Welcome to the digital edition of the November/December 2020 issue of CERN Courier.

Superconducting radio-frequency (SRF) cavities drive accelerators around the world, transferring energy efficiently from high-power radio waves to beams of charged particles. Behind the march to higher SRF-cavity performance is the TESLA Technology Collaboration (p35), which was established in 1990 to advance technology for a linear electron–positron collider. Though the linear collider envisaged by TESLA is yet to be built (p9), its cavity technology is already established at the European X-Ray Free-Electron Laser at DESY (a cavity string for which graces the cover of this edition) and is being applied at similar broad-user-base facilities in the US and China.

Accelerator technology developed for fundamental physics also continues to impact the medical arena. Normal-conducting RF technology developed for the proposed Compact Linear Collider at CERN is now being applied to a first-of-a-kind “FLASH-therapy” facility that uses electrons to destroy deep-seated tumours (p7), while proton beams are being used for novel non-invasive treatments of cardiac arrhythmias (p49). Meanwhile, GANIL’s innovative new SPIRAL2 linac will advance a wide range of applications in nuclear physics (p39).

Detector technology also continues to offer unpredictable benefits— a powerful example being the potential for detectors developed to search for sterile neutrinos to replace increasingly outmoded traditional approaches to nuclear nonproliferation (p30).

Elsewhere in the issue: hints of low-frequency gravitational waves (p12), feebly interacting particles to the fore (p21), PCs and the future of computing (p43), the latest from the LHC experiments (p17), and more—not least the Courier’s inaugural end-of-year cryptic crossword (p58).

To sign up to the new-issue alert, please visit: http://comms.iop.org/k/iop/cerncourier

To subscribe to the magazine, please visit: https://cerncourier.com/p/about-cern-courier
It’s Time for a New Generation of Power Solutions!

FOR RESISTIVE AND SUPERCONDUCTING MAGNETS

CT-BOX
All-In-One Current Measurement and Calibration System
Up to ±10,000 A, 1 ppm/K TC, 100 kps Data-Logger and Oscilloscope
CT Viewer software included with Ethernet, Serial and USB

EASY-DRIVER
±5 A and ±10 A / ±20 V Bipolar Power Supply Series
Full-Bipolar operation, Digital Control Loop, Ethernet Connectivity
Device supported by Visual Ezy-Drriver software

FAST-PS-M
Digital Monopolar Power Supplies - up to 100 A
High-Precision Monopolar Power Converters with Gigabit Ethernet
Embedded Linux OS, device supported by Visual PS software

FAST-PS
Digital Bipolar Power Supplies - up to ±30 A and ±80 V
Full-Bipolar, Digital Control Loop, High-Bandwidth, 10/100/1000 Ethernet
Embedded Linux OS, device supported by Visual PS software

FAST-PS-1K5
Digital Bipolar Power Supplies - up to ±100 A and ±100 V
1.500 W, Paralleling via SFP/SFP+, 10/100/1000 Ethernet
Embedded Linux OS, device supported by Visual PS software

NGPS
High-Stability 10-kW Power Supply - 200 A / 50 V
Digital Control Loop, Paralleling via SFP/SFP+, 10/100/1000 Ethernet
Embedded Linux OS, device supported by Visual PS software

EASY-DRIVER
±5 A and ±10 A / ±20 V Bipolar Power Supply Series
Full-Bipolar operation, Digital Control Loop, Ethernet Connectivity
Device supported by Visual Ezy-Drriver software

www.caenels.com
FROM THE EDITOR

Accelerator applications shine

Tens of thousands of particle accelerators are in operation worldwide – almost all of them in industry and clinical settings, with only a few percent used in research. In recent decades, particle physicists have perfected the art of superconducting radio-frequency (RF) acceleration (the cover theme of this issue), whereby metallic cavities provide a pristine, resonant space in which to transfer energy from high-power radio waves to a beam of charged particles. While both superconducting and normal-conducting cavities still vie for inclusion in the biggest projects, as evidenced by the designs of the proposed electron–positron Higgs factories ILC and CLIC, SRF cavities store energy with very low losses and offer a high conversion efficiency from "plug- to beam-" power.

SRF accelerator technology took hold in the mid-1980s with bulk-niobium cavities at Cornell’s CESR facility. Lab’s CERF followed suit, while CERN turned to niobium–coated copper cavities to extend the energy reach of LEP from the Z to the WW threshold. These days, niobium–copper cavities ramp the LHC’s protons to 6.5 TeV and keep them tightly bunched, while SRF "crab-cavities" built entirely from ultra-pure niobium are undergoing tests for the high-luminosity LHC, where they will tilt proton bunches to ensure maximum collision intensity. SRF underpins the ALPI and SPIRAL2 (1993) linacs at INFN and GANIL, and drives advanced X-ray and neutron sources.

Though to the untrained eye the RF cavity might look like a simple metal shell, subtle material effects, fabrication techniques, surface smoothness and, above all, surface cleanliness have a dramatic effect on its performance. In recent years, bulk-niobium SRF technology has seen big increases in attainable accelerating gradients and quality factors due to technology also continues to impact the medical arena. Normal-conducting X-band RF technology developed for CLIC is now being applied to a first-of-a-kind "FLASH-therapy" facility that uses electrons to destroy tumours (p17), while proton beams are being used for novel non-invasive treatments of cardiovascular disease (p18). Further powerful examples of the unexpected benefits of fundamental research is the role of the art of neutrino detectors in nuclear safeguards (p14).

Elsewhere in the issue: hints of low-frequency gravitational waves (p12), forcibly interacting particles in the fire (p13), PCs and the future of computing (p24), the latest from the LHC experiments (p17), and more – not least the Courier’s inaugural end-of-year cryptic crossword (p58).

Unforeseen benefits

Behind this march to higher SRF performance is the TESLA Technology Collaboration (p35), which was established in 1990 to advance technology for a linear electron–positron collider. Its remit later expanded to cover the full diversity of applications, enabling the sharing of ideas, planning and testing across associated projects, and all the major particle–physics laboratories are members. Though the linear collider envisaged by TESLA is yet to be built, it’s in a lively arena. It will be deployed in neutron sources such as the ESS and in Fermilab’s PIP-II line, serving short- and long-baseline neutrino experiments.

Advanced accelerator technology continues to impact the medical arena.

**Reporting on international high-energy physics**

**Editors**
Matthew Chalmers, Associate editor: Mark Rayner, Associate editor: Jo Allen, Content and production manager: Rik Leopold, Business development manager: Ed Jost, Marketing and production manager: Chris Thomas, Technical illustrator: Laura Gillham, E-mail sales: marketing@cern.ch, Recruitment sales: recruitment@cern.ch, Advertising sales: advertising@cern.ch, IOP Publishing sales: sales@iop.org, Printed by Warners (Midlands) plc, Bourne, Lincolnshire, UK.

**Production**
CERN, 1211 Geneva 23, Switzerland; Tel +44 (0)117 929 7481, Advertising sales: (for UK/Europe display advertising); +44 (0)117 930 1164 (for UK/Europe subscription advertising).

**Advertising**
Tel +44 (0)117 930 1170, Fax +44 (0)117 929 7484; e-mail: sales@iop.org, head of sales: Steve Atkins, head of marketing: Andrew Smailes, head of advertising: Spencer Klein.

**CERN Courier** is distributed to governments, institutions and laboratories affiliated with CERN and to individual subscribers. It is published six times a year and aims to keep the international scientific community informed about CERN’s management.

Your **TRUSTED** Control System Partner

Your **TRUSTED** Control System Partner

COSYLAB PUTS IT TOGETHER FOR YOU

IF ONLY THE CONTROL SYSTEM WORKED LIKE THIS

WELL, IT MIGHT, IF COSYLAB PUTS IT TOGETHER FOR YOU

CERN COURIER NOVEMBER/DECEMBER 2020

Volume 60 Number 6 November/December 2020

CERN COURIER
NEWS ANALYSIS

Applications

CLIC lights the way for FLASH therapy

Technology developed for the proposed Compact Linear Collider (CLIC) at CERN is poised to make a novel cancer radio-therapy facility a reality. Building on recently revived research from the 1990s, oncologists believe that ultrafast bursts of electrons damage tumours more than healthy tissue. This “FLASH effect” could be realised by using high-gradient accelerator technology from CLIC to create a new facility at Switzerland’s Lausanne University Hospital (CHUV).

Traditional radiotherapy scans photon beams from multiple angles to focus a radiation dose on tumours inside the body. More recently, hadron therapy has offered a further treatment modality: by tuning the energy of a beam of protons or ions so that they stop in the tumour, the particles deposit most of the radiation dose there (the so-called Bragg peak), while sparing the surrounding healthy tissue by comparison. Both of these treatments deliver small doses of radiation to a patient over an extended period, whereas FLASH radiotherapy is thought to require a maximum of three doses, all lasting less than 100ms.

Look again

When the FLASH effect was first studied in the 1970s, it was assumed that all tissues suffer less damage when a dose is ultrafast, regardless of whether they are healthy or tumorous. In 2012, however, CHUV researchers published a study in which 300 mice were given a single dose of 4.5 MeV gamma rays at a conventional therapy dose-rate, while others were given an equivalent dose at the much faster FLASH-therapy rate. The results showed explicitly that while the normal tissue was damaged significantly less by the ultrafast bursts, the damage to the tumour stayed consistent for both therapies. In 2019, CHUV applied the first FLASH treatment to a cancer patient, finding similarly positive results: a 3.5cm diameter skin tumour completely disappeared using electrons from a 5.6MeV Linear accelerator, “with nearly no side effects.” The challenge was to reach deeper tumours.

Now, using high-gradient “X-band” radio-frequency cavity technology developed for CLIC, CHUV has teamed up with CERN to develop a facility that can produce electron beams with energies around 10 MeV, in order to reach tumour depths of up to 20cm. The idea came about three years ago when it was realised that CLIC technology was almost a perfect match for what CHUV were looking for: a high-powered accelerator, which uses X-band technology to accelerate particles over a short distance, has a high luminosity, and utilises a high current that allows a higher volume of tumour to be targeted.

“CLIC has the ability to accelerate a large amount of charge to get enough luminosity for physics studies,” explains Walter Wuensch of CERN, who heads the FLASH project at CERN. “People tend to focus on the accelerating gradient, but it is important, or arguably more important, is the ability to control high-current, low-emittance beams.”

The first phase of the collaboration is nearing completion, with a conceptual design report, funded by CHUV, being created in collaboration with CERN and CHUV. The development and construction of the first facility, which would be housed at CHUV, is predicted to cost around €25 million, and CHUV aims to complete the facility within three years.

“The intention of CERN and the team is to be heavily involved in the process of getting the facility built and operating,” states Wuensch. “It really looks like it has the potential to be an important complement to existing radiation therapies.”

Cancer therapies have taken advantage of particle accelerators for many decades, with proton radiotherapy entering the scene in the 1990s. The CERN-based Proton-Ion Medical Machine Study, spawned by the TERA Foundation, resulted in the National Centre for Cancer Hadron Therapy (CNAO) in Italy and MedAustron in Austria, which have made significant progress in the field of proton and ion therapy. FLASH radiotherapy would add electrons to the growing modality of particle therapy.
CERN has a formal objective that, by 2024, direct greenhouse emissions will be reduced by 28%.

Electron manufacture studied for the SPS

CERN’s Super Proton Synchrotron (SPS) could be upgraded so that not only its direct, high-emission particle accelerators could be accelerated, but also electrons. A 2013 paper published in the journal Nature Physics showed that with SPS “wips” posted on Alice in 2015 describes the installation of a high-precision electron accelerator. This could provide the potential for use for accelerator R&D, dark-sector physics, and for electron-nuclear measurements for future neutrino experiments. First proposed in 2018 by Troitsen Akesson of Lund University, the project is conceived as a possible first stage, noting that the technical design report.

NEWS ANALYSIS

CERN publishes first environmental report

CERN’s Super Proton Synchrotron (SPS) could be upgraded so that not only its direct, high-emission particle accelerators could be accelerated, but also electrons. A 2013 paper published in the journal Nature Physics showed that with SPS “wips” posted on Alice in 2015 describes the installation of a high-precision electron accelerator. This could provide the potential for use for accelerator R&D, dark-sector physics, and for electron-nuclear measurements for future neutrino experiments. First proposed in 2018 by Troitsen Akesson of Lund University, the project is conceived as a possible first stage, noting that the technical design report.
**How do you adapt the real world for electromagnetic simulations?**

When the ultimate goal is to design more efficient and productive electronic devices, design engineers need to run antenna measurements. If you know what attributes of the real world are important, you could instead test the designs with simulation.

The COMSOL Multiphysics® software is used for simulating designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. See how you can apply it to electromagnetics simulation.

<comsol.blog/EM-simulations>

---

**Black holes attract 2020 Nobel Prize**

The 2020 Nobel Prize in Physics, announced on 6 October, has recognised seminal achievements in the theoretical and experimental understanding of black holes. One half of the SEK 10 million ($1.15 million) award went to Roger Penrose of the University of Oxford “for the discovery that black-hole formation is a robust prediction of the general theory of relativity.” The other half was awarded jointly to Andrea Ghez at the University of California, Los Angeles and Reinhard Genzel of the Max Planck Institute for Extraterrestrial Physics “for the discovery of a supermassive compact object at the centre of our galaxy,” after the pair led separate research teams during the 1990s to identify a black hole at the center of the Milky Way. As soon as Einstein had completed his theory of general relativity in 1915, it was clear that solutions in the vicinity of a spherically symmetric, non-rotating mass allow space-time to be “pinched” to a point, or singularity, where known physics ceases to apply. Few people, including Einstein himself, however, thought that black holes really exist.
**NEWS ANALYSIS**

**Astrowatch**

**Pulsars hint at low-frequency gravitational waves**

The direct detection of a gravitational wave (GW) in 2015 by the LIGO and Virgo collaborations confirmed the existence of these long-sought-after events. However, the kHz-regime GW-events detected so far constitute only a small fraction of the vast GW spectrum. As a result, they only probe phenomena such as stellar mass black-hole and neutron-star mergers. On the opposite side of the spectrum to LIGO and Virgo are pulsar timing array (PTA) experiments, which search for kHz-frequency GWs. Such low-frequency signals can originate from supermassive black-hole binaries (SMBHBs), while in more exotic models they can be proof of cosmic strings, phase transitions or a primordial GW background. The NANOGrav (North American Neutron-Observe-ry for Gravitational Waves) collaboration has now found possible first hints of low-frequency GWs.

**Track and trace**

To detect such rumbles of space-time, which also have tiny amplitudes, researchers need to track subtle movements of measurement points spread out over the galaxy. For this purpose, the NANOGrav collaboration uses light from millisecond pulsars, several tens of which have been detected in our galaxy. Pulsars are quickly rotating neutron stars that emit cones of electromagnetic emission from their poles. When a pole points towards Earth it is detected via a short pulse of electromagnetic radiation. Not only is the frequency of millisecond pulsars high, making it easier to detect small variations in arrival time, but it is very stable over periods of many years. Combined with their great distances from Earth, this makes millisecond-pulsar emissions sensitive to any small alterations in their travel path — for example, those introduced by distortions of space-time by low-frequency gravitational waves. Such waves would cause the movement of Earth with respect to the pulsar to change the arrival time of the pulses. The complexity of the measurements lies mostly in correcting for all these effects. The latest results from NANOGrav, for example, reduce systematics by incorporating unprecedented precision of the order of tens of km in the orbital parameters of Jupiter.

**Researchers track measurement points spread out over the galaxy**

Whereas previous results by NANOGrav and other PTA collaborations only allowed upper limits to be set on the amplitude of the GW background travelling through our galaxy, the new results show a clear sign of a common spectrum between the studied pulsars. Based on 1215 years of data and a total of 27 pulsars studied using the ultra-sensitive Arecibo Observatory and Green Bank Telescope, the spectrum of variations in the pulsar signal arrival time was found to agree with theoretical predictions of the GW background produced by SMBHBs. The uncertainties remain large, however. This fulfills alternative interpretations such as cosmic strings — domain structures in the universe predicted to arise from a spontaneously broken gauge symmetry — that predict only a slightly different spectral shape. Furthermore, any ingredient is still missing: a spatial correlation between the pulsar variations, which would confirm the quadrupole nature of GWs and provide clear proof of the nature of the signal. Finding this “smoking gun” will require longer observation times, more pulsars and smaller systematic errors — something the NANOGrav team is now working towards.

**Bright and beautiful**

Several Krauss interpretations have also been proposed, though the NANOGrav collaboration remains cautious. The final sentences of their preprint summarise the status of the field well: “The LIGO–Virgo-discovery of high-frequency, transient GWs from stellar black-hole binaries appeared meteorically, with incontrovertible statistical significance. By contrast, the PTA discovery of very-low-frequency GWs from SMBHBs will emerge from the gradual and not always monotonous accumulation of evidence and arguments. Still, our GW vista on the unseen universe continues to get brighter.”

**Further reading**

Unstable sterile neutrinos with a mass of 10 MeV could account for the needed 40% of an effective neutrino flavour, they claim. Though potentially oscillating far too fast to be seen by conventional sterile-neutrino searches, the authors suggest that simple models could be within the reach of Japan’s Super-Kamiokande detector or the NA62 experiment at CERN (arXiv:1909.10196).

Snowmass limbers up
A virtual community planning meeting for the 2021 Snowmass exercise, which will plot a course for US particle physics over the coming decade, took place from 5 to 8 October. The meeting attracted some 3000 participants and more than 1000 letters of intent across 10 “Snowmass frontiers”, from the energy frontier to community engagement. First convened in the eponymous Coloradoan mountain resort in 1982, Snowmass studies have been produced on numerous occasions throughout the years, most recently in 2013. A final report will be published in October 2021.

Magnet milestone
Engineers at Tokamak Energy have come within a whisker (0.2 T) of the world-record field for a magnet based on high-temperature superconductors (HTS). The UK company, which pursues “desktop” fusion reactors, teamed up with CERN’s FRESCA2 magnet to just reach 16 T Nb3Sn magnets envisaged for a twin beam pipes of the LHC. Linked by a centrepiece on an artist’s impression of the Science Gateway facility, the new spaces will house exhibitions, laboratories and educational activities, surrounded by 400 newly planted trees. 80% of the total budget, which will be entirely funded by donations, has been secured. The facility is due to be open at the end of 2022.

Green light for Science Gateway
Local authorities in Geneva in September approved the construction of the Science Gateway – a new education and outreach facility at CERN designed by Renzo Piano’s architecture firm to evoke the twin beam pipes of the LHC. Linked by a centrepiece as the true artist behind the painting of the Madonna and Child commissioned by Lee X in 1517. Since the early 1990s, Medipix collaborators have developed the “colour X-ray” for a wide range of applications, including, for instance, differentiating brushstrokes and pigments. A group of independent experts used eleven 50 μm-resolution scans at different wavelengths to establish that the work was touched up by Raphael personally, without the help of apprentices. The painting was stolen from the Holy See by Napoleon’s army in 1798, before being sold into private property by Napoleon’s brother Louis XVIII in 1813.

Time travel without paradoxes
University of Queensland theorist Fabio Costa and student Germain Tobar have delighted physicists, and has worked to increase the representation of African Americans in physics and technology ever since. SURF was home to Ray Davis’s Homestake experiment, which discovered the solar neutrino problem. The facility is due to be open at the end of 2022.

APS recognises black history
Baltimore’s Morgan State University (MSU) and the Sanford Underground Research Facility (SURF) have designated historic sites by the American Physical Society (APS). MSU was the birthplace in 1977 of the National Society of Black Physicists, and has worked to increase the representation of African Americans in physics and technology ever since. APS was home to Ray Davis’s Homestake experiment, which discovered the solar neutrino problem. The sites join 48 others on the APS list.

Time travel without paradoxes
University of Queensland theorist Fabio Costa and student Germain Tobar have delighted physicists, and has worked to increase the representation of African Americans in physics and technology ever since. SURF was home to Ray Davis’s Homestake experiment, which discovered the solar neutrino problem. The facility is due to be open at the end of 2022.
ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

**LHCb**

**In pursuit of right-handed photons**

On 17 January 1957, a few months after Chien–Shiung Wu’s discovery of parity violation, Wolfgang Pauli wrote to Victor Weisskopf: “Ich glaube aber nicht, daß der Herrgott ein solcher Linkshänder ist” (I cannot believe that God is a left-hander). But maximal parity violation is now well established within the Standard Model (SM). The weak interaction only couples to left-handed particles, as dramatically seen in the continuing absence of experimental evidence for right-handed neutralinos. In the same way, the polarisation of photons originating from transitions that involve the weak interaction is expected to be completely left-handed.

The LHCb collaboration recently tested the handedness of photons emitted in rare flavour-changing transitions from a b-quark to a s-quark. These are mediated by the bosons of the weak interaction according to the SM, but what if new virtual particles contribute too? Their presence could be clearly signalled by a right-handed contribution to the photon polarisation.

The b→sγ transition is rare. Fewer than one in a thousand b-quarks transform into s-quarks and a photon. This reaction has been studied for almost 30 years at particle colliders around the world. By precise measurements of its properties, physicists hope to detect hints of new heavy particles that current colliders are not powerful enough to produce.

The probability of this b→sγ decay has been measured in previous experiments with a precision of about 5%, and found to agree with the SM prediction, which bears a similar theoretical uncertainty. A promising way to go further is to study the polarisation of the emitted photon. Measuring the b→sγ polarisation is not easy though. The emitted photons are too energetic to be analysed directly, and leptons must be found to infer the contributions to photon polarisation.

In a recent CMS analysis, where the b→sγ decays were reconstructed using polarisation information on the photon, researchers measured the b→sγ effective decay rate. These results have been put under stress by a series of anomalies observed in precision measurements of certain B→Kγ decays by the LHCb, Belle, and BaBar collaborations (CERN Courier May/June 2019, p33). A possible explanation for these anomalies, which are still under investigation and not yet confirmed, lies in the existence of leptoquarks that preferentially couple to the heaviest fermions. The new CMS search looks for both single and double production of leptoquarks. It considers leptoquarks that decay to a γγ gauge bosons are flavour independent. This principle is built into the SM, but has recently been put under stress by a series of anomalies observed in precision measurements of certain B→Kγ decays by the LHCb, Belle, and BaBar collaborations (CERN Courier May/June 2019, p33). A possible explanation for these anomalies, which are still under investigation and not yet confirmed, lies in the existence of leptoquarks that preferentially couple to the heaviest fermions. The new CMS search looks for both single and double production of leptoquarks. It considers leptoquarks that decay to a γγ.
ATLAS

Cornering WIMPs with ATLAS

Dark matter is estimated to account for an unseen 88% of matter in the universe, but its nature is unknown. One possible explanation is weakly-interacting massive particles, or WIMPs, which could interact with ordinary matter through the exchange of a Higgs boson (“Higgs-portal” models) or a new mediator field yet to be discovered. The ATLAS collaboration has recently released new limits on WIMP backgrounds based on data from the full 2016 run.

ATLAS preliminary

VOLUME 60 NUMBER 6 NOVEMBER/DECEMBER 2020

ENERGY FRONTIERS

Ultra-relativistic heavy-ion collisions create a system of deconfined quarks and gluons known as the quark–gluon plasma (QGP). Among other particles, a large number of light nuclei such as the deuteron, triton, helium-3, helium-4, and their corresponding antinuclei are produced, and can be measured with very good precision by the ALICE experiment at the LHC thanks to its excellent tracking and particle identification capabilities in specific energy loss and time-of-flight measurements. Considering that the binding energies of light nuclei do not exceed a few MeV, it is not clear how such a system can survive the gas-phase created after the phase transition from the QGP to hadrons, where particle production is typically a thermal production and transverse momentum distribution of the hadrons.

The elliptic flow of light nuclei has been measured in Pb–Pb collisions at √sNN = 5.02 TeV, as well as in p–Pb collisions at √s = 5.02 TeV, the first measurement of their triangular flow. A clear mass ordering is observed in the elliptic flow of small- and central-Pb–Pb collisions at low pT, when the deuteron results are compared to other particles, as expected for an expanding hydrodynamical system (figure 1). A possible hint of unconventional elliptic flow is observed for light nuclei, which might indicate a different mechanism for their production.

The elliptic flow of deuterons, compared with other species (left) and phenomenological models (middle), and their triangular flow (right), in Pb–Pb collisions at √sNN = 5.02 TeV in the centrality class 20–40%.
SUPERCON, Inc.
Superconducting Wire Products

Standard and Specialty designs are available to meet your most demanding superconductor requirements.

SUPERCON, Inc. has been producing niobium-based superconducting wires and cables for 58 years. We are the original SUPERCON – the world’s first commercial producer of niobium-alloy based wire and cable for superconducting applications.

**Product Applications**
- Magnetic Resonance Imaging
- Nuclear Magnetic Resonance
- High Energy Physics
- SC Magnetic Energy Storage
- Medical Therapeutic Devices
- Superconducting Magnets and Coils
- Crystal Growth Magnets
- Scientific Projects

“*We deliver when you need us!”*

www.SUPERCON-WIRE.com

---

**ULTRATHIN METAL FOIL 0.1-25μ**

Filters
Windows
Targets
Photocathodes
Vacuum Tight
Be Windows

**vaqtec**

vacuum technology & components

Full range of vacuum components

Custom manufacturing

Chambers and special projects

www.vaqtec.com

T: +39.011.0968907
Corso Grossato 437 – 10151 Turin - Italy

---

**FIELD NOTES**

Reports from events, conferences and meetings

**FIPs 2020**

Strong interest in feeble interactions

Since the discovery of the Higgs boson in 2012, great progress has been made in our understanding of the Standard Model (SM) and the prospects for the discovery of new physics beyond it. Despite excellent advances in Higgs-sector measurements, searches for WIMP dark matter and exploration of very rare processes in the flavour realm, however, unambiguous signals of new fundamental physics have been seen. This is the reason behind the explosion of interest in feeble interacting particles (FIPs) over the past decade or so.

The inaugural FIPs 2020 workshop, hosted online by CERN from 31 August to 4 September, convened almost 200 physicists from around the world. Structured around the four “portals” that may link SM particles and fields to a rich dark sector – axions, dark photons, dark scalars and heavy neutral leptons – the workshop highlighted the synergies and complementarities among a great variety of experimental facilities, and called for close collaboration across different physics communities.

Today, conventional experimental efforts are driven by arguments based on the naturalness of the electroweak scale. They result in searches for new particles with sizeable couplings to the SM and masses near the electroweak scale. FIPs represent an alternative paradigm to the traditional beyond-the-SM physics explored at the LHC. With masses below the electroweak scale, FIPs could belong to a rich dark sector and answer many open questions in particle physics (see “Four portals” figure). Diverse searches, using proton beams (CERN and Fermilab), kaon beams (CERN and FNAL), neutrino beams (FNAL and Fermilab) and muon beams (PSI) today join more adiabatic experiments across the globe in a worldwide search for FIPs.

---

**Scaling the ALPs** Searches for axion-like particles (ALPs) or haloscopes, halocupes and accelerators span more than 10 orders of magnitude in mass and are important new fields in physics, with the coupling of axions to photons (left image), with the accelerator experiments investigating high masses and stronger couplings (see zoom image, right). The regions excluded at 90% confidence are plotted alongside a strip favoured by mainstream theoretical models (gold) and a range of potential astrophysical sources. The estimated future sensitivities are indicated by the dashed regions.
Exotic Higgs bosons could also have important cosmological implications, as they might be stabilised dynamically via the time evolution of a so-called "relaxion" mechanism. They could also have been responsible for cosmological inflation.

Finally, consider right-handed neutrinos, often referred to as sterile neutrinos or heavy neutral leptons, which could account for the origin of the tiny, nearly-degenerate masses of the neutrinos in the SM and their oscillations, as well as providing a mechanism for our universe’s matter–antimatter asymmetry.

Scientific diversity

No single experimental approach can ever cover the large parameter space of masses and couplings that FIPs models allow. The interconnections between open questions require that we construct a diverse research programme incorporating accelerators, physics, dark-matter detection, cosmology, astrophysics, and precision atomic experiments, with a strong theoretical involvement. The breadth of searches for axions or axion–like particles (ALPs) is a good indication of the growing interest in FIPs (see “Scaling the ALPs” figure). Experimental efforts here span particle and astroparticle physics. In the coming years, helioscopes, which aim to detect solar axions by their conversion into photons (X-rays) in a strong magnetic field, will improve the sensitivity by several orders of magnitude for dark-matter properties. At the same time, the interplay of theoretical and experimental approaches will allow the interpretation of astrophysical and cosmological bounds, which can only be determined by the full Run 1 and Run 2 data sets and will set stringent constraints on the potential of new physics beyond the SM.

Heavy-flavour highlights from Beauty 2020

The international conference devoted to b-hadron physics at the KEK particle factory, Beauty 2020, took place from 21 to 24 September, hosted by KEK (Kavli IPMU, University of Tokyo). This year’s edition, the 19th in the series, attracted around 350 registrants, significantly more than any previous event, with live streaming for the first time. There were more than 64 invited talks, of which 13 were parallel, the upgrades of ATLAS and CMS in the next decade, and the possible use of high-luminosity Run 3.

Studies of tau-lepton universality anomalies, in particular those observed in the Belle II experiment, have emerged from analyses of decays into pairs of leptons and accompanying hadrons. The most recent anomaly could be explained by the existence of new particles such as leptoquarks or Z’ bosons. We will see how much is learned in the future.

Heavy-flavour highlights from Beauty 2020

In the field of CP violation, LHCb presented the first ever observation of time-dependent CP violation in the b– → sγ channel. This phenomenon has been established in previous experiments by the observation of the very fast (a rate of about 10^{-11} Hz) B_s oscillations and inadequate sample size. In addition, since LHCb (or LHCb-II) is the only experiment capable of doing b→sγ, and b→Xγ in the CP-violating phase. The most precise results come from an analysis that isolates B→DK decays which are followed by D→X_sγ. The rates of these decays are measured in the low-energy region and allow for important physics results. All these results were complemented by a lively theoretical activity aimed at interpreting cosmological signals within axion and ALP models.

FIPs 2020 triggered lively discussions that will continue in the coming months via topical meetings on different subjects. Topics that motivated particular interest included possible ways of comparing results from direct–detection dark-matter experiments in the MeV–GeV range.

The field of CP violation will be complemented by a lively theoretical activity aimed at interpreting results from direct–detection dark-matter experiments in the MeV–GeV range. The most precise results come from an analysis that isolates B→DK decays which are followed by D→X_sγ. The rates of these decays are measured in the low-energy region and allow for important physics results. All these results were complemented by a lively theoretical activity aimed at interpreting cosmological signals within axion and ALP models.

FIPs 2020 triggered lively discussions that will continue in the coming months via topical meetings on different subjects. Topics that motivated particular interest included possible ways of comparing results from direct–detection dark-matter experiments in the MeV–GeV range.

The field of CP violation will be complemented by a lively theoretical activity aimed at interpreting results from direct–detection dark-matter experiments in the MeV–GeV range. The most precise results come from an analysis that isolates B→DK decays which are followed by D→X_sγ. The rates of these decays are measured in the low-energy region and allow for important physics results. All these results were complemented by a lively theoretical activity aimed at interpreting cosmological signals within axion and ALP models.

FIPs 2020 triggered lively discussions that will continue in the coming months via topical meetings on different subjects. Topics that motivated particular interest included possible ways of comparing results from direct–detection dark-matter experiments in the MeV–GeV range.

The field of CP violation will be complemented by a lively theoretical activity aimed at interpreting results from direct–detection dark-matter experiments in the MeV–GeV range. The most precise results come from an analysis that isolates B→DK decays which are followed by D→X_sγ. The rates of these decays are measured in the low-energy region and allow for important physics results. All these results were complemented by a lively theoretical activity aimed at interpreting cosmological signals within axion and ALP models.

FIPs 2020 triggered lively discussions that will continue in the coming months via topical meetings on different subjects. Topics that motivated particular interest included possible ways of comparing results from direct–detection dark-matter experiments in the MeV–GeV range.

The field of CP violation will be complemented by a lively theoretical activity aimed at interpreting results from direct–detection dark-matter experiments in the MeV–GeV range. The most precise results come from an analysis that isolates B→DK decays which are followed by D→X_sγ. The rates of these decays are measured in the low-energy region and allow for important physics results. All these results were complemented by a lively theoretical activity aimed at interpreting cosmological signals within axion and ALP models.
The nature of dark matter (DM) remains one of the most intriguing unsolved questions of modern physics. Astrophysical and cosmological observations suggest that DM accounts for roughly 27% of the mass-energy of the universe, with dark energy comprising 68% and ordinary baryonic matter as described by the Standard Model accounting for a paltry 5%. This massive hole in our understanding of the universe continues to drive multiple experimental searches for DM both in the laboratory and in space. No clear evidence for DM has yet been found, severely constraining the parameter space of the most popular “thermal” DM models. Assuming DM is a material substance comprised of particles – not an illusion resulting from an imperfect

### ALICE’S DARK SIDE

Precision measurements of the production and annihilation of light antinuclei at the LHC’s ALICE experiment are sharpening the search for dark matter, explain Maximiliano Puccio and Ivan Vorobyev.

When Compromise is Not an Option.

High-Performance Digitizers for Big Physics Applications

Digitizers from Teledyne SP Devices utilize patented calibration technology, the latest data converters, and state-of-the-art FPGAs in order to achieve an unrivaled combination of high resolution and sampling rate. Their versatility makes them ideal for applications such as beam position monitoring, Thomson scattering plasma diagnostics, and more.

Supported features include:
- Up to 10 GSPS sampling rate with 14 bits resolution
- Open FPGA for custom real-time signal processing
- Multiple form factors including MTCA.4, PXie, and PCIe
- Multi-channel synchronization capabilities
- White Rabbit synchronization (MTCA.4 only)
- Peer-to-peer streaming to GPU (PCIe only)
- Application-specific firmware shortens design time
antinuclei

Production and
that is able
experiment
the only

The inelastic annihilation cross section in various colliding systems can be constrained from the ALICE data by comparing the measured ratio with detailed Monte Carlo simulations. The resulting antideuteron inelastic cross section is shown in “Interaction probability” (figure), where the two panels correspond to the different sub-detectors employed in the analysis and therefore to different average phase-space acceptance. The inelastic cross sections include all possible inelastic antideuteron processes such as break-up, annihilation or capture. The achievable precision of the measurement is limited by the available data: the antideuteron production rate in pp collisions goes down by a factor of about 1000 for every additional antinucleon in the antinucleus.

The measurement range covered in this latest analysis is of particular importance to evaluate the signal predictions for indirect dark-matter searches. With the increased integrated luminosity that will be acquired by ALICE during LHC Run 3 from early 2022, it will be possible to extend the current analyses to more easily identified by satellite-borne experiments and thus expected to provide an even clearer DM signature. Further work is required to understand how to use these data in the context of the current and future DM searches, forcing current estimates to rely on extrapolations and modelling.

Fortunately, both the antinuclei production mechanism and the interactions between antinuclei and ordinary matter can be studied on Earth using large accelerators. The main contributions so far have come from the LHC at CERN and from the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. Thanks to its unique low-material-budget tracker, which provides excellent tracking and particle-identification performance for low-momentum particles, ALICE is the only experiment at the LHC that is able to study the production and annihilation of low-energy antinuclei.

Antinucleisynthesis in the lab

While antinuclei can also be produced at lower collision energies, only at the LHC are antinuclei generated in equal abundances in the region transverse to the beam direction. The most abundant non-trivial antinucleus produced is the antideuteron, which consists of an antiproton and a neutron. At low momentum, deuterons and antideuterons can be clearly identified thanks to their high-energy loss in the ALICE time-projection chamber. At larger momenta, a clean identification of antideuterons is possible using the ALICE time-of-flight detector. This information, combined with the measured track length and the particle momentum, provide a precise determination of the particle mass. Using these and other techniques, the ALICE collaboration has recently measured the production of (anti)deuterons in proton–proton collisions, as well as in other colliding systems, and set tight constraints on the production models of antinuclei.

There are two main ways to model the production mechanism of (anti)nuclei. Coalescence models assume that antinucleon–nucleon annihilations take place at the close enough in space and time. The hadronisation processes, on the other hand, assume that hadrons and (anti)nuclei are formed from the initial state in collisions of dynamical equilibrium, making the temperature and the volume of the system the key parameters. Measurements of nuclei-to-proton ratios in various colliding systems have recently enabled the ALICE collaboration to compare the two model approaches (see “Competing models” figure). As can be seen by comparing the predictions for the evolution of the nuclei–to-proton ratio versus particle multiplicity, with the latest ALICE measurements slightly favouring the coalescence approach.

Further helping clarify the results of indirect DM searches, ALICE has recently performed the first measurements of the antideuteron inelastic cross section in the momentum range 0.3 < p < 4 GeV/c – significantly extending our knowledge about this cross section from previous measurements at momenta of 1.1 and 2.7 GeV/c at the Serpukhov accelerator complex in Russia in the early 1990s. The collaboration took advantage of the ability of antideuteron production to be observed simultaneously with the detector material. To quantify this process, ALICE has employed a novel approach based on the antideuteron–deuteron ratio reconstructed in collisions of deuterons and heavy ions at a centre-of-mass energy of 5.02, 5.5 and 6.3 TeV. This ratio depends on both the inelastic cross sections of antideuterons and the deuteron. The former has been measured in various previous experiments at different momenta, the latter can be constrained from the ALICE data by comparing the measured ratio with detailed Monte Carlo simulations. The resulting antideuteron inelastic cross section is shown in “Interaction probability” (figure), where the two panels correspond to the different sub-detectors employed in the analysis and therefore to different average phase-space acceptance. The inelastic cross sections include all possible inelastic antideuteron processes such as break-up, annihilation or capture. The achievable precision of the measurement is limited by the available data: the antideuteron production rate in pp collisions goes down by a factor of about 1000 for every additional antinucleon in the antinucleus.

The precision of the measurements from proton–proton collisions places strong constraints on the production mechanisms also in hadronic collisions between cosmic rays and the interstellar medium. However, the production of light antinuclei is expected to be low with respect to the interstellar medium. However, the production of light antinuclei is expected to be low with respect to the interstellar medium. However, the production of light antinuclei is expected to be low with respect to the interstellar medium. However, the production of light antinuclei is expected to be low with respect to the interstellar medium.
CERN COURIER

Volume 60 Number 6 November/December 2020

Best® Cyclotron Systems

New Best Cyclotrons

<table>
<thead>
<tr>
<th>Energy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–3 MeV</td>
<td>Deuterons for materials analysis (Patent Pending)</td>
</tr>
<tr>
<td>70–150 MeV</td>
<td>For Proton Therapy (Patent Pending)</td>
</tr>
<tr>
<td>3–90 MeV</td>
<td>High current proton beams for neutron production and delivery (Patent Pending)</td>
</tr>
<tr>
<td>15 MeV</td>
<td>Proton only, capable of high current up to 1000 Micro Amps, for medical radionuclides</td>
</tr>
<tr>
<td>20, 25–15 MeV</td>
<td>Proton only, capable of high current up to 1000 Micro Amps, for medical radionuclides</td>
</tr>
<tr>
<td>30, 35–15 MeV</td>
<td>Proton only, capable of high current up to 1000 Micro Amps, for medical radionuclides</td>
</tr>
<tr>
<td>70–15 MeV</td>
<td>Proton only, capable of high current up to 1000 Micro Amps, for medical radionuclides</td>
</tr>
<tr>
<td>70 MeV up to 150 MeV (non-variable)</td>
<td>For all Medical Treatments including Benign and Malignant Tumors for Neurological, Eye, Head/Neck, Pediatric, Lung Cancers, Vascular/Cardiac/Stenosis/Ablation, etc. (Patent Pending)</td>
</tr>
</tbody>
</table>

Best® Particle Therapy

400 MeV ion Rapid Cycling Medical Synchrotron (iRCMS) for Proton-to-Carbon Heavy Ion Therapy:
- Intrinsically small beams facilitating beam delivery with precision
- Small beam sizes – small magnets, light gantries – smaller footprint
- Highly efficient single turn extraction
- Efficient extraction – less shielding
- Flexibility – heavy ion beam therapy (protons and/or carbon), beam delivery modalities

COMING SOON!
Best Proton Therapy Cyclotron up to 150 MeV dedicated for proton therapy with two beam lines and two treatment rooms (Patent Pending)

Best™ Molecular Imaging

The BG-75 Best 7.5 MeV Cyclotron for in-house production of 18F-FDG and other biomarkers
- Push button graphic interface
- Kit based chemistry
- Single or batch dose production
- Final dose delivery to syringe or vial (option)
- Automated quality control testing
- Integrated cyclotron and chemistry self-shielding
- Complete production lab in a 5 x 5 meter area

www.bestcyclotron.com • www.bestabt.com • www.bestproton.com
BCS tel: 604 681 3327 • Best ABT tel: 865 982 0098 • BPT tel: 703 451 2378

First Century of Contributions of TeamBest Global in Healthcare Worldwide

A book to be published and distributed free of cost at the 2021 ASTRO Annual Meeting!
Detectors similar to those used to hunt for sterile neutrinos could help guard against the extraction of plutonium-239 for nuclear weapons, writes Patrick Huber.

The first nuclear-weapons test shook the desert in New Mexico 73 years ago. Weeks later, Hiroshima and Nagasaki were obliterated. So far, these two Japanese cities have been the only ones to suffer such a fate. Neutrinos can help to ensure that no other city has to be added to this dreadful list.

At the height of the arms race between the US and the USSR, stockpiles of nuclear weapons exceeded 50,000 warheads, with the majority being thermonuclear designs vastly more destructive than the fission bombs used in World War II. Significant reductions in global nuclear stockpiles followed the end of the Cold War, but the US and Russia still have about 12,500 nuclear weapons in total, and the other seven nuclear-armed nations have about 1500. Today, the politics of non-proliferation is once again tense and unpredictable. New nuclear security challenges have appeared, often from unexpected actors, as a result of leadership changes on both sides of the table. Nuclear arms races and the dissolution of arms-control treaties have yet again become a real possibility.

A regional nuclear war involving just 1% of the global arsenal would cause a massive loss of life, trigger climate effects leading to crop failures and jeopardise the food supply of a billion people. Until we achieve global disarmament, nuclear non-proliferation efforts and arms control are still the most effective tools for nuclear security.

Not a bang but a whimper

The story of the neutrino is closely tied to nuclear weapons. The first serious proposal to detect the particle hypothesised by Pauli, put forward by Clyde Cowan and Frederick Reines in the early 1950s, was to use a nuclear explosion as the source (see “Daring experiment” figure). Inverse beta decay, whereby an electron-antineutrino strikes a free proton and transforms it into a neutron and a positron, was to be the detection reaction. The proposal was approved in 1952 as an addition to an already planned atmospheric nuclear-weapons test. However, while preparing for this experiment, Cowan and Reines realised that by capturing the neutron on a cadmium nucleus, and observing the delayed coincidence between the positron and this neutron, they could use the lower, but steady flux of neutrinos from a nuclear reactor instead (see “First detection” figure). This technique is still used today, but with gadolinium or lithium in place of cadmium.

The P reactor at the Savannah River site at Oak Ridge National Laboratory, which had been built and used to make plutonium and tritium for nuclear weapons, eventually hosted the successful experiment to first detect the neutrino in 1956. Neutrino experiments testing the properties of the neutrino including oscillation searches continued there until 1988, when the P reactor was shut down.

Neutrinos are not produced in nuclear fission itself, but by the beta decays of neutron-rich fission fragments – on average about six per fission. In a typical reactor fuelled by natural uranium or low-enriched uranium, the reactor starts out with only uranium-235 as its fuel. During operation a significant number of neutrons are absorbed on uranium-238, which is far more abundant, leading to the formation of uranium-239, which after two beta decays becomes plutonium-239. Plutonium-239 eventually contributes to about 40% of the fissions, and hence energy production, in a commercial reactor. It is also the isotope used in nuclear weapons.

The dual-use nature of reactors is at the crux of nuclear non-proliferation. What distinguishes a plutonium-production reactor from a regular reactor producing electricity is whether it is operated in such a way that the plutonium can be taken out of the reactor core before it deterritorialises and becomes difficult to use in weapons applications. A reactor with a low content of plutonium-239 makes more and higher energy neutrinos than one rich in plutonium-239.

Lev Mikaelyan and Alexander Borovoi, from the Kurchatov Institute in Moscow, realised that neutrino emissions can be used to infer the power and plutonium content of a reactor. In a series of trailblazing experiments at the Rovno nuclear power plant in the 1980s and early 1990s, their group demonstrated that a tone-scale underground neutrino detector situated 10 to 20 metres from a reactor can indeed track its power and plutonium content.

The significant drawback of neutrino detectors in the 1980s was that they needed to be situated underground, beneath a substantial overburden of rock, to shield them from cosmic rays. This greatly limited potential deployment sites. There was a series of application-related experiments – notably the successful SONGS experiment conducted by researchers at Lawrence Livermore National Laboratory, which aimed to reduce cost and improve the robustness and remote-operation capabilities of neutrino detectors – but all of these detectors still needed shielding.

From cadmium to gadolinium

Synergies with fundamental physics grew in the 1990s, when the evidence for neutrino oscillations was becoming impossible to ignore. With the range of potential oscillations frequencies narrowing, the Palo Verde and Chooz...
FEATURE DETECTOR TECHNOLOGY

Purpose driven

A spin-off from Double Chooz, the Nucifer detector was small and efficient at detecting neutrons, but required a significant overburden of rock.

reactor experiments placed multi-tonne detectors about 1 km from nuclear reactors, and sought to measure the relatively small β parameter of the neutrino mixing matrix, which expresses the mixing between electron neutrons and the third neutrino mass eigenstate. Both experiments used large amounts of liquid organic scintillator doped with gadolinium. The goal was to tag antineutrino events by capturing the neutrons on gadolinium, rather than the cadmium, by Reines and Cowan. Gadolinium produces 8 MeV of gamma rays upon de-excitation after a neutron capture. As it has an enormous neutron-capture cross section, even small amounts greatly enhance an experiment’s ability to identify neutrons.

Eventually, neutrino oscillations became an accepted fact, redoubling the interest in measuring neutrino density. In 2011, however, shortly before the experiments established that θ13 ≠ 0, fundamental research once again galvanized the development of detector technology for reactor monitoring. In the run-up to the Double Chooz experiment, a group at CERN started to re-evaluate the predictions for reactor neutron fluxes – then and now based on measurements at the Institut Laue-Langevin in the 1990s – and found themselves surprised at the reactor flux predictions coming out 6% higher than before. Given that all prior experiments were in agreement with the old flux predictions, neutrino mixing was missing. This “reactor-antineutrino anomaly” persisted to this day. A sterile neutrino with a mass of about 1 eV would be a simple explanation. This mass range has been suggested in the context of sterile neutrinos, most notably LSND and MiniBooNE, though it conflicts with predictions that muon neutrinos should oscillate into such a sterile neutrino, which experiments such as MINOS have failed to confirm.

To directly observe the high-frequency oscillations of an eV-scale sterile neutrino you need to get within about 10 m of the reactor. At this distance, backgrounds from the operation of the reactor are often surprising. If no overburden is possible – the same conditions a detector on a safeguards mission would encounter.

From gadolinium to lithium

Around half a dozen experimental groups are chasing sterile neutrinos using small detectors close to reactors. Some of the most advanced designs use fine spatial segmentation to reject backgrounds, and replace gadolinium with lithium –6 as the nuclear capture tag. Lithium has the advantage that upon neutron capture it produces an alpha particle and a triton rather than a handful of photons, resulting in a very well-localized tag. In a small detector this improves event containment and thus efficiency, and also helps constrain event topology.

Following the lithium and finely segmented technical paths, the PROSPECT collaboration and the CHANDLER collaboration (see “Rapid deployment” figure), in which I participate, independently reported the detection of a neutron spectrum with minimal overburden and a high detection efficiency in 2018. This is a major milestone in making non-proliferation applications a reality, since it is the first demonstration of the technology needed for tonne-scale detectors capable of monitoring the plutonium content of a nuclear reactor that could be universally deployed without the need for special site preparation.

The main difference between the two detectors is that PROSPECT, with its reactor limit at the Neutrino 2020 conference, uses a traditional approach with liquid scintillator, whereas CHANDLER, currently an R&D project, uses plastic scintillator. The use of plastic scintillator allows the deployment time-frame to be shortened to less than 24 hours. On the other hand, liquid scintillator and its electronics can take up to two weeks. The use of plastic scintillator allows the deployment time-frame to be shortened to less than 24 hours. On the other hand, liquid scintillator and its electronics can take up to two weeks.

This resulted in three advantages: double the ability to identify neutrons; double the interest in measuring ν[bar]e density. In month N+1, the reactor is restarted and full safeguards are reinstalled.

In parallel to detector development, studies are being undertaken to understand how reactor monitoring with neutrino oscillations would impact nuclear security and support safeguards-specific scenarios. For example, to prevent the unnoticed opening of the reactor, and cameras to record the movement of fuel, most crucially during reactor shutdowns. In the N-th month shortly after reactor shut-down, in the pre-KPOA configuration (40 MW, rather than the reneged power of 20 MW), runs under full safeguards for N-1 months. In month N, a neutrino detector will be deployed. The reactor will contain 16 kg of weapons-grade plutonium. For unspecified reasons the safeguards are then interrupted. In this 1-hour interval, the reactor core will be briefly unsecured.

The question is: are the plutonium fuels still in the reactor core, or has the core been replaced with fresh fuel?

The disruption of safeguards could either be due to equipment failure – a more frequent event than one might assume – or due to events in the political realm ranging from a minor unpleasantness to a full-throttle dash for a nuclear weapon. Distinguishing the two scenarios would be a matter of utmost urgency. According to an analysis following the June 1994 crisis at Yongbyon st i l l overshadows negotiations with North Korea, since, as far as North Korea is concerned, it discredited the IAEA. Both during the crisis, and subsequently, international attempts at non-proliferation failed to prevent North Korea from acquiring nuclear weapons – its first nuclear-weapons test took place in 2006 – or even to constrain its programs towards a small-scale operational nuclear force. New approaches are therefore needed, and recent attempts by the US to achieve progress on this issue prompted an international group of about 20 neutrino experts from Europe, the US, Russia, South Korea, China and Japan to develop specific deployment scenarios for neutrino detectors at the Yongbyon nuclear complex.

The main concern is the 5 MWe reactor, which, though named for its electrical power, has a thermal power of 20 MW. This gas-cooled graphite-water reactor, fuelled with natural uranium, has been the source of all North Korea’s plutonium. The specifics of this reactor, and in particular its fuel cladding, which makes prolonged wet-storage of irradiated fuel impossible, represent such a proliferation risk that anything but a monitored shutdown prior to a complete dismantling appears inappropriate. To safeguard against the regime regaining on such a deal, would be to agree, a relatedly modest tone-scale neutrino detector right outside the reactor building could detect a powering up of this reactor within a day.

To directly observe the high-frequency oscillations of an eV-scale sterile neutrino you need to get within about 10 m of the reactor.

To directly observe the high-frequency oscillations of an eV-scale sterile neutrino you need to get within about 10 m of the reactor.
detectors that would be needed. A more promising future application of neutrino-detector technology is to meet the new challenges posed by advanced nuclear-reactor designs.

Advanced safeguards

The current safeguards regime relies on two key assumptions: that fuel comes in large, indivisible and individually identifiable units called “fuel assemblies”, and that power reactors need to be refueled frequently. Most advanced reactor designs violate at least one of these design characteristics. Fuel may come in thousands of small pebbles or be molten, and its coolant may not be transparent, in contrast to current designs, where water is used as moderator, coolant and storage medium in the first years after discharge. Either way, counting and identification of the fuel by serial number may be impossible. And unlike current power reactors, which are refueled on a 12- to 18-month cycle, allowing in-core fuel to be verified as well, advanced reactors may be refueled only once in their lifetime.

Neutrino detectors would not be hampered by any of these novel features. Detailed simulations indicate that they could be effective in addressing the safeguard challenges presented by advanced reactors. Crucially, they would work in a very similar fashion for any of the new reactor designs.

In 2019 the US Department of Energy chartered and funded a study (which I co-chaired) with the goal of determining the utility of the unique capabilities offered by neutrino detectors for nuclear security and energy applications. This study includes investigators from US national laboratories and academia more broadly, and will engage and interview nuclear security and policy experts within the Department of Energy, the State Department, NOGs, academia, and international agencies such as the IAEA. The results are expected early in 2021. They should provide a good understanding of where neutrinos can play a role in current and future monitoring and verification agreements, and may help to guide neutrino detectors towards their first real-world applications.

The idea of using neutrinos to monitor reactors has been around for about 40 years. However, as a result of a surge of interest in sterile neutrinos, has detector technology become available that would be practical in real-world scenarios such as the TESLA/TESLA-like North Korean nuclear agreement. The most likely initial applications will be near-field reactor monitoring with detectors inside the fence of the monitored facility as part of a regional nuclear deal. Such detectors will not be a panacea to all verification and monitoring needs, and can only be effective if there is a sincere political will on both sides, but they do offer more room for creative diplomacy, and a technology that is robust against the kinds of political failures which have marked many past safeguards agreements.

Further reading

A. Bernstein et al. 2020 Rev. Mod. Phys. 92 011003.
C Stewart et al. 2019 Nat. Comm. 10 5352.

Neutrino detectors could be effective in addressing the safeguards challenges presented by advanced reactors

Effective in could be detectors of the 20 tonne A different scenario: Three of the 20 tonne neutrino detectors employed by the Daya Bay experiment in China. To monitor a total shutdown of all reactors at Yongbyon, it would be feasible to bury a 50 tonne single volume detector of similar design under a nearby mountain in North Korea.

Neutrino detectors could be effective in addressing the safeguards challenges presented by advanced reactors

A different scenario: Three of the 20 tonne neutrino detectors employed by the Daya Bay experiment in China. To monitor a total shutdown of all reactors at Yongbyon, it would be feasible to bury a 50 tonne single volume detector of similar design under a nearby mountain in North Korea.

It's design is not dissimilar to much larger reactors used throughout the world to produce electricity, and it could help address the perennial lack of electricity that has limited the development and growth of the country’s economy. North Korea may wish to operate it independently. Larger, 50 tonne neutrino detector could detect any irregularities during its refueling - a role sign of a non-civilian use of the reactor - on a timescale of three months, which is within the goals set by the IAEA.

In a different scenario, wherein the goal would be to monitor a total shutdown of all reactors at Yongbyon, it would be feasible to bury a Daya-Bay-style 50 tonne single volume detector under the Yak-san, a mountain about 2 km outside of the perimeter of the nuclear installations (see “A different scenario” figure). The cost and deployment timescale would be more onerous than in the other scenarios.

In the case of longer distances between reactor and detector, detector masses must increase to compensate an inverse square reduction in the reactor-neutrino flux. As cosine-squared background remains constant, the detectors must be deployed deep underground, beneath an over-burden of several 100 m of rock. To this end, the UK’s Science and Technology Facilities Council, the UK Atomic Weapons Establishment and the US Department of Energy, are funding the WATCHMAN collaboration to pursue construction of a multi-kilo-tonne water-Cherenkov detector at the Bouby pond, 20 km from two reactors in Hartlepool, in the UK. The goal is to demonstrate the ability to monitor the operational status of the reactors, which have a combined power of 3000 MW. In a use-case context this would translate to excluding the operation of an undeclared to 2000 MW reactor within a radius of a few kilometres, but no safeguards scenarios has emerged where this would give a unique advantage.

Inverse-square scaling eventually breaks down around 100 km, as at that distance the backgrounds caused by civilian reactors far outshine any undeclared small reactor anywhere in the northern hemisphere. Small signals also prevent the use of neutrino detectors for nuclear-exploration monitoring, or to confirm the origin of a suspicious seismic event as being nuclear, as conventional technologies are more feasible than the very large
The Tesla Technology Collaboration had a scope beyond the original motivation of high-energy physics. The TTC, with its incredible worldwide collaboration spirit, has had a major role in the growth of the SRF community, facilitating numerous important contributions over the past 30 years.

### 30 years of gradient march

Conceptually, the objective of simply providing “nice clean” niobium surfaces on RF structures seems pretty straightforward. Important subtleties begin to emerge, however, as one considers that the high RF-surface currents required to support magnetic fields up to ~100 MV/m in the top 100 nm of the niobium surface, which must offer routine field emission, whereby very high peak surface electric fields can turn even micron-scale foreign material into parasitic electron field emission sources, with resulting cryogenic and radiation burdens.

The most recent transformation has come with the recognition that interstitial doping of the niobium surface with nitrogen can reduce SRF surface resistance much more than was dreamed possible, reducing the cryogenic heat load to be cooled. While still the subject of material research, this new capability was rapidly adopted into the specification for LCLS-II cavities and is also being considered for ITER. The effort started in the US and quickly propagated internationally via the TTC, for example in cavity tests at the European Spallation Source (see “Vertical test” image).

### Cleaning up

The most common challenge for developers and users of SRF accelerating cavities: particulate-induced field emission, whereby very high peak surface electric fields can turn even micron-scale foreign material into parasitic electron field emission sources, with resulting cryogenic and radiation burdens. Extended interior final cleaning and cleanroom techniques, which have evolved considerably over the past 30 years, has helped to beat down the most common challenge for developers and users of SRF accelerating cavities: particulate-induced field emission, whereby very high peak surface electric fields can turn even micron-scale foreign material into parasitic electron field emission sources, with resulting cryogenic and radiation burdens.

### Accelerating gradients above 40 MV/m are now attainable with niobium

Pushing up the purity of deliverable material has required a concerted push, resulting in the avoidance of foreign material inclusions, which can be deadly to performance when uncovered in the final step of surface processing. The figure-of-merit for purity is the ratio of room-temperature to cryogenic normalconducting resistivity — the residual resistance ratio, RRR. The common cavity-grade niobium material specification has thus come to be known as high-RRR grade.

Another vexing problem that TTC member institutions helped to solve was the presence of “Q-drop” in the region of high surface magnetic field, for which present explanations point to subtle migration of near-surface oxygen deeper into the lattice, where it inhibits the subsequent formation of lossy nanohydrides on cool-down. Avoidance of nanohydrides, whose superconductivity by proximity effect breaks down in the Q-drop regime, is required to sustain accelerating gradients above 25 MV/m for some structures.

### Energy Superconducting Linear Accelerator workshop

With some notable exceptions, bulk niobium cavities fabricated for ITER at CERN and CEA/IRFM were made of what has thus come to be known as high-RRR grade.

### Cleaning up

Another later pursuit of pure niobium is the so-called “large grain” or “direct-from-ingot” material. Rather than insist on controlled ~30 µm grain-size distribution (grains being microrystallites in the structure), this material uses sheet slits cut directly from large ingots having much larger, but arbitrarily sized, grains. Although not yet widely used, this material has produced the highest gradient TESLA-style cavities to date — 45 MV/m with a quality factor Q > 10⁷. Here again, though the topic was initiated at LBL, this fruitful week's accomplishments could not have been completed via worldwide international collaborations.

### As niobium is a refractory metal that promptly cools itself with 14% of dielectric oxide, welding niobium components has to be performed by vacuum electron beam welding. Collaborative efforts in Europe, North America and Asia refined the parameters required to yield consistent niobium welds. The community gradually realised that extreme cleanliness is required in the surface-weld preparation, since even microscopic foreign material will be vapourised during the weld process, leaving behind small voids that definitely require perfect cleaning and cleanroom techniques, which have evolved considerably over the past 30 years. This has helped to beat down the most common challenge for developers and users of SRF accelerating cavities: particulate-induced field emission, whereby very high peak surface electric fields can turn even micron-scale foreign material into parasitic electron field emission sources, with resulting cryogenic and radiation burdens.
FEATURE: TESLA TECHNOLOGY COLLABORATION

Global view
Distribution of superconducting particle accelerators using SRF structures for electrons (orange), protons (purple) and heavy ions (pink). More than 30 SRF accelerators are in operation (circles), approximately 15 are presently under construction (triangles) and more than 30 future projects are under consideration (squares).

One of the main goals of the TTC has been to bridge the gap between state-of-the-art R&D on laboratory prototypes and actual accelerator components in operating facilities, with the clear long-term objective to enable superconducting technology for a TeV-scale linear collider. This objective demanded a staged approach and intense work on the development of all the many peripherals and subcomponents. The collaboration embraced a joint effort between the initial partners to develop the TTF at DESY, which aimed to demonstrate reliable operation of an electron superconducting linear collider at gradients above 15 MV/m in “vector sum” control – whereby many cavities are fed by a single high-power RF source to improve cost-effectiveness. In 1999 the collaboration finalised a 1.3 GHz cavity design that is still the baseline of large projects like the European XFEL, LCLS-II and SHINE, and nearly all L-band-based facilities.

Towards a linear collider
An intense collaborative effort started for the development of all peripheral components, for example power couplers, high-order mode dampers, digital low-level RF systems and cryomodules with unprecedented heat load performances. Several of these components were designed by TTC partners in an open collaborative and competitive effort, and a number of them can be found in existing projects around the world. The tight requirements imposed by the scale of a linear collider required an integrated design of the accelerating modules, containing the cavities and their peripheral components, which led to the concept of the “TESLA style” cryomodule, one of which provide the building blocks of the linacs in TTF, European XFEL, LCLS-II and SHINE.

The success of the TTF, which delivered its first beam in 1997, led to become the driver for a next-generation light source at DESY, the VUV-FEL, which produced first light in 2005 and which later became the FLASH facility. The European XFEL, built on this strong heritage, its large scale demanding a new level of design consolidation and industrialisation. It is remarkable to note that the total number of such TESLA-style cavities installed or to be installed in presently approved accelerators is more than 1800. Were a 250 GeV ILC to go ahead in Japan, approximately 800 such units would be required. (Note that an alternative proposal for a high-energy linear collider, the Compact Linear Collider, relies on a novel dual-beam acceleration scheme that does not require SRF cavities.)

Since the partners collaborating on the early TESLA goal of a linear collider were also involved in other national and international projects for a variety of applications and domains, the first decade of the 21st century saw the TTC broaden its reach. For example, we started including reports from other projects, most notably the US Spallation Neutron Source, and gradually opened to the community working on low-beta ion and proton superconducting cavities, such as the half-wave resonator string collaboratively developed at Argonne National Lab and now destined for use in PIP-II at Fermilab (see “Low-beta cavities” image). TTC meetings include topical sessions with industries to discuss how to shorten the path from development to production. Recently, the TTC has also begun to facilitate collaborative exchanges on alternative SRF materials to bulk niobium, such as Nb3Sn and even hybrid multilayer films, for potential accelerator applications.

Sustaining success
The mission of the TTC is to advance SRF technology R&D and related accelerator studies across the broad diversity of scientific applications. It is to provide a bridge for open communication and sharing of ideas, development and testing across associated projects. The TTC supports and encourages the free and open exchange of scientific and technical knowledge from different linear accelerator projects. The current TTC membership consists of 60 laboratories and institutes in 15 countries across Europe, North America and Asia. Since progress in cavity performance and related SRF technologies is so rapid, the major TTC meetings have been frequent.

Particle accelerators using SRF technologies have been applied widely, from small facilities for medical applications up to large-scale projects for particle physics, nuclear physics, neutron sources and free-electron lasers (see “Global view” figure). Five large-scale (> 500 cavities) SRF projects are currently under construction in three regions: ESS in Europe, PRBB and LCLS-II in the US, and SHINE (Japan) and RAIN (Korea) in Asia. Close international collaboration will continue to support progress in these and future projects, including SRF thin-film technology relevant for a possible future circular electron–positron collider. Perhaps the next wave of SRF technology will be the maturation of economical small-scale applications with high multiplicity and international standards. As an example, the TTC has compiled a list of nearly 400 SRF projects worldwide.

Nuclear physics is as wide-ranging and relevant today as ever before in the century-long history of the subject. Researchers study exotic systems from hydrogen-1 to the heaviest nuclides at the boundaries of the nuclear landscape. By constraining the nuclear equation of state using heavy-ion collisions, they peer inside stars in controlled laboratory tests. By studying weak nuclear processes such as beta decays, they can even probe the Standard Model of particle physics. And this is not to mention numerous applications in accelerator-based atomic and condensed-matter physics, radiobiology and industry. These nuclear-physics research areas are just a selection of the diverse works done at the Gend Accelerateur National d’Ions Lourds (GANIL), in Caen, France.

GANIL has been operating since 1976, initially using four cyclotrons, with a fifth Cyclotron pour la Recherche en Energie (CIME) added in 2001. The latter is used to reaccelerate short-lived nuclei produced using beams from the other cyclotrons – the Systeme de Produktion d’Ions Radioactifs en Ligne (SPIRAL) facility. The various beams produced by these cyclotrons drive eight beams with specialised instrumentation. Parallel operation allows the running of three experiments simultaneously, thereby optimising the available beam time. These facilities enable both high-intensity heavy-ion beams, from carbon-12 to uranium-238, and lower intensity radioactive-ion beams of short-lived nuclei, with lifetimes from nanoseconds to milliseconds, such as helium-6, helium-8, silicon-28 and nickel-68. Coupled with advanced detectors, all these beams allow nuclei to be explored in terms of excitation energy, angular momentum and isospin.

The new SPIRAL2 facility, which is currently being

SPIRAL2 is equipped with a new superconducting linac, the SPIRAL2 facility at GANIL will probe short-lived heavy nuclei and address applications in fission and materials science using charged and neutron beams.

On the plus side, inside view of the radio-frequency quadrupole at the entrance to SPIRAL2’s superconducting linear accelerator.
**High intensity SPIRAL2’s new superconducting linac and its experimental halls.**

SPIRAL2 was approved in 2005. It now joins a roster of cutting-edge European nuclear-physics-research facilities which also features the Facility for Antiproton and Ion Research (FAIR), in Darmstadt, Germany, ISOLDE and SNS at Oak Ridge National Laboratory, and the Joint Institute for Nuclear Research (JINR) in Russia. Due to their importance in the European nuclear-physics roadmap, SPIRAL2 and FAIR are both now recognised as European Strategy Forum on Research Infrastructures (ESFRI) Landmark projects, alongside 11 other facilities, including accelerator complexes such as the European X-Ray Free-Electron Laser, and telecopes such as the Square Kilometre Array.

SPIRAL2 joins a roster of cutting-edge European nuclear-physics-research facilities.
A unique period for computing, but will it last?

The increase in computing demands expected this decade puts high-energy physics in a similar position to 1995 when the field moved to PCs, argues Sverre Jarp.

N Jarp
CTO of CERN

Twenty-five years ago in Rio de Janeiro, at the 8th International Conference on Computing in High-Energy and Nuclear Physics (CHEP'95), I presented a paper on behalf of my research team titled “The PC as Physics Computer for LHC.” We highlighted impressive improvements in price and performance compared to other solutions on offer. In the years that followed, the community started moving to PCs in a massive way, and today the PC remains unchallenged as the workhorse for high-energy physics (HEP) computing.

HEP-computing demands have always been greater than the available capacity. However, our community does not have the financial clout to dictate the way computing should evolve, demanding constant innovation and research in computing and IT to maintain progress. A few years before CHEP'95, RISC workstations and servers had started complementing the mainframes that had been acquired at high cost at the start-up of LEP in 1989. We thought we could do even better than RISC. The increased-energy LEP phase needed lots of simulations, and the same needs were already manifest for the LHC. These were our inspirations that led PC servers to start populating our computer centres—a move that was also helped by a fair amount of luck.

Fast change

HEP programs need good floating-point computing capabilities and early generations of the Intel x86 processors, such as the i486/i487 chips, offered mediocre capabilities. The Pentium processors that emerged in the mid-1990s changed the scene significantly, and the competitive race between Intel and AMD was a major driver of continued hardware innovation.

Another strong tailwind came from the relentless efforts to shrink transistor sizes in line with Moore’s law, which saw processor speeds increase from 50/100 MHz to 2000/3000 MHz in little more than a decade. After 2006, when speed increases became impossible for thermal reasons, efforts moved to producing multi-core chips. However, HEP continued to profit. Since all physics events at colliders such as the LHC are independent of all others, it was sufficient to split a job into multiple jobs across all cores.

The HEP community was also lucky with software. Back in 1995, we had chosen Windows/NT as the operating system, mainly because it supported multiprocessing, which significantly enhanced our price/performance. Physicists, however, insisted on Linux. In 1995, Linus Torvalds released Linux version 0.01 and it quickly gathered momentum as a worldwide open-source project. When release 2.0 appeared in 1996, multiprocessor support was included and the operating system was quickly adopted by our community.

The contenders

The end of CPU scaling, argued a recent report by the HEP Software Foundation, demands radical changes in computing and software to ensure the success of the LHC and other experiments into the 2020s and beyond (CERN Courier April 2018 p99). There are many contenders that would like to replace the x86 PC architecture. It could be graphics processors, where both Intel and AMD and Nvidia are active. A wilder guess is quantum computing, whereas a more conservative guess would be processors similar to the x86, but based on other architectures, such as ARM or RISC-V.

During the PC project we collaborated with Hewlett-Packard, which had a division in Grenoble, not too far away. Such R&D collaborations have been vital to CERN and the community since the beginning and they remain so today. They allow us to get insight into forthcoming products and future plans, while our feedback can help to influence the products in plan. CERN openlab, which has been the focal point for such collaborations for two decades, early-on coined the phrase “You make it, we break it.” However, whatever the future holds, it is fair to assume that PCs will remain the workhorse for HEP computing for many years to come. 
reduces the transmission of photons near the carbon K edge, around 285 eV, as well as at higher energies around 1000 eV. As early as the 1980s, this carbon contamination layer was shown to cause intensity modulations in X-ray absorption spectra that closely resembled those above the carbon K edge in bulk crystalline graphite. These results suggested the formation of graphitic carbon contamination even under UHV conditions. Carbon contamination is not only experimentally detected, it is also visually evident after a few months to a year of beamline operation. It will usually appear as a black line where the X-rays strike the optics.

Vacuum engineers and scientists have long known that even if a sample material is initially clean and handled with ultrahigh-vacuum (UHV) standards, a carbon contamination layer will deposit and grow on the X-ray optics. As next-generation synchrotrons usher in new orders of magnitude, it is critical to minimize these losses from carbon contamination. Multiple studies have shown that carbon contamination on the X-ray optics can be significant, and as next-generation synchrotrons usher in new orders of magnitude, it is critical to minimize these losses from carbon contamination. Multiple studies have shown that carbon contamination develops on X-ray optics and as next-generation synchrotrons usher in new orders of magnitude, it is critical to minimize these losses from carbon contamination.

What do collider phenomenologists do? I tend to prefer the term particle phenomenology because the collider is just the tool that we use. However, compared to other experiments, such as those searching for dark matter or axions, colliders provide a controlled laboratory where you decouple how many collisions and what energy these collisions should have. This is quite unique. Today, accelerators and detectors have reached an immense level of sophistication, and this allows us to perform a vast amount of fundamental measurements. So, the field spans precision measurements of fundamental properties of particles, in particular of the Higgs boson, consistency tests of the Standard Model (SM), direct and indirect searches for new physics, measurements of rare decays, and much more. For essentially all these topics we have had new results in recent years, so it’s a very active and continuously evolving field. But of course we do not just measure things for the sake of it. We have big, fundamental questions and we are looking for hints from LHC data as to how to address them.

What’s hot in the field today? One topic that I think is very cool is that we can benefit from the LHC, in its current setup, also as lepton collider. In fact, at the LHC we are looking at elementary collisions between the proton’s constituents, quarks and gluons. But since the proton is charged, it also emits photons, and one can talk about the photon parton distribution function (PDF), i.e. the photonic content of protons. These photons can split into lepton pairs, when one collides protons and one is also colliding leptons. The fascinating thing is that the “content” of leptons in protons is rather democratic, so one can look at collisions between, say, a muon and a tau lepton – something that can’t be done even at future proposed lepton colliders. Furthermore, by picking up a lepton from one proton and a quark from the other proton, one can place new constraints on leptoquarks, and plenty of other things. This idea was already proposed in the 1990s, but was essentially forgotten because the lepton PDF was not known. Now we know this very precisely, bringing new possibilities. But let me stress that this is just one idea – there are many other new ideas out there. For instance, one major branch of phenomenology is to use machine learning or deep learning to recognize the SM and extract from data what is not SM-like.

How does the Max Planck Institute differ from your previous positions, for example at CERN and Oxford? A long time ago, somebody told me that the best thing that can happen to you in Germany is the Max Planck Society. It’s true. You are given independence and the means to fully focus on research and ideas, largely free of teaching duties or the need to apply for grants. Also, there are very valuable interactions with universities, be it in research or via the international Max Planck Research Schools for PhD students. Our institute in Munich is a very unique place. One can feel it immediately. As a guest in the theory department, for example, you get to sit in the Heisenberg office, which feels like going back in time. Our institute was founded in Berlin in 1917 with Albert Einstein as a first director. In 1938 the institute moved to Munich with Werner Heisenberg as director. After more than 90 years I’m the first female director, which of course is a great responsibility. But I also really loved both CERN and Oxford. At CERN I felt like I was at the centre of the world. It is such a vibrant environment, and I loved the proximity to the experiments and the chats in the cafeteria about calculations or measurements. In Oxford I loved the multidisciplinary aspect, the dinners in college sitting next to other academics working in completely different fields. I guess I’m lucky that I’ve been in so many and such different places.

What is the biggest challenge to reach higher precision in quantum-field-theory calculations or measurements? The biggest challenge is that often there is no single biggest challenge. For instance, for inclusive Higgs boson production we have a number of theoretical uncertainties, but they are all quite comparable in size. This means that to reduce the overall uncertainty considerably, one needs to reduce all uncertainties, and they all have very different physics origins and difficulties – from a better understanding of the incoming parton densities and a better knowledge of the strong coupling constant, to higher order QCD or electroweak effects and effects related to heavy particles in virtual loops, etc. Computing power can be a limiting factor for certain calculations, so making things easier.

Theorist Giulia Zanderighi, collider phenomenologist and director at the Max Planck Institute for Physics, discusses fundamental physics at the boundary between theory and experiment.
When I entered the field as a student, the precision, but you can’t put a figure on it. Hit the wall in terms of experimental precision. Of course, if you have a super precise measurement, we are exploring deeper in the mass–versus–coupling plane.

Which collider should follow the LHC? That is the trillion-dollar question. To me one should go for the machines that explore as much as possible the new frontier, namely a 100 TeV hadron collider. It is a compromise between what we might be able to achieve from a machine–building/accelerator cost–benefit point of view and really exploring a new frontier. For instance, at a 100 TeV machine one can measure the Higgs self–coupling, which is intimately connected with the Higgs Georgi–professor to the precision question of the stability of the vacuum.

Which open question would you most like to see answered during your career? The question of the stability of the vacuum. The presence of dark matter is overwhelming in the universe and it is embarrassing to us scientists to nothing about its nature and properties. There are many, many exciting possibilities, ranging from the lightest neutral states to new physics models to a non–particle–like interpretation of the dark matter. Either way, an answer to this question would be an incredible breakthrough.
Beating cardiac arrhythmia

Accelerator engineer Adriano Garonna is CEO and co-founder of EBAMed, which is developing technologies to enable non-invasive treatments of heart arrhythmia using proton beams.

In December last year, a beam of protons was used to treat a patient with cardiac arrhythmia – an irregular beating of the heart that affects around 15 million people in Europe and North America alone. The successful procedure, performed at the National Center of Oncological Hadrontherapy (CNAO) in Italy, signalled a new application of proton therapy, which has been used to treat up to 100,000 cancer patients worldwide since the early 1990s.

In parallel to CNAO – which is based on accelerator technologies developed in conjunction with CERN via the TERA Foundation (CERN Courier January/February 2016 pp5) – a Geneva-based start-up called EBAMed (External Beam Ablation) founded by CERN alumnus Adriano Garonna aims to develop and commercialise image-guidance solutions for non-invasive treatments of heart arrhythmias. EBAMed’s technology is centred on an ultrasound imaging system that monitors a patient’s heart activity, interprets the motion, and sends a signal to the proton-therapy machine when the radiation should be sent. Once targeted, the proton beam ablates specific heart tissues to stop the electrical conduction of disrupted electrical signals.

Fast learner “Our challenge was to find a solution using the precision of proton therapy. The irregular moving target: the heart,” explains Garonna. “This device senses motion at a very fast rate, and we use machine learning to interpret the images in real time, which allows robust decision-making.”

Unlike other treatments, which can be lengthy and costly, he adds, patients can be treated as outpatients; the intervention is non-invasive and done under local anaesthesia.

The recipient of several awards – including TOP Innovator at the 2018 Swiss Entrepreneurship Business Plan 2018, MausChallenge 2018, Venture Kirk 2018 and IMD 2017 Start-up Competition – EBAMed recently received a €2.4 million grant from the European Union to fund product development and the first human tests.

Garonna’s professional journey began when he was a summer student at CERN in 2007, working on user-interface software for a new optical position-monitoring system at LHC Point 5 (CMS). Following his graduation, Garonna returned to CERN as a PhD student with the CERN Foundation and École Polytechnique Fédérale de Lausanne, and then as a fellow working for the Marie Curie programme PARTNER, attaining network for European radiotherapy. This led to a position as head of therapy accelerator commissioning at MedAustron in Austria – a facility for proton and ion therapy based, like CNAO, on TERA Foundation/CERN technology.

After helping deliver the first patient treatments at MedAustron, Garonna returned to CERN and entered informal discussions with TERA founder Ugo Amaldi, who was one of Garonna’s PhD supervisors, about how to take the technology further. Along with former CERN engineer Giovanni Leo and arrhythmia expert Douglas Packer, the group founded EBAMed in 2018.

“Being an entrepreneur was not my initial purpose, but I was fascinated by the project and convinced that a start-up was the best vehicle to bring it to market,” says Garonna. Not having a business background, he benefited from the CERN Knowledge Transfer entrepreneurship seminars as well as the support from the Geneva incubator Forgynd and courses organised by Innosuisse, the Swiss innovation agency. Garonna also drew on previous experience gained while working at CERN. “At CERN most of my projects involved exploring new areas. While I benefited from the support of my supervisors, I had to drive projects on my own, seek the right solutions and build the appropriate ecosystem to obtain results. This certainly developed an initiative-driven, entrepreneurial streak in me.”

Healthy competition Proton therapy is booming, with almost 100 facilities operating worldwide and more than 35 under construction. EBAMed’s equipment can be installed in any proton-therapy centre irrespective of its technology, says Garonna. “We already have prospective patients contacting us as they have heard of our device and wish to benefit from the treatment. As a company, we want to be the leaders in our field. We do have a US competitor, who has developed a planning system using conventional radiotherapy, and we are grateful that there is another player on the market as it helps pave the way to non-invasive treatments. Additionally, it is dangerous to be alone, as that could imply that there is no market in the first place.”

Leaving the security of a job to risk it all with a start-up is a gradual process, says Garonna. “It’s definitely challenging to jump into what seems like cold water… you have to think if it is worth the journey. If you believe in what you are doing, it will be worth it.”

Craig Edwards (based on material supplied by the Office for CERN Alumni Relations)
Following the re-election of Fabiola Gianotti as CERN Director-General last year, the CERN Council has approved the appointment of four directors for the period 2021–2023. Mike Lamont (pictured top left), a CERN accelerator physicist of more than 30 years and former deputy head of the beams department, has replaced Frédérick Bordry as director for accelerators and technology. Joachim Mnich (top right), who joined CERN in 2016, is reappointed as director for finance and human resources, replacing Martin Steinacher. Charlotte Warakaulle (bottom left), a CERN spokesperson, with Gautier Hamel de Monchenault and Phiala E Shanahan of MIT (below right), who joined CERN in 2016, is reappointed as director for international relations.

CMS management change

The CMS collaboration has announced its new management for the period 2020–2022. Former deputy spokesperson Luca Malgeri (pictured), who has been a CMS member since 2015, is now spokesperson, with Gérard Hamel de Monchenault and Jim Olson appointed deputy spokespersons.

Appointments and awards

2021 APS awards

Several outstanding particle physicists have been recognised by the 2021 spring awards of the American Physical Society (APS). The W K H Panofsky Prize in experimental particle physics has been awarded to Henry Sobel (pictured below left) of the University of California, Irvine and Edward Kears of Boston University (below right) for pioneering and leadership contributions to large underground experiments for the discovery of neutrino oscillations and sensitive searches for baryon number violation. The [T] Sakurai Prize for theoretical particle physics has been given to Vernon Barger (bottom left) of University of Wisconsin–Madison for pioneering work in collider physics contributing to the discovery and characterisation of the W boson, top quark and Higgs bosons, and for the development of inclusive strategies to test theoretical ideas with experiments. In the field of accelerators, Yuri Fyodorovich Orlov (below right), formerly of Cornell University, was awarded the Robert W Wilson Prize for his pioneering innovation in accelerator theory and practice. Orlov received the news shortly before his passing on 27 September.

Fabiola Gianotti wins energy prize

Carlo Rubbia is one of three winners of the 2021 Global Energy Prize for “the promotion of sustainable nuclear energy use and natural–gas policies”. The 39 million ruble (US$500,000) award was announced on 8 September in Kaluga, Russia by the Global Energy Association. Rubbia is more widely known as the winner, alongside Simon van der Meer, of the 1984 Nobel Prize in Physics, for using the SPS to discover the W and Z bosons, before being appointed CERN Director-General in 1989. There have been 42 winners of the annual prize, with 78 scientists from 20 countries put forward this year. Previous winners include former CERN Director-General, Robert Aymar, who was recognised in 2001 for work to develop the scientific and engineering foundation of the ITER project.

Pontifical appointment

On 29 September, Pope Francis appointed CERN Director-General Fabiola Gianotti to the Pontifical Academy of Sciences. Candidates for a seat in the academy are chosen “on the basis of their eminent original scientific studies and of their acknowledged moral personality, without any ethical or religious discrimination”. The body has formally existed since 1936 but its origins go back to 1663 with the founding of the Academy dei Lincei, to which Galileo Galilei was one of the first appointees. Other ordinary members of the academy today include Carlo Rubbia, Ed Witten and Juan Maldacena.

CMS management change

The CMS collaboration has announced its new management for the period 2020–2022. Former deputy spokesperson Luca Malgeri (pictured), who has been a CMS member since 2015, is now spokesperson, with Gérard Hamel de Monchenault and Jim Olson appointed deputy spokespersons.

Appointments and awards

2021 APS awards

Several outstanding particle physicists have been recognised by the 2021 spring awards of the American Physical Society (APS). The W K H Panofsky Prize in experimental particle physics has been awarded to Henry Sobel (pictured below left) of the University of California, Irvine and Edward Kears of Boston University (below right) for pioneering and leadership contributions to large underground experiments for the discovery of neutrino oscillations and sensitive searches for baryon number violation. The [T] Sakurai Prize for theoretical particle physics has been given to Vernon Barger (bottom left) of University of Wisconsin–Madison for pioneering work in collider physics contributing to the discovery and characterisation of the W boson, top quark and Higgs bosons, and for the development of inclusive strategies to test theoretical ideas with experiments. In the field of accelerators, Yuri Fyodorovich Orlov (below right), formerly of Cornell University, was awarded the Robert W Wilson Prize for his pioneering innovation in accelerator theory and practice. Orlov received the news shortly before his passing on 27 September.

Fabiola Gianotti wins energy prize

Carlo Rubbia is one of three winners of the 2021 Global Energy Prize for “the promotion of sustainable nuclear energy use and natural–gas policies”. The 39 million ruble (US$500,000) award was announced on 8 September in Kaluga, Russia by the Global Energy Association. Rubbia is more widely known as the winner, alongside Simon van der Meer, of the 1984 Nobel Prize in Physics, for using the SPS to discover the W and Z bosons, before being appointed CERN Director-General in 1989. There have been 42 winners of the annual prize, with 78 scientists from 20 countries put forward this year. Previous winners include former CERN Director-General, Robert Aymar, who was recognised in 2001 for work to develop the scientific and engineering foundation of the ITER project.

Pontifical appointment

On 29 September, Pope Francis appointed CERN Director-General Fabiola Gianotti to the Pontifical Academy of Sciences. Candidates for a seat in the academy are chosen “on the basis of their eminent original scientific studies and of their acknowledged moral personality, without any ethical or religious discrimination”. The body has formally existed since 1936 but its origins go back to 1663 with the founding of the Academy dei Lincei, to which Galileo Galilei was one of the first appointees. Other ordinary members of the academy today include Carlo Rubbia, Ed Witten and Juan Maldacena.

CMS management change

The CMS collaboration has announced its new management for the period 2020–2022. Former deputy spokesperson Luca Malgeri (pictured), who has been a CMS member since 2015, is now spokesperson, with Gérard Hamel de Monchenault and Jim Olson appointed deputy spokespersons.

Appointments and awards

2021 APS awards

Several outstanding particle physicists have been recognised by the 2021 spring awards of the American Physical Society (APS). The W K H Panofsky Prize in experimental particle physics has been awarded to Henry Sobel (pictured below left) of the University of California, Irvine and Edward Kears of Boston University (below right) for pioneering and leadership contributions to large underground experiments for the discovery of neutrino oscillations and sensitive searches for baryon number violation. The [T] Sakurai Prize for theoretical particle physics has been given to Vernon Barger (bottom left) of University of Wisconsin–Madison for pioneering work in collider physics contributing to the discovery and characterisation of the W boson, top quark and Higgs bosons, and for the development of inclusive strategies to test theoretical ideas with experiments. In the field of accelerators, Yuri Fyodorovich Orlov (below right), formerly of Cornell University, was awarded the Robert W Wilson Prize for his pioneering innovation in accelerator theory and practice. Orlov received the news shortly before his passing on 27 September.

Fabiola Gianotti wins energy prize

Carlo Rubbia is one of three winners of the 2021 Global Energy Prize for “the promotion of sustainable nuclear energy use and natural–gas policies”. The 39 million ruble (US$500,000) award was announced on 8 September in Kaluga, Russia by the Global Energy Association. Rubbia is more widely known as the winner, alongside Simon van der Meer, of the 1984 Nobel Prize in Physics, for using the SPS to discover the W and Z bosons, before being appointed CERN Director-General in 1989. There have been 42 winners of the annual prize, with 78 scientists from 20 countries put forward this year. Previous winners include former CERN Director-General, Robert Aymar, who was recognised in 2001 for work to develop the scientific and engineering foundation of the ITER project.

Pontifical appointment

On 29 September, Pope Francis appointed CERN Director-General Fabiola Gianotti to the Pontifical Academy of Sciences. Candidates for a seat in the academy are chosen “on the basis of their eminent original scientific studies and of their acknowledged moral personality, without any ethical or religious discrimination”. The body has formally existed since 1936 but its origins go back to 1663 with the founding of the Academy dei Lincei, to which Galileo Galilei was one of the first appointees. Other ordinary members of the academy today include Carlo Rubbia, Ed Witten and Juan Maldacena.
JOIN US!
The future is in laser technologies

We are ready to design and build this accelerator. Are you?

At MYRHA (www.myrha.be), based in Mol, Belgium, we firmly believe that our unique research facility must serve society. That’s why we’re building an Accelerator Driven System (ADS): our sub-critical lead–bismuth cooled reactor will be driven by a super conducting, high power proton linear accelerator.

“Building the most reliable accelerator in the world is a challenge that appeals to me.”
Angélique Gatéra

Our goal is to build the first 100 MeV stage of the superconducting, high power proton linear. This includes selecting systems and components with redundancy and extreme reliability in mind. Join a community of energetic explorers! We are looking for your expertise in many accelerator technology fields.

For now we are looking for a:
- Head of the accelerator group
- Beamline Engineering
- Beam Diagnostics Engineer
- Project engineer (control system)
- Power converter engineer
- …

Are you searching for a challenge that contributes to solving some of society’s most important issues, such as closing the nuclear fuel cycle, transforming the lives of cancer patients or conducting fundamental physics research?

Don’t look any further and apply!


Find more information and apply at: bit.ly/MSSL_MSc

DATA SCIENTIST / SOFTWARE DEVELOPER
EXCITING CAREERS FOR STEM GRADUATES AND POSTGRADUATES

Tessella is one of the world’s leading data science and AI consultancies. We are scientists and engineers who enjoy solving the real-world technical challenges faced by companies at the forefront of science and technology. Using a combination of deep domain knowledge and technical expertise, we work with our clients to unlock the value held within their data, enabling better-informed business decisions.

Our projects are varied and typically at the cutting-edge of high-tech R&D, for example:

- Solving computational problems for chemists in drug discovery and development.
- Modelling and simulating new products for FMCG clients and analyzing data to improve processes.
- Writing algorithms and solving complex mathematical problems to control satellites and radar systems.
- Solving the computational challenges of oil and gas exploration and production, from reservoir modelling to writing control systems.

We are looking for science, mathematics and engineering graduates and postgraduates to join us. Supported by our extensive training package, you will apply your deep domain knowledge and use a range of skills to create and develop innovative solutions that truly make a difference in the world.

careers.tessella.com | jobs@tessella.com

INVESTORS IN PEOPLE®
We invest in people

Tessella
•ALTRAN GROUP

Department of Space and Climate Physics

Now accepting applications for:

MSc Space Science and Engineering

The space industry is a multi-billion pound industry in the UK and is growing world-wide. In a programme taught by the UK’s largest university space science department, learn how to design a space mission from payload selection to launch and operation. Taking the Space Technology pathway, you will learn cutting edge space applications for science and technology including mechanical and electrical design of satellites.

The Space Science pathway prepares you for a career in the exciting fields of experimental solar-, planetary- or astro- physics. Learn how to design and operate scientific instrument in space from scientists and engineers that work on ESA and NASA missions.

Find more information and apply at: bit.ly/MSSL_MSc

MSc Space Risk and Disaster Reduction

In an increasingly technological and globally connected world, risks to space-based communications systems and critical infrastructure are emerging threats to national security and businesses.

This unique programme unites emergency response, disaster risk reduction and space technology, you will learn about satellite technology, mission design, hazards and vulnerabilities unique to outer space, and the monitoring of hazards on Earth from outer space. Taught jointly with the Institute of Risk and Disaster Reduction, this programme is a blend of disaster science and space technology.

Find more information and apply at: bit.ly/MSSL_MSc
Horst Wenninger 1938–2020
Relishing the CERN adventure

Horst Wenninger, who played key roles in the approval of the LHC and in establishing knowledge transfer at CERN, passed away in July. Horst was universally trusted and his advice was sought regularly by colleagues. He knew his way around CERN like no one else, and played key roles in the approval of the LHC and in establishing knowledge transfer at CERN.

Horst at his retirement party at CERN in 2003.

Horst was appointed as a leader of the accelerator technology division, providing support for Omega, UA1 and other experiments. At the end of his career he was asked to provide guidance for the FAIR project at GSI Darmstadt, where he was instrumental in arranging the involvement of CERN accelerator experts and later served as the director of the LHC project.

Horst’s five-year term as CERN research and technical director began in 1996 – the year LHC approval was expected. The day before the crucial vote by the CERN Council in December of that year, the German delegation was still not authorized to vote in support of the project. In a late-night action Horst managed to arrange contact with the head of the German chancellor, with the mission to sway the minister responsible for the decision. His cryptic reaction was conveniently interpreted by the supportive German delegate as a green light, a determined move for the good of CERN. Horst was later awarded the Order of Merit (First Class) of the German Republic.

Horst left his mark on CERN. The wider community also benefited immensely from his contributions in advisory roles throughout his active life. We have lost an outstanding colleague and a true friend for all of us.

John Thompson 1930–2020
A first rate, hands-on physicist

John Thompson, a senior physicist at the UK’s Rutherford Appleton Laboratory (RAL), passed away on 20 August.

John obtained his PhD in nuclear physics for work on the Van de Graaff accelerator at the University of Liverpool in the early 1960s before moving to the University of Manitoba, Canada to work on particle physics. He then took a post at Daresbury Laboratory in the UK to work on experiments using the 5 GeV electron synchrotron, NINA. His group developed a measurement of the total hadron production cross sections for energies from 1 to 4 GeV. These precise measurements have been superseded and remain the definitive values documented by the Particle Data Group.

John was central to the formation of Daresbury’s LAMP group, which focused on a series of hadronic production experiments. He played a leading role in the development of the 40-keV bubble-chamber at RAL and in the high-intensity beam measurement campaign at CERN. As NINA came to the end of its life at Daresbury and LAMP moved to a second site of operation at CERN, John worked hard to ensure that the group maintained the task of building the end-cap electromagnetic calorimeters, which worked successfully during the early years of the LEP operation. John became involved with early results for which the calorimeter performance was crucial, such as its use in counting the number of neutrino species from the radiative return reaction e+ + e− → γνν. During the LEP period to the late 1990s, John’s major contribution concerned the measurement of the W mass and width. This led to a highly productive collaboration between the Imperial, College and RAL ALEPH teams, and saw John become instrumental in guiding

David Newton 1937–2020
Focusing on photons

David Newton was an excellent teacher, physicist, he then took a position at Lawrence Berkeley National Laboratory in the US, returning to the UK in 1968 as a lecturer in physics at the recently formed particle-physics group at Lancaster University. He quickly became interested in high-energy photon interactions, initially carrying out experiments at the Rutherford Laboratory.

Following his postgraduate studies in particle physics, he then took a position at Lawrence Berkeley National Laboratory in the US, returning to the UK in 1968 as a lecturer in physics at the recently formed particle-physics group at Lancaster University. He quickly became interested in high-energy photon interactions, initially carrying out experiments at the Rutherford Laboratory.

David Newton was an excellent teacher, physicist, he then took a position at Lawrence Berkeley National Laboratory in the US, returning to the UK in 1968 as a lecturer in physics at the recently formed particle-physics group at Lancaster University. He quickly became interested in high-energy photon interactions, initially carrying out experiments at the Rutherford Laboratory.

David Newton was an excellent teacher, physicist, he then took a position at Lawrence Berkeley National Laboratory in the US, returning to the UK in 1968 as a lecturer in physics at the recently formed particle-physics group at Lancaster University. He quickly became interested in high-energy photon interactions, initially carrying out experiments at the Rutherford Laboratory.

David Newton was an excellent teacher, physicist, he then took a position at Lawrence Berkeley National Laboratory in the US, returning to the UK in 1968 as a lecturer in physics at the recently formed particle-physics group at Lancaster University. He quickly became interested in high-energy photon interactions, initially carrying out experiments at the Rutherford Laboratory.

David Newton was an excellent teacher, physicist, he then took a position at Lawrence Berkeley National Laboratory in the US, returning to the UK in 1968 as a lecturer in physics at the recently formed particle-physics group at Lancaster University. He quickly became interested in high-energy photon interactions, initially carrying out experiments at the Rutherford Laboratory.
Ronald Fortune 1929–2019

At CERN from its beginnings

Experimental physicist Ronald Fortune, who joined CERN’s first nuclear research group in January 1956, passed away on 16 June 2019 at the age of 90.

Ron graduated with a degree in physics and mathematics from the University of Aberdeen, UK, before joining electrical engineering firm AAI in Manchester, where he acquired valuable practical training in several departments and research experience in high-voltage techniques and electronics–microscope design. This training was put to immediate use in his first post as scientific officer in the British Royal Nuclear Science Service, where he developed automated instrumentation for the study of atomic–weapon explosions at the Weapon testing range in Australia.

Ron’s main career was as a senior scientist at CERN, where he spent 17 years engaged in a wide variety of projects. This included six years in high–energy physics research studying k-mesons, relativistic ionization and the magnetic hunting for quarks, during which Ron pioneered methods for identifying high–energy particles by measurement of their momentum and ionizing power, and developed high–precision optical generating a happy and productive atmosphere;

An intense career cut short

Philippe Mermod, a member of the ATLAS and SHiP collaborations at CERN, passed away on 20 August.

Born in Geneva in 1978, Philippe obtained his Master’s degree in 2002 from the University of Geneva and his PhD in 2006 from Uppsala University in Sweden. He joined ATLAS in 2007, affiliated first with Stockholm University and then with the University of Oxford and, in 2011, rejoined the University of Geneva as a research associate, becoming assistant professor in 2014.

Philippe made several contributions to ATLAS. Among them, he pioneered the search for displaced heavy neutral leptons and led the effort on the search for highly ionising particles in Run 2. He also made important contributions to the trigger system. Philippe’s preferred topic was the search for magnetic monopoles, which he participated in the proposed SHiP experiment. Moreover, he recently made significant contributions to the design and construction of the time–of–flight detector for the near–detector upgrade of the T2K collaboration in Japan; this is the first modern neutrino detector applying this technology.

Philippe was an intense scientist, curious to explore new paths, who devoted his attention and efforts to fundamental phenomena and who sought the answer to questions rather than personal promotion. He was also an active citizen, concerned of the needs for fairness and sustainability. If humanity was to have a future, whether he would see it himself or, alas, not. We will miss his energy, ideas and vision.

His colleagues and friends
Notes and observations from the high-energy physics community

End-of-year crossword

Pit your wits against fellow CERN Courier readers and review the year in particle physics with our inaugural cryptic crossword, compiled by associate editor Mark Rayner. The first correct entry to reach cern.courier@cern.ch will win a mystery prize.

Across
1 Amount of data collected so far at the LHC (4,2,3,6)
2 Robert, François and Peter seem to have predicted this coupling correctly too (4)
3 Control and monitoring software beloved of DAQ experts like Gilgamesh (5)
4 Unstable academic position discovered by the Curies (2)
5 Parenthetical quantum state (3)
6 Figurative status of a Director-General with a fresh mandate (4,2,3,6)
7 Denis Villeneuve’s sci-fi epic (5,10)
8 Byes-by for now to Homi Bhabha’s institute (4)
9 Once again the world’s most luminous lab – the belle of the ball, you might say (2)
10 Letters bestowed to avoid paying grad students (2)
11 Cosmic plumber, fixed a leak for $100 million (4,9)
12 Cosmic plumber, fixed a leak for $10 million (4,3,3)
13 No wimps allowed in this noble medium – but maybe axions? (2)
14 Biological effectiveness is a factor for this absolute unit (2)
15 Status of baguette after LHC switched on (5)
16 Serious lattice constant? new microwave looks closed but not flat (6)
17 Simon says focus your neutrons beams with this (4)
18 Elemental for sporting neutrinos, according to Yankee timekeepers (2)
19 NAK’s neutral beam will first knock off trillions o’background (4)
20 Could symmetries actually emerge here, initially, and dissolve in the extreme ultraviolet? (2)
21 Island lab to ditch an ion for an electron by the end of the decade (10)
22 Ideal surrogate for academic preeminence – enough to drive colleagues to do a backflip (2)
23 Presidential huygen that decays to a hyperon and a pion (2)
24 Initially, a European bid to triangulate gravitational waves (2)
25 Now dissolved in a super detector, will tag neutrinos in a flash (10)
26 Lab with emissions equivalent to a cruise liner, says new report (4)

Down
1 Tunnel vision
2 From the archive: November 1980
3 No wimps allowed in this noble medium – but maybe axions? (2)
4 Experimental for sporting neutrinos, according to Yankee timekeepers (2)
5 Elemental for sporting neutrinos, according to Yankee timekeepers (2)
6 Ideal surrogate for academic preeminence – enough to drive colleagues to do a backflip (2)
7 Presidential huygen that decays to a hyperon and a pion (2)
8 Initially, a European bid to triangulate gravitational waves (2)
9 Now dissolved in a super detector, will tag neutrinos in a flash (10)
10 Lab with emissions equivalent to a cruise liner, says new report (4)

From the archive: November 1980

Tunnel vision

On 18 September 1980 the CERN Finance Committee approved a contract with a Franco–Swiss consortium for a tunnel under the Jura mountains, where it is planned to build the large electron–positron storage ring, LEPI. Ten kilometres of LEP’s 30 km circumference would pass under the Jura and, though the probable tunnelling conditions around the rest of the ring are known from SPS construction experience, it is felt important to gain knowledge of the sub-Jura conditions before launching the project.

Based on CERN Courier November 1980 p345.

Publisher’s note

The LEPI tunnel, Europe’s largest civil-engineering project prior to the Channel Tunnel, will serve the physics community well for half a century. It housed LEPI from 1989 until 2009, when it was recycled to accommodate the LHC, which is expected to run with increased luminosity until around 2038.

Another? On 19 June the CERN Council approved an update to the European strategy for particle physics, recommending further studies towards a huge somewhere future Circular Collider at CERN. If that, the FCC will be a dream project for tunnel engineers. The region around CERN will confront the more with another every known subterranean challenge, going where no tunnel has gone before (CERN Courier Sept/Oct 2019 p26).
Desktop and NIM modules

NEW DT1081A - N1081A
Four-Fold Programmable Logic Unit

Make your set-up flexible with local and remote configuration

The DT1081A and N1081A are innovative laboratory tools that incorporate in a single module the most common functionalities that you need to implement the logic capabilities of your experiment.

Wide range of user-selectable functionalities:
- Touch screen and Web interface for easy programming and optimal user-experience
- User-friendly widgets to configure each section, monitor real-time output data and access the online help
- Ethernet (1 Gbps) and USB2.0 connectivity

A new CAEN Tool in your Laboratory!

www.caen.it
Small details... Great differences