WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the January/February 2018 issue of *CERN Courier*.

Proton therapy was first administered in a patient at Berkeley National Laboratory in September 1954, the same month CERN was founded. The breakthrough followed the invention of the cyclotron, and the relationship between high-energy physicists and oncologists has grown closer ever since. This issue of the *Courier* takes a look at some of the medical applications of accelerators, in particular for particle therapy. Hadron beams can allow tumours to be targeted more precisely than conventional radiotherapy and the number of centres is growing rapidly across Europe, for example thanks to efforts such as the TERA Foundation. A shift to more compact linac-driven treatment centres, meanwhile, promises to expand access to particle and radiotherapy in the challenging environments of low- and middle-income countries, where cancer rates are predicted to be highest in the coming decades. Accelerator technology is also bringing new opportunities in radioisotope production for theragnostics and advanced treatment modes, as exemplified by the recently completed MEDICIS research facility at CERN, while detector and computing technology from particle physics continue to have a major impact on medical imaging and treatment planning.

Also distributed with the January/February 2018 print issue is the inaugural *Courier* year-planner, copies of which can be obtained by getting in touch at **cern.courier@cern.ch**.

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Contents

Covering current developments in high-energy physics and related fields worldwide

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CERN COURIER

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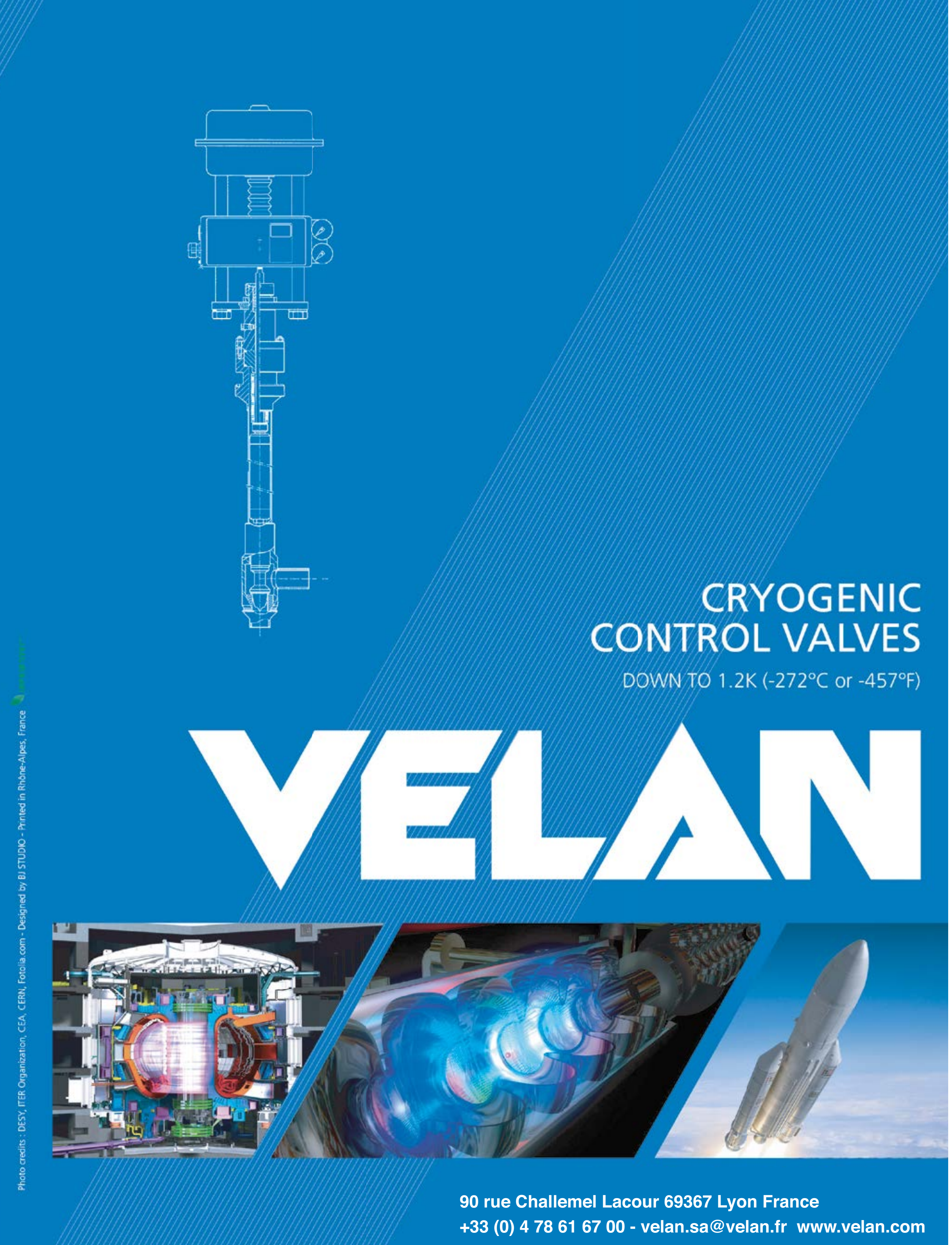
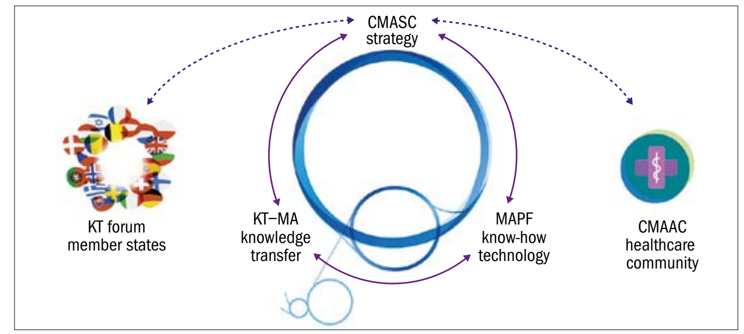
On the cover: A patient receiving radiotherapy for cancer.



Viewpoint

Strategic step for medical impact

Knowledge transfer for the benefit of medical applications is a thriving part of CERN's programme.



CERN's "medtech" strategy, showing the relationship between the KT–MA (KT Medical Applications section), CMASC (CERN Medical Applications Steering Committee), CMAAC (CERN Medical Applications Advisory Committee) and MAPF (Medical Applications Project Forum).

By Frédérick Bordry

Innovative ideas and technologies from physics have contributed to great advances in medicine, in particular radiation-based medical diagnosis and treatment. Today, state-of-the-art techniques derived from particle physics research are routinely used in clinical practice and medical research centres: from technology for PET scanners and dedicated accelerators for cancer therapy (see p32), to simulation and data analysis tools.

Transferring CERN's know-how to other fields is an integral part of its mission. Over the past 60 years, CERN has developed widely recognised expertise and unique competencies in particle accelerators, detectors and computing. While CERN's core mission is basic research in particle physics, these "tools of the trade" have found applications in a variety of fields and can have an impact far beyond their initial expectations. An excellent recent example is the completion of CERN MEDICIS, which uses a proton beam to produce radioisotopes for medical research (see p29).

Knowledge transfer (KT) for the benefit of medical applications has become an established part of CERN's programme, formalised within the KT group. CERN has further initiated numerous international and multidisciplinary collaborations, partially or entirely devoted to technologies with applications in the medical field, some of which have been funded by the European Commission (EC). Until recently, the transfer of knowledge and technology from physics to medicine at CERN has essentially been driven by enthusiastic individuals on an ad hoc basis. In light of significant growth in medical applications-related activities, in 2017 CERN published a formal medical applications strategy (approved by the Council in June).

Its aims are to ensure that medical applications-related knowledge transfer activities are carried out without affecting CERN's core mission of fundamental research, are relevant to the medical community and delivered within a sustainable funding model.

The focus is on R&D projects using technologies and infrastructures that are uniquely available at CERN, seeking to minimise any duplication of efforts taking place in Member States and associate Member States. The most promising CERN technologies and infrastructure that are relevant to the medical domain shall be identified – and the results matched with the requirements of the medical research communities, in particular in CERN's Member States and associate Member States. Projects shall then be identified, taking into account such things as: maximising the impact of CERN's engagement; complementarities with work at other laboratories; and the existence of sufficient external funding and resources.

CERN's medical applications-related activities are co-ordinated by the CERN KT medical applications section, which also negotiates the necessary agreements with project partners. A new KT thematic forum, meanwhile, brings together CERN and Member State representatives to exchange information and ideas about medical applications (see p46). The CERN Medical Applications Steering Committee (CMASC) selects, prioritises, approves and coordinates all proposed medical applications-related projects. The committee receives input from the Medical Applications Project Forum (MAPF), the CERN Medical Applications Advisory Committee (CMAAC) and various KT bodies.

Although CERN can provide a limited amount of seed funding for medical applications projects, external stakeholders must provide the funding needed to deliver their project. Additional funding may be obtained through the EC Framework Programmes, and the CERN & Society Foundation is another potential source.

The transfer of know-how and technologies from CERN to the medical community represents one of the natural vehicles for CERN to disseminate the results of its work to society as widely as possible. The publication of a formal strategy document represents an important evolution of CERN's program and highlights its commitment to maximise the societal impact of its research and to transfer CERN's know-how and technology to its Member States and associate Member States.

Frédérick Bordry is CERN director for accelerators and technology and chair of the CMASC.

News

ACCELERATORS

International committee backs 250 GeV ILC

On 7 November, during its triennial seminar in Ottawa, Canada, the International Committee for Future Accelerators (ICFA) issued a statement of support for the International Linear Collider (ILC) as a Higgs-boson factory operating at a centre-of-mass energy of 250 GeV. That is half the energy set out five years ago in the ILC's technical design report (TDR), shortening the length of the previous design (31 km) by around a third and slashing its cost by up to 40%.

The statement follows physics studies by the Japanese Association of High Energy Physicists (JAHEP) and Linear Collider Collaboration (LCC) outlining the physics case for a 250 GeV Higgs factory. Following the 2012 discovery of the Higgs boson, the first elementary scalar particle, it is imperative that physicists undertake precision studies of its properties and couplings to further scrutinise the Standard Model. The ILC would produce copious quantities of Higgs bosons in association with Z bosons in a clean electron–positron collision environment, making it complementary to the LHC and its high-luminosity upgrade.

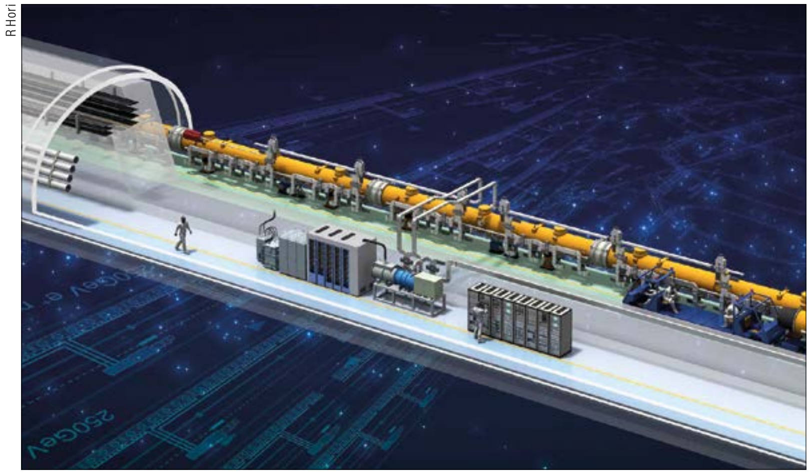
One loss to the ILC physics program would be top-quark physics, which requires a centre-of-mass energy of around 350 GeV. However, ICFA underscored the extendibility of the ILC to higher energies via improving the acceleration technology and/or extending the tunnel length – a unique advantage of linear colliders – and noted the large discovery potential accessible beyond 250 GeV. The committee also reinforced the ILC as an international project led by a Japanese initiative.

Thanks to experience gained from advanced X-ray sources, in particular the European XFEL in Hamburg (*CERN Courier* July/August 2017 p25), the superconducting radiofrequency (SRF) acceleration technology of the ILC is now well established. Achieving a 40% cost reduction relative to the TDR price tag of $7.8 billion also requires new "nitrogen-infusion" SRF technology recently discovered at Fermilab.

"We have demonstrated that with nitrogen doping a factor-three improvement in the cavity quality-factor is realisable in large scale machines such as LCLS-II, which can bring substantial cost reduction for the ILC and all future SRF machines," explains Fermilab's Anna Grassellino, who is leading the SRF R&D. "With nitrogen doping at low temperature, we are now paving the way for simultaneous improvement of efficiency and accelerating gradients of SRF cavities. Fermilab, KEK, Cornell, JLAB and DESY are all working towards higher gradients with higher quality factors that can be realised within the ILC timeline."

With the ILC having been on the table for more than two decades, the linear-collider community is keen that the machine's future is decided soon. Results from LHC Run 2 are a key factor in shaping the physics case for the next collider, and important discussions about the post-LHC accelerator landscape will also take place during the update of the European Strategy for Particle Physics in the next two years.

"The Linear Collider Board strongly supports the JAHEP proposal to construct a 250 GeV ILC in Japan and encourages the Japanese government to give the proposal serious consideration for a timely decision," says LCC director Lyn Evans.



R Hori

Plans for the International Linear Collider, an electron–positron collider to complement the LHC, have been scaled back in light of developments in the field.

Further reading

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S Asai *et al.* 2017 arXiv:1710.08639.
L Evans & S Michizono 2017 arXiv:1711.00568.

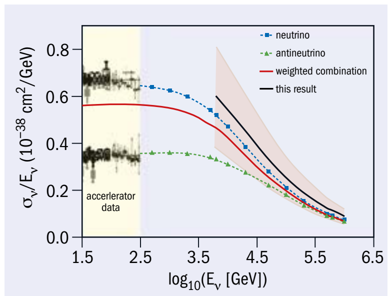
Sommaire en français

NEUTRINOS

The case of the disappearing neutrinos

Neutrinos are popularly thought to penetrate everything owing to their extremely weak interactions with matter. A recent analysis by the IceCube neutrino observatory at the South Pole proves this is not the case, confirming predictions that the neutrino-nucleon interaction cross section rises with energy to the point where even an object as tiny as the Earth can stop high-energy neutrinos in their tracks.

By studying a sample of 10,784 neutrino events, the IceCube team found that neutrinos with energies between 6.3 and 980 TeV were absorbed in the Earth. From this, they concluded that the neutrino–nucleon cross-section was $1.30^{+0.21}_{-0.19}$ (stat) $^{+0.39}_{-0.43}$(syst) times the Standard Model (SM) cross-section in that energy range. IceCube did not observe a large increase in the cross-section as is predicted in some models of physics beyond the SM, including those with leptoquarks or extra dimensions.



The neutrino cross-section, divided by the neutrino energy, as measured by IceCube (black line, with shaded regions showing the one-sigma uncertainties), along with previous accelerator data (points in yellow-shaded region). At low energies the cross-section is proportional to the neutrino energy, while above about 3 TeV the increase slows due to the finite W and Z masses.

The analysis used the 1 km^3 volume of IceCube to collect a sample of upward-going muons produced by neutrino interactions in the rock and ice below and around the detector, selecting 10,784 muons with an energy above 1 TeV. Since the zenith angles of these neutrinos are known to about one degree, the absorber thickness can be precisely determined. The data were compared to a simulation containing atmospheric and astrophysical neutrinos, including simulated neutrino interactions in the Earth such as neutral-current interactions. Consequently, IceCube extended previous accelerator measurements upward in energy by several orders of magnitude, with the result in good agreement with the SM prediction (see figure, above).

Neutrinos are key to probing the deep structure of matter and the high-energy universe, yet until recently their interactions had only been measured at laboratory energies up to about 350 GeV. The high-energy neutrinos detected by IceCube, partially of astrophysical origin, provide an opportunity to measure their interactions at higher energies.

In an additional analysis of six years of IceCube data, Amy Connolly and Mauricio Bustamante of Ohio State University employ an alternative approach which uses 58 IceCube-contained events (in which the neutrino interaction took place within the detector) to measure the neutrino cross-section. Although these events mostly have well-measured energies, their neutrino zenith angles are less well known and they are also much less numerous, limiting the statistical precision.

Nevertheless, the team was able to measure the neutrino cross-section in four energy bins from 18 TeV to 2 PeV with factor-of-ten uncertainties, showing for the first time that the energy dependence of the cross section above 18 TeV agrees with the predicted softer-than-linear dependence and reaffirming the absence of new physics at TeV energy scales.

Future analyses from the IceCube Collaboration will use more data to measure the cross-sections in narrower bins of neutrino energy and to reach higher energies, making the measurements considerably more sensitive to beyond-SM physics. Planned larger detectors such as IceCube-Gen2 and the full KM3NeT can push these measurements further upwards in energy, while even larger detectors would be able to search for the coherent radio Cherenkov pulses produced when neutrinos with energies above 10^{17} eV interact in ice.

Proposals for future experiments such as ARA and ARIANNA envision the use of relatively-inexpensive detector arrays to instrument volumes above 100 km^3, enough to measure "GZK" neutrinos produced when cosmic-rays interact with the cosmic-microwave background radiation. At these energies, the Earth is almost opaque and detectors should be able to extend cross-section measurements above 10^{19} eV, thereby probing beyond LHC energies.

These analyses join previous results on neutrino oscillations and exotic particle searches in showing that IceCube can also contribute to nuclear and particle physics, going beyond its original mission of studying astrophysical neutrinos.

Further reading

IceCube Collaboration 2017 *Nature* **551** 596.
M Bustamante and A Connolly 2017 arXiv:1711.11043.

NUCLEAR PHYSICS

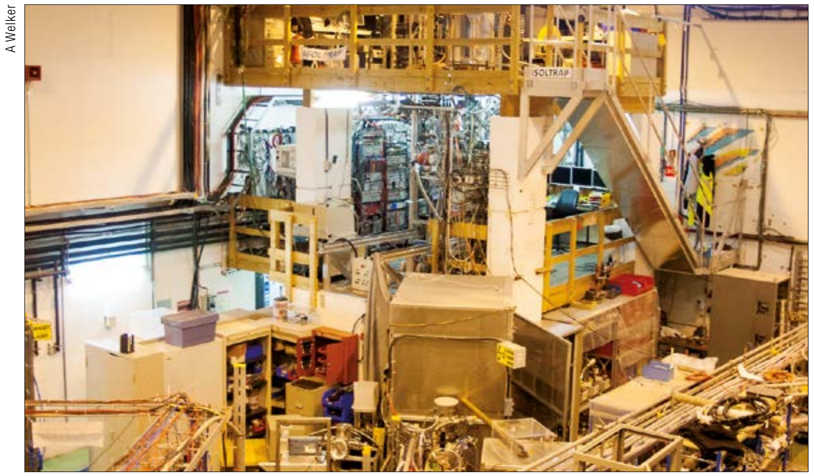
Copper reveals nickel's doubly magic nature

Teams at CERN's ISOLDE facility and at RIKEN in Japan have found evidence that an exotic isotope of the metallic element nickel (^{78}Ni) is doubly magic, opening a new vista on an important region of the nuclear-stability chart.

Like electrons in an atom, protons and neutrons in a nucleus have a penchant for configurations that offer extra stability, called magic numbers. Nuclei that have magic numbers of both protons and neutrons are of particular interest for understanding how nucleons bind together. Examples are ^{16}O, containing eight protons and eight neutrons, and ^{40}Ca (20 protons and 20 neutrons), both of which are stable nuclides.

One of the main efforts in modern nuclear physics is to create systems at the extremes of nuclear stability to test whether these magic numbers, and the nuclear shell model from which they derive, are still valid. Two usual suspects are ^{132}Sn (with a half-life of 40 s) and ^{78}Ni (0.12 s). Sn (tin) is the element with the highest number of stable isotopes (10), attesting to the magic nature of its 50 protons.

A Welker



The mass spectrometer setup ISOLTRAP at CERN's ISOLDE radioactive-beam facility.

The next magic number is 82, corresponding to the number of neutrons in ^{132}Sn. Nickel has a magic number of 28 protons but the recipe for adding the magic 50 neutrons to make ^{78}Ni has proven challenging for today's radioactive beam factories. CERN's ISOLDE facility has now got very close, taking researchers to the precipice via nickel's nuclear neighbour ^{79}Cu containing 50 neutrons and 29 protons.

Andree Welker of TU Dresden and collaborators used ISOLDE's precision mass spectrometer ISOLTRAP to determine the masses and thus binding energies of the neutron-rich copper isotope ^{79}Cu, revealing that this next-door neighbour of ^{78}Ni also exhibits a binding-energy enhancement. To probe the enhancement, Ruben de Groote of KU Leuven and collaborators used another setup at ISOLDE called CRIS to measure the electromagnetic moments of the odd-N neighbour ^{78}Cu, providing detailed information about the underlying wave functions. Both the ISOLTRAP masses and the CRIS moments were compared with large-scale shell-model calculations involving the many relevant orbitals. Both are in excellent agreement with the ISOLDE results, suggesting that the predictions for the neighbouring ^{78}Ni can be taken with great confidence.

An independent study of ^{79}Cu carried out by Louis Olivier at the IN2P3–CNRS in France and colleagues based on a totally different technique has reached the same conclusion. Using in-beam gamma-ray spectroscopy of ^{79}Cu at the Radioactive Isotope Beam Factory at RIKEN in Japan, the team produced ^{79}Cu via proton "knockout" reactions in a 270 MeV beam of ^{80}Zn. No significant knockout was observed in the relevant energy region, showing that the ^{79}Cu nucleus can be described in terms of a valence proton outside a ^{78}Ni core and affirming nickel's doubly magic character.

Further reading

R de Groote *et al.* 2017 *Phys. Rev. C* **96** 041302.
L Olivier *et al.* 2017 *Phys. Rev. Lett.* **119** 192501.
A Welker *et al.* 2017 *Phys. Rev. Lett.* **119** 192502.

MEDICAL APPLICATIONS

Novartis acquires CERN spin-off

Global healthcare company Novartis has announced plans to acquire Advanced Accelerator Applications (AAA), a spin-off radiopharmaceutical firm established by former CERN physicist Stefano Buono in 2002. With an expected price of $3.9B, said the firm in a statement, the acquisition will strengthen Novartis' oncology portfolio by introducing a new therapy platform for tackling neuroendocrine tumours. Trademarked Lutathera, and based on the isotope lutetium-177, the technology was approved in Europe in September 2017 for the treatment of certain neuroendocrine tumours and is under review in the US.

AAA

AAA's headquarters in Saint-Genis-Pouilly, France, just across the border from CERN.

With its roots in nuclear-physics expertise acquired at CERN, AAA started its commercial activity with the production of radiotracers for medical imaging. The successful model made it possible for AAA to invest in nuclear research to produce innovative radiopharmaceuticals. "We believe that the combination of our expertise in radiopharmaceuticals and theragnostic strategy together with the global oncology experience and infrastructure of Novartis, provide the best prospects for our patients, physicians and employees, as well as the broader nuclear medicine community," said Buono, who is CEO of AAA.

Computing

Fermilab joins CERN openlab on data reduction


R Hradil

CERN's computing centre, photographed in 2017.

In November, Fermilab became a research member of CERN openlab – a public-private partnership between CERN and major ICT companies established in 2001 to meet the demands of particle-physics research. Fermilab researchers will now collaborate with members of the LHC's CMS experiment and the CERN IT department to improve technologies related to physics data reduction, which is vital for gaining insights from the vast amounts of data produced by high-energy physics experiments.

The work will take place within an existing CERN openlab project with Intel on big-data analytics. The goal is to use industry-standard big-data tools to create a new tool for filtering many petabytes of heterogeneous collision data to create manageable, but still rich, datasets of a few terabytes for analysis. Using current systems, this kind of targeted data reduction can often take weeks, but the Intel-CERN project aims to reduce it to a matter of hours.

The team plans to first create a prototype capable of processing 1 PB of data with about 1000 computer cores. Based on current projections, this is about one twentieth of the scale of the final system that would be needed to handle the data produced when the High-Luminosity LHC comes online in 2026. "This kind of work, investigating big-data analytics techniques is vital for high-energy physics — both in terms of physics data and data from industrial control systems on the LHC," says Maria Girone, CERN openlab CTO.

Lightsources

SESAME sees first light ...


SESAME

SESAME beamline scientist Messaoud Harfouche points out SESAME's first monochromatic light.

At 10.50 a.m. on 22 November 2017, the third-generation light source SESAME in Jordan produced its first X-ray photons, signalling the start of the regional laboratory's experimental program. Researchers sent a beam of monochromatic light through the XAFS/XRF (X-ray absorption fine structure/X-ray fluorescence) spectroscopy beamline, the first to come on stream at SESAME and targeted at research ranging from solid state physics to environmental science and archaeology.

Obtaining first light is an important step in the commissioning of a new synchrotron light source, and the milestone comes 10 months after SESAME circulated its first electrons (*CERN Courier* March 2017 p8). Nevertheless, it is just one step on the way to full operation. The SESAME synchrotron is currently operating with a beam current of just over 80 milliamps while the design value is 400 milliamps. Over the coming weeks and months as experiments get underway, the current will be gradually increased.

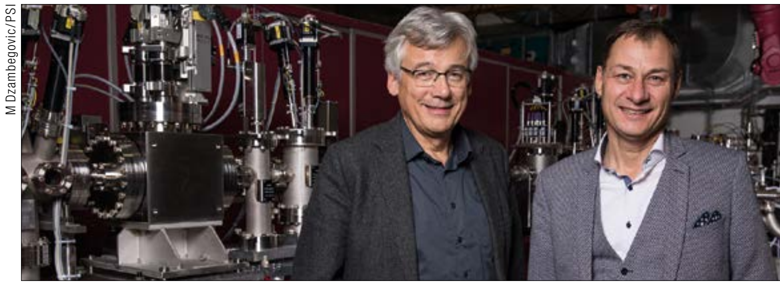
SESAME's initial research program will be carried out at two beamlines, the XAFS/XRF beamline and an infrared spectro-microscopy beamline that is scheduled to join the XAFS/XRF beamline this year. A third beamline devoted to materials science will come on stream in 2018. "After years of preparation, it's great to see light on target," said XAFS/XRF beamline scientist Messaoud Harfouche. "We have a fantastic experimental programme ahead of us, starting with an experiment to investigate heavy metals contaminating soils in the region."

... while SwissFEL carries out first experiment

The free-electron X-ray laser SwissFEL at the Paul Scherrer Institute (PSI) in Switzerland has hosted its inaugural experiment, marking the facility's first science result and demonstrating that its many complex components are working as expected. Construction of 740m-long SwissFEL began in April 2013, with the aim of producing extremely short X-ray laser pulses for the study of ultrafast reactions and processes.

Between 27 November and 4 December 2017, PSI researchers and a research group from the University of Rennes in France conducted the first in a series of pilot experiments.

The high-energy X-ray light pulses enabled the team to investigate the electrical and magnetic properties of titanium pentoxide nanocrystals, which have potential applications in high-density data storage. This and further pilot experiments will help hone SwissFEL operations before regular user operations begin in January 2019.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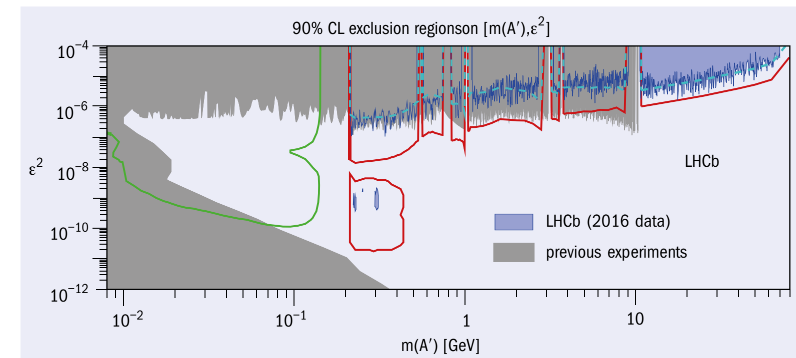
SwissFEL project leaders Hans Braun (left) and Luc Patthey in front of the end-station where the first experiment took place.

LHC experiments

Searches for dark photons at LHCb



Comparison of the new LHCb results to existing constraints from previous experiments. Red and green curves show the predictions from LHC Run 3, while the dashed cyan curve is the prediction rescaled to the 2016 data sample.

The possibility that dark-matter particles may interact via an unknown force, felt only feebly by Standard Model (SM) particles, has motivated an effort to search for so-called dark forces.

The force-carrying particle for such hypothesised interactions is referred to as a dark photon, A′, in analogy with the ordinary photon that mediates the electromagnetic interaction. While the dark photon does not couple directly to SM particles, quantum-mechanical mixing between the photon and dark-photon fields can generate a small interaction. This provides a portal through which dark photons may be produced and through which they might decay into visible final states.

The minimal A′ model has two unknown parameters: the dark photon mass, m(A′), and the strength of its quantum-mechanical mixing with the photon field. Constraints have been placed on visible A′ decays by previous beam-dump, fixed-target, collider, and rare-meson-decay experiments.

However, much of the A′ parameter space that is of greatest interest (based on quantum field theory arguments) is currently unexplored. Using data collected in 2016, LHCb recently performed a search for the decay $A'\to\mu^+\mu^-$ in a mass range from the dimuon threshold up to 70 GeV. While no evidence for a signal was found, strong limits were placed on the A′–photon mixing strength. These constraints are the most stringent to date for the mass range $10.6 < m(A') < 70$ GeV and are comparable to the best existing limits on this parameter.

Furthermore, the search was the first to achieve sensitivity to long-lived dark photons using a displaced-vertex signature, providing the first constraints in an otherwise unexplored region of A′ parameter space. These results demonstrate the unique sensitivity of the LHCb experiment to dark photons, even using a data sample collected with a trigger that is inefficient for low-mass A′ decays. Looking forward to Run 3, the number of expected $A'\to\mu^+\mu^-$ decays in the low-mass region should increase by a factor of 100 to 1000 compared to the 2016 data sample. LHCb is now developing searches for $A'\to e^+e^-$ decays which are sensitive to lower-mass dark photons, both in LHC Run 2 and in particular Run 3 when the luminosity will be higher. This will further expand LHCb's dark-photon programme.

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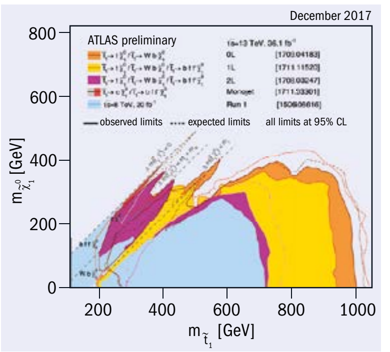
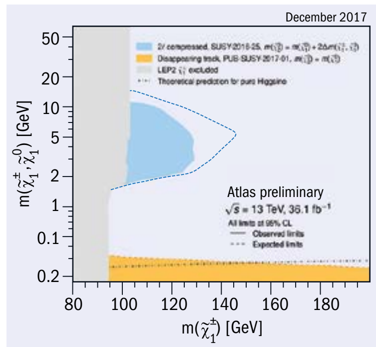
P Ilten *et al.* 2015 *Phys. Rev. D* **92** 115017.

ATLAS extends searches for natural supersymmetry

Despite many negative searches during the last decade and more, supersymmetry (SUSY) remains a popular extension of the Standard Model (SM). Not only can SUSY accommodate dark matter and gauge–force unification at high energy, it offers a natural explanation for why the Higgs boson is so light compared to the Planck scale. In the SM, the Higgs boson mass can be decomposed into a "bare" mass and a modification due to quantum corrections. Without SUSY, but in the presence of a high-energy new physics scale, these two numbers are extremely large and thus must almost exactly oppose one another – a peculiar coincidence called the hierarchy problem. SUSY introduces a set of new particles that each balances the mass correction of its SM partner,





(Left) Summary of ATLAS exclusion limits (95% C.L.) on top squark pair production considering various decay possibilities. The x-axis represents the mass of the top squark while the y-axis is the mass of the lightest SUSY particle. (Right) Exclusion limits on higgsino pair production for scenarios where the lightest higgsino is the lightest SUSY particle, with grey representing the LEP exclusion.

providing a "natural" explanation for the Higgs boson mass.

Thanks to searches at the LHC and previous colliders, we know that SUSY particles must be heavier than their SM counterparts. But if this difference in mass becomes too large, particularly for the particles that produce the largest corrections to the Higgs boson mass, SUSY would not provide a natural solution of the hierarchy problem.

New SUSY searches from ATLAS using data recorded at an energy of 13 TeV in 2015 and 2016 (some of which were shown for the first time at SUSY 2017 in Mumbai from 11–15 December) have extended existing bounds on the masses of the top squark and higgsinos, the SUSY partners of the top quark and Higgs bosons, respectively, that are critical for natural SUSY. For SUSY to remain natural, the mass of the top squark should be below around 1 TeV and that of the higgsinos below a few hundred GeV.

ATLAS has now completed a set of searches for the top squark that push the mass limits up to 1 TeV. With no sign of SUSY yet, these searches have begun to focus on more difficult to detect scenarios in which SUSY could hide amongst the SM background. Sophisticated techniques including machine learning are employed to ensure no signal is missed.

First ATLAS results have also been released for higgsino searches. If the lightest SUSY particles are higgsino-like, their masses will often be close together and such "compressed" scenarios lead to the production of low-momentum particles. One new search at ATLAS targets scenarios with leptons reconstructed at the lowest momenta still detectable. If the SUSY mass spectrum is extremely compressed, the lightest charged SUSY particle will have an extended lifetime, decay invisibly, and leave an unusual detector signature known as a "disappearing track".

Such a scenario is targeted by another new ATLAS analysis. These searches extend for the first time the limits on the lightest higgsino set by the Large Electron Positron (LEP) collider 15 years ago. The search for higgsinos remains among the most challenging and important for natural SUSY. With more data and new ideas, it may well be possible to discover, or exclude, natural SUSY in the coming years.

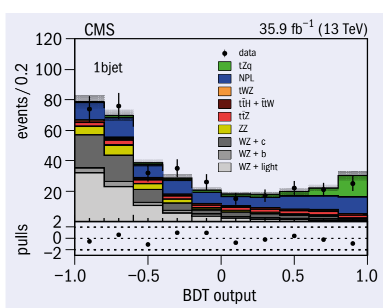
Further reading

ATLAS Collaboration 2017 arXiv:1709.04183.
ATLAS Collaboration 2017 arXiv:1711.11520.
ATLAS Collaboration 2017 arXiv:1708.03247.
ATLAS Collaboration 2017.
ATL-PHYS-PUB-2017-019.

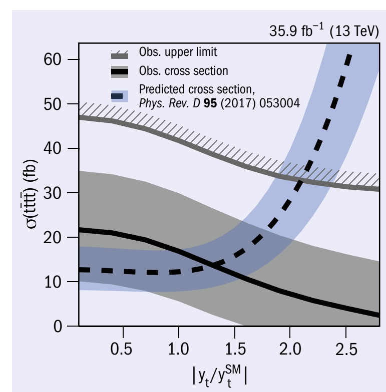
CMS studies rare top-quark processes

Now that all the particles predicted in the Standard Model (SM) have been discovered, most recently the Higgs boson in 2012, experiments at the LHC are active on two fronts: a deeper scrutiny of the SM and the search for new particles produced by beyond-SM (BSM) physics. Recent studies of rare processes involving the top quark serve both purposes. On one hand, they probe SM predictions and parameters in regions not accessed so far. On the other hand, if BSM couplings to the massive particles of the third generation of the SM are substantial, rare processes involving the top quark are golden candidates to reveal signs of BSM physics.

Based on data taken during 2016, the CMS Collaboration has recently published two such studies of rare top quark processes: the production of a single top quark associated with a Z boson and one or more jets (tZq) and the production of four top quarks ($t\bar{t}t\bar{t}$). Detecting these processes is very difficult due to their tiny cross sections (about 0.8 pb for tZq and 0.01 pb for $t\bar{t}t\bar{t}$ in proton–proton collisions at 13 TeV), which means that no more than a few hundred tZq events and a dozen $t\bar{t}t\bar{t}$ events were expected after selection. If this was not challenging enough, these events have to be separated from an overwhelming amount of background from several other SM processes. To achieve a sufficient control of the background, the analyses are restricted to final states containing multiple electrons and muons. Furthermore, the tZq analysis uses multivariate techniques to classify event candidates according to their topologies.



The tZq fit, displaying the Boosted Decision Tree output for one analysis region.



Probing the Yukawa coupling between the top and the Higgs via the $t\bar{t}t\bar{t}$ analysis.

In both analyses, the signal is extracted with maximum-likelihood fits performed simultaneously in the control regions with different selections. As a result, CMS was able to report evidence of the tZq process with a significance of 3.1 standard deviations (3.7 expected) against the background-only hypothesis, and a cross section of $0.123^{+0.033}_{-0.031}$ (stat) $^{+0.029}_{-0.023}$ (syst) pb, in agreement with the SM. CMS also reported a small excess of $\bar{t}\,t\bar{t}\,t$ events over the background-only hypothesis, with a significance of 1.6 standard deviations (1.0 expected), and derived an upper limit of $0.0208^{+0.0112}_{-0.0069}$ pb on the $\bar{t}t\bar{t}t$ production cross section. The high energy and the large integrated luminosities provided by the LHC have opened a new window on precision physics, in which measurements of rare processes involving top quarks play a central role.

As more LHC data become available, these studies will provide more stringent tests of the SM while increasing the chances of revealing BSM processes.

Further reading

CMS Collaboration 2017 arXiv:1712.02825.
CMS Collaboration 2017 arXiv:1710.10614.

Longitudinal asymmetry tracked in heavy-ion collisions

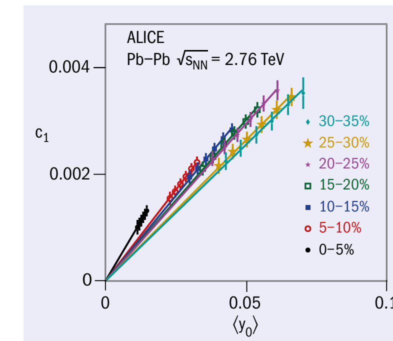
In a heavy-ion collision, a longitudinal asymmetry arises due to unequal numbers of participating nucleons from the two colliding nuclei, causing a shift in the centre-of-mass (CM) of the overlapping "participant zone" with respect to the nucleon-nucleon CM. The asymmetry may be expressed as $\alpha = (A-B)/(A+B)$, where A and B are the number of nucleons participating from the two colliding nuclei. This shifts the rapidity (y_0) of the participant zone with respect to the nucleon-nucleon CM rapidity, where $y_0 \cong \frac{1}{2}\ln(A/B)$.

First results on the asymmetry in the longitudinal direction and its effect on the pseudorapidity distributions in lead-lead collisions at a nucleon-nucleon CM energy of 2.76 TeV have been obtained with the ALICE detector, allowing investigations of the effect of variations in the initial conditions on other measurable quantities.

Since the number of participants cannot be measured directly, the asymmetry in an event was estimated by measuring the energy in the forward neutron-zero-degree-calorimeters (ZNs) in the ALICE detector. The observed distribution of asymmetry in ZNs, α_{zn}, is used to classify events into symmetric and asymmetric by a choice of α_{zn}. A Monte Carlo simulation using a Glauber model for the colliding nuclei is tuned to reproduce the spectrum in the ZNs and provides a relation between the measurable longitudinal asymmetry and the shift in the rapidity of the participant zone formed by the unequal number of participating nucleons.

The effect of the longitudinal asymmetry was measured on the pseudorapidity distributions of charged particles in the mid and forward regions by taking the ratio of the pseudorapidity distributions from events corresponding to different regions of asymmetry (see figure). The coefficients of a polynomial fit to the ratio characterise the effect of the asymmetry, with the coefficient of the linear term in the polynomial expansion, c_1, showing a linear dependence on the mean value of y_0.

This analysis confirms that the longitudinal distributions are affected by the rapidity-shift of the participant zone with respect to the nucleon-nucleon CM frame, highlighting the relevance of nucleon numbers in the production of charged particles, even at high energies. The method is potentially a new event classifier for the study of initial state fluctuations and different particle production mechanisms.



Measured values of coefficient c_1 as a function of estimated values of mean rapidity-shift ($\langle y_0 \rangle$) for different collision centralities. The lines show linear fits passing through the origin and the differences in slopes are due to changes in the width of the rapidity distributions for different centralities.

Further reading

ALICE Collaboration 2017 arXiv:1710.07975.

CERNCOURIER
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IOP Publishing

Sciencewatch

Compiled by John Swain, Northeastern University

World's oldest wine found

Something resembling wine, made from a mixture of grapes, hawthorn fruit wine, rice beer and honey mead, appears to have been made in the Yellow Valley in China around 7000 BC. However, what about wine as we know it, made just from grapes? This goes back almost as far, according to a study by Patrick McGovern of the University of Pennsylvania Museum of Archaeology and Anthropology in Philadelphia in the US. Advanced archaeological, archaeobotanical, climatic, and chemical methods applied to newly excavated materials from two sites in Georgia in the South Caucasus, reveal evidence for grape wine and viniculture in the Near East as early as 6000–5800 BC during the early neolithic period. Wine is key to many civilisations and requires sophisticated horticultural techniques, such as domestication, propagation, pressing and the use of suitable containers.

Wine became the focus of religious cults, pharmacopoeias, cuisines, economies, and society in the ancient Near East, suggests new evidence.

● **Further reading**
P McGovern *et al.* 2017 *PNAS* **114** 12627.

Toroidal plasma

In a first for plasma physics, a stable room-temperature topologically confined plasma has been created without the need for external electromagnetic fields. Morteza Gharib of Caltech and colleagues fired a high-speed 100 micron jet of deionised water onto a polished quartz wafer. This, they found, creates a stable coherent toroid of glowing plasma for speeds of the water jet above 200 ms^{-1}. The mechanism appears to be tribo-electricification caused by the large hydrodynamic shear.

● **Further reading**
M Gharib *et al.* 2017 *PNAS* **114** 12657.

Ageing unavoidable

Hopes that aging might be defeated by identifying and interfering with culpable genes, have run into an obstacle. Paul Nelson and Joanna Masel of the University of Arizona in Tucson have shown that, while competition between cells within one organism should seemingly just remove ones that work less well, the need for cells to co-operate with other cells can also select ones which do not themselves work as well, but co-operate better. This is at odds with the idea that aging is simply be due to a weakness in removing genes that only affect mortality late in life, and suggests aging is a fundamental feature of multicellular life.

● **Further reading**
P Nelson and J Masel 2017 *PNAS* **114** 12982.

Nuclear reactions in lighting

Following the observation of neutrons and gamma rays in association with lightning, a new study reports evidence that lightning also triggers specific nuclear reactions. On 6 February 2016, Teruaki Enoto of Kyoto University in Japan and colleagues observed a gamma-ray flash lasting less than 1 ms followed by an exponentially decaying gamma-ray spectrum and then prolonged line emission around 0.511 MeV (indicative of electron–positron annihilation). The process is well-explained by photo-dissociation processes such as $^{14}N + \gamma \rightarrow {}^{13}N + n$ with emission of de-excitation gamma rays, followed by positron decay of the nucleus to ^{13}C, and finally the positron annihilating with an electron. In addition to its intrinsic interest, the result reveals a new source of isotopes, including ^{14}C, used for carbon dating.

● **Further reading**
T Enoto 2017 *Nature* **551** 481.

Lightning and thunderclouds are natural particle accelerators.

Quark fusion

Following the recent observation by the LHCb experiment of a doubly charmed baryon Ξ_{cc}^{++} with a large (130 MeV) binding energy between the two charm quarks, Marek Karliner of Tel Aviv University and Jonathan Rosner of the University of Chicago have shown that this opens the door for a quark analog of nuclear fusion. For example, two Λ_c baryons can fuse to form a Ξ_{cc}^{++} and a neutron, releasing an energy of 12 MeV, with an analogous process for b quarks releasing 138 MeV. While unlikely to ever be a source of useful energy, this novel form of fusion could help in studies of strange hadronic matter.

● **Further reading**
M Karliner and J Rosner 2017 *Nature* **551** 89.

Cosmic rays image pyramid

Modern particle physics has teamed up with ancient Egyptian archaeology to discover a void in the Great Pyramid, similar in size to the Grand Gallery but located above it. Kunihiro Morishima of Nagoya University in Japan and colleagues used cosmic-ray muons and external micro-pattern gaseous detectors to perform the analog of X-ray tomography. In addition to confirming earlier results, it brings the significance of the void now to almost six standard deviations. Half of the muon detectors positioned around the pyramid, based on a design by CEA SACLAY, were built at CERN.

● **Further reading**
K Morishima *et al.* 2017 *Nature* doi:10.1038/nature24647.

Astrowatch

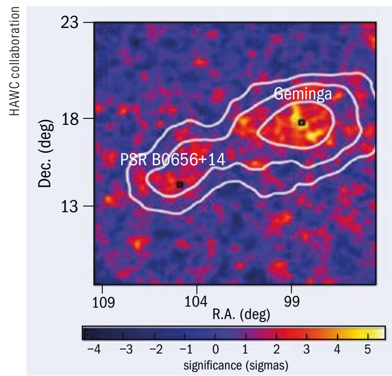
Compiled by Merlin Kole, Department of Particle Physics, University of Geneva

HAWC clarifies cosmic positron excess

Since 2008, astronomers have been puzzled by a mysterious feature in the cosmic-ray energy spectrum. Data from the PAMELA satellite showed a significant increase in the ratio of positrons to electrons at energies above 10 GeV. This unexpected positron excess was subsequently confirmed by both the Fermi-LAT satellite and the AMS-02 experiment onboard the ISS (*CERN Courier* December 2016 p26–30), sparking many explanations, ranging from dark-matter annihilation to positron emission by nearby pulsars. New measurements by the High-Altitude Water Cherenkov (HAWC) experiment now seem to rule out the second explanation, hinting at a more exotic origin of the positron excess.

Although standard cosmic-ray propagation models predict the production of positrons from interactions of high-energy protons travelling through the galaxy, the positron fraction is expected to decrease as a function of energy. One explanation for the excess is the annihilation of dark-matter particles with masses of several TeV, which would result in a bump in the electron–positron fraction, with the measured increase perhaps being the rising part of such a bump. According to other models, however, the excess is the result of positron production by astrophysical sources such as pulsars (rapidly spinning neutron stars). Since these charged particles lose energy due to interactions with interstellar magnetic and radiation fields they must be produced relatively close to Earth, making nearby pulsars a prime suspect.

HAWC, situated near the city of Puebla in Mexico, detects charged particles created in the Earth's atmosphere from collisions between high-energy photons and atmospheric nuclei. The charged particles produced in the resulting shower produce Cherenkov radiation in HAWC's 300 water tanks, their high altitude location making HAWC the most sensitive survey instrument to measure astrophysical photons in the TeV range. This allows the study of TeV-scale photon emission from nearby pulsars, such as Geminga and PSR B0656+14, to investigate if these objects could be responsible for the positron excess.



The area around Geminga and PSR B0656+14 as measured by HAWC in the 1–50 TeV energy region, showing the large area around the two pulsars from where high-energy gamma rays are emitted.

Pulsars are thought to emit electrons and positrons with energies up to several hundred TeV, which diffuse into the interstellar medium, but the details of the emission, acceleration and propagation of these leptons are not well understood. The TeV photons measured by HAWC are produced as the electrons and positrons emitted by the pulsars interact with low energy photons in the interstellar medium. One can, therefore, use the intensity of the TeV photon emission and the size of the emitting region to indirectly measure the high-energy positrons. The HAWC data show the large emitting regions of both the pulsars Geminga and PSR B0656+14 (see figure). The spectral and spatial features of the TeV emission were then inserted in a diffusion model for the positrons, allowing the team to calculate the positron flux from these sources reaching Earth. The results, published in *Science*, indicate that the positron flux from these sources reaching Earth is significantly smaller than that measured by PAMELA and AMS-02.

These indirect measurements of the positron emission appear to rule out a significant contribution of the local positron flux by these two pulsars, making it unlikely that pulsars are the origin of the positron excess. More exotic explanations such as dark matter, or other astrophysical sources such as micro-quasars and supernovae remnants, are not ruled out, however. Results from gamma-ray observations of such sources, along with more detailed measurements of the lepton flux at even higher energies by AMS-02, DAMPE or CALET, are therefore highly anticipated to fully solve the mystery of the cosmic positron excess.

Further reading

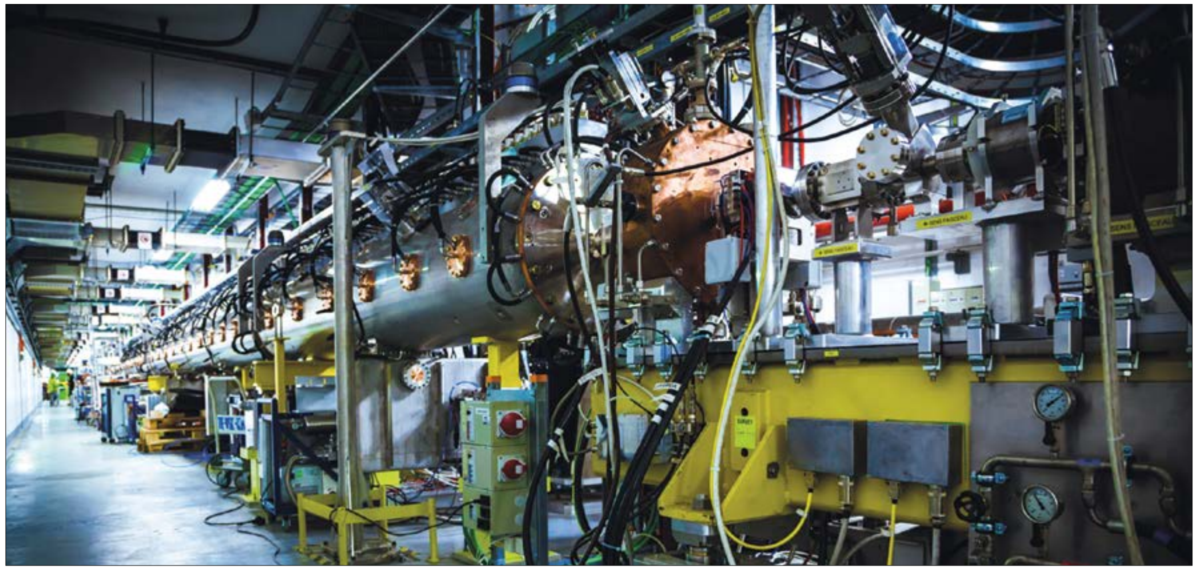
HAWC Collaboration 2017 *Science* **358** 911.

Picture of the month

This image shows a nebula named after Edwin Hubble, recorded by the observatory that bears his name. Hubble's Variable Nebula was discovered more than 200 years ago and later studied in detail by Hubble in the 20th century. This object is peculiar because its appearance is known to change within a matter of weeks. This so-called reflection nebula consists of gas and fine dust fanning out from the star R Monocerotis. The faint nebula is about one light-year across and lies about 2500 light-years away towards the Unicorn constellation. One of the explanations for the fast variability of such a large object is that dense clouds of opaque dust move around the star, which is seen in the top left of the image. As the clouds move between the star and the nebula they cast shadows on the reflective gasses, causing different parts of the nebula to light up at different times.

Hubble, NASA, ESA

F Piccini/CERN



The drift-tube-linac section of CERN's latest accelerator, Linac4.

The long road to Linac4

After two decades of design and construction, CERN's newest accelerator, Linac4, is on its way to join the LHC injection chain.

For the past 40 years, CERN's accelerator complex has been served by a little-known linear accelerator called Linac2. Commissioned in 1978, the 50 MeV linac was constructed to provide a higher beam intensity to the newly built Proton Synchrotron Booster (PSB).

It superseded Linac1, which accelerated its first beam in 1958 and was the only supplier of protons to the CERN Proton Synchrotron (PS) for the following 20 years. Linac1 was sent into retirement in 1992, having spent 33 years accelerating protons as well as deuterons, alpha particles and oxygen and sulphur ions, and is now an exhibit in the CERN Microcosm. Linac3 took over CERN's ion production in 1994, but today Linac2 is still injecting protons into the PS and SPS from where they end up in the Large Hadron Collider (LHC).

Although the construction of this workhorse of the CERN accelerator chain was an important step forward for CERN, and contributed to major physics discoveries, including the W, Z and Higgs bosons, Linac2's relatively low energy and intensity are not compatible with the demanding requirements of the LHC luminosity upgrade (HL-LHC). Persistent vacuum problems in the accelerating vessels over the past years also raise major concerns for the performance of the LHC. For this reason, in 2007, it was decided to replace Linac2 with a more suitable injector for the LHC's future.

A decade later, in spring 2017, the 160 MeV Linac4 was fully commissioned and entered a stand-alone operation run to assess and improve its reliability, prior to being connected to the CERN accelerator complex. The machine's overall availability during this initial run reached 91 per cent – an amazing value for an accelerator whose beam commissioning was completed only a few months earlier. The Linac4 reliability run will continue well into 2018, sending the beam round-the-clock to a dump located at the end of the accelerating section under the supervision of the CERN Control Centre (CCC) operation team. After a consolidation phase to address any teething troubles identified during the reliability run, Linac4 will be connected to the next accelerator in the chain, the PSB, in 2019 at the beginning of the LHC Long Shutdown 2. Test beams will be made available to the PSB as soon as 2020, and from 2021 all protons at CERN will come from the new Linac4, marking the end of a 20 year-long journey of design and construction that has raised many challenges and inspired innovative solutions.

Linac4 has the privilege of being the only new accelerator built at CERN since the LHC. With an accelerating length of 86 m, plus 76 m of new transfer line, Linac4 is definitely the smallest accelerator in the LHC injection chain. Yet it plays a fundamental role in the preparation of the beam. The linac is where the beam

M Vretenar

Excavating the Linac4 tunnel in 2009.

S Mickael

The surface hall after completion.

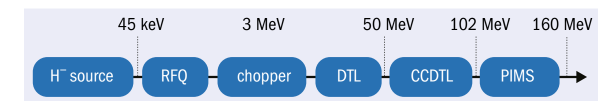
density is generated under the influence of the strong defocusing forces coming from Coulomb repulsion (space charge), and where negative ions initially at rest (containing protons emerging from a bottle of hydrogen gas) are progressively brought close to the relativistic velocities required for acceleration in a synchrotron. This rapid increase in beam velocity requires the use of complex and differentiated mechanical designs to accelerate and focus the beam. Combined with the need for high accelerating gradients (the beam passes only once through the linac), particular demands were placed on Linac4 to achieve the high values of availability required by the first element of the acceleration chain.

The main improvements provided by Linac4 stem from the use of negative hydrogen ions instead of protons and from a higher injection energy into the PSB. Negative hydrogen ions – a proton with two electrons – are converted into protons by passing them through a thin carbon foil, after their injection into the PSB to strip them of electrons. This charge-exchange technique involves progressively injecting the negatively charged ions over the circulating proton beam to achieve a higher particle density. After injection, both beams pass through the stripping foil leaving only protons in the beam. This provides an extremely flexible way to load particles into a synchrotron, making the accumulation of many turns possible with a tight control of the beam density.

Extensive modifications

However, the use of hydrogen ions does not come without complications. It requires extensive modifications to the injection area of the synchrotron and a complex ion source in front of the linac. The other key element for generating the high-brightness beams required by the LHC upgrade is the increase of the injection energy in the PSB by more than a factor three with respect to the present Linac2, which reduces space-charge effects at the PSB injection and allows the accumulation of more intense beams.

On top of these crucial advantages for the HL-LHC, Linac4 is designed to be more flexible and more environmentally clean than Linac2. Modulation at low energy of the beam-pulse structure, the option of varying beam energy during injection and a useful margin in the peak beam current will help prepare the large variety of beams required by the injector complex, at the same time reduc-

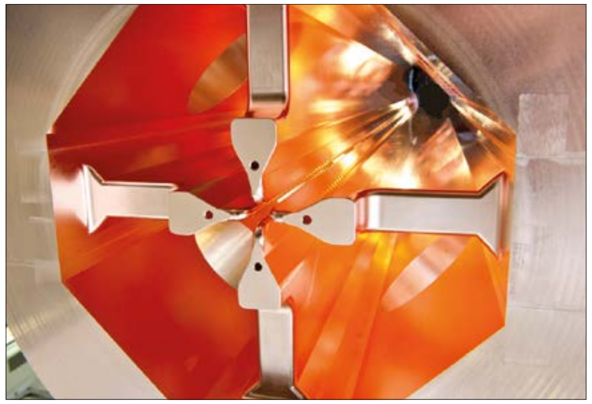


Linac4 begins with the hydrogen source, followed by the radio-frequency quadrupole (RFQ), chopper, drift-tube linac (DTL), cell-coupled DTL (CCDTL) and finally a Pi-mode structure (PIMS).

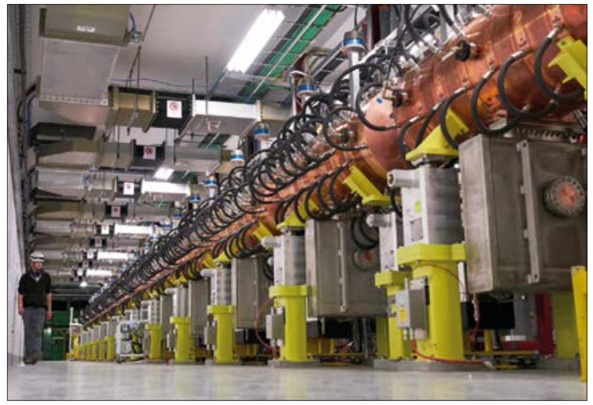
ing beam loss and activation in the PSB. Linac4 is also designed for the long term. Having originated from studies at the end of the 1990s, the goal was to progressively replace the PS complex (Linac2, PSB and PS) with more modern accelerators capable of higher intensities for the future needs of the LHC and other non-LHC programmes. Alas, this ambitious staged approach was later discarded to give priority to the consolidation of CERN's older synchrotrons, but Linac4 retains features related to the old staged programme that could be exploited to adapt the CERN injector complex to future physics programmes. Examples are the orientation of the Linac4 tunnel, which leaves space for future extensions to higher energies, and its pulse-repetition frequency. The latter is currently limited by the rise time of the PSB magnets to about 1 Hz, but this could be upgraded up to 50 Hz were the PSB to be replaced one day by another accelerator.

Last but not least, Linac4 is a model for the successful reuse of old equipment. All its accelerating structures operate at a frequency of 352 MHz, which is precisely that of the old Large Electron Positron (LEP) collider. Linac4 reuses a large quantity of LEP's RF components, such as klystrons and waveguides, which were carefully stored and maintained following LEP's closure in 2000. However, the LEP klystrons installed in Linac4 will gradually be replaced in pairs by modern klystrons with twice the power.

Reaching Linac4's required performance and reliability posed several problems in the design and construction of the new linac. The first challenge was to build a reliable source of negative hydrogen ions, starting from a new design developed at CERN that profited from the experience of other laboratories such as DESY and Brookhaven National Laboratory. The ion source is a complex device that starts from a bottle of hydrogen similar to the one used


M Vretenar

The Linac4 radio frequency quadrupole.


M Brice / CERN

The Linac4 high-energy section.

in Linac2 and generates ions in a plasma heated by a high-frequency wave of several dozen kilowatts. Following some initial difficulties, the new ion source is now steadily providing the minimum beam intensity required by the LHC, while improvements are still ongoing.

Accelerating elements

After the ion source, the challenge for the main Linac4 accelerating section has been to integrate focusing and accelerating elements in the small linac cells, achieving a good power efficiency at the same time. These requirements motivated the use of four different types of accelerating structure: an RF quadrupole (RFQ) to take the energy to 3 MeV; a drift-tube linac (DTL) of the Alvarez type to 50 MeV; a cell-coupled drift-tube linac (CCDTL) to 102 MeV; and finally a Pi-mode structure (PIMS) to the final energy of 160 MeV. Most of these accelerating sections include important innovations. The CCDTL and PIMS structures are a world-first developed specifically for Linac4 and used for the first time to accelerate a beam. The DTL includes a novel patented mechanism to support and adjust the drift tubes and makes use for the first time at CERN of a long focusing section made of 108 permanent magnet quadrupoles. To these innovations we had to add a novel scheme to "chop" the beam pulse at low energy, a simplified RFQ mechanical design, and finally the flexible and upgradeable beam optics design.

In spite of a general trend towards superconducting accelerators, Linac4 is entirely normal-conducting. This is a logical choice for a low-energy linear accelerator injecting into a synchrotron and operating at low duty cycle. Linac4 is pulsed, and the short particle beam is in the linac only for a tiny fraction of time. Although as much as 24 MW of RF power are needed for acceleration during the beam pulse, the average power to the accelerating structures will be only 8 kW, out of which only about 6 kW are dissipated in the copper, the rest going to the beam. The power required to cool Linac4 to cryogenic temperatures would be much higher than the power lost into the copper structures.

The construction of Linac4 is a great example of international collaboration, expanding well beyond the boundaries of CERN. Already in the R&D phase between 2004–2008, Linac4 collected support from the European Commission and a group of Russian institutes supported by the ISTC international organisation. The construction of the accelerator received important contributions from a large number of collaborating institutes. These included CEA and CNRS in France, BINP and VNIITF in Russia, NCBJ in Poland, ESS Bilbao in Spain, INFN in Italy and RRCAT in India. Organising this wide network of collaborations was a great challenge, but the results were excellent both in terms of technical quality of the components and in terms of developing a common working culture.

Linac4 brought proton-linac technology back to Europe. Since the construction of Linac2 in 1978 and of the HERA injector at DESY a few years later, all new proton linac developments took place in the US and in Japan. The development effort coordinated by CERN for the construction of Linac4 allowed bringing back to Europe the latest developments in linac technology described above, with a strong involvement of European companies. A measure of the success of this endeavour is the fact that many technical solutions developed for Linac4 will be now adopted by the normal-conducting section of the new European Spallation Source linac under construction at Lund, Sweden.

The inauguration of Linac4 on 9 May 2017 marked the coronation of a long project. The ground-breaking on so-called "Mount Citron" (made in the 1950s with the spoil from the construction of the PS ring) took place in October 2008 and the new linac building started to take shape. Construction extended over the mandate of three CERN Directors General. It's expected that Linac4 will have a long life – at least as long as Linac2 – and play a vital role at the high-luminosity LHC and beyond.

Résumé

Sur la route du Linac 4

Après deux décennies de conception et de construction, l'accélérateur linéaire Linac 4 du CERN est sur le point d'être intégré à la chaîne d'injection du LHC. Cet accélérateur, qui jouera un rôle vital pour le LHC à haute luminosité, utilise, non pas des protons, mais des ions d'hydrogène négatifs, qu'il injecte, après avoir augmenté leur énergie, dans le Booster du PS.

Maurizio Vretenar and **Alessandra Lombardi**, CERN.

Therapeutic particles

The accelerator technology underpinning Europe's first particle-therapy facilities, driven by the TERA Foundation during the past 25 years, is poised to unleash new treatment modes in more compact ways.

Last September the TERA Foundation – dedicated to the study and development of accelerators for particle therapy – celebrated its 25th anniversary. Led by visionary Italian physicist Ugo Amaldi, TERA gathered and trained hundreds of brilliant scientists who carried out research on accelerator physics. This culminated in the first carbon-ion facility for hadron therapy in Italy, and the second in Europe: the National Centre for Cancer Hadron Therapy (CNAO), located in Pavia, which treated its first patient in 2011.

The forerunner to CNAO was the Heidelberg Ion-Beam Therapy Centre (HIT) in Germany, which treated its first patient in 2009 following experience accumulated over 12 years in a pilot project at GSI near Darmstadt. After CNAO came the Marburg Ion-Beam Therapy Centre (MIT) in Germany, which has been operational since 2015, and MedAustron in Wiener Neustadt, Austria, which delivered its first treatment in December 2016.

While conventional radiotherapy based on beams of X-rays or electrons is already widespread worldwide, the treatment of cancer with charged particles has seen significant growth in recent years. The use of proton beams in radiation oncology was first proposed in 1946 by Robert Wilson, a student of Ernest Lawrence and founding director of Fermilab. The key advantage of proton beams over X-rays is that the absorption profile of protons in matter exhibits a sharp peak towards the end of their path, concentrating the dose on the tumour target while sparing healthy tissues. Following the first treatment of patients with protons at Lawrence Berkeley Laboratory in the US in 1954, treatment centres in the US, the former USSR and Japan gradually appeared. At the same time, interest arose around the idea of using heavier ions, which offer a higher radiobiological effectiveness and, causing more severe damage to DNA, can control the 3% of all tumours that are radioresistant both to X-rays and protons. It is expected that by 2020 there will be almost 100 centres delivering particle therapy around the world, with more than 30 of them in Europe (see p32).

We passed through hard times and we had to struggle, but we never gave up.

MedAustron

A treatment room at the MedAustron centre in Austria, behind which lies a 25m-diameter synchrotron that precisely directs high-energy protons and light ions at tumours.

Europe entered the hadron-therapy field in 1987, when the European Commission launched the European Light Ion Medical Accelerator (EULIMA) project to realise a particle-therapy centre. The facility was not built in the end, but interest in the topic continued to grow. In 1991, together with Italian medical physicist Giampiero Tosi, Amaldi wrote a report outlining the design of a hospital facility for therapy with light ions and protons to be built in Italy. One year later, the pair established the TERA Foundation to raise the necessary funding to employ students and researchers to work on the project. Within months, TERA could count on the work of about 100 physicists, engineers, medical doctors and radiobiologists, who joined forces to design a synchrotron for particle therapy and the beamlines and monitoring systems necessary for its operation.

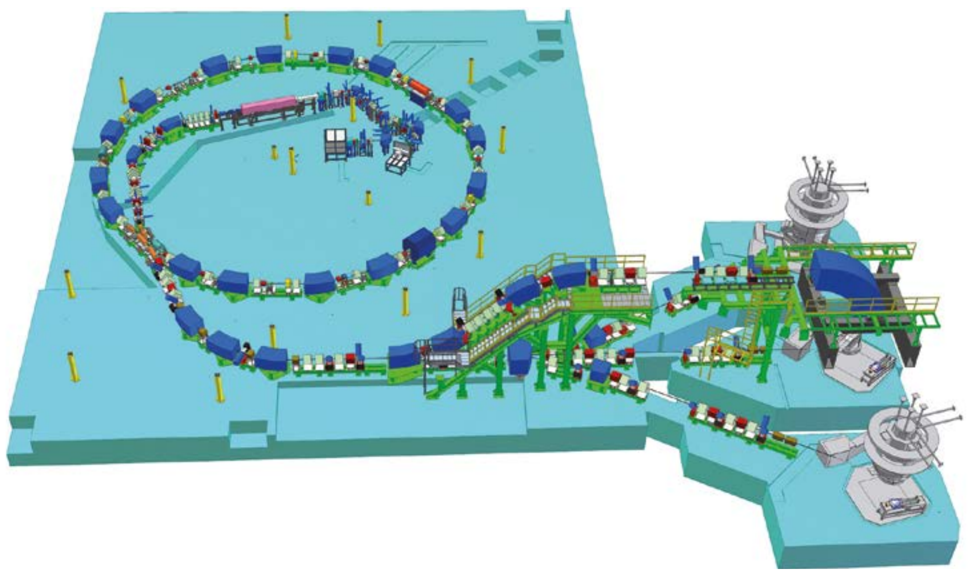
Ten years of ups and downs followed, during which TERA scientists developed three designs for a proton-therapy facility initially to be built in Novara, then in the outskirts of Milan and finally in Pavia. Political, legislative and economic issues delayed the project until 2001 when, thanks to the support of Italian health minister and oncologist Umberto Veronesi, the CNAO Foundation was created. The construction of the actual facility began four years later.

"We passed through hard times and we had to struggle, but we never gave up," says Amaldi. "Besides, we kept ourselves busy with improving the design of our accelerator."

Introducing PIMMS

Meanwhile, in Austria, experimental physicist Meinhard Regler had launched a project called Austron – a sort of precursor to

CNAO



To minimise the footprint of the CNAO centre while still offering three treatment rooms, TERA modified the layout of the PIMMS design by locating the linac inside the synchrotron and by splitting in three the accelerated beam with a fan-out magnet.

the European Spallation Source. In 1995, together with the head designer – accelerator physicist Phil Bryant – he proposed the addition of a ring to the facility that would be used for particle therapy (and led to the name of the project being changed to MedAustron). Amaldi, Regler and Bryant then decided to work on a common project, and the "Proton-Ion Medical Machine Study" (PIMMS) was created. Developed at CERN between 1996 and 2000 under the leadership of Bryant and with the collaboration of several CERN physicists and engineers, PIMMS aimed to be a toolkit for any European country interested in building a proton–ion facility for hadron therapy. Rather than being a blueprint for a final facility on a specific site, it was an open study from which different parts could be included in any hadron-therapy centre according to its specific needs.

The design of CNAO itself is based on the PIMMS project, with some modifications introduced by TERA to reduce the footprint of the structure. The MedAustron centre, designed in the early 2000s, also drew upon the PIMMS report. Built between 2011 and 2013, with the first beam extracted by the synchrotron in autumn 2014, MedAustron received official certification as a centre for cancer therapy in December 2016 and, a few days after, treated its first patient. "In the past few years we have worked hard to provide the MedAustron trainees with a unique opportunity to acquire CERN's know-how in the diverse fields of accelerator design, construction and operation," says Michael Benedikt of CERN, who led the MedAustron accelerator project. Synergies with other CERN projects were also created, he explains. "The vacuum control system built for MedAustron was successfully used in the Linac4 test set-up, while in the synchrotron a novel radiofrequency system that was jointly developed for the CERN PS Booster and MedAustron is used. The synchrotron's power converter control uses the same top-notch technology as CERN's accelerators, while its control system and several of its core components are derived from technologies developed for the CMS experiment."

All the existing facilities using hadrons for cancer therapy are based on circular cyclotrons and synchrotrons. For some years, however, the TERA Foundation has been working on the design of a linear accelerator for hadron therapy. As early as 1993, Amaldi set up a study group, in collaboration with the Italian institutions ENEA and INFN, dedicated to the design of a linac for protons that would run at the same frequency (3 GHz) as the electron linacs used for conventional radiotherapy. The linac could use a cyclotron as an injector, making it a hybrid solution called a cyclinac, which reduces the sizes of both accelerators while allowing the beam energy to be rapidly changed from pulse to pulse by acting on the radiofrequency system of the linac. In 1998 a 3 GHz 1.2 metre-long linac booster (LIBO) was built by a TERA–CERN–INFN collaboration led by retired CERN engineer Mario Weiss, and in 2001 it was connected to the cyclotron of the INFN South Laboratories in Catania where it accelerated protons from 62 MeV to 74 MeV. This was meant to be the first of 10 modules that would kick protons to 230 MeV.

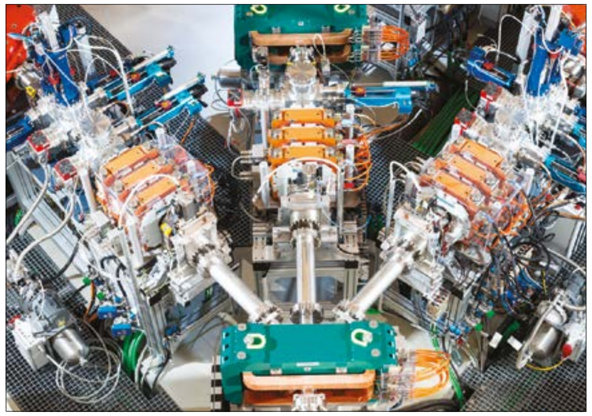
Linear ambition

In 2007 a CERN spin-off company called ADAM (Applications of Detectors and Accelerators to Medicine) was founded by businessman Alberto Colussi to build a commercial high-frequency linac based on the TERA design. Under the leadership of Stephen Myers, a former CERN director for accelerators and technology and initiator of the CERN medical applications office, ADAM is now completing the first prototype. It is called Linac for Image Guided Hadron Therapy (LIGHT), and the full accelerator comprises: a proton source; a novel 750 MHz RF quadrupole (RFQ) – designed by CERN – which takes the particles up to 5 MeV; four side-coupled drift-tube linacs (SCDTL) – designed by ENEA – to accelerate the beam from 5–37.5 MeV; and a different type of accelerating module, called coupled-cavity linac (CCL) – the LIBO designed by TERA – which gives the final kick to the beam from 37.5 to 230 MeV. The complex will be 24 m long, similar to the circumference of a proton synchrotron.

CNAO

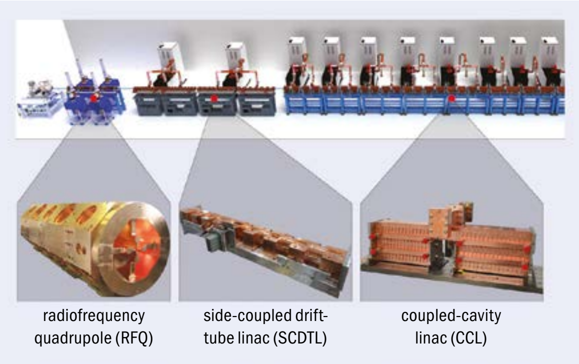
The 25 m-diameter synchrotron of CNAO in Italy.

MedAustron/T Kästenbauer



The ion-beam injectors of the MedAustron facility in Austria.

AVO-ADAM



The Linac for Image Guided Hadron Therapy (LIGHT) developed by AVO-ADAM comprises: a proton source; a 750 MHz RF quadrupole (RFQ); four side-coupled drift-tube linac (SCDTL) modules; and a coupled-cavity linac (CCL) module.

Compared to cyclotrons and synchrotrons, linear accelerators are lighter and potentially less costly because they are modular. Most importantly, they produce a beam much more suited to treat patients, in particular when the tumour is moving, as in the lungs. The machine developed by ADAM is modular in structure to make it easier to maintain and more flexible when it comes to upgrading or customising the system. In addition, thanks to an active longitudinal modulation system, the beam energy can be varied during therapy and thus the treatment depth changed. LIGHT also has a dynamic transversal modulation system, allowing the beam to be rapidly and precisely modulated to "paint the tumour" many times in a short time – in other words, delivering a homogeneous dose to the whole cancerous tissue while minimising the irradiation of healthy organs. The energy variation of cyclotrons and synchrotrons is 20–100 times slower.

"The beauty of the linac is that you can electronically modulate its output energy," Myers explains. "Since our accelerator is modular, the energy can be changed either by switching off some of the units or by reducing the power in all of them, or by rephasing the units. Another big advantage of the linac is that it has a small emittance, i.e. beam size, which translates into smaller, lighter and cheaper magnets and allows to have a simpler and lighter gantry as well." In the last decade, LIBO has inspired other TERA projects. Its scientists have designed a linac booster for carbon ions (while LIBO was only for protons) and a compact single-room facility called TULIP, in which a 7 m-long proton linac is mounted on a rotating gantry.

The new frontier of hadron therapy, however, could be helium ion treatment. Some tests with these ions were done in the past, but the technique still has to be proven. TERA scientists are currently working on a new accelerator for helium ions, says Amaldi. "Helium can bring great benefit to medical treatments: it is lighter than carbon, thus requiring a smaller accelerator, and it has much less lateral scattering than protons, resulting in sharper lateral fall-offs next to organs at risk." In order to accelerate helium ions with a linac, we need either a longer linac compared to the one used for protons or higher gradients, as demonstrated by high-energy physics research at CERN and elsewhere in Europe. The need for future, compact and cost-effective ion-therapy accelerators is being addressed by a new collaborative design study coordinated by Maurizio Vretenar and Alessandra Lombardi of CERN, dubbed "PIMMS2". A proposal, which includes a carbon linac, is being prepared for submission to the CERN Medical Application group, potentially opening the next phase of TERA's impressive journey.

Résumé

Particules thérapeutiques

Les technologies d'accélérateur qui se sont concrétisées par les premières installations de thérapies par particules en Europe ont été en grande partie le résultat du travail de la Fondation TERA. Celle-ci, au cours des 25 dernières années, a rassemblé et formé des centaines de scientifiques, lesquels ont ensuite mené des recherches sur la physique des accélérateurs. Tout cela a abouti au premier centre d'hadronthérapie à ions carbone d'Italie (le CNAO), ou encore à la mise en place de MedAustron en Autriche. Les efforts se concentrent à présent sur la création de centres de traitement plus petits utilisant des accélérateurs linéaires.

Virginia Greco, CERN.

Isotopes for precision medicine

The CERN-MEDICIS facility has produced its first radioisotopes for medical research, targeting novel diagnostic agents and treatments for diseases such as brain and pancreatic cancers.

M Brice/CERN

The robot sample handler at MEDICIS, a unique facility for the production of unconventional isotopes.

The use of radioisotopes to treat cancer goes back to the late 19th century, with the first clinical trials taking place in France and the US at the beginning of the 20th century. Great strides have been made, and today radioisotopes are widely used by the medical community. Produced mostly in dedicated reactors, radioisotopes are used in precision medicine, both to diagnose cancers and other diseases, such as heart irregularities, as well as to deliver very small radiation doses exactly where they are needed to avoid destroying the surrounding healthy tissue.

However, many currently available isotopes do not combine the most appropriate physical and chemical properties and, in the case of certain tumours, a different type of radiation could be better suited. This is particularly true of the aggressive brain cancer glioblastoma multiforme and of pancreatic adenocarcinoma. Although external beam gamma radiation and chemotherapy can improve patient survival rates, there is a clear need for novel treatment modalities for these and other cancers.

> **MEDICIS will expand the range of novel radioisotopes available, which will be sent to hospitals and research centres.**

On 12 December, a new facility at CERN called MEDICIS produced its first radioisotopes: a batch of terbium (^{155}Tb), which is part of the $^{149/152/155/161}$Tb family considered a promising quadruplet suited for both diagnosis and treatment. MEDICIS is designed to produce unconventional radioisotopes with the right properties to enhance the precision of both patient imaging and treatment. It will expand the range of radioisotopes available – some of which can be produced only at CERN – and send them to hospitals and research centres in Switzerland and across Europe for further study.

Initiated in 2010 by CERN with contributions from the Knowledge Transfer Fund, private foundations and partner institutes, and also benefitting from a European Commission Marie Skłodowska-Curie training grant titled MEDICIS-Promed, MEDICIS is driven by CERN's Isotope Mass Separator Online (ISOLDE) facility. ISOLDE has been running for 50 years, producing 1300 different isotopes from 73 chemicals for research in many areas including fundamental nuclear research, astrophysics and life sciences.

Although ISOLDE already produces isotopes for medical research, MEDICIS will more regularly produce isotopes with specific types of emission, tissue penetration and half-life – all purified based on expertise acquired at ISOLDE. This will allow CERN to provide radioisotopes meeting the requirements of the medical research community as a matter of course.

ISOLDE directs a high-intensity proton beam from the Proton Synchrotron Booster onto specially developed thick targets, yielding a large variety of atomic fragments. Different devices are used to ionise, extract and separate nuclei according to their masses, forming a low-energy beam that is delivered to various experimental stations. MEDICIS works by placing a second target behind

CERN-MEDICIS

ISOLDE's: once the isotopes have been produced on the MEDICIS target, an automated conveyor belt carries them to a facility where the radioisotopes of interest are extracted via mass separation and implanted in a metallic foil. The final product is then delivered to local research facilities including the Paul Scherrer Institute, the University Hospital of Vaud and Geneva University Hospitals.

Clinical setting

Once in a medical-research environment, researchers dissolve the isotope and attach it to a molecule, such as a protein or sugar, which is chosen to target the tumour precisely. This makes the isotope injectable, and the molecule can then adhere to the tumour or organ that needs imaging or treating. Selected isotopes will first be tested *in vitro*, and *in vivo* by using mouse models of cancer. Researchers will test the isotopes for their direct effect on tumours and when they are coupled to peptides with tumour-homing capacities, and establish new delivery methods for brachytherapy using stereotactic or robotic-assisted surgery in large-animal models for their capacity to target glioblastoma or pancreatic adenocarcinoma or neuroendocrine tumour cells.

MEDICIS is not just a world-class facility for novel radioisotopes. It also marks the entrance of CERN into the growing field of theranostics, whereby physicians verify and quantify the presence of cellular and molecular targets in a given patient with a diagnostic radioisotope, before treating the disease with the therapeutic radioisotope. The prospect of a dedicated facility at CERN for the production of innovative isotopes, together with local leading institutes in life and medical sciences and a large network of laboratories, gives MEDICIS an exciting scientific programme in the years to come. It is also a prime example of the crossover between fundamental physics research and health applications, with accelerators set to play an increasing role in the production of life-changing medical isotopes.

Résumé

Des isotopes pour une médecine de précision

Le 12 décembre, une nouvelle installation au CERN, appelée MEDICIS, a produit son premier radio-isotope : du terbium-155. Lancée en 2010, l'installation MEDICIS est conçue pour produire des radio-isotopes spécifiques capables d'améliorer la précision de l'imagerie et du traitement, ciblant des agents de diagnostic et des traitement innovants pour, notamment, le cancer du cerveau ou du pancréas. MEDICIS développera la gamme de radio-isotopes innovants disponibles, dont certains ne peuvent être produits qu'au CERN ; ces nucléides seront envoyés à des hôpitaux et des centres de recherche en Suisse et dans toute l'Europe pour de nouvelles études.

Thierry Stora, CERN.

Status of hadron therapy

The changing landscape of cancer therapy

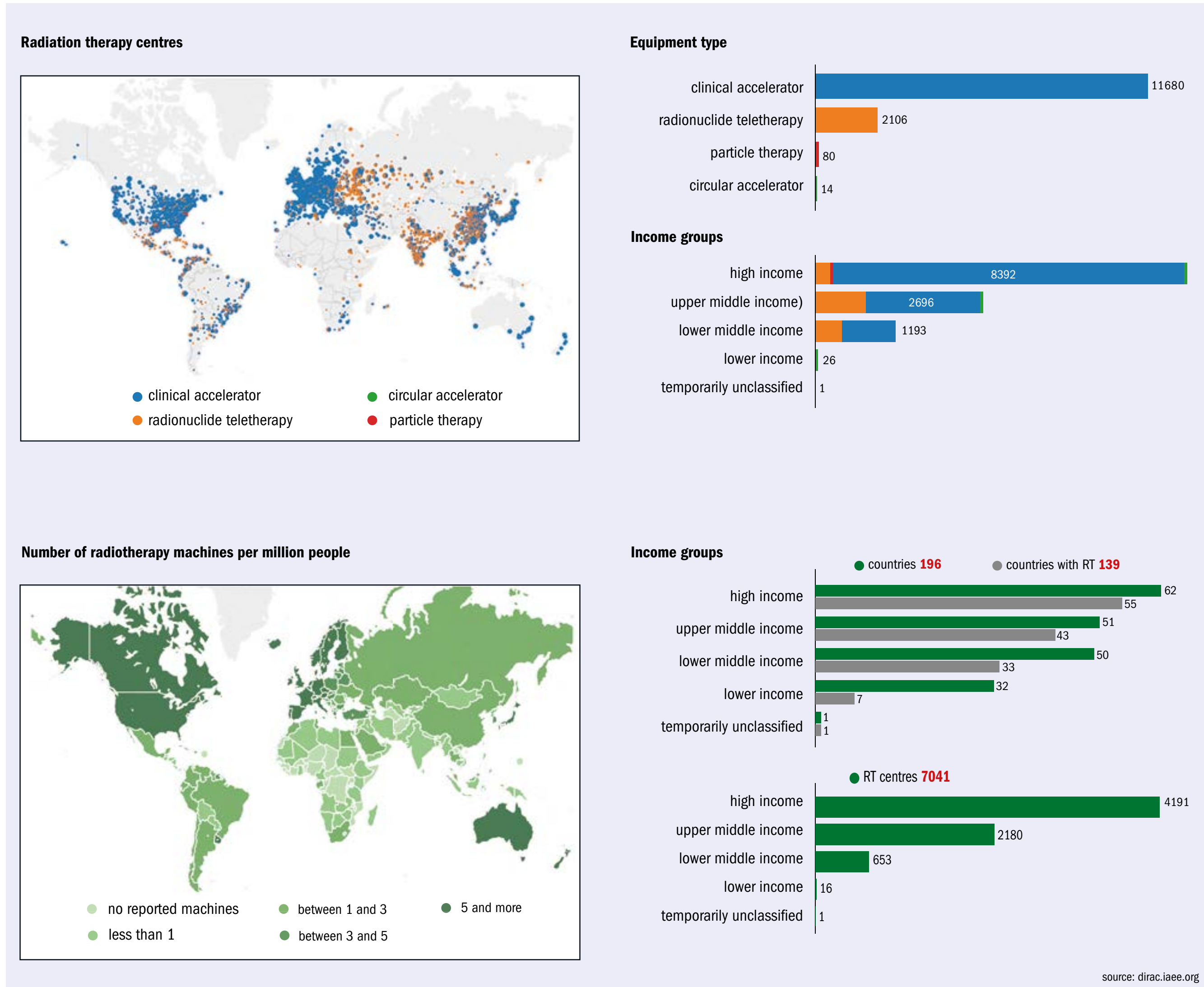
Following decades of development in particle physics labs, the use of beams of protons or ions to kill tumours is beginning to transform the global cancer therapy scene.

Cancer is a critical societal issue. Worldwide, in 2012 alone, 14.1 million cases were diagnosed, 8.2 million people died and 32.5 million people were living with cancer. These numbers are projected to rise by 2030 to reach 24.6 million newly diagnosed patients and projected deaths of 13 million. While the rate of cancer diagnoses is growing only steadily in the most developed countries, less developed countries can expect a two-fold increase in the next 20 years or so. The growing economic burden imposed by cancer – amounting to around $2 trillion worldwide in 2010 – is putting considerable pressure on public healthcare budgets.

Radiotherapy, in which ionising radiation is used to control or kill malignant cells, is a fundamental component of effective cancer treatment. It is estimated that about half of cancer patients would benefit from radiotherapy for treatment of localised disease, local control, and palliation. The projected rise in cancer cases will place increased demand on already scarce radiotherapy services worldwide, particularly in less developed countries.

In 2013, member states of the World Health Organisation agreed to develop a global monitoring framework for comprehensive, non-communicable diseases (NCDs). The aim is to reduce premature mortality from cardiovascular and chronic respiratory diseases, cancers and diabetes by 25%, relative to 2010 levels, which means 1.5 million deaths from cancer will need to be prevented each year.

Advanced cancer therapy techniques based on beams of protons or ions are among several tools that are expected to play a significant role in this effort (see p25). In addition, advanced imaging and detection technologies for high-energy physics research – many being driven by CERN and the physics community – are needed. These include in-beam positron emission tomography (PET) and prompt-gamma imaging, and treatment planning based on the latest Monte Carlo simulation codes.



Optimal dose

The main goal of radiotherapy is to maximise the damage to the tumour while minimising the damage to the surrounding healthy tissue, thereby reducing acute and late side effects. The most frequently used radiotherapy modalities use high-energy (MeV) photon or electron beams. Conventional X-ray radiation therapy is characterised by almost exponential attenuation and absorption, delivering the maximum energy near the beam entrance, but continuing to deposit significant energy at distances beyond the cancer target. The maximum energy deposition, for X-ray beams with energy of about 8 MeV, is reached at a depth of 2–3 cm in soft tissue. To deliver dose optimally to the tumour, while protecting surrounding healthy tissues, radiotherapy has progressed rapidly with the development of new technologies and methodologies. The latest developments include MRI-guided radiotherapy, which combines simultaneous use of MRI-imaging and photon irradiation.

Such advanced radiation therapy modalities are becoming increasingly important and offer new opportunities to treat different cancers, in particular the combination with other emerging areas such as cancer-immunotherapy and the integration of sequencing data, with clinical-decision support systems for personalised medicine.

However, if one looks at the dose deposition profile of photons compared to other particles (figure 1), the conspicuous feature of this graph is that, in the case of protons and carbon ions, a significant fraction of the energy is deposited in a narrow depth range near the endpoint of the trajectory, after which very little energy is deposited. It was precisely these differences in dose – the so-called Bragg-peak effect – that led visionary physicist and founder of Fermilab, Robert Wilson, to propose the use of hadrons for cancer treatment in 1946.

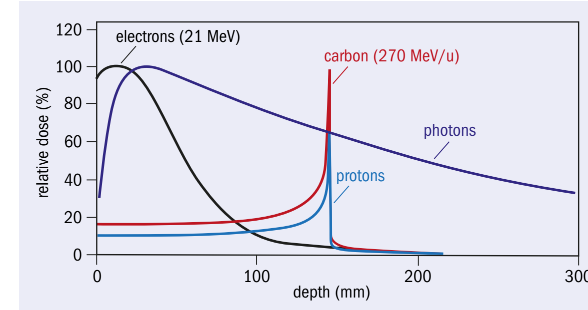


Fig. 1. For protons and other ions the peak of energy loss occurs just before the particles reach a halt. This is called the Bragg peak, first put to use at Lawrence Berkeley Laboratory to treat the first patient with protons in 1954.

Several advantages

Hadron or particle therapy is a precise form of radiotherapy that uses charged particles instead of X-rays, to deliver a dose of radiotherapy to patients. Radiation therapy with hadrons or particles (protons and other light ions) offers several advantages over X-rays: not only do hadrons and particles deposit most of their energy at the end of their range, but particle beams can be shaped with great precision. This allows for more accurate treatment of the tumour, destroying the cancer cells more precisely with minimal damage to surrounding tissue. Radiotherapy using the unique physical and radiobiological properties of charged hadrons, also allows highly conformal treatment of various kinds of tumours, in particular those that are radio-resistant.

Over the past two decades, particle-beam cancer therapy has gained huge momentum. Many new centres have been built, and many more are under construction (figure 2). At the end of 2016 there were 67 centres in operation worldwide and another 63 are in construction or in the planning stage. Most of these are proton centres: 25 in US (protons only); 19 in Europe (three dual centres); 15 in Japan (four carbon and one dual); three (one carbon and one dual) in China; and four in other parts of the world. By 2021 there will be 130 centres operating in nearly 30 countries. European centres are shown in figure 3, while figure 4 shows that the cumulated number of treated patients is growing almost exponentially.

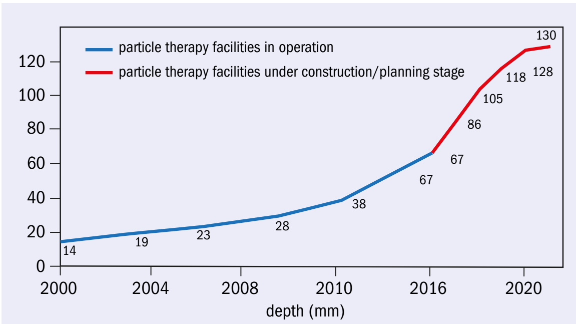


Fig. 2. Hadron therapy facilities in operation worldwide, under construction and in the planning stage, at the end of 2016.

At the end of 2007, 61,855 patients had been treated (53,818 with protons and 4,450 with carbon ions). At the end of 2016 the number had grown to 168,000 (145,000 with protons and 23,000 with carbon ions). This is due primarily to the greater availability of dedicated centres able to meet the growing demand for this particular form of radiotherapy, and most probably in future it will have a larger growth rate, with an increase of the patient throughput per centre.

Particle-physics foundation

High-energy physics research has played a major role in initiating, and now expanding, the use of particle therapy. The first patient was treated at Berkeley National Laboratory in the US with hadrons in September 1954 – the same year CERN was founded – and was made possible by the invention of the cyclotron by Ernest Lawrence and subsequent collaboration with his medical-doctor brother, John. The first hospital-based, particle-therapy centres opened in 1989 at Clatterbridge in the UK and in 1990 at the Loma Linda University Medical Center in the US. Before this time, all research related to hadron therapy and patient treatment was carried out in particle-physics labs.

In addition to the technologies and research facilities coming from the physics community, the culture of collaboration at the heart of organisations such as CERN is finding its way into other fields. This has inspired the European Network for Light Ion Therapy (ENLIGHT) to promote international discussions and collaboration in the multidisciplinary field of hadron therapy, which has now been running for 15 years (see p37).

Were it not for the prohibitively large cost of installing proton-therapy treatment in hospitals, it would be the treatment of choice for most patients with localised tumours. Proton-therapy technology is significantly more compact today than it once was, but when combined with the gantry and other necessary equipment, even the most compact systems on the market occupy an area of a couple of hundred square metres. Most hospitals lack the financial resources and space to construct a special building for proton therapy, so we need to make facilities smaller and cheaper, with costs of around \$5–10 million for a single room, similar to state-of-the-art photon-therapy systems. An ageing population, and the need for a more patient-specific approach to cancer treatment and other age-related diseases, present major challenges for

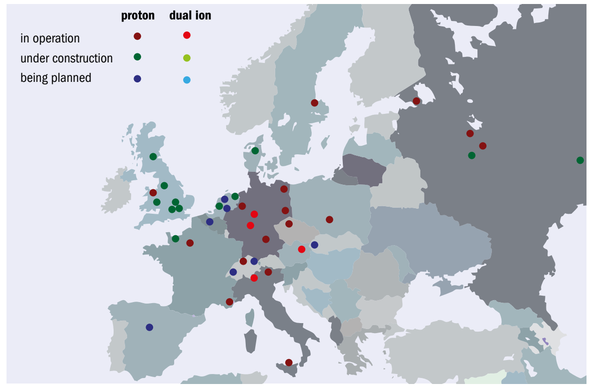


Fig. 3. European hadron therapy facilities in operation or under construction in 2016.

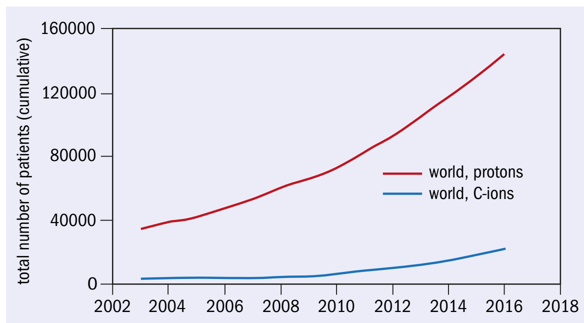


Fig. 4. Patients treated with protons and carbon ions worldwide by the end of 2016.

future technologies to control rising health costs, while continuing to deliver better outcomes for patients. Scientists working at the frontiers of particle physics have much to contribute to these goals, and the culture of collaboration will ensure that breakthrough technologies find their way into the medical clinics of the future.

Further reading

J Ferlay *et al.* 2013 *Eur. J. Cancer* **49** 1374.
R Atun *et al.* 2015 *Lancet Oncol.* **16** 1153.
Particle therapy co-operative group: ptcog.com.

Résumé

De nouvelles perspectives pour la thérapie du cancer

La charge économique croissante du traitement du cancer, évaluée à environ 2 000 milliards de dollars des États-Unis dans le monde pour l'année 2010, pèse lourdement sur les budgets de santé publics. Après des décennies de développement dans des laboratoires de physique des particules, l'utilisation de faisceaux de protons ou d'ions pour détruire les tumeurs commence à apporter de nouvelles perspectives pour la thérapie du cancer.

Manjit Dosanjh, CERN.

Bridging the gap

Participants of the "Innovative, robust and affordable medical linear accelerators for challenging environments" workshop, which included representatives of five UK Official Development Assistance (ODA) countries.

A major effort is under way to develop innovative, robust and affordable medical linear accelerators for use in low- to middle-income countries.

If you live in a low- or middle-income country (LMIC), your chances of surviving cancer are significantly lower than if you live in a wealthier economy. That's largely due to the availability of radiation therapy (see p32). Between 2015 and 2035, the number of cancer diagnoses worldwide is expected to increase by 10 million, with around 65% of those cases in poorer economies. Approximately 12,600 new radiotherapy treatment machines and up to 130,000 trained oncologists, medical physicists and technicians will be needed to treat those patients.

Experts in accelerator design, medical physics and oncology met at CERN on 26–27 October 2017 to address the technical challenge of designing a robust linear accelerator (linac) for use in more challenging environments. Jointly organised by CERN, the International Cancer Expert Corps (ICEC) and the UK Science and Technology Facilities Council (STFC), the workshop was funded through the UK Global Challenges Research Fund, enabling participants from Botswana, Ghana, Jordan, Nigeria and Tanzania to share their local knowledge and perspectives. The event followed a successful inaugural workshop in November 2016, also held at CERN (*CERN Courier* March 2017 p31).

These centres, and their machines, should be able to provide treatment on a 24/7 basis if needed.

The goal is to develop a medical linear accelerator that provides state-of-the-art radiation therapy in situations where the power supply is unreliable, the climate harsh and/or communications poor. The immediate objective is to develop work plans involving Official Development Assistance (ODA) countries that link to the following technical areas (which correspond to technical sessions in the October workshop): RF power systems; durable and sustainable power supplies; beam production and control; safety and operability; and computing.

Participants agreed that improving the operation and reliability of selected components of medical linear accelerators is essential to deliver better linear accelerator and associated instrumentation in the next three to seven years. A frequent impediment to reliable delivery of radiotherapy in LMICs, and other underserved regions of the world, is the environment within which the sophisticated linear accelerator must function. Excessive ambient temperatures, inadequate cooling of machines and buildings, extensive dust in the dry season and the high humidity in some ODA countries are only a few of the environmental factors that can challenge both the robustness of treatment machines and the general infrastructure.

Simplicity of operation is another significant factor in using linear accelerators in clinics. Limiting factors to the development of radiotherapy in lower-resourced nations don't just include the cost of equipment and infrastructure, but also a shortage of trained personnel to properly calibrate and maintain the equipment and to deliver high-quality treatment. On one hand, the radiation technologist should be able to set treatments up under the direction of the radiation oncologist and in accordance with the treatment plan. On the other hand, maintenance of the linear accelerators should also be as easy as possible – from remote upgrades and monitoring to anticipate failure of components. These centres, and their

Radiotherapy treatment setups in Tanzania (left and right, the latter based on a cobalt-60 source). Middle: imaging equipment in Nigeria lies dormant.

machines, should be able to provide treatment on a 24/7 basis if needed, and, at the same time, deliver exclusive first-class treatment consistent with that offered in richer countries. STFC will help to transform ideas and projects presented in the next workshop, scheduled for March 2018, into a comprehensive technology proposal for a novel linear accelerator. This will then be submitted to the Global Challenges Research Fund Foundation Awards 2018 call for further funding. This ambitious project aims to have facilities and staff available to treat patients in low- and middle-income countries within 10 years.

Résumé
Réduire la fracture thérapeutique

Une réunion d'experts, tenue au CERN les 26 et 27 octobre, était consacrée au développement d'un accélérateur linéaire pour applications médicales pouvant être utilisé dans des situation difficiles, telles qu'alimentation électrique peu fiable, climats extrêmes ou communications défectueuses.

Charlotte Jamieson, STFC, **Norman Coleman**, ICEC, **Paul Collier**, CERN.

Networking against cancer

Established in 2002, the European network for light-ion hadron therapy (ENLIGHT) is focusing on education and training to promote hadron therapy in Europe.

The inaugural meeting of the European Network for Light Ion Hadron Therapy (ENLIGHT) took place at CERN in February 2002, with the aim of co-ordinating European efforts in innovative cancer treatment strategies using radiation. Specialists from different disciplines, including radiation biology, oncology, physics and engineering, with experience and interest in particle therapy have nurtured the network ever since.

Today, ENLIGHT can count on the contribution of more than 700 members from all continents. Together, they identify and tackle the technical challenges related to the use of highly sophisticated machines, train young and specialist researchers, and seek funding to ensure the sustainability and effectiveness of the organisation.

Started with the support of the European Commission (EC), ENLIGHT has coordinated four other EC projects in particle therapy: ULICE, PARTNER, ENVISION and ENTERVISION. In the past 15 years, the network has evolved into an open, collaborative and multidisciplinary platform to establish priorities and assess the effectiveness of various treatment modalities. Initially based on the three technologies and innovation pillars – accelerators, detectors and computing – of high-energy physics, the ENLIGHT initiative has evolved into a global effort.

15 SUCCESSES in 15 YEARS

700 members from all continents
25+ countries
15 annual meetings
50+ training courses
5 EU projects
45 Marie Curie researchers
25+ dedicated issues in open access journals
200+ journal publications
500+ posters and conferences
9 ENLIGHT highlights
4 Physics for Health conferences
10+ videos and animations
50+ outreach articles/news
2 European Researchers' Nights

Training essential

ENLIGHT has witnessed a large increase in dedicated particle therapy centres, and innovative medical imaging techniques are starting to make their way into hospitals. Skilled experts for high-tech cancer treatment are, therefore, in high demand. Thanks to the large number of scientists involved and its wide reach, ENLIGHT has enormous potential to offer education and training and, since 2015, has included training sessions in its annual meetings.

Education and training, in addition to pitching for research funding, are the main thrusts of ENLIGHT's activities today. A project within the CERN & Society Foundation has just been approved, opening a new chapter for ENLIGHT and its community. The benefits lie, not only in reinforcing the hadron therapy field with qualified multidisciplinary groups of experts, but especially in helping young scientists flourish in the future.

● www.cern.ch/ENLIGHT.

Résumé
Un réseau contre le cancer

Mis en place en 2002, le réseau européen consacré à l'hadronthérapie par ions légers centre ses efforts sur l'éducation et la formation en vue de promouvoir l'hadronthérapie en Europe.

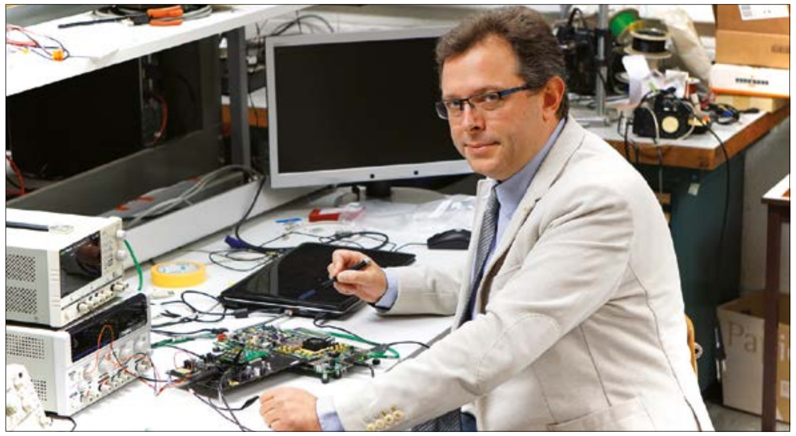
Manjit Dosanjh, CERN.

Faces & Places

Appointments

ECFA elects new chairperson

O Devroede



Newly elected ECFA chair Jorgen D'Hondt is also a member of the CMS Collaboration.

At a plenary meeting of the European Committee for Future Accelerators (ECFA) held at CERN on 16–17 November, Jorgen D'Hondt of the Vrije Universiteit Brussel in Belgium was elected ECFA chairperson, with a three-year-long mandate running from 2018 to 2020. ECFA carries out long-range planning for European high-energy accelerators, large-scale facilities and equipment, and plays an important role in building the physics community in preparation for the upcoming update of the European Strategy for Particle Physics. D'Hondt, who works on the CMS experiment, is co-director of the Interuniversity Institute for High Energies in Brussels, with research activities including top-quark physics and dark matter. His team is also involved in the upgrade of the CMS silicon tracker and in the development of heavy-flavour tagging algorithms. He takes over from previous ECFA chairperson Halina Abramowicz of Tel Aviv University in Israel, who is now secretary of the European Strategy Group (*CERN Courier* November p37).

Change of director at US accelerator school

MSU

Steven Lund takes the helm at USPAS.

Steven Lund of Michigan State University in the US has been named the new director of the US Particle Accelerator School (USPAS), succeeding William Barletta of Fermilab who has led the school since 2006. Lund, whose focus is theoretical accelerator physics, took up the role on 1 December with a four-year renewable term. Considered the premier training programme in accelerator science and engineering in the US, USPAS offers a continually updated curriculum of courses ranging from the fundamentals of accelerator science to advanced physics and engineering concepts. The school, which is a collaboration of 10 institutions hosted at Fermilab on behalf of the US Department of Energy, has many parallels with its European cousin the CERN Accelerator School, and is intended to train, develop and educate people on the many uses of particle accelerators in particle physics and beyond.

Awards

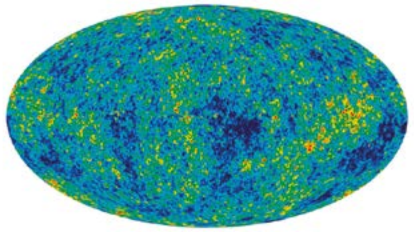
WMAP scientists awarded 2018 Breakthrough Prize

The team that mapped the temperature of the cosmic microwave background using NASA's Wilkinson Microwave Anisotropy Probe (WMAP) has won the 2018 Breakthrough Prize in fundamental physics. The $3 million sum was awarded to Charles Bennett (Johns Hopkins University), Gary Hinshaw (University of British Columbia), Norman Jarosik (Princeton University), Lyman Page Jr. (Princeton University), David N Spergel (Princeton University) and the WMAP Science Team on 3 December.

NASA launched WMAP in 2001 to measure tiny temperature fluctuations across the sky imprinted by processes in the very early universe. Its many precise measurements have helped establish the standard model of cosmology.

Now in their sixth year, the Breakthrough prizes honour top achievements in the fields of physics, life sciences and mathematics. They were founded by Sergey Brin, Yuri and Julia Milner, Mark Zuckerberg and Priscilla Chan, Anne Wojcicki, and Pony Ma, with seven $3 million prizes awarded this year at a televised ceremony in Silicon Valley.

In addition, three New Horizons in Physics Prizes of $100,000 were awarded to promising junior researchers who have already produced important work: Christopher Hirata of Ohio State University, Andrea Young of the University of California, Santa Barbara, and Douglas Stanford of the Institute for Advanced Study and Stanford University.



WMAP's results have helped transform cosmology into a precision science. (Image: NASA)

AWARDS

Weizmann Institute honours Jenni

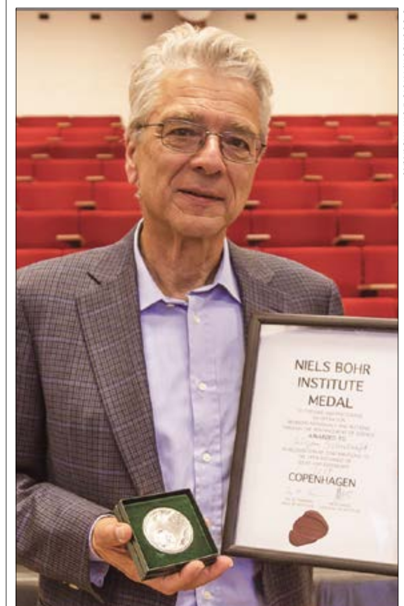
Weizmann Institute of Science

Peter Jenni before the ceremony at the Weizmann Institute of Science.

On 6 November the Weizmann Institute of Science in Israel awarded Peter Jenni of CERN and Albert Ludwigs University of Freiburg an honorary PhD. The award recognizes Jenni's landmark contributions to experimental particle physics and his impressive achievements leading the LHC's ATLAS experiment. It also noted his advocacy of high-energy physics research and education, and his instrumental role in inducting Israel into CERN as its first non-European Member State. Jenni was a founding spokesperson of ATLAS, continuing to lead the experiment until 2009, and previously played a major role in the UA2 experiment at the Super Proton Synchrotron.

Schukraft receives Niels Bohr Institute's Honorary Medal

O Joensen/Niels Bohr Institute



Jürgen Schukraft with his medal.

Heavy-ion physicist Jürgen Schukraft of CERN has been awarded the Niels Bohr Institute's Honorary Medal for his long-standing work in the study of heavy-ion collisions at relativistic energies and for his role as leader of the ALICE experiment at the LHC. Schukraft is one of the people behind the creation of ALICE and was spokesperson of the collaboration for its first 20 years from 1990, overseeing groundbreaking results concerning the quark–gluon plasma. Over the years Schukraft has been closely connected with the Niels Bohr Institute group in ALICE and he is also a member of the Discovery Danish National Research Foundation (DNRF) centre of excellence advisory board.

Dublin City University acclaim for Myers

DCU

Myers spoke about the benefits of CERN membership for Ireland.

Stephen Myers, former CERN director of accelerators and technology, has been awarded an honorary doctorate by Dublin City University in Ireland for his outstanding contributions to the physics community. Myers trained as an electronical engineer at Queen's University Belfast and spent most of his career at CERN, where he was responsible for the operation and exploitation of the CERN accelerator complex. He is currently executive chairman of CERN spin-out company ADAM Advanced Oncotherapy. On acceptance of his honorary degree on 3 November, Myers highlighted the importance of CERN and the benefits of membership. "Ireland's continued non-membership of CERN puts our country at an enormous technological disadvantage, since we cannot profit from the technology transfer and training that comes from being a member state of CERN," he said.

ANNIVERSARY

25 years of the LHC experimental programme

J Ordan/CERN

The symposium "25 years since Evian" attracted leading figures linked to the LHC programme.

On 15 December a special scientific symposium at CERN celebrated the 25th anniversary of the LHC experimental programme. During the event, speakers reflected on the LHC's history, the physics landscape into which the LHC experiments were born, and the challenging path that led to the very successful LHC programme today.

In early March 1992 a meeting took place in the town of Evian on Lake Geneva titled "Towards the LHC Experimental Programme". It would, quoting *CERN Courier* in May that year, "always be remembered as the stage where these ideas made their debut". The road since then has been full of challenges, new ideas and innovative techniques. A great deal of motivation, determination and patience was finally rewarded with excellent performance from the accelerators, detectors and computing, and with major physics results such as the discovery of the Higgs boson.

At the Evian event, a dozen teams presented an expression of interest (EOI) to carry out research at the LHC, including: four for general-purpose experiments; three for dedicated B-physics experiments; two for neutrino experiments; and two for dedicated heavy-ion experiments. The 12th EOI concerned a heavy-ion programme within the CMS experiment. ATLAS was formed from the merger of two proposals, ASCOT and EAGLE, whereas CMS had evolved from a single proposal at Evian. ATLAS and CMS submitted their letters of intent on 1 October 1992, with ALICE following in 1993 and LHCb in 1995 – completing the set of large LHC experiments.

Evian was a landmark, but it was also part of a longer process. The LHC had been formally launched at a workshop in Lausanne in 1984 and was recommended by CERN's long-range planning committee three years later, leading to a succession of meetings and workshops and, finally, to the CERN Council voting unanimously at its December 1991 meeting that the LHC was the "right machine for the advance of the subject and the future of CERN".

The December symposium concluded with a presentation of the latest results from the four large LHC experiments, which continue to subject the Standard Model of particle physics to unprecedented levels of scrutiny.

EVENTS

Inauguration ceremony promotes Hyper-Kamiokande project

On 1 October the University of Tokyo inaugurated the Next-generation Neutrino Science Organization (NNSO) and appointed the 2015 Nobel Prize-winning neutrino physicist Takaaki Kajita as its director. The NNSO's main purpose is to promote the construction of the Hyper-Kamiokande project, a new neutrino facility in Japan, involving some 74 institutions in 14 countries, and to work towards the development of state-of-the-art neutrino research techniques and detector technologies. Hyper-Kamiokande will investigate CP violation in the neutrino sector by observing oscillations in a neutrino/anti-neutrino beam produced by the J-PARC accelerator. It will use a 260,000 tonne tank of pure water located 650 m underground in Kamioka to detect the Cherenkov radiation produced by the collision of neutrinos with water molecules using 40,000 photomultiplier tubes. "Understanding the neutrino is not only important to particle physics, but is also thought to have deep connections to the origins of matter," said Kajita in his opening remarks.

The ceremony was attended by about 100 people from MEXT, the University of Tokyo, KEK, local government and community, the Kamioka Mining and Smelting Company, and collaborating scientists.

Dark-matter and cosmic-ray celebrations

Towards the end of 2017, two world-wide cosmic celebrations reached out to new audiences with tales about dark matter and cosmic rays. On 31 October the historic hunt for dark matter was celebrated with the first ever "Dark Matter Day". Many laboratories and institutes organised dedicated events targeting new audiences, including CERN, which opened its doors to the public and invited experts to talk about the status of dark-matter science. The following month, on 30 November, International Cosmic Day took place for the sixth time, organised by DESY in Germany. Young people around the word had the chance to experience research in an international collaboration in science by analysing real cosmic-ray data, with more than 60 groups of young people in 17 countries around the world taking part.

Japan science festival looks beyond the boundaries

Science Agora 2017, Japan's largest science festival, took place in Tokyo on 24–26 November, giving researchers the opportunity to interact with non-scientists and policy-makers alike. The key theme of this year's festival was "beyond the boundaries", including a dedicated session in which the European Union (EU) delegation to Japan highlighted several big-science projects enabled by the collaboration of European and Japanese researchers.

The Future Circular Collider (FCC) study, launched at CERN in 2014 and supported through the European Commission's EuroCirCol programme, was presented as a primary example of how scientific collaboration in a big scientific project transcends geographical and cultural boundaries. The neutrino project Super-Kamiokande Plus was also highlighted, as were joint international projects concerning fusion energy, photovoltaic cells, smart cities and climate change. "Participation in Science Agora is driven by our twofold desire to show in a tangible manner some of the best science and innovation that are being developed in Europe, and to demonstrate the diverse ways in which European and Japanese researchers and scientists are cooperating," said EU ambassador Viorel Isticioaia-Budura.

K Tomihisa

Deputy FCC study leader Frank Zimmermann discusses how the project requires experts from different fields and countries.

● *The fourth annual meeting of the FCC study will take place from 9–13 April 2018 in Amsterdam:* cern.ch/fccw2018.

Fun at the fair

M Brice/CERN

Science immersion at the Geneva exhibition.

CERN was guest of honour at Geneva's major annual fair the Automnales, held from 10 to 19 November. Some 145,000 people attended the event and most of them stopped at the CERN stand to immerse themselves in the world of fundamental science. The stand covered an area of $1000\,m^2$ and was designed to resemble a particle collision. Guests young and old had the chance to take a virtual-reality tour of the LHC and one of its detectors, learn how to conduct physics experiments using household objects, play proton football and program robots, among other activities. Most importantly, they met enthusiastic researchers, engineers, technicians and administrative employees who were delighted to share their passion for research.

Letters

ISOLDE then and now

I was pleased to see your piece about the 50th anniversary of the ISOLDE project (*CERN Courier* December 2017 p36). It is truly remarkable how ISOLDE, over such a long time and in its evolving shapes, has succeeded in maintaining world leadership in the study of exotic nuclei. This is a success story for the scientists involved and CERN as an organisation willing to support excellent science in areas other than mainstream particle physics.

The picture from 1967 that you used shows the original ISOLDE team in the underground cavern between the Synchrocyclotron building and the main gates (note the white lab coats – the experiment was run by the then nuclear chemistry group). The person standing to the right in the picture is group leader Arve Kjelberg, a nuclear chemist originating from Pappas' group in Oslo. Kjelberg moved on to become deputy director of the nuclear physics division under Herwig Schopper and, after leaving CERN, he held senior positions in the Norwegian Ministry of Science and Education until retirement. He passed peacefully away in June 2016.

● *Leif Westgaard*

Neutrinos and the Standard Model

I read with interest your interview with Weinberg (*CERN Courier* November 2017 p31) and would like to draw attention to a statement made on page 34, "Whereas simply inserting neutrino masses into the theory would violate the $SU(2)\times U(1)$ symmetry."

There is a simple way to put neutrino masses into the Standard Model (SM): just add their right-handed terms like any other fermion, and standard Higgs doublet couplings, and you get masses, $SU(2)\times U(1)$ symmetry and renormalisability. This point was not addressed in the article and it gives the impression that it is really impossible to maintain SM renormalisibility and give mass to the neutrinos at the same time. This would be a clear failure of the SM and gauge theories, but it isn't the case.

● *Biagio Di Micco*

Editor's reply:

The article perhaps could have been clearer that the symmetries of the SM make it impossible to give masses to neutrinos without introducing either non-renormalisable interactions *or* new fields, namely right-handed neutrino fields that have no interactions with SM gauge fields. The latter would leave the mystery of why neutrino masses are so tiny, however, while the effective-field theory point of view ensures that non-renormalisable terms in the SM are naturally very small, explaining the smallness of neutrino masses and potentially other observables, too.

Dick Garwin and g-2

Last year *CERN Courier* reported on measurements of the anomalous magnetic moment of the muon, g-2 (July/August 2017 p11). There was a second (hidden) occasion in the January/February issue (p50) where it was reported that Dick Garwin received the Presidential Medal of Freedom from former US president Barack Obama for his long career in research and invention. Garwin's significant contributions to particle physics and his work at CERN, however, were not mentioned.

In an experiment undertaken at Columbia in 1957 together with Leon Lederman and Marcel Weinreich, Garwin made the first observation of parity violation in muon decay and measured the value of g-2 to a precision of around 10%. At CERN, starting in 1959, Garwin was also a member of the group that performed the first g-2 experiment at the Synchrocyclotron.

● *Pier Giorgio Innocenti*

Diversity

Berkeley physicists march in Pride Parade

A group of about 30 Lawrence Berkeley National Laboratory employees and friends, along with staff from Sandia and Lawrence Livermore National Labs, marched in the 2017 San Francisco Pride Parade. The group, which included many with strong ties to nuclear and particle physics, raised colourful placards and demonstrated the lab's support for diversity and inclusion. Berkeley Lab's participation was organized by the Lambda Alliance, which aims to promote an inclusive atmosphere, enhance policies of non-discrimination, create guidance for institutional processes, identify and address emerging challenges, and increase awareness of issues impacting the Berkeley Lab community.

W Lile

The 2017 Pride Parade celebrated the 50th anniversary of the "Summer of Love".

Colourisation by S Dullaway

G Cavulli/University of Trento

Ninety years after the famous photograph of the 1927 Solvay conference (top) was taken, depicting 28 male scientists and a single woman (Marie Skłodowska Curie), the University of Trento and the Italian Physical Society created a more modern picture: a new photo showing 28 female physicists and one man (former CMS spokesperson Guido Tonelli). The aim was to give more visibility to women in physics, one of the topics of the conference of the Italian Physical Society in Trento after which the photo was taken on 14 September. At the 1927 Solvay conference, devoted to electrons and photons, 17 of the 29 attendees photographed were or became Nobel Prize winners – including Curie, who alone among them, had won Nobel Prizes in two separate scientific disciplines.

MEETINGS

Weighing up the LHC's future

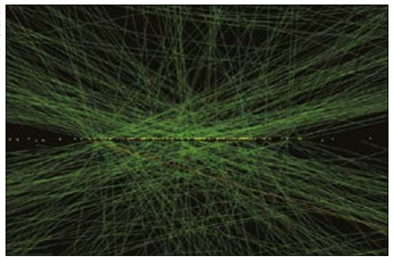
As the LHC's 2017 run drew to a close late last year, CERN hosted a workshop addressing future physics opportunities at the flagship collider. The first workshop on the physics of High-Luminosity LHC (HL-LHC) and perspectives at High-Energy LHC (HE-LHC) took place from 30 October to 1 November, attracting around 500 participants. HL-LHC is an approved extension of the LHC programme that aims to achieve a total integrated luminosity of 3 ab^{-1} by the second half of the 2030s (for reference, the LHC has amassed around 0.1 ab^{-1} so far). HE-LHC, by contrast, is one of CERN's possible options for the future beyond the LHC; its target collision energy of 27 TeV, twice the LHC energy, would be made possible using the 16 T dipole magnets under development in the context of the Future Circular Collider study.

The workshop was the first of a series of meetings scheduled throughout 2018 to review and further refine our understanding of the physics potential of the HL-LHC, and to begin a systematic study of physics at the HE-LHC.

Close to 2000 physics papers have been published by the LHC experiments. In addition to the discovery of the Higgs boson and the first studies of its properties, these papers document progress in hundreds of different directions, ranging from searches for new particles and interactions to the measurement of a multitude of cross-sections with unprecedented precision, from the improved determination of the top-quark and W-boson masses to the opening of new directions in the exploration of flavour phenomena, from the discovery of hadrons made of exotic quark configurations to the observation of new collective phenomena in both proton and nuclear collisions. That these results were extracted from datasets representing only a few percent of the data sample promised by the HL-LHC, shows how vast and incisive its ultimate achievements may be.

There is nevertheless a recurrent concern expressed by many physicists that the lack of direct evidence for new physics at the LHC is already diminishing the expected returns from the HL-LHC. The conflict with the expectation that new physics should have already appeared at the LHC forces us to reconsider that prejudice, and strongly underscores the mysterious origin of the Higgs boson and the need to study it in the greatest detail. This orients the HL-LHC goals towards increasing the sensitivity to elusive exotic phenomena, and increasing the precision of Standard Model measurements and of their interpretation, in particular for the Higgs. These directions pose severe challenges to experimentalists and theorists, pushing us to develop original approaches for the best exploitation of the HL-LHC statistics and to use experience to reduce future systematic uncertainties in theory and experiment. The full HL-LHC dataset will be needed to challenge the Higgs mechanism. With it, we will be able to attain percent-level precision for the most prominent of the Higgs interactions, test the couplings to the second fermion generation, and find evidence for the self-interaction of the Higgs.

A Holzner



HL-LHC will produce ~200 simultaneous proton collisions in a single bunch crossing. Shown is a real-life example of 78 reconstructed collisions in a single event.

Progress and precision

A priority of the workshop series is to study the added value provided by the HE-LHC. And, since minor deviations from the Standard Model could be hiding anywhere, no stone should be left unturned. We have already seen the emergence of new proposals and techniques, which have extended beyond expectations the new-physics reach. Examples include the use of boosted jet topologies to enhance sensitivity to weakly interacting light particles decaying hadronically, or the use of quantum interference effects to constrain the Higgs-decay width. New proposals are also emerging to detect exotic long-lived particles, with the possible help of additional detector elements. The workshop environment should stimulate the youngest researchers to develop ideas and leave their own signature on future analyses.

Indications of lepton-flavour-universality violation (see p48) are being closely monitored and will be further scrutinised during the workshop. Were these hints to be confirmed with more data, it would open a hunt for their microscopic origin and provide concrete ground in which to examine the power of the HL-LHC and the potential of a future HE-LHC to test the proposed models. The workshop series will explore the synergy and complementarity of the flavour studies carried out with the precise measurement of b-hadron decays and with the direct search for these new interactions.

The LHC running into the mid-2030s also provides new opportunities for the study of hadronic matter at high densities. The established existence of a quark-gluon plasma phase should be probed under a broader set of experimental conditions, using ions lighter than lead, and thoroughly addressing the novel indications that unexpected collective effects appear in proton collisions. Surprises such as this show that the field of high-density hadronic matter is rapidly evolving, and the workshop will outline the ambitious future programme needed to answer all open questions.

The discussion of the prospects of HL-LHC physics builds on the experience gained so far by the LHC experiments, in particular the dedicated work done for the preparation of future detector upgrades to cope with the harsher high-luminosity environment of HL-LHC, addressing problems of increased event rates and complexity. The workshop will try to go beyond the existing performance studies, exploring the opportunities offered by the superior detector and data-acquisition systems.

On the theory side, the computing techniques discovered in the last few years are being pushed to new heights, promising continued progress in the modelling of LHC interactions. This goes hand in hand with the improved precision of the measurements, and the workshop will examine new ideas for the direct validation of theoretical calculations, to improve the extraction of Standard Model parameters and to gain higher sensitivity to deviations from the Standard Model.

The strong attendance at the kick-off workshop attests the great interest present in the community in the post-LHC era. The outcomes will be documented in a report to be submitted to the 2019 review of the European Strategy for Particle Physics. The projections for the ultimate outcome of the HL-LHC will provide an essential reference for the assessment of the other future initiatives to be evaluated during the strategy review.

● indico.cern.ch/event/647676

Sizing up physics beyond colliders

The Physics Beyond Colliders (PBC) initiative, launched in 2016, explores the opportunities offered by the CERN accelerator complex and infrastructure that are complementary to high-energy collider experiments and other initiatives worldwide. It takes place in an exciting and quickly developing physics landscape. To quote a contribution by theorist Jonathan Feng at the recent ICFA seminar in Ottawa: "In particle theory, this is a time of great creativity, new ideas, and best of all, new proposals for experiments and connections to other fields."

Following a kick-off workshop in September 2016 (*CERN Courier* November 2016 p28), the second general PBC workshop took place at CERN on 21–22 November. With more than 230 physicists in attendance, it provided an opportunity to review the progress of the studies and to collect further ideas from the community.

During the past year, the PBC study was organised into working groups to connect experts in the various relevant fields to representatives of the projects. Two physics working groups dealing with searches for physics beyond the Standard Model (BSM) and QCD measurements address the design of the experiments and their physics motivation, while several accelerator working groups are pursuing initiatives ranging from exploratory studies to more concrete plans for possible implementation at CERN. The effort has already spawned new collaborations between different groups at CERN and with external institutes, and significant progress is already visible in many areas.

The potential performance increase for existing and new users of the upgraded HL-LHC injector chain, following the culmination of the LHC injector upgrade project (*CERN Courier* October 2017 p22), is being actively pursued with one key client being the SPS North Area at CERN. The interplay between potential future operation of the existing SPS fixed-target experiments (NA61, NA62, NA64, COMPASS) and the installation of new proposed detectors (NA64++, MUonE, DIRAC++, NA60++) has started to be addressed in both accelerator and physics respects. The technical study of the SPS proton beam dump facility and the optimisation of the SHiP detector for investigating the hidden sector are also advancing well.

Different options for fixed-target experiments at the LHC, for instance using

S de Jong

The November workshop at CERN is the second in the Physics Beyond Colliders series.

gas targets or crystal extraction, are under investigation, including feasibility tests with the LHC beams. The novel use of partially stripped ions (PSI) to produce high-energy gamma rays in a so-called gamma factory (*CERN Courier* November 2017 p7) is also gaining traction. Having taken PSI into the SPS this year, near-term plans include the injection of partially stripped lead ions into the SPS and LHC in 2018.

New opportunities

The design study of a storage ring for a proton electric-dipole-moment (EDM) measurement is progressing, and new opportunities to use such a ring for relic axion searches through oscillating EDMs have been put forward. In the loop are the COSY team at Jülich who continue to break new ground with polarised deuteron experiments (*CERN Courier* September 2016 p27).

Last but not least are non-accelerator projects that wish to benefit from CERN's technological expertise. One highlight is the future IAXO helioscope, proposed as a successor of the CERN CAST experiment for the search of solar axions. Recently IAXO has formed as a full collaboration and is in discussion with DESY as a potential site. IAXO and a potential precursor experiment (Baby-IAXO) benefit from CERN PBC support for the design of their magnets.

The workshop also included a session devoted to the presentation of exciting new ideas, following a call for contributions from the community. One noticeable new idea consists of the construction of a low-energy linac using CLIC technology for electron injection and acceleration in the SPS. A slow extracted SPS e-beam in the 10–20 GeV energy range would allow hidden sector searches similar to NA64 but at higher intensity, and the linac would provide unique R&D possibilities for future linear accelerators. Another highlight is the prospect of performing the first optical detection of vacuum magnetic birefringence using high-field magnets under development at CERN. New projects are also being proposed elsewhere, including a first QED measurement in the strong field regime at the DESY XFEL (LUXE project) and a search for η meson rare decays at FNAL (REDTOP experiment).

The presentations and discussions at the workshop have also shown that, beyond its support to the individual projects, the PBC study group provides a useful forum for communication between communities with similar motivations. This will be an important ingredient to optimise the scope of the future projects.

The PBC study is now at a crucial point, with deliverables due at the end of 2018 as input to the European Strategy for Particle Physics Update the following year. The PBC documents will include the results of the design studies of the accelerator working groups, with a level of detail matched to the maturity of the projects, and summaries of the physics motivation of the proposed experiments in the worldwide context by the BSM and QCD physics groups. One overview document will provide an executive summary of the overall landscape, prospects and relevant issues. It should also be emphasised that the goal of the PBC study is to gather facts on the proposed projects, not to rank them.

A follow-up plenary meeting of the PBC working groups is foreseen in mid-2018, and the main findings of the PBC study will be presented to the community in an open closeout workshop towards the end of the year.

● pbc.web.cern.ch

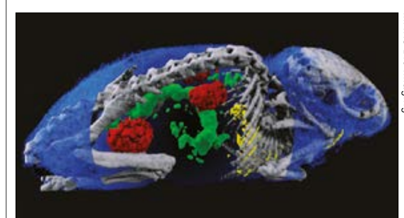
CERN and Member States talk med-tech

The first annual knowledge-transfer thematic forum on medical applications took place at CERN on 30 November, bringing CERN and its Member State and associate Member State representatives together to discuss the application of CERN's technologies and know-how to the medical field.

The knowledge transfer (KT) forum, known as ENET until the end of 2015 comprises one or more representatives for each country, allowing CERN to develop common approaches with its Member States and to identify potential industry and academic partners while minimising duplication of effort. Medical applications are one of CERN's most significant KT activities, and this year CERN gave each country the chance to nominate an expert in the field to attend special sessions of the KT forum dedicated to medical applications.

Some 20 invited speakers from the physics and medical communities took part in the inaugural event in November. The scope of the discussions demonstrated CERN's deep and longstanding involvement in areas such as medical imaging, hadron therapy and computing, and highlighted the enormous potential for future applications of high-energy physics technologies to the medical arena.

MARS Bio Imaging



3D colour X-ray imaging of a mouse carried out by a start-up company based on CERN-developed Medipix technology.

After an introduction regarding CERN's strategy for medical applications and the governance put in place for these activities (see p5), much of the event was devoted to updates from individual Member States and associate Member States, where much activity is taking place. Some of them clearly indicated that medical applications are an important activity in their countries, and that engaging with CERN more closely is of great added value to such efforts.

In the second half of the meeting, presentations from CERN experts introduced the various technology fields in which CERN is already actively pursuing the application of its technologies to the medical fields, such as high-field superconducting magnets, computing and simulations, and high-performance particle detectors.

The event was an all-round success, and more will follow this year to continue identifying ways in which CERN can contribute to the medical applications strategy of its Member States.

Top physics focus in Portugal

J Kvita & C Nellist

Participants of TOP2017 in Braga, Portugal.

Since its discovery in 1995 by the CDF and D0 experiments at the Tevatron, Fermilab, the top quark has provided physicists with a powerful handle on the Standard Model (SM). Being the heaviest known elementary particle, the top quark is difficult to produce and study but its large mass makes it sensitive to new physics beyond the SM.

The series of international workshops on top-quark physics started in 2006 in Coimbra, Portugal, with the main goal of establishing a close collaboration between experimentalists and theorists. The 10th edition took place in Bom Jesus Sanctuary in Braga, northern Portugal, from 17–22 September and attracted around 150 participants.

The mass of the top quark has always triggered passionate discussion, given the increasing precision of its measurement. The mass measurement has come a long way since the first edition of the top-quark workshop, when the Tevatron Run I/II mass combination was 172.7 ± 2.9 GeV, to the present sub-GeV precision obtained at the LHC in 2017. Still, the interpretation of the measurement, both from theoretical and experimental points of view, is a continuing hot topic that motivated vivid sessions at TOP2017.

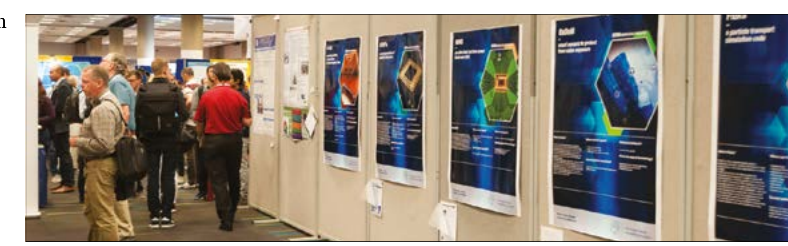
Measured cross sections for both double and single top-quark production are in remarkable agreement with the SM predictions. It is also noteworthy that the measurements can now be compared with predictions at next-to-next-to-leading order (NNLO) in QCD with next-to-next-to-leading-logarithm (NNLL) soft gluon resummation, as presented at TOP2017. Describing the differential distributions, for instance of the transverse momentum of top quarks, is an increasing challenge to top-quark researchers. In particular, the mis-modelling of the distribution tails are coming under increasing scrutiny in case they contain hidden signs of physics beyond the SM, and will be a particularly important target of analyses at the high-luminosity LHC. A significant effort from the theoretical community is ongoing to understand the shape of differential distributions.

The top-quark couplings to gauge bosons can be tested at the LHC via measurements of the production cross sections of $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}\gamma$ and $t\bar{t}H$ processes, which was another source of detailed discussion at the Portugal event. The measurements are particularly challenging given the low predicted cross sections and the overwhelming irreducible backgrounds. These measurements will become more important during the high luminosity phase of the LHC. The current precision of the measurements, as presented at TOP2017, ranged from 13% for the $t\bar{t}\gamma$ channel to 15% for the $t\bar{t}Z$ production and 22% for $t\bar{t}W$. All measurements are within the SM expectations and were therefore used to set constraints on new physics. Also, for the first time, the search for the production of the rare four top-quark production at the LHC ($pp \to t\bar{t}t\bar{t}$) was shown at TOP2017. This process puts in perspective the different contributions from the gauge bosons to the overall production cross section, allowing a reinterpretation of the result as a constraint on the Yukawa couplings of top quarks to the Higgs boson.

On its 10th anniversary, the series of International Workshops on Top Quark Physics continues to build a sense of community worldwide on top-quark physics, with a strong physics case ahead. Stay tuned for the next edition in Bad Neuenahr, Germany, in 2018.

CERN presents high readiness-level technologies in Atlanta

R Engels



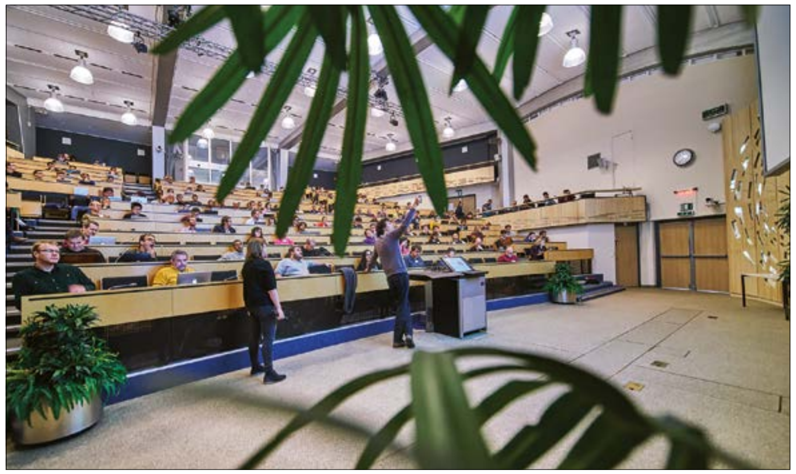
The poster-themed knowledge-transfer event was attended by more than 500 visitors.

During the IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), held on 21–28 October in Atlanta in the US, a technology-transfer programme organised by HEPTech, CERN and Siemens presented CERN technologies with a high technology-readiness level. To be selected for the programme, the technologies had to prove the availability of solid academic substance in addition to clear IP access conditions, applications and dissemination/commercialisation plans. Ten posters were exhibited, representing mature technologies originating from the US, Canada and Europe. Seven of them visualised CERN's radiation detection, pixel detector and electronic technologies, as well as software developments.

Among the CERN technologies presented were: Timepix3, a general-purpose integrated circuit for read-out of semiconductor and gas-filled detectors that can be applied in X-ray imaging, particle track reconstruction or radiation detection and monitoring; GEMPix, a novel generation of radiation detectors for dose measurements in hadron therapy; NINO ASIC, an ultrafast and low-power front-end amplifier discriminator ASIC chip for use in medical imaging, life science or materials research; FLUKA, a particle-transport simulation code with many applications in high-energy particle physics and engineering; and RaDoM, a very compact radon detector measuring indoor radiation concentrations rapidly and accurately. The annual IEEE NSS/MIC forum is the main event for the detector and electronic community and attracts more than 1500 participants.

Implications of LHCb results brought into focus

More than 300 physicists from the LHCb Collaboration and the theory community met at CERN on 8–10 November for a workshop devoted to the implications of LHCb measurements, the seventh since the series began. The very accurate results obtained by LHCb in a broad range of topics have made a large impact on the flavour-physics landscape and have implications on classes of extensions of the Standard Model (SM). The discussions also considered the interplay of searches for on-shell production of new particles at ATLAS and CMS. This series of joint workshops allows informal discussions between theorists and LHCb experimentalists, leading to a fruitful, mutual exchange of information.



The attendance at the LHCb workshop in November was such that it had to be moved to the more spacious main auditorium.

New ideas

Four streams were addressed: mixing and CP violation in beauty and charm; semileptonic decays, rare decays and tests of lepton-flavour universality; electroweak physics, heavy-flavour production, implications for PDFs and exotic searches; and QCD spectroscopy and exotic hadrons. Following an experimental overview of each stream, a series of theoretical presentations covered the latest calculations or suggested interesting observables or analysis methods to test new ideas.

Examples of recent results that have attracted a lot of interest include spectroscopy of conventional and exotic hadrons such as four- and five-quark hadrons, which provide new challenges for QCD. Measurements of CP-violating observables in B meson decays are another hot topic, since they can be used to determine the angles of the unitarity triangle and hence probe for manifestations of new physics beyond the SM paradigm. Unfortunately, the data present an overwhelming agreement with the SM, but the majority of these measurements are so far statistically limited, with theoretical uncertainties on the interpretation of the physical observables much smaller than the attainable experimental precision.

A significant part of the workshop was devoted to exciting and intriguing anomalies in the b-quark sector that test lepton-flavour universality (LFU), a cornerstone of the SM. These anomalies can naturally be grouped into two categories according to the underlying quark-level transition: those arising in $b \to sl^+l^-$ flavour-changing neutral-currents at one-loop level when measuring $B^0 \to K^*l^+l^-$, or $B^+ \to K^+l^+l^-$ (with $l = e$ or μ); and those arising in $b \to c\,l\,\nu$ charged-currents at tree level, when measuring $B^0 \to D(^*)l\,\nu$, or $B_c^+ \to J/\psi\,l\,\nu$ (with $l = \tau, \mu$ or e). Taken together, these anomalies represent the largest coherent set of possible new-physics effects in the present LHCb data.

Although there are well-motivated models that attempt to explain the effects, it is too early to draw definite conclusions. So far not a single LFU measurement deviates with respect to the SM above the 3σ level. However, what is particularly interesting, is that these anomalies challenge the assumption of LFU, which we have taken for granted for many years. Furthermore, these measurements have been performed so far with Run-1 data only. Updates with Run-2 data are under way and should allow LHCb to rule out the possibility of statistical fluctuations.

Electromagnetic interactions with nucleons

The 12th Electromagnetic Interactions with Nucleons and Nuclei (EINN) conference took place in Paphos, Cyprus on 29 October to 4 November and attracted 84 participants from 39 institutes located in 15 countries in Europe, North America, Asia and Australia. The conference was dedicated to the memory of Kees de Jager, the first conference chair in 1995 who passed away in 2016. The conference series covers experimental and theoretical topics in the areas of nuclear and hadronic physics. It also serves as a forum for contacts and discussions of current and future developments in the field.

The conference covered a wide range of theoretical and experimental developments in hadron physics including: contributions beyond single-photon exchange; the proton radius puzzle; new experimental facilities; dark-matter searches; neutrino physics; lattice QCD; spectroscopy; spin structure of the proton; precision electroweak physics; and new physics searches. With the study of QCD being a major focus of present activities and future plans in physics research worldwide, the EINN conference will continue to provide an important international forum, particularly for young physicists, for the foreseeable future. Since 2011 the event has also offered dedicated skills sessions for postdoctoral fellows and advanced graduate students.

Particle physics meets quantum optics

The sixth International Conference on New Frontiers in Physics (ICNFP) took place on 17–29 August in Kolymbari, Crete, Greece, bringing together about 360 participants. Results from LHC Run 2 were shown, in addition to some of the latest advances in quantum optics.

A mini-workshop dedicated to "highly-ionising avatars of new physics" brought together an ever-growing community of theorists, astroparticle physicists and collider experimentalists. There were also presentations of advances in the theory of highly ionising particles as well as light monopoles, with masses accessible to LHC and future colliders, and discussions included experimental searches both extraterrestrial and terrestrial, including results on magnetic monopoles from MoEDAL-LHC experiment that have set the strongest limits so far on high-charge monopoles at colliders.

In the "quantum" workshops, this year dedicated to the 85th birthday of theorist Yakir Aharonov, leading experts addressed fundamental concepts and topics in quantum mechanics, such as continuous variables and relativistic quantum information measurement theory, collapse, time's arrow, entanglement and nonlocality.

The roundtable discussion, with panel members including former CERN director of research, Sergio Bertolucci (left), and two directors-general of major laboratories: John Womersley of the ESS (middle) and Victor Matveev of JINR (right).

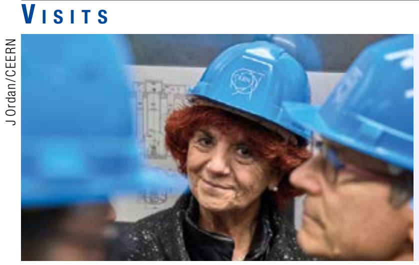
In the exotic hadron workshop the nature of the exotic meson X(3872) was discussed in considerable detail, especially with regard to its content: is it a mixture of a hadronic molecule and excited charmonium, or a diquark–antidiquark state? Detailed studies of the decay modes and p_T dependence of the production cross section in proton–proton collisions emerged as two most promising avenues for clarifying this issue. Following the recent LHCb discovery of doubly-charmed χ_{cc} baryon, new results were reported including the prediction of a stable $bb\bar{u}\bar{d}$ tetraquark and a quark-level analogue of nuclear fusion.

Presentations on the future low-energy heavy-ion accelerator centres, FAIR in Darmstadt and NICA at JINR in Dubna, showed that the projects are progressing on schedule for operation in the mid-2020s. Delegates were also treated to the role of non-commutative geometry as a way to unify gauge theories and gravity, self-interactions among right-handed neutrinos with masses in the warm-dark-matter regime, and the subtle physics behind sunsets and the aurora.

The conference ended with two-day workshops on supergravity and strings, and a workshop on the future of fundamental physics. Major future projects were presented, together with visionary talks about the future of accelerators and the challenges ahead in the interaction of fundamental physics and society. The conference also hosted a well-attended special session on physics education and outreach. The next ICNFP conference will take place on 4–12 July 2018 in Kolymbari, Crete.

● https://indico.cern.ch/event/559774/

Visits



J Ordan/CERN

Italian minister for education, university and research, **Valeria Fedeli**, came to CERN on 18 December. After signing the guestbook she toured ATLAS and met with Italian staff at CERN.

S Bennett/CERN

On 8 November, Czech minister for regional development **Karla Šlechtová** toured CERN's Synchrocyclotron, ATLAS experiment and LHC superconducting magnet test hall. She is photographed signing the guest book with management liaison Vladislav Benda (left) and Czech engineer David Belohrad.

J Ordan/CERN

Manuel Heitor, minister of science, technology and higher education of the Portuguese Republic, visited CERN on 15 December on the occasion of the symposium "25 Years of the LHC Experimental Programme", during which he signed an administrative protocol between Portugal and CERN, represented by Director-General Fabiola Gianotti.

S Bennett/CERN

On 17 November, **Wolfgang Burtscher**, deputy director-general for research and innovation at the European Commission (EC), visited CERN for the annual EC–CERN meeting, signing the guestbook with CERN Director-General Fabiola Gianotti.

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OBITUARIES

Lev Lipatov 1940–2017

On 4 September our friend and colleague Lev Nikolaevich Lipatov of the Russian Academy of Sciences (RAS) passed away unexpectedly while attending a physics meeting in Dubna. Lev grew up in Leningrad (now St. Petersburg) and entered the physics faculty at the Leningrad State University in 1957. In 1963 he joined the group of Vladimir Gribov at the Ioffe Physical-Technical Institute of RAS, defending his dissertation in 1968. He remained in Gribov's group when it moved to the Leningrad Nuclear Physics Institute in Gatchina in 1970 and obtained a permanent position. He became a professor of physics in 1990 and, since 1997, was the director of the theory division. In 1998 he also became a member of St. Petersburg State University, where he lectured, and in 2011 he was elected as a full member of the RAS.

Lev was a leading figure worldwide in the high-energy behaviour of quantum field theory. Supported by Gribov, he began to analyse the high-energy behaviour of QED processes and became involved in the investigation of the "double logarithms". His main focus was first on the Regge limit (at the time, Regge theory had just started to become popular for analysing high-energy scattering processes), but the discovery of Bjorken scaling transferred his focus to the kinematic limit of deep inelastic scattering. It was after a seminar given by Gribov when Lev spotted a gap in the theoretical argument – leading to the famous "GL" paper, which later became a theoretical cornerstone of the DGLAP evolution equations. These are now an important pillar in the analysis of high-energy scattering processes at the LHC.

After the rise of non-abelian gauge theories in the early 1970s, it was again the Regge limit that attracted Lev's interest: together with his collaborators in 1975 he derived an integral equation which, after

PNPI

Lipatov was an expert in the high-energy behaviour of quantum field theory.

applying it to QCD, became known as the "BFKL" equation. It took several years before this equation received international attention, but today the BFKL papers are among the publications with the highest numbers of citations in high-energy physics.

Lev's scientific work extends much further, however. He found a new approach for investigating large orders in perturbation theory, generalized the concept of partonic evolution equations beyond the leading-twist approximation and spent several years computing the NLO corrections to the BFKL equation. He discovered that the BFKL Hamiltonian (after generalizing to many-gluon states) is equivalent to an integrable Heisenberg spin model, thus demonstrating that the concept of integrability plays an important role in high-energy physics, and developed a new formulation in terms of a gauge-invariant "effective action". In gravity he discovered the reggeization of the graviton and within the conjectured AdS/CFT duality he pointed out the need for correcting the BDS formula using remainder functions, and worked on the duality of the BFKL pomeron with the graviton. Although Lev's work was purely theoretical, he never neglected experimental data: his last papers studied the application of the QCD BFKL equation to HERA data, thus gaining a deeper understanding of his "favourite child", the BFKL pomeron.

Lev was well known in the high-energy physics community and was invited to give talks at countless international meetings and conferences. He set up numerous collaborations, paid several visits to CERN and, since the early 1990s, made regular visits to DESY. Lev received many national and international prizes and awards, including the research award of the Alexander von Humboldt Foundation in 1993, the Pomeranchuk Prize in 2001, the Marie Curie Excellence Chair of the European Community, hosted by Hamburg University in 2006–2009, and the European Physical Society High Energy and Particle Physics Prize in 2015. As well as his research in Russia, he set up collaborations in Germany, France, England, Spain, Israel and Chile.

Those who had the privilege to know Lev up close experienced a very friendly person whose interest and understanding in physics was extraordinary. In any situation he was ready and more than happy to discuss physics, and was enthusiastic about new ideas. Behind this, Lev was a loving husband to his wife Elvira and a caring father of his daughters Irina and Katja, and their families. Last but not least, he was very attached to his home city of Leningrad and to his home country of Russia.

Together with his numerous collaborators and friends, we deeply regret that Lev is no longer with us.

● *Jochen Bartels, on behalf of his collaborators and friends.*

John Smith 1938–2017

John Smith, an eminent theoretical particle physicist at the C. N. Yang Institute for Theoretical Physics (ITP) at Stony Brook University in the US, passed away on 16 July aged 79. John, who was known by everyone as "Jack", was born in Selkirk, Scotland, and earned a BSc, MSc and PhD at the University of Edinburgh. During his graduate study, he spent a year at the Joint Institute for Nuclear Research (JINR) in Dubna, receiving his doctorate in 1963. He held postdoctoral positions at Nordita as a NATO fellow and at the University of Adelaide as a Rothman fellow. In 1967 he joined the ITP as a research associate, becoming a key member of the faculty for more than three decades. Jack retired in 2007 but kept active in research as professor emeritus.

Jack made important contributions spanning a range of areas in particle physics, and a constant theme in his work was to perform calculations that could be compared with data. Among his early works were papers on weak interactions, calculating predictions of various electroweak gauge theories for neutral-current reactions and using these in conjunction with new data to constrain the theories. In a 1983 paper he co-authored, Jack demonstrated the power of the Jacobean peak in determining the mass and width of the W boson – a method still in use today at the LHC. Over the ensuing years, Jack's often-legendary calculations in perturbative QCD contributed mightily toward establishing the contemporary picture of fundamental interactions. These included several papers in 1989 and the early 1990s with various coauthors, in which calculations of the production of heavy quark–antiquark pairs in $\bar{p}p$ and pp collisions were presented. Theese provided valuable and timely input for the analysis of Fermilab data by the CDF and D0 collaborations that led to the discovery of the top quark in 1995.

In 2003, together with his colleagues Willy van Neerven and Vajravelu Ravindran, Jack published a landmark calculation of higher-order QCD corrections to the cross-section for Higgs-boson production in hadronic collisions. This work was valuable in the analysis of LHC by the ATLAS and CMS collaborations that led to the discovery of the Higgs boson in 2012. It was quite fitting that Jack was invited to attend the 2013 ceremony at which his doctoral advisor, Peter Higgs, received the Nobel Prize (shared with François Englert).

Jack was renowned for his modest and

Smith carried out landmark calculations in QCD.

gentle personality. He gave generously of his time to colleagues and students, and taught the full range of courses, from advanced quantum field theory to freshman physics. Students were very much aware of his expertise in research, his dedication to teaching and mentoring, and his kind nature. Jack served as the supervisor for many doctoral thesis students and as a mentor for a number of postdoctoral research associates at Stony Brook. His excellent pedagogical skills were evident in the textbook *Field Theory and Particle Physics* (1986), and one of the last projects he worked on was the completion of a new textbook on quantum field theory.

Jack Smith's research accomplishments were recognised with a Humboldt Research Award and as a fellow of the American Physical Society. In the autumn of 1993 he held the visiting Kramers chair at Utrecht University, in 2005 he received the Stony Brook President's Award for Excellence in Scholarship and Creative Activities, and in October 2016 we were honoured when he was able to participate in a symposium celebrating the anniversary of the establishment of the ITP, in whose development he played such an important role.

We miss Jack greatly. He will always be remembered by his former students, postdocs, colleagues and co-authors, and, indeed, by all the people who knew him across the world.

● *Bernard de Wit, Rohini Godbole, Eric Laenen, Robert Shrock, George Sterman, and Jos Vermaseren.*

Maria Krawczyk 1946–2017

Maria Krawczyk passed away suddenly on 24 May 2017. It was a shock not only for her family but also for many of the physicists and her friends in the faculty of physics at the University of Warsaw and abroad. She was a very well-known and respected scientist within the physics community for her passion and involvement in research, teaching and outreach.

Maria graduated from the University of Warsaw, and her scientific career was intertwined with the university, first as an assistant, then adjunct university professor and full professor. In 1975 she defended her PhD thesis under the supervision of Grzegorz Białkowski based on studies of the charge exchange reaction $\pi^- p \rightarrow \pi^0 n$. During a postdoc at the Max Planck Institute in Munich in 1977/78 her scientific interest shifted towards the parton model and quantum chromodynamics (QCD). She worked on the hadronic properties of photons within QCD, where her speculations on direct photon pair production in hard collisions were then verified by experiments. Later she worked on the resummation of higher order QCD corrections.

In 1990 Maria became interested in electroweak interactions, in particular the Brout–Englert–Higgs mechanism of spontaneous electroweak symmetry breaking and the Higgs sector. The Higgs particle became her main research direction,

G Branco

Maria Krawczyk was a proponent of the International Linear Collider, in particular the photon–photon option.

including the two-Higgs-doublet models, searches for light Higgs particles in existing and planned accelerators, the CP properties of the scalar sector, the role of the Higgs in astrophysics and cosmology, and the structure of the vacuum. She was an enthusiast for studying photon collisions at a future linear collider, and took an active role in workshops devoted to the physics potential of future experiments. During a stay at CERN in 2002 she initiated discussions and studies of CP violation in non-standard Higgs models, becoming an organiser of the workshop on CP studies and non-standard Higgs physics – which culminated in the delivery of a CERN Yellow Report. With the advent of the LHC, she concentrated mainly on LHC physics.

During her career, Maria collaborated with many distinguished physicists around the world and coordinated a number of scientific grants financed by Polish and European agencies – right up to her last project, HARMONIA. She served in a number of advisory committees and was involved in several international workshops and conferences. Maria served on the TESLA collaboration board, represented Poland in outreach within the European linear collider steering group, and in 2004 was invited to join the programme committee of the Rencontres de Moriond series of conferences on QCD.

Maria enjoyed contact with students. She was concerned not only with their scientific development but also their living conditions, and helped in sending them to physics schools and conferences, finding grant opportunities and editing grant applications. She was very active in daily matters at the faculty and university, and engaged heavily in outreach activities, giving radio and TV interviews, lecturing at scientific festivals and organising LHC exhibitions.

Maria was a very kind and helpful person. Her advice, including in private matters, and friendliness will be greatly missed. She was also a beloved wife, a mother of two children and grandmother of four grandchildren.

● *Colleagues and friends from the University of Warsaw.*

Recruitment

For advertising enquiries, contact *CERN Courier* recruitment/classified, IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK.
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in **LHCb with focus on detector development**

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The **ATLAS** candidate is expected to lead a high-profile data analysis effort and to take responsibilities in ongoing upgrade activities. The Nikhef ATLAS group has as strong track record in data analysis on Higgs and top quark decays, as well as searches for dark matter, supersymmetry and lepton flavor violation.

Further information on this position can be obtained from prof. dr. Wouter Verkerke (Verkerke@nikhef.nl).

The **LHCb** candidate is expected to work on advanced particle detector systems and have extensive knowledge on particle detection technology. The Nikhef LHCb group has strong involvements in the construction of the upgrade VELO pixel detector and the scintillating fiber tracker.

Further information on this position can be obtained from prof. dr. Marcel Merk (Marcel.Merk@nikhef.nl).

For more information and applications, please consult the Nikhef portal www.nikhef.nl/en/vacancies/
The deadline for applications is 11 Februari 2018.
All qualified individuals are encouraged to apply.

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GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

The Collaborative Research Center CRC 1073 "Atomic scale control of energy conversion" at the Georg-August Universität Göttingen and collaborating institutions invite applications for a PhD Position (Salary group 13 TV-L, at least 50 %, i.e. 19.9 h/week) in project B03 "Relaxation, thermalization, transport and condensation in highly excited solids". The position will start at the earliest by April 1st 2018 and is limited to three years.

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CRC and to enjoy an intense collaboration with the other PhD students of the collaborative research center. For further detailed information, please refer to our website: www.sfb1073.uni-goettingen.de. In your application, please mention explicitly the project B03 (group Manmana, Institute for Theoretical Physics). We are looking for excellent PhD candidates with an above-average university degree in physics or theoretical physics. You know English very well both in writing and speaking. Good German language skills are desirable. You are enthusiastic about the subject and interested in understanding scientific mechanisms in detail. You like developing codes and numerical approaches to Theoretical Physics. You are a team-worker and you possibly possess the appropriate prior knowledge in quantum many-body theory or programming. Please send your application either in electronic form or via mail – only in copies – by 31 January 2018 to the Georg-August-Universität Göttingen, SFB 1073 – Office, Friedrich-Hund-Platz 1, 37077 Göttingen, eMail: SFB1073@ump.gwdg.de.

PhD Excellence Fellowships

University of Basel
Department of Physics

at the
Department of Physics, University of Basel, Switzerland

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2. Official transcripts MSc, BSc, diplomas etc. with grades, from all relevant institutions of higher education (all in English or German).
3. Statement of objectives/Motivational letter. A short statement of your research interests and how they relate to the work of our department. To increase your chances to be accepted to the PhD school, we encourage you to contact one of the professors of our department and secure their support for your application.
4. List of publications, if available.
5. One to three recommendation letters. The referees should upload their recommendation letters directly to the portal. It is your responsibility to contact your referees and to check that the recommendation letters are uploaded before the deadline.
6. Masters thesis (pdf).

Please address your questions to Dr. Thilo Glatzel: **thilo.glatzel@unibas.ch**

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DESY

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- Development of innovative concepts and techniques for the diagnostics of high-quality electron and laser beams
- Organization of and participation in the shift operation of PITZ for accelerator R&D

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- Excellent university degree in physics or engineering with PhD
- Extensive experience in beam dynamics simulations with space charge dominated beams as well as in numerical methods
- Very deep knowledge of accelerator physics and accelerator technology
- Very good knowledge of English is required and knowledge of German is of advantage

For further information please contact Dr. Mikhail Krasilnikov, +49-33762-7-7213 or mikhail.krasilnikov@desy.de.

The position is limited to 3 years.
Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. Handicapped persons will be given preference to other equally qualified applicants. DESY operates flexible work schemes. DESY is an equal opportunity, affirmative action employer and encourages applications from women. Vacant positions at DESY are in general open to part-time-work. During each application procedure DESY will assess whether the post can be filled with part-time employees.

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Bookshelf

COMPILED BY VIRGINIA GRECO, CERN

I am the Smartest Man I know: A Nobel Laureate's Difficult Journey

By Ivar Giaever

World Scientific

At the end of his last semester studying mechanical engineering at the Norwegian Institute of Technology, Ivar Giaever gained a grade of 3.5 for a thesis on the efficiency of refrigeration machines – just a little better than the 4.0 needed to pass. The thesis had been hastily written as the machines worked badly, and he and his friend had had little time to collect their data. But they both scraped through and, as Giaever writes, "maybe sometimes life is a little bit fair after all?".

It's a reference to the opening words of his light-hearted autobiography: "Life is not fair, and I, for one, am happy about that." The title sounds provocative, but the book is a reflection on how life's little twists and turns can have extremely important consequences.

Giaever calls this "luck" and admits that he has had more than his share of it – from relatively humble beginnings in Norway to a Nobel prize and beyond.

In many respects Giaever had been a "bad" student. Good at cards, billiards, chess – and drinking – he had little interest in mechanical engineering. He finished with a grade of 4.0 in both physics and mathematics; but had at least married Inger, his long-time sweetheart.

His first job was at the patent office in Oslo, but apartments were hard to find, so the couple decided to emigrate to Canada. A few twists led Giaever to General Electric (GE), where he had the chance to study again through the company's "A, B and C" courses.

This second chance to learn proved pivotal. Seeing how the studies related to GE's production of generators, motors and such like, made learning exciting, and Giaever graduated as the best student on the A course. But GE in Canada offered only the A course and, eager to learn more, he moved to GE's Research Laboratory in Schenectady in the US.

There he completed the B and C courses, and also began studying for a master's degree in physics at the Rensselaer Polytechnic Institute (RPI). He was to remain with GE for the next 30 years, after being offered a permanent job, even though he did not yet have a PhD.

As a fully-fledged member of the research lab, Giaever needed a project. John Fisher proposed that he look into

quantum mechanical tunnelling between thin films, which Giaever went on to do with great success in 1959.

Then, during his studies at RPI, he learned about the new Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity, which predicted the appearance of a forbidden energy gap near the Fermi level when a metal becomes superconducting. Giaever realised that he could measure this gap using his tunnelling apparatus, and so provide crucial verification of the BCS theory. He also realised that tunnelling between two superconductors with different energy gaps would produce a negative resistance, and could allow for active devices such as amplifiers. He worried that if he talked about his work, others would realise this before he had done the relevant experiment.

To his surprise nobody did, hence his comment to his family: "I am the smartest man I know!". His children thought he was being big-headed, but in 1973 the whole family went with him to Stockholm when he was rewarded with a share of the Nobel Prize in Physics in 1973 for his work on tunnelling in superconductors.

Giaever, of course, covers much more of his life story in this book. There is little technical detail, but a plethora of anecdotes that provide fascinating insight into a person who has made the most of his life.

Two impressions stand out: he is lucky to have found in Inger a partner with whom he has been able to share his long life; and he is lucky to have had a second chance to study and discover that he is smarter than many people thought.

● *Christine Sutton, former CERN Courier editor.*

Books received

Fermilab at 50

By Swapan Chattopadhyay and Joseph David Lykken (eds.)

World Scientific

On the occasion of the 50th anniversary of its foundation (*CERN Courier* June 2017 p18), the management of Fermilab asked leading scientists and supporters, whose careers and life paths crossed at the US laboratory, to share their memories and thoughts about its past, present and future. The short essays received have been collected in this commemorative book.

Among the many prestigious contributors are Nobel laureates T D Lee, Burton Richter and Jack Steinberger; in addition to present and former Fermilab directors (Nigel Lockyer, Piermaria Oddone and John Peoples); present and former CERN Directors-General (Fabiola Gianotti and Rolf Heuer), as well as many other important physicists, scientific leaders and even politicians and businessmen.

Through the recollections of the authors, key events in Fermilab's history are brought to life. The milestone of 50 years of research are also retraced in a rich photo gallery.

While celebrating its glorious past, Fermilab is also looking towards its future, as highlighted in the book. Many experiments are ongoing, or planned at the laboratory and its scientific programme includes research on neutrinos; accelerator science; quantum computing; dark matter and the cosmic background radiation, as well as a continuous participation in the LHC physics, especially in the CMS experiment.

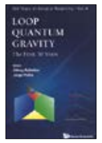
A light read, this book will appeal to all the scientists who at some point in their career stepped on the floor of Fermilab. It will also appeal to those readers who are interested in discovering more about the history of the laboratory through the records of the people who participated in it, whether it was directly or indirectly.

Bookshelf

Loop Quantum Gravity: The First 30 Years

By Abhay Ashtekar and Jorge Pullin (eds.)

World Scientific



This book, which is part of the "100 Years of General Relativity" series of monographs, aims to provide an overview of the foundations and recent developments of loop quantum gravity (LQG).

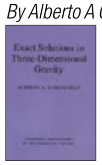
This is a theory that merges quantum mechanics and general relativity in an effort to unify gravity with the other three fundamental forces. In the approach of LQG, space–time is not a continuum, but it is quantised, and is considered as a dynamic entity. Different from string theory, loop quantum gravity is a "background-independent" theory, which aims to explain space and time instead of being plugged into an already existing space–time structure.

The book comprises eight chapters, distributed in three parts. The first is a general introduction that sets the scene and anticipates what will be discussed in detail in the following sections. The second part, comprising five chapters, introduces the conceptual, mathematical and physical foundation of LQG. In part three, the application of this theory to cosmology and black holes is discussed, also introducing predictions that might be testable in the foreseeable future.

Written by young theoretical physicists who are expert in the field, this volume is meant both to provide an introduction to the field and to offer a review of the latest developments, not discussed in many other existing books, for senior researchers. It will also appeal to scientists who do not work directly on LQG but are interested in issues at the interface of general relativity and quantum physics.

Exact Solutions in Three-Dimensional Gravity

By Alberto A García-Díaz



Cambridge University Press

As stated by the author himself, this book is the result of many years of work and has the purpose of providing a comprehensive, but concise, account of exact solutions in three-dimensional (or 2+1) Einstein gravity. It presents the theoretical frameworks and the general physical and geometrical characteristics of each class of solutions, and includes information about the researchers who discovered or studied them.

These solutions are identified and ordered on the basis of their geometrical invariant properties, their symmetries and their algebraic classifications, or according to their physical nature. They are also examined from different perspectives.

Emphasis is given to solutions to the Einstein equation in the presence of matter and fields, such as: point particle solutions, perfect fluids, dilatons, inflatons and cosmological space-times.

The second part of the book discusses solutions to vacuum topologically massive gravity with a cosmological constant.

Overall, this text serves as a thorough catalogue of exact solutions in (2+1) Einstein gravity and is a very valuable resource for graduate students, as well as researchers in gravitational physics.

Mosquitoes

A play by Lucy Kirkwood

National Theatre, London 18 July–28 Sept 2017

M Mogenburg

Lucy Kirkwood's play *Mosquitoes* is an ambitious piece of theatre. It combines the telling of an eclectic family drama with the asking of a variety of questions ranging from personal relationships to the remit of science. Mosquitoes tells the story of CERN scientist Alice (Olivia Williams), and the fractious relationship she has with her sister Jenny (Olivia Colman). After working for 11 years at CERN on the French–Swiss border, Alice is visited by Jenny just as work on discovering the Higgs boson is nearing its peak. Conflict between Jenny and Alice's challenged son, Luke (Joseph Quinn), drives much of the plot.

Domestic scenes between these three characters are interspersed with glimpses of Luke's absent father, who momentarily turns the theatre into a planetarium while waxing lyrical over the science which the play is set against.

The spectacle of these brief moments is a highlight of the play; contrasting wonderfully with the often mundane lives of the characters. Kirkwood also makes a poignant contrast between the characters' personal and professional lives. Alice, despite exuding a certain confidence in her professional life as a scientist, often struggles to relate personally to those around her. Chief amongst those is her son Luke who, despite showing the occasional interest in his mother's work, is ultimately critical of it for a number or reasons. He questions the environmental impact of what she is doing, believing that the LHC poses existential risks. He also frequently bemoans his mother's commitment to her work, which he believes comes at the expense of himself. Through the play, it becomes apparent that Luke and his mother previously lived in the UK, and that he was made to follow her to Switzerland, but he would like to go back to England.

These personal relationships are played out in front of the sisters' ailing mother Karen (Amanda Boxer). A former physicist herself now suffering from dementia, Karen frequently laments missing out on her chances at winning a Nobel Prize. Karen's character, who provides the audience with a glimpse of her daughter Alice's future, adds a sense of futility to Alice's work.

Overall, *Mosquitoes* – the title coming from a line of dialogue in which protons smashing in the Large Hadron Collider are compared to mosquitoes hitting each other head on – is a stunning piece of work.

Not just for the way it weaves together story lines to explore a range of complex questions, but also for the immensely high quality of acting talent which it boasts. This is bettered only by the faultless light, sound, and set design, which complement each other perfectly during the play's most dramatic moments.

● *Mack Grenfell, Brainlabs, UK.*

CERN Courier Archive: 1975

A look back to CERN Courier vol. 15, January and February 1975, compiled by Peggie Rimmer

Triumf

TRIUMF triumph

On 15 December the 500 MeV cyclotron at Vancouver produced its first full energy beams. After a month of gradually spiralling the beam further and further out in the machine, success came precipitately.

On 14 December an energy of 360 MeV had been reached at 690 cm machine radius and beam transmission out to this energy was looking good. By 12 noon the following day, protons were again at 360 MeV. In the next hour, appropriately with the TRIUMF Director J R Richardson at the helm, the beam was taken to the design energy of 500 MeV by tuning the trim coils.

An hour later, extracted beam of 10 nA was detected and soon manoeuvred over 15 m to a beam dump. Using quadrupoles, it could be focused on a 1 cm^2 spot.

TRIUMF

Champagne flows in the TRIUMF control room to celebrate first operation of the cyclotron at 500 MeV. Towards the right of the picture, E W Vogt (chairman of the TRIUMF board of management) is congratulating the laboratory director, J R Richardson.

By 16.00 hours the champagne corks had been popped.

We congratulate Professor Richardson and his team on their success in bringing such an adventurous machine into action. They join Los Alamos and Villigen as the world's three major 'meson factories'.

● Compiled from texts on pp11–12.

Villigen

Superconducting muon channel begins operation

Operation of the 590 MeV cyclotron at the Swiss Institute for Nuclear Research, SIN, is going very well following improvements carried out during a shutdown last year. The most satisfying success was the smooth start of operation of the new superconducting muon channel.

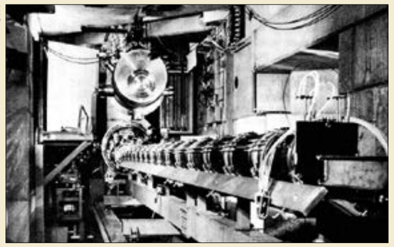
Muon beamlines at intermediate energies have almost always used quadrupoles to focus the pions produced when the ejected proton beam hits a target, and to retain some of the muons produced as the pions decay. The idea of a solenoid is to produce a beam of pions on large spirals with small radii, close to the axis, so that the decay muons are much less likely to escape. Close on 100% efficiency can be expected.

Long, large aperture solenoids are needed – the SIN solenoid is 8 m long with a 12 cm aperture and a field of 5 T. To provide these conditions with a conventional magnet would involve a power consumption of 10 MW.

The solenoid uses copper stabilized niobium-titanium superconductor wound in sixteen sections on reinforced epoxy resin. The outer surface is in contact with a layer of copper pipes carrying the helium cooling, all enclosed in a thick walled steel tube, which is a magnetic return path. Gas cooled current leads connect the solenoid to a 1 kA supply. Cooling is by supercritical helium under a pressure of 6 to 10 atmospheres.

In the first test of the full solenoid in December, the current climbed to 690 A before a quench. After repair, on 15 January the magnet immediately reached 5 T and stayed there for days. Since then it has operated continuously with no problems in following the shutdown and re-starts of the accelerator schedule.

SIN



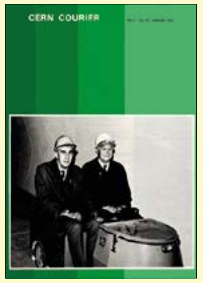
The long superconducting solenoid at the SIN cyclotron has yielded the world's highest fluxes of muons.

Pions are focused on the entrance to the solenoid and it can take a wide range of momenta. Muons emerge from the solenoid within a 20 cm^2 area and can be transported to two experimental regions by conventional magnets.

When the solenoid worked so well on 15 January, pions of 200 MeV/c were fed to the channel. The muon extraction was slowly brought down to lower momenta and at 180 MeV/c a pure muon beam was achieved. Maximum muon flux was reached at 115 MeV/c. The design intensity was 2.4×10^7 muons per second. After only a preliminary tuning 2×10^7 was achieved. Already the SIN cyclotron has the world's highest muon fluxes.

● Compiled from texts on pp36–37.

Compiler's Note



The photo of TRIUMF triumphant shows the prevailing gender demographics. Data aides and scanners apart, females were rare in physics, the Nobel category in which they are the least represented. Of the 206 physics Nobel prize winners since 1901, only two have been women: Marie Curie in 1903 with a 1/4 share, and Maria Goeppert-Mayer in 1963 also with a 1/4 share, Curie however becoming the sole recipient of the 1911 chemistry Nobel.

The lack of role models for women has long been overwhelming. The Royal Greenwich Observatory, founded in 1675, took almost 300 years before entrusting executive responsibility to a woman, Margaret Burbidge in 1972, though denying her the associated illustrious post of Astronomer Royal. In 1945 she had been turned down for a Carnegie Fellowship because only men were allowed to observe at Mount Wilson. But things look brighter for the daughters of today and tomorrow. In 2016, barely a year beyond its 60th anniversary, CERN appointed its first female Director-General, Fabiola Gianotti.

CERNCOURIER

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