Welcome to the digital edition of the January/February 2023 issue of CERN Courier.

The ATLAS and CMS detectors are being prepared for their biggest overhauls yet, in preparation for the tenfold increase in data to be delivered by the High-Luminosity LHC from 2029. The “Phase II” detector upgrades include state-of-the-art all-silicon inner trackers, high-granularity calorimeters and faster trigger and data-acquisition systems (p22 and 33). ALICE and LHCb are also preparing major upgrades for the 2030s. Meanwhile, the LHC keeps on breaking records, producing a peak proton–proton luminosity of $2.5 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ and providing lead–lead collisions at 5.36 TeV per nucleon pair (p11) before CERN’s year-end-technical stop on 28 November.

This issue looks back to the discovery of the W and Z bosons at the SPS 40 years ago (p41) and to the origins of the SESAME light source in the CERN theory corridors 30 years ago (p28). We also showcase new applications of accelerator technology in radiotherapy (p8) and future hydrogen-powered aircraft (p9), and report on the most precise tests of lepton-flavour universality from LHCb (p7). Also in the issue: Effective Field Theory (p37), sphere-stacking (p42), the latest conference reports (p15) and LHC-experiment results (p12), reviews (p44), careers (p46) and more.

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From detector upgrades to anomaly downgrades

Three decades since the ATLAS and CMS collaborations submitted letters of intent for the construction of their proton detectors, these marvels of technology and engineering are being prepared for their biggest overhauls yet. The tenfold increase in data to be delivered by the High-Luminosity LHC from 2029 onwards promises sub-percent precision on many Standard Model measurements—but only if the detectors can fully exploit the more complex and higher-rate collisions. Involving thousands of physicists and engineers from many tens of countries, and mostly due to be installed during Long Shutdown 3 in 2026–2029, many of the “Phase II” upgrades push detector technologies to new heights.

For ATLAS, they include a state-of-the-art all-silicon inner tracker, a new high-granularity timing detector, new and upgraded forward and luminosity detectors, improved muon coverage, faster trigger and data-acquisition systems, and new calorimeter readout electronics (p32). In CMS, the tracker and the calorimeter endcaps will be replaced with innovative new systems, a new minimum-ionising-particle-timing detector and luminosity detector will be installed, almost all of the electronics will be replaced, and additional muon forward stations will be mounted (p33). ALICE and LHCb are also preparing major upgrades for the 2029, which will be explored in upcoming issues. In the meantime, the LHC keeps on breaking records: the period leading up to CERN’s year-end–technical stop on 28 November saw the peak proton–proton luminosity reach 2.5 × 10 ^ 34 cm ^ -2 s ^ -1 and test collisions between lead nuclei take place at 5.36 TeV per nucleon pair (p91).

This issue also takes a look back—to the discovery of the W and Z bosons at the LEP40 years ago (p102) and to the origin of the MSSM light source in the CERN theory corridors 30 years ago (p108)—and showcases applications of accelerator science. UK-based firm Advanced Oncology, using a novel proton linac system, is preparing to treat its first patients (p8). French firm THERYQ has joined a collaboration between CERN and Lausanne University Hospital to develop FLASH radiotherapy using electrons (p9). And CERN has teamed up with Airbus to explore superconducting technologies for future hydrogen–powered aircraft (p9).

This issue also showcases applications of accelerator science.
On 20 December, the LHCb collaboration presented new measurements of rare B-meson decays that provide a high-precision test of lepton flavour universality, a key feature of the Standard Model (SM). Previous studies of these decays hadn't hit intrinsically higher tensions with predictions, but the improved and wider-reaching analysis of the full LHCb dataset is fully in line with the SM.

A central mystery of particle physics is why the 12 elementary quarks and leptons are arranged in pairs across three generations, identical in all but mass. Lepton flavour universality (LFU) states that the SM gauge bosons are indifferent to which generation a charged lepton belongs, implying that certain decays of hadrons involving leptons from different generations should occur at the same rates. In recent years, however, an accumulation of results has suggested a possible violation of LFU in B-meson decays involving fundamental b–s quark transitions, such as the decay of a B into a K meson. Such processes are highly suppressed in the SM because they proceed through higher-order diagrams, making them promising channels in a possible violation of LFU in B-meson decays involving fundamental b–s quark transitions. Among the forerunner is the parameter $\mathcal{R}(b\to s)$, based on angular distributions of the decay products of B–meson decays. Although these remain unaffected by the new LHCb result, tests of LFU via $\mathcal{R}(b\to s)$–type measurements are theoretically clean. On 18 October, complementing previous results by Belle, Ballar and LHCb, the LHCb collaboration made the first simultaneous measurement at a hadron collider of $\mathcal{R}(b\to s)$ and its counterpart $\mathcal{R}(c\to s)$, which probe b–c quark transitions.

Earlier LHCb indications of anomalies with lepton flavour universality triggered immense excitement.

\begin{align*}
R_K\; & = 1.027_{-0.077}^{+0.087} \\
R_{K^*}\; & = 1.6_{-0.047}^{+0.077}
\end{align*}

Earlier LHCb indications of anomalies with lepton flavour universality triggered immense excitement, not least because possible new-physics explanations resonated with other hints of deviations from the SM, says CERN theorist Michelangelo Mangano.

“That such anomalies could have been real shows how little we know about the deep origin of flavour symmetries and their relation with the Higgs, and highlights the key role of experimental guidance. Theoretical efforts to interpret the anomalies explored novel avenues, exposing a myriad of unanticipated phenomena possibly emerging at distances shorter than those so far described by the SM. The latest LHCb findings take nothing away from our mission to push further the boundary of our knowledge, and the search for answers goes on!”

Further reading
Radiotherapy debut for proton linac

In November, CERN signed an agreement with the Lausanne University Hospital (CHUV) and medical-technology spinoff THERYQ to develop a novel “FLASH” radiotherapy device. The device – the first of its kind based on CERN technology – will use very-high-energy electrons (VHEEs) to treat cancers with a precision and speed that are unprecedented. The technology will provide a much faster and less invasive alternative to conventional treatments, with reduced side effects. Currently, around one third of cancers are resistant to conventional radiotherapy.

Developing high-temperature and high-magnetic-field superconducting technologies both for societal applications and for next-generation particle accelerators is a goal of a new project in Italy called IRIS, launched in November and led by the INFN. IRIS (Innovative Research Infrastructure on applied Superconductors) is a 460 million Euro project, which aims to create a distributed R&D infrastructure throughout the country. It will focus on cables and magnets, as well as accelerator technology, and on the construction of superconducting magnets with high-temperature superconductors. The project is expected to last for 30 years, with more than 50% of the funds going to laboratories in Italy.

One of the main objectives will be the construction in Salerno of a large superconducting magnet. “This is a key technology that is essential for the creation of new materials for energy saving technologies, and those involved in the fields of superconductivity and magnetism,” explains INFN technical coordinator Lucio Rossi of the University of Milan. “An aspect not to be overlooked is also the high educational value of the project, which will guarantee numerous doctoral and high-level training opportunities for generations of researchers and technicians.”

The activities of IRIS will be coordinated by the Laboratori Nazionali del Gran Sasso and the INFN chapter at the University of Genoa.

In Italy, the INFN’s Institute for Superconductors, Innovative Materials and Devices (SPIN) is a base in Bergamo, co-ordinated by the INFN Milan, with many partners including the universities of Genova, Milano, Napoli, Salerno and Sannio, and the CERN Institute for Superconductors, Innovative Materials and Devices (SPIN). The SPIN activities are part of a broader programme of research much of which is being carried out at SPIN, with the aim of making Italy a pole of excellence in superconductivity R&D. The project includes research on the future of high-power superconductors and is supported by the European Union through the framework programme Horizon 2020. "We are already developing a superconductivity demonstrator called ASCEND (Advanced Superconducting and Cryogenic Experimental power network Demonstrator) to study the feasibility of this technology for electric power and hybrid aircraft. Combining knowledge and expertise from our demonstration and CERN’s unique capabilities in the field of superconductors makes for a natural partnership."
Highly energetic cosmic rays reach Earth from all directions and at all times. It has been challenging to conclusively identify their sources. Being charged, cosmic rays are easily deflected by interstellar magnetic fields during their propagation and thereby lose any indication of where they originated from. On the other hand, highly energetic photons and neutrinos remain unaffected. Observations of high-energy photons and neutrinos are therefore crucial clues towards unravelling the mystery of cosmic-ray sources and accelerators.

Four years ago, the IceCube collaboration announced the identification of the blazar TXS 0506+056 as a source of extremely energetic cosmic rays during their propagation through the intergalactic medium. This was one of the early examples of multi-messenger astronomy wherein a high-energy neutrino event detected by IceCube, which was coincident in direction and time with a gamma-ray flare from the blazar, prompted an investigation into this object as a potential astrophysical neutrino source.

**Point source**

In the following years, IceCube made a full-sky scan for point-like neutrino sources, and in 2020, the collaboration found an excess coincident with the Seyfert II galaxy, NGC1068, that was inconsistent with a background-only hypothesis. However, with a statistical significance of only 4.9σ, it was insufficient to claim a detection. In November 2022, after a more-detailed analysis with a longer five-year data set, IceCube announced the discovery of a point source at high-energy neutrinos at a 4.7σ significance level. The point source was also found to be consistent with a background-only hypothesis. In a report published on 25 October, the IceCube Collaboration published the first detection of a source leading to a joint analysis with the Fermi-LAT collaboration on excesses of gamma-ray emission from the same direction, suggesting that the source is a Milky Way galaxy.

**IceCube’s measurements usher in a new era of neutrino astronomy**

Since the first detection of a source leading to a joint analysis with the Fermi-LAT collaboration on excesses of gamma-ray emission from the same direction, suggesting that the source is a Milky Way galaxy, IceCube’s measurements usher in a new era of neutrino astronomy:

1. **Galactic accelerators**
   - A Hubble image of the spiral galaxy Messier 77, also known as the Squid Galaxy or NGC 7793, was released in 2023. The galaxy is located in the constellation Ursa Major and is a nearby galaxy that is part of the Local Group. The galaxy is known for its bright spiral arms, which are thought to be powered by massive black holes at the center. The galaxy is also known for its active galactic nucleus (AGN), which is a luminous and compact region at the center of the galaxy, where matter is accelerated to near-light speeds.

2. **Muon-neutrino events**
   - The main contribution coming from neutrinos in the energy range of 1 to 15 TeV, an important range for multi-messenger astronomy, was found. IceCube has observed two batches of high-energy neutrino events in this energy range.

3. **Muon Lamb shift**
   - As a test of quantum electrodynamics due to the point-like structure of the electron and muon, IceCube’s measurements of muon-neutrino events were used to calculate the Lamb shift, a quantum mechanical effect that causes the energy levels of the muon and electron to differ slightly. The result was in excellent agreement with the theoretical prediction, providing further evidence for the validity of quantum electrodynamics.

4. **Félix-Kalb effect**
   - The effect was discovered in 1962 by Félix-Kalb, a French physicist, who predicted the existence of a small mass difference between the muon and electron. IceCube’s measurements allowed for an accurate measurement of this mass difference, confirming the prediction.

5. **Artificial intelligence**
   - IceCube’s data acquisition and event reconstruction algorithms were deployed, allowing for a more efficient and accurate analysis of the data. The collaboration also used advanced event reconstruction algorithms to enhance the detection efficiency and reduce background.

6. **Neutrino astronomy**
   - IceCube’s measurements led to the discovery of a point source of high-energy neutrinos that was coincident with the Seyfert II galaxy, NGC1068. The results were in line with previous studies and suggested that the source could be a source of cosmic rays.

7. **IceCube’s measurements**
   - The multipurpose hybrid pixel detector chip, Timepix, was used to classify signals into different categories. Timepix is a silicon detector chip that can accurately classify signals based on their arrival time, allowing for a more efficient analysis of the data.

8. **Flying to the Moon**
   - The launch of the first Timpax chip was flown to the Moon in 2023 as part of the Artemis I mission. Timpax is a detector chip that can detect cosmic rays and other high-energy particles in space.

9. **EOS programme**
   - The EOS programme is a new era of neutrino astronomy. IceCube’s measurements usher in a new era of neutrino astronomy, and the results were in line with previous studies and suggested that the source could be a source of cosmic rays.
**Hunting dark matter with invisible Higgs decays**

In the Standard Model (SM) of particle physics, the only way the Higgs boson can decay without leaving any traces in the LHC detectors is through the four-neutrino decay, \( H \rightarrow \nu \nu \nu \nu \), which has an expected branching fraction of only 0.9%. This very small value can be seen as a difficulty but is also an exciting opportunity. Indeed, several theories of physics beyond the SM predict considerably enhanced values for the branching fraction of invisible Higgs boson decays. In one of the most interesting scenarios, the Higgs boson acts as a portal to the dark sector by decaying to a pair of dark matter (DM) particles. Measurements of the “Higgs to invisible” branching fraction are clearly among the most important tools available to the LHC experiments in their search for direct evidence of DM particles.

The CMS collaboration recently reported the combined results of different searches for invisible Higgs boson decays, using data collected at 7, 8 and 13 TeV centre-of-mass energies. To find such a rare signal amidst the overwhelming background produced by SM processes, the study considers events in most Higgs-boson production modes via vector bosons (Z) fusion, via gluon fusion and in association with a top quark–antiquark pair or a vector boson. In particular, the analysis looked at hadronically decaying vector bosons or top quark–antiquark pairs. A typical signature for invisible Higgs–boson decay is a large missing energy in the detector, so that the missing transverse energy plays a crucial role in the analysis. No significant signal has been seen, so a new and stricter upper limit is set on the probability that the Higgs boson decays to invisible particles: 15% at 95% confidence level.

This result has been interpreted in the context of Higgs portal models, which introduce a dark Higgs sector and consider several dark Higgs-boson masses. The extracted upper limits on the spin-independent DM-nucleon scattering cross-section, shown in figure 1 for a range of DM masses, can have better sensitivities than those of direct searches over the 1–1000 GeV range of DM masses. Once the Run 3 data will be added to the analysis, much stricter limits will be reached, or, if we are lucky, evidence for DM production at the LHC will be seen.

**Further reading**

CMS-PAS-HIG-21-007

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**B to D decays reduce uncertainty on CP violation**

The Cabibbo–Kobayashi–Maskawa (CKM) matrix describes the couplings between the quarks and the weak charged currents, and contains within it a parameter that changes sign under consideration of antiparticles rather than quarks. In the Standard Model (SM), this phase is the only known difference in the interactions of matter and anti-matter, a consequence of the breaking of charge-parity (CP) symmetry. While the differences within the SM are known to be too small to explain the matter–anti-matter asymmetry of the universe, it is still of paramount importance to precisely determine this phase to provide a benchmark against which any contribution from new physics can be compared.

A new measurement recently presented at the conference LHCb-2022 (Edinburgh, 25–26 August 2022) uses a novel method to determine \( \Delta \phi_G \) using decays of the type \( B^- \rightarrow D^0 \pi^- \rightarrow \mu^- \nu \) and \( B^+ \rightarrow D^0 \pi^+ \rightarrow \mu^+ \nu \). CP violation in such decays is a consequence of the interference between two phase-level structures relevant to the \( B \rightarrow D \pi \) weak phase that differs by \( \pi \), and thus provides a theoretically clean probe of the SM. The new aspect of this measurement compared to those performed previously lies in the partitioning of the five-dimensional phase space of the \( B \rightarrow D \) decay into a series of independent regions, or bins. In these bins, the asymmetries between the \( B \) and \( B^\ast \) meson decay rates can be sensitive to new physics, such as new CP-violating phases, and can provide a stringent test of CP violation in the SM, as well as a sensitivity to new physics beyond the SM. The results of this measurement have been combined with measurements of the CP-violating phase \( \Delta \phi_G \) obtained from many other CP-violating decays, and the combined result is:

\[
\Delta \phi_G = (2.5 \pm 0.2) \pi
\]

This measurement will be particularly important as the sensitivity of other experiments to CP violation decreases. The LHC Average of the results of this measurement is in agreement with the SM prediction, and the expected sensitivity of the LHCb experiment on this observable is around 0.5%.

**Further reading**

ATLAS Collab. 2022 ATLAS-CONF-2022–060
The matter–antimatter asymmetry reaches 85% in a certain region, the largest ever observed

For almost 40 years, charmonium, a bound state of heavy charm–anticharm pair (hence also called a hidden charm), has provided a unique probe to study the properties of the quark–gluon plasma (QGP), the state of matter composed of deconfined quarks and gluons present in the early instants of the universe and produced experimentally in ultra-relativistic heavy-ion collisions. Charm production experimentally in ultrarelativistic heavy-ion collisions and deconfined quarks and gluons present in the early instants of the universe and produced experimentally in ultrarelativistic heavy-ion collisions. Charm production experimentally in ultrarelativistic heavy-ion collisions and deconfined quarks and gluons present in the early instants of the universe and produced experimentally in ultrarelativistic heavy-ion collisions. 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of the facility, including detector design, background analyses and monitoring, measurements, civil engineering and inte-
gration studies is in preparation. Small prototypes of the MATHILDA, ANUBIS, and CODEX-b detectors aiming at the  
search for long-lived particles at large angles from LHC collisions are also being built for installation during the  
recent LHC run.

Crystal clear

Fixed-target experiments are also being developed that would extract such
protons from LHC beams by channeling the beam halo with a bent crystal. The  
extracted protons would impinge on a target and be used for measurements of  
proton structure functions (“single-crystal setup”) or estimation of the  
magnetic and electric dipole moments of short-lived heavy baryons (“double-crystal setup”). In the latter case, the
measurement would be based on the baryon spin precession in the strong
electric field of a second bent crystal installed immediately downstream from the
baryon–production proton target. A proof-of-principle experiment of the
double-crystal setup is being designed for installation in the LHC to determine the
channeling efficiency for long crystals at TeV energies, as well as to demon-
strate the control and management of the secondary halo and validate the
estimate of the achievable luminosity.

The technology know–how at CERN can also benefit non–accelerator experiments,
opening the door for new physics measurements. Among possible applications is
the construction of a state-of-the-art facility for the detection of long-lived
particles, such as those produced in LHC collisions by channelling the
beam halo with a bent crystal. The secondary halo and validate the
estimate of the achievable luminosity.

The conference was organized by the
CERN Quantum Technology Initiative
(CERN QTI), which was established in
2020 (CERN Courier 2020 p47), and followed a successful workshop on quantum
computers, quantum computing and
materials; quantum computing and
metamaterials; quantum computing and
information science and par

Quantum leap

In one of the sessions focused
on the two remaining areas, with talks on
quantum–machine–learning, noise
and gate quantum computing, the
journey towards a quantum internet, and much
more. These talks clearly demonstrated
the importance of working in interdis-
siplinary teams when approaching particle–physics research
with quantum–computing techniques.

Building partnerships

Participants showed an interest in broad-
ening collaborations related to particle
physics. Members of the particle
and quantum sensing communities
discussed ways to identify and promote
areas of promise and mutual
benefit. As a result of the
workshop, participants agreed to
work towards

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The main conclusion of the workshop was that, given the need for aluminium- stabilised Nb-Ti/Cu conductors for future superconducting detector magnet projects, there is no commercially available conductor of this composition and a co-extraction effort from international institutes through collaboration and cooperation with industry. This world-wide effort will advance technologies to be transfersed openly to industry and other laboratories. Of particular importance is the co-extraction technology needed to bond the aluminium stabiliser to the Rutherford cable. Hybrid-structure technology through electron-beam welding or other approaches to maximise the performance of an AI-stabilised superconducting conductor combined with high-strength Al-alloy is needed for high-stress-detector magnets. Back-up solutions such as precoated or cold worked aluminium stabilisers, copper-based stabilisers and aluminium-alloy reinforced conductors are to be considered. In the long term, aluminium-stabilised HTS technology will be important for specific detector-magnet applications.

The workshop was received with strong interest and enthusiasm, and it is expected that another will be organised in two years, depending on the progress being made.

Matthew Mennink: CERN, Andrea Bazzocchi, Olguta KEK and Akira Yamamoto, KEK/CERN.

**EPFL 2023**

FEC-ee, a proposed ykm future circular e+ e− collider at CERN foreseen to begin operations in the third decade of the current century. Enormous samples of collision data at a wide range of energies, allowing far more precise measurements of the Higgs, W and Z bosons, and the top-quark. For example, when combined with other efforts, it will produce — in little more than one minute — a data set the same size that accumulated by the LEP collider during its entire year-long period of operation.

For the preparation of FEC-ee, data era will require exquisite systematic control at a level far beyond that achieved at previous colliders.

One of a kind

The long Nb-Ti superconducting magnets of the CMS detector are being installed in 2023.

One of the key issues is the availability of aluminium- stabilised Nb-Ti/Cu conductor technology. Fifteen physical research projects, which had either been approved or are in the design phase, presented their needs and plans for superconducting detector magnets.

The workshop provided a strong demand for aluminium-stabilised Nb-Ti/Cu conductor technology. Other conductor technologies that were featured during the workshop included cable-in-conduit technology (CTC) and aluminium-stabilised high-temperature superconducting (HTS) superconductors.

Presentations by leading industrial partners showed that the industrial capabilities to support the high-strength conductors does exist, as long as a suitable conductor is available. It was also shown that aluminium-stabilised Nb-Ti/Cu conductors are currently not commercially available, although an R&D effort is currently going on with HEP in China. In particular, the co-extraction process needed to clad the Nb-Ti/Rutherford cable with aluminium is a key missing ingredient in industry.

At the same time, the presentations showed that other ingredients, such as Nb-Ti/Cu wire production, the cabling of strands into Rutherford cables, the high-purity aluminium stabiliser itself and the technique for welding aluminium alloy reinforcements to high-strength conductors are still available.

ITF 2023

Keeping research infrastructures safe

Safety is a priority for CERN. It spans all areas of occupational health and work safety — supporting research at the interface of the environment and the safe operation of facilities. Continuous exchanges with industry and research institutions worldwide gathered in the Globe of Science and Innovation at CERN for the International Technical Safety Forum (ITSF). This key conference gives a voice to the entire ITSF community, which includes representatives from 22 research organizations.

We all learn from each other to create a safer world environment
In its 25-year existence, the forum has evolved with the times, all the while increasing its attractiveness for experts to share their knowledge, experience and challenges,” says Full Tray, of the CERN technology department. “The scope has broadened from high-energy physics to a wider range of disciplines and participating institutes in Europe and beyond, with Asian labs joining in addition to American institutes, which have been involved since the beginning.”

Opening the event, Benoît Delille, head of the CERN safety, health and environment unit, noted: “For colleagues from different institutes who visit CERN for the first time, it is an occasion for us to share the values on which this organisation is built, that we are proud of, and also how we make them come to life through the prism of safety.” A first session on environmental protection and sustainability saw CERN share its approach to minimising its environmental footprint in test facilities. Improvements such as new isotope-enriched targets for high-quality standalone medical imaging and improved beam-profile monitors, or magnetic-field measurement instruments in cryogenic conditions will further enhance the capabilities of facilities to address the challenges of the coming decades. Through an active and open data-management plan following the FAIR principle, EURO-LABS will act as a gateway for information to facilitate research across disciplines and provide training for young researchers.

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A NEW ATLAS FOR THE HIGH-LUMINOSITY ERA

Stefan Guindon, Christian Ohm and Caterina Vernieri describe the major ‘Phase II’ upgrades taking place to prepare the ATLAS detector for the High-Luminosity LHC.

Pixel perfection The ATLAS, comprising strip (outer layers) and pixel (inner layers) detectors with more than five billion readout channels.

The discovery of the Higgs boson at the LHC in 2012 changed the landscape of high-energy physics forever. After just a few short years of data-taking by the ATLAS and CMS experiments, this last piece of the Standard Model (SM) was proven to exist. Since then, the Higgs sector has been studied using a rapidly growing dataset and, so far, all measurements agree with the SM predictions within the experimental uncertainties. In parallel, a comprehensive programme of searches for beyond-SM processes has been carried out, resulting in strong constraints on new physics. A harvest of precise measurements of a large variety of processes, confronted with state-of-the-art theoretical predictions, has further supported the SM. However, the theory lacks explanations for, among others, the nature of dark matter, the cosmological baryon asymmetry and neutrino masses. Importantly, the Higgs sector is related to “naturalness” problems that suggest the existence of new physics at the TeV scale, which the LHC can probe (CERN Courier July/August 2022 p42).

The high-luminosity phase of the LHC (HL-LHC) will provide an order of magnitude more data starting from 2029, allowing precision tests of the properties of the Higgs boson and sensitivity to a wealth of new-physics scenarios. The HL-LHC will deliver to each of the ATLAS and CMS experiments approximately 170 million Higgs bosons and 120,000 Higgs–boson pairs over a period of about 10 years. By extrapolating Run 2 results to the HL-LHC dataset, this will increase the precision of most Higgs-boson coupling measurements: 2–4% precision on the couplings to W, Z and third-generation fermions; and approximately 50% precision on the self-coupling by combining the ATLAS and CMS datasets. The larger dataset will also give improved sensitivity to rare vector-boson scattering processes that will offer further insights into the Higgs sector.

Precision measurements could reveal discrepancies with the SM predictions, which in turn could inform us about the energy scale of beyond-SM physics. In addition to improving SM measurements, the upgraded detectors and trigger systems being developed and constructed for the HL-LHC era will enable direct searches to better target new physics with challenging signatures. To achieve these goals, it will be essential to achieve a detailed understanding of the detector performance as well as to measure the integrated luminosity of the collected dataset to 1% precision.

Rising to the challenge To cope with the increased number of interactions when proton bunches collide at the HL-LHC, the ATLAS collaboration is working hard to upgrade its detectors with state-of-the-art instrumentation and technologies. These new detectors will need to cope with challenging radiation levels, higher data rates and an extreme high-occupancy environment with up to 200 proton–proton interactions per bunch crossing (see “Pileup” figure). Upgrades will include changes to the trigger and data-acquisition systems, a completely new inner tracker, as well as a new silicon timing detector (see “ATLAS Phase II” figure).

The trigger and data-acquisition system will need to cope with a readout rate of 1 MHz, which is about 50 times higher than today. To achieve this, ATLAS will use a new architecture with a level-0 trigger (the first-level hardware trigger) based on the calorimeter and muon systems. Building on the upgrades for Run 3, which started in July 2022, the calorimeter will include capabilities for triggering at higher pseudorapidity, up to |η| < 4. During HL-LHC running, the global trigger system will be required to handle 50 TB/s as input and to decide within 10 μs whether each event should be recorded or discarded, allowing for more sophisticated algorithms to be run online for particle identification. All the detectors will require substantial upgrades to handle the additional acceptance rates from the trigger.

The readout electronics for the electromagnetic, forward and hadronic end-cap argon calorimeters, along with the hadronic tile calorimeter, will be replaced. The full-calorimeter systems, segmented into 902,740 cells that are read out individually, will be read out for every bunch crossing at the full 40 MHz to provide full-granularity information to the trigger. This will require changes to both front-end electronics and off-detector components.

The muon system will also see significant upgrades to the on-detector electronics of the resistive plate chambers (RPCs) and thin-gap chambers (TGCs) responsible for triggering on muons, as well as the muon drift tubes (MDTs) responsible for measuring the curvature of the tracks precisely. The MDTs will also be used for the first time in the level-0 trigger decisions. These improvements will allow all data to be sent to the back-end at 40 MHz, removing the need for buffers on the detector itself. All hits in the detector will be used to perform trigger logic in hardware using field programmable gate-arrays. Additional improvements to increase the trigger acceptance for muons will come in the form of a new layer of RPCs to be installed in the inner barrel layer, along with new MDTs in the small sectors. The Muon New Small Wheel system was installed during Long Shutdown 2 (LS2) from 2019 to 2020 (CERN Courier November/December 2021 p27). The Muon New Small Wheel is a 4 T solenoid magnet containing both triggering and precision tracking chambers. Additional
RPC upgrades were also made in the barrel leading up to Run 3, and the TGCs will be upgraded in the endcap region of the muon system during LS5.

State-of-the-art tracking

The success of the research programme at the HL-LHC will strongly rely on the tracking performance, which in turn determines the ability to efficiently identify hadrons containing b and c-quarks, in addition to tau and other charged leptons. Reconstructing individual particles in the HL-LHC collision environment with thousands of charged particles being produced within a region of about 10 cm will be very challenging. The entire tracking system, presently consisting of pixel and strip detectors and the transition radiation tracker, will be replaced by a new all-silicon pixel and strip tracker – the ITk. This will feature higher granularity, increased radiation hard- ness and readout electronics that allow higher data rates and a longer trigger latency. The new pixel detector will also extend the pseudorapidity coverage in the forward region from $|\eta| < 2.5$ to $|\eta| < 4$, increasing the acceptance for important physics processes like vector-boson fusion (see “Pixel perfection” image, p.22).

The ITk will comprise nine barrel layers, positioned at radii from 35.2 mm to 1 m from the beam line, plus end-cap rings. It will be much more complex with respect to the present ATLAS tracker, featuring 10 times the number of strip barrel staves and 60 times the number of pixel channels.

The detector will cover a pseudorapidity range of $|\eta| < 4$ and will comprise two double-sided silicon layers on each side of ATLAS with a total active area of 6.4 m$^2$. The precise timing information will allow the collaboration to disentangle proton–proton interactions in the same bunch crossing in the time dimension, complementing the impressive spatial resolution of the TPK. The Low-gain avalanche diodes (see “Clocking tracks” image) provide timing information that can be associated with tracks in the forward regions, where they are more difficult to assign to individual interactions using spatial information.

The ATLAS and CMS collaborations are working hard to upgrade their detectors with state-of-the-art instrumentation and technologies.

To cope with the increased number of interactions when proton bunches collide at the HL-LHC, the ATLAS collaboration is working hard to upgrade its detectors with state-of-the-art instrumenta

tion and technologies.
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FROM DREAMS TO BEAMS
SESAME’S 30 YEAR–LONG JOURNEY IN SCIENCE DIPLOMACY

Scientists in the Middle East broke ground for the SESAME light source in January 2003. Founder Eliezer Rabinovici describes the story behind this beacon for peaceful international collaboration, what its achievements have been, and what the future holds.

SESAME (Synchrontron-light for Experimental Science and Applications in the Middle East) is the Middle East’s first major international research centre. It is a regional third-generation synchrotron X-ray source situated in Allan, Jordan, which broke ground on 6 January 2003 and officially opened on 16 May 2017. The current members of SESAME are Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine and Turkey. Active current observers include, among others: the European Union, France, Germany, Greece, Italy, Japan, Kuwait, Portugal, Spain, Sweden, Switzerland, the UK and the US. The common vision driving SESAME is the belief that human beings can work together for a cause that furthers the interests of their own nations and that of humanity as a whole.

The story of SESAME started at CERN 30 years ago. One day in 1993, shortly after the signature of the Oslo Accords by Israel and the Palestine Liberation Organization, the late Sergio Fubini, an outstanding scientist and a close friend and collaborator, approached me in the corridor of the CERN theory group. He told me that now was the time to test what he called “your idealism”, referring to future joint Arab–Israeli scientific projects.

CERN is a very appropriate venue for the inception of such a project. It was built after World War II to help heal Europe and European science in particular. Abdus Salam, as far back as the 1950s, identified the light source as a tool that could help trust what were then considered “third-world” countries directly to the forefront of scientific research. The very same Salam joined our efforts in 1993 as a member of the Middle Eastern Science Committee (MESC), founded by Sergio, myself and many others to forge meaningful scientific contacts in the region. By joining our scientific committee, Salam made public his belief in the value of Arab–Israeli scientific collaborations, something the Nobel laureate had expressed several times in private.

To focus our vision, that year I gave a talk on the status of Arab–Israeli collaborations at a meeting in Torino held on the occasion of Sergio’s 69th birthday. Afterwards we travelled to Cairo to meet Venice Gouda, the Egyptian minister for higher education, and other Egyptian officials. At that stage we were just self-appointed entrepreneurs. We were told that president Hosni Mubarak had made a decision to take politics out of scientific collaborations with Israel and, so together we organized a high–quality scientific meeting in Dahab, in the Sinai desert. The meeting, held in a large Bedouin tent on 19–20 November 1993, brought together about 100 young and senior scientists from the region and beyond. It took place in the weeks after the murder of the Israeli prime minister Yitzhak Rabin, for whom, at the request of Venice Gouda, all of us stood for a moment of silence in respect. The silence echoes in my ears to this day. The first day of the meeting was attended by Jacob Ziv, president of the Israel Academy of Sciences and Humanities, which had been supporting such efforts in general. It was thanks to the additional financial help of Miguel Virasoro, director–general of ESRF at the time, and also Danièle Anani, director of SESAME, that the meeting was held. All three decisions of support were made at watershed moments and on the spur of the moment. The meeting was followed by a very successful effort to identify concrete projects in which Arab–Israeli collaboration could be beneficial to both sides.

But attempts to continue the project were blocked by a turn for the worse in the political situation. MESC decided to retreat to Torino, where, during a meeting in November 1996, there was a session devoted to studying the possibilities of cooperation via experimental activities in high–energy physics and light–source science. During that session, the late German scientist Gust Voss suggested (on behalf of himself and Hermann Winnick from SLAC) to bring the parts of a German light source situated in Berlin, called BESSY, which was about to be dismantled, to the Middle East. Former Director–General of CERN Herwig Schopper also attended the workshop. MESC had built sufficient trust among the parties to provide an appropriate infrastructure to turn such an idea into something concrete.

Targeting excellent science
A light source was very attractive thanks to the rich diversity of fields that can make use of such a facility, from biology through chemistry, physics and many more to archaeology and environmental sciences. Such a diversity could also allow for the formation of a critical mass of real users in the region. The major drawback of the BESSY–based proposal was that there was no way a reconstructed dismantled “old” machine would be able to attract first–class scientists and science.

Around that time, Fabini asked Schopper, who had a rich experience in managing complex experimental projects, to take a leadership position. The focus of possible collaborations was narrowed down to the construction of a large light source and, it was decided to use the German machine as a nucleus around which to build the administrative structure of the project. The non–relations among several of the members presented a serious challenge.

The non–relations among several of the members presented a serious challenge. At the suggestion of Schopper, following the example of the way CERN was assembled in the 1950s, the impasse was overcome by using the auspices of UNESCO to deposit the instruments for joining the project. The statutes of SESAME were a large extent copied from those of CERN. A band of self–appointed entrepreneurs had evolved into a self–declared interim Council of SESAME, with Schopper as its president. The next major challenge was to choose a site.

On 3 March 2000 I flew to Amman for a meeting on the subject. I met Khalil Talash (the current director–general of SESAME) and, after studying a map sold at the hotel

The AUTHORS

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Beginnings
Above left: the setting for the November 1995 meeting in Dahab, Egypt. Above right: the SESAME groundbreaking ceremony on 6 January 2003, attended by King Abdullah II of Jordan (third from right).

where we met, we discussed which site Israel would support. We also asked that a Palestinian be the director general. Due to various developments, none of which depended on Israel, this was not to happen. The decision on the site venue was taken at a meeting at CERN on 21 April 2000. Jordan, which had and has diplomatic relations with all the parties involved, was selected as the host state. BESSY was dismantled by Russian scientists, placed in boxes and shipped with assembly instructions to the Jordanian desert to be kept until the appropriate moment would arise. This was made possible thanks to a direct contribution by Koichiro Matsuura, director-general of UNESCO at the time, and to the efforts of Khaled Toukan who has served in several ministerial capacities in Jordan.

With the administrative structure in place, it was time to address the engineering and scientific aspects of the project. Technical committees had designed a totally new machine, with BESSY serving as a boosting complement. Many scientists in the region were introduced via workshops to the scientific possibilities that SESAME could offer. Scientific committees considered appropriate ‘day-one’ beamlines, yet that day seemed very far in the future. Technical and scientific directors from abroad helped define the parameters of a new machine and identified appropriate beamlines to be constructed. Administrators and civil servants from the members started meeting regularly in the finance committee. Jordan began to build the facility to host the light source and made major additional financial contributions.

Transformative agreements
At this stage it was time for the SESAME interim council to transform into a permanent body and in the process cut its umbilical cord from UNESCO. This transformation presented new hurdles because it was required of every member that wished to become a member of the permanent council that its head of state, or someone authorised by the head of state, sign an official document sent to UNESCO confirming that its head of state, or someone authorised by the member that wished to become a member of the permanent council. Each member of the unlikely coalition—consisting of Iran, Israel, Jordan and Turkey—pledged an extra $5 million for the project in an agreement signed in Amman. In the end, several million Euros from those projects did stand their way to SESAME, but the coffers of SESAME and its infrastructure remained skeletal.

Changing perceptions
In 2008 Hervé Schopper was succeeded by Chris Llewellyn Smith, another former Director-General of CERN, as president of the SESAME Council. His main challenge was to get the funding needed to construct a new light source and to remove from SESAME the perception that it was simply an empty shell. This was made possible thanks to a direct contribution directed earlier from a bilateral EU–Jordan agreement. In 2015 the INFN, under director Fernando Ferroni, gave almost $2 million. This made it possible to build a host, as offered by most light sources, which was named appropriately after Sergio Fuhini. Many leading world labs, in a heartwarming expression of support, have donated equipment for future beam lines as well as fellowships for the training of young people.

Point of no return
With their help, SESAME crossed the point of no return. The undefined stuff dreams are made of turned into magnets and girdles made of real hard steel, which I was able to touch as they were being assembled at CERN. The pace of events had finally accelerated, and a star-studded inauguration including attendance by the king of Jordan took place on 16 May 2017. During the ceremony, amazingly, the political delegates of different member states listened to each other without leaving the room (as is the standard practice in other international organisations). Even more unique was that each member-state delegate taking the podium gave essentially the same speech: “We are trying here to achieve understanding via collaboration.”

At that moment the SESAME council presidency passed from Chris Llewellyn Smith to a third former CERN Director-General, Rob Heer. The high-quality 2.5 GeV electron storage ring at the heart of SESAME started operation later that year, driving two X-ray beamlines: one dedicated to X-ray absorption fine structure/XAFS and powder-diffraction experiments, and the second to X-ray fluorescence (XAFS/XRF) spectroscopy, and another to infrared spectroscopy. A third powder-diffraction beamline on infrared absorption fine structure is being added, while a fourth X-ray beamline “HISEP” designed and constructed by five Helmholtz research centres is being commissioned. In 2023 the HIME beamline for Tomography at SESAME (HIME) will also be completed, with the construction and commissioning of a beamline for hard X-ray full-field tomography.

The unique SESAME facility started operating with uncanny normality. Well over 100 proposals for experiments were submitted and refereed, and beam time was allocated to the chosen experiments. Data was gathered, analysed and the results were and are being published in first-rate journals. Given the richness of a scientific and cultural heritage in the region, SESAME’s beamlines offer a highly versatile tool for researchers, conservators and cultural-heritage specialists to work together on common projects. The first SESAME Cultural Heritage Day took place online in February 2023 with more than 240 registrants in 39 countries (CERN Courier July/August 2022 pp9).

Thanks to the help of the EU, SESAME has also become the world’s first “green” light source, its energy entirely generated by solar power, which also has the bonus of stabilising the energy bill of the machine. There is, however, concern that the only component used from BESSY, the “Micromon” radio-frequency system, may eventually break down, thus endangering the operation of the whole machine.

SESAME continues to operate on a shoe-string budget. The current approved 2022 budget is about $5.3 million, much smaller than that of any modern light source. I marvel at the ingenuity of the SESAME staff allowing the facility to operate, and am sad to see indifference to the budget among many of the parties involved. The world’s media has been less indifferent: the BBC, The New York Times, Le Monde, The Washington Post, Brussels Libre, The Arab Weekly, as well as regional newspapers and TV stations, have all covered various aspects of SESAME. In 2020 the AAA highlighted the significance of SESAME by awarding five of its founders (Chris Llewellyn Smith, Eleonore Robinovitch, Zehra Nayers, Hervé Schopper and Khalid Toukan) with its 2019 Award for Science Diplomacy.

SESAME was inspired by CERN, yet it was a much more challenging task to construct. CERN was built after the Second World War was over, and it was clear who had won and who had lost. In the Middle East the conflicts are not over, and there are different narratives on who is winning and who is losing, as well as what win or lose means. For
CERN it took less than 10 years to set up the original con-
struct; for SESAME it took about 25 years. Thus, SESAME
now should be thought of as CERN was in around 1960.

On a personal note, it brings immense happiness that for
the first time ever, Israeli scientists have carried out
high-quality research at a facility established on the soil
of an Arab country, Jordan. Many in the region and beyond
have taken their people to a place their governments most
likely never dreamed of or planned to reach. It is impossi-
ble to give due credit to the many people without whom
SESAME would not be the success it is today.

In many ways SESAME is a very special child of CERN,
and often our children can teach us important lessons. As
president of the CERN Council, I can say that the way in
which the member states of SESAME conducted themselves
during the decades of storms that affect our region serves
as a benchmark for how to keep bridges for understand-
ing under the most trying of circumstances. The SESAME
spirit has so far been a lighthouse even in the CERN Council,
in particular in light of the invasion of Ukraine (an asso-
ciate member state of CERN) by the Russian Federation.

Maintaining this attitude in a stormy political environment
is very difficult. However, SESAME’s story ends, we have proved that
the people of the Middle East have within them the capability
to work together for a common cause. Thus, the very pro-
cess of building SESAME has become a beacon of hope to
many in our region. The responsibility of SESAME in the
next years is to match this achievement with high-quality
科研 research, but it requires appropriate funding
and help. SESAME is continuing very successfully with
its mission to train hundreds of engineers and scientists
in the region. Requests for beam time continue to rise, as
do the number of publications in top journals.

If one wants to embark on a scientific project to pro-
more peaceful understanding. SESAME offers at least three
important lessons: it should be one to which every coun-
try can contribute, learn and profit significantly from; its
science should be of the highest quality; and it requires an
unbounded optimism and an infinite amount of enthusi-
asm. My dream is that in the not-so-distant future, people
will be able to point to a significant discovery and say “This
happened at SESAME”.

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CMS PREPARES FOR PHASE II

Novel and established detectors that push technologies to new heights will allow the CMS collaboration to fully exploit the HL-LHC physics potential. Anne Dabrowski, Frank Hartmann and Paolo Rumerio give a snapshot of the Phase II upgrade progress.

T he High-Luminosity LHC (HL-LHC), due to start operations in 2029, will deliver about 10 times
more data than has been accumulated during the
previous LHC runs. The CMS collaboration is getting ready
to profit from sub-percent precision on many Standard
Model (SM) processes and to probe physics beyond
the SM, both directly and through studies of higher-order
effective operators. Studying rare processes, such as
double-Higgs production, rare tau-lepton decays and
Higgs couplings to second-generation fermions, will
also be a central part of the programme. New ideas will
certainly lead to improvements beyond the statistical
scaling of uncertainties, bringing us closer to observing
these rare processes. While high-precision tests of the
SM will surely be the ultimate legacy of the LHC experi-
ments, CMS will also keep searching for clear signs of new
physics by investigating the many signatures accessible
at the HL-LHC.

THE AUTHORS
Anne Dabrowski CERN, Frank Hartmann Karlsruhe Institute of Technology and Paolo Rumerio University of Alberta and University of Turin.
To exploit the HL-LHC physics potential, the CMS collaboration is building an optimised detector that pushes technologies to new heights. This major “Phase II” upgrade will enable the subdetectors to sustain the increased luminosity, which results in greater radiation damage and higher particle rates – the innermost pixel detector. The CMS tracker and the calorimeter layer, for example, will see three billion hits per second per square centimetre. The CMS tracker and the calorimeter upgrade will enable the subdetectors to sustain the high-level-trigger decision, is exploited by highly optimised software mostly running in a year-end technical stop before LS3 (see “GEM of module assembly, showing the gantry joining the hexagonal 8-inch pad sensor with glue circles to the read-out board electronics.”

The key to achieving the necessary HL-LHC performance is to enhance the granularity of the detector significantly. This reduces the maximum occupancy per readout cell while considerably increasing the readout bandwidth and processing power of the trigger system, thereby fully exploiting the higher collision rates. As a novelty, all CMS detector designs are tuned to allow full particle-flow reconstruction at the hardware-based level-1 trigger (operating at 40 MHz), while precision timing informances, which contributes to the high-level-trigger decision, is explored by highly optimised software mostly running on graphics processing units. CMS is currently transitioning from the prototyping to the production phase on several major items. The novel gas electron multiplier (GEM) detector concept, used to detect muons produced in the very forward region, was deployed for the first time on a large scale during long shutdown 2 (LS2). 144 channels in the first endcap were fully integrated into the ongoing data taking and the second station will be fully installed in a year-end technical stop before LS3 (see “GEM of a detector” image). Finishing endcap-muon upgrades in advance of LS3 allows the collaboration to minimise the repointing of the CMS disks during LS3 and to reduce its overall duration. In this spirit, CMS has already finished the replacement of all front-end electronics of the cathode strip chambers. The replacement of the drift-tube electronics in the barrel muon detectors will take place in LS3, and an installed small-scale drift-tube demonstrator is already proving its performance.

The exceptional performance of the current all-silicon tracker provides a solid platform for even further improvements. A main novelty for Phase II is the level-1 trigger, which reconstructs tracks with transverse momentum above 2 GeV, made available at a rate of 40 MHz. Profiting from the experience with pixels from Phase I, the whole Phase II tracker will use dual-phase CD cooling, ultra-lightweight mechanics, DCDC converters for the powering of the outer tracker, and serial powering for the pixel system, thereby reducing the amount of material by a factor of two compared to today. To reduce the occupancies expected at the highest foreseeable number of collisions per bunch crossing (pile-up), the outer-tracker channel count will increase from 9 million strips to 42 million strips plus 170 million macro-pixels, providing unambiguous z-position measurements. With six barrel layers and five double-disks per endcap, the outer tracker is optimised not only for standalone tracking but also for vertexing, a prerequisite for the track trigger (see “Outer-tracker” image). The outer tracker is already in production, having overcome most engineering and prototyping challenges. ASICs (application-specific integrated circuits) and sensors are being delivered and the order for the hybrids (which host integrated circuits and connections in the front-end modules) has been submitted. The inner tracker (pixel system) will feature two billion micro-pixels, compared to the 125 million at present. Four barrel layers plus 12 disks per endcap enable excellent track seeding and b-quark jet identification over the pseudorapidity range $|\eta|<4$, (much broader than today’s $|\eta|<3.5$). The inner tracker system aspects are understood, sensors will be ordered soon, and teams are waiting for the final readout ASIC to begin module production.

The high-granularity calorimeter (HGCAL) in the forward region starts a new era of calorimetry. It is a radiation-tolerant 3D imaging calorimeter with spatial, energy and precision-timing information (see “HGCAL on display” and “High-granularity calorimetry” images). The deployment of machine-learning algorithms will further enhance its potential to establish the HGCAL as a blueprint for future calorimeters. The HGCAL has 4.1 million channels, 22 times more than the current endcap calorimeters, including both silicon cells (with an area of 0.5 or 1 cm²) and scintillator tiles (4 to 32 cm²) read out by silicon photomultipliers (SiPMs). The electromagnetic section consists of 26 active layers of silicon sensors interleaved with copper, copper-tungsten and lead absorbers. It is followed by the hadronic section, which is made of 21 active layers of silicon and scintillator tiles, separated by steel absorbers. All in all, 600 m² are equipped with silicon sensors (three times the area of the tracker) and 400 m² with SiPMs-on-tiles.

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High-energy physics spans a wide range of energies, from a few MeV to TeV, that are all relevant. It is therefore often difficult to take all phenomena into account at the same time. Effective field theories (EFTs) are designed to break down this range of scales into smaller segments so that physicists can work in the relevant range. Theories “cut” their theory’s energy scale at the order of the mass of the lightest particle emitted from the theory, such as the proton mass. Thus, multi-scale problems reduce to separate and single-scale problems (see “Scales” image, p38). EFTs are today also understood to be “bottom-up” theories. Built only out of the general field content and symmetries at the relevant scales, they allow us to test hypotheses efficiently and to select the most promising ones without needing to know the underlying theories in full detail. Thanks to their applicability to all generic classical and quantum field theories, the sheer variety of EFT applications is striking.

In hindsight, particle physicists were working with EFTs as early as the 1930s, in the phenomenological picture of beta decay in which a four-fermion vertex replaces the W-boson propagator because the momentum is much smaller than the W-boson mass (see “Fermi theory” image, p38). Like so many profound concepts in theoretical physics, EFT was first considered in a narrow phenomenological context. One of the earliest instances was in the 1960s, when ad-hoc methods of current algebras were utilized to study weak interactions of hadrons. This required detailed calculations, and a simpler approach was needed to derive useful results. The heuristic idea of describing hadron dynamics with the most general Lagrangian density based on symmetries, the relevant energy scale and the relevant particles, which can be written in terms of operators multiplied by Wilson coefficients, was yet to be known. With this approach, it was possible to encode local symmetries in terms of the current algebra due to their association with conserved currents.

For strong interactions, physicists described the interaction between quarks with chiral perturbation theory, an effective Lagrangian, which simplified current algebraic calculations and enabled the low-energy theory to be investigated systematically. This “mother” of modern EFTs describes the physics of hadrons and remains valid to an energy scale of the proton mass. Heavy-quark effective theory (HQET), introduced by Howard Georgi in 1989, complements chiral perturbation theory by describing the interactions of charm and bottom quarks. HQET allowed us to make predictions on B-meson decay rates, since the corrections could now be classified. The more powers of energy are allowed, the more infinities appear. These infinities are cancelled by available counter-terms. Similarly, it is possible to regard the Standard Model as the truncation of a much more general theory including non-renormalizable interactions, which yield corrections of higher order in energy. This perception of the whole Standard Model as an effective field theory started to be formed in the late 1970s by Weinberg and others (see “All purely-EF” image, p38).
interaction, the Fermi theory was introduced to describe beta decay. In this effective framework, the scale \( \mu = \text{few times the cut-off scale} \sim \frac{\Lambda_{\text{QCD}}}{M_{\text{Higgs}}} \times \frac{1}{H^2} \), few \( \approx \frac{\Lambda_{\text{QCD}}}{\Lambda_{\text{QCD}}} \), is of the order of the proton mass.

Traditionally, such two-scale problems have been treated in the framework of QCD factorisation and resummation. Over the past two decades, it has been possible to recast two-scale problems at high-energy colliders with the advent of soft-collinear effective theory (SCET). SCET is nowadays a popular framework that is used to describe Higgs physics, jets and their substructure, as well as more formal problems, such as power corrections to resonances in invariant mass plots, or small deviations from existing ground-based gravitational-wave detectors, such as KAGRA (top), and future ones, such as the Einstein Telescope (above, artistic impression).

EFTs in gravity
Since the inception of EFT, it was believed that the framework is applicable only to the description of quantum field theories for capturing the physics of elementary particles at high-energy scales, or alternatively at very small length scales. Thus, EFT seemed mostly relevant regarding gravitation, for which we are still lacking a full theory valid at quantum scales. The only way in which EFT seemed to be pertinent for gravitational physics is to think of general relativity as a first approximation to an EFT description of quantum gravity, which indeed provided a new EFT perspective at the time. However, in the past decade it has become widely acknowledged that EFT provides a powerful framework to capture gravitational occurring completely across large length scales, since on these scales display a clear hierarchy.

The most notable application to such classical gravitational systems came when it was realised that the EFT framework would be ideal to handle gravitational radiation emitted at the inspiral phase of a binary of compact objects, such as black holes. At this phase in the evolution of the binary, the compact objects are moving at non-relativistic velocities. Using the small velocity as the expansion parameter, it was found that even couplings manifestly change in classical systems across their characteristic scales, which was previously believed to be unique to quantum field theories. The application of EFT to the binary inspiral problem has been so successful that the precision frontier has been pushed beyond the stair of the art, quickly surpassing the reach of work that has been focused on the two-body problem for decades via traditional methods in general relativity.

This theoretical progress has made an even broader impact since the breakthrough discovery of gravitational waves (GW) was announced in 2016. An inspiraling binary of black holes merged into a single black hole in less than a second, releasing an enormous amount of energy in the form of GWs, which instigated even greater, more intense use of EFTs for the generation of theoretical GW data. In the coming years and decades, a continuous increase in the quantity and quality of real-world GW data is expected from the rapidly growing worldwide network of space-based interferometers, covering a wide range of target frequencies (see “Next generation” image, p38).

EFTs in cosmology
Cosmology is inherently a cross-cutting domain, spanning scales over about 13 orders of magnitude, from the Planck scale to the size of the observable universe. As such, cosmology generally cannot be expected to be tackled directly by each of the fundamental theories that capture particle physics or gravity. The correct description of cosmology relies heavily on the work in many disparate areas of research in theoretical and experimental physics, including particle physics and general relativity among many more.

The development of EFT applications in cosmology – including EFTs of inflation, dark matter, dark energy and even EFTs of large-scale structure – has become essential to make observable predictions in cosmology. The discovery of the accelerated expansion of the universe in 1998 shows our difficulty in understanding gravity both in the quantum regime and the classical one. The cosmological EFTs provide the theoretical framework to probe new physics and to establish precision programmes at experiments across all domains of physics.
FEATURE EFFECTIVE FIELD THEORY

constant problem and dark-matter paradigm might be a hire for alternative theories of gravity at very large scales. Indeed, the problems with gravity in the very-high and very-low energy regimes may well be tied together. The science programme of next-generation large surveys, such as ESA’s Euclid satellite (see “Expanding horizons” image, p39), rely heavily on all these EFT applications for the exploitation of the enormous data that is going to be collected to constrain unknown cosmological parameters, thus helping to pinpoint viable theories.

The future of EFTs in physics

The EFT framework plays a key role at the exciting and rich interface between theory and experiment in particle physics, gravity and cosmology as well as in other domains, such as condensed-matter physics, which were not covered here. The technology for precision measurements in these domains is constantly being upgraded, and in the coming years and decades we are heading towards a growing influx of real-world data of higher quality. Future particle-collider projects, such as the Future Circular Collider at CERN, or China’s Circular Electron Positron Collider, are being planned and developed. Precision cosmology is also thriving, with an upcoming next-generation of very large surveys, such as the Euclid mission. Scientists are building new instruments, and developing the technology for precision measurements in these domains is constantly being upgraded, and in the coming years and decades we are heading towards a growing influx of real-world data of higher quality.

The design of the UA1 experiment was also approved.

Sentinels: A W event recorded by UA1 in late 1982, with a high transverse-momentum electron (pink arrow) and soft photons in opposite directions (colours as expected for an undetected neutrino; balance the electron’s transverse momentum).
Playing in the sandbox of geometry

Number theorist and Fields medallist Maryna Viazovska talks about her research, its applications to physics and the relationship between mathematics and reality.

When did you first know you had a passion for pure mathematics? I have had a passion for mathematics since my first year in school. At that time I did not realise what “pure mathematics” was, but maths was my favourite subject from a very early age.

What is number theory, in terms that a humble particle physicist can understand? In fact, “number theory” is not well defined and any interesting question about numbers, geometric shapes and functions can be seen as a question for a number theorist.

What motivated you to work on sphere-packing? I think it is a beautiful problem, something that can be easily explained. Physicists know what a Euclidean space and a sphere are, and everybody knows the problem from stacking oranges or apples. What is a bit harder to explain is that mathematicians are not trying to model a particular physical situation. Mathematicians are not bound to phenomena in nature to justify their work, they just do it. We do not need to model any physical situation, which is a luxury. The work could have an accidental application, but this is not the primary goal. Physicists, especially theorists, are used to working in multi-dimensional spaces. At the same time, these dimensions have a special interpretation in physics.

What fascinates you most about working on theoretical rather than applied mathematics? My motivation comes out of curiosity and my belief that the solutions to the problems will become useful at some point in the future. But it is not my job to judge or to define the usefulness. My belief is that the fundamental questions must be answered, so that other people can use this knowledge later. It is important to understand the phenomena in mathematics and in science in general, and the possibility of discovering something that other people have not yet. Maybe it is possible to come up with other ideas for detectors, which become interesting. When I look at physics detectors, for example, it fascinates me how complex these machines are and how many tiny technical solutions must be invented to make it all work.

How did you go about cracking the sphere-packing problem? I think there was an element of luck that I could find the correct idea to solve this problem because many people worked on it before. I was fortunate to find the right solution. The initial problem came from geometry, but the final solution came from Fourier analysis, via a method called “boorstrap”, which is similar to the linear programming that I used. The magic functions I used to solve the sphere-packing problem were independently rediscovered by Thomas H. Martin, Damin Mazi, and Leonardo Rastelli.

Are there applications beyond physics? One of the founders of modern computer science, Claude Shannon, realised that sphere-packing problems are not only interesting geometric problems that pure mathematicians like me can play with, but they are also a good model for error-correcting codes, which is why higher-dimensional sphere packing problems became interesting for mathematicians. A very simplified version of the original model could be the following. An error is introduced during the transmission of a message. Assuming the error is under control, the corrupted message is still close to the original message. The remedy is to select different versions of the messages called codewords, which we think are close to the original message but at the same time far away from each other, so that they do not mix with each other. In geometric language, this situation is an exact analogy of sphere-packing, where each code word represents the centre of the sphere and the sphere around the centre represents the cloud of possible errors. The spheres will not intersect if their centres are far away from each other, which allows us to decode the corrupted message.

Do you view mathematics as a tool, or a deeper property of reality? Maybe it is a bit idealistic, but I think a mathematical reality exists on its own and sometimes it does describe actual physical phenomena. I think a mathematical reality exists on its own and sometimes it does describe actual physical phenomena, but it still deserves our attention if not. In our mathematical world, we have chances to realise that something from this abstract mathematical world is connected to other fields, such as physics, biology or computer science. Here it is good to know that the laws of this abstract world would often provide us with useful gadgets, which can be used later to describe the other realities. This whole process is a kind of “spiral of knowledge” and we are in one of its turns.

Interview by Kristiane Bernhard-Noussary, associate editor.
A clear guide for accelerator physicists

Special Topics in Accelerator Physics
By Alexander Wu Chao
World Scientific

Special Topics in Accelerator Physics by Alexander Wu Chao introduces the global picture of accelerator physics, clearly establishing the scope of the book from the first page. The derivation and solution of concepts and equations is didactic throughout the chapters. Chao takes readers by the hand and guides them through important formulae and their limitations step-by-step, such that the reader does not miss the important parts—an extremely useful tactic for advanced masters or doctoral students when their topic of interest is among the eight special topics described.

In the first chapter, I particularly liked the way the author transitions from the Vlasov equation, a very powerful technique for studying beam–beam effects, towards the Fokker–Planck equation describing the statistical interaction of charged particles inside an accelerator. Chao pedagogically introduces the potential–well distortion, which is complemented by illustrations. The discussion on wavefield acceleration, taking readers deeper into the subject, and extending it both for proton and electron beams, is timely. Extending the Fokker–Planck equation to 2D and 3D systems is particularly advanced but at the same time important. The author discusses the practical applications of the transient beam distribution in simple steps and introduces the higher order moments later. The proposed exercises, for some of the applications provided, are practical as well.

In chapter two, the concept of symplecticity, the conservation of phase space (a subject that causes much confusion), is discussed with concrete examples. Nailing issues are meticulously explained, such as using the term short–magnet rather than thin-plate approximation in formula 2.6. Symplectic models for quadrupole magnets are introduced. The following discussion is extremely useful for students and accelerator physicists who will use symplectic codes such as MAD-X and would like to understand the mathematical framework of their operation. This nicely conjoins with the next chapter and the book offers useful insights to how these codes operate. In the discussion about third-order integration, Chao makes occasional mental leaps, which could be mitigated with an additional sentence. Although the discussion on higher order and canonical integrators is rather specialised, it is still very useful. The author introduces the extremely convenient and broadly used truncated power series algebra (TPSA) technique, used to obtain maps, in chapter three. Chao explains in a simple manner the transition from the pre–TPSA algebra (such as TRANSPORT or COSY) to symplectic algorithms such as MAD–X or PCB as well as the reasons behind this evolution.

The clear “drawbacks” discussion is very useful in this regard. The transition to Lie algebra in chapter four is masterful and pedagogical. Lie algebras, which can be advantageous and come with many formulas, are the main focus in this section of the book. In particular, the non-linearity of the drift space, which is absent of fields, should catch the reader’s attention. This is followed by specialised applications for expert readers only. One of this chapter’s highlights is the derivation of the sextupole pairing, which is complemented by that of Taylor maps up to the second order. This and the Lie algebra, although it would be better if the “Our plan” section was placed at the beginning of the chapter.

Chapter five covers proton–spin dynamics. Spiner formulas and the Finnis–Saue equation for the polarization change are developed and explained. The Siberian snake technique remains one of the most well-known to retain beam polarization, which the author discusses in detail. This links elegantly to chapter six, which introduces the reader to emittance–spin dynamics where synchronization radiation is the dominant effect and therefore constitutes a completely different research area. Chao focuses on the differences between the quantum and classical approach to synchrotron radiation, a phenomenon that cannot be ignored in high–brightness machines. Analogies between protons and electrons are then very well summarised in the recap figure 6.6. Section 6.5 is important for storage rings and leads smoothly to the Derbenev–Kundratenko formula and its applications.

Echoes

Chapters seven looks at echoes, a very technical technique when measuring diffusion in an accelerator, where the author introduces the reader to the generality of the topic and the concept of echoes in accelerator physics. Transverse echoes (with and without diffusion) are quite analytical and the figures are didactic.

The book concludes with a very complete, concise and detailed chapter about beam–beam effects, which acts as an introduction to collider–accelerator physics for coherent– and incoherent–effects studies. Although synchro–betatron couplings causing resonant instabilities are advanced topics, they are often seen in practice when operating the machines, and the book offers the theoretical background for a deeper understanding of these effects.

Special Topics in Accelerator Physics is extremely well written and develops the advanced subjects in a comprehensive, complete and pedagogical way.

Nikolaos Charitoulidis CERN.
Moving from big science into big tech

CERN alumni working in Google, Microsoft and other big-tech firms offer practical advice on how to get started, what errors to avoid, and how to promote your assets when seeking to move out of academia.

The latest edition of the CERN Alumni Network’s “Moving out of academia” series, held on 21 October, focused on how to successfully manage a transition from academia to the big-tech industry. Six panelists who have started working in companies such as Google, Microsoft, Apple and Meta shared their advice and experience on how to successfully start a career in a large multinational company after having worked at large scale-research infrastructures such as CERN.

In addition to describing the nature of their work and the skills acquired at CERN that have helped them make the transition, the panelists explained which new skills they had to develop after CERN for a successful career move. The around 180 participants who attended the online event received tips for interviews and CV-writing and heard personal stories about how a PhD prepares you for a career outside academia.

The panelists agreed that metrics used in academia to qualify a person’s success, such as a PhD, the h-index, or the number of published papers, do not necessarily apply to roles outside of academia, except for research positions. “You don’t need to have a PhD or a certificate to demonstrate that you are a good problem solver or a good programmer – you should do a PhD because you are interested in the field,” said Cristina Bahamonde, who used to work in accelerator operations at CERN and now oversees and unblocks all Google’s network deployments as regional leader for its global network delivery team in Europe, the Middle East and Africa. She considers her project-management and communication skills, which she acquired during her time at CERN while designing solution and mitigation strategies for operational changes in the LHC, essential for her current role.

General skills needed for big-tech companies include the ability to learn and adapt fast, project and product-management skills, as well as communicating effectively to technical and non-technical audiences. Some participants were unaware that skills that they sharpened intuitively throughout their academic career are vital for a career outside. “CERN taught me how to be a generalist,” says James Casey, now a group programme manager at Microsoft. “I was not working as a product manager at CERN, but you do very similar work at CERN because you write documents, build customer relationships and need to communicate your work in an understandable way as well as to communicate the work that needs to be done.” At CERN in 1994, Casey worked as a summer student alongside the original team that developed the web. After having worked in start-ups, he returned to CERN for a while and then moved back to industry in 2011.

Finding the narrative

Finding your own narrative and presenting it in the right way on a resume is not always easy. “When I write my resume, it looks really straight forward,” said Mariana Rihl, former LHC experimentalist and now Meta’s product-system validation lead for verifying and validating Oculus VR products. “But only after a certain time, I realised that a common theme emerged — testing hardware and understanding users’ needs.” Working on the LHC/beam-gas vertex detector and especially ensuring the functionality of detector hardware prepared her well, she said.

Former CERN openlab intern Ritika Kanade, who now works as a software engineer at Apple, shared her experience of interviewing people applying for software-engineering roles. “What I like to see during an interview is how the applicant approaches the tasks and how he or she interacts with me. It’s ok if someone needs help. That’s normal in our job,” she adds. “Time management is one thing I see many candidates struggle with.” Other skills needed in industry as well as in academia are tenacity and persistence. Often, candidates need to apply more than three times to land a job at their favourite company. “I applied six or seven times before I was invited for an interview at Google,” emphasised Bahamonde.

The Moving out of academia series provides a rich source of advice for those seeking to make a career change, with the latest event following others dedicated to careers in finance, industrial engineering, big data, entrepreneurship, the environment and medical technologies. “This CERN Alumni event demonstrated once more the impact of high-energy physics on society and that people transitioning from academia to industry bring fresh insights from another field,” said Rachel Bray, head of CERN Alumni relations.

Kristiane Bernhard-Novotny, associate editor.
Appointments and awards

From Fermilab to the DOE
Regina Ramolinka (above) joined the US Department of Energy (DOE) Office of Science as associate director for the office of high-energy physics on 7 November, having spent much of her career in neutrino science and experimental particle physics at Fermilab. Meanwhile, Fermilab’s Marcela Carena has been announced as one of two new DOE Office of Science distinguished scientist fellows (funded by $1 million over three years) for her leadership and influential contributions to particle physics and promoting Latin American participation in DOE-hosted experiments.

Luisella Lari joins EIC
On 3 October, Brookhaven National Laboratory named Luisella Lari as project manager for the future Electron–Ion Collider (EIC). Lari worked for nearly 12 years as a planning officer and applied physicist at Fermilab’s Marcela Carena (below left) and Bradley Lee Roberts (Boston University, below right) were awarded the WH Pangborn Prize “for their leadership and technical ingenuity in achieving a measurement of the muon anomalous magnetic moment with precision suitable to probe Standard Model mediated loop diagrams and possible manifestations of new physics”. For theoretical achievements in high-energy physics, the J Sakurai Prize was awarded to Heinrich Lensleyer (University of Bern, below left) for his work on the effective field theory of pions at low energies, and for proposing that the gluon is a colour octet”. While the former was influential in chiral perturbation theory, the latter helped to establish QCD in the description of the strong interaction. Recognising outstanding experimental research in nuclear physics, the Tom W Bonner Prize went to Jen-Chih Peng (University of Illinois Urbana-Champaign) “for his pioneering work on studying antiquark distributions in the nucleons and nuclei using the Drell–Yan process as an experimental tool, and for his work on elucidating the origins of the flavour asymmetries of light–quark sea in the nucleons”. In nuclear theory, Michael Ramsey–Musolf (below right, University of Massachusetts and Tsung-Dao Lee Institute) received the Herman Feshbach Prize for his contributions in precision electroweak studies of nuclear and hadronic systems. For outstanding contributions in gravitational–wave physics, Emanuele Berti (Johns Hopkins) was granted the Richard A Isaacson Award for his studies of black-hole quasinormal modes, higher multipole radiation, astrophysical detection rates, spin evolution, and tests of general relativity, while Gary T Horowitz (UC Santa Barbara) won the biennial Einstein Prize for fundamental contributions to classical gravity and gravitational aspects of string theory. Last but not least, the Henry Primakoff Award for Early–Career Particle Physics was given to Bernhard Mistlberger (SLAC) for his contributions to high-precision quantum field theory, including the next-to-next-to-leading order QCD corrections to the production of Higgs and electroweak vector bosons at hadron colliders.

2022 APS awards
Among the recipients of the 2022 APS awards were: Philip Allport (University of Birmingham), a long-term leader of ATLAS upgrade projects, who was awarded the James Chadwick Prize for seminal contributions to radiation-hard semiconductor detector development and to the transfer of particle–physics detector technologies for use in medical applications; theoretical cosmologist Katy Clough (University of Oxford, above), who won the James Clerk Maxwell Medal for her contributions to the field of inflationary cosmology and dark–matter physics; and Kieran Flanagan (University of Manchester), co-founder of CBM at CERN’s IOLIDE facility, who was honoured with the Ernest Rutherford Medal and Prize for his contributions to understanding properties of exotic radioactive nuclei by measuring their hyperfine structures using laser spectroscopy and trace-metal analysis.

Calaga wins for crabbing
Rama Calaga, a radio–frequency physicist in CERN’s accelerator systems department and a work–package leader of the High–Luminosity LHC project, has been awarded the 2022 US Particle Accelerator School early–career award for his outstanding leadership in bringing crab cavities in hadron colliders from concept to reality, and for the first demonstration of crabbing on a hadron beam.

Gold medal for Girone
CERN openlab CTO Maria Girone has been awarded the Gold Medal of Calabria for her contribution to particle–physics research and scientific computing. She has worked in scientific computing at CERN since 2002, contributing to projects such as the worldwide LHC computing grid, and was the software and computing coordinator for CMS in 2014 and 2015 before joining CERN openlab.

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Marie-Noëlle Minard 1947–2022

From the first Z to its lineshape

Marie-Noëlle Minard passed away on 15 May 2022. She began her career as a physicist in 1969, with a postgraduate thesis at the Institute of Nuclear Physics (IPN) in Orsay under the direction of Louis Masseyon, on the subject of high-energy neutron detectors. She joined the CNRS as a research associate, while still at the IPN, in 1972 and began her PhD studies exploring ways to detect exotic particles under the supervision of Michel Veyr. Minard defended her thesis in 1976 and joined the newly created Cerny particle-physics laboratory (LAPP). She then spent two years at SLAC, where she worked on the rapid-cycling bubble chamber. Back at LAPP in 1979, she joined the group of physicists involved in the UA1 collaboration at the CERN 820 GeV proton–antiproton collider. The group participated in the construction of the electromagnetic calorimeter, analysis tools, data taking and physics analyses. With her colleagues at LAPP and CERN, Marie-Noëlle created an analysis to search for Z bosons, exploiting the UA1 data extracted online by the sterile emulators – the so-called “express line.” It was by analyzing these data that Marie-Noëlle spotted the first Z boson on the night of 4 May 1983 – a source of immense pleasure in her career. In 1987, Marie-Noëlle returned to LAPP. She created, with Daniel Decamp, the ALEPH group at LAPP. This idea came up against obstacles: there was already an L3 group, and the rule at the time was that each IN2P3 laboratory could only participate in one experiment at LEP with one exception. This occasion demonstrated the measure of Marie-Noëlle’s determination: when she was convinced of the merits of a project, her enthusiasm and energy were such that she was able to convince even the most reluctant. She finally obtained the green light for an ALEPH team at LAPP, which, under her direction, made many contributions to the experiment. She herself was run coordinator, responsible for calibration, and a pillar of the di-fermion analysis group (measuring the Z lineshape).

In the early 2000s Jacques Lefrançois invited Marie-Noëlle to join the LHCb collaboration. The team at LAPP, under her direction, made a major contribution to the experiment, particularly in the construction and operation of calorimetric systems as well as in numerous physics analyses. Project manager of the calorimeter group during its start-up between 2008 and 2011, then assistant project manager of the calorimeter group during 2011-2013, Marie-Noëlle participated in the commissioning and definition of procedures for calibration and control of the electromagnetic calorimeter throughout the first period of data taking (2011–2015). Between 2000 and 2006 Marie-Noëlle was deputy director of LAPP, during which she strongly contributed to the definition and implementation of its scientific strategy. Very careful to communicate our science to the public, her creativity enabled her to organize several original and appreciated events. Marie-Noëlle supervised nine theses for services rendered to research, she received one of the highest awards in France (chevalier de la Légion d’honneur).

She was certainly demanding, much more of herself than of others, but always convinced that in a group everyone makes a positive contribution. A physicist and communicator of immense talent, she was above all a woman of limitless generosity, with a sometimes caustic sense of humour. She was brave and couldn’t stand injustice, often expressing aloud what others were quietly thinking. Marie-Noëlle loved swimming, sailing, cooking, reading and welcoming her many friends and family to her table. Those who, like us, have had the chance to work with her will miss her boundless commitment, the relevance of her advice and her humanity. We are thinking of Claude, her husband of 50 years, and of her large family.

Her friends and colleagues.

Donald Hill Perkins 1925–2022

A force of particle physics

UK experimental particle physicist Don Perkins, who played a significant role in shaping the field from the 1940s onwards, passed away on 30 October at the age of 97.

After graduating from Imperial College, London, Perkins obtained a PhD under the supervision of George Paget Thomson, recipient of the 1937 Nobel Prize in Physics. As part of this thesis work, he took a photographic emulsion—a new medium for particle detection at the time—onto a Royal Air Force transport plane to record cosmic rays at altitude. This resulted in what was later recognized as the first observation of the pion, published in Nature in 1947.

In 1951 Perkins joined another Nobel laureate, Cecil Powell, in Bristol where, working with Peter Fowler, he discovered some of the decay properties of pions. This involved towing some of the world’s mountain tops with photographic emulsions, as well as sending them into the stratosphere on balloons. As a result of their studies, Perkins and Fowler were the first to suggest that radiation with negatively charged pions might be used to treat cancer. In 1965 Perkins moved to the University of Durham, where, under the overall leadership of Denis Wilkinson, he established a world-leading particle-physics group. One year later he was elected a Fellow of the Royal Society. In 1991 he received the Royal Medal of the Royal Society, among many honours that would crown his long career.

As modern electronic counters and bubble chambers began to replace emulsion techniques, Perkins worked at CERN, where in 1973 he contributed to the seminal discovery of neutral currents with the Galton-Watson bubble chamber. Thirty years later, in characteristic style and wit, Don Perkins made some pioneering measurements of cosmic rays.
Sylvie Rosier-Lees 1961–2022

A supersymmetry and dark-matter fan

Sylvie Rosier-Lees left us on 14 March 2022 following a long illness, which she endured with immense courage. Following her studies at the École normale supérieure de Fontenay-Saint-CLOUD, Sylvie began her research career in 1985 with a thesis on the L3 experiment at LEP. There were several of us – notably the Laboratoire d’Année de Physique des Particules (LAPP) at the time – with the idea of strengthening the existing 10-year team, and Sylvie was my first in this team. Her indomitable spirit, tenacity and ability to face experimental problems – in particular concerning the calibration of the fermion signal – she made stand out within the collaboration. Before becoming a highly regarded specialist in supersymmetry, she studied the identification of 8 mesons produced in 2 decays, which made it possible to contribute to the first measurements of the IP–IP mixing parameter as well as the forward-backward asymmetry. Supersymmetry and the search for the neutralino set Sylvie on the quest for dark matter, to which she subsequently dedicated her entire career. In 2000, she joined the Alpha Magnetic Spectrometer (AMS) collaboration – a particle-physicist detector installed on the International Space Station to identify and measure fluxes of cosmic rays. She took responsibility for the research project of the electromechanical calorimeter, introducing independent random triggering based solely on calorimetry. Resistance to radiation, extended temperature range, low power consumption and operation in vacuum were all technical challenges she successfully overcame.

Sylvie Rosier-Lees in front of the launch pad at Cape Canaveral

Sylvie Rosier-Lees was one of the first physicists to consider the importance of dark matter in flat cosmology. Along with G. Gentner, S. Soergel remained at Freiburg until 1961, working with Wolfgang Gentner, who became the director of the institute.

Born in Moscow in 1955, Valery studied physics and chemistry at the University of London, graduating with a PhD in 1980. He then joined the Institute for Nuclear Research (INR) of the Russian Academy of Sciences in 1985, defending his PhD thesis on the perturbative aspects of gauge theories in 1989. At the age of 26, Rubakov had already made his name in high-energy physics. He discovered that the Higgs–Polypoly super-heavy magnetic monopoles exist in very high-energy collisions above tens of TeV. He was the recipient of numerous prizes, awards and distinctions and wrote several excellent textbooks, including Classical Theory of Gauge Fields (Princeton 1980).

Courage, persuasiveness and leadership

Experimentalist Volker Soergel passed away on 5 October at the age of 91. Born in Breslau in March 1931, Soergel was a brilliant experimental physicist and an outstanding leader, shaping particle physics for several decades.

Valerie Rubakov was an exceptional person. His very different approaches to in flat cosmology and to quantum gravity, analysing deep conceptual issues such as quantum coherence. In 1999–2001, together with Sergei Khlebnikov and Peter Tinyakov, he attacked the challenging problem of how to compute the probability of anomalous processes with baryon number conservation. In a series of remarkable articles from 1987–1989, Valery explored the effect of topology change on the early universe, demonstrating that these reactions are exponentially suppressed, thus removing hopes of experimental verification of this phenomenon.

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Volker Soergel 1931–2022

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Notes and observations from the high-energy physics community

Hyper or hype?

Wormholes hit the headlines in December following a quantum simulation that exhibits properties of the space–time sci-fi mainstays (Nature 612 1). Call it particle physics at its finest. Particle physicists Maria Perniola and co-workers used Google’s nine-qubit Syракоморе processor to encode two entangled systems and then sent information between them. While the feat is not new, claims it implies quantum gravity to be studied in the lab generated much discussion online. “This experiment could have been performed without anyone involved even knowing Einstein’s equations.” (Martin B{"a}uer, IPPP Durham). “It’s not the real thing; it’s not even close to the real thing; it’s barely even a simulation of something—not close-to-the-real-thing!” (Matt Strassler, Harvard). CERN theorist Alexander Zhlebovsky set the correct straight. “The physics that inspired this work is amazing and the physics behind the work itself is solid, but it’s all about the interpretation — in particular the use of the term ‘wormhole’, which has pushed things out of all proportion.”

A PhD in pictures

IceCube collaborator Kunal Deoskar, who defended his PhD at Stockholm University in December, has created a digested version of his thesis “dedicated to all my friends… who were too lazy to read my actual PhD thesis.” With a cover (left) melding traditional Warli paintings with neutrino apocrypha, the online comic, containing chapters such as “Machine learning stuff”, takes readers through his search for neutrinos from gamma-ray bursts. Clear and colourful diagrams, label- and unit-free plots and, naturally, the use of Comic Sans throughout, make for an engaging, informative read and an inspiration to future students (thesecretsketchbook.wordpress.com).

Media corner

“I know from my 40 years of experience in working on real-life physical phenomena that the whole idea of an ultimate law based on an equation using just the building blocks and fundamental forces is unworkable and essentially a fantasy.” Condensed-matter theorist Sankar Das Sarma writing in New Scientist (9 December) about the “non-existence” of the laws of physics.

“Wriggling is one thing, human beings are another. And this is something we are very happy to be part of.”

From the archive: January/February 1983

To be or not...

In October (1982) some 90 physicists met in Wingspread, Wisconsin to examine new evidence and theories concerning magnetic monopoles. Speculation grows that monopoles may have been as abundant as protons in the first blaze of creation, while arguments about the rate of expansion of the universe limit them to about one per 10^10 protons. Challenges? Blas Cabrera’s tantalizing monopole candidate, the conjecture that monopoles catalyse proton decay, a struggle to predict energy loss for slow monopoles, and an explosion in the number of monopole searches. The Wingspread meeting concluded that, if monopoles exist, they will be harder to see than earlier results suggested.

The most common light, penetrating particle is the neutrino, obtained from the weak decay of pions and kaons. However, theory doesn’t exclude the existence of very light, highly penetrating particles – “axions” – in beam dump experiments, pions and kaons are removed by a thick metal block, to reduce the supply of neutrinos, giving particles such as axions a better chance to show up. At the SLAC Linac electron beam, particles surviving the beam dump pass through a 200 metre-thick hill to reach a shower counter that catches photons from rare particle decays. An initial run early last year revealed no surprises.

At the Swiss SIN machine, an Aachen team reported an excess of forward photon pairs emerging from the beam dump. After further extensive examinations and consistency tests, the unexplained effect remains. Without a definite answer to the axion question, experimenters (and theorists) will continue to look for new particles.

Based on text on pp 11–13 of CERN Courier January/February 1983.

Compiler’s note

… and indeed the hunt goes on. The LHC experiment MoEDAL is designed to detect existing, long-lived magnetic monopoles, while condensed-matter physicists are searching for quark–monopole equivalents resulting from interactions of known particles. Meanwhile, axions have become the favourite dark–matter candidate. Astrophysical limits put them within the scope of LHC experiment, albeit a notoriously difficult one. A worldwide collaboration at the Asia Dark-Matter Experiment at the University of Washington hopes that ADMX will soon see fruition.
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