WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the September/October 2026 issue of *CERN Courier*.

In his landmark 1945 report *Science, the Endless Frontier*, Vannevar Bush argued that basic research is the fund from which applications, and with them prosperity, are drawn. Eight decades on, the High-Luminosity LHC is expected to return to society nearly twice its cost, before a single discovery is counted (p29). The largest share comes from the skills researchers take into the wider economy. Technological spillovers come close behind, as demanding contracts leave suppliers with new techniques and markets.

The LHC required large-scale industrial production of superconductors. Yet the thousands of magnets built from them all descend from a single thread of mercury Heike Kamerlingh Onnes cooled in 1911, finding a resistance too small to detect below 4.2 K (p36).

This edition of *CERN Courier* also explores lattice quantum chromodynamics, which simulates the strong force in a discrete, finite box. A calculation published this spring stepped through a sequence of such boxes, fixing the strong coupling to five parts per mille (p41).

Samuel Ting recounts a career spent checking and rechecking ever finer measurements (p51). His latest instrument, the Alpha Magnetic Spectrometer, has now recorded more than 265 billion cosmic rays. Their spectra follow patterns no current model quite captures (p8).

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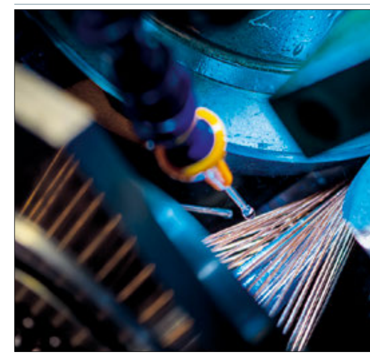
EDITOR: DAVIDE DE BIASIO

IN THIS ISSUE

Volume 66 Number 5 September/October 2026



Zero resistance *The history of CERN's superconducting magnets.* **36**

Taking stock *ATLAS surveyed its members ahead of the High-Luminosity LHC.* **45**

Measure twice *Samuel Ting reflects on seven decades of experimental physics.* **51**

FROM THE EDITOR

Charting the endless frontier

Davide De Biasio
Editor

"New frontiers of the mind are before us," US president Franklin Roosevelt wrote to Vannevar Bush, his adviser on science, in November 1944. In them, he foresaw "a fuller and more fruitful life". Bush answered with the landmark report *Science, the Endless Frontier*, arguing that basic research is part of a nation's capital. Pursued without practical ends in view, it is nonetheless the fund from which applications, and with them prosperity, are drawn.

History supplies plenty of examples. The web began as a way for physicists to exchange information, doctors image tumours with antimatter, satellites correct their clocks for the bending of spacetime. While such notable cases left a clear trail, today's research infrastructures have grown so complex, and so deeply embedded in the societies around them, that appreciating their benefits in full takes a discipline of its own. The economics of Big Science estimates their social return with rigorous, quantitative techniques.

Its most thorough analysis yet concerns the High-Luminosity LHC (HL-LHC). Setting aside the discovery of any new physics, the study expects it to return nearly twice its cost (p29). The largest share comes from the skills researchers take into the wider economy. Technological spillovers come close behind, as demanding contracts leave suppliers with new techniques and markets. The chair and vice-chair of the CERN Industrial Liaison Officer Forum argue that keeping such firms on board takes a partnership in spirit, with open communication and shared risk (p49).

The HL-LHC is expected to return to society nearly twice its cost

The LHC demanded large-scale industrial production of superconductors. Yet the thousands of magnets built from them all descend from a single thread of mercury Heike Kamerlingh Onnes cooled in 1911, finding a resistance too small to detect below 4.2 K (p36). On this issue's cover, a cryostat in CERN's SM18 hall feeds current to the magnets of the HL-LHC's inner-triplet string, a full-scale replica of the chain that will sit on either side of ATLAS and CMS. Its new focusing magnets, whose niobium–tin coils reach beyond the ten teslas Onnes had dreamt of, ran at full nominal current in July (p9).

Big Science also breaks new ground in human organisation.


M Pinggera/CERN

Common descent *The lineage of the magnets that came to drive CERN's colliders begins with a thread of frozen mercury.*

To learn where its some 6000 members stand on strategy, operations and work culture, ATLAS conducted a survey of more than 200 questions (p45).

Sticky evidence

All hadrons catalogued so far consist of quarks bound by gluons. Having sifted 10 billion J/ψ decays, BESIII has now reported evidence that a lump of pure gluons – the long-sought glueball – dominates the X(2370) resonance (p7). Its predicted properties come from lattice quantum chromodynamics, which simulates the strong force in a discrete, finite box. A calculation published this spring stepped through a sequence of such boxes, fixing the strong coupling to five parts per mille (p41).

Samuel Ting gave the J/ψ the first half of its name, identifying it at Brookhaven in 1974. In this edition's interview, he recounts a career spent checking and rechecking ever finer measurements (p51). His latest instrument, the Alpha Magnetic Spectrometer, has recorded more than 265 billion cosmic rays aboard the International Space Station, and the spectra analysed so far fall into patterns no current model quite captures (p8). Elsewhere in these pages, LIGO, Virgo and KAGRA release their new gravitational-wave catalogue (p11), CLOUD proposes a new source of marine cloud seeds (p10), and much more.

Reporting on international high-energy physics

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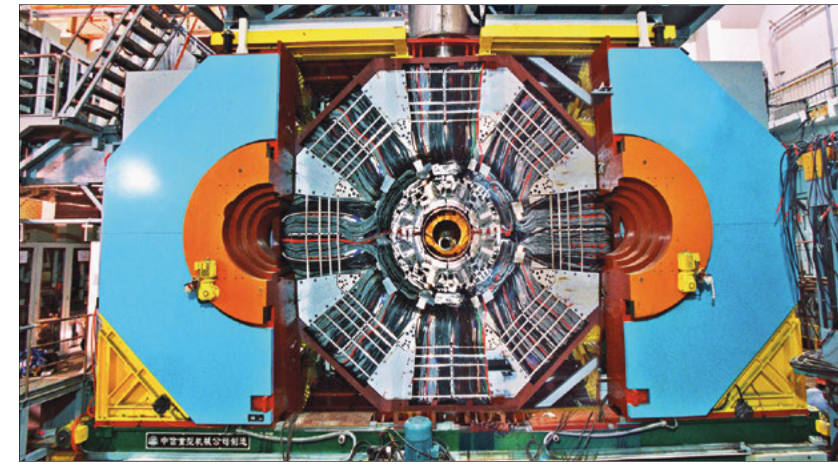
NEWS ANALYSIS

GLUEBALLS

A case for pure glue

Every hadron catalogued so far consists of quarks bound by gluons. The BESIII collaboration has now reported evidence that the dominant constituent of the X(2370) resonance is a glueball – a long-conjectured hadron made of gluons alone. The analysis spans the state's mass, quantum numbers, production rate and decay patterns, and rests on 10 billion J/ψ events recorded at the BEPCII collider in Beijing.

Gluons, unlike photons, are charged under the very interaction they mediate. As a consequence, they attract one another, and quantum chromodynamics (QCD) predicts them to bind into composite particles of their own. Calculations on a discretised spacetime lattice place the lightest such states, with scalar, tensor and pseudoscalar quantum numbers, between 1.3 and 3 GeV (p41). There, glueballs are notoriously hard to single out.



IHEP

Where evidence sticks *With its endcaps drawn back, the BESIII detector reveals the BEPCII collider's beam pipe, where electrons and positrons collide to produce billions of J/ψ mesons.*

"Historically, there were many candidates, such as the $f_0(1710)$ and $f_0(1500)$, but none of them was ever established," says Shan Jin of Nanjing University, who presented the results on 5 August at the International Conference on High Energy Physics in Natal, Brazil. "The difficulties mainly come from mixing with nearby mesons, and from other interpretations that are hard to exclude, such as multi-quark and hybrid states."

Pure force

The appeal of the search, for Jin, goes beyond expanding the taxonomy of hadrons. "Glueballs are a unique kind of matter, made of pure force rather than fermions," he says. "And since gluons do not couple directly to the Higgs boson, an established glueball would directly probe how the strong interaction generates mass."

The hunt has long centred on radiative J/ψ decays, in which the charm quark and its antiquark annihilate into a photon and two gluons. The pair, flavourless and even under charge conjugation, carries exactly the quantum numbers a glueball needs, and the recoiling photon tags the decay cleanly. A lattice calculation by Ying Chen of Beijing's Institute of High Energy Physics and colleagues predicts around two in every ten thousand J/ψ decays to yield a pseudoscalar glueball, with mass 2395 ± 14 MeV.

BESIII first observed the X(2370) resonance in $J/\psi \to \gamma\pi^+\pi^-\eta'$ decays in 2011, with a significance above 6.4σ, and later confirmed it in $K\bar{K}\eta'$ final states. Pinning down its quantum numbers proved much more demanding. "It took us 13 years to determine the spin-parity of the X(2370)," says Jin. "Many processes containing the signal suffer from huge backgrounds of neutral pions, which are easily misidentified as photons. We finally found one, $J/\psi \to \gamma K^0_S K^0_S \eta'$, that is free of them." The 2024 analysis gave $J_{PC} = 0^{-+}$ at a significance above 9.8σ and a mass of $2395 \pm 11\,(\text{stat})^{+26}_{-94}\,(\text{syst})$ MeV, in agreement with the lattice prediction. The full J/ψ sample was essential. "With one billion events, the significance naively scales down by a factor of three, below 5σ," notes Jin. "These studies would have been impossible."

Over the past two years, three further decay modes, to $K^0_S K^0_S \pi^0$, $\pi^0\pi^0\eta$ and $a_0(980)\pi^0$, have been observed, each with a significance above 9σ. A combination across the new channels gives a mass of 2359^{+13}_{-14} MeV and a width of 170^{+44}_{-29} MeV. The measured product branching fractions alone sum to nearly 10^{-3}, larger than expected for an unmixed glueball. In May, Chen and colleagues proposed that a small admixture of pseudoscalar charmonium could account for the enhanced production rate.

An established glueball would directly probe how the strong interaction generates mass

Suppressed decays

No single X(2370) decay mode is expected to dominate. The collaboration estimates that each S-wave quasi-two-body mode accounts for about one to ten percent of the total width, around 170 MeV. "These narrow partial widths are consistent with the glueball expectation, since its decays are suppressed by the Okubo–Zweig–Iizuka (OZI) rule," explains Jin. "All other kinds of hadrons have quark–antiquark content, so their decays are OZI-allowed, with typical partial widths of the order of 100 MeV, much larger than what we observed." The ω and ϕ mesons couple to light quark–antiquark pairs, so a state containing such pairs can decay readily to $\gamma\omega$ and $\gamma\phi$. The $X(2370) \to \gamma\omega$ and $\gamma\phi$ decays turned out to be strongly suppressed, Jin adds, showing that any light quark–antiquark content in the state must be very small.

Another indication comes from flavour. Gluons couple to all quark flavours equally, so a glueball must be a flavour ▷

CERNCOURIER
VOLUME 66 NUMBER 5 SEPTEMBER/OCTOBER 2026

singlet, and a pseudoscalar flavour singlet is expected not to decay to $K^*(892)\bar{K}$ due to the conservation of generalised G-parity – a symmetry that combines charge conjugation with a flavour rotation. An η–η' pseudoscalar excitation in this mass range would instead do so copiously, with a predicted partial width of about 15–200 MeV. BESIII searched for the mode in $J/\psi \to \gamma K^0_S K^0_S \pi^0$ decays and found nothing, implying a partial width below about 2 MeV. According to the collaboration, the X(2370) is thus the first flavour-singlet light hadron observed above 1 GeV. "We do need the 0^{-+} glueball to have a natural and complete explanation of all the X(2370) properties, while all other interpretations can hardly explain all of them simultaneously," says Jin.

The next step would be to determine the mixing angle

A note of caution comes from the theory side. "The only available first-principles prediction for the spectrum of glueballs in the continuum limit completely neglects the effect of quarks," says Davide Vadacchino, a theorist at the University of Plymouth. While the spectrum is under numerical control in this approximation, known as quenching, full QCD is still far off. "The glueball in nature is not an asymptotic state, and it also mixes with other flavour singlets," he explains. "Its decay rate and mixing angle are in principle very interesting quantities, but obtaining them on the lattice is challenging." Calculations with dynamical quarks remain exploratory, limited by poor signal-to-noise ratios and still awaiting a continuum limit, so the agreement with the quenched mass should be read with care. "The case made at BESIII seems to be strong," concludes Vadacchino nonetheless. "The next step would be to determine the mixing angle between the glue component of the X(2370) and its matter component," he adds.

Other interpretations have been proposed. On 1 September, Di Ben, Li-Ke Yang and Bing-Song Zou of Tsinghua University and the Chinese Academy of Sciences argued that a state dominated by a $\Sigma\bar{\Sigma}$ molecular component can account for the observed properties. At BESIII, further decay modes of the X(2370) remain to be studied, and the search will extend to the scalar and tensor glueballs.

Further reading

BESIII Collab. 2026 arXiv:2607.20366.

BESIII Collab. 2026 arXiv:2605.26495.

Y Chen *et al.* 2026 arXiv:2605.01757.

BESIII Collab. 2024 *Phys. Rev. Lett.* **132** 181901.

Ben D *et al.* 2026 arXiv:2609.01342.

COSMIC RAYS

Four ways for cosmic rays

The Alpha Magnetic Spectrometer (AMS) collaboration has now analysed the spectra of 20 cosmic-ray elements. These new results, published in *Physical Review Letters*, sort the cosmic radiation into four classes, two primary and two secondary. None behave quite as current models predict.

AMS has been taking data aboard the International Space Station (ISS) since May 2011, when it arrived on the space shuttle *Endeavour* (*CERN Courier* July/August 2011 p19). Since then, it has detected more than 260 billion events. Cosmic rays range in energy from about 1 GeV to as much as 10^8 TeV, far beyond the reach of any collider, and analysing the elements found amongst them provides a direct way to study their origin and journey through space.

K Struik/CERN

Fresh eyes *The new silicon tracker layer for AMS, suspended from a robotic arm during proton-beam scans in CERN's North Area. It is due to fly to the International Space Station in 2027.*

Cosmic rays are traditionally divided into primary and secondary components. Primary cosmic rays originate in astrophysical sources, producing secondary rays when they collide with matter in the interstellar medium. The two can be told apart by their energy spectra: although both fluxes decrease with energy, that of secondary rays falls much more steeply.

Precision improvement

The first major results from AMS, in 2013, showed the fraction of positrons among cosmic rays rising with energy rather than falling, as it would if they came only from secondary collisions (*CERN Courier* October 2013 p23). The picture has grown more complex ever since. "AMS provides an orders-of-magnitude improvement in precision over previous detectors," explains spokesperson Samuel Ting (p51). "And most of its results disagree with current theory, necessitating the development of new models of cosmic rays."

Earlier AMS surveys of 15 elements had revealed that primary cosmic rays can be divided into two distinct classes, according to how their flux varies with rigidity – the momentum of a charged particle divided by its electric charge, which determines how strongly it is deflected by magnetic fields.

The new analysis of phosphorus, chlorine, argon, potassium and calcium draws on about one million events collected over 13.5 years. The fluxes reveal that secondary cosmic rays can also be divided into two classes based on their rigidity dependence. Across the 20 elements whose spectra AMS has measured so far, out of the 28 it has identified, the fluxes therefore fall into four classes. For the five new elements, the analysis also determines the primary and secondary contributions to each flux.

"When measurements are inaccurate, even the most simplified theoretical ▷

models can adequately account for the data," says Sunil Gupta, an astroparticle physicist and honorary fellow of the Tata Institute of Fundamental Research and president-designate of the International Union of Pure and Applied Physics. "But those explanations fail when precision improves."

The even-numbered elements argon and calcium prove more abundant at the cosmic-ray source than their odd-numbered neighbours phosphorus, chlorine and potassium. Possible explanations for this, and for AMS's other unexpected results, remain under debate. Gupta cautions that further analysis, and more refined propagation models, will be needed, but says the new data "offer extremely significant constraints on the theoretical models essential for progress in this field."

The upgrade will allow for the collection of as much data in five years as was recorded in the previous 15

Understanding what cosmic rays are made of and how they travel is also the first step in the search for new physics in space, since they form the background against which any dark-matter signal or trace of primordial antimatter would have to stand out. AMS is set to sharpen its measurements with an additional silicon tracker layer, due to be installed in 2027. "The upgrade will increase the acceptance of AMS by 300%," says Ting, "allowing for the collection of as much data in five years as was recorded in the previous 15. This will greatly extend the capabilities of AMS in the study of dark matter, antimatter and high-Z cosmic rays."

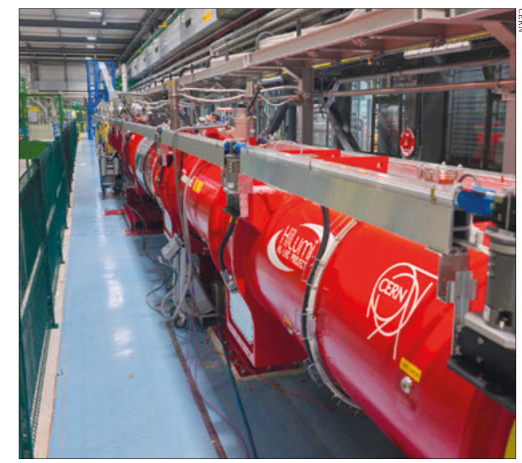
Further reading

A Aceituno *et al.* 2026 *Phys. Rev. Lett.* **136** 241002.

HIGH-LUMINOSITY LHC

HL-LHC magnets reach full current

CERN has carried out a successful full-scale test of the focusing magnets for the High-Luminosity LHC (HL-LHC). On 8 July 2026, the new superconducting quadrupole magnets at CERN's Inner Triplet (IT) String facility reached their nominal operating current of 16,230 amperes without a quench. The result validates a key element of the magnet technology that will be installed on either side of the ATLAS and CMS interaction points during the LHC's third Long Shutdown (LS3).



CERN

Niobium-tin *The new quadrupole magnets for the HL-LHC reached nominal operating current at the IT String test facility.*

Known as inner triplet magnets, the new focusing quadrupoles have been in development for more than a decade (*CERN Courier* May 2016 p31). Their role is to squeeze proton beams just before they collide, increasing the number of proton–proton interactions and hence the accelerator's luminosity. The new magnets have a much larger aperture than those currently installed in the LHC, 150 millimetres compared with 70, providing the space required to accommodate the new beam optics.

Peak fields

The quadrupoles use niobium–tin (Nb_3Sn) superconducting coils in place of the niobium–titanium (Nb–Ti) used in the present LHC magnets (p36). Nb_3Sn allows the coils to reach peak fields of around 11.3 T, roughly 35% higher than those of the current generation (*CERN Courier* March/April 2026 p30). When the HL-LHC starts, the quadrupoles will become the first Nb_3Sn magnets to be used in a working accelerator.

Before a superconducting magnet can be put into operation, it must first undergo a process known as training, which consists of gradually increasing the current during successive powering cycles. As the process unfolds, small mechanical movements within the coils can trigger losses of superconductivity known as quenches. Repeated cycles allow the coils to settle into a mechanically stable configuration, and the magnet to reach progressively higher currents. The ability to retain this trained performance is called memory.

Good memory is a key performance requirement for accelerator magnets

"Good memory is a key performance requirement for accelerator magnets, as it minimises commissioning time, cryogenic consumption and operational delays," explains Susana Izquierdo Bermudez, who leads CERN's Large Magnet Facility, where the new superconducting magnets were developed and assembled.

The quadrupoles are only part of the system under test. All 17 electrical circuits of the IT String were also successfully powered to their operating currents. The separation dipole, which will steer the two beams apart after they pass the interaction point, reached its nominal current after only a few training quenches. The corrector-magnet circuits likewise reached their target currents, both individually and in combined operation.

Superconducting magnets store large amounts of energy, which must be safely removed if a quench occurs. During the tests, the machine-protection systems successfully extracted and dissipated up to 38 MJ of stored magnetic energy into the helium bath that keeps the magnets at their operating temperature of 1.9 K.

Big data

"The successful powering of all circuits marked the completion of the IT String hardware commissioning phase," explains Samer Yammine, responsible for IT String operations. "The campaign generated a vast amount of data that we are now analysing to better understand how all the systems interact." The results of the analyses – which cover the superconducting magnets, cold powering system, power converters, quench detection and protection, cryogenics, vacuum, controls and alignment – will help refine the commissioning and operations procedures for the HL-LHC.

Further tests of the superconducting circuits, machine cycles, electromagnetic coupling and alignment will be followed by a warm-up to room temperature and a second cooldown ahead of a new round of testing. "This second operational campaign in September will primarily focus on validating the commissioning procedures and analysis tools, as well as demonstrating the reproducibility of the integrated system performance," remarks Marta Bajko, head of the IT String facility. "We will test the systems under conditions close to those of the future HL-LHC."

CERNCOURIER

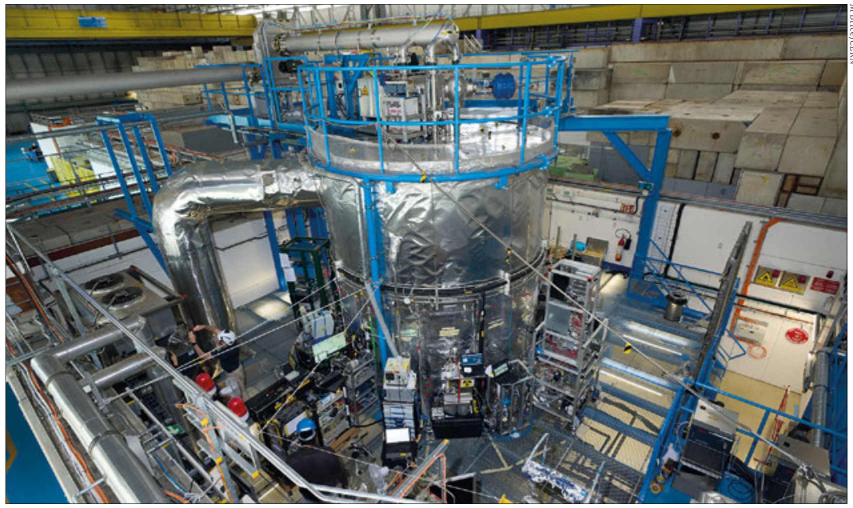
VOLUME 66 NUMBER 5 SEPTEMBER/OCTOBER 2026

ATMOSPHERIC PHYSICS

A new seed for marine clouds

Climate models typically assume sulphuric acid is the only vapour driving the formation of aerosol particles that seed marine clouds. In a paper published in *Nature* on 24 June, the CLOUD (Cosmics Leaving Outdoor Droplets) collaboration at CERN reports that a second vapour, methanesulphonic acid (MSA), drives the process just as effectively in cold marine air. Particle formation over cool oceans may therefore run up to ten times, and particle growth up to twice, as fast as models predict.

The condensation of water vapour in the atmosphere into droplets requires a cloud condensation nucleus (CCN), a suspended speck of liquid or solid matter larger than about 50 nm. More than half of all CCN form when trace low-volatility vapours cluster spontaneously, a process called nucleation. In 1987, Robert Charlson, James Lovelock, Meinrat Andreae and Stephen Warren proposed that some nucleating vapours could come from oceanic life. In their "Gaian" picture, tiny algae called phytoplankton release dimethyl sulphide (DMS) from the ocean surface, and its oxidation products seed clouds, which in turn shade the waters below and help regulate the climate. The oxidation of DMS yields two acids in comparable amounts, sulphuric acid and MSA. While the former has been known for many years to drive particle nucleation, the role of the latter has long remained unclear.


M Brice/CERN

Chamber ensemble *Surrounded by the instruments that analyse its contents, the 26 m^3 CLOUD chamber in CERN's East Area holds synthetic marine air at temperatures down to −52 °C for experiments with methanesulphonic acid.*

Nucleation

MSA's capacity to nucleate was first tested in the 1980s, at concentrations orders of magnitude above the typical 10^5 to 10^7 molecules per cubic centimetre of marine air. Later studies concluded that MSA could not compete with sulphuric acid in the real atmosphere, and experimental attention faded for two decades. Interest revived when MSA kept turning up inside small marine particles, but composition alone could not distinguish between nucleation and condensational growth of pre-existing aerosol particles. The next step called for controlled experiments under atmospheric conditions.

"CLOUD is essentially a highly controlled artificial atmosphere," says Rima Baalbaki of the University of Helsinki and the Cyprus Institute, who co-led the study, "filled with ultrapure air made from liquid nitrogen and oxygen, in which temperature, humidity, ionisation and trace gases are adjusted to reproduce conditions from the boundary layer to the lower stratosphere." Settling the question also demanded realistic vapour concentrations and instruments that watch every step at once, from the precursor gases through the first clusters to the grown particles. "No previous experiment had brought all these elements together," she adds.

For sulphuric acid to nucleate at atmospheric concentrations, a base vapour such as ammonia is needed to form acid-base pairs that suppress the particle's evaporation. CLOUD tested whether MSA can play a similar role, dialling MSA, sulphuric acid and ammonia up and down across the temperature range of marine air. At +9 °C, no MSA appeared in the embryonic molecular clusters. At −10 °C the picture changed: MSA entered the very first clusters, paired with ammonia, and nucleated without any sulphuric acid, while mixed clusters of both acids with ammonia were the most abundant of all. Without a base vapour, MSA contributed nothing to nucleation, even at −52 °C. However, once the first few molecules had clustered, ammonia was no longer required for MSA to drive rapid particle growth, limited only by the molecular arrival rate.

CLOUD is essentially a highly controlled artificial atmosphere

"What changes below −10 °C is the balance between cluster growth and evaporation," explains Baalbaki. "At warmer temperatures, MSA molecules may collide and form a cluster, but they tend to evaporate before additional molecules can attach. Cooling lowers MSA's saturation vapour pressure, so the molecules remain together long enough for others to join." Cooling also raises the MSA yield from DMS oxidation, so the mechanism should matter most over polar oceans and in the upper troposphere.

Missing source

"Aircraft campaigns over the Atlantic and Pacific oceans have found a major unexplained source of nucleated particles at high altitude, which grow as they descend to seed low-latitude marine clouds that strongly influence Earth's albedo," says CLOUD spokesperson Jasper Kirkby. "Furthermore, for more than a decade, models have underestimated CCN over the Southern Ocean by roughly a factor of two. With this study, we have likely identified MSA as the key missing source of CCN for both." CLOUD had previously reached a similar conclusion over land, linking abundant particle formation observed by research aircraft high above tropical rainforests to forest-emitted isoprene (*CERN Courier* January/February 2025 p5).

The collaboration has made an initial evaluation of the impact of their new measurements on CCN concentrations over the Arctic and Antarctic regions. Adding their measured mechanisms to a global model, they find that MSA may close much of the gap in CCN concentrations that causes current climate models to run unrealistically warm over the Southern Ocean.

The stakes reach beyond the poles. Emissions of sulphur dioxide from fossil fuels, which provide most atmospheric sulphuric acid, are being cut because fine-particle pollution causes millions of premature deaths each year. However, these same particles also cool the climate by making clouds brighter and more extensive. "Aerosols have short lifetimes, so as we stop producing them they will disappear rapidly and then temperatures will rise further," says Kirkby. "Most climate models consider only particles nucleated from sulphuric acid, so they predict much less cloud as anthropogenic emissions fall. The overarching conclusion from CLOUD studies over the last 15 years is that the biosphere is much more capable than previously thought of producing abundant aerosol particles over both land and sea. So, as anthropogenic aerosol particles fall with emission controls, the biosphere should partially buffer the reduction more effectively, and the additional aerosol warming of the climate should be less than presently expected. But now we need to quantify it with model studies based on the CLOUD measurements."

Most of the key players are probably now known

Experiments at intermediate temperatures must still pin down where MSA begins to nucleate, and a companion CLOUD study shows that with dimethylamine, a stronger base than ammonia, MSA forms particles at +5 °C and speeds sulphuric-acid nucleation tenfold to a hundredfold. "Particle physicists are careful about saying we're done," adds Kirkby. "We are not close to a 'Standard Model' of atmospheric aerosol formation, but most of the key players in particle nucleation and growth are probably now known. A major goal over the next few years is to prepare systematic parameterisations of our CLOUD measurements for climate models. And no doubt there are still more surprises in store for us along the way."

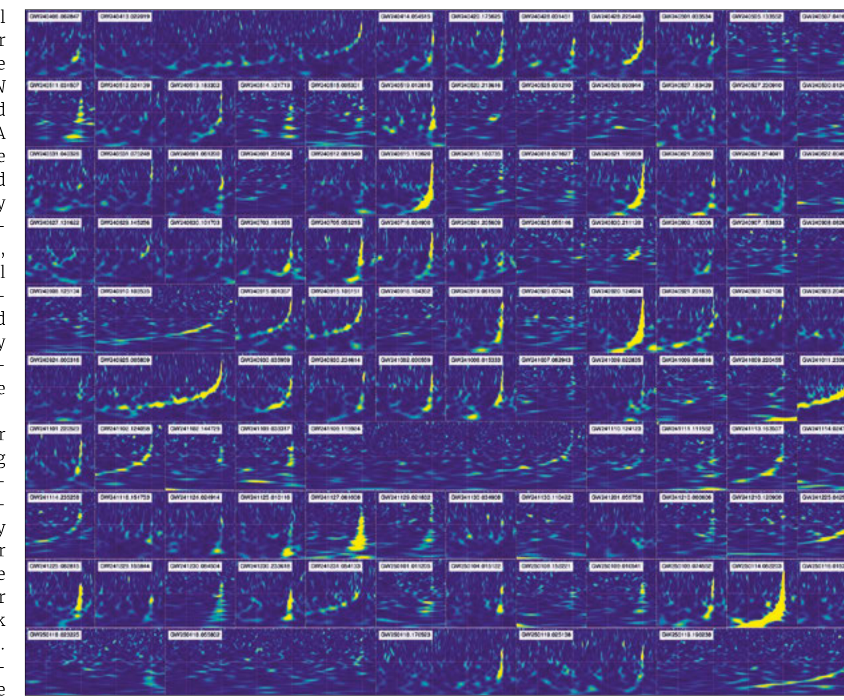
Further reading
R Baalbaki *et al.* 2026 *Nature* **655** 1204.
H Klebach *et al.* 2026 *Environ. Sci.: Atmos.* **6** 1028.
J Shen *et al.* 2024 *Nature* **636** 115.

ASTROWATCH

Highlights from the cosmic census

On 14 September 2015, the gravitational waves emitted by a black-hole merger more than a billion light-years away were observed on Earth for the first time (*CERN Courier* April 2016 p19). The challenge had long seemed daring – if not impossible. A decade on, precision gravitational-wave astronomy has become an established observational discipline. This maturity is most evident in the new Gravitational-Wave Transient Catalog (GWTC-5.0), released in May by the international LIGO–Virgo–KAGRA (LVK) Collaboration, which adds 161 events recorded between 10 April 2024 and 28 January 2025, and brings the number of gravitational-wave signals observed to date to an astounding 390.

The LVK Collaboration brings together several thousand scientists working with the two Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors in the United States, Virgo in Italy and KAGRA in Japan. Thanks to their steadily improving sensitivity, these interferometers detected three to four gravitational-wave signals every week during the most recent observing run. This growing collection of data is transforming our understanding of black-hole populations, providing clues about how black holes form, evolve and merge.


D Davis/University of Rhode Island/LIGO–Virgo–KAGRA

Family portrait *The black-hole mergers added to the GWTC-5.0 catalogue in the latest observing run, one signal per panel, with time running rightward and frequency upward. Each sweep rises in pitch as the two black holes spiral together. Brighter traces indicate louder signals.*

One of the most striking findings is that some of the black holes taking part in the observed mergers appear to be second-generation objects, the products of earlier mergers rather than of stellar collapse. The case rests largely on the GW241011 and GW241110 signals, generated by events at about 700 million and 2.4 billion light-years from Earth and detected in October and November 2024, respectively. Several of their measured properties, above all the spin of each pair's heavier black hole, are best explained if these objects are themselves merger remnants. Astronomers have long suggested that in dense environments, such as stellar clusters, black holes may be ▷

CERNCOURIER
VOLUME 66 NUMBER 5 SEPTEMBER/OCTOBER 2026

more likely to collide and merge repeatedly, and gravitational waves provide insights into these extreme astrophysical environments that are difficult to obtain by other means.

The new catalogue also offers a wide variety of increasingly precise tests of general relativity, enabling us to study how gravity and spacetime behave in the immediate vicinity of a black hole, where Einstein's theory might intersect with quantum mechanics. GW250114, a particularly clear signal that reached Earth on 14 January 2025, enabled the first detection of two dominant vibrational tones from a black hole, along with hints of a third. As the merged remnant settled, it rang like a struck bell, each tone characterised by an oscillation frequency and a damping time. Measuring the dominant tone and its first overtone made this the most accurate such test so far, and the data agreed with the theory's predictions. By comparing the inferred areas of the two initial black holes with that of the remnant, LVK researchers also found the result consistent with the increase predicted by Stephen Hawking's area theorem, which states that the total black-hole horizon area cannot decrease.

Another signal in the catalogue, GW240615, detected on 15 June 2024 by LIGO and Virgo, is the most precisely localised gravitational-wave source yet, pinpointed to an area of only six square degrees. Accurate localisation is of tremendous importance to the broader astronomical community, as it enables the search for electromagnetic counterparts to the observed events, in particular for mergers involving neutron stars. GW240615 originated more than 3 billion light-years from Earth and was produced by the merger of two black holes with masses of approximately 26 and 30 times that of the Sun. As expected for a binary black-hole merger, no electromagnetic counterpart was identified.

The expanding universe

Gravitational waves can also be used to measure the expansion of the universe. Improvements in the localisation capabilities of the detector network and the larger GWTC-5.0 dataset have yielded a new independent measurement of the Hubble constant, $H_0 = 71.7^{+9.4}_{-7.5}$ km s^{-1}Mpc^{-1}, 22% more precise than the previous gravitational-wave estimate. The result bears on one of modern cosmology's unsolved puzzles, the Hubble tension. Its uncertainties are still broad enough to be consistent with determinations from both the nearby and the early universe, which disagree with each other, but gravitational-wave observations add an independent perspective to the debate and may ultimately help to resolve it.

Taken together, these findings show how, in the years to come, gravitational waves will help explore unresolved questions in fundamental physics and in the origin and evolution of the universe. As the census of cosmic mergers grows, they will continue to reveal phenomena that are difficult or impossible to study through electromagnetic observations alone.

Further reading

LIGO–Virgo–KAGRA Collab. 2026 arXiv:2605.27225.
LIGO–Virgo–KAGRA Collab. 2026 arXiv:2605.27227.
LIGO–Virgo–KAGRA Collab. 2025 *Phys. Rev. Lett.* **135** 111403.

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NEWS DIGEST

The Rubin Observatory at twilight on Cerro Pachón.

LSST under way

On 30 June 2026, the NSF–DOE Vera C. Rubin Observatory officially began the Legacy Survey of Space and Time (LSST). Rubin's record 3200-megapixel digital camera will image the entire southern sky every few nights, building up a decade-long time-lapse for studies of the Milky Way, the solar system, and dark matter and energy, traced through billions of galaxies. Test observations had already identified more than 11,000 previously unknown asteroids, including 33 near-Earth and 380 trans-Neptunian objects. "It is amazing and humbling to be here at this time and place as we start the LSST, after more than two decades of incredible work by our dedicated team," said Bob Blum, director of the Rubin Observatory at NSF NOIRLab.

Benefits beyond the ring

A new study has assessed the socio-economic benefits generated by CERN's activities over the past 25 years (doi:10.5281/zenodo.19910290). The report identifies research and knowledge flows, procurement, innovation and technology transfer, skills development and science diplomacy as the main pathways through which the laboratory's impact extends beyond particle physics. From 1989 to 2024, research carried out at CERN produced more than 160,000 scientific and technical publications, cited in more than 1300 patent applications, as well as in policy literature and general information systems. Firms that secured their first CERN order between 2016 and 2024 recorded, on average, a 15% increase in patent stock and a 63% growth in intangible assets within five years, compared with similar firms without CERN engagement.

Heavy ions in Huizhou

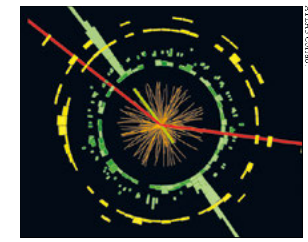
On 21 July 2026, the High Intensity Heavy-ion Accelerator Facility (HIAF) in Huizhou, China, began trial operations, following its completion and formal acceptance after seven years of construction. Designed and developed by the Institute of Modern Physics of the Chinese Academy of Sciences, HIAF is the first heavy-ion facility to integrate a superconducting linear accelerator with a fast-cycling synchrotron, and is designed to deliver the world's most intense pulsed heavy-ion beams. Able to deal with species from hydrogen to uranium and to produce thousands of unstable isotopes, HIAF will probe the limits of nuclear existence, with applications from astrophysics and spacecraft radiation testing to heavy-ion cancer therapy. During commissioning, the facility accelerated 2.5×10^{11} oxygen ions and 3.2×10^{10} bismuth ions per pulse.


Institute of Modern Physics

HIAF's rings in the hills of Huizhou.

Longitudinal, twice over

At a CERN seminar on 28 July 2026, the ATLAS collaboration reported the first observation of events containing two longitudinally polarised Z bosons, together with evidence, at 4.0σ, for longitudinal polarisation of the Z boson in electroweak WZ production with two jets (ATLAS Collab. 2026 arXiv:2607.12879 and 2607.20246). Since massless particles cannot be longitudinally polarised, these states exist only because the weak bosons gain their mass through the Brout–Englert–Higgs mechanism. The measurements, long considered beyond the reach of hadron colliders, thus probe its workings directly. The ZZ analysis combines Run 3 data at 13.6 TeV with the earlier Run 2 measurement to reach an observed significance of 6.5σ, and the measured polarisation fractions agree with Standard Model predictions. Advanced machine-learning techniques helped isolate the second channel, in which two quarks radiate weak bosons that then scatter off one another.


ATLAS Collab.

A four-lepton ZZ candidate in ATLAS.

Geoneutrinos put to sea

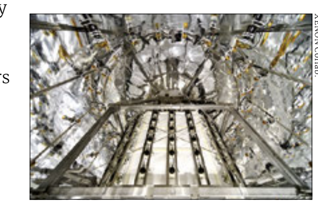
An international team has proposed the Deep-Ocean Application-Specific Neutrino Experiment, a mobile detector for the electron antineutrinos emitted in the decay chains of uranium and thorium in the Earth's mantle (T Araki *et al.* 2026 arXiv:2606.20780). Detectors on land, such as KamLAND and Borexino, see a signal dominated by the crust beneath them. Placed on the thin oceanic crust instead, the proposed experiment would suppress this background by a factor of 50 to 100 relative to continental instruments of similar size, opening direct access to the mantle. Repositioning it between sites could map spatial variations in the mantle's heat-producing elements.

A moment for the deuteron

The JEDI collaboration has set the first experimental limit on the electric dipole moment (EDM) of the deuteron, $|d| < 2.5\times10^{-17}$ e cm at a 95% confidence level (Andres *et al.* 2026 *Phys. Rev. Lett.* **136** 241801). A permanent EDM violates CP symmetry, and the Standard Model predicts values so small that any detection, given the current experimental sensitivities, would reveal a new source of CP violation, of the kind needed to explain the matter–antimatter asymmetry of the universe. At the Cooler Synchrotron (COSY) in Jülich, the spins of stored deuterons precess about an axis that, in the absence of an EDM, would stand exactly perpendicular to the ring plane. The team measured the orientation of such an axis and found deviations of just a few milliradians, which known systematic effects can account for.

New limits from XENON

On 30 July 2026, the XENON collaboration published new limits on dark-matter particles up to a few GeV scattering off atomic nuclei and electrons, and on sub-keV axion-like particles and dark photons absorbed by xenon atoms (XENON Collab. 2026 *Phys. Rev. Lett.* **137** 051003). The analysis draws on 7.83 tonne-years of data from the XENONnT detector at the INFN Gran Sasso National Laboratory.


XENON Collab.

The XENONnT cryostat inside its water tank.

Particle interactions in the detector produce a flash of light and ionisation electrons, and standard searches for weakly interacting massive particles require both. Light dark matter can deposit too little energy for a detectable flash, so this search relied on the charge signal alone, counting the electrons freed in the detector's 5.9 tonnes of liquid xenon. No significant excess appeared.

ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

ALICE

Whirlpools in the perfect fluid

Over the past two decades, heavy-ion experiments have established that the quark–gluon plasma (QGP) expands collectively and behaves as an almost perfect fluid. Much like water swirling in a whirlpool, the QGP can develop vortices – regions where it circulates around an axis. The ALICE collaboration has now probed this local rotation using Λ and anti-Λ hyperons, weakly decaying particles containing a strange quark or antiquark, respectively.

When two nuclei collide off-centre, their overlap region is, on average, elongated rather than circular. Pressure is then higher along some directions, and the QGP formed in the collision expands unevenly. As a result, neighbouring regions of the fluid flow past one another, seeding many local vortices. Some of these rotate about axes parallel to the beam, in directions that alternate across the plane perpendicular to it. This local rotation tends to align the spins of the medium's quarks. When the plasma cools and its components bind into hadrons, part of this alignment survives as a spin polarisation. Λ and anti-Λ hyperons are excellent probes of the phenomenon, since the proton emitted in the Λ decay tends to follow the parent's spin direction, and the antiproton in the anti-Λ decay to oppose it.

In the plane transverse to the beam, the direction of each hyperon's momentum is specified by its azimuthal angle, measured with respect to reference directions known as "event planes" and inferred in each collision from the pattern of emitted particles. Each order of the collision shape defines its own such direction. The second-order plane follows the average elliptic shape of the overlap region, while the third-order one traces a triangular distortion, arising mainly from collision-by-collision variations. The longitudinal polarisation is predicted to rise and fall as the angle changes, with a distinct pattern relative to each plane.

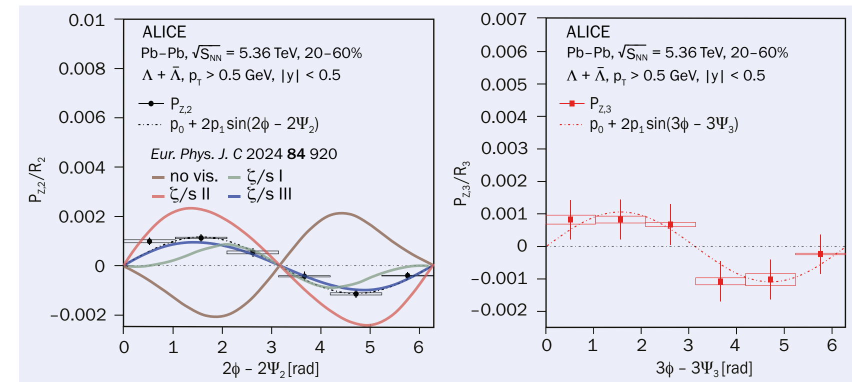


Fig. 1. *Longitudinal polarisation of Λ and anti-Λ hyperons as a function of azimuthal angle relative to the second- (left) and third-order (right) event planes, in 20–60% central Pb–Pb collisions at 5.36 TeV per nucleon pair. Bars and boxes show statistical and systematic uncertainties, and the dash-dotted curves are sine fits. The coloured curves in the left panel are hydrodynamic calculations with different treatments of bulk viscosity.*

Λ and anti-Λ hyperons are excellent probes of local QGP vortices

Using the high-statistics Run-3 data sample of Pb–Pb collisions at a centre-of-mass energy per nucleon pair of 5.36 TeV, the collaboration has studied the second-order polarisation with improved precision and, for the first time at the LHC, the third-order component (see figure 1). The improvement allows a more stringent comparison with recent viscous hydrodynamic calculations, which shows that polarisation is sensitive to bulk viscosity – the fluid's resistance to uniform expansion or compression. Bulk viscosity does not generate the alignment directly, but modifies the space–time evolution of the medium and the velocity gradients that do.

The first measurement of the third-order polarisation gives access to the vortices arising from event-specific fluctuations, beyond those tied to the average collision geometry. An interesting feature of the measurement is that the second- and third-order polarisation signals are of comparable magnitude, although the corresponding anisotropic-flow harmonics – the patterns in the particle emission – exhibit a clear hierarchy. This suggests that hyperon polarisation is not simply a reflection of the system's momentum anisotropy, but carries additional information about the local vortical structure and how viscosity affects the evolution of the QGP. While theoretical calculations for the third-order component are not yet available, the present measurement provides an important benchmark for future studies.

Further reading

ALICE Collab. 2026 arXiv:2606.18070.

LHCb

A new purely baryonic decay

Almost every particle decay process recorded to date involves at least a meson or a lepton. Only two feature nothing but baryons and antibaryons, and both include a charmed product. The LHCb collaboration has now observed a third, $\Lambda_b^0 \to \Lambda p \bar{p}$, this time with no final-state charm quarks, and the first to emerge from a dedicated search.

The first to emerge from a dedicated search

It is the intricate internal structure of baryons that makes purely baryonic decay processes so interesting. The two previously known cases, $\Lambda_b^0 \to \Sigma_c^0 p \bar{p}$ and $\Lambda_b^0 \to \Sigma_c^{*0} p \bar{p}$, surfaced in 2018 from an LHCb analysis of $\Lambda_b^0 \to \Lambda_c^+ p \bar{p} \pi^-$. ▷

In both these modes, as well as in the new one, the original three-quark baryon transforms into three other baryons and antibaryons containing nine valence quarks and antiquarks altogether. The transition must therefore create several quark–antiquark pairs. Measuring these processes can help clarify how the weak decay of a heavy quark is followed by the strong interactions that bind quarks into observable particles. Their spin structure also gives access to angular observables, including triple-product correlations, that are sensitive to CP-violating and time-reversal-odd effects.

The recent search was conducted using 6.0 fb^{-1} of proton–proton collision data recorded by LHCb during Run 2 of the LHC, at a centre-of-mass energy of 13 TeV. The relatively long-lived Λ baryon was reconstructed through its decay into a proton and a pion. Since the Λ can travel an appreciable distance before decaying, the data are divided into two categories based on where the decay takes place inside the detector. In the “long–long” (LL) category, both decay products leave hits in the vertex detector near the collision point and in the tracking stations downstream, providing the best mass and vertex resolution (see figure 1). A complementary “downstream–downstream” (DD) category recovers Λ baryons that decay outside the vertex detector and contributes about half of the signal.

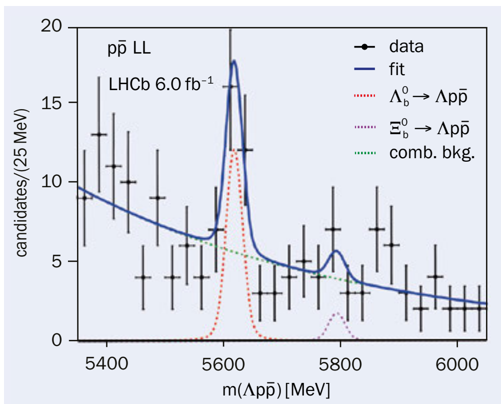


Fig. 1. *Invariant-mass distribution of the selected $\Lambda_b^0 \to \Lambda p\bar{p}$ candidates in the higher-resolution LL category of the full Run-2 dataset. The total fit (solid blue) comprises the $\Lambda_b^0 \to \Lambda p\bar{p}$ signal (dotted red), a small possible $\Xi_b^0 \to \Lambda p\bar{p}$ contribution (dotted magenta) and the combinatorial background (dotted green).*

Larger Run-3 datasets will allow the dynamics of this decay to be explored in much greater detail

The candidates were separated from random combinations of particles using the displaced-decay topology, multivariate algorithms and LHCb’s particle-identification detectors. Backgrounds containing charm hadrons were removed, while decays through intermediate charmonium resonances were excluded by requiring the proton–antiproton invariant mass to be below 2.85 GeV. A simultaneous fit to both reconstruction categories yields 39 ± 10 decays with a significance of 5.1 standard deviations, including systematic uncertainties. The $\Lambda_b^0 \to \Lambda p\bar{p}$ decay rate is measured relative to the similar $\Lambda_b^0 \to \Lambda K^+K^-$, giving a ratio of branching fractions of (5.1 ± 1.3 (stat.) ± 0.3 (syst.)) × 10^{-2}. Since the measurement is restricted to this charmonium-free region for both decays, while the published branching fraction of the normalisation mode covers the full phase space, the ratio cannot yet be converted directly into an absolute branching fraction for $\Lambda_b^0 \to \Lambda p\bar{p}$.

Larger Run-3 datasets from the upgraded LHCb detector will allow the internal dynamics of this decay to be explored in much greater detail, including possible threshold enhancements and searches for CP-violating effects through spin-dependent observables. The related decay $\Xi_b^0 \to \Lambda p\bar{p}$, for which the Run-2 analysis found a modest 2.3 standard-deviation excess, will also be studied in finer detail.

Further reading
LHCb Collab. arXiv:2605.04348.

CMS

New limits on a composite Higgs

Fourteen years of measurements have shown the Higgs boson to behave exactly as the Standard Model (SM) prescribes. However, the data remain compatible with a bound state of undiscovered constituents, held together by a new strong interaction. A recent CMS analysis places stringent constraints on composite-Higgs scenarios by searching for their signatures in high-mass dilepton production.

The possibility has long been motivated by the hierarchy problem (*CERN Courier* July/August 2022 p47). Quantum corrections tend to drive the Higgs-boson mass far above the electroweak scale, requiring an unnatural cancellation to recover the measured value of 125 GeV. Composite Higgs bosons evade this fine-tuning, as the scale of the new interaction naturally cuts off quantum corrections. The same dynamics predicts additional heavy resonances and small deviations from SM expectations, with lepton pairs offering one of the cleanest examples. The CMS collaboration searched for these effects in dielectron and dimuon events recorded at centre-of-mass energies of 13 and 13.6 TeV.

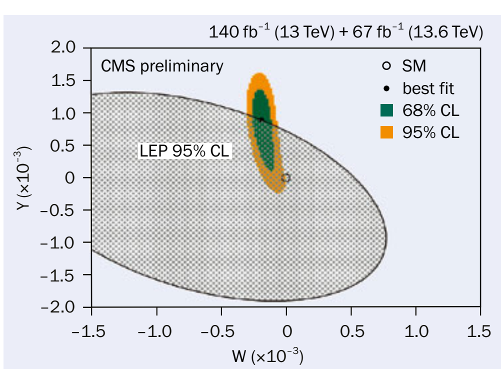


Fig. 1. *Simultaneous fit of the electroweak oblique parameters W and Y, combined with a previous CMS measurement of W and using 140 fb^{-1} of collision data at 13 TeV and 67 fb^{-1} at 13.6 TeV. The green and yellow contours enclose the regions favoured by the data at 68% and 95% confidence level, and the best-fit point lies about 2σ from the SM expectation W = Y = 0. The dotted ellipse shows the much larger region allowed by precision measurements at LEP.*

Rather than generating dedicated samples for each theoretical model, the collaboration reweighted simulated events using next-to-leading-order QCD predictions, allowing a wide range of scenarios to be tested efficiently. Two complementary signatures were investigated. The first is a broad, mass-dependent distortion of the dilepton spectrum, characterised by the electroweak oblique parameters W and Y, which vanish in the SM and quantify new contributions that can be absorbed as modifications to the propagation of the electroweak bosons. The second is a localised excess from a massive vector-boson resonance coupling to fermions and bosons, among ▷

the heavy states that composite-Higgs models predict.

No significant deviation from the SM was observed. When fitted separately, the W and Y parameters are consistent with zero, yielding tight constraints on both. A simultaneous fit reveals instead a mild excess at the 2σ level, largely driven by a single dielectron event with an invariant mass of 5.2 TeV recorded in 2022 (*CERN Courier* July/August 2026 p12). The excess is compatible with a statistical fluctuation, and further data will clarify its origin.

By combining these results with previous CMS constraints on W from a search in final states with one high-energy lepton and missing transverse momentum, the analysis delivered the most stringent limits to date on the oblique parameters (see figure 1). Limits were also set on the Z′ resonances predicted by Y-universal and Little Higgs scenarios with custodial symmetry, within or slightly above the visible mass spectrum.

Precision measurements can probe physics at energy scales beyond direct collider reach

The result illustrates how precision measurements can probe physics at energy scales beyond direct collider reach. Even without discovering new particles, exclusion limits guide theoretical development and experimental priorities, and the combination of direct resonance searches and indirect oblique-parameter constraints sharpens the picture of the allowed scenarios. As larger datasets accumulate during Run 3 and the High-Luminosity LHC era, increasingly precise measurements of the dilepton spectrum will continue to test the SM at energy scales approaching 10 TeV.

Further reading
CMS Collab. 2026 CMS-PAS-EXO-25-001.

ATLAS

Hyperfine splitting in the B_c system

The B_c^+ mesons are heavy bound states of a charm quark and a beauty antiquark, intermediate in mass between charmonium ($c\bar{c}$) and bottomonium ($b\bar{b}$). The ATLAS collaboration has now reported the first observation of the B_c^{*+} meson, the lightest excitation of the system, using the full 140 fb^{-1} of 13 TeV proton–proton collisions recorded during Run 2 of the LHC. The spectrum of this system is largely uncharted, and mapping it offers a powerful test of QCD.

The ground-state B_c^+ meson was first observed by the CDF collaboration at the Tevatron in 1998 (*CERN Courier* Summer 1998 p22), but excited $\bar{b}c$ states have proved considerably more challenging to identify. In analogy with the hyperfine splitting of the hydrogen atom, the B_c^{*+} meson’s quark and antiquark spins are aligned in the same direction, whereas they are oppositely oriented in the ground-state B_c^+. The mass difference between the two states is therefore expected to be only a few tens of MeV, the smallest splitting among all known B_c excitations. The excited B_c^{*+} meson decays into the ground-state B_c^+ meson by emitting a correspondingly low-energy photon, which is extremely difficult to measure.

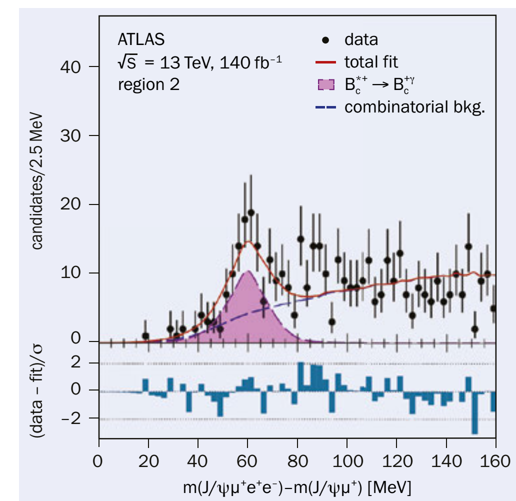


Fig. 1. *Distribution of the mass difference between the reconstructed B_c^{*+} and B_c^+ candidates. The fit (solid red) reveals a significant excess above the smoothly rising background (dashed blue), corresponding to the $B_c^{*+} \to B_c^+\gamma$ decay (purple area).*

The analysis identified the B_c^+ mesons through their semileptonic decays to $J/\psi(\to\mu^+\mu^-)\mu^+\nu_\mu X$. Such modes are not typically used in hadron spectroscopy, because the missing neutrino prevents the full kinematics from being reconstructed. However, the branching fraction of this channel is about 20 times larger than that of the hadronic decay to $J/\psi\pi^+$ used in earlier studies of excited $\bar{b}c$ states. This gain in statistics, along with a relatively low level of background, outweighs the complication of the partial final-state reconstruction.

The low-energy photons were identified using their conversions to electron–positron pairs in the material of the beampipe or of the innermost part of the ATLAS tracking detector. A conversion candidate is marked by a pair of oppositely charged tracks emerging from a common vertex, sufficiently displaced from the collision point. To increase the acceptance for the soft photons, a dedicated track reconstruction procedure was introduced with a transverse momentum threshold as low as 100 MeV, compared with the about 500 MeV typical of ATLAS track reconstruction. While running it on the entire dataset would be computationally impractical, the analysis benefited from a recent development in distributed data management that enabled individual raw events containing a B_c^+ candidate to be “picked” from the tapes. This way, the dedicated tracking was executed only on several hundred thousand preselected events, instead of the billions in the full dataset.

Once the B_c^+ decay and photon candidates are combined, the signal of the B_c^{*+} decay is identified using the distribution of the mass difference $m(J/\psi\mu^+\gamma) - m(J/\psi\mu^+)$. The signal produces a distinct peak in this distribution, despite the missing neutrino from the B_c^+ decay (see figure 1). The statistical significance of the observed signal exceeds eight standard deviations. The mass difference between the new particle and the ground-state B_c^+ meson is measured to be $64.5 \pm 1.4\,(\text{stat.})^{+1.0}_{-1.4}\,(\text{syst.})$ MeV. This value is within the range of the available theoretical expectations, although it lies slightly above the most recent precise lattice-QCD calculations, which predict values below 60 MeV.

This discovery fills a gap in the spectrum of experimentally observed states of the $\bar{b}c$ system and will help inform the development of theoretical models. It also demonstrates the potential of ATLAS for heavy-flavour hadron spectroscopy, a capability that will be further explored with Run-3 data and at the High-Luminosity LHC.

Further reading
ATLAS Collab. arXiv:2605.16228.

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FIELD NOTES

Reports from events, conferences and meetings

LHCP 2026

Precision holds court in Paris

Coherent state *Participants of LHCP 2026 assembled at Sorbonne University, where the four large LHC collaborations presented measurements in broad agreement with the Standard Model.*

From 18 to 22 May, the 14th Large Hadron Collider Physics conference (LHCP 2026) brought 424 physicists to Sorbonne University's Pierre and Marie Curie campus, in Paris. Over five days of plenary talks, parallel sessions and poster presentations, the ALICE, ATLAS, CMS and LHCb collaborations, and the theory community, presented a flurry of new results, alongside updates on detector upgrades for the High-Luminosity LHC (HL-LHC) phase. The picture that emerged was of a Standard Model (SM) holding up under ever-sharper scrutiny, with experimental uncertainties increasingly rivalling those from theory.

Direct implications

When ATLAS and CMS discovered the Higgs boson, in 2012, they did so with only about 10 fb^{-1} of data. Today, the field they opened is entering the era of precision measurements. The Higgs production rate measured across all channels after Run 2 of the LHC agrees with the SM prediction within 5%, and theory is now the dominant source of uncertainty. A preliminary combination of the four most precise ATLAS and CMS measurements using Run 1 and Run 2 data yields $m_H = 125.09 \pm 0.07$ GeV, a precision of 0.6‰ that places the Higgs mass among the best-known parameters of the SM, with direct implications for the stability of the electroweak vacuum.

Precision measurements of fundamental SM parameters continue to advance on multiple fronts. CMS and LHCb measured the W- and Z-boson masses to be 80360.2 ± 9.9 MeV and 91184.2 ± 9.3 MeV, respectively. Together with the ATLAS + CMS combined top-quark mass of 172.52 ± 0.33 GeV and the strong coupling α_s (p41), determined by a wide range of experiments and methods, these results provide essential inputs to global electroweak fits. Vector-boson scattering, first observed during Run 2, has now also been established in Run-3 data in the WW, WZ and ZZ channels, and ATLAS and CMS presented first evidence for $ZZ\gamma$ production, the smallest cross-section yet measured at the LHC.

The Higgs-boson mass tells us how sharply the Higgs potential curves at its minimum, but not its full shape. The self-coupling λ, which provides a first look beyond the minimum, bears on whether the electroweak vacuum is truly stable, and therefore on the ultimate fate of our universe (*CERN Courier* January/February 2026 p31). Directly accessing λ requires measuring Higgs pair production, a process roughly a thousand times rarer than single Higgs production and one of the most ambitious goals of the LHC and HL-LHC programme. Combining their Run-2 searches, ATLAS and CMS constrained κ_λ, the measured self-coupling divided by its SM value, to between −0.71 and 6.1 at 95% confidence level (CL). Newly presented HH analyses using Run-3 data in the $HH \to bbbb$, $HH \to bb\gamma\gamma$ and $HH \to bbWW$ channels significantly improved on the sensitivity of the Run-2 measurements, even with smaller datasets, thanks to refined analysis techniques. ATLAS also presented the first search for ttHH production, excluding cross-sections above 20 times the SM prediction at 95% CL.

The picture that emerged was of a Standard Model holding up under ever-sharper scrutiny

Sharpening up

In the flavour sector, LHCb and CMS presented new precision results on the Cabibbo–Kobayashi–Maskawa matrix angles γ and β, with CMS measuring time-dependent CP violation in neutral B decays using the full Run-3 statistics. These measurements provide increasingly stringent tests of the unitarity triangle and sharpen the sensitivity to potential new-physics contributions. ▷

Quantum chromodynamics (QCD) governs both the dominant and some of the least understood processes at the LHC. New results on the dead-cone effect, the suppression of gluon radiation close to the flight direction of a massive quark, confirm simulation predictions and reveal large differences between b and light quarks. The catalogue of bound states keeps growing as well, with new exotic ones from LHCb bringing the number of hadrons discovered at the LHC to 82 and toponium candidates coming from ATLAS and CMS (*CERN Courier* May/June 2026 p8). The first oxygen–oxygen and neon–neon collisions at the LHC, delivered in 2025, offered several different views of the quark–gluon plasma, from collective flow to nuclear geometry (*CERN Courier* November/December 2025 p8). Among them, the rates at which J/ψ and Υ mesons melt in the medium and re-form from it differ distinctly from those seen in lead–lead.

The most interesting years may still lie ahead

Some 90 theorists attended, with many young researchers presenting new ideas and precision calculations reaching next-to-next-to- and next-to-next-to-next-to-leading order accuracy for key benchmark processes. The SM effective-field-theory framework has become a central tool for interpreting precision data and probing new physics indirectly, while lattice QCD has matured into an indispensable tool for controlling flavour observables. Achieving consistent precision across perturbative calculations, parton distribution functions, parton showers and hadronisation remains a major challenge, and reliable uncertainty estimates are now as important as the higher perturbative orders themselves.

An extensive beyond-the-SM programme covered supersymmetry, dark matter, exotic Higgs decays and rare processes, with much emphasis on searches for long-lived particles. No discovery has emerged, but exclusion limits now reach multi-TeV scales, driven by new triggers, dedicated reconstruction and dramatic machine-learning improvements deployed at every stage of the analysis chain.

Bright lights

The LHC has delivered luminosity at an extraordinary rate. With more than 1 ab^{-1} of collisions provided to ATLAS and CMS, half of which in the last two and a half years, the field has firmly entered the attobarn era. Improved analysis techniques are now providing sensitivity gains that rival integrated luminosity itself, through better efficiencies and signal-to-background discrimination. The most interesting years may still lie ahead, with progress being driven by the ingenuity and creativity of the young community.

Chiara Mariotti *INFN Torino and Boston University.*

BEAUTY 2026

Beauty preaches from Maastricht

The 21st International Conference on B-Physics at Frontier Machines, Beauty 2026, took place from 1 to 5 June in the charming setting of St. Jan's Church in Maastricht, the Netherlands. Maastricht University and Nikhef, the Dutch National Institute for Subatomic Physics, welcomed around 100 participants from all over the world for a programme ranging from CP violation and rare decays to spectroscopy, the production of heavy-flavoured hadrons and the prospects for quark-flavour studies at the High-Luminosity LHC (HL-LHC), Belle II, the Super Tau Charm Facility (STCF) and the Future Circular Collider (FCC).

Congregation *Participants of Beauty 2026 outside St. Jan's Church in Maastricht.*

Powerful probes

Heavy-flavour decays, in particular those of hadrons containing b quarks, offer powerful probes for testing the Standard Model (SM) and searching for new physics at the high-precision frontier. Reviewing the latest results in this field and discussing its future directions has been the central goal of the Beauty conference series since its first edition, held in Prague in 1993. This year, the LHC experiments showed an impressively broad range of new results.

LHCb reported a new study of the highly suppressed flavour-changing neutral-current decay $B^+ \to \pi^+\mu^+\mu^-$, based on data from Runs 1 and 2 of the LHC, as well as early results from Run 3. Notably, the other LHC experiments are also contributing a growing breadth of flavour results. For example, CMS presented its first study of CP violation in the "golden mode" $B^0 \to J/\psi K_S$, which is sensitive to the unitarity-triangle angle β. To control hadronic uncertainties in the interpretation of this result, the analysis also determined CP-violating observables in the sister mode $B^0_s \to J/\psi K_S$ to record precision.

The collaborations also reported on their achievements in hadron spectroscopy, including through the observation by ATLAS of a low-lying excited B_c meson (p17). The conference hosted the exciting announcement of LHCb's discovery of the doubly charmed baryon Ω^+_{cc} (*CERN Courier* July/August 2026 p12), a result that showcases the improved capabilities of the upgraded Run-3 detector. This particle completes the family of doubly charmed ground-state baryons, extensively studied by theorists since the 1970s. Interesting in themselves, these and other multi-charmed baryons may also serve as important probes of the quark–gluon plasma at ALICE and other experiments in the HL-LHC era. Beyond the LHC, participants heard about the impressive studies of lower-mass hadrons possible at BESIII in Beijing, including the X(2370), a tantalising candidate ▷

The LHC experiments showed an impressively broad range of new results

CERNCOURIER
VOLUME 66 NUMBER 5 SEPTEMBER/OCTOBER 2026

for the elusive glueball (p7).

The event featured more talks from Belle II than any previous edition, reflecting the steadily improving performance of the SuperKEKB accelerator, which has delivered a dataset at the $\Upsilon(4S)$ resonance that now exceeds that collected by the earlier Belle experiment. One of the most striking results was a measurement of the time-dependent CP-violating asymmetry in $B^0 \to \pi^0\pi^0$ decays, exploiting a novel technique that circumvents the need to reconstruct the decay vertex of the signal B meson and exploits the quantum-entanglement of the two beauty mesons produced in the $\Upsilon(4S)$ decay.

First observed in 1947, kaons were fundamental in establishing flavour physics as a discipline, and remain of high interest today. A report was given of the ongoing measurement programme of the super-rare decay $K^+ \to \pi^+ \nu\bar{\nu}$ at CERN's NA62 (*CERN Courier* May/June 2026 p9), and on the prospects for observing the even more suppressed neutral-kaon analogue $K_L \to \pi^0 \nu\bar{\nu}$ at the KOTO experiment in Japan, predicted to occur only three times every 100 billion decays.

A flavour of the future

The final day of the conference turned to the future, laying out how the upgrades of the LHC experiments for Run 4 and beyond will enable substantial increases in sensitivity. Complementary studies, targeting decays with neutrals and missing energy, will take place at Belle II, while the STCF in China, if realised, would extend them to lower energies. On a longer timescale, the FCC, proposed to begin operation at CERN in the 2040s, would open up rich flavour opportunities, in particular with a vast sample of b hadrons produced at the Z resonance.

The next generation took central stage

A key aspect of the event was the close interaction between theorists and experimentalists, fostered by 14 invited theory talks ranging from the global flavour-physics landscape to lattice QCD and models with Z′ bosons and invisible particles. Furthermore, the next generation took central stage through new sessions dedicated to early-career researchers, including lightning talks and posters presented by Maastricht University BSc students. The week left no doubt that flavour physics remains a vibrant field and a key player in the search for physics beyond the SM.

Robert Fleischer *Nikhef and Vrije Universiteit Amsterdam*, **Marcel Merk** *Nikhef and Maastricht University*, **Keri Vos** *Nikhef and Maastricht University and* **Guy Wilkinson** *University of Oxford.*

SUSTAINABLE HIGH-ENERGY PHYSICS

Shared goals for colliders and climate

While particle physics accounts for only a small share of global emissions, its laboratories have long worked to reduce their footprint, showing how cutting-edge science can be pursued sustainably. The fifth Sustainable HEP conference, held online from 8 to 10 July, attracted more than 220 participants worldwide to take stock of that effort, and of the ingenious technologies meant to carry it forward.

N Caraban Gonzalez

Light for light *The solar plant powering SESAME, the synchrotron light source in Allan, Jordan. Since 2019, SESAME has been the first accelerator in the world to run entirely on renewable energy.*

Environmental impact

Archana Sharma (CERN) highlighted a fundamental shift in the questions asked of gaseous detectors in high-energy physics. In the 1970s, the challenge was to detect particles at all, while the LHC era demanded survival in extreme conditions. Today, minimal environmental impact has joined the list of priorities. Emissions from the LHC detector systems have already fallen over the past decade, thanks to gas recuperation, recirculation and the use of climate-friendly alternatives to traditional gas mixtures. Future facilities, Sharma stressed, should be designed for sustainability from the outset, rather than retrofitted later. Her point was echoed across the sessions. Contributions covered the operation of resistive-plate chambers in CMS and ATLAS, along with the EcoGas@GIF++ collaboration, which tests eco-friendly mixtures under LHC-like irradiation at CERN's Gamma Irradiation Facility. Others explored material choices for future detectors, from high-strength copper alloys to greener shielding and cryogenics.

Future facilities should be designed for sustainability from the outset

Accelerators and other large-scale projects received similar attention. Ben Shepherd (STFC) reported on the activities of the Laboratory Directors Group's sustainability working group, comparing the environmental impact of proposed colliders from construction to decommissioning. He described efforts to avoid environmental impacts where possible, reduce those that cannot be avoided, and compensate for the remainder, spanning civil engineering, procurement and energy optimisation. Examples include heat-recovery systems, energy-recovery linacs, and the growing use of high-temperature superconductors and permanent magnets.

Veronique Boisvert (Royal Holloway) briefed participants on the sustainability recommendations of the European Strategy for Particle Physics update, the roadmap defining Europe's priorities for future particle-physics research and facilities. William van Sprolant (CvS énergies sàrl) presented the ULISSE Project, an exploratory large-scale initiative aiming at storing CERN's summer waste heat in Lake Geneva for use in winter. Speakers presented initiatives across the field including Nikhef's laboratory-wide roadmap, the iSAS programme on energy-efficient accelerating technology, sustainability work at the Electron–Ion Collider and lifecycle studies at LHCb. Other presentations covered methane recovery from livestock emissions and updates from the SC4RC computing conference.

Scientific computing came under the same scrutiny. Contributions included a particularly clear introduction to Fast Generative Simulation for HEP from Henry Day-Hall (DESY), alongside discussions of current and future efforts to shrink its carbon footprint by optimising the use of resources, improving simulation efficiency and adopting GPU-based systems, whose parallel architecture delivers more computation per watt. Participants heard of the power-efficient operation of large-scale computing facilities through the Worldwide LHC Computing Grid, which links centres around the world to process LHC data, carbon-aware computing schedules in ATLAS and the GreenPhysECS project, aimed at designing energy-efficient computing architectures for future facilities.

Lasting change requires ambitious policies and collective solutions

From physics to sustainability

As in previous editions, voices from beyond particle physics widened the view. Juan Pablo Cordero (University of York) presented open-source predictive models for transparent food policymaking. This year's conference hosted a panel session featuring five speakers, who shared their experiences of transitioning from physics to sustainability. They cited adaptability, continuous learning and collaboration as the skills that helped them move into their new fields.

In his keynote speech, climate scientist Jagadish Shukla (George Mason University) discussed the science, politics and ethics of climate change. Those who have contributed least to global warming, he reminded participants, will suffer most and earliest. Yet he argued for hope, grounded in technological progress and shared effort. Lasting change requires ambitious policies and collective solutions, as the antidote to climate anxiety, he concluded, is climate action.

Shreyasi Acharya *University of Cagliari,* **Chandramauli Agrawal** *IIT Hyderabad,* **Yann Coadou** *CPPM, CNRS/IN2P3 and Aix Marseille Université.*

LLP2026

Patience pays at the lifetime frontier

The 16th workshop of the Long-Lived Particle Community (LLP2026) gathered more than 70 theorists, phenomenologists and experimentalists at Cambridge's Ray Dolby Centre, the new home of the Cavendish Laboratory, from 29 June to 3 July. Discussions centred on particles that live long enough to travel a measurable distance before decaying, and on the searches, algorithms and detectors designed to catch them.

Long-lived particles (LLPs) arise in a wide range of theories beyond the Standard Model (SM), from supersymmetry and extended Higgs sectors to models of neutrino masses or dark matter. Due to their long lifetimes, LLPs could decay far from the collision point and leave signatures that are exotic and hard to identify.

B Allanach

Long and healthy *Participants of LLP2026 at the Ray Dolby Centre, the new home of the University of Cambridge's Cavendish Laboratory.*

On the hunt

The CMS collaboration presented eight new searches in which displaced muons and dedicated LLP triggers played a central role. Anna Mascellani (ETH Zurich) presented a search for heavy neutral leptons (HNLs). Among the simplest and best-motivated LLP candidates, they could explain the origin of neutrino masses through the so-called "seesaw" mechanism. The new channel targets HNL decays beyond the tracker using standalone displaced muons, reconstructed exclusively in the muon system. The gain in sensitivity at longer lifetimes yields the best expected limits on HNL mixing with muon neutrinos for masses between 2.5 and 4.2 GeV. Celia Fernandez Madrazo (Boston University) presented a search for light, narrow resonances decaying to two displaced muons, recorded with a dedicated scouting trigger stream, in which events are kept at a high rate by recording only a reduced amount of trigger-level information. The saving in bandwidth allows muons with transverse momenta down to 3 GeV to be collected, and relaxed requirements on the number of hits give Run-3 scouting access – for the first time – to muons displaced by more than 11 cm. Together, the two extensions yield the most stringent limits to date on dark-shower models, which predict light, long-lived dark pions decaying after 10 cm or more.

ATLAS presented several results with 13 and 13.6 TeV data. Paul Swallow (University of Cambridge) reported a search for displaced vertices and missing transverse momentum built on a novel fuzzy-vertexing algorithm, optimised for displaced decays to heavy quarks. Since b quarks themselves travel a sizeable distance before decaying, an LLP decaying to them need not produce particles pointing back to a single vertex. Rather than forcing one, the algorithm reconstructs several nearby seed vertices and then merges them into a single one, improving efficiency for the high-mass, high-multiplicity displaced vertices expected from such decays.

Models predicting quirks drew particular interest

Models predicting quirks, hypothetical particles charged both under the SM and a new confining force analogous to the ▷

CERNCOURIER
VOLUME 66 NUMBER 5 SEPTEMBER/OCTOBER 2026

strong force, drew particular interest. Produced in pairs and bound to each other by a confining string, quirks would cross a detector slowly, as charged long-lived particles. Arash Jofrehei (University of Geneva) presented the first direct LHC search for quirks with masses above the weak scale, performed with FASER, and Alejandro Novo Cal (IGFAE, University of Santiago de Compostela) proposed a search at LHCb, complementary in reach to those of heavy stable charged particles or monojets at ATLAS and CMS. Thanks to the forward acceptance and lack of magnetic field of the LHCb Vertex Locator (VELO), alongside a flexible trigger design, the approach could probe values of the new confining scale between 0.1 and 10 keV. The stakes reach into cosmology, as Graham Kribs (CERN and University of Oregon) stressed. If macroscopic dark-colour strings were observed, the reheating temperature at which the hot Big Bang began after inflation would have to lie below about 100 GeV, since a hotter start would have left long-lived bound states of dark gluons in conflict with early-universe observations.

Martin Hirsch (IFIC, CSIC and University of Valencia) showed that axion-like particles (ALPs) can couple HNLs to gluons, giving the LHC and proposed

The workshop showed how new triggers and analysis strategies are testing a wide range of theoretical models

LLP detectors high sensitivity to long-lived HNLs for GeV-scale ALP masses. As Oleg Brandt (University of Cambridge) observed, the two candidates are usually treated separately, and their combination offers interesting new benchmarks.

Future facilities

On the facilities side, John Anders (University of Liverpool) reviewed design and detector studies for the proposed Forward Physics Facility, including a full simulation of its cavern. Updates followed from SHiP/NA67, CODEX-b, MATHUSLA and ANUBIS, with sensitivity studies for benchmark models ranging from HNLs and Higgs-portal scalars to dark photons and ALPs. Looking further ahead, Rhitaja Sengupta (BCTP, University of Bonn) presented dedicated LLP detector concepts for FCC-ee and FCC-hh, including DELIGHT, FOREHUNT and DELIGHT-SHIELD, stressing how a future collider's design phase offers the best opportunity to integrate dedicated LLP detectors within the main detector designs.

Discussions extended beyond CERN. Zeren Simon Wang (Hefei University of Technology) presented prospects for searching for very long-lived HNLs through baryon-number-violating decays of charmed baryons at the Super Tau Charm Facility proposed in Hefei, China. The same symmetry violation motivated Patrick Adolf (TU Dortmund) to propose a new class of nucleon-decay observables involving LLPs, in which a vector mediator produced in the decay travels a macroscopic distance before turning into an electron–positron pair inside a detector such as Super-Kamiokande, leaving temporally correlated "echo" vertices.

LLP2026 opened just as the LHC entered Long Shutdown 3, and the results presented drew on only part of the Run-3 dataset. Even so, the workshop showed how new triggers and analysis strategies are testing a wide range of theoretical models. The detectors and facilities now taking shape promise to go further, so that no new physics remains hidden at the long-lifetime frontier.

Giovanna Cottin *UC Chile.*

SciArtDialogue Week

Physicists and artists entangle at CERN

From 11 to 18 January 2026, the SciArtDialogue Week brought 36 students, researchers, artists and educators to CERN's IdeaSquare for a week of joint scientific and artistic work, marking the centenary of the quantum wave function. Organised by art@CMS/ORIGIN, an art-and-science education programme rooted in the CMS collaboration, the event drew support from institutions across Austria, Germany, the US and Australia.

The wave function entered physics in the first half of 1926, when Erwin Schrödinger reformulated quantum theory as a form of wave mechanics. Its meaning, though, was disputed from the beginning. Schrödinger himself took it to be a real wave of matter propagating through space. Within months, Max Born linked its squared modulus to the probabilities of measurement outcomes, and this settled the matter for all practical purposes. Yet whether the wave function describes the world itself or only our knowledge of it is still debated, and the week set scientists and artists to explore this tension together.

M Hoch

Thought experiments *A workshop session from the SciArtDialogue Week at CERN's IdeaSquare, where students, artists and educators interacted with CERN researchers.*

A comprehensive visit programme immersed participants in CERN's unique scientific infrastructure. Based at Idea Square, they encountered large-scale experiments, gained insights into how data is collected and processed, reflected on the technological ingenuity behind particle physics and gathered important personal connections with the CERN scientific community. These experiences were complemented by in-depth contributions on quantum mechanics, the historical significance of Schrödinger's work and the broader evolution of contemporary scientific paradigms.

ORF Ö1 journalist Susanna Niedermayr accompanied the whole workshop, documenting discussions among professors of fine arts, musicology and religious studies, and tracing how scientific concepts migrate into artistic practice. For the Austrian students, the week doubled as the start of a semester-long university course, in which they will further develop their projects. The resulting works, spanning sound, performance, visual media and conceptual installations, will be shown at the ORF festival in Graz, from 8 to 11 October. Whether art can bring an advanced scientific idea to a wider public is the question the initiative exists to test, and the answer will be on display there. The SciArtDialogue Week will return to CERN IdeaSquare in February 2027 to mark the centenary of the fifth Solvay Conference.

Michael Hoch *Karlsruhe Institute for Technology.*

FCC Week 2026

Helsinki muses on the FCC

From 8 to 12 June, FCC Week brought 656 scientists, engineers, industry representatives and policymakers from 38 countries to the University of Helsinki. With its primary focus on FCC-ee, the meeting examined how the FCC study can progress from demonstrating feasibility to a coherent reference design, treating physics goals, accelerator parameters, detector concepts, theory, software and the machine–detector interface as parts of a single system.

Paula Eerola, president of the Research Council of Finland, opened the week by reflecting on CERN as a place where scientific responsibility is carried across borders and generations. CERN Director-General Mark Thomson described the coming years as a critical period, in which CERN must deliver the High-Luminosity LHC while advancing the FCC-ee as a possible next flagship project (*CERN Courier* July/August 2026 p7). Both efforts will rely on CERN's close cooperation with its Member States, and Costas Fountas, president of the CERN Council, underlined their growing alignment with the laboratory and the particle-physics community. For European Commissioner Valdis Dombrovskis, the same model of international cooperation underpins Europe's competitiveness, its technological capacity and its ability to invest over the long term.

J Kalimbo/FCC collaboration

Scaling up *The participants of FCC Week 2026 on the steps of Helsinki Cathedral.*

Broad programme

The scientific case for the FCC-ee is often summarised in terms of the Higgs boson, but the programme discussed in Helsinki was considerably broader. Runs at the Z resonance, the W-pair threshold, the Higgs-production maximum and the top-quark threshold would yield around six trillion Z bosons and hundreds of millions of W pairs, improving statistical precision by three orders of magnitude and probing the Standard Model as an interconnected whole. The top-threshold run, for example, would determine the top mass, width, Yukawa coupling and strong coupling in a uniquely controlled environment, and a precise top mass is needed in turn to exploit the projected W-mass precision. The FCC-ee would also be a major flavour facility, with its clean initial state, vertex reconstruction and near-complete angular coverage, enabling studies of beauty, charm and tau decays, many of which are statistically limited today. As a precision-QCD machine, it could determine the strong coupling at the per-mille level (p41).

Discovery potential would not depend solely on producing new particles. Heavy states can alter measured quantities through quantum effects, leaving correlated deviations across electroweak, Higgs, flavour and top observables that global analyses could trace well beyond the machine's direct reach. Direct searches would complement this programme, with the enormous Z and Higgs samples providing sensitivity to long-lived particles, heavy neutral leptons, axion-like particles and other hidden-sector states. The projected precision also creates a theoretical challenge. For the W-boson mass, a possible experimental uncertainty of about 0.24 MeV stands against a current theoretical uncertainty of several MeV, and closing such gaps will require higher-order calculations, better event generators and improved control of hadronisation, in a coordinated effort lasting many years.

On the accelerator side, the main news concerned the radiofrequency system. Studies indicate that it could be built entirely from 800 MHz superconducting cavities, instead of the planned mix of 400 and 800 MHz, and still reach the target collision rate with the new beam optics, although beam lifetime and the mutual disturbance of the colliding beams remain to be assessed. That collision rate calls for beams that are exceptionally flat, their vertical spread up to 2000 times smaller than the horizontal, demanding tight control of alignment, vibration and focusing. The rings would also need continuous refilling to hold the luminosity steady, a top-up injection that simulations now show can be performed with efficiencies above 90%.

Advancing hardware

Hardware is advancing too. Drawings for the 400 MHz superconducting cavities are nearly complete, and a first integrated cryomodule demonstrator is due by 2031. The cavities will only be as efficient as the klystrons that power them, and these are gaining ground, with a single-beam device in China reaching 78% and a CERN tristron targeting above 90%. Magnet studies now feed manufacturing imperfections into predictions of field quality, and alignment on the supporting girders aims at 10 to 20 micrometres. The synchrotron radiation emitted by the circulating electrons, an intense X-ray glare, would deposit its power along ▷

CERNCOURIER

Volume 66 Number 5 September/October 2026

the vacuum chamber, with absorbers every 5 to 6 m to intercept it. At the Z pole, however, where the circulating current would be highest, the budget for the chamber's electromagnetic response to the beam remains tight, and the effects of stray-electron clouds in the pipe are not yet fully resolved.

The interaction region is where accelerator and detector choices meet most directly. A longitudinal detector-opening scenario is now the baseline, and a full-scale mock-up of the cooled central beam pipe and vertex detector has validated assembly and cooling. Moving the first final-focus element to 2.4 m from the interaction point has reduced the radiation load on the superconducting coils. Synchrotron-radiation backgrounds, however, have emerged as one of the most serious potential problems. Current estimates indicate that unless the radiation can be reduced by orders of magnitude, it would leave unacceptably high hit rates in the trackers. Masks, revised beam-pipe geometry, shielding and optics changes all show promise, but a final solution is still to be defined, making the interaction region a defining test of the integrated design.

Six detector concepts are under study, providing redundancy and comparative optimisation

Detailed simulation

Six detector concepts are under study, providing redundancy and comparative optimisation. All concepts place silicon pixel sensors closest to the beam, in chips that combine sensor and readout. Ideas diverge further out. Calorimeter concepts range from silicon–tungsten and crystal systems to noble-liquid and dual-readout approaches, while trackers include full-silicon, drift-chamber and time-projection-chamber solutions. Comparing the concepts, and finding their weaknesses early, takes detailed simulation, and simulation in turn calls for common tools. The shared software platform Key4hep has matured, and a distributed computing model is already operating ahead of formal collaborations.

The Industry and Technology Day, opened by Finland's minister of economic affairs Sakari Puisto, asked how companies can become involved early enough to shape the design, from superconducting RF and cryogenics to civil construction. Many technologies will need to be adapted, scaled up or made more efficient, while others will have to be co-developed.

The FCC-ee tunnel could later host a much higher-energy proton collider, the FCC-hh, which Helsinki discussed as a possible second stage rather than as the justification for the whole programme. The case for the FCC-ee rests on its own precision measurements, flavour physics and direct searches, while the FCC-hh would extend direct searches to masses of tens of TeV and improve the measurement of the Higgs self-coupling.

FCC Week 2026 showed substantial progress in all project domains, and equally how much remains to be done. Synchrotron-radiation backgrounds must fall dramatically, theory precision must catch up with experimental ambition, and industrial capacity and long-term expertise need sustained investment. The central outcome was the growing integration of the many strands of a credible international project.

Panos Charitos *CERN.*

CERNCOURIER
Volume 66 Number 5 September/October 2026

THE COLLIDER DIVIDEND

The High-Luminosity LHC is expected to return to society nearly twice what it costs, before a single discovery is counted. Massimo Florio and Jessica Catalano explain the economics behind this number.


CERN/M Muzzi

Skilled labour *A technician at work in the new galleries of the High-Luminosity LHC. Trained people and upgraded suppliers are among the largest components of the machine's projected societal benefits.*

A particle collider is among the most ambitious projects a society can take on, and one whose worth is hard to capture in conventional economic terms. The instinctive argument for such machines rests on the knowledge they may produce, but no economist can attach a probability, let alone a monetary value, to a discovery that has not yet happened. For decades, this apparent impasse left funding decisions to the scientific case and to mostly qualitative socioeconomic narratives.

In 1945, Vannevar Bush, science adviser to two US presidents, identified the value of basic research in the foundations it may lay for practical progress. Robert Wilson, asked in Congress in 1969 whether the facility that became Fermilab would help defend the United States, answered that it would not, except by making the country worth defending. Reasoning of this kind is no longer enough on its own, and must now be backed by more quantitative evidence. The European Commission and national funding agencies, such as UK Research and Innovation (UKRI) and France Stratégie, expect proposers of large research

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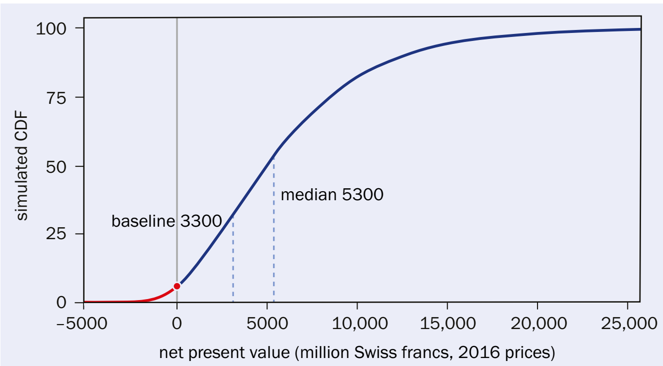
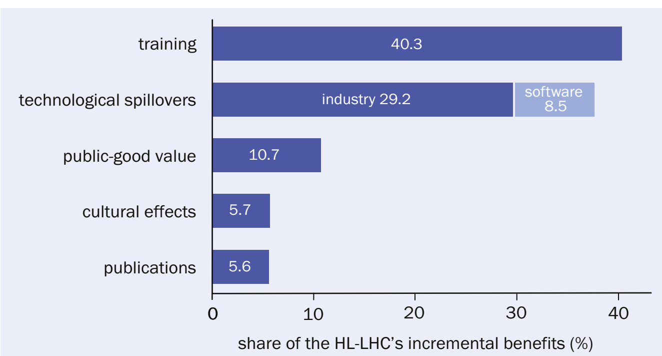


Odds on *The simulated cumulative distribution function (CDF) of the HL-LHC's net present value across 50,000 Monte Carlo runs. A mere 6% fell below zero, putting the chance of a positive social return at 94%. Half the runs return more than 5300 million francs, well above the 3300 million baseline in which each model parameter was fixed at its best estimate rather than drawn at random.*



Measuring value *The incremental benefits of the HL-LHC, set against a counterfactual in which the LHC runs without the upgrade, across five channels of social return, one of which is further split into two. Potential gains from new physics discoveries cannot be meaningfully quantified and are excluded from the count.*

infrastructures to provide detailed cost-benefit analyses (CBAs), estimating their projects' societal returns.

The most thorough evaluation of this kind yet performed concerns the LHC and its high-luminosity upgrade (HL-LHC), which entered the main installation phase when the machine completed its third run on 27 June 2026 (*CERN Courier* July/August 2026 p8). Four years of work will refit the ring with new hardware, including advanced focusing magnets, crab cavities to increase the collision rate and superconducting power lines. The corresponding CBA, developed over more than a decade at the University of Milan and CSIL, rests on a set of carefully chosen assumptions that provide crucial context for interpreting its results.

Discovery set aside

A CBA asks whether an investment's benefits to society exceed its costs over a defined horizon. Any value available now is worth more than the same amount later, if only because it can earn a return in the meantime, so costs and benefits arising in different future years cannot simply be added: each must be scaled down, or "discounted", the further ahead it lies. The inverse happens for past values, which must be "capitalised". The difference between discounted (or capitalised) benefits and costs then yields the net present value (NPV), and a positive expected NPV indicates that the project passes the test. For the HL-LHC CBA, the accounting window ran from 1993, when expenditure attributable to the LHC programme began, to 2038, the machine's expected end of operations at the time of the analysis, since revised to 2041. All sums, after discounting or capitalising at the 3% rate recommended by the European Commission for public projects, were expressed in constant 2016 Swiss francs, removing the effect of inflation.

Two methodological choices defined the whole exercise. The first was to set discoveries aside. Scientific outcomes at the frontier are subject to what economists call Knightian uncertainty: no probability distribution can be assigned to them, and any attempt to price the discovery of new physics would be arbitrary. The analysis, therefore, excluded the intrinsic value of scientific results altogether and asked a narrower, more disciplined question: do the measurable side effects of the investment – such as the training of early-stage researchers or the technological gains of supplier firms – repay its cost on their own? In this sense, the test was deliberately conservative. Whatever knowledge the machine ultimately produces comes on top of, not inside, the calculated return.

The second choice concerns the counterfactual scenario. An upgrade cannot be assessed against a baseline of no machine at all. The LHC exists either way. The counterfactual scenario assumed an LHC that continues without the luminosity boost, under ordinary maintenance, until its discovery potential is exhausted. In the study's timeline, that point was conjectured to fall in 2030. Data-taking then ceases, staff are redeployed and the tunnel is kept safe but idle. Constructing this alternative future in detail, down to its cost profiles, researcher numbers and procurement volumes, was among the hardest challenges of the study. It is also what allows every result to be read in incremental terms, as the difference between a world with and one without the high-luminosity upgrade.

Uncertainty was handled through Monte Carlo simulation. Fifteen critical parameters, among them the early-stage researchers' salary premium, the suppliers' sales multiplier, visitor numbers, taxpayers' willingness to pay and total costs, were treated as random variables. Their distributions were calibrated from data where possible, and from earlier studies and structured expert judgement where they were not. Fifty thousand simulation runs then generated a probability distribution for the project's NPV (see "Odds on" figure).

That distribution, rather than any point estimate, is what the model ultimately delivers to decision-makers. Against the LHC counterfactual, the HL-LHC incremental NPV is positive: each Swiss franc invested returns about 1.8 francs in societal benefits, and the chance of a positive social return is 94%.

Each Swiss franc invested in the HL-LHC returns about 1.8 francs in societal benefits, and the chance of a positive social return is 94%

Human capital

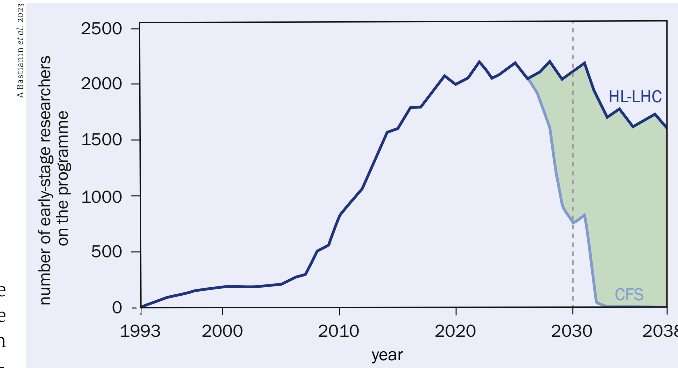
When the two scenarios are compared, the most valuable benefit of the HL-LHC to society is the people it trains (see "Measuring value" figure). Early-stage researchers, from technical, doctoral and postdoctoral trainees to young registered users of the experiments, acquire frontier technical and collaborative skills that employers reward for the rest of their careers. The benefit was measured as the lifetime salary premium these individuals earn relative to comparable peers who never passed through CERN, estimated from surveys of current students, alumni and more than 330 team leaders. Because a career lasts decades, benefits accruing to the final 2038 cohort extend to around 2080, long after the machine has been switched off.

In incremental terms, the salary premium for early-stage researchers accounts for roughly 40% of incremental benefits, the single largest share. The analysis assumes that employers pay the premium because training and hands-on experience make people more productive, so the figure is taken to gauge the value of skills flowing into the economy. The counterfactual clarifies why the share is so large: without the upgrade, the pipeline of early-stage researchers collapses once data-taking ends, whereas the HL-LHC keeps training thousands more through the 2030s (see "Two futures" figure). The FCC Feasibility Study predicts similar effects (*CERN Courier* May/June 2025 p9).

A new study of CERN's overall impact over the past 25 years corroborates the pattern (p13). In the 2025 CERN alumni survey, 95% of the almost 1000 respondents said that their experience at CERN had helped advance their careers, in fields ranging from software development to information technology, mechanical and industrial engineering, academia and financial services.

Technological spillovers

About 38% of the HL-LHC's incremental benefits arise from technological spillovers. Firms that win high-tech procurement contracts learn from working with CERN and the experimental collaborations, file patents, refine processes and open new markets. The learning shows up as higher sales and profits in their business with customers other than CERN. The evidence base here is unusually rich, triangulated from a long-run econometric study of supplier accounts before and after their first CERN contract, a survey of more than 650 suppliers, and over two dozen in-depth case studies. In the model, each franc of high-tech procurement returns about three francs to the supplier in extra turnover or saved costs, a ratio first measured in surveys of CERN's contractors in the 1980s, and confirmed by new evidence.



Two futures *Number of early-stage researchers on the LHC programme with the upgrade (HL-LHC) and in the counterfactual scenario (CFS), where data-taking ends in 2030. The additional trainees carry a salary premium throughout their careers, running to around 2080.*

A second kind of spillover is software released freely to the world. Updated packages initially developed for the LHC programme, such as ROOT and Geant4, were valued at what users would otherwise have paid for commercial equivalents.

Colliders and culture

A particle collider is also a cultural asset. About 5.7% of the HL-LHC's incremental benefits stem from cultural engagement – mostly people travelling to the Geneva site or attending CERN's touring exhibitions (see "Worth the trip" image). These are valued through the travel cost method, a standard technique that infers what an experience is worth from what visitors spend to reach it: fares, time, tickets. Websites, social media, volunteer computing, films and popular books are counted too, though each contributes far less than the visits. Visitor numbers rise and fall with discovery announcements and with CERN's own capacity to attract and receive an audience, which makes outreach strategy part of the calculation.

Publications

Scientific publications might seem the most natural benefit of a research infrastructure, yet in the accounting their value is limited. The reason lies in methodology. What is measured is not the content of the papers, which would smuggle discovery value back in, but the volume of scientific production and its uptake. A paper's production cost, in terms of its authors' salaries, is assumed to cancel against the value of the time spent writing it, evaluated at what those hours would otherwise have earned, so that its net benefit comes entirely from downstream citations. A paper never cited is worth zero. The category matters less for its size than for what its treatment reveals about the method's discipline: even the most visible benefit of science is valued only through observable, countable channels.

Public-good value

The final category captures the value citizens place on fundamental knowledge being created at all, analogous to the existence value of biodiversity or cultural heritage. This

CERNCOURIER

Volume 66 Number 5 September/October 2026

M Brice/CERN

Worth the trip *CERN's Science Gateway, designed by architect Renzo Piano and opened in 2023, is the Laboratory's centre for education and outreach. It passed one million visitors on 1 July 2026.*

item accounts for about 11% of the incremental benefits and is estimated through direct taxpayer surveys. In February 2018, a representative sample of French adults was asked whether they would accept a specific, small annual tax rise to fund a new accelerator, the alternative being that research at the LHC gradually winds down. Across models, the average willingness to pay exceeded the €2.70 that a French adult contributed to CERN through taxes in 2017. Earlier experiments with students in Italy, France, Spain and the UK, a later survey of Swiss taxpayers, and more recent studies in eight further countries – with more than 10,000 respondents in total – all point in the same direction.

The French survey also exposed an awareness gap. Only 46% of respondents had heard of CERN before the interview, compared with 89% for UNESCO, 86% for NASA and 77% for France's own CNRS. Prior awareness was among the strongest predictors of willingness to pay, and the gap leaves headroom for the public value of CERN's fundamental science to grow.

A sharper picture

Readers of earlier presentations on the socioeconomic impact of the HL-LHC will recognise these categories of benefits (*CERN Courier* September 2018 p51), but the picture has now sharpened in four ways. First, the analysis has fully embraced a probabilistic approach, with quantified simulation errors. Second, risk itself has become an object of analysis. Since cost overruns are the classic killer of Big Science, with the 1993 cancellation of the Superconducting Super Collider being a key example, the studies built a pessimistic scenario, pinning total costs above the reference value. Even then, the probability of a positive NPV stays around 80%. Third, the headline shares are now read strictly against the counterfactual, and the effect is remarkable. Cultural engagement, 13% of the HL-LHC's total benefits, falls to about 6% incrementally, because some visitors come to CERN regardless of whether the upgrade happens. Publications rise from 2% to about 6%, because additional papers are only written if the machine runs. Fourth, the environmental dimension has more recently been incorporated into the evaluation of Big Science projects. A case in point is the FCC Feasibility Study, which accounts for the carbon footprint of construction and operation on the cost side, and for energy-efficiency technologies developed for the machine on the benefit side.

The HL-LHC is very likely to repay society more than it costs, principally through the people it trains and the firms it transforms

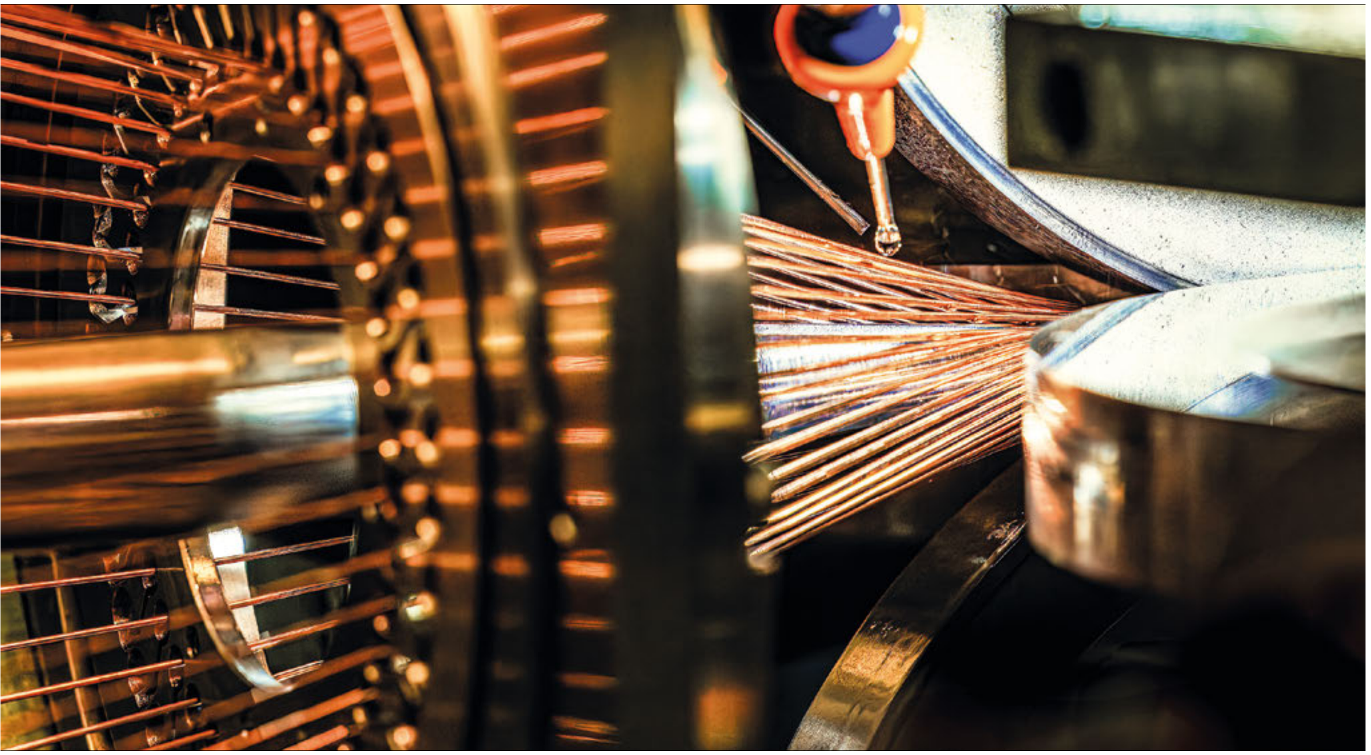
A conservative floor

The honest conclusion is double-edged. A social CBA of Big Science does not tell us whether the HL-LHC will find new physics, and no econometric methodology can. What it establishes is a floor. Even with new discoveries valued at zero, and under conservative assumptions throughout, the upgrade is very likely to repay society more than it costs, principally through the people it trains and the firms it transforms.

The approach is also portable. It has travelled from proton colliders to hadron therapy, synchrotron light sources, a protein database, the Einstein Telescope and Earth-observation satellites. Any major research infrastructure can be assessed the same way, provided the critical variables can be identified – their plausible ranges established from data and expert judgement – and the temptation to price potential discoveries resisted. Each application, moreover, feeds the next, since parameters estimated ex-post for one facility become the calibration base for appraising another. The economics of science, a young field grown alongside more than a decade of dialogue with CERN scientists, advances much like the instruments it studies. ●

Further reading

M Florio 2019 *Investing in Science: Social Cost-Benefit Analysis of Research Infrastructures* (MIT Press).
A Bastianin *et al.* 2023 *Appl. Econ.* **55** 5768.
CSIL and CERN 2025 Zenodo 10.5281/zenodo.15421975.
G Catalano *et al.* 2026 Zenodo 10.5281/zenodo.21072658.



Forty strands *In CERN's Rutherford cabling machine, spools of niobium–tin wire ride a rotating drum, which twists them around a mandrel and rolls them flat. The resulting cable will wind the focusing magnets of the High-Luminosity LHC. (Credit: E Kuna/CERN)*

TEN THOUSAND MAGNETS LATER

Heike Kamerlingh Onnes first observed superconductivity in a thread of frozen mercury. A century after his death, Lucio Rossi and Markus Zerlauth trace how his discovery came to drive CERN's colliders.

Each main dipole of the Large Hadron Collider (LHC) sustains a current of about 12,000 amperes, confined to filaments of niobium–titanium (Nb–Ti) way finer than a human hair. For the collider's high-luminosity upgrade (HL-LHC), flexible lines of magnesium diboride (MgB_2) will carry 10 times as much. Currents of this intensity would melt any ordinary cable. Yet these filaments bear them unscathed, for their resistance is exactly zero. Much of the reach of particle colliders rests on this fragile, emergent phenomenon: superconductivity. The man who first observed it, Heike Kamerlingh Onnes, died 100 years ago, on 21 February 1926.

His discovery, made in Leiden in 1911, was not an isolated event (see "Practically zero" figure). It crowned a long and systematic programme aimed at reaching and mastering temperatures close to absolute zero. Behind it stood physicists, engineers and technicians working in concert towards common scientific goals, in a style that anticipated

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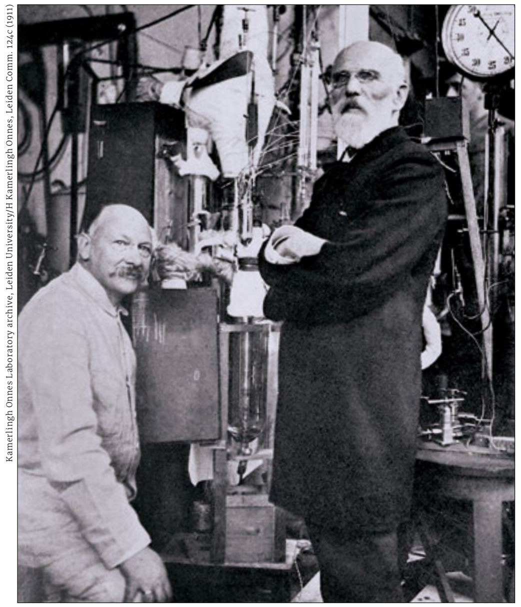
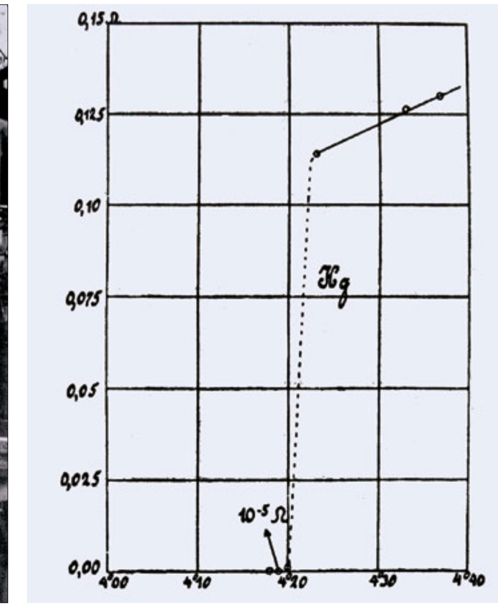
Kamerlingh Onnes Laboratory archive, Leiden University/H Kamerlingh Onnes, Leiden Comm. 124c (1911)





Practically zero
On the left, Heike Kamerlingh Onnes (seated) at the helium liquefier in Leiden, with Johannes Diderik van der Waals (standing). On the right, the resistance of a mercury thread against temperature, measured by Onnes's assistants Gilles Holst and Cornelis Dorsman in October 1911. Near 4.2 K, it drops abruptly below the instrument's sensitivity.

the research infrastructures on which laboratories such as CERN would later be founded. The liquefaction of helium in 1908 brought the lowest temperatures within reach, and Onnes turned to how metals conduct in that regime. In a wire of mercury below 4.2 K, he found a resistance smaller than anything his instruments could measure, a phenomenon he christened "supraconductivity".

An explanation of the effect would wait another 46 years, until Bardeen, Cooper and Schrieffer showed that, below a critical temperature, conduction electrons bind into pairs and condense into a single collective state, through which current flows without loss. Still, Onnes rapidly grasped how such behaviour could transform magnet technology, and in 1913 envisaged superconducting coils producing 100,000 gauss, or 10 T – far beyond any electromagnet of the day. The discovery, in 1914, that superconductivity in the materials then available was destroyed by fields of a few hundred gauss made this objective unattainable for half a century. The deadlock broke only in 1961, at Bell Telephone Laboratories, where John Kunzler and his colleagues drove a very heavy current through niobium–tin (Nb_3Sn) at 88,000 gauss.

At CERN, superconductivity eventually developed along two complementary paths. Superconducting magnets enable accelerators of practicable size to steer and focus ever more energetic beams, while superconducting radio-frequency (SRF) cavities provide high accelerating voltages at acceptable electrical and cryogenic costs. Together, the two technologies have progressively pushed the energy, luminosity and reach of the laboratory's accelerator complex up to the LHC and its upcoming upgrade.

CERN's first operational use of superconductivity in a collider's magnet lattice came with the high-luminosity insertion of the Intersecting Storage Rings (ISR). Its eight superconducting quadrupoles, developed during the 1970s and brought into operation in 1980, focused the beams more tightly at one intersection, and were the first superconducting magnets routinely operated in an accelerator (see "Cold quartet" image). Their design introduced concepts that became central to accelerator-magnet technology, among them Romeo Perin's "Roman arch" coil, in which electromagnetic forces are contained by compression. At the same time, their operation gave CERN direct experience of field quality, conductor stability, quench protection and cryogenics in an accelerator environment.

Feeling the squeeze

At the Large Electron–Positron collider (LEP), superconductivity entered the ALEPH and DELPHI detectors through their large solenoids, built at CEA-Saclay in France and the Rutherford Appleton Laboratory in the UK, respectively, and reached the beamline in the cold low-beta quadrupoles that squeezed the beams at all four experiments. More direct still was the impact of SRF technology, which came to shape the whole LEP programme. At the Z resonance, LEP operated at about 45.6 GeV per beam, with its original 128 copper cavities working at 352.2 MHz and supplying approximately 280 MV. Increasing the beam energy towards and beyond the W-pair threshold posed a fundamentally different problem: in a circular electron–positron collider, the energy lost to synchrotron radiation, which the cavities must restore on every turn, scales with the fourth power of the beam energy. The accelerating voltage, therefore, had to increase by more than one order of magnitude, which could not be achieved efficiently with a conventional copper system.

The LEP2 upgrade provided the answer. From the early 1990s, superconducting cavities were progressively installed, reaching a final system of 288 four-cell cavities powered by 36 klystrons. Most used a thin niobium film sputtered onto a copper substrate, a technology initi-

In 1913, Onnes envisaged superconducting coils producing 10 T – far beyond any electromagnet of the day

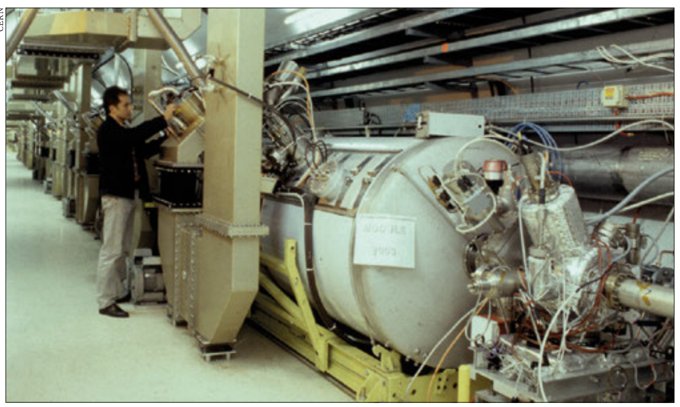
CERNCOURIER

VOLUME 66 NUMBER 5 SEPTEMBER/OCTOBER 2026

CERN

Cold quartet *Four of the eight superconducting quadrupoles of the ISR's high-luminosity insertion, assembled in their liquid-helium cryostats at CERN.*

CERN



Copper underneath *A string of superconducting cavities is installed in the LEP tunnel. Each carries a thin film of niobium sputtered onto a copper substrate, a technology that returned in the LHC's accelerating system.*

ated and mastered at CERN by Cristoforo Benvenuti and subsequently transferred to industry, which combined a superconducting RF surface with the thermal stability of copper (see "Copper underneath" image). The system eventually supplied a total RF voltage of about 3.5 GV and enabled operation above 100 GeV per beam, opening the study of W-pair production, precision measurements of the W boson and searches for the Higgs boson and potential new particles.

Breaking out

With the LHC, superconductivity ceased to be a technology reserved for just a few cutting-edge components. The collider was to reuse the existing 27 km LEP tunnel, so its collision energy was tied to the fields of the bending dipoles. Conventional magnets were far too weak and energy-consuming, and even Nb–Ti, the most mature accelerator superconductor of the time, had to operate close to its practical limits.

The counter-rotating beams were accommodated in twin apertures within a common magnet structure, to fit the narrow tunnel and cut costs. The 1232 main dipoles were designed to operate at 8.33 T, with 392 main quadrupoles providing the arc focusing. On top of these came more than 7600 corrector magnets, together with the specialised quadrupoles and dipoles of the matching and interaction regions, bringing the total to nearly 10,000 superconducting magnets around the ring. To wring such fields from Nb–Ti with sufficient margin, the magnets were cooled by superfluid helium at 1.9 K. During Run 3, at a beam energy of 6.8 TeV and 8 T in the dipoles, the main-dipole system alone held nearly 8 GJ of magnetic energy. The LHC thus became both the largest superconducting magnet system in operation and the largest cryogenic installation ever built.

Working at such a scale transformed magnet development into an industrial enterprise (see "Mass production" image). Nearly 300,000 km of superconducting strand were produced, of which 250,000 km were assembled into Rutherford cables and wound into magnets manufactured by European industry under CERN coordination. As at the ISR and LEP, superconducting quadrupoles squeezed the beams at the interaction points, the final-focusing triplets coming through collaborations with the US laboratories, led by Fermilab, and with KEK in Japan. The large superconducting magnets of the CMS and ATLAS experiments, built with major contributions from laboratories around the world, extended the technology to the experiments.

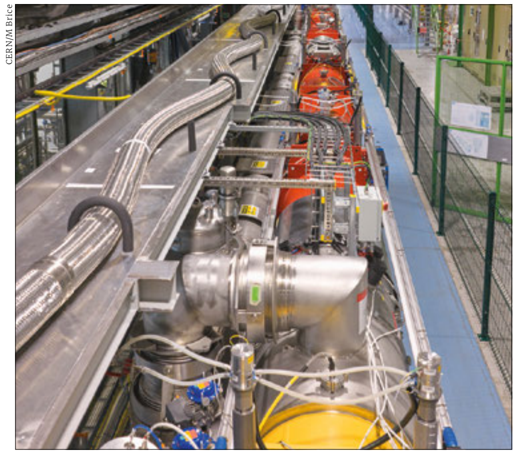
Scaling up

Superconductivity also entered the LHC through its accelerating system. Each beam came to be served by eight single-cell cavities operating at 400 MHz and delivering a nominal voltage of 16 MV, built with the niobium-on-copper technology established for LEP2. Meanwhile, more than 1000 current leads – the components that feed the magnet circuits from room temperature – employ ceramic high-temperature superconductors (HTSs) of the kind discovered by J Georg Bednorz and K Alex Müller in 1986, whose high critical temperatures let them carry extreme currents without a liquid-helium bath. Their resistive upper sections can get cooled by helium gas at about 20 K, already used in other parts of the machine. This sharply reduces the heat reaching the liquid-helium level, and with it the refrigeration power. When it came online, the LHC was the first large-scale application of HTS materials.

Over the next four years, the machine will evolve into the HL-LHC, an even more efficient and powerful proton collider, extending its operation into the early 2040s and promising a tenfold increase in collected data over the initial design (*CERN Courier* July/August 2026 p8). Colliding much brighter, more intense beams, focused more strongly at the interaction points, requires a profound transformation of the regions around ATLAS and CMS.

Among the key technologies of the upgrade is a new generation of final-focusing quadrupoles built from Nb$_3$Sn, never before used in an accelerator, with twice the mechanical aperture and up to a 50% higher peak field than their predecessors. The development of this technology began more than two decades ago, when the LHC itself was still under construction, as a joint effort between CERN and the US LHC Accelerator Research Program (LARP). The transition from the robust Nb–Ti to the far more brittle and strain-sensitive Nb$_3$Sn required new mechanical structures, fabrication processes and protection strategies, developed and industrialised within an international collaboration in which the US Accelerator Upgrade Project (AUP), LARP's successor, and CERN are each building half of the quadrupoles. In-kind contributions reach well beyond the Nb$_3$Sn quadrupoles. The dipole orbit correctors are built by CIEMAT in Spain and IHEP in China, and the separation and recombination dipoles by KEK in Japan and INFN in Italy, which also provided nine types of higher-order correctors.

CERN/M Brice



Cold-blooded *The inner-triplet string under test at CERN's SM18 facility replicates, at full scale, the magnet chain that will focus the beams on either side of ATLAS and CMS. The flexible cryostat of the superconducting link, nicknamed "the python", runs alongside the platform, feeding the magnets with up to 120 kA through 19 MgB$_2$ cables.*

CERN/P Ginter

Mass production *Cryostats for the LHC's main dipole magnets mid-assembly at CERN. The nearest is open, revealing the magnet wrapped in reflective insulation inside its blue outer vessel. More than 1200 were built, tested and installed in under a decade.*

The upgrade will also make the first operational use of superconducting links based on MgB$_2$. Eight such links, up to 140 m long and carrying up to 120 kA at temperatures of about 25 K, will conduct the high DC currents from the power converters, housed in new galleries shielded from the increased collision rates, down to the magnets on the beamline (see "Cold-blooded" image).

Peak energy

In parallel, CERN built its SRF expertise into High Intensity and Energy ISOLDE (HIE-ISOLDE), the superconducting post-accelerator that takes the exotic nuclei produced at the ISOLDE facility, which decay within seconds, and brings them to the energies of nuclear reactions. Its cavities carry a thin film of niobium on copper, like those of LEP2, and they came close to the performance of counterparts made entirely of niobium at 4.5 K, while keeping copper's engineering advantages. The first radioactive beams came in 2015, and by 2018 the machine had reached 10 MeV per nucleon.

Superconductivity offers two complementary paths for increasing accelerator performance: higher magnetic fields for steering and focusing charged particles, and higher accelerating fields for efficiently increasing their energy. Any future flagship collider will need both, in proportions that depend on the machine's design. Among the proposed facilities, a high-luminosity electron–positron collider such as the FCC-ee (*CERN Courier* May/June 2026 p41) would lean most heavily on SRF technology. Its accelerating system would have to compensate substantial synchrotron-radiation losses while serving operating points as different as the Z pole, with its large beam currents, and the top-quark threshold, with its high accelerating voltage. In addition, superconducting magnets, with Nb–Ti as the baseline and designs based on the HTS under consideration, would focus the beams at the interaction points and equip the detectors.

By contrast, a future hadron collider at the energy frontier would depend primarily on a new generation of high-field superconducting dipole magnets, reaching fields well beyond those deployed in today's accelerators (*CERN Courier* March/April 2026 p30). Producing these magnets at industrial scale, and operating them reliably, would be among the main challenges of such a machine. High-field magnets would also open an alternative route to higher energy by reusing the existing LHC tunnel and infrastructure.

A century after Onnes's death, the influence of his discovery on accelerator science continues to grow, and the two trajectories that emerged from it remain the principal paths along which superconductivity may extend the reach of particle accelerators. Dipole magnets developed within the scope of the HL-LHC project were designed to be the first in any collider to bend beams at the 100,000 gauss he imagined in 1913, while the High Field Magnet programme is exploring the territory beyond that dream. ●

A future hadron collider at the energy frontier would depend primarily on a new generation of high-field superconducting dipole magnets

Further reading

D van Delft and P Kes 2010 *Physics Today* **63** 38.
O Brüning and L Rossi (eds.) 2024 *The High Luminosity Large Hadron Collider* 2nd edn (World Scientific).
L Rossi, A Yamamoto and H Padamsee 2025 Talks at the 4th International Symposium on the History of Particle Physics, CERN.
https://indico.cern.ch/event/1696285/.

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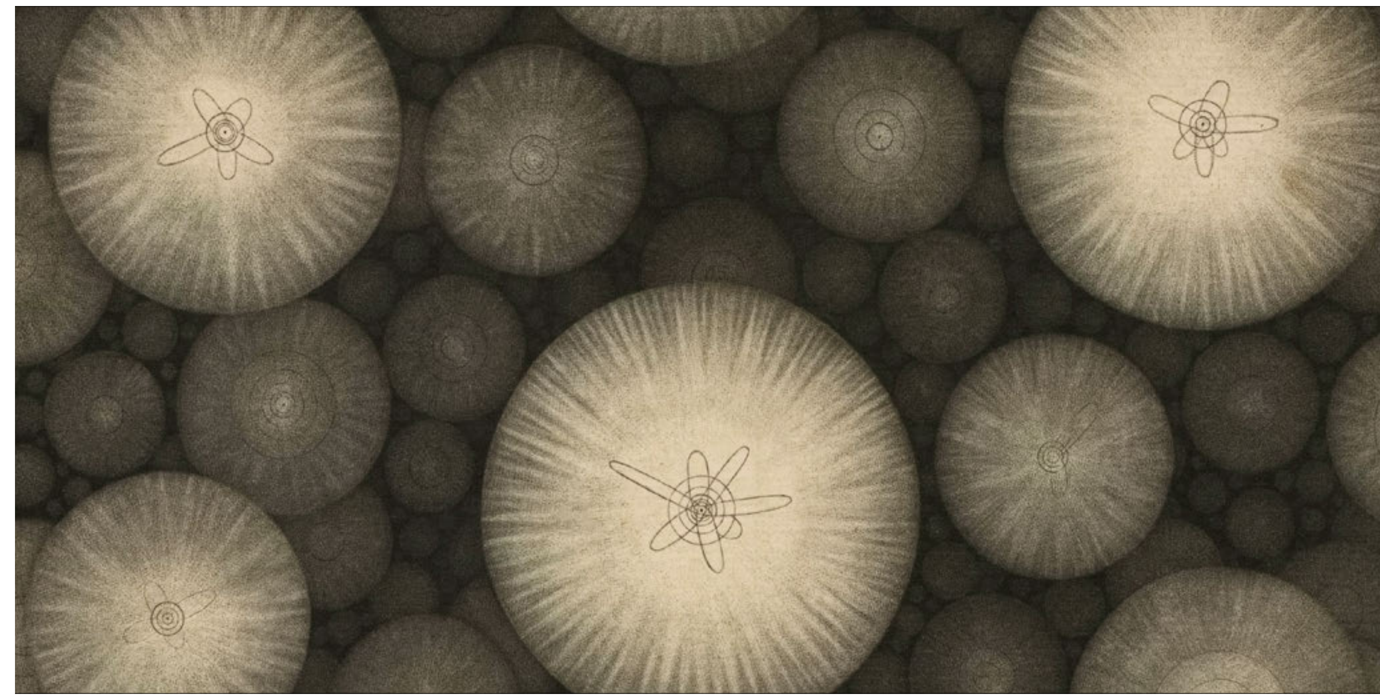
HOW STRONG IS THE STRONG INTERACTION?

Of the Standard Model's three gauge couplings, the one between quarks and gluons is by far the least well known. Harvey Meyer recounts the decades of lattice QCD behind its recent determination to five parts per mille.



Ever smaller worlds *Thomas Wright's 1750 engraving of an array of bounded worlds. Physicists have now pinned down the strong coupling in a kindred family of tiny universes, each simulated on its own. (Credit: Spencer Collection, The New York Public Library. "Plate XVII" The New York Public Library Digital Collections. 1750. https://digitalcollections.nypl.org/items/783751f0-c60a-012f-e5fc-58d385a7bc34)*

The force between two quarks in a near-miss collision is of the same kind as that between two electrons, but far more intense. It is also known far less precisely. While the fine-structure constant of electromagnetism has been measured to better than one part in a billion, the strong coupling α_s is only known to one in a hundred.

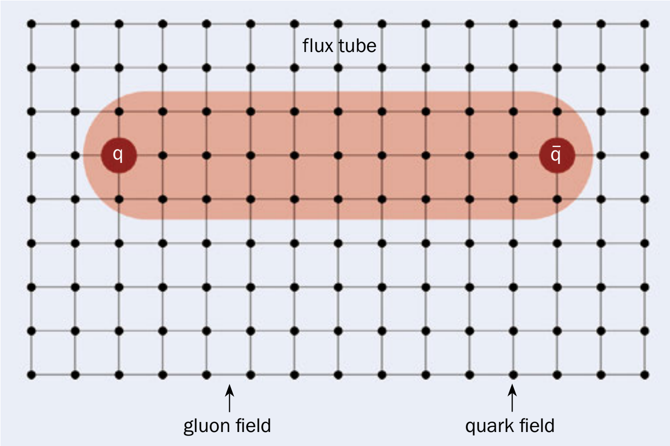
At the LHC, with its enormous number of proton–proton collisions, many process rates are now measured to the percent level. The uncertainty on the strong coupling is then becoming a theoretical bottleneck. The High-Luminosity LHC and a future Higgs factory such as the proposed FCC-ee will demand greater precision still, since new physics may first appear as small discrepancies between measurements and predictions. A calculation recently published in *Nature* has now reduced the uncertainty on α_s to five parts per mille using only low-energy input. The value can therefore enter collider predictions without having been fitted to collider data.

A force apart

Protons are not elementary. Collisions at momenta far above their mass scale resolve them into quarks, held together by gluons, the carriers of the strong force. Hardly any process at a hadron collider can therefore be understood without the part of the Standard Model (SM) that describes this interaction, quantum chromodynamics (QCD).

THE AUTHOR

Harvey B Meyer, *CERN and Johannes Gutenberg University Mainz.*



On the lattice *In lattice QCD, quark fields live on the sites of a grid and gluon fields on the links between them. A quark q and an antiquark q̄ pulled apart remain joined by a flux tube, whose energy grows steadily with the distance, and no quark is ever freed. Stretched far enough, the tube snaps and its energy materialises as new hadrons.*

The theory, defined

Beyond its computational role, the lattice occupies a privileged conceptual position. The perturbative series that typically define QCD are "asymptotic" expansions, believed not to be summable by any known method. They therefore cannot serve as a definition of the theory.

Wilson's lattice can – at least, in part. Once space and time are replaced by a discrete grid and the system is enclosed in a finite volume, the theory is specified exactly by a finite set of well-defined quantities. The physical theory should emerge as the spacing shrinks to zero and the volume grows without bound, removing discretisation and finite-volume effects. While the existence of that limit has not been proved at a fully non-perturbative level, an all-order proof in perturbation theory exists for a class of discretisations. Even for a simplified theory with gluons alone, a truly rigorous construction, including a proof that its lightest state is massive, would settle one of the Clay Millennium Prize Problems.

The approach has a further price. The grid breaks translational, rotational and boost symmetry, and the simplest quark discretisations also sacrifice chiral symmetry. A further issue is that lattice QCD is formulated in imaginary time, which is well suited to statistical sampling but makes real-time scattering processes only partially and indirectly accessible. Many theorists nonetheless regard the lattice not as an approximation of QCD but as its true definition, and the broken symmetries as artefacts expected to vanish in the continuum limit. Providing a similarly rigorous definition of *chiral* non-Abelian gauge theories, as needed for a non-perturbative definition of the full Standard Model, remains an active area of research.

In QCD, the strength of the force between two quarks, two gluons, or a quark and a gluon is parametrised by the single coupling α_s. Predicting the cross-section of any process that involves these particles requires, therefore, a precise input value for this constant. For instance, gluon fusion – the process that produces Higgs bosons most copiously at the LHC – proceeds via a virtual top-quark loop, and its probability is proportional to α_s^2.

The strong coupling has an unusual property, inherited from a structural difference between QCD and quantum electrodynamics. Gluons, unlike the electrically neutral photon, carry colour, the very charge whose force they mediate, and thus interact among themselves. This leads to the coupling weakening as colour charges approach each other and growing as they separate. In a collision, the momentum transferred between the quarks and gluons sets the probed distance, and with it the scale at which α_s must be evaluated. The conventional choice of a reference scale is the Z-boson mass, $Q = M_Z = 91.2$ GeV in natural units. There, the current world average from the Particle Data Group (PDG) for α_s is 0.1180 ± 0.0009. The precision is thus 7.6 parts per mille.

The weakness of the coupling at high-momentum transfers, where quarks and gluons behave almost as free particles, is known as "asymptotic freedom" and makes precise calculations possible as expansions in powers of α_s. By contrast, at transfers below about a GeV, the coupling grows to order one, perturbative expansions in powers of α_s break down, and any description in terms of quarks and gluons loses all predictivity. The strong interaction enforces this limit by confining quarks and gluons inside bound hadrons, and only these composites are ever seen in particle detectors. They include the proton and neutron, but also the pions, the kaons and an entire zoo of species, lately enlarged by the tetraquarks and pentaquarks discovered in collider experiments (*CERN Courier* November/December 2024 p33).

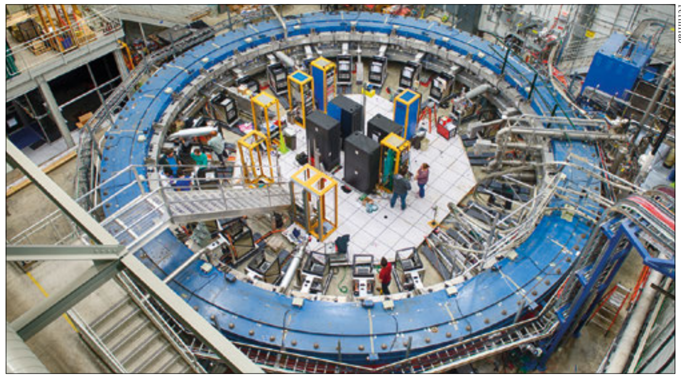
Spacetime on a grid

What fails at low energies are perturbative expansions, though, not QCD itself. The theory can predict the masses and key properties of bound states, but extracting these quantities requires a formulation that is not restricted to the weak-coupling regime. This was provided in a landmark 1974 paper by Kenneth Wilson. The idea is to approximate space and time as a four-dimensional lattice of points with a small spacing, later sent to zero to recover continuous spacetime (see the "On the lattice" figure). Enclosed in a finite volume, the lattice reduces QCD to a finite number of degrees of freedom. The theory's predictions can then be evaluated by statistically sampling the possible configurations of the quark and gluon fields, and confinement emerges directly from the simulated dynamics (see "The theory, defined" panel).

Still, the lattice became a quantitative tool only once algorithms and machines could generate enough field configurations for reliable statistical averages. For two decades, computing power forced severe compromises, most notoriously the quenched approximation, which neglected quark loops in the vacuum and therefore their backreaction on the gluon fields. This introduced an uncontrolled systematic error. Simulations with realistic dynamical quarks became feasible in the 2000s, and several collaborations obtained the masses of light hadrons and other low-energy observables in agreement with observation. Since 2011, the Flavour Lattice Averaging Group (FLAG) has compiled and averaged such results every two to three years, doing for lattice calculations what the PDG does for measurements and focusing on quantities central to particle phenomenology, such as the leptonic and semi-leptonic decay rates of K, D and B mesons. Lattice QCD has also shed light on how the proton's charge, magnetisation and momentum are shared among its quarks and gluons, and distributed in space, and delivered high-impact ab-initio results on the phase diagram of QCD.

Over the past decade, the magnetic moment of the muon, a precision observable used to search for deviations from the SM, has proved a fruitful ground for demonstrating the maturity of lattice QCD. The measured value of the observable long disagreed with the SM prediction, whose largest theoretical uncertainty came from non-perturbative QCD effects. These comprise hadronic vacuum polarisation, traditionally estimated from measured $e^+e^- \to$ hadrons cross sections, and the smaller hadronic light-by-light contribution (*CERN Courier* March/April 2025 p21). By 2025, independent lattice calculations of the dominant vacuum-polarisation term agreed, while measurements of its dominant two-pion channel disagreed well beyond the stated uncertainties. This led the Muon g-2 Theory Initiative to base the value of the leading hadronic contribution in that year's white paper solely on lattice results (*CERN Courier* January/February 2026 p41). The resulting prediction turned out to be in agreement with the final direct measurement of the muon's magnetic moment from Fermilab (see "The verdict" figure).

Lattice QCD also makes it possible to determine the fundamental parameters of QCD, namely the quark masses and the coupling at momentum M_Z, from experimentally well-measured quantities such as the pion, kaon and proton masses. Finally, it offers theorists the possibility of studying strong interactions in ways not accessible via observations – for example, at vanishing quark masses or when particles are confined to a small volume.

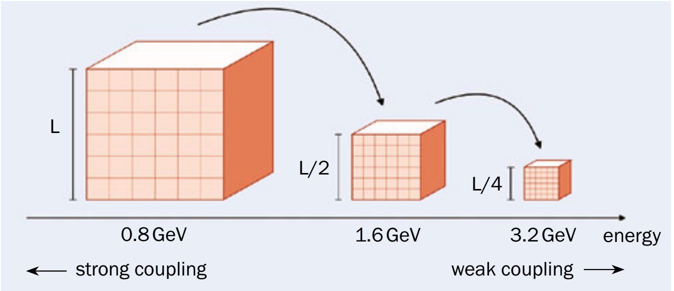


The verdict *The muon g−2 storage ring at Fermilab, where the muon's anomalous magnetic moment was measured to a precision of 127 parts per billion. The value agrees with the Standard Model prediction, once its leading hadronic contribution is computed with lattice QCD.*

The femto-universe

Theorists from condensed matter to particle physics have long worked at finite size to perform better-controlled calculations, before taking the infinite-volume limit. Placing a system in a box, however, can be more than an intermediate step. How an observable changes with the size of the box is dictated by the dynamics under study, and is therefore itself a prediction of the theory. The idea of exploiting a very small volume to interrogate QCD goes back to James Bjorken, who in 1979 coined the term femto-universe for the degrees of freedom of the strong interaction in a box less than 10^{-15} metres across.

Building on Bjorken's suggestive idea, Martin Lüscher, Peter Weisz and Ulli Wolff proposed in 1991 a systematic way to compute the momentum-dependence of α_s in an asymptotically free theory, and implemented it in a model with one space dimension. The obstacle they faced is that a direct determination of α_s would need a lattice large enough to hold hadrons, yet sufficiently fine to resolve energies above roughly 70 GeV, where low-order perturbation theory is accurate. No computer could span both scales at once. Their "step-scaling" method avoided the problem by using a family of femto-universes, each simulated separately and covering a narrow range of energies inversely proportional to its size (see "One box at a time" figure). Stepping down through the family, each member half the size of the last, the coupling can be followed upward in energies, until perturbation theory takes over. The extension to non-Abelian gauge theories, the class to which QCD belongs, followed the next year. The development of these techniques was among the reasons why Lüscher, who joined the CERN Theory Division in 1999, earned a share of the 2025 EPS High Energy and Particle Physics Prize, together with Jürg Gasser and Heinrich Leutwyler, for their theoretical work on the non-perturbative aspects of the strong interaction.



One box at a time *In the step-scaling method, a QCD observable is computed in a family of simulated universes, each half the size and twice the energy of the last. Since every box holds an equal number of lattice points, they cost roughly the same to simulate. The strong coupling can then be carried from the hadronic scale up to where perturbation theory takes over.*

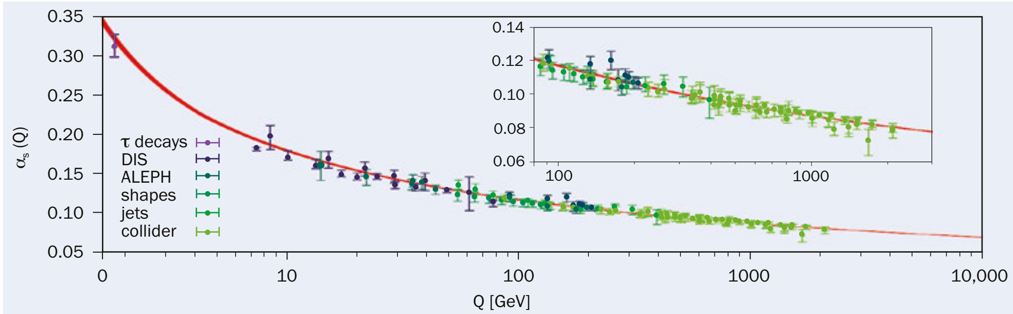
The magnetic moment of the muon has proved a fruitful ground for demonstrating the maturity of lattice QCD

Heavy by design

In a *Nature* paper, published last April, seven theorists from the ALPHA collaboration computed α_s at the reference momentum M_Z using step scaling. The result, $\alpha_s = 0.11876 \pm 0.00058$, carries a precision of 4.9 parts per mille and is consistent with the PDG average (see "Running down" figure). The calculation takes only low-energy quantities as input, namely the pion and kaon masses, together with a benchmark length of about 0.14 fm, itself determined by several independent lattice collaborations from well-measured quantities such as baryon masses and meson decay rates. The simulations contain only the three lightest quarks (up, down and strange), and the effect of the heavier charm and bottom quarks, negligible at low energies, is restored at the end using high-order perturbative QCD results and the measured values of their masses.

The same team's 2017 determination, the first below one percent and until now the dominant input to the world average, rested on a single step-scaling analysis. The new work

Running down *The strong coupling α_s (red band) as a function of the momentum scale Q, extracted from the new lattice analysis. The points are individual phenomenological determinations compiled by the PDG.*



adapted from M Dalla Brida et al. 2026 Nature 652 328 (CC BY 4.0)

repeats it with finer lattices and adds a second approach, in which the masses of the three simulated quarks are increased to as high as 10 GeV. QCD then reduces, up to corrections falling as the inverse square of the masses, to a far simpler quarkless theory, in which the evolution of the coupling with energy can be determined independently. The two routes agree, and their average, resting on some 400 million core hours of simulation, gives the headline number.

The view from below

To many particle physicists, the idea that α_s at M_Z can be predicted by the SM with input solely from the low-energy world of hadrons is still unfamiliar. Nearly every phenomenological determination in the PDG runs the opposite way, fitting perturbative QCD predictions to high-energy collider observables. The comparison between the new result and these is therefore best read as a test of the SM: a heavy new particle at or above the Z mass would shift the collider determinations while leaving the low-energy ones practically unchanged. So far, the SM has passed the test with flying colours. ●

Further reading

M Lüscher, P Weisz and U Wolff 1991 *Nucl. Phys. B* **359** 221.
M Dalla Brida *et al.* 2026 *Nature* **652** 328.
D d'Enterria *et al.* 2024 *J. Phys. G* **51** 090501.

A COLLABORATION AT HIGH LUMINOSITY

With the High-Luminosity LHC on the horizon, the ATLAS collaboration took stock of itself through a survey of its members on strategy, operations and work culture.

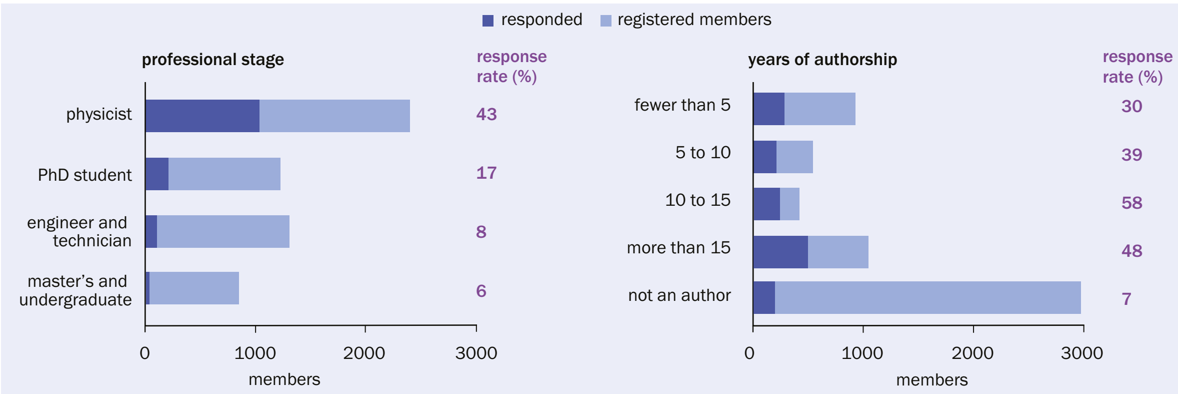
M Struik/CERN

Bunch crossing *Members of the ATLAS collaboration gathered in December 2024. The mural of the detector, which sits about 100 metres below their feet, was painted by artist Josef Kristofoletti.*

The ATLAS collaboration has approximately 6000 members from 262 institutes in 40 countries, about half of them scientific authors. This large and diverse community has spent the past few years carrying out detector operations, data analyses and upgrades all at once, through a global pandemic and a succession of geopolitical crises. As the High-Luminosity LHC (HL-LHC) era draws closer, the collaboration decided to find out where its members stand on fundamental strategic questions and how they feel about its organisation and operating model.

Collaborations in particle physics have not always been this large. The Gargamelle team that discovered weak neutral currents in 1973 counted 55 authors from seven European laboratories, with guests from Japan, the Soviet

THE AUTHORS
The ATLAS collaboration.



Demographics *Participation in the ATLAS Big Survey by professional stage and years of scientific authorship. In each row, the lighter blue bar spans the members registered in that category, and the darker one those who responded to the survey, with a rounded response rate reported in the right-hand column. Engineers and technicians are grouped together, as are master's and undergraduate students.*

Union and the United States. The W boson was found a decade later by two collaborations, UA1 and UA2, of roughly 140 and 60 physicists, respectively. At LEP, the four experiments ALEPH, DELPHI, L3 and OPAL each counted several hundred physicists from a few tens of institutes. When ATLAS and CMS jointly measured the Higgs-boson mass in 2015, in the first paper the two collaborations signed together, the author list ran to 5154 names and filled 24 of the article's 33 pages.

A collaboration of this scale can only be consulted through an organised, sustained effort. In the case of ATLAS, this meant establishing a working group of 14 members to draft survey questions, collecting responses from July to September 2024, and forming an analysis team of five to read and interpret the results, with each step of the process taking several months. Designed to be concise, focused and actionable, the "Big Survey" still comprised more than 200 questions. To limit the burden on participants and maximise reach, these were divided into four modules of approximately 20 minutes each, the first on strategic collaboration issues, the second on physics and performance, the third on operations, the upgrade and practical matters such as travel, meetings and remote working, and the fourth on career development and work culture.

Survey rates

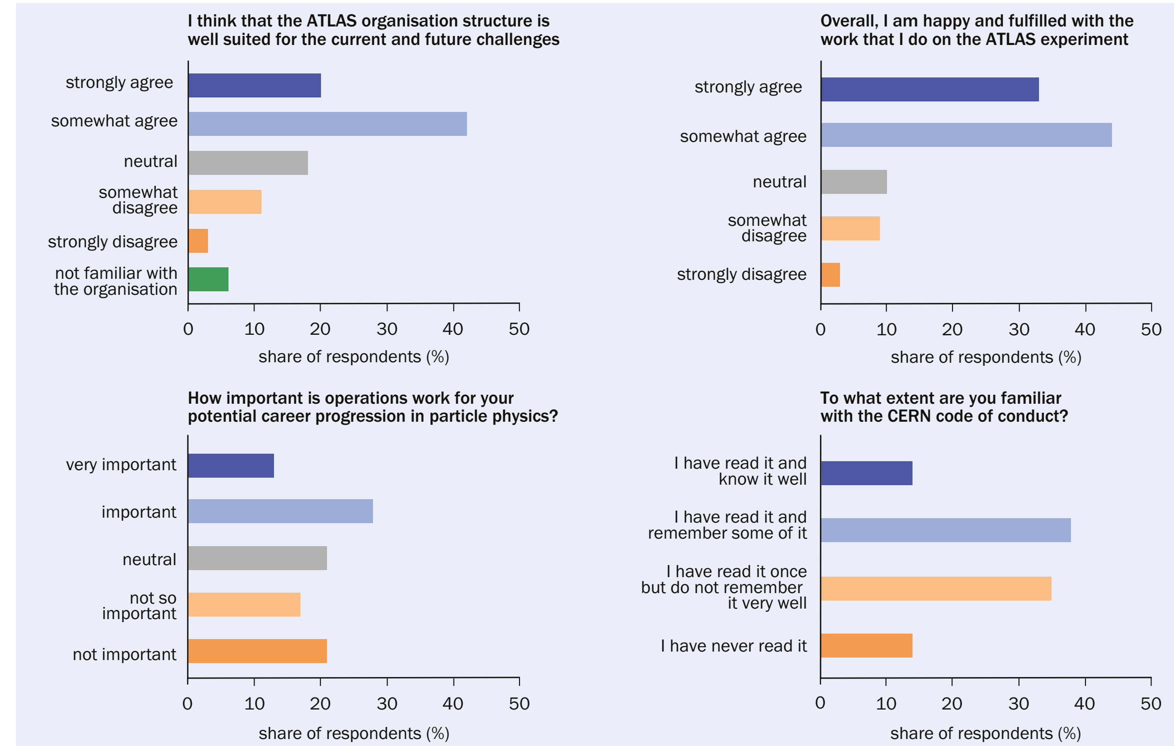
Replies came from nearly 1500 members (see "Demographics" figure). The rate of participation rose steeply with seniority, from fewer than 10% of master's and undergraduate students, engineers and technicians, and about 17% of PhD students, to around 30% of scientific authors with fewer than 5 years of authorship and nearly 60% of those with between 10 and 15. The overall response rate was slightly below 25% and was approximately uniform across world regions.

The results were examined across demographic groups, compiled into an internal document and then discussed with the collaboration at large during plenary meetings. An online tool also allowed members to explore the correlations for themselves. The conclusions comprise 37 actions to address the areas of improvement identified in the survey, and many have already been implemented. For instance, all active members, not only scientific authors and students, now have access to the collaboration's complete internal documentation, and the operational workload institutions must cover has been rebalanced towards those less engaged in upgrade construction.

Most members plan to take part in the HL-LHC programme and stressed the importance of remaining engaged with the collaboration to successfully complete the upgrade

The survey showed overall satisfaction. Asked whether the ATLAS organisational structure is well suited to current and future challenges in data-taking, analysis and upgrades, 62% of respondents agreed, and 14% disagreed (see "Four of two hundred" figure). Most plan to take part in the HL-LHC programme, and they stressed the importance of remaining engaged with the collaboration to successfully complete the upgrade, move smoothly from construction to operations with the new detector, and then sustain years of running to collect much larger datasets. Responses highlighted the need for simple, intuitive workflows and well-documented tools for data analysis. The collaboration is strengthening its documentation team to bring order and searchability to the sprawling records. Moreover, over the past few years, its many analysis frameworks have been consolidated into a few broadly used ones with common statistical tools. On the physics programme itself, respondents see much still to explore, with the caution that effort remains balanced across topics and analysis teams are sufficiently staffed.

Among the aspects examined in detail were participation in detector upgrade activities, the organisation of physics analyses and publications, and the long-term operation



Four of two hundred *A selection of four questions out of more than 200 asked in the ATLAS Big Survey. The collaboration's organisation and the work itself are viewed favourably, but opinion divides over the value of operations work for career progress, and about half of the respondents have at best a vague memory of the CERN code of conduct.*

of the experiment. One finding stands out. Contributions such as detector operation and maintenance are regarded as insufficiently recognised by the broad scientific community and research institutions. While most respondents feel satisfied with the recognition received within the collaboration for their work in operations, a large share does not consider this work important for their career progression in particle physics. The actions proposed in response are to make the rules behind authorship, speaker selection and operational credit public on an accessible, single web page, so that committees outside ATLAS can weigh a member's contributions, and to brief funding agencies more often on technical achievements while pressing the need for long-term contracts for experimental experts.

The responses from early-career scientists showed that further attention is needed to fulfil their aspirations and underscored the importance of understanding the mindsets of the collaboration's different generations. The ATLAS Early Career Scientists Board took an active part in the analysis and proposed measures to strengthen its initiatives and its role in connecting young researchers with the wider community. Those adopted include allowing all individuals, not only PhD students, to share non-controversial internal results confidentially with job and grant panels, and deepening ties with the CERN Alumni network.

ATLAS strives to provide an equal-opportunity environment, and inclusion and diversity are among its founding values. Members rated its multicultural character highly, with 80% of respondents agreeing that it is inclusive and open, 16% being neutral, and 4% finding it non-inclusive and closed. Since 2017, ATLAS has appointed four collaboration members as diversity and inclusion contacts, and a dedicated equity, diversity and inclusion office has been created to enhance their work. Nevertheless, many collaborators were not fully aware of the CERN code of conduct, and the ATLAS management is now communicating the code more actively, including whom to approach in the event of a potential violation.

The strength within

Overall, the actions resulting from the survey were defined to strengthen communication within ATLAS and with external stakeholders, improve documentation and accessibility for greater efficiency and transparency, and ensure an effective transition from Phase-II construction to optimal Run 4 operations, across data-taking and analysis. They also seek to retain expertise, recognise diverse contributions, and continue promoting the CERN code of conduct and a working environment that supports mental health and wellbeing. The 37-item list concluded a broad, introspective exercise and delivered a roadmap for preparing ATLAS for its high-luminosity phase. ●

The responses underscored the importance of understanding the mindsets of the collaboration's different generations

CERNCOURIER

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A journey worth sharing

Big Science asks industry for some of its most demanding work, then may never place an order again. Richard Farrow and Jan Visser set out what laboratories can do to keep suppliers on board.

R Farrow

Richard Farrow *is head of the UK Industrial Liaison Office at STFC and chair of the CERN ILO Forum.*

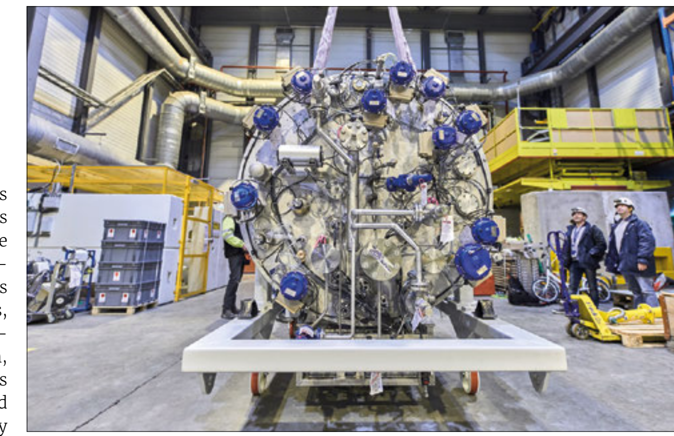
J Berger

Jan Visser *is the Dutch industrial liaison officer for CERN and vice-chair of the CERN ILO Forum.*

Over the past few decades, relations between Big Science organisations (BSOs) and their industrial suppliers have changed substantially. Global circumstances have forced companies to focus on their regular markets and products, leaving less room for contracts that deviate from that core business. Deviation, however, is often what BSOs need, as the technologies their projects demand grow more complex. In addition, they often require large numbers of custom components that may be just purchased once, and only through formal tender procedures. Companies, therefore, often prefer to do business with other companies, where shared long-term interests and mutual trust are typically enough to strike a deal.

The challenge for BSOs is then to remain, or to become again, interesting to industry, with projects at a price both can afford. In achieving this, laboratories have more to offer than is generally appreciated. Companies that work with BSOs have been shown to benefit in their marketing, to expand and improve their product portfolios, and to attract and retain key personnel, because challenging specifications drive innovation.

Relations in the Big Science domain can take many forms, from the supply of standard services and commodities, through collaborative technical development, to the licensing of technology and know-how. No single model fits every company, and each arrangement must serve both sides. Industry, for its part, is indispensable at every scale, from standard cables and connectors to complete magnet and cryogenic systems, and in some areas it moves faster than the BSOs themselves. Design for manufacturability and design for cost, the arts of shaping a component for efficient and affordable production, are cases in point, and both matter more as systems get bigger. Industry's experience should be brought into a project's design phase as early as possible, especially where components are needed in large numbers and for long lifetimes.



J M Ordan/G Vandoni/CERN

Cold on delivery *The cold-box built by Linde Kryotechnik arrives at CERN in January 2018. From an alcove off the SPS tunnel, it supplied cryogenic helium for the first beam tests of the HL-LHC's crab cavities.*

On demanding and innovative projects, openness is what keeps industry on board

Given their status, BSOs must deal with industry within specific procurement rules. Still, the relationship in spirit must be closer to a partnership, in which communication is open, risk is shared, and both parties ultimately gain. Communication must flow freely within each organisation, between technical and commercial teams, and between the two partners. As the work proceeds, both must exchange detailed specifications and flag problems as they arise. On demanding and innovative projects, where sharing risk matters most, this openness is what keeps industry on board.

The stakes reach beyond the laboratories, of course. For countries participating in a BSO, the return on membership rests not only on the science but also on wider societal benefits (p29). Chief among them at present is industrial growth and development, with new products, skills, partnerships, markets and intellectual property flowing back to the member states.

While the scientific return largely takes care of itself, through the institutes and universities involved in the experiments, national support for companies to connect with BSOs via industrial liaison officers (ILOs) varies significantly across countries. For the role to be effective, we must see challenges coming early, in time to identify potential suppliers or to help existing companies and incubators profit from the technologies being developed. ILOs, whether employed by a BSO or representing a country, are therefore central to building these partnerships.

Across their technical, management and commercial teams, BSOs must never lose sight of how fundamental long-term, mutually beneficial relationships with industry are. Their value exceeds limited, short-term financial gains, and savings won contract by contract can, over time, leave fewer companies willing to bid, to the detriment of science and industry alike.

OPINION
INTERVIEW

You have to go forward

Samuel Ting reflects on seven decades in experimental physics, from testing quantum electrodynamics, through the discovery of the J particle, to the magnetic spectrometer he still runs in orbit.


CERN, N Caraban Gonzalez

Measure once, measure twice *Samuel Ting, Nobel laureate and holder of the Thomas D. Cabot Institute Chair at MIT, in his office at CERN. He has led the AMS collaboration since proposing the experiment in the mid-1990s.*

Where did your path to research begin?
I was born in 1936 in Ann Arbor, Michigan, where my parents were graduate students. Soon after, as war was breaking out between China and Japan, they decided to return to save their country. I was only a few months old, so I had nothing to say. I grew up as a refugee, in many cities, one step ahead of the advancing Japanese army. In 1948, I moved to Taiwan, where I realised I was a US citizen by birth. When a delegation from the University of Michigan visited, my mother mentioned I had been born in their hospital, and its president said I could study there without paying. So I left for Michigan in 1956, flying from Taipei through Okinawa, Tokyo, Anchorage and Seattle. It was a long way. I had asked my parents for $100, telling them that American students put themselves through college without taking money from home. “You may need more,” they said. As soon as I landed in Detroit, I bought a hamburger, and it cost $1. I immediately realised the mistake I had made. Fortunately, the dean of engineering, George Granger Brown, knew my parents and took me into his home, where I discovered American football. In six years, from freshman to PhD, I never missed a single game, and I still go back every year.

Physics was not the original plan, though.
My mother was a professor of psychology, and my father of engineering. I went for engineering, too. In my second term, I had extremely good grades in all courses except engineering drawing. I could not get a single straight line. My advisor told me I was no engineer, and that I had to switch to physics and mathematics.

Once inside physics, you first head for theory. What changed your mind?
Like most students with good grades, I wanted to do theoretical physics, and I worked with George Uhlenbeck, who had co-discovered the electron spin. One day, over tea in his office, he suddenly said: “If I were to do my life over again, I would be an experimentalist rather than a theorist.” This was one of the giants of the century, so I asked him why. He said: “Every experimentalist is very useful, because you always measure a number, you contribute knowledge. Every theorist is not. You can count them in the 20th century. There is Einstein, there is Dirac, there is Heisenberg…” I took a walk in the garden, came back and said: “You are right. I am leaving you.” I knew absolutely nothing about experiments. After my PhD, I went to CERN, where Giuseppe Cocconi taught me instrumentation. Understanding your instrument is the single most important thing for an experimentalist. You must know what you can do, what to treat with suspicion and what to check, and recheck, and recheck.

From CERN, you went to Columbia, just as quantum electrodynamics (QED) was running into trouble…
A Harvard group had measured electron–positron pair production and found an electron radius of

10^{-13} to 10^{-14} cm, in contrast with QED. The result was soon confirmed independently. No question mattered more, and I decided to do the experiment myself. Colleagues I had met through my work at CERN put me in touch with Willibald Jentschke, the founder of the Deutsches Elektronen-Synchrotron (DESY) in Hamburg, and he invited me.

How did your experiment work?
We repeated the measurement with an independent method. When you send photons onto a target, the rate at which they convert into wide-angle electron–positron pairs tells you whether QED holds at small distances. To deal with the enormous background associated with our 10^{11} photons on target, we built a pair spectrometer. In it, a magnet bends the pairs away from the photon beam, and the detector sits behind it. Measure once and measure twice, and the magnet sweeps away the background of the first measurement before the second. We showed that QED was correct, presenting the result at a 1966 conference in Berkeley. Feynman, of course, was very happy. The spectrometer then led us to the heavy photons: the vector mesons rho, omega and phi, which share the photon's quantum numbers, apart from their masses. After years of this work, I asked myself why every vector meson sat near 1 GeV. Rho at 765 MeV, omega at 783, phi at 1020. Could there be something heavier?

What did it take to find out?
At the time, people were more interested in the strong interaction, so it was hard to get the experiment approved. Fortunately, Brookhaven accepted it, and MIT, where I had just returned, went all the way to support us. The design was the same as at DESY: we sent protons onto a target and measured the mass of the electron–positron pairs coming out, looking for a peak. With some 10^8 hadrons produced for every electron pair, the detector had to misidentify no more than one hadron in 10^{10}. We were extremely careful with the instrument. In July, I was taking data at higher pair masses, around 4 to 5 GeV, and finding absolutely nothing. So I moved to lower energies, and suddenly all the particles came out, always at a mass of 3.1 GeV (see "The peak" image). No other particle, nothing. To verify it, we lowered the magnetic field by 10%, which moved the particles to a different region of the detector. Had it been background, it would have disappeared.

The peak *Samuel Ting at Brookhaven in 1974, holding the electron–positron mass spectrum that revealed the J particle. The discovery earned him the 1976 Nobel Prize in Physics, shared with SLAC's Burton Richter.*

Before, the quark model had been one respected idea among many. Afterwards, it carried a much heavier weight. As it deserved.

It did not disappear, of course. What happened next?
On 11 November, I learned that Burton Richter had also seen the same peak at SLAC, and we called Giorgio Bellettini at Frascati, where they reproduced the result within days. The particle, which we called J, lived some 10,000 times longer than comparable hadrons, indicating a new kind of matter: a fourth quark bound to its antiquark. Before, the quark model had been one respected idea among many. Afterwards, it carried a much heavier weight. As it deserved.

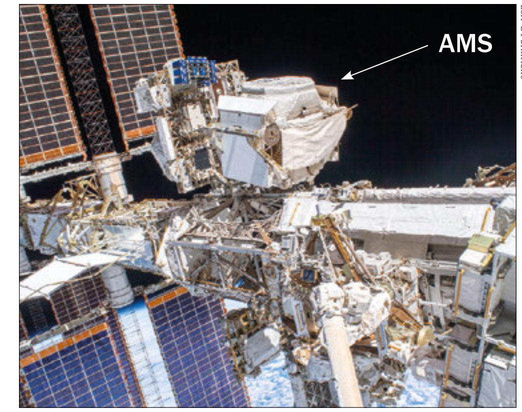
The name itself has gathered legends. Can you set the record straight, once and for all?
There are many theories. One says that J resembles my name in Chinese. Another that J is the first letter of Jeanne, my daughter's name. Neither is true. We had come from the vector mesons, and in the vector-meson dominance model, the electromagnetic current is J_μ. That is where the J came from.

Those were also the years of your return to China, almost 30 years after you had left. How did it happen?
I had left in 1948, on a boat from Shanghai. I was 12 years old, and my mother took me up to the deck to look at China. "You may never see it again," she said. In 1975, an invitation from the Chinese Academy of Sciences brought me back, and in 1978 came another, to lunch with Deng Xiaoping. He turned out to know his nuclear physics, and his wife and son were physicists. The lunch was excellent, as he had very good taste in food. It was just after the Cultural Revolution, and he asked: "How about we send some physicists to work with you?" That night, I called Herwig Schopper, who led DESY, and Schopper called Bonn. The next day, I could tell Deng that the German government would welcome them. "Good," he said, "let me send 100 people." I answered: "There is a difference between training soldiers and physicists. Select of the order of 10, and let me interview them." I spent hours with each one, asking them to ask me questions, because when I asked, they could not answer. From that year on, they kept coming, and the three most recent director-generals of the Institute of High Energy Physics in Beijing all came from this school.

At PETRA you led the MARK-J experiment, which shared in the discovery of the gluon. Then came L3, at CERN's Large Electron–Positron collider (LEP)...
MARK-J was built to measure the forward–backward asymmetry of muon pairs, seeking evidence for the existence of the intermediate vector bosons, and could rotate in both θ and ϕ to reduce the systematic errors. It went on to provide the first experimental evidence for the existence of the Z^0. The accidental discovery of gluons at MARK-J was due to the detector's ability to show that the three-jet distributions and their production rate were both in agreement with QCD. L3 then took 20 years, and 20 countries, East and West Germany, Pakistan and India, China and Taiwan among them. We never found a name for the detector, which remained simply the third letter of intent submitted for LEP. From L3 came 300 PhDs, and results that can be stated simply. Three charged leptons, three neutrinos, six quarks. Everything agreed with the electroweak theory. I knew Steven Weinberg quite well, and he was very happy. I told him, "I would be much happier if I did not agree with you!"

You were also involved in the Superconducting Super Collider (SSC), cancelled in 1993. Where did that leave you?
When Congress closed the SSC, I was almost 60 and had spent my entire career at accelerators. I remember distinctly walking back and forth in my garden and realising that retirement was not an option. I decided to work on something completely different, a problem I knew nothing about. Years earlier, at Brookhaven with Leon Lederman, I had helped find the antideuteron, the first antimatter nucleus, and the question had stayed with me: if antimatter binds into nuclei and exists anywhere in the universe, some of its nuclei would reach us as cosmic rays. Looking for them meant putting a magnet in space, and nobody thought that was possible. A magnet in the Earth's field is a compass: one end points north, the other south. On a space station, it is unstable. Working out a magnet whose torques would cancel took many years.

... and a rocket to carry it to space. How did you get NASA on board?
Roald Sagdeev, who ran Russian space research, recommended me to Dan Goldin, the head of NASA. When Goldin asked how heavy my detector was, he caught me off guard. "My last experiment, Mr Goldin, weighed 10,000 tonnes," I said. His advice was to build a magnet, fly a prototype on the shuttle and, if it worked, go to the International Space Station (ISS). That magnet became the Alpha Magnetic Spectrometer (AMS). The prototype flew in 1998 and went quite well, so for the ISS we built something more ambitious: a superconducting magnet. Then, in April 2010, I discovered the shuttle programme had been cancelled, and without shuttles to refill its superfluid helium, the superconducting magnet could not survive. When you have been totally involved in an experiment for years, you can only go forward. We took AMS apart and rebuilt it around the permanent magnet very quickly. Otherwise, it would not be flying today.



Above the clouds *The view of ESA astronaut Luca Parmitano during a spacewalk to service AMS, in November 2019. The detector, wrapped in insulation, is attached to the ISS's main truss.*

Looking for cosmic rays meant putting a magnet in space, and nobody thought that was possible

AMS has now spent 15 years on the ISS. What is it like to run such an experiment from Earth?
In space, there is no Christmas, no summer vacation, no weekend. The ISS never stops, so you take data all the time. And space is unforgiving: if something goes wrong and you do not know it, you will make a mistake, so we check the instrument every two minutes. When the cooling system stopped, the only way to replace it was an open-heart surgery, performed by astronauts, where one wrong cut would have ended the experiment. NASA spent three years training them in a swimming pool. I have known many astronauts. They are all very intelligent, but also extremely calm. In space, the distance between life and death is very short. You must discipline yourself.

On to the results, then. AMS has been collecting positrons since day one. What have they shown?
So far we have 4.2 million of them, up to the TeV region, and the spectrum is not a smooth curve. The low-energy part can be explained by ordinary cosmic-ray collisions. But at high energies, there are far more positrons than collisions can produce, and this excess rises and then drops suddenly, around 810 GeV. It must come either from a new source, such as pulsars, or from dark-matter collisions, and we cannot yet tell which. The antiprotons, though, behave in the same way, and antiprotons cannot come from pulsars. If it is dark matter, its mass must be around 1.5 TeV.

And the antimatter?
We have a few antihelium candidates, particles with a charge of minus two and masses up to about 3.8 GeV, but we have announced nothing. The rate is one in 10^8, and no one knows their instrument to better than 1%. Even 1% is a miracle. Another magnet on top would settle it, but it would weigh 15 tonnes, and nothing can carry 15 tonnes to space. So we wait patiently, either for more candidates or for anti-carbon and anti-oxygen. Fortunately, there is no competition.

AMS also measures matter nuclei in cosmic rays. What have you found there?
In total, we have measured 265 billion cosmic rays. Among them, we can identify 28 elements of the periodic table, from hydrogen up to nickel, and measure them all very precisely. Each element has its own rigidity spectrum, so you would expect them to have different spectral shapes. In the 20 elements we have analysed so far, we see only four, two from the primary cosmic rays and two from secondaries produced by collisions along the way. Every element is a combination of these four, and none is explained by current models. There are hundreds of suggestions as to why. I do not spend time on them, because our first obligation is to ensure the data are correct: over the next 40 or 50 years, no spectrometer will repeat this measurement. The coming upgrade, a new tracker layer on top of the detector, exists just for that.

More broadly, where do you see particle physics going?
I do not know who is qualified to answer this question! Before the discovery of the J particle, nobody would have done physics on it. The future really depends on the next discovery. You have to go forward.

Interview by **Davide De Biasio** *editor.*

CERNCOURIER
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OPINION REVIEWS

Copper, klystrons and the Cold War

Memories from Paris to Stanford: Life, Particles and Politics

By Gregory A Loew

Regent Press

Memories from Paris to Stanford is a deeply personal account of the fascinating and varied life of Gregory Loew. A renowned accelerator physicist, Loew made seminal contributions to the accelerators at the Stanford Linear Accelerator Center (SLAC) that underpinned its Nobel Prize-winning scientific programme. Among them were the klystron drive and phasing systems for the 20 GeV linac, the S-band radiofrequency (RF) particle separators for the initial linac-based experiments, and the electron–positron injection system for the B-factory. He also directed the three-year effort that cured the beam breakup plaguing early operation, and through the 1970s, as head of the Accelerator Physics Department, led all the linac improvement projects. Later, Loew went on to chair two large international committees, whose comparisons of the competing linear-collider proposals paved the way for the 2004 selection of the superconducting technology of the DESY-led TESLA collaboration.

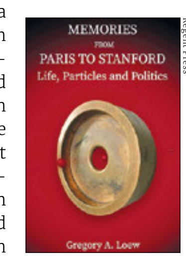
G Loew/SLAC/Zawojski

State visit *Wolfgang "Pief" Panofsky (left, with glasses), Gregory Loew (centre) and French president Georges Pompidou (right) during a visit to SLAC on 27 February 1970.*

Core values

The memoir is divided into three parts: his early life and education, his career at SLAC, and his later engagement in politics. The diverse cultural environments and upheavals of his pre-college years recur throughout, intertwined with his science and activism, and matched by the value he places on family, friendship and collegiality.

The early chapters follow a childhood scattered by war. Loew was born in Vienna in 1930 to Jewish parents, with roots in Prague and Hamburg. In 1932, the family moved from Bucharest to Paris and switched their home tongue from German to French. In 1939, with antisemitism rife and war declared, they were forced out again, reaching Buenos Aires on 1 January 1940 – two weeks after the German battleship *Admiral Graf Spee* was scuttled off Montevideo. Somewhat screened in Argentina from the ravages of the war, the family nonetheless followed its perils, finding immense relief in the liberation of Paris in August 1944. A three-month visit to New York at the end of the same year marked his first encounter with the United States of America. There, operas at the Met and concerts conducted by Toscanini and Stravinsky sparked a lifelong love of the performing arts.



Regent Press

Loew knew from an early age that he wanted to pursue a career in physics, a desire cemented by excellent maths and science teachers at his high school in Buenos Aires. He returned to Paris in 1948 for undergraduate studies at the Sorbonne, and his account of those four highly eventful years is captivating. After his licence-ès-sciences in mathematics, physics, chemistry and radioactivity, he chose Caltech for his PhD studies, where he enjoyed easy access to figures such as Richard Feynman, Robert Millikan, Fred Hoyle and James Watson. Gregarious by nature, Loew never quite took to campus life at Caltech and, on completing his master's in electrical engineering, accepted a generous scholarship from Stanford University to do his PhD. So began an illustrious 54-year career at Stanford and SLAC, including about five years as deputy director from 2001 to 2005.

The heart of the book, and its strongest claim on a physicist's attention, is Loew's chronicle of the internationally competitive development of linear electron accelerators from its Stanford origins. It began with William Hansen in the 1930s and advanced when the Varian brothers, Sigurd and Russell, arrived in 1937. That year, they built the first working klystron, a technology that still powers RF cavities today (*CERN Courier* May/June 2025 p30). After the war, Hansen resumed the work with Ed Ginzton and Richard Neal. Hansen died in 1949, and in 1951 Wolfgang "Pief" Panofsky arrived from Berkeley and carried the programme forward. By the mid-1950s, Stanford had a machine capable of delivering electron beams up to 1 GeV, which Robert Hofstadter used for his Nobel Prize-winning study of the structure of protons and neutrons. Loew himself arrived in 1954 as an electrical-engineering graduate student. His thesis, fortuitous given his later role, involved a microwave amplifier and oscillator system much like those used in the 1 GeV machine.

The Monster

Panofsky had larger ambitions. In 1957, he led a Stanford group that audaciously proposed Project M, the Monster, a two-mile accelerator for electron beams of up to 20 GeV. Loew completed his PhD in 1958 and joined the project, taking on the critical task of designing copper microwave structures to accelerate the electrons. Project M was funded in 1961, with Panofsky as SLAC's first director, and construction began in 1962.

SLAC's scientific breakthroughs resulted from decade after decade of far-reaching technical invention driven by a group of brilliant, ambitious and colourful scientists. And who better to describe that history than Loew? From the start until his retirement in 2008, he contributed to the technical development, the unfolding science and the laboratory's management. His astute people skills and benevolent character enliven his account and lend it veracity. ▷

One further thread gives these chapters their texture: the laboratory's role, largely driven by Panofsky, in building relationships and intergovernmental agreements with high-energy physics laboratories in Russia, Japan and China. Those friendships outlasted the science and at times served as back channels during political tension, and Loew's insider account of those brave endeavours opens a window onto their workings.

Ambassador extraordinaire

As SLAC's "ambassador extraordinaire", Loew was often called on to host its most prominent visitors. He describes two, the visits of French president Georges Pompidou in 1970 and of the emperor and empress of Japan in 1994. He also devotes a chapter to his wife of 30 years, Gilda, who passed away in 2001. She was a PhD quantum chemist, with an adjunct professorship at Stanford, and worked with Nobel laureate Joshua Lederberg.

A fascinating blend of Stanford and SLAC's groundbreaking accelerator-based science

The third part of the book steps outside SLAC. Loew had been alert to politics and the causes of war since boyhood, and a call from the Stanford administration prompted him, in 1970, to devise a one-quarter course on the origins of war. It proved popular enough to run for more than a decade. Its range, from international relations and history to economics, anthropology and biology, later fed his first book, *The Human Condition: Reality, Science and History* (*CERN Courier* March/April 2020 p68). Since 1995, he has been active in democratic politics, serving on local and national committees and as a delegate to the 2012 convention. He closes with chapters on the threats to democracy and the existential threat of global warming.

Memories from Paris to Stanford is a fascinating blend of Stanford and SLAC's groundbreaking accelerator-based science from the early 1950s to the present and the socio-political currents that shaped that post-WWII period. The scientific reader will likely be captivated by the discovery potential unleashed by innovative technology in the hands of brilliant practitioners and by how world events played into that adventure. The non-scientific reader can equally appreciate the transformative nature of the technology, but for them the primary fascination may well be how dramatic world events shaped the multifaceted career of a brilliant scientist and humanitarian.

Jonathan Dorfan *SLAC.*

The Best Science Stories and How They Work: A Collection with Commentary

Edited by Siri Carpenter

University of Chicago Press

University of Chicago Press

Science journalism has the difficult task of making complex ideas accessible without sacrificing the uncertainty, nuance and sometimes messiness that accompany scientific research. Yet when it succeeds, much of the work involved is invisible. Readers encounter the finished story, not the reporting decisions, discarded approaches, structural choices and conversations with sources that produced it. *The Best Science Stories and How They Work* turns its attention to this hidden process. Each of its 11 reprinted stories comes with an introduction and annotations by a fellow science journalist, followed by a conversation in which writer and annotator discuss how the piece came together. The result is both an anthology of contemporary science writing and an attempt to take that writing apart and see what makes it work.

A persuasive case for paying closer attention to how science stories are assembled

A wide world of topics

The subjects are remarkably varied, encompassing medicine, climate change, genetics, conservation, mathematics and space exploration, and drawing on journalism originally published in outlets including *Nature*, *Scientific American*, *The Atlantic*, *MIT Technology Review* and *The New York Times Magazine*. Ed Yong's "Fatigue can shatter a person", for example, examines the debilitating experience of pathological fatigue, particularly in the context of long COVID, while Kendra Pierre-Louis investigates "How rising groundwater caused by climate change could devastate coastal communities". Juxtaposing such different stories is crucial, as it shows how similar questions about evidence, explanation, narrative and human experience arise across scientific disciplines.

What makes the collection distinctive, however, is what happens around each article. Rather than asking readers simply to admire a successful piece of journalism, the annotations encourage them to notice its construction. Why does a story begin where it does? How is technical information introduced without interrupting the narrative? What makes a source compelling, and how should a journalist balance curiosity with scepticism? Such questions turn reading into a more active exercise. The conversations between writers and annotators add another layer by focusing attention on the decisions and challenges behind each piece.

This emphasis on process makes the book relevant beyond aspiring science journalists. Communicating science is often described as a problem of translation: taking specialist knowledge and making it understandable to a non-specialist audience. The examples collected here suggest something much richer. Good communication also depends on judgement – what a reader needs to know, what can safely be omitted, where uncertainty matters and where explanation should give way to narrative. These decisions will be recognisable to any scientist who has tried to explain a result outside their immediate field.

There is inevitably a degree of artificiality in dismantling writing that was designed to be experienced as a whole. Not every reader will want to interrupt an engaging story to consider its underlying mechanics, and those looking primarily for physics or another particular discipline will find much of the collection removed from the subject of their interest. But that breadth is also one of the book's strengths. Moving between very different flavours of science and storytelling, it resists the idea that successful science communication can be reduced to a single template. It offers instead something closer to a workshop built around examples: read the story, examine the choices behind it and consider what might be learnt.

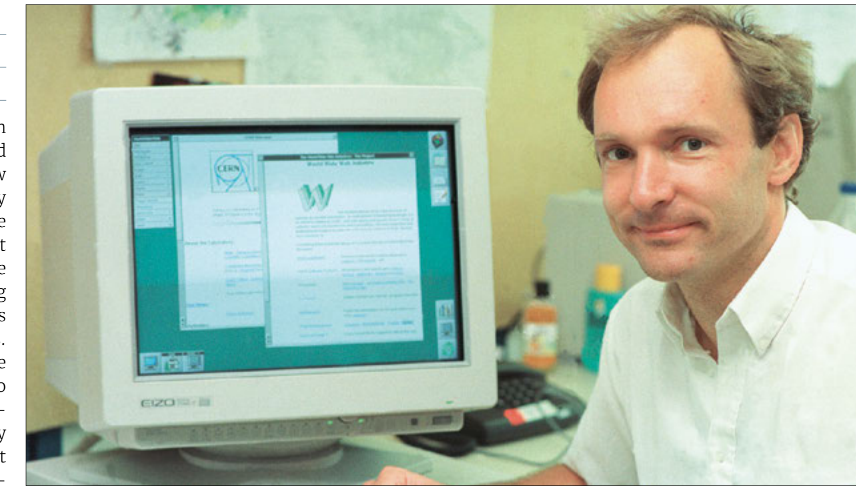
The Best Science Stories and How They Work makes a persuasive case for paying closer attention to how science stories are assembled, as well as to what they say. To early-career journalists, it offers an opportunity to examine the working methods behind effective reporting. To scientists, it provides a reminder that making science understandable involves more than simplifying terminology.

Caroline Clavien *CERN.*

This Is for Everyone

By Tim Berners-Lee

Macmillan


CERN

One degree of separation *Tim Berners-Lee at CERN in July 1994. On his screen is an early World Wide Web page.*

As the recent dramatic improvement in AI leads to its increasingly widespread adoption, many of us are left unsure how to respond. The narrative, particularly among digital natives, is that we are living through an experience without precedent. Of course, to some extent, we are – AI is a technology unlike anything that came before it. However, this does not mean history has nothing to teach us.

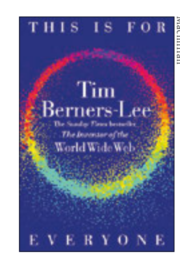
Tim Berners-Lee's invention of the World Wide Web in 1989 went on to transform global communication, economics, and societies, leaving many scrambling to keep up. While his latest book does not attempt to comprehensively answer every question sparked by the rise of AI, it provides a useful reference for anyone grappling with them. *This Is for Everyone* delivers a detailed yet compact history of the web, accompanied by its inventor's reflections on what it has and could become.

The book starts by describing Berners-Lee's childhood in London, where – raised by parents who were both mathematicians and electronic engineers – he was constantly exposed to technology. Born in 1955, he discusses his cohort's "magic-carpet ride through the wave of tech", where computing was developing at a perfect pace for their education and career development.

The CERN years

His interest in technology eventually took him to CERN. The book contains a positive description of the Organization, set alongside a relatable caveat of how challenging it was to facilitate communication within its community. It was this challenge that he sought to address through inventing the web, supported by many CERN colleagues he describes with great affection.

The story of the web's origin is relatively well known within the particle-physics community, but perhaps less so is what happened next. Depicted in detail in the book is the work of the World Wide Web Consortium (W3C), which brought together companies, non-profits, universities and governments to develop standards that would help preserve the web's "universal" nature. The history of the governance of the web is set alongside Berners-Lee's own memories of its increasingly widespread adoption. His joy in the many products of his creation leaps off the page, from the first online museum exhibitions of the nascent web to the later growth of Wikipedia and podcasts.



Macmillan

When describing some early side-effects of the web, Berners-Lee is sometimes too dismissive of their significance. He does not, however, shy away from describing how the negative impact of the web has grown with time, alongside his despair at modern social media. While the book regrettably does not thoroughly discuss what could have been done to prevent social media from reaching their current state, it does include some ideas on how to improve them. Berners-Lee believes that online lack of compassion is a design issue, not a human failing, and that the solution is mostly technical. He proposes a switch to algorithms trained for constructive engagement, similar to those used by music apps, which could be designed to give us more of the things we enjoy.

Berners-Lee also outlines his belief in the importance of data privacy and sovereignty, lamenting how web users have often become products for advertisers, as well as the web's abuse by authoritarian governments. The book explains how this led him to develop the web decentralisation protocol Solid, which gives people ownership of their data through a "pod" they control, and his company Inrupt – a part of his career many may be unfamiliar with. Although Berners-Lee has an obvious vested interest in the protocol, it certainly appears to be an interesting approach to data sovereignty.

The book states Berners-Lee's concern that the rise of AI risks exacerbating current problems with the web and broader digital landscape. Although he emphasises his excitement about AI's potential to benefit the world, he also stresses the need to act quickly to mitigate "the risk that it turns into something darker, more coercive and exploitative, as happened with social media." It is in this area that his experience spearheading a new technology provides some necessary weight to his often bold arguments. His rejection of the false dichotomy between AI "doomers" and "boomers", and his push for a nuanced discussion of its development, reflect the careful approach of the W3C. His emphasis on the need to avoid monopolies and prioritise the rights of the end user for the AI-powered web is likewise a continuation of his original principles for the web. His belief in the importance of international collaboration, first sparked during his time at CERN, leads him to call for "a CERN-like institution for AI before something catastrophic happens."

Although the book is not the most fluently written, it is generally easy to understand, even for readers with no expertise in web development or computing. The anecdotes included about the early web community will likely pique the interest of many *Courier* readers. As seems characteristic of its author, the book presents a very idealistic vision of the future of technology. Given the often toxic nature of debate in this area, however, such optimism is refreshing.

This Is for Everyone will leave you in no doubt that building an AI-powered web with humanity's best interest at heart is one of the most significant global challenges today. Luckily, as Berners-Lee concludes, "There's still time."

Emma Hattersley *CERN.*

Appointments and awards

New ETH president

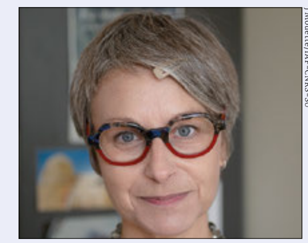
On 24 June, the Swiss Federal Council appointed Günther Dissertori the next president of ETH Zurich, as requested by the ETH Board. Dissertori, professor of particle physics at the university since 2001 and its rector since 2022, takes office on 1 January 2027 for a four-year term, succeeding Joël Mesot at the end of his second term. He began his career at the ALEPH experiment at LEP with precision studies of the strong interaction in electron–positron collisions. Within the CMS collaboration, he worked on the electromagnetic crystal calorimeter. He later served as the experiment's deputy spokesperson and as the Swiss scientific delegate to the CERN Council. Dissertori has also driven the application of particle-detector technologies in medicine, including an ETH spin-off that developed a cost-efficient brain PET scanner.

Thaler to lead LNS

On 1 August, Jesse Thaler succeeded Bolek Wyslouch as director of the MIT Laboratory for Nuclear Science. Thaler received his PhD from Harvard University in 2006 and joined MIT in 2010, where he is the William and Emma Rogers Professor of Physics at the Center for Theoretical Physics – a Leinweber Institute. He was also the inaugural director of the US National Science Foundation's Institute for Artificial Intelligence and Fundamental Interactions. He worked on methods to analyse the internal structure of particle jets, now in routine use at the LHC to identify the decays of heavy boosted objects. More recently, he has combined quantum field theory with machine learning to search collider data for signs of new physics without prescribing in advance what form it should take.

German astronomy prizes

The German Astronomical Society has awarded its 2026 Karl Schwarzschild Medal to Marta Volonteri (pictured below; Institut d'Astrophysique de Paris, CNRS), for pioneering contributions to understanding the formation and evolution of massive black holes and their role in shaping the universe. The Doctoral Thesis Award goes to Maximilian Häberle (European Southern Observatory), whose astrometric catalogue of Omega Centauri revealed fast-moving stars in the globular cluster's core, compelling evidence for an intermediate-mass black



hole of more than 8000 solar masses. Cornelis Dullemond (Heidelberg University) receives the Astrophysical Software Prize for the radiative-transfer code RADMC-3D, and Caroline Gieser (Max Planck Institute for Astronomy) the Ludwig Biermann Award for studies of the physical and chemical processes that govern star formation. The Bruno H. Bürgel Prize for science communication goes to the writer Florian Freistetter, the Hans-Ludwig Neumann Prize for astronomy education to Klaus Hünig (AstroMedia), and the Jugend forscht special prize to school students Alexander Leukert and Leon Heinisch (Isolde-Kurz-Gymnasium, Reutlingen) for a study of satellite orbits.

Jayawardhana takes the helm

On 1 July, astrophysicist Ray Jayawardhana became the 10th president of the California Institute of Technology. Previously provost of Johns Hopkins University, Jayawardhana also holds the Sonja and William Davidow Presidential Chair and joined the Caltech faculty as a professor of astronomy. As president he oversees Caltech's Pasadena campus, the Jet Propulsion Laboratory and the institute's international observatories and

research facilities, including LIGO and the W. M. Keck and Palomar observatories.

Dirac Medal for 2026

On 8 August, the Abdus Salam International Centre for Theoretical Physics awarded its 2026 Dirac Medal to Bernard Derrida (Collège de France), Deepak Dhar (International Centre for Theoretical Sciences), Marc Mézard (Bocconi University) and Haim Sompolinsky (Hebrew University of Jerusalem and Harvard University) "for their pioneering contributions to equilibrium statistical mechanics and for extending its concepts and methods into non-equilibrium statistical mechanics, optimization problems, theoretical neuroscience, and, finally, artificial intelligence". Dhar is honoured for his work on the sandpile model of self-organised criticality, in which single grains occasionally trigger large avalanches, Derrida for introducing the Random Energy Model and for exact solutions of non-equilibrium systems, Mézard for the cavity method and new approaches to the optimisation problems it yields, and Sompolinsky for the statistical physics of neural networks, including his solution of the Hopfield model of associative memory.

Fields Medals awarded

The International Mathematical Union announced the 2026 Fields Medals at the opening ceremony of the International Congress of Mathematicians in Philadelphia, on 23 July. The medals, awarded every four years to up to four mathematicians under the age of 40, went to Yu Deng (University of Chicago), John Pardon (Stony Brook University), Jacob Tsimerman (University of Toronto) and Hong Wang (New York University and IHES). Deng is recognised for advances including the derivation of Boltzmann's kinetic equation from the dynamics of colliding particles, and Pardon for achievements in symplectic geometry, including new approaches to counting holomorphic curves. Tsimerman is honoured for his contributions to arithmetic and complex algebraic geometry and Wang for her work in harmonic analysis and geometric measure theory, including the proof of the three-dimensional Kakeya conjecture.

Award for Hamamatsu

The ATLAS and CMS collaborations presented their 2026 Industrial Award to Hamamatsu Photonics at a ceremony on 15 July, recognising the company's role in the development and production of detector technologies for the LHC and its High-Luminosity upgrade.

Over several decades, the Japanese manufacturer has supplied sensors for the ATLAS Inner Tracker, the CMS Outer and Inner Trackers, the CMS High-Granularity Calorimeter and the CMS MIP Timing Detector, detectors that must survive intense radiation while disentangling the up to 200 simultaneous proton–proton collisions per bunch crossing expected at the upgraded machine. More than 1500 m^2 of silicon wafers have been procured across the two experiments, and the partnership's achievements range from high-quality p-type sensors to the first large-scale production of eight-inch pad sensors, as well as low-gain avalanche diodes and silicon photomultipliers.

PEOPLE OBITUARIES

François Englert 1932–2026

An architect of fundamental interactions

François Englert died on 18 June in Uccle, in the Brussels region, aged 93. Beyond his major contributions to fundamental physics, he had a profound, if discreet, influence on the Belgian scientific community.

He was born on 6 November 1932 in Etterbeek (Brussels), to a family of Jewish immigrants from Poland. During World War II, François and his older brother Marc became *enfants cachés* – hidden children – finding refuge in the countryside at great risk to those who sheltered them. For a child so young, it was a traumatic experience, which François long kept to himself. After the war, he enrolled at the Université Libre de Bruxelles (ULB) in the Faculty of Applied Sciences, a frequent choice at the time, as it guaranteed employment and claimed to offer the same training as a physics degree. After graduating in 1955 he switched to physics, quickly completing a licence in 1958 and a PhD, under the supervision of Jules Géhéniau, the following year.

A turning point in his career came with a postdoctoral stay at Cornell University, where Robert Brout, at first his adviser, became a lifelong colleague. He came back to ULB in 1961, as a lecturer in general physics, and Robert soon followed him. Only later, in 1980, would they formally found the Theoretical Physics group – a generic name chosen to avoid dissecting physics into separate specialities.

Open culture

From Cornell, they had brought back an informal culture: the door was always open to anyone who wanted to discuss physics. As students, we were completely immersed in the research, spending whole afternoons with the two leaders in a sort of musical-chairs brainstorming at the blackboard. They also made sure that a permanent position could be considered only after a postdoctoral stay abroad, an attitude that eventually spread to other departments, reversing a long tradition of internal recruitment.

In the early 1960s, François and Robert were looking for a way to formulate short-distance interactions in the formalism of quantum field theory (QFT). Gauge-invariant QFT was known to describe quantum electrodynamics, but dealt only with massless gauge bosons and hence long-distance interactions. The mechanism they found was submitted to *Physical Review Letters* in June 1964, in a paper that showed diagrammatically how gauge bosons could acquire mass. Independently, in July, Peter Higgs approached


J-M Frère

François Englert shaped fundamental physics and Belgian science with the same discreet authority.

the problem focusing on the elimination of unwanted Goldstone bosons, and included the mass of the gauge bosons in a later paper.

That short paper by François and Robert was in fact remarkably complete: it included the basic spontaneous symmetry breaking by a fundamental scalar field, as is now standard, but also a dynamical approach assuming fermion condensates, and it covered the non-abelian case. The mechanism also opened the way to the proof of the renormalisability of the theory. At the time, both the strong and the weak interactions were candidates for such symmetry breaking, but a concrete realisation awaited a 1967 paper by Steven Weinberg. A different mechanism, confinement, was eventually shown to operate in strong interactions.

François and Robert soon turned their attention to cosmology, first joined by Edgard Gunzig, then by Philippe Spindel and eventually by the whole Brussels group – an exceptional case, as they had insisted that its members operate as independent individuals. One puzzle, in particular, drew them. In an expanding universe, regions thought never to have been in causal contact show almost the same temperature in the cosmic microwave background, the fossil radiation of the Big Bang. Their explanation relied on a fast initial expansion phase, a scenario they called the "causal universe". Here, too, they were precursors. François's curiosity extended to a wide variety of topics, with more interest in finding mechanisms than in a tedious zoology of nature. These ranged from generating the spacetime metric out of a fractal structure to the classification of monopoles and even the structure of viruses!

While François and Robert played a formative role in the Belgian physics community, François never mentioned his role in the student revolts at ULB in 1968, since the structures that emerged from them had fallen short of his hopes. In fact, he kept clear of institutional academic roles altogether. His influence was felt otherwise. Formal recognition, too, was long in coming. It began with the Gravity Research Foundation award (1978), followed by the Francqui Prize (1982), the European Physical Society Prize (1997), the Wolf Prize (2004) and the Sakurai Prize (2010). In 2013 came the Prince of Asturias Award and the Nobel Prize, awarded to François and Peter Higgs, Robert Brout having died in 2011. King Albert II made François a baron in the same year, and he was also appointed professor at Tel Aviv University.

A point of reference

It must be realised that, by the time of François's and Robert's seminal paper, QFT itself had fallen out of fashion. Despite its success in quantum electrodynamics, the framework could not be applied to short-distance interactions, and many preferred more holistic approaches, such as the unitary S-matrix. Interest returned progressively as spontaneous symmetry breaking gained acceptance, a shift that can be followed in the paper's own citation curve, and François and Robert embarked on an inter-university series of lectures and seminars. Despite the philosophical and linguistic differences between the universities, this seeded or cemented the contacts between the theoretical physics groups of Brussels, Leuven and Louvain-la-Neuve. The effort made them a point of reference for Belgian physics.

Interestingly, this path had been trodden before them by Monsignor Georges Lemaître, father of the Big Bang, who visited ULB frequently. To celebrate these unifying efforts, the Belgian Senate, later joined by the Brussels Region, encouraged the formation of the Brout–Englert–Lemaître (BEL) Centre, common to ULB, the Vrije Universiteit Brussel (VUB), the Université Catholique de Louvain (UCLouvain) and the Katholieke Universiteit Leuven (KU Leuven).

Jean-Marie Frère *Université Libre de Bruxelles.*

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GUENAKH MITSELMAKHER 1945–2026

A relentless advocate for physics

Guenakh Mitselmakher, an experimental high-energy physicist of international stature, passed away on 28 January at the age of 80. He was born on 5 December 1945 in Vilnius, Lithuania. After graduating from Moscow State University in 1968, Guenakh started his professional career at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. He often recalled that his mentor Bruno Pontecorvo made the largest impact on his scientific vision and "physics taste".

For his PhD, he joined a collaboration of four that was designing an experiment to search for the charged-lepton flavour violating decay $\mu \to 3e$. The result, published in 1976, improved on the best previous limit by two orders of magnitude. Next, he took part in the first measurement of the charged-pion radius at the Serpukhov accelerator, published in 1974. He then proposed and co-led an experiment that yielded the first measurements of the pion's polarisability and the $\gamma \to 3\pi$ coupling in 1983 and 1986, respectively. In the mid-1980s, he and his group joined the DELPHI experiment at LEP. Guenakh co-led the construction of the DELPHI hadron calorimeter and made critical contributions to the measurement of the number of light neutrinos coupling to the Z boson. To this end, he co-initiated the collaboration of theorists and experimentalists that developed the analysis framework later known as ZFITTER.

Guenakh Mitselmakher, pictured here celebrating the 2013 Nobel Prize in Physics, had a career spanning rare decays, the Higgs boson and gravitational waves.

Guenakh moved to the US in 1991, to join the Superconducting Super Collider (SSC) laboratory in Texas. After the closure of the SSC, in 1993, and having worked briefly at Fermilab, he joined the University of Florida (UF) physics department in 1995. There, he spearheaded a vigorous experimental hadron-collider programme, building a group that at its peak counted seven faculty and more than 40 members, including students, postdocs and engineers. Together they made major contributions to the CDF experiment at Fermilab and to the CMS experiment at CERN, where Guenakh led the design and construction of the endcap muon system.

In both experiments, the UF group held leading roles in the physics programme, most notably in the Higgs-boson discovery in 2012, in precision measurements of the new particle's properties, and in many searches for new physics. Among them, the recent search for the charged-lepton flavour violating decay $\tau \to 3\mu$ echoes Guenakh's research from the early years of his career. He was also the driving force behind UF joining the Laser Interferometer Gravitational-Wave Observatory (LIGO) in 1996, where the group contributed prominently to the design and construction of the apparatus and to data analysis. Indeed, the first gravitational-wave event, in 2015, was initially identified by coherent WaveBurst, a real-time analysis algorithm conceived in a 2008 paper that Guenakh co-authored.

Guenakh Mitselmakher was a relentless advocate for the pursuit of physics of pivotal significance. His scientific legacy will persist through the many scientists he mentored during his career.

Philip Chang, Jacobo Konigsberg, Andrey Korytov *and* **Yuta Takahashi**
University of Florida.

GEORGE KALMUS 1935–2026

A leader through changing times

It is with great sadness that we learned George Kalmus passed away on 27 May, at the age of 91. George had a long and distinguished career in particle physics, which took him from the early days of bubble chambers to the LHC and beyond.

Born in Beočin, Yugoslavia, on 21 April 1935, George moved to London with his family in 1939. He obtained his physics degrees at University College London (UCL), gaining his PhD in 1959 with the pioneering study "Physical properties of bubble chambers". As a research assistant at UCL, he was responsible for the design and specification of the magnet for the British Heavy Liquid Bubble Chamber. He also studied semileptonic decays of Λ hyperons with UCL colleagues and a group at the Lawrence Radiation Laboratory in Berkeley, later the Lawrence Berkeley Laboratory (LBL), using their 30-inch heavy liquid chamber.

From the early days of bubble chambers to the LHC and beyond

From 1962 to 1967, apart from one year back at UCL, he worked at LBL as a research assistant, studying semileptonic Λ decays and all aspects of K^+ meson decays, especially the rare semileptonic four-body K^+_{e4} channel. He became a tenured senior physicist at LBL in 1967, switching to the study of hadron resonances using K^- and π^+ beams.

In 1972, George returned to Europe to lead the bubble-chamber group at the Rutherford Appleton Laboratory (RAL). His large group participated in various collaborations, with George himself proposing and working on K^-p and $K^0_L p$ experiments in the 2 m hydrogen bubble chamber at CERN.

Following the discovery of open charm in 1976, he proposed and led a major experiment to investigate direct electron production by hadrons using a track-sensitive target in the Big European Bubble Chamber at CERN. He subsequently led a collaboration at the SLAC Hybrid Facility, where he instigated the addition of a high-resolution camera. This was ▷

crucial to the successful measurement, in 1982, of the decays of D mesons produced by 20 GeV photons in the 1 m hydrogen bubble chamber. His exploitation of bubble chambers and work on kaon and charm physics contributed to his election as fellow of the Royal Society in 1988.

George went on to establish the UK collaboration working on DELPHI at CERN's LEP collider, where he applied his formidable expertise to all aspects of the experiment: design, realisation and analysis. He led RAL's involvement in the construction of the superconducting solenoid – at the time the largest in the world – and pushed for the addition of a silicon microvertex detector, one of the first at LEP. He was elected deputy spokesman for DELPHI and chaired its collaboration board from 1986 to 1993.

George was director of RAL's Particle Physics Department from 1986 to 1997, with wide-ranging responsibilities for the whole of the UK's particle-physics programme, latterly including the preparation of the LHC experiments. He was appointed to CERN's Scientific Policy Committee from 1990 to 1997 – a time that saw the approval of the LHC – and chaired it from 1999 to 2001.

George Kalmus had a special combination of scientific ability, integrity and human skills.

In 1998 George returned to his earlier interest in ultra-rare kaon decays by joining the NA48 experiment at CERN. He retired from RAL in 2000, but not from physics, joining the ZEPLIN-III experiment to search for dark matter in the Boulby Underground Laboratory in Yorkshire, UK.

George had a special combination of scientific ability, integrity and human skills, all greatly appreciated by those who knew and worked with him. He helped many careers and led UK particle physics with a sure hand through sometimes tempestuous waters for more than a decade. We owe him a great deal. He was survived by his brother, Peter, professor at Queen Mary University of London, his three daughters and his grandchildren. Our deepest sympathy goes to the whole family.

His former colleagues and friends.

- *We are very saddened to have learned that Peter Kalmus passed away on 2 August. A full obituary will appear in a later edition of* CERN Courier.

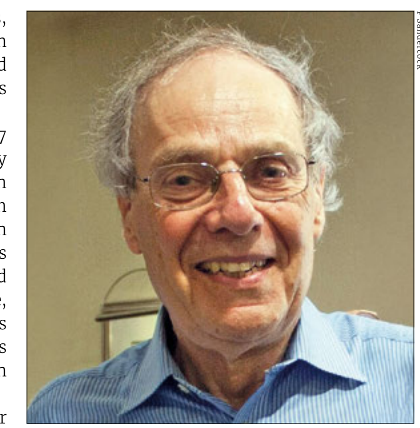
NORMAN MCCUBBIN 1948–2026

A Renaissance man in particle physics

To the shock of family, colleagues and friends, Norman McCubbin died suddenly at his home in Oxford on 22 June. His long and distinguished career included vital roles in UK particle physics and at CERN.

Norman was born in north London on 27 June 1948, the eldest of three sons. His family later left Leicester for Kenya, where Norman attended Kenton College in Nairobi. He then boarded at the prestigious Repton School in Derbyshire, to which he jokingly ascribed his success in winning ballot tickets to England test cricket matches. He attended New College, University of Oxford, achieving a first-class honours degree and a doctorate. His thesis contained an analysis of K^-p interactions in the CERN 2 m bubble chamber.

Norman moved to CERN as a Lancaster postdoc, working on the CHLM experiment at the Intersecting Storage Rings. After joining the Rutherford Appleton Laboratory (RAL) as a postdoc in 1976, he moved to the British-French-Scandinavian collaboration on the Wide-Angle Spectrometer and then the Axial Field Spectrometer, where he worked on the world's first uranium compensating calorimeter. After getting tenure at RAL, Norman joined the HELIOS fixed-target heavy-ion experiment, of which he became spokesperson.



Norman McCubbin was a Renaissance man, broad in interests and expertise.

His advice was greatly valued by successive ATLAS spokespersons

He was involved in the early stages of the ZEUS experiment at DESY, becoming leader of the RAL ZEUS group in 1990, and managed a large group of capable technical staff and research associates who worked on the construction and commissioning of the central tracking detector. Norman also played an important role in developing the experiment's software and held senior positions, including simulation coordinator. He remained closely involved throughout ZEUS's running.

As ZEUS matured, he began to work on ATLAS, again leading the development of the software. He was computing coordinator from 1999 to 2003, steering the decision on computing language with typically consummate tact. His advice was greatly valued by successive ATLAS spokespersons, who gave him numerous important responsibilities, including chairing the committee that in 2007 recommended task-sharing algorithms and criteria for ATLAS membership, authorship and financial contributions. He was assiduous in employing his exceptional command of English to correct and polish ATLAS papers, and maintained his keen interest in heavy ions as an expert within ATLAS.

Norman was a leader of UK particle physics, becoming first division leader and, from 2007, director of RAL's Particle Physics Department, while gaining the admiration and respect of all who worked with him. After officially retiring from RAL in 2012, Norman continued to contribute to ATLAS and taught physics to undergraduates at St Anne's College, Oxford. He inspired many generations of students and was an extremely popular tutor, relishing the core subjects of thermodynamics, statistical mechanics, relativity and symmetries.

Norman McCubbin was a Renaissance man, learned but never pedantic, broad in interests and expertise. He loved cricket and golf, music and current affairs. He was an exceptional physicist, publishing both cutting-edge particle-physics papers and articles on the history of physics. He will be greatly missed by his family and his many colleagues and friends.

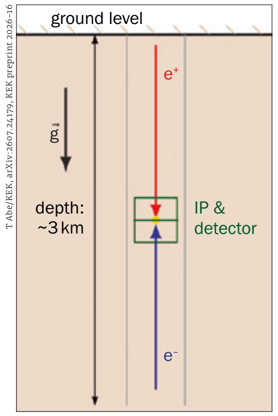
Brian Foster *and* **Neville Harnew**
University of Oxford.

BACKGROUND

Notes and observations from the high-energy physics community

Falling for the Higgs

In a recent preprint, Tetsuo Abe (KEK) proposed an audacious vertical electron–positron collider for precision Higgs studies, housed in a single shaft about 3 km deep. Positrons would be accelerated downwards from the surface and electrons upwards from the bottom, colliding near mid-depth. Such a compact design would demand accelerating gradients far beyond anything a collider has yet sustained. In return, the machine's liquid-nitrogen coolant would flow downhill under its own weight, and its detector would enjoy the quiet of deep rock.



T Abe/KEK, arXiv:2607.24179, KEK preprint 2026-16

5.6 trillion

Pixels in the largest two-dimensional map of the universe, assembled over 13 years by the DESI Legacy Surveys

Media corner

"When you're looking at trillions of objects, a one-in-a-million chance is happening, like, two or three times a day."

Jeremy Perkins (NASA Goddard), on the discovery potential of the Roman Space Telescope's surveys (*Discover*, 8 August).

"It's an experimental triumph."

Colin Morningstar (Carnegie Mellon University), on BESIII evidence that the X(2370) is predominantly a glueball, a particle made of gluons alone (*Science*, 11 August).

"This limitation was already recognised in the 1990s and it has been the elephant in the room since then."

Abhay Ashtekar (Penn State), on the difficulty of defining entropy for dynamical black holes (*Physics World*, 12 August).

"The way in which particles are emitted in a collision is different depending on which model you use. So it's not just semantics."

Chun Yuen Tsang (Argonne National Laboratory), on measurements favouring a Y-shaped junction of gluons over valence quarks as the carrier of the proton's baryon number (*Science News*, 13 August).

"Until now, reactor antineutrino experiments have mainly focused on operating reactors, where the antineutrino flux is much larger."

Anthony Onillon (Max Planck Institute for Nuclear Physics), on the first measurement of antineutrinos from spent nuclear fuel after reactor shutdown (Max Planck Institute for Nuclear Physics, 4 August).

From the archive: September/October 1986

Rubbia Committee recommends increased research and development

Presenting an interim report of the Long Range Planning Committee set up by CERN Council in June 1985, Chairman Carlo Rubbia advocated that to safeguard its future CERN should increase its commitment for research and development work.

The Committee has as its mandate 'to explore various options for the long range future of CERN, taking into account existing facilities, emphasizing respective pros and cons ... [within] realistic boundary conditions concerning financial and manpower limitations'. The Committee set up subpanels to look into the feasibility of a hadron collider in the LEP tunnel, to investigate the possibility of a large electron–positron collider in the 1000 GeV range, and to look into the underlying physics issues.

To drive forward the twin spearheads of a hadron collider in the LEP tunnel and a 1000 GeV electron–positron collider, the Committee advocates that a 'programme of research and development in advanced accelerator technology be immediately undertaken in collaboration with outside Laboratories and with industry.'

● Text adapted from *CERN Courier* September 1986 p17.

'Mountain top' experience

I have reached home, but am not the same. I have been to a mountain top experience in the Conference on the Teaching of Modern Physics. It is a rare experience for a teacher to be permitted to associate with the recognized leadership of a field and feel no fear of appearing 'ignorant'. On top of that, meeting in one of the premiere facilities of science compounds the feeling of respect and privilege to be one of those studying physics, and striving to teach the subject. I love teaching, but need to be fed myself. That is what this session has done for me.

● Text adapted from *CERN Courier* September 1986 p26 and p39.

CERN-PHOTO-8606616

Teachers from European schools came to CERN in June for a four-day practical course on microelectronics given by Peter Hayman (standing) of Liverpool and supported by Plessey Semiconductors.

Compiler's note

When the "Rubbia Committee" presented its final report in June 1987, it recommended a proton–proton collider in the LEP tunnel, based on superconducting magnets in the 8–10 T range, as the first choice for CERN's next major facility. That machine became the LHC. The report also acknowledged the route to higher electron–positron collision energies through a purpose-built linear collider.

The "mountain top" experience reflected the feelings of teachers who went to Fermilab in 1986 for the second conference in a series on teaching modern physics. The first had been held at CERN in 1984. Courses for teachers continue at CERN and Fermilab, contributing to the socio-economic benefits of the high-tech research at both laboratories (p29).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