior to CMD-3) by about 4σ, while the short-distance window comes out in agreement. Plans for improved evaluations of the long-distance window and isospin-breaking corrections were presented, leading to the expectation of new, full computations for the total HVP contribution in addition to the BMW result in 2024. Several talks

CMD-3 generated shock waves by disagreeing with all previous measurements at the level of 2.5–5σ

addressed detailed comparisons between lattice-QCD and data-driven evaluations, which will allow physicists to better isolate the origin of the differences once more results from each method become available. A presentation on possible beyond-SM effects in the context of the HVP contribution showed that it seems quite unlikely that new physics can be invoked to solve the puzzles.

Light-by-light scattering

The fourth day of the workshop was devoted to the HLbL contribution, whereby the interaction of the muon with the magnetic field is mediated by a hadronic blob connected to three virtual photons. In contrast to HVP, here the data-driven and lattice-QCD evaluations agree. However, reducing the uncertainty by a further factor of two is required in view of the final precision expected from the Fermilab experiment. A number of talks discussed the various contributions that feed into improved phenomenological evaluations, including sub-leading contributions such as axial-vector intermediate states as well as short-distance constraints and their implementation. Updates on HLbL from lattice QCD were presented by the Mainz and RBC/UKQCD groups, as were results on the pseudoscalar transition form factor by ETMC and BMW. The latter in particular allow cross checks of the numerically dominant pseudoscalar-pole contributions between lattice QCD and data-driven evaluations.

On the final day, the status of alternative methods to determine the HVP contribution were discussed, first from the MUonE experiment at CERN, then from τ data (by Belle, CLEOc, ALEPH and other LEP experiments). First MUonE results could become available at few-percent precision with data taken in 2025, while a competitive measurement would proceed after Long Shutdown 3. For the τ data, new input is expected from the Belle II experiment, but the critical concern continues to be control over isospin-breaking corrections. Progress in this direction from lattice QCD was presented by the RBC/UKQCD ▷

collaboration, together with a roadmap showing how, potentially in combination with data-driven methods, τ data could lead to a robust, complementary determination of the HVP contribution.

The workshop concluded with a discussion on how to converge on a recommendation for the SM prediction in time for the final Fermilab result, expected in 2025, including new information expected from lattice QCD, the BaBar 2π analysis and radiative corrections. A final decision for the procedure for an update of the 2020 white paper is planned to be taken at the next plenary meeting in Japan in September 2024. In view of the long-term developments discussed at the workshop – not least the J-PARC Muon g-2/EDM experiment, due to start taking data in 2028 – it is critical that the work by the Theory Initiative continues beyond the lifespan of the Fermilab experiment, to maximise the amount of information on physics beyond the SM that can be inferred from precision measurements of the anomalous magnetic moment of the muon.

It is critical that the Theory Initiative work continues beyond the lifespan of the Fermilab experiment

Gilberto Colangelo *and* **Martin Hoferichter** *University of Bern.*

EPS-HEP 2023

Setting sail for HEP in Hamburg

The European Physical Society Conference on High Energy Physics (EPS-HEP), which took place in Hamburg from 21 to 25 August, attracted around 900 physicists in-person and online to discuss a plethora of topics and results. An intense programme underlined both the vibrancy and diversity of the field, including the first evidence for a stochastic gravitational-wave background (*CERN Courier* September/October 2023 p7) as well as the latest measurement of the anomalous magnetic moment of the muon (p8) – the latter sparking many discussions that continued during the breaks.

M Mayer/DESY

Together again *Participants at the first in-person EPS conference since the COVID-19 pandemic.*

The participants were treated to many LHC Run 2 legacy results, as well as brand-new ones using freshly analysed Run 3 data. A large chunk of these results comprised precision measurements of the Higgs boson in view of gaining a deeper understanding of the origin of electroweak symmetry breaking. As the Higgs boson is deeply connected to many open questions potentially linked to physics beyond the Standard Model (SM), such as the origin of particle masses and flavour, studying it in the context of effective field theory is a particularly hot topic. A rich potential programme of "simplified" models for Higgs physics that can better quantify the reach of the LHC and offer new observables is also under development.

New frontiers

The ATLAS and CMS collaborations presented no fewer than 37 and 27 new preliminary results, respectively. Besides Higgs-sector physics, the experiments revealed their latest results of searches for physics beyond the SM, including new limits on the existence of supersymmetric and dark-matter particles. At the intensity frontier, the latest search for the ultra-rare decay $K^+ \to \pi^+ e^+ e^- e^+ e^-$ from the NA62 experiment placed upper limits on dark-boson candidate masses, underlining the powerful complementarity between CERN's fixed-target and LHC programmes. The Belle II collaboration presented first evidence of the decay $B^+ \to K^+ \nu\bar{\nu}$, as well as the result of their $R(X) = Br(B \to X\tau\nu_\tau)/Br(B \to X\ell\nu_\ell)$ measurement – the first at a B factory. The LHCb collaboration also presented an update of its recent $R(D^*) = Br(B \to D^*\tau\nu_\tau)/Br(B \to D^*\ell\nu_\ell)$ measurement. Another highlight was LHCb's observation of the hypernuclei antihypertriton and hypertriton (p15).

The state of the art in neutrino physics was presented, covering the vast landscape of experiments seeking to shed light on the three-flavour paradigm as well as the origin of the neutrino masses and mixings. So far, analyses by T2K and NOvA show a weak preference for a normal mass ordering, while the inverted mass ordering is not yet ruled out. With a joint analysis between T2K and NOvA in progress, updates are expected next year. At CERN the FASER experiment, which made the first observation of muon neutrinos at a collider earlier this year (*CERN Courier* May/June 2023 p9), presented the first observation of collider electron neutrinos. Looking outwards, a long-awaited discovery of galactic neutrinos was presented by IceCube.

The current FCC feasibility status was presented, along with that of other proposed colliders that could serve as Higgs factories. The overarching need to join forces between the circular- and linear-collider communities and to use all the gained knowledge for getting at least one accelerator approved was reflected during the discussions and many talks, as were the sustainability and energy consumption of detector and accelerator concepts. Intense discussions took place on novel and potentially game-changing accelerator concepts, such as energy recovery technologies or plasma acceleration. While not yet ready to be used on a large scale, they promise to have a big impact on the way accelerators are built in the future. Beyond colliders, the community also looked ahead to the DUNE and Hyper-Kamiokande experiments, and to proposed experiments such as the Einstein Telescope and those searching for axions.

Intense discussions took place on novel and potentially game-changing accelerator concepts

A rich social programme included a public lecture by Andreas Hoecker (CERN) about particle physics at the highest energies, a concert with an introduction to the physics of the organ by Wolfgang Hillert (University of Hamburg), as well as an art exhibition called "High Energy" and a Ukrainian photo exhibition depicting science during times of war.

The next EPS-HEP conference will take place in 2025 in Marseille.

Kristiane Bernhard-Novotny *associate editor.*

LEPTON PHOTON 2023

Lepton Photon shines down under

The cold was biting the morning of 17 July, when Wurundjeri Elder Uncle Tony Garvey welcomed 219 particle physicists to the unceded lands of the Wurundjeri, Bunurong and Wadawurrung peoples for the 31st International Conference on Lepton Photon Interactions, hosted in Melbourne, Australia. Although the distance to Melbourne is considerable, a broad range of nationalities were represented, and about a third of participants were students.

rudi1976 – Fotolia.com

Bright lights *Melbourne's skyline and the Yarra river.*

Over five days of pronouncements, presentations and posters, topics included current and future prospects in detector technologies, advances in theoretical calculations (with a particular focus on effective field theories), and improving diversity and outreach in physics. Results from a large number of experiments were presented, many of which are building excitement for the next generation of measurements that seek to provide even more rigorous tests of the Standard Model (SM) and improved searches for physics beyond it (BSM).

The results presented were too numerous to review comprehensively. However, they tended to skew towards flavour physics, with a particular emphasis on searches for CP- and lepton flavour-violation and tests of lepton-flavour universality (LFU). Overall, tensions between the SM and experimental measurements of LFU remain. In particular, Kazuki Kojima (Nagoya University) presented a measurement of $R(D^*)$, which is a test of LFU performed with B-meson decays, finding the ratio $R(D^*) = 0.267^{+0.041}_{-0.039}\,(\text{stat.})^{+0.028}_{-0.033}\,(\text{syst.})$. While compatible with the SM, it increases the tension with theory from 3.2σ to 3.3σ when all measurements of R(D) and $R(D^*)$ are combined.

Not to be outdone, the LHC experiments presented a range of precision measurements of SM parameters, further reducing the available parameter space for BSM physics. In particular, Linda Finco (INFN Torino) from ATLAS presented the most precise measurement of the Higgs-boson mass (*CERN Courier* September/October 2023 p16): 125.11 ± 0.09 (stat.) ± 0.06 (syst.) GeV, using the full Run 1 and Run 2 datasets for both the $H \to ZZ \to 4\ell$ and $H \to \gamma\gamma$ channels. This is one of the most precisely determined masses of any SM particle, a real achievement of precision physics.

Now that the available parameter space for BSM models is shrinking, more innovative approaches to particle physics are needed. One such approach, presented by Ling Sun (Australian National University), is to use the phenomenon of superradiance to search for ultralight bosons around rapidly rotating black holes. The boson clouds extract angular momentum from the black hole when the superradiance condition is met, producing gravitational radiation that could be measured by current and future gravitational-wave detectors. Such a method provides an avenue to measure particles that interact only through gravity, opening a novel avenue for exploring particles beyond the SM.

On the penultimate evening, Alan Duffy (Swinburne University) and Suzie Sheehy (University of Oxford and University of Melbourne) delivered a public lecture "How to discover a universe" to a mix of conference participants, high-school students and the interested public, stressing that science is cultural as well as technological. The best poster was awarded to Emily Filmer (University of Adelaide) for "Searches for BSM physics using challenging long-lived signatures with the ATLAS detector", while the "people's choice" was awarded to Eliot Walton (Monash University) for her poster "The Queer History of Physics". Australia's small but growing particle-physics community was extremely well represented, and the exposure of the global community to us made Lepton Photon 2023 a resounding success.

Eliot Walton *Monash University.*

PLANCK 2023

Celebrating 25 years of Planck

On its silver jubilee, the Planck 2023 conference took place at the University of Warsaw from 22 to 26 May, attracting around 180 participants. Initiated by a meeting in a small town near Warsaw, Kazimierz Dolny, in 1998 and hosted each year by theory groups across Europe, the series has become one of the key conferences on beyond-the-Standard Model physics. Plenary talks covering the latest topics in theory and phenomenology as well as many parallel talks given by young researchers are the core of the conference programme, following the evolving trends in particle physics and cosmology from the Planck to the electroweak scales.

M Mikołajczyk / Candela Foundation

Joining forces *Planck 2023 focused on the interface between particle physics and cosmology.*

This year's conference focused on "Hot topics in particle physics and cosmology: theory facing experimental prospects". The first day's plenaries were mainly devoted to machine-learning techniques and to collider physics. Enthusiastic speakers on the former met with some reservation in parts of the audience, which stressed the need for a good balance between new techniques and new physics ideas, while the collider talks emphasised the importance of precision Higgs physics and its prospects at the LHC and HL-LHC for a full understanding of the Brout–Englert–Higgs mechanism. On the theory side, the approach of effective field theory was strongly advocated. A separate session was devoted to flavour physics, in which new ideas on the ▷

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origin of flavour were presented. A review of rare decays as precision tests of the Standard Model (SM) and as probes of new physics complemented the experimental summary.

The conference was dominated by topics at the interface between particle physics and cosmology. Covered in the many talks were axion couplings and search strategies, axions in rare decays, models of CP violation with nucleon and atomic electric dipole moments with or without the QCD axion, searches for very light and weakly interacting axion-like particles as a complementarity to heavy new particle searches in colliders, and much more.

Another issue vividly under consideration was dark matter. Among important theoretical questions is the role of gravity in the production of dark matter. Avoiding overabundance of gravitationally produced dark matter is an important constraint on effective quantum gravity. Similar logic concerns right-handed neutrinos as a dark-matter candidate in simple extensions of the SM. Both were analysed in a number of presentations. Anticipating the results from the Nanograv experiment (*CERN Courier* September/October 2023 p7), various concrete sources of such signals were reviewed, such as primordial black-hole production, domain walls, cosmic strings and phase transitions in the early universe. Selected theoretical aspects of dark-matter models (such as accidental dark matter with its several realisations) and the analysis of their experimental signatures through new theoretical developments in computing high-energy photon signals from heavy classic WIMPs were presented.

The conference was very successful in connecting new theoretical ideas with planned experimental programmes

More exotic problems at the interface between particle physics and cosmology were also touched upon. One example is how annihilating dark matter can affect late stellar evolution and the spectrum of black holes, which can be tested with gravitational-wave observations. Another is how the apparent anomaly in the primordial abundance of ^{4}He can be linked to a neutrino–antineutrino asymmetry in the early universe that impacts Big Bang nucleosynthesis. Gravitational waves as a probe of beyond-the-SM physics were discussed at length, also including possible new-physics signals from pulsar timing arrays.

The conference was very successful in connecting new theoretical ideas with planned experimental programmes. The next Planck meeting will be held in Lisbon.

Hans Peter Nilles *University of Bonn and* **Stefan Pokorski** *University of Warsaw.*

Rencontres du Vietnam

Thirty years of growth in Vietnam

Exactly three decades ago, the first conference in the Les Rencontres du Vietnam series was held in Hanoi, initiated by Jean Trần Thanh Vân, who is also the architect of the Rencontres de Moriond series held each March in La Thuile, Italy. 2023 also marks the 10th anniversary of the International Centre for Interdisciplinary Science and Education (ICISE) in Quy Nhon, host of the Vietnam event.

An official partner of UNESCO, Rencontres du Vietnam's scientific conferences and schools promote collaboration between Vietnamese or Asia-Pacific scientists and colleagues from other parts of the world. ICISE's ambitious goal is to focus on the development of science and education, helping young Asian students and scientists to grow their knowledge by attending lectures and exchanging ideas with high-level overseas counterparts.

Window on the universe *John Kovac (Harvard University, Cambridge) talking about challenges for CMB cosmology.*

Rencontres du Vietnam

The 2023 event, entitled "Windows on the Universe", took place from 6 to 12 August and consisted of two joint conferences, one reporting on the progress and developments in particle physics and the other discussing recent developments in astrophysics. The conference featured joint sessions between both communities, as well as separate plenary and parallel sessions for each discipline. The event attracted some 150 participants, including theorist and 1999 Nobel Laureate Gerard 't Hooft.

In the tradition of ICISE-based conferences, a significant proportion of participants came from Asia, in particular from Vietnam, where the fundamental-research community has grown considerably since the start of ICISE activities. For example, Vietnam is now a member of the T2K experiment. Son Cao (IFIRSE) gave the plenary review on the results from this and other long-baseline neutrino experiments. Many others, including young scientists, presented their latest work during the parallel sessions.

During an extended opening session, some of the very first "Rencontres" participants shared entertaining memories of how it all began. The scientific part of the meeting followed, with keynote talks from a select group of excellent speakers covering most of the activities in particle physics and astrophysics. A highlight was the final day, when different views on future directions in particle physics were discussed, and the latest Fermilab muon g-2 measurement experiment – released just hours beforehand (see p8) – was presented.

Throughout the week, ICISE confirmed its reputation as an excellent venue for conferences in Southeast Asia. At the end of the meeting, a group of some 40 scientists accepted an invitation to spend a day in Hanoi for an audience with Vietnam's president, Võ Văn Thưởng, who, together with his staff, discussed science and education in the country. This was the final highlight of a very successful celebratory edition of the Rencontres du Vietnam in 2023.

Monica Pepe Altarelli *INFN*
Albert De Roeck *CERN and*
Jacques Dumarchez *LPHNE.*

Beauty 2023

Vibrant beauty in the Auvergne

S Monteil

A flavour of success *Members of the 30th anniversary of the Beauty series, who reviewed the latest results in heavy-flavour physics.*

The 20th International Conference on B-Physics at Frontier Machines (Beauty 2023) was held in Clermont-Ferrand, France, from 3 to 7 July, hosted by the Laboratoire de Physique de Clermont (IN2P3/CNRS, Université Clermont Auvergne). It was the first in-person edition of the series since the pandemic, and attracted 75 participants from all over the world. The programme had 53 invited talks, of which 13 were theoretical overviews. An important element was also the Young Scientist Forum, with seven short presentations on recent results.

The key focus of the conference series is to review the latest results in heavy-flavour physics and discuss future directions. Heavy-flavour decays, in particular those of hadrons that contain b quarks, offer powerful probes of physics beyond the Standard Model (SM). Beauty 2023 took place 30 years after the opening meeting in the series. A dedicated session was devoted to reflections on the developments in flavour physics over this period, and also celebrated the life of Sheldon Stone, who passed away in October 2021. Sheldon was both an inspirational figure in flavour physics as a whole, a driving force behind the CLEO, BTeV and LHCb experiments, and a long-term supporter of the Beauty conference series.

LHC results

Many important results have emerged from the LHC since the last Beauty conference. One concerns the CP-violating parameter sin2β, for which measurements by the BaBar and Belle experiments at the start of the millennium marked the dawn of the modern flavour-physics era. LHCb has now measured sin2β with a precision better than any other experiment, to match its achievement for ϕ_s, the analogous parameter in B_s^0 decays, where ATLAS and CMS have also made a major contribution. Continued improvements in the knowledge of these fundamental parameters will be vital in probing for other sources of CP violation beyond the SM.

Over the past decade, the community has been intrigued by strong hints of the breakdown of lepton-flavour universality, one of the guiding tenets of the SM, in B decays. Following a recent update from LHCb, it seems that lepton universality may remain a good symmetry, at least in the class of electroweak-penguin decays such as $B \rightarrow K^{(*)} \ell^+ \ell^-$, where much of the excitement was focused (*CERN Courier* January/February 2023 p7). Nonetheless, there remain puzzles to be understood in this sector of flavour physics, and anomalies are emerging elsewhere. For example, non-leptonic decays of the kind $B_s \rightarrow D_s^+ K^-$ show intriguing patterns through CP-violation and decay-rate information.

The July conference was noteworthy as being a showcase for the first major results to emerge from the Belle II experiment at Super KEKB in Japan. Belle II has now collected 362 fb^{-1} of integrated luminosity on the $\Upsilon(4S)$ resonance, which constitutes a dataset similar in size to that accumulated by BaBar and the original Belle experiment, and results were shown from early tranches of this sample.

In some cases, these results already match or exceed in sensitivity and precision what was achieved at the first generation of B-factory experiments, or indeed elsewhere. These advances can be attributed to improved instrumentation and analysis techniques. World-leading measurements of the lifetimes of several charm hadrons were presented, including the D^0, D^+, D_s^+ and Λ_c^+. Belle II and SuperKEKB will emerge from a year-long shutdown in December with the goal to increase the dataset by a factor of 10–20 during the coming half decade.

The conference was noteworthy as being a showcase for the first major results to emerge from the Belle II experiment

Full of promise

The future experimental programme of flavour physics is full of promise. In addition to the upcoming riches expected from Belle II, an upgraded LHCb detector is being commissioned in order to collect significantly larger event samples over the coming decade. Upgrades to ATLAS and CMS will enhance the capabilities of these experiments in flavour physics during the High-Luminosity LHC era, for which a second upgrade to LHCb is also foreseen. Conference participants also learned of the exciting possibilities for flavour physics at the proposed future collider FCC-ee, where samples of several 10^{12} Z decays will open the door to ultra-precise measurements in an analysis environment much cleaner than at the LHC. These projects will be complemented by continued exploration of the kaon sector, and studies at the charm threshold for which a high-luminosity Super Tau Charm Factory is proposed in China.

The scientific programme of Beauty 2023 was complemented by outreach events in the city, including a "Pints of Science" evening and a public lecture, as well as a variety of social events. These, and the stimulating presentations, made the conference a huge success, demonstrating that flavour remains a vibrant field and continues to be a key player in the search for new physics beyond the Standard Model.

Robert Fleischer *Nikhef and Vrije Universiteit Amsterdam,* **Guy Wilkinson** *University of Oxford,* **Régis Lefèvre** *LPC and University Clermont-Auvergne,* **Stéphane Monteil** *LPC and University Clermont-Auvergne.*

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TAUP 2023

Going underground in Vienna

From 28 August to 1 September, the 18th International Conference on Topics in Astroparticle and Underground Physics took place at the University of Vienna, organised by HEPHY/Austrian Academy of Sciences (ÖAW), and attracting about 450 participants. An extensive offer of parallel sessions each afternoon spanned direct dark-matter detection, advances in gravitational-wave (GW) searches, neutrino physics, astrophysics and cosmology, cosmic rays and astroparticle physics, as well as intertrack sessions on two or more subjects. A broad stage was also given to outreach and education, featuring science-communication projects from around the world, open science and masterclasses.

HEPHY

Serious science *Participants enjoying a light-hearted moment during one of the daily plenaries.*

The conference provided an excellent review of the status of scientific questions being addressed by experiments in underground labs, including the latest constraints on dark matter from PandaX, LUX-ZEPLIN, SuperCDMS, CRESST and XENONnT. The various techniques for studying dark matter indirectly, for example via cosmic radiation, were reviewed, as well as direct searches at accelerator facilities. The many and diverse efforts ongoing worldwide to understand the nature of neutrinos were covered comprehensively, including the parametrisation of their mixing properties, their absolute mass, whether neutrinos are their own antiparticle, and their role in the early and late universe and in supernova explosions. Two plenary presentations focused on recent highlights in the field: IceCube's confirmation of neutrinos from the galactic plane, and evidence of a GW background at nanohertz frequencies measured with pulsar timing arrays (*CERN Courier* September/October 2023 p7). Others summarised the status of cosmology in theory and experiment, cosmic-ray physics and the detection of GWs.

Among participants was Arthur McDonald, co-recipient of the 2015 Nobel Prize in Physics for the discovery of neutrino oscillations, who gave a talk "Using messengers from outer space to understand our universe and its evolution" to a packed audience of all ages in the Festsaal ÖAW. He also celebrated his 80th birthday during the conference, earning a big round of applause.

A total of 110 posters were presented, more than half from early-career scientists. The five winners were: Korbinian Urban (TUM) for "TRISTAN: A novel detector for searching keV-sterile neutrinos at the KATRIN experiment"; Christoph Wiesinger (TUM) for "TAXO – Towards an ultra-low background semiconductor detector for IAXO"; Steffen Turkat (TU Dresden) for "Low-background radioactivity counting at the most sensitive HPGE detector in Germany"; Angelina Kinast (TUM) for "First results on 170 enrichment of $CaWO_4$ crystals for spin-dependent DM search with CRESST"; and Krystal Alfonso (Virginia Tech) for "Analysis techniques for the search of neutrinoless double-beta decay of Te-130 with CUORE".

The next edition of TAUP will take place in 2025 in Chengdu, China.

Jochen Schieck *HEPHY and TU Wien*, **Nicolao Fornengo** *University of Torino and INFN and* **Sanje Fenkart** *CERN.*

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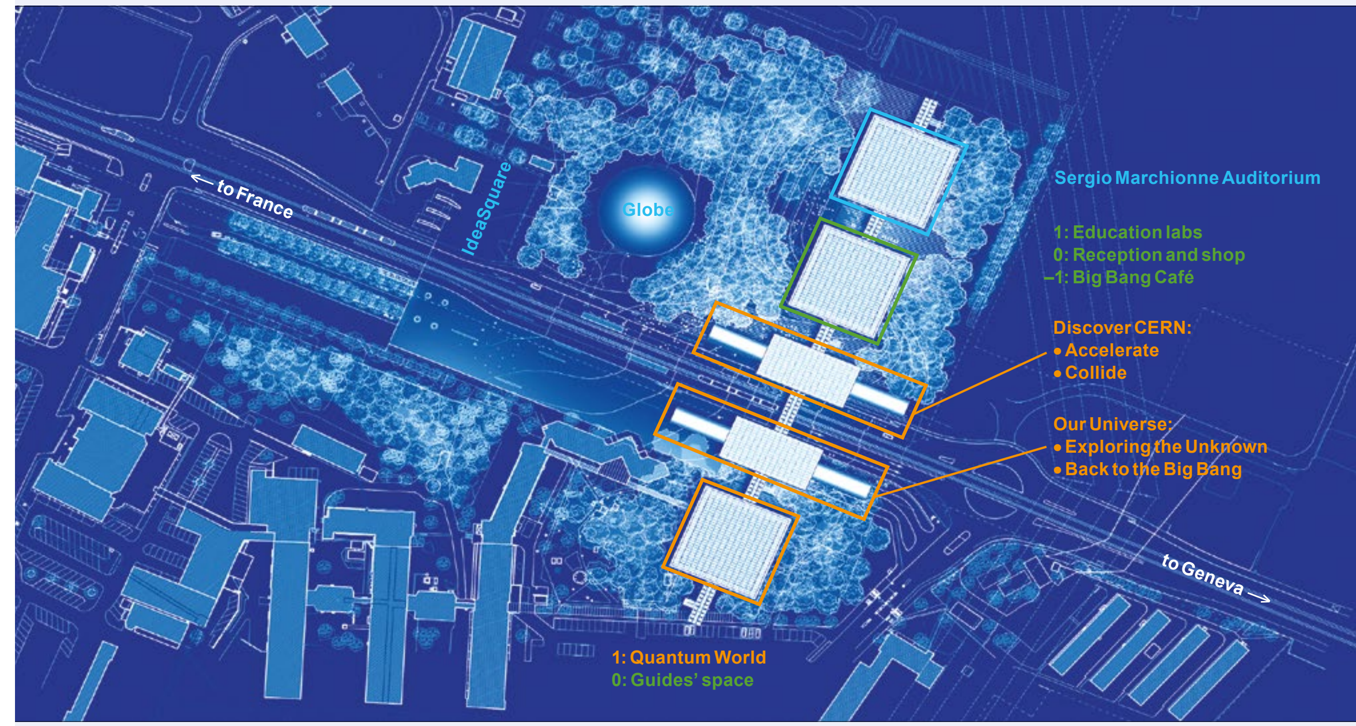
EDUCATION AND OUTREACH IN PARTICLE PHYSICS

Welcome to a special selection of features to celebrate the opening of CERN Science Gateway, a new flagship centre for science education and outreach.



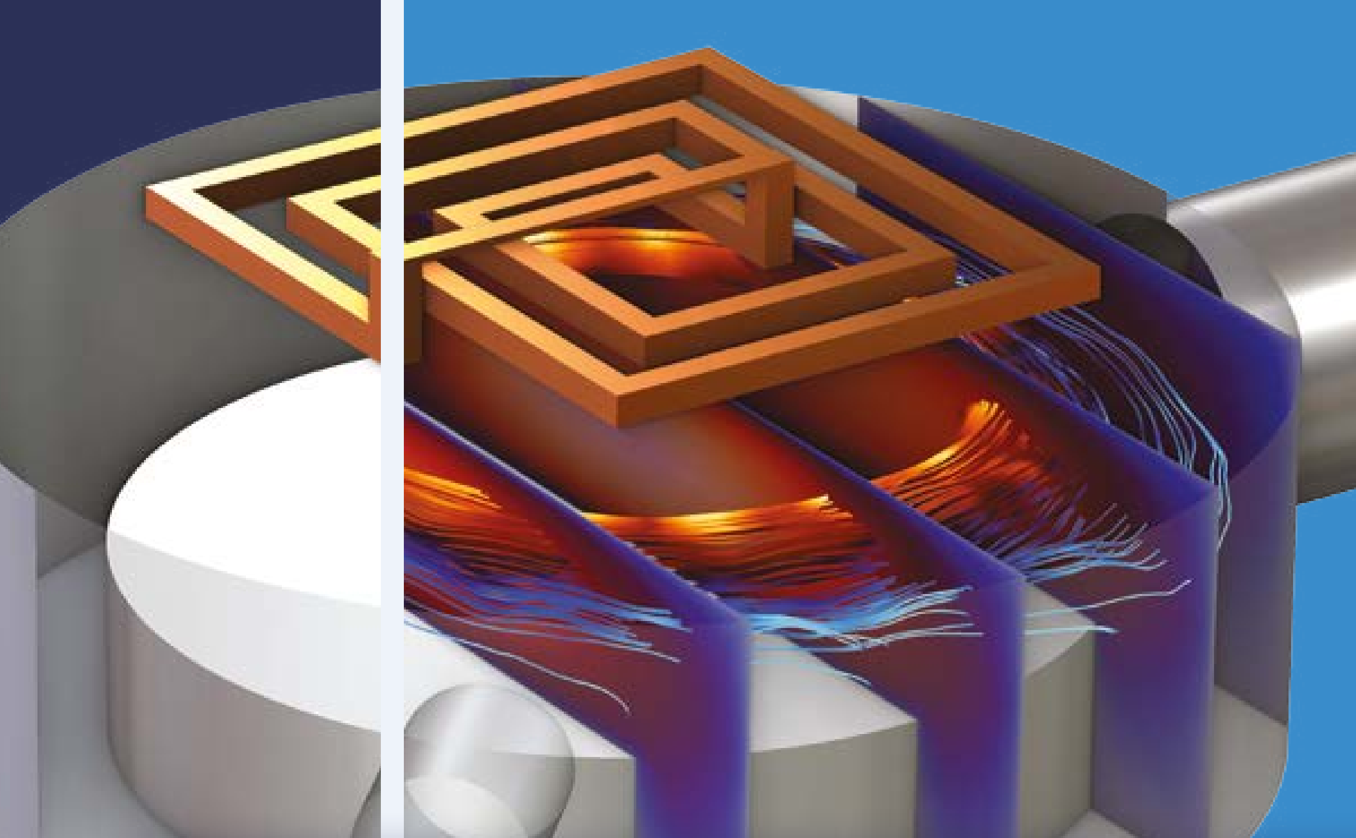
The imposing structure of CERN Science Gateway has been likened to a space station. In fact, it was CERN's technical buildings and underground tunnels that were the inspiration for chief architect Renzo Piano. Its three pavilions and two tubes house exhibitions, hands-on laboratories, artworks, a 900-seat auditorium, a shop and a restaurant – all connected by a 220 m-long bridge and nestled amongst 400 trees and 13,000 shrubs. It has a net-zero carbon footprint, with 2000 m² of solar panels on the pavilion roofs providing all the energy needed, while feeding 40% back into the CERN grid. The Gateway is free to enter and open all year, every day except Mondays, offering the capacity to welcome up to 500,000 visitors of all ages per year.

The following pages of expert exposition and opinion lift the lid on CERN Science Gateway. In addition to hearing from the teams behind its content, we explore the broader issues surrounding the theory and practice of education, communication and outreach in particle physics – beginning with what these three terms mean today (p27). Exploring the Gateway's exhibition spaces, authors reflect on four stunning art installations (p36), the secrets of success for an interactive exhibit (p31) and the simple power of objects (p39). Following a deep-dive into the new educational labs (p41), learn about CERN's physics-education research (p43), the impact of its hugely popular teacher programmes (p45), and how particle physics is or is not integrated in school curricula (p47). From empowering children to aspire to science (p49) to taking physics to festivals (p50), and transcending physical and neurological boundaries (p51), three articles emphasise the importance of reaching out as far and wide as possible. Last but certainly not least, we consider the invaluable role played by physicists (p52 and 53) and weave the rich experiences of CERN guides throughout the pages. Feel inspired? Your nifty red Science Gateway vest awaits!

We look at the importance of reaching out as far and wide as possible

THE AUTHOR

Sanje Fenkart *editorial assistant.*



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Nebulous *The difficulties that non-scientists have with visualising the real world from 2D inputs, such as this image of the Carina Nebula from the James Webb Space Telescope, can be understood in the context of a new framework called disciplinary discernment. (Credit: NASA/ESA/CSA/STScI)*

FROM THE COSMOS TO THE CLASSROOM

Physicists turned science-education researchers Magdalena Kersting and Urban Eriksson explore the latest thinking in physics education, communication and outreach.

Although science education, communication and public outreach are distinct fields of research and practice, they often overlap and intertwine. Common to the three fields is their shared goal of increasing scientific literacy, improving attitudes to STEM (science, technology, engineering and mathematics) and empowering society to engage with and apply scientific knowledge in decision-making processes. In light of challenges such as climate change and rapid advances in artificial intelligence, achieving these goals has become more relevant than ever.

Science education, communication and outreach have developed from different origins, at different times, and in response to diverse public needs. The formation of science education as a proper discipline, for example, dates back to educational reform movements in the late 19th century. Science communication, on the other hand, is a relatively young field that only took a clear form in the second half of the 20th century in response to a growing awareness of the role and impact of scientific progress.

While it is true that practitioners often cross the disciplinary boundaries of these fields, education, communication and outreach today represent distinct professions, each with its own identity, methods and target groups. Whereas science educators tend to focus on individual

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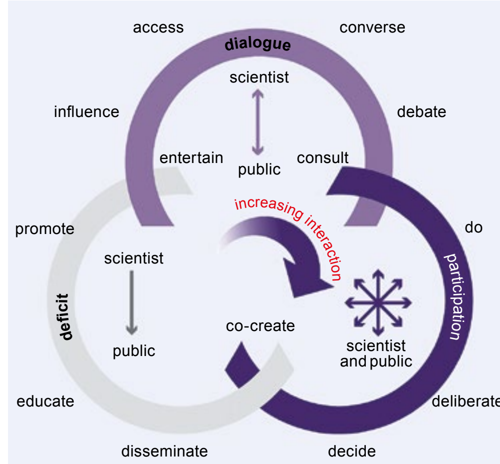
Mission gravity *Students can be immersed in virtual-reality experiences to study topics such as stellar evolution.*

J Metcalfe



Increasing interaction *The "rosette" model of science communication illustrates how traditional one-way approaches have evolved into a more active exchange between scientists and the public.*

learners, often in school settings, public-outreach professionals aim to inspire interest in and engagement with science among the general public in out-of-school settings. Besides, the differences go beyond variations in target groups and domains. After all, the distinction between education and communication is substantial: many science journalists resist the suggestion that they serve a role in education, arguing that their primary goal is to provide information.

Questions then arise: how do these disciplines overlap, diverge and interact, and how have their practices evolved over time? And how do these evolutions affect our understanding of science and its place in society? As two academics whose career trajectories have spanned science, education and communication, we have experienced intersections and interactions between these fields up close and see exciting opportunities for the future of science engagement.

Magdalena: farewell to the deficit model

What stands out to me is the parallel development that science education and communication have undergone over the past decades. Despite their different origins, traditions, ideas, models and theories, all have seen a move away from simple one-way knowledge transmission to genuine and meaningful engagement with their respective target groups, whether that's in a classroom, a public lecture or at a science festival.

In classrooms, there has been a noticeable shift from teacher-centred to student-centred instructional practices. In the past, science teachers used to be active (talking and explaining), while students were passive (listening). Today, the focus is the students and how to engage them actively in the learning process. A popular approach to engaging students is enquiry-based science education, where students take the lead (asking questions, formulating hypotheses, running experiments and drawing conclusions) and teachers act as facilitators.

One excellent example of such an enquiry-based approach is Mission Gravity, an immersive virtual-reality (VR) programme for lower- and upper-secondary students (see "Mission gravity" image). Developed by the education and public outreach team at OzGrav, the Australian Research Council Centre of Excellence for Gravitational Wave Discovery, the programme aims to teach stellar evolution and scientific modelling by inviting students on a virtual field trip to nearby stars. The VR environment enables students to interact with stars, make measurements and investigate stellar remnants. By collecting data, forming hypotheses and trying to figure out how stars change over time, the students discover the laws of physics instead of merely hearing about them.

The shift towards student-centric education has been accompanied by an evolution in our understanding of student learning. Early-learning theories used to lean heavily on ideas of conditioning, treating learning as a predictable process that teachers could control through repetition and reinforcement. Contemporary models consider cognitive functions, including perception, problem-solving and imagination, and recognise the crucial role of social and cultural contexts in learning science. Nowadays, we acknowledge that education is most meaningful when students take responsibility for their learning and connect the subject matter to their own lives.

For instance, my PhD project on general-relativity education leveraged sociocultural learning theory to design an interactive learning environment, incorporating collaborative activities that encourage students to articulate and discuss physics concepts. This "talking physics" approach is great for fostering conceptual understanding in modern physics, and we refined the approach further

through iterative trials with physics teachers to ensure an authentic learning experience. Again, collaboration between science education researchers and practitioners (in this case, physics teachers) is critical to improving science education.

Similarly, science communication has transitioned from deficit models to more dialogic and participatory ones. The earlier deficit models perceived society as lacking scientific understanding and envisaged a one-way flow of information from expert scientists to a passive audience – quite similar to the behaviourist approach prevalent in the early days of science education. Modern science communication practices foster a dialogue where scientists and the public engage in meaningful discussions. In particular, the participatory model positions scientists and the public as equal participants in an open conversation about science. Here, the interaction is as critical as the outcomes of the discussions. This places emphasis on the quality of communication and meaning-making, similar to what many consider the goals of good science education (see "Increasing interaction" figure).

To illustrate a participatory approach to science communication, consider the City-Lab: Galileo initiative in Zurich. This initiative integrates theatre, podcasts and direct interactions between scientists, actors and citizens to foster dynamic conversations about the role of science in society. A range of media and formats were employed to engage the public beyond traditional forms, ranging from audio-visual exhibits to experiences where the public could attend a play and then engage in a post-show discussion with scientists. By directly involving scientists and the public in such exchanges, City-Lab: Galileo invites everyone to shape a dialogue about science and society, underlining the shifting paradigms in science communication.

Urban: the power of semiotics

For me, a ground-breaking moment in how we communicate disciplinary knowledge came when I saw two astronomers in a coffee room discussing the evolution of a stellar cluster. They were using their hands to sign the so-called turn-off point in a Hertzsprung–Russell diagram in mid-air, indicating their individual perspective on the age of the cluster. These hand-wavings would most likely not mean anything to anyone outside the discipline and I was intrigued by how powerful communication using such semiotic resources can be. The conclusion is that communicating science does not just involve speech or text.

Particularly intriguing are the challenges students and others have with visualising the world in 3D and 4D from 2D input, for example in astronomical images, which I started to notice while teaching astronomy. How hard can it be to "see", in one's head, the 3D structure of a nebula (see "Nebulous" image) a galaxy or even the Sun–Earth–Moon system when looking at a 2D representation of it? It turns out to be very hard for most people. This led to an investigation of the ability of people to extrapolate 3D in their mind, which immediately raised another question: what do people actually "see" or discern when engaged in disciplinary communication, or when looking at the stunning images from the Hubble or Webb space telescopes? Nowadays this is referred to as disciplinary discernment in the literature.

Researching such questions relies on methods that are quite different from those used in the natural sciences. Often data exists in the form of transcripts of interviews, which are then read, coded and characterised for categories of discernment. In the case of spatial perception, this inductive process led to an anatomy of multidimensional discernment describing the different ways that the participants experience three-dimensionality in particular and disciplinary discernment in general. It also identified

Collaboration between science education researchers and practitioners is critical to improving science education

Tales of a CERN guide Tobias Patrick Treczoks

Guide since October 2022
Position Masters student for VITO at ISOLDE (User, University of Oldenburg)
Languages German, English

One thing that makes being a CERN guide so interesting and exciting is the diversity of our visitors. You might have a super-interested 10 year-old, for whom the visit to CERN is his birthday present, or you could find yourself discussing the connection between Buddhism and the Higgs boson with a monk.

One visit that I remember vividly was with a group of Swiss–German retirees. All of the visitors were hard of hearing, with the majority of them being deaf. To facilitate communication they brought two sign-language translators with them. Before the start of the tour some of the visitors were concerned that their cochlear implants, which can restore some hearing,

might be influenced by CERN's equipment. Luckily, I studied medical physics and audiology before coming to CERN, so I was able to reassure them that everything will be fine. On that day we were showing the group the Synchrocyclotron and the ATLAS Visitor Centre. Communicating via the translators was something that was completely new for me, as I am sure terms such as muon spectrometer or superconducting magnet were to them. Due to the translation, it naturally took a few seconds longer than usual to see the audience's reaction. In most cases, however, it was full of excitement and often more effusive than with a group of hearing visitors. Many questions were asked and a lot of photos were taken, later to be shown to their grandchildren.

Although the tour took much longer than planned, I do not regret a single second I got to spend with them. When the group finally left CERN, there was not only a bright smile on their faces but on mine as well. Engaging people in our research and making it accessible to everybody regardless of their background, age or impairments is something which to me is a vital part of CERN's mission.

a deeper underlying challenge that all science learning depends upon: large and small spacetime scales. Spatial and temporal scales, in particular large and small, are identified as threshold concepts in science. As a result, the success of any teaching activity in schools, science centres and other outreach activities depends on how well students come to understand these scales. With very little currently known, there is much to explore.

As an educational researcher in physics, one has to be humbled by the great diversity of ideas about what it means and entails to teach and learn physics. However, I've come to appreciate a particular theoretical framework based on studies of the disciplinary communication in a special group in society: physicists. This, and indeed any group with the same interests, develops and shares a special way of communicating knowledge. In addition to highly specialised language, they use a whole setup of representations, tools and activities. These are often referred to as semiotic resources and are studied in a theoretical framework called social semiotics.

Social semiotics turns out to be a powerful way to study and analyse the disciplinary communication in physics and astronomy departments. I usually describe the framework as a jigsaw puzzle that we are still building. We have identified, and described in detail, certain pieces in this theory but there are more to explore. One such piece is embodiment and what the use of gestures means for communicating disciplinary knowledge, such as the hand-waving astronomers in the coffee room. It is similar to the theory-building processes in physics, where through empirical investigations physicists try to construct a solid theory for how nature works.

Joint conclusion

Understanding how we think about and communicate physics is as interesting and challenging as physics itself. We believe that they are inseparable, and as we explore the landscape of physics to understand the universe we are also exploring the human mind and how we can understand the universe. Physicists too have to be able to communicate with and engage other physicists. The scientific process of publishing research is an excellent example of how challenging this can be: researchers must convince their colleagues around the world that what they have found is correct, or else they fail. The history of science is full of such examples. For example, in the 1920s Swedish astronomer Knut Lundmark made observations of stars in distant galaxies and found that these galaxies seem to move away from us – in essence he had discovered the expansion of the universe. However, he was unable to convince (read: communicate this to) his colleagues, and a few years later Edwin Hubble did the same thing and made a more convincing case.

Finally, this article tries to shed light on the challenges in communicating physics to not just physicists but also students, and the public. The challenges are similar but at different levels, depending on the persons involved and engaged in this interchange of knowledge. What the physicist tries to communicate and what the audience discerns and ultimately learns about the universe are often two different things. ●

Further reading

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THE AUTHORS

Urban Eriksson *head of Uppsala University Physics Education Research Division;* **Magdalena Kersting** *Department of Science Education, University of Copenhagen.*

Tales of a CERN guide **Imtiaz Ahmed**

Guide since 2013
Position Electronics engineer at CMS (User, NCIP Estonia)
Languages English

I've been guiding for nearly a decade, and during this time have had plenty of exciting tours. When I first started, I helped my supervisor as a translator. I joined her at the virtual CMS visits for Pakistani prisoners in a jail in Athens.

For in-person tours I like to take visitors to the Synchrocyclotron, ATLAS Visitor Centre, CERN Control Centre, SM18 (currently under renovation) and CMS. There they get a good overview of how accelerators and detectors work. One of the typical questions I get is about the power consumption of CERN.

Weekends are busy times. The visitors are always curious and come with many questions. Besides power consumption, they want to know about quantum computers, how data gets stored and handled, and the technologies that are used for electronics, vacuum, magnets and cryogenic cooling. Of course, the Higgs boson as well as future goals are always of interest, too. As we give guided tours in radiation surveillance areas, people also have questions about the safety risks. Once a fellow took her mother on a regular tour where we don't even need dosimeters, yet she was concerned for her and her daughter's safety. Together we explained all the safety measures in place at CERN and that no one is exposed to high radiation, even when working in the tunnels and caverns.

I like guiding very much. It is very rewarding to represent CERN in this way, especially when the visitors appreciate it with their compliments and applauds. The loveliest I heard was when a girl told me that she had taken a tour with me a few years before and that it had motivated her to become a CERN technical student.

INTERACTIVE EXHIBITS: THEORY AND PRACTICE

Whether they are about trapping antimatter or keeping the LHC cold, interactive exhibits are key to engage diverse audiences in science and technology. Daria Dvorzhitskaia and Patricia Verheyden present a step-by-step recipe for exhibition development.

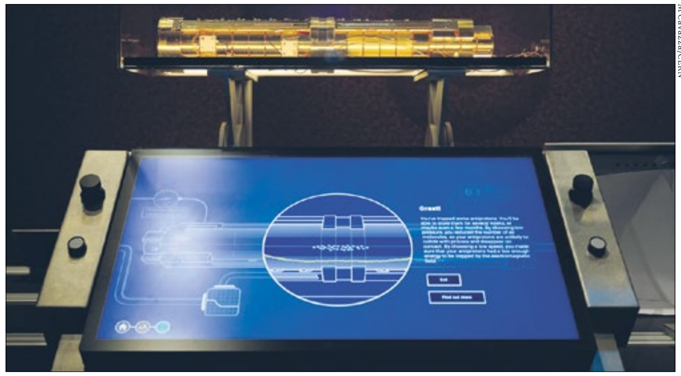
Alongside a hands-on education laboratory and large auditorium, Science Gateway houses three permanent exhibitions: *Discover CERN*, *Our Universe* and *Quantum World*. As they come through the doors, visitors discover a rich mixture of exhibition elements: authentic objects, contemporary artworks, audiovisual content, immersive spaces – and, of course, an abundance of interactive exhibits. The latter go through many carefully considered steps to present a spot-on experience to visitors, and must meet a number of criteria (see "Criteria that a good interactive exhibit should meet" panel).

Irrespective of the topic, there is a basic recipe for making an interactive exhibit. Once the clear message the exhibit aims to convey has been identified, developers write a draft that sets up a scenario of visitor interaction and sketches how the exhibit may look. What will visitors see when they approach the exhibit? What can they do? Are there several ways in which it is possible to interact with the exhibit?

Model making

The next step is to make a prototype. Depending on the nature of the exhibit, it may be a "quick and dirty" mockup, a simple 3D model, a paper prototype, or even just a verbal description. Then, the prototype is tested with at least several members of the target audience. What do they conclude from their interaction with the exhibit and why? How enjoyable and interesting do they find it? How well does the exhibit convey its key message? Afterwards comes the design and building of the exhibit. This stage often involves a lot of technical testing – for example, when choosing the materials or trying to keep within the available budget. In addition, texts that accompany the exhibit need to be written and translated. When the (nearly) final version of the exhibit is ready, it is evaluated again with the target audience. How clear are the instructions and the gameplay? What needs to be changed in the exhibit and how exactly? The final step, if necessary, is to reiterate.

In reality, however, the development process rarely turns out to be simply moving from one step to the next. Sometimes, the results of testing a prototype with the public show that the scenario needs to be rewritten completely, bringing developers back to where they started. In other cases, time or budgetary constraints force the team to merge some steps or even skip them entirely. Two Science Gateway exhibits illustrate the twists and turns of developing a state-of-the-art science exhibit.



Trial and error *With the antimatter-trap exhibit in Science Gateway, visitors can reconstruct how capturing antiparticles works at CERN.*

The starting point for the antimatter-trap exhibit (see image above) was a real antimatter trap – an eye-catching piece of scientific equipment that is well suited to an interactive exhibit. Following several brainstorms with antimatter scientists, a PhD student who specialised in the design of interactive science-communication experiences, and who developed the exhibit scenario further, made a paper prototype. In this version of the exhibit, visitors first had to slow an antiproton down in a decelerator, and only after that shoot the antiproton into the trap. The trap had several parameters (for example, a magnetic field that could be switched on and off) that visitors could play with before injecting the antiproton into the decelerator. Depending on how the parameters had been set, the antiproton would fly through the trap, annihilate or become captured.

We then tested this prototype with six small groups of visitors at the CERN Microcosm exhibition and six groups of CERN members of personnel who did not have a background in science or technology. Results from the testing led to many changes. For example, we learnt that many people were confused about deceleration. We therefore removed this stage from the gameplay but kept the speed of the antiproton coming into the trap as one of the parameters. A bigger problem was the fact that visitors, most of whom had heard nothing about antimatter prior to their interaction with the exhibit, still did not understand anything about it after successfully trapping the antiproton. We were faced with a dilemma: should the main message of the exhibit be about the antimatter itself, or should the exhibit still focus on how the antimatter trap works? After a difficult consid-

THE AUTHORS

Patricia Verheyden and **Daria Dvorzhitskaia** *are members of the CERN exhibition team.*

Criteria that a good interactive exhibit should (or at least should try to) meet

✓ **Focus** The exhibit should aim to convey only one, clearly defined message. For example: "In the LHC, particles are accelerated with the help of an electric field."
✓ **Edutainment** Visitors can/should have fun when interacting with the exhibit and at the same time learn something new.
✓ **Responsiveness** Visitors should immediately receive a reaction from the exhibit when they do something. Simple encouragement like "Good job!" or "Keep going!" is helpful.
✓ **Multi-sensory experience** Interaction with the exhibit should involve as many senses as possible.
✓ **Self-sufficiency** People should understand how to use the exhibit, as well as the key ideas of the exhibit, without the help of a guide.
✓ **Zero position** After visitors leave the exhibit, it should self-restore to the state where it is ready to be used by the next person.
✓ **Safety** The exhibit should be safe for everyone to use, including children.
✓ **Maintenance** The technical team needs to have easy access to the exhibit and be able to use standard components to fix it if necessary.
✓ **Physical accessibility** The exhibit must be usable by – and feel welcoming for – diverse groups of visitors, for example, wheelchair users.
✓ **Content accessibility** Target audiences need to understand the language, key messages, ideas.
✓ **Social interactions** Co-operation between visitors should be encouraged, for example through gameplay.

Cool down *Aided by an infrared camera, visitors isolate a heated plate to create a well-insulated environment, as is needed in the LHC.*

eration, we decided to stick to the latter, whilst ensuring the former is included elsewhere in the exhibition.

An updated version of the exhibit scenario was handed over to the multimedia company that had been contracted to develop the exhibit, and further tests were conducted with two classes of Italian middle-school students. Apart from some minor usability issues, the exhibit proved to be challenging yet engaging: students yelled proudly and happily high-fived their team members after managing to trap the antiproton. The exhibit was then improved further, eventually taking its current shape in Science Gateway's "Back to the Big Bang" exhibition. This was also the moment to come back to the antimatter scientists who helped ensure that all the texts and drawings in the exhibit were correct.

Keep the heat out

The goal here was to come up with a hands-on exhibit that would allow Science Gateway visitors to discover what keeps the LHC superconducting magnets cold. Similar to the experience with the antimatter exhibit, we again worked side-by-side with a CERN scientist. The original plan was to recreate a real situation: place a cold source at the centre and cover it with layers of different insulation materials. Visitors would be able to open and close these layers, as well as create a vacuum. They would observe that when the cold source was shielded from the environment, it required less power consumption to stay cool. This idea looked very promising on paper, especially given that the exhibit would be integrated into a full-scale mockup of the LHC.

However, calculations showed that the effect would only become visible after approximately half an hour. While this may not seem like a deal-breaker, in this context it certainly is: visitors at science exhibitions expect immediate feedback and typically do not spend more than just a few minutes at each exhibit. Moreover, having a surface that is sufficiently colder that the environment leads to condensation, which would create difficulties for the technical maintenance of the exhibit.

Alternative ideas were needed. To avoid reinventing the wheel, we explored which exhibits on the topic already existed in other science centres and museums. Eventually we decided to focus on a very basic idea: certain materials block heat, other materials conduct it. Communicating this message required a plate heated to 45 °C (not so hot that visitors risk burning themselves, but still warm enough to see the effect), a bunch of conducting and insulating materials that come in different shapes and thicknesses, and an infrared camera. Lots of technical prototyping and testing allowed us to determine how thick the materials should be to ensure that the effect was both visible and revealed itself quickly enough for the exhibit to be interesting. As the reflective metallic surfaces produce incorrect readings on the infrared camera, all metal materials were painted black. Finally, to keep the link between the exhibit and the actual LHC insulation, key elements such as mylar, vacuum and minimal surface contact were incorporated.

In its final form, the exhibit enables open-ended exploration, such that visitors discover the phenomenon by going through the stages of the scientific method. First, visitors face a challenge: in the instructions accompanying the exhibit, they are invited to try shielding the heated plate from the infrared camera. Then, by picking a certain type of material, visitors form a hypothesis – "maybe this piece made of copper will do the job?" – and test it by placing the material on the plate. As the copper piece quickly reaches the same temperature as the heated plate, visitors observe it with the help of the infrared camera and conclude that copper is not a good choice. This leads to a new hypothesis, another material... and so on. Visitors are free to explore the exhibit as long as they want, and we hope that for many Science Gateway visitors this open exploration will culminate in the magical "aha!" moment – the reason why we developed all these interactive exhibits in the first place. ●

Visitors discover the phenomenon by going through the stages of the scientific method

Tales of a CERN guide David Amorim

Guide since 2017
Position Senior fellow for the Muon Collider study
Languages French, English

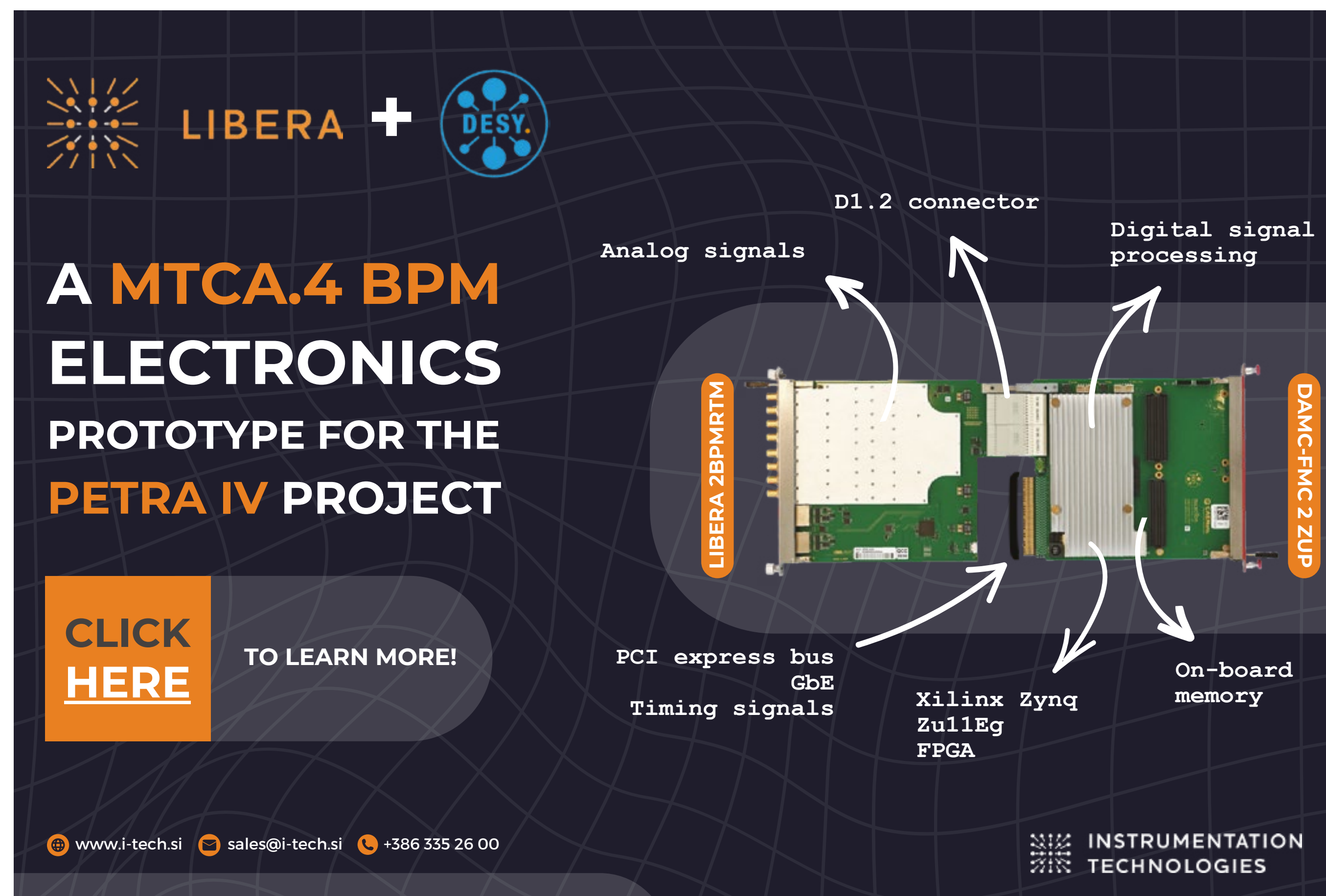
In 2008, I had the great opportunity to undertake a one-week middle-school internship at CERN, during which I discovered the contagious passion for science and technology I saw in my supervisors. Today, it's my turn to try and pass on that passion to everyone, especially young people.

Whether it's showing visitors around the most iconic places at CERN or at events such as Science Night, I've been able to meet and talk to people of all ages and backgrounds. Many visitors initially feel that what is done at CERN and in physics research in general is too difficult to understand. However, after a few discussions and by making connections with everyday phenomena or objects, people become interested and grasp the value of such research, and often want to find out more or come back to CERN.

I also particularly enjoy guiding school classes and taking part in activities aimed at children. Whether it's working with schools when their classes come to visit us, or taking part in science shows such as "Fun with Physics", I always see a sense of wonder and a "wow" effect, not just in the children's eyes but also those of the teachers and adults who accompany them.

Children are curious about everything and ask lots of questions about the world around them and how we study it. This requires that we, as guides, question ourselves and stay curious, because some questions, such as "How does the Higgs boson work?" are not easy to answer. This offers an opportunity to involve everyone: the group of children act as the Higgs field, their parents or teachers then try to make their way through while the kids can gently heckle the adults, giving the "particles" mass. Together they reconstruct the Higgs mechanism!

Being a guide at CERN brings a dimension to one's work that I think is necessary to our profession: that of sparking curiosity. For example, I remember a 12-year-old girl from nearby Meyrin who told me that she wanted to understand the world around us by becoming a physicist and then go into politics to better protect it.



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In early 1977, Dr. Henschke and Dr. Suthanthiran traveled to California and met with the management of Varian and Siemens. They urged the companies to produce electron-only Linacs for IORT, but unfortunately, their efforts were unsuccessful.

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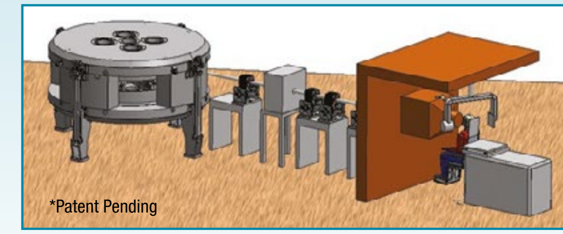

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B25u–35adp Cyclotron	25–35 MeV	• Proton or alpha/deuteron/proton, capable of high current up to 1000 Micro Amps, for medical radioisotopes
B35 Cyclotron	35 MeV	• Proton only system for medical radioisotopes production
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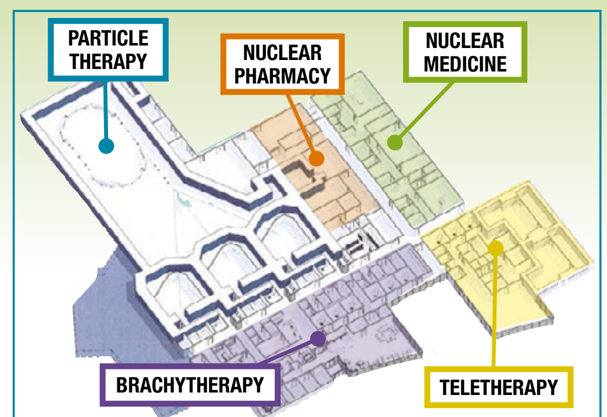

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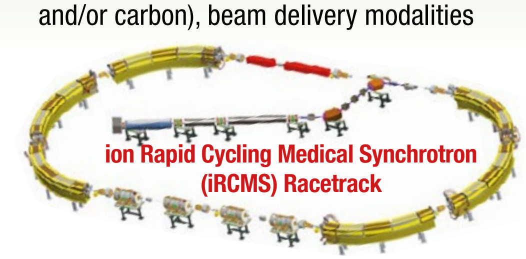

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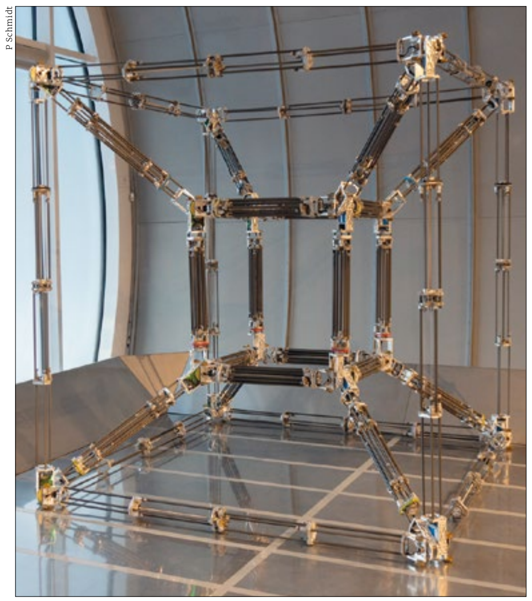
BEAUTIFUL MINDS COLLIDE

Engaging with the abstract world of theoretical physics, artists find new inspiration. In return, scientists can see their own research in a new light. Iliana Tatsi and Mónica Bello describe the interdisciplinary journey behind the stunning installations in CERN Science Gateway.

Within the naturally lit expanse of the *Exploring the Unknown* exhibition at CERN Science Gateway, an artwork both intrigues and challenges: Julius von Bismarck's *Round About Four Dimensions*, commonly referred to as the "tesseract". As light interacts with its surfaces, the tesseract – a 3D representation of a 4D cube – unfolds and refolds, turning inside out in a hypnotic sequence that draws viewers into its rhythm (see "Round About Four Dimensions" image). This kinetic piece not only captivates with movement but also signifies the deep-rooted relationship between art and science.

Organised around themes of space and time, dark matter, and the quantum vacuum, the *Exploring the Unknown* exhibition becomes a meeting point, inviting spectators to dive into the collective curiosity of both artists and scientists. In particular it channels the imaginative spirit of CERN's theoretical physicists, including Joachim Kopp, who remarked during an encounter with a visiting artist: "I try to visualise the maths. So, whenever I work on something, I need to have some pictures in my head, even when it's mathematical concepts." This sentiment illuminates the profound visual connection artists and scientists alike experience when confronted with complex ideas.

P Schmidt



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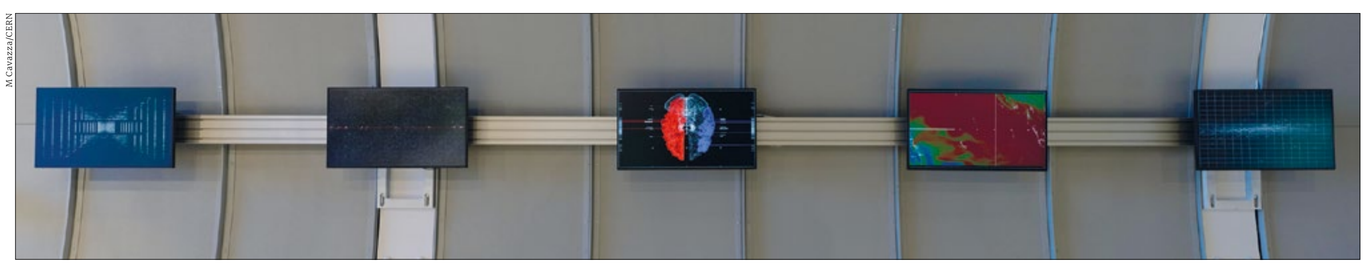

Round About Four Dimensions *(top left) Moving and changing shape, the tesseract throws the shadows of four dimensions into our 3D world.* **Chroma VII** *(top middle) With its contracting and colour-shifting "scales", Chroma VII considers how invisible and imperceptible entities such as dark matter may influence an ever-changing universe.* **TAFAA** *(top right) Chloé Delarue explores the concept of uncertainty in an enigmatic digital display of the cosmos.* **data.gram [n°4]** *(left) A sequence of displays of scientific data on different scales: from elementary particles to galaxy clusters.*

Rich dialogue

Born from the collaborative efforts between the Arts at CERN programme and the CERN exhibitions section, this display vividly encapsulates the synergy between art and science. By championing artist residencies, commissioning distinct art pieces and curating exhibitions, a rich dialogue is fostered between two seemingly distinct worlds. For the first time, Science Gateway will spotlight works born from residencies and commissions, proudly featuring creations from celebrated resident artists including Yunchul Kim, Chloé Delarue, Ryoji Ikeda and Julius von Bismarck.

Within CERN's corridors, serendipitous dialogues emerge. An artist might gain fresh inspiration from a casual chat about the universe, looking at their work through a new lens. On the other hand, physicists can discover a fresh perspective on their familiar theories through the artist's interpretation. As former CERN theorist Tevong You insightfully shared during one such discussion, "In the quantum world of particles and waves, there's a beauty that artists instinctively grasp. They bring to life the equations we scribble on paper."

The dialogue between diverse minds takes centre-stage at Science Gateway. Yunchul Kim harnesses the intricacies of fluid dynamics (see "Chroma VII" image), capturing space and time and the elusive nature of dark matter in his sculptures. Chloé Delarue crafts tangible experiences around the mystery and the uncertainty of the unknown (see "TAFAA" image), while the avant-garde audiovisual installations of Ryoji Ikeda breathe life into the elusive quantum vacuum (see "data.gram [n°4]" image). As artists immerse in these scientific domains, they unearth fresh inspiration and, in return, challenge scientists to see their own work through a different prism. This unconventional collaboration amplifies both fields: artists distill vast, abstract concepts into evocative forms, and scientists, inspired by this artistic partnership, discover enriched avenues through which to communicate their research.

Navigating the confluence of art and science is no straightforward journey. For every moment of synergy, there are hurdles to clear – terminology gaps, differing methodologies and the occasional skepticism from both sides. However, through the many interactions we've experienced between scientists and artists, it's clear that these challenges can be overcome. Artists, through their residencies at CERN, have cultivated an understanding of complex scientific narratives. Conversely, CERN scientists have come to appreciate the evocative power of art, expanding beyond their traditional vocabulary. This endeavour is about building bridges, recognising the need for compromise, and ultimately celebrating the beauty that emerges when diverse worlds collide.

Finding equilibrium between artistic liberty and scientific truthfulness is also a delicate dance. In the vast realm of creativity, an artist might sometimes venture far from the core scientific concepts in their pursuit of artistic expression. In *Exploring the Unknown*, such balances are impressively maintained by von Bismarck's tesseract and Ikeda's audiovisual installation *data.gram [n°4]*. The exhibition shows that neither art's freedom nor science's precision need to be sacrificed; when approached with mutual respect, they can coexist, each enhancing the other's message. ●

THE AUTHORS

Iliana Tatsi *is a curator of the Exploring the Unknown exhibition;* **Mónica Bello** *is head of Arts at CERN.*

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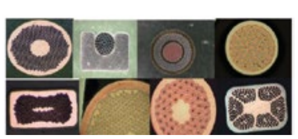

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THE POWER OF OBJECTS

Modern science visitor centres are equipped with the latest digital gadgets, offering breathtaking audio-visual experiences. But real objects hold a particular power to connect to people. Alison Boyle describes the importance of heritage in science.

MOSI Manchester/Chris Foster

Message in a bottle *The bottle Peter Higgs drank from the night before the big announcement, displayed at the former Collider exhibition.*

One of the key challenges of communicating particle physics – particularly when preserving and presenting tangible artefacts – is the sheer scale of the endeavour. The infrastructure of particle physics has frequently been likened to cathedrals: great vaulted caverns built by the hands of many in search of truths about our universe. And even the major facilities are only one part in the international network of particle physics. Museums, which are also often likened to cathedrals, weren't typically designed with gigantic and internationally distributed artefacts in mind. And that's before we consider the objects of study: you can't display a particle in a glass case. So how can we find tangible ways to represent abstract physical phenomena? What does it mean to represent the work of the thousands of people involved in today's particle-physics projects? And is it possible to capture a fleeting moment of discovery for posterity?

Sometimes, those fleeting moments are best captured by ephemeral objects. Something that might seem mundane or throwaway can provide eloquent insights into the real life of physics. The announcement of the discovery of the Higgs Boson at CERN on 4 July 2012 was recorded in several formats, notably the film footage of Peter Higgs wiping away a tear in CERN's main auditorium as the ATLAS and CMS teams announced the discovery of the particle whose existence he, François Englert and Robert Brout had predicted decades before.

A material memorial of the Higgs-boson discovery is the champagne bottle emptied by Higgs and John Ellis the night before the announcement. In fact, the quiet and modest Higgs usually prefers London Pride beer; unfortunately, the can that he drank on his flight home from Geneva after the announcement was not saved for posterity. But the champagne bottle also speaks to a common practice at CERN: around the site, particularly in the CERN Control Centre, there are arrays of empty bottles, opened in celebration of events including the LHC start-up, first physics collisions, major publications and other milestones.

Familiar yet unexpected objects such as the champagne bottle in the context of a display about physics can pique visitors' interest and encourage them to move on to more complex-looking displays that they might otherwise pass by. As such, Higgs' champagne bottle featured in the Collider exhibition (see above picture) produced by the London Science Museum in 2013 and another bottle is part of CERN's heritage collection – a curated assortment of more than 200 objects that encapsulate CERN's history.

Magic moments

Connecting to newsworthy moments or well-known people is usually a successful draw for visitors. Capitalising on the global success of the movie *Oppenheimer*, this year the Bradbury Science Museum at Los Alamos developed an exhibition of Oppenheimer-related artefacts, including his own copy of the *Bhagavad Gita*. At CERN Science Gateway, Tim Berners-Lee's NeXT computer – used to host the first website – creates an immediate talking point for visitors who can barely imagine life without the web, despite the object itself being literally a black box.

That said, it is rare for a scientific or technological artefact to be a "show piece" that would attract visitors in its own right, in the same way that they would

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Revolutionary *Tim Berners-Lee's NeXT machine – the very first server to host the web – on display at CERN Science Gateway.*

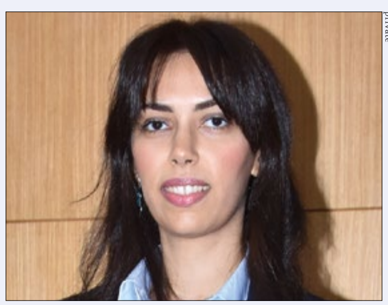
queue to see a famous artwork. The Antikythera mechanism at the National Archaeological Museum in Athens, Galileo's telescopes at the Museo Galileo in Florence, or the Apollo 11 command module at the National Air and Space Museum in Washington are not representative of the types of material generally found in science heritage collections. Most science-related objects are not that easy for non-specialists to engage with; to the uninitiated eye the tools of particle physics mostly look like wiring and plumbing. Exhibition developers therefore usually adopt the "key pieces" approach advocated by Dutch curator Ad Maas: setting objects in the context of an overall narrative and a rich array of materials including photographs, documents, film, audio and personal testimony brings them to life and allows developers to layer information for different audience tastes and interest levels. Thanks to CERN's archives and heritage collection, there is a wide range of material to draw from.

Using the key-pieces approach, a single small part can be revealing of a much larger whole: for example, by following the "life story" of a lead tungstate crystal used in the CMS electromagnetic calorimeter – which was also featured at the Collider exhibition – we gain insights into the decades-long design and planning process for the CMS detector, and an adventure in production and testing that takes us on a journey via Moscow, Shanghai and Rome (with a detour to the UBS bank vaults in Zurich). The physical nature of the object itself reflects its design and production history, while also illustrating the phenomena of particle decay and scintillation. At CERN, you'll find displays of crystals like these around the site, in public and private spaces.

Much of the scientific heritage of the 20th and 21st centuries was originally preserved by practitioners with a sixth sense of "this might be useful someday" rather than by professional curators. Today, CERN has detailed archival and heritage collection policies that offer guidance as to what kinds of material might be worth keeping for posterity. Of course it's impossible to keep everything; we can't predict for certain what avenues future historians might be interested in exploring, or what kinds of objects will be used to popularise science. But by preserving storehouses of memories, we might be keeping some building blocks for the cathedrals of a future age. ●

Tales of a CERN guide **Hassnae El Jarrari**

Guide since October 2021
Position CERN Research Fellow in Experimental Physics
Languages English, French, Arabic



I became a CERN guide because I wanted to expand my knowledge beyond my research topic and to explore other experimental sites. Little did I know how much excitement and challenges await me each time I lead a group of visitors.

At CERN, the diverse range of visitors creates a unique cultural experience as people come from different backgrounds and with varying scientific interests. They are often curious to verify information they have heard about CERN in the media and elsewhere. However, language barriers can occasionally lead to amusing situations. For example, I once had a group of visitors who spoke neither English nor French, so I had to use my imagination to create a universal scientific language to guide them through the Synchrocyclotron and ATLAS Visitor Centre facilities.

Throughout my time as a CERN guide, I have had many unforgettable moments that have only deepened my appreciation for the work that we do. One experience that stands out is when I had the pleasure of meeting a five-year-old boy and his parents who were visiting for his birthday. Despite his young age, this child had an impressive understanding of particle physics and the activities taking place at CERN. I couldn't help but wonder if he was one of those rare geniuses who start university at a young age. To my surprise, his parents informed me that they don't have any physics books at home and that his knowledge has solely come from the internet. His enthusiasm for the subject was truly inspiring and I couldn't help but think that I may have been in the presence of a future physicist.

Another vivid memory was when an American father approached me after his visit and asked if I could help him get in touch with his high-school daughter in the US. She was interested in physics but lacked a female role model to explore and pursue her passion. We are still exchanging emails whenever she needs guidance or information. Her father has even promised to bring her to CERN at the first opportunity.

I was also part of the ATLAS virtual visits and initiated a programme dedicated to Moroccan universities and high schools. These virtual visits proved to be an effective means of promoting not only the ATLAS experiment but also CERN's overall activities to a wider audience, resulting in an increased number of Moroccan students and visitors at CERN.

Full of potential *A 3D rendering of school students in the new educational labs at CERN Science Gateway.*

HANDS ON, MINDS ON, GOGGLES ON!

During its eight years of operations, CERN S'Cool LAB gave nearly 40,000 visitors hands-on experience in particle physics. Julia Woithe explains how the new educational labs at Science Gateway will awaken the inner scientist in even larger and more diverse audiences.

In 1826, the Swiss pedagogue and educational reformer Johann Heinrich Pestalozzi advocated for a natural and meaningful education through a holistic learning approach that engaged "the hands, head and heart". One prime example of such an approach is found in science education, where experiments allow learners to experience scientific phenomena while manipulating ideas about experiments in their minds. Experiments are also associated with high affective value, as school students generally enjoy practical tasks and often rank them as preferred learning activities in school. As a result, experiments have long been considered an essential part of teaching the nature of science, and only very few science educators have questioned their necessity.

Consequently, it was long overdue for CERN to offer opportunities for visiting high-school students to get hands-on with particle physics. In 2014, CERN inaugurated its first particle-physics learning laboratory for high-school students. During its eight years of operations, "S'Cool LAB" gave nearly 40,000 visitors a unique opportunity to make discoveries independently, work scientifically and gain insight into modern science in the making.

A major factor in S'Cool LAB's success was its connection to the latest thinking in physics education research. Interestingly, learning from hands-on experiments is (still) one of the central problems of physics education research. Even though students often enjoy doing experiments, various factors influence what and how much students learn from the exercise. To address this research gap, educational activities at S'Cool LAB were continually developed and improved through accompanying physics education research projects. For example, experimental tasks were designed to challenge scientifically inaccurate mental models (such as bar magnets having electrically charged poles) by allowing students to compare their predictions with surprising observations and thus foster conceptual understanding. Moreover, empirical research carried out based on questionnaires from students before and after taking part in lab workshops confirmed significant positive effects on high-school students' interest in physics and their beliefs in their physics-related capabilities, and a surprisingly high correlation between these affective out-

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Lofty learning *High-school students observing cloud chambers at S'Cool LAB, which was dismantled in 2023 to make way for new educational labs at CERN Science Gateway.*

comes and students' perceived level of cognitive activation. Remarkably, girls benefited more from S'Cool LAB with respect to their interest and self-beliefs. Consequently, the initial gender gap (with girls reporting slightly lower interest and self-beliefs than boys) was closed.

New incarnation

On 12 January 2023, excavators arrived to dismantle S'Cool LAB to make space for the new educational labs at CERN Science Gateway. Several considerations went into the design of the new labs. Firstly, they have a broader scope, catering not only to high-school students and their teachers but also to school students as young as five, as well as the general public. Indeed, Science Gateway offers regular workshops open to individual visitors, tourists and families. Moreover, workshops are adapted to different age groups and cover many different topics such as engineering challenges, different technologies, detection principles, or medical applications of particle physics. This diversity allows for better adaptation to the needs of students and teachers, who often prefer workshops that can be easily integrated into their science curriculum.

When designing labs for young learners, a critical choice involves balancing the level of openness and guidance. While open exploration is considered to be the ideal form of experimentation, young students can feel overwhelmed by the choices involved in developing research questions, experiment design and the interpretation of evidence. At the same time, giving students a choice in their learning can foster a sense of ownership and autonomy, leading to increased engagement and motivation to explore topics of personal interest. Providing the right level of guidance and support is therefore crucial to meaningful experimentation and a key element of the education labs at Science Gateway. It helps students enjoy hands-on activities while freeing up mental capacity to process new information effectively. To help teachers prepare their students for the new lab workshops, they now receive detailed information about its planned content and suggestions on how to integrate their experience at CERN into their classroom practice.

The impact of volunteers on students' interest and self-beliefs was a striking result from physics education research at S'Cool LAB

Despite the variety of lab workshops offered, all activities are anchored in authentic CERN contexts and can even be linked to real objects and authentic equipment in the interactive exhibitions at Science Gateway. This approach helps foster students' interest in science and provides them with an accurate image of science and scientists. For instance, one lab workshop for students aged 8–15 – the "Power of Air" – allows students to use 3D-printed components and toy balloons to investigate balloon hovercrafts on different surfaces, drawing connections with how engineers at CERN move massive slices of the LHC detectors via air pads.

Community input

To enhance the authenticity of lab workshops, volunteers from CERN's scientific community accompany students during their learning process and engage in discussions about their findings. The impact of volunteers on students' interest and self-beliefs was a striking result from physics education research at S'Cool LAB. Students were inspired by the enthusiasm displayed by their guides and appreciated the opportunity to ask questions in an enjoyable learning atmosphere. Therefore, the education labs at Science Gateway will continue to rely on volunteers to facilitate workshops and inspire the next generation of engineers and scientists. To address new challenges related to groups of very young learners, heterogeneous audiences, the diverse collection of lab workshops and the high volume of workshops held each year, a team of professional science educators provides continuous support and guidance to volunteers.

In conclusion, the educational labs at CERN Science Gateway have been designed to provide a wide range of hands-on learning experiences for learners of all ages. These labs aim to not only promote scientific understanding but also foster curiosity, interest and positive self-beliefs in students, empowering them to explore the world of science by demonstrating that science is for everyone. ●

Further reading

J Woithe *et al.* 2022 *J. Res. Sci. Teach.* **59** 930.

WHY RESEARCH EDUCATION?

CERN is best known for researching the fundamental laws of the universe, but it also hosts a strong programme in physics education research. Sascha Schmeling explains why.

School's out *Winners of the 2023 Beamline for Schools competition in the Science Gateway educational labs.*

When CERN was founded in 1954, four missions were given to the new organisation: performing fundamental research at the frontier of knowledge; development of innovative technologies to pursue fundamental research; international collaboration for the good of humanity; and education and inspiration for future generations of scientists, engineers and the public at large. The latter mission has been given a powerful new platform in the form of the CERN Science Gateway.

CERN is well known for outreach, most recently via the switch-on of the LHC and the search for and discovery of the Higgs boson. It also trains thousands of people through a variety of student and graduate programmes, ranging from internships, studentships and fellowships to professional training, such as at the CERN Accelerator School, the CERN School of Computing, and several physics and instrumentation Schools. Less well known, perhaps, is CERN's influential work in science education.

Growth initiatives

CERN offers many professional-development programmes for teachers (see p45), as well as dedicated experiment sessions at the former "S'Cool LAB" (reincarnated in the Science Gateway educational labs, p41) and the highly popular Beamline for Schools competition. These efforts are also underpinned by an education-research programme that has seen seven PhD theses produced during the past five years as well as 82 published articles since the programme began in 2009. This is made possible by the significant contributions of doctoral students, who make up much of the team, and cooperation with their almae matres in CERN's member states. In addition, CERN is the publisher of the multilingual international journal *Progress in Science Education*.

The question "what is science education?" probably has more answers than the number of science educators in Europe. Nevertheless, the nature of science – the scientific method itself, without which we could not formulate science correctly, reproducibly and understandably – is a basic principle. Teaching the nature of science as the basis and conveying scientific results as examples is widely regarded as the best way to inspire learners young and old, although methods vary. A frequently asked question in this respect is: what to educate?

The traditional answer, which will be familiar to people who went to school in the 1970s or earlier, is "pure knowledge". Later, it was realised that "skills" were important, too. While both remain core to science curricula, "competencies" are now seen as an effective way to advance society. In terms of physics, key topics in this regard are education for sustainable development, quantum physics and its applications, radiation and artificial intelligence.

Fulfilling its mission, CERN strives to reach everyone with its education programmes. The CERN Science Gateway offers exhibitions, large education labs, as well as educational science shows for audiences aged five and above. Education is key to sustainability, and thus to society, so let's all work together. The CERN team is open to your proposals! ●

THE AUTHOR

Sascha Schmeling *is head of teacher and student programmes at CERN, chairs the CERN Council forum on teacher and student affairs, and is chairperson of the EPS physics education division.*

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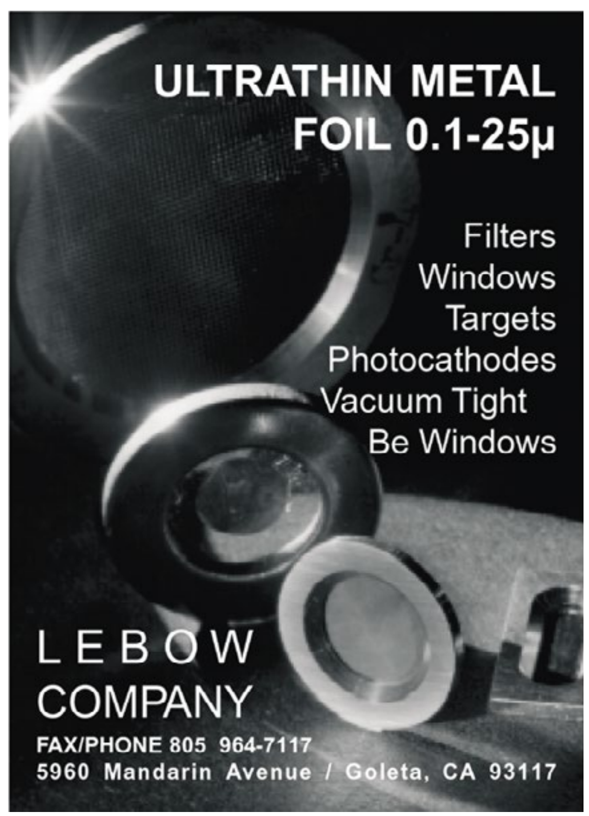


INSPIRING THE INSPIRERS

Jeff Wiener explains how CERN's national and international teacher programmes inspire and empower thousands of teachers and, through them, their students.

High demand *Participants of the International High School Teacher Programme at CERN in 2019.*

"The reason I want to talk to you today is that I myself had a very good physics teacher, which is why I'm now here at CERN. So, thank you for the important work you are all doing. You really make a difference!" This heartfelt sentiment, echoing the gratitude often expressed by CERN scientists when addressing visiting high-school teachers, encapsulates the essence of CERN's teacher programmes.

Over the past quarter-century, CERN's teacher programmes have played a vital role in bridging the gap between particle physics and educators from across the globe. What started originally in 1998, when the first International High School Teacher Programme took place with a small group of teachers, has grown into one of CERN's many success stories. Today, CERN's teacher programmes run on an almost weekly basis, welcoming about 1000 teachers from more than 60 countries every year, which makes them one of the largest and most successful professional development offers for in-service high-school science teachers worldwide.

The vast bulk are week-long programmes for teachers from one country or from one language group, predominantly targeting teachers from CERN's member states, associate member states and the occasional non-member state. In addition, two international teacher programmes take place every year in the summer, significantly broadening the reach. Each international teacher programme lasts two weeks and hosts up to 48 teachers from around the world. So far, about 14,500 teachers from 106 countries have participated in CERN's national and international teacher programmes, and every year another 1000 teachers travel to CERN to attend lectures, on-site visits, hands-on workshops, discussions and Q&A sessions.

Multifaceted

Teacher programmes at CERN serve multiple purposes. First and foremost, they are professional development programmes that enable high-school teachers to keep up to date with the latest developments in particle physics and related areas, and to experience a dynamic, international research environment. As such, they answer the call to bring more modern science into the classroom, which goes

THE AUTHOR

Jeff Wiener *is CERN's teacher programmes manager.*

The overall picture is clear: teachers' satisfaction with CERN's teacher programmes is extremely high

hand in hand with a slow yet steadily increasing change in curriculum development (see p47). Second, teacher programmes are an acknowledgement of the critical role that teachers play in preparing the future of humanity. They inspire and empower teachers and, through them, their students. Last but not least, teacher programmes showcase the importance of science diplomacy – colloquially referred to as a soft power in the world of international relations. For instance, before joining CERN as associate member states, several countries already brought high-school teachers to CERN for dedicated national teacher programmes; these, in turn served as door-openers in the respective ministries and supported the country's application to join CERN. The same is true for distant countries, with which CERN has no other connections than teachers who took part in one of the international teacher programmes.

High impact

But what about the impact of CERN's teacher programmes? Is it possible to measure the effectiveness of such a variety of programmes and perform an evaluation that goes beyond documenting teachers' feedback? Combined with anecdotal data from alumni teachers, who frequently return to CERN with their students or take part in other education activities such as the Beamline for Schools (BL4S) competition, and the fact that CERN's teacher programmes are heavily overbooked, the overall picture is clear: teachers' satisfaction with CERN's teacher programmes is extremely high.

To deepen the level of evaluation of CERN's teacher programmes and to allow for further development in the future, in 2021 a multi-stakeholder study was performed to document and illustrate the goals of professional development programmes at particle-physics laboratories. This study led to a hierarchical list of the 10 most important learning goals, such as enhancing teachers' knowledge of scientific concepts and models, and enhancing their knowledge of curricula, which now represent the baseline for future evaluations of teachers' learning. Here, a large-scale study is currently ongoing to assess their knowledge in a pre-post setting by using concept maps. The aim of this approach is not only to study the learning progression throughout a teacher programme but also to support teachers in constructing meaningful mental models and knowledge structures, which are key indicators of successful educators. Indeed, CERN's teacher programmes continue to serve as a prime testbed for the Organization's physics-education research efforts, with one doctoral research project already successfully completed and a second on its way. Future research projects will aim to evaluate teachers' use of their new knowledge and skills after their participation in CERN's teacher programmes and consequently their students' learning outcomes.

The most important dimension of CERN's teacher programmes, however, is the social one. Over the past 25 years, teachers from different parts of the world have met at CERN, became friends and remained in touch with one another. This has led to several cross-border Erasmus projects, combined school events and even tri-national proposals for the BL4S competition.

Today, CERN's teacher programmes are more popular than ever, with teachers from all around the world being more than eager to apply for one of the limited spots. One participant of this year's International High School Teacher Programme even had to move his wedding date, which originally coincided with the programme dates. Luckily, his fiancée was understanding and not only agreed to the postponed date but also smiled when he put on his CERN helmet for the wedding picture. ●

Tales of a CERN guide Noemi Calace

Guide since 2014
Position ATLAS physicist (staff)
Languages English, Italian, French

private

I have the honour of wearing two hats: that of a scientist and a guide. As a CERN physicist, I have long believed that one of my core missions is to contribute to raise awareness about the different activities and research projects carried out at CERN. By doing so, we dispel fear and create opportunities to educate people about the significance of scientific research.

Guiding young students, especially those from high school, is where my heart finds joy. When students interact with scientists at CERN, they often feel intimidated, perceiving them as superhuman figures. However, as their guide, I consistently receive comments expressing relief and surprise when they realise that scientists are just ordinary individuals like themselves. This relief often sparks a sense of confidence, which makes them realise that pursuing a career in science is within their reach – often at a crucial juncture in their education, having to decide which field of study to pursue. My impact may be just one jigsaw piece in their decision, yet, in some sense, I feel a certain level of responsibility for their future choices.

One heartfelt tale involved a girl who expressed her fear of pursuing research, believing it to be a field dominated by men. I told her stories of incredible women who have made significant contributions to science, and I shared with her my own experience: woman, mother, physicist. I saw her eyes glimmer with a fresh sense of hope and determination. Imagine my overwhelming joy when a few years later I received an email from her, revealing that she had started university in a scientific field and had a strong desire to pursue a PhD. She expressed how our conversation had ignited a fire within her, dispelling her doubts and fuelling her ambition.

These rich and fulfilling experiences as a guide at CERN not only underscore the significance of outreach but also serve as a rewarding testament to the impact of our efforts in nurturing young minds.

PARTICLE PHYSICS IN SCHOOL CURRICULA

Anja Kranjc Horvat surveys the representation of particle physics in high-school curricula across the world, revealing gaps that need to be bridged.

The 2020 update of the European strategy for particle physics couldn't have put it better: "The particle-physics community should work with educators and relevant authorities to explore the adoption of basic knowledge of elementary particles and their interactions in the regular school curriculum". The past decades have witnessed a heightened interest in introducing particle physics to high-school students. On top of the growing number of educational activities proposed in physics-education research literature, more and more high-school curricula explicitly include particle-physics topics. Yet, a big question lingers: what is the true extent of particle-physics representation in current high-school curricula?

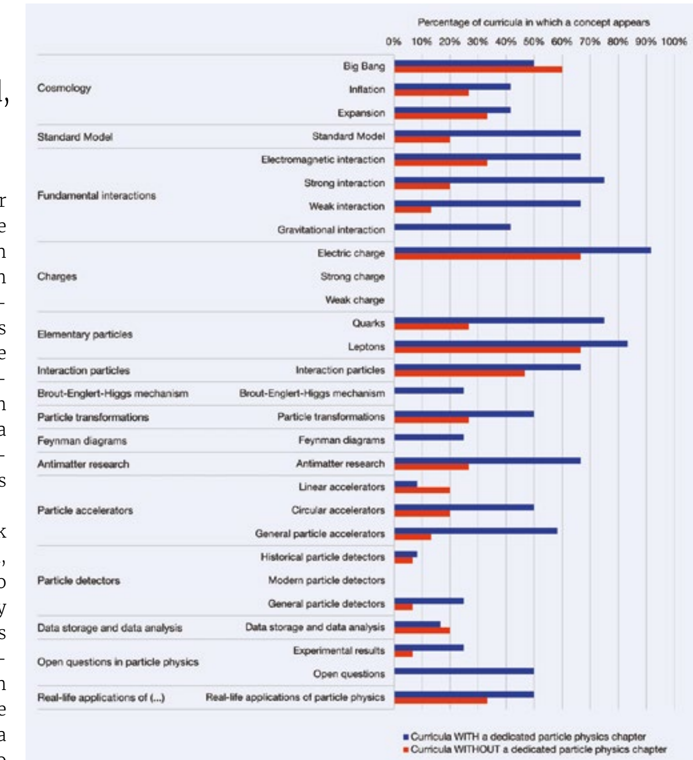
In 2021, CERN physics-education researchers undertook a review encompassing 27 high-school physics curricula, spanning both CERN member and non-member states, to address this question. Each curriculum was analysed by at least two teachers from the CERN teacher programmes alumni network who are well acquainted with their respective curricula and the 28 particle-physics concepts on which the review was based (see "Standard Model" image). The review sought to identify existing trends and chart a roadmap for future curricular developments while also providing a benchmark for CERN's outreach and educational initiatives.

Two types

The curricula included in the review can be split into two types depending on whether they contain any chapters that explicitly focus on particle-physics content. For the curricula with an explicit emphasis on particle physics (International Baccalaureate, Austria, Australia [Queensland], Croatia, Germany [Brandenburg], Israel, Russia, Switzerland [Nidwalden], Serbia, South Africa, Spain and the UK), the results show that more than half contain the following 10 particle-physics concepts (out of 28 included in the review): the Standard Model, electromagnetic interaction, strong interaction, weak interaction, quarks, leptons, interaction particles, antimatter research, general particle accelerators and open questions in particle physics.

For the curricula *without* any focus on particle physics (Brazil [São Paolo], Canada [Manitoba], Germany [Baden-Württemberg; Saxony], France, Ghana, Greece, Italy, Lebanon, the Netherlands, Poland, Slovakia, Slovenia, Sweden and the US), only four particle-physics concepts (out of 28 included in the review) were found in more than half of them: the Big Bang, electromagnetic interaction, electric charge and leptons.

The great majority of the concepts that appeared in more than half of the reviewed curricula were classified as theoretical particle-physics concepts. On the other hand, experimental concepts were generally lacking. Indeed, only particle accelerators appeared in a notable number of curricula with a dedicated particle-physics chapter. Even then, particle accelerators mostly appeared as context within electromagnetism without being explicitly connected to particle physics. Particle detectors appeared even less often in the curricula. Some historical particle detectors, such as the Geiger–Müller counter, were occasionally featured within the context of radiation. However,



A Kranjc Horvat *et al.*

Standard Model *28 particle-physics concepts are identified as topics for high-school curricula.*

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state-of-the-art detectors such as the LHC experiments were conspicuously absent from all reviewed curricula.

This lack of the experimental aspects of physics in high-school physics curricula is not limited to particle physics. Excplicit examples of the importance and value of experiments in science is often absent in high-school curricula, showing physics as a set of solidified facts. Ultimately, this can lead to gaps in students' understanding of the role of experiments in science. Indeed, the contemporary relevance and the blend of theory and experiments within particle physics can offer students a unique opportunity to learn about how real modern science is done and what is the nature of science. Furthermore, emphasising real-world experimental contexts, such as modern particle detectors and their applications across domains such as medicine and art, could enrich student learning and interest.

The connection between particle interactions and the charges that govern them represents another noticeable gap. While the idea of an electric charge is relatively common within discussions on electromagnetism, concepts such as strong and weak charge are conspicuously absent. This is intriguing, especially since the strong and weak interactions are mentioned in several curricula either within the particle-physics or the nuclear-physics chapters. Moreover, electric charge remains referred to merely as charge, which can lead to difficulties in understanding different types of charge down the line. Hence, introducing strong and weak charge can provide a more rounded understanding, even without delving into unnecessary mathematical interpretations. Such introductions could form foundational pillars for students aiming to move further into particle physics and its related domains.

What next?

Particle physics has unequivocally made its mark in high-school education. The consistent presence of certain foundational concepts – electromagnetic interaction, leptons and electric charge – across curricula signals a universal baseline. However, the road to a meaningful introduction of particle-physics concepts in high-school classrooms is still long.

The glaring gap in experimental particle physics underscores that there is an immediate area of focus for our outreach efforts. Bridging this gap will ensure that students gain a more well-rounded understanding, synergising theoretical knowledge with cutting-edge experimental practices.

In addition, a review of particle-physics vocabulary, both in the context of charges and beyond, could improve students' overall understanding of particle physics. By using clear and consistent language, communicators and educators can help reduce possible misunderstandings in the future.

Finally, the narrative around particle physics can serve as more than just a lesson on subatomic particles. It can be a lens, magnifying the very process of science: its challenges, its dynamism and its unparalleled ability to shape and reshape our understanding of the universe. As curricula designers ponder the next iteration, one hopes that particle physics finds a more holistic representation. The next generation of physicists, scientists and curious minds deserve nothing less. ●

Further reading

A Kranjc Horvat *et al.* 2022 *Physics* **4** 1278.

THE AUTHOR

Anja Kranjc Horvat *is a physics-education researcher and science-show developer for Science Gateway.*

Tales of a CERN guide **Dominique Bertola**

Guide since 1999

Position Visits service operations manager (staff)

Languages French, English

D Bertola

In 2015 I was contacted by the president of a local association, *Les Enfants de la lune* ("Moon children"), which helps families and children who suffer from a rare but serious and restrictive disease that forbids them from exposure to ultraviolet (UV) radiation under risk of developing skin or eye cancer. The president wanted to organise a visit to CERN to show them science in a fun way if possible. I immediately responded, taking care to check with the medical service and colleagues from HSE that the site we were visiting offered no or very little UV light, and measuring UV levels in the main auditorium. Together with the visits service we were able to invite about 40 children accompanied by adults to the afternoon event. They arrived by bus, with windows protected by an anti-UV film, equipped with anti-UV suits, resembling astronaut masks and gloves. As soon as they disembarked, they were accompanied to the auditorium in which they were able to remove their suits and helmets in complete safety. I performed several demonstrations that delighted the youngest visitors (from age five) and their parents alike – especially when they were able to taste a few marshmallows immersed in liquid nitrogen! After being re-equipped, they toured the Synchrocyclotron, which is safe from UV exposure. When the visit was over, I met looks, smiles and the sparkling eyes of all these children.

During the following weeks I organised a meeting with physicists and engineers from CERN who proposed a hackathon to improve the daily lives of the children. This resulted in more efficient, lighter and better ventilated helmets at a much lower cost than existed on the market. The group also worked on a more sensitive and cheaper UV detector to help children know if they can safely remove their protective gear.

I received a message from the group soon after: "We would like to thank you again for this magnificent visit. We were able to feel your passion and enthusiasm for CERN. Very happy to visit CERN with such young children, discovering some aspects allowed us to understand how fantastic this place is. I can say the children of the Moon left with lots of stars in their eyes."

EMPOWERING CHILDREN TO ASPIRE TO SCIENCE

To improve the diversity of future generations of scientists, writes Emma Sanders, it is imperative to attract younger audiences today.

C Pralavorio

Fun day out *The exhibits at Science Gateway are open to the youngest audiences.*

The new labs and exhibitions in Science Gateway offer children as young as five and eight, respectively, the opportunity to have fun with science. Why would CERN target such young audiences? And what CERN-related content could possibly be accessible to such an age group?

CERN has traditionally tailored education and outreach material predominantly towards high-school students, in particular those already expressing an interest in science. For this age group, it is relatively easy to find overlaps between school curricula and work at CERN. Such visitors will continue to find engaging content in our exhibitions. However, if CERN is to connect to a broader section of the public and attract a more diverse cohort of future scientists, it needs to reach out beyond existing science fans, attracting younger audiences before stereotypes set in.

Positive contacts

Over the decades, communication best-practice has evolved from the idea that to inspire children to choose a career in science, you just need to make it sound interesting. Now, it is recognised that there are multiple factors influencing choice. The Aspires research project at University College London, for example, has highlighted the importance of "science capital", a notion based on the variety of positive contacts with science that children experience. This includes knowing people who work in science, talking with family and friends, doing science-based activities outside school and there being a generally positive attitude towards science within the family setting.

At schools, careers information often comes once choices to drop science subjects have already been made. And without role models to identify with, or contact with science or science-related professions through family and friends, it can be extremely difficult for some students to imagine themselves as future scientists. Hence the drop in pupils expressing such aspirations from the end of primary education onwards that occurs in many countries. By offering younger students the opportunity to experiment and play in a scientific environment, Science Gateway seeks to counter this drop. In addition to the existing science-fan visitors, it aims to reach those with less science capital at home, so that children can discover new opportunities.

There is a slogan in the exhibitions world: "hands on, minds on". A good exhibit creates memorable experiences that empower visitors to explore and engage, rather than simply transmitting knowledge in a unidirectional way. Science Gateway offers activities – such as designing a detector or collaborating to lower equipment into a cavern – where children are encouraged to think logically, and exhibits that encourage them to make their own deductions, helping them to become more confident that science is for them. Here the exhibition guides play a key role in encouraging interaction and play.

Sometimes in a hands-on science centre, one can have the impression that children are having so much fun racing from exhibit to exhibit that there is no valid experience. This is countered by research which shows that learning comes in a broad variety of forms. Informal learning experiences, such as those at Science Gateway, can have just as much impact as in-school learning.

The exhibitions offer a variety of different environments – playful areas and beautiful spaces, including artworks, that can be enjoyed by simply sitting back and reflecting. The exhibitions team has also collaborated with community groups to develop tactile content and ensure the exhibits are accessible to wheelchair users. Not all exhibits will be accessible for younger children, or for the visually impaired, but throughout there is a spread of different experiences that give something for everyone to enjoy.

The ambition is for CERN to become a popular destination for a fun day out, attracting a broad section of the public, both those who might one day become scientists themselves and those who might never choose that path, but who are curious to explore the new buildings that have popped up in their local area. Successful outcomes can be as simple as visitors having fun in a scientific environment. This is a first step towards being open to scientific ideas and methods – a valid goal in today's world of misinformation and distrust, where science is sometimes talked of as something you might or might not choose to believe in. ●

THE AUTHOR

Emma Sanders *is head of the exhibitions team at CERN.*

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GOING WHERE THE CROWD IS

Connie Potter describes the growing impact of the CERN Festival Programme, which brings cutting-edge physics to untapped audiences worldwide in a relaxed and informal setting.

C Potter

Summer means holidays, beaches, long evenings outside and, for many, attending an outdoor festival. Music festivals in particular have expanded all over the world, and the competition to offer new experiences to curious festival goers has created opportunities to share CERN's work and science with this untapped audience, many of whom never normally go to science events. Based on the success of CERN's first Science Pavilion at Peter Gabriel's world music festival WOMAD in 2016, the project has grown to become a highly successful outreach effort known as the CERN Festival Programme. The generally three-day programme offers a variety of shows, presentations, talks and hands-on workshops tailored to each country and demographic. The Pavilions are a real collaboration, a partnership between CERN, collaborating institutes in each country and the festival itself, each sharing costs and person power.

In 2019, four Science Pavilions were held in four different music and culture festivals in four different countries: the Big Bang Stage at the Ostrava festival in the Czech Republic, produced in partnership with Charles University and the Czech Technical University; the Magical Science Pavilion at the Pohoda Festival in Slovakia – an incredible space produced with Comenius University; the World of Physics at WOMAD in the UK, going strong year after year thanks to an enduring collaboration with Roger Jones of Lancaster University; and the Science Pavilion at the Roskilde Festival in Denmark, a highly successful relationship with Jørgen Beck Hansen at the Niels Bohr Institute in Copenhagen. More than 20,000 people came to the four spaces in 2019!

Workshops give people a chance to interact in a direct way with science and technology, as well as with physicists working on different experiments at CERN. They often can't believe that these people who work for CERN have actually come to the festival to talk to them. A variety of topics are covered ranging from what's new in physics to technological and scientific advances in the news that touch on people's everyday lives, such as artificial intelligence. For 2023 we introduced a successful "scientific speed dating" with the young audience at Roskilde. A talk from CERN's director for accelerators and technology Mike Lamont on physics and medicine and an informal "Chat with the AI experts" in the sunshine also proved incredibly popular at WOMAD this year. Between 4000 and 6000 people come to each Science Pavilion in each festival every year. Requests for new collaborations in other countries are coming in, and as a result there are currently ongoing discussions for Pavilions at festivals in the Netherlands and Spain. Physicists love the idea and their students are always an important asset to the event, with the most forward-thinking institutes keen to be part of the programme.

The feedback from visitors is clear: people love finding science at a music festival. The fact that the science is taken to them, where they are at their most comfortable, relaxed and receptive to new things, is key to the programme's success. Comments range from "It's a welcome break to sit in a cool space and learn something interesting and talk about stuff other than drinking and partying" to "I never liked science at school, I found it so boring and complicated, but here you make it fun and I've come back every year, I love it!".

Recently, the Festival Programme was approved to be part of the CERN and Society Foundation. This means that an individual wishing to support this fantastic form of outreach and communication, or a company that understands the benefit of the programme and would like to have their logo at the festival next to ours, can now do so. It's a great opportunity to reach new audiences, and especially to engage in those countries whose people are actually funding CERN. ●

Tuning in
Since 2016, the Science Pavilions act as "break-out" rooms to explore physics with the public at music festivals.

Further reading

cernandsocietyfoundation.cern/projects/cern-festival-programme.

THE AUTHOR

Connie Potter
is producer for the CERN Festival Programme.

EXPANDING THE SENSES

Science communication often relies on visualisations of complex phenomena, yet not all target groups – especially visually impaired people – profit from it. Sezen Sekmen makes the case for festivals of 3D learning to unlock accessibility.

E Sanders

Feeling physics
Blind visitors test a tactile exhibit of a detector in CERN Science Gateway.

Whether it is grasping the intricate workings of the Higgs mechanism, catching a glimpse of how gravitational waves propagate or contemplating the profound interconnectedness of these phenomena, fundamental physics awakes excitement in scientists and non-scientists alike. Curiosity and the endeavour to fulfil it transcends the constraints of physical, neurological and cultural boundaries, uniting us all in the pursuit of knowledge.

Yet, physics is inherently abstract, and the complex series of interconnected cause-and-effect reasoning is often not straightforward to grasp. The challenge becomes even more daunting when the audience does not share the visual or neurological setup typical to the majority. The main bottleneck is the traditional mode of visual physics communication, which relies mostly on 2D descriptions. We are all familiar with such examples: screens or slides full of overwhelming text with occasional images and graphs. Clearly, such descriptions are not accessible to the visually impaired. Moreover, they usually fall short of creating intuitive understanding, even in people with regular visual perception.

Tangible representations

The key to unlock accessibility is to broaden the number of dimensions and directions through which physics is communicated. Tactile models are the foremost example. They transform abstract concepts into tangible representations, offering a hands-on, immersive and engaging learning experience. The structures of complex entities such as an atom, a gravitational wave, an LHC detector and how particles interact with it are best "visualised" by "feeling" their 3D models. Yet, these are relatively concrete concepts that are straightforward to model. Much more fascinating is to extend this idea and build models to represent the workings of more abstract phenomena. For example: how are the LHC magnets cooled? How does wakefield acceleration work? How are particles reconstructed in a detector? And how does a data analysis searching for new particles progress?

Designing models for these concepts requires more than simply adding an extra dimension to a visual representation. It involves discerning the core aspects of the physical concept that hold the most significance, simplifying them without diluting their essence, and weaving them into a tangible story – a story that takes into account the perception spectrum of the intended audience and aligns with their lived experiences. We can all share a part in this process: physicists, educators, accessibility experts and the target audience itself. Thanks to amazing improvements in 3D printing, realising the models is now much easier, which gives us the freedom to imagine and build with boundless creativity.

Fresh perspectives

It is highly worthwhile for all of us to attempt this expansion of expression in what we are experts at. In the realm of accessibility initiatives, what proves beneficial for one audience usually translates into advantages for all. For instance, tactile content originally tailored for the visually impaired resonates with children who possess an innate curiosity for tactile experiences. Enhancing access to captivating physics, as is done by the informal science-learning encounters at CERN Science Gateway, can make a great impact. Another pioneering example, specifically designed for the visually impaired, is Tactile Collider, an immersive workshop developed by particle physicists in the UK that allows participants to explore the science of particle accelerators and the Higgs boson through touch, sound and embodied learning techniques (*CERN Courier* January/February 2020 p33).

The thorough internalisation and fresh perspectives brought whilst sculpting a tangible 3D story out of a physics theme and seeking connections to familiar daily concepts can also amplify our own intuition. Most rewarding would be to share our models in festivals of 3D learning wherever curiosity dwells, from classrooms to exhibitions and public scientific discussions, to inspire and encourage brilliant ideas born through "feeling physics". ●

THE AUTHOR

Sezen Sekmen
is a physicist at Kyungpook National University and a member of the CMS collaboration.

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PHYSICISTS GO DIRECT

Outreach can take many shapes and forms, and can be performed successfully by trained communicators and science enthusiasts. But its original form in particle physics – passionate researchers engaging directly with a wide range of the general public – remains as vivid and vital as ever. Claire Adam highlights key examples of this high-energy physics success story.

As recently as 10 years ago, scientists had to work hard to convince conference organisers of the value of sessions on communication, education and outreach. Today, major conferences such as ICHEP, EPS-HEP and LHCP not only offer parallel sessions, but also plenary talks where the state of the art in the field is reviewed. Abstracts from around the world describe events organised in multiple contexts and languages, via formal and informal partnerships between scientists and local communities, artists, teachers and many others. Each of the major LHC experiments now has a dedicated outreach group that, with the help of a few professional communicators, develops material and shares best practice within the collaboration. Institutes and funding agencies are on board, and younger generations are increasingly encouraged to include outreach on their CVs. A fraction of this energy and creativity is captured in reports, such as the one presented each year to the CERN Council by the International Particle Physics Outreach Group (IPPOG) – a collaboration initiated by former CERN Director-General Chris Llewellyn-Smith in the early days of the LHC project, and that now counts 33 countries, seven experiments and three large laboratories.

Netzwerk Teilchenwelt

Eventful *Students and scientists analyse LHC data via the International Masterclasses.*

Reaching out to the world

Workshops and hands-on activities have multiplied in recent years. Cloud-chamber building is one of the most popular, and is used by a growing number of institutes when they host students for a day. Created in 2005, the International Masterclasses programme brings another level of activity, offering guests the chance to analyse data from contemporary experiments with direct help from the physicists involved. Each year, more than 10,000 teachers and 15–19-year-old students have been given this opportunity. Initially organised in the EU time zone with a scientist at CERN, the programme now also runs in US and Japanese time zones. The range of analyses offered encompasses the four LHC experiments, Belle II, particle therapy, the Pierre Auger cosmic-ray detector and neutrino experiments in the US. During the pandemic, masterclasses were made available online, and the tools developed now help to reach people in countries and regions that do not yet have any high-energy physics institutes.

The large number of CERN visitors is proof of public interest in face-to-face interactions. But what about those who can't come in person? What about teachers who want to inspire their students by inviting a scientist into their classrooms? Or institutes that would like to show a detector their teams have built and where the data come from? Pioneered by ATLAS in 2010, the LHC experiments virtual-visit programme breaks down geographical barriers. Thanks to a video conference tool, a scientist working on an experiment can walk audiences through underground installations or control rooms, the diversity of international-collaboration members offering a wide range of languages to let the public meet and engage with "one of theirs". The most important part of the event is a lengthy Q&A session, which has allowed tens of thousands of children and adults to share the scientific experience.

Coming together

Organised by interactions.org, a network that groups the communications activities of the world's particle-physics labs, Dark Matter Day offers a scientific twist to Halloween. Since 2017, more than 350 global, regional and local events have been held on and around 31 October. Institutions and individuals engage the public in discussions about what is known and what mysteries experiments are seeking to solve. International Cosmic Day, where students, teachers and scientists come together to talk and learn about cosmic rays, follows each November. Activities range from the construction of a detector to data analysis, and the coordination of such events is kept light, to let the primary actors – the scientists who proposed and built the 17 presently listed activities – be as creative and engaged as they are in everyday life. As with all community-driven outreach activities, that authenticity is hard to beat. ●

THE AUTHOR

Claire Adam *(LAPP, Annecy) is an ATLAS physicist and current IPPOG chair.*

TIME FOR AN UPGRADE

Particle physicists have a duty to engage broader society in our adventure. But to do so effectively, says Ivo van Vulpen, we need to take a more critical look at our current practices.

M Smeets

Crafting skills *The inaugural COMPASSS summer school organised between TU Eindhoven and the University of Leiden at the end of August aims to inspire early-career physicists to take part in science communication.*

What's not to like about particle physics? Exploring the fundamental workings of the universe at international laboratories such as CERN is an inspiration to all, and regularly attracts media attention. However, despite the abundance of wonderful outreach activities by physicists and professional communicators, and science centres such as CERN's new Science Gateway, it is important that we also take a critical look at our attitude towards science communication (and colleagues who engage in it) to see where we can improve.

Like many of my colleagues, I have always devoted a significant fraction of my time to share my passion for the field with diverse audiences. Society funds our research, so we have a fundamental duty to report back about our discoveries, act as an advocate for science in general, and educate and inspire the next generation. Doing outreach is not only enjoyable but also a valuable exercise that forces you to look at your own work from an outside perspective and to adapt your story for different audiences. Given the collective responsibility of particle physicists for garnering societal support for fundamental science, one might expect the entire field to support individuals involved in outreach activities. Regrettably, this is not always the case.

A new programme at the Leiden Institute of Physics, in collaboration with colleagues from the science communication research group, is investigating how we approach physics communication. When studying our attitudes, certain "points of attention" become rapidly apparent.

Critical points

One concerns cultural appreciation and the role of the scientist. Outreach is often still perceived as something someone does in their spare time and not a valuable activity for "serious" scientists. Many young researchers are all too aware of this attitude, and given the limited number of permanent positions and the emphasis on leadership roles and scientific output for career advancement, outreach often gets reduced priority. This means we're missing out on an enormous potential of energy and ideas to connect with society. It is important that scientists realise that good communication skills are indispensable for an academic career, which, after all, includes teaching and grant writing. While professional communicators do great work, it's crucial that more physicists are directly involved as they inherently radiate their passion and drive.

A second point is public relations versus the role of science in society. While every country can simultaneously benefit from new discoveries, communication departments within universities and research institutes – including CERN – often struggle to move beyond the frame of public relations and the latest scientific breakthroughs. In doing so, there is an increasing tendency to project a polished image and to be too self-focused while neglecting opportunities to provide insights into laboratory life – including failure, which is an inevitable aspect of the scientific process – and the stories behind the publications.

Impact assessment is a third factor where we could do better. Despite the increasing encouragement from funding agencies to make societal engagement an integral component of research proposals, we frequently fall short when it comes to conducting impact assessments. While researchers invest years in writing academic papers and scrutinise collaborators for failing to cite the most recent articles, we seem perfectly happy to ignore the literature on science-communication research and input from experts when developing outreach initiatives. Moreover, owing to our lack of collective memory, we do not have a systematic way to learn from good and bad practices.

Last but not least, developing effective communication skills is also critical in peer-to-peer interactions. We don't often talk about it openly, but it is remarkable how physicists perpetuate the poor quality of presentations and seemingly endless meetings, and how increasingly challenging it is to understand developments in other sub-fields. With proper attention given to our internal communication, we would all stand to benefit significantly.

A change in culture does not happen overnight. Nevertheless, given the ongoing discussions about the future of the field, for example about a future collider at CERN, it is vital that we develop a stronger, broader and especially more open science communication strategy. It should be centred around curiosity and the amazing people in our field, as that is how we can connect with society to start a dialogue, while at the same time finding ways to support and acknowledge the work of colleagues who engage in outreach activities. Particle physics is a wonderful adventure. Let's make sure the world knows about it. ●

THE AUTHOR

Ivo van Vulpen, *University of Amsterdam, is a member of the ATLAS collaboration and a professor by special appointment in science communication at the Leiden Institute of Physics.*

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Advertisement

Where pressure prevails

SEN pressure sensors from KOBOLD Messring GmbH, based in Hofheim in Germany, are extremely compact and can be used in a variety of applications. The approved measuring principle uses a thick-film ceramic measuring cell, and has very good repeatability and reliability. The automatic temperature compensation also provides great accuracy. As these robust devices are so well protected against overloading, and cope very well with pressure peaks, they are highly suitable for use in hydraulic systems. Other typical applications include use in compressor and pump engineering, and cooling circuits.

These handy devices are connected to G 1/4, G 1/2, 1/4 NPT or 1/2 NPT thread processes, with other connections available as options. There is also a choice of 16 measuring ranges, reaching from –1 to 0 bar up to 0 to 600 bar relative pressure.

Analogue outputs of 4 to 20 mA, 0 to 5 V and 0 to 10 V are available for signal transmission. Fast, on-the-spot information about the current pressure is provided by the practical AUF-type plug-on display. With protection type IP65, the stainless steel and resistant ceramic sensors can cope with jet water, and the protection type IP68 models can handle complete flooding.

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OPINION
VIEWPOINT

We need to talk about CERN's future

Finding a crisp narrative that better reflects our research after the discovery of the Higgs boson is vital to inspire current and future generations, argues Urs Wiedemann.

iStock/Kateryna Kovarzh

Thinking ahead *A common intellectual denominator is key when formulating a narrative.*

M Chalmers

Urs Wiedemann *is a senior physicist in the CERN theoretical physics department.*

In big science, long-term planning for future colliders is a careful process of consensus building. Particle physics has successfully institutionalised this discourse in the many working groups and R&D projects that contribute, for example, to the European strategy updates and the US Snowmass exercise. But long timescales and political dimensions can render these processes impersonal and uninspiring. Ultimately, a powerful vision that captures the imagination of current and future generations must go beyond consensus building; it should provide a crisp, common intellectual denominator of how we talk about what we are doing and why we are doing it.

A lack of uniqueness

For several decades, the hunt for the Higgs boson has been central to such a captivating narrative. Today, 11 years after its discovery, all other fundamental open questions remain open, and questions about the precise nature of the Higgs mechanism have become newly accessible to experimentation. What the field is facing today is not a lack of long-term challenges and opportunities, but a lack of uniqueness of one scientific hypothesis behind which a broad and intrinsically heterogeneous international research community could be assembled most easily.

We need to learn how to communicate this reality more effectively. Particle physics, even if no longer driven by the hypothesis of a particular particle within guaranteed experimental reach, continues to have a well-defined aim in understanding the fundamental composition of the universe. From discussions, however, I sense that many of my colleagues find it harder to develop long-term motivation in this more versatile situation. As a theorist I know that nature does not care about the words I attach to its equations. And yet, our research community is not immune to the motivational power of snappy formulations.

What makes the physics of the infinitesimally small exciting for the public is also what makes it difficult to communicate

The exploration of the Higgs sector provides a two-decade-long perspective for future experimentation at the LHC and its high-luminosity upgrade (HL-LHC). However, any thorough exploration of the Brout–Englert–Higgs mechanism exceeds the capabilities of the HL-LHC and motivates a new machine. Why is it then challenging to communicate to the greater public that collecting 3 ab^{-1} of data by the end of the HL-LHC is more than filling-in details on a discovery made in 2012? How can our narrative better reflect the evolving emphasis of our research? Should we talk, for example, about the Higgs' self-interaction as a "fifth force"? Or would this be misleading cheerleader language, given that the Higgs self-coupling, unlike the other forces in the Standard Model Lagrangian, is not gauged? Whatever the best pitch is, it deserves to be sharpened within our community and more homogeneously disseminated.

Another compelling narrative for a future collider is the growing synergy with other fields. In recent decades, space-based astrophysical observatories have started to reach a complexity and cost comparable to the LHC. In addition, there is a multitude of smaller astrophysical observatories. We should welcome the important complementarities between lab-based experimental and space-based observational approaches. In the case of dark matter, for example, there are strong generic reasons to expect that collider experiments can constrain (and finally, establish) the microscopic nature of dark matter and that the solution lies in experimentally unchartered territory, such as either very massive or very feebly interacting particles.

What makes the physics of the infinitesimally small exciting for the public is also what makes it difficult to communicate, starting with subtle differences in the use of everyday language. For a lay audience, for instance, a "search for something" is easy to picture, and not finding the something is a failure. In physics, however, particles can reveal themselves in quantum fluctuations even if the energy needed to produce them can't be reached. Far from being a failure, not-finding with increased precision becomes an intrinsic mark of progress. When talking to non-scientists, should we try to bring to the forefront such unique and subtle features of our search logic? Could this be a safeguard against the foes of our science who misrepresent the perspectives and consequences of our research by naively equating any unconfirmed hypothesis with failure? Or is this simply too subtle and intellectual to be heard?

Clearly, in our everyday work at CERN, getting the numbers out is the focus. But going beyond this operational attitude and fighting for the most adequate words and pictures that give meaning to what we are doing is crucial to keep the community focused and motivated for the long march ahead.

- *Adapted from text originally published in the CERN Staff Association newsletter.*

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Elevating the performance of ionization vacuum gauges with simulation

Instrumentation manufacturer INFICON used multiphysics modelling to develop an ionization gauge for measuring pressure in high-vacuum and ultrahigh-vacuum (HV/UHV) environments.

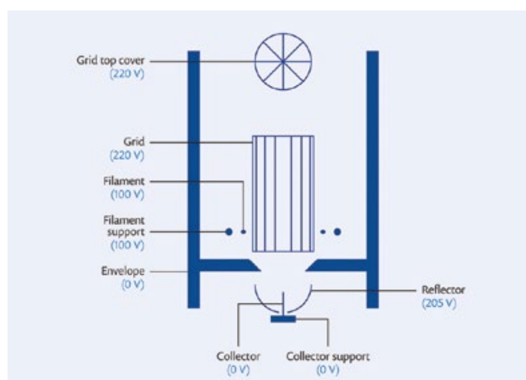
Innovation often becomes a form of competition. It can be thought of as a race among creative people, where standardized tools measure progress toward the finish line. For many who strive for technological innovation, one such tool is the vacuum gauge.

High-vacuum and ultra-high-vacuum (HV/UHV) environments are used for researching, refining and producing many manufactured goods. But how can scientists and engineers be sure that pressure levels in their vacuum systems are truly aligned with those in other facilities? Without shared vacuum standards and reliable tools for meeting these standards, key performance metrics – whether for scientific experiments or products being tested – may not be comparable. To realize a better ionization gauge for measuring pressure in HV/UHV environments, INFICON of Liechtenstein used multiphysics modelling and simulation to refine its product design.

High performance *Francesco Scuderi (left) and Martin Wüest of INFICON analyze their multiphysics model of the Ion Reference Gauge 080 (IRG080).*

A focus on gas density

The resulting Ion Reference Gauge 080 (IRG080) from INFICON is more accurate and reproducible when compared with existing ionization gauges. Development of the IRG080 was coordinated by the European Metrology Programme for Innovation and Research (EMPIR). This collaborative R&D effort by private companies and government research organizations aims to make Europe's "research and innovation system more competitive on a global scale". The project participants, working within EMPIR'S 16NRM05 Ion Gauge project, considered multiple options before agreeing that INFICON's gauge design best fulfilled the performance goals.



Left *The Ion Reference Gauge 080, designed and manufactured by INFICON.* **Right** *Key components in the INFICON IE514 gauge. Three groups within EMPIR's 16NRM05 Ion Gauge consortium created simulation models for this design.*

Of course, different degrees of vacuum require their own specific approaches to pressure measurement. "Depending on conditions, certain means of measuring pressure work better than others," explained Martin Wüest, head of sensor technology at INFICON. "At near-atmospheric pressures, you can use a capacitive diaphragm gauge. At middle vacuum, you can measure heat transfer occurring via convection." Neither of these approaches is suitable for HV/UHV applications. "At HV/UHV pressures, there are not enough particles to force a diaphragm to move, nor are we able to reliably measure heat transfer," added Wüest. "This is where we use ionization to determine gas density and corresponding pressure."

The most common HV/UHV pressure-measuring tool is a Bayard–Alpert hot-filament ionization gauge, which is placed inside the vacuum chamber. The instrument includes three core building blocks: the filament (or hot cathode), the grid and the ion collector. Its operation requires the supply of low-voltage electric current to the filament, causing it to heat up. As the filament becomes hotter, it emits electrons that are attracted to the grid, which is supplied with a higher voltage. Some of the electrons flowing toward and within the grid will collide with any free-floating gas molecules that are circulating in the vacuum chamber. Electrons that collide with gas molecules will form ions that then flow toward the collector, with the measurable ion current in the collector proportional to the density of gas molecules in the chamber.

"We can then convert density to pressure, according to the ideal gas law," explained Wüest. "Pressure will be proportional to the ion current divided by the electron current, [in turn] divided by a sensitivity factor that is adjusted depending on what gas is in the chamber."

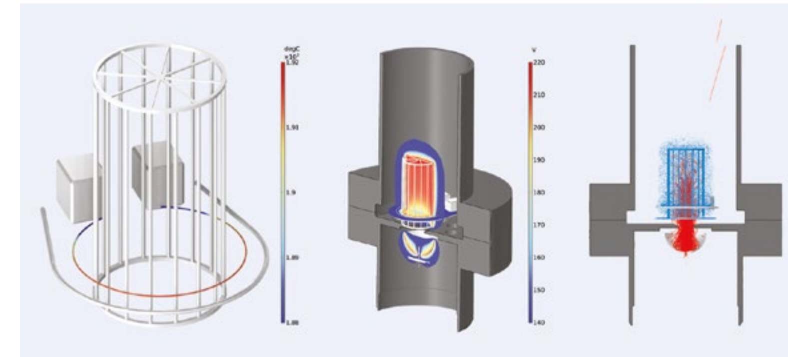
Better by design

Unfortunately, while the operational principles of the Bayard–Alpert ionization gauge are sound and well understood, their performance is sensitive to heat and rough handling. "A typical ionization gauge contains fine metal structures that are held in spring-loaded tension," said Wüest. "Each time you use the device, you heat the filament to between 1200 and 2000 °C. That affects the metal in the spring and can distort the shape of the filament, [thereby] changing the starting location of the electron flow and the paths the electrons follow."

At the same time, the core components of a Bayard–Alpert gauge can become misaligned all too easily, introducing measurement uncertainties of 10 to 20% – an unacceptably wide range of variation. "Most vacuum-chamber systems are overbuilt as a result," noted Wüest, and the need for frequent gauge recalibration also wastes precious development time and money.

With this in mind, the 16NRM05 Ion Gauge project team set a measurement uncertainty target of 1% or less for its benchmark gauge design (when used to detect nitrogen gas). Another goal was to eliminate the need to recalibrate gas sensitivity factors for each gauge and gas species under study. The new design also needed to be unaffected by minor shocks and reproducible by multiple manufacturers.

To achieve these goals, the project team first dedicated itself to studying HV/UHV measurement. Their research encompassed a broad review of 260 relevant studies. After completing their review, the project partners selected one design that incorporates current best practice for ionization gauge design: INFICON's IE514 extractor-type gauge. Subsequently, three project participants – at NOVA University Lisbon, CERN and INFICON – each developed their own simulation models of the IE514 design. Their results were compared to test results from a physical prototype of the IE514 gauge to ensure the accuracy of the respective models before proceeding towards an optimized gauge design.



Continuous improvement *Simulation results for the IE514 gauge showing the filament temperature (left) and the electric potential surrounding the grid structure (middle). A ray-tracing model (right) shows the simulated path of electrons (blue) and ions (red) in the IE514.*

Computing the sensitivity factor

Francesco Scuderi, an INFICON engineer who specializes in simulation, used the COMSOL Multiphysics® software to model the IE514. The model enabled analysis of thermionic electron emissions from the filament and the ionization of gas by those electrons. The model can also be used for ray-tracing the paths of generated ions toward the collector. With these simulated outputs, Scuderi could calculate an expected sensitivity factor, which is based on how many ions are detected per emitted electron – a useful metric for comparing the overall fidelity of the model with actual test results.

"After constructing the model geometry and mesh, we set boundary conditions for our simulation," Scuderi explained. "We are looking to express the coupled relationship of electron emissions and filament temperature, which will vary from approximately 1400 to 2000 °C across the length of the filament. This variation thermionically affects the distribution of electrons and the paths they will follow."

He continued: "Once we simulate thermal conditions and the electric field, we can begin our ray-tracing simulation. The software enables us to trace the flow of electrons to the grid and the resulting coupled heating effects."

Next, the model is used to calculate the percentage of electrons that collide with gas particles. From there, ray-tracing of the resulting ions can be performed, tracing their paths toward the collector. "We can then compare the quantity of circulating electrons with the number of ions and their positions," noted Scuderi. "From this, we can extrapolate a value for ion current in the collector and then compute the sensitivity factor."

INFICON's model did an impressive job of generating simulated values that aligned closely with test results from the benchmark prototype. This enabled the team to observe how changes to the modelled design affected key performance metrics, including ionization energy, the paths of electrons and ions, emission and transmission current, and sensitivity.

The end-product of INFICON's design process, the IRG080, incorporates many of the same components as existing Bayard–Alpert gauges, but key parts look quite different. For example, the new design's filament is a solid suspended disc, not a thin wire. The grid is no longer a delicate wire cage but is instead made from stronger formed metal parts. The collector now consists of two components: a single pin or rod that attracts ions and a solid metal ring that directs electron flow away from the collector and toward a Faraday cup (to catch the charged particles in vacuum). This arrangement, refined through ray-tracing simulation with the COMSOL Multiphysics® software, improves accuracy by better separating the paths of ions and electrons.

A more precise, reproducible gauge

INFICON, for its part, built 13 prototypes for evaluation by the project consortium. Testing showed that the IRG080 achieved the goal of reducing measurement uncertainty to below 1%. As for sensitivity, the IRG080 performed eight times better than the consortium's benchmark gauge design. Equally important, the INFICON prototype yielded consistent results during multiple testing sessions, delivering sensitivity repeatability performance that was 13 times better than that of the benchmark gauge. In all, 23 identical gauges were built and tested during the project, confirming that INFICON had created a more precise, robust and reproducible tool for measuring HV/UHV conditions.

"We consider [the IRG080] a good demonstration of [INFICON's] capabilities," said Wüest.

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OPINION INTERVIEW

The future is international

Incoming director-general of KEK, Shoji Asai, describes the latest activities in Japan's diverse high-energy physics programme and how to build on the field's successes in international collaboration.

What has been your career trajectory so far?
I completed my PhD at the University of Tokyo (U-Tokyo) in 1995 on precise measurements of the orthopositronium decay rate, in which I solved the problem of the orthopositronium lifetime puzzle. The measurement ultimately confirmed second-order QED predictions with an accuracy of 100 ppm, and positronium's hyperfine structure and Bose–Einstein condensation are ongoing projects in the Tokyo group. I remained at U-Tokyo as an assistant, associate and then full professor, and in 1995 I joined the OPAL experiment at LEP and then ATLAS at the LHC. At OPAL I took an initiative in electroweak gaugino searches and performed a new search for scalar top quarks. I continued to work on supersymmetry searches at ATLAS, and also made a contribution to the discovery of the Higgs boson. From 2017, I became director of the International Center for Elementary Particle Physics at U-Tokyo, and on 31 March 2024 I will leave the university after close to 40 years to take up my new role at KEK.

How does it feel to be taking over as KEK director general, and what will be your priorities in the coming years?
I am honoured and feel a sense of humility at the same time. We are at a critical time to determine future project(s), and strong international collaborations are crucial. I want to have fun and do my best! The successful accomplishment of ongoing programmes (SuperKEKB, J-PARC upgrade and Hyper-Kamiokande) is the top priority in the coming years. KEK also has photon factories, and upgrades to these are urgent. The International Linear Collider (ILC) is the top priority after SuperKEKB and the construction of Hyper-Kamiokande (Hyper-K).


U-Tokyo

Sharp focus *Particle-physics experimentalist Shoji Asai will take over from Masanori Yamauchi as KEK director general on 1 April 2024.*


KEK

Hyper bowl *The 69 m-diameter, 21 m-high dome section of the main cavern for Hyper-Kamiokande was completed on 3 October 2023.*

Will you still play a role in ATLAS?
Personally, I will leave the ATLAS experiment. I thank all ATLAS collaborators with whom I have had a wonderful and exciting time for more than 20 years. Japan has contributed to the HL-LHC projects and the associated ATLAS upgrades, as it did for the first phase of LHC/ATLAS. Now we begin an additional contribution to HL-LHC concerning the power supply for the quench heater and radio-frequency generators for the crab cavities. The Japanese high-energy physics community and MEXT (Ministry of Education, Culture, Sports, Science and Technology) would like to continue their large contributions to CERN, the LHC and ATLAS.

How is data collection progressing at SuperKEKB, and what are the current luminosity targets?
SuperKEKB represents a new generation of electron–positron colliders based on nanobeam technology. The highest instantaneous luminosity achieved so far ($5\times10^{34}\,cm^{-2}s^{-1}$, a record for an e^+e^- machine) was obtained with only half the beam current of its predecessor KEKB. Now, SuperKEKB is emerging from a long shutdown and will restart in December. The first target is to reach higher than $10^{35}\,cm^{-2}s^{-1}$ with the nominal beam current, after which the beam will be squeezed further to reach a final target that is a factor of 10 higher. SuperKEKB opens up opportunities for the discovery of a new CP phase and phenomena beyond the Standard Model. Many new baryon and meson states will be discovered, and a deep understanding of QCD at low energy will be obtained.

What is the current situation with the ILC, and do you expect any advances in the near future regarding Japan's hosting of the facility?
The Japanese community considers the ILC as the top-priority project after SuperKEKB and the neutrino CP-violation programme at Hyper-K. We would like to realise the ILC as a "global project" built up through a worldwide collaborative effort in which all decisions (such as the construction decision itself, cost sharing, the construction location, risk management and organisation scheme) are taken collectively by all partners from the beginning. This is a new approach in particle physics. We are setting up the ILC technology network and a global discussion framework in collaboration with the IDT (the International Development Team established by the International Committee for Future Accelerators).

Moving to neutrinos, how are things going with the T2K upgrade and Hyper-K projects, and how strongly do these relate to LBNF/DUNE in the US?
A megawatt power-upgrade of the drive accelerator at J-PARC and the construction of the Hyper-K detector are ongoing without any serious problems. We expect to start the neutrino programme with Hyper-K in 2027, with the main goal of establishing the CP phase in the neutrino sector. We have much experience with T2K and water Cherenkov detectors, which are an advantage for this programme. We can also share our experience of the target of the high-power proton beam with LBNF. DUNE and Hyper-K are quite different detectors, so we can cover each other.

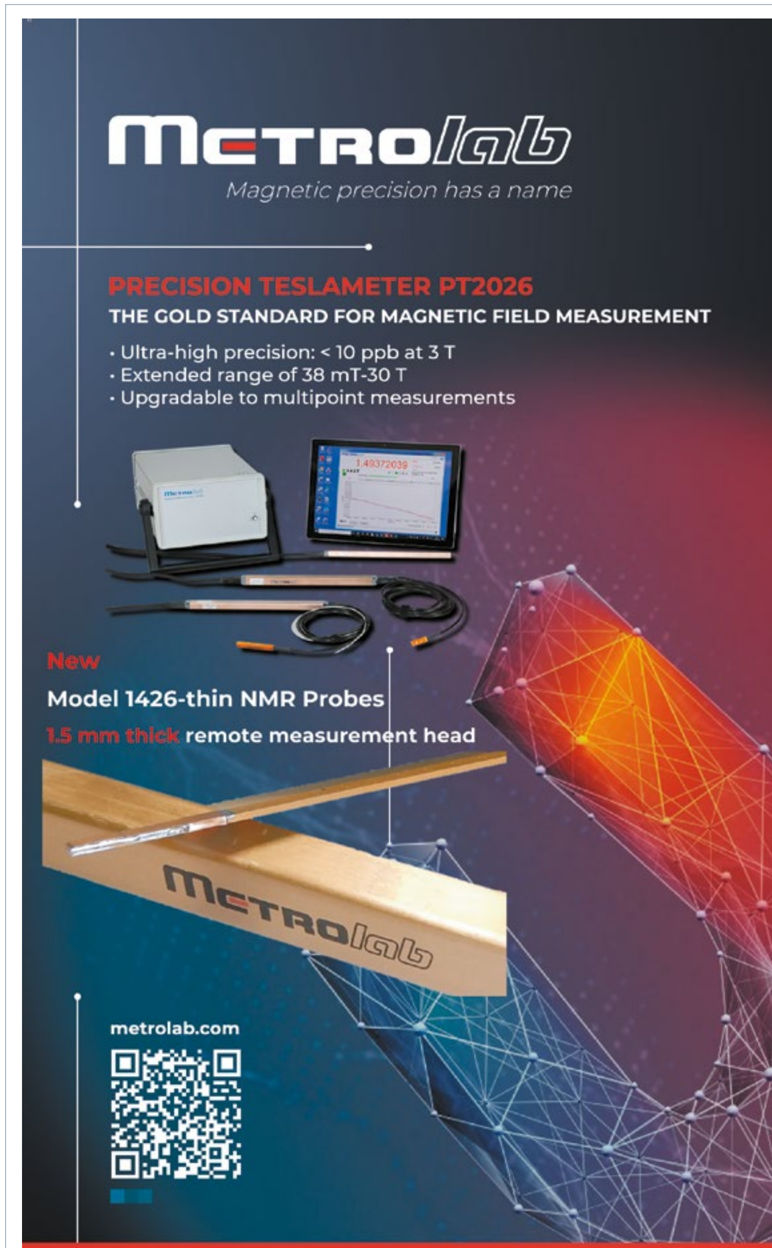
What are KEK's major collaborations in the broader region, for example JUNO and the Super Charm-Tau factory?
These are very interesting programmes. The Japanese high-energy physics community has contributed to many ongoing programmes overseas, and we also have many important projects in Japan. Human resources are limited and focussing on these ongoing programmes is the priority.

The SuperKEKB and neutrino programmes, in addition to the muon programmes in Japan, always open a window for the world. New collaborators are always welcome to these programmes. As for involvement in other proposed future-collider projects, for example FCC and CEPC, it depends on the realisation of the ILC and the collaboration frameworks that will be proposed.

The success of LEP and the LHC prove that international collaboration is very successful in our field

How do you view the current global picture of high-energy physics?
My happy time as a scientist in OPAL and with ATLAS, and the enormous success of LEP and the LHC prove that international collaboration is very successful in our field. I am afraid that our next major project has become too large and will cost more than one country can afford, which is why we need the ILC to be a global project. I understand that this approach will not be easy, but we have fantastic experience to build on. Now we face problems in international relations generally, such as war, pandemics and budget tensions in many counties. We can overcome them, I hope.

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



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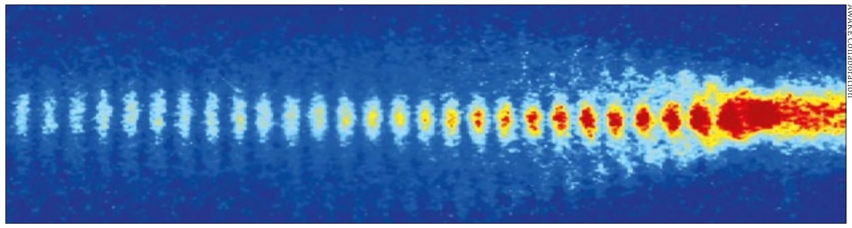
OPINION REVIEWS

Connecting the accelerator dots

Unifying Physics of Accelerators, Lasers and Plasma, 2nd Edition

By Andrei Seryi and Elena Seraia

CRC Press, Taylor & Francis Group



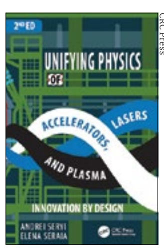
AWAKE Collaboration

Surfing *Advanced accelerator concepts such as plasma wakefield acceleration are among many topics covered.*

The book *Unifying Physics of Accelerators, Lasers and Plasma*, by Andrei Seryi and Elena Seraia, provides a comprehensive overview of the fundamental principles and physics of three distinct areas: accelerators, lasers and plasma, bridging them via inventive principles that offer readers a unified perspective. The strength of the book lies in its accessibility and clarity.

Originally published in 2016, the first edition was picked up by CERN's "eBooks for all!" programme to be converted to open access. The second edition, released in April 2023, has been updated throughout to cover new and essential areas in accelerator science. The material for the book originated from lectures and courses with the aim to teach undergraduate and graduate students several physics disciplines in a coherent way, while at the same time ensuring that this training would develop and stimulate innovativeness. It is written with a fine balance between technical rigour and a conversational tone, avoiding heavy mathematics and using back-of-the-envelope-type derivations and estimations wherever possible. This makes the book inspiring for both experts seeking in-depth knowledge and curious minds looking for an introduction to the field.

With the authors' systematic approach, readers can easily follow the logical progression of ideas, facilitating comprehension and aiding future reference. They introduce the reader to the basics of accelerators and the art of inventiveness, and provide a solid foundation for understanding the key concepts of accelerators, lasers and plasma, and how they can be integrated and used together to advance scientific research.



CRC Press

The book includes a wide range of relevant topics such as beam dynamics, cavities, synchrotron radiation, laser and plasma physics and their role in accelerators. It then delves into advanced accelerator concepts such as radiation generation, wakefield acceleration and laser-plasma accelerators, free-electron lasers and plasma-based light sources. The authors also weave in the historical development of accelerator, laser and plasma technologies, highlighting milestones that have shaped the scientific landscape. They also extensively explore the next generation of accelerators, cutting-edge technologies and state-of-the-art facilities employed in these fields. New chapters added to the second edition, which are crucial in the accelerator area and relevant for future projects, include topics such as superconducting technology, beam cooling, final focusing, polarisation, beam stability, energy recovery, advanced technologies and no fewer than 40 inventive principles.

Also remarkable are the more than 380 illustrative diagrams that allow the reader to visualise the content for a better understanding. In the eBook most of the pictures have been changed to even more attractive colour versions.

The authors commit to scientific integrity, reinforcing their authority in the field. In addition, their pedagogical strength and clear aim to help the reader develop a deeper understanding of the material is emphasised with numerous end-of-chapter exercises. In the second edition, the guide to the solutions has been added directly into the book.

This book is the first of its kind where the three disciplines of accelerators, lasers and plasmas are connected towards building more compact accelerators. One of the highlights is the authors' emphasis on the potential synergistic effects that can arise from integrating these three areas. With its accessible explanations, cutting-edge research coverage, and compelling arguments for interdisciplinary collaboration, this is an indispensable resource for physicists, researchers and students alike.

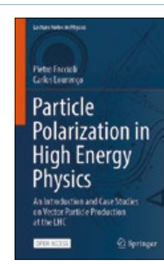
Edda Gschwendtner *CERN.*

Particle Polarization in High Energy Physics: An Introduction and Case Studies on Vector Particle Production at the LHC

By Pietro Faccioli and Carlos Lourenço

Springer

At the end of two pedagogical seminars that Pietro Faccioli gave in April 2013 at CERN and HEPHY, Vienna, on the topic "Angular momentum and decay distributions in high energy physics: an introduction and use cases for the LHC", several people, including myself, encouraged him to turn his slides into a textbook on particle polarisation. Ten years later I received a copy of *Particle Polarization in High Energy Physics: An Introduction and Case Studies on Vector Particle Production at the LHC* from Carlos Lourenço, co-author and Pietro's long-term colleague. During this decade, much has been learned about particle polarisation and related topics, in particular thanks to measurements made at the LHC. As someone who had a front-row seat to observe this progress in the context of polarisation measurements in the CMS experiment, I can attest to the importance and timeliness of this book.



Springer

Throughout the first four chapters, the authors guide the reader through a mosaic of relatively easy paths that introduce important concepts, including among others: helicity conservation, parity properties, polarisation frames and their transformations, frame-independent polarisation, and the Lam–Tung relation. Throughout the narrative, they often present real or simulated examples of caveats that can induce irreversible distortions in the measured distributions, potentially biasing the experimental results or their interpretation. The second half of the book (running to another 150 pages) targets a more expert audience, interested, for example, in acquiring the background knowledge needed to study cascade decays to vector particles or smearing effects of higher-order QCD ("non-planar") processes. Appendix B, in particular, with page-long equations and no figures, must have been prepared "on demand" for people studying rare Z and W radiative decays with LHC data.

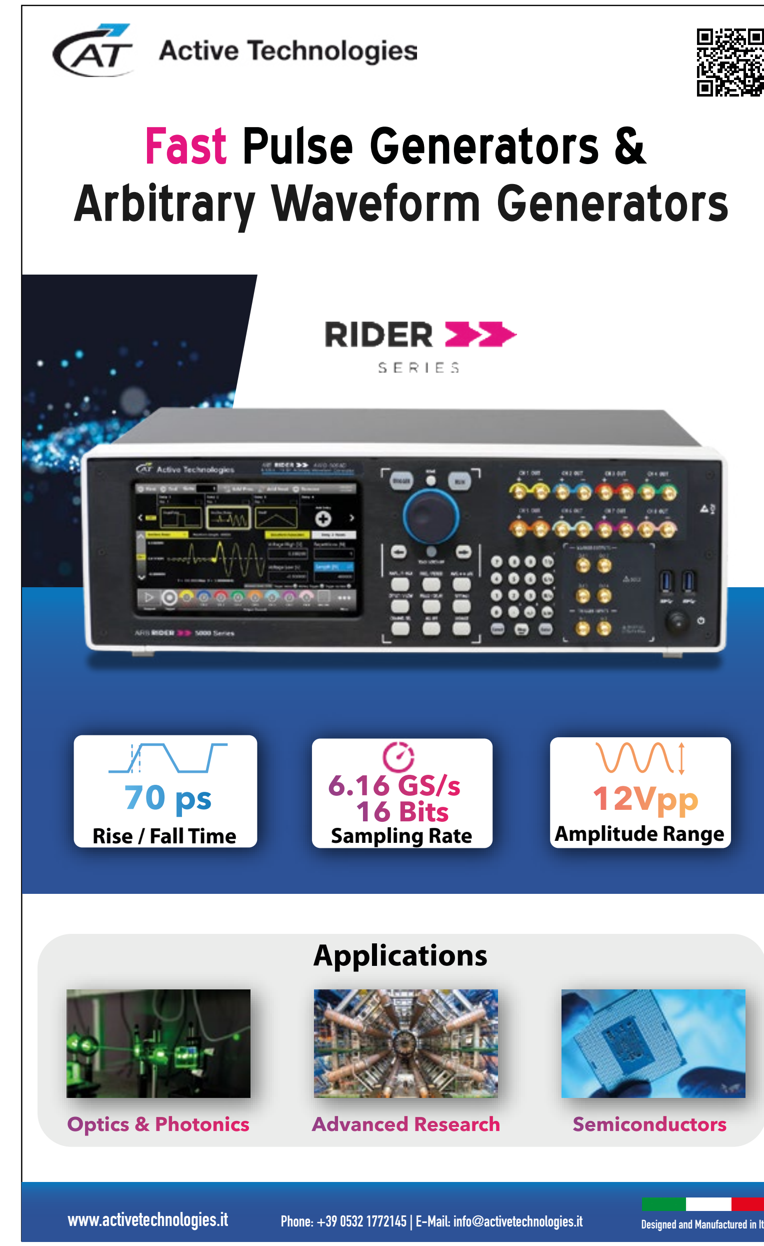
The authors contributed to the field of particle polarisation with several original ideas

The pedagogical style of the text and the quality of the figures have clearly benefitted from the multiple interactions that the authors had with many people through physics schools, university seminars and workshops. The reader can also easily appreciate that the authors contributed to the field of particle polarisation with several original ideas, both regarding the development of robust data-analysis methods and their phenomenological interpretations. It is particularly eye-opening to see how easy it is to obtain biased experimental results if the analysis methods follow simplified approaches, ignoring the intrinsic multidimensionality of polarisation measurements. While thetext is very well written, the aspect that most distinguishes this book from others on similar topics is the presence of several beautiful figures, providing a welcome visual presentation of non-trivial concepts.

Thanks to the CERN-supported open-access publication, the book can be directly downloaded by anyone who is interested. Although many readers will prefer a paper copy, the PDF file has the advantage that the reader can very easily navigate within the book by clicking on the many links connecting the text to figures, equations, cited references, and even to words in the very useful index. It is particularly practical to be one click away from an equation shown, sometimes, a hundred pages earlier.

Given the steady increase in the size of data samples being collected by the LHC experiments and the role that the polarisation aspects play in precision measurements of Standard Model processes, as well as in improving the efficiency of searches for new particles, the authors may soon be tempted to write a sequel. In such a future edition, it would be good to include a list of exercises for the interested reader, based on the authors' behind-the-scenes knowledge and including realistic "traps" that readers should avoid. This would strengthen even further the role of the book as a guide for students and researchers involved in analysis of experimental data or in the interpretation of results.

Claudia-Elisabeth Wulz *HEPHY, Austrian Academy of Sciences.*



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PEOPLE CAREERS

Mixing physics and music

Former CERN electronics engineer Matteo Di Cosmo reflects on the difficult decision to leave CERN and pursue his passion for electronic music.

When Matteo Di Cosmo was 16 and listening to German electronic band Kraftwerk, he decided that he wanted to build his own synthesiser. "I fell in love with a track called 'Radioactivity', which starts with morse code of the word 'radioactivity', and I decided I wanted to build equipment to produce these sounds," he explains. He had already built his own keyboards, but taking it to the next level pushed him to do a bachelor's in electronics engineering at the University of Turin. Originally from Puglia in southern Italy, he went on to obtain two master's degrees, one in mechatronics and one in electronics engineering.

In sync *The skills and knowledge Matteo acquired at CERN enabled him to fulfil a childhood dream of building his own synthesiser.*

Inspired by CERN

It was during this time that Matteo visited CERN. The experience left him with a strong desire to work there but he felt it was an unattainable ambition. Nevertheless, in 2011 he applied for a position through the "Volontaires Internationaux" programme and was successful. He joined the physics department in 2012 as a fellow, testing commercial equipment used in the backend electronics for CERN experiments. A year later he obtained a staff contract with increased responsibilities, including managing a team of around five and hiring people. Making use of CERN's internal mobility programme, he then joined the electrical power converter group in the technology department and spent six years working with a multicultural team of 15 people. "CERN is the greatest example of a united Europe, as the incarnation of teamwork no matter what language or nationality," he says, adding that his experience has undoubtedly affected his personality. "It left me with the sensation that I can no longer be in an environment that is not diverse."

Finally, in 2018, the knowledge that Matteo had acquired at CERN enabled him to realise his teenage ambition, and he built his own synthesiser: the "tiny synth", based on field-programmable gate arrays (FPGAs). At the time, there were no other products on the market using this technology. Subsequently, he was contacted by the CEO of the organisation he works for today, who was looking for an engineer. Matteo was not ready to leave CERN so he asked the human resources department if he could work as a contractor alongside his job. The request was accepted as there was no conflict of interest.

Invest time in acquiring the skills relevant for your sector, but don't forget to also spend some time thinking about where you are going

Four years into his dual role, however, Matteo began to reconsider his position. He wanted a job more centred on managing people, in the private sector and that was more focused on profitability. "I was very confident in my work, and I also appreciated my colleagues, but at the same time I think I had reached a 'plateau' of knowledge, so I felt I was not able to move forward." Initially, he struggled with the decision whether to leave CERN. He turned to the CERN Alumni Network to find members who had held indefinite contracts at CERN but chose to pursue a career elsewhere. He met with three such people who took the time to listen and share their experiences, but it was a conversation with a colleague that brought him to the realisation that he needed a change. "One of my best friends asked me 'are you happy?' and I was not able to answer."

Matteo left CERN in 2020 after eight enjoyable years, forever grateful of what it taught him. He is now based in Bari, Italy, where he works with people from around the world as an innovation leader at Music Tribe, delivering audio products for DJs and music producers.

As for his advice to others: "Invest time in acquiring the necessary skills relevant for your sector, but don't forget to also spend some time thinking about where you are going. I was working all the time, developing electronics. But I forgot to ask myself if I am in the right place doing the right thing. We should all spend some time not only working, but on introspection."

Based on an interview originally published by the CERN Alumni Network.

Appointments and awards

SLAC appoints new director

On 2 October, John Sarrao became the sixth director of SLAC National Accelerator Laboratory, taking over from Chi-Chang Kao, who has led the US lab for the past 10 years. Previously deputy director for science, technology and engineering at Los Alamos National Laboratory, Sarrao's main research has focused on synthesis and characterisation of correlated electron systems, in particular actinide materials and novel superconductors. "As the lab enters its seventh decade, the future is very bright, building on a distinguished history of innovation and discovery, and a dedicated community," he said. "I look forward to the world-leading advances we'll make together with our partners at Stanford and in the DOE system."

Shoji Asai to lead KEK

On 8 September, Shoji Asai was announced as the next director general of the KEK national laboratory in Japan. He will take over from Masanori Yamauchi, who has held the position for three terms, in April 2024. Asai is currently a professor at the department of physics at the University of Tokyo and director of the International Centre for Elementary Particle Physics in Tokyo. His research interests include the origin of mass and supersymmetric particles using the ATLAS experiment, and precise tests of QED using tabletop experiments (see p58).

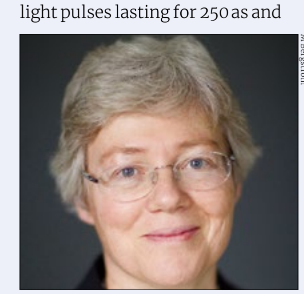
STFC executive director

In June, experimental particle physicist David Newbold was appointed executive director, national laboratories science and technologies at the UK's Science and Technology Facilities Council (STFC). Previously STFC director for particle physics, he is also current chair of the European laboratory directors group.

On 4 October, STFC released a report *UK Strategy for Engagement with CERN: Unlocking the full potential of UK membership of CERN* as part of a new government strategy to maximise the potential of the UK's investment in CERN for the benefit of the UK and the international particle-physics community.

Nobel spotlight

Announced by the Royal Swedish Academy of Sciences on 3 October, the 2023 Nobel Prize in Physics has been awarded to Pierre Agostini (Ohio State University), Ferenc Krausz (MPI Garching, LMU Munich) and Anne L'Huillier (Lund University) "for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter". Laying the ground in 1987, L'Huillier (pictured) – who becomes the fifth woman to receive a Nobel Prize in Physics – found that when transmitted through noble gases, infrared laser light is split into different harmonics that, when superimposed and in phase, create strong attosecond pulses. In 2001, Agostini and Krausz separately worked on consecutive light pulses lasting for 250 as and



isolating a single light pulse with a duration of 650 as, respectively. Attosecond science is also now within reach of advanced X-ray free electron lasers (XFELs) driven by electron linacs, such as the recently operational LCLS-II facility at SLAC. Novel light sources were also the subject of the 2023 Nobel Prize in Chemistry, awarded to physicist Alexei Ekimov (Nanocrystals Technology Inc.), Moungi Bawendi (MIT) and Louis Brus (Columbia University) for the discovery and synthesis of quantum dots. The 2023 Nobel Peace Prize was awarded to Iranian human rights activist Narges Mohammadi, who studied physics at Imam Khomeini International University, for her fight against the oppression of women in Iran and the promotion of human rights and freedom for all. Mohammadi is currently serving a prison sentence in Tehran.

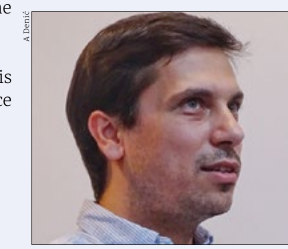
Swiss Science Prize

Ukrainian LHCb physicist Lesya Shchutska has won this year's Swiss Science Prize Latsis, which is awarded to researchers up to the age of 40 and comes with a prize of CHF 100,000. Shchutska studied

at Moscow Institute of Physics and Technology and obtained her PhD at Ècole Polytechnique Federale de Lausanne (EPFL) on electromagnetic calorimeters for balloon-borne experiments. Following CMS postdocs at the University of Florida and ETH Zürich, she is currently a tenure-track assistant professor at EPFL with research interests in heavy neutrinos using the LHCb and SND experiments at CERN.

2024 Breakthrough Prizes

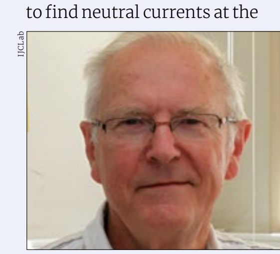
In September, the winners of the 2024 Breakthrough Prize were announced by the Breakthrough Prize Foundation. The $3 million Breakthrough Prize in Fundamental Physics is shared between John Cardy (University of Oxford) and Alexander Zamolodchikov (Stony Brook) "for profound contributions to statistical physics and quantum field theory, with diverse and far-reaching applications in different branches of physics and mathematics". Among nine winners of the New Horizons in Physics Prize, which recognises early-career researchers, are former CERN theorist Marko Simonović (University of Florence, pictured), Mikhail Ivanov (MIT) and Oliver Philcox (Columbia



University/Simons Foundation), who share $100,000 for contributions to the understanding of the large-scale structure of the universe and the development of new tools to extract fundamental physics from galaxy surveys. All Breakthrough laureates will be honoured at a ceremony in Los Angeles on 14 April 2024.

Lagarrigue Prize 2023

Granted by the French Physics Society in honour of André Lagarrigue, who led the endeavour to find neutral currents at the



Gargamelle experiment 50 years ago, Daniel Fournier (University of Paris-Sud) has been awarded this year's Lagarrigue Prize. He is recognised for building a novel liquid-argon electromagnetic calorimeter for the CELLO experiment in the 1970s, and for adapting the concept to the ATLAS detector. Now retired, Fournier has taken part in ATLAS data analysis and is involved in the design of a noble-liquid calorimeter for the proposed collider FCC-ee.

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RECRUITMENT

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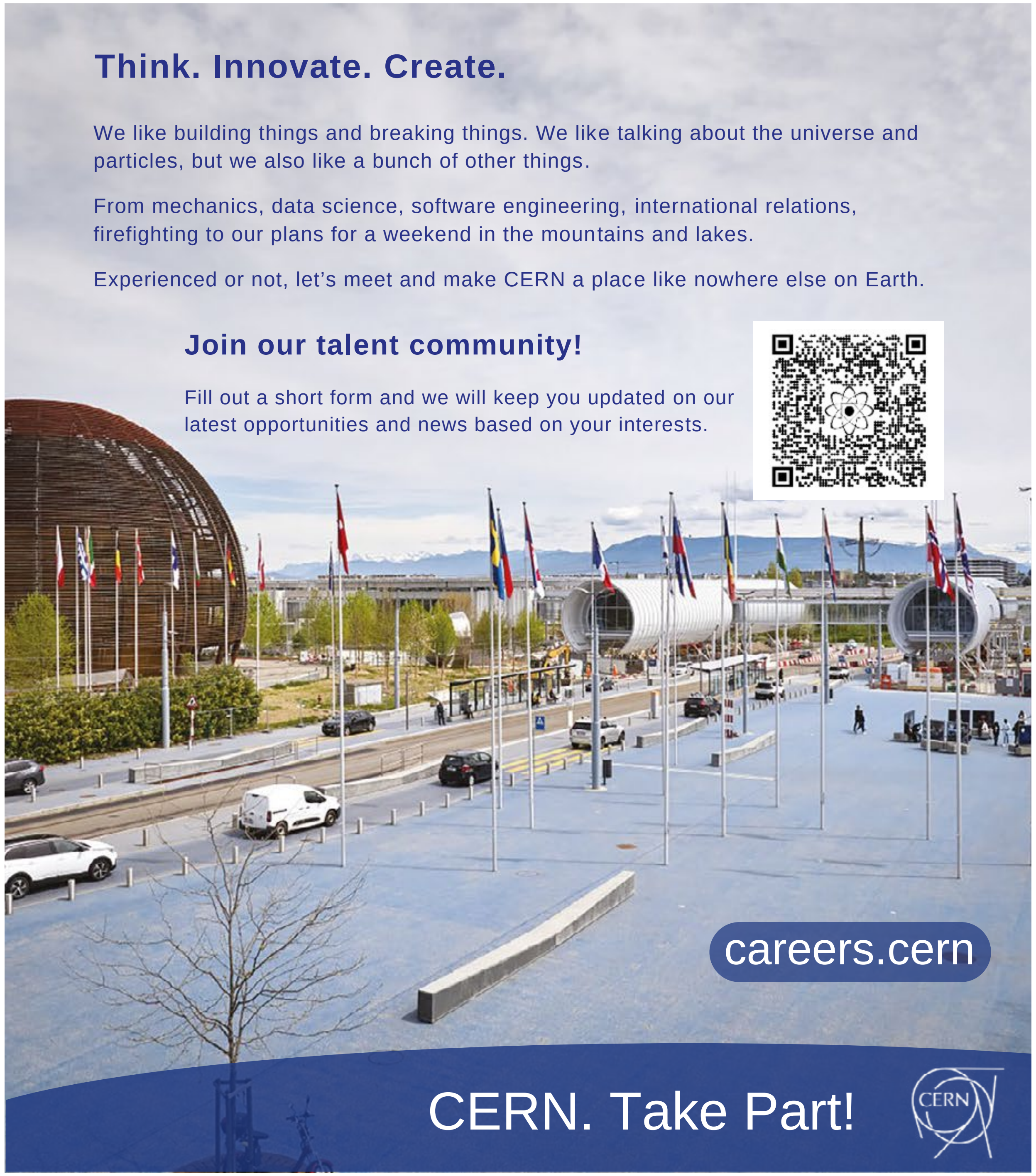

Within the CEA, the Institute of research into the fundamental laws of the Universe (IRFU) carries out technological and basic research, in order to study the fundamental laws of physics.

Nearly 1,000 employees conduct international research in particle physics, astrophysics, and nuclear physics, developing particle accelerators, detectors, analysis pipelines, satellite payloads, and ground-based telescopes.

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PEOPLE OBITUARIES

Maria Fidecaro 1930–2023

From the Synchrocyclotron onward

Maria Fidecaro, an experimental physicist who joined CERN in 1957, passed away on 17 September. Maria was a familiar face to the CERN community until long into her retirement, often seen arm-in-arm with her husband Giuseppe as they made their way through the CERN corridors. She was also well-known to CERN visitors, featuring prominently in the Synchrocyclotron exhibition's film.

Born in Rome in 1930, Maria completed her university studies at La Sapienza in 1951. There she met Giuseppe, and the pair studied cosmic rays at the Tête Grise laboratory located on the Matterhorn. In 1954 she obtained a fellowship from the International Federation of University Women and joined her future husband at the University of Liverpool developing techniques and experiments for the Synchrocyclotron, CERN's first accelerator.

CERN-HOMEWEB-PHO-2023-111-2

Maria Fidecaro at her retirement party in 1995.

In summer 1956 the couple moved to Geneva, joining only a few hundred people at CERN, which had been established just two years earlier. Maria obtained a CERN fellowship in 1957 and began working in a team of three that was developing a novel method to provide polarised proton beams at the Synchrocyclotron – techniques that she would later adapt to carry out polarisation experiments at the Proton Synchrotron and the Super Proton Synchrotron (SPS). She remained at CERN for the rest of her career, where her early research interests included charge-exchange nucleon–nucleon scattering and proton–proton elastic scattering.

In the 1980s Maria participated in the WA78 experiment at the SPS, which was dedicated to the production of $b\bar{b}$ pairs. She then worked on detectors and analysis for the CPLEAR experiment, which was designed to enable precision measurements of CP, T and CPT violation in the neutral kaon system. She designed and led the construction of a high-granularity electromagnetic calorimeter, helping CPLEAR to achieve new levels of precision in the study of fundamental symmetries.

From 1991 to 1995 Maria was group leader of the CPL group in the Particle Physics Experiments division. She also took part in the NA48/2 experiment, searching for CP violation in the decay of charged kaons, and contributed to the early phases of NA62.

Maria celebrated her retirement in 1995, but continued her work at CERN as an honorary member of the personnel. She had a reserved attitude in all circumstances and a deep sense of duty to the community. As Maria explained in an interview in 2012, "every day or every week there is something new connected with our old work".

Her friends and colleagues.

Michel Gaudin 1931–2023

The quest for elegance

Theoretical physicist Michel Gaudin, known for his influential works in the domain of integrable models, passed away on 4 August. Michel entered L'Ecole Polytechnique in 1951 and obtained his PhD in 1967 at the Université de Paris. In his PhD thesis he found a solution, given simultaneously in the famous paper by C N Yang, to the Fermi gas with delta-function interaction, introducing what was later called the nested or higher-level Bethe ansatz. Except for a year spent visiting Yang at Stony Brook in 1970, he spent all his scientific life at the fundamental research division of the Commissariat de l'Energie Atomique (CEA-Saclay).

Michel used only French as a scientific language and a significant part of his research remained unpublished. The publication of his book *La fonction d'onde de Bethe* in 1983 was thus a major event, remaining an inspiring and pedagogical source of a variety of original information that cannot be found anywhere else. Translated into Russian in 1987 and English in 2013, it is considered a classic in the field.

V Pasquier

Mathematical physicist Michel Gaudin.

One of the most well-known of his findings is the so-called Gaudin determinant for the norm of the Bethe eigenstates, which now plays a fundamental role in the computation of correlation functions. In another essential work, following the method of C N Yang and C P Yang, Michel solved the thermodynamics of the Heisenberg-Ising ring, simultaneously with Takahashi. He also diagonalised a class of quadratic Hamiltonians in spin variables, now referred to as the Gaudin model, and considered various extensions, in particular a system comprising a single oscillator coupled to a collection of independent two-level atoms, which has become a classic in the cold-atom and Bardeen–Cooper–Schrieffer communities. In addition, his pioneering early works on random matrices with M L Mehta introduced elegant and powerful new methods that played a key role in many developments in random matrix theory, with applications ranging from nuclear physics to non-critical string theories.

An original and prolific personality, Michel was principally guided by a quest for elegance. Although he cared little for recognition, in 2019 he was awarded the prestigious Dannie Heineman Prize for Mathematical Physics.

Michel Gaudin was a man of high integrity and modesty whose life was completely devoted to science. He was known for his rigour and reclusive style of work, but when approached by his colleagues, he generously shared his knowledge and insights.

His friends and colleagues *at IPhT, CEA-Saclay.*

James Hartle 1939–2023

Quantum-cosmology pioneer

James Burkett Hartle passed away on 17 May in Zurich at the age of 83. Known as the father of quantum cosmology, Jim made landmark contributions to our understanding of the origin of the universe.

Born in Baltimore, Maryland, Jim obtained his undergraduate degree in physics at Princeton University, where he was mentored by John Wheeler. He attended graduate school at Caltech where he worked under Murray Gell-Mann, earning his PhD in 1964 with a dissertation entitled *The complex angular momentum in three-particle potential scattering*.

After graduating, Jim briefly taught at Princeton before joining the faculty at the University of California, Santa Barbara (UCSB) in 1966. Excited by the discoveries of pulsars, quasars and the cosmic microwave background radiation, Jim turned away from particle physics. In the late 1960s he wrote a series of influential papers, one with Kip Thorne, on the dynamics of rotating neutron stars. The pair organised regular gatherings between their research groups, which turned into the Pacific Coast Gravity Meetings that still run today.

In 1971 Jim used a Sloan Fellowship to go to the University of Cambridge, where he was immersed in the emerging fields of relativistic astrophysics and cosmology. There he met Stephen Hawking, with whom he developed a remarkable long-term collaboration. Two of their papers became classics: one, in 1976, introduced the Hartle–Hawking quantum state for matter outside a black hole, which is fundamental to black-hole thermodynamics and inspired the so-called Euclidean approach to quantum gravity; the other, in 1983, put forward the Hartle–Hawking "no-boundary" wave function of the universe, showing for the first time how the conditions at the Big Bang could be determined by physical theory.

Except for a brief appointment at the University of Chicago, Jim spent his entire career at UCSB, an environment he found congenial, supportive and inspiring. Jim was a wise and caring mentor to countless young scientists and, though reluctant to venture into the public arena, he also did much to forge a strong physics community. In 1979 he cofounded the Institute for Theoretical Physics (now the Kavli Institute for Theoretical Physics) at Santa Barbara, a mecca for physicists ever since.

CTC Cambridge/flickr

Jim Hartle delved deeply into the fundamentals of physics.

The Hartle–Hawking wave function not only revolutionised quantum cosmology but also raised tantalising new questions. Jim began to think more deeply about what it entails to apply quantum mechanics to the universe as a whole. Throughout the 1990s, he and Gell-Mann developed the consistent-histories formulation of quantum mechanics, which clarified the physical nature of the branching process in Everettian quantum mechanics and was sufficiently general to describe single closed systems.

While part of some extraordinary collaborations, Jim was also an independent thinker. About one-third of his publications are beautifully written single-author papers often touching on seemingly intractable questions, far from current fashions and approached with enormous care and open-mindedness. In 2003 Jim published *Gravity: An Introduction to Einstein's General Relativity*, a textbook gem with a minimum of new mathematics and a wealth of illustrations that made Einstein's theory accessible to nearly all physics majors.

Jim retired in 2005, to focus on physics. In 2006 he became an external professor at the Santa Fe Institute, collaborating with Gell-Mann during summer visits. That year also marks the start of my own collaboration with Jim. We took up quantum cosmology again and became immersed in some of the field's heated debates. Unperturbed, Jim set out the beacons. Often, we would be joined by Hawking, who by then had great difficulties communicating, to flesh out the predictions of the no-boundary wave function. Studying the role of the observer in a quantum universe, we were led to a top-down approach to cosmology in which quantum observations retroactively determine the outcome of the Big Bang, thereby realising an old vision of Wheeler's.

Few scholars ventured as deeply into the fundamentals of physics as Jim did. A selection of his reflections on the deeper nature of physical theory were published in 2021 in *The Quantum Universe: Essays on Quantum Mechanics, Quantum Cosmology, and Physics in General*. With characteristic humility, however, Jim reminded us that he didn't have a philosophical agenda.

Despite suffering the devastations of Alzheimer's disease, physics remained the driving force in Jim's life until the very end. Yet his intellectual curiosity stretched much further. He was a polymath and an eclectic reader whose interests ranged from Middle Eastern and Mayan archaeology, to American colonial history, Russian literature and eccentric 19th-century religious female figures. Above all, Jim was an exceptionally generous, wise, humble and gentle man.

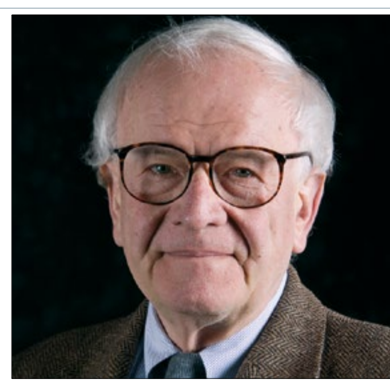
Thomas Hertog *KU Leuven.*

Roman Jackiw 1939–2023

A brilliant and profound theorist

On 14 June, Roman Jackiw, one of the most brilliant and profound theorists of his generation, passed away at the age of 83.

Roman Jackiw graduated from Cornell University in 1966 under the supervision of Ken Wilson, moving to Harvard as a junior fellow until 1969. Thereafter, he was a member of the Centre for Theoretical Physics at MIT. Having myself been a postdoc at MIT from 1968 to 1972, we got to know each other well and kept in touch since.



MIT

Roman Jackiw made important contributions to the theory of fundamental interactions.

During the Harvard period, while visiting CERN, he wrote, together with John Bell, what is arguably his most famous paper. It became known as the Adler–Bell–Jackiw (ABJ) anomaly. Here "anomaly" stands for a symmetry that, while classically exact, is broken by quantum mechanical effects. This breaking makes it possible for the neutral pion to decay, as observed, into two photons. Another version of the ABJ anomaly, in the context of the strong interaction, provides a solution of the so-called U(1) problem: the absence of a ninth light pseudoscalar meson besides the π, K and η. Indeed, the relatively heavy η′ meson gets most of its mass through the ABJ anomaly and some topologically non-trivial gauge-field configurations.

Later, together with Claudio Rebbi of Boston University, Jackiw introduced the concept of theta-vacua in quantum chromodynamics by which the strong interaction, because of the above-mentioned non-trivial topology, depends on a somewhat hidden angular parameter, θ. Unless vanishing, the θ parameter introduces violations of time-reversal symmetry and, consequently, an electric dipole moment of the neutron for which very strong experimental upper bounds exist.

Interestingly, the combination of these two remarkable contributions by Jackiw imply what is perhaps the only serious theoretical tension facing the Standard Model today. Its resolution calls for the existence of a new particle, the axion, which turns out to also be an interesting candidate for explaining the dark-matter content of the universe.

Roman Jackiw made many other important contributions to the theory of fundamental interactions. One that gained lots of attention now goes under the name of Jackiw–Teitelboim (JK) gravity, a two-dimensional version of general relativity that can be used as a simple theoretical laboratory for addressing several conceptual problems also occurring in the real world. Another pioneering contribution is the discovery (again with Claudio Rebbi) that fractional charges and spins are easily generated in field theories of interest to condensed-matter physics. Quasiparticles with such properties have indeed been "seen" experimentally.

Jackiw received much recognition for his work: among these the prestigious Dannie Heineman Prize for Mathematical Physics of the American Physical Society and the Dirac Medal of the International Center for Theoretical Physics in Italy.

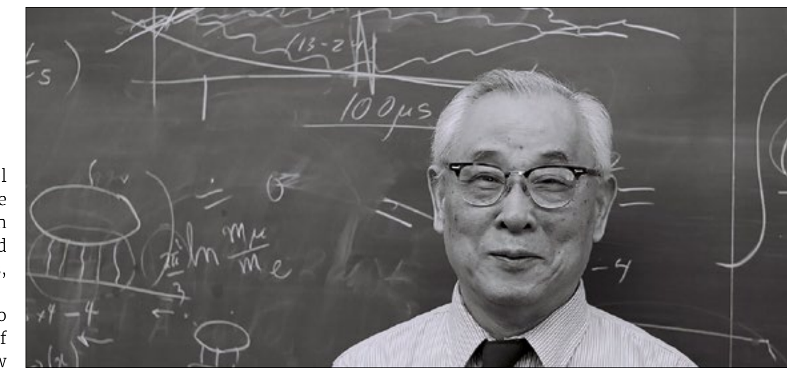
Since the time of his work with John Bell, Jackiw was very attached to CERN and to the theoretical division/department. It was always a pleasure listening to his clear and inspiring talks while benefitting from his willingness to share – with scientific assurance but also much modesty – his deep ideas about quantum field theory. In one such occasion he told me: "you know, proving an exact result is like having a deposit in a bank: it keeps giving you interest forever". He was certainly aware of the importance of his contributions to theoretical physics but never boasted too much about them.

Gabriele Veneziano *CERN.*

Toichiro Kinoshita 1925–2023

Thinking of the highest order

Goldwin Smith Professor of Physics at Cornell University, Toichiro Kinoshita, whose precise calculations of the electron and the muon g-factors remain milestones in the field, passed away on 23 March in Amherst, Massachusetts, at the age of 98.



K B Acquilano/Cornell University

Toichiro Kinoshita pioneered 10th-order QED calculations of muon g–2.

Toichiro "Tom" Kinoshita was born in Tokyo and raised in Tottori, the western rural part of Japan. When Tokyo Imperial University (now the University of Tokyo) reopened in 1946 after World War II, he returned to the campus. He was interested in theoretical particle physics, and asked Kunihiko Kodaira, an associate professor of mathematics and physics, to supervise him. He also attended the weekly seminars held by Sin-Itiro Tomonaga, who went on to share the Nobel Prize (with Schwinger and Feynman) for his fundamental work in quantum electrodynamics, QED. Equipped with a strong understanding of the renormalisation of QED from Tomonaga's group, he began to investigate the renormalisability of charged vector bosons and collaborated with Yoichiro Nambu. Both were accepted by the Institute for Advanced Study at Princeton (IAS) as postdoctoral fellows in 1952. After a two-year stay at IAS, Kinoshita became a postdoc at Columbia University and within a year he was offered a research associate position at Cornell University, where he spent the rest of his career.

In 1966 Kinoshita revisited CERN. During a tour on the first day, a "wiggle plot" posted on the wall captured his gaze. An experiment to measure the anomalous magnetic moment of the muon (muon g–2) at CERN was in progress, and Kinoshita immediately dropped off the tour and rushed to the library to look for the known QED results on charge-renormalisation constants. His earlier study of the mass singularity brought him the inspiration that the leading contribution of the sixth-order term for muon g–2 can be obtained by simply multiplying the already-known quantities. It was the moment he started his life-long quest on the QED calculation of the lepton g–2 values.

After returning to Cornell, he started investigating all the sixth-order QED vertex diagrams. Due to their complexity he chose numerical means to evaluate them, his earlier studies on the three-body variational calculation of the helium atom in the 1950s helping him on his way. The new rules were invented to construct pointwise-subtraction terms for ultraviolet and infrared divergences of a Feynman integral, with which renormalisation could be realised without breaking the gauge symmetry of QED. After the first result came out in 1972, he kept improving the precision of the sixth-order term. His results were used for a quarter of a century to compare the theory to the measurement and to determine the fine-structure constant, among other calculations.

Retired from Cornell University in 1995, Kinoshita was delighted not to have duties other than physics research and started calculating the 10th-order QED contribution to g–2. We joined the 10th-order project in 2004, and his passion was the driving force of our collaboration. He visited RIKEN in Japan every year, and while he was in the US we received an e-mail every morning notifying us of his progress, queries and suggestions. The first entire 10th-order results were published in 2012. His final paper came out in 2019. He wished to be active until he was 100 years old and almost accomplished it.

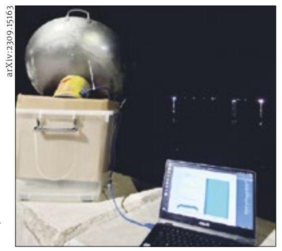
Tom was always polite and calm, even when physics discussions heated up, and had an inner passion for the pursuit of truth that persisted throughout his life. He is survived by his three daughters and six grandchildren. His wife Masako, a well-known expert in Japanese loop braiding, passed away in 2022. Two diagrams are engraved on their tombstone: a Feynman diagram of QED at 10th order, and a loop-manipulation method. The family also established two undergraduate scholarships at Cornell in their memory.

Tatsumi Aoyama *The University of Tokyo*, **Masashi Hayakawa** *Nagoya University and* **Makiko Nio** *RIKEN.*

BACKGROUND

Notes and observations from the high-energy physics community

Star-fried science


arXiv:2309.15163

Woks not only provide quick and easy meals, they also come in handy to build low-cost radio telescopes. A team from Hong Kong University of Science and Technology has presented a detailed recipe to (ob)serve the 21cm emission line of neutral hydrogen from the Milky Way from any urban balcony: get a Chinese wok of 61cm diameter; attach a hand-crafted dipole antenna made from copper wires (if available, an amplifier can be used to boost the signal); mix to the desired bandwidth using software (in case the signal gets too noisy an additional grounding wire can be used); and discreetly Fourier-transform the result into a power spectrum. Designed for educational purposes, "Wok the Hydrogen" can be enjoyed in all weather, but is best avoided during thunderstorms (arXiv:2309.15163).

The truth is still out there

NASA

A weather balloon.

On 14 September, NASA announced the findings of an independent study to examine unidentified anomalous phenomena (UAP) – a new term that encompasses unexplained events observed in the sky as well as under water – from a scientific perspective. The 33-page report calls on NASA to exploit resources such as Earth-observing satellites, and to use crowdsourcing techniques and AI, to build a more robust understanding of UAPs. "One of the main goals of what we're trying to do here today is to move conjecture and conspiracy towards science and sanity, and you do that with data," said Dan Evans, NASA assistant deputy associate administrator for research.

Media corner

"The idea was to create an unforgettable experience, which is why I wanted to create architecture capable of astonishing."

Architect ***Renzo Piano*** discussing his vision for CERN Science Gateway in *Elle Decor*, 18 September (translated).

"It is not just a celebration of data capacity, it is also a performance achievement, thanks to the reading rate of the combined data store crossing, for the first time, the 1 TB/s threshold."

CERN's ***Andreas Peters*** talking to *The Register* (2 October) about CERN's data-storage capacity passing one exabyte.

"There's a sense of momentum building. There's been a lot of buy-in from the various European players at all levels. They've been really pushing hard."

CERN director for accelerators and technology ***Mike Lamont*** talking to *Swissinfo* (6 October) about the proposed Future Circular Collider at CERN.

"The bottom line is that there's no free lunch, and we're not going to be able to levitate using antimatter."

Berkeley's ***Joel Fajans*** on the ALPHA collaboration's measurement of antihydrogen in free-fall (*The New York Times*, 27 September).

From the archive: November 1983

LEP, before and after


On 13 September 1983, CERN Director-General Herwig Schopper (centre) greeted Presidents Francois Mitterand of France (left) and Pierre Aubert of Switzerland (right) at the 'groundbreaking' ceremony for the 27-kilometre ring of the LEP electron–positron collider.

The quest for unification – to explain as many things as possible from a minimal number of postulates – is a central theme in basic physics. A hundred years before the formulation of the electroweak theory, James Clerk Maxwell produced a unified description of electricity and magnetism. With the advent of quantum theory, the communicators of the electromagnetic force were defined as massless lumps of energy, photons.

In the 1930s, Enrico Fermi and others tried unsuccessfully to unify electromagnetism and the weak force – new concepts were needed. In the mid 60s, Abdus Salam and Steven Weinberg working independently came up with an innovative solution, the existence of two types of heavy weak force communicators, the W (with electrical charge exchange) and Z (without charge exchange).

Brilliant innovations in accelerator technologies, especially Simon van der Meer's 'beam cooling', opened the door to CERN's antiproton accumulator project. The conversion of the Super Proton Synchrotron in 1979 eventually made it possible to collide intense beams of antiprotons and protons with enough energy to make $W^{\pm}$ and Z particles. By mid-1983 they were discovered [earning the 1984 Nobel Prize in Physics for van der Meer and Carlo Rubbia].

● Text adapted from *CERN Courier* November 1983 pp355–377.

Compiler's note

On 20 September 1989, six years after ground breaking, physics runs began at LEP. By 13 October the four experiments, ALEPH, DELPHI, L3 and OPAL, had each recorded around 30,000 Z particles and proved that only three types of neutrinos exist, constraining the Standard Model to three generations of matter particles. The LEP experiments went on to collect about 4.5 million events each at the Z peak before the collider was upgraded in 1995, enabling precision measurements of the W boson until its closure in 2000 to make way for CERN's next electroweak adventure: the hunt for the Higgs boson at the LHC.

1.4 feV

The width of a nuclear transition in scandium resonantly excited with high-energy X-rays by a team at the European XFEL, with potential applications for a reference oscillator that is accurate to one second in 300 billion years (*Nature* doi:10.1038/s41586-023-06491-w)

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RADIOROC Radioroc is a 64-channel front-end ASIC designed to readout silicon photo-multipliers (SiPM)	64 Channel Input Polarity Positive	- Free running trigger - External trigger - Charge (shaper,ToT) - Time and Charge (trigger) - Photon Counting	- selectable per channel: • 1 LVDS trigger • 2 single ended triggers • 2 shaper outputs - 3 OR triggers - 2 analog multiplexers (charge)	- Energy meas. - ToF - Photon Counting rate ~100MHz - Dual time thresholds - SPE spectrum - SiPM HV adjustment
PSIROC Psiroc is a 64-channel front-end ASIC designed to readout PIN diodes, silicon strips and GEMs, handling detector capacitances ranging from 0 up to few hundreds of pF.	64 Channel Input Polarity Positive/Negative	- Free running trigger - External trigger - Charge (shaper,ToT) - Time (trigger)	- selectable per channel: • 1 LVDS trigger • 2 single ended triggers • 2 shaper outputs - 3 OR triggers - 2 analog multiplexers (charge)	- Energy meas.
LIROC Liroc is a 64-channel front-end ASIC designed to readout silicon photo-multipliers (SiPM) for LIDAR/fast photon counting	64 Channel Input Polarity Positive/Negative	- Free running trigger - Time (trigger) - Photon Counting - Charge (ToT)	64 LVDS trigger outputs	- ToF - Photon Counting rate ~300MHz - SPE spectrum - Energy meas. - SiPM HV adjustment

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