CERN Courier – digital edition

Welcome to the digital edition of the May/June 2024 issue of CERN Courier.

Uncovering the fundamental laws and constituents of the universe is not just a source of fascination for particle physicists. Engineers, chemists and materials scientists draw similar motivation in meeting the challenging and strange requirements of cutting-edge accelerator and detector technologies. The interdisciplinary materials, metrology and non-destructive testing section at CERN supports projects such as the HL-LHC magnet development with state-of-the-art equipment and analysis, and its services are increasingly in demand from projects outside – including the ITER fusion experiment (p37).

Also explored in depth in this issue are the next steps for the AWAKE plasma-wakefield experiment (p25), the new-physics implications of neutrino masses (p29) and a lesser-known approach to quantum gravity called asymptotic safety (p43). Advanced triggers for the HL-LHC experiments (p8), the selection of the SHiP experiment for CERN’s North Area (p7) and DESI’s first cosmology results (p11) are among other highlights, along with the latest LHC results (p15), conference reports (p19), news in brief (p13), opinion (p49), reviews (p52), careers (p55) and more.

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From materials science to quantum gravity

Uncertainty is the fundamental law and constituents of the universe is not just a source of fascination for particle physicists. Engineers, chemists and materials scientists draw similar motivation in meeting the challenging and strange requirements of cutting-edge accelerator and detector technologies. The interdisciplinary materials, metrology and non-destructive testing section at CERN supports projects such as the HL-LHC magnet development with state-of-the-art equipment and analysis, and its services are increasingly in demand from outside (p37).

Also explored in depth in this issue are the AWAKE experiment (p25), the profound implications of neutrino masses (p28) and a lesser-known approach to quantum gravity called asymptotic safety (p33). Advanced triggers for the HL-LHC (p7), the SHIP experiment (p17) and DESY’s first cosmology results (p14) are among other highlights, along with the latest LHC results (p9), conference reports (p99) and news in brief (p1). The view (p1), plus opinion (p2), reviews (p23), careers (p16) and more.

From materials science to quantum gravity, the Courier has been capturing developments in global high-energy physics and related fields for 65 years. A de facto journal of record, you might say, that enables readers to keep up with developments beyond their specialist fields in an accessible and hopefully enjoyable way. The magazine has undergone several changes, including this page, allowing the editor to bring to light the less well-known aspects of the field’s agendas. More than 50 new hadrons have been discovered. Neutrino and dark-matter experiments have carved out swathes of new parameter space. Antihydrogen spectroscopy has taken off.

The Courier offers a professional, informal forum in which to explore and debate such weighty matters, which the next European strategy update is about to bring into sharp focus. This relies on the continued efforts of individuals to take precious time out of their routines to get in touch and write. Another pillar of the Courier to be guarded closely is its editorial independence from CERN’s organisational hierarchy. Supported by a seasoned advisory board, the editor’s decision is final. Amusing the changes made to the magazine in 2019 was the introduction of this page, allowing the editor to bring context to the articles in each issue. It’s now over to former deputy editor Mark Rayner to embrace global high-energy physics in all its shapes, sizes and wonder.
ShiP to chart hidden sector

In March, CERN selected a new experiment called SHiP to search for hidden particles using high-intensity proton beams from the SPS. First proposed in 2013, SHiP is scheduled to operate in the North Area’s ECN3 hall from 2031, where it will enable searches for new physics at the “coupling frontier” complementary to those at high-energy and precision-flavour experiments.

Interest in hidden sectors has grown in recent years, given the absence of evidence for non-Standard Model particles at the LHC, yet the existence of several phenomena (such as dark matter, neutrino masses and the cosmic baryon asymmetry) that require new particles or interactions. It is possible that the reason why such particles have not been seen is not that they are too heavy but that they are light and extremely feeble interacting. With such small couplings and mixings, and thus long lifetimes, hidden particles are extremely difficult to constrain. Operating in beam-dump configuration that will produce copious quantities of photons and charm and beauty hadrons, SHiP will generically explore hidden-sector particles in the MeV to multiple-GeV mass range.

Optimised searching

SHiP is designed to search for signatures of models with hidden-sector particles, which include heavy neutral leptons, dark photons and dark scalars, by full reconstruction and particle identification of Standard Model final states. It will also search for light-dark-matter scattering signatures via the direct detection of atomic-electron or nuclear results in a high-density medium, and is optimised to make measurements of rare neutrinos and of neutrino-induced-charm production by all three neutrino species.

The experiment will be built in the existing TCC/ECN experimental facility in the North Area. The beam–dump setup consists of a high-density proton target located in the target bunker, followed by a hadron stopper and a muon shield. Sharing the SPS beam time with other fixed-target experiments and the LHC should allow around 6 × 10^20 protons on target to be produced during 15 years of nominal operation. The detector itself consists of two parts that are designed to be sensitive to as many physics models and final states as possible. The scattering and neutrino detector will search for light dark matter and perform neutrino measurements. Further downstream is the much larger hidden-sector decay spectrometer, which is designed to reconstruct the decay vertex of a hidden-sector particle, measure its mass and provide particle identification of the decay products in an extremely low-background environment.

One of the most critical and challenging components of the facility is the proton target, which has to sustain an energy of 2.6 MJ impinging on it every 7.2 s. Another is the muon shield. To control the beam-induced background from muons, the flux in the detector acceptance must be reduced by some six orders of magnitude over the shortest possible distance, for which an active muon shield entirely based on magnetic deflection has been developed.

The focus of the SHiP collaboration now is to produce technical design reports. “Given adequate funding, we believe that the TDR phase for BDF/SHiP will take us about three years, followed by production and construction, with the aim to commission the facility towards the end of 2023 and the detector in 2025,” says SHiP spokesperson Andrey Golubtsov of Imperial College London.

“This will allow up to two years of data-taking during Run 4, before the start of Long Shutdown 4, which would be the obvious opportunity to improve or consolidate, if necessary, following the experience of the first years of data-taking.”

The decision to proceed with SHiP concluded a process that took more than a year, involving the Physics Beyond Colliders study group and the SPS and PS experiments committees. Two other experiments, HIKE and SHADOWS, were proposed to explore the high-intensity beam from the SPS. Continuing the successful tradition of kaon experiments in the ECN hall, which currently hosts the NA62 experiment, HIKE (high-intensity kaon experiment) proposed to search for new physics in rare charged and neutral kaon decays and also allowing on-axis searches for hidden particles. For SHADOWS (search for hidden and dark objects with the SPS), which would have taken data concurrently with HIKE while the beamline is operated in beam-dump mode, the focus was low-background searches for off-axis hidden-sector particles in the MeV–GeV region.

“In terms of their science, SHiP and HIKE/SHADOWS were ranked equally by the relevant scientific committees,” explains CERN director for research and computing Joachim Mnich. “But a strategic choice for CERN.”
Next-generation triggers for HL-LHC and beyond

The LHC experiments have surpassed expectations in their ability to squeeze the most out of their large datasets, also demonstrating the wealth of scientific understanding to be gained from improvements to data-acquisition pipelines. Colliding proton bunches at a rate of 40 MHz, the LHC produces a huge quantity of data that must be filtered in real-time to levels that are manageable for offline computing and ensuing physics analysis. When the High-Luminosity LHC (HL-LHC) enters operation from 2029, the data rate and event complexity will further increase significantly.

To meet this challenge, the general-purpose LHC experiments ATLAS and CMS are preparing significant detector upgrades, which include improvements to the online triggering or trigger-selection processes. In view of the importance of this step, the collaborations seek to further enhance their trigger and analysis capabilities, and thus their scientific potential, beyond their currently projected scope.

Following a visit by a group of private-sector donors, in 2023, CERN, in close collaboration with the ATLAS and CMS collaborations, submitted a proposal to the US Department of Energy and the National Science Foundation, which resulted in a $48 million grant. The donation laid the foundations of the Next Generation Triggers project, which kicked off in early 2024. The five-year-long project aims to accelerate novel computing, engineering and scientific ideas for the ATLAS and CMS upgrades, also taking advantage of advanced AI technology, not only in large-scale data analysis and simulation but also embedded in front-end detector electronics. These include quantum-inspired algorithms to improve simulations, and heterogeneous computing architectures and new strategies to optimize the performance of GPU-accelerated experiment code. The project will also provide insight to detectors and data flows for future projects, such as experiments at the proposed Future Circular Collider, while the associated infrastructure will support the advancement of software and algorithms for simulations that are vital to the HL-LHC and future-collider physics programs. Through the direct involvement of the CERN experimental physics, information technology and theory departments, it is expected that results from the project will bring benefits across the lab’s scientific programme.

The strategy update

On 21 March the CERN Council decided to launch the process for updating the European strategy document. The European strategy – the cornerstone of Europe’s decision-making process for the long-term future of the lab, as described in the CERN Council, the European strategy is

BESIII passes milestone at the charm threshold

The BESIII collaboration has marked a significant milestone in its pursuit to measure properties of the Higgs boson with unprecedented precision. In the last 15 years, the collaboration has collected 20 fb⁻¹ of e⁻/μ⁻/τ⁻+hadron data at the CERN energy of 3.5 GeV, a notoriously challenging environment due to the large number of background events.

The BESIII collaboration is an international effort involving more than 1,200 physicists from 77 institutes in 18 countries. The detector has collected data at a range of running points with centre-of-mass energies from 1.8 to 4.95 GeV, most of which are inaccessible to other operating colliders. This energy regime allows researchers to make largely unique studies of physics above and below the charm threshold, and has led to important discoveries and measurements in a wide range of fields, including charm and tau physics.

The FCC-ee feasibility study will be a key input for the next strategy update

The European strategy process was initiated in 2007, placing the LHC at the top of particle physics’ scientific priorities, with significant luminosity upgrades being mooted. A ramp-up of R&D for future accelerators also featured highly on the priority list, followed by coordination with a potential International Linear Collider (ILC) or a Global Muon neutrino programme.

Putting the ILC proposal in 2015, which kept the LHC at top priority and attached increasing importance to its high-precision upgrade, stated that Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next strategy update. The latter charge was formulated in more detail in the second strategy update, completed in 2020, which recommended a High-luminosity LHC (HL-LHC) project at CERN by the time of the next strategy update. The latter charge was formulated in more detail in the second strategy update, completed in 2020, which recommended a High-luminosity LHC (HL-LHC) project at CERN by the time of the next strategy update.

The final report of the FCC feasibility study will be a key input for the next strategy update.

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The EIC project will offer the unique ability to collide a beam of polarised high energy electrons with polarised protons/polarised light charged ions, or heavy ions. Its aim is to produce 100 nanoparticles and provide insight to detectors and data flows for future projects, such as experiments at the proposed Future Circular Collider, while the associated infrastructure will support the advancement of software and algorithms for simulations that are vital to the HL-LHC and future-collider physics programs. Through the direct involvement of the CERN experimental physics, information technology and theory departments, it is expected that results from the project will bring benefits across the lab’s scientific programme.

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New subdetectors to extend ALICE’s reach

The LHC’s dedicated heavy-ion experiment, ALICE, is to be equipped with an upgraded inner tracking system and a new forward calorimeter to extend its physics reach. The upgrades have been approved for installation during the next long shutdown from 2026 to 2028.

With 10% of active Silicon and nearly 13 billion pixels, the current ALICE inner tracker, which has been in place since 2011, is the largest pixel detector ever built. It is also the first detector at the LHC to use monolithic active pixel sensors (MAPS) instead of the more traditional Hybrid pixel and silicon microstrips. The new inner tracking system, ITS3, uses a novel stitching technology to connect MAPS of 30 μm thickness and up to 260 x 260 km in size that can be bent around the beam pipe in a truly cylindrical shape. The first layer will be placed just 2 mm from the beam pipe and will extend to the injection point, with a much lighter support structure that significantly reduces the material volume and therefore its effect on particle trajectories. Overall, the new system will boost the pointing resolution of the tracks by a factor of two compared to the present ITS detector, significantly enhancing measurements of thermal radiation emitted by the quark–gluon plasma and enabling insights into the interactions of charm and beauty quarks as they propagate through it.

The new forward calorimeter, FCal, is optimised for photon detection in the forward direction. It consists of a highly granular electromagnetic calorimeter, composed of 18 layers of 1 x 1 cm² silicon-on-pad sensors patterned with tungsten converter plates and two additional layers of 2 x 2 cm² pixels, and a hadronic calorimeter made of copper calorimeter tubes and scintillating fibres. By measuring inclusive photons and their correlations with neutral mesons, as well as the production of jets and charmonia, FCal will add new capabilities to explore the small Biotron-X parton structure of nucleons and nuclei.

Technical design reports for the ITS3 and FCal projects were endorsed by the relevant CERN review committees in March. The construction phase has now started, with the detectors due to be installed in early 2028 in order to be ready for data taking in 2029. By upgrades, in particular ITS3, are also an important step on the way to ALICE 3 – a major proposed upgrade of ALICE that is approved, would enter operation in the mid-2030s.

Upgrade ahead: ALICE’s new forward calorimeter (left), and the components of the Inner Tracker System 3 (right).

CP-violating angle γ of the unitarity triangle in events where a beauty meson decays into a D meson and an accompanying kaon. Exploitation of the full 2027 sample will be essential in helping LHCB and Belle II realise their full potential in CP-violation measurements with larger data sets in the future, he adds. “Hence BESSII is very complementary to the higher energy experiments, demonstrating the strong synergies that exist between particle- physics facilities worldwide.”

This summer, BEPCII will undergo an upgrade that will increase its luminosity. Over the next few years, it is expected that the tracking power of ALICE will be increased by a factor of two compared to the present. In the longer term, there are plans, elsewhere in China, for a Super Tau-Charm Facility – an accelerator that would be integrated with the BEPCII and BESSII programme with datasets that are two orders of magnitude larger.

First DESI results shine a light on Hubble tension

The expansion of the universe has been a well-established fact of physics for almost a century. By the turn of the millennium the ratio of this expansion, referred to as the Hubble constant (H), has converged to a value of around 70 km/s/Mpc. However, more recent measurements have given rise to tension: whereas those derived from the cosmic microwave background (CMB) cluster around a value of 67 km/s/Mpc, direct measurements using a local distance ladder (such as those based on Cepheids) mostly prefer larger values around 73 km/s/Mpc.

This disagreement between early- and late-universe measurements, respectively, stands at the 4–5σ level, thereby calling for novel measurements.

One such source of new information are large galaxy surveys, such as the one currently being performed by the Dark Energy Spectroscopic Instrument (DESI). This Arizona-based instrument uses 5000 individual robots that optimise the focal plane of the detector to allow it to measure 5000 galaxies at the same time. The goal of the survey is to provide a detailed picture of the evolution of the universe by focusing on how structures form between galaxies. During its first year of observation, the results of which have now been released, DESI has provided a catalogue of millions of objects.

### Primordial imprints

Small fluctuations in the density of the early universe resulted not only in structures in the CMB, as measured for example by the Planck probe, but also left imprints in the distribution of baryonic matter. Each over-dense region is nowadays surrounded by a nearly homogeneous baryonic matter and photons. The gravitational force from dark matter on the baryonic component can be probed by measuring the pressure that dark matter exerts on the photon gas through relativistic effects or its clustering.

### Hubble tension

#### Definitions

- **CMB**: CMB anisotropy measurements from Planck and the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT).
- **DESI**: BAO+rd, BAO+BBN, BAO+BBN+θ∗, BAO+BBN+θ∗+CMB
- **SDSS**: BAO+BBN
- **DESI+SDSS**: BAO+BBN+θ∗+CMB
- **SHOES** (D): BAO+BBN
- **SHOES** (Δ): BAO+rd

#### Data release

- **DESI** released in 2021
- **SDSS** released in 2022
- **DESI+SDSS** released in 2023

#### Measurements

**BAO**: Baryonic acoustic oscillation measurements in combination with other data (blue, red), corresponding results from the Sloan Digital Sky Survey and combinations thereof (blue), CMB anisotropy measurements from Planck and the Atacama Cosmology Telescope (orange), and measurements using Cepheids or tip-of-the-red-giant branch distance ladders (green).

**H0**

- **DESI** measurement: 68.2 ± 1.4 km/s/Mpc
- **SDSS** measurement: 68.5 ± 1.7 km/s/Mpc
- **DESI+SDSS** measurement: 70.0 ± 1.6 km/s/Mpc

**θ∗**

- **DESI** measurement: 35 ± 17°
- **SDSS** measurement: 32 ± 17°
- **DESI+SDSS** measurement: 31 ± 17°

#### Analysis

- **DESI** first-year results better match a time-evolving equation of state, w.
- **SDSS** and **DESI+SDSS** results differ from **DESI** by 1.3σ.
- **DESI+SDSS** results are consistent with the standard model of cosmology.

### Further reading

- C. S. Koch et al., 2022, *arXiv* 2204.03900
- C. S. Koch et al., 2022, *arXiv* 2204.03901
- C. S. Koch et al., 2022, *arXiv* 2204.03902
NEWS DIGEST

A new piece for FERS (Front End Readout System) 5200
A5203/DT5203 64/128 ch TDC unit housing the CERN picotDC chip

- 3.125 ps LSB, 52.2 µs / 210 µs dynamic range
- 7 ps RMS typ, with no change in the input signal amplitude
- 20 ps RMS typ with variable amplitude input pulses and walk correction

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- FERS-5203 Accessories
- A5255 Quad Connector Adapter
- A5256 16+1 ch Leading/Trailing Edge Discriminator
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CMS measures Weinberg angle
The CMS collaboration has presented the most precise measurement of the effective leptonic electroweak mixing angle yet performed at a hadron collider (CMS: PAS–HIG-22–012). Also known as the Weinberg angle, the electroweak mixing angle mixes the fundamental W and Z fields to generate photons and Z bosons in electroweak symmetry breaking, and links the masses of the W and Z bosons. CMS’s measurement is effective and leptonic as it includes quantum corrections and is extracted from forward–backward asymmetries in dimuon and dilepton events. Differing measurements at LEP and by the SDL experiment at SLAC have puzzled physicists for more than a decade. “This result shows that precision physics can be carried out at hadron colliders,” says CMS spokesperson Patricia McElrath.

STAR targets QCP conductivity
Peripheral collisions between heavy ions are thought to produce magnetic fields of order 10^15 T that dissipate within 10^-10 seconds. The rapid decay of such ultra–strong magnetic fields should deflect particles and antiparticles in the resulting quark–gluon plasma (QGP) differently, with the potential to reduce the radioactivity of long–lived waste from 300,000 years to 300 years, they claim, with reduced risk of proliferation and safety features allowing the reactor to be shut down within two milliseconds. With uranium prices at their highest level since the Fukushima disaster in 2011, thorium’s greater abundance also makes the technology more sustainable than traditional reactors.

Fermilab boosts local economy
Fermilab contributed $3.8 billion to the US economy and supported more than 7,000 jobs in FY2022, says a new report by the lab. The study models direct economic impacts as well as business-to-business and consumer spending resulting from procurement and employment. Fermilab’s home state of Illinois received 38% of the $2 billion spent on new contracts. South Dakota received 4% as excavation and engineering activities continued at the Sanford Underground Research Facility, in preparation for the DUNE experiment. Economic output due to DUNE and related projects is expected to peak between 2025 and 2028.

Majorana fermions emerge
In the latest example of fundamental symmetries being unearthed in condensed–matter systems, emergent quasiparticle excitations resembling Majorana fermions may have been observed in a “spin liquid” – in this case, a honeycomb lattice of ruthenium atoms with magnetic moments that cannot arrange themselves into a stable configuration even at low temperatures. The study exploits the thermal Hall effect, whereby a heat current is generated perpendicular to a temperature gradient when an orthogonal magnetic field is applied. Researchers in Japan and Korea claim conclusive evidence that their experiment’s current carriers resemble Majorana fermions (Sci. Adv. 10.1126/sciadv.abj9311).
The CMS collaboration has reported the first observation of $\gamma\gamma\rightarrow\tau\tau$ collisions. The results set a new benchmark for the tau lepton's magnetic moment, surpassing previous constraints and paving the way for studies probing new physics.

For the tau lepton's less massive cousins, measurements of magnetic moments offer exceptional sensitivity to beyond-the-Standard Model physics. In quantum electrodynamics (QED), quantum effects modify the Dirac equation, which predicts a gyromagnetic factor $g$ precisely equal to two. The first-order correction, an effect of only $\pm 0.2\%$, was calculated by Julian Schwinger in 1948. Taking into account higher orders too, the electron anomalous magnetic moment, $a = (g-2)/2$, is one of the most precisely measured quantities in physics and is in remarkable agreement with QED predictions. The $g-2$ of the muon has also been measured with high precision and shows a persistent discrepancy with certain theoretical predictions. By contrast, however, the tau lepton’s $g-2$ suffers from a lack of precision, given that its short lifetime makes direct measurements very challenging. If new physics effects scale with the squared lepton mass, deviations from QED predictions in this measurement would be about 280 times larger than the muon $g-2$ measurement. Experimental insights on $g-2$ can be indirectly obtained by measuring the exclusive production of tau-lepton pairs created in photon–photon collisions. As charged particles pass each other at relativistic velocities in the LHC beampipe, they generate intense electromagnetic fields, leading to photon–photon collisions. The production of tau-lepton pairs in photon collisions was first observed by the ATLAS and CMS collaborations in Pb–Pb runs. The CMS collaboration has now observed the same process in proton–proton (pp) data. When photon collisions occur in pp runs, the photons can remain intact. As a result, final-state particles can be produced exclusively, with no other particles coming from the same production vertex.

Separating these low particle multiplicity events from ordinary pp collisions is extremely challenging, as events “pile up” within the same bunch crossing. Thanks to the precise tracking capabilities of the CMS detector, tau-lepton tracks were isolated within just a millimetre around the interaction vertex. Figure 1 shows the resulting excess of $\gamma\gamma\rightarrow\tau\tau$ events rising above the estimated backgrounds when few additional tracks were observed within the selected mm window. This process was used to constrain a using an effective-field-theory approach. BSM physics affecting $g-2$ would modify the expected number of $\gamma\gamma\rightarrow\tau\tau$ events, with the effect increasing with the di-tau invariant mass. Compared to Pb–Pb collisions, the pp data sample provides a more precise $g-2$ value because of the larger number of events and higher invariant masses probed, thanks to the higher energy of the photons. Using the invariant-mass distributions collected in pp collisions during the full LHC Run 2, the CMS collaboration has not observed any statistically significant deviations from the Standard Model. The tightest constraint ever on $a$ was set, as shown in figure 2. The uncertainty is only three times larger than the value of Schwinger’s correction.

Further reading
CMS Collab. 2024 CMS-PAS-SMP-23-005.

CMS closes in on tau g–2

The CMS collaboration has reported the first observation of $\gamma\gamma\rightarrow\tau\tau$ collisions. The results set a new benchmark for the tau lepton’s magnetic moment, surpassing previous constraints and paving the way for studies probing new physics.

For the tau lepton’s less massive cousins, measurements of magnetic moments offer exceptional sensitivity to beyond-the-Standard Model physics. In quantum electrodynamics (QED), quantum effects modify the Dirac equation, which predicts a gyromagnetic factor $g$ precisely equal to two. The first-order correction, an effect of only $\pm 0.2\%$, was calculated by Julian Schwinger in 1948. Taking into account higher orders too, the electron anomalous magnetic moment, $a = (g-2)/2$, is one of the most precisely measured quantities in physics and is in remarkable agreement with QED predictions. The $g-2$ of the muon has also been measured with high precision and shows a persistent discrepancy with certain theoretical predictions. By contrast, however, the tau lepton’s $g-2$ suffers from a lack of precision, given that its short lifetime makes direct measurements very challenging. If new physics effects scale with the squared lepton mass, deviations from QED predictions in this measurement would be about 280 times larger than the muon $g-2$ measurement. Experimental insights on $g-2$ can be indirectly obtained by measuring the exclusive production of tau-lepton pairs created in photon–photon collisions. As charged particles pass each other at relativistic velocities in the LHC beampipe, they generate intense electromagnetic fields, leading to photon–photon collisions. The production of tau-lepton pairs in photon collisions was first observed by the ATLAS and CMS collaborations in Pb–Pb runs. The CMS collaboration has now observed the same process in proton–proton (pp) data. When photon collisions occur in pp runs, the photons can remain intact. As a result, final-state particles can be produced exclusively, with no other particles coming from the same production vertex.

Separating these low particle multiplicity events from ordinary pp collisions is extremely challenging, as events “pile up” within the same bunch crossing. Thanks to the precise tracking capabilities of the CMS detector, tau-lepton tracks were isolated within just a millimetre around the interaction vertex. Figure 1 shows the resulting excess of $\gamma\gamma\rightarrow\tau\tau$ events rising above the estimated backgrounds when few additional tracks were observed within the selected mm window. This process was used to constrain a using an effective-field-theory approach. BSM physics affecting $g-2$ would modify the expected number of $\gamma\gamma\rightarrow\tau\tau$ events, with the effect increasing with the di-tau invariant mass. Compared to Pb–Pb collisions, the pp data sample provides a more precise $g-2$ value because of the larger number of events and higher invariant masses probed, thanks to the higher energy of the photons. Using the invariant-mass distributions collected in pp collisions during the full LHC Run 2, the CMS collaboration has not observed any statistically significant deviations from the Standard Model. The tightest constraint ever on $a$ was set, as shown in figure 2. The uncertainty is only three times larger than the value of Schwinger’s correction.

Further reading
CMS Collab. 2024 CMS-PAS-SMP-23-005.

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Further reading
CMS Collab. 2024 CMS-PAS-SMP-23-005.
is performed separately for each dimuon mass range to the branching fraction along the spectrum, such as the \( e^+ e^- / e^+ e^- \) meson contribution in the low invariant mass region. The \( \pi^0 / \pi^0 \) signal decay provides a unique opportunity to validate the different theoretical approaches, which do not agree with each other, as shown by the coloured bands in figure 2. Theoretical calculations of branching fractions are currently below the experimental limits. The upgraded LHCb detector and the increased luminosity of the LHC's Run 3 is currently providing conditions for studying rare radiative \( B^- \rightarrow \gamma \mu^- \gamma \) decays with greater precision and, eventually, for finding evidence for the \( \pi^- / \pi^- \) decay.

Further reading
LHCb Collab. 2024 arXiv:2404.03735

ALICE

Shy charm mesons confound predictions

In the past two decades, it has become clear that three–quark baryons and quark–hadron mixtures are common in the full spectrum of hadrons. Dozens of exclusive or semi-exclusive charm–hadron and charm–charmonium states have been discovered in hadron collisions. These states are either interpreted as compact objects with four or five valence quarks or as hadron molecules, however, their inner structures remain uncertain due to the complexity of hadronization in quantum chromodynamics (QCD) and the lack of direct experimental measurements of the residual strong interaction between charm and light hadrons. New fentoscopy measurement by the ALICE collaboration challenge theoretical expectations and the current understanding of QCD. Fentoscopy is a well-established method for studying the strong interaction of a hadron–on–meson collision. In the high–energy collisions of protons at the LHC, the strong interaction between hadrons at the time of production is about one fentosmear, which is within the range of the predictions of the strong nuclear force. From the momentum correlations of particle pairs, one extracts the scattering length, which quantifies the final–state strong interaction between the hadrons. By studying the momentum correlations of different mass regions, one could possibly access the final–state interactions of even short–lived hadrons such as D mesons. The ALICE collaboration has now, for the first time, measured the interaction of open–charm mesons (\( D^0 \) and \( D^+ \)) with charged pions and kaons for all the charge combinations. The momentum correlation function of each system was then introduced into the basis of the QCD calculations in the LHC, at a centre–of–mass energy of \( 5 \) TeV. As predicted by heavy–quark spin symmetry, the scattering lengths of \( D^0 \) and \( D^+ \) agree with each other, but they are found to be significantly smaller than the theoretical predictions (figure 1). This implies that the interaction between these mesons can be fully explained by the Coulomb force, and the contribution from strong interactions is negligible within experimental precision (figure 1). The small measured values of the scattering lengths challenge our understanding of the residual strong force of heavy–flavour hadrons in the non–perturbative limit of QCD.

These results also have an important impact on the study of the quark–gluon plasma (QGP) – a deconfined state of matter created in ultra–relativistic heavy–ion collisions. The rescattering of D mesons with the other hadrons (mostly pions and kaons) created in such collisions was thought to modify the D–meson spectrum, in addition to the modification expected from the QGP formation. The present ALICE measurement demonstrates, however, that the effect of rescattering is expected to be very small. More precise and systematic studies of charm–hadron interactions will be carried out with the upgraded ALICE detector in the upcoming years.

Further reading
ALICE Collab. 2024 arXiv:2401.13541

LHCb targets rare radiative decay

Rare radiative \( B^- \rightarrow \gamma \mu^- \gamma \) decays are potential probes for sensitive to small deviations caused by potential new physics in virtual loops. A recent prediction is the decay of \( B^- \rightarrow \gamma \mu^- \gamma \). The dimuon decay of the \( B^- \) meson is known to exhibit unusual behaviour and has been measured with unprecedented precision by LHCb and CMS. While performing this measurement, the LHCb collaboration observed a signal in the \( \pi^- / \pi^- \) decay, partially reconstructed due to the missing photon, as a background to the signal of the \( \pi^- / \pi^- \) decay. The LHCb collaboration claims that this could be the first evidence for the rare radiative decay of the \( B^- \) meson. The search for the radiative decay of the \( B^- \) meson is performed using a data sample of 11.7 fb\(^{-1}\), corresponding to 1.4 × 10\(^{30}\) \( p \bar{p} \) interactions. The likelihood of the signal is evaluated using a data driven method to model the background. The analysis shows a significant excess in the \( 3 \) GeV/c\(^2\) range of the dimuon mass, with a mass resolution of about 1.4 GeV/c\(^2\) and a significance of about 3.8 standard deviations. The analysis is performed separately for each dimuon mass range to the branching fraction along the spectrum, such as the \( e^+ e^- / e^+ e^- \) meson contribution in the low invariant mass region. The \( \pi^- / \pi^- \) signal decay provides a unique opportunity to validate the different theoretical approaches, which do not agree with each other, as shown by the coloured bands in figure 1. Theoretical calculations of branching fractions are currently below the experimental limits. The upgraded LHCb detector and the increased luminosity of the LHC's Run 3 is currently providing conditions for studying rare radiative \( B^- \rightarrow \gamma \mu^- \gamma \) decays with greater precision and, eventually, for finding evidence for the \( \pi^- / \pi^- \) decay.

Further reading
LHCb Collab. 2024 arXiv:2404.03735

ENERGY FRONTIERS

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The inventive pursuit of UHF gravitational waves

Since their first direct detection in 2015, gravitational waves (GWs) have become pivotal in our quest to understand the universe. The ultra-high-frequency (UHF) band offers a window to discover new physics beyond the Standard Model. (CERN Courier March/April 2022 p22).

Unleashing this potential requires theoretical work to investigate possible GW sources and experiments with far greater sensitivities than those achieved today.

A workshop at DESY from 14-18 December 2022 leveraged impressive experimental progress in a range of fields. Attended by nearly ten international scientists—a noteworthy increase from the 40 experts who attended the first workshop at ICTP Trieste in 2019—the workshop showcased the field’s expanded research interest and collaborative efforts. Currently, about 10 novel detector concepts have been developed since the first workshop.

One can look for GWs in a few different ways: observing changes in the space between detector components, exciting vibrations in detectors, and converting GWs into electromagnetic radiation in strong magnetic fields. Substantial progress has been made in all three experimental directions.

Levitating concepts

The leading concepts for the first approach involve optically levitated sensors such as high-aspect-ratio sodium–crytrium–fluoride prisms, and semi–levitated sensors such as thin silicon or silicon–nitride nanomembranes in long optical resonators. These technologies are currently under study by various groups in the Levitated Sensor Detectors collaboration and at DESY.

For the second approach, the main focus is on millimetre-scale quartz cavities similar to those used in precision clocks. A network of such detectors, known as GOLDI, is being planned, involving collaborations among UC Davis, University College London and Northwestern University. Superconducting radio-frequency cavities also play a promising technology. A joint effort between Fermilab and DESY is leveraging the existing MAGO prototype to gain insights and design further optimised cavities.

Detecting ultra-high-frequency gravitational waves remains a visionary goal.

The workshop highlighted how strong magnetic fields in the universe, such as in extragalactic black holes and planetary magnetospheres, can help set limits on the conversion between electromagnetic and gravitational waves. Despite much progress, the sensitivity needed to detect UHF GWs remains a visionary goal, requiring the constant pursuit of innovative new ideas. To add this, the community is taking steps to be more inclusive. The living review produced after the first workshop (arXiv:2211.12414) will be revised to be more accessible for people outside our community, breaking down the barriers for easier understanding.

Cross-disciplinary research is also crucial to understand cosmological sources and constraints on UHF GWs. For the former, our understanding of primordial black holes has significantly improved, a robust framework. For the latter, constraints on axion dark matter are crucial at this stage, and can be facilitated by incremental investments. Such collaboration builds awareness within the scientific community and presents UHF searches as an additional, compelling science case for their construction.

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The workshop showcased the field’s expanded research interest and collaborative efforts. Regarding the third approach, a prominent example is optical high-precision interferometry, combined with a series of accelerable dipole magnets similar to those used in the light-shining-through-a-wall axion-search experiment, ALPS II (Any Light Particle Search II), or the axion helioscope CAST and its planned successor XIAX. In fact, ALPS II is anticipated to commence a dedicated GW search in 2023. Additionally, other notable concepts inspired by axion dark-matter searches involve toroidal magnets, exemplified by experiments like ABRACADABRA, or solenoidal magnets such as BASS or MADMAD.

The workshop explored how strong magnetic fields in the universe, such as in extragalactic black holes and planetary magnetospheres, can help set limits on the conversion between electromagnetic and gravitational waves. Despite much progress, the sensitivity needed to detect UHF GWs remains a visionary goal, requiring the constant pursuit of innovative new ideas. To add this, the community is taking steps to be more inclusive. The living review produced after the first workshop (arXiv:2211.12414) will be revised to be more accessible for people outside our community, breaking down the barriers for easier understanding.

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Countless ideas inspired by axion dark-matter searches involve toroidal magnets, exemplified by experiments like ABRACADABRA, or solenoidal magnets such as BASS or MADMAD.

The three approaches stand to benefit from burgeoning advances in quantum sensing, which promise to enhance sensitivity by orders of magnitude. In this landscape, axion dark-matter searches and UHF GW detection are poised to work in close collaboration, leveraging quantum sensors to achieve unprecedented results. Concepts that demonstrate synergies with axion-physics searches are crucial at this stage, and can be facilitated by incremental investments. Such collaboration builds awareness within the scientific community and presents UHF searches as an additional, compelling science case for their construction.

The journey towards detecting UHF GWs is just beginning. While current sensitivities are not yet sufficient, the community’s commitment to developing innovative ideas is unwavering. With the collective efforts of a dedicated scientific community, the next leap in gravitational-wave research is on the horizon. Limits exist to be surpassed!
Ultra-peripheral collisions 2023

Ultra-peripheral conference debuts in Mexico

Delegates discussed the future opportunities for UPC physics with the large integrated luminosity expected for Runs 3 and 4 at the LHC

Ultra peripheral The UPC23 conference took place in Playa del Carmen, Mexico.
CERN celebrates 100 years of science and diplomacy

Since his birth in Bohemia in 1924, Herwig Schopper has been a prisoner of war, an experimentalist with pioneering contributions in nuclear, accelerator and detector physics, director general (DG) of DESY and then CERN during a golden age of particle physics, and a celebrated science diplomat. Shortly after his centenary, colleagues, family and friends gathered on 3 March to celebrate the life of the first DG in either institution to reach 100.

“He is a restless person,” noted Achim Denig (Heidelberg HCP), who presented a whirlwind tour of Schopper’s 85 years working in Germany, following his childhood in Bohemia. Whether in Hamburg, Erlangen, Mainz or Karlsruhe, he never missed out on an opportunity to see new places — though always maintaining the Austrian diet to which his children attribute his longevity. On one occasion, Schopper took a subaltern to work with Lise Meitner in Stockholm’s Royal Institute of Technology. At the time, the great physicist was performing the first nuclear-physics studies in the keV range, said Wagner, and directed Schopper to measure the absorption rate of beta-decay electrons in various materials using radioactive sources and a Geiger–Müller counter. Schopper is one of the last surviving physicists to have worked with her, observed Wagner.

Schopper’s scientific contributions have included playing a major part in the world’s first polarised proton source, Europe’s first full programme for superconducting accelerators and the development of hadronic calorimeters as precision instruments, explained Christian Fabjan (TU Vienna/HEPHY). Schopper dubbed the latter the sampling total absorption calorimeter, or TTAC, playing on the detector’s stacked design, but the name didn’t stick. In recognition of his contributions, hadronic calorimeters might now be renamed Schopper total absorption calorimeters, joked Fabjan.

As CERN DG from 1981 to 1988, Schopper oversaw the lion’s share of the conception of the LEP, before it began operations in July 1989. To accomplish this, he didn’t shy away from risks, budget cuts or unpopular opinions when the situation called for it, said Chris Toukan (CERN), who worked with Schopper since his time together at DESY, and the Heidelberg medal. “You’ve even been, in contact with the man himself,” noted Heisenberg Society president Johannes Bluemer, referring to several occasions Schopper met Heisenberg at conferences and even once discussed politics with him.

Schopper continues to counsel DGs to this day — and not only on physics. Commenting on occasionally being intimidated by his lifetime of achievements, CERN DG Fabiola Gianotti intimated that they often discuss music. “Herwig likes all com- poses, but not baroque ones. For him, they are too rational and intellectual.” For this, he will always have physics.

SANJE FENkart

CENTENARIAN HERWIG SCHOPPER RECEIVES THE HEISENBERG MEDAL

Fabiola Gianotti intimated that they often discuss music. “Herwig likes all composers, but not baroque ones. For him, they are too rational and intellectual.” For this, he will always have physics.

Menu 2023

Slim, charming protons on the menu in Mainz

The triennial international conference on meson–nucleon physics and the structure of the nucleon (MENU) attracted more than 140 participants to the historic centre of Mainz from 16 to 20 October 2023.

Among MENU 2023’s highlights on nucleon structure, a preliminary analysis suggesting that the proton contains more charm than anticharm than anticharm, with Niccolò Lauer- renti (University of Milan-Bicocca) showing evidence of a non-vanishing intrinsic valence charm contribution to the proton’s wavefunction. Meanwhile, Michael Kohl (Hampson University) concluded that the proton—radius puzzle is still not resolved.

Imaging dark-matter searches.

Hadron physics

A large part of this year’s conference was dedicated to hadron spectroscopy, with updates from Belle II, BESIII, GlueX, Jefferson Lab, BES(III), XENON/XLQE-2 and LHCb, as well as theoretical overviews covering everything from lattice quantum chromodynamics to effective-field theories.

Special emphasis was also given to future directions in hadron physics at future facilities such as FAIR, the Electron-Ion Collider and the local Mainz Energy-Recovering Superconducting Accelerator (MESA) facility — a future zero-energy but high-intensity electron accelerator that will make it possible to carry out experiments in nuclear astrophysics, dark-sector searches and tests of the SM. Among upgrade plans at Jefferson Lab, Eric Vourc’h (Paris-Saclay) presented a future experimental programme with positron beams at CEBAF, the institute’s Continuous Electron Beam Accelerator Facility. The upgrade will allow for a rich physics programme covering two-photon exchange, generalised polarisabilities, generalised parton distribution functions and direct dark-matter searches.

Hadron physics is also closely related to searches for new physics, as precision observables of the Standard Model are in many cases limited by the non-perturbative regime of quantum chromodynamics. A prime example is the physics of the anomalous magnetic moment of the muon, for which a puzzling discrepancy between data-driven dispersive and lattice—quantum chromodynamics calculations of hadronic contributions to the muon’s wavefunction.

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The AWAKE experiment is adapting plasma–wakefield acceleration for applications in particle physics.

A laser ionises rubidium vapour, turning it into plasma. A proton bunch plunges inside, evolving into millimetre-long microbunches. The microbunches pull the plasma’s electrons, forming wakes in the plasma, like a speedboat displacing water. Crests and troughs of the plasma’s electric field trail the proton microbunches at almost the speed of light. If injected at just the right moment, relativistic electrons surf on the accelerating phase of the field over a distance of metres, gaining energy up to a factor of 1000 times faster than can be achieved in conventional accelerators.

Plasma wakefield acceleration is a cutting-edge technology that promises to revolutionise the field of particle acceleration by paving the way for smaller and more cost-effective linear accelerators. The technique traces back to a seminal paper published in 1979 by Toshiki Tajima and John Dawson which laid the foundations for subsequent breakthroughs. At its core, the principle involves using a driver to generate wakefields in a plasma, upon which a witness beam surfs to undergo acceleration. Since the publication of the first paper, the field has demonstrated remarkable success in achieving large accelerating gradients.

The AWAKE experiment is experimenting with plasma technologies to scale proton–driven wakefields to greater lengths.
AWAKE technology promises to bridge the gap between global developments at small scales and possible future electron–positron colliders

SPS is sent into a 10 m-long plasma source containing rubidium vapour at a temperature of around 200°C (see “Rubidium source” figure). A laser pulse accompanies the proton bunch, ionising the vapour and transforming it into a plasma.

To induce the necessary wakefields, the drive bunch length must be of the order of the plasma wavelength, which corresponds to the natural oscillation period of the plasma. However, the length of the SPS proton bunch is around 6 cm, significantly longer than the 1 mm plasma wavelength in AWAKE, and short wavelengths are required to reach large accelerating gradients.

The solution is to take advantage of a beam–plasma instability, which transforms long particle bunches into microbunches with the period of the plasma through a process known as self-modulation. In other words, as the long proton bunch traverses the plasma, it can be coaxially split into a train of shorter “microbunches”. The bunch train resonantly excites the plasma wave, like a pendulum or a child on a swing, being pushed with small kicks at its natural oscillation interval or resonant frequency. If applied at the right time, each kick increases the oscillation amplitude or height of the wave. When the amplitude is sufficiently high, a witness electron bunch from an external source is injected into the plasma wakefields, to ride the wakefields and gain energy.

The first phase of AWAKE (Run 1, from 2018 to 2019) served as a proof-of-concept demonstration of the acceleration scheme. First, it was shown that a plasma can be used as a compact device to self-modulate a highly relativistic and highly energetic proton bunch (see “Self-modulation” figure). Second, it was shown that the resulting bunch train resonantly excites strong wakefields. Third – the most direct demonstration – it was shown that externally injected electrons can be captured, focused and accelerated to GeV energies by the wakefields.

The addition of a percent-level positive gradient in density along the plasma led to 20% boosts in the energy gained by the accelerated electrons.

Traditionally, only laser pulses and electron bunches have been used as drive beams. However, since 2016 the Advanced Wakefield Experiment (AWAKE) at CERN has used proton bunches from the Super Proton Synchrotron (SPS) as drive beams – an innovative approach with profound implications. Thanks to their high stored energy, proton bunches enable AWAKE to accelerate an electron bunch to energies relevant for high-energy physics in a single plasma, circumventing the need for the multiple accelerating stages that are required when using lasers or electron bunches.

Bridging the divide

Relevant to any accelerator concept based on plasma wakefields, AWAKE technology promises to bridge the gap between global developments at small scales and possible future electron–positron colliders. The experiment is therefore an integral component of the European strategy for particle physics’ plasma roadmap, aiming to advance the concept to a level of technological maturity that would allow their application to particle-physics experiments. An international collaboration of approximately 100 people across 23 institutes worldwide, AWAKE has already published more than 90 papers, many in high-impact journals, alongside significant efforts to train the next generation, culminating in the completion of over 28 doctoral theses to date.

In the experiment, a 400 GeV proton bunch from the SPS is sent into a 10 m-long plasma source containing rubidium vapour at a temperature of around 200°C (see “Rubidium source” figure). A laser pulse accompanies the proton bunch, ionising the vapour and transforming it into a plasma.

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Based on these proof-of-principle experimental results and expertise at CERN and in the collaboration, AWAKE developed a well-defined programme for Run 2, which launched in 2020 following Long Shutdown 3, and which will run for several more years from now. The goal is to achieve electron acceleration with GeV/m energy gain and beam quality similar to a normalized emittance of 10 mm·mrad and a relative energy spread of a few per cent. In parallel, scalable plasma sources are being developed that can be extended up to hundreds of metres in length (see “Helicon plasma source” and “Discharge source” figures). Once these goals are reached, the concepts of AWAKE could be used in particle-physics applications such as using electron beams with energy between 40 and 200 GeV impinging on a fixed target to search for new phenomena related to dark matter.

Controlled instability

The first Run 2 milestone, on track for completion by the end of the year, is to complete the self-modulator – the plasma that transforms the long proton bunch into a train of microbunches. The demonstration has been staged in two experimental phases.

The first phase was completed in 2022. The results prove that wakefields driven by a full proton bunch can have a reproducible and tunable timing. This is not at all a trivial demonstration given that the experiment is based on an instability!

Techniques to tune the instability are similar to those used with free-electron lasers: provide a controlled initial signal for the instability to grow from and operate in the saturated regime, for example. In AWAKE, the self-modulation instability is initiated by the wakefields driven by an electron bunch placed ahead of the proton bunch. The wakefields from the electron bunch imprint themselves on the proton bunch right from the start, leading to a well-defined bunch train. This electron bunch is distinct from the witness bunches, which are later accelerated.

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Techniques to tune the instability are similar to those used with free-electron lasers: provide a controlled initial signal for the instability to grow from and operate in the saturated regime, for example. In AWAKE, the self-modulation instability is initiated by the wakefields driven by an electron bunch placed ahead of the proton bunch. The wakefields from the electron bunch imprint themselves on the proton bunch right from the start, leading to a well-defined bunch train. This electron bunch is distinct from the witness bunches, which are later accelerated.

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Two enabling technologies are needed to achieve high-quality electron acceleration. The first is a source and transport line to inject the electron bunch on-axis into the accelerator plasma. A radio-frequency (RF) injector source was chosen because of the maturity of the technology, although the combination of S- and X-band structures is novel, and forms a compact accelerator with possible medical applications. It is followed by a transport line that preserves the parameters of the 150 MeV 100 pC bunch, and allows for its tight focusing (5 to 10 µm) at the entrance of the accelerator plasma. External injection into plasma-based accelerators is challenging because of the high frequency (about 235 GHz in AWAKE) and thus small source size (roughly 200 µm) at which they operate.

The main goal is to demonstrate that the electron bunch can be accelerated to 4 to 10 GeV, with a relative energy spread of 5 to 8%, and emerge with approximately the same normalised emittance as at the entrance of the plasma (2–30 mm mrad).

For these experiments, rubidium vapour sources will be used for both the self-modulator and accelerator plasmas, as they provide the uniformity, tunability and reproducibility required for the acceleration process. However, the laser-ionisation process of the rubidium vapour does not scale to lengths beyond 20 m. The alternative enabling technology is therefore a plasma source whose length can be scaled to the 50 to 100 metres required for the bunch to reach 50–100 GeV energies. To achieve this, a laboratory to develop discharge and helicon-plasma sources has been set up at CERN (see “Discharge source” figure). Multiple units can in principle be stacked to reach the desired plasma length. The challenge with such sources is to demonstrate that they can produce required plasma parameters other than length.

The third and final experimental milestone for Run 2 will then be to replace the 10 m-long accelerator plasma with a longer source and achieve proportionally larger energy gains. The AWAKE acceleration concept will then essentially be mature to propose particle-physics experiments, for example with bunches of a billion or so 50 GeV electrons.

After all these years, neutrinos remain extraordinary – and somewhat deceptive. The experimental success of the three-massive-neutrino paradigm over the past 25 years makes it easy to forget that massive neutrinos are not part of the Standard Model (SM) of particle physics. Nonzero neutrino masses are not possible without the existence of new fundamental fields, beyond those that are part of the SM. And we know virtually nothing about the particles associated with them. They could be bosons or fermions, light or heavy, charged or neutral, and experimentally accessible or hopelessly out of reach.

This is the neutrino mass puzzle. At its heart is the particle’s uniquely elusive nature, which is both the source of the problem and the main challenge in resolving it.
Neutrino masses require the existence of new fields, and hence new particles, beyond those in the Standard Model

To understand why the SM predicts neutrino masses to be zero, it is necessary to appreciate that particle masses are complicated in this theory. The reason is as follows. The SM is a quantum field theory. Interactions between the fields are strictly governed by their properties: spin, various “local” charges, which are conserved in interactions, and – for fermions – like the neutrinos, charged leptons and quarks – another quantum number called chirality.

In quantum field theories, mass is the interaction between the fermion and a different left-chiral field. A naive picture is that the mass-interaction constantly converts left-chiral states into right-chiral ones (and vice versa) and the end result is a particle with a nonzero mass. It turns out, however, that for all known fermions, the left-chiral and right-chiral fermions have different charges. The immediate consequence of this is that you can’t turn one into the other without violating the conservation of some charge so none of the fermions are allowed to have masses. The SM naively predicts that all fermion masses are zero.

The Higgs field was invented to fix this shortcoming. It is charged in such a way that some right- and left- chiral fermions are allowed to interact with one another plus the Higgs field which, uniquely among all known fields, is thought to have been turned on everywhere since the phase transition that triggered electroweak symmetry breaking very early in the history of the universe. In other words, so long as the vacuum contains the Higgs field, it is not trivial, fermions acquire a mass thanks to these interactions.

This is not only a great idea, it is also at least mostly correct: as spectacularly confirmed by the discovery of the Higgs boson a little over a decade ago. It has many verifiable consequences. One is that the strength with which the Higgs boson couples to different particles is proportional to the particle’s mass – the Higgs prefers to interact with the top quark or the Z or W bosons relative to the electron or the light quarks. Another consequence is that all masses are proportional to the value of the Higgs field in the vacuum (≈ 133 GeV) and, in the SM, we naively expect all particle masses to be similar.

Neutrino masses are predicted to be zero because, in the SM, there are no right-chiral neutrino fields and hence none for the left-chiral neutrinos – the ones we know about – to “pair up” with. Neutrino masses therefore require the existence of new fields, and hence new particles, beyond those in the SM.

Wanted: new fields

The list of candidate new fields is long and diverse. For example, the new fields that allow for nonzero neutrino fields would be fermions or bosons; they could be neutral or charged under SM interactions, and they could be related to a new mass scale other than the vacuum value of the SM Higgs field (≈ 133 GeV), which could be either much smaller or much larger. Finally, while these new fields might be “easy” to discover with the current and near-future generation of experiments, they might equally turn out to be impossible to probe directly in any particle-physics experiment in the foreseeable future.

Though there are too many possibilities to list, they can be classified into three very broad categories: neutrinos acquire mass by interacting with the same Higgs field that gives mass to the charged fermions; by interacting with a similar Higgs field with different properties; or through a different mechanism entirely.

At first glance, the simplest idea is to postulate the existence of right-chiral neutrino fields and further assume they interact with the Higgs field and the left-chiral neutrinos, just like right-chiral and left-chiral charged leptons and quarks. There is, however, something special about right-chiral neutrino fields: they are completely neutral relative to all local SM charges. Returning to the rules of quantum field theory, completely neutral chiral fermions are allowed to interact “amongst themselves” independent of whether there are other right-chiral or left-chiral fields around. This means the right-chiral neutrino fields should come along with a different mass that is independent from the vacuum value of the Higgs field of ≈ 133 GeV.

To prevent this from happening, the right-chiral neu-
The neutrinos must possess some kind of conserved charge that is shared with the left-chiral neutrinos. If this scenario is realized, there is some new, unknown fundamental conserved charge out there. This hypothetical new charge is called lepton number: electrons, muons, tau leptons and neutrinos are assigned charge plus one, while positrons, antimuons, antitau leptons and antineutrinos have charge minus one. A prediction of this scenario is that the neutrino and the antineutrino are different particles since they have different lepton numbers. In more technical terms, the neutrinos are massive Dirac fermions, like the charged leptons and the quarks. In this scenario, there are new particles associated with the right-chiral neutrino field, and a new conservation law in nature.

Accidental conservation

As of today, there is no experimental evidence that lepton number is conserved, and readers may question if this really is a new conservation law. In the SM, however, the conservation of lepton number is merely “accidental” – once all other symmetries and constraints are taken into account, the theory happens to possess this symmetry. But lepton number conservation is no longer an accidental symmetry when right-chiral neutrinos are added, and these chargeless and apparently undetectable particles should have completely different properties if it is not imposed.

If lepton number conservation is imposed as a new symmetry of nature, making neutrinos pure Dirac fermions, there appears to be no observable consequence other than nonzero neutrino masses. Given the tiny neutrino masses, the strength of the interaction between the Higgs boson and the neutrinos is predicted to be at least seven orders of magnitude smaller than all other Higgs couplings to fermions. Various ideas have been proposed to explain this remarkable contrast between the strength of the neutrino’s interaction with the Higgs field relative to that of all other fermions. They involve a plurality of theoretical concepts including extra-dimensions of space, mirror copies of our universe and dark sectors.

A second possibility is that there are more Higgs fields in nature and that the neutrinos acquire a mass by interacting with a Higgs field that is different from the one that gives a mass to the charged fermions. Since the neutrino mass is proportional to the vacuum value of a different Higgs field, the fact that the neutrino masses are so small is easy to tolerate: they are simply proportional to a different mass scale that could be much smaller than 10^16 eV. Here, there are no right-chiral neutrino fields and the neutrino masses are interactions of the left-chiral neutrino fields amongst themselves. This is possible because, while the neutrinos possess weak-force charge they have no electric charge. In the presence of the nontrivial vacuum of the Higgs fields, the weak-force charge is effectively not conserved and these interactions may be allowed. The fact that the Higgs particle discovered at the LHC – associated with the SM Higgs field – does not allow for this possibility is a consequence of its charges. Different Higgs fields can have different weak-force charges and end up doing different things. In this scenario, the neutrino and the antineutrino are, in fact, the same particle. In more technical terms: the neutrinos are massive Majorana fermions.

One way to think about this is as follows: the mass interaction transforms left-chiral objects into right-chiral objects. For electrons, for example, the mass converts left-chiral electrons into right-chiral electrons. It turns out that the antiparticle of a left-chiral electron is right-chiral and vice versa, and it is tempting to ask whether a mass interaction could convert a left-chiral electron into a right-chiral position. The answer is no: electrons and positrons are different objects and converting one into the other would violate the conservation of electric charge. But this is no barrier for the neutrino, and we can contemplate the possibility of converting a left-chiral neutrino into its right-chiral antiparticle without violating any known law of physics. If this hypothesis is correct, the hypothetical lepton-number charge, discussed earlier, cannot be conserved. This hypothesis is experimentally neither confirmed nor contradicted but could soon be confirmed with the observation of neutrinoless double-beta decays – nuclear decays which can only occur if lepton-number symmetry is violated. There is an ongoing worldwide campaign to search for the neutrinoless double-beta decay of various nuclei.

Challenging scenarios

Since the origin of the neutrino masses here is qualitatively different from that of all other particles, the values of the neutrino masses are expected to be qualitatively different. Experimentally, we know that neutrino masses are much smaller than all charged-fermion masses, so many physicists believe that the tiny neutrino masses are strong indirect evidence for a source of mass beyond the vacuum value of the Higgs field. In most of these scenarios, the neutrinos are also massive Majorana fermions. The challenge here is that if a new mass scale exists in fundamental physics, we know close to nothing about it. It could be within direct reach of particle-physics experiments, or it could be astronomically high, perhaps as large as 10^23 times the vacuum value of the SM’s Higgs field. How do we hope to learn more? We need more experimental input. There are many outstanding questions that can only be answered with oscillation experiments. These could provide evidence for new neutrino-like particles or new neutrino interactions and properties. Meanwhile, searching for neutrinoless double-beta decay is the most promising avenue to experimentally reveal whether neutrinos are Majorana or Dirac fermions. Other activities include high-energy collider searches for new Higgs bosons that like to talk to neutrinos and new heavy neutrino-like particles that could be related to the mechanism of neutrino mass generation. Charged-lepton probes, including measurement of the anomalous magnetic moment of muons and searches for lepton-flavour violation, may provide invaluable clues, while surveys of the cosmic microwave background and the distribution of galaxies could also reveal footprints of the neutrino masses in the structure of the universe.

We still know very little about the new physics uncovered by neutrino oscillations. Only a diverse experimental programme will reveal the nature of the new physics behind the neutrino mass puzzle.
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ENGINEERING MATERIALS FOR BIG SCIENCE

From the HL–LHC magnets to the ITER fusion project, Stefano Sgobba, Katie Buchanan and Ana Teresa Perez Fontenla describe how CERN deals with complex demands for mechanical design, production facilities and material science at CERN and beyond.

The nature of CERN’s research often demands unusual and highly complex materials to be developed and tested. A good example is the LHC beam screen that limits the energy transfer from the beam to the cold mass of the magnets, for which a new non-magnetic stainless steel had to be developed in the mid-1990s to meet the physical and mechanical requirements at cryogenic temperatures. The same is true of the external cylinder of the CMS solenoid magnet, for which a process enabling the production of 7 m-diameter high-strength seamless aluminium–alloy rings had to be identified and qualified in time for the HL-LHC. The LHC has been the solution adopted for the end covers of the HL-LHC coils up close in a magnet coil for the HL-LHC observed by scanning electron microscopy after deep etching of the copper supports.

The future of particle accelerators is strongly linked to the development of high-field superconducting magnets that enable higher energies and luminosities to be attained. The HL–LHC will be the first operational facility to employ high-performance Nb₃Sn accelerator technologies—manufactured at CERN achieved a record purity and conductivity for this kind of product. For the new HL–LHC magnets, which are necessary to focus the beams more tightly at the collision points, detailed qualifications of the soundness of niobium–tin (Nb₃Sn) filaments has been critical, as has the development and qualification of methods to test the weld of the quadrupole magnet cold masses.

These and numerous other projects are the domain of the EN–MME–MM section, whose mission is to provide material science for accelerators and detectors spanning the whole CERN community, in close coordination with the mechanical design and production facilities of the EN–MME group. The interdisciplinary, expert-staffed section guarantees a full life-cycle management of materials—from functional requirements to prototyping, series production, inspection and end-of-life—and includes the identification and qualification of material solutions, the specification and qualification of suppliers, the definition of manufacturing and inspection plans, and inspections of received materials and parts before and after their integration into the machines and experiments. This challenging mission requires advanced microscopic materials analysis, high-precision optical metrology, mechanical static and cyclic measurements, including at cryogenic temperatures, and, last but not least, state of the art non-destructive testing techniques (see “Section facilities” figure).
The future of particle accelerators is strongly linked to the development of high-field superconducting magnets

magnets, surpassing the intrinsic performance limitations of NbTi-based magnets as used for the LHC. The fabrication of Nb$_3$Sn magnets is a challenging process because the conductor is an extremely brittle intermetallic phase. While the difficulty of working with brittle compounds is compounded by the use of the traditional wind-and-react-impregnate approach, uncertainties remain due to volume changes associated with phase transformations occurring during the reaction treatment necessary to form the Nb$_3$Sn phase.

Needle in a haystack
To investigate the root causes of performance limitation or degradation observed on early magnets, several HL–LHC dipole and quadrupole magnet coils were examined. This project has been one of the most complex failure analyses ever undertaken by the MM section, demanding an innovative investigation methodology to be identified and performed at several fabrication stages and after cool-down and powering. Internal shear and bending loads on unsupported superconducting wires, which can cause their dislocation as well as cracks in the aggregates of Nb$_3$Sn filaments, were suspected to be the main cause of limitation or degradation. Like hunting for a needle in a haystack, the challenge was to find microscopic damage at the level of the filaments in the large volume of coils covering a length up to 7.2 m.

Starting in 2020 with 11 T magnet-coil ends, a sequence of mesoscale observations of whole coil sections was carried out non-destructively using innovative high-energy X-ray computed tomography (CT). This enabled the critical volumes to be identified and was followed up with a microscopic assessment of internal events, geometrical distortions and potential flaws using advanced microscopy. As a result, the MM section was able to unequivocally identify strands with transversely broken elements (see “Dipole diagnostics” and “Cracking niobium tin” figures). Techniques such as scanning electron microscopy (SEM) and focussed ion beam (FIB) were used to analyse damage to strands or sub-elements at particular localised positions as well as failure modes. In addition, an X-ray etching technique allowed a decisive observation of completely broken filaments (see “HL–LHC coils up close” figure). Taken together, this comprehensive approach provided an in-depth view of the examined coils by identifying and characterising atypical features and imperfections in both the superconducting phase of the strands and the glass fibre/resin insulation system. It also clearly associated the phenomena (a sudden loss of the superconducting state) experienced by the coils with physical events, namely broken superconducting filaments or damaged strands. The successful analysis of the CERN coil limitations led the MM section to receive several coils from different non-conforming quadrupole magnets, fabricated in the US in the framework of the Accelerator Upgrade Project collaboration, and successfully carry out the same type of investigations.

Effective recovery
Investigating the massive HL-LHC coils required a high-energy (6 MeV) X-ray CT that was subcontracted to TEC Eurotab in Italy and Diemme GmbH in Germany, two of only a few companies in the world that are equipped with this technique. However, the MM section also has an X-ray CT facility with an energy of 225 keV, which enables sufficient penetration for less massive samples. One of the most recent of countless examples employing this technique concerns the staves for the future ATLAS tracker (ITk) for the HL–LHC upgrade. During 2023 a significant fraction of the ITk modules suffered from high-voltage breakdowns, despite appearing to perform satisfactorily during earlier stages of quality control. A subset of these modules exhibited breakdowns following thermal cycling, with some failing during the cold phases of the cycle. Additionally, others experienced reductions after being loaded onto their supporting staves. High-resolution CT scans at CERN combined with other techniques confirmed the presence and propagation of cracks through the entire sensor thickness, and enabled the MM team to identify the gluing process between the carbon structure and the sensors as the root cause of the vulnerability, which is now being addressed by the ATLAS project team (see “ATLAS modules” figure). Also for the HL–LHC, the section is working on the internalisation process of the beryllium vacuum-chamber fabrication technology required for the experiments.

While carrying out failure analyses of extremely high-tech components is the core business of the MM section, in some cases understanding the failure of the most basic objects can be paramount. This does not necessarily mean that the investigations are simpler. At 11 a.m. on 13 October 2022, a pipe supplying CERN with water burst under the main road near the French–Swiss border, which was closed until early afternoons. The damage was quickly repaired by the Swiss services, and the road re-opened. But it was critical to understand if this was an isolated incident of an individual pipe, in service for 20 years, or if there was the potential risk of bursts in other ducts of the same type.

The damaged portion of the duct, measuring 1.7 m in length and 0.5 m in diameter, is the largest sample ever brought to the MM facilities for root-cause analysis (see “Water pipe” figure). As such, it required most of the available techniques to be deployed. For the receiving inspections, visual and radiographic testing and high-precision optical dimensional metrology in a volume of almost 17 m$^3$ were used. For microstructural examinations, tests by CT, microscopic and SEM observations on
The change of boundary conditions may have been due to droughts during summer periods that altered the soil conditions. To the great relief of all, the composite material of the pipe or its constituents were not the main cause of the failure.

Beyond CERN

The services of the MM section, provided via cooperation agreements with CERN, are also in wide demand externally. ITER is a strong example. As of 2009, a major multi-year cooperation agreement is in place specifically covering metallurgical and material testing for the construction of the ITER magnet and vacuum systems. Many results and achievements of this long-lasting cooperation include: the qualification of high-strength stainless-steel jacket material for the conductor of the ITER central solenoid, including their cryogenic properties; the development and application of advanced examination techniques to assess the vacuum pressure impregnation process used in the correction coils and their critical welds, which are not insurable with conventional techniques; and the assessment of a high-strength austenitic stainless steel for the precompression structure of the central solenoid, involving forgings featuring an unprecedented combination of size and aspect ratio.

The section has also been fully entrusted by the ITER organisation for major failure analysis, such as the root-cause analysis of a heavy gauge fastener of the toroidal-field gravity support system and, more recently, the analysis of leakage events in the thermal-shield cooling pipes of the ITER magnet system. Several agreements are also in place via the CERN knowledge transfer group for the assessment of structural materials for a fusion project beyond ITER, and for a subcritical fission reactor project. Also note to be forgotten is the major involvement of CERN in the Einstein Telescope project, for example in assessing suitable materials and fabrication solutions for its vacuum system, one of the largest ultra-high vacuum systems ever built. A three-year-long project that started in September 2014 aims to deliver a technical design report for the Einstein Telescope beampipes, in which CERN’s contribution is structured in eight work packages spanning design and materials choice to logistics, installation and surface treatments (CERN Courier September/October 2012 p46).

Beyond fundamental physics, the section is also working on the selection of materials for a future hydrogen economy, namely the definition of the proper specification and procedures for operation in a liquid-hydrogen environment. The watchmaking industry, which places high requirements on materials, also cooperates in this field.

The sample surrounding the crack – including a post-resin burn-off test – were carried out. The cracking (one of the most common found in water and sewer pipes) turned out to be the result of bending forces due to local soil movement. This generated a flexural constraint between the supported ends of the failing section, contributing to the proper selection and qualification of materials, parts and processes to enable the creation of the giant colliders and detectors that allow physicists to explore the fundamental constituents of the universe.

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The photo on the right is our first 1497 MHz CW 20 kW prototype magnetron, now being tested at JLab as a possible high-efficiency replacement for CEBAF’z klystrons. New methods of control are being pursued based on operating the magnetron with anode voltage below that needed for self-excitation – that can allow a wider range of power output as well as the possibility to operate in pulsed mode without the need for expensive modulators.
After 25 years of steady progress, recent advances in theory and computing are enabling researchers to connect an approach to quantum gravity called asymptotic safety to the Standard Model. Frank Saueressig and Maximilian Becker explain the power and potential of this approach.

A SAFE APPROACH TO QUANTUM GRAVITY

The LHC experiments at CERN have been extremely successful in verifying the Standard Model (SM) of particle physics to very high precision. From the theoretical perspective, however, this model has two conceptual shortcomings. One is that the SM appears to be an “effective field theory” that is valid up to a certain energy scale only; the other is that gravity is not part of the model. This raises the question of what a theory comprising particle physics and gravity that is valid for all energy scales might look like. This directly leads to the domain of quantum gravity.

The typical scale associated with quantum-gravity effects is the Planck scale: $10^{15}$ TeV, or $10^{-35}$ m. This exceeds the scales accessible at the LHC by approximately 14 orders of magnitude, forcing us to ask: what can theorists possibly gain from investigating physics at energies beyond the Planck scale? The answer is simple: the SM includes many free parameters that must be fixed by experimental data. Since the number of these parameters proliferates when higher order interactions are included, one would like to constrain this high-dimensional parameter space. At low energies, this can be done by implementing bounds derived from demanding unitarity and causality of physical processes. Ideally, one would like to derive similar constraints from consistency at trans-Planckian scales where quantum-gravity effects may play a major role.

Under the microscope A snapshot of a quantum spacetime obtained from Monte Carlo simulations (front). If the quantum spacetime is not resolved with sufficient resolution, only the spacetime of classical general relativity (background) is observed. (Credit: T Budd).

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At first sight, this may seem counterintuitive. It is certainly true that gravity treated as an effective field theory itself does not yield any effect measurable at LHC scales due to its weakness; the additional constraints then arise from requiring that the effective field theories underlying the SM and gravity can be combined and extended into a

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The asymptotic-safety approach towards quantum gravity may offer a more tractable option for implementing a top-down idea. The asymptotic safety scenario is based on the hypothesis that quantum field theories emerging from fixed-point conditions exhibit a non-trivial running of the coupling constants. This running is described by an interacting renormalisation-group fixed point at high energies, which is a feature of quantum field theories. The asymptotic-safety mechanism expresses these couplings in terms of the free parameters associated with the interacting fixed point.

Asymptotic safety is a promising candidate for a consistent description of quantum gravity. It provides a framework for linking quantum gravity to particle physics. The asymptotic-safety scenario was first proposed by Steven Weinberg in the late 1970s. Starting with the seminal work by Martin Reuter (University of Mainz) in 1998, this approach has been developed by the Schwinger-Dyson equation framework.

The asymptotic-safety scenario is a promising candidate for a consistent description of quantum gravity. It provides a framework for linking quantum gravity to particle physics. The asymptotic-safety scenario was first proposed by Steven Weinberg in the late 1970s. Starting with the seminal work by Martin Reuter (University of Mainz) in 1998, this approach has been developed by the Schwinger-Dyson equation framework.
Element Six Synthetic Diamond Protects CERN Particle Detectors in Higgs boson Experiment Results

Back in 2012, CERN (European Organization for Nuclear Research) particle detection systems used Element Six synthetic diamond in their first line of defence against beam-induced radiation damage in their Higgs boson experiment results. Element Six, a world leader in synthetic diamond supermaterials, supplied its highest purity synthetic diamond as an integral part of the CERN LHC (Large Hadron Collider) CMS (Compact Muon Solenoid) and ATLAS Beam Condition Monitoring Systems, used in the milestone experiments which revealed the discovery of the Higgs boson.

“The diamond synthesised by Element Six measures LHC beam conditions in key areas of the main experiments that have been used in the search for the Higgs boson,” said Heinz Penzegger, CERN scientist at the ATLAS experiment.

“The CMS experiment relies on the stability of the synthetic diamond sensors produced by Element Six to monitor the LHC beam arriving to the CMS experiment and the particles created in the collision. The robustness of this synthetic diamond-based system is crucial in protecting the most sensitive components of the 66 million channel pixel-tracking detector,” said Anna Dabrowski, CERN scientist at the CMS experiment.

“The use of synthetic diamond sensors was essential for a smooth operation of the LHC and the collection of high quality data by the LHC experiments, making the observation of the new particle possible,” concluded Professor Wolfgang Lohmann from the Brandenburg University of Technology.

Element Six electronic grade synthetic diamond was selected as the optimum detector material by CERN scientists over the decade-long development of CERN’s CMS and ATLAS Beam Condition Monitoring Systems. Synthetic diamond was shown to be the most robust sensor material available which could withstand the harsh, high radiation environment and react almost instantaneously to be able to protect the advanced measurement systems. Element Six manufactures the synthetic diamond used in the detectors using a process called chemical vapour deposition (CVD). This process takes a mixture of gases and forms plasma with the extreme high temperature of a sun spot to allow carbon to precipitate onto a substrate layer as synthetic diamond.

The purpose of the CERN CMS and ATLAS experiments was to count, track and characterise the different particles produced from the particle collisions inside the LHC. The synthetic diamond detectors in the monitoring system protected the experiments from adverse beam conditions and contributed to the luminosity measurement, which was crucial for obtaining the five sigma result.

Leveraging Element Six’s over 70 years of innovation leadership and patented technology, the grades of synthetic diamond used in these monitoring systems are grown to ultra high levels of purity, incorporating less than one part per billion of boron, and less than 50 parts per billion of nitrogen. When diamond is synthesised with these levels of purity, it becomes an ideal radiation detector material. It can exhibit properties such as very low leakage current with negligible temperature dependence, a fast signal response and a vastly improved radiation hardness and reduction of leakage-current compared to silicon, the material traditionally used for detectors.

“Beam condition monitoring is critical to the safe operation of the LHC at CERN. The diamond synthesised by Element Six was able to provide that protection in key areas of the main experiments that have been used in the search for the Higgs boson. Now that the synthetic diamond has been proven in this application, there is scope for its further use in medicine such as radiation therapy and diagnostic imaging.”

To find out more about Element Six’s collaboration with CIVIDEC, read the related case study here

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UHV Feedthroughs

Why theoretical cosmology?
I was first trained as a mathematician, and then as a physicist. I’ve always worked at the interface between theory and data, where one of the most interesting things is to test cosmological models inspired by some fundamental theory. For example, you can create a model based on string theory or on a non-perturbative approach to quantum gravity, and then use data to constrain the quantum gravity theory. Today we receive a wealth of data from different kinds of experiments, which allows us to test early-universe models without relying on ad hoc ideas. Although it is not something I directly work on, the current tension in the value of the Hubble constant serves as an example. This of course could be telling us something about new physics, but it seems to me it is more likely to be an issue with the way we interpret data and apply the same models across different scales. Supernovae are taken as “standard candles” when measuring the expansion rate of the universe, for example, and one may wonder how correct this assumption is. It is important to perform systematic studies of the raw data before we rush to new theories.

My current work mainly bears on gravitational waves. I am also editor-in-chief of the journal General Relativity and Gravitation. I joined the LIGO collaboration in the year of the discovery, studying the implications of gravitational-wave background searches for new physics. I am working on similar studies for the proposed Einstein Telescope. Gravitational waves allow us to test high-energy models beyond the Standard Model at energy scales that are above those that can be reached by accelerators. There are also new results coming from pulsar timing arrays. We live in a time where many exciting results are coming fast.

Clear goals
Mairi Sakellariadou, professor of theoretical physics at King’s College London, became EPS president on 30 March 2024.

How big is the European Physical Society, and what led you to be elected president?
The European Physical Society (EPS) is the federation of all national physics societies in Europe. It was founded in 1968 by particle physicist Gilberto Bernardini, who contributed to the foundation of CERN and later became director of the Synchrocyclotron division and directorate member for research. Several years ago, following the LIGO/Virgo discoveries, I initiated the gravitational physics division of the EPS and, in doing so, entered the EPS council. Then I was elected a member of the executive committee and was eventually contacted to run for election. I admit that I was reluctant at first because it’s another task with a lot of responsibilities. But it turned out I was elected, and I took up the position formally on April 27th. I am proud to have been elected as president and I will do my best to serve the EPS and respect the confidence that representatives of so many European national societies have put in me.

What do you hope to achieve during your two-year mandate?
I have several goals as president. The most important one is to strengthen the position of Europe. What do I mean by that? There are important issues that we all face together, such as our economic independence (for instance, sources of energy, technological advances in electronics, biophysics and medical applications) and the preservation of the environment. The EPS can play a role by building teams of experts to address these issues, to be in a position to advise policy makers at the European level.

Scientific policy is another example. We live in an era with very large changes in the scale of experiments, the size of datasets, as well as advanced data-analysis techniques such as artificial intelligence. We should be able to have a say about how these things are dealt with and what the priorities are. The EPS can have a solid dialogue with large experimental teams and important research centres such as CERN. We can pass the message, for example via the national physics societies, and provide lists of experts able to advise politicians on such matters.

Last but not least is education. We need to adapt the programmes offered to the students because there is huge demand for soft skills, and I am not sure they are adequately provided. We also need to offer opportunities to welcome students and early-career researchers from regions around the world that need support. We should collaborate with them and provide scholarships to enable them to spend time at a facility such as CERN or DESY and develop key skills.
**Collider Talk:** The EPS can support constructive dialogue about major projects such as the proposed Future Circular Collider at CERN.

**Money can’t go to everyone in equal amounts, so we need a way to set scientific priorities in Europe**

To achieve all that, we should strengthen the links between the EPS and the national societies (be they small or large). We represent the interest of all physicists in Europe equally. We also need to have a more active dialogue with our colleagues in North America and Asia because we share common challenges. Of course, to do that requires hard work and commitment.

How can the EPS support fundamental research such as particle physics? We have a high-energy physics division, of course. From my point of view, we need to accentuate the motivation for exploring the laws of the universe. CERN obviously plays a key role in this because colliders are one of the basic experimental devices to do so. Gravitational-wave observatories are another example. These experiments have to go hand-in-hand because they have a common ambition. The EPS can give an extra voice to the scientific aspects of this enterprise. Of course, the question of financing next-generation experiments remains to be solved, as well as the balance between fundamental science and applied research. For me there is no doubt that such experiments should continue. Unfortunately, today one often has to state the implications for industry and the applications for society. This can sometimes be difficult to square with curiosity-driven science.

If approved, would a new collider at CERN take away funding from other fields? This is a very simplistic view. Science funding is not a zero-sum game. As CERN did for the LHC, it’s good to find external sources. Money can’t go to everyone in equal amounts, so we need a way to set scientific priorities in Europe.

Is the scientific case for the Future Circular Collider sufficiently clear in this respect? If the argument is to find supersymmetry, in particular, as some other framework of physics beyond the Standard Model, then I’m afraid it will fail. Of course, in scientific working groups you need to go into specifics such as which hypotheses will be tested, and which signatures are possible. But such detail is a trap when engaging with broader audiences because we can’t be sure that such things exist at the energies we can explore. Instead, the argument should be that we try to understand better the elementary particles and laws. We need to pass the message to politicians, to the person on the street and to scientists that there are some important questions that can only be addressed with future colliders. While CERN and particle physicists should not be defensive, they should be clearer about what the role and ultimate hope of a collider is. Then there is no argument that can go against it.

This is something that could be elaborated by the high-energy physics division of the EPS, for example by providing a document stating the views of particle physicists. We should also be prepared for a critical dialogue, to identify the strengths and weaknesses of the arguments. One should in any case ensure that anyone invited to give their views should have an established scientific reputation within their field, a prerequisite that is not met in some high-level discussions and media outlets.

Does the existence of several future-collider options pose a problem from a communications perspective? I think it’s problematic if, scientifically, a consensus cannot be reached. There is something similar going on in the gravitational-wave community, where divisions exist about where to build the Einstein Telescope and which configuration it should have. This may lead to a healthy process of course, but discussions should be kept between experts. Indeed, it can weaken the case for a new experiment if scientists are seen to be disagreeing strongly.

What effects are current political shifts in Europe having on physics? I’m afraid that there could be very negative effects. To this we have to add the risks created by the conflicts we see expanding. One effect could also be the changes in priorities for funding. As one of the largest scientific societies, we need to keep supporting collaborations among scientists no matter their country of origin, ethnicity, gender, or any other discriminating factor. We also need to provide financial support where possible, for example as we have done recently for Ukrainian colleagues to participate in our activities, and to make statements in response to events going way beyond the world of physics.

Interview by Matthew Chalmers, editor.
A logical freight train

Steven Weinberg – Selected Papers
Edited by Michael Duff

World Scientific

Steven Weinberg was a logical freight train – for many, the greatest theorist of the second half of the 20th century. It is timely to reflect on his legacy, the scientific component of which is laid out in a new collection of his publications selected by theoretical physicist Michael Duff (Imperial College).

Six chapters cover Weinberg’s most consequential contributions to effective field theory, the Standard Model, symmetries, gravity, cosmology and short-term popular science writing. I can identify any notable omissions and I doubt many others would, though some may raise an eyebrow at the exclusion of this paper: deriving the Lee–Weinberg bound. Duff brings each chapter to life with first-hand anecdotes and details that will delight those of us most greatly separated from historical events. I am relatively young, and had only meaningful interaction with Steven Weinberg. Though my contemporaries and I inhabited a scientific world whose core concepts had been interwoven with, if not formed by, Steven Weinberg’s scientific legacy, unlike Michael Duff we are poorly qualified to comment historically on the ecosystem in which this legacy grew, nor on aspects of personality. This makes his commentary particularly valuable to younger readers. I can convey those insights to younger students for this new collection.

The first is the lay-theater - Duff’s readers are widely enough read to recognise the depth of Weinberg’s impact. He was a very influential protagonist. Particle theorists consult his articles often that they may as well have them close at hand. This collection contains those most often revisited and ought to be useful in this respect. Duff’s introductions also expose technical interconnections between the articles that might otherwise be missed.

The second audience is practising theoretical physicists. If you’re going to invest in a printed collection of publications, then Weinberg is an obvious protagonist. Particle theorists consult his articles often that they may as well have them close at hand. This collection contains those most often revisited and ought to be useful in this respect. Duff’s introductions also expose technical interconnections between the articles that might otherwise be missed.

The third audience I have in mind are beginning graduate students in particle theory. The second half of the book starts a cohesive narrative, but the second half nevertheless captures the title of the book perfectly – ICTs are the epitome of new opportunities in physics education. While much has been said about them in other works, this book offers a cherry-picked but well rounded collection of ideas for enhancing educational experiences. The authors not only emphasise modern physics and technology, but also advocate for very different characteristics of modern education. The second half of the book is packed with an overview of ICT resources and recent studies into a cohesive narrative, but the second half nevertheless captures the title of the book perfectly – ICTs are the epitome of new opportunities in physics education. While much has been said about them in other works, this book offers a cherry-picked but well rounded collection of ideas for enhancing educational experiences. The authors not only emphasise modern physics and technology, but also advocate for very different characteristics of modern education.

The Many Voices of Modern Physics: Written Communication Practices of Key Physicists
By Joseph E Harmon and Alan G Gross
University of Pittsburgh Press

This book provides a rich glimpse into written communication science within a quarter century that introduced many new and special concepts in physics. It begins with Einstein’s 1905 paper “On the Electrodynamics of Moving Bodies” in which he introduced special relativity. Arisingly, the paper starts with a thought experiment concerning the complex and novel physical mechanism. Harmon and Gross analyse and express that the contributions of Enrico Fermi and Mattieu Tuveri are navigating modern challenges in physics education. The book is structured in two distinct sections on modern physics topics and the latest information and communication technologies (ICTs) for classrooms. The editors bring together a diverse blend of experts in modern physics, physics education and modern educational approaches. The editors would like to thank the people who were interviewed with, if not formed by, Steven Weinberg’s scientific legacy, unlike Michael Duff we are poorly qualified to comment historically on the ecosystem in which this legacy grew, nor on aspects of personality. This makes his commentary particularly valuable to younger readers. I can convey those insights to younger students for this new collection.

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In Galilei’s case, he regularly wrestled with big questions. The papers presented in this volume are packed with insightful ideas and novel physical mechanisms. Harmon and Gross have established a clear and coherent narrative, while the book leaves room for further exploration. The book is a valuable resource for educators seeking to engage with the public, and it provides a comprehensive guide to high school physics.

Anja Kranjc Horvat CERN
Sabbatical in space

Project astronaut and CERN engineer Sławosz Uznański points to the growing opportunities for high-energy physicists and engineers in space.

Sławosz Uznański had to bide his time. Since its foundation in 1975, the European Space Agency (ESA) had only opened four selection rounds for new astronauts. When a fresh opportunity arose in 2021, Uznański’s colleagues in CERN’s electric power converters group were supportive of his ambitions to take an extended sabbatical in space. Now confirmed as one of 17 astronauts selected from among more than 22,000 applicants, Uznański is in training for future missions to the International Space Station (ISS).

His new colleagues are a diverse bunch, including geologists, medical doctors, astro-physicists, biologists, biotechnologists, jet fighter pilots and helicopter pilots. His own background is as a physicist and systems engineer. Following academic work studying the effect of radiation on semiconductors, Uznański spent 12 years at CERN working on powering existing infrastructure and future projects such as the Future Circular Collider. He’s most proud of being a project leader in reliability engineering and helping to design and deploy a new radiation-tolerant power-converter control system to the entire LHC accelerator complex.

Preparing for orbit

For now, Uznański’s astronaut training is mostly theoretical, preparing him for the ISS’s orbit-trajectory control, thermal control, communications, data handling, guidance, navigation and power generation, where he has deep expertise. But lift-off may not be far away, and one of his reserve-astronaut colleagues, Marcus Wandt, is already sitting up in the ISS capsule.

“I had the chance, in January, to see him launch from Cape Canaveral. And then, thanks to my operational experience at CERN, being in the control room, I came back directly to Columbus Control Center in Munich. Throughout the entire mission, I was in the control room, to support the mission and learn what I might live through one day.”

Rather than expertise or physical fitness, Uznański sees curiosity as the golden thread for astronauts – not least because they have to be able to perform any type of experiment that is assigned to them. As a Polish astronaut, he will have responsibility for the scientific experiments that are intended to accompany his country’s first mission to the ISS, most likely in late 2024, or early 2025. Among 66 proposals from Polish institutes, a dozen or more are currently being considered to fly.

The experiments are as diverse as the astronauts’ professional backgrounds. One will non-invasively monitor astronauts’ brain activity to help develop human–machine interfaces for artificial limbs. Another – a radiation monitor developed at CERN – plays on the fact that shielded high-energy physics environments have a similar radiation environment to the ISS in low-earth orbit. Uznański hopes that this technology can be commercialised and become another example of the opportunities out there for budding space-entrepreneurs.

“I think we are in a fascinating moment for space exploration,” he explains, pointing to the boom in the commercial sector since 2014. “Space technology has gotten really democratised and commercialised. And I think it opens up possibilities for all types of engineers who build systems with great ideas and great science.”

Open science is a hot topic here. It’s increasingly possible to access venture capital to develop related technologies, notes Uznański, and the challenge is to ensure that the science is used in an open manner. “There is a big overlap between CERN culture and ESA culture in this respect. CERN is extremely open in terms of technologies and I very much identify myself with that.”

However societies choose to shape the future of open science in space, the two organisations are already partnering on several projects devoted to the pure curiosity that is dear to Uznański’s heart. These range from Euclid’s study of dark energy (CERN Courier May/June 2023 p7) to the ongoing study of cosmic rays by the Alpha Magnetic Spectrometer (AMS). With AMS due for an upgrade in 2026 (CERN Courier March/April 2022 p7), he cannot help but hope to be on that flight.

“If the opportunity arises, it’s a clear yes from me.”

Mark Rayner CERN.

CERN is extremely open in terms of technologies and I very much identify myself with that.

People and Careers

From CERN to ESA: Project astronaut Sławosz Uznański.

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PEOPLE

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Appointments and awards

New leadership for EuCAPT
Silvia Pascoli (Above, University & INFN Bologna) has taken over as director of the European Consortium for Astroparticle Physics (EuCAPT), succeeding founding director Gianfranco Bertone (IRAPPA). EuCAPT brings together European astroparticle-physics researchers and has CERN as its home institution. It was formally established through a joint action supported by the European Astroparticle Physics European Consortium, APPEC. During her mandate, Pascoli will work on the strategic development of EuCAPT aided by David Marsh (Stockholm University) in his role as EuCAPT vice-president. Marsh is a cosmologist focusing on string compactifications, inflation theory and astronomical signals from axions. The last new addition is Francesca Calore (CNRS-LAPTh) as chair of EuCAPT council. Calore started out as a theoretical particle physicist and now works on searches for dark matter with astrophysical experiments.

EPS new president
Mairi Sakellariadou (King’s College London) started her mandate as president of the European Physical Society (EPS) on 30 March, taking over from Luc Bergé (CFA). Sakellariadou specialises in theoretical cosmology, with an emphasis on the early universe.

Second term at J-PARC
Takahsi Kobayashi (RIKEN) began a second term as director of the Japan Proton Accelerator Research Complex (J-PARC) on 1 April. A nuclear physicist and member of the long-baseline T2K experiment since 1999, Kobayashi will lead the lab for the next three years as it proceeds with a major beam–power upgrade. “Going forward, I see it as my mission to transform J-PARC into a research facility that contributes more to the advancement of humanity,” he said in a statement.

ATLAS thesis awards
During the February ATLAS week, the collaboration celebrated the seven winners of the 2023 ATLAS PhD thesis awards. Joshua Beiter (CERN, University of Göteborg), Pragya Bhattachar (Brandeis University), Savannah Clawson (University of Manchester), Hassan El Jarrai (Université Mohammed-V de Rabat), Nicole Hartman (Stanford & SLAC), Samuel Van Stroud (UCL) and Xiao Yang (University of Science and Technology of China) were awarded for their outstanding contributions to the ATLAS collaboration as doctoral students. Their theses span a wide range from the electroweak sector, via exotice physics to performance studies and detector R&D.

Wu-Ki Tung award
The 2023 Wu-Ki Tung award goes to theoretical physicist Ian Moir (Yale) “for his pioneering work on QCD energy correlators, including their all–order factorisation, multi–loop-structure, phenomenological applications and connections to conformal field theory”. After graduating from the University of British Columbia, Moir obtained his PhD in 2016 from MIT and worked as a postdoctoral fellow at UC Berkeley and SLAC before moving to Yale. Moir’s research is focused on the development of new quantum field theory techniques for improving the understanding of high–energy particle–physics experiments, ranging from dark matter detection to collisions at the LHC.

Alfvén plasma–physics prize
Tibor Fuks (Gdansk University of Technology) and Per Hulander (MPI for Plasma Physics) are the winners of the 2024 EPS Hannes Alfvén Prize for “outstanding contributions to theoretical plasma physics, yielding groundbreaking results that significantly impact the understanding and optimisation of magnetically confined fusion plasma”. Fuks explored the physics of runaway electrons in tokamaks and elsewhere, and their associated electromagnetic instabilities, while Hulander made seminal contributions to the theory of stellarator plasmas by investigating how the properties of a magnetically confined plasma depend on the magnetic field geometry.

La Fondation pour Genève
In recognition of her exceptional commitment to Geneva’s international reputation, CERN Director-General Fabiola Gianotti will be awarded the 30th prize of La Fondation pour Genève during a ceremony on 11 May. From the realisation of the ATLAS experiment at the LHC, to the discovery of the Higgs boson and the creation of CERN Science Gateway, Gianotti has contributed to a number of major projects that have made Geneva a leading player in the world of science and in the diplomatic arena, states the citation: “Her dynamism, passion for the transmission of knowledge, democratisation of science and openness to all the public make her a real inspiration for the younger generations.”

Top–end user award
At a conference of the Cloud Native Computing Foundation (CNCF) in Paris (19–22 March), CERN was presented as winner of the top–end user award. Cited for its “forward thinking approach to leveraging cloud-native technologies to address future scientific and operational challenges”, CERN joins the ranks of previous awardees including Spotify and Apple. Cloud-native technologies are software solutions that allow system engineers to improve basic cloud features such as scalability, flexibility and data resiliency. This award is a special CNCF community award that recognises major contributions in the cloud-native ecosystem.
**Title:** Five PhD Positions in Experimental Particle Physics  
**Location:** Jožef Stefan Institute, Ljubljana, Slovenia  
**Doctoral Study:** Faculty of Mathematics and Physics at the University of Ljubljana  
**Start Date:** October 1st, 2024  
**Duration:** 4 years  
**Application Deadline:** May 31st, 2024  

**About Us:**  
The Jožef Stefan Institute (JSI) is a leading research institution in Ljubljana, Slovenia, committed to excellence in scientific research and innovation. We are seeking highly motivated and talented students to join our team working on cutting-edge experiments, including the ATLAS and LHCb experiments at CERN, and the Belle II Experiment at KEK. Ljubljana is a vibrant, easy-to-navigate capital with easy road access to the Alps, the Adriatic, and cities such as Venice, Vienna, and Munich.

The Experimental Particle Physics Department (F9 - [https://www-f9.ijs.si/en/]) at JSI is currently comprised of over 20 faculty members and staff scientists and over 10 PhD students and postdocs. A significant part of the group is involved in detector R&D: Cherenkov detectors and their applications in medical imaging ([https://photodetectors.ijs.si](https://photodetectors.ijs.si)), and solid-state detectors for the ATLAS Phase-II upgrade (ITk, HGTD, BCM). The group also plays a leading role in the newly formed DRD3 ([https://drd3.web.cern.ch](https://drd3.web.cern.ch)) and DRD4 ([https://drd4.web.cern.ch](https://drd4.web.cern.ch)) collaborations. The group is strongly involved in physics data analysis at Belle II and ATLAS experiments, ranging from measurements of rare processes with B meson decays at Belle II to direct searches for new phenomena and Higgs and Standard Model precision measurements at the ATLAS Experiment. The group has recently won two ERC projects: FAIME ([https://faime.ijs.si](https://faime.ijs.si)) and its spin-off CherPET, a proof-of-concept ERC project aiming to apply the detectors developed in particle physics to advances in medical imaging methods.

**Position Overview:**  
As a PhD student, you will have the opportunity to contribute to groundbreaking research in experimental particle physics. Several positions are available, spanning the analysis of experimental data within the framework of the ATLAS and Belle II collaborations to detector research and development for the ATLAS and LHCb experiments. The workplace for all positions will be the JSI, Ljubljana, with possible shorter or longer periods at CERN, Geneva, or KEK, Japan. Your doctoral studies will be conducted at the Faculty of Mathematics and Physics at the University of Ljubljana, with guidance from experienced supervisors from both institutions.

**ATLAS Experiment Positions:**  
**Topic:** Machine learning-assisted data analysis at ATLAS  
**Contacts:** Miha Muškinja (miha.muskinja@ijs.si), Borut Kerševan (borut.kersevan@ijs.si)  
**Topic:** Development of semiconductor detectors for charged particle tracking for future experiments at particle colliders  
**Contact:** Igor Mandić ([https://faime.ijs.si](https://faime.ijs.si))

**Belle II & LHCb Experiment Positions:**  
**Topic:** Measurements of rare processes at B meson decays at the Belle II experiment  
**Contact:** Marko Bračko ([marko.bracko@ijs.si](mailto:marko.bracko@ijs.si))  
**Topic:** Particle identification system upgrade at LHCb  
**Contact:** Rok Pestotnik ([rok.pestotnik@ijs.si](mailto:rok.pestotnik@ijs.si))

**Benefits:**  
- Competitive salary commensurate with experience.  
- Full doctoral scholarship at the Faculty of Mathematics and Physics at the University of Ljubljana.  
- Full health coverage plan.  
- Opportunity for professional development and networking within the international particle physics community.  
- Supportive and collaborative work environment.

**General Inquiries:**  
For general inquiries, please contact f9-jobs@ijs.si or respective contacts listed above for specific inquiries.

**Application Process:**  
Send your motivation letter and CV to [f9-jobs@ijs.si](mailto:f9-jobs@ijs.si) and arrange for up to three reference letters to be sent to the same address.

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**CERN. Take part!**
Peter Higgs 1929–2024
A massive legacy for particle physics

Peter Higgs, an iconic figure in modern science who in 1964 postulated the existence of the eponymous Higgs boson, passed away on 8 April 2024, at the age of 94.

Peter Higgs was born in Newcastle upon Tyne in the UK on 29 May 1929. His family moved around when he was young, and he suffered from childhood asthma, so he was often taught at home. However, from 1933 to 1946, he attended Cottingham Grammar School in Grimsby, where he completed his bachelor’s degree in 1940 and his PhD for research in molecular physics in 1952. After periods at the University of Edinburgh, Imperial College and University College London, in 1960 he settled at the University of Edinburgh where he remained for the rest of his career.

Seeds of success

Following his PhD, Higgs’s research interests shifted to field theory, with a first paper on vacuum expectation values of fields in 1956, followed by a couple of papers on general relativity. Then, in 1964, came his two famous papers introducing spontaneous gauge symmetry breaking to relativistic quantum field theory and showing how a vector boson could acquire a mass in a consistent manner — as long as it was accompanied by a massive scalar boson. Related ideas had been discussed previously by Phillip Anderson and Yoichiro Nambu in the context of non-relativistic condensed–matter physics, namely in models of superconductivity, where a condensate of electron pairs enables a photon to acquire an effective mass. Anderson conjured that a similar mechanism should be possible in a relativistic theory, but he did not develop the idea. On the other hand, Nambu used spontaneous symmetry breaking to describe the properties of the pion, but also did not discuss the extension to a relativistic vector boson.

In early 1964, Walter Gilbert (later a winner of the Nobel Prize in Chemistry) wrote a paper arguing that Anderson and Nambu’s ideas for generating mass for a vector boson could not work in a relativistic theory. This was Higgs’s cue: a few weeks later he wrote a first paper pointing out a potential loophole in Gilbert’s argument (though not a specific model). He sent his paper to the journal Physics Letters, which quickly accepted it for publication. A few days later, he wrote a second paper, which contained an explicit model for mass generation, but was taken aback when the same journal rejected this paper as not being of practical interest. Undeterred, Higgs tweeted his paper to make his message more explicit, and submitted it to Physical Review Letters, where it was accepted.

Unknown to Higgs, François Englert and Robert Brout had already published a paper describing a similar model to the same journal, where it was published ahead of Higgs’s paper. Both papers postulated a scalar field with a non-zero vacuum expectation value that gave mass to a vector boson. However, there was a key difference: Higgs pointed out explicitly that his model predicted the existence of a massive scalar boson, whereas this was not mentioned in the Englert–Brout paper. For this reason, the particle he predicted became known as the Higgs boson. Shortly after the publication of the Englert–Brout papers, Gerry Guralnik, Carl Hagen and Tom Kibble published an article referring to their papers and filling in some aspects of the theory, but also not mentioning the existence of the massive scalar boson.

In 1969, Higgs went for a sabbatical to the University of North Carolina, where he continued working on his theory. Remarkably prescient, he wrote a third paper discussing how his boson could decay into a pair of massive gauge bosons as well as calculating associated scattering processes. However, he encountered scepticism about the validity of his theory, and neither he nor the other pioneering mass-generation papers garnered significant attention for several years. This started to change in 1973 and 1974 when Steven Weinberg and Abdus Salam incorporated the mass-generation mechanism into their formulation of the electroweak sector of the Standard Model. But interest only really took off a few years later, after Gerard ‘t Hooft and Martinus Veltman showed that spontaneously broken gauge theories are renormalisable and hence could be used to make accurate and reliable predictions for comparison with experiment, and when neutral weak interactions were discovered in the UA1 giga-zelle bubble chamber at CERN in 1973.

Peter Higgs during a visit to the CMS experiment in April 2008.
Superior intelligence and unwavering will

Experimental physicist Giuseppe Fidecaro, who joined CERN in 1956 and continued there until his retirement, passed away on 28 March.

Born in Messina, Italy in 1916, Giuseppe studied physics at the University of Rome in 1932. He became interested in 1937 under the supervision of Edoardo Amaldi. Amaldi had become interested in cosmic rays and asked young “Pippo” to help him build a large detector to study the scattering of mesons on an iron target to explore the nuclear force. Between 1952 and 1954, Giuseppe continued to work on cosmic rays at the Villa della Regina laboratory in Cernobbio, north of Como, from which he received his Ph.D. in 1953.

In January 1958, during a conference in New York, Giuseppe attended a presentation by Feynman describing the Universal “V–A” theory of weak forces. He left the meeting bemused and wrote to Amaldi: “I don’t think that I am completely blind.”

Giuseppe’s decision to work at CERN in 1964 was made for several reasons. He was impressed with the work being done there, which was producing rare and beautiful results, and was aware of the international excellence of the experiments being carried out there. He was also attracted by the social life and the possibility of meeting interesting people. He was particularly attracted by the possibility of working with Dieter Reuter, who was known for his technical and experimental skills.

In 1967, Giuseppe became a member of the CERN staff and worked with Dieter on the development of superconducting accelerator technology. He was responsible for the design, construction and assembly of superconducting resonators and was also involved in the development of the International TESLA Collaboration. He continued to work at CERN until his retirement in 2001.

Giuseppe Fidecaro at CERN in 1964.

**Giuseppe Fidecaro 1926–2024**

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**Dieter Proch** 1943–2024

A super force for accelerators

Dieter Proch, who made significant contributions to accelerator science, passed away unexpectedly on 27 February 2024, at the age of 80.

Dieter studied physics at the University of Bonn, where he joined the group of Helmut Piel, who had just started working on superconducting accelerator resonators. He then followed Piel, who had accepted an appointment as professor at the newly founded University of Wuppertal, and completed his doctorate on magnetic properties of superconducting accelerator resonators. Soon after, he joined the international group of physicists working on the construction of the International Linear Collider (ILC) in Japan. Dieter was a key member of this group and made important contributions to the design and construction of superconducting accelerator structures.

Following his appointment, Dieter was involved in the development of superconducting accelerator structures for the HERA accelerator at DESY and later on the International Linear Collider (ILC). His contributions continued to shape our understanding of superconducting accelerator technology. Dieter leaves behind him a legacy of innovation and excellence that will be remembered by many in the field of particle physics.

**Dieter Proch significantly enhanced DESY’s scientific reputation.**

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**Marcello Ciafaloni** 1940–2023

Master of QCD and gravitational scattering

Internationally known theorist Marcello Ciafaloni passed away in Florence, Italy on 8 September 2023. Born 1940 in the small town of Serravalle in southern Italy, he was admitted for his outstanding potential to theselective Scuola Normale Superiore in Pisa where he graduated in 1962. Since then, he was a professor in theoretical physics at the University of Florence. As a research associate at Berkeley (1969–1970) and a fellow at CERN (1972–1973), Ciafaloni initially focused his research on high-energy strong and had been confirmed important results in the context of Regge–field theory. Towards the end of the seventies, he shifted his attention to perturbative QCD, in particular to hard processes and small-x physics where sophisticated re–summation techniques are needed. Since then, and throughout his career, he produced many fundamental results in perturbative QCD, including his single-author contribution to the celebrated CCFM equation (where the first C stands for his name), an important ingredient for QCD–based event generators.

**Marcello Ciafaloni’s work underpinned QCD–based event generators.**

Since 1989, Ciafaloni added a second dimension to his research spectrum by the use of his expertise in the gravitational scattering of strings, a thought–experiment for understanding gravity in the early universe. This work originated from one of his periodic visits to the CERN TH division and involved, besides Marcello himself, Giuseppe Veneziano and myself. The so–called ACV collaboration carried out important results in the 1990s. This collaboration was continued in 1999 and 2001, but my own collaboration with Marcello continued until 2018, when his health started deteriorating. More recently, the techniques used for this “academia” problem turned out to be relevant for describing real accelerators and merging the missing gravitational radiation.

I had the great privilege of working with Marcello on many occasions throughout his career. His deep knowledge of physics and his passion were only matched by his amazing technical skills. He had set very demanding standards for himself and pursued them with that intellectual honesty and much generosity towards his students and collaborators. His passing is a loss for our community.

**Giuseppe Veneziano** CERN

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**Gabriele Veneziano**

CERN.

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**Dieter Proch**

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**Dieter Proch**

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Igor Golutvin 1934–2023

A pioneer of the CMS experiment

Igor Anatolievich Golutvin, an outstanding scientist who founded new directions and research techniques in particle physics, died on 13 September 2023.

Born on 8 August 1934 in Moscow, Golutvin graduated from MIPT in 1957 and started his work at JINR in 1959. Several generations of detectors for large-scale physics facilities were developed under his supervision at the JINR Synchrophasotron, the IHEP accelerator in Serpukhov, and at the Proton Synchrotron and the LHC at CERN. Golutvin became one of the pioneers of the CMS experiment, driving the cooperation of Russia and other JINR member states via the Russia and Dubna Member States (RDMS) CMS collaboration. Over the past 30 years, under his supervision, RDMS physicists have completed the development of unique detectors for CMS. Igor was also instrumental in initiating Grid computing for CMS in Russia. He was awarded the 2014 Cherenkov Prize of the Russian Academy of Sciences for his outstanding contribution to the development of CMS. In recent years, he played an important role in the preparation of upgrades for CMS, in particular concerning the calorimeters.

During his work at JINR, Golutvin established a scientific school and trained a team of active, qualified physicists and engineers. Within the framework of cooperation between CMS Russia and other JINR member states, he brought together like-minded people with the aim of preserving Russian scientific schools, building unique teams of engineers and physicists, and developing favourable conditions for attracting gifted young physicists, which he saw as extremely important for the implementation of long-term scientific projects.

Golutvin was a member of the equipment committee of the International Committee for Future Accelerators, an editorial board member of the journal Nuclear Instruments and Methods, a director member of the CMS collaboration at CERN, head of the collaboration of the Institutes of Russia and JINR in CMS, and the organiser and head of numerous international and Russian scientific conferences and symposia.

He was also a professor/full member of the Russian Academy of Engineering Sciences, Russian Academy of Natural Sciences, International Academy of Sciences, Honoured Scientist of the Russian Federation and chief researcher for CMS at VBLHEP. For many years of fruitful work, Golutvin was awarded numerous state and scientific awards and prizes.

His friends and colleagues at JINR.
**BACKGROUND**

Notes and observations from the high-energy physics community

### Instrumental X-rays

"Il Cannone", crafted in 1743 and reputed to be the virtuoso Niccolò Paganini’s favourite violin, ranks among the most important instruments in the history of Western music. To help understand and preserve it, the Municipality of Genoa and the Premio Paganini in Italy teamed up with researchers at the ESRF in Grenoble to place the precious artifact in the path of an ultra-bright X-ray beam. Multi-resolution propagation phase-contrast X-ray microtomography, a non-destructive technique widely used for palaeontology, produced a 3D image of the violin at the level of its cellular structure, enabling deeper study of the structural status of the wood and the secrets behind Il Cannone’s acoustic prowess.

**From the archive: April/May 1984, Multitasking, CERN–style**

On 17 April 1984, CERN, the Joint European Torus nuclear fusion project, was formally opened at Culham, UK, by Britain’s Queen Elizabeth II and France’s President Francois Mitterrand. The guests of honour were escorted by CERN Council President Jean Teillac, formerly President of CERN Council. Two rows behind the Queen in Hans-Otto Winter, JET Director and a former member of the CERN Directorate.

**Compiler’s note**

Extensive members of CERN’s Directorate often feature prominently in other international physics projects. Cernanefiurk Hierwyf Schopper, CERN DGE from 1994 to 1998, played a pivotal role in setting SÉSAME, the synchrotron-light for Experimental Science and Applications in the Middle East centre, established in Jeddah in 2017. Hans-Otto Winter, deputy DG of CERN Lab II from 1973 to 1975, was JET director from its inception in 1983 until this sudden death in 1989. In a swaying run of September 2023, JET broke the world record for sustained nuclear fusion, generating 64 megawatts of energy over a period of 6 seconds from 0.2 mg of fuel. That’s only enough for four or five hot baths, but the achievement instills confidence in projects such as ITER, the International Thermonuclear Experimental Reactor, scheduled to start up this decade in southern France. Chris Llewellyn Smith, CERN DGE from 1994 to 1998, served chairmen of the ITER Council from 2007 to 2009.

### Know your footprint

The Young High-Energy Physicists association encourages you to enter a personal commitment to the carbon footprint of a benchmark, a period of 6 seconds from 0.2 mg of fuel. That’s only enough for four or five hot baths, but the achievement instills confidence in projects such as ITER, the International Thermonuclear Experimental Reactor, scheduled to start up this decade in southern France. Chris Llewellyn Smith, CERN DGE from 1994 to 1998, served chairmen of the ITER Council from 2007 to 2009.

**Text adapted from CERN Courier April 1984, (1957) and May 1984 (1993).**

### Media corner

"How the story of these anomalies will end is unclear. But the wealth of emerging evidence does suggest that physics may be on the brink of something big."

LHC physicist Harry Cliff tells the new book Space Oddities about the newly approved SHiP experiment at CERN (see p7).

"It is also a way to guarantee the fixation and even return of ‘brains’ to Brazil. Furthermore, we are entering a promising market for metals and minerals."

Luciana Santos, Brazilian minister of science, technology and innovation, on the country’s formal ascension to CERN as an associate member state (29/March, 28 March) (translated).

"Le CERN a honoré donc d’organiser en toute transparence un grand débat démocratique sur le sujet et de se doter d’une commission d’étude de crédibilité de la CEA et de la CERN."

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### Why choose Fujikura?

- Superior in-field performance, high critical current and excellent mechanical properties for high field applications.
- Fujikura pioneered the key manufacturing techniques of IBAD and PLD.
- Excellent uniformity over long lengths.

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- **R5560C**: 32 channels 14-bit 125 MS/s Pulse Processor.
- **R8033**: High Voltage board (Mod. R8033DP: 16-ch +4kV/3mA).

**Typical thermal neutron spectrum acquired with the Thanos DAQ, collecting charge from just one end of a 3He tube.**

**Energy spectrum measured at the two ends of one 3He tube** – x-axis is not-calibrated energy.

**Position heatmap (counts over position) corresponding to four different 3He tubes and 2D projection of counts onto the y-axis of a single tube.**