WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the January/February 2024 issue of *CERN Courier.*

With just under two years of LHC operations remaining before the collider is shut down to make way for its high-luminosity upgrade (HL-LHC), 2024 is a big year for teams across CERN and beyond. The focus now is on the validation of key technologies, tests of prototypes and the series production of equipment (p37). Due to deliver high-brightness beams from 2029, the HL-LHC will bring rich physics opportunities for the four main experiments into the early 2040s.

The experience gained from the HL-LHC will also be key to the success of a future collider at CERN. On that note, a February session of the CERN Council is to assess impressive progress documented in the mid-term review of the Future Circular Collider feasibility study. Meanwhile, in December the US "P5" report expressed strong support for a Higgs factory in Europe or Japan (p7).

December also brought news from the CERN Council that CERN's cooperation with Russia and Belarus will conclude at the expiry of their respective international collaboration agreements: 30 November and 27 June 2024. This issue looks at how the war has impacted particle physics in Ukraine through the experiences of researchers at institutes in Kharkiv, Kyiv, Odesa and Uzhhorod (p30).

The lure of the CERN model (p43), 3D-printed detectors (p9), fair and transparent web search (p45), 40 years of the CERN Accelerator School (p25), and how to lead in collaborations (p50) are other must-reads.

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IN THIS ISSUE

VOLUME 64 NUMBER 1 JANUARY/FEBRUARY 2024

FROM THE EDITOR

A luminous future comes into view

Matthew Chalmers
Editor

With just under two years of LHC operations remaining before the collider is shut down to make way for its high-luminosity upgrade (HL-LHC), 2024 is a big year for teams across CERN and beyond. A recent HL-LHC cost-and-schedule review agreed with the projection to be ready for installation of the major equipment starting in 2026. As project leaders Oliver Brüning and Markus Zerlauth explain (p37), the focus now is on the validation of key magnet and radio-frequency technologies, tests of prototypes and the series production of equipment – a key milestone being the completion and operation of the 90 m-long inner-triplet "string" in the SM18 hall.

Due to deliver high-brightness beams from 2029, the upgrade will extend LHC operations to the early 2040s and bring rich physics opportunities for the four main experiments. These include a deeper understanding of the mechanisms leading to thermal equilibrium and the formation of hadrons in quark–gluon plasma, unprecedented tests of CP violation, indirect searches for new phenomena at higher mass scales, and significant advances in the Higgs sector. Assuming the Higgs boson is Standard Model-like, the HL-LHC will guarantee the discovery of its decay to two muons, proving that fermions other than those from the heaviest generation also get their mass via the mysterious Yukawa mechanism. Further down the line, ATLAS and CMS are expected to observe di-Higgs production – a rare process that opens the door to studies of the Higgs' self-interaction.

Due to deliver high-brightness beams from 2029, the HL-LHC will bring rich physics opportunities for the four main experiments

A subsequent Higgs factory and energy-frontier collider would map these fundamental scalar interactions in full to tackle the nature of the electroweak phase transition and the ultimate stability of the vacuum, among other enigmas. The experience gained from the HL-LHC – whether it be grappling with next-generation accelerator magnets or handling vastly more complex collision environments – will be key to this staged programme's success. On that note, 2024 also marks an important milestone for the proposed Future Circular Collider, with a February session of the CERN Council to assess impressive progress documented in the mid-term review of the FCC feasibility study. Meanwhile, in December the US "P5" report expressed strong support for a Higgs factory in Europe or Japan and an ambition to host a subsequent high-energy collider (p7), while physicists in China completed a technical design report for the Circular Electron–Positron Collider.

CERN-PHOTO-202312-301-7

Good signs *The first completed HL-LHC "Q1/Q3" cryo-assembly was celebrated with US colleagues on 18 December.*

Ukraine in focus

December also brought news from the CERN Council on the International Cooperation Agreements (ICAs) with Russia and Belarus, in view of the ongoing military invasion of Ukraine. It was agreed that CERN's cooperation with both countries will conclude at the expiry of the respective ICAs: 27 June 2024 for the Republic of Belarus, and 30 November 2024 for the Russian Federation. All relations between CERN and Russian and Belarusian institutions will cease as of these dates, but relations continue with scientists of Russian or Belarusian nationality otherwise affiliated with CERN.

This issue looks at how the war has impacted particle physics in Ukraine through the experiences of researchers at institutes in Kharkiv, Kyiv, Odesa and Uzhhorod (p30). The lure of the CERN model (p43), 3D-printed detectors (p9), fair and transparent web search (p45), 40 years of the CERN Accelerator School (p25), and how to lead in collaborations (p50) are other must-reads.

Reporting on international high-energy physics

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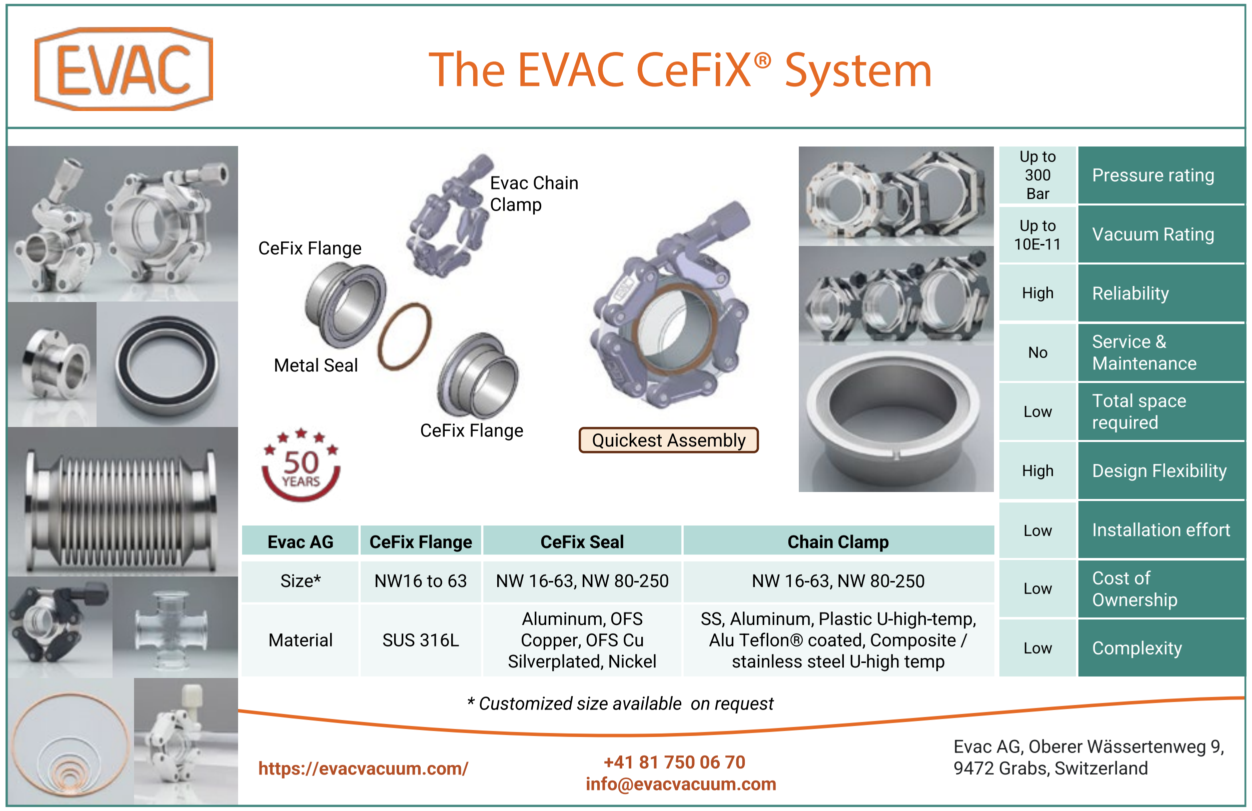
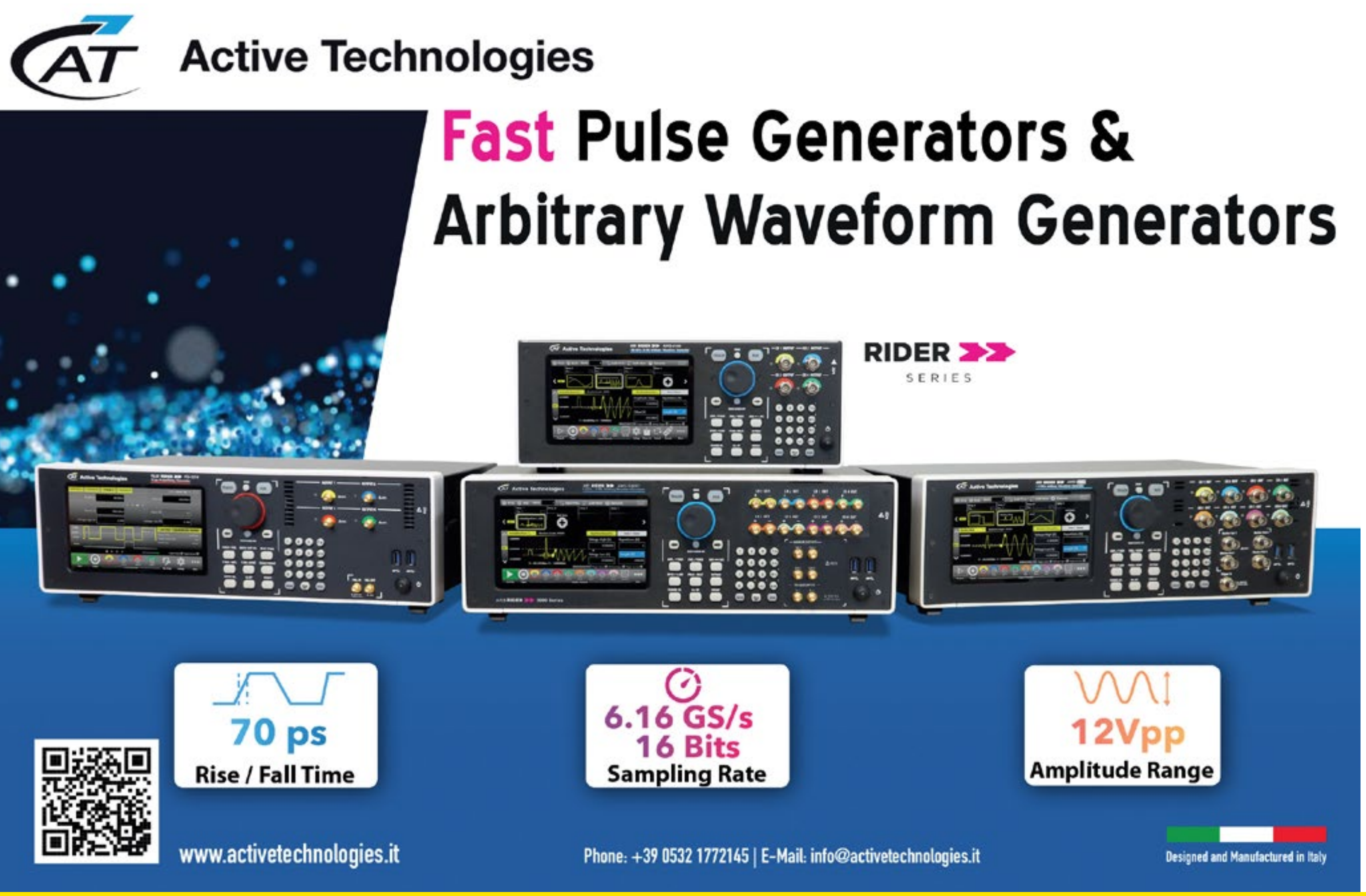
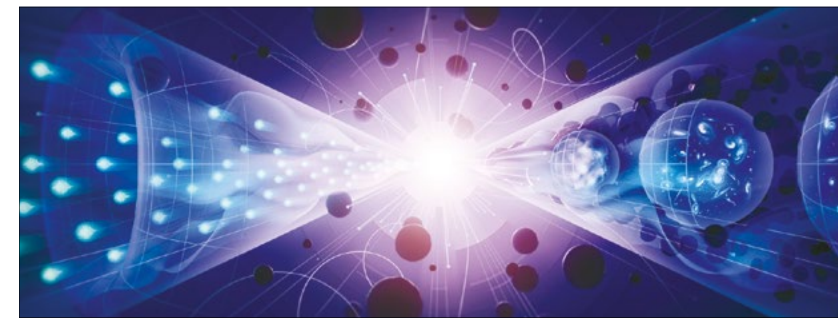




NEWS ANALYSIS

P5 REPORT

US unveils 10-year strategy for particle physics


HEPAP

On 8 December, the high-energy physics advisory panel to the US Department of Energy and National Science Foundation released a 10-year strategic plan for US particle physics. The Particle Physics Project Prioritization Panel (P5) report recommends projects across high-energy physics for different budget scenarios. Extensive input from the 2021 Snowmass exercise and other community efforts was distilled into three overarching themes: decipher the quantum realm; explore new paradigms in physics; and illuminate the hidden universe, each of which has been linked to science drivers that represent the most promising avenues of investigation for the next 10 years and beyond.

Future priorities *The P5 report includes a range of budget-conscious recommendations for federal investments in research programmes across high-energy physics.*

"The Higgs boson had just been discovered before the previous P5 process, and now our continued study of the particle has greatly informed what we think may lie beyond the standard model of particle physics," said panel chair Hitoshi Murayama (UCB). "Our thinking about what dark matter might be has also changed, forcing the community to look elsewhere – to the cosmos. And in 2015, the discovery of gravitational waves was reported. Accelerator technology is changing too, which has shifted the discussion to the technology R&D needed to build the next-generation particle collider."

Independent of the budget scenario, realising the full scientific potential of existing projects is the highest P5 priority, including the High-Luminosity LHC, DUNE and PIP-II, and the Vera C Rubin Observatory. In addition, the panel recommends continued support for the medium-scale experiments NOvA, SBN, T2K and IceCube; DarkSide-20k, LZ, SuperCDMS and XENONnT; DESI; Belle II and LHCb; and Mu2e.

On the hot topic of future colliders, the P5 report endorses an off-shore Higgs factory, naming FCC-ee and ILC, to advance studies of the Higgs boson following the HL-LHC. The US should actively engage in design studies to establish the technical feasibility and cost of Higgs factories and convene a targeted panel to make decisions in US accelerator physics at the time when major decisions concerning an off-shore Higgs factory are expected, at which point the US should commit funds commensurate with its involvement in the LHC and HL-LHC. Looking further into the future "and ultimately aim to bring an unparalleled global facility to US soil", the P5 report supports vigorous R&D toward a 10 TeV parton-centre-of-momentum collider, including a targeted programme to establish the feasibility of a 10 TeV muon collider at Fermilab – dubbed "our Muon Shot".

The P5 report supports vigorous R&D toward a 10 TeV parton-centre-of-momentum collider

Astro-matters

Looking outward, the panel identified several critical areas in cosmic evolution, neutrinos and dark matter where next-generation facilities could make a dramatic impact. Topping the list are: CMB-S4, which will use telescopes in Chile and Antarctica to study the cosmic microwave background (*CERN Courier* March/April 2022 p34); early implementation of a planned accelerator upgrade at Fermilab to advance the timeline of DUNE (in addition to a re-envisioned second phase of DUNE and R&D towards an advanced fourth detector); and a comprehensive Generation-3 dark-matter experiment to be coordinated with international partners and preferably sited in the US. Here, states the report, the impact of the more constrained budget scenario is severe, and could force the US to cede leadership in Generation-3 and to descope or delay elements of DUNE: "Limiting of DUNE's physics reach would negatively impact the reputation of the US as an international host, and more limited contributions to an off-shore Higgs factory would tarnish our standing as a partner for future global facilities."

Multi-messenger observatories with dark-matter sensitivity, including IceCube Gen-2 for the study of neutrino properties, and small-scale dark-matter experiments employing innovative technologies, are singled out for support. In addition, the panel recommends that the Department of Energy create a new competitive programme to support a portfolio of smaller, more agile experiments in high-energy physics.

Investing in the scientific workforce and enhancing computational and technological infrastructure are described as "crucial", with increased support for theory, general accelerator R&D, instrumentation and computing needed to bolster areas where US leadership has begun to erode. The report also urges broader engagement with and support for the workforce, suggesting that all projects, workshops, conferences and collaborations incorporate ethics agreements that detail expectations for professional conduct and establish mechanisms for transparent reporting, response and training.

"In the P5 exercise, it's really important that we take this broad look at where the field of particle physics is headed, to deliver a report that amounts to a strategic plan for the US community with a 10-year budgetary timeline and a 20-year context," said P5 panel deputy chair Karsten Heeger (Yale). "The panel thought about where the next big discoveries might lie and how we could maximise impact within budget, to support future discoveries and the next generation of researchers and technical workers who will be needed to achieve them."

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ADVANCED ACCELERATORS

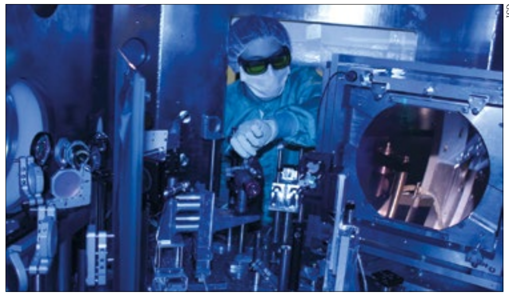
Plasma accelerators target polarised beams

Spin-polarised particle beams are commonly used in particle and nuclear physics to test the Standard Model or to map out hadronic resonances. Until now, their production has relied on conventional radio-frequency-based accelerators. Laser–plasma interactions and beam-driven plasma acceleration have been shown to be feasible methods for obtaining high-energy particle beams over much shorter distances. Despite much progress in understanding the underlying phenomena of plasma-based acceleration, however, its ability to produce polarised beams has remained unproven.

Ten years ago, a group from Forschungszentrum Jülich and Heinrich-Heine University Düsseldorf in Germany proposed a concept for producing highly polarised electron, proton or ion beams through plasma acceleration based on the use of polarised targets. Here the spins of the particles to be accelerated are already aligned before plasma formation. Although the method seems simple in principle, it requires careful consideration of various technical challenges associated with maintaining and utilising polarisation in a plasma environment. After all, spin alignments typically require low temperatures, making it counter-intuitive that they could endure in a 10^8 K plasma for long enough to have practical applications.

A 2020 theoretical study of the scaling laws for the depolarisation times revealed the feasibility of polarised particle acceleration in strong plasma fields. Dozens of numerical simulations led to the conclusion that polarised beams from plasma acceleration should be within reach, with hadron beams requiring the simplest implementation. This is because hadrons have much smaller magnetic moments and, therefore, their spin alignment in the plasma magnetic fields is much more inert compared to electrons. Also, from the target point-of-view, polarised nuclei can be provided more easily than electrons.

In an experiment at the PHELIX petawatt laser at GSI Darmstadt, the Jülich–Düsseldorf group has now provided the first evidence for an almost complete persistence of nuclear polarisation after plasma acceleration to MeV energies. The group used an up-to 50% polarised ^{3}He gas-jet target, which was irradiated by 2.2 ps laser pulses each with an energy of about 50 J. The polarisation of the accelerated ^{3}He ions was measured with two identical polarimeters, optimised for short ion bunches from plasma acceleration and mounted perpendicular to the laser axis. For those cases where the nuclear spins in the target gas were aligned perpendicular to the flight direction of the helium ions, an angular asymmetry of the scattered particles in the polarimeters was observed, which is in line with a transversal polarisation of the accelerated ^{3}He ions. No such asymmetries were found for the unpolarised gas.



GSI

Intense *The Petawatt High-Energy Laser for Heavy Ion EXperiments (PHELIX) at GSI Darmstadt.*

The team now plans to repeat the experiments at PHELIX with higher gas polarisation and the use of a shorter (0.5 mm instead of 1.0 mm) gas-jet target. This would have the advantage that the ^{3}He ions are dominantly emitted in the direction of the laser beam and at significantly higher energies (10–15 MeV). "For even higher laser intensities (> 10 PW), we have proposed a scheme based on shock acceleration to produce > 100 MeV polarised ^{3}He beams," says Markus Büscher of Jülich. "Also, a polarised hydrogen-chloride gas target for laser- or beam-driven acceleration of polarised proton and electron beams is being developed."

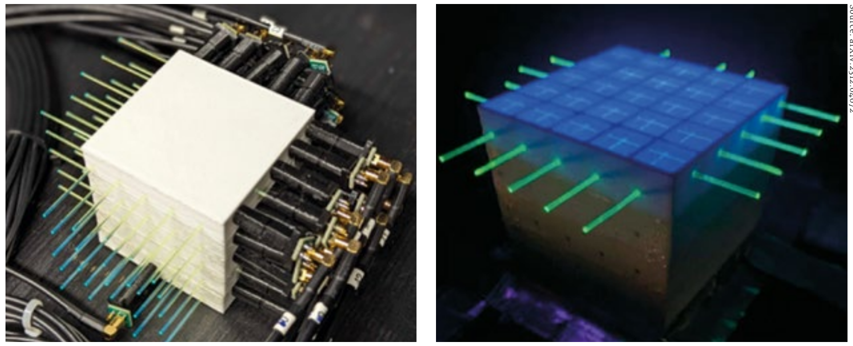
Further reading

J Thomas *et al.* 2020 *Phys. Rev. Accel. Beams* **23** 064401.
L Reichwein *et al.* 2023 arXiv:2309.06271.
C Zheng *et al.* 2023 arXiv:2310.04184.

DETECTORS

3D-printing milestone at CERN

Plastic scintillator detectors are used extensively in high-energy physics experiments because they are cost-effective and enable sub-ns particle tracking and calorimetry. The next generation of plastic-scintillator detectors aims to instrument large active volumes with a fine 3D segmentation, raising major challenges for both production and assembly. One example is the two-tonne "super fine-granularity detector", an active target made of two million $1\times1\times1\,cm^3$ scintillating cubes at the T2K neutrino experiment in Japan. Scaling up this intricate workflow or aiming for more precise segmentation calls for technological innovation.



Source: arXiv:2312.04672

Super cube *The prototype detector (left) instrumented with wavelength-shifting optical fibres and silicon photomultipliers, and (right) illuminated with UV light without the reflector on its top face to show the inner structure of the optically isolated plastic-scintillator cubes.*

Enter the 3DET (3D printed detector) R&D collaboration at CERN. Also involving ETH Zurich, the School of Management and Engineering Vaud in Yverdon-les-Bains and the Institute for Scintillation Materials in Ukraine, ▷

3DET is advancing additive-manufacturing methods to create plastic scintillator detectors that do not require post-processing and machining, thereby significantly streamlining the assembly process.

The 3DET collaboration has now passed a major milestone with a completely 3D-printed monolithic detector comprising active plastic scintillator cubes, the reflective coating to make the cubes optically independent, and the holes to insert wavelength-shifting optical fibres through the whole structure. Without the need for additional production steps, the prototype can be instrumented with fibres, photocounters and readout electronics right after the printing process to produce a working particle-physics detector. The team used the device to image cosmic rays with a scintillation light yield and cube-to-cube optical separation of the same quality as state-of-the-art detectors, and the results were confirmed with beam tests at the T9 area.

This achievement represents a substantial advance in facilitating the creation of intricate, monolithic geometries in just one step

"This achievement represents a substantial advance in facilitating the creation of intricate, monolithic geometries in just one step. Moreover, it demonstrates that upscaling to larger volumes should be easy, cheaper and may be produced fast," write authors Davide Sgalaberna and Tim Weber of ETH Zurich. "Applications that can profit from sub-ns particle tracking and calorimetry in large volumes will be massive neutrino detectors, hadronic and electromagnetic calorimeters or high-efficiency neutron detectors."

Further reading

T Weber *et al.* 2023 arXiv:2312.04672.

MUONE

Scrutinising g–2 from all angles

The anomalous magnetic moment of the muon has long exhibited an intriguing tension between experiment and theory. The latest measurement from Fermilab is around 5σ higher than the official Standard Model prediction, but newer calculations based on lattice-QCD reduce the gap significantly. Confusion surrounds how best to determine the leading quantum correction to the muon's magnetic moment: a process called hadronic vacuum polarisation (HVP), whereby a virtual photon briefly transforms into a hadronic blob before being reabsorbed.

MUonE

Promising results *A test run for the proposed MUonE experiment took place at CERN in the summer.*

While theorists are working hard to resolve this tension, the MUonE project aims to provide an independent determination of HVP using an intense muon beam from the CERN Super Proton Synchrotron. Whereas HVP is traditionally determined via hadron-production cross sections in e^+e^- data, or via theory-based estimates from recent lattice calculations, MUonE would make a very precise measurement of the shape of the differential cross section of $\mu^+e^- \to \mu^+e^-$ scattering. This will enable a direct measurement of the hadronic contribution to the running of the electromagnetic coupling constant α, which governs the HVP process.

MUonE was first proposed in 2017 as part of the Physics Beyond Colliders initiative, and a test run in 2018 was performed to validate the basic idea of a detector. Following a decision by CERN in 2019 to carry out a three-week long pilot run to validate the experimental idea, the MUonE team collected data at the M2 beamline from 21 August to 10 September 2023, using a 160 GeV/c muon beam fired at atomic electrons in a fixed target located at CERN's North Area. The main purpose of the run was to verify the system's engineering and to attempt to measure the leptonic corrections to the running of α, for which an analysis is in progress.

The full experiment would have 40 stations comprising a 1.5 cm thick beryllium target followed by a tracking system, which can measure the scattering angles with high precision; further downstream lies an electromagnetic calorimeter and a muon detector. During the 2023 run, two MUonE stations followed by a calorimeter were installed, and a further tracking station without target was placed upstream of the apparatus to detect the incoming muons; the upstream station, towards the beam and without target, was dedicated to tracking the incoming muons. The next step is to install further detector stations in stages.

"The original schedule has been delayed, partly due to the COVID pandemic, and the final measurement is expected to be performed after Long Shutdown 3," explains MUonE collaboration board chair Clara Matteuzzi (INFN Milano Bicocca). "A first stage with a scaled detector, comprising a few stations followed by a calorimeter and a muon identifier, which could provide a very first measurement of HVP with low accuracy and a demonstration of the whole concept before the full final run, is under consideration."

The overall goal of the experiment is to gather around 3.5×10^{12} elastic scattering events with an electron energy larger than 1 GeV, during three years of data-taking at the M2 beam. This would allow the team to achieve a statistical error of 0.3% and thus make MUonE competitive with the latest HVP results computed by other means. The challenge, however, is to keep the systematic error at the level of the statistical one.

"This successful test run gives MUonE confidence that the final goal can be reached, and we are very much looking forward to submitting the proposal for the full run," adds Matteuzzi.

Further reading

G Abbiendi 2022 *Phys. Scr.* **97** 054007.
R Pilato 2023 *PoS* EP-HEP2023 305.

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Third environment report demonstrates progress


CERN

Efficient *CERN Science Gateway is fitted with almost 4000 m² of solar panels that also provide energy for other CERN buildings.*

CERN's third environment report, published on 4 December, chronicles progress made in various high-priority environmental domains during the years 2021 and 2022, and reflects a proactive approach to environmental protection across the laboratory.

CERN's strategy with respect to the environment is based on three pillars: minimise the lab's impact on the environment, reduce energy consumption and increase energy reuse, and develop technologies that can help society to preserve the planet. For a large part of the latest reporting period, CERN's accelerator complex was undergoing a long shutdown that ended in July 2022 with the start of Run 3 (scheduled to end in 2025). The report charts progress made in domains such as waste, noise, ionising radiation and biodiversity, land use and landscape change. It specifically covers measures taken to reach objectives set out in the first report published in 2020: limiting the rise in electricity and water consumption and reducing direct emissions ("Scope 1") of fluorinated gases from large experiments.

CERN is committed to limiting the rise in electricity consumption to 5% up to the end of Run 3 compared to the 2018 baseline year (which corresponds to a maximum target of 1314 GWh), while delivering significantly increased performance of its facilities. It is also committed to increasing energy reuse. A total of 1215 GWh was consumed in 2022, and the accelerator complex is now more efficient, delivering more data per unit of energy consumed (*CERN Courier* May/June 2022 p55). In light of the energy crisis, CERN implemented additional energy-saving measures as a mark of social responsibility, and further explored diversification of energy sources and heat-recovery projects. The process to obtain the internationally recognised ISO 50001 energy-management certification was also undertaken in the reporting period, and has since been awarded.

CERN's objective is to reduce direct greenhouse-gas emissions by 28% by the end of Run 3 compared to 2018, which corresponds to a maximum target of 138,300 tCO_2e. In 2022, 184,300 tCO_2e direct emissions were generated, with a comprehensive programme to ensure progress towards the objective. For example, the experiments have increased efforts to repair leaks in gas systems and worked towards replacing current gases with more environmentally friendly ones. With respect to indirect greenhouse-gas emissions ("Scope 3"), CERN first reported these in the second environment report (2019–2020) spanning catering, commuting and duty travel. This third report now includes scope 3 emissions arising from procurement, which represent 92% of this total, and details the main sources of related emissions.

Regarding water consumption, CERN is committed to keeping the increase in its water consumption below 5% up to the end of Run 3 compared to 2018 (which corresponds to a maximum target of 3651 ML) despite a growing demand for water cooling at the upgraded facilities. Since 2000, CERN has radically decreased its water consumption by about 80%. The report also explores how waste is managed. CERN's aim over the reporting period has been to increase its recycling rate for non-hazardous waste, which represents over 70% of the total waste generated. In 2022 this recycling rate was 69% compared to 56% in 2018.

Biodiversity, land use and landscape change are another important focus of the report, as is the latest on how CERN's technology and knowledge benefit society, notably with the new CERN Innovation Programme on Environmental Applications launched in March 2022.

Benoît Delille, head of the CERN Occupational Health and Safety and Environmental Protection unit, concludes: "Over the years since we embarked on our first environment report, we have learned a great deal about our footprint, implemented mechanisms to better understand and control it, and increased our efforts to identify and develop technologies stemming from our core research that have the potential to benefit the environment."

Further reading
doi:10.25325/CERN-Environment-2023-003.

A year of celebrations

D Dominguez

2024 marks CERN's 70th anniversary, with a packed programme of events that connect CERN's heritage with its exciting future. This will culminate in a grand celebration for the CERN community on 17 September followed by a high-level official ceremony on 1 October. Kicking off proceedings in CERN Science Gateway on 30 January is a public event exploring CERN's science. Two events on 7 March and 18 April will showcase how innovation and technologies in high-energy physics have found applications in daily life and medicine, while the transformative potential of global collaboration is the topic of a fourth public event in mid-May. Events in June and July will focus on open questions in the field and on the future facilities needed to address them, and public events will also be organised in CERN's member states and beyond. The full programme can be found at: cern70.web.cern.ch/.

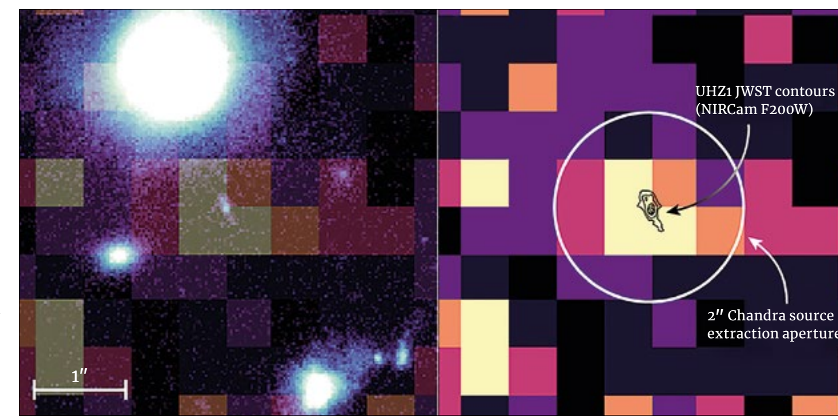
CERN welcomes host-state presidents


CERN-PHOTO-202311-266-21

Wrapping up a two-day state visit to Switzerland, president of the French Republic, Emmanuel Macron (right) came to CERN on 16 November accompanied by the president of the Swiss Confederation Alain Berset (left). CERN Director-General Fabiola Gianotti took the host-state leaders on a tour of the ATLAS cavern and to the recently inaugurated Science Gateway. Speaking to journalists during the visit, Macron said: "If I came here today, it is to reiterate my confidence in the scientific community and our ambition to maintain our leadership in this domain." (translated)

ASTROWATCH

Webb sheds light on oldest black holes



Source: Nat. Astron. 2023 doi:10.1038/s41550-023-02111-9

Back in time *Overlays of the JWST image of the distant galaxies with the Chandra X-ray image. The left version shows all the sources as seen using the JWST, while the right indicates the position of the distant galaxy, which clearly correlates Webb's image with a high-intensity X-ray source seen using the Chandra data.*

While it is believed that each galaxy, including our own, contains a supermassive black hole (SMBH) at its centre, much remains unknown about the origin of these extreme objects. The seeds for SMBHs are thought to have existed as early as 200 million years after the Big Bang, after which they accreted mass for 13 billion years to turn into black holes with sizes of up to tens of billions of solar masses. But what were the seeds of these massive black holes? Some theories state that they were formed after the collapse of the first generation of stars, thereby making them tens to hundreds of solar masses, while other theories attribute their origin to the collapse of massive gas clouds that could produce seeds with masses of 10^4–10^5 solar masses.

The recent joint detection of a SMBH dating from 500 million years after the Big Bang by the James Webb Space Telescope (JWST) and the Chandra X-ray Observatory provides new insights into this debate. The JWST, sensitive to highly redshifted emission from the early universe, observed a gravitationally lensed area to provide images of some of the oldest galaxies. One such galaxy, called UHZ1, has a redshift corresponding to 13.2 billion years ago, or 500 million years after the Big Bang. Apart from its age, the observations allow an estimate of its stellar mass, while the SMBH expected to be at its centre remains hidden in these wavelengths. This is where Chandra, which is sensitive in the 0.2 to 10 keV energy range, came in.

Observations by Chandra of the area of the cluster lens, Abel 2744, which magnifies UHZ1, shows an excess at energies of 2–7 keV. The measured emission spectrum and luminosity correspond to that from an accreting black hole with a mass of 10^7 to 10^8 solar masses, which is about half of the total mass of the galaxy. This can be compared to our own galaxy where the SMBH is estimated to make up only 0.1% of the total mass.

Such a mass can be explained by a seed black-hole of 10^4 to 10^5 solar masses accreting matter for 300 million years. A small seed is more difficult to explain, however, because such sources would have to continuously accrete matter at twice their Eddington limit (the point at which the gravitational pull of the object is cancelled by the radiation pressure it applies through the accretion to the surrounding matter). Although super-Eddington accretion is possible, as this limit assumes for example spherical emission of the radiation, which is not necessarily correct, the accretion rates required for light seeds are difficult to explain.

The measurements of a single early galaxy already provide strong hints regarding the source of SMBHs. As JWST continues to observe the early universe, more such sources will likely be revealed. This will allow us to better understand the masses of the seeds, as well as how they grew over a period of 13 billion years.

Further reading
Á Bogdán *et al.* 2023 *Nat. Astron.* doi:10.1038/s41550-023-02111-9.

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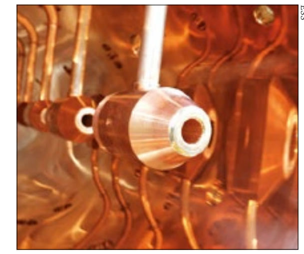
NEWS DIGEST



Copper drift tubes inside a DTL tank.

ESS linac takes shape

The installation of the first part of the linear accelerator to drive the European Spallation Source (ESS) was completed in October. The normal-conductive drift tube linac (DTL) will be a key component of the facility in Lund, Sweden, which is due to start first scientific activities in 2026. Consisting of five 8 m-long sections, the ESS DTL will accelerate protons from 3.6 to 90 MeV and was designed by researchers and engineers at INFN Legnaro and Turin, which also coordinated all stages related to the production, assembly, testing and installation.

Aluminium and unitarity

The first direct measurement of the charge radius of ^{26m}Al, which undergoes a super-allowed beta decay to ^{26}Mg, has enabled new insights into the Standard Model's consistency. Using collinear laser spectroscopy at CERN ISOLDE and the University of Jyväskylä, Peter Plattner and co-workers determined the ^{26m}Al charge radius to be 3.130(15) fm – 4.5σ higher than previously estimated. As one of the inputs characterising nuclear beta decay, this shifts the experimentally determined value of the CKM matrix element V_{ud}, which governs the probability of an up quark transforming into a down quark, and takes the sum of squares of the first row of the CKM matrix, for which a roughly 2σ difference between experiment and theory persists, slightly closer to its predicted value of unity (*Phys. Rev. Lett.* **131** 222502).

Nanophotonic accelerator

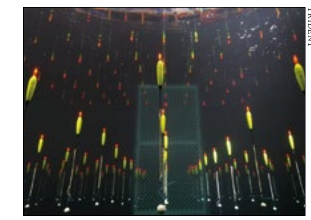
Researchers at Friedrich-Alexander University of Erlangen-Nuremberg in Germany have demonstrated a "nanophotonic" accelerator that takes dielectric laser-driven particle accelerators a step closer to applications. The device consists of hundreds of 2 μm-high silicon pillars arranged in two rows to form a 225 nm-wide channel; a laser illuminates the pillars to generate the required nearfield mode. This setup enabled electrons to be accelerated from 28.4 to 40.7 keV while remaining confined over a distance of 0.5 mm. The authors expect the work to lead directly to nanophotonic acceleration in the GeV m^{-1} range by utilising high-damage-threshold dielectric materials, and say that on-chip particle accelerators will enable transformative applications in medicine, industry, materials research and science (*Nature* **622** 476).

MEG II debuts

The MEG II experiment has released the results of its first search for the charged-lepton flavour-violating decay $\mu^+ \rightarrow e^+\gamma$ using data taken at Paul Scherrer Institut in 2021. Combined with data obtained with its predecessor MEG, the total branching ratio is found to be < 3.1×10^{-13}, which is the most stringent limit to date. If found, the decay would be an unambiguous sign of new physics. The upgraded MEG II detector, in which incoming muons decay and emitted positrons would be swept away by the magnetic field of the superconducting magnet, is designed to measure e^+ and γ kinematics and their relative production times with much higher precision. A 10-fold larger data sample was collected during 2022–2023, and a more than 20-fold increase in statistics is foreseen by 2026 (arXiv: 2310.12614).

TRIDENT for the tropics

Physicists in China have presented the design and expected performance of a next-generation neutrino observatory in the Northern Hemisphere to complement IceCube at the South Pole. The Tropical Deep-sea Neutrino Telescope (TRIDENT) could be built on an abyssal plain at a depth of approximately 3.5 km in the western Pacific Ocean, consisting of 1211 strings, each containing 20 hybrid digital optical modules, separated vertically by 30 m and covering



A simulation of TRIDENT.

a volume of about 7.5 km^3. Its advanced photon-detection technology and large dimensions would allow TRIDENT to observe the IceCube steady-source candidate NGC 1068 with 5σ significance within one year of operation, say the authors, and open a new arena for diagnosing the origin of cosmic rays and probing fundamental physics over astronomical baselines (*Nat. Astron.* doi.org/10.1038/s41550-023-02087-6).

ATLAS and CMS on top

The ATLAS and CMS collaborations have joined forces to measure the mass of the top quark. Their new result, presented at TOP2023 in Michigan, takes a weighted average of 15 previous individual measurements from ATLAS and CMS, and required a detailed study of shared uncertainties. With a total uncertainty of 0.33 GeV, the new value is the most precise to date: 172.52 ± 0.14 (stat) ± 0.30 (syst) GeV. Better knowledge of the top-quark mass allows the precision of theoretical calculations to be improved and therefore guides searches for new phenomena (ATLAS-CONF-2023-066, CMS-PAS-TOP-22-001).

Gluons under the skin

Emergent bulk properties of matter governed by the strong force, which give rise to phenomena ranging from the shape of atomic nuclei to the masses of neutron stars, can be probed by measuring the thickness of an intriguing outer "skin" of neutrons that characterises heavy nuclei. Now, Wilke van der Schee (CERN and Utrecht University) and co-workers have established a new method to do this based on processes predominantly involving gluons. Comparing a hydrodynamic model to measurements of particle distributions and collective flow in ultrarelativistic ^{208}Pb + ^{208}Pb collisions recorded at the LHC, the theorists determined the thickness of neutron skin to be 0.217 ± 0.058 fm, in line with calculations and competitive with previous measurements (*Phys. Rev. Lett.* **131** 202302).

Quantum tech for SDGs

On 13 October, during the 2023 Geneva Science and Diplomacy Anticipator (GESDA) summit, a three-year pilot phase was announced to make quantum computing resources and technical expertise available to support the UN's Sustainable Development Goals. The Open Quantum Institute (OQI), hosted by CERN, was designed in collaboration with some 130 experts and will be funded by UBS as lead impact partner. Managed by CERN's IT department, the institute will be embedded in CERN's wider Quantum Technology Initiative as of 1 March 2024, with the goal to find ways to enable quantum computing to have the widest possible societal impact.

ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

ATLAS

Magnetic monopoles where art thou?

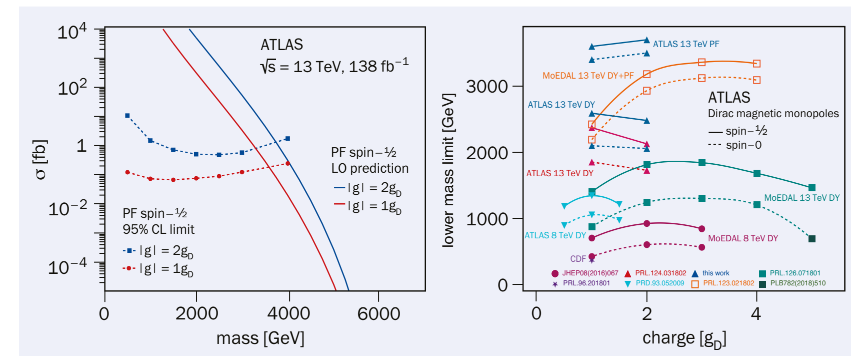


Fig. 1. *(left) Observed 95% confidence upper limits on the cross section for all masses and charges of photon-fusion pair-produced monopoles of spin-½. The solid lines are the predicted leading-order cross sections as a function of mass. (right) Comparison of the lower mass limits obtained by LHC searches in Run 1 and Run 2 pp collisions for Drell–Yan and photon-fusion pair-produced magnetic monopoles. A Tevatron measurement by CDF in proton–antiproton collisions is also shown. The dashed and solid lines represent spin-0 and spin-½ measurements, respectively.*

Magnetic monopoles are hypothetical particles that possess a magnetic charge. In 1864 James Clerk Maxwell assumed that magnetic monopoles didn't exist because no one had ever observed one. Hence, he did not incorporate the concept of magnetic charges in his unified theory of electricity and magnetism, despite their being fully consistent with classical electrodynamics. Interest in magnetic monopoles intensified in 1931 when Dirac showed that quantum mechanics can accommodate magnetic charges, g, allowed by the quantisation condition $g = N\frac{e}{2\alpha} = Ng_D$, where e is the elementary electric charge, α is the fine structure constant, g_D is the fundamental magnetic charge and N is an integer. Grand unified theories predict very massive magnetic monopoles, but several recent extensions of the Standard Model feature monopoles in a mass range accessible at the LHC. Scientists have explored cosmic rays, particle collisions, polar volcanic rocks and lunar materials in their quest for magnetic monopoles, yet no experiment has found conclusive evidence thus far.

Signature strategy

The ATLAS collaboration recently reported the results of the search for magnetic monopoles using the full LHC Run 2 dataset recorded in 2015–2018. Magnetic charge conservation dictates that magnetic monopoles are stable and would be created in pairs of oppositely charged particles. Point-like magnetic monopoles could be produced in proton–proton collisions via two mechanisms: Drell–Yan, in which a virtual photon from the collision creates a magnetic monopole pair; or photon-fusion, whereby two virtual photons scattering off proton collisions interact to create a magnetic monopole pair. Dirac's quantisation condition implies that a $1g_D$ monopole would ionise matter in a similar way as a high-electric-charge object (HECO) of charge 68.5e. Hence, magnetic monopoles and HECOs are expected to be highly ionising. In contrast to the behaviour of electrically charged particles, however, the Lorentz force on a monopole in the solenoidal magnetic field encompassing the ATLAS inner tracking detector would cause it to be accelerated in the direction of the field rather than in the orthogonal plane – a trajectory that precludes the application of usual track-reconstruction methods. The ATLAS detection strategy therefore relies on characterising the highly ionising signature of magnetic monopoles and HECOs in the electromagnetic calorimeter and in the transition radiation tracker.

This is the first ATLAS analysis to consider the photon-fusion production mechanism

The ATLAS search considered magnetic monopoles of magnetic charge $1g_D$ and $2g_D$, and HECOs of 20e, 40e, 60e, 80e and 100e of both spin-0 and spin-½ in the mass range 0.2–4 TeV. ATLAS is not sensitive to higher charge monopoles or HECOs because they stop before the calorimeter due to their higher ionisation. Since particles in the considered mass range are too heavy to produce significant electromagnetic showers in the calorimeter, their narrow high-energy deposits are readily distinguished from the broader lower-energy ones of electrons and photons. Events with multiple high-energy deposits in the transition radiation tracker aligned with a narrow high-energy deposit in the calorimeter are therefore characteristic of magnetic monopoles and HECOs.

Random combinations of rare processes, such as superpositions of high-energy electrons, could potentially mimic such a signature. Since such rare processes cannot be easily simulated, the background in the signal region is estimated to be 0.15 ± 0.04 (stat) ± 0.05 (syst) events through extrapolation from the lower ionisation event yields in the data.

With no magnetic monopole or HECO candidate observed in the analysed ATLAS data, upper cross-section limits and lower mass limits on these particles were set at 95% confidence level. The Drell–Yan cross-section limits are approximately a factor of three better than those from the previous search using the 2015–2016 Run 2 data.

This is the first ATLAS analysis to consider the photon-fusion production mechanism, the results of which are shown in figure 1 (left) for spin-½ monopoles. ATLAS is also currently the most sensitive experiment to magnetic monopoles in the charge range 1–$2g_D$, as shown in figure 1 (right), and to HECOs in the charge range of 20–100e. The collaboration is further refining search techniques and developing new strategies to search for magnetic monopoles and HECOs in both Run 2 and Run 3 data.

Further reading
ATLAS Collab. 2023 *JHEP* **11** 112.

CMS

QGP production studied at record energies

The very-high-energy densities reached in heavy-ion collisions at the LHC result in the production of an extremely hot form of matter, known as the quark–gluon plasma (QGP), consisting of freely roaming quarks and gluons. This medium undergoes a dynamic evolution before eventually transitioning to a collection of hadrons. But the details of this temporal evolution and phase transition are very challenging to calculate from first principles using quantum chromodynamics. The experimental study of the final-state hadrons produced in heavy-ion collisions therefore provides important insights into the nature of these processes. In particular, measurements of the pseudorapidity (η) distributions of charged hadrons help in understanding the initial energy density of the produced QGP and how this energy is transported throughout the event. These measurements involve different classes of collisions, sorted according to the degree of overlap between the two colliding nuclei; collisions with the largest overlap have the highest energy densities.

In 2022 the LHC entered Run 3, with higher collision energies and integrated luminosities than previous running periods. The CMS collaboration has now reported the first measurement using Run 3 heavy-ion data. Charged hadrons produced in lead–lead collisions at the record nucleon–nucleon centre-of-mass collision energy of 5.36 TeV were reconstructed by exploiting the pixel layers of the silicon tracker. At mid-rapidity and in the 5% most central collisions (which have the largest overlap between the two colliding nuclei), 2032 ± 91 charged hadrons are produced per unit of pseudorapidity. The data-to-theory comparisons show that models can successfully predict either the total charged-hadron multiplicity or the shape of its η distribution, but struggle to simultaneously describe both aspects.

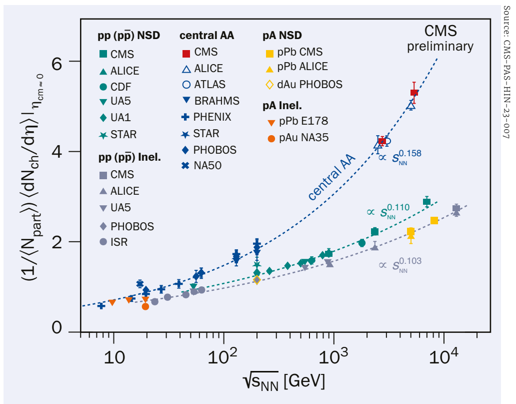


Fig. 1. *Measurements of the pseudorapidity density of charged hadrons, scaled by the number of nucleons participating in the collision, as a function of the nucleon–nucleon centre-of-mass energy for proton–proton, proton–antiproton, proton–nucleus and central nucleus–nucleus collisions. The new CMS measurement is shown by the rightmost red square.*

Previous measurements have shown that the mid-rapidity yield of charged hadrons in proton–proton and heavy-ion collisions are comparable when scaled by the average number of nucleons participating in the collisions, $\langle N_{part}\rangle$. Figure 1 shows measurements of this quantity in several collision systems as a function of collision energy. It was previously observed that central nucleus–nucleus collisions exhibit a power-law scaling, as illustrated by the blue dashed curve; the new CMS result agrees with this trend. In addition, the measurement is about two times larger than the values of proton–proton collisions at similar energies, indicating that heavy-ion collisions are more efficient at converting initial-state energy into final-state hadrons at mid-rapidity.

This measurement opens a new chapter in the CMS heavy-ion programme. At the end of 2023 the LHC delivered an integrated luminosity of around 2 nb^{-1} to CMS, and more data will be collected in the coming years, enabling more precise analyses of the QGP features.

Further reading

CMS Collab. 2023 CMS-PAS-HIN-23-007.

ALICE

Dielectrons take the temperature of Pb–Pb collisions

Collisions between lead ions at the LHC produce the hottest system ever created in the lab, exceeding those in stellar interiors by about a factor of 10^5. At such temperatures, nucleons no longer exist and quark–gluon plasma (QGP) is formed. Yet, a precise measurement of the initial temperature of the QGP created in these collisions remains challenging. Information about the early stage of the collision gets washed out because the system constituents continue to interact as it evolves. As a result, deriving the initial temperature from the hadronic final state requires a model-dependent extrapolation of system properties (such as energy density) by more than an order of magnitude.

In contrast, electromagnetic radiation in the form of real and virtual photons escapes the strongly interacting system. Moreover, virtual photons – emerging ▷

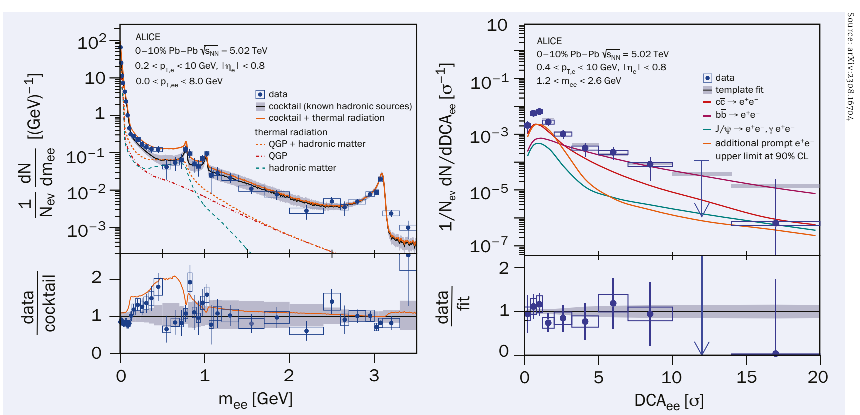


Fig. 1. *(left) Dielectron invariant-mass distribution in central Pb–Pb collisions compared to a cocktail of known hadronic decay contributions and a state-of-the-art expanding-fireball model. (right) Dielectron offset at the collision vertex, expressed in terms of the pair transverse impact parameter of the electron pairs DCA_{ee} in the IMR compared to template distributions from Monte Carlo simulations.*

in the final state as electron–positron pairs (dielectrons) – carry mass, which allows early and late emission stages to be separated.

Radiation from the late hadronic phase dominates the thermal dielectron spectrum at invariant masses below 1 GeV. The yield and spectral shape in this mass window reflects the in-medium properties of vector mesons, mainly the ρ, and can be connected to the restoration of chiral symmetry in hot and dense matter. In the intermediate-mass region (IMR) between about 1 and 3 GeV, thermal radiation is expected to originate predominantly from the QGP, and an estimate of the initial QGP temperature can be derived from the slope of the exponential spectrum. This makes dielectrons a unique tool to study the properties of the system at its hottest and densest stage.

At the LHC, this measurement is challenging because the expected thermal dielectron yield in the IMR is outshined by a physical background that is about 10 times larger, mainly from semileptonic decays of correlated pairs of $c\bar{c}$ or $b\bar{b}$ hadrons. In ALICE, the electron and positron candidates are selected in the central barrel using complementary information provided by the inner tracking system (ITS), time projection chamber and time-of-flight measurements. Figure 1 (left) shows the dielectron invariant-mass spectrum in central lead-lead (Pb–Pb) collisions. The measured distribution is compared with a "cocktail" of all known contributions from hadronic decays. At masses below 0.5 GeV, an enhancement of the dielectron yield over the cocktail expectation is observed, which is consistent with calculations that include thermal radiation from the hadronic phase and an in-medium modification of the ρ-meson. Between 0.5 GeV and the ρ mass (0.77 GeV) a small discrepancy between the data and calculations is observed.

In the IMR, however, systematic uncertainties on the cocktail contributions from charm and beauty prevent any conclusion being drawn about thermal radiation from QGP. To overcome this limitation, a new approach to separate the heavy-flavour contribution experimentally has been employed for the first time at the LHC. This approach exploits the high-precision vertexing capabilities of the ITS to measure the displaced vertices of heavy-quark pairs. Figure 1 (right) shows the dielectron distribution in the IMR compared to template distributions from Monte Carlo simulations. The best fit includes templates from heavy-quark pairs and an additional prompt dielectron contribution, presumably from thermal radiation. This is the first experimental hint of thermal radiation from the QGP in Pb–Pb collisions at the LHC, albeit with a significance of 1σ.

A new approach to separate the heavy-flavour contribution experimentally has been employed for the first time at the LHC

Ongoing measurements with the upgraded ALICE detector will provide an unprecedented improvement in precision, paving the way for a detailed study of thermal radiation from hot QGP.

Further reading

ALICE Collab. 2023 arXiv:2308.16704.

LHCb

Resolving asymmetries in B^0 and B^0_s oscillations

In the Standard Model (SM), CP violation originates from a single complex phase in the 3 × 3 Cabibbo–Kobayashi–Maskawa (CKM) quark-mixing matrix. The unitarity condition of the CKM matrix ($V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$, where V_{ij} are the CKM matrix elements) can be represented as a triangle in the complex plane, with an area proportional to the amount of CP violation in the quark sector. One angle of this triangle, $\gamma = \arg(-V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$, is of particular interest as it can be probed both indirectly under the assumption of unitarity and in tree-level processes that make no such assumption. Its most sensitive direct experimental determination is currently given by a combination of LHCb measurements of B^+, B^0, B^0_s decays to final states containing a $D_{(s)}$ meson and one or more light mesons. Decay-time-dependent analyses of tree-level $B^0_s \to D^\mp_s K^\pm$ and $B^0 \to D^\mp\pi^\pm$ decays are sensitive to the angle γ through CP violation in the interference between mixing and decay amplitudes. Thus, comparing the value of γ obtained from tree-level processes with indirect measurements of γ and other unitary triangle parameters in loop-level processes provides an important consistency check of the SM.

Measurements using neutral B^0 and B^0_s mesons are particularly powerful because they resolve ambiguities that other measurements cannot. Due to the interference between $B^0_{(s)}$–$\bar{B}^0_{(s)}$ mixing and decay amplitudes, the physical CP-violating parameters in these decays are functions of a combination of γ and the relevant mixing phase, namely $\gamma + 2\beta$ in the B^0 system, where $\beta = \arg(-V_{cd}V^*_{cb}/V_{td}V^*_{tb})$, and $\gamma - 2\beta_s$ in the B^0_s system, where $\beta_s = \arg(-V_{ts}V^*_{tb}/V_{cs}V^*_{cb})$. Measurements of these physical quantities can therefore be interpreted in terms of the angles γ and $\beta_{(s)}$, and γ can be derived using independent determinations of the other parameter as input.

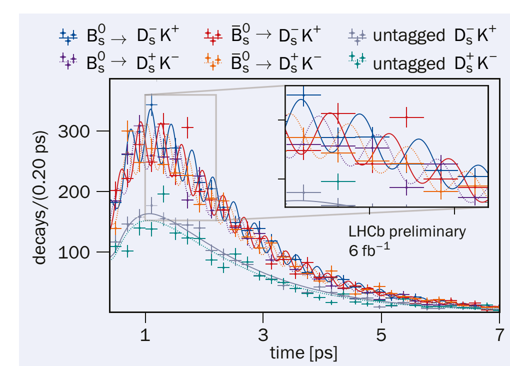


Fig. 1. *Decay-time distribution of $B^0 \to D^\mp K^\pm$ decays. The four decay amplitudes can be separated by final-state charge and by resolving the B^0 and B^0_s flavour at production. Candidates where the initial flavour could not be determined are shown in grey.*

The LHCb collaboration recently presented a new measurement of $B^0_s \to D^\mp_s K^\pm$ decays collected during Run 2. This is a challenging analysis, as it requires a decay time-dependent fit to extract the CP-violating observables expressed as amplitudes of the four different decay paths that arise from B^0_s and $\bar{B}^0_s$ to $D^\mp_s K^\pm$ final states. Previously, LHCb measured γ in this decay using the Run 1 dataset, obtaining $\gamma = 128^{+17}_{-22}$°. The B^0_s–$\bar{B}^0_s$ oscillation frequency Δm_s must be precisely constrained in order to determine the phase differences between the amplitudes. In the Run 2 measurement, the established uncertainty on Δm_s would have been a limiting systematic uncertainty, which motivated the recent LHCb measurement of Δm_s using the flavour-specific $B^0_s \to D^-_s \pi^+$ decays from the same dataset. Combined with Run 1 measurements of Δm_s, this has led to the most precise contribution to the world average and has greatly improved the precision on γ in the $B^0_s \to D^\mp_s K^\pm$ analysis. Indeed, for the first time the four amplitudes are resolved with sufficient precision to show the decay rates separately (see figure 1).

The angle γ is determined using inputs from other LHCb measurements of the CP-violating weak phase $-2\beta_s$, along with measurements of the decay width and decay-width difference. The final result, $\gamma = 74 \pm 11$°, is compatible with the SM and is the most precise determination of γ using B^0_s meson decays to date.

Further reading

LHCb Collab. 2023 LHCb-CONF-2023-004.

FIELD NOTES

Reports from events, conferences and meetings

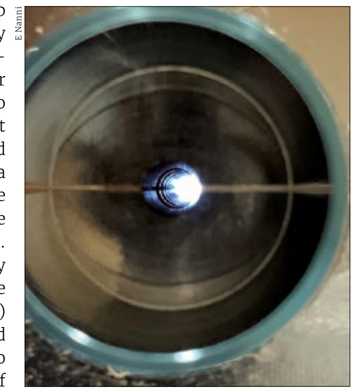
Cold Copper Accelerator Technology and Applications Workshop

Keeping it cool at Cornell

The first ICFA Beam Dynamics workshop on Cold Copper Accelerator Technology and Applications was held at Cornell University from 31 August to 1 September 2023. Nearly 100 people came together to discuss the technology and explore next directions for R&D. Originally conceived at SLAC as an attractive approach to a linear-collider Higgs factory (dubbed the Cool Copper Collider, C^3), interest in the technology has expanded to other areas.

Following opening presentations by Julia Thom-Levy (Cornell associate vice provost for research and innovation) and Jared Maxson (who leads the cold copper programme at Cornell), Emilio Nanni (SLAC) presented an overview of radio-frequency (RF) breakthroughs using cold copper cavities. He described three major advantages over conventional materials such as superconducting niobium: increased material conductivity at cryogenic temperatures (a reduction in resistance by a factor of three), significant reduction in pulsed heating, and improved yield strength and thermal diffusion. Combined, these lead to a high potential acceleration gradient of 70–120 MV/m, and an estimated 8 km footprint for a 550 GeV Higgs factory.

The optimised C-band cavity design enables a novel coupling of RF signals into each of the 40 cells along the cavity. A 9 m-long cryomodule would provide 1 GeV of acceleration. Some challenges identified for future R&D in the coming years are vibration control, meeting linac alignment specifications of 10 microns, and reducing the cost via optimised RF. Other applications of cold-copper technology include an ultra-compact free-electron laser (FEL) with 10–100 fs timing resolution as well as synergies with other proposed colliders such as ILC and FCC, where it could be used for positron production or as an injector, respectively. Walter Wuensch (CERN) summarised the extensive work over the past two decades on high-field limitations to copper performance. Breakdowns, field emission current and pulsed heating are fundamental limitations to performance, along with some practical ones such as limited RF power, conditioning time, small-aperture requirements, wakefields, power feeds and cooling capacity. Wuensch concluded that the community has a reasonably good understanding of copper, but that the demands for higher gradients and more performant cavities require careful optimisation.



E. Nanni

Down the line *A view of the electron beam tunnel for a cool-copper linac.*

The accelerator R&D community has a reasonably good understanding of copper, but the demands for higher gradients and more performant cavities require careful optimisation

The workshop also delved into the details of cryomodule design, fabrication and damping, as well as the progress of relevant developments at LANL and INFN Frascati. Numerous industry participants gave presentations, including researchers from Radiabeam, Scandinova, Canon, EEC Permanent Magnets and Calabazas Creek.

Day two started with Caterina Vernieri (SLAC) presenting the C^3 ambition for a Higgs factory based on extensive, recently published studies. Jamie Rosenzweig (UCLA) presented the design for an ultra-compact FEL and Paul Gueye (Michigan State) provided an overview of a potential high-gradient linac at the Facility for Rare Isotope Beams. Sami Tantawi (SLAC) presented potential medical applications of the technology, aimed at FLASH and very-high-energy-electron treatment modalities. Xi Yang (BNL) reviewed ultrafast electron diffraction devices and how moving from keV to MeV energies using compact copper accelerators could open new research opportunities. A session devoted to sustainability at CERN was covered by Maxim Titov (CEA Saclay), while Sarah Carsen (Cornell) presented the renewable programme at Cornell, which includes lake-source cooling of the campus and CESR accelerator complex, 28 MW of installed solar power, as well as geothermal plans. The successful mini-workshop concluded with a request to complete a report summarising the R&D discussions and post them on the Indico workshop site.

The accelerator R&D community awaits the P5 report (see p7) and the resulting strategies of the Department of Energy and National Science Foundation for accelerator research over the next decade.

Caterina Vernieri *SLAC*, **Emilio Nanni** *SLAC and* **Jared Maxson** *Cornell.*

Fast Machine Learning for Science Workshop

Machine-learning speedup for HL-LHC

The fourth edition of the Fast Machine Learning for Science Workshop was hosted by Imperial College London from 25 to 28 September 2023, marking its first venture outside the US. The series was launched in response to the need for microsecond-speed machine-learning inference for the High-Luminosity LHC (HL-LHC) detectors, in particular in the hardware trigger systems of the ATLAS and CMS experiments. Achieving this level of speed requires non-standard and generally custom hardware platforms, which are traditionally very challenging to program. While machine learning is becoming widespread in society, this ultrafast niche is not well served by commercial tools. Consequently, ▷

The tools and techniques from particle physics could be game-changing

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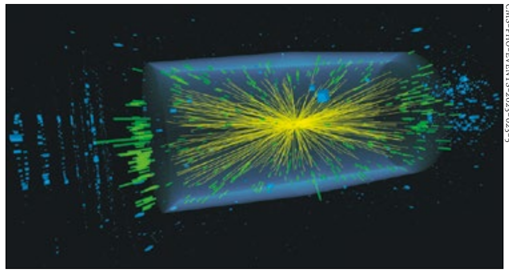
CERN

particle physicists have developed tools, techniques and an active community in this area.

The workshop gathered almost 200 scientists and engineers in a hybrid format. Students, including undergraduates, and early-career researchers were strongly represented, as were key industry partners. A strong aim of the conference was to engage scientific communities outside particle physics to develop areas where the tools and techniques from particle physics could be game-changing.

The workshop focused on current and emerging techniques and scientific applications for deep learning and inference acceleration, including novel methods for efficient algorithm design, ultrafast on-detector inference and real-time systems. Acceleration as a service, hardware platforms, coprocessor technologies, distributed learning and hyper-parameter optimisation. The four-day event consisted of three workshop-style days with invited and contributed talks, and a final day dedicated to technical demonstrations and satellite meetings.

The interdisciplinary nature of the workshop – which encompassed particle physics, free electron lasers, nuclear fusion, astrophysics, computer science and biology – made for a varied and interesting agenda. Attendees heard talks on how fast machine learning is being harnessed to speed up the identification of gravitational waves, and how it is needed to handle the high data rates and fast turnaround of experiments at free-electron lasers. In the medical arena, speakers addressed the need for faster image processing and data analysis for diagnosis and treatment, and the use of fast machine learning in biology to search for known and unknown features in large, heterogeneous datasets. The use of machine learning in control systems and simulations was discussed in the context of laser-driven accelerators and nuclear-fusion experiments,


CMS-PHO-EVENTS-2023-023-5

Fast physics *To cope with the increased collision rate during the HL-LHC era, CMS and ATLAS require microsecond-speed inference.*

while in theoretical physics the application of machine learning to solve the electron wave equation in condensed matter, working towards a detailed and fundamental understanding of superconductivity, was presented.

Industry partners including AMD, Graphcore, Groq and Intel discussed current- and future-generation hardware platforms and architectures, and facilitated tutorials on their development toolchains. Researchers from Groq and Graphcore presented their latest dedicated chips for artificial-intelligence applications and showed that they have interesting applications to problems in particle physics, weather forecasting, protein folding, fluid dynamics, materials science and solving partial differential equations. AMD and Intel demonstrated the flexibility of their FPGA platforms and explained how to optimise them for scientific machine-learning applications.

A highlight of the social programme was a public lecture from Grammy Award-winning rapper Lupe Fiasco, who discussed his work with Google on large-language models. The workshop will return to the US next year, before landing in Zurich in 2025.

Sioni Summers *CERN and* **Alexander Tapper** *Imperial College London.*

20 YEARS OF SEENET-MTP

Widening Balkan bridges in theory

Twenty years ago, the participants of the UNESCO-sponsored Balkan Workshop BW2003 in Vrnjačka Banja, Serbia came to a common agreement on the creation of the Southeast European Network in Mathematical and Theoretical Physics (SEENET-MTP). The platform for the network was provided by the 1999–2003 Julius Wess initiative "Wissenschaftler in Global Verantwortung" (WIGV), which translates to "scientists in global responsibility". Starting with a focus on the former Yugoslavia, WIGV aimed to connect and support individual researchers, groups and institutions from all over the Balkan region. The next natural step was then to expand the WIGV initiative to bridge the gap between the southeast region and the rest of Europe. Countries to the east and south of former Yugoslavia – such as Bulgaria, Greece, Romania and Turkey – have a reasonably strong presence in high-energy physics. On the other hand, they share similar economic and scientific problems, with many research groups facing insufficient financing, isolation and lacking critical mass.


M Milošević

Still going strong *The participants of the 2023 BWXX workshop in Vrnjačka Banja, Serbia.*

The SEENET-MTP network has since grown to include 24 institutions from 12 countries, and more than 450 individual members. There are also 13 partner institutions worldwide. During its 20 years of existence, the network has undertaken: more than 20 projects; 30 conferences, workshops and schools; more than 360 researcher and student exchanges and fellowships; and more than 350 joint papers. Following initial support from CERN's theoretical physics department, a formal collaboration agreement resulted in the joint CERN–▷

SEENET–MTP PhD training programme with at least 150 students taking part in the first two cycles from 2015 to 2022. Significant support also came from the European Physical Society and ICTP Trieste, and the third cycle of the PhD programme will start in June 2024 in Thessaloniki, Greece.

Unfortunately, the general focus on (Western) Balkan states has shifted during the past few years to other parts of the world. However, networking is the most natural and promising auxiliary mechanism to preserve and build local capacity in fundamental physics in the region. The central SEENET-MTP event in this anniversary year, the BWXX workshop held in Vrnjačka Banja from 29 to 31 August 2023, marked the endurance of the initiative and offered 30 participants an opportunity to consider topics such as safe supersymmetry breaking (B Bajc, Slovenia), string model building using quantum annealers (I Rizos, Greece), entropy production in open quantum systems (A Isar, Romania), advances in noncommutative field theories and gravity (M Dimitrijević Ćirić, Serbia), and the thermodynamic length for 3D holographic models and optimal processes (T Vetsov, Bulgaria).

Networking is the most promising auxiliary mechanism to preserve and build local capacity in fundamental physics in the region

A subsequent meeting held during an ICTP workshop on string theory, holography and black holes from 23 to 27 October 2023, partially supported by CERN, invited participants to brainstorm about future SEENET-MTP activities – the perfect setting to trace the directions of this important network's activity in its third decade.

Goran Djordjevic *University of Niš.*

HIGGS HUNTING 2023

A bright future for the Higgs sector

The 13th Higgs Hunting workshop, organised in Orsay and Paris from 11 to 13 September 2023, was a timely opportunity to gather theorists and experimentalists interested in recent results related to the Higgs sector. While the large $140\,fb^{-1}$ dataset collected by the ATLAS and CMS experiments during LHC Run 2 is still being exploited to measure the Higgs-boson properties in more detail, the first results based on Run 3 data collected since 2022 were also shown, along with searches for phenomena beyond the Standard Model.


L Fayard

Higgs busters *Strategies to tickle out the mysteries of the Higgs boson using the LHC Run 3 dataset were the main topic of this year's workshop.*

Experimental highlights focused on the latest results from CMS and ATLAS. CMS presented a new measurement of the associated production of a Higgs boson with top quarks decaying into b quarks, while ATLAS showed a new measurement of the associated production of a vector boson and a boosted Higgs boson in fully hadronic final states. A major highlight was a new CMS measurement of the Higgs-boson mass in the four-lepton decay channel, reaching the highest precision to date in a single decay channel as well as placing indirect constraints on the Higgs-boson width. Precision measurements were also shown in the framework of effective field theory, which allows potential subtle deviations with respect to the Standard Model to be probed. A small number of intriguing excesses observed, for instance, in the search for partners of the Higgs boson decaying into W-boson or photon pairs were also extensively discussed.

Following a historical talk on the "long and winding road" that led particle physicists from LEP to the discovery of the Higgs boson by Steve Myers, who was CERN director of accelerators and technology when the LHC started up, a dedicated session discussed Higgs-physics prospects at colliders beyond the High-Luminosity LHC (HL-LHC). Patrizia Azzi (INFN Padova) presented the experimental prospects at the proposed Future Circular Collider, and Daniel Schulte (CERN) described the status of muon colliders, highlighting the strong interest within the community and leading to a lively discussion.

The latest theory developments related to Higgs physics were discussed in detail, starting with state-of-the-art predictions for the various Higgs-boson production modes by Aude Gehrmann-De Ridder (ETH Zurich). Andrea Wulzer (CERN) overviewed the theory prospects relevant for future collider projects, while Raffaele Tito D'Agnolo (IPhT, Saclay) presented the connections between the properties of the Higgs boson and cosmology and Arttu Rajantie (Imperial College) focused on implications of the Higgs vacuum metastability on new physics. Finally, a "vision" talk by Matthew McCullough (CERN) questioned our common assumption that the Higgs boson discovered at the LHC is really compatible with Standard Model expectations, considering the current precision of the measurements of its properties.

During several experimental sessions, recent results covering a wide range of topics were presented – in particular those related to vector-boson scattering, since their high-energy behaviour is driven by the properties of the Higgs boson. The Higgs-boson self-coupling was another topic of interest. The best precision on this measurement is currently achieved by combining indirect constraints from processes involving a single Higgs boson together with direct searches for the rare production of a Higgs-boson pair. While the Run 3 data set will provide an opportunity to further improve the sensitivity to the latter, its observation is expected to take place towards the end of HL-LHC operations. Finally, Stéphanie Roccia (LPSC) presented the implications of experimental measurements of the neutron electron dipole moment on the CP-violating couplings of the Higgs boson to fermions, absent in the Standard Model. Concluding talks were given by Massimiliano Grazzini (University of Zurich) and Andrea Rizzi (University and INFN Pisa). The next Higgs Hunting workshop will be held in Orsay and Paris from 23 to 25 September 2024.

Nicolas Berger *CERN and LAPP Annecy,* **Louis Fayard** *IJCLab,* **Anne-Catherine Le Bihan** *IPHC and* **Thomas Strebler** *CPPM.*

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50 years of IMFP23 and CPAN Days

Golden anniversaries in Spain

The golden jubilees of the International Meeting on Fundamental Physics (IMFP23) and the National Centre for Particle Physics, Astroparticles and Nuclear Physics (CPAN) Days were celebrated from 2 to 6 October 2023 at Palacio de la Magdalena in Santander, Spain, organised by the Institute of Physics of Cantabria (IFCA). More than 180 participants representing the entire Spanish community in these disciplines, together with several international researchers, convened to foster cooperation between Spanish research groups and identify key priorities.

N Falcó

Celebrations *More than 180 participants marked the 50th editions of the International Meeting on Fundamental Physics and the National Centre for Particle Physics, Astroparticles and Nuclear Physics Days.*

The congress started with parallel meetings on LHC physics, astroparticle physics, nuclear physics and theoretical physics. Two extra sessions were held, one covering technology transfer and the other discussing instrumentation R&D aimed at supporting the HL-LHC, future Higgs factories, and other developments in line with the European strategy for particle physics. The opening ceremony was followed by a lecture by Manuel Aguilar (CIEMAT), who gave an overview of the past 50 years of research in high-energy physics in Spain and the IMFP series. The first edition, held in Formigal (Spanish Pyrenees) in February 1973, was of great significance given the withdrawal of Spain from CERN in 1969, which put high-energy physics in Spain in a precarious position. The participation of prestigious foreign scientists in the first and subsequent editions undoubtedly contributed to the return of Spain to CERN in 1983.

LHC physics was one of the central themes of the event, in particular the first results from Run 3 as well as improvements in theoretical precision and Spain's contribution to the HL-LHC upgrades. Other discussions and presentations focused on the search for new physics and especially dark-matter candidates, as well as new technologies such as quantum sensors. The conference also reviewed the status of studies related to neutrino oscillations and mass measurements, as well as searches for neutrinoless double beta decay and high-energy neutrinos in astrophysics. Results from gamma-ray and gravitational-wave observatories were discussed, as well as prospects for future experiments.

The programme included plenary sessions devoted to nuclear physics (such as the use of quantum computing to study the formation of nuclei), QCD studies in collisions of very high-energy heavy ions and in neutron stars, and nuclear reactions in storage rings. New technologies applied in nuclear and high-energy physics and their most relevant applications, especially in medical physics, complemented the programme alongside an overview of observational cosmology.

Roundtable discussions focused on grants offered by the European Research Council, R&D strategies and, following a clear presentation of the perspectives of future accelerators by ECFA chair Karl Jacobs (University of Freiburg), possible Spanish strategies for future projects with the participation of industry representatives. The congress also covered science policy, with the participation of the national programme manager Pilar Hernández (University of Valencia).

Prior to the opening of the conference, 170 students from various schools in Cantabria were welcomed to take part in an outreach activity "A morning among scientists" organised by IFCA and CPAN, while Álvaro de Rújula (University of Boston) gave a public talk on artificial intelligence. Finally, an excellent presentation by Antonio Pich (University of Valencia) on open questions in high-energy physics brought the conference to a close.

Manuel Aguilar *CIEMAT and* **Alberto Ruiz Jimeno** *University of Cantabria.*

6th Conference of Technology and Instrumentation in Particle Physics

First TIPP in Africa a roaring success

The Conference of Technology and Instrumentation in Particle Physics (TIPP) is the largest conference of its kind. The sixth edition, which took place in Cape Town from 4 to 8 September 2023 and attracted 250 participants, was the first in Africa. More than 200 presentations covered state-of-the-art developments in detector development and instrumentation in particle physics, astroparticle physics and closely related fields.

"As South Africa, we regard this opportunity as a great privilege for us to host this year's edition of the TIPP conference," said minister of higher education, science and innovation Blade Nzimande during an opening address. He was followed by speeches from Angus Paterson, deputy CEO of the National Research Foundation, and Makondelele Victor Tshivhase, director of the national research facility iThemba LABS.

The SA–CERN programme identifies technology transfer in particle physics as key to South African society

The South African CERN (SA–CERN) programme within the National Research Foundation and iThemba LABS supports more than 120 physicists, engineers and students that contribute to the ALICE, ATLAS and ISOLDE experiments, and to theoretical particle physics. The SA–CERN programme identifies technology transfer in particle physics as key to South African society. This aligns symbiotically with the technology innovation platform of iThemba LABS to create a platform for innovation, incubation, ▷

D Delso/Wikimedia Commons

Knowledge-transfer opportunities *Cape Town's "City Bowl" as viewed from Lion's Head.*

industry collaboration and growth. For the first time, TIPP 2023 included a dedicated parallel session on technology transfer, which was chaired by Massimo Caccia (University of Insubria), Paolo Giacomelli (INFN Bologna) and Christophe De La Taille (CNRS/IN2P3).

The scientific programme kicked off with a plenary presentation on the implementation of the ECFA detector R&D roadmap in Europe by Thomas Bergauer (HEPHY). Other plenary presentations included overviews on bolometers for neutrinos, the Square Kilometre Array (SKA), technological advances by the LHC experiments, NaI experiments, advances in instrumentation at iThemba LABS, micro-pattern gaseous detectors, inorganic and liquid scintillator detectors, noble liquid experiments, axion detection, water cherenkov detectors for neutrinos, superconducting technology for future colliders and detectors, and the PAUL facility in South Africa.

A panel discussion between former CERN Director-General Rolf Heuer (DESY), Michel Spiro (IRFU) and Manfred Krammer (CERN), Imraan Patel (deputy director general of the Department of Science and Innovation), Angus Paterson and Rob Adam (SKA) triggered an exchange of insights about international research infrastructures such as CERN and SESAME for particle physics and science diplomacy.

Prior to TIPP2023, 25 graduate students from Botswana, Cameroon, Ghana, South Africa and Zambia participated in a school of instrumentation in particle, nuclear and medical physics held at iThemba LABS, comprising lectures, hands-on demonstrations, and insightful presentations by researchers from CERN, DESY and IJCLAB, which provided a global perspective on instrumentation.

Bruce Mellado *Wits University and iThemba LABS and* **Maxim Titov** *CEA Saclay.*

50 years of neutral currents, 40 years of W and Z bosons

Electroweak milestones at CERN

Celebrating the 1973 discovery of weak neutral currents by the Gargamelle experiment and the 1983 discoveries of the W and Z bosons by the UA1 and UA2 experiments at the Sp$\bar{p}$S, a highly memorable scientific symposium in the new CERN Science Gateway on 31 October brought the past, present and future of electroweak exploration into vivid focus. "Weak neutral currents were the foundation, the W and Z bosons the pillars, and the Higgs boson the crown of the 50-year-long journey that paved the electroweak way," said former Gargamelle member Dieter Haidt (DESY) in his opening presentation.

CERN-PHOTO-202310-256-20

Historic *Director-General Fabiola Gianotti opening the first scientific symposium in CERN Science Gateway.*

History could have turned out differently, said Haidt, since both CERN and Brookhaven National Laboratory (BNL) were competing in the new era of high-energy neutrino physics: "The CERN beam was a flop initially, allowing BNL to snatch the muon-neutrino discovery in 1962, but a second attempt at CERN was better." This led André Lagarrigue to dream of a giant bubble chamber, Gargamelle, financed and built by French institutes and operated by CERN with beams from the Proton Synchrotron (PS) from 1970 to 1976. Picking out the neutral-current signal from the neutron-cascade background was a major challenge, and a solution seemed hopeless until Haidt and his collaborators made a breakthrough regarding the meson component of the cascade.

By early July 1973, it was realised that Gargamelle had seen a new effect. Paul Musset presented the results in the CERN auditorium on 19 July, yet by that autumn Gargamelle was "treated with derision" due to conflicting results from a competitor experiment in the US. "The Gargamelle claim is the worst thing to happen to CERN," Director-General John Adams was said to have remarked. Jack Steinberger even wagered his cellar that it was wrong. Following further cross checks by bombarding the detector ▷

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with protons, the Gargamelle result stood firm. At the end of Haidt's presentation, collaboration members who were present in the audience were recognised with a warm round of applause.

From the PS to the SPS

The neutral-current discovery and the subsequent Gargamelle measurement of the weak mixing angle made it clear not only that the electroweak theory was right but that the W and Z were within reach of the technology of the day. Moving from the PS to the SPS, Jean-Pierre Revol (Yonsei University) took the audience to the UA1 and UA2 experiments 10 years later. Again, history could have taken a different turn. While CERN was working towards a e^+e^- collider to find the W and Z, said Revol, Carlo Rubbia proposed the radically different concept of a hadron collider – first to Fermilab, which, luckily for CERN, declined. All the ingredients were presented by Rubbia, Peter McIntyre and David Cline in 1976; the UA1 detector was proposed in 1978 and a second detector, UA2, was proposed by CERN six months later. UA1 was huge by the standards of the day, said Revol. "I was advised not to join, as there were too many people! It was a truly innovative project: the largest wire chamber ever built, with 4π coverage. The central tracker, which allowed online event displays, made UA1 the crucial stepping stone from bubble chambers to modern electronic ones. The data acquisition was also revolutionary. It was the beginning of computer clusters, with the same power as IBM mainframes."

First Sp$\bar{p}$S collisions took place on 10 July 1981, and by mid-January 1983, 10 candidate W events had been spotted by the two experiments. The W discovery was officially announced at CERN on 25 January 1983. The search for the Z then started to ramp up, with the UA1 team monitoring the "express line" event display around the clock. On 30 April, Marie-Noëlle Minard called Revol to say she had seen the first Z. Rubbia announced the result at a seminar on 27 May, and UA2 confirmed the discovery on 7 June. "The Sp$\bar{p}$S was a most unlikely project but was a game changer," said Revol. "It gave CERN tremendous recognition and paved the way for future collaborations, at LEP and then the LHC."

Former UA2 member Pierre Darriulat (Vietnam National Space Center) concurred: "It was not clear at all at that time if the collider would work, but the machine worked better than expected and the detectors better than we could dream of." He also spoke powerfully

Neutral currents *Former Gargamelle collaborator Dieter Haidt recounted the story of CERN's first major discovery.*

Brothers in arms *Pierre Darriulat (left, UA2), Carlo Rubbia (middle, UA1) and Jean-Pierre Revol (right, UA1).*

about the competition between UA1 and UA2: "We were happy, but it was spoiled in a way because there was all this talk of who would be 'first' to discover. It was so childish, so ridiculous, so unscientific. Our competition with UA1 was intense, but friendly and somewhat fun. We were deeply conscious of our debt toward Carlo and Simon [van der Meer], so we shared their joy when they were awarded the Nobel prize two years later." Darriulat emphasised the major role of the Intersecting Storage Rings and the input of theorists such as John Ellis and Mary K Gaillard, reserving particular praise for Rubbia. "Carlo did the hard work. We joined at the last moment. We regarded him as the King, even if we were not all in his court, and we enjoyed the rare times when we saw the King naked!"

World leader

The 10 years between the discovery of neutral currents and the W and Z bosons are what took CERN "from competent mediocrity to world leader", said Lyn Evans in his account of the Sp$\bar{p}$S feat. Simon van der Meer deserved special recognition, not just for his 1972 paper on stochastic cooling, but also his earlier invention of the magnetic horn, which was pivotal in increasing the neutrino flux in Gargamelle. Evans explained the crucial roles of the Initial Cooling Experiment and the Antiproton Accumulator, and the many modifications needed to turn the SPS into a proton–antiproton collider. "All of this knowledge was put into the LHC, which worked extremely well from the beginning and continues to do so. One example was intrabeam scattering. Understanding this is what gives us the very long beam lifetimes at the LHC."

Long journey

The electroweak adventure began long before CERN existed, pointed out Wolfgang Hollik, with 2023 also marking the 90th anniversary of Fermi's four-fermion model. The incorporation of parity violation came in 1957 and the theory itself was constructed in the 1960s by Glashow, Salam, Weinberg and others. But it wasn't until 't Hooft and Veltmann showed that the theory is renormalisable in the early 1970s that it became a fully-fledged quantum field theory. This opened the door to precision electroweak physics and the ability to search for new particles, in particular the top quark and Higgs boson, that were not directly accessible to experiments. Electroweak theory also drove a new approach in theoretical particle physics based around working groups and common codes, noted Hollik.

The afternoon session of the symposium took participants deep into the myriad electroweak measurements at LEP and SLC (Guy Wilkinson, University of Oxford), Tevatron and HERA (Bo Jayatilaka, Fermilab), and finally the LHC (Maarten Boonekamp, Université Paris-Saclay and Elisabetta Manca, UCLA). The challenges of such measurements at a hadron collider, especially of the W-boson mass, were emphasised, as were their synergies with QCD measurements in improving the precision of parton distribution functions.

The electroweak journey is far from over, however, with the Higgs boson offering the newest exploration tool. Rounding off a day of excellent presentations and personal reflections, Rebeca Gonzalez Suarez (Uppsala University) imagined a symposium 40 years from now when the proposed collider FCC-ee at CERN has been operating for 16 years and physicists have reconstructed nearly 10^{13} W and Z bosons. Such a machine would take the precision of electroweak physics into the keV realm and translate to a factor of seven increase in energy scale. "All of this brings exciting challenges: accelerator R&D, machine–detector interface, detector design, software development, theory calculations," she said. "If we want to make it happen, now is the time to join and contribute!"

Matthew Chalmers *CERN.*

40 YEARS OF ACCELERATING KNOWLEDGE

Frank Tecker, Hermann Schmickler and Christine Vollinger take a look at the history, impact and future of the CERN Accelerator School.

Forty years ago, the accelerator world looked quite different to what it is now. With the web yet to be invented, communication relied on telephones and written texts received via faxes or letters. Available information existed in the form of published books, conference proceedings or scripts from university lectures. Accelerator-physics models were essentially based on approximate solutions of differential equations, or on even simpler linearisation of the problem at hand. Technologies relied on experience from accelerators that had previously worked well, with new concepts tested after sometimes cumbersome calculations and usually by building prototypes. Completely new accelerator technologies such as superconducting magnets required the construction of full-size accelerators (such as the Tevatron at Fermilab) to learn, often painfully, about the phenomenon and impact of persistent current decays.

It is into this landscape that the CERN Accelerator School (CAS) was born in 1983. CAS lectures at that time were based on hand-written transparencies, sometimes pictures and sketches, or transparency copies from books. On some occasions, the transparencies were "hot off the press", edited only the night before the presentation, using whisky as a solvent for the ink, with some traces remaining quite visible. The CAS lectures had to fulfil several objectives, notably the communication of deep knowledge and how to team-build at a time when significant progress could still be achieved by a single inventive scientist.

During the decades since, there has been a continuous evolution of the field of accelerators, driven by the rapid development of computing and telecommunications, and by the need for higher performance, leading to tighter tolerances or even novel acceleration technologies. Nowadays, much of the necessary information is only a mouse-click away, at any moment, at any location. Video, telephone and messenger exchanges are part of daily practice. The available computing power allows researchers to carry out complex simulations of beam behaviour by tracking thousands of particles over millions of turns in a reasonable time. No single accelerator component is built without

Grassroots *Marking the 40th anniversary of the CERN Accelerator School on the CERN lawn on 14 September 2023.*

extensive computer simulations beforehand, and the available simulation tools are extremely powerful and reliable. They do not yet, however, replace an innovative mind.

Collaboration

In this context, the present-day CAS has to play a new and even more demanding role. Knowledge about accelerators is available to every participant well before a CAS course begins. The multitude of information is enormous, which means that each CAS course, in particular the annual introductory course on accelerator physics, has to concentrate on the essential elements. Lecturers certainly have to be experts in their domain, but they also must have the capacity to explain their topic in simple terms.

The concept of the ingenious physicist designing an accelerator all by themselves also belongs in the past. Today, any new accelerator is the result of international collaborations featuring many individual contributions. CAS supports this development concept by fostering collaboration right from the start of the initial courses, ensuring that the students work in teams and that the links established during the courses are maintained throughout their professional lives.

The 40th anniversary of CAS offers an ideal opportunity to reflect on the school's history, its educational approach, its impact and its bright future.

THE AUTHORS

Frank Tecker *CAS director,* **Hermann Schmickler** *former CAS director and* **Christine Vollinger** *deputy CAS director.*

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School starts *The first CAS course in October 1983 "Antiprotons for colliding beam facilities" being introduced by Kjell Johnsen, with Simon van der Meer in the front row.*

Hands-on RF *In 2023 the CERN Accelerator School collaborated with the Helmholtz-Zentrum Berlin to organise a unique two-week-long residential course called "RF for Accelerators".*

The seeds for the CERN Accelerator School were sown in the early 1980s by a group of visionary scientists and engineers at CERN. Driven by the high specialisation of the field, this group recognised the need for a dedicated educational programme that could provide comprehensive training in the rapidly evolving field of accelerator physics and technology. Textbooks on accelerator physics were sparse at the time, and courses at universities were practically non-existent. As Herwig Schopper, CERN Director-General at the time, put it: "An enormous amount of expertise is stored in the brains of quite a number of people […]. However, very little of this knowledge has so far been documented or published in book form."

The first CAS course took place in Geneva in 1983 and attracted an impressive 107 participants. It focused on the special topic of colliding antiprotons. The W and Z bosons had just been discovered at CERN's Super Proton–Antiproton Synchrotron (Sp$\bar{\text{p}}$S), making this topic fully justified, as Kjell Johnson, the first CAS head, noted in his opening speech. This course was followed just a year later by a general one in accelerator physics, which is a classic today and remains one of the pillars of CAS. The general physics course covers topics such as beam dynamics, magnet technology, beam diagnostics, radiofrequency and vacuum systems. In this way, the school represents various types of accelerators and different accelerator components.

As the demand for specialised knowledge in accelerator physics grew, so did the CAS curriculum. While historically courses were more focused on high-energy colliders for particle physics, the scope broadened due to the development of applications in other fields, such as light sources, industry use and medicine. Over the years, the school has introduced a wide range of new topical courses to its portfolio, including radiofrequency systems, beam diagnostics, normal- and superconducting magnets, general superconductivity and cryogenics, vacuum systems and technology, high-gradient wakefield acceleration, high-intensity accelerators, medical accelerators and many more. This diversification has ensured that all participants are provided with up-to-date training in the latest developments. The curricula of the courses in "General Introduction to Accelerator Physics" and "Advanced Accelerator Physics" are also constantly adapting to the evolving landscape.

The success of CAS in Europe quickly caught the attention of the global accelerator community, leading to a surge in demand for its courses. To accommodate this growing interest, CAS began organising courses outside Europe from 1985 in collaboration with other institutions and organisations working in accelerator physics, such as the US Particle Accelerator School (USPAS), as well as the Joint Institute for Nuclear Research (JINR) in Russia and the High Energy Accelerator Research Organization (KEK) in Japan. Since then, these joint schools have trained more than 1000 participants via 16 courses in Asia, Europe and the Americas.

CAS has been instrumental in nurturing generations of experts who are continuing to push the boundaries of scientific knowledge

Educational approach

A key factor to the school's success has been its innovative educational approach and the flexibility to adapt to new learning processes. Participants attend lectures delivered by selected lecturers, including some of the world's foremost experts in accelerator physics, who willingly share their knowledge and insights in an engaging and accessible manner. By recognising the diverse backgrounds and needs of its participants, CAS offers courses at both the introductory and advanced physics levels. The former provide a solid foundation in the fundamental concepts of accelerator physics and technology, while the latter cater to participants with prior experience, act as a motivating refresher, or offer a deeper dive into specialised topics and the latest developments.

Today's CAS experience is not limited to classroom lectures. The extensive availability of powerful computational tools has led to the introduction of hands-on sessions, first introduced in 2001, during which participants are not only put in touch with experimental set-ups but also dedicated expert-tool programmes. Particle-tracking codes or numerical-simulation programmes are examples where the participants are exposed to case studies and challenged to solve actual problems with expert guidance. Today, the introductory course offers hands-on software training in transverse and longitudinal beam dynamics as a regular course session. The advanced course, on the other hand, offers practical insight into beam optics as well as accelerator components from radiofrequency to beam diagnostics. Truckloads of equipment are shipped to the course venues, and the most recent topical CAS course on normal and superconducting magnets brought set-ups to perform superconducting experiments cooled down with liquid nitrogen to provide a real laboratory frame for teaching.

The heart of the CAS educational approach is clearly beating for an emphasis on problem-solving and collaborative learning. Participants are encouraged to work together on exercises and projects, fostering a sense of community and teamwork that extends beyond the classroom. It is the CAS spirit to work hand-in-hand with colleagues from different fields to solve a given task, very much as in a real work setting. This collaborative atmosphere not only enhances the learning experience but also offers the opportunity to build lasting relationships and to lay the ground for professional networks among participants. Throughout the CAS courses, participants profit from direct contact with the lecturers and their availability. Almost every lecturer has fond memories of long evening discussions with particularly interested participants – often fruitful for both sides. Equally legendary are the midnight hands-on sessions, carried out on request when all of a sudden another interest peak is sparking.

More to come

As the CERN Accelerator School celebrates its 40th anniversary, it is clear that its legacy of excellence, innovation and collaboration has left an indelible mark on the world of accelerator physics and technology. CAS has been instrumental in nurturing generations of experts who are continuing to push the boundaries of scientific knowledge, contributing significantly to our understanding of the universe. Over its 40 year-long history, more than 6000 participants from across the globe have been trained. Many of its alumni have gone on to play crucial roles in the development, construction and operation of particle accelerators around the world, including the LHC, to date still the largest machine ever built. However, no celebration would be complete without a projection into an even more promising future.

The variety of accelerator technologies, as much as the diversity and complexity of accelerator theory, will continue to grow. While the pre-education at European universities concerning basics in mathematics, electronics or computing already varies significantly between countries, worldwide collaborations make this aspect even more of a challenge. Over the years, the CAS teams have noticed, in particular in the introductory physics course, an ever-increasing spread in the basic accelerator-related knowledge that participants bring. Consequently, the CAS curriculum has been revised, but the problem persists: some participants are overwhelmed by the complexity of the course materials, whereas another large fraction is happily satisfied with the course and the progress they are able to make. As a first measure, the presently non-residential one-week "basic" CAS course on accelerator physics and technology will now be held on a yearly basis, and future participants of the introductory physics course will be strongly recommended to follow the basic CAS course first. If required, further adjustments for the general physics course will be made in the years to come.

All smiles *Participants of the 2022 school with the latest of almost 70 volumes of CAS proceedings.*

With the ever-increasing diversity in technological disciplines and related scientific descriptions, CAS has stepped up the number of courses from two to four per year and, in addition, to offer at least two topical CAS courses per year. This allows the school to keep pace with the fast technological progress by teaching the major accelerator technologies (beam instrumentation, accelerator magnets, radiofrequency and superconductivity) roughly every five years, compared to every 10 years previously. While from a financial and organisational point of view four courses per year seem to be the maximum that can be offered, with the strong support of the CERN management this established rhythm can be maintained. In keeping with the long CAS tradition of publishing comprehensive proceedings for most of the courses, the higher frequency of courses has significantly increased the associated workload for authors and editors. Nevertheless, experience shows that these proceedings are vital to support the "post learning-process" of the CAS participants.

Finally, two years ago, a project called CASopedia was launched to record the CAS lectures. Fully in line with the CAS spirit, CASopedia aims to complement the regular written proceedings with a new learning approach where all recorded CAS lectures will be equipped with a catalogue of keywords and associated software with competent markers that allows topics to be searched via a keyword marker directly in the video material. Although a lot of work on this has already been done, significant effort is still needed to insert the many video-markers and to link them with the keyword database and the related time-code marker.

With these prospects in mind, and a rich legacy to build on, the school will undoubtedly continue to play a crucial role in the development of accelerator science by ensuring that future generations of physicists, engineers and technicians are well-equipped to tackle the ongoing challenges as well as the vast opportunities that always lie ahead. In this sense: happy birthday CAS, with hopes for an even bigger party to come in 10 years' time! ●

Further reading

cas.web.cern.ch.

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The Future of Flash Therapy, Particle Therapy & Theranostics

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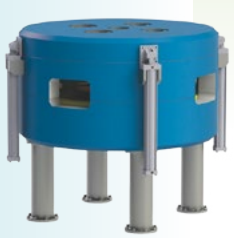

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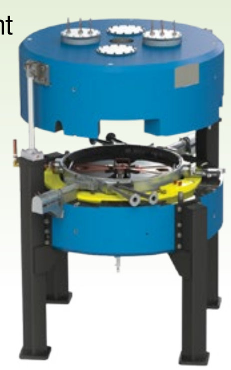

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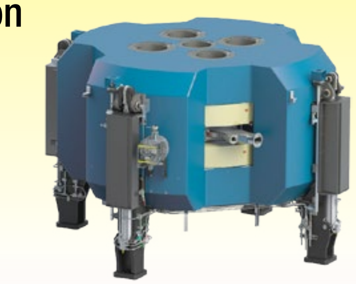

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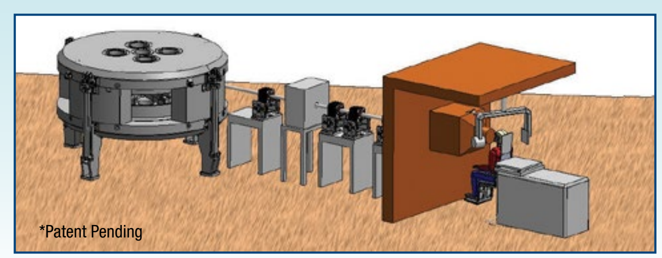

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PORTRAITS OF PARTICLE PHYSICS IN UKRAINE

Ukrainian physicists have a rich history in fundamental research and Ukraine joined CERN as an associate member state in 2016. Russian scientists also have a long and distinguished involvement with particle physics, and Russia was granted Observer status (currently suspended) in recognition of its contributions to the construction of the LHC. On 24 February 2022 the Russian army launched a full-scale invasion of Ukraine. In the first hours of the war, the majority of scientific organisations in Ukraine found themselves in the war zone, either directly or through missile strikes. In a short period, faced with huge challenges, most laboratories and institutes have recovered and many people are back at work. But the war has taken a terrible toll, especially on the composition of research groups and on young researchers. Here, we collect some of the experiences from physicists in Ukraine about how they and their institutes are recovering from the damage so far, the importance of continued global support, and how science in Ukraine can be rebuilt when the war is over.

On the ground *Physicists from the Institute for Scintillation Materials in Kharkiv, Taras Shevchenko National University of Kyiv, Odesa National University, Uzhhorod National University and Kharkiv Institute of Physics and Technology describe how the war has affected their work in particle physics.*

Institute for Scintillation Materials, Kharkiv

Located in Kharkiv, the Institute for Scintillation Materials (ISMA) of Ukraine has both a large scientific base and technological facilities for the production of scintillation materials and detectors. It has been a member of the CMS collaboration for about 20 years, including participation in the production of scintillation tiles for the current calorimeter and as a potential manufacturer of tiles for the HGCAL upgrade. Since 2021, ISMA has also been a technical associate member of LHCb hosted by the University of Bologna, where we participate in the PLUME (probe for luminosity measurement) project. ISMA is also a member of the Crystal Clear Collaboration at CERN and, since 2019, of the 3D printed detectors (3DET) project (see p8). In addition, ISMA is a supplier of scintillation materials and detectors for projects outside CERN.

With the outbreak of the war in Ukraine, the Institute became a home for many. In the months following March 2022, about 50 staff members lived in the basement with their families and pets. In addition, some 300 people who were living nearby moved into the Institute's bomb shelter, where staff provided food and helped people to adapt.

At the beginning of March 2022, one of our processing areas for crystals growth was damaged due to an air raid. This was shocking not only to us, but also for our partners for whom we serve as the main supplier of products. It was necessary to make a quick and important decision: wait until the end of active hostilities and then reconstruct infrastructure and technology, or start doing something now. We realised that technological downtime would result in the loss of a market that had been developed over decades and would also make it economically impossible for us to restart production cycles with the necessary volumes. We got together with our staff, who were living on the Institute's territory. Some people even came to besieged Kharkiv from other cities to help. Between alarms and artillery shelling, the guys were coming out of the bomb shelters to go to work. Just one month after the war started, products were already being shipped to our customers. Once temperatures started to rise above zero, we started to move the processing equipment and growth units out of the damaged processing area. Not only did we have to repair these, but we also had to clear the premises of other equipment, calculate and pour new foundations, hook up the entire infrastructure and lay the lines for services – all in a period of a few months. By May 2022, we had already started growing large crystals of up to 500 mm in diameter at the new location. Some of our partners did not even notice the delays in delivery and we were able to meet our delivery commitments for 2022 in full.

ISMA *Top left: celebrating International Women's Day on 8 March 2022 in the basement of the Institute for Scintillation Materials (ISMA) in Kharkiv. Bottom left and middle: installation of a furnace and crystal-growth facility at a new location in spring 2022, and (right) the first grown CsI(Na) crystal in the new crystal growth facility in May 2022.*

We are very grateful to our colleagues, and to our friends at CERN, who offered their help and supported us from the early days of the war. They were not only CERN staff members, but also people from other institutes and organisations who called and wrote letters every day. They even organised a special programme to welcome families who had to leave Kharkiv at that time, and helped to persuade those who did not want to leave to move to safer cities in Ukraine or in Europe, at least temporarily.

In April 2022 we started discussions on future cooperation with our colleagues at CERN. Unfortunately, it was impossible to continue any work during the first two months of the war. However, we agreed that work should not stop and that some of it could be carried out in the organisations of our partners. We collected all the materials from Kharkiv that our colleagues needed and sent it to them. Some female colleagues, who could leave Ukraine, were also invited temporarily to continue their work abroad in these organisations. This allowed us to continue joint research programmes with our European partners. All our R&D projects were maintained either in Kharkiv or at the partner institutes abroad.

In May 2022 we were informed that ISMA, together with CNRS, Université Claude Bernard Lyon 1 and CERN, had won a project financed from the European Union's Horizon Europe programme to develop inorganic scintillation crystals for innovative calorimeters for high-energy physics. By mid-summer, ISMA resumed the production of experimental scintillator tiles for CMS. We also continued work on developing technology for the synthesis of scintillation granules based on inorganic crystals. At the end of summer 2022, the crystals had already been shipped to our partners. Work on the 3D printing of scintillators in Kharkiv continued unabated.

By mid-summer, ISMA resumed the production of experimental scintillator tiles for CMS

Despite the war and its impact on life in Kharkiv and work at our Institute, over the past 18 months ISMA was able to contribute to all of the ongoing projects at CERN, and even expanded its capacity by transferring some work to other European institutes – strengthening our capabilities to do world-class research. The technological aspect of scintillator production has been restored and ISMA is receiving new requests to design and manufacture scintillators for international projects. We are grateful to our partners for their support and cooperation.
***Andriy Boyaryntsev** deputy director ISMA.*

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University of Kyiv *Top left to right: damage to university buildings in Kyiv caused by Russian shelling on 31 December 2022. Bottom left: CNRS research director Marie-Hélène Schune lecturing in the nearest subway during the autumn school on high-energy physics at the University of Kyiv on 13–17 November 2023. Bottom right: LHCb spokesperson Vincenzo Vagnoni lecturing in the university buildings during the school.*

Taras Shevchenko National University of Kyiv

Our group at Kyiv has cooperation with many European universities and groups. We collaborate on LHCb and on the proposed SHiP experiment at CERN, and the International Large Detector – a general-purpose detector for an electron–positron collider, primarily the ILC. The group has many scientific contacts with IJCLab at Paris-Saclay and cooperates with ETH Zurich on the study of perovskite materials. Before the war and COVID periods, our students had many internships in various European institutes and staff travelled regularly to Europe.

Since autumn 2022, we have resumed our scientific work and the connections with students

In the first weeks of the war, there was a serious disruption to life and to hopes for the future. Many of the women and girls were evacuated from Kyiv to the west of Ukraine and abroad. With the help of our graduates and foreign colleagues, I sent 17 female students to various European cities for long-term internships. Many other teachers also helped some travel to Europe.

At that time, we were really expecting a nuclear strike from a maddened neighbour. Thanks to our colleagues abroad, the registration of internships took place instantly, in just a few days. Meanwhile, the men in Kyiv were preparing for battles on the streets. I actively read how to use various types of weapons, even though I was not accepted due to my age. I was sure that I would find weapons on the streets during the fighting, and I collected equipment and materials for actions after a nuclear explosion (nuclear physics is our department specialty). Now it already looks childish, but at the beginning of March 2022 I said goodbye to my wife, who was evacuated to Europe to join her daughter, because we thought that we would never meet again.

I was not afraid: there were almost only men left in the city, and those who remained were ready to stand to the death. The general feeling of a joint struggle united us and supported our spirit. It was clear in those weeks that this was not the time for science. I did some volunteering, first buying body armour and other military equipment, then collecting money for the purchase of jeeps for the front line and prostheses for crippled soldiers. We (with the alumni of our department in Ukraine and abroad) collected for the army very quickly, raising the necessary several thousand euros in a few days.

After the defeat of the Russian forces near Kyiv and Kharkiv, and especially after the return of Kherson, it became a little easier and we began to implement grants for students. This partially compensated for the decrease in real salaries and scholarships, and the high inflation of the hryvnia. Since autumn 2022, we have resumed our scientific work and the connections with students. We also have a lot of volunteer work as physicists and engineers. Many of the women and children have returned home – as has my wife. The main problem now is a more than two-fold drop in wages, taking into account inflation.

Odesa University *The southern city of Odesa in the first months of the war, showing the monument to city founder Duc de Richelieu (left), barricades in front of the Odesa Opera Theatre (middle) and the observatory of Odesa National University which, fortunately, was not damaged.*

On 31 December 2022 a large Russian missile exploded between the buildings of the university. The explosion occurred at a height of several metres (the rocket had impacted a large tree), completely or partially destroying more than 500 large windows in seven buildings, including two thirds of the windows in our building.

Our small group now has acceptable working conditions. Currently, quite a lot of European and partial US grants are provided to our students for remote work. However, the necessary restriction during the war period on trips abroad for boys and men of conscription age has greatly hindered both scientific work and effective teaching. There has been a rapid washout of qualified personnel from scientific groups, especially young people who have been driven to look elsewhere for acceptable wages in Ukraine or abroad. After the end of the war, it will be difficult (or even impossible in some areas) to restore an effective group composition. Obtaining scientific grants during the war can significantly stop this degradation of science in our country.

Ukrainian science has been seriously affected due to the constant bombing of buildings and scientific facilities, the large outflow of personnel (especially women) to institutes and universities abroad, the decrease in real salaries, and the blocking of international internships and scientific travel for male scientists. I am sure that, step by step, we will restore lost contacts with foreign scientific centres and rebuild the scientific and educational resources of Ukraine that have been destroyed by the Russian invasion.

***Oleg Bezshyyko** associate professor, Taras Shevchenko National University of Kyiv.*

Odesa National University

When the war started on 24 February 2022, I was with my family in Odesa. At around 4 a.m. I saw from the window in my flat how Russia had bombed Odesa port. In that moment, it was very difficult to understand what was going on and how to act. Yet, within a week, when it became clear that this was a real war, I received invitations from people in the physics department of the Jagiellonian University in Krakow, Poland, to visit them in the capacity of a visiting professor. I drove with my family through Moldova, Romania, Hungary, Slovakia and finally arrived in Krakow, where the people from the department adopted us. The children went to school the next day. There is only a small difference in language between Polish and Ukrainian, so it was not too difficult for them to adapt. Two months later I received an invitation from a new institute near Dresden called the Center for Advanced System Understanding (CASUS), where I have been based ever since.

As a theoretical physicist, and a frequent visitor to the CERN theory department, it's much easier for me to move than it is for those who are connected to an experiment. Many of the laboratories in Ukraine have been completely destroyed. How they manage is difficult for me to comprehend. Odesa was not occupied, so it was possible to remain there. But in winter there was no electricity or heating, and during the day there were often air alarms when residents had to go to shelters. We were also worried about our grandchildren. A few weeks after the war started, a rocket fell a couple of hundred metres from my apartment.

Without investing money into science it is impossible to build a strong country

Prior to the invasion, I would travel to Russia for conferences but I didn't have any collaborations with Russian institutes. For me to work abroad is quite a normal situation. But I thought it was just my own will. Now I will stay here because of the war. But I also miss Ukraine and Odesa. The question is what will happen when we win? The answer is not so simple.

Without investing money into science it is impossible to build a strong country. But to have that requires a good level of education, and that's not easy because many young people are abroad. Will they go back, and how? If we have a good scientific climate, I think many would like to return. But if there is no money for science, then no. The government situation is not easy. The eastern part of the country is completely destroyed. Up to now only a small percent of the nation's budget goes to science. The level of education and science in Ukraine already went down in the 1990s compared to when it was part of the Soviet Union. Many good scientists went abroad and have not returned.

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Uzhhorod National University *Top: the participants of the IX Ukrainian Conference on Physics of Semiconductors at Uzhhorod University in May 2023. Bottom: a student's laboratory on electronics, the semiconductors laboratory for nonlinear optics, and the microtron at the Institute of Electron Physics.*

We are currently living in a state of stress and uncertainty. Our minds are completely occupied by the news. The situation is even worse for those who stay in Ukraine. Many young scientists would like to go to foreign institutions and many foreign universities and institutes have adopted Ukrainian people, especially female scientists. But for boys it is forbidden. The border is closed. How many cross it illegally is probably only a small percentage. They stay mainly inside of Ukraine, often to fight against Russia. I know many people who were killed, including a former astronomy student who was educated at Odesa University.

The second year of the war is ending. A difficult winter is ahead. Russia will again try to destroy infrastructure with missiles and drones, so that people have neither heat nor light, so that they lose the will to win. The situation is very difficult. I don't know what will happen next year or the year after. I can't imagine where my family and I will live. I really want to return to Odesa. But for this, Ukraine must win.

***Oleksandr Zhuk** Odesa National University; currently CASUS Germany.*

Uzhhorod National University

Uzhhorod National University was established in 1945, and five years later the faculty of physics and mathematics began its work. Today, the university has cooperation with around 90 institutions worldwide. We have activities in solid-state physics, optics and laser physics, physics of electron–atom collisions and plasma, quantum theory of scattering, and astrophysics and astronomy. For the past five years our group (comprising 10 engineers, technicians, senior scientists and PhD students) has been cooperating with the ISOLDE facility at CERN. At the beginning this was a multidisciplinary project to investigate materials that have spontaneous magnetisation and polarisation. We have published several articles in this area and in particular have proposed layered van-der-Waals crystals – a promising field for applications that can be further investigated with ISOLDE.

It took some time to get back to a reality where you can concentrate

Uzhhorod is located just at the western Ukrainian border towards Slovakia and 20 km to the border with Hungary. While there were a few attacks from Russian forces, the situation here is relatively okay compared to other parts of Ukraine. We have the possibility to work, although there were times where we wouldn't have electricity, so we couldn't do any measurements or calculations. When the war started I immediately received calls from many colleagues outside Ukraine, who asked me to come to their labs. I did not expect this at all. Generally, many scientists left, especially from Kharkiv. Many of them came to Uzhhorod, others went abroad, for example to Poland, the US, the UK or France. For many who are from highly bombarded regions, this was certainly the correct decision; otherwise, they could have been killed. We keep in touch and continue our work.

After the first week of the invasion, we evaluated the situation and hoped that Kyiv would remain unoccupied. After about a month, we fully resumed work. It took some time to get back to a reality where you can concentrate. Looking back, it felt like a state of hypnosis, because the situation was so bad. Now, it's better. I have published three papers in *Physical Review* since the beginning of the war. I hope we continue to receive support from European countries, the US, Canada, Australia and Japan.

Long before the invasion, I often participated in meetings and worked with Russian scientists. After the annexation of Crimea in 2014, I stopped. Many others continued to collaborate after 2014. We are academics after all, and we work in science. Maybe after the war, some peace regulation will make scientific and diplomatic co-operations possible again. To use an analogy from solid-state physics, the 2014 invasion of Crimea was a first-order transition whereas this one was a second-order transition that continues with a modulated phase.

Since the invasion, we have prepared and submitted a proposal to the European Union Horizon programme. After successful evaluation at the beginning of October, together with scientists from Portugal, Spain, Denmark, Poland and from Kyiv, we have started the Piezo2D project to investigate piezoelectricity in 2D materials and their relevant device performance.

It is crucial to have Ukrainian universities participate in academic European programmes, not just formally on paper but to be actively involved. We don't ask for any preference. We want to have the same possibilities as any other country to participate and for our people have the experience to be part of it.

As I am over 60 years old, I am allowed to leave the country. But younger male scientists can't leave unless they have a permit for special services or duties. Some find special permission to study abroad as PhD students. Many others went to join the Ukrainian army. Some of us, especially physicists and chemists, are involved in special technology R&D programmes.

I'm sure that Ukraine will win the war. Then we will rebuild the economy, society and science. The latter will be especially important. Our government understands that science produces knowledge, and now is the time for it. For now, however, we must hope and work with the situation at hand. And here goes a big "thank you" from me and my colleagues to all those helping and supporting us at CERN and beyond.

***Yulian Vysochanskii** head of the semiconductor physics department, Uzhhorod National University.*

Kharkiv Institute of Physics and Technology

Our institute, founded in 1928, has a long connection with high-energy physics and with CERN. Theorists Dmitrij Volkov and Vladimir Akulov played a crucial role in the development of supergravity and supersymmetry, for example, and for more than 20 years researchers at Kharkiv Institute of Physics and Technology (KIPT) have been actively working with the LHC experiments. In CMS, for which we contributed to the endcap hadron calorimeters, we host a Tier-2 computational cluster that is considered one of the best; in LHCb we have participated in the calorimeter system maintenance and support. In collaboration with colleagues at Bogolyubov Institute for Theoretical Physics in Kyiv, we participate in the inner tracking project for ALICE and are working on ITS3 upgrade. We also have collaborations with CERN concerning new theoretical and experimental proposals, for instance on the interaction of half-bare particles with matter. The first electron accelerator with an energy of 2 GeV in Europe was created and launched at KIPT in 1965. Before February 2022, the institute continued to operate a number of electron accelerators of lower energies and several large installations, such as the stellarator and quasi-stationary plasma accelerator.

Wikidata

KIPT *The Kharkiv Institute of Physics and Technology, photographed before the Russian army's invasion.*

The institute has sharply increased cooperation with major international scientific centres

Prior to the Russian invasion, our institute had a staff of more than 2000 people. In former Soviet Union times it was three times larger, and subordinate to the ministry within which the atomic project was performed (our institute had the status of laboratory no. 1). It was not so well known at the time because we were a closed-regime facility. In 1993 our institute became the first national scientific centre of Ukraine, with the full name National Science Centre "Kharkiv Institute of Physics and Technology" (NSC-KIPT), and our scientists started to cooperate actively with CERN and other international centres. NSC KIPT consists of institutes devoted to theoretical physics, high-energy and nuclear physics, solid-state physics, plasma physics, plasma electronics and new methods of acceleration, in addition to a number of quite large scientific complexes. A significant portion of the institute's work centres around the Neutron Source facility (which is being created jointly with the US Department of Energy) and R&D into fuels for nuclear power plants. Based on this setup we are promoting the creation of an international centre for nuclear physics and medicine, a preliminary proposal for which has been supported by the US and the IAEA. COVID, followed by the full-scale invasion of the Russian army, have temporarily put this project on hold.

At the beginning of the invasion, an idea was spread quickly by Russian media that our institute was still working on the creation of nuclear weapons. It was a lie. Similar things were also said by the Russian media, incorrectly, to be taking place at Chernobyl. On 6 March 2022 we got together with the head of the institute of safety operations for nuclear power plants in Kyiv and made a joint declaration rejecting these accusations. Since 1994, and especially lately (even during the war), the institute has been regularly inspected by the IAEA. Of course, no violations were discovered, nor was any work on the creation of nuclear weapons discovered.

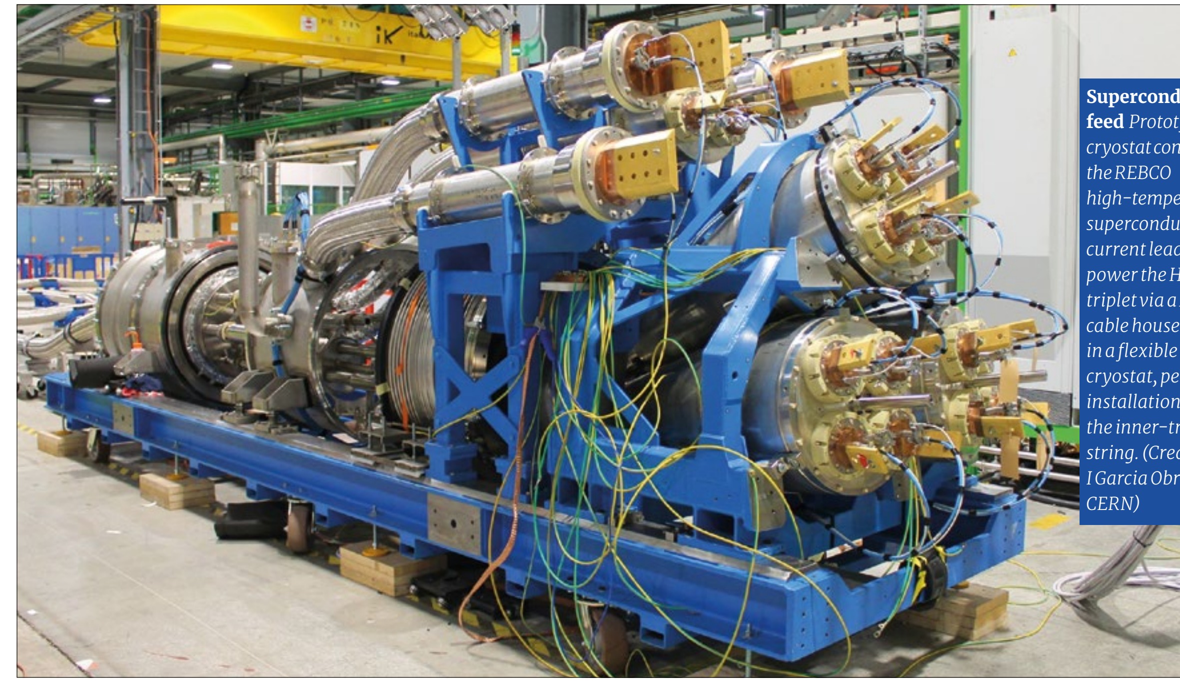
Thanks to the hard work of the staff who remained, we managed to restore everything, often while bombs were falling

Our institute is located around 30 km from the border of Russia. Since 24 February 2022, it has been repeatedly shelled and has suffered significant damage. More than 100 shells, rockets and bombs fell on its territory. At the very beginning, Russian troops started their movement to Kharkiv along the road near our institute; it was stopped by our soldiers. About one month later, Russia made a second attempt to take Kharkiv, which came within 500 m of our institute before being stopped. Outside the institute in a residential area called Piatykhatky, where many staff members live, multiple buildings were destroyed. For 40 days following the shelling of 31 March 2022, the entire area didn't have water, electricity or phone networks. Thanks to the hard work of the staff who remained, we managed to restore everything, often while bombs were falling.

With the start of military activity, many specialists from the institute left Kharkiv and continued to work remotely. Some large installations intended for conducting physical experiments have remained operational. The institute has sharply increased cooperation with major international scientific centres such as CERN, DESY, Orsay, the Italian centres at Frascati and Ferrara, and others.

With great hope, enthusiasm and optimism we believe that it will be possible to defend the territorial integrity of Ukraine and look to reviving its economic and scientific potential.

***Mykola Shulga** director-general National Science Centre Kharkiv Institute of Physics and Technology.*



Superconducting feed *Prototype cryostat containing the REBCO high-temperature-superconducting current leads that power the HL-LHC triplet via a MgB_2 cable housed in a flexible cryostat, pending installation in the inner-triplet string. (Credit: I Garcia Obrero/CERN)*

HL-LHC COUNTS DOWN TO LS3

With less than two years of LHC operations before the start of long-shutdown three (LS3), when the main installation phase of the High-Luminosity LHC will begin, Oliver Brüning and Markus Zerlauth describe the latest progress and next steps for the validation of key technologies, tests of prototypes and the series production of equipment.

Since the start of physics operations in 2010, the Large Hadron Collider (LHC) has enabled a global user community of more than 10,000 physicists to explore the high-energy frontier. This unique scientific programme – which has seen the discovery of the Higgs boson, countless measurements of high-energy phenomena, and exhaustive searches for new particles – has already transformed the field. To increase the LHC's discovery potential further, for example by enabling higher precision and the observation of rare processes, the High-Luminosity LHC (HL-LHC) upgrade aims to boost the amount of data collected by the ATLAS and CMS experiments by a factor of 10 and enable CERN's flagship collider to operate until the early 2040s.

Following the completion of the second long shutdown (LS2) in 2022, during which the LHC injectors upgrade project was successfully implemented, Run 3 commenced at a record centre-of-mass energy of 13.6 TeV. Only two years of operation remain before the start of LS3 in 2026. This is when the main installation phase of the HL-LHC will commence, starting with the excavation of the vertical cores that will link the LHC tunnel to the new HL-LHC galleries and followed by the installation of new accelerator components. Approved in 2016, the HL-LHC project is driving several innovative technologies, including: niobium-tin (Nb_3Sn) accelerator magnets, a cold powering system made from MgB_2 high-temperature superconducting cables and a flexible

THE AUTHORS

Oliver Brüning *HL-LHC project leader and* **Markus Zerlauth** *HL-LHC deputy project leader.*

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Buildings and infrastructure *The new gallery at Point 1 (ATLAS) for power converters and other equipment (left); the surface building for cooling and ventilation at Point 5 (CMS) (middle); and the underground service cavern (right).*

Quadrupole magnets *The first CERN-made inner-triplet cryo-magnet assembly (Q2b), comprising an MQXFB prototype magnet and an MCBXF corrector magnet, ready for powering tests on the SM18 test bench (left), and (right) the MQXFB03 magnet in SMI2.*

cryostat, the integration of compact niobium crab cavities to compensate for the larger beam crossing angle, and new technology for beam collimation and machine protection.

Efforts at CERN and across the HL-LHC collaboration are now focusing on the series production of all project deliverables in view of their installation and validation in the LHC tunnel. A centrepiece of this effort, which involves institutes from around the world and strong collaboration with industry, is the assembly and commissioning of the new insertion-region magnets that will be installed on either side of ATLAS and CMS to enable high-luminosity operations from 2029. In parallel, intense work continues on the corresponding upgrades of the LHC detectors: completely new inner trackers will be installed by ATLAS and CMS during LS3 (*CERN Courier* January/February 2023 p22 and 33), while LHCb and ALICE are working on proposals for radically new detectors for installation in the 2030s (*CERN Courier* March/April 2023 p22 and 35).

Civil-engineering complete

The targeted higher performance at the ATLAS and CMS interaction points (IPs) demands increased cooling capacity for the final focusing quadrupole magnets left and right of the experiments to deal with the larger flux of collision debris. Additional space is also needed to accommodate new equipment such as power converters and machine-protection devices, as well as shielding to reduce their exposure to radiation, and to allow easy access for faster interventions and thus improved machine availability. All these requirements have been addressed by the construction of new underground structures at ATLAS and CMS. Both sites feature a new access shaft and cavern that will house a new refrigerator cold box, a roughly 400 m-long gallery for the new power converters and protection equipment, four service tunnels and 12 vertical cores connecting the gallery to the existing LHC tunnel. A new staircase at each side of the experiment also connects the new underground structures to the existing LHC tunnel for personnel.

Civil-engineering works started at the end of 2018 to allow the bulk of the interventions requiring heavy machinery to be carried out during LS2, since it was estimated that the vibrations would otherwise have a detrimental impact on the LHC performance. All underground civil-engineering works were completed in 2022 and the construction of the new surface buildings, five at each IP, in spring 2023. The new access lifts encountered a delay of about six months due to some localised concrete spalling inside the shafts, but the installation at both sites was completed in autumn 2023.

The installation of the technical infrastructures is now progressing at full speed in both the underground and surface areas (see "Buildings and infrastructure" image). It is remarkable that, even though the civil-engineering work extended throughout the COVID-19 shutdown period and was exposed to market volatility in the aftermath of Russia's invasion of Ukraine, it could essentially be completed on schedule and within budget. This represents a huge milestone for the HL-LHC project and for CERN.

A cornerstone of the HL-LHC upgrade are the new triplet quadrupole magnets with increased radiation tolerance.

Dipole magnets *Prototypes of a single-aperture dipole D1 (left) and a twin-aperture dipole D2 (right) on the test bench in SM18.*

Corrector magnets *An HL-LHC corrector package in its cryostat (left) and construction of the corrector-magnet cold mass (right).*

A total of 24 large-aperture Nb$_3$Sn focusing quadrupole magnets will be installed around ATLAS and CMS to focus the beams more tightly, representing the first use of Nb$_3$Sn magnet technology in an accelerator for particle physics. Due to the higher collision rates in the experiments, radiation levels and integrated dose rates will increase accordingly, requiring particular care in the choice of materials used to construct the magnet coils (as well as the integration of additional tungsten shielding into the beam screens). In order to have sufficient space for the shielding, the coil apertures need to be roughly doubled compared to the existing Nb-Ti LHC triplets, thus reducing the β^* parameter (which relates to the beam size at the collision points) by a factor of four compared to the nominal LHC design and fully exploiting the improved beam emittances following the upgrade of the LHC injector chain.

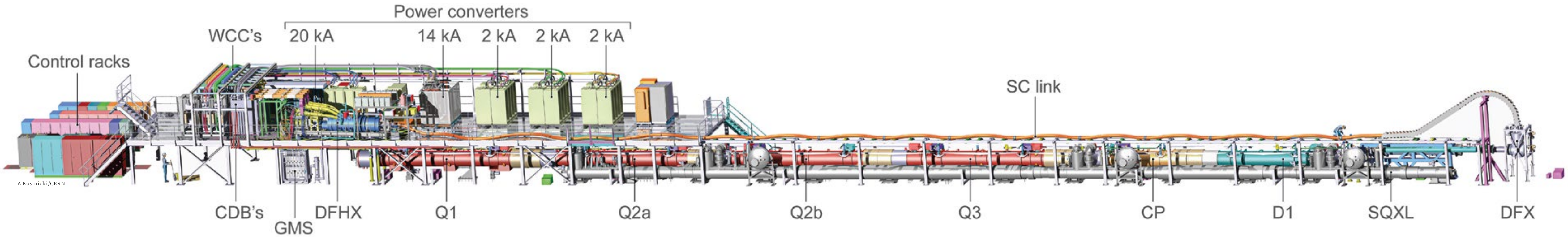
For the HL-LHC, reaching the required integrated magnetic gradient with Nb-Ti technology and twice the magnet aperture would require a much longer triplet. Choosing Nb$_3$Sn allows fields of 12 T to be reached, and therefore a doubling of the triplet aperture while keeping the magnet relatively compact (the total length is increased from 23 m to 32 m). Intensive R&D and prototyping of Nb$_3$Sn magnets started 20 years ago under the US-based LHC Accelerator Research Program (LARP), which united LBNL, SLAC, Fermilab and BNL. Officially launched as a design study in 2011, it has since been converted into the Accelerator Upgrade Program (AUP, which involves LBNL, Fermilab and BNL) in the industrialisation and series-production phase of all main components.

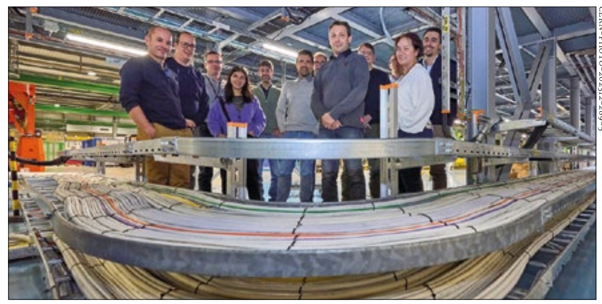
The HL-LHC inner-triplet magnets are designed and constructed in a collaboration between AUP and CERN. The 10 (eight for installation and two spares) Q1 and Q3 cryo-assemblies, which contain two 4.2 m-long individual quadrupole magnets (MQXFA), will be provided as an in-kind contribution from AUP, while the 10 longer versions for Q2 (containing a single 7.2 m-long quadrupole magnet, MQXFB, and one dipole orbit-corrector assembly) will be produced at CERN. The first of these magnets was tested and fully validated in the US in 2019 and the first cryo-assembly consisting of two individual magnets was assembled, tested and validated at Fermilab in 2023. This cryo-assembly arrived at CERN in November 2023 and is now being prepared for validation and testing. The US cable and coil production reached completion in 2023 and the magnet and cryo-assembly production is picking up pace for series production.

The first three Q2 prototype magnets showed some limitations. This prompted an extensive three-phase improvement plan after the second prototype test to address the different stages of coil production, the coil and stainless-steel shell assembly procedure, and welding for the final cold mass. All three improvement steps were implemented in the third prototype (MQXFBP3), which is the first magnet that no longer shows any limitations, neither at 1.9 K nor 4.5 K operating temperatures, and thus the first from the production that is earmarked for installation in the tunnel (see "Quadrupole magnets" image).

Beyond the triplets, the HL-LHC insertion regions require several other novel magnets to manipulate the beams. For

A cornerstone of the HL-LHC upgrade are the new triplet quadrupole magnets with increased radiation tolerance





Inner-triplet string *Top: the key elements constituting the new insertion regions for the high-luminosity LHC experiment, showing the quadrupole (Q) and dipole (D) assemblies, superconducting-link feedboxes (DFHX and DFH), cryogenic distribution line (SQXL) and auxiliary equipment. Above: the string in SM18 (left) and the installation of electrical infrastructure and signal cables in December 2023 (right).*

A novel cold powering system featuring a flexible cryostat and MgB_2 cables can carry the required currents at temperatures of up to 50 K

some magnet types, such as the nonlinear corrector magnets (produced by LASA in Milan as an in-kind contribution from INFN), the full production has been completed and all magnets have been delivered to CERN. The new separation and recombination dipole magnets – which are located on the far side of the insertion regions to guide the two counterrotating beams from the separated apertures in the arc onto a common trajectory that allows collisions at the IPs – are produced as in-kind contributions from Japan and Italy. The single-aperture D1 dipole magnets are produced by KEK with Hitachi as the industrial partner, while the twin-aperture D2 dipole magnets are produced in industry by ASG in Genoa, again as an in-kind contribution from INFN. Even though both dipole types are based on established Nb-Ti superconductor technology (the workhorse of the LHC), they push the conductor into unchartered territory. For example, the D1 dipole features a large aperture of 150 mm and a peak dipole field of 5.6 T, resulting in very large forces in the coils during operation. Hitachi has already produced three of the six series magnets. The prototype D1 dipole magnet was delivered to CERN in 2023 and cryostated in its final configuration, and the D2 prototype magnet has been tested and fully validated at CERN in its final cryostat configuration and the first series D2 magnet has been delivered from ASG to CERN (see "Dipole magnets" image).

Production of the remaining new HL-LHC magnets is also in full swing. The nested canted-cosine-theta magnets – a novel magnet design comprising two solenoids with canted coil layers, needed to correct the orbit next to the D2 dipole – is progressing well in China as an in-kind contribution from IHEP with Bama as the industrial partner. The nested dipole orbit-corrector magnets, required for the orbit correction within the triplet area, are based on Nb-Ti technology (an in-kind contribution from CIEMAT in Spain) and are also advancing well, with the final validation of the long-magnet version demonstrated in 2023 (see "Corrector magnets" image).

Superconducting link

With the new power converters in the HL-LHC underground galleries being located approximately 100 m away from and 8 m above the magnets in the tunnel, a cost- and energy-efficient way to carry currents of up to 18 kA between them was needed. It was foreseen that "simple" water-cooled copper cables and busbars would lead to an undesirable inefficiency in cooling-off the Ohmic losses, and that Nb-Ti links requiring cooling with liquid helium would be too technically challenging and expensive given the height difference between the new galleries and the LHC tunnel. Instead, it was decided to develop a novel cold powering system featuring a flexible cryostat and magnesium-diboride (MgB_2) cables that can carry the required currents at temperatures of up to 50 K.

With this unprecedented system, helium boils off from the magnet cryostats in the tunnel and propagates through the flexible cryostat to the new underground galleries. This process cools both the MgB_2 cable and the high-temperature superconducting current leads (which connect the normal-conducting power converters to the

Crystal collimators *Installation of new crystal collimators in the LHC tunnel at Point 7 in 2023.*

superconducting magnets) to nominal temperatures between 15 K and 35 K. The gaseous helium is then collected in the new galleries, compressed, liquefied and fed back into the cryogenic system. The new cables and cryostats have been developed with companies in Italy (ASG and Tratos) and the Netherlands (Cryoworld), and are now available as commercial materials for other projects (*CERN Courier* May/June 2023 p37).

Three demonstrator tests conducted in CERN's SM18 facility have already fully validated the MgB_2 cable and flexible-cryostat concept. The feed boxes that connect the MgB_2 cable to the power converters in the galleries and the magnets in the tunnel have been developed and produced as in-kind contributions with the University of Southampton and Puma as industrial partner in the UK and the University of Uppsala and RFR as industrial partner in Sweden. A complete assembly of the superconducting link with the two feed boxes has been assembled and is being tested in SM18 in preparation for its installation in the inner-triplet string in 2024 (see "Superconducting feed" image).

IT string assembly

The inner-triplet (IT) string – which replicates the full magnet, powering and protection assembly left of CMS from the triplet magnets up to the D1 separation dipole magnet – is the next emerging milestone of the HL-LHC project (see "Inner-triplet string" image). The goal of the IT string is to validate the assembly and connection procedures and tools required for its construction. It also serves to assess the collective behaviour of the superconducting magnet chain in conditions as close as possible to those of their later operation in the HL-LHC, and as a training opportunity for the equipment teams for their later work in the LHC tunnel. The IT string includes all the systems required for operation at nominal conditions, such as the vacuum (albeit without the magnet beam screens), cryogenics, powering and protection systems. The installation is planned to be completed in 2024, and the main operational period will take place in 2025.

The entire IT string – measuring about 90 m long – just fits at the back of the SM18 test hall, where the necessary liquid-helium infrastructure is available. The new underground galleries are mimicked by a metallic structure situated above the magnets. The structure houses the power converters and quench-protection system, the electrical disconnector box, and the feed box that connects the superconducting link to normal-conducting powering systems. The superconducting link extends from the metallic structure above the magnet assembly to the D1 end of the IT string where (after a vertical descent mimicking the passage through the underground vertical cores) it is connected to a prototype of the feed box that connects to the magnets.

The installation of the normal-conducting powering and machine-protection systems of the IT string is nearing completion. Together with the already completed infrastructures of the facility, the complete normal-conducting powering system of the string entered its first commissioning phase in December 2023 with the execution of short-circuit tests. The cryogenic distribution line for the IT string has been successfully tested at cold temperatures and will soon undergo a second cooldown to nominal temperature, ahead of the installation of the magnets and cold-powering system this year.

Collimation

Controlling beam losses caused by high-energy particles deviating from their ideal trajectory is essential to ensure the protection and efficient operation of accelerator components, and in particular superconducting elements such as magnets and cavities. The existing LHC collimation system, which already comprises more than 100 individual collimators installed around the ring, needs to be upgraded to address the unprecedented challenges brought about by the brighter HL-LHC beams. Following a first upgrade of the LHC collimation and shielding systems deployed during LS2, the production of new insertion-region collimators

The inner-triplet string is the next emerging milestone of the HL-LHC project

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Crab cavities *The insertion of a beam screen in a DQW crab cavity (left) and the arrival and unpacking of the RFD cryomodule (right), both in the SM18 hall in November 2023.*

and the second batch of low-impedance collimators is now being launched in industry.

LS2 and the subsequent year-end technical stop also saw the completion of the novel crystal-collimation scheme (*CERN Courier* November/December 2022 p35). Located in “IR7” between CMS and LHCb, this scheme comprises four goniometers with bent crystals – one per beam and plane – to channel halo particles onto a downstream absorber (see “Crystal collimators” image). After extensive studies with beam during the past few years, crystal collimation was used operationally in a nominal physics run for the first time during the 2023 heavy-ion run, where it was shown to increase the cleaning efficiency by a factor of up to five compared to the standard collimation scheme. Following this successful deployment and comprehensive machine-development tests, the HL-LHC performance goals have been conclusively confirmed for both proton and ion operations. This has enabled the baseline solution using a standard collimator inserted in IR7 (which would have required replacing a standard 8.3 T LHC dipole with two short 11 T Nb_3Sn dipoles to create the necessary space) to be descoped from the HL-LHC project.

Crab cavities

A second cornerstone of the HL-LHC project after the triplet magnets are the superconducting radiofrequency “crab” cavities. Positioned next to the D2 dipole and the Q4 matching-section quadrupole magnet in the insertion regions, these are necessary to compensate for the detrimental effect of the crossing angle on luminosity by applying a transverse momentum kick to each bunch entering the interaction regions of ATLAS and CMS. Two different types of cavities will be installed: the radio-frequency dipole (RFD) and the double quarter wave (DQW), deflecting bunches in the horizontal and vertical crossing planes, respectively (see “Crab cavities” image). Series production of the RFD cavities is about to begin at Zanon, Italy under the lead of AUP, while the DQW cavity series production is well underway at RI in Germany under the lead of CERN following the successful validation of two pre-series bare cavities.

A fully assembled DQW cryomodule has been undergoing highly successful beam tests in the Super Proton Synchrotron (SPS) since 2018, demonstrating the crabbing of proton beams and allowing for the development and validation of the necessary low-level RF and machine-protection systems (*CERN Courier* March/April 2022 p45). For the RFD, two dressed cavities were delivered at the end of 2021 to the UK collaboration after their successful qualification at CERN. These were assembled into a first complete RFD cryomodule that was returned to CERN in autumn 2023 and is currently undergoing validation tests at 1.9 K, revealing some non-conformities to be resolved before it is ready for installation in the SPS in 2025 for tests with beams. Series production of the necessary ancillaries and higher-order-mode couplers has also started for both cavity types at CERN and AUP after the successful validation of prototypes. Prior to fabrication, the crab-cavity concept underwent a long period of R&D with the support of LARP, JLAB, UK-STFC and KEK.

On schedule

2023 and 2024 are the last two years of major spending and allocation of industrial contracts for the HL-LHC project. With the completion of the civil-engineering contracts and the placement of contracts for the new cryogenic compressors and distribution systems, the project has now committed more than 75% of its budget at completion. An HL-LHC cost-and-schedule review held at CERN in November 2023, conducted by an international panel of accelerator experts from other laboratories, congratulated the project on the overall good progress and agreed with the projection to be ready for installation of the major equipment during LS3 starting in 2026.

The major milestones for the HL-LHC project over the next two years will be the completion and operation of the IT-string installation in 2024 and 2025, and the completion of the installation of the technical infrastructures in the new underground galleries. All new magnet components should be delivered to CERN by the end of 2026, while the drilling of the vertical cores connecting the new and old underground areas should complete the major construction activities and mark the start of the installation of the new equipment in the LHC tunnel.

The HL-LHC will push the largest scientific instrument ever built to unprecedented levels of performance and extend the flagship collider of the European and US high-energy physics programme by another 15 years. It is the culmination of more than 25 years of R&D, with close cooperation with industry in CERN’s member states and the establishment of new accelerator technologies for the use of future projects. All hands are now on deck to ensure the brightest future possible for the LHC. ●

OPINION VIEWPOINT

New CERNs for a fractured world

Rising geopolitical tensions and techno-nationalism offer opportunities for new global organisations that build on the success of the CERN model, argue policy researchers Leonard Lynn and Hal Salzman.

Good fit *CERN’s potential contributions to the organisation of global science and technology cooperation deserve greater attention.*

Leonard Lynn *is professor emeritus of management policy at Case Western Reserve University.*

Hal Salzman *is professor of planning and policy at Rutgers University.*

Although a brief period of hubris and short-sightedness at the end of the Cold War led some in the West to proclaim “the end of history” and a path to a unified global community, underlying and historically ever-present geopolitical tensions have surfaced again, perhaps as strongly as in the past. At the same time, the past decades have witnessed increased education of talented scientists and technologists across the globe, including in low- and middle-income countries that were once outside the leading science communities. To address the science and technology challenges of our time, we need to find ways to steady the ship to best navigate this changing global scene.

Just as CERN was born out of the ashes of global destruction and disarray – a condition that called for collaboration out of necessity – we propose that the resurgence of nationalism along with pressing challenges such as climate change, disease and artificial intelligence call for stronger scientific communities. At the time of CERN’s founding 70 years ago, European physicists, especially in subatomic physics, faced marginalisation. Devastated European countries could not separately fund the “big science” facilities necessary to do cutting-edge research. Moreover, physicists were divided by national loyalties to countries that had been enemies during the war. In the period that followed, it seemed that subatomic research would be dominated by the US and the USSR. Worse, it seemed all too likely that the nationalistic agendas in those nations would push for advances in catastrophic new military technologies.

The creation and operation of CERN in that environment was monumental. CERN brought together scientists from various countries, eventually extending beyond Europe. It greatly advanced basic knowledge in fundamental physics and spun-off practical technologies such as the web and medical equipment. It has also served as a template (greatly underused in our view) for other international science and technology organisations such as SESAME in the Middle East. Today, the challenges for global cooperation in science and technology are different from those facing the founders of CERN. Mostly Western Europeans, with a few US supporters, they shared the discipline of subatomic physics and included Nobel Laureates and other highly respected people who were able to enlist the help of supportive diplomats in the various founding states.

New global institutes and organisations to address global problems will have to span a broad range of countries and cultures

Moment for change

The current geopolitical moment calls forth the need for more CERN-like organisations, just as occurred in that brief post-war moment. New global institutes and organisations to address global problems will have to span a broad range of countries and cultures. They will have to overcome techno-nationalistic opportunism and fears, and deal with potential capture by multinational enterprises (as happened with the response to COVID).

Since its founding, CERN has increasingly shown the ability to cross cultural and political boundaries – most nations of the world have sent scientists to participate in CERN projects, and non-European countries such as India, Pakistan and Turkey are associate members. Some mention the importance of facility cafeterias and other venues where scientists from different countries can meet and have unofficial discussions. CERN has striven to keep decision-making separate from national interests by having a convention that precludes its involvement in military technologies, and by having decisions about projects made primarily by scientists. It has strong policies regarding the sharing of intellectual property developed at its facilities.

CERN’s contributions to basic science and to various important technologies is undisputed. We suggest its potential contributions to the organisation of global science and technology cooperation also deserve greater attention. A systematic examination of CERN’s governance system and membership should be undertaken and compared with the experiences of others. Analysing how the CERN model fits social science-studies of design principles, it is clear that the CERN success brings important additional principles for when the common-pool resources are science and technology, and members come from diverse cultural backgrounds. CERN has addressed issues of bringing together scientists from countries that may have competing techno-nationalistic agendas, providing shelter against not only government but also multinational enterprises. It has focused on non-military technologies and on sharing its intellectual property. It is time that this organisational experience is rolled out for even greater common good.

Further reading

L Lynn & H Salzman 2023 *Global Policy* doi:10.1111/1758-5899.13258 and *Issues Sci. Technol.* doi:10.58875/ADGU5787.

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OPINION
INTERVIEW

Towards an unbiased digital world

Most search engines provide information based on commercial interests and profiling. Andreas Wagner describes a European Union project called Open Web Search which aims to offer free and transparent information access.

What is Open Web Search?
The Open Web Search project was started by a group of people who were concerned that navigation in the digital world is led by a handful of big commercial players (the European search market is largely dominated by Google, for example), who don't simply offer their services out of generosity but because they want to generate revenue from advertisements. To achieve that they put great effort into profiling users: they analyse what you are searching for and then use this information to create more targeted adverts that create more revenue for them. They also filter search results to present information that fits your world view, to make sure that you come back because you feel at home on those web pages. For some people, and for the European Commission in the context of striving for open access to information and digital sovereignty, as well as becoming independent of US-based tech giants, this is a big concern.

How did the project come about?
In 2017 the founder of the Open Search Foundation reached out to me because I was working on CERN's institutional search. He had a visionary idea: an open web index that is free, accessible to everyone and completely transparent in terms of the algorithms that it uses. Another angle was to create a valuable resource for building future services, especially data services. Building an index of the web is a massive endeavour, especially when you consider that the estimated total number of web pages worldwide is around 50 billion.

A group of technical experts from different institutes and universities, along with the CERN IT department, began with a number of experiments

Eric Gianchet

Supporting the vision *CERN IT department member Andreas Wagner leads work package five "federated data infrastructure" for OpenWebSearch.EU.*

> **You could argue that unbiased, transparent access to information in the digital world should be on the level of a basic right**

that were used to get a feel for the scale of the project. For example, to see how many web pages a single server can index and to evaluate the open source projects used for crawling and indexing web pages. The results of these experiments were highly valuable when it came to replying to the Horizon Europe funding call later on.

In parallel, we started a conference series, the Open Search Symposia (OSSYM). Two years ago there was a call for funding in the framework of the European Union (EU) Horizon Europe programme dedicated to Open Web search. Together with 13 other institutions and organisations, the CERN IT department participated and we were awarded a grant. We were then able to start the project in September 2022.

What are the technical challenges in building a new search engine?
We don't want to copy what others are doing. For one, we don't have the resources to build a new, massive data centre. The idea is a more collaborative approach, to have a distributed system where people can join depending on their means and interests. CERN is leading work-package five "federated data infrastructure", in which we and our four infrastructure partners (DLR and LRZ in Germany, CSC in Finland and IT4I in the Czech Republic) provide the infrastructure to set up the system that will ultimately allow the index itself to be built in a purely distributed way. At CERN we are running the so-called URL frontier – a system that oversees what is going on in terms of crawling and preparing this index, and has a long list of URLs that should be collected. When running the crawlers, they report back on what they have found on different web pages. It's basically bookkeeping to ensure that we coordinate activities and don't duplicate the efforts already made by others.

Open Web Search is said to be based on European values and jurisdiction. Who and what defines these?
That's an interesting question. Within the project there is a dedicated work package six titled "open web search ecosystem and sustainability" that covers the ethical, legal and societal

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aspects of open search and addresses the need for building an ecosystem around open search, including the proper governance processes for the infrastructure.

The legal aspect is quite challenging because it is all new territory. The digital world evolves much faster than a legislator can keep up! Information on the web is freely available to anyone, but the moment you start downloading and redistributing it you are taking on ownership and responsibility. So you need you take copyright into account, which is regulated by most EU countries. Criminal law is more delicate in terms of the legal content. Every country has its own rules and there is no conformity. Overall, European values include transparency, fairness for data availability and adhering to democratic core principles. We are aiming at including these European values into the core design of our solution from the very beginning.

What is the status of the project right now?
The project was launched just over a year ago. On the infrastructure side the aim was to have the components in place, meaning having workflows ready and running. It's not fully automated yet and there is still a lot of challenging work to do, but we have a fully functional set-up, so some institutes have been able to start crawling; they feed the data and it gets stored and distributed to the participating infrastructure partners including CERN. At the CERN data centre we coordinate the crawling efforts and provide advanced monitoring. As we go forward, we will work on aspects of scalability so that there won't be any problems when we go bigger.

What would a long-term funding model look like for this project?
You could argue that unbiased, transparent access to information in the digital world that has become so omnipresent in our daily lives should be on the level of a basic right. With that in mind, one could imagine a governmental funding scheme. Additionally, this index would be open to companies that can use it to build commercial applications on top of it, and for this use-case a back-charging model might be suitable. So, I could imagine a combination of public and usage-based funding.

Ad-free *The Open Web Search project aims to develop a search tool that provides unbiased, transparent information based on European values.*

I see the purpose of Open Web Search as being an invaluable investment in the future

In October last year the Open Search Symposium was hosted by the CERN IT department. What was the main focus there?
This is purposely not focused on one single aspect but is an interdisciplinary meeting. Participants include researchers, data centres, libraries, policy makers, legal and ethical experts, and society. This year we had some brilliant keynote speakers such as Věra Jourová, the vice president of the European Commission for Values and Transparency, and Christoph Schumann from LAION, a non-profit organisation that looks to democratise artificial intelligence models.

Ricardo Baeza-Yates (Institute for Experiential Artificial Intelligence, Northeastern University) gave a keynote speech about "Bias in Search and Recommender Systems" and Angella Ndaka (The Centre for Africa Epistemic Justice and University of Otago) talked about "Inclusion by whose terms? When being in doesn't mean digital and web search inclusion", the challenges of providing equal access to information to all parts of the world. We also had some of the founders of alternative search engines joining, and it was very interesting and inspiring to see what they are working on. And we had representatives from different universities looking at how research is advancing in different areas.

In general, OSSYM 2023 was about a wide range of topics related to internet search and information access in the digital world. We will shortly publish the proceedings of the nearly 25 scientific papers that were submitted and presented.

How realistic is it for this type of search engine to compete with the big players?
I don't see it as our aim or purpose to compete with the big players. They have unlimited resources so they will continue what they are doing now. I see the purpose of Open Web Search as being an invaluable investment in the future. The Open Web Index could pave the way for upcoming competitors, creating new ideas and questioning the monopoly or gatekeeper roles of the big players. This could make accessing digital information more competitive and a fairer marketplace. I like the analogy of cartography: in the physical world, having access to (unbiased) maps is a common good. If you compare maps from different suppliers you still get basically the same information, which you can rely on. At present, in the digital world there is no unbiased, independent cartography available. For instance, if you look up the way to travel from Geneva to Paris online, you might have the most straightforward option suggested to you, but you might also be pointed towards diversions via restaurants, where you then might consider stopping for a drink or some food, all to support a commercial interest. An unbiased map of the digital world should give you the opportunity to decide for yourself where and how you wish to get to your destination.

The project will also help CERN to improve its own search capabilities and will provide an open-science search across CERN's multiple information repositories. For me, it's nice to think that we are helping to develop this tool at the place where the web was born. We want to make sure, just as CERN gave the web to the world, that this is a public right and to steer it in the right direction.

Interview by **Sanje Fenkart** *CERN.*

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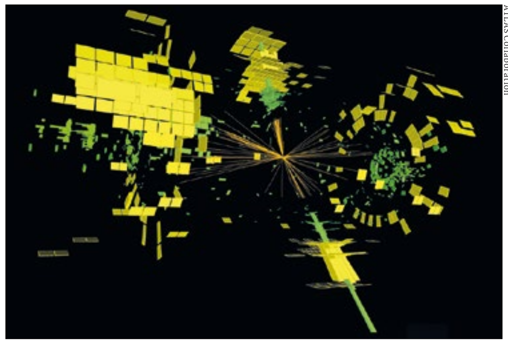
OPINION REVIEWS

Bite-sized travels in particle physics

Faszinierende Teilchenphysik
Von Quarks, Neutrinos und Higgs zu den Rätseln des Universums

By Philip Bechtle, Florian Bernlochner, Herbi Dreiner, Christoph Hanhart, Josef Jochum, Jörg Pretz, Kristin Riebe

Springer

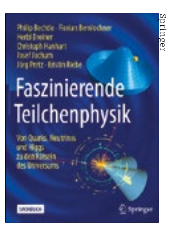

ATLAS Collaboration

Into the universe *"Faszinierende Teilchenphysik" is a great hitchhiker's guide to modern particle physics.*

"Faszinierende Teilchenphysik" is certainly not the first popular book about elementary particle physics, and it won't be the last. But its unique and clever structure make it stand out.

Think of it as a collection of short stories, organised in 12 chapters covering all ground from underlying theories and technologies to the limits of the Standard Model and ideas beyond it. The book begins with a gentle introduction to the world of particles and finishes by linking the infinitely small to the infinitely large. Each double-page spread within these chapters features a different topic in particle physics, its players, rules of play, tools, concepts and mysteries. Turn a page, and you find a new topic.

Among these 150 spreads, which are referred to as "articles" by the diverse team of authors, the reader can learn about neutrinos, lattice QCD, plasma acceleration, Feynman diagrams, multi-messenger astronomy and much more. Each one manages to convey both the fascination of the subject as well as all the central ideas and open questions within the two allocated pages. This makes for a great way of reading: the article about antimatter, for example, cross-references to the article about baryogenesis, so flip from page 18 to page 304 to dig deeper into the antimatter mystery. Not sure what a baryon is? Check the glossary, then maybe jump on the article about matter and antimatter, CP violation or symmetries. There is no need to read this book from cover to cover. On the contrary, browsing is so deeply embedded in its concept that it even features a flip-book illustration of a particle collision on the bottom right-hand-side of each spread. With a bit more care for captivating illustrations and graphic design, it could pass as a Dorling Kindersley-style travel guide to particle physics.



Springer

The authors, who are based at different universities and labs in Germany, have backgrounds covering theoretical and experimental particle physics, astroparticle physics, accelerator and nuclear physics, and science communication. They have obviously put as much thought into this publication as they put in hours, because they manage to write about each topic in a way that is easy to follow, even if it's hard to digest. Puns, comparisons to everyday life and drawings to accompany the articles make for a full browsing experience, and the references within the text and at the bottom of each page show how everything is connected deep down.

When I received "Faszinierende Teilchenphysik" for review, one of the authors jokingly accompanied it with the words "this book is meant for retired engineers and for aunts looking for a present for their science-student-to-be nieces." That may well be the case, but this book's target audience is much wider. Physics fans and amateurs will enjoy sinking their teeth into a new world of interlinked topics; undergraduates will value it as a quick reference source that is less obscure and more fun to read than Wikipedia; and physics professionals will find it a useful refresher for topics beyond their expertise. The book even dedicates its final article to those questioning whether it is worth spending money and brain power on tiny particles, ending with a passionate case for the many benefits of fundamental research – not just spin-offs such as tumour therapy or artificial intelligence, but in pushing boundaries of knowledge outward.

And if you're afraid that your school German might let you down, don't worry: the English edition is already in the works and due to come out in 2024.

Barbara Warmbein *freelance science writer.*

Complexity, Entropy and the Physics of Information

Edited by Wojciech Zurek

Santa Fe Institute

"This quantum business is so incredibly important and difficult that everyone should busy himself with it," wrote Einstein in a 1908 letter, cited by John Wheeler at the workshop "Complexity, Entropy and the Physics of Information" held at the Santa Fe Institute in 1989. More than a century after Einstein's letter, many fundamental questions connecting physics and information remain unanswered.

The book *Complexity, Entropy and the Physics of Information* consists of 32 essays capturing the talks given at the Santa Fe workshop. Building on the fundamental work by Claude Shannon, the aim of the workshop was to explore fundamental questions relating to the foundations of quantum theory and quantum information science. Most of the questions raised are still relevant today, as many contributions to this two-volume reprint of proceedings demonstrate.


Santa Fe Institute

The workshop started with Wheeler's famous talk "It from bit", in which he aimed to "deduce the quantum from existence". Those remain a guiding principle in the life of a researcher in the field. Indeed, in a talk at the QTML 2023 conference held at CERN, Max Welling (University of Amsterdam) motivated his recent work on "General Message Belief Propagation" for quantum computations using Wheeler's principle, linking machine-learning models to thermodynamics.

William Wootters' contribution, on the other hand, builds on the work of John Bell, who showed that quantum mechanics is inherently non-local, i.e. that correlations between spatially separated systems are stronger than what is allowed in a hidden-variable theory. In contrast, Wootters focusses on the locality of quantum mechanics – specifically stating that local measurements on parts of a system and correlations between those measurements allow the state of an ensemble to be determined. Furthermore, Benjamin Schumacher presents his thoughts on the "physics of communication" and discusses the connections between information and entropy. He promotes the idea that "it is not the number of available signals but rather their distinguishability that matters in communication."

Wojciech Zurek focusses on the implications of a quantum measurement, which converts a collection of possible alternatives to a definite outcome and thus decreases the statistical entropy. In this regard, he discusses the connections between physical and statistical entropy (Shannon entropy) and the algorithmic information content of the data (Kolmogorov complexity). Applications in non-equilibrium systems highlight the fundamental cost of information erasure that was first mentioned by Landauer in 1961.

Charles Bennett asks "what is complexity?" and presents various suitable notions for a "formal measure of complexity" based on computational theory, information theory and thermodynamics. He thus highlights the notion of "logical depth", which is the execution time needed to generate the object of interest by a near-incompressible universal computer program. The behaviour of complexity measures in dynamical systems exhibiting self-organisation and phase transitions are also discussed.

Tommaso Toffoli explores whether the principles of mechanics are universal and fundamental because they emerge from an extremely fine-grained underlying structure, in which case they would be of mathematical rather than physical origin. This mode of thought is in line with statistical mechanics, where laws emerge due to collective effects in systems with many elements.

In his contribution, Edwin Jaynes focuses on the meaning of probability in quantum mechanics, which he regards not as a "physically real thing" but relevant for quantifying the role of incomplete information and the precision with which a theory is able to predict results. In case of its infiniteness, the theory is unable to predict this quantity and, hence, the uncertainty is infinite. But he stresses that it does not mean that the physical quantity is infinite.

This is just snapshot of the many rich contributions. Besides quantum information theory, the book also touches on cosmology, quantum gravity and dynamical systems. An introduction from Seth Lloyd, who attended the Santa Fe workshop, also provides valuable context to the significance of the proceedings.

A noteworthy collection of essays

Complexity, Entropy and the Physics of Information forms a noteworthy collection of essays linking information, computation and complexity, as well as physics and especially quantum mechanics. As it contains many individual essays grouped thematically, readers may pick out topics based on their own interest. I would recommend this work for anyone who is interested in this area, especially researchers and students working in quantum physics and computational theory.

Carla Rieger *CERN and TU Munich.*

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PEOPLE CAREERS

Leading in collaborations

Gabriel Facini describes a new programme developed in partnership with industry to help particle physicists become effective leaders in large collaborations.


F Bitzeni

Driving change *Physicists at University College London during the inaugural Leading in Collaborations Programme, which hopes to change the culture of leadership in large collaborations.*

Are we at the vanguard of every facet of our field? In our quest for knowledge, physicists have charted nebulae, quantified quarks and built instruments and machines at the edge of technology. Yet, there is a frontier that remains less explored: leadership. As a field, particle physics has only just begun to navigate the complexities of guiding our brightest minds.

Large-experiment collaborations such as those at the LHC achieve remarkable feats. Indeed, social scientists have praised our ability to coordinate thousands of researchers with limited "power" while retaining individual independence. Similarly, as we continuously optimise experiments for performance and quality, and there also exist opportunities to refine behaviours and practices to facilitate progress and collective success.

A voice for all

Hierarchies in any organisation can inadvertently become a barrier rather than a facilitator of open idea exchange. Often, decision-making is confined to higher levels, reducing the agency of those implementing actions and leading to disconnects in roles and responsibilities. Excellence in physics doesn't guarantee the interpersonal skills that are essential for inspiring teams. Moreover, imposter syndrome infects us all, especially junior collaborators who may lack soft-skills training. While striving for diversity we sometimes overlook the need to embrace different personality types, which, for example, can make large meetings daunting for the less outspoken. Good leadership can help navigate these challenges, ensuring that every voice contributes to our collective progress.

Leadership is not management (using resources to get a particular job done), nor is it rank (merely a line on a CV). It is guidance and influence of others towards a shared vision – a pivotal force as essential as any tool in our research arsenal. Good leadership is a combination of strategic foresight, emotional intelligence and adaptive communication; it creates an inclusive environment where individual contributions are not commanded but empowered. These practices would improve any collaboration. In large physics experiments this type of leadership is incidental instead of being broadly acknowledged and pursued.

Luckily, leadership is a skill that can be taught and developed through training. True training is a craft and is best delivered by experts who are not just versed in theory but are also skilled practitioners. Launched in autumn 2023 based on the innovative training approach of Resilient Leaders Elements, a new course "Leading in Collaborations" is tailored specifically for our community. The three-month expert-facilitated course includes four half-day workshops and two one-hour clinics, addressing two main themes: "what I do", which equips participants with decision-making skills to set clear goals and navigate the path to achieving them; and "who I am", which encourages participants to channel their emotions positively and motivate both themselves and others effectively. The course confronts participants with the question "What is leadership in a large physics collaboration?" and provides a new framework of concepts. Through self-assessment, peer-feedback sessions, individualised challenges and buddy-coaching, participants are able to identify blind spots and hidden talents. A final assessment shows measurable change in each skill.

The first cohort of 20 participants, displaying a diverse mix of physics experience from various institutions and nationalities, was welcomed to the programme at University College London on 14 and 15 November 2023. More than half of the participants were women – in line with the programme's aim to ensure that those often overshadowed are given the visibility and support to become more impactful leaders. The lead facilitator, Chris Russell, masterfully connected with the audience via his technical physics background and proceeded to build trust and impart knowledge in an open and supportive atmosphere. When discussing leadership, the initial examples given cited military and political figures; reframing led to a participant's description of a conductor giving their orchestra space to play through an often-rehearsed tough section as an example of great leadership.

Crucial catalyst

Building on the experience of the first cohort, the aim is to offer the programme more broadly so that we can encourage common practice and change the culture of leadership in large collaborations. Given that the LHC hosts the largest collaborations in physics, the programme also hopes to find a home within CERN's learning and development portfolio.

The Leading in Collaborations programme is a crucial catalyst in the endeavour to ensure that our precious resources are wielded with precision and purpose, and thus to amplify our collective capacity for discovery. Join the leadership revolution by being the leader you wish you had, no matter your rank. Together, we will become the cultural vanguard!

Gabriel Facini *is a member of the ATLAS collaboration, in which he has convened physics and detector-performance groups.*

Appointments and awards


Kavli IPMU

New Kavli IPMU director

On 1 November, theorist Jun'ichi Yokoyama became the new director of the Kavli Institute for the Physics and Mathematics of the Universe (IPMU) in Kashiwa, Japan. He succeeds Hirosi Ooguri, who has held the position for the past five years. Yokoyama obtained his PhD from The University of Tokyo and held positions at Kyoto University, Osaka University, Fermilab and Stanford University before becoming professor at the research centre for the early universe at The University of Tokyo in 2005, and its director since 2023.

Raimondi leads PIP-II

On 20 November, accelerator physicist Pantaleo Raimondi took over as project director of the Proton Improvement Plan II (PIP-II) – an upgrade to Fermilab's accelerator complex that will drive a broad physics programme including the long-baseline neutrino experiment DUNE. Raimondi brings extensive expertise from his many previous positions – ranging from ENEA–Frascati in Italy, where he worked on radiofrequency power systems, to SLAC where he worked on beam-based alignment and final focus systems. As head of INFN-LNF, he participated in commissioning the DAFNE e^+e^- collider, and as source division director at the ESRF he invented and drove the Extremely Brilliant Source upgrade. Raimondi moves to Fermilab after spending the past year at CERN working on the proposed FCC-ee collider.

Fermilab communication

Fermilab welcomed a new director of its communication division on 2 October. Previously director of communications at Idaho National Lab and head of Pacific Northwest external engagement, Rae Moss brings 20 years of experience of leadership in communication and outreach for different national laboratories and federal organisations. "I am excited to move the mission of the lab ahead with dynamic communications and stories telling the public about the exciting work being done here," she said.

Highest US honour for Barish

During a ceremony on 24 October, US president Joe Biden presented the 2022 National Science and Technology Medal to 21 laureates, including experimental physicist Barry Barish (Stony Brook, Caltech) for his "exemplary service to science, including ground-breaking research on sub-atomic particles", also citing his leading role in the discovery of gravitational waves with LIGO.

CNRS médaille d'honneur

On 18 October, chair of the board of directors at Forschungszentrum Jülich, Astrid Lambrecht, the first woman to hold the role, received the "médaille d'honneur" from CNRS. Lambrecht has spent her career investigating vacuum


FZ Jülich/Sascha Kreklau

fluctuations, in particular Casimir forces, and from 1996 until 2021 held positions including deputy director, acting director and director of the CNRS Institute of Physics.

APS spring prizes

The American Physical Society has announced the recipients of its 2024 spring prizes and awards, recognising researchers across high-energy physics. David Tanner (University of Florida) and Leslie Rosenberg (University of Washington) are awarded the Panofsky Prize in experimental particle physics for the synthesis of precision microwave cavity techniques and cryogenic technologies for axion haloscopes, while the J J Sakurai Prize for


The DeLauras

theoretical particle physics goes to Andrzej Buras (TUM) for his calculations of higher-order QCD effects in electroweak transitions. In accelerator physics, Kaoru Yokoya (KEK) has been awarded the Robert R Wilson Prize for his achievements in the theory and control of beam polarisation and beam–beam interactions in various colliders and, recognising early-career particle physicists, CMS collaborator Javier Mauricio Duarte (above; UCSD) receives the Henry Primakoff award for his work on trigger technologies based on machine learning. In nuclear physics, the Tom W Bonner Prize goes to Wit Busza (MIT) for pioneering work on multi-particle production in proton–nucleus and nucleus–nucleus collisions and for the conception and leadership of the PHOBOS experiment. Finally, the APS division of particles and fields awarded its instrumentation early-career award to Dan Dwyer (LBNL) for his work on LArPix for DUNE.

IOP awards 2023

The 2023 awards of the UK Institute of Physics (IOP) have been announced, with Gavin Salam (University of Oxford) receiving the Paul Dirac gold medal and prize for his wide-ranging and impactful contributions to particle physics, especially the identification and structure of hadronic jets. In the silver category, Themis Bowcock (University of Liverpool) receives the James Chadwick medal and prize for his leading role in designing and constructing various particle detectors such as the LHCb VELO, and Harry Cliff (University of Cambridge) is awarded the Lise Meitner medal for outreach efforts including books and the Collider exhibition. Among the 2023 honorary IOP fellows are Ian Shipsey (University of Oxford) for his endeavours in flavour physics and novel applications of quantum instrumentation, and Jim Virdee (Imperial College London) for his achievements in particle physics, especially being one of the founders of the CMS experiment and for promoting physics in Africa.

Hamburg prize for Witten

On 8 November Edward Witten (Institute for Advanced Study) received the Hamburg Prize for Theoretical Physics for his key contributions to a unified mathematical description of the


Joachim Hery Stiftung/Claudia Höhne

fundamental forces of nature. The Hamburg prize is jointly awarded by the Joachim Herz Foundation, DESY and the University of Hamburg, and comes with an award of €137,036, referencing the fine structure constant.

Shaw prize for FRBs

The 2023 Shaw Prize in Astronomy is awarded to Matthew Bailes (Swinburne University, ARC), Duncan Lorimer and Maura McLaughlin (both West Virginia University). Together with their collaborators David Narkević and Fronefield Crawford, the trio discovered and characterised the first fast radio bursts (FRBs) in 2007. FRBs are strong, short pulses of radio emission from very distant sources, typically other galaxies, although the mechanism that drives them is not yet clear.

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PEOPLE OBITUARIES

Oscar Barbalat 1935–2023

A pioneer of knowledge transfer

Electronics engineer Oscar Barbalat, who pioneered knowledge-transfer at CERN, died on 8 September 2023, aged 87.

Born in Liège, Belgium in 1935, Oscar joined CERN in 1961, working initially in the Proton Synchrotron (PS) radio-frequency (RF) group. At the time, the PS beam intensity was still below 10^9 protons per pulse and the beam-control system was somewhat difficult to master, even though the operations consisted mainly of striking internal targets at 24 GeV/c. The control system became increasingly complex when the PS slow-resonant extraction system of Hugh Hereward was put into service. As part of a team of expert accelerator physicists that included Dieter Möhl, Werner Hardt, Pierre Lefèvre and Aymar Sörensen, Oscar wrote a substantial FORTRAN simulation program to understand how the extraction efficiency depended on its numerous correlated parameters.

In the 1970s, the PS division set out to digitise the controls of all PS subsystems (Linac, PS Booster, RF, beam transport systems, vacuum system, beam observation, etc). These subsystems used independent control systems, which were based on different computers or operated manually. Oscar was tasked with devising a structured naming scheme for all the components of the PS complex. After producing several versions, in collaboration with all the experts, the fourth iteration of his proposed scheme was adopted in 1977. To design the scheme, Oscar used the detailed knowledge he had acquired of the accelerator systems and their control needs.

Oscar Barbalat at work on the Proton Synchrotron.

His respectful and friendly but tenacious way with colleagues enabled him to explore their desires and problems, which he was then able to reconcile with the needs of the automated controls. Oscar was modest. In the acknowledgements of his naming scheme, he wrote: "This proposal is the result of numerous contributions and suggestions from the many members of the division who were interested in this problem and the author is only responsible for the inconsistencies that remain."

On Giorgio Brianti's initiative, following the interest of the CERN Council's finance committee, the "Bureau de Liaison pour l'Industrie et la Technologie" (BLIT) was founded, with Oscar in charge. His activity began in 1974 and ended on his retirement in 1997. His approach to this new task was typical of his and CERN's collaborative style: low-key and constructive. He was eager to inform himself of details and he had a talent for explaining technical aspects to others. It helped that he was well educated with broad interests in people, science, technology, languages along with cultural and societal purposes. He built a network of people who helped him and whom he convinced of the relevance of sharing technological insights beyond CERN.

After more than 20 years developing this area, he summarised the activities, successes and obstacles in *Technology Transfer from Particle Physics, the CERN Experience 1974–1997*. When activities began in the 1970s, few considered the usefulness of CERN technologies outside particle physics as a relevant objective. Now, CERN prominently showcases its impact on society. After his retirement, Oscar continued to be interested in CERN technology-transfer, and in 2012 he became a founding member of the international Thorium Energy Committee (iThEC), promoting R&D in thorium energy technologies.

No doubt, Oscar is the pioneer of what is now known as knowledge-transfer at CERN.

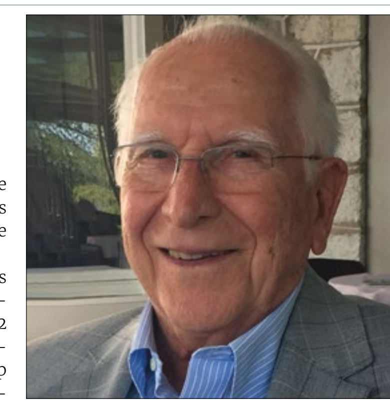
His colleagues and friends.

Philippe Bernard 1935–2023

CERN engineer par excellence

Electrical engineer Philippe Bernard, who made notable technical and managerial contributions across the various sectors at CERN in which he worked, passed away on 10 October 2023.

Born in 1935, Philippe completed his studies at the prestigious Ecole supérieure d'éléctricité in 1956. He began working at CERN in 1962 as engineer-in-charge of the Proton Synchrotron. He went on to design and develop radio-frequency (RF) separators, making substantial contributions to the improvement of these devices that provide well-selected secondary beams. This was particularly important in the early 1970s for experiments with the CERN 2 m hydrogen chamber, the Saclay-built Mirabelle chamber at Serpukhov, and the Big European Bubble Chamber at CERN.



Philippe Bernard played a key role in the development of superconducting radio-frequency cavities.

Realising the potential of superconductivity for RF structures, Philippe, together with Herbert Lengeler, was entrusted by CERN Director-General John Adams to develop RF cavities for CERN accelerators in 1978. A vigorous programme with international participation led to the development of five-cell cavities, first made of pure niobium and, later, of niobium sputtered on the more stable copper-substrate to produce robust cavities. This allowed accelerating fields of up to 7 MV/m to be reached.

After tests of prototypes at PETRA (DESY) and the Super Proton Synchrotron, 320 such cavities were produced for the Large Electron-Positron ▷

collider (LEP) using niobium-film technology. In the framework of the LEP2 upgrade programme, which started in 1987, these cavities were gradually added to the complement of normal-conducting cavities, which were partially replaced. This enabled an increase in the electron and positron beam energy from 46 GeV in 1989 to 104 GeV by 2000. In addition to this successful development, in the late 1990s Philippe took a strong interest in the design and development of a system of coupled superconducting cavities as a sensitive detector of gravitational waves.

Philippe was also involved in numerous CERN-wide activities, including chairing the purchasing policy monitoring board and serving as president of the CERN health insurance scheme (CHIS). He also served as president and vice-president of the CERN Pensioners' Association during a critical period.

His open mind, his wide-ranging views and his solid technical knowledge made Philippe a recognised leader. His critical and thoughtful attitude made him a respected discussion partner for the CERN management. Philippe's commitment to CHIS and to long-term improvements in the social conditions of CERN and ESO staff was widely appreciated and acknowledged. We remember him as a generous, witty and vivacious friend.

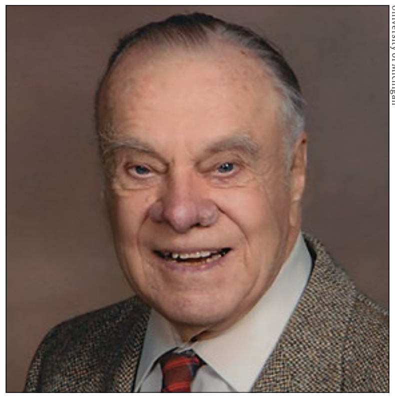
His friends and colleagues.

LAWRENCE W JONES 1925–2023

A rich and varied career

Experimental particle physicist Lawrence W Jones, a well-respected mentor and educator who contributed to important developments in accelerators and detectors, passed away on 30 June 2023.

Born in Evanston, Illinois on 16 November 1925, he enrolled at Northwestern University in autumn 1943 but was drafted into the US army a few months later. He served in Europe during World War II in 1944 and 1945, returning to Northwestern to complete a BSc in zoology and physics in 1948, followed by an MSc in 1949. After completing a PhD from the University of California, Berkeley in 1952, Jones went to the University of Michigan to begin a lifetime career in the physics faculty. In 1962 he acted as dissertation adviser to future Nobel laureate Samuel Ting and was promoted to full professor in 1963. He served as the physics department chair from 1982 to 1987 and was named professor emeritus in 1998.


University of Michigan

Lawrence Jones also had a strong interest in entomology.

Jones collaborated in the 1950s in the Midwestern Universities Research Association, a collaboration of US universities that developed key concepts for colliding beams, and built the first fixed-focus alternating gradient accelerator. Over the course of his career, Jones also contributed to the development of scintillation counters, optical spark chambers and hadron calorimeters. He participated in experiments designed to measure inelastic and elastic scattering, particle production, dimuon events, neutrino physics and charm production.

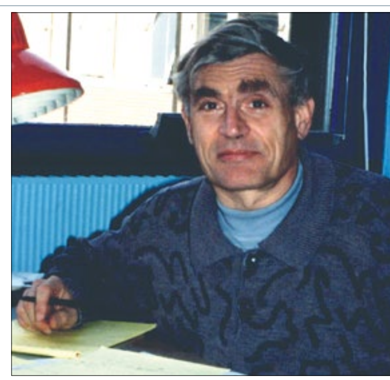
Jones came to CERN as a Ford Foundation Fellow (1961–1962) and as a Guggenheim Fellow (1964–1965), and then contributed to cosmic-ray experiments on Mount Evans, Colorado and nearby Echo Lake. In 1983 he joined the L3 experiment at LEP, which was led by his former student Ting. The Michigan team, led by Byron Roe, helped to design, construct and install the experiment's hadron calorimeter – a key component used to determine the number of elementary neutrino families. Jones also contributed to the construction of L3 cosmics, a programme to trigger on and measure cosmic rays using the detector's precision muon detector and surrounding solenoidal magnet.

Jones' interest in entomology led to a species of beetle (*Cryptorhinula jonsi*) being named after him. On the first Earth Day, in 1970, Jones introduced the term "liquid hydrogen fuel economy" and, in 1976, he joined the advisory board of the International Association for Hydrogen Energy. He had a long involvement with the Ann Arbor Ecology Center, which he led in 1974–1975, and became co-chair of the Michigan Environmental Council's Science Advisory Committee in 2000.

Steven Goldfarb *University of Melbourne and* **Byron Roe** *University of Michigan.*

HENRY NAVELET 1938–2023

A specialist in strong interactions


CNRS

Henri Navelet stood out for his theoretical rigour.

Henri Navelet died on 3 July 2023 in Bordeaux, at the age of 84. Born on 28 October 1938, he studied at the École Normale Supérieure in Paris. He went on to become a specialist in strong interactions and was a leading member of the Service de Physique Théorique (SPhT, now Institut de Physique Théorique) of CEA Saclay since its creation in 1963. Henri stood out for his theoretical rigour and remarkable computational skills, which meant a great deal to his many collaborators.

In the 1960s, Henri was a member of the famous "CoMoNav" trio with two other SPhT researchers, Gilles Cohen-Tannoudji and André Morel. The trio was famous in particular for introducing the so-called Regge-pole absorption model into the phenomenology of high-energy (at the time!) strong interactions. This model was used by many physicists to untangle the multitude of reactions studied at CERN. Henri's other noteworthy contributions include his work with Alfred H Mueller on very-high-energy particle jets, today commonly referred to as "Mueller–Navelet jets", which are still the subject of experimental research and theoretical calculations in quantum chromodynamics.

Henri had a great sense of humour and human qualities that were highly motivating for his colleagues and the young researchers who met him during his long career. He was not only a great theoretical physicist, but also a passionate sportsman, training the younger generations. In particular, he ran the marathon in two hours, 59 minutes and 59 seconds. A valued researcher and friend has left us.

His friends and colleagues at IPhT Saclay.

GABRIELLA PÁLLA 1934–2022

Building capacity in Hungary

Gabriella Pálla, who laid the foundations for the participation of Hungarian groups in CERN experiments, passed away on 11 October 2022 at the age of 88.

Gabriella attended Eötvös Loránd University in 1953, and began her career in nuclear physics in 1958 at the KFKI Research Institute for Particle and Nuclear Physics. Her first position was at the atomic physics department under the supervision of Károly Simonyi (on the topic of fast neutron reactions). In the 1970s she received a Humboldt Research Fellowship and worked at the cyclotron at the University of Hamburg, later at Julich. She received her PhD in 1972 at Eötvös University and gained a DSc titled "Direct reactions and the collective properties of nuclei" in 1987.

In the 1990s Gabriella's attention turned towards heavy-ion physics. She helped initiate the Buda-TOF project at NA49 and NA61 and later became the Hungarian ALICE representative in the early years of the experiment. She received the Academy Prize in Physics from the Hungarian Academy of Sciences in 1999 and the Simonyi Károly Award in 2010.


Private photo

Gabriella Pálla was the Hungarian ALICE representative in the early years of the experiment.

Pálla laid the foundations for the participation of Hungarian groups in CERN experiments

Gergely Gábor Barnaföldi *Wigner Research Centre for Physics,* **on behalf of the ALICE Collaboration.**

BIKASH SINHA 1945–2023

A strong force for India

Bikash Sinha, a pioneer in the field of quark–gluon plasma and the early universe, passed away on 11 August 2023 at the age of 78. His influence on heavy-ion physics is woven into the fabric of not only the ALICE experiment but also the broader field.

Bikash Sinha was born on 16 June 1945 in Kandi, Murshidabad in the state of West Bengal, India. After graduating in physics from Presidency College, Kolkata in 1964, he went to the UK where he completed the natural sciences Tripos course at King's College, Cambridge in 1967, and then gained a PhD in nuclear physics from the University of London in 1970. He returned to India on invitation from nuclear physicist Raja Ramanna and joined the Bhabha Atomic Research Centre (BARC) in 1976.

In the early 1980s Bikash started working in high-energy physics, particularly relativistic heavy-ion collisions and the formation of quark–gluon plasma. He was appointed director of the Variable Energy Cyclotron Centre in 1987 and held concurrent charge as director of Saha Institute of Nuclear Physics from 1992 to 2009. He received numerous awards and honours, including the Padma Shri Award in 2001 and the Padma Bhusan Award (the third-highest civilian award in the Republic of India) in 2010 for his significant contributions to science and technology. He had also been a member of the scientific advisory council to the Indian prime minister.

As the director of two major institutes in Kolkata, Bikash promoted research in different fields of science. In nuclear and particle physics, his efforts put India on the global map, and he was a strong supporter of the engagement of India with the international community via programmes at CERN. Early on, he broke through scientific bureaucracy to press the need for a multi-agency funding model for the nascent collaborations taking shape for the SPS WA93/WA98 experiments. Subsequently, India's contributions expanded to the LHC, to RHIC at Brookhaven National Laboratory, and then to FAIR at GSI in Germany.


T Nayak

Bikash Sinha paved the way for India's associate membership of CERN.

From modest beginnings in the early 1990s – armed with only a handful of collaborators, students and borrowed equipment, but a grand vision and unbeatable spirit – Bikash nourished and led the Indian team to become a major pillar of ALICE, and of heavy-ion physics more broadly. He embraced every challenge, be it the MANAS chip for the large muon chambers or the photon multiplicity detector, made possible on account of his generous attitude in promoting talents and giving chances to youngsters.

As an individual, Bikash was a synthesis of science, culture, philosophy and society. He initiated the medical cyclotron in Kolkata for the diagnosis and treatment of prostate cancer, and was inspired by the works of the great Indian poet and Nobel Laureate Rabindranath Tagore. In May 2022 he fused his passions for science and art in a one-of-a-kind international conference Microcosmos, Macrocosmos, Accelerator and Philosophy (*CERN Courier* July/August 2023 p22).

In 1988 Bikash initiated a very successful international conference series on the Physics and Astrophysics of Quark Gluon Plasma, and in 2008 he organised and chaired the annual Quark Matter conference in 2008 held in Jaipur, India. Along the way, his efforts paved the way for India to become one of the most prominent non-member-state participants at CERN, culminating in its accession to associate member in 2017.

While the passing of Bikash leaves an undeniable void, his legacy is a vibrant and thriving team that is primed to continue the journey he embarked upon. We will always remember him for his charismatic personality, great kindness, openness and generosity. We honour his memory, and with deepest condolences we extend our sympathy to his family.

His friends and colleagues in the ALICE collaboration.

CERNCOURIER

VOLUME 64 NUMBER 1 JANUARY/FEBRUARY 2024

IOP Publishing

BACKGROUND

Notes and observations from the high-energy physics community

Prize names matter

Nobel Prize Foundation

Women number less than 2% of all Nobel Laureates in physics.

Increasing diversification of the academic community is not adequately reflected in the award of scientific prizes, concludes an analysis of 8747 recipients of 345 different awards across science disciplines. Authors Katja Gehmlich and Stefan Krause of the University of Birmingham found that just 15% of awards go to women and suggest that the naming of prizes is a crucial factor: female recipients constitute 12% of awards named after a man, whereas this rises to 24% and 47% for awards that do not bear the name of a specific individual or are named after a woman, respectively. A lower rate of self-promotion by women and gender bias in award committees are among possible explanations, say the authors, who propose several pathways to address the disparity (*Nature Hum. Behav.* 10.1038/s41562-023-01773-9).

Nikhef renewal

M Kraan/Nikhef

The Vertex at Nikhef.

After spending two and a half years housed in a temporary building, staff at Nikhef were keen to return to the newly renovated Dutch lab in late October. The building, dating from 1978, sports a new entrance, sustainable windows, large skylights, an updated mechanical workplace and a striking atrium, fittingly named the Vertex. Office units have been completely renovated, sound-damping panels embossed with images of experiments decorate the walls, and each floor hosts an "anchor place" with a meeting room and kitchen unit. As an institute, Nikhef has pledged to be climate neutral by 2030, with energy for the building among five lines of travel.

Media corner

"This is a development that has been, for decades, eagerly awaited by our academic community."

Ireland's minister for further and higher education, research, innovation and science **Simon Harris** on the Irish government's application to become an associate member of CERN (*Engineers Ireland*, 15 November).

"I cannot recall a more exciting time to explore particle physics."

Sally Seidel, University of New Mexico and HEPAP chair, on the US P5 recommendations (*The New York Times*, 7 December).

"À la lumiére du rapport qui sera remis en février prochain, nous prendrons les engagements qui conviennent pour ce qui est du government français. On espère mobiliser nos partenaires et le secteur privé."

French president **Emmanuel Macron** discussing the proposed Future Circular Collider during his visit to CERN on 16 November (*RTS*, 16 November).

"Today, we are demonstrating we are a think-tank that is also capable of carrying out large-scale projects."

GESDA chair **Peter Brabeck-Letmathe** on the launch of the Open Quantum Institute (*crowdfundinsider.com*, 19 October).

From the archive: January/February 1984

A story of scales

CERN 584.11.83

R. Mössbauer gave an excellent talk on recent measurements of neutrino parameters.

In November 1983 about 200 specialists from particle physics, cosmology and astronomy attended a symposium at CERN on the 'Large Scale Structure of the Universe, Cosmology and Fundamental Physics' organized by CERN and the European Southern Observatory ESO.

Epic discoveries of the W and Z particles at CERN's proton–antiproton collider in 1983 had unified the electromagnetic and weak forces, and at its December session the CERN Council supported an improvement programme for the CERN antiproton project. Theorists are already working on GUTs, Grand Unified Theories synthesizing the electroweak and strong interactions, naturally encompassing the enormous ranges of energy and extreme temperatures that must have existed in the primaeval fireball, the Big Bang.

Supersymmetry doubles the number of integer and half-integer spin particles, giving new ways to account for the vast quantities of dark matter not directly observable but thought to exist. Inflation postulates a tremendous release of energy at about 10^{-36} seconds, setting off baryon creation and 'seeding' subsequent galaxy formation. These early quantum fluctuations provide an explanation for the Universe being homogeneous, isotropic and flat.

Cosmology sets limits on neutrino masses at less than 50 eV, and a new measurement from Moscow on the beta decay of tritium has further restrained the electron neutrino mass to 20 eV. Detection of the 3K cosmic background radiation [in 1965] was a major breakthrough, but measuring these tiny extragalactic signals poses almost insurmountable difficulties. Hopefully satellite-borne experiments should soon yield incisive new results.

● Text adapted from *CERN Courier* January/February 1984 pp 3–5.

Compiler's note

Breath-taking feats on Earth and in space continue to enhance our understanding of the origin and evolution of the universe. The Hubble and James Webb telescopes capture spectacular scenes from its remotest reaches, and in 2015 the LIGO detector was the first to record space–time ripples, induced when two black holes collided 1.3 billion light-years away. More recently, the ALPHA collaboration at CERN has shown matter and antimatter both "falling down" under gravity and a NASA mission scraped dust off the Bennu asteroid, currently at two thirds the distance to the Sun, and delivered it to Earth with astonishing precision, to provide clues for how compounds such as water might have reached our planet.

12 billion

Approximate number of lead–lead collisions recorded by the ALICE experiment during the 2023 heavy-ion run – 40 times more than the total recorded by ALICE in previous runs from 2010 to 2018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