WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the October 2016 issue of *CERN Courier*.

Particle physics, and CERN in particular, has made major contributions to medicine. Key to this, in addition to detectors for diagnosis and medical imaging, is accelerator technology. A new high-energy proton therapy centre in Nice, which has its roots in a CERN project, is about to treat its first patients, offering more precise treatment of tumours than is possible with conventional X-rays. Particle beams are also playing an increasingly vital role in the production of medical isotopes, which have traditionally been produced by research reactors. With global demand for isotopes such as technetium-99m growing and many reactors reaching the end of their operational lifetimes, CERN has recently launched a project called MEDICIS to produce isotopes from high-energy proton beams. Meanwhile, Brookhaven National Laboratory in the US has undergone a series of upgrades to boost its long-running isotope programme, and TRIUMF in Canada is pursuing isotopes for the rapidly growing field of targeted alpha therapy. Other particle-physics laboratories are pursuing similar cross-disciplinary programmes, illustrating the benefit of basic science to society.

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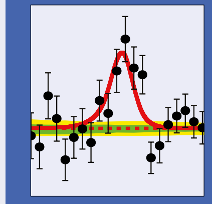

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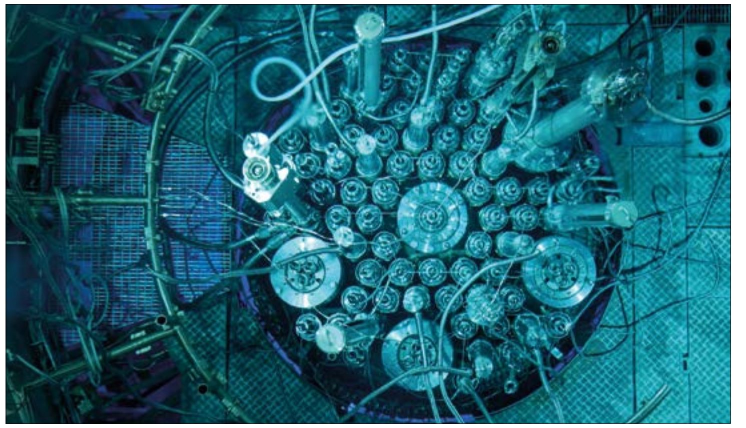
On the cover: The robotic isotope handler for CERN-MEDICIS. (Image credit: Yury Gavrikov.)

Viewpoint

Reactors and accelerators join forces

Demand for medical isotopes requires reactor- and accelerator-based production methods.

SCK•CEN



Belgian Reactor 2 (BR2), which started operation in 1962, is among the most powerful research reactors in the world.

By Sven van den Berghe

Nuclear reactors are usually thought of in the context of electricity generation, whereby heat generated by nuclear fission produces steam to drive an alternator. A less well-known class of nuclear-fission reactors fulfils an entirely different societal goal. Known as research and test reactors, the heat they produce is a by-product, while the neutrons resulting from the fission reactions are used to irradiate materials or as probes for materials science. In some reactors, neutrons are used to transmute stable isotopes into radioactive ones, which are subsequently utilised for industrial or medical purposes.

Used in diagnostics and treatment, medical radioisotopes are a vital tool in the arsenal of oncologists in detecting and fighting cancer. In the case of ^{99m}Tc, which is a daughter product of ^{99}Mo, roughly 30 million patients per year are injected with this isotope. This accounts for 80% of all nuclear-medicine diagnostic procedures, and demand is only growing as more of the global population gain access to advanced medicine. Classically, ^{99}Mo is produced as a fission product in uranium targets: after irradiation lasting around one week, the targets are rushed off to the processing facility where the ^{99}Mo is extracted. Since its half-life is only around six days, there is no way to stock up on the isotope, and therefore a continuous chain of target production, irradiation, isotope extraction and purification – and finally supply to hospitals – is required.

The importance of a steady supply of medical radioisotopes such as ^{99}Mo cannot be overestimated, yet it is generally not possible to cover the cost of operating a large research reactor or other facility solely for the production of radioisotopes, and the yield needs to be sufficiently high for such a production to even significantly reduce the cost. Traditionally, the economics of constructing an accelerator facility for the sole purpose of generating ^{99}Mo have been challenging, especially since the fission yield of ^{99}Mo outweighs the possible yields from non-reactor methods by at least a factor of 10. Recently, however, a reduction in the construction costs of high-power accelerators and the increasing costs associated with operating reactors has generated interest in accelerator-based production of ^{99}Mo, for example via semi-commercial initiatives such as SHINE and NorthStar in the US.

One of the driving forces behind these developments is the ageing of existing research reactors. The global supply of ^{99}Mo mainly originates in a handful of reactors such as the BR2 in Belgium, the NRU in Canada or the HFR in the Netherlands, and most of them are more than 50 years old. The NRU, which alone is responsible for about a third of the global demand of ^{99}Mo, is scheduled to cease production this year. Some reactors are still planned to continue operation for multiple decades (such as OPAL in Australia, SAFARI in South Africa and BR2), while smaller research reactors such as MARIA in Poland and LVR-15 in the Czech Republic are getting increasingly involved in radioisotope production and new research reactors are being contemplated: MYRRHA in Belgium, PALLAS in the Netherlands and JHR in France (for which construction is ongoing), for instance. Despite these developments, it is uncertain if the rising demand can continue to be met without assistance from accelerator-based production.

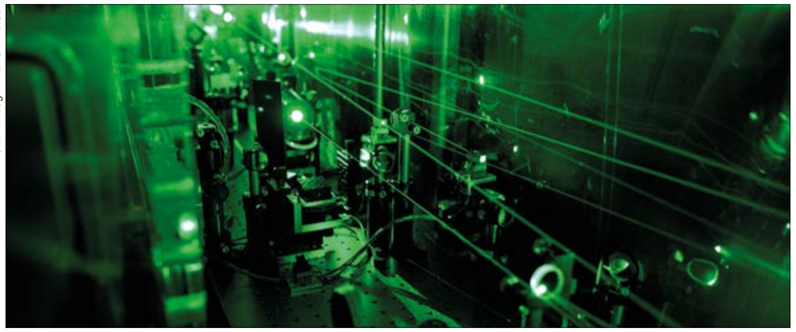
Neutrons are very suitable for isotope production because the cross-sections for neutron-induced nuclear reactions are often much larger than those for charged particles. As such, there is an advantage in using the neutrons already available at research reactors for isotope production. But it is clear that accelerators and reactors are highly complementary. Reactors generate neutron-rich isotopes through fission or activation, whereas accelerators typically allow the production of proton-rich isotopes. Alpha emitters are also becoming more popular in nuclear medicine, particularly in palliative care, and the role of accelerators will likely become more important in the future production of such isotopes. It is therefore healthy to maintain multiple production routes open for such vital and rare products, on which people's lives can depend.

Sven van den Berghe is stakeholder manager for the Belgian Reactor 2 (BR2) at the Belgian Nuclear Research Centre SCK•CEN, where he is responsible for the fuel development programme.

News

NUCLEAR STRUCTURE

Proton-radius puzzle deepens



PSI/A Antognini and F Reiser

Part of the laser system used to determine the size of the deuteron at the Paul Scherrer Institute.

The international CREMA (Charge Radius Experiment with Muonic Atoms) collaboration has measured the radius of the deuteron more accurately than ever before, finding that it is significantly smaller than previously thought. The result, which was obtained using laser spectroscopy of muonic deuterium at the Paul Scherrer Institute (PSI) in Switzerland, is consistent with a 2010 measurement of the proton radius by the same group, which also showed a significantly smaller value than expected.

The 2010 result, which found a proton radius of 0.84087±0.00039 fm versus the CODATA value of 0.8751±0.0061 fm, formed the basis of what has been dubbed the proton-radius puzzle. The new measurement of the deuteron's size gives rise to an analogous mystery. If the results hold firm, they could force physicists to adjust the Rydberg constant, which is currently known to the eleventh decimal place, and perhaps imply the existence of an as-yet-unknown force beyond the Standard Model.

Consisting of one proton and one neutron, the deuteron is the simplest compound nucleus. Its properties, such as the root-mean-square charge radius and polarisability, therefore serve as important benchmarks for understanding nuclear forces and structure. Using the most intense source of muons available, provided by the PSI proton accelerator, the CREMA team injected around 300 low-energy muons per second into an experimental chamber filled with gaseous deuterium molecules. Here, muons eject electrons from the molecules, which break up to form muonic deuterium. A complex pulsed laser system was then used to raise muonic-deuterium atoms from the metastable 2s state into the next excited state, 2p, after which the muons fall back to the ground state and emit an X-ray photon. Because the energy levels of the muonic atom strongly depend on the size of the nucleus, measuring the 2s–2p energy splitting in muonic deuterium by means of laser spectroscopy reveals the size of the deuteron with unprecedented precision.

Based on measurements of three 2s–2p transitions, the team found a value of 2.12562±0.00078 fm for the deuteron radius. This is 2.7 times more accurate but 7.5σ smaller than the CODATA-2010 value of 2.1424±0.0021 fm. The value is also 3.5σ smaller than the radius obtained by electronic deuterium spectroscopy. When combined with the electronic isotope shift, says the team, this yields a proton radius similar to the one measured from muonic hydrogen and thereby amplifies the proton-radius puzzle.

"You could say that the mystery has now doubly confirmed itself," says lead-author Randolf Pohl of the University of Mainz, Germany. "After our first study came out in 2010, I was afraid some veteran physicist would get in touch with us and point out our great blunder. But the years have passed, and so far nothing of the kind has happened."

As to the possible cause of the discrepancy, physicists remain cautious. "Naturally, it can't be that the deuteron – any more than the proton – has two different sizes," says CREMA-member Aldo Antognini of the PSI. The most likely explanation would be experimental imprecision, he says. For example, there could be an error with the hydrogen spectroscopy, which was used in some of the earlier measurements of both the proton and deuteron's size. "If it should actually turn out that the hydrogen spectroscopy is giving a false – that is, minimally shifted – value, that would mean that the Rydberg constant must be minimally changed," he says.

Currently, research groups in Munich, Paris, Toronto and Amsterdam are working to obtain more accurate measurements via hydrogen spectroscopy, and their results are expected in the coming years. The CREMA collaboration has also recently studied muonic helium-3 and helium-4 ions, and expects at least a five-fold reduction in uncertainties in their charge radii compared with the electron-scattering results. Next, the team plans to target the magnetic properties of the proton by measuring the so-called Zemach radius, which is the limiting quantity when comparing experiment and theory of the 1s hyperfine splitting in regular hydrogen.

"If all of the relevant experiments are ▷

Sommaire en français

correct, there must be some physics beyond the Standard Model going on," says Gerald A Miller of the University of Washington, who was not involved in the PSI study. "In particular, the muon–proton and electron–proton interactions differ in ways that cannot be accounted for by the electron–muon mass difference, and that statement is strengthened by the newly published result."

Further experiments should show whether the proton-radius measurements based on hydrogen atoms are less accurate than originally stated, he adds. One is CREMA's measurement of the helium-4 radius using muonic atoms, while another is the MUon proton Scattering Experiment (MUSE) at PSI, which compares muon– to electron–proton scattering for both charges. "Given enough experiments, the proton-radius puzzle will be solved in a few years," says Miller. "We can all speculate about the final result, but it's more scientific to wait for results."

● Further reading

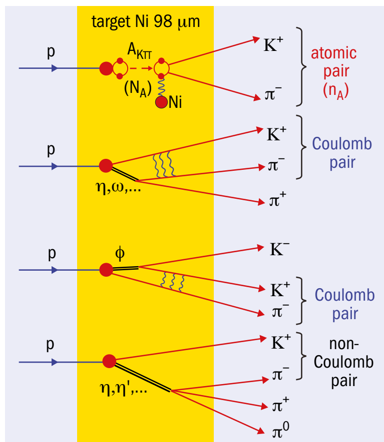
A Antognini *et al.* 2013 *Science* **339** 417.
R Pohl *et al.* 2010 *Nature* **466** 213.
R Pohl *et al.* 2016 *Science* **353** 669.

Exotic atoms

DIRAC experiment observes new exotic atom

The DIRAC (DImeson Relativistic Atom Complex) experiment at CERN has discovered a new type of exotic atom made up of a π and K meson. The "strange dimesonic" state provides an ideal laboratory for testing quantum chromodynamics (QCD) in the low-energy region and joins a long list of non-standard atoms, which also include positronium, muonic atoms and antihydrogen, that help physicists study in detail how particles interact.

The πK system is a type of hadronic atom in which meson pairs are bound electromagnetically, similar to pionium (a $\pi^+\pi^-$ atom), which was studied previously by the DIRAC experiment. It was produced by firing 24 GeV/c protons from CERN's Proton Synchrotron (PS) into platinum or nickel foil targets. Here, relativistic dimesonic bound states formed by Coulomb final-state interactions move inside the target and can break up, resulting in particle pairs characterised by a small relative momentum in the centre-of-mass system of the pair. The recently upgraded DIRAC experiment observed 349±62 such atomic pairs, corresponding to a signal of 5.6σ.



Inclusive πK production via the interaction $p + Ni \rightarrow \pi^- K^+ + X$. The ionisation or break up of $A_{K\pi}$ leads to so-called atomic pairs.

The observation is part of an effort that began almost a decade ago, when the DIRAC collaboration reported a 3.2σ enhancement of πK pairs at low relative momentum based on a platinum target. This was followed in 2014 by 3.6σ evidence using a nickel target. The latest result is based on data obtained in both platinum and nickel targets, also using information from all subdetectors and enhanced background description based on Monte Carlo simulations, and represents the first statistically significant observation of the strange dimesonic πK atom.

The team is now working towards a measurement of the πK atom lifetime, which is predicted to be 3.5±0.4 fs. This will allow DIRAC to measure for the first time a parameter of low-energy πK interactions called the scattering length. With an expected precision of around 35%, the result can then be compared with precise predictions from lattice QCD and chiral perturbation theory. The latter provides a way to predict scattering lengths in the low-energy sector of QCD and to study a potential flavour dependence of the quark condensate responsible for chiral-symmetry breaking.

"A recent study has shown that the production rate of πK atoms from the proton beam of CERN's Super Proton Synchrotron will be 25 times higher compared to that from the PS," explains DIRAC spokesperson Leonid Nemenov. "This will allow us to measure the πK scattering lengths with a precision better than 5% and to check the precise predictions of QCD for these values basing on a Lagrangian describing u, d and s quarks. The DIRAC collaboration is now planning to prepare the dedicated Letter of Intent for such an experiment."

● Further reading

B Adeva *et al.* 2009 *Phys. Lett. B* **674** 11.
B Adeva *et al.* 2014 *Phys. Lett. B* **735** 288.
B Adeva *et al.* 2016 *Phys. Rev. Lett.* in press arXiv:1605.06103v1.

Astroparticle physics

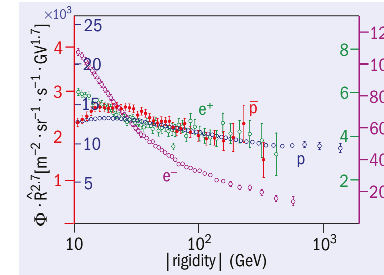
AMS reports unexpected result in antiproton data

Researchers working on the AMS (Alpha Magnetic Spectrometer) experiment, which is attached to the International Space Station, have reported precision measurements of antiprotons in primary cosmic rays at energies never before attained. Based on 3.49×10^5 antiproton events and 2.42×10^9 proton events, the AMS data represent new and unexpected observations of the properties of elementary particles in the cosmos.

Assembled at CERN and launched in May 2011, AMS is a 7.5 tonne detector module that measures the type, energy and direction of particles. The goals of AMS are to use its unique position in space to search for dark matter and antimatter, and to study the origin and propagation of charged cosmic rays: electrons, positrons, protons, antiprotons and nuclei. So far, the collaboration has published several key measurements of energetic cosmic-ray electrons, positrons, protons and helium, for example finding an excess in the positron flux (*CERN Courier* November 2014 p6). This latter measurement placed constraints on existing models and gave rise to new ones, including collisions of dark-matter particles, astrophysical sources and collisions of cosmic rays – some of which make specific predictions about the antiproton flux and the antiproton-to-proton flux ratio in cosmic rays.

With its latest antiproton results, AMS has now simultaneously measured all of the charged-elementary-particle cosmic-ray fluxes and flux ratios. Due to the scarcity of antiprotons in space (being outnumbered by protons by a factor 10,000), experimental data on antiprotons are limited. Using the first four years of data, AMS has now measured the antiproton flux and the antiproton-to-proton flux ratio in primary cosmic rays with unprecedented precision. The measurements, which demanded AMS provide a separation power of approximately 10^6, provide precise experimental information over an extended energy range in the study of elementary particles travelling through space.

In the absolute-rigidity (the absolute value of the momentum/charge) range 60–500 GV, the antiproton ($\bar{p}$), proton (p), and positron (e^+) fluxes are found to have nearly identical rigidity dependence, while the electron (e^-) flux exhibits a markedly different rigidity dependence. In the absolute-rigidity range below 60 GV, the $\bar{p}$/p, $\bar{p}/e^+$ and p/e^+ flux ratios each reach a maximum, while in the range 60–500 GV these ratios unexpectedly show no rigidity dependence.



The measured fluxes of elementary particles multiplied by $|R|^{2.7}$. The antiproton flux (red, left axis) is compared to the proton flux (blue, left axis), the electron flux (purple, right axis), and the positron flux (green, right axis). The fluxes show different behaviour at low rigidities, while at $|R|$ above ~60 GV the functional behaviour of the antiproton, proton and positron fluxes are nearly identical and distinctly different from the electron flux.

"These are precise and completely unexpected results. It is difficult to imagine why the flux of positrons, protons and antiprotons have exactly the same rigidity dependence and the electron flux is so different," says AMS-spokesperson Samuel Ting. "AMS will be on the Space Station for its lifetime. With more statistics at higher energies, we will probe further into these mysteries."

● Further reading

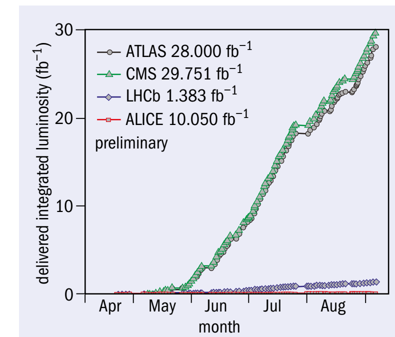
M Aguilar *et al.* (AMS Collaboration) 2016 *Phys. Rev. Lett.* **117** 091103.

LHC news

LHC hits 2016 luminosity target

At the end of August, two months ahead of schedule, the integrated luminosity delivered by the LHC reached the 2016 target value of 25 fb^{-1} in both the ATLAS and CMS experiments. The milestone is the result of a large group of scientists and technical experts who work behind the scenes to keep the 27 km-circumference machine operating at the highest possible performance.

Following a push to produce as many proton–proton collisions as possible before the summer conferences, several new ideas, such as a novel beam-production technique in the injectors, have been incorporated to boost the LHC performance. Thanks to these improvements, over the summer the LHC was routinely operating with peak luminosities 10%–15% above the design value of 10^{34} cm^{-2} s^{-1}.



Integrated luminosity recorded by the main LHC experiments by 6 September 2016.

This is a notable success, especially considering that a temporary limitation in the Super Proton Synchrotron only allows the injection of 2220 bunches per beam instead of the foreseen 2750, and that the LHC energy is currently limited to 6.5 TeV instead of the nominal 7 TeV. The excellent availability of all the key systems of the LHC is one of the main reasons behind these achievements.

The accelerator team is now gearing up for the season finale. Following a technical stop, a forward proton–proton physics run took place in mid-September. Proton–proton physics is scheduled to continue until the last week in October, after which proton–lead physics will take over for a period of one month. The LHC and its experiments can look forward to the completion of what is already a very successful year.

Education

Beamline competition calls all schools

CERN has announced the 4th edition of its Beamline for Schools Competition, which will see two winning teams of students undertake an experiment of their design at a fully equipped CERN beamline next year. The 2017 competition, which is made possible thanks to the Alcoa Foundation, is open to teams of high-school students aged 16 or older. A maximum of nine students per winning team will be invited to CERN, and teams can be composed of pupils from a single school or a number of schools working together.

The 2016 Beamline for Schools competition attracted 151 teams from 37 countries (blue), representing a total of 1261 students. Two teams from Poland and the UK were selected to travel to CERN in September to carry out their winning experiment proposals.

Previous winners have tested webcams and classroom-grown crystals in the beamline, and also studied how particles decay and investigated high-energy gamma rays. Interested schools can pre-register their team to receive the latest updates, and further information about how to apply can be found at cern.ch/bl4s. The deadline for submissions is 31 March 2017.

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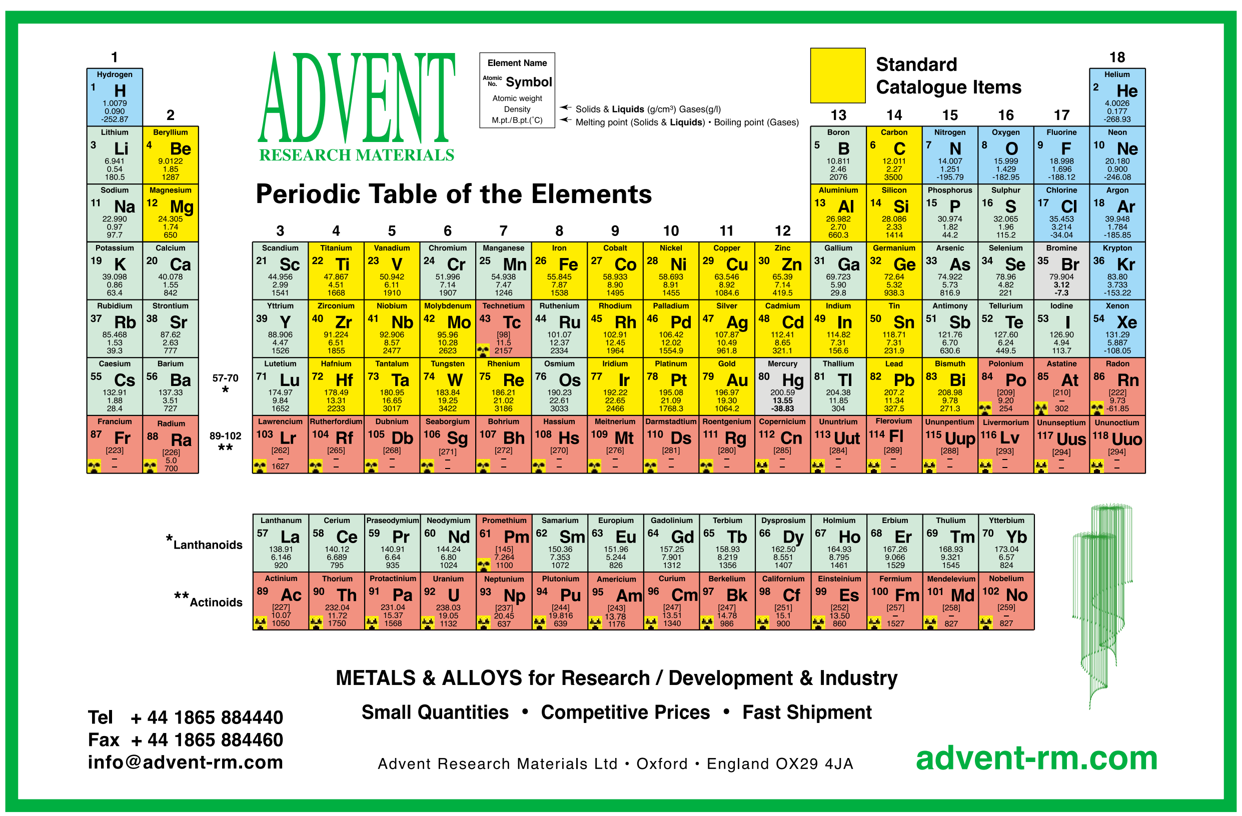


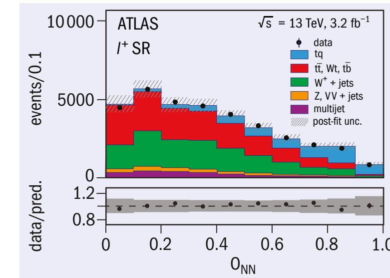
LHC Experiments

ATLAS observes single top-quarks at 13 TeV

The ATLAS collaboration is exploiting the window of opportunity opened by the LHC's 13 TeV run to search directly for unknown particles. Complementary to this approach, the collaboration is also looking for deviations in the cross-sections and kinematic distributions of Standard Model processes, which could be caused by energy-dependent couplings that become accessible at the higher collision energy.

Using data recorded in 2015 corresponding to an integrated luminosity of 3.2 fb^{-1}, ATLAS has recently measured the total cross-sections of single top-quark and top-antiquark production via the t-channel exchange of virtual W bosons. This channel has exciting kinematic features such as polarised top-quarks and forward spectator jets. Compared to the dominant top-quark–top-antiquark ($t\bar{t}$) pair-production process, however, the single-production process is experimentally more challenging due to a higher background level. Because the two major background processes are W+jets and $t\bar{t}$ pair production, the selection of candidate events requires one charged lepton, missing transverse momentum and two hadronic jets to be present (exactly one of which has to be identified to contain b hadrons).

To measure the cross-section of top-quark and top-antiquark production separately, the events are separated into two channels according to the sign of the lepton charge.



The neural-network discriminant for the positive lepton channel in the signal region. The signal and backgrounds are normalised to the fit results and the hatched and grey histograms represent the uncertainty.

ATLAS uses neural networks to exploit the kinematic differences between the signal and background processes as much as possible, thereby optimising the statistical power of the data set. Ten different kinematic variables were combined into a discriminant, which is assumed to be close to zero for background-like events and unity for signal-like events (see figure).

The cross-sections were measured to be 156±28 pb for top-quark production and 91±19 pb for top-antiquark production. These are slightly higher than expected (+15% and +12%, respectively), but still in good agreement with the predictions. The largest uncertainties are related to the Monte Carlo generators used to model the t-channel single top-quark process and the $t\bar{t}$ pair-production process, the b-jet identification efficiency and the jet energy scale. In future measurements of the single top-quark process, the focus will be on reducing the uncertainties, exploiting improved calibrations and extending studies of the Monte Carlo generators.

Further reading

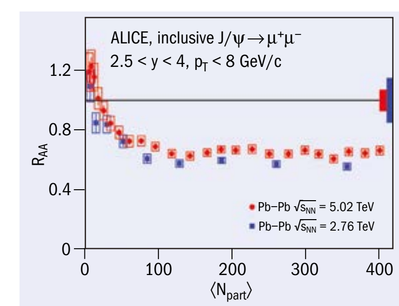
ATLAS Collaboration 2016 CERN-EP-2016-197.

ALICE pinpoints J/ψ regeneration

The ALICE Collaboration has measured with high precision the production of J/ψ mesons in collisions of lead nuclei at the highest LHC energy, confirming the role of the "regeneration mechanism" in J/ψ production.

J/ψ mesons are bound states of a charm (c) and anticharm ($\bar{c}$) quark and they are particularly sensitive probes of the quark–gluon plasma (QGP) formed in high-energy heavy-ion collisions. The production of J/ψ mesons is suppressed in the QGP by the screening of the $c\bar{c}$ binding, which is generated by the large surrounding colour-charge density. Such suppression was observed at RHIC in the US in AuAu collisions at a collision energy of 0.2 TeV. Using data from LHC Run 1, ALICE also measured a suppression in PbPb collisions at 2.76 TeV. However, the value was smaller than that measured at lower collision energy (see *CERN Courier* March 2012 p14), hinting at a new mechanism of J/ψ production in the QGP: regeneration by recombination of deconfined charm and anticharm quarks.

The J/ψ suppression is quantified by the nuclear modification factor (R_{AA}), which is defined as the ratio of the yield in PbPb to that in an equivalent number of pp collisions. The J/ψ R_{AA} measured by ALICE as a function of the average number of nucleons participating in the collision in PbPb collisions at 5.02 TeV is compared to the value at 2.76 TeV. The larger the number of participating nucleons, the more head-on and violent the collisions.



The J/ψ nuclear modification factor versus the average number of nucleons participating in Pb–Pb collisions at nucleon–nucleon collision energies of 5.02 (red) and 2.76 (blue) TeV.

A clear decreasing trend of the R_{AA} with increasing participating nucleons is observed for peripheral collisions, followed by a constant evolution for more central collisions (see figure). Thanks to the increased integrated luminosity delivered by the LHC, the higher collision energy and improved detection techniques, the accuracy of the new measurement is drastically improved and unambiguously confirms ALICE's earlier observation. In short, at LHC energies, a J/ψ regeneration mechanism competes with the J/ψ suppression mechanism, both of which are due to the formation of the QGP.

The improved accuracy of the R_{AA} measurement at 5.02 TeV imposes strong constraints on theoretical calculations, the uncertainties of which are now significantly larger than the experimental ones. The additional data expected to be accumulated during LHC Run 2 will further constrain the models through more differential measurements, including the J/ψ elliptic flow.

Further reading

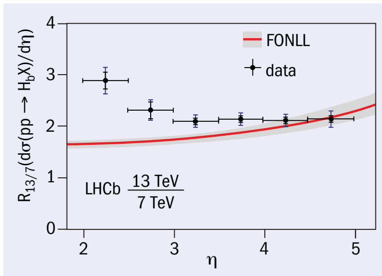
J Adam *et al.* (ALICE Collaboration) arXiv:1606.08197.

News

LHCb finds early surprises at Run 2

The bumper data harvest at LHC Run 2 continues for the LHCb experiment. In mid-August, the collaboration celebrated the milestone of 1 fb^{-1} integrated luminosity collected so far during 2016, with significantly more expected to come during the remainder of the year. This corresponds to the production of around 10^{12} beauty hadrons, of which the most interesting decays have been selected and recorded for offline analysis. The stupendous performance of the LHC has been central to this success. Indeed, the LHCb operations team has had to adjust trigger and offline procedures to prevent the torrent of incoming data from overflowing the experiment's data-storage resources.

With LHCb's physics programme centred around painstaking precision measurements, the most eagerly awaited results from the Run 2 data set will not begin to appear until early next year. However, the first glimpses into the new sample are already revealing surprising results. For example, a measurement of the production cross-section of beauty hadrons at 13 TeV has shown unexpected behaviour when compared to what was observed at 7 TeV during Run 1. Although the ratio of the cross-sections at the two energies is roughly equal to two, as predicted, there is a clear dependence on pseudorapidity (which is related to the angle of production) that differs markedly from the current model expectations. The ratio in the data is significantly higher at low values of pseudorapidity, which corresponds to the more central regions of production (see figure).



The ratio of differential cross-sections for b-hadron production with respect to pseudorapidity, η, measured at collision energies of 13 and 7 TeV. Data are compared to predictions described in Eur. Phys. J **C** 75 610.

This result, which was first shown at the ICHEP conference in Chicago in August, is still being digested by theorists. Although it is too early to speculate on the causes of this intriguing behaviour, and indeed the consequences for other measurements, it is hoped that many other surprises lurk in the Run-2 data set.

● Further reading

LHCb Collaboration 2016 LHCb-PAPER-2016-031.

Probing dark matter with CMS

Understanding the nature of dark matter (DM) is the focus of extensive research at collider- and astrophysics-based experiments. The most well-known signature for DM production at the LHC is the so-called "mono-X" topology, for which events are characterised by the presence of a high-momentum object (e.g. a jet in the case of a mono-jet signature) from initial-state radiation in combination with significant missing transverse energy (ETmiss). The ETmiss signature may arise from DM particles that are stable yet electrically neutral and part of a colour-singlet, which means they will escape detection in the CMS experiment.

For a large class of DM models, however, the mediator cannot only be probed by conventional DM searches (such as the mono-X plus ETmiss analyses) but also by direct searches for the mediator. Such searches measure the mediator's decay into Standard Model (SM) particles such as quarks, gluons and leptons. The most prominent example is the dijet-resonance search but also, depending on specific properties of the DM model considered, dilepton and diphoton searches may be relevant.

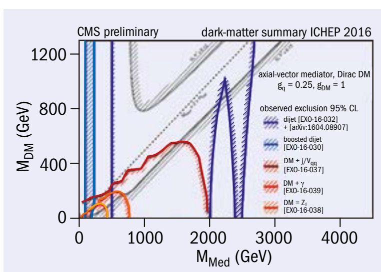


Fig. 1. (Left) 95% CL exclusion regions in the mass plane of the mediator and DM candidate for dijet searches and different values of ETmiss.

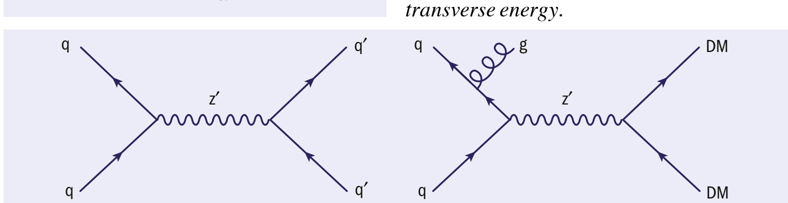


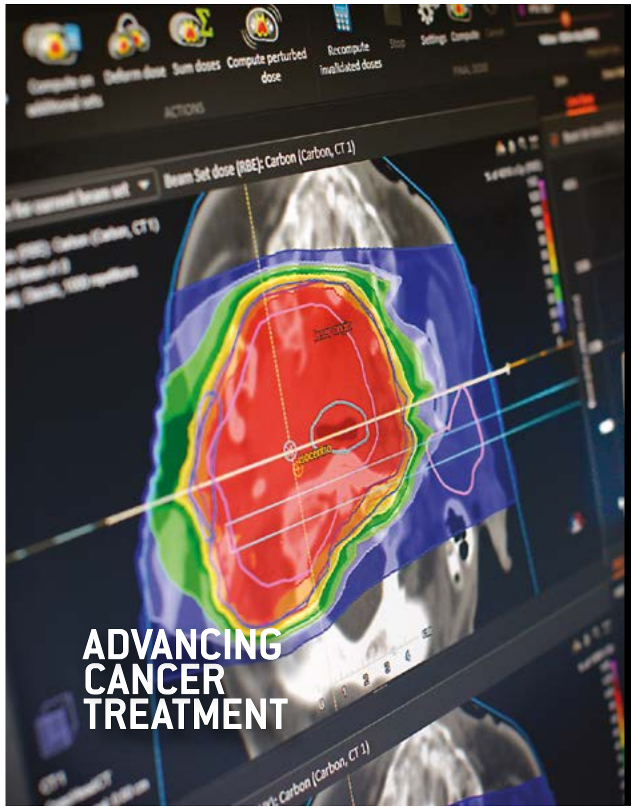
Fig. 2. (Below) Feynman diagrams showing the production of the mediator and its decay to SM (left) and DM (right) particles. The former yields a dijet topology while the latter produces events with a high-momentum jet in combination with significant missing transverse energy.

Using proton–proton collision data from the LHC collected at a centre-of-mass energy of 13 TeV, the CMS collaboration has recently updated several of its DM searches and placed stringent constraints on interesting DM parameter space (see figure 1). The limits shown in this plot are obtained by interpreting different collider searches from CMS in a simplified DM model. The model corresponds to an axial-vector mediator particle that is excited in proton–proton collisions and decays into two DM particles (figure 2, right) or SM particles (figure 2, left).

Although the absolute exclusions provided by these searches depend strongly on the chosen coupling and DM model scenario, the example of the axial-vector model illustrates that, in addition to the conventional mono-X plus ETmiss searches, dijet constraints can place significant bounds on relevant DM models and thus are an important ingredient in our quest of searching for DM at colliders.

● Further reading

CMS Collaboration cms.web.cern.ch/news/latest-results-cms-presented-ichep-2016.

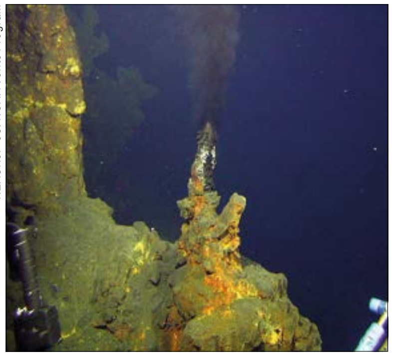


Sciencewatch

Compiled by John Swain, Northeastern University

Deep-sea vents likely origin of life

The last universal common ancestor (LUCA) of all life is known to have lived about 3.4 billion years ago, yet how and where LUCA lived has remained a mystery. Now, research by William Martin and colleagues of Heinrich Heine University in Düsseldorf, Germany, supports the view that this ancient life form existed in a hydrothermal vent with low oxygen levels. By reconstructing evolutionary trees for more than six million genes from bacteria and single-celled micro-organisms, the team was able to identify 355 protein families that were likely in the LUCA genome and are involved in anaerobic metabolism and the fixing of carbon dioxide and nitrogen. This suggests an environment where lots of those gases were present, in addition to iron, making hydrothermal vents the likely origin of life.



The last universal common ancestor inhabited a geochemically active environment rich in hydrogen, carbon dioxide and iron. Data support the theory of an autotrophic origin of life in a hydrothermal setting.

● **Further reading**
M Weiss *et al.* 2016 *Nature Microbiology* **1** 16116.

Seeing single photons

While it is known that rod cells in the retina respond to single photons, it has remained an open question whether or not a single photon can actually be perceived by a human being, or whether a few (typically thought to be 5–7) are needed. Jonathan Tinsley of the Research Institute of Molecular Pathology in Vienna, Austria, and colleagues have now shown that we can indeed recognise single photons. The team used a single-photon source based on spontaneous parametric down-conversion and a "two-alternative forced-choice" protocol, in which subjects were asked to distinguish a light stimulus from a blank and were then given feedback about the correctness of their answers. Interestingly, the probability of reporting a single photon is affected by a previous photon having been sent, suggesting a priming process that boosts the visual system on a timescale of seconds.

● **Further reading**
J Tinsley *et al.* 2016 *Nature Communications* **7** 12172.

Nuclear forensics

An analysis of stable isotopes in bomb debris has revealed details of the 70 year-old Trinity nuclear test, offering a new diagnostic for non-proliferation and verification efforts. Susan Hanson and colleagues of Los Alamos National Laboratory in New Mexico, US, used molybdenum-isotope ratios, plus the total amount of molybdenum (all of which are stable decay products of short-lived zirconium isotopes produced in the explosion), to calculate the original post-blast zirconium-isotope levels. They found a yield that is in agreement with the official reported yield, suggesting that a nuclear detonation can be characterised at any time.

● **Further reading**
S Hanson *et al.* 2016 *PNAS* **113** 8104.

Trinity was the code name for the first atomic test. (Image credit: Los Alamos National Laboratory.)

Electricity from carbon dioxide

Carbon dioxide (CO_2) can be used as fuel in a battery made from easily obtainable materials, offering a novel approach to sequester CO_2 emissions, according to researchers at Cornell University in the US. Wajdi Al Sadat and Lynden Archer constructed an electrochemical cell with metallic aluminium as the anode and a CO_2/oxygen gas mixture as the active material in the cathode. Oxygen is reduced to form superoxide at the cathode, which then bonds to CO_2 and combines with aluminium from the anode to make aluminium oxalate. For each kilogram of aluminium, more than 9 kg of CO_2 can be captured from flue gas while providing 3.6 kWh of electricity – enough to make the new cell a potentially useful strategy to reduce CO_2 emissions and produce power at the same time.

● **Further reading**
W Sadat and L Archer 2016 *Science Advances* **2** e1600968.

Centuries-old sharks

A novel application of radiocarbon dating suggests that the Greenland shark (*Somniosus microcephalus*) is the longest-lived vertebrate known, boasting a lifespan of at least 272 years. Julius Nielsen of the University of Copenhagen and colleagues dated eye-lens nuclei from 28 female Greenland sharks measuring 81–502 cm in length using the pulse of carbon-14 produced by nuclear tests in the 1950s. Only the smallest sharks (measuring 220 cm or less) showed signs of the radiocarbon bomb pulse, which is a time marker of the early 1960s. The age of the sharks at sexual maturity was 156 ±22 years and the largest shark was 392±120 years old, suggesting that some Greenland sharks today were alive at the same time as Copernicus.

● **Further reading**
J Nielsen *et al.* 2016 *Science* **353** 702.

Astrowatch

Compiled by Marc Türler, ISDC and Observatory of the University of Geneva, and CHIPP, University of Zurich

Earth-like planet orbits our nearest star

Astronomers have found clear evidence of a planet orbiting the closest star to Earth, Proxima Centauri. The extrasolar planet is only slightly more massive than the Earth and orbits its star within the habitable zone, where the temperature would allow liquid water on its surface. The discovery represents a new milestone in the search for exoplanets that possibly harbour life.

Since the discovery of the first exoplanet in 1995, more than 3000 have been found. Most were detected either via radial velocity or transit techniques. The former relies on spectroscopic measurements of the weak back-and-forth wobbling of the star induced by the gravitational pull of the orbiting planet, while the latter method measures the slight drop in the star's brightness due to the occultation of part of its surface when the planet passes in front of it.

Exoplanets discovered so far exhibit a diverse range of properties, with masses ranging from Earth-like values to several times the mass of Jupiter. Massive planets close to their parent star are the easiest to find: the first known exoplanet, called 51 Peg b, was a gaseous Jupiter-sized planet (a "hot Jupiter") with a temperature of the order of 1000 °C due to its proximity to the star. The ultimate goal of exoplanet hunters is to find an Earth twin or at least an Earth-sized planet at the right distance from its parent star to have liquid water on its surface. This condition defines the habitable zone, which is the range of distance around the star that would be suitable for life.

ESO/M Kornmesser

An artist's impression of the surface of the planet Proxima b orbiting the red-dwarf star Proxima Centauri, the closest star to the solar system. The rocky planet is a little more massive than the Earth and has an orbit within the habitable zone, where liquid water could flow on its surface.

Proxima Centauri b matches this condition and is also a special planet for us because it orbits our nearest star, located just 4.2 light-years away. Near does not necessarily mean bright, however. Proxima Centauri is actually a cool red star that is much too dim to be seen with the naked eye and, with a mass about eight times smaller than the Sun, it is also around 600 times less luminous. The habitable zone around this red-dwarf star is therefore at much shorter distances than the corresponding distances in our solar system – equivalent to a small fraction of the orbit of Mercury. Proxima Centauri b orbits the star in only 11.2 days and has a minimum mass of 1.27 Earth masses. The exact value of the mass cannot be determined by the radial-velocity method because it depends on the unknown inclination of the orbit with respect to the line of sight.

During the first half of 2016, Proxima Centauri was regularly observed with the HARPS spectrograph on the ESO 3.6 m telescope at La Silla in Chile, and simultaneously monitored by other telescopes around the world. This campaign, which was led by Guillem Anglada-Escudé of Queen Mary University of London and shared publicly online as it happened, was called the Pale Red Dot.

The final results have now been published, concluding with a discussion on the habitability of the planet. Whether there is an atmosphere and liquid water on the surface is the subject of intense debate because red-dwarf stars can display quite violent behaviour. The main threats identified in the paper are tidal locking (for example, does the planet always present the same face to the star, as does our Moon?), strong stellar magnetic fields and strong flares with high ultraviolet and X-ray fluxes. Whereas robotic exploration is some time away, the future European Extremely Large Telescope (E-ELT) should be able to see the planet and probe its atmosphere spectroscopically.

Further reading

G Anglada-Escudé *et al.* 2016 *Nature* **536** 437.

Picture of the month

This stunning view of the distant galaxy-cluster Abell S1063 was taken by the NASA/ESA Hubble Space Telescope as part of the Frontier Field programme. The cluster itself is seen as it was four-billion years ago – the time it took light to reach us. But the main goal of this observation is to explore a time even earlier than this, where no telescope has looked before. The huge mass of the cluster distorts and magnifies the light from galaxies that lie behind it due to gravitational lensing. This allows Hubble to see galaxies that would otherwise be too faint to observe and makes it possible to study the very first generation of galaxies in the universe. Three other clusters have already been observed as part of the Frontier Fields programme and two more will be observed over the next few years, giving astronomers a remarkable picture of how they work and what lies both within and beyond them.

NASA, ESA, and J Lotz (STScI)

ICHEP 2016 attracted particle physicists from across the globe. (Image credit: Reidar Hahn, Fermilab.)

Particle physics under the spotlight in Chicago

Mysterious bumps, rediscovered Higgs bosons, neutrino oscillations and dark matter were among the scientific highlights at ICHEP 2016, which took place in Chicago from 3 to 11 August. **Young-Kee Kim**, **Joe Lykken** and **Katie Yurkewicz** reveal all.

This summer, the city of Chicago in Illinois was not only a vacation destination for North American tourists – it was also the preferred destination for more than 1400 scientists, students, educators and members of industry from around the world. Fifty-one countries from Africa, Asia, Australia, Europe, North America and South America were represented at the 38th International Conference on High Energy Physics (ICHEP), which is the largest such conference ever held.

Indeed, the unexpectedly large interest in the meeting caused some re-thinking of the conference agenda. A record 1600 abstracts were submitted, of which 600 were selected for parallel presentations and 500 for posters by 65 conveners. During three days of plenary sessions, 36 speakers from around the world overviewed results presented at the parallel and poster sessions.

One of the most popular parallel-session themes concerned enabling technologies, totalling around 400 abstract submissions, and rich collaborative opportunities were discussed in the new "technology applications and industrial opportunities" track. Another innovation at ICHEP 2016 concerned diversity and inclusion, which appeared as a separate parallel track. A number of new initiatives in communication, education and outreach were also piloted. These included lunchtime sessions aimed at increasing ICHEP participants' skills in outreach and communication through news and social media, "art interventions" and a physics slam, where five scientists competed to earn audience applause through presentations of their research. The outreach programme was complemented by events at 30 public libraries in Chicago and a public lecture about gravitational waves.

While the public had an increasing number of ways to connect with the conference, however, the main attraction for attendees remained the same: new science results. And no result was more highly anticipated than the updates on the 750 GeV diphoton resonance hinted at in data from the ATLAS and CMS experiments recorded during 2015. ▷

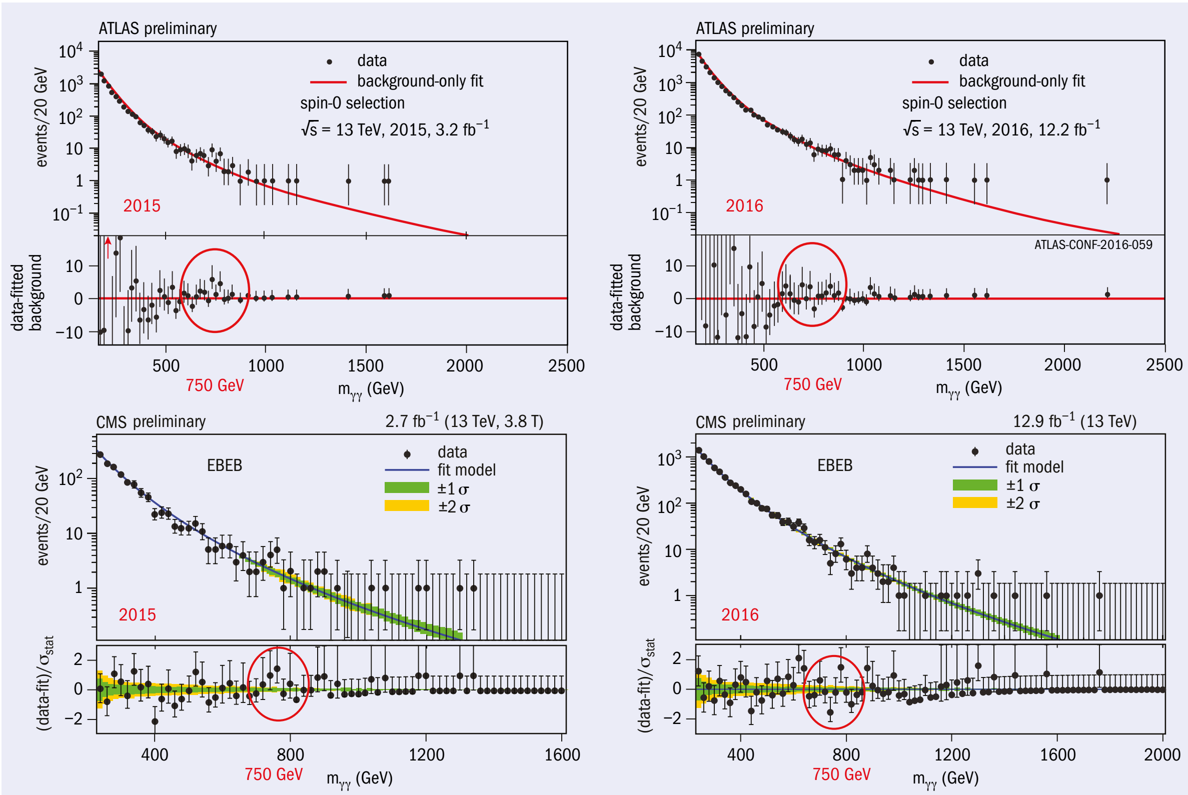


Fig. 1. A slight excess in the number of diphoton events corresponding to a mass of 750 GeV observed by ATLAS and CMS in 2015 (left) did not reappear in data recorded this year (right), showing that the famous "bump", which generated hundreds of theoretical explanations, was likely to be a statistical effect.

Exploring the unknown

The spectacular performance of the LHC during 2016, which saw about 20 fb^{-1} of 13 TeV proton–proton collisions delivered to ATLAS and CMS by the time of the conference, gave both experiments unprecedented sensitivity to new particles and interactions. The collaborations reported on dozens of different searches for new phenomena. In a dramatic parallel session, both ATLAS and CMS revealed that their 2016 data do not confirm the previous hints of a diphoton resonance at 750 GeV (figure 1); apparently, those hints were nothing more than tantalising statistical fluctuations. Disappointed theorists were happily distracted by other new results, however. As expected, these include interesting excesses worth keeping an eye on as more data become available. Still in the running for future big discoveries are the production of heavy particles predicted by supersymmetry and exotic theories, and the direct production at the LHC of dark-matter particles. So far, no signs of such particles have been seen at ATLAS or CMS.

Many other experiments reported on their own searches for new particles and interactions, including new LHCb results on the most sensitive search to date for CP violation in the decays of neutral D mesons which, if detected, would allow researchers to probe CP violation in the up-type quark sector. Final results from the MEG (Mu to E Gamma) experiment at the Paul Scherrer Institute in Switzerland revealed the most sensitive search to date for charged lepton-flavour violation, which would also be a clear signature of new physics. Using bottom and charm quarks to probe new physics, the Beijing Spectrometer (BES) at IHEP in China and the Belle experiment at KEK in Japan showcased a series of precision and rare-process results. While they have a few interesting discrepancies from Standard Model (SM) predictions, presently no signs of physics beyond the SM have emerged.

Meanwhile on the heavy-ion front, the ALICE experiment at the LHC joined ATLAS, CMS and LHCb in presenting new observations of the dramatic and mysterious properties of quark–gluon plasma. This was complemented by results from the STAR and PHENIX experiments at RHIC at the Brookhaven National Laboratory in the US.

Rediscovering the Higgs

Perhaps unsurprisingly, given that its discovery in 2012 was one of the biggest in particle physics for a generation, the Higgs boson was the subject of 30 parallel-session talks. New LHC measurements are a great indicator of how the Higgs boson is being used as a new tool for discovery. Already Run 2 of the LHC has produced more

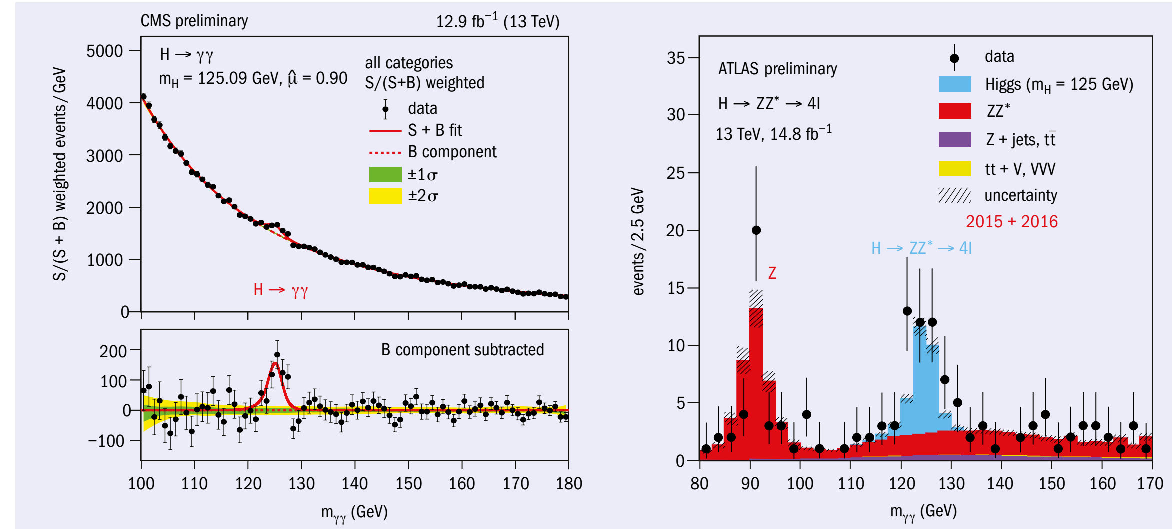


Fig. 2. In case there was any doubt about the existence of the Higgs boson, the CMS (left) and ATLAS (right) experiments have rediscovered the 125 GeV-mass particle in independent data recorded at almost twice the collision energy (13 TeV).

Higgs bosons than in Run 1, and the Higgs has been "rediscovered" in the new data with a significance of 10σ (figure 2). A major focus of the new analyses is to demonstrate the production of Higgs particles in association with a W or Z boson, or with a pair of top quarks and their decay patterns. These production and decay channels are important tests of Higgs properties, and so far the Higgs seems to behave just as the SM predicts.

About 20 new searches looking for heavier cousins of the Higgs were reported. These "heavy Higgs", once produced, could decay in ways very similar to the Higgs itself, or might decay into a pair of Higgs bosons. Other searches covered the possibility that the Higgs boson itself has exotic decays: "invisible" decays into undetected particles, decays into exotic bosons or decays that violate the conservation of lepton flavour. No signals have emerged yet, but the LHC experiments are providing increasing sensitivity and coverage of the full menu of possibilities.

Neutrino mysteries

With neutrinos currently among the most interesting objects to study to look for signs of physics beyond the SM, ICHEP included reports from three powerful long-baseline neutrino experiments: T2K at J-PARC in Japan, and NOvA and MINOS at Fermilab in the US, which are addressing some of the fundamental questions about neutrinos such as CP violation, the ordering of their masses and their mixing behaviour. While not yet conclusive, the results presented at ICHEP show that neutrino physics is entering a new era of sensitivity and maturity. Data from T2K currently favour the idea of CP violation in the lepton sector, which is one of the conditions required for the observed dominance of matter over antimatter in the universe, while data from NOvA disfavour the idea that mixing of the second and third neutrino flavours is maximal, representing a test of a new symmetry that underlies maximal mixing (figure 3, overleaf).

Neutrino physics is entering a new era of sensitivity and maturity.

The long simmering issue of sterile neutrinos – hypothesised particles that do not interact via SM forces – also received new attention in Chicago. The 20 year-old signal from the LSND experiment at Los Alamos National Laboratory in the US, which indicates 4σ evidence for such a particle, was matched some years ago by anomalies from the MiniBooNE experiment at Fermilab. As reported at ICHEP, however, cosmological data and new results from IceCUBE in Antarctica and MINOS+ at Fermilab do not confirm the existence of sterile neutrinos. On the other hand, the Daya Bay experiment in China, Reno in South Korea and Double Chooz in France all confirm a reactor neutrino flux that is low compared with the latest modelling, which could arise from mixing with sterile neutrinos. However, all three of these experiments also confirm a "bump" in the neutrino spectrum at an energy of around 5 MeV that is not predicted, so there is certainly more work to be done in understanding the modelling.

Probing the dark sector

Dark matter dominates the universe, but its identity is still a mystery. Indeed, some theorists speculate about the existence of an entire "dark sector" made up of dark photons and multiple species of dark matter. Numerous approaches are being pursued to detect dark matter directly, and these are complemented by searches at the LHC, surveys of large-scale structure and attempts to observe high-energy particles from dark-matter annihilation or decay in or around our Galaxy. Regarding direct detection, experiments are advancing steadily in sensitivity: the latest examples reported at ICHEP came from LUX in the US and PandaX-II in China, and already they exclude a substantial fraction of the parameter space of supersymmetric dark-matter candidates (figure 4, overleaf). ▷

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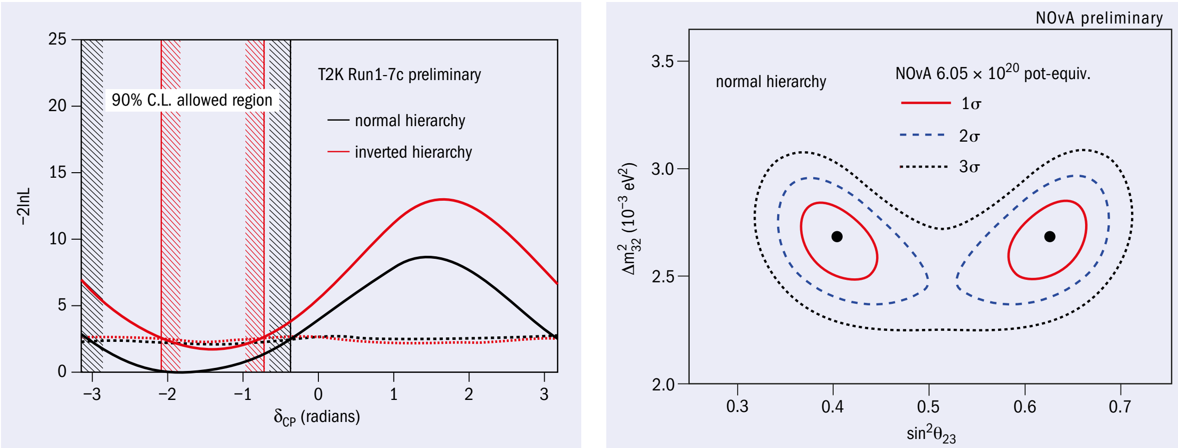


Fig. 3. With nearly twice the antineutrino data in 2016 compared with its 2015 result, the T2K experiment's observed electron antineutrino appearance rate is lower than would be expected if CP asymmetry is conserved (left). With data accumulated until May 2016, representing 16% of its planned total, NOvA's results (right) show an intriguing preference for non-maximal mixing – that is, a preference for $\sin^2\theta_{23} \neq 0.5$.

Dark energy – the name given to the entity thought to be driving the cosmic acceleration of today's universe – is one of two provocative mysteries, the other concerning the primordial epoch of cosmic inflation. ICHEP sessions concerned both current and planned observations of such effects, using either optical surveys of large-scale structure or the cosmic microwave background. Both approaches together can probe the nature of dark energy by looking at the abundance of galaxy clusters as a function of redshift; as reported at the Chicago event, this is already happening via the Dark Energy Survey and the South Pole Telescope.

Progress in theory

Particle theory has been advancing rapidly along two main lines: new ideas and approaches for persistent mysteries such as dark matter and naturalness, and more precise calculations of SM processes that are relevant for ongoing experiments. As emphasised at ICHEP 2016, new ideas for the identity of dark matter have had implications for LHC searches and for attempts to observe astrophysical dark-matter annihilation, in addition to motivating a new experimental programme looking for dark photons. A balanced view of the naturalness problem, which concerns the extent to which fundamental parameters appear tuned for our existence, was presented at ICHEP. While supersymmetry is still the leading explanation, theorists are also studying alternatives such as the "relaxion". This shifts attention to the dynamics of the early universe, with consequences that may be observable in future experiments.

There have also been tremendous developments in theoretical calculations with higher-order QCD and electroweak corrections, which are critical for understanding the SM backgrounds when searching for new physics – particularly at the LHC and, soon, at the SuperKEKB B factory in Japan. The LHC's experimental precision on top-quark production is now reaching the point where theory requires next-to-next-to-next-to-leading-order corrections just to keep up, and this is starting to happen. In addition, recent lattice QCD calculations play a key role in extracting fundamental parameters such as the CKM mixing matrix, as well as squeezing down uncertainties to the point where effects of new phenomena may conclusively emerge.

Facilities focus

With particle physics being a global endeavour, the LHC at CERN serves as a shining example of a successful large international science project. At a session devoted to future facilities, leaders from major institutions presented the science case and current status of new projects that require international co-operation. These include the International Linear Collider (ILC) in Japan, the Circular Electron–Positron Collider (CEPC) in China, an energy upgrade of the LHC, the Compact Linear Collider (CLIC) and the Future Circular Collider (FCC) at CERN, the Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) in the US, and the Hyper-K neutrino experiment in Japan.

While the high-energy physics experiments of the future were a key focus, one of the well-attended sessions at ICHEP 2016 concerned professional issues critical to a successful future for the field of particle physics. Diversity and inclusion were the subject of four hours of parallel sessions, discussions and posters, with themes such as communication, inclusion and respect in international collaboration and how harassment and discrimination in scientific communities create barriers to access. The sessions were mostly standing-room only, with supportive but candid discussion of the deep divides, harassment, and biases – both explicit and implicit – that need to be overcome in the science community. Speakers described a number of positive initiatives, including the Early Career, Gender and Diversity office established by the LHCb collaboration, the Study Group on Diversity in the ATLAS collaboration, and the American Physical Society's "Bridge Program" to increase the number of physics PhDs among students from under-represented backgrounds.

ICHEP 2016 clearly showed that there are a vast number of scientific opportunities on offer now and in the future with which to further explore the smallest and largest structures in the universe. The LHC is performing beyond expectations, and will soon enter a new era with its planned high-luminosity upgrade. Meanwhile, propelled by surprising discoveries from a series of pioneering experiments, neutrino physics has progressed dramatically, and its progress will continue with new and innovative experiments. Intense kaon and muon beams, and SuperKEKB, will provide excellent opportunities to search for new physics in different ways, and will help to inform future research directions. Diverse approaches to probe the nature of dark matter and dark energy are also on their way. While we cannot know what will be the headline results at the next ICHEP event – which will be held in 2018 in Seoul, South Korea – we can be certain that surprises are in store.

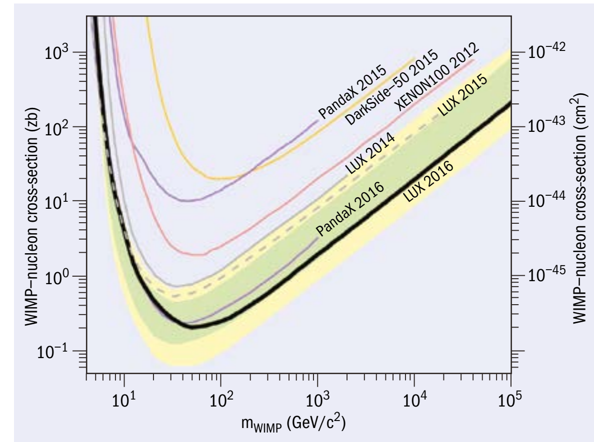


Fig. 4. The LUX and PandaX experiments saw no signals of dark-matter candidates and their results were consistent with background expectations. A substantial region of parameter space is now excluded.

Résumé

La physique des particules à l'honneur à Chicago

Cet été, du 3 au 11 août, plus de 1 400 scientifiques, étudiants, enseignants et industriels du monde entier se sont réunis à Chicago (Illinois, États-Unis) pour la 38e Conférence internationale sur la physique des hautes énergies (ICHEP). Il s'agissait de la plus grande conférence jamais organisée sur le sujet, avec 51 pays d'Afrique, d'Asie, d'Océanie, d'Europe et d'Amérique du Nord et du Sud représentés. Les bosses mystérieuses, les bosons de Higgs redécouverts, les oscillations de neutrinos et la matière noire étaient parmi les principaux sujets scientifiques. Les technologies prometteuses ont également été un thème important, avec environ 400 résumés d'articles ou de présentations soumis ; les sessions portant sur des questions liées à la communication, à la diversité et à l'inclusion ont elles aussi attiré un large public.

Young-Kee Kim (chair of ICHEP 2016), University of Chicago, and **Joe Lykken** and **Katie Yurkewicz**, Fermilab.

Proton therapy enters precision phase

A high-energy proton-therapy facility in Nice that has its roots in a collaboration with CERN is preparing to treat patients, describe **Joel Hérault**, **Pierre Mandrillon**, **François Demard** and **Richard Trimaud**.

Each year, millions of people worldwide undergo treatment for cancer based on focused beams of high-energy photons. Produced by electron linear accelerators (linacs), photons with energies in the MeV range are targeted on cancerous tissue where they indirectly ionise DNA atoms and therefore reduce the ability of cells to reproduce. Photon therapy has been in clinical use for more than a century, following the discovery of X-rays by Roentgen in 1896, and has helped to save or improve the quality of countless lives.

Proton therapy, which is a subclass of particle or hadron therapy, is an innovative alternative technique in radiotherapy. It can treat tumours in a much more precise manner than X- or gamma-rays because the radiation dose of protons is ballistic: protons have a definite range characterised by the Bragg peak, which depends on their energy. This initial ballistic advantage gives protons their advantage over X-rays to provide a dose deposition that better matches tumour contours while limiting the dose in the vicinity. This property, which was first identified by accelerator-pioneer Robert Wilson in 1946 when he was involved in the design of the Harvard Cyclotron Laboratory, results in a greater treatment efficiency and a lower risk of complications.

The pioneers of proton therapy used accelerators from physics laboratories at locations including Uppsala in Sweden in 1957; Boston Harvard Cyclotron Laboratory in the US in 1961; and the Swiss Institute for Nuclear Research in Switzerland in 1984. The first dedicated clinical proton-therapy facility, which was driven by a low-energy cyclotron, was inaugurated in 1989 at the Clatterbridge Centre for Oncology in the UK. The following year, a dedicated synchrotron designed at Fermilab began operating in the US at the Loma Linda University Medical Center in California. By the early 2000s, the number of treatment centres had risen to around 20, and today proton therapy is booming: some 45 facilities are in operation worldwide, with around 20 under construction and a further 30 at the planning stage in various countries around the world (see www.ptcog.ch).

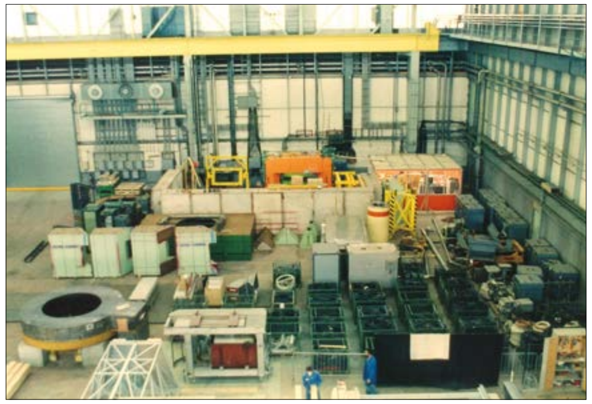

The compact-gantry treatment room embedded in a bunker.

Towards MEDICYC

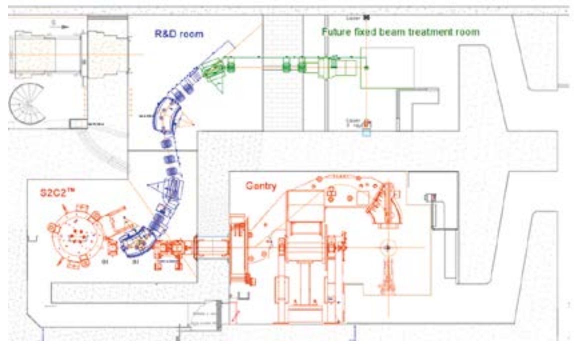
Modern proton therapy exploits an active technique called pencil-beam scanning, which creates a pointillist 3D tumour-volume painting by displacing the proton beam with appropriate magnets. Moreover, different irradiation ports are generally possible thanks to rotating gantries. This delivery technique is competitive with the most advanced forms of X-ray irradiation, such as intensity-modulated radiation therapy (IMRT), tomotherapy, cyberknife and others, because it uses a smaller number of entering ports and hence reduces the overall absorbed dose to the patient.

Owing to its high dose accuracy, proton therapy has historically been oriented towards the treatment of uveal melanoma and base-of-skull tumours, for which X-rays are less efficient. Today, however, proton therapy is used to treat any tumour type with a predilection for paediatric treatment. Indeed, by limiting the integral dose to an absolute minimum at the whole-body level, the side effects of radiotherapy occurring from radiation-induced cancer are reduced to a minimum.

Particle physics, and CERN in particular, has played a key role in the success of proton therapy. One of the first facilities operating in Europe was MEDICYC – a 65 MeV proton medical cyclotron that was initially devoted to neutron production for cancer therapy. It was installed at the Centre Antoine Lacassagne (CAL) in Nice in 1991, where the first proton-therapy treatment for ocular ▷



The MEDICYC Cyclotron (the orange magnet in the back) in the PS East Hall during tests in the early 1990s.



The S2C2 cyclotron and its compact gantry produced by IBA. Blue shows the beamline that feeds the R&D room for the France Hadron research teams, while green shows the second fixed-beam treatment room, which will be installed in the near future.

melanoma was achieved in France. MEDICYC was designed by a small team of young CAL members hosted by CERN in the PS division, and the advice of the passionate experts there was key to the success of this accelerator. Preliminary studies for MEDICYC and the first test of the radiofrequency accelerating system were performed at CERN. Indeed, because the cyclotron was completed before the building that would house it, it was proposed to assemble the cyclotron magnet at CERN in the East Hall of the PS division, to perform the magnetic-measurement campaigns.

During its 25 year operational lifetime, which began in June 1991, MEDICYC has reached a high level of reliability and successfully treated more than 5500 patients for various ocular tumours with a 96% local control rate. Owing to its high-dose-profile quality (0.8 mm dose fall-off beyond the Bragg peak, which is of the utmost importance for irradiating tumours close to the optical nerve), MEDICYC will continue to run its medium-energy proton-therapy programme. Moreover, CAL is investigating a MEDICYC improvement programme for increasing the beam intensities in view of new medical-isotope production at high energies with protons and deuterons.

On 30 June this year, a new proton therapy centre called the Institut Méditerranéen de Protonthérapie (IMPT) was inaugurated at CAL, marking a new phase in European advanced hadron therapy. Joining MEDICYC as the driver of this new facility is a new cyclotron called the Superconducting Synchro-cyclotron (S2C2). This facility, which will expand the proton-therapy activity of MEDICYC, uses the latest technology to precisely target tumours while controlling the intensity and spatial distribution of the dose with fine precision. It is therefore ideal for treating base of skull, head and neck, sarcomas tumours and with priority oncopediatics tumours, and is expected to treat up to 250 patients per year in its first phase.

CERN beginnings

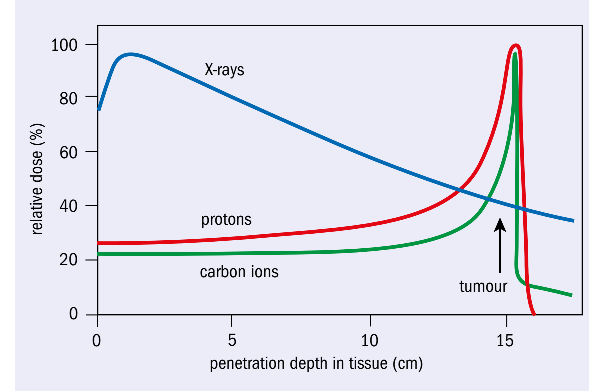
The new facility at CAL has its roots in a CERN-led project called EULIMA (European Light Ions Medical Accelerator) – a joint initiative at the end of the 1980s to bring the potential benefit of hadron therapy with light ions to cancer patients in Europe. Historically, CAL was involved with several European institutes to undertake feasibility studies for EULIMA. The feasibility study group was hosted by CERN and the main design option for the accelerator was a four-magnetic-sector cyclotron with a single large cylindrical superconducting excitation coil designed by CERN magnet-specialist Mario Morpurgo. CAL was selected as a candidate site to host the EULIMA prototype because it offered both adequate space in the MEDICYC building to house the machine and treatment rooms, while also offering an adequate supply of medical, scientific and technical staff in an attractive site.

When the EULIMA came to an end in 1992, the empty EULIMA hall was available for future development projects in high-energy proton therapy. However, in 2011, we were able to construct the new S2C2 facility at CAL at low cost. This compact, approximately 40 tonne facility provides proton beams with an energy of 230 MeV and delivers its dose using dynamic pencil-beam scanning (PBS). Its design is the result of a collaboration between AIMA (a spin-out company from CAL) and Belgian medical firm IBA.

The facility comprises a beamline that feeds an R&D room for research teams, which have decided to commit themselves to a national research programme called France Hadron. The programme gathers several hadron-therapy centres based at Paris-Orsay, Lyon, Caen, Toulouse and Nice, in addition to several universities and national public research institutions, to co-ordinate and organise a national programme of research and training in hadron therapy. This programme aims at bringing nuclear-physics techniques to clinical research through dosimetry, radiation biology, imaging, control of target positioning, and quality-control instruments.

MEDICYC was designed by a small team hosted by CERN, and the advice of the passionate experts there was key to its success.

As is the case for eye treatment at MEDICYC, the new facility will operate in co-operation with the Léon Bérard cancer centre in Lyon and other oncologic centres in the south of France. The new high-energy proton facility displays many innovative technological



Effective relative dose versus tissue depth for different forms of radiation.

breakthroughs compared with existing systems. The accelerator is four-times lighter and consumes eight-times less energy than current machines for the same performance, and its maximum energy of 230 MeV can treat all tumours deep in the human body up to a depth of 32 cm. Its significantly lower cost represents a particularly attractive alternative compared with the global industrial standard. It also foreshadows a major development of proton therapy in the coming years, because compact synchrocyclotron technology is also being developed for the acceleration of alpha particles and heavier ions for hadron therapy.

A major innovation is its rotating compact gantry, the first prototype of which was installed in the US in 2013. The new beamline has a mobility that allows operators to direct the radiation beam in different incidences around the patient and offer unprecedented compactness, reducing costs further. The new S2C2 and the future upgrading programme of MEDICYC embody the medical mission of CAL at large by bringing together advanced proton therapy for treating patients and scientific research activities with multidisciplinary teams of medical physicists and radiobiologists.

Résumé

Protonthérapie : l'ère de la précision

La protonthérapie est une technique de radiothérapie innovante, qui peut traiter des tumeurs avec beaucoup plus de précision que les rayons X ou les rayons gamma. Le nombre de centres de traitement par protonthérapie augmente rapidement, et offre aux patients des traitements plus efficaces avec un risque de complications moindre. Au Centre Antoine Lacassagne, à Nice, une nouvelle installation de protonthérapie de haute énergie, qui tire son origine d'une collaboration avec le CERN vieille de 30 ans, se prépare à présent à traiter son premier patient. À performance égale, son accélérateur est quatre fois plus léger et consomme huit fois moins d'énergie que les machines actuelles, et il peut traiter tous types de tumeurs situées profondément à l'intérieur du corps humain.

Joel Hérault, **Pierre Mandrillon**, **François Demard** and **Richard Trimaud**, Centre Antoine Lacassagne (CAL), Nice.

CERN Courier October 2016
CERN MEDICIS

CERN to produce radioisotopes for health

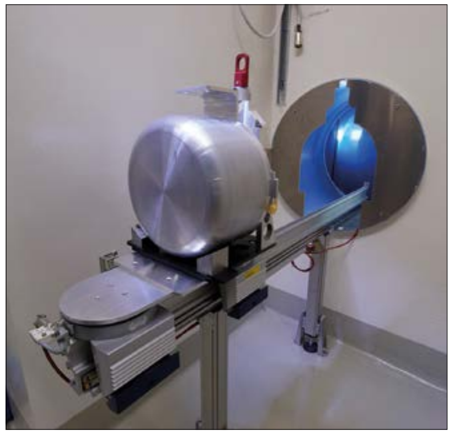
A new project called CERN MEDICIS aims to produce novel isotopes as diagnostic agents and treatments for brain and pancreatic cancers, explain **Leo Buehler**, **Thomas Cocolios**, **John Prior** and **Thierry Stora**.

Accelerators and their related technologies have long been developed at CERN to undertake fundamental research in nuclear physics, probe the high-energy frontier or explore the properties of antimatter. Some of the spin-offs of this activity have become key to society. A famous example is the World Wide Web, while another is medical applications such as positron emission tomography (PET) scanner prototypes and image reconstruction algorithms developed in collaboration between CERN and Geneva University Hospitals in the early 1990s. Today, as accelerator physicists develop the next-generation radioactive beam facilities to address new questions in nuclear structure – in particular HIE-ISOLDE at CERN, SPIRAL 2 at GANIL in France, ISOL@Myrrha at SCK•CEN in Belgium and SPES at INFN in Italy – medical doctors are devising new approaches to diagnose and treat diseases such as neurodegenerative disorders and cancers.

The bridge between the radioactive-beam and medical communities dates back to the late 1970s, when radioisotopes collected from a secondary beam at CERN's Isotope mass Separator On-Line facility (ISOLDE) were used to synthesise an injectable radiopharmaceutical in a patient suffering from cancer. ^{167}Tm-citrate, a radiolanthanide associated to a chelating chemical, was used to perform a PET image of a lymphoma, which revealed the spread-out cancerous tumours. While PET became a reference protocol to provide quantitative imaging information, several other pre-clinical and pilot clinical tests have been performed with non-conventional radioisotopes collected at radioactive-ion-beam facilities – both for diagnosis and for therapeutic applications.

Despite significant progress made in the past decade in the field of oncology, however, the prognosis of certain tumours is still poor – particularly for patients presenting advanced glioblastoma multiforme (a form of very aggressive brain cancer) or pancreatic adenocarcinoma. The latter is a leading cause of cancer death in the developed world and surgical resection is the only potential treatment, although many patients are not candidates for surgery. Although external-beam gamma radiation and chemotherapy are used to treat patients with non-operable pancreatic tumours, and survival rates can be improved by combined radio- and chemotherapy, there is still a clear need for novel treatment modalities for pancreatic cancer.

A new project at CERN called MEDICIS aims to develop non-conventional isotopes to be used as a diagnostic agent and for brachytherapy or unsealed internal radiotherapy for the treatment of non-resectable brain and pancreatic cancer, among other forms of the disease. Initiated in 2010, the facility will use a proton beam at ISOLDE to produce isotopes that first will be destined for hospitals and research centres in Switzerland, followed by a progressive roll-out to a larger network of laboratories in Europe and beyond. The project is now approaching its final phase, with start-up foreseen in June 2017.



Clockwise from top left: Storage shelves for ISOLDE and CERN-MEDICIS targets after their operation, showing the robot for remote handling. A "fresh" target unit stands on the CERN-MEDICIS supply point, ready for the robot pick-up and transportation to the irradiation point. A rail conveyor system end-station for target transportation, showing the inspection camera and two modern target units. The MEDICIS building at CERN, next to ISOLDE. (Image credits: Yury Gavrikov.)

A century of treatment

The idea of using radioisotopes to cure cancer was first proposed by Pierre Curie soon after his discovery of radium in 1898. The use of radium seduced many physicians because the penetrating rays could be used superficially or be inserted surgically into the body – a method called brachytherapy. The first clinical trials took place at the Curie Institute in France and at St Luke's Memorial Hospital in New York at the beginning of the 20th century, for the treatment of prostate cancer.

A century later, in 2013, a milestone was met with the successful clinical trials of ^{223}Ra in the form of the salt-solution $RaCl_2$, which was injected into patients suffering from prostate cancers with bone metastasis. The positive effect on patient survival was so clear in the last clinical validation (so-called phase III), that the trial was terminated prematurely to allow patients who had received a placebo to be given the effective drug. Today, the availability of new isotopes, medical imagery, robotics, monoclonal antibodies and a better understanding of tumour mechanisms has enabled progress in both brachytherapy and unsealed internal radiotherapy. Radioisotopes can now be placed closer to and even inside the tumour cells, killing them with minimal damage to healthy tissue.

CERN-MEDICIS aims to further advance this area of medicine. New isotopes with specific types of emission, tissue penetration and half-life will be produced and purified based on expertise acquired during the past 50 years in producing beams of radioisotope ions for ISOLDE's experimental programme. Diagnosis by single photon emission computed tomography (SPECT), a form of scintigraphy, covers the vast majority of worldwide isotope consumption based on the gamma-emitting ^{99m}Tc, which is used for functional probing of the brain and various other organs. PET protocols are increasingly used based on the positron emitter ^{18}F and, more recently, a ^{68}Ga compound. Therapy, on the other hand, is mostly carried out with beta emitters such as ^{131}I, more recently with ^{177}Lu, or with ^{223}Ra for the new application of targeted alpha therapy (see p35). Other isotopes also offer clear benefits, such as ^{149}Tb, which is the lightest alpha-emitting radiolanthanide and also combines positron-emitting properties.

Driven by ISOLDE

With 17 Member States and an ever-growing number of users, ISOLDE is a dynamic facility that has provided beams for around 300 experiments at CERN in its 50 year history. It allows researchers to explore the structure of the atomic nucleus, study particle physics at low energies, and provides radioactive probes for solid-state and biophysics. Through 50 years of collaboration between the technical teams and the users, a deep bond has formed, and the facility evolves hand-in-hand with new technologies and research topics.

CERN MEDICIS is the next step in this adventure, and the user community is joining in efforts to push the development of the machine in a new direction. The project was initiated six years ago by a relatively small collaboration involving CERN, KU Leuven, EPFL and two local University Hospitals (CHUV in Lausanne and HUG in Geneva). One year later, in 2011, CERN decided to streamline medical production of radioisotopes and to offer grants dedicated to technology transfer. While the mechanical conveyor system to transport the irradiated targets was covered by such a grant, the construction of the CERN MEDICIS building began in September 2013. The installation of the services, mass separator and laboratory is now under way.

At ISOLDE, physicists direct a high-energy proton beam from the Proton Synchrotron Booster (PSB) at a target. Since the beam loses only 10% of its intensity and energy on hitting the target, the particles that pass through it can still be used. For CERN-MEDICIS, a second target therefore sits behind the first and is used for exotic isotope generation. Key to the project is a mechanical system that transports a fresh target and its ion source into one of the two ISOLDE target-stations' high resolution separator (HRS) beam dump, irradiates it with the proton beam from the PSB to generate the isotopes, then returns it to the CERN-MEDICIS ▷

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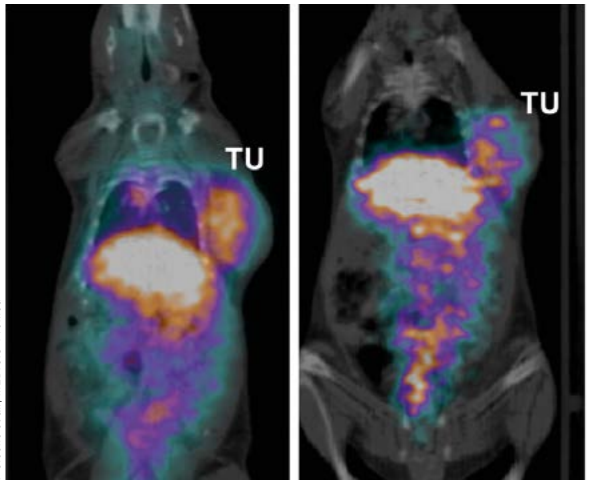

F Cicone *et al.*, MEDICIS-Promed

Fig. 1. Pre-clinical imaging of ^{152}Tb anti-TEM1 antibodies in a mouse grafted with tumour cells using a PET scanner at 24 (left) and 48 (right) hours, showing targeting of the radiopharmaceutical within the tumour. The grafted tumour tissues (TU on the upper right) can be visualised as bright spots. Other organs are also visible in the centre.

laboratory. The system was fully commissioned in 2014 under proton-beam irradiation with a target that was later used to produce a secondary beam, thus validating the full principle. A crucial functional element was still missing: the isotope mass separator, along with its services and target station. Coincidentally, however, CERN MEDICIS started just as the operation of KU Leuven's isotope-separation facility ended, and a new lease of life could therefore be given to its dipole magnet separator, which was delivered to CERN earlier this year for testing and refurbishment.

A close collaboration is growing at MEDICIS centred around the core team at CERN but involving partners from fundamental nuclear physics, material science, radiopharmacy, medical physics, immunology, radiobiology, oncology and surgery, with more to come.

Training network

With such an exceptional tool at hand, and based on growing pre-clinical research experiments performed at local university hospitals, in 2014 a H2020 Innovative Training Network was set up by CERN to ensure MEDICIS is fully exploited. This "Marie Skłodowska-Curie actions" proposal was submitted to

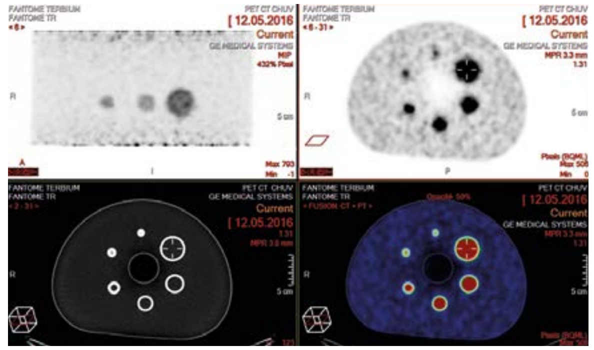

Fig. 2. Characterisation of the PET imaging capability of the long-lived (17.5 hours) isotope ^{152}Tb for clinical PET scans. The figure shows the image of a standardisation phantom (wells of increasing diameters) used in pre-clinical nuclear-medicine laboratories. A good resolution obtained after 10 minutes with a clinical PET scanner shows that clinical imaging with 50 MBq activities will be possible in humans.

the European Commission entitled MEDICIS-Promed, which stands for MEDICIS-produced radioisotope beams for medicine. The goal of this 14-institution consortium is to train a new generation of scientists to develop systems for personalised medicine combining functional imaging and treatments based on radioactive ion-beam mass separation. Subsystems for the development of new radiopharmaceuticals, isotope mass separators at medical cyclotrons, and of mass-separated ^{11}Carbon for PET-aided hadron therapy are to be specifically developed to treat ovarian cancer. Pre-clinical experiments have already started, with the first imaging studies ever done with these exotic radioisotopes. For this, a specific ethical review board has been implemented within the consortium and is chaired by independent members.

With the MEDICIS facility entering operation next year, an increasing range of innovative isotopes will progressively become accessible. These will be used for fundamental studies in cancer research, for new imaging and therapy protocols in cell and animal models, and for pre-clinical trials – possibly extended to early phase clinical studies up to Phase I trials. During the next few years, 500 MBq isotope batches purified by electromagnetic mass separation combined with chemical methods will be collected on a weekly basis. This is a step increase in production to make these innovative isotopes more available to biomedical research laboratories, compared with the present production of a few days per year in a facility such as ISOLDE.

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Staged production

During its initial stage in 2017, only low-Z materials, such as titanium foils and Y_2O_3 ceramics, will be used as targets. From these, we will produce batches of several hundred MBq of ^{44,47}Sc and ^{61,64}Cu. In the second stage, tentatively scheduled for 2018, we will use targets from the nuclei of higher atomic numbers, such as tantalum foils, to reach some of the most interesting terbium and lanthanide isotopes. In a final phase in 2018, we foresee the use of uranium and thorium targets to reach an even wider range of isotopes and most of the other alpha-emitters.

Selected isotopes will first be tested *in vitro* for their capacity to destroy glioblastoma or pancreatic adenocarcinoma or neudoendocine tumour cells, and *in vivo* by using mouse models of cancer. We will also test the isotopes for their direct effect on tumours and when they are coupled to peptides with tumour-homing capacities. New delivery methods for brachytherapy using stereotactic, endoscopic ultrasonographic-guided or robotic-assisted surgery will be established in large-animal models.

Moreover, this new facility marks the entrance of CERN into the era of theranostics. This growing oncological field allows nuclear-medicine physicians to verify and quantify the presence of cellular and molecular targets in a given patient with the 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, makes this an exciting scientific programme in the coming years.

● Further reading

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Résumé

Le CERN produira des radio-isotopes pour la médecine

Le lien entre les communautés des accélérateurs et de la médecine remonte à presque 50 ans. Aujourd'hui, alors que les physiciens développent la nouvelle génération de machines pour la recherche, les médecins imaginent de nouvelles méthodes pour diagnostiquer et traiter les maladies neurodégénératives et les cancers. Le projet MEDICIS du CERN vise à développer de nouveaux isotopes pouvant être utilisés à la fois comme agents de diagnostic et pour la curiethérapie ou la radiothérapie interne avec source non scellée, pour le traitement de cancers du cerveau ou du pancréas non opérables et d'autres formes de cette maladie. L'installation, dont l'idée a germé en 2010 et qui sera opérationnelle en 2017, utilise un faisceau de protons et l'installation de faisceaux d'ions radioactifs ISOLDE pour produire des isotopes médicaux. Ces isotopes seront d'abord destinés à des hôpitaux et des centres de recherche en Suisse, puis progressivement à d'autres laboratoires en Europe et ailleurs dans le monde.

Leo Buehler, Geneva University Hospitals, **Thomas Cocolios**, KU Leuven, **John Prior**, CHUV, and **Thierry Stora**, CERN.

Energetic protons boost BNL isotope production

Recent accelerator upgrades and associated improvements to medical-isotope production at Brookhaven National Laboratory will help to meet global demand for strontium-82 and actinium-225, explain **Cathy Cutler** and **Leonard Mausner.**

The mission of the US Department of Energy (DOE) isotope programme is to produce and distribute radioisotopes that are in short supply and in high demand for medical, industrial and environmental uses. The DOE programme also maintains the unique infrastructure of national laboratories across the country, one of which is Brookhaven National Laboratory's medical radioisotope programme, MIRP. Although there are many small accelerators in the US that produce radioisotopes, the availability of proton energies up to 200 MeV from the Brookhaven Linac Isotope Producer (BLIP) is unique.

Radioisotopes are of interest both for nuclear medicine and for diagnostic imaging and therapy. The most important aspect of Brookhaven's isotope programme is the large-scale production and supply of clinical-grade strontium-82 (^{82}Sr). Although ^{82}Sr is not directly used in humans, its short-lived daughter product ^{82}Rb is a potassium mimic and upon injection is rapidly taken up by viable cardiac tissue. It is therefore supplied to hospitals as a generator for positron emission tomography (PET) scans of the heart, where its short half-life (76 seconds) allows multiple scans to be performed and minimal doses delivered to the patient. At present, up to 350,000 patients per year in the US receive such PET scans, but demand is growing beyond capacity.

There is also significant promise for the utilisation of alpha emitters for treating a variety of diseases including metastatic cancer, viral and fungal infections and even HIV, for which the leading candidate is the alpha-emitter ^{225}Ac. Thanks to a series of upgrades completed this year, Brookhaven is now in a position to boost production of both of these vital medical isotopes.

Protons on target

The BLIP was built in 1972 and was the world's first facility to utilise high-energy, high-current protons for radioisotope production.

BNL

Brookhaven's linear accelerator is 144.8 m long and feeds a beam either to the BLIP or the Booster accelerator.

It works by diverting the excess beam of Brookhaven's 200 MeV proton linac to water-cooled target assemblies that contain specially engineered targets and degraders to allow optimal energy to be delivered to the targets. The use of higher-energy particles allows relatively thick targets to be irradiated, in which the large number of target nuclei compensate for the generally smaller reaction cross-sections compared to low-energy nuclear reactions.

Although the maximum proton energy is 200 MeV, lower energies can be delivered by sequentially turning off the accelerating sections to achieve 66, 92, 117, 139, 160, 181 and 200 MeV beams. This is the only linac with such a capability, and its energy and intensity can be controlled on a pulse-by-pulse basis. As a result, the linac can simultaneously supply high-intensity pulses to the BLIP and a low-intensity polarised proton beam to the booster synchrotron for injection into the Alternating Gradient Synchrotron (AGS) and the Relativistic Heavy Ion Collider (RHIC) for Brookhaven's nuclear-physics programme. This shared use allows for cost-effective operation. The BLIP design also enables bombardment of up to eight targets, offering the unique ability to produce multiple radioisotopes at the same time (see table overleaf). Target irradiations for radiation-damage studies are also performed, including for materials relevant to collimators used at the LHC and Fermilab.

The Gaussian beam profile of the linac results in very high power density in the target centre. Until recently, the intensity of the beam was limited to 115 µA to ensure the survival of the target. This year, however, a raster system was installed that allows the current on the target to be increased by allowing a more uniform deposition

Radioisotope	Half-life	Decay mode	Target	Application
Be-7	53.2 days	EC	water	gamma-ray source
Mg-28	20.9 hours	β^-	KCl	Mg tracer
Sc-47	3.3 days	β^-	Ti metal	immunotherapy
Fe-52	8.3 hours	EC, β^+	Ni metal	Fe metabolism
Co-55	17.5 hours	EC, β^+	Fe-56	PET label
Zn-65	244.1 days	EC	Ga metal	Zn tracer
Cu-67	2.6 days	β^-	ZnO	immunotherapy
Ge-68/Ga-68	270.8 days /1.13 hours	EC, β^+	Ga metal	PET calibration, generator parent
As-73	80.3 days	EC	Ge metal	As tracer
Rb-81/Kr-81m	4.6 hours/ 13.1 seconds	EC	Kr gas	lung ventilation
Sr-82/Rb-82	25.6 days /1.27 minutes	EC/β^+	RbCl	cardiac studies
Y-86	14.7 hours	EC, β^+	$SrCl_2$	cancer imaging
Y-88	106.6 days	EC, β^+	Nb metal	gamma-ray source
Tc-95m	61 days	EC	Rh metal	Tc-99m stand in
Ru-97	2.9 days	EC	Rh metal	gastric studies
Cd-109	461.4 days	EC	Ag metal	gamma-ray source
Sn-117m	13.8 days	IT	Sb metal	bone-pain palliation
I-123	13.3 hours	EC	NaI	thyroid and other imaging studies
Xe-127	36.4 days	EC	CsCl	lung ventilation
Pb-203	51.9 hours	EC	Bi metal	immunotherapy

Radioisotopes developed and distributed at BLIP, where EC = electron capture, IT = isomeric transition, β^- = beta decay and β^+ = positron decay.

of the beam across the target. This system requires rapid cycling magnets and power supplies to continuously move the beam spot, and has been fully operational since January 2016.

Production of ^{82}Sr is accomplished by irradiating a target comprising rubidium-chloride salt with 117 MeV protons, with the raster parameters driven by the thermal properties of the target. This demanded diagnostic devices in the BLIP beamline that enable the profile of the beam spot to be measured, both for initial device tuning and commissioning and for routine monitoring. These included a laser-profile monitor, beam-position monitor and plunging multi-wire devices. It was also necessary to build an interlock system to detect raster failure, because the target could be destroyed rapidly if the smaller-diameter beam spot stopped moving. The beam is moved in a circular pattern at a rate of 5 kHz with two different

BNL

Two of the hot cells used for radioisotope processing at BNL to protect workers from high radiation levels while performing chemical separation.

radii to create one large and one smaller circle. The radius values and the number of beam pulses for each radius can be programmed to optimise the beam distribution, allowing a five-fold reduction in peak power density.

Given the resulting increase in current from these upgrades, a parallel effort was required to increase the linac-beam intensity. This was accomplished by extending the present pulse length by approximately five per cent and optimising low-energy beam-transport parameters. These adjustments have now raised the maximum beam current to 173 µA, boosting radioisotope production by more than a third. After irradiation, all targets need to be chemically processed to purify the radioisotope of interest from target material and all other coproduced radioisotopes, which is carried out at Brookhaven's dedicated target-processing laboratory.

Tri-lab effort

Among the highest-priority research efforts of the MIRP is to assess the feasibility of using an accelerator to produce the alpha emitter ^{225}Ac. Alpha particles impart a high dose in a very short path length, which means that high doses to abnormal diseased tissues can be delivered while limiting the dose to normal tissues. Although there have been several promising preclinical and clinical trials of alpha emitters in the US and Europe, the 10 day half-life of ^{225}Ac would enable targeted alpha radiotherapy using large proteins such as monoclonal antibodies and peptides for selective treatments of metastatic disease. ^{225}Ac decays through multiple alpha emissions to ^{213}Bi, which is an alpha emitter with a half-life of 46 minutes and can therefore be used with peptides and small molecules for rapid targeted alpha therapy (see article on p35).

Although ^{225}Ac is the leading-candidate alpha emitter, vital research has been hindered by its very limited availability. To accelerate this development, a formal "Tri-Lab" collaboration has been established between BNL and two other DOE laboratories: Los Alamos National Laboratory (LANL) and Oak Ridge National ▷

Laboratory (ORNL). The aim is to evaluate the feasibility of irradiating thorium targets with high-energy proton beams to produce much larger quantities of ^{225}Ac for medical applications. Because there is a direct correlation between beam intensity and radioisotope yields, the higher the intensity the higher the yield of these and other useful isotopes. So far, BNL and LANL have measured cross-sections, developed and irradiated relevant alpha-emitter targets for shipment to ORNL and other laboratories. These include several targets containing ^{225}Ac-radioactivity up to 5.9 GBq and others for chemical and biological evaluation of both direct ^{225}Ac use as well as use of a generator to provide the shorter-lived ^{213}Bi. Similar irradiation methods are available at LANL and also TRIUMF in Canada.

Irradiation of thorium metal at high energy also creates copious fission products. This complicates the chemical purification but also creates an opportunity because some coproduced radiometals are of interest for other medical applications. The BNL group therefore plans to develop and evaluate methods to extract these from the irradiated-thorium target in a form suitable for use. In addition to ^{225}Ac, the BNL programme is evaluating the future production of other radioisotopes that can be used as "theranostics". This term refers to isotope pairs or even the same radioisotope that can be used for both imaging and therapeutic applications. Among the potentially attractive isotopes for this purpose that can be produced at BLIP are the beta- and gamma-emitters ^{186}Re and ^{47}Sc.

BNL has served as the birthplace for nuclear medicine from the 1950s, and saw the first use of high-intensity, high-power beams for radioisotope production. Under the guidance of the DOE isotope programme, the laboratory is using its unique accelerator facilities to develop and supply radioisotopes for imaging and therapy. Completed and future upgrades will enable large-scale production of alpha emitters and theranostics to meet presently unmet clinical need. These will enable personalised patient treatments and overall improvements in patient health and quality of life.

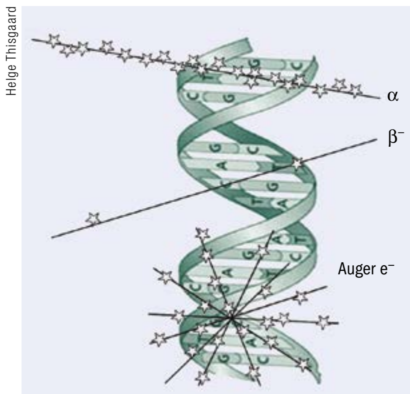
Résumé
Des protons énergétiques pour stimuler la production d'isotopes à Brookhaven

Les récentes améliorations des accélérateurs et les améliorations associées de la production d'isotopes médicaux au Laboratoire national de Brookhaven (États-Unis) aideront à répondre à la demande mondiale de strontium-82 et d'actinium-225. Le premier, ou plutôt son produit de filiation de courte durée de vie, le rubidium-82, est absorbé rapidement par les tissus cardiaques viables, et il est par conséquent très demandé par les hôpitaux en tant que générateur pour les scanners du cœur utilisant la technique de la tomographie par émission de positons (TEP). Chaque année, rien qu'aux États-Unis, jusqu'à 350 000 patients reçoivent ce type de scanners par TEP, et la demande est en train de dépasser les capacités. Les améliorations réalisées des installations de Brookhaven, et celles à venir, permettront une production à grande échelle d'émetteurs alpha et d'isotopes utilisables à la fois pour la thérapie et pour le diagnostic afin de répondre à la demande clinique, actuellement insatisfaite.

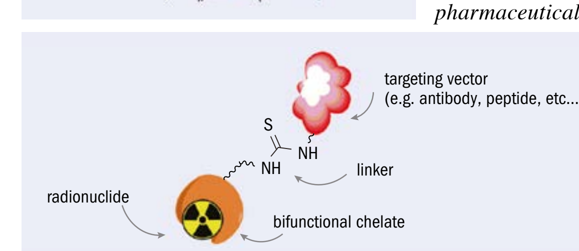
Cathy Cutler (director of MIRP) and **Leonard Mausner**, Brookhaven National Laboratory, US.

TRIUMF targets alpha therapy

Proton beamlines from TRIUMF's 520 MeV cyclotron will irradiate thorium and uranium targets to produce a variety of radiometals for the production of alpha emitters, describe **Paul Schaffer** and **Valery Radchenko**.



Helge Thisgaard



Caterina F Ramogida

Fig. 1. (Left) Representation of the linear energy transfer of alpha, beta, and Auger electron radiation on DNA.

Fig. 2. (Below) Simplified representation of a targeted radiation-therapy radio-pharmaceutical.

External-beam radiation therapy is used routinely to treat many different types of cancerous tumours, delivering a targeted dose of radiation to cancer cells while sparing surrounding healthy tissue as much as possible. While there have been dramatic improvements in the control of patient and tumour dose during recent years, many challenges persist. These include side effects such as depressed immunity, which makes patients susceptible to post-treatment infections, and an increase in secondary cancers.

An alternative approach involves delivering a therapeutic radiation dose to tumour cells selectively through a strategy similar to that for molecular imaging: therapeutic isotopes are incorporated into complex pharmaceuticals for specific, targeted delivery of a potent radiation dose directly to cancerous cells. This approach has been recognised since the time of Madame Curie, but even after a century of development, this application remains woefully unoptimised.

To study the full potential of radionuclide therapy, the medical research community is increasingly demanding therapeutic alpha- and beta-emitting isotopes to treat advanced metastatic cancer and other diffuse diseases. Such therapeutic isotopes are changing the cancer-treatment landscape, yet lack of availability and cost are significantly affecting further research and development.

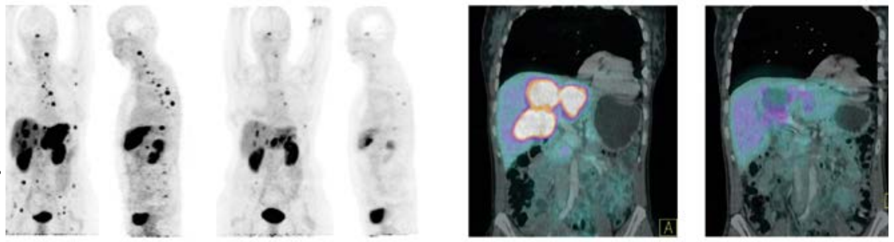
Targeted radionuclide therapy

Targeted radionuclide therapy (TRT) involves the injection of particle-emitting radionuclides appended to a biological targeting molecule, which direct a lethal dose of radiation to a specific site within the body. The short range and highly cytotoxic nature of alpha and beta particles destroys small, diffuse and post-operative residual tumours while minimising damage to healthy tissue. TRT's strength lies in the diversity and adaptability of both isotopes and targeting molecules, which include monoclonal antibodies, antibody fragments, nanoparticles, and small peptides and molecules. Because this allows an optimal delivery regimen to be developed for each application, TRT isotopes are generating significant interest internationally.

Within the Life Sciences Division of TRIUMF in Vancouver, Canada, TRT is now an active research effort. The goal is to exploit TRIUMF's production and radiochemistry capabilities to enable fundamental and applied research with a spectrum of isotopes across different disciplines. In the near-to-medium term, TRIUMF plans to develop platform technologies to enable accelerator-based radiometallic isotope production and applications beyond the current state-of-the-art. Access to a host of metallic isotopes will allow TRIUMF to leverage its radiochemistry expertise to demonstrate the synthesis of novel radiopharmaceuticals, including TRT drugs.

Alpha therapy in sight

Targeted alpha therapy (TAT) is a type of TRT that exploits the high linear-energy transfer of alpha particles (figure 1) to maximise tumour-cell destruction while minimising damage to surrounding cells. As such, TAT has tremendous potential to become a very powerful, selective tool for personalised cancer treatments. To fulfil its promise, however, TAT relies heavily on new developments in ▷



Alfred Morgenstern

The Society of Nuclear Medicine 2012 Image of the Year, showing the shrinkage of liver lesions and bone metastases after treatment with 11 GBq of ^{213}Bi DOTATOC in patients with tumours resistant to previous therapy with ^{90}Y and ^{177}Lu.

isotope production. It also demands organic, bioinorganic and organometallic synthesis techniques to create new molecular probes, and novel techniques to address the stability of metal complexes *in vivo*.

Several promising alpha-emitting radionuclides are currently under consideration worldwide – including ^{149}Tb, ^{211}At, ^{212}Bi, ^{212}Pb, ^{213}Bi, ^{223}Ra, ^{225}Ac, ^{226}Th and ^{230}U – and very promising results have already emerged from clinical and pre-clinical studies of TAT agents. Progress at several laboratories is fuelling great optimism in the medical community. For example, the US Food and Drug Administration recently approved the use of the alpha emitter $^{223}RaCl_2$ (registered under the trademark Xofigo) for pain relief from bone metastases, and several other TAT drugs are in the clinical-trial pipeline.

Securing a constant supply of clinically relevant amounts of alpha-emitting radionuclides remains a challenge, since their production requires high-Z targets and a complex infrastructure. "Generator systems" are a convenient source of TAT isotopes: for example, ^{225}Ac (which has a half-life of 9.92 days) can be harvested as a decay product of ^{229}Th. Because the global quantity of ^{229}Th is not being replenished and the ^{229}Th/^{225}Ac generator can only be eluted every nine weeks, annual worldwide production is limited to approximately 1.7 curies. Several alternative strategies are therefore being proposed to produce such isotopes directly.

TAT radionuclides must be carefully processed before being used in medical applications. They first must be isolated with high radiochemical purity from the target material, which can be achieved using classical chemical procedures such as ion exchange, extraction and precipitation. Purified TAT radionuclides are then attached to biomolecule targeting vectors via a bifunctional chelator, which connects the biomolecule with a radionuclide complex (figure 2). The stability of compounds containing alpha-emitting radionuclides is a challenge because after decay most of the daughter isotopes are radioactive elements that no longer remain chelated. Moreover, the radioactive daughters can accumulate and cause unwanted toxicity in healthy organs, especially those involved in excretion such as the liver and kidneys. These issues have driven demand for a more robust and stable chelation system and/or encapsulation methods that contribute to an optimised pharmacokinetic profile with rapid cell internalisation. By doing so, the hope is to keep radioactive daughter nuclei proximal to the original decay site and thus close to the targeted tissue.

TRT isotopes are generating significant interest internationally.

Several clinical trials with alpha-emitting radionuclides – including ^{225}Ac (phase II trial) and ^{213}Bi (phase III) – are under way around the world, based on the standard chelation approach. Despite the challenges involved, these trials are already showing extremely high promise and superiority over existing beta-emitting radionuclides. Further research is therefore warranted to investigate and optimise various production strategies designed to make TAT a viable clinical modality. The TAT isotope ^{225}Ac has demonstrated particularly high potential in recent years because its half-life correlates well with the biological half-lives of intact antibodies, and its multiple alpha-emitting daughters enhance the therapeutic effect. ^{225}Ac also can be used as a parent radionuclide for a ^{225}Ac/^{213}Bi generator system.

TRIUMF's strategy

TRIUMF has extensive expertise in all aspects of the production of medical isotopes, including the development of high-powered targets for large-scale production and expertise in isotope-production simulations with its existing Monte Carlo code FLUKA and the new Geant4. TRIUMF's strategy involves using both existing and new proton beamlines from its 520 MeV cyclotron, along with a newly built 30 MeV electron linac in the upcoming Advanced Rare IsotopE Laboratory (ARIEL) facility, to irradiate thorium and uranium targets to produce a variety of radiometals. These include ^{225}Ra and ^{224}Ra, which are parent isotopes for the daughter products ^{225}Ac, ^{212,213}Bi and ^{212}Pb. Because these targets can be positioned downstream from the science targets, the symbiotic production of these radiometals is limited only by the beam intensity.

Under the envisioned operating conditions of the new proton beamline, FLUKA simulations of the ARIEL proton target station predict yields of several-hundred millicuries of ^{225}Ac per irradiation and significant quantities of other isotopes. While only very small quantities of ^{225}Ac are required for radionuclide therapy, larger quantities are required to produce enough ^{213}Bi in those treatments where it's preferred. A larger demand for ^{213}Bi will then drive a similarly increased demand for ^{225}Ac to provide adequate ^{225}Ac/^{213}Bi generators. Thus, TRIUMF's emerging production capacity would yield sufficient ^{225}Ac to enable the assembly of multiple ^{225}Ac/^{213}Bi generators for therapeutic research studies in patients at multiple centres. Based on typical operating-schedule estimates, this technique could result in the production of several curies of ^{225}Ac per year, compared to the current global output of 1 to 2 curies per year, making the proposed infrastructure a potentially potent source of this valuable isotope. Furthermore, many other medically relevant radioisotopes apart from ^{225}Ac are produced from a thorium or uranium target. The higher current proton beam at ARIEL will enable TRIUMF researchers to explore this exciting medical isotope further.

TRIUMF

The Advanced Rare IsotopE Laboratory (ARIEL) is TRIUMF's flagship facility aimed at expanding its ability to produce and study isotopes for science and medicine.

The ultimate goal of TRIUMF's TRT programme is to carry out clinical testing and establish the efficacy of TRT agents, enabling a national and possibly international clinical-trial programme for promising therapeutics. TRIUMF research partners will develop new radiopharmaceuticals incorporating therapeutic nuclei into targeting molecules, producing therapeutic conjugates that are used to shepherd their targeted payload to tumours. In addition, research will be carried out to design new molecules that can be used to target different types of tumours.

By leveraging TRIUMF's existing infrastructure and established research partnerships, the medical community can look forward to production of higher quantities of TRT isotopes. Should the promising results seen to date materialise into a viable treatment option for late stage and/or currently untreatable cancers, the results will bring new hope for a significant number of cancer patients worldwide.

Résumé

TRIUMF vise la thérapie par rayonnement alpha

La radiothérapie par faisceaux externes est régulièrement utilisée pour traiter les tumeurs cancéreuses, mais le contrôle de la dose administrée au patient est une difficulté constante. Une alternative consiste à délivrer une dose de radiation puissante directement à l'intérieur des cellules cancéreuses. Cependant, même après un siècle de développement, cette méthode n'a malheureusement toujours pas été optimisée. Afin d'étudier tout le potentiel de la thérapie par radionucléides, les chercheurs ont besoin de toujours plus d'isotopes émettant des rayonnements alpha et bêta pour traiter des cancers avancés, des métastases et d'autres maladies diffuses. En vue d'atteindre cet objectif, une nouvelle ligne de faisceau de protons du cyclotron de 520 MeV TRIUMF sera utilisée ; elle irradiera des cibles de thorium et d'uranium afin de produire divers radiométaux pour la production d'émetteurs alpha.

Paul Schaffer and **Valery Radchenko**, TRIUMF, Canada.

Faces & Places

Appointments

New leader for UK fusion programme

The UK Atomic Energy Authority (UKAEA) has appointed plasma-physicist Ian Chapman as its new chief executive. Taking over the role from Steve Cowley on 1 October, Chapman will lead the UK's magnetic-confinement fusion research programme at Culham Science Centre and operation of the JET fusion device on behalf of European scientists. Aged 34, Chapman is one of the youngest scientist to lead a major research centre and held various roles at Culham prior to the appointment, including head of tokamak science and fusion programme manager. "I hope my profile means that fusion, and its huge potential to give the world cleaner energy, will get noticed," he says. "Furthermore, I hope my appointment will inspire the next generation of scientists and engineers to make a success of ITER, the international fusion project that in my opinion is the most important experiment mankind has ever done."

UKAEA

Ian Chapman is one of the youngest CEOs of a major research facility.

Awards

QCD pioneer wins Prange prize

Theorist Frank Wilczek of the Massachusetts Institute of Technology in the US has been named the 2016 recipient of the Richard E Prange Prize and Lectureship in Condensed Matter Theory and Related Areas. He received a $10,000 honorarium and delivered a public lecture, "Some Intersections of Art and Science", at the University of Maryland, which established the award, in September. Wilczek, who shared the 2004 Nobel Prize in Physics, is a pioneer of asymptotic freedom, which underpins quantum chromodynamics (QCD). The Prange Prize honours the late Richard E Prange, whose career at Maryland spanned four decades.

Frank Wilczek at the 2003 HEP-EPS conference in Aachen.

Order of Alfonso X the Wise

Javier Martínez de la Torre

From left: Marcial Marín Hellín, José María Lassalle Ruiz, Íñigo Méndez de Vigo y Montojo, José Miguel Jiménez and Carmen Vela Olmo.

Head of CERN's technology department, José Miguel Jiménez, has been awarded a Spanish civil decoration called the Order of Alfonso X the Wise for his outstanding experience in research and scientific management in particle physics. The ceremony took place at the National Library of Spain, Madrid, on 12 July, in the presence of government ministers.

Exhibitions

CERN tours more popular than ever

CERN is Geneva's top tourist attraction, according to TripAdvisor, welcoming almost 110,000 visitors per year. The laboratory has been listed on the TripAdvisor website since 2012 and currently tops the charts of both the 24 tours and the 28 museums listed for Geneva. CERN has also received a 2016 Certificate of Excellence from the firm in recognition of the quality of its tours and the service it provides to visitors.

CERN's visitor numbers have soared since the start-up of the LHC in 2008 and the discovery of the Higgs boson in 2012, and on 15 July a record number of 755 visitors entered the site (the average is around 400 per day). Recently, the visits service introduced individual guided tours, which are proving to be a great success: every morning the tour slots are fully booked in less than five minutes.

Maximilien Brice, Claudia Marcelloni/CERN

The Globe of Science and Innovation is a landmark for CERN's visitors.

CERN hits the festival circuit

Charlotte Potter-Landua

More than 30,000 people attended the WOMAD festival in the UK this summer.

On 28–31 July, CERN continued its efforts to reach new audiences by organising a "physics pavilion" at the annual WOMAD music festival in the UK countryside. A three-day programme of talks and events was on offer, including topics such as "What's the matter with antimatter?" in addition to shows featuring the Cosmic Piano and a musical piece created from the sonification of LHC data. Activities such as two "Build your own cloud chamber" workshops and a live link-up with the ATLAS visitor centre took festival goers up close and personal with particle physics.

The physics pavilion, which was organised in conjunction with the UK Institute of Physics, the University of Lancaster and the Science and Technology Facilities Council, received more than 3600 visitors and generated considerable media attention. The event culminated in a packed audience, which had queued for 90 minutes to hear about the science of the long-running science-fiction series *Dr Who*. "I knew we'd got something right when a little girl raised her hand at the end of one session and asked the speaker: 'How old were you when you knew you wanted to be a physicist?'" says pavilion manager Connie Potter of CERN.

● womad.co.uk/the-physics-pavilion/.

Vintage silicon detectors preserved

The Nikhef laboratory in Amsterdam has teamed up with the Museum Boerhaave in Leiden to preserve some of the earliest silicon detectors. Developed for the "BOL" nuclear research project between 1967 and 1977, 64 silicon units were located inside of a cast-bronze spherical frame that fully surrounded the beam target. The system's 4π coverage, position measurements for several coincident particles and full-absorption energy determination for hadrons preluded the standard concept used today in collider experiments in particle physics. Although the historical roots of the silicon detectors in the LHC experiments can be traced to this "checkerboard" design, today the position precision of the silicon trackers is at least 50 times better. The BOL inner-detector body, together with silicon-detector units, the associated front-end electronics, read-out boards and multiple-ADC boards, will become part of the Dutch scientific heritage collection in the Rijksmuseum Boerhaave – where they will join the helium liquefier used by Heike Kamerlingh Onnes in 1908 to discover superconductivity and microscopes made by Antoni van Leeuwenhoek in the late 17th century.

IKO-Nikhef

View of the BOL chamber, which was installed in a beam at the IKO cyclotron in Amsterdam in 1969.

CERN Courier October 2016

Faces & Places

10,000th teacher visits CERN

Maximilien Brice/CERN

HST 2016 teachers with CERN Director-General Fabiola Gianotti.

This summer, CERN welcomed its 10,000th school teacher, who was a participant of this year's International High School Teacher (HST) programme. This three-week-long residential programme, which has taken place every July since 1998, saw 48 teachers come to CERN from across the world. The HST programme aims to increase teachers' knowledge about the research being carried out at CERN and offers a range of educational resources for use by the teachers to inspire their students' curious minds (see also p53).

CONFERENCES

Strong interactions in Montpellier

Alize photo

Delegates at QCD16 in Montpellier.

The 19th International Montpellier Conference in Quantum Chromodynamics (QCD16) took place in Montpellier, France, on 4–8 July. Around 50 participants took part, with equal numbers of theorists and experimentalists, to discuss all aspects of QCD. This ranged from formal field-theory approaches to confinement, in addition to phenomenological facets such as proton structure, pion form factors, exotic and standard meson spectroscopy, determinations of the strong coupling constant α_s, and searches for new physics beyond the Standard Model.

Highlights from this year's event included a summary of new determinations of α_s and the experimental status of the exotic XYZ spectra by the BESIII experiment, with new improved determinations of their masses from QCD spectral sum rules at NNLO. Meanwhile, CLAS, HERA, the LHC and the NICA-SPD project have gained deeper insights on the structure functions and properties of the proton. BESIII has also obtained improved results on light hadron spectroscopy from J/ψ decays and, along with NA62, made new measurements of baryon and pion form factors. New BaBar results on the low-energy cross-sections relevant for the muon g-2 contribution were also presented, confirming previous experimental results. The meeting also saw a formal non-trivial proof of the gauge invariance of the gluon operator A^2 among presentations about the non-perturbative aspects of QCD and the quark–gluon plasma. These QCD presentations were complemented by talks from ATLAS and CMS about precise measurements of the top-quark mass, electroweak parameters such as those relevant to the Higgs boson, and searches for new physics.

The 20th International Conference in Quantum Chromodynamics, which celebrated its 30th anniversary last year, will be held in Montpellier on 3–7 July 2017.

Extreme QCD weighs up results

The summer of 2016 will be remembered as a time of some confusion in particle physics. The main event of the summer conference season was the confirmation that a statistical fluctuation at an energy of 750 GeV seen by the LHC's ATLAS and CMS detectors was indeed just that, and not evidence for a new fundamental particle, as had been hoped by many. It was therefore reassuring to spend three days discussing a theory we traditionally do not understand very well, but where there are copious experimental data and many exciting applications: non-perturbative quantum chromodynamics (QCD).

The "extreme QCD" conference, the 14th conference in the series, was held at Plymouth University in the UK from 1 to 3 August, with 80 participants. Here, "extreme" refers to conditions of high temperature or density that can occur in neutron stars, the early universe or heavy-ion collisions at the LHC and at the Relativistic Heavy Ion Collider (RHIC) in the US.

Ulrich Heinz of Ohio State University started the presentations by reviewing ▷

Keynote speakers at XQCD 2016: Anders Hansen, Ulrich Heinz, Yuya Tanizaki, Daniel Nogradi, George Fleming, Claudia Ratti, Biagio Lucini and Guido Cossu.

Alan Stewart Plymouth University

some of the intriguing and puzzling results that have come out of the LHC, including hints of collective flow behaviour not only in heavy-ion collisions but even in high-multiplicity proton–proton collisions. In other talks, we heard of progress in lattice QCD calculations of thermodynamic quantities, which form the basis of the analysis of heavy-ion experiments, including novel ways of computing the energy-momentum tensor and calculations of transport properties of the quark–gluon plasma. There were also stimulating talks on topics as varied as the eigenvalue spectrum from the Dirac operator in QCD, and new approaches to thermalisation in heavy-ion collisions.

The ever-increasing speed of supercomputers and the continual improvement of algorithms have turned lattice field techniques into a precision tool for physical systems that can be written as a path integral with similar properties to a probability problem. However, there are still classes of problems, such as working at nonzero chemical potential, that require path integrals with complex actions, and thus are almost impossible to solve using standard Monte Carlo algorithms. Delegates heard about recent progress that has been made towards tackling this so-called "sign problem" using methods such as the density of states, complex Langevin and Lefschetz thimble integration.

This was followed by a wide-ranging and thought-provoking panel discussion about the problems and prospects of finite-density QCD. Speakers gave a clear overview of the issues of critical interest to the experimental heavy-ion programmes, and many of the non-perturbative techniques developed to solve QCD are now being applied to other systems. For example, lattice field theory is being used to study the 2D carbon allotrope graphene, in addition to calculating the properties of novel dark-matter candidates from strongly interacting theories.

The next extreme QCD conference will be held in Pisa in June 2017, where further progress on the sign problem and pertinent theory relevant to the heavy-ion programme will no doubt be reported.

● xqcd2016.math-sciences.org.

Event spotlight

The fourth biennial Workshop on **Discovery Physics at the LHC (Kruger 2016)** will be held in South Africa on **4–9 December** at the Protea Hotel Kruger Gate, which is located 100 m from the entrance to the Kruger National Park. The surroundings and the physics results presented during this workshop will serve to inspire discussions between theorists and experimentalists on the latest LHC and Tevatron measurements, as well as expectations for the future. Attendance will be limited to about 100 participants, and more information can be found at www.kruger2016.tlabs.ac.za.

Visits

Sophia Bennett/CERN

On 16 August, ambassadors and mission staff from the Group of Fifteen – a group formed in 1989 comprising countries from Latin America, Africa and Asia, with a common goal of enhanced growth and prosperity – visited the ATLAS visitor centre with former collaboration spokesperson **Peter Jenni** (4th from the left) and young ATLAS scientist **Nedaa Asbah** (6th from the right).

Maximilien Brice/CERN

Following Romania's ascension to full CERN membership in July, a ceremony was held on 5 September at which the Romanian flag was raised at the CERN entrance. The blue, yellow and red flag joined those of the other 21 Member States of CERN in a ceremony attended by the president of Romania, **Klaus Iohannis**, the Romanian minister for education and scientific research, **Mircea Dumitru**, and several other members of the president's office, the government and academia in Romania.

Letters

The home of the SPS

The article by Lyn Evans celebrating 40 years of SPS operation (*CERN Courier* July/August 2016 p61) raised a lot of memories, but I must take issue with the author on one point. He says that the machine was initially supposed to be built in the south of France, whereas in fact there were five candidate sites advanced by the Member States. The achievement of John Adams in presenting an acceptable – and cheaper – plan for the SPS at CERN was enormous. It was helped by one simple point: CERN was where the skills were, where the people best equipped to design and build the machine lived.

This same argument played a part in the approval of LEP a decade later. Papers had been published that purported to show that the new machine should be built in Hamburg rather than Geneva. This caused problems at the political level in one Member State to my knowledge, and I guess at least two.

● *John Walsh, Swindon, UK.*

Neutrino discovery date

Christine Sutton's article about the detection of neutrinos (*CERN Courier* July/August 2016 pp17–19) correctly states that Cowan and Reines were the first to see neutrinos at a distance from the emitting nucleus via inverse beta decay.

However, a series of experiments beginning in 1936 (e.g. *Proc. Camb Phil. Soc.* **32** 301) searched for evidence of the neutrino's existence by measuring the energy and momentum of the recoil of the nucleus and of all other particles emitted in a beta-disintegration decay process. These experiments showed clearly that missing momentum and energy in beta decay required an explanation and that the neutrino hypothesis was the best candidate.

In 1938, Crane and Halpern (*Phys. Rev.* **53** 789) used a chlorine-38 beta source in a cloud chamber to observe the recoiling nucleus and the associated beta particle for individual events. Although the track left by the recoiling nucleus was not long enough to allow an energy measurement, it generated ionisation that was assumed to be proportional to the kinetic energy of the recoil motion. Crane himself did not claim to have detected neutrinos, but stated: "It seems now to have been adequately shown experimentally that there is apparent non-conservation of momentum in the beta decay, and that, quantitatively, the maximum amount of extra momentum found is in satisfactory agreement with that called for either by the neutrino hypothesis, or by much more general theoretical arguments which relate the disappearance of momentum to the disappearance of energy."

● *Andrew Sabersky, Chico, California.*

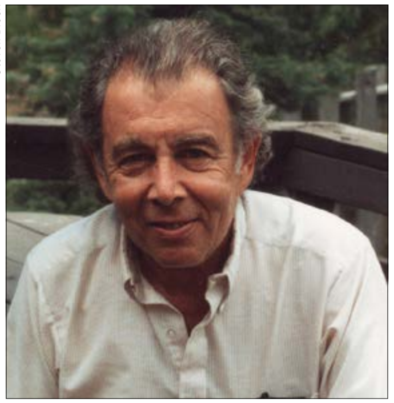
Obituaries

Martin Block 1925–2016

Particle physicist Martin M Block died on 22 July in Los Angeles, California, aged 90, following a short illness. His career was distinguished not only in terms of the contributions he made but also by its longevity: his first paper was published in 1949 and his most recent in 2016. Block was also an active participant in the Aspen Center for Physics, where he founded its enduring Aspen Winter Physics Conferences in 1985.

Block completed his doctorate at Columbia University in 1952, where he helped to design magnets for the Nevis Cyclotron. As a young professor at Duke University, he contributed the revolutionary notion that parity was not conserved in weak interactions. The idea, which came to him while he shared a room with Richard Feynman at a Rochester meeting on high-energy physics in 1956, offered a solution to the so-called "tau-theta" paradox: two otherwise identical particles that decay into different parity states and thus were believed to be distinct.

The story was recounted in Feynman's 1985 memoir *Surely You're Joking, Mr. Feynman*: "Anyway, I was sharing a room with a guy named Martin Block, an experimenter. And one evening he said to me, 'Why are you guys so insistent on this parity rule? Maybe the tau and theta are the same particle. What would be the consequences if the parity rule were wrong?' I thought a minute and said, 'It would mean that nature's laws are different for the right hand and the left hand, that there's a way to define the right hand by physical phenomena. I don't know that that's so terrible, though there must be some bad consequences of that, but I don't know. Why don't you ask the experts tomorrow?' He said, 'No, they won't listen to me. You ask.' So the next day, at the meeting…I got up and said, 'I'm asking this question for Martin Block: What would be the consequences if the parity rule was wrong?' Murray Gell-Mann often teased me about this, saying I didn't have the nerve to ask the question for myself. But that's not the reason. I thought it might very well be an important idea."


Steven Block

Martin Block questioned parity conservation.

Important, indeed. The 1957 Nobel Prize in Physics went to Tsung-Dao Lee and Chen-Ning Yang for their theoretical analysis of the process, but it was not shared by Madame Chien-Shiung Wu for her 1956 experimental demonstration of parity violation in the beta decay of cobalt-60 nuclei, nor was Block's contribution acknowledged at the time.

At Duke, Block developed the first liquid-helium bubble chamber and used it to study the properties of several newly discovered particles. He left Duke for Northwestern University in 1961, where he served on the faculty for the remainder of his experimental career. He co-discovered the eta meson and later worked on collaborations at ever-higher energies, involving heavy-liquid bubble chambers and, eventually, modern counter detectors. His work took him to accelerators all over the world, with extended experimental stints at Berkeley, Brookhaven, Fermilab – and particularly at CERN, which he visited in every decade from the 1960s until the 1990s.

His lifelong passion for the mountains, especially skiing and fly fishing, eventually took him to Aspen, where he purchased a home and joined the Aspen Center for Physics in its nascent years. There, he embarked upon a second career in theoretical and computational physics. A central focus of this work concerned the forward-scattering amplitudes of hadron collisions, specifically the issue of why the proton–proton interaction cross-section grows with the square of the logarithm of the energy. His work anticipated quantitatively measurements that were eventually performed at the LHC. In one of his final papers, he showed that data demonstrate convincingly that both the proton–proton and antiproton–proton scattering amplitudes asymptotically approach those of a so-called "black disc," presumably as a consequence of gluon saturation.

Block is survived by his wife, Beate, his two children, Steven and Gail, and two grandchildren.

● *Steven Block, Stanford University, and Francis Halzen, University of Wisconsin-Madison.*

John Madey 1943–2016

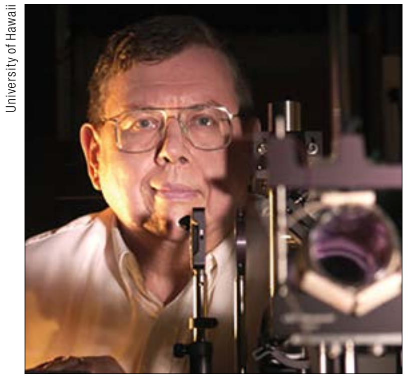
The international accelerator community was saddened to learn about the passing of the pioneer of the free-electron laser, John M J Madey of the University of Hawaii at Mānoa, on 5 July.

Raised in Clark, New Jersey, John Madey and his older brother Jules took an early interest in amateur radio. In 1956, when John was 13 and Jules was 16, they began relaying communications from the South Pole to families and friends in the US. Madey received a degree in physics and a masters in quantum electronics from the California Institute of Technology in 1964 and 1965, where he first raised the question of whether it was possible to enhance the transition rate for bremsstrahlung through stimulated emission. He continued thinking about the question while working on his doctoral degree at Stanford, at which time he invented the free-electron laser (FEL).

A FEL can produce coherent electromagnetic radiation of extremely high intensity and high quality that is tunable over a wide range of frequencies, which is of great interest for research in physics, chemistry, biology and medicine. While classical FELs use mirrors or optical cavities, a more recent FEL variant, operating at ever-shorter wavelengths, is the linac-based FEL such as the Linac Coherent Light Source at SLAC or the European X-FEL in Hamburg, Germany.

Madey was awarded a PhD in 1970 and appointed professor of electrical engineering in 1986. In 1988, he left Stanford to take up a tenured position at Duke University, moving his FEL research laboratory with him the following year. He joined the University of Hawaii at Mānoa in 1998.

Madey was bestowed with numerous awards and international recognitions, including the Stuart Ballantine Medal from the Franklin Institute in 1989, the 2012 Robert R Wilson Prize from the American Physical Society and the 2016 Willis E Lamb Award for Laser Science and Quantum Optics. He was also the keynote speaker at the 2015 Nobel Symposium on Free-Electron Lasers in Sigtuna, Sweden. Madey held 13 patents on FEL-related technological inventions and published many important papers. These included a seminal publication on stimulated emission in 1976 (*Phys. Rev. Lett.* **36** 717) and, more recently, a comprehensive review article on the history of the FEL invention (*Phys. Rev. ST Accel. Beams* **17** 074901).


University of Hawaii

Free-electron laser pioneer John Madey.

John Madey was also a highly dedicated teacher, patiently mentoring his students and sharing with them his vast knowledge and wisdom.

● *Pui Lam, University of Hawaii, Vladimir Shiltsev, Fermilab, and Frank Zimmermann, CERN.*

Roberto Petronzio 1949–2016

Our dear colleague Roberto Petronzio passed away on 28 July at the age of 67. He was a CERN fellow from 1977 until 1979 and a staff member in the theory division from 1980 until 1986. He played a significant role in our field as professor at the University of Tor Vergata, president of the INFN (2004–2011) and as a member of the CERN Council. Roberto was a major contributor to the development of QCD. He was involved, among other projects, in the first complete calculation of the NLO anomalous dimensions, and in the resummation of soft-gluon emission in partonic processes. He was also involved in the non-perturbative analysis of the theory. In particular, along with Cabibbo and Parisi, he was one of the first members of the APE collaboration, which managed to construct the famous series of supercomputers for numerical simulations. Together with Cabibbo and Martinelli, he proposed the use of lattice simulations to compute weak amplitudes. These results are of great importance in flavour physics, for example in analyses at B factories and in similar work carried out at CERN by the LHCb, ATLAS and CMS collaborations.

Roberto was well-anchored in the Standard Model but always looking for harbingers of new physics. He had an eclectic knowledge of particle physics and related subjects. His legacy is also represented by several generations of brilliant young physicists spread across different laboratories and universities throughout the world. He had a charming and wonderful personality and was a great asset to our community. He will be dearly missed.

Theorist Roberto Petronzio served on the CERN Council.

● *His colleagues and friends.*

Yoshio Yamaguchi 1926–2016

Yoshio Yamaguchi, who propelled particle physics in the post-war world, passed away on 12 August. His research encompassed a wide field of particle physics.

After his education at the University of Tokyo, Yamaguchi joined Osaka City University and co-founded a particle-physics group. The group was soon attracted by the new particles that were being detected in collisions between cosmic rays and the atmosphere, and Yamaguchi proposed that they are created in pairs – marking the first step towards understanding strange particles.

Yamaguchi spent much time abroad and first went to the University of Illinois at Urbana, where he proposed a separable potential of nuclear interactions. Shortly afterwards, he was invited to the newly founded theory division of CERN, where he stayed from 1957 to 1961. Former CERN Director-General Viki Weisskopf wrote in his memoir: "Yamaguchi contributed much to the scientific atmosphere in the theoretical

Yoshio Yamaguchi helped to establish KEK.

division at CERN." He was very quick to catch the essence of new experiments and it was general lore at CERN that when you made an experimental proposal, you must go and talk to Yamaguchi in advance to convince him, or you would get in trouble in the proposal meeting.

Yamaguchi then moved to the Institute for Nuclear Study (INS) at the University of Tokyo, where he led the theory group. Besides theory, he helped to create a new particle-physics laboratory in Japan that was realised eventually as KEK. He later moved to the physics department at Tokyo to teach. His lectures were popular, although he worked his students hard and had high expectations.

Yamaguchi was not only an excellent and versatile physicist, but a first-class manager. He returned to the INS as director until his retirement, and was a co-founder of the International Committee for Future Accelerators in the 1970s, chair of the International Union of Pure and Applied Physics from 1993 to 1996, and contributed to creating the Asian Pacific Center for Theoretical Physics.

Yamaguchi also had a wide cultural background in European and Japanese classics. We will greatly miss this giant of particle physics.

● *His friends and students.*

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 721559.

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The branch Astronomy & Cosmic Physics is the International Max Planck Research School (IMPRS) for Astronomy and Cosmic Physics at the University of Heidelberg (**http://www.mpia.de/imprs-hd**). Students accepted into the Graduate School will automatically be members of the IMPRS-HD and conversely. Admission to the IMPRS for Precision Tests of Fundamental Symmetries (**www.mpi-hd.mpg.de/imprs-ptfs**), to the IMPRS for Quantum Dynamics in Physics, Chemistry and Biology (**http://www.mpi-hd.mpg.de/imprs-qd**), to the RTG Particle Physics Beyond the Standard Model (**http://www.thphys.uni-heidelberg.de/~gk_ppbsm**) or the RTG HighRR (High Resolution and High Rate Detectors in Nuclear and Particle Physics) is also possible. The IMPRS and RTGs offer doctoral positions and fellowships as well, and are combined efforts of Heidelberg University with the Max Planck Institutes for Astronomy and Nuclear Physics, which form an integral part of the exciting and broad research environment in Heidelberg.

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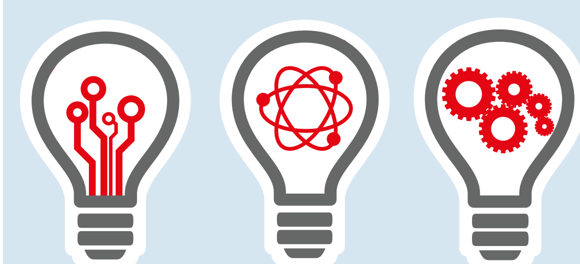

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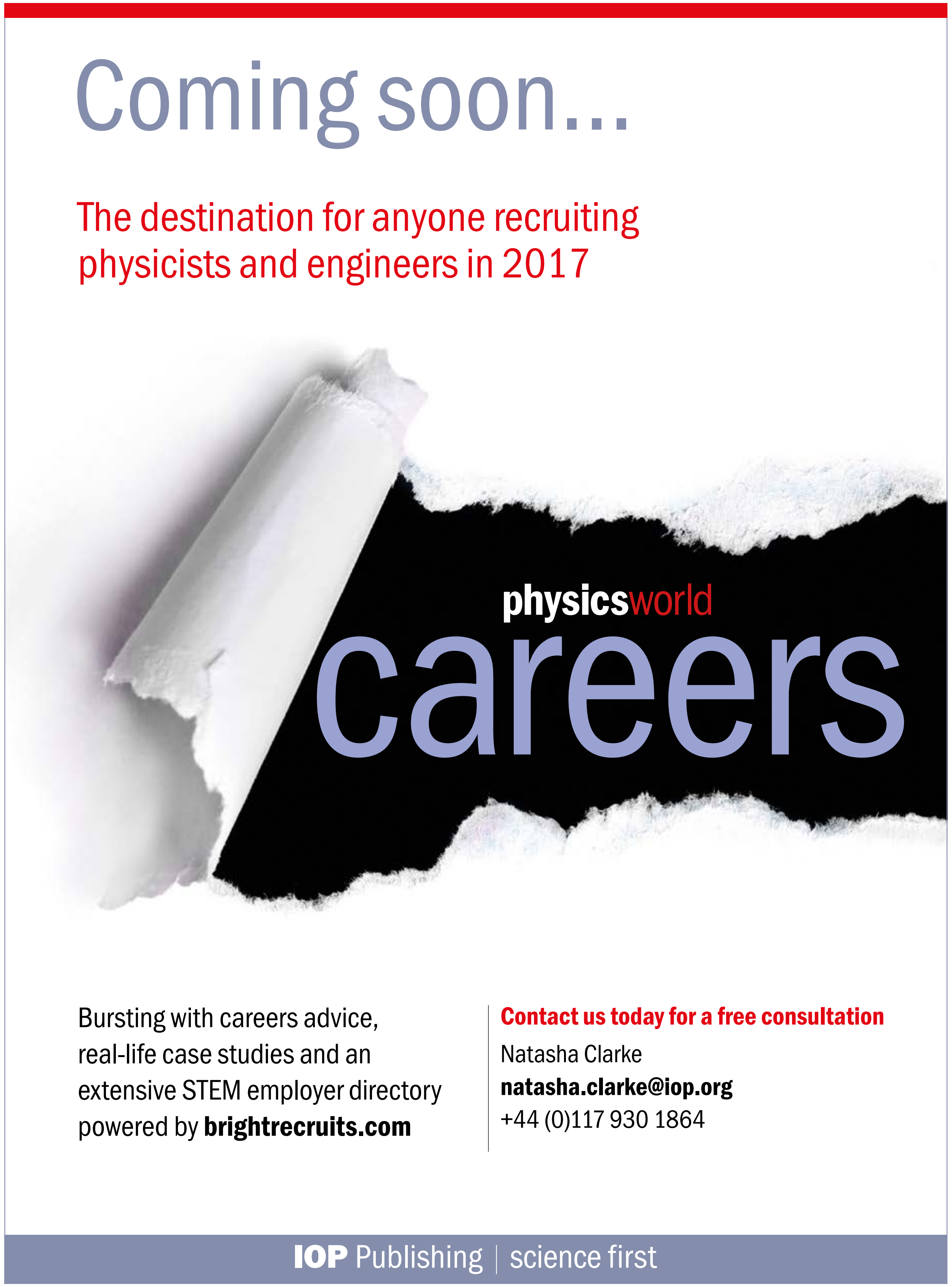
Interested students are asked to apply via web form at: http://www.mpi-hd.mpg.de/imprs-qd/appladmiss.html.
The application deadline is 22 November 2016.



Bookshelf

Compiled by Virginia Greco, CERN

Half Life: The Divided Life of Bruno Pontecorvo, Physicist or Spy
By Frank Close
Oneworld
Also available at the CERN bookshop

In this book, Frank Close tells the story of the enigmatic life of renowned Italian physicist Bruno Pontecorvo, reporting plenty of historical details about his work and personal affairs. The reader is taken on a fascinating story, which develops in difficult times – the years just before, during and after World War Two.

Following an introduction about Pontecorvo's early life, the story continues with a discussion of the discovery of neutron moderation in 1934 and the role played by Pontecorvo, along with its scientific and political consequences. The author gives many insights that will amaze physicist readers.

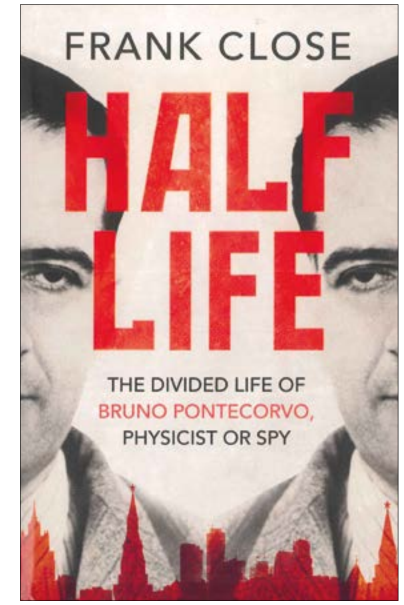
After this discovery, Pontecorvo begins his career as an international scientist. He moves to France in 1936, where he works with Frederic Jolit-Curie and meets Marianne Nordblom, his future wife. In 1938, Marianne and Bruno have their first son, Gil.

The events of the life and work of Pontecorvo are embedded in an incredible historical background. As an example, in March 1940, about 40 gallons of heavy water are shipped from Norway and hidden from Nazis in France. This precious treasure would later be taken to the UK by two scientists who were working with Pontecorvo. The heavy water is clearly related to the attempt to use and control nuclear fission.

In Paris, Pontecorvo joins the Communist Party. His political ideas will play a crucial role in his personal and professional life. When the Nazis invade France, Pontecorvo has to move away. Helped by his friend and colleague Emilio Segré, in 1940 he and his family set off for the US and settle in Tulsa, Oklahoma.

In November 1942 he meets again his mentor, Enrico Fermi, who was interested – together with his collaborators – in the activities of Pontecorvo, and in particular in an instrument he designed to search for oil underground by detecting neutrons. As a consequence of this event, Pontecorvo gets the opportunity to move to Canada and join the Anglo-Canadian reactor project at Montreal, aimed at making a reactor based on uranium and heavy water.

In January 1943, Pontecorvo sets off for his new job, which he will hold for seven years. In Canada, he joins an active team made of some 100 scientists and engineers.



At this time, the FBI sends three letters to the British Security Coordination Office in Washington because of concerns about the physicist's communist sympathies. A number of interesting details and anecdotes are given by Close about this and other related events.

For security reasons, the Anglo-Canadian project is carried out at Chalk River, which then becomes a target for Soviet agents. The author provides fascinating insights about the spy network, collecting information on the nuclear programme in the years after the end of World War Two. Nunn May, a collaborator on the project, is arrested in 1946 for espionage.

During his years at Chalk River, Pontecorvo also becomes interested in neutrinos and carries out important studies.

He joins the Atomic Energy Research Establishment in Harwell, UK, in January 1949. Although offered a number of positions in the US, he prefers to move to the UK. One month later, another colleague, Klaus Fuchs, is arrested for espionage. This is a difficult time for Pontecorvo, whose movements are followed by Military Intelligence. Close probes into events in Pontecorvo's life during these years, to give the reader an idea of the role that he plays. He tells the story of the Soviet agent Lona Cohen, as well as of Kim Philby, another agent who might have had an important impact on Pontecorvo's decision to escape to the Soviet Union at the end of the summer of 1950. The reader can try to solve the Pontecorvo enigma on the basis of the information reported – did he give information about the reactor commissioned in 1947 to the Soviet Union?

The life of Pontecorvo and his family in the Soviet Union is also described, detailing the problems they faced settling yet again into a new country, after France, the US, Canada and the UK. Many other interesting aspects of his life are discussed, including the events following 4 March 1955 when the physicist was interviewed in Moscow after five years of silence, and the happenings at an international meeting on high-energy physics that he attended in Kiev in 1959.

Close also reports on an interview with Pontecorvo by Italian journalist and writer Miriam Mafai, which gives a profound insight into his mysterious life. In my opinion, the book is very much worth reading and the amount of detail is impressive. The publication of this wonderful book is already stimulating discussions among physicists and will reawaken interest in the Pontecorvo enigma.

● *Aldo Ianni, Canfranc Underground Laboratory, Spain.*

Inside CERN's Large Hadron Collider: From the Proton to the Higgs Boson
By Mario Campanelli
World Scientific
Also available at the CERN bookshop

In this concise book, Mario Campanelli provides an overview of particle-physics research at CERN. He starts with an introduction about the history of this branch of science, tracing the steps of its evolution through speculative theories and experimental proofs, up to the completion of the Standard Model puzzle with the discovery of the Higgs boson in 2012. It is hard to condense – and explain in relatively simple terms – all of this complex material. As a consequence, the first section of the book should be considered by particle-physicist readers as a brief summary of known concepts, while by non-experts in the field as a very quick overview of the basics of particle physics.

The following chapters focus on CERN, home to the Large Hadron Collider (LHC). After a short account of the history of the laboratory concerning the different accelerators and relative detectors that followed one another, the author discusses the challenges that scientists had to face to design, construct and ▷

Bookshelf

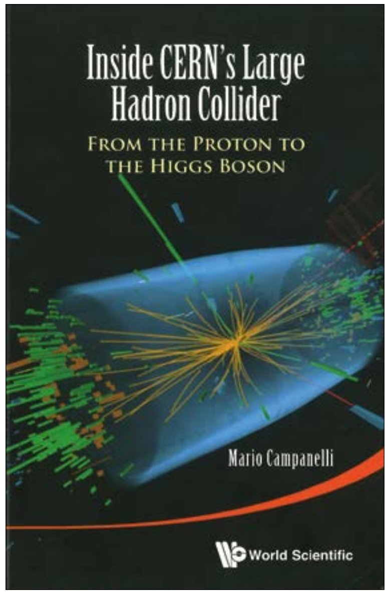
commission the LHC – a giant, complex and technologically advanced apparatus. He explains how the machine works, from the superconducting magnets to the acceleration phases (realised consecutively in different pre-accelerators and, finally, in the collider) and the beam extraction, showing that the LHC is a marvel of engineering. No less important, of course, are the detectors, which are necessary to study the products of collisions for different research purposes. A chapter is then dedicated to describing the experimental apparatus of the four main experiments: ATLAS, CMS, ALICE and LHCb.

The reader is also given an idea of how data are selected, stored and analysed to extract interesting information, as well as of the physics topics that are investigated by these experiments, including the Standard Model (SM), quantum chromodynamics, b-quark and top-quark physics, supersymmetry and any sign of new physics. The latter is what physicists working at CERN are really eager to find – particles or phenomena that could enable theorists to go beyond the SM. A chapter is dedicated to the discovery of the Higgs boson – the most important result accomplished with the LHC up to now.

Since such a great endeavour cannot be realised without hard work, professionalism and collaboration, the author highlights the importance of the human factor in such a varied, multicultural and highly competitive environment. Finally, a few paragraphs on the impact of high-energy physics research on industry and society conclude the book.

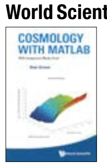
Written in a fluid style, this book would appeal to those who, even if not completely unfamiliar with the topic, know little about collider physics, CERN and its experiments.

● *Virginia Greco, CERN.*



Books received

Cosmology with MATLAB
By Dan Green
World Scientific

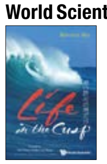


The aim of this book is to show how software packages such as MATLAB can be extremely useful for studying cosmology problems by means of complex simulations. Thanks to the greatly improved accuracy of cosmological data and the increased computing power available, the calculation and graphic tools offered by this software can be profitably employed to study physics problems and compare different models.

A theory that successfully describes the universe and its evolution in terms of only six fundamental parameters has been developed. It accounts for the Big Bang (BB), cosmic microwave background (CMB) radiation and the evolution of matter to the present day. However, the model cannot explain some experimental results. The inflation hypothesis, which postulates the existence of a scalar field that caused an exponential expansion of the very early universe, can solve some of these open problems.

This book provides a basic exposition of BB cosmology and the inflationary model using MATLAB tools for visualisation and to develop the reader's understanding of the parametric dependence of the observables. Different models are compared, including one that assumes the Higgs field as the scalar inflationary field. In this way, readers can gain experience in using various MATLAB tools (including symbolic mathematics, numerical-solution methods and plots) and also apply them to other problems.

Life on the Cusp
By Weimin Wu
World Scientific



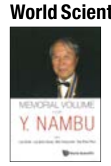
The extraordinary scientific career and personal life of the Chinese-naturalised American physicist Weimin Wu have played out against the backdrop of profound political and cultural changes in China during the last 70 years.

In this autobiography, Wu describes the diverse and colourful events of his life and sketches a portrait of the social environment where they took place. He was personally involved in the making of the first atomic bomb in China, aged just 17, and he participated in the analysis of the data collected by the first artificial Chinese satellite, as well as in the construction of the first electron–positron collider. An e-mail that he sent from Beijing to Switzerland in 1986 is considered to be the first in the history of the internet in China. He was also a member of the research team that observed the first J/ψ particle in Beijing, and of the CMS experiment, where he worked on the search for the Higgs boson.

Not only has he had a remarkable career, his personal life has also been marked by many unusual and stormy events. He had a poor childhood, undertook various jobs as a labourer or a farmer, and was forced to emigrate to the US after becoming personally involved in the Tiananmen Square protest.

The author tells the story of his scientific trajectory and life "on the cusp" with a candid spirit, describing both the events and his inner feelings – details of his emotional experience and love stories add to the book.

Memorial Volume for Y Nambu
By Lars Brink, Lay Nam Chang, Moo-Young Han and Kok Khoo Phua (eds)
World Scientific



Less than a year after his death at the age of 94, World Scientific has published a book honouring the memory of Yoichiro Nambu, who was one of the greatest physicists of the second half of the 20th century. A brilliant mind and a visionary thinker, Nambu contributed to the development of many areas of theory – from particle to condensed-matter physics.

In the 1960s, he introduced the concept of spontaneously broken symmetries (with G Jona-Lasinio) and identified a new symmetry for quarks and gluons (with M-Y Han). Both works can be considered cornerstones of the Standard Model of particles and forces.

This book provides an interesting collection of articles written by Nambu's former collaborators, colleagues, students and friends. Through these contributions, the reader can gain an idea of the importance and variety of Nambu's work, as well as learn about his personality. He is described by many of those who knew him as kind, warm and humble. Besides being very clever and "many years ahead", he was also a good mentor. The volume concludes with the last scientific writing by Nambu himself, discussing the origin and development of particle physics.

Inside Story

A teacher's discerning perspective

Physical-sciences teacher **Lizelle Swanepoel** describes how her participation in CERN's High School Teacher (HST) programme is helping her to inspire a new generation of scientists.

Deborah Hunter

The author inside the LHC tunnel near CMS, during her stay at CERN in 2015.

I was one of 50 teachers who took part in a three-week residential programme at CERN in July 2015 to get a taste of frontier research in modern physics. Participants in the programme were selected from 32 countries across the world, and I was also the only teacher from the African continent. Having been selected to undertake a course at CERN has been a career highlight and a personal dream come true.

The grand scale of innovation going on at CERN is impressive. After its famous discovery of the Higgs boson in 2012, the second run of experiments started last year. Since then, they have discovered another new particle called the pentaquark. I feel privileged to have been at CERN during that time, and to have received a lecture about the pentaquark just days after its discovery. Of course, in addition to the large LHC experiments, there are many other cool experiments going on at CERN. These include the radioactive ion-beam facility ISOLDE, COMPASS, AMS (which is attached to the International Space Station to look for dark matter) and the Antimatter Factory.

The feeling of collaboration and discovery is tangible at CERN. It was a hub of activity while I was there, with so many summer students from across the world doing experiments. Young and old all contribute to physics at CERN. Nobel laureates can also be spotted. It is truly the most inspiring place on Earth from a scientific point of view!

Our programme consisted of three hours of daily lectures in particle physics, cosmology and astrophysics, in addition to workshops, visits to facilities and time spent on chosen projects for presentation at the end of the course. The projects ranged from the detection of cosmic rays, LHC data analysis and medical applications of CERN technologies to the importance of women in physics, educational games and comparing science curricula from across the globe. My workgroup had hours of fun building a working prototype of the

The feeling of collaboration and discovery is tangible at CERN.

ATLAS detector's magnetic system. We also had Q&A sessions with experiment leaders and the former Director-General, where we discussed the future of CERN and education, CERN in the media, and how to educate the public about science. I also had the opportunity to meet the new Director-General, Fabiola Gianotti, who is the first woman to head CERN.

CERN's International High School Teacher (HST) programme inspires teachers to raise and maintain the interest of students in science and specifically modern physics. CERN recognises the teacher's ability to instil a feeling of mystery and the potential for discovery in their students, which can motivate them to study science and engineering at university. My time at CERN has enabled me to promote what goes on at this extraordinary laboratory by sharing it with pupils and teachers alike.

The HST programme is the ideal platform for equipping teachers to inspire and prepare our future scientists and engineers.

Since my return from CERN, I have enjoyed sharing my experience with students and with other teachers in South Africa, in addition to writing articles about CERN for the wider public in newspapers and magazines. I have also championed an after-school science club (appropriately named CERN Club), in which we create activities to teach our budding young scientists how to explore the wonders of the universe. It is truly rewarding to see how interested these young people have become in physics, and science in general.

I will cherish my experience at CERN and will continue to share it in the years to come. Connections made with like-minded teachers from so many different countries have been hugely valuable. We have become ambassadors for CERN and would like to expose our students to the spirit of collaboration and internationalism felt there. I hope to continue to foster more of these qualities in my students, and to take a group of students to CERN in the near future. Thank you, CERN and the HST programme!

● *Lizelle Swanepoel, head of chemistry at Saheti School, Johannesburg, South Africa.*

CERN Courier Archive: 1973

A look back to CERN Courier vol. 13, October 1973, compiled by Peggie Rimmer

Meeting

Physics at Bonn and Aix

Two important conferences came close together at the end of the summer: the 6th International Symposium on Electron and Photon Interactions at High Energies in Bonn, 27 to 31 August, and the 2nd Aix-en-Provence International Conference on Elementary Particles, 6 to 12 September.

At both conferences the highlight and main talking point was the evidence of neutral currents. The discovery came in a CERN experiment with a neutrino beam into the heavy liquid bubble chamber Gargamelle, and was confirmed at the National Accelerator Laboratory USA with a neutrino beam into a huge counter-spark chamber array.

During the week of the Aix conference much more attention than usual was given to the need for communication with non-physicists. In the plenary session on "Popularizing High Energy Physics", V F Weisskopf made the telling comment that not a single science writer had been invited to the conference. He was adamant that the physicist had a duty to explain what he [sic] was doing to the people who paid him.

A most agreeable series of soirees, "La Physique dans la Rue", attracted several hundred people per evening to a courtyard where they could talk to physicists in an informal atmosphere. Subjects ranged from astrology to homoeopathy, nuclear reactors, scientific conscience and occasionally high-energy physics.

For a few brief days Aix-en-Provence had the feeling that it knew what a physicist looked like. Perhaps just as important, quite a few physicists had the opportunity of finding out what the public looked like.


H Nicollas

A typical courtyard scene at Aix where small groups gathered to discuss anything from Madame Soleil to high-energy physics.

● Compiled from texts on pp 291–298.

Other labs

Environmental research at Berkeley

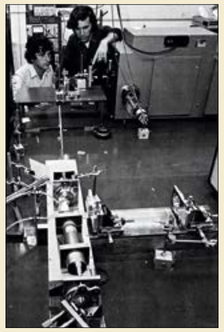
In recent years several high-energy physics laboratories in the USA have become more involved in research on environmental problems. The new involvement at the Lawrence Berkeley Laboratory emerged in 1970 from the personal initiative of a few of the staff deeply concerned at the seriousness of many of the problems.

A series of weekly seminars began in which a wide range of environmental science experts built up the laboratory's awareness of what is being done, what remains to be done and where the problems lie.

In April, the staff at large were sounded out to gauge interest and search for ideas on contributions that the laboratory might make. About 50 specific ideas emerged and the most interesting were assembled into a booklet *A Programme for Environmental Research*. At the end of 1970 J M Hollander and A M Sessler [LBL director 1973–1980] were appointed "co-ordinators of environmental research" and early the following year the first project was launched, funded by the National Science Foundation. It was a survey of instrumentation in environmental monitoring.

After building up a base research programme relevant to environmental problems, the philosophy moved towards looking at the nation's urgent problems in the field of energy and environment. Proposals were drawn up on such topics as geothermal energy, solar energy and the biomedical effects of non-nuclear energy sources. These were presented to the Atomic Energy Commission but non-nuclear work was pruned from the AEC programme for the present fiscal year and none of the proposals have got off the ground.

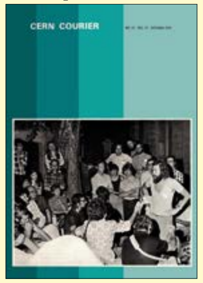
Nevertheless, the LBL environmental science programme involves an expenditure of about a million dollars per year with 40 scientists committed to it. Coming from the personal concern of a few people three years ago, this is no small achievement.


LBL

The alignment of instrument components using resonance Raman scattering. The incident beam comes from a tunable dye laser in the foreground; a high-resolution spectrometer is visible top right.

● Compiled from texts on pp303–306.

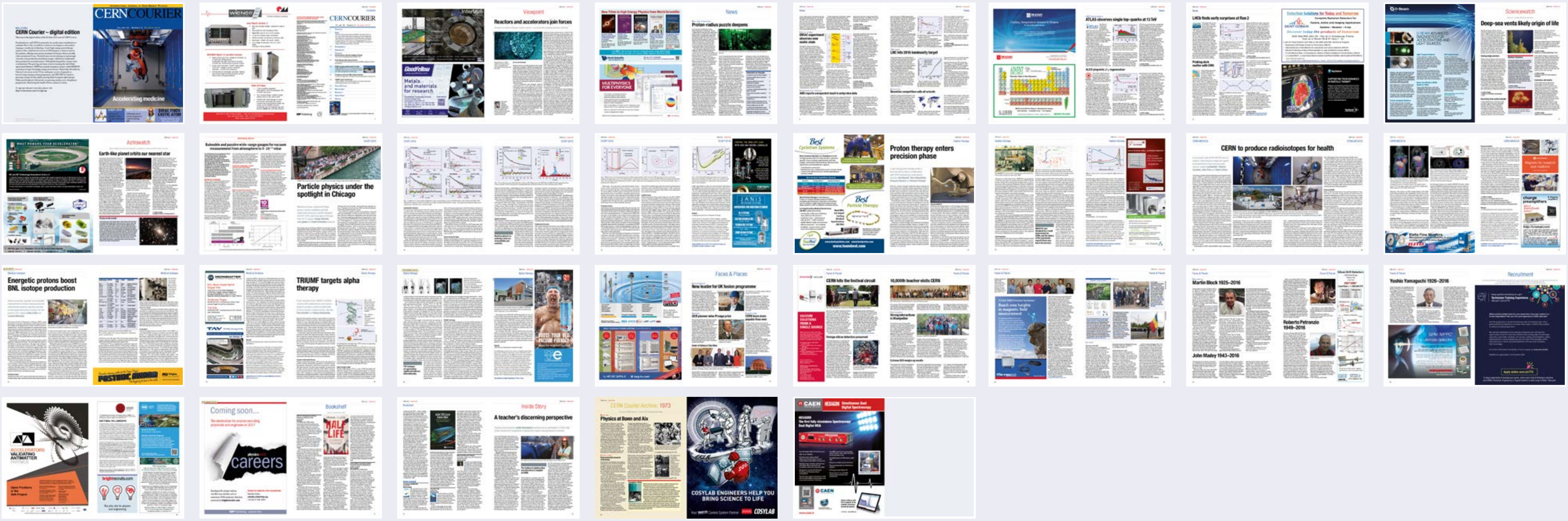
Compiler's Note



While the discovery of neutral currents is recalled, its importance is so well known by now that it is not covered at length in this note.

However, the progress made in popularising physics has been truly astounding. Already in December 2012 at the Fête de l'Escalade, Geneva's annual celebration of the defeat of a surprise attack by the Duke of Savoy in 1602, a souvenir tin tray doubling as an Echelles & Dragons/ Snakes & Ladders board featured a Higgs boson in square 87, taken by the promoters to be as recognisable as other cartooned notables such as Professeur Tournesol, square 16, and Marilyn Monroe, square 24.

Although most members of the public are aware of the spin-off from particle physics to nuclear medicine, the transfer of technology to environmental science is less widely acclaimed. Under Andrew Sessler's direction, LBL became a truly multidisciplinary research centre and a stop on celebrity tours. It seems likely that it was primarily the work on environmental problems that appealed to eco-champions Prince Charles and the Dalai Lama during their visits to the laboratory in the 1970s.



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