WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the October 2018 issue of *CERN Courier*.

Of all the particle colliders that have been built over the past half-century or so, one type stands out for its rarity: the electron–hadron collider. The only machine so far in this class is the 6.3 km-circumference electron–proton collider HERA, which operated at DESY in Germany between 1992 and 2007. Together with its four large detectors (H1, ZEUS, HERMES and HERA-B), HERA transformed our view of proton structure and led to major insights into other areas of quantum chromodynamics. This summer, the US Academy of Sciences positively endorsed a proposal for a high-energy, high-luminosity electron–ion collider that would go even further than HERA in precisely mapping the internal structure of nuclear matter and determining how nucleon properties emerge from quark and gluon interactions. Two pre-conceptual designs have evolved at Brookhaven National Laboratory and Jefferson Laboratory, setting in motion the process towards approval and eventual construction. Other topics featured in this issue include: the African Institute for Mathematical Sciences; a background-free dark-matter experiment called DarkSide; proton-driven plasma-wakefield acceleration at CERN; Hyper-Kamiokande's green light for construction; and the 50th anniversary of the European Physical Society, whose role in bridging political divides is more important than ever.

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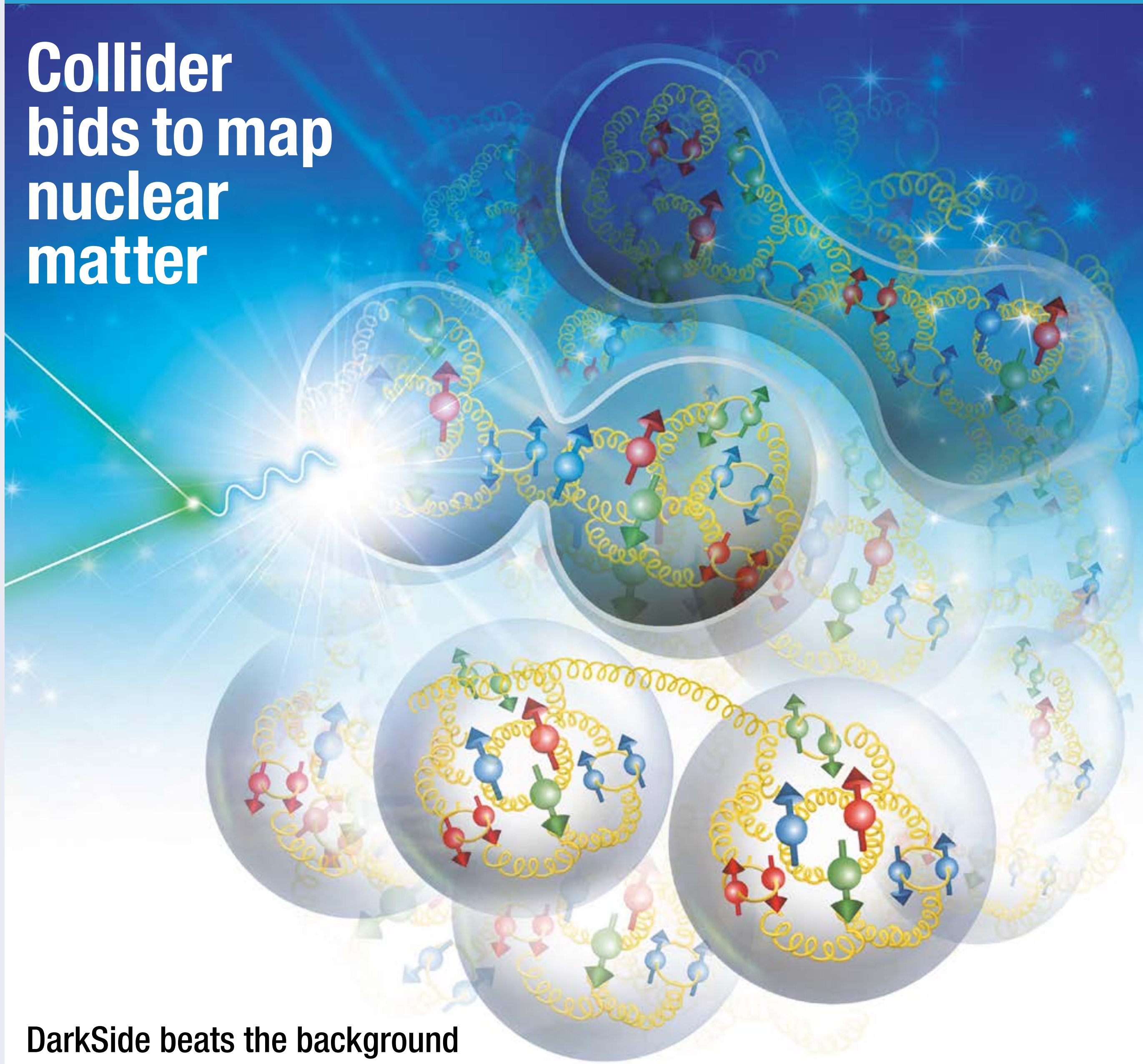
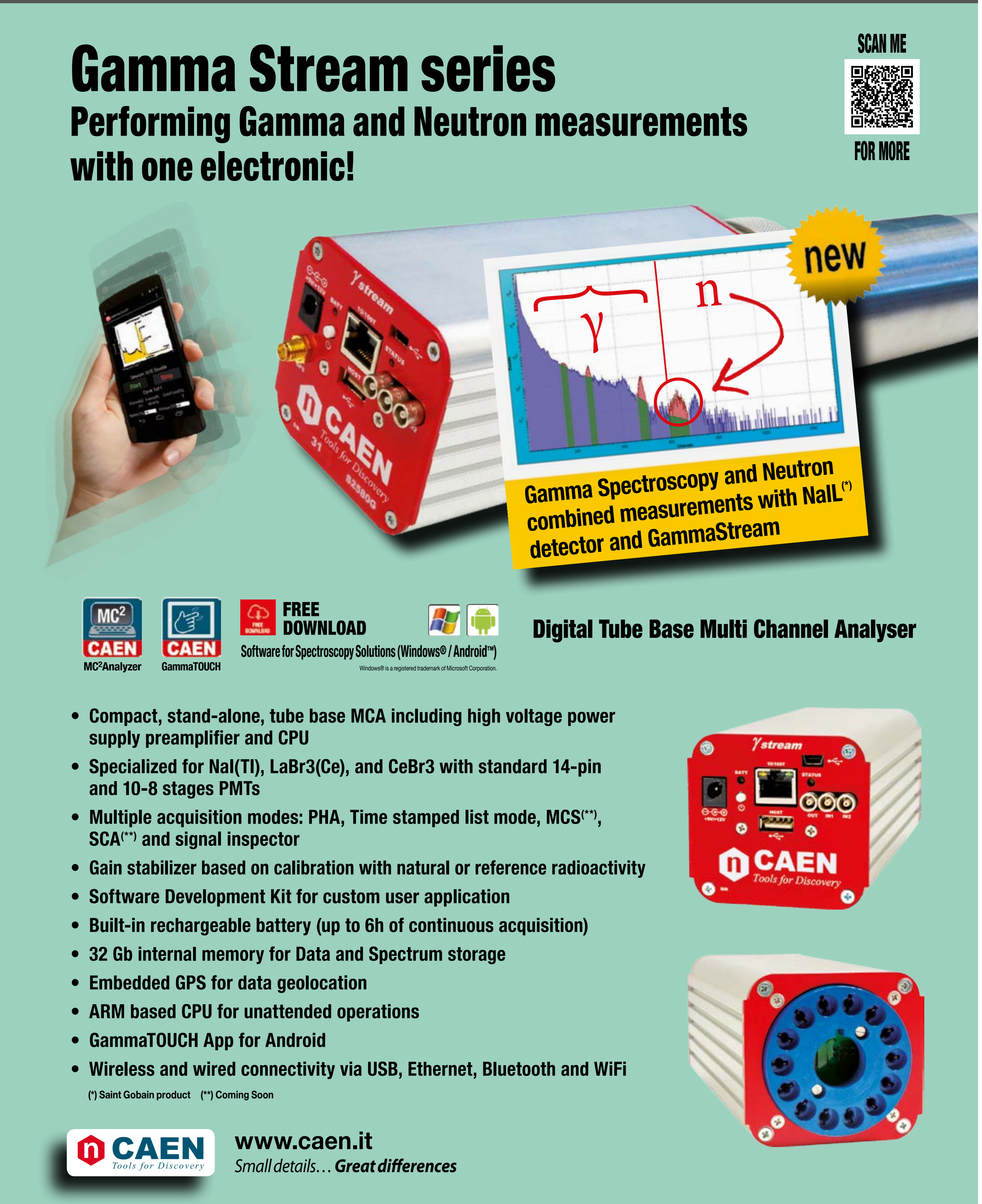
EDITOR: MATTHEW CHALMERS, CERN
DIGITAL EDITION CREATED BY DESIGN STUDIO/IOP PUBLISHING, UK

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERNCOURIER
VOLUME 58 NUMBER 8 OCTOBER 2018



Collider bids to map nuclear matter

DarkSide beats the background
Speaking up for European unity
AIMS: empowering Africa's youth



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

CERN Courier is distributed to member-state governments, institutes and laboratories affiliated with CERN, and to their personnel. It is published monthly, except for January and August. The views expressed are not necessarily those of the CERN management.

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Produced for CERN by IOP Publishing Ltd
IOP Publishing Ltd, Temple Circus, Temple Way, Bristol BS1 6HG, UK
Tel +44 (0)117 929 7481

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Tel +44 (0)117 930 1026 (for UK/Europe display advertising) or +44 (0)117 930 1164 (for recruitment advertising); E-mail sales@cerncourier.com; fax +44 (0)117 930 1178

General distribution Courrier Adressage, CERN, 1211 Geneva 23, Switzerland
E-mail courrier-adressage@cern.ch
In certain countries, to request copies or to make address changes, contact:
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UK Sian Giles, Science and Technology Facilities Council, Polaris House, North Star Avenue, Swindon, SN2 1SZ
E-mail sian.giles@stfc.ac.uk
US/Canada Published by Cern Courier, 6N246 Willow Drive, St Charles, IL 60175, US. Periodical postage paid in St Charles, IL, US
Fax 630 377 1569. E-mail creative_mailing@att.net
POSTMASTER: send address changes to Creative Mailing Services, PO Box 1147, St Charles, IL 60174, US

Published by European Organization for Nuclear Research, CERN, 1211 Geneva 23, Switzerland
Tel +41 (0) 22 767 61 11. Telefax +41 (0) 22 767 65 55

Printed by Warners (Midlands) plc, Bourne, Lincolnshire, UK

 ISSN 0304-288X

IOP Publishing

CERNCOURIER

VOLUME 58 NUMBER 8 OCTOBER 2018

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On the cover: An artist's impression of physics at an electron–ion collider, p31. (Image credit: Jefferson Lab.)

Viewpoint

Preserving European unity in physics

As the EPS turns 50, building scientific bridges across political divides remains as vital as ever.

The European Physical Society (EPS) was founded in Geneva on 26 September 1968.

By Rüdiger Voss

The year 1968 marked a turning point in the history of post-war Europe that remains engraved in our collective memory. Global politics were marked by massive student unrest, the Cold War and East–West confrontation. On 21 August the Soviet Union and other Warsaw Pact states invaded Czechoslovakia to crush the movement of liberalisation, democratisation and civil rights, which had become known as the Prague Spring.

Against this background, it seems a miracle that the European Physical Society (EPS) was established only a few weeks later, on 26 September, with representatives of the Czechoslovak Physical Society and the USSR Academy of Sciences sitting at the same table. The EPS was probably the first learned society in Europe involving physicists from both sides of the Iron Curtain. Ever since, building scientific bridges across political divides has been core to the society's mission.

The EPS was founded in Geneva not by accident. Whereas CERN did not play a formal role, the CERN model of European cooperation made a substantial impact on the genesis of the new society. CERN was at that time principally an organisation of Western European states, but it had started early to develop scientific collaboration with the Soviet Union and other Eastern countries, notably through the Joint Institute for Nuclear Research in Dubna. Leading CERN physicists – including Director-General Bernard Gregory – were instrumental in setting up the new society; Gilberto Bernardini, who had been CERN's first director of research in 1960–1961 and was a strong advocate of international collaboration in science, became the first EPS president. From the 20 national physical societies and similar organisations that participated in the 1968 foundation, this has now grown to 42, covering almost all of Europe plus Israel, and representing more than 130,000 members. In addition, there are about 42 associate members – mostly major research institutions including CERN – and, last but not least, around 3500 individual members.

Today, the EPS serves the European physics community in a twofold way: by promoting collaboration across borders and disciplines, through activities such as conferences, publications and prizes; and by reaching out to political decision makers, media and the public to promote awareness of the importance of physics education and research.

The Iron Curtain is history, but the EPS celebrates its 50th anniversary at a time when new, more complex and subtle political divides are opening up in Europe: the UK's departure from the European Union (EU) is only the most prominent example. While respecting the result of democratic votes, a continued erosion of European unity will undermine fundamental values and best practices that many of us take for granted: free cross-border collaboration, unrestricted mobility of researchers and students, and access to European funding and infrastructures. For almost 30 years now, in Europe, we have taken such freedoms in science as self-evident. Today, prestigious universities in the heart of Europe are threatened with closure on political grounds, while in other countries physicists are jailed for claiming the right to freely exercise their academic profession. These concerns are not unique to physics and must be addressed by the scientific community at large. The EPS, representing a science with a long tradition and highly developed culture of international collaboration, has a special responsibility to uphold these values.

We have taken such freedoms in science as self-evident.

Against this challenging background, the EPS is undertaking efforts to make the voice of the physics community more clearly heard in European science-policy making, principally through a point of presence in Brussels to facilitate communication with the European Commission and with partner organisations defending similar interests. In an environment where funding opportunities are increasingly organised around societal rather than scientific challenges, the EPS must advocate a healthy and sustained balance between basic and applied research. The next European Framework Programme *Horizon Europe* must not only provide fair access to funds, research opportunities and infrastructure for researchers from EU countries, but should remain equally open to participation from third countries, following the example of the successful association of countries like Norway and Switzerland with *Horizon 2020*. Building scientific bridges across political divides remains as vital as ever, in the best interest of a strong cohesion of the European physics community.

CERN

Rüdiger Voss is president of the European Physical Society, and a former CERN physicist who has served as head of international relations, among other senior roles.

News

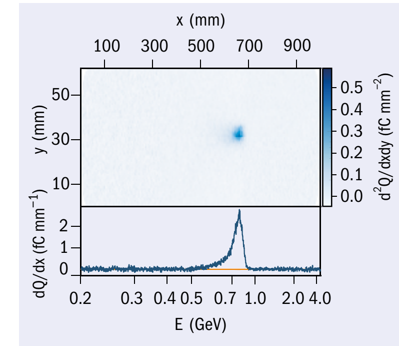
Accelerators

AWAKE accelerates electrons in world first

The AWAKE experiment at CERN has passed an important milestone towards compact, high-energy accelerators for applications in future high-energy physics experiments. Reporting in *Nature* on 29 August, the 18 institute-strong international collaboration has for the first time demonstrated the acceleration of electrons in a plasma wakefield generated by a proton beam. The AWAKE team injected electrons into plasma at an energy of around 19 MeV and, after travelling a distance of 10 m, the electrons emerged with an energy of about 2 GeV – representing an average acceleration gradient of around 200 MV/m. For comparison, radio-frequency (RF) cavities in high-energy linear accelerators used for X-ray free-electron lasers achieve typical gradients of a few tens of MV/m.

Plasma-wakefield acceleration still has far to go before it can rival the performance of conventional RF technology, however. First proposed in the late 1970s, the technique accelerates charged particles by forcing them to "surf" atop a longitudinal plasma wave that contains regions of positive and negative charges. Two beams are required: a "witness" beam, which is to be accelerated, and a "drive" beam that generates the wakefield. Initial experiments took place with laser and electron drive beams at SLAC and elsewhere in the 1990s, and the advent of high-power lasers as wakefield drivers led to increased activity. Such techniques are now capable of bringing electrons to energies of a few GeV over a distance of a few centimetres.

AWAKE (the Advanced Wakefield Experiment) is a proof-of-principle R&D project that is the first to use protons for the drive beam. Since protons penetrate deeper into the plasma than electrons and lasers, thereby accelerating witness beams for a greater distance, they potentially can accelerate electrons to much higher energies in a single plasma stage. The experiment is driven by a bunch of 400 GeV protons from the Super Proton Synchrotron, which is injected into a plasma cell containing rubidium gas at a temperature of around 200°C. An accompanying laser pulse is used to ionise the rubidium gas and transform it into a plasma. As the proton bunch travels through the plasma, it splits into a series of smaller bunches via a process called self-modulation, generating a strong wakefield as they move. A bunch of witness electrons is then injected at an angle into this oscillating plasma at relatively low energies and rides the plasma wave to get accelerated. At the other end of the plasma, a dipole magnet bends the incoming electrons onto a scintillator to allow the energy of the outgoing particles to be measured (see figure).



The signal in the AWAKE electron spectrometer (top) and a vertical integration over the observed charge in the central region of the image (bottom), showing electron acceleration in a proton-driven plasma wakefield.

AWAKE has made rapid progress since its inception in 2013. Following the installation of the plasma cell in early 2016, in the tunnel formerly used by part of the CNGS facility at CERN, a proton-driven wakefield in a plasma was observed for the first time by the end of the year (*CERN Courier* January/February 2017 p8). The electron source, electron beam line and electron spectrometer were installed during 2017, completing the preparatory phase beginning in 2018, and the first electron acceleration was recorded early in the morning of 26 May.

So far, the AWAKE demonstration involves low-intensity electron bunches; the next steps include plans to create an electron beam at high energy with sufficient quality to be useful for applications, although tests will pause at the end of the year when the CERN accelerator complex shuts down for two years for upgrades and maintenance. A first application of AWAKE is to deliver accelerated electrons to an experiment and extending the project with a fully-fledged physics programme of its own. For eventual collider experiments, another hurdle is to be able to accelerate positrons. In the longer term, a global effort is under way to develop wakefield-acceleration techniques for a multi-TeV linear collider (*CERN Courier* December 2017 p31).

Although still at an early stage of development, the use of plasma wakefields could drastically reduce the size and therefore cost of accelerators. Edda Gschwendtner, technical coordinator and CERN project leader for AWAKE, says that the ultimate aim is to attain an average acceleration gradient of around 1 GV/m so that electrons can be accelerated to the TeV scale in a single stage. "We are looking forward to obtaining more results from our experiment to demonstrate the scope of plasma wakefields as the basis for future particle accelerators."

Further reading

AWAKE Collaboration 2018 *Nature* **561** 363.

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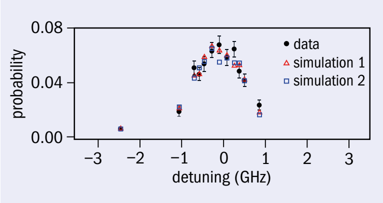
Antimatter

ALPHA takes antihydrogen to the next level

The ALPHA experiment at CERN's Antiproton Decelerator (AD) has made yet another seminal measurement of the properties of antiatoms. Following its determination last year of both the ground-state hyperfine and the 1S–2S transitions in antihydrogen, the latter representing the most precise measurement of antimatter ever made (*CERN Courier* May 2018 p7), the collaboration has reported in *Nature* the first measurement of the next fundamental energy level: the Lyman-alpha transition. The result demonstrates that ALPHA is quickly and steadily paving the way for precision experiments that could uncover as yet unseen differences between the behaviour of matter and antimatter (*CERN Courier* March 2018 p30).

The Lyman-alpha (or 1S–2P) transition is one of several in the Lyman series that were discovered in atomic hydrogen just over a century ago. It corresponds to a wavelength of 121.6 nm and is a special transition in astronomy because it allows researchers to probe the state of the intergalactic medium. Finding any slight difference between such transitions in antimatter and matter would shake one of the foundations of quantum field theory, charge–parity–time (CPT) symmetry, and perhaps cast light on the observed cosmic imbalance of matter and antimatter.

The ALPHA team makes antihydrogen atoms by taking antiprotons from the AD and binding them with positrons from a sodium-22 source, confining the resulting antihydrogen atoms in a magnetic trap. A laser is used to measure the antiatoms' spectral response, requiring a range of laser frequencies and the ability to count the number of atoms that drop out of the trap as a result of interactions between the laser and the trapped atoms. Having successfully employed this technique to measure the 1S–2S transition, ALPHA has now measured the Lyman-alpha transition frequency with a precision of a few parts in a hundred million: 2,466,051.7 ± 0.12 GHz. The result agrees with the prediction for the equivalent transition hydrogen to a precision of 5×10^{-8}.



The antihydrogen 1S–2P spectral line shape showing detected events (black), with the error bars representing the statistical counting uncertainties, and simulated line shapes for different initial conditions.

Although the precision is not as high as that achieved in hydrogen, the finding represents a pivotal technological step towards laser cooling of antihydrogen and the extension of antimatter spectroscopy to quantum states possessing orbital angular momentum. Simulations indicate that cooling to about 20 mK is possible with the current ALPHA set-up, which, combined with other planned improvements, would reduce the 1S–2S transition line width (see figure) by more than an order of magnitude. At such levels of precision, says the team, antihydrogen spectroscopy will have an impact on the determination of fundamental constants, in addition to providing elegant tests of CPT symmetry. Laser cooling will also allow precision tests of the weak equivalence principle via antihydrogen free-fall or antiatom-interferometry experiments.

"The Lyman-alpha transition is notoriously difficult to probe – even in normal hydrogen", says ALPHA spokesperson Jeffrey Hangst. "But by exploiting our ability to trap and hold large numbers of antihydrogen atoms for several hours, and using a pulsed source of Lyman-alpha laser light, we were able to observe this transition. Next up is laser cooling, which will be a game-changer for precision spectroscopy and gravitational measurements."

Further reading

M Ahmadi *et al.* 2018 *Nature* **561** 211.

Policy

Europe calls for advanced detector and imaging ideas

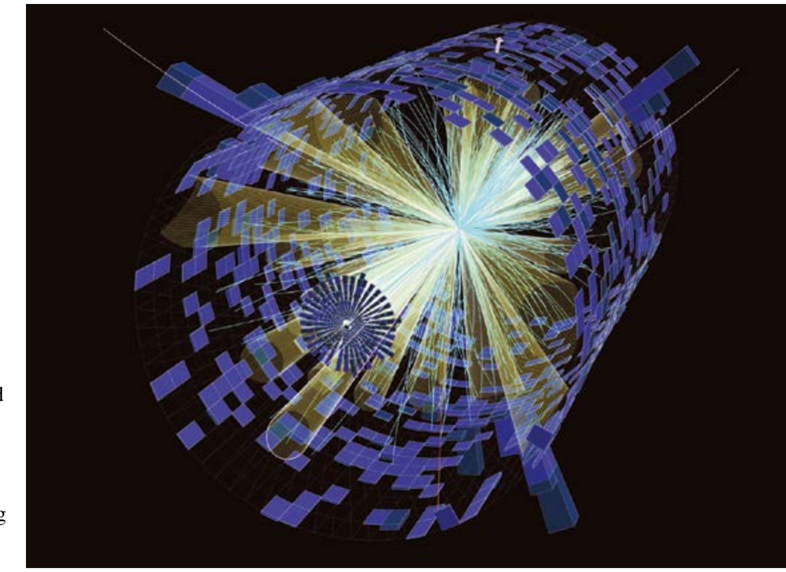
The European Union (EU) has committed €17 million to help bring a total of 170 breakthrough detection and imaging ideas to market. Led by CERN and funded by the EU's Horizon 2020 programme, the ATTRACT initiative involves several other European research infrastructures and institutes: the European Molecular Biology Laboratory, European Southern Observatory, European Synchrotron Radiation Facility, European XFEL, Institut Laue-Langevin, Aalto University, the European Industrial Research Management Association (EIRMA) and ESADE. It will focus on the development of new radiation sensor and imaging technologies both for scientific purposes and to address broader challenges in the domains of health, sustainable materials and information, and communication technologies.

Markus Nordberg of the CERN-IPT development and innovation unit laid the foundations for ATTRACT back in 2013, observing then how detector developers found it difficult to find suitable programmes to facilitate the wider use of generic detector R&D. "The detector R&D community, for example regarding the LHC upgrades and beyond, has ideas of the potential suitability of its technologies in other fields, but limited contacts, mechanisms or resources available to follow these ideas further or to make a case," he says. "ATTRACT builds upon the collaborative spirit of open science and co-innovation, where the experience and available infrastructure at laboratories such as CERN could turn out to be useful."

The ATTRACT seed fund (www.attract-eu.com) is open to researchers and entrepreneurs from organisations all over Europe. The call for proposals for CERN users and other outside laboratories working on detection and imaging technologies will close on 31 October, and the successful proposals will be announced in early 2019. The 170 projects funded by ATTRACT will have one year to develop their ideas, during which business and innovation experts from Aalto University, EIRMA and ESADE Business School will help project teams transform their technology into products, services, companies and jobs.

COMPUTING

US initiative to tackle data demands of HL-LHC



A simulation of a possible signal for new physics in the CMS detector at the HL-LHC, where analyses will be complicated by the simultaneous presence of up to 200 background events.

The US National Science Foundation (NSF) has launched a $25 million effort to help tackle the torrent of data from the High-Luminosity Large Hadron Collider (HL-LHC). The Institute for Research and Innovation in Software for High-Energy Physics (IRIS-HEP), announced on 4 September, brings together multidisciplinary teams of researchers and educators from 17 universities in the US. It will receive $5 million per year for a period of five years, with a focus on developing new software tools, algorithms, system designs and training the next generation of users.

Construction for the HL-LHC upgrade is already under way (*CERN Courier* July/August 2018 p7) and the machine is expected to reach full capability in the mid-2020s. Boosting the LHC's luminosity by a factor of almost 10, HL-LHC will collect around 25 times more data than the LHC has produced up to now and push data processing and storage to the limit. How to address the immense computing challenges ahead was the subject of a recent community white paper published by the HEP Software Foundation (*CERN Courier* April 2018 p38).

In 2016, the NSF convened a project to gauge the LHC data challenge, bringing together representatives from the high-energy physics and computer-science communities to review two decades of successful LHC data-processing approaches and discuss ways to address the obstacles that lay ahead. The new software institute emerged from that effort.

The institute is primarily about people, rather than computing hardware, explains IRIS-HEP principal investigator and executive director Peter Elmer of Princeton University, who is also a member of the CMS collaboration. "The institute will be virtual, with a core at Princeton, but coordinated as a single distributed collaborative project involving the participating universities similar to many activities in high-energy physics," he says. "High-energy physics had a rush of discoveries in the 1960s and 1970s that led to the Standard Model of particle physics, and the Higgs boson was the last missing piece of that puzzle. We are now searching for the next layer of physics beyond the Standard Model. The software institute will be key to getting us there."

Co-funded by NSF's Office of Advanced Cyberinfrastructure (OAC) and the NSF division of physics, IRIS-HEP is the third OAC software institute, following the Molecular Sciences Software Institute and the Science Gateways Community Institute.

"Our US colleagues worked with us very closely preparing the community white paper last year, which was then used as one of the significant inputs into the NSF proposal," says Graeme Stewart of CERN and the HEP Software Foundation. "So we're really happy about the funding announcement and very much looking forward to working together with them."

FACILITIES

Hyper-Kamiokande construction to start in 2020

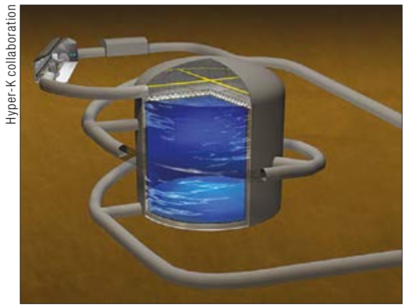
On 12 September, the Japanese government granted seed funding towards the construction of the Hyper-Kamiokande experiment, a next-generation detector for the study of neutrinos. Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) allocated $700,000 within its budget request for the 2019 fiscal year, which will enable progress in preparatory work for construction and efforts to secure international collaboration.

Coinciding with the MEXT announcement, the University of Tokyo pledged to ensure that construction of the Hyper-Kamiokande detector commences in April 2020. According to a statement from university president Makoto Gonokami: "The University of Tokyo has made this decision in recognition of both the project's importance and value both nationally and internationally. … Seed fundings in the past projects usually lead to full funding in the following year, as was the case for the Super-Kamiokande project."

Hyper-Kamiokande (Hyper-K) is a water Cherenkov detector centered on a huge underground tank containing 300,000 tonnes of water, with a sensitive volume about a factor of 10 larger than its predecessor Super-Kamiokande (Super-K). Like Super-K, Hyper-K will be located in Kamioka on the west coast of Japan directly in the path of a neutrino beam generated 295 km away at the J-PARC facility in Tokai, allowing it to make high-statistics measurements of neutrino oscillations. Together with a near-detector located close to J-PARC, Super-K formed the "T2K" long-baseline neutrino programme. An order of magnitude bigger than Super-K, ▷

Hyper-K will serve as the next far-detector at T2K, with a rich physics portfolio. This ranges from the study of the CP violation in the leptonic sector and measurements of neutrino-mixing parameters, to studies of proton decay, atmospheric neutrinos and neutrinos from astrophysical sources.

It was at Super-K in 1998 that researchers discovered neutrino oscillations, proving that neutrinos are massive and leading to the award of the 2015 Nobel Prize in Physics to Takaaki Kajita of the University of Tokyo and Arthur McDonald of Queen's University in Canada. The Japanese neutrino programme has progressed steadily since the 1998 discovery (*CERN Courier* July/August 2016 p29). Hyper-K was discussed as long ago as 2002 and a letter of intent was published in 2011, following the first measurement of the neutrino mixing angle θ_{13} at T2K, which boosted the expectation of a discovery of leptonic CP violation by Hyper-K. The experiment was placed in Japan's list of priority projects in 2014 but was not short-listed. The project was proposed again in 2017, this time making the short-list of seven projects to be funded by MEXT. The Hyper-K conceptual design report was published earlier this year (see further reading).



Hyper-K collaboration

Hyper-K's giant tank will take neutrino science into uncharted waters.

"Hyper-Kamiokande now moves from planning to construction," said Hyper-K project co-leader Francesca Di Lodovico of Queen Mary University of London, in a statement released by the Kavli Institute for the Physics and Mathematics of the Universe in Japan on behalf of the Hyper-K collaboration. "The collaboration will now work on finalising designs, and is very open to more international partners joining this exciting, far-reaching new experiment." The Hyper-K proto-collaboration was formed in 2015 and currently comprises around 300 members from 73 institutes in 15 countries. Many European institutes are involved, including the CERN neutrino group, which is already participating in the upgrade of the T2K near detector to serve Hyper-K. To this end, in the summer of last year a detector called Baby MIND that was designed and built at CERN was shipped to J-PARC (*CERN Courier* July/August 2017 p12).

"Hyper-K is the next step in the Japanese neutrino adventure," says Baby MIND spokesperson and Hyper-K collaborator Alain Blondel of the University of Geneva. "This success comes from wise choices and intelligent planning. The increase in the far-detector mass is exciting: demonstration of an asymmetry between neutrinos and antineutrinos was identified as the 'great discovery' goal as soon as neutrino oscillations were discovered, although it presents a challenge regarding systematics. And if a proton decay is detected or a supernova strikes, it will be fireworks!"

Further reading

K Abe *et al.* 2018 arXiv:1805.04163.

Policy

Survey addresses recognition in large collaborations

The European Committee for Future Accelerators (ECFA) has created a working group to examine the recognition of individual achievements in large scientific collaborations. Based on feedback from an initial survey of the leaders of 29 CERN-based or CERN-recognised experiments in particle, nuclear, astroparticle and astrophysics, ECFA found that the community is ready to engage in dialogue on this topic and receptive to potential recommendations.

In response, ECFA has launched a community-wide survey to verify how individual researchers perceive the systems put in place to recognise their achievements. The survey will be distributed widely, and can be found on the ECFA website (https://ecfa.web.cern.ch) with a deadline for responses by 26 October.

The results of the survey will be disseminated and discussed at the upcoming plenary ECFA meeting at CERN on 15–16 November. An open session during the morning of 15 November, also to be webcast, will be devoted to the discussion of the outcomes of the survey, and aims to gather input to be submitted to the update of the European Strategy for Particle Physics (*CERN Courier* April 2018 p7). During the remaining open sessions, comprehensive overviews of all major future collider projects in and beyond Europe, and related accelerator technologies, will be given.

CMS-PHO-PUBLIC-2012-014-1

CMS physicists in CERN's Building 40. The ATLAS and CMS collaborations at the LHC each number more than 3000 members from over 200 institutes.

"Visibility and promotion of young scientists is of utmost importance in science and in particular also for the large collaborations in high-energy physics," says ECFA chairperson Jorgen D'Hondt. "On the eve of the update process of the European Strategy, it is an outstanding opportunity for ECFA to take on its responsibility for informing the community about the opportunities and challenges ahead of us. Everybody is welcome."

Detectors

Thin silicon sharpens STAR imaging

A new technology has enabled the STAR collaboration at Brookhaven National Laboratory's Relativistic Heavy-Ion Collider (RHIC) to greatly expand its ability to reconstruct short-lived charm hadron decays, even in collisions containing thousands of tracks. A group of STAR collaborators, led by Lawrence Berkeley National Laboratory, used 400 Monolithic Active Pixel Sensor (MAPS) chips in its new vertex detector, called the heavy-flavour tracker (HFT), representing the first application of this technology in a collider experiment.

The HFT reconstructs charmed hadrons over a broad momentum range by identifying their secondary decay vertices, which are a few tens to hundreds of micrometres away from the collision vertex. The charmed hadrons are used to study heavy-quark energy loss in a quark–gluon plasma (QGP) and to determine emergent QGP-medium transport parameters.

BNL/STAR collaboration

A gold–gold collision recorded by STAR with the MAPS pixel detector (two most inner layers) and one layer of silicon-strip detector (outer layer). The white points show the measured hits that were used to reconstruct charged particle tracks (red and green lines).

The MAPS sensor is based on the same commercial CMOS technology that is widely used in digital cameras. It comprises an array of 928 × 960 square pixels with a pitch of 20.7 × 20.7 μm² to provide a single-hit resolution of <6 μm. The sensors are thinned to a thickness of 50 μm and mounted on a carbon-fibre mechanical support, and their relatively low power consumption (170 mW/cm²) allows the detector to be air-cooled. The thinness is important to minimise multiple scattering in the HFT, allowing for good pointing resolution even for low transverse-momentum charged tracks.

The heavy-flavour physics programme enabled by the HFT has been one of the driving forces for RHIC runs from 2014 to 2016. The first measurement with the HFT on the D^0 elliptic collective flow shows that D^0 mesons have significant hydrodynamic flow in gold–gold collisions, and the HFT pointing resolution also enabled the first measurement of charmed-baryon production in heavy-ion collisions.

Building on the success of the STAR HFT, the ALICE collaboration at CERN's Large Hadron Collider is now building its own MAPS-based vertex detector – the ITS upgrade – and the sPHENIX collaboration at RHIC is also planning a MAPS-based detector. These next-generation detectors will have much faster event readout, by a factor of 20, to reduce event pileup and therefore allow physicists to reconstruct bottom hadrons more efficiently in high-luminosity, heavy-ion collision environments.

Further reading

G Contin *et al.* 2018 *Nucl. Instrum. Methods Phys. Res A* doi:10.1016/j.nima.2018.03.003.

LHC experiments

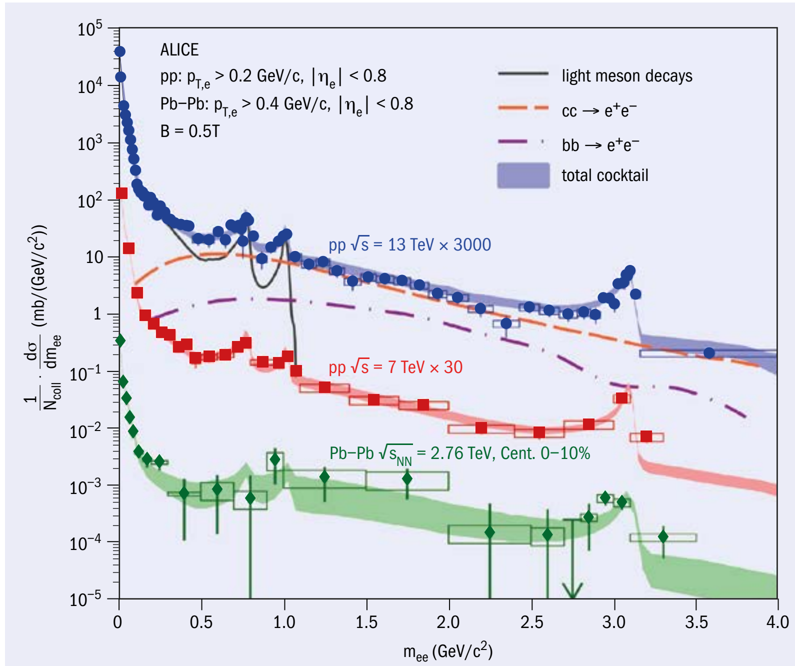
First low-mass dielectron results ahead of LHC Run 3

ALICE

One of the main objectives of the ALICE physics programme for future LHC runs is the precise measurement of the e^+e^- (dielectron) invariant-mass continuum produced in heavy-ion collisions. In contrast to strongly interacting hadronic probes, dielectrons provide an unperturbed view into the quark–gluon plasma (QGP), a phase of deconfined quarks and gluons that is produced in such collisions. For example, they will allow physicists to determine the initial temperature of the QGP and to study the effects of the predicted restoration of chiral symmetry. In order to perform these measurements, important upgrades to the ALICE detector system are underway, most notably a new inner tracking system and a new readout system for the time projection chamber.

Meanwhile, the ALICE collaboration has also analysed the proton–proton (pp) and lead–lead (Pb–Pb) collision data recorded so far during LHC Runs 1 and 2. The results, which have recently been submitted for publication, provide new physics insights, in particular into the production of heavy quarks (charm and beauty) in pp collisions at centre-of-mass energies of 7 and 13 TeV. The measured invariant-mass spectrum of dielectrons (see figure) has been found to be in good agreement with the expected distribution of dielectrons from decays of light mesons and J/ψ, as well as semileptonic decays of correlated heavy-flavour pairs. The Pb–Pb results, recorded at a centre-of-mass energy of 2.76 TeV per nucleon–nucleon pair, are not yet sensitive enough to quantify the presence of thermal radiation and signs of chiral symmetry restoration on top of the vacuum expectation.

The results obtained in pp collisions at 13 TeV provide the first measurements of charm and beauty production cross sections at mid-rapidity integrated over all transverse momenta at the current highest LHC energy. Fitting the data with two different models of heavy-flavour production (PYTHIA ▷



Dielectron cross section as a function of invariant mass measured in pp collisions at a centre-of-mass energy of 7 TeV (red) and 13 TeV (blue), as well as Pb–Pb collisions at a centre-of-mass energy of 2.76 TeV per nucleon–nucleon pair (green) scaled by the number of binary collisions (N_{coll}). The data are compared to a cocktail of known hadronic sources.

6.4 and POWHEG), ALICE observes significant differences in the obtained charm cross sections at both investigated collision energies. The difference arises from different rapidity correlations between charm and anti-charm quarks in the two calculations. Hence, the data provide crucial input to improve models of charm production that is complementary to single charmed-hadron measurements.

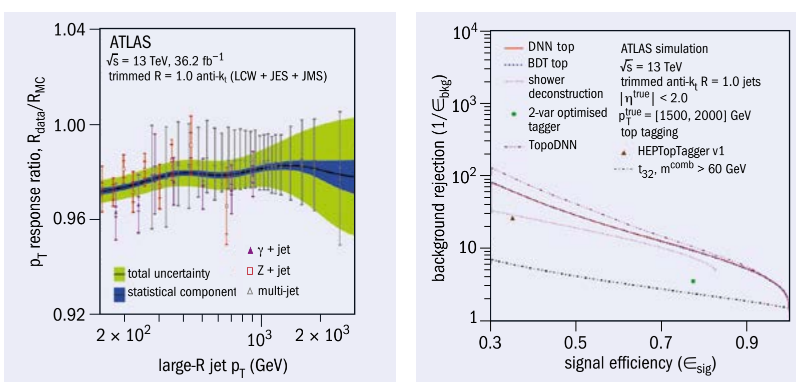
In addition, the distance of the closest approach (dca) of the electrons to the collision vertex has been successfully used in the analysis of pp collisions at 7 TeV to distinguish displaced dielectrons from open-heavy flavour decays and prompt decays of light hadrons. This is an important test as the dca will be a crucial tool to isolate a thermal signal in the mass region 1–3 GeV/c² in the data that will be collected in LHC Runs 3 and 4 (starting in 2021). Part of the data will be recorded with the magnetic field of the central barrel solenoid reduced from 0.5 to 0.2 T in order to further increase the acceptance of dielectrons with low mass and transverse momentum.

Further reading
ALICE Collaboration 2018 arXiv:1805.04391, arXiv:1805.04407 and arXiv:1807.00923.

A decade of advances in jet substructure

Ten years ago, the first in a series of annual meetings devoted to the theoretical and experimental understanding of massive hadronically decaying particles with high transverse momenta took place at SLAC. These "BOOST" workshops coincided with influential publications on the subject of reconstructing such Lorentz-boosted decays as single jets with large radius parameters [1], which kick-started the field of jet substructure. Such techniques have become a critical aspect of the ATLAS and CMS experimental programmes searching for new physics at the highest scales accessible with the LHC.

The understanding of large-radius jets and their substructure has progressed considerably. Analytical calculations have recently been published that predict the distribution of jet substructure observables at high accuracy, and these have been compared to data by both ATLAS [2] and CMS [3] in proton–proton collisions.



Left: the data-to-simulation ratio of the average large-radius jet transverse momentum response as a function of the large-radius jet transverse momentum, with the combined result based on three in situ *techniques. The total uncertainty is shown as the green band, reaching percent level for jets with low-to-intermediate transverse momenta. Right: the background rejection versus signal efficiency for various algorithms, which identify hadronically decaying top quarks with large transverse momenta. The application of machine learning (DNN top, BDT top, TopoDNN) leads to large improvements over traditional approaches.*

Measurements of substructure observables have also recently been made by the ALICE, CMS and ATLAS collaborations in heavy ion collisions [4,5,6]. Such

results were among the many topics discussed at the 10th BOOST workshop in Paris this July, where the ATLAS collaboration presented new results accentuating the advances in jet substructure.

Recent focus on measuring Standard Model properties using jet substructure has motivated ATLAS to measure the energy and mass response of large-radius jets with the highest possible precision [7]. A new *in situ* (that is, data-driven) calibration for large-radius jets provides percent-level uncertainties by combining several measurements of the jet energy scale in events where the jet is balanced by a well-measured reference object such as a leptonically decaying Z boson, a photon or a system of well-calibrated jets with lower momenta (figure, left). The mass scale of these jets is also measured using fits to the jet mass distribution obtained from hadronically decaying W bosons and top quarks in data, and by combining information from the ATLAS inner tracking detector and calorimeters. The precision for the jet mass scale in certain regions of parameter space also reaches the percent level, which is unprecedented for substructure observables.

Meanwhile, the ongoing revolution in machine learning has directly intersected with jet-substructure studies. Techniques such as boosted decision trees and deep neural networks have been studied by ATLAS to identify W bosons and top quarks with high transverse momenta [8]. These approaches allow several high-level substructure observables such as the mass, or low-level information such as measured energy depositions from the calorimeter, to be utilised simultaneously using their complex correlation pattern to gain information. Such techniques achieve improvements of more than 100% in terms of background rejection for top quark identification over previous results (figure, right).

In situ measurements of tagging and the background efficiencies of these algorithms robustly demonstrate that they are well understood in terms of the QCD-based models implemented in Monte Carlo generators, and are stable in the face of the challenging high pile-up environment of Run 2 at the LHC.

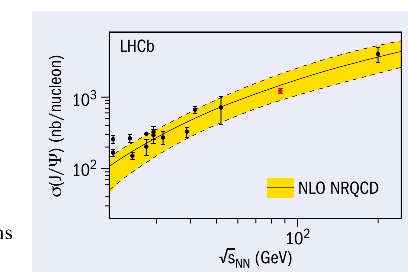
In two ATLAS publications, the early Run-2 data have allowed for rapid progress by enabling powerful *in situ* techniques. The collaboration is now looking forward to the possibilities offered by the larger full Run-2 dataset, where such data-driven calibrations will bring precision to an increasing number of observables. This will improve the quality of both searches and measurements exploring the energy frontier.

Further reading
[1] J Butterworth *et al.* 2008 *Phys. Rev. Lett.* **100** 242001.
[2] ATLAS Collaboration 2018 *Phys. Rev. Lett.* **121** 092001.
[3] CMS Collaboration 2018 arXiv:1807.05974.
[4] ALICE Collaboration 2018 arXiv:1807.06854.
[5] CMS Collaboration 2018 arXiv:1805.05145.
[6] ATLAS Collaboration 2018 ATLAS-CONF-2018-014.
[7] ATLAS Collaboration 2018 arXiv:1807.09477.
[8] ATLAS Collaboration 2018 arXiv:1808.07858.

Fixed-target physics in collider mode at LHCb

This year, the LHCb collaboration reached an important milestone in its fixed-target physics programme, publishing two key results on the production rates of particles in proton–ion collisions: measurements of the cross section of antiprotons that constrain models of cosmic rays, and of charmonium and open-charm cross sections (see further reading).

The LHCb fixed-target system, known as SMOG (System for Measuring Overlap with Gas), injects a small amount of noble gas inside the LHC beam pipe, at a pressure of the order 10^{-7} mbar, within the LHCb vertex detector region (*CERN Courier* January/February 2016 p10). This system was initially designed to improve the determination of the luminosity via beam-profile measurements, and can produce hundreds of millions of beam–gas collisions per hour. This provides a unique opportunity to exploit the LHC proton and ion beams in a fixed-target mode, opening many physics opportunities such as a precise study of the quark–gluon plasma (QGP) in the as-yet-unexplored energy regime between existing fixed-target and collider measurements.



The J/ψ cross-section, measured with the 4 TeV LHC proton beam hitting gaseous helium (red point) compared to previous experimental results (black) and a fit based on theoretical calculations (yellow).

LHCb has just taken the first step towards the use of charmonium and open-charm hadrons as probes of the QGP by measuring their cross-sections in proton–nucleus collisions, where no QGP is expected to be formed. The data for these measurements come from two SMOG data-taking campaigns with proton beams – one carried out over a period of 18 hours in 2015 with a beam of energy 6.5 TeV and an argon gas target (meaning a centre-of-mass energy per colliding nucleon–nucleon pair, $\sqrt{s_{NN}}$, of 110.4 GeV), and the other over a period of 87 hours in 2016 with a 4 TeV beam and a helium target ($\sqrt{s_{NN}}$ = 86.6 GeV).

Thanks to the high-precision tracking and advanced particle-identification capabilities of the LHCb detector, the production rate of J/ψ and D^0 mesons were measured with a very good precision (see figure). Taking advantage of the forward geometry of the detector and the boost induced by the multi-TeV proton beam, the detector also measures very backward particles in the centre-of-mass frame of the collision, giving access to the large Bjorken-x region in the target nucleon. In this kinematic region, no significant contribution from an intrinsic $c\bar{c}$ component within the nucleon structure was observed.

Building on the success of these analyses of the 2015 and 2016 data, LHCb plans to carry out studies of charmonium suppression with the large sample of proton–neon collisions collected in 2017, and with samples of lead–neon collisions that will be taken in the upcoming LHC heavy-ion run in November 2018.

Further reading
LHCb Collaboration 2018 arXiv:1808.06127.
LHCb Collaboration 2018 LHCb-PAPER-2018-023.
F Maltoni *et al.* 2006 *Phys. Lett.* B **638** 202.

News

Observation of Higgs-boson decay to bottom quarks

The observation of the Higgs-boson decay to bottom quark–antiquark ($b\bar{b}$) by the CMS experiment is a seminal achievement that sheds light on one of the key missing pieces of the Higgs sector of the Standard Model (SM).

Processes that include the Higgs boson's favoured decay mode to b-quarks (with about 58% probability) have until now remained elusive because of the overwhelming background of b-quark events produced via strong interactions. While the recent CMS observation of Higgs-boson production in association with top quarks (ttH) constitutes the first confirmation of the tree-level coupling of the Higgs boson to quarks (*CERN Courier* June 2018 p10), the Higgs-boson decay to $b\bar{b}$ tests directly its coupling to down-type quarks. Moreover, this decay is crucial for constraining, under fairly general assumptions, the overall Higgs-boson decay width and thus reducing the uncertainty on the measurement of absolute couplings. This observation effectively narrows down the remaining window available for exotic or undetected decays.

At the LHC, the most effective strategy to observe the Higgs $b\bar{b}$ decay is to exploit the associated production mechanism with an electroweak vector boson VH, where V corresponds to a W or Z boson. The leptons and neutrinos arising from the V decay provide large suppression of the multijet background, and further background reduction is achieved by requiring the Higgs-boson candidates to have large transverse momentum.

Advanced machine-learning techniques (deep neural networks, DNN) are used in different steps of the analysis including: the b-jet identification, the measurement of the b-jet energy, the classification of different backgrounds in control regions, and the final signal extraction.

This result uses LHC data collected in 2016 and 2017 at an energy of 13 TeV and has benefited from the recent CMS pixel tracker upgrade with further improved b-quark identification performance.

A signal region enriched in VH events is selected together with several dedicated control regions to monitor the different background processes. Then, a simultaneous binned-likelihood fit of the signal and control regions is performed to extract the Higgs-boson signal.

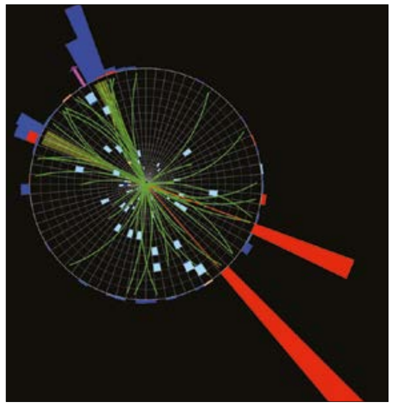
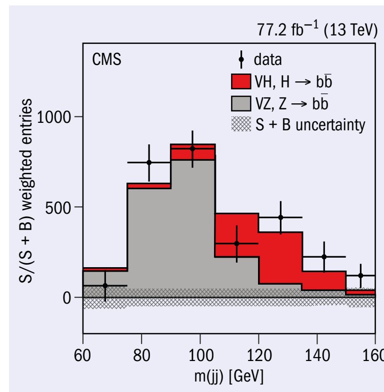
The score of the DNN separating signal from the background is used for the signal extraction fit. Several observables are combined and the most discriminating are: the angular separation between the two b-quarks and the b-tagging properties of the Higgs candidate jets. An event candidate for the production of a Z boson in conjunction with a Higgs boson is shown in the left figure.

A clear excess of events is observed in the combined 2016 and 2017 data, in comparison with the expectation in the absence of a $H\rightarrow b\bar{b}$ signal. The significance of this excess is 4.4σ, where the expectation from SM Higgs-boson production is 4.2σ. The signal strength corresponding to this excess, in relation to the SM expectation, is 1.06 ± 0.26. When combined with the measurement from LHC Run 1 at 7 and 8 TeV, the signal significance increases to 4.8σ, while 4.9σ is expected. The corresponding signal strength is 1.01 ± 0.22.

The dijet invariant mass distribution (figure, right) allows for a more direct visualisation of the Higgs-boson signal. The contributions of the VH and VZ processes are separately visible, after all other background processes have been subtracted.

The VH results are combined with CMS measurements in other production processes, including gluon-fusion, vector-boson fusion, and associated production with top quarks, with data collected at 7, 8 and 13 TeV, depending on the process. The observed combined significance is raised to 5.6σ, where the expectation from SM Higgs-boson production is 5.5σ. The signal strength corresponding to this excess, relative to the SM expectation, is 1.04 ± 0.20, in perfect agreement with the latter.

With the direct observation of the Higgs-boson couplings to bottom quarks complementing those involving tau leptons and top quarks (see further reading), the Yukawa couplings to all accessible third-generation fermions have now been firmly established. This opens a new era of precision studies in the Higgs sector that will fully benefit from the larger dataset that will be available by the end of Run 2.

Left: a CMS candidate event for the Higgs boson decaying to two bottom quarks, in association with a Z boson decaying to an electron and a positron. Right: weighted dijet invariant mass distribution comparing data with the VH and VZ processes, with all other background processes subtracted. Weights are derived from the dijet invariant mass distribution.

Further reading

CMS Collaboration 2018 *Phys. Rev. Lett.* **121** 121801.
CMS Collaboration 2018 *Phys. Lett. B* **779** 283.
CMS Collaboration 2018 *Phys. Rev. Lett.* **120** 231801.

***Les physiciens des particules du monde entier sont invités** à apporter leurs contributions au CERN Courier, en français ou en anglais. Les articles retenus seront publiés dans la langue d'origine. Si vous souhaitez proposer un article, faites part de vos suggestions à la rédaction à l'adresse cern.courier@cern.ch.*

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Astrowatch

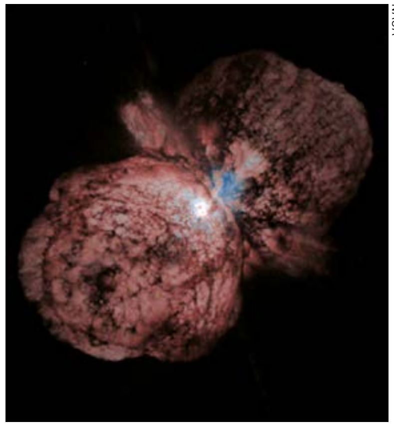
Compiled by Merlin Kole, Department of Particle Physics, University of Geneva

Solving the mystery of a historic stellar blast

Some 180 years ago, a relatively normal star called Eta Carinae suddenly brightened to become the second brightest star in the sky, before almost disappearing at the end of the 19th century. The sudden brightening and subsequent disappearance, recorded by astronomer John Herschel, suggested that the star had undergone a supernova explosion, leaving behind a black hole. More recent observations have shown, however, that the star still exists – ruling out the supernova hypothesis. Even more remarkably, what remains is a binary system of two stars, the more massive of which is surrounded by a large nebula.

Although supernovae imposters such as Eta Carinea are now known to occur in other galaxies, this event – known as the Great Eruption – appeared relatively close to Earth at a distance of around 7500 light years. It is therefore a perfect laboratory in which to study what exactly happens when stars appear to survive a supernova.

The fate of Eta Carinae has remained mysterious, but since the turn of the millennium clues have emerged in echoes of the light emitted during the Great Eruption. While the light observed in the 19th century travelled directly from the system towards Earth, other light initially travelled towards distant clouds surrounding the stars before being reflected in our direction. In 2003, the light echoes from this event were bright enough to be observed using the moderate-sized telescopes at the Cerro Tololo Inter-American Observatory in Chile, while the different gas clouds reflecting the light were observed more recently using the larger scale Magellan Observatory and the Gemini South Observatory, also located in Chile. By comparing historical records of the variability observed in the 19th century with the variability of the light reflected from a gas cloud, it can be determined how far in the past astronomers are observing the explosion.


NASA

A Hubble Space Telescope image of Eta Carinae using a combination of image-processing techniques, showing a huge pair of gas and dust clouds.

Now, a team led by Nathan Smith of the University of Arizona in Tucson has studied the spectra of the light echo in more detail using the 6.5 m Magellan telescopes and found that it matches observations during the 1840s and 1850s, when the Great Eruption was at its peak. Spectral analysis of the reflected light indicates that initially matter was ejected at relatively low velocities of 150–200 km^{-1}, while during the 1850s some matter was travelling at speeds of 10,000–20,000 km^{-1}. The data are compatible with a system that first ejects material as one star brightens followed by more violent ejection from an explosion.

Smith and collaborators claim that the scenario which best matches the data, including information about the age and mass of the two remaining stars, is that the system originally consisted of three stars. The two closest stars initially interacted to form one massive star, while the donor star moved further away, losing mass and thereby increasing the radius of its orbit around the massive star. The gravitational field of the far-away donor star would have caused the orbiting third star to dramatically change orbit, forcing it to spiral into the massive central star. In doing so, its gravitational interactions with the massive star caused it to shed large amounts of matter as it started to burn brighter. Finally, the binary system merged, causing a violent explosion where large amounts of stellar material were ejected at large velocities towards the earlier ejected material. As the fast ejecta smashed into the slower moving ejecta, a bright object was formed on the night sky that was visible for many years during the 1850s. The remaining binary system still lights up every few years as the old donor star moves through the nebula left over from the merger.

The new details about the evolution of this complex and relatively nearby system not only teach us more about what was observed by Herschel almost two centuries ago, but also provide valuable information about the evolution of massive stars, binary and triple systems, and the nature of the supernovae imposters.

Further reading

N Smith *et al.* 2018 *MNRAS* **480** 1457.

N Smith *et al.* 2018 *MNRAS* **480** 1466.

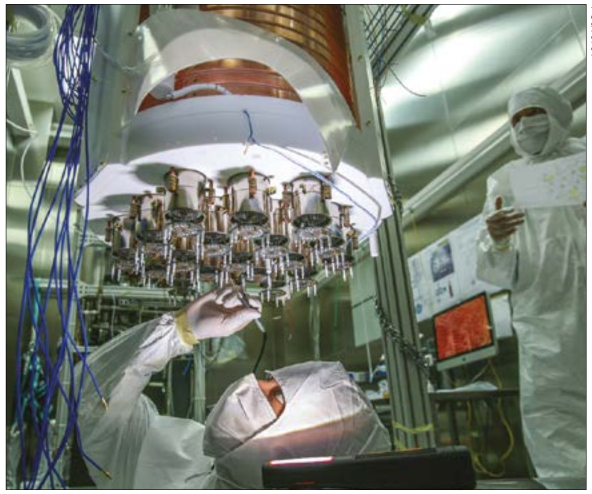
Picture of the month

This image of the Andromeda galaxy, the closest neighbouring major galaxy to our Milky Way, is disturbed by a bright green line. The line is a result of a meteor the size of a grain of sand entering the Earth's atmosphere during the Perseid meteor shower visible every August. The meteor can be seen to flare several times as it travels through the atmosphere for only a fraction of a second. The green colour is the result of the meteor vaporising in the Earth's atmosphere. As both the atmosphere and the meteor itself glow, different colours can be created. The green colour observed here hints that the meteor contains large amounts of nickel.


Fritz Helmut Hemmerich

Defeating the background in the search for dark matter

A global effort is under way to carry out a complete search for high-mass dark-matter particles using an experiment called DarkSide-20k and its successor, which rely on novel liquid-argon technologies.



Y Suvorov

Inspecting photomultiplier tubes for the DarkSide-50 detector.

Compelling cosmological and astrophysical evidence for the existence of dark matter suggests that there is a new world beyond the Standard Model of particle physics still to be discovered and explored. Yet, despite decades of effort, direct searches for dark matter at particle accelerators and underground laboratories alike have so far come up empty handed. This calls for new and improved methods to spot the mysterious substance thought to make up most of the matter in the universe.

Dark-matter searches using detectors based on liquefied noble gases such as xenon and argon have long demonstrated great discovery potential and continue to play a major role in the field. Such experiments use a large volume of material in which nuclei struck by a dark-matter particle would create a tiny burst of scintillation light, and the very low expected event rate requires that backgrounds are kept to a minimum. Searches employing argon detectors have a particular advantage because they can significantly reduce events from background sources, such as background from the abundant radioactive decays from detector materials and from electron scattering by solar neutrinos. That will leave the low-rate nuclear recoils induced by coherent scattering of atmospheric neutrinos as the sole residual background – the so-called "neutrino floor".

Enter the Global Argon Dark Matter Collaboration (GADMC), which was formed in September 2017. Comprising more than 300 scientists from 15 countries and 60 institutions involved in four first-generation dark-matter experiments – ArDM at Laboratorio Subterráneo de Canfranc in Spain, DarkSide-50 at INFN's Laboratori Nazionali del Gran Sasso (LNGS) in Italy, DEAP-3600 and MiniCLEAN at SNOLAB in Canada – GADMC is working towards the immediate deployment of a dark-matter detector called DarkSide-20k. The experiment would accumulate an exposure of 100 tonne × year and be followed by a much larger detector to collect more than 1000 tonne × year, both potentially with no instrumental background. These experiments promise the most complete exploration of the mass/parameter range of the present dark-matter paradigm.

Argon-based dark-matter searches have had a number of successes in the past two years.

Direct detection with liquid argon

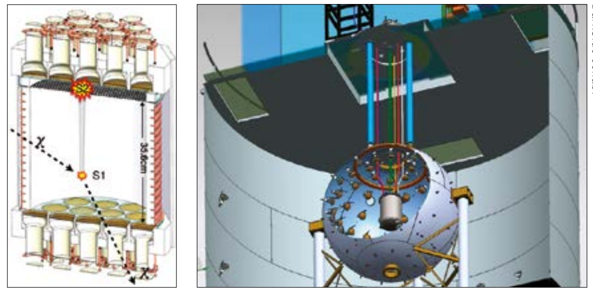
One well-considered form of dark matter that matches astronomical measurements is weakly interacting massive particles (WIMPs), which would exist in our galaxy with defined numbers and velocities. In a dark-matter experiment employing a liquid-argon detector, such particles would collide with argon nuclei, causing them to recoil. These nuclear recoils produce ionised and excited argon atoms which, after a series of reactions, form short-lived argon dimers (weakly bonded molecules) that decay and emit scintillation light. The time profile of the scintillation light is significantly different from that created by argon-ionising events associated with radioactivity in the detector material, and has been shown to enable a strong rejection of background sources through a technique known as pulse-shape discrimination.

Located at LNGS, DarkSide-50 is the first physics detector of the DarkSide programme for dark-matter detection, with a fiducial mass of 50 kg. The experiment produced its first WIMP search results in December 2014 using argon harvested from the atmosphere and, in October the following year, reported the first ever WIMP search results using lower-radioactivity underground argon.

DarkSide-50 uses a detection scheme based on a dual-phase time projection chamber (TPC), which contains a small region of gaseous argon above a larger region of liquid argon (figure 1, left). In this configuration, secondary scintillation light, generated by ionisation electrons that drift up through the liquid region and are accelerated into the gaseous one, are used together with the primary scintillation light to look for a signal. Compared to single-phase detectors using only the pulse-shape discrimination technique, this search method requires even greater care in restricting the radioactive background through detector design and fabrication but provides excellent position resolution. For low-mass (<10 GeV/c²) WIMPs, the primary scintillation light is nearly absent, but the detectors remain sensitive to dark matter through the observation of the secondary scintillation light.

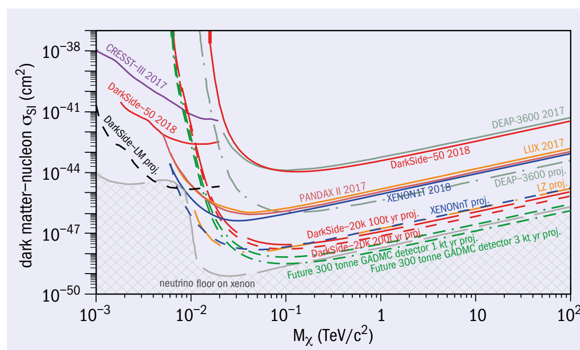
Argon-based dark-matter searches have had a number of successes in the past two years (figure 2). DarkSide-50 established the availability of an underground source of argon strongly depleted in the radioactive isotope ^{39}Ar, while DEAP-3600 (figure 3), the largest (3.3 tonnes) single-phase liquid-argon running experiment, provided the best value to date on the precision of pulse-shape discrimination for scintillation light, better than 1 part in 10^9. In terms of measurements, DarkSide-50 released results from a 500-day detector exposure completely free of instrumental background and set the best exclusion limit yet for interactions of WIMPs with masses between 1.8 and 6 GeV/c². Similar results to those from Darkside-50 for the mass region above 40 GeV/c² were reported in the first paper from DEAP-3600, and results from a one-year exposure of DEAP-3600 with a fiducial mass of about 1000 kg are expected to be released in the near future.

High-sensitivity searches for WIMPs using noble-gas dual-phase TPC detectors are complementary to searches conducted at the Large Hadron Collider (LHC) in the mass region accessible at the current LHC energy of 13 TeV (which is limited to masses of a few TeV/c²) and can reach masses of 100 TeV/c² and beyond with very good sensitivity.



DarkSide collab.

Fig. 1. (Left) In a dual-phase TPC, scintillation light (S1) is produced by the bombardment of an argon molecule by a dark-matter particle, upon which electrons drift upwards to a second chamber to produce electro-luminescence (S2); the distribution of S2 light gives the lateral position, while the time difference between S1 and S2 gives the longitudinal position. (Right) Schematic of DarkSide-50 inside a spherical 30-tonne organic liquid scintillator veto, which itself is contained in a 1000 tonne Cherenkov cosmic-ray veto.



DarkSide collab.

Fig. 2. Current limits on WIMP dark matter, showing the expected sensitivity from the DarkSide programme (red and green).

Leading limits

The best limits to date on high-mass WIMPs have been provided by xenon-based dual-phase TPCs – the leading result given by the recently released XENON1T exposure of 1 tonne × year (figure 2). In spite of a small residual background, they were able to exclude WIMP-nucleon spin-independent elastic-scatter cross-sections above 4.1×10^{-47} cm² at 30 GeV/c² at 90% confidence level (*CERN Courier* July/August 2018 p9). Larger xenon detectors (XENONnT and DARWIN) are also planned by the same collaboration (*CERN Courier* March 2017 p35).

The next generation of xenon and argon detectors have the potential to extend the present sensitivity by about a factor of 10. But there is still a further factor of 10 to be increased before one reaches the neutrino floor – the ultimate level at which interactions of solar and atmospheric neutrinos with the detector material become the limiting background. This is where the GADMC liquid-argon detectors, which are designed to have pulse-shape discrimination capable of eliminating the background from electron scatters of solar neutrinos and internal radioactive decays, can provide an advantage.

CERN plays an important role in DarkSide-20k.

GADMC envisages a two-step programme to explore high-mass dark matter. The first step, DarkSide-20k, has been approved for construction at LNGS by Italy's National Institute for Nuclear Physics (INFN) and by the US National Science Foundation, with present and potentially future funding from Canada. Also a recognised experiment at CERN called RE-37, DarkSide-20k is designed to collect an exposure of 100 tonne × year in a period of five years (to be possibly extended to 200 tonne × year in 10 years), completely free of any instrumental background. The start of data taking is foreseen for 2022–2023. The second step of the programme will involve building an argon detector that is able to collect an exposure of more than 1000 tonne × year. SNOLAB in Canada is a strong candidate to host this second-stage experiment.

Argon can deliver the ultimate background-free search for dark matter, but that comes with extensive technological development. First and foremost, researchers need to extract and distill large volumes of the gas from underground deposits, as argon in the Earth's atmosphere is unsuitable owing to its high content of the radioactive isotope ^{39}Ar. Second, the scintillation light has to be efficiently detected, requiring innovative photodetector R&D.

M Ward

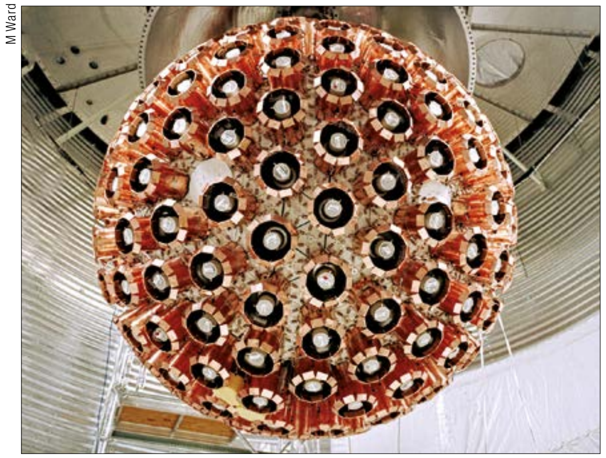


Fig. 3. The DEAP-3600 detector during construction showing the sphere of inward-looking photomultipliers used for light detection.

CERN-PHOTO-201711-287-5

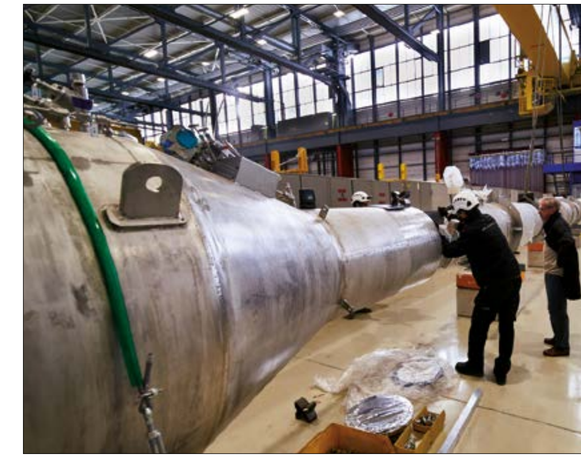


Fig. 4. The ARIA modules for purifying liquid argon being tested at CERN.

Sourcing pure argon

Focusing on the first need, atmospheric argon has a radioactivity of 1 Bq/kg, which is entirely caused by the activation of ^{40}Ar by cosmic rays. Given that the drift time of ionisation electrons over a length of 1 m is 1 ms, a dual-phase TPC detector reaches a complete pile-up condition (i.e. when the event rate exceeds the detector's ability to read out the information), at a mass of 1 tonne. Scintillation-only detectors do not fare much better, and given that the scintillation lifetime is 10 µs, they are limited to detectors with a fiducial mass of a few tonnes. The argon road to dark matter has thus required early concentration on solving the problem of procuring large batches of argon that are much more depleted in ^{39}Ar than atmospheric argon is. The solution came through an unlikely path: the discovery that underground sources of CO_2 originating from Earth's mantle carry sizable quantities of noble gases, in reservoirs where secondary production of ^{39}Ar is significantly suppressed.

As part of a project called Urania, funded by INFN, GADMC will soon deploy a plant that is able to extract underground argon at a rate of 250 kg per day from the same site in Colorado, US, where argon for DarkSide-50 was extracted. Argon from this underground source is more depleted in ^{39}Ar than atmospheric argon by a factor of at least 1400, making detectors of hundreds of tonnes possible for high-mass WIMP searches.

Not content with this gift of nature, another project called ARIA, also funded by INFN, by the Italian Ministry of University and Research (MIUR), and by the local government of the Sardinia region, is developing a further innovative plant to actively increase the depletion in ^{39}Ar. The plant will consist of a 350 m-tall cryogenic-distillation tower called Seruci-I, which is under construction in the Monte Sinni coal mine in Sardinia operated by the Carbosulcis mining company. Seruci-I will study the active depletion of ^{39}Ar by cryogenic distillation, which exploits the tiny dependence of the vapour pressure upon the atomic number. Seruci-I is expected to reach a production capacity of 10 kg of argon per day with a factor of 10 of ^{39}Ar depletion per pass. This is more than sufficient to deliver – starting from the gas extracted with the Urania underground source – a one-tonne ultra-depleted-argon target that could enable a leading programme of searches for low-mass dark matter. Seruci-I is also expected to perform strong chemical purification at the rate of several tonnes per day and will be used to perform the final stage of purification for the 50 tonne underground argon batch for DarkSide-20k as well as for GADMC's final detector.

CERN plays an important role in DarkSide-20k by carrying out vacuum tests of the 30 modules for the Seruci-I column (figure 4) and by hosting the construction of the cryogenics for DarkSide-20k. At the time of its approval in 2017, DarkSide-20k was set to be deployed within a very efficient system of neutron and cosmic-ray rejection, based on that used for DarkSide-50 and featuring a large organic liquid scintillator detector hosted within a tank of ultrapure deionised water. But with the deployment of new organic scintillator detectors now discouraged at LNGS due to tightening environmental regulations, GADMC is completing the design of a large, and more environmentally friendly, liquid-argon detector for neutron and cosmic-ray rejection based on the cryostat technology developed at CERN to support prototype detector modules for the future Deep Underground Neutrino Experiment (DUNE) in the US.

Turning now to the second need of a background-free search for dark matter – the efficient detection of the scintillation light – researchers are focusing on perfecting existing technology to make low-radioactivity silicon photomultipliers (SiPMs) and using them to build large-area photosensors that are capable of replacing the traditional 3″ cryogenic photomultipliers. Plans for DarkSide-20k settled on the use of so-called NUV-HD-TripleDose SiPMs, designed by Fondazione Bruno Kessler of Trento, Italy, and produced by LFoundry of Avezzano, also in Italy. In the meantime, researchers at LNGS and other institutions succeeded in overcoming the huge capacitance per unit surface (50 pF/mm^2) required to build photosensors that have an area of 25 cm^2 and deliver a signal-to-noise ratio of 15 or larger. A new INFN facility, the Nuova Officina Assergi, was designed to enable the high-throughput production of SiPMs to make such photosensors for DarkSide-20k and future detectors, and it is now under construction.

GADMC's programme is complemented by a world-class effort to calibrate noble-liquid detectors for low-energy nuclear recoils created by low-mass dark matter. On the heels of the SCENE programme that took place at the University of Notre Dame Tandem accelerator in 2013–2015, the R&D programme, developed at the University of Naples Federico II and now installed at the INFN Laboratori Nazionali del Sud, plans to improve the characterisation of the argon response to nuclear recoils. Of special interest is the extension of measurements to 1 keV, in support of searches for low-mass dark matter, and the verification of the possible dependence of the nuclear-recoil signals upon the direction of the initial recoil momentum relative to the drift electric field, which would enable measurements below the neutrino floor. Directionality in argon has already been established for alpha particles, protons and deuterons, and its presence for nuclear recoils was hinted at by the last results of the SCENE experiment.

Although only recently established, GADMC is enthusiastically pursuing this long-term, staged approach to dark-matter detection in a background-free mode, which has great discovery potential extending all the way to the neutrino floor and perhaps beyond.

Further reading

DEAP-3600 Collaboration 2018 *Phys. Rev. Lett.* **121** 071801.
DarkSide Collaboration 2018 *Phys. Rev. Lett.* **121** 111303.
DarkSide Collaboration 2018 *Phys. Rev. Lett.* **121** 081307.
DarkSide Collaboration 2018 *Eur. Phys. J. Plus* **133** 131.

Résumé

Traquer la matière noire sans bruit de fond

Des laboratoires de plusieurs pays à travers le monde unissent leurs forces en vue d'une future expérience, DarkSide-20k, qui mènera la quête la plus complète jusqu'ici pour trouver des particules de matière noire de masse élevée. Établie au Laboratoire national du Gran Sasso (Italie), l'expérience utilisera des détecteurs à argon liquide de pointe afin d'éliminer les sources de bruit de fond et d'accroître ainsi la sensibilité aux particules de matière noire. Pour répondre aux besoins de DarkSide, des technologies pour l'extraction de l'argon purifié sont actuellement développées en partenariat avec le CERN. Un groupe de travail appelé Global Argon Dark Matter Collaboration *et consacré à ce projet a été créé en septembre 2017 et travaille au déploiement imminent du détecteur.*

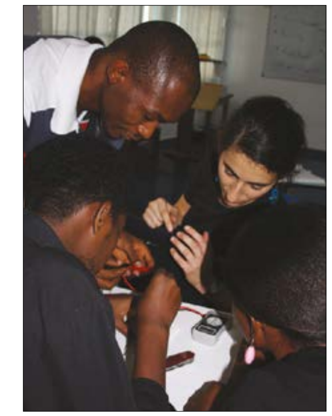
Giuliana Fiorillo, University of Naples Federico II and INFN Napoli; **Art McDonald**, Queen's University; and **Cristiano Galbiati**, Princeton University and Gran Sasso Science Institute.

Empowering Africa's youth to shape its future

Established 15 years ago, the African Institute for Mathematical Sciences (AIMS) has seen nearly 2000 students in mathematics and physics from 43 nations graduate as part of a pan-African model for sustainable development.

B Döbrich

S Meehan



B Döbrich

AIMS South Africa

Clockwise from top left: the quantum-mechanics class of 2015, South Africa; a tutorial at the South Africa centre delivered by Samuel Meehan (left, and coauthor of this article); a discussion about measurement coordinated by Babette Döbrich (right, and coauthor of this article); the AIMS logo; the AIMS South Africa graduates of 2017–2018; and the AIMS final party at the South Africa centre.

It was 2001 and Neil Turok, a cosmologist at the University of Cambridge at the time, was on sabbatical in his home town of Cape Town, South Africa. At dinner one evening, his father, who himself was a member of the first South African congress following the end of apartheid in 1994, posed the question: what will you do for Africa? Two years later, Turok founded the African Institute for Mathematical Science (AIMS), with the mission to improve mathematics and science education throughout the African continent. The first centre, in 2003 at a derelict resort hotel in the small surfer town of Muizenberg, just south of Cape Town, saw 12 students graduate. Since that time, AIMS has grown to span the whole continent, with five more centres founded in Tanzania, Ghana, Senegal, Cameroon and most recently in Rwanda. The centres have produced almost 2000 graduates and form part of a pan-African and global network of mathematicians and physicists called the Next Einstein Initiative (NEI), a number of whom work in high-energy physics experiments at CERN and elsewhere.

Africa is a continent filled with potential, rich in natural resources and with a population that is projected to comprise nearly 50% of the world population before the end of the century. But it is also a continent plagued by problems that hinder development and success, particularly in mathematics and science (figure 1). More people there die each year from AIDS and civil war than anywhere else in the world, and access to quality education at all levels is tenuous, at best. The mission of AIMS and NEI is to address these issues by empowering Africa's brightest students and propelling them towards scientific, educational and economic self-sufficiency.

Worldmapper

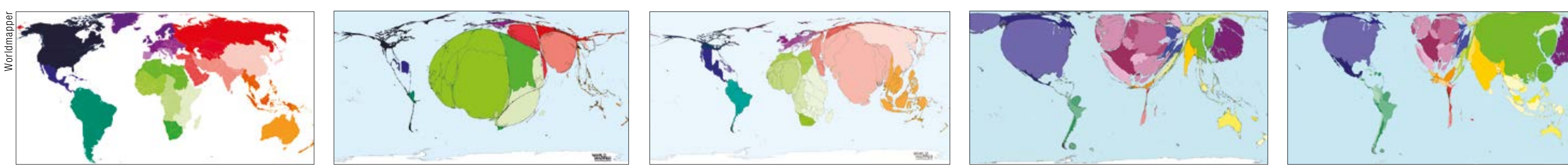


Fig. 1. (From left) normal-scaled map of the world compared to four rescaled maps with areas proportional to: lack of primary education; lack of access to universities; number of peer-reviewed publications produced; and economic output. Source: https://worldmapper.org.

The AIMS curriculum

The primary way that AIMS contributes to this transformation is an intensive one-year master's programme that runs from August to June each year. Preparations begin well in advance, starting in January when lecturers from around the world submit proposals to teach three-week courses at one of the six centres. In parallel, students from all over Africa apply and are selected through a very competitive process, with upwards of 2000 students vying for around 50 spots at each centre. The goal of both sets of applications, for lecturers as well as students, is to ensure that the very best people are brought together.

The course is highly structured. For the first 10 weeks, students attend a series of skills courses with an emphasis on problem solving and computing. The curriculum then enters a review phase, where students elect to follow two courses for every three-week block. The courses are dynamic, selected by the academic director of each centre every year and then taught by (mostly foreign) lecturers, who have complete freedom to write the course as they so choose. The beauty of such a curriculum is the diverse set of topics that can be taught side-by-side, which allows students to sample new topics – a day that begins with a course on financial mathematics could end with students writing a simulation for computational neuroscience. Three weeks later, the courses change and students can find themselves immersed in knot theory or Monte Carlo methods in particle physics.

This cadence continues for 18 weeks, during which time the students are able to build connections with academics from around the world and find the course that suits them best. This builds to the final portion of the course, called the essay phase, in which students identify a mentor and a project from a list of proposed topics. The student then works independently for a period of 10 weeks under the supervision of a mentor, culminating in a thesis essay and oral examination. If this fast-paced academic course were not enough, the entire course is taught in English, which for many students is not their first language. Adding to their workloads, students are taught courses in English and writing throughout.

Strong support

Unlike many institutions, success at AIMS is limited only by a student's will to achieve. All fees are paid by AIMS, as well as the costs of relocating, accommodation and food. Each student is provided with a personal computer (which for many students is the first computer they have ever owned) and a team of five to 10 academic tutors are hired to support the students in their studies and augment the lectures when necessary. This all ensures that the complete focus of the student can be on their studies and development as an academic.

The result is a nearly 100% success rate, with more than 30% of graduates being female and AIMS graduates representing 43 out of 54 African nations. These students most often go on to enter research master's and PhD programmes in Africa and elsewhere, their university education having been in some way validated through the standards set by AIMS and the international institutions that support it. However, nearly all AIMS graduates eventually desire to return to Africa, whether it be in industry or research, thus contributing to their home nation. Some alumni even return to the school as lecturers themselves. Ultimately, the goal of AIMS and NEI is to establish 15 centres throughout Africa by 2030 and to establish a sustainable pan-African academic culture.

A lecturer's perspective

To offer a first-hand account of a typical day as a lecturer, it's 19:00 and you have just sent the last e-mail of the day. Dusk is welcome since it promises to relieve some of the heat. If you're in Biriwa, Ghana, you make sure to close the window and put on some mosquito repellant. There was a student in your class who excused himself yesterday for not completely finishing his homework. He has Malaria. He's working a lot anyhow and he'll be better soon, but you would be completely knocked out if you caught it. As you are about to close the laptop, you hear someone at the door: it is your students, waiting for their ad-hoc evening tutorial. Teaching at AIMS is a full-day immersion. Finding students discussing your lecture, assignments or books that you showed them is not uncommon, even after midnight.

Your average AIMS student is inquisitive, hard-working and passionate, and the vastly different academic backgrounds of students in your class will force you to have to answer questions from very basic to very advanced levels. One day, a student might be "angry" because you told them that morning how light is both a wave and a particle. After the first days of shyness (many students have never been encouraged to state their own opinion over a science matter), they'll question what you say, and clearly it is not possible that a thing is a wave but also a particle, is it?!

Don't expect to spend your evening not doing physics unless you really need a break, in which case take a walk on the beach or, if you're at the Muizenberg centre in South Africa, grab a surfboard. For those of you familiar with CERN, the parallel that might best explain the AIMS atmosphere is the "Bermuda triangle" of Restaurant 1, the hostel and your office: you can manage to spend weeks there before breaking out and spending some time to explore Geneva, the Jura, and the world around you. AIMS students are ambitious and grateful for the opportunity to work and learn, so they can easily spend their days between the lecture room, the canteen and the computer lab without leaving the building once. As an AIMS lecturer, it is thus good to come prepared for a few extra-curricular activities. This could range from showing students how to swim in the shallow waters of the Indian Ocean in Bagamoyo, taking them on an all-day hike to Table Mountain in Cape Town, or an extra tutorial on how to write a good application or give a talk, not to mention a discussion about how to shape Africa's future. Topics such as how a woman can be a president in some countries (or a physics lecturer for that matter!) are sure to attract the attention of all students, even those not directly in your class.

The last few days of your three-week lecture block are the most special. Students give presentations on topics that go beyond what your lecture contains, having spent every free minute preparing. Building confidence in the student's mind is your most important mission at AIMS, and the students have every reason to be confident. Most of them had to fight to get a good education that is taken for granted in many countries, and they all want to make an impact in building Africa's future. After the student's talks, the ceremony and party starts. Lecturers are bid farewell, and you may well be handed a traditional African costume to be dressed properly for the party. Then, with some exceptionally gifted dancers taking the lead, you'll not be let go before at least attempting to move gracefully to the latest African pop-music, all without a single drop of alcohol in sight.

Back at your workplace, AIMS stays with you. Many students will keep you updated on their career, seek a reference letter from you, or eventually join you as researcher.

Becoming involved with AIMS is for anyone who is interested in working with some of the best students in the world, most of whom have had to fight hard to get there. There are a variety of options. For those with master's degrees in mathematics and science, it is possible to serve as an academic tutor at an AIMS institute for a period of one year, during which time you will work closely with students as a mentor and act as a bridge between the shorter term lecturers. For those with PhD degrees, it is possible to act as either an essay supervisor or a lecturer. In both instances, the topic of instruction is designed by you, giving you control and flexibility to tailor the course to your interests and expertise. In whatever capacity you decide to become involved, it is an opportunity you will not regret.

• Further reading

www.nexteinstein.org.
https://aims.ac.za.

Résumé

Le futur de l'Afrique entre les mains des jeunes

Depuis sa création il y a quinze ans, l'Institut africain des sciences mathématiques (AIMS), qui s'inscrit dans un projet panafricain pour le développement durable, a décerné des diplômes en mathématiques et en physique à près de 2 000 étudiants de 43 pays. L'AIMS propose un programme de master intensif d'un an, qui se déroule chaque année d'août à juin. Si vous êtes un scientifique titulaire d'un doctorat et que ce projet vous intéresse, vous pouvez venir enseigner à l'AIMS et ainsi travailler avec certains des meilleurs étudiants du monde. Le choix des sujets d'enseignement est libre, et, quelle que soit la forme que prendra votre participation, vous ne regretterez pas d'avoir saisi cette occasion.

Babette Döbrich, CERN, and **Samuel Meehan**, University of Washington.

Student case study: Lijoka Oluwaseun from Nigeria graduated from AIMS-Ghana in 2013

"We never know what we will become at the start of life until we get to a certain destination. I have had a continuous form of education, but at each level I started at one institution and completed it at a better one, either by transfer or scholarship. As a result, I have attended many institutions across Africa and beyond. Each has had an impact, from the competitive mentality acquired at Aquinas College to the spirit of self-discipline at the Federal University of Technology Akure in Nigeria. However, AIMS has taught me a different approach to life and academia. I discovered the spirit of learning together through discussions and collaborating with colleagues, and realised that there is more gain in knowledge, discovery and results when colleagues collaborate. Also at AIMS, I was subjected to the rigorous theoretical discipline of mathematics as well as the practical aspects of the physical sciences. Unlike many Nigerian universities, AIMS is a 24/7 learning environment equipped with many facilities and the best lecturers from around the world. Many of these lecturers are now role models in different areas of my academic life. I am now a PhD student at the University of Lethbridge, Canada. I believe that I have not yet reached my destination in terms of academic career, but AIMS has given me a blueprint to academic success, an impactful ideology and the fortitude to overcome challenges."

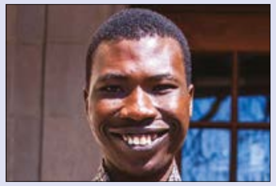
Student case study: Arnaud Andrianavalomahefa from Madagascar graduated from AIMS-South Africa in 2015

"I received a full scholarship from AIMS to undertake postgraduate studies in mathematical sciences in South Africa. It was a crucial turning point in the course of my life. Education in Madagascar lacks means and infrastructure, and remains barely accessible for the average person, despite free public universities. This is where AIMS kicks in, giving students access to a high educational standard regardless of their financial means, and even removing the traditional language barrier. AIMS is an intensive 10-month-long boot camp for maths lovers; physicists, engineers, biologists, or chemists... all gathered in one place. But AIMS is also a family where diverse cultures meet, greet, might clash and often fuse, resulting in a lively and lovely social dynamic. During my year at AIMS I had the opportunity to collaborate with international experts at the frontier of science, and part of my work dealt with the quark–gluon plasma. Being further seduced by particle physics, after graduating successfully from AIMS I decided to embark on another master's programme and was accepted by Durham University in the UK. I am now halfway through a PhD at the Karlsruhe Institute of Technology, Germany, working on dark matter – another topic inspired by an AIMS lecturer. Studying abroad was definitely something I could not have afforded, and the role of AIMS in making that possible is unquantifiable."

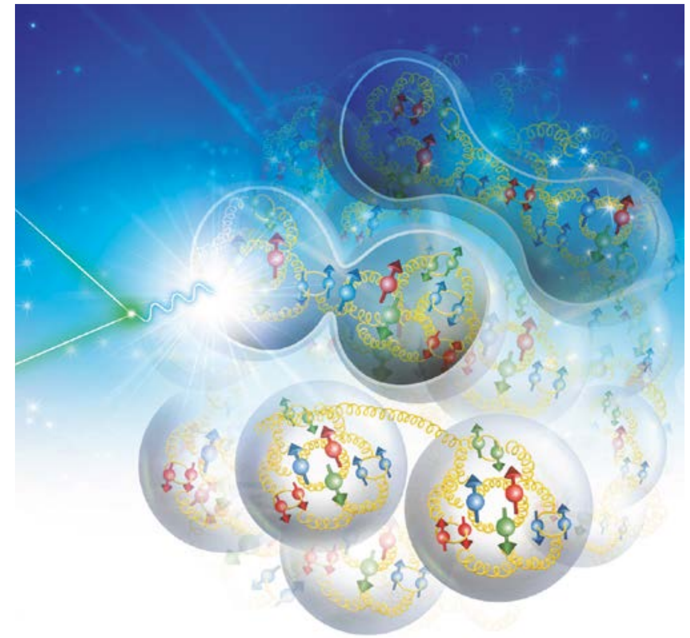
Student case study: Chilufya Mwewa from Zambia graduated from AIMS-South Africa in 2012

"As a child growing up in Zambia, my dream was to pursue a career in medical science. However, my aptitude in physics and mathematics was clearly higher than it was in chemistry and biology and, after performing poorly in my first year of undergraduate studies, I decided to pursue a career in physics. I had no idea where this path would take me. A career in physics was shunned in the society in which I grew up, as it was not seen as a prestigious and rewarding career, so initially I chose medical physics. At this point, I had lost hope and my sense of direction; I was simply moving with the wind! Then, in my final year of undergraduate studies, I attended the African school of Physics (ASP) where I heard about CERN and where my fascination with particle physics began. It was also at ASP that a friend told me about AIMS, and I applied the following year. Lectures in particle physics were presented with great enthusiasm and I decided to pursue a master's in particle physics at the University of Cape Town. It was during my master's that I came to CERN for the very first time as a summer student. The experience was like nothing I had ever dreamed of, and it led to a PhD studentship within the ATLAS experiment where I work on the "New Small Wheel" project and also in the Standard Model electroweak subgroup. AIMS has connected me to the world."

Student case study: Adebayo Adeleke from Nigeria graduated from AIMS-South Africa in 2015



"I had a first-class bachelor's degree in physics/telecommunication from the Federal University of Technology Minna, Nigeria, before applying to AIMS, where I bagged a master's degree in mathematical science. I heard about AIMS from my former supervisor at the Federal Polytechnic Offa in Nigeria, just as I was making the critical decision to change field from pure to computational theoretical physics. AIMS exposed me to an international level of education, and my experience was deep and full of fun. The rigour in the way AIMS modules were delivered is world class, supported by dedicated and experienced tutors, which makes learning easier and less challenging. AIMS opened new opportunities for my academic career: I received three fully-funded offers (two in South Africa and one in Canada) for a research master's before I had completed the course. Beyond that, AIMS also supported me financially to take up the study in my preferred institution – the University of Saskatchewan, Canada. AIMS has influenced and shaped my career in a positive way, and I am currently in the second year of my PhD programme, for which I am the recipient of the Gerhard Herzberg Memorial Scholarship in Physics for 2018/2019. My thesis is in computational design of functional and high-energy-density materials. I can say with certainty that AIMS launched me into the international academic community and even supported me in finding my feet afterwards."



Electron–ion collider on the horizon

The National Academy of Sciences in the US finds a compelling scientific case for an advanced collider that would reveal how visible matter emerges from fundamental quarks and gluons.

Protons and neutrons, the building blocks of nuclear matter, constitute about 99.9% of the mass of all visible matter in the universe. In contrast to more familiar atomic and molecular matter, nuclear matter is also inherently complex because the interactions and structures in nuclear matter are inextricably mixed up: its constituent quarks are bound by gluons that also bind themselves. Consequently, the observed properties of nucleons and nuclei, such as their mass and spin, emerge from a complex, dynamical system governed by quantum chromodynamics (QCD). The quark masses, generated via the Higgs mechanism, only account for a tiny fraction of the mass of a proton, leaving fundamental questions about the role of gluons in nucleons and nuclei unanswered.

The underlying nonlinear dynamics of the gluon's self-interaction is key to understanding QCD and fundamental features of the strong interactions such as dynamical chiral symmetry breaking and confinement. Despite the central role of gluons, and the many successes in our understanding of QCD, the properties and dynamics of gluons remain largely unexplored.

Positive evaluation

To address these outstanding puzzles in modern nuclear physics, researchers in the US have proposed a new machine called the Electron Ion Collider (EIC). In July this year, a report by the National Academies of Sciences, Engineering, and Medicine commissioned by the US Department of Energy (DOE) positively endorsed the EIC proposal. "In summary, the committee finds a compelling scientific case for such a facility. The science questions (see "EIC's scientific goals: in brief") that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today. In addition, the development of an EIC would advance accelerator science and technology in nuclear science; it would also benefit other fields of accelerator-based science and society, from medicine through materials science to elementary particle physics."

From a broader perspective, the versatile EIC will, for the first time, be able to systematically explore and map out the dynamical system that is the ordinary QCD bound state, triggering a new area of study. Just as the advent of X-ray diffraction a century ago triggered tremendous progress in visualising and understanding the atomic and molecular structure of matter, and as the introduction of large-scale terrestrial and space-based probes in the last two to three decades led to precision observational cosmology with noteworthy findings, the EIC is foreseen to play a similarly

Image credit: Jefferson Lab.

EIC's scientific goals: in brief

An electron–ion collider would answer core questions about strongly interacting matter:

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties emerge from quark and gluon interactions?
- How do colour-charged quarks and gluons, and colourless jets, interact with a nuclear medium? How do confined hadronic states emerge from quarks and gluons? How do quark–gluon interactions create nuclear binding?
- How does a dense nuclear environment affect quarks and gluons, their correlations, and their interactions? What happens to the gluon density in nuclei: does it saturate at high energy, giving rise to gluonic matter with universal properties in all nuclei, even the proton?

BNL

JLab

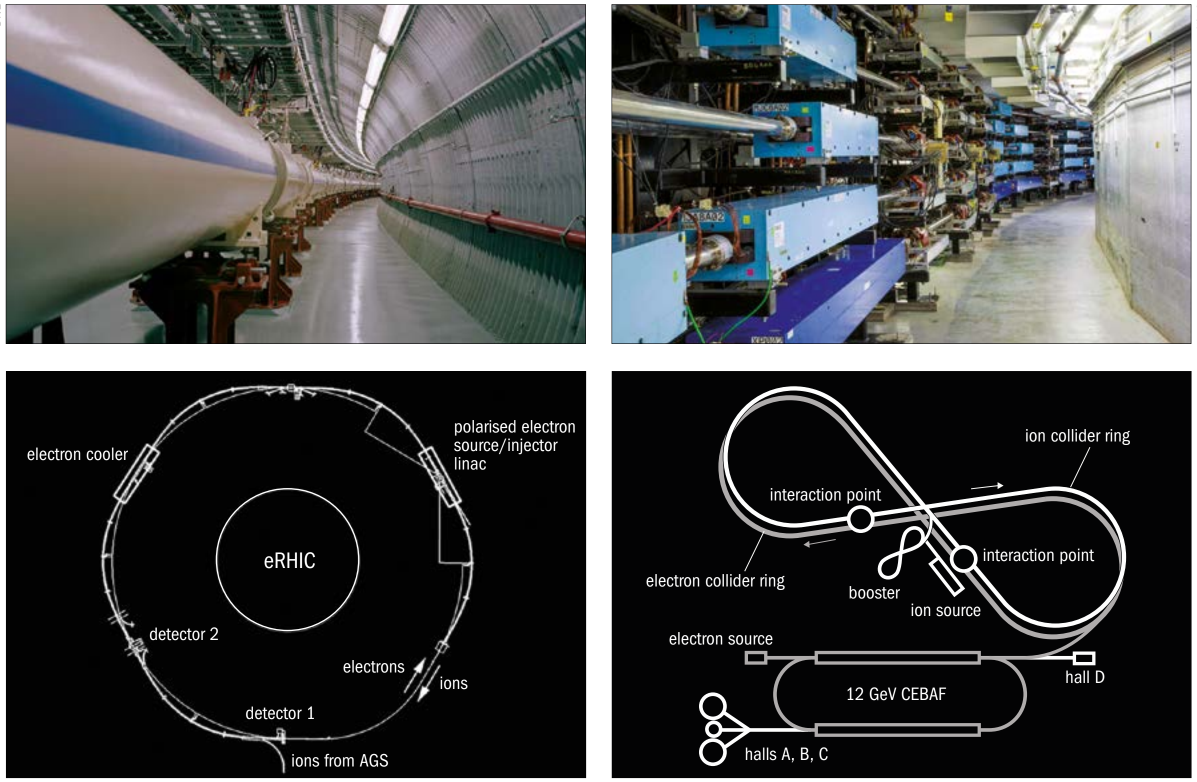


Fig. 1. Two US labs are bidding to host the EIC: Brookhaven National Laboratory, which would add an electron storage ring to its RHIC facility (left), and Jefferson Lab, which would use its upgraded CEBAF complex as an electron injector (right).

transformative role in our understanding of the rich variety of structures at the subatomic scale.

Two pre-conceptual designs for a future high-energy and high-luminosity polarised EIC have evolved in the US using existing infrastructure and facilities (figure 1). One proposes to add an electron storage ring to the existing Relativistic Heavy-Ion Collider (RHIC) complex at Brookhaven National Laboratory (BNL) to enable electron–ion collisions. The other pre-conceptual design proposes a new electron and ion collider ring at Jefferson Laboratory (JLab), utilising the 12 GeV upgraded CEBAF facility (*CERN Courier* March 2018 p19) as the electron injector. The requirement that the EIC has a high luminosity (approximately $10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$) demands new ways to "cool" the hadrons, beyond the capabilities of current technology. A novel, coherent electron-cooling technique is under development at BNL, while JLab is focussing on the extension of conventional electron cooling techniques to significantly higher energy and to use bunched electron beams for the first time. The luminosity, polarisation and cooling requirements are coupled to the existence and further development of high brilliance (polarised) electron and ion sources, benefitting from the existing experience at JLab, BNL and collaborating institutions.

The EIC is foreseen to have at least two interaction regions and thus two large detectors. The physics-driven requirements on the EIC accelerator parameters, and extreme demands on the kinematic coverage for measurements, makes it particularly challenging to integrate into the interaction regions of the main detector and dedicated detectors along the beamline in order to register all particles down to the smallest angles. The detectors would be fully integrated in the accelerator over a region of about 100 m, with a secondary focus to even detect particles with angles and rigidities near the main ion beams. To quickly separate both beams into their respective beam lines while providing the space and geometry required by the physics programme, both the BNL and JLab pre-conceptual designs incorporate a large crossing angle of 20–50 mrad. This achieves a hermetic acceptance and also has the advantage of avoiding the introduction of separator dipoles in the detector vicinity that would generate huge amounts of synchrotron radiation. The detrimental effects of this crossing angle on the luminosity and beam dynamics would be compensated by a crab-crossing radio-frequency scheme, which has many synergies with the LHC high-luminosity upgrade (*CERN Courier* May 2018 p18).

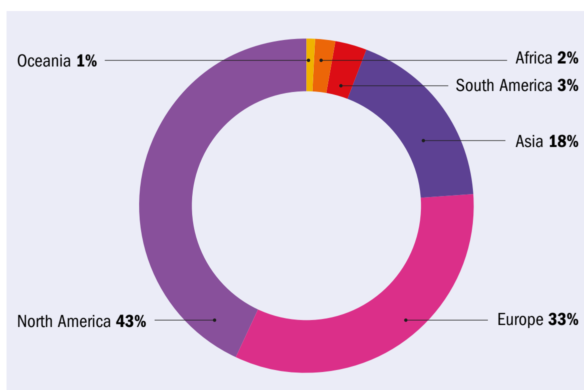


Fig. 2. Distribution per continent of institutions that are members of the EIC user group.

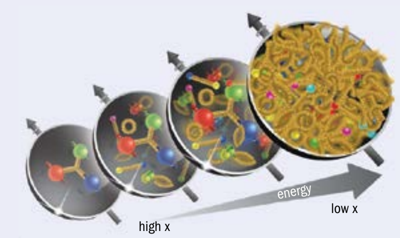
Nuclear femtography to delve deep into nuclear matter

The way in which a nucleon or nucleus reveals itself in an experiment depends on the kinematic regime being probed. A dynamic structure of quarks and gluons is revealed when probing nucleons and nuclei at higher energies, or with higher resolutions. Here, the nucleon transforms from a few-body system with its structure dominated by the three valence quarks to a regime where it is increasingly dominated by gluons generated through gluon radiation, as discovered at the former HERA electron–proton collider at DESY. Eventually, the gluon density becomes so large that the gluon radiation is balanced by gluon recombination, leading to nonlinear features of the strong interaction.

From the LHC and RHIC we learned that neutrons and protons bound inside nuclei already exhibit the collective behaviour that reveals QCD substructure under extreme conditions, as initially seen with heavy-ion collisions. This has triggered widespread interest in the study of the strong force in the context of condensed matter physics, and the understanding that the formation and evolution of this extreme phase of QCD matter is dominated by the properties of gluons at high density.

An electron–ion collider (EIC) will open up the unique opportunity to go far beyond the present one-dimensional picture of nuclei and nucleons, where the composite nucleon appears as a bunch of fast-moving (anti-)quarks and gluons whose transverse momenta or spatial extent are not resolved. Specifically, by correlating the information of the quark and gluon longitudinal momentum component with their transverse momentum and spatial distribution inside the nucleon, it will enable nuclear "femtography". Such femtographic images will provide, for the first time, insight into the QCD dynamics inside hadrons, such as the interplay between sea quarks and gluons. The ultimate goal is to experimentally reconstruct and constrain the so-called Wigner functions – the quantities that encode the complete tomographic information and constitute a QCD "genetic map" of nucleons and nuclei. The proposed centre-of-mass energies of the EIC (20–100 GeV, upgradable to 140 GeV) are strongly linked to the scales of transverse momentum and spatial distributions to probe in nucleons and nuclei, of the order Λ_{QCD}, and hence do not require an energy-frontier machine such as the LHC.

Investigating gluons in nuclei instead of protons has multiple advantages. One is that they act as an efficient amplifier of the physics of high gluon densities, which enhances the impact of nonlinear gluon interactions and possibly leads to gluon saturation, also known as the colour glass condensate. An EIC has the potential to map the transition from a linear to a nonlinear regime in QCD and characterise the relevant parameters governing this transition. Using polarisation, an EIC can also make quark and gluon femtographic maps of the deuteron in its dumbbell and doughnut shapes – revealing whether this nuclear structure impacts the quark–gluon polarisation or quark-flavour dependence of nucleon properties.



The internal quark and gluon structure of the proton grows more complex when probed at increasing centre-of-mass energies. (Credit: BNL.)

Modern particle detector and readout systems will be at the heart of the EIC, driven by the demand for high precision on particle detection and identification of final-state particles. A multipurpose EIC detector needs excellent hadron–lepton–photon separation and characterisation, full acceptance, and to go beyond the requirements of most particle-physics detectors when it comes to identifying pions, kaons and protons. This means that different particle-identification technologies have to be integrated over a wide rapidity range in the detector to cover particle momenta from a couple of 100 MeV to several tens of GeV. To address the demands on detector requirements, an active detector R&D programme is ongoing, with key technology developments including large, low-mass high-resolution tracking detectors and compact, high-resolution calorimetry and particle identification.

The path ahead

A high-energy and high-luminosity electron–ion collider capable of a versatile range of beam energies, polarisations and ion species is the only tool to precisely image the quarks and gluons, and their interactions, and to explore the new QCD frontier of strong colour fields in nuclei – to understand how matter at its most fundamental level is made. In recognition of this, in 2015 the Nuclear Science Advisory Committee (NSAC), advising the DOE, and the National Science Foundation (NSF) recommended an EIC in its long-range plan as the highest priority for new facility construction. Subsequently, a National Academy of Sciences (NAS) panel was charged to review both the scientific opportunities enabled by an EIC and the benefits to other fields of science and society, leading to the report published in July.

The NAS report strongly articulates the merit of an EIC, also citing its role in maintaining US leadership in accelerator science. This could be the basis for what is called a Critical Decision-0 or Mission Need approval for the DOE Office of Science, setting in motion the process towards formal project

R&D, engineering and design, and construction. The DOE Office of Nuclear Physics is already supporting increased efforts towards the most critical generic EIC-related accelerator research and design.

But the EIC is by no means a US-only facility (figure 2). A large international physics community, comprising more than 800 members from 150 institutions in 30 countries and six continents, is now energised and working on the scientific and technical challenges of the machine. An EIC users group (www.eicug.org) was formed in late 2015 and has held meetings at the University of California at Berkeley, Argonne National Laboratory, and Trieste, Italy, with the most recent taking place at the Catholic University of America in Washington, DC in July. The EIC user group meetings in Trieste and Washington included presentations of US and international funding agency perspectives, further endorsing the strong international interest in the EIC. Such a facility would have capabilities beyond all previous electron-scattering machines in the US, Europe and Asia, and would be the most sophisticated and challenging accelerator currently proposed for construction in the US.

Further reading

National Academies of Sciences, Engineering, and Medicine 2018 doi: 10.17226/25171.

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Résumé

Un collisionneur électron-ion se profile à l'horizon

Des académies nationales américaines ont souligné le très grand intérêt scientifique qu'aurait un collisionneur électron-ion de pointe capable de révéler comment la matière se forme à partir de quarks et de gluons. Deux pré-études de conception ont été proposées, l'une au Laboratoire national de Brookhaven et l'autre au Laboratoire Jefferson. Les exigences pour un accélérateur de ce type repousseraient les frontières de la technologie actuelle. Tout comme la diffraction des rayons X, qui a conduit, il y a un siècle, à des progrès considérables dans la visualisation de la structure atomique et moléculaire de la matière, un collisionneur électron-ion pourrait marquer un tournant dans notre compréhension de la QCD et des caractéristiques fondamentales de l'interaction forte.

Elke-Caroline Aschenauer, Brookhaven National Laboratory, and **Rolf Ent,** Jefferson Lab.

Faces & Places

APPOINTMENT

New director for particle physics at RAL

Dave Newbold from the University of Bristol has been appointed director of the particle physics department for the UK's Science and Technology Facilities Council (STFC), based at the Rutherford Appleton Laboratory (RAL) in Oxfordshire. Previously head of particle physics at the University of Bristol, Newbold is a member of the CMS collaboration and currently leads the UK's CMS upgrade programme. He is also trigger and data-acquisition coordinator for the international Deep Underground Neutrino Experiment based in the US. Succeeding Dave Wark of the University of Oxford, Newbold took up the new position at RAL in September.

Funded and managed by the STFC, RAL supports the UK particle physics programme by providing capabilities that complement and go beyond what can be done in individual universities. The laboratory recently marked its 60th anniversary (*CERN Courier* March 2018 p46) and comprises more than 1000 researchers, engineers and technicians working across a number of areas. It currently hosts two major research facilities – the ISIS neutron and muon source and the Central Laser Facility – and is a Tier-1 node of the CERN–UK distributed computing grid, GridPP.

D Newbold

Dave Newbold took up his new role at Rutherford in September.

Among his goals as director of the particle physics department, Newbold intends to focus on integrating RAL more closely with UK universities and to strengthen relations with CERN and other international laboratories. "RAL particle physics has a world-class team, backed with all the facilities of the national lab," he says. "With LHC upgrade construction now starting, we have an intense few years of activity coming up across the UK institutes – we'll be supporting that, and developing plans for a number of new projects in particle physics. I'm looking forward to the challenge."

AWARDS

Friedrich Wilhelm Bessel award for Higgs phenomenology

Theorist Michael Spannowsky of the Institute for Particle Physics Phenomenology at Durham University in the UK has been awarded a Friedrich Wilhelm Bessel Research Award in recognition of his work on Higgs-boson phenomenology.

The award recognises a recipient's outstanding research record and covers a number of disciplines, not just physics. The Alexander von Humboldt Foundation grants about 20 awards per year and winners receive funding to enable them to spend up to a year collaborating on a long-term research project with colleagues at a German institution.

Durham University

Michael Spannowsky of Durham University.

Spannowsky's research has contributed to the design of novel reconstruction and analysis strategies to improve measurements of the top- and bottom-quark Yukawa couplings and the Higgs self-interaction. He will use his award to collaborate with colleagues at the University of Tübingen in southwest Germany on research into dark matter and Higgs phenomenology.

NSREC accolade for radiation paper

Federico Faccio from CERN has received the Outstanding Conference Paper Award for the 2017 IEEE Nuclear and Space Radiation Effects Conference (NSREC), as lead author of the paper titled "Influence of LDD spacers and H^+ transport on the total ionising-dose response of 65 nm MOSFETs irradiated to ultra-high doses". The prestigious award was presented at this year's NSREC, which took place in Kona, Hawaii, on 16–20 July.

D Bushmire

Faccio (far left) together with co-authors from the other collaborating institutes.

The paper (doi:10.1109/TNS.2017.2760629), which summarises the work of a collaborative effort between CERN and the universities of Padova, Salento, Udine and Vanderbilt, marks an important contribution to the understanding of how radiation influences the behaviour of modern CMOS processes. Faccio leads a small team of experts at CERN studying radiation effects in microelectronics, for instance identifying commercially available processes for use in the extreme radiation environment of the LHC detectors.

Swiss Physical Society presents annual awards

Swiss Physical Society

Clockwise from top left: Lavinia Heisenberg (on right, with SPS president Hans Peter Beck), Roland Horisberger (right), Maurice Bourquin, and Claudia Tambasco (on right, with Adrian Signer, chair of the CHIPP Prize committee).

At its 2018 annual meeting, held at École Polytechnique Fédérale de Lausanne (EPFL) on 28–31 August, the Swiss Physical Society (SPS) recognised the achievements of four researchers working in the area of high-energy physics.

Theorist Lavinia Heisenberg, a junior fellow at ETH Zurich, was presented with the ABB General Physics Prize "for her pioneering and essential contributions to alternative theories of gravity". Heisenberg studies the fundamental properties of field theories, their cosmological consequences and possible signatures, with the aim of comparing general relativity with alternative theories of gravity.

The Charpak-Ritz Prize 2018, granted jointly by the SPS and the French Physical Society, was presented to Roland Horisberger of the Paul Scherrer Institute at the Journées de la Matière Condensée in Grenoble on 27 August for his extensive work development of precision silicon vertex detectors. Horisberger made important contributions to the silicon microstrip detector for the DELPHI experiment at CERN's Large Electron Positron Collider, the H1-central vertex detector at DESY's HERA collider, and the pixel detector for the CMS experiment at the Large Hadron Collider (LHC). He has also successfully transferred novel detector technologies, such as PILATUS pixel detectors, to the field of synchrotron science.

Accelerator physicist Claudia Tambasco of EPFL received the 2018 Swiss Institute of Particle Physics (CHIPP) Prize for PhD research that improved the understanding of the stability of proton beams in the LHC. In her thesis work she measured the Landau damping of the LHC beams, a process that reduces beam losses caused by interactions between the proton beam and the vacuum pipe. The results led to a proposal that increased the integrated luminosity, and have also been applied to future colliders such as the FCC.

Finally, Maurice Bourquin of the University of Geneva, who in 2001 was elected as the first and so-far-only Swiss president of the CERN Council, was made an honorary member of the SPS. Bourquin was recognised for his enormous scientific achievements in particle and astroparticle physics, his extraordinary commitment in science policy at CERN and at Swiss universities implementing the Bologna Reform, and also for his far-sighted commitment to the promotion of future thorium-based nuclear reactors.

Meetings

Particle interactions up to the highest energies

The 20th International Symposium on Very High Energy Cosmic Ray Interactions (ISVHECRI 2018) was held in Nagoya, Japan, on 21–25 May. More than 120 attendees from 19 countries discussed various aspects of hadronic interactions at the intersection between high-energy cosmic-ray physics and classical accelerator-based particle physics. The 65 contributions reflected the large diversity and interdisciplinary character of this biennial series, which is held under the auspices of the International Union of Pure and Applied Physics.

In his opening address, Sunil Gupta paid a tribute to Oscar Saavedra, one of the leading scientists and founders of the ISVHECRI series, who passed away in 2018. Following the long tradition of this symposium series, the main topic was the discussion of particle physics of relevance to extensive air showers, secondary cosmic-ray production, and hadronic multi-particle production at accelerators. This time, the symposium expanded its coverage of multi-messenger astrophysics, especially to neutrino and gamma-ray astrophysics. Many talks were invited from the Pierre Auger Observatory and Telescope Array, as well as from IceCube, Super-Kamiokande, CTA and HAWC, and space-borne experiments such as AMS-02, Fermi and CALET.

Participants discussed how many open questions in high-energy astroparticle physics are related to our understanding of cosmic-ray interactions from the multi-messenger point of view; for example, the relevance of production and propagation of positrons or antimatter for indirect dark-matter searches, or of atmospheric-neutrino production for neutrino oscillations or neutrino astronomy. ▷

A Minamizaki

The participants of the ISVHECRI 2018 symposium, which took place in Nagoya in Japan.

Showcasing several models of high-energy cosmic-ray interactions, and their verification by accelerator measurements, was also a highlight of the symposium. The event offered a unique opportunity for developers of major cosmic-ray interaction models to gather and engage in valuable discussions. Other highlights were the talks about accelerator data relevant to cosmic-ray observations, reported by the teams behind CERN's large LHC experiments as well as smaller fixed-target experiments such as NA61. Emphasis was put on forward measurements by ATLAS, CMS, LHCb and LHCf, including first results from the SMOG gas-jet target measurements of LHCb (see p15).

A public lecture, "Exploring the Invisible Universe" by Nobel Laureate Takaaki Kajita, attracted more than 250 participants, which was complemented by a tour of the nuclear emulsion lab of Nagoya University to see state-of-the-art emulsion technology. The progress in this technology was clearly visible when Edison Shibuya and others recalled the early days of studying cosmic rays with emulsion chambers and Saavedra's related pioneering contributions.

There were many discussions on future studies of relevance to cosmic-ray interactions and astroparticle physics. Hans Dembinski discussed prospects in the near and far future in collider experiments, including possible proton–oxygen runs at the LHC and a study of multi-particle production at a future circular collider. The cosmic-ray community is very enthusiastic about a future proton–oxygen run since, even with a short run of 100 million events, charged particle and pion spectra could be measured to an accuracy of 10% – a five-fold improvement over current model uncertainties that would bring us a crucial step closer to unveiling the cosmic accelerators of the highest energy particles in the universe.

The next ISVHECRI will be held in June 2020 at Ooty, the location of the GRAPES air-shower experiment in India.

● *Yoshitaka Itow, Nagoya University, and Ralph Engel (KIT, Karlsruhe).*

Higgs hunters meet up in Orsay and Paris

L Fayard

The Higgs Hunting 2018 workshop participants.

The 9th Higgs Hunting workshop took place in Orsay and Paris on 23–25 July, attracting 120 physicists for lively discussions about recent results in the Higgs sector. The ATLAS and CMS collaborations presented results based on up to 80 fb^{-1} of data recorded at an energy of 13 TeV, which corresponds to almost all the data that has been taken so far at the LHC. The statistical uncertainty on some measured properties of the Higgs boson, such as the production cross-section, is now almost three times smaller with the 13 TeV data than it was after LHC Run 1 at energies of 7 and 8 TeV, and in several cases the overall uncertainty is reaching a point at which the systematic uncertainty becomes dominant.

Several searches for phenomena beyond the Standard Model, in particular for additional Higgs bosons, were presented. No significant excess above background expectations was reported. The historical talk was given by Lyn Evans, who served as the project leader of the LHC. The last day of the event was devoted to the physics potential of the High Luminosity LHC and possible future colliders, in view of the upcoming update of the European strategy for particle physics. The last session was chaired by Halina Abramowicz, the strategy secretary for the update.

The next Higgs Hunting workshop will be in Orsay and/or Paris from 29 to 31 July 2019.

● *Louis Fayard, Laboratoire de l'Accélérateur Linéaire.*

Göttingen hosts HASCO summer school

This year's Hadron Collider Physics Summer School (HASCO 2018) took place on 22–27 July in Göttingen, Germany, marking the seventh consecutive year that this dynamic and international school, primarily aimed at master's students, has been offered.

This year, 40 undergraduate students from 18 different institutes in 12 countries came together for a week to learn about hadron-collider physics. The nine lecturers also came from a variety of institutes throughout the world. The students learnt about the foundations of quantum field theory and hadron-collider physics, particularly in the context the Large Hadron Collider (LHC).

At the HASCO school, numerous research topics are discussed, among them quantum chromodynamics, jet physics, statistical methods in data analysis, accelerator physics, detector physics, top-quark physics and searches for supersymmetry or exotic models and particles. The focus was on the physics of the Higgs boson and the new opportunities that come with the high-statistics data sample being recorded during the LHC's 13 TeV run.

Almost all participating students passed the written examination at the end of the school and received three European Credit Transfer System points, for which they can obtain course credits at their home universities.

● *Stan Lai and Arnulf Quadt, University of Göttingen.*

C Nellist

The HASCO 2018 students.

Research infrastructures event brings particle physics into focus

The 4th International Conference on Research Infrastructures (ICRI 2018), held in Vienna on 12–14 September, offered a forum for discussions about international cooperation for research infrastructures (RIs), with participants from more than 50 countries taking part. During an intense programme, participants drafted a roadmap to inform Europe's policy and investment in RIs, with CERN's director for international relations, Charlotte Warakaulle, offering a glimpse of the organisation's plans and ongoing R&D for future colliders and detectors. The new ESFRI 2018 roadmap was presented, including a "landmark" portfolio of 37 long-term engagements in all fields of science and 18 projects.

During the event, a new exhibition "CODE of the Universe" also made its first international stop. The exhibition (pictured) addresses open questions in physics and the role of particle accelerators both in fundamental research and as concrete applications. It is organised by CERN, the Institute of High Energy Physics (HEPHY), the Natural History Museum of Vienna and publisher Edition Lammerhuber. A public event was hosted on the evening of the same day, bringing together scientists, entrepreneurs and politicians to discuss: "Research: Why does it matter to me?" Participants included former CERN Director-General Rolf Heuer and George Bednorz, who shared the 1987 Nobel Prize in Physics for the discovery of high-temperature superconductivity.

● *Panos Charitos, CERN.*

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The ICRI 2018 conference featured a new photography exhibition.

OUTREACH

CERN is guest of honour at Swiss National Day

On 1 August, CERN was the City of Geneva's guest of honour at the Swiss National Day celebrations. Many thousands of visitors had the opportunity to learn about the laboratory's activities via workshops, virtual-reality tours, physics demonstrations, educational games and a new "Particle Identities" quiz. Participants also visited the CERN Data Centre via virtual-reality headsets.

CERN-PHOTO-201808-185-7

OUTREACH

Packed house for CHEP public event

A large and enthusiastic crowd attended "Universal Science," a public event preceding the International Conference on Computing for High Energy and Nuclear Physics (CHEP), in Sofia, Bulgaria, on 8 July. With the three-part theme of research, computing and diversity, tickets for the event sold out well before deadline, and overflow had to be accommodated through online participation.

Such an outreach event is not typical for CHEP, a conference that focuses on specialised topics such as distributed computing, event reconstruction, data handling and virtualisation. This year's organising committee, however, saw it as an opportunity to reach out to the local public and to foster open discussion on the impact of particle-physics research on society. Similar events have grown in popularity at other major conferences, such as ICHEP, EPS and LHCP, and the particle-physics-computing community has become increasingly engaged in public outreach.

Hands-on exhibits, including interactive virtual-reality displays, entertained and informed the audience. Andreas Salzburger, a physicist on the ATLAS experiment, kicked off the evening with a short talk on the motivation for and history of particle physics. This was followed by talks on diversity by Lee Bitsoi of Stony Brook University and on the growth of distributed computing by CERN computer engineer Hannah Short. Talks were followed by a panel discussion generating a barrage of questions from both the local audience and those connecting via Facebook Live. The event was organised by CHEP, Ratio, IPPOG, Brookhaven National Lab, ATLAS and Belle II.

● *Steven Goldfarb, University of Melbourne.*

N Kasioumis

Audience Q&A with the scientific panel (from left): Steven Goldfarb, Andreas Salzburger, Lee Bitsoi, and Hannah Short.

OBITUARIES

Joachim Kupsch 1939–2018

Eminent mathematical physicist Joachim Kupsch passed away in Heidelberg, Germany, on 19 June aged 78. He made wide-ranging contributions to scattering theory and elementary particle physics, quantum field theory and infinite-dimensional analysis, Fermionic integration and supersymmetry, not to mention open systems and decoherence. He also had many collaborators, most of them from Germany. His work, always characterised by mathematical rigour and scholarly exposition, includes three books. The last – *Quantum Fields and Processes: A combinatorial approach* (Cambridge University Press) came out in March 2018.

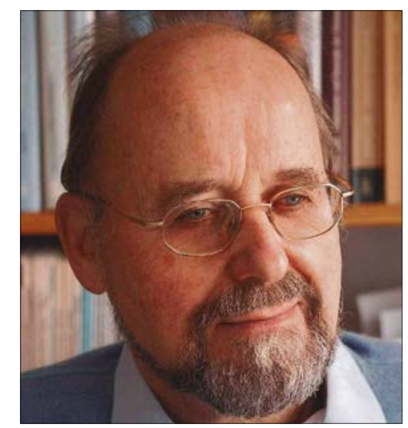
Joachim received his diploma in physics from the University of Köln in 1966 and embarked on a postdoc at the University of Bonn. He worked on analytic scattering theory during his tenure as a CERN fellow from 1968 to 1970, where he was influenced deeply by André Martin. After postdoctoral work and habilitation at the University of Heidelberg (1970–1973), Joachim secured a permanent position at the University of Kaiserslautern from 1973 to 2005 and then became an emeritus professor. During 1985–1986 he visited CERN many times, and until 2008 had guest-professor positions in China (Beijing and Shanghai), Portugal (Lisbon) and India (Mumbai, Chennai, Pune and Delhi).

One of the outstanding results of the analytic S-matrix theory is the Froissart–Martin bound, which sets an upper limit (equal to a constant times the square of the logarithm of energy) on the total cross section of a two-particle scattering process. It was first derived by Marcel Froissart in 1961 assuming Mandelstam representation with a finite number of subtractions; and was rigorously proved by Martin in 1966 using only unitarity and analyticity properties following from axiomatic field theory, in particular the analyticity of the absorptive part in the Lehmann–Martin ellipse. The question was whether it was possible to construct scattering amplitudes that saturate this bound and obey fundamental analyticity constraints?

In 1968, David Atkinson pioneered the theoretical construction of pion–pion scattering amplitudes obeying Mandelstam representation, crossing symmetry and elastic unitarity in the elastic region, and the inelastic unitarity inequalities in the inelastic region. Atkinson obtained an amplitude with a total cross section decreasing at high energies. Joachim joined this research with full vigour. After persevering for nearly 12 years, and after many intermediate results, he constructed a pion–pion amplitude saturating the Froissart–Martin bound, and obeying Mandelstam analyticity, crossing symmetry and inelastic unitarity in the inelastic region. The result is significant because the bound appears to be saturated at the LHC. An essential ingredient in his proof is the Auberson–Kinoshita–Martin theorem. Perhaps Joachim's efforts in 1970 did not succeed because this theorem was not yet published. The main constraint not yet incorporated in Joachim's 1982 construction is elastic unitarity in the elastic region.

Joachim died in the arms of Sigrid Kupsch-Losereit, his beloved wife of 45 years. His friends knew him to be a warm, soft spoken, affable and kind person; he will be sorely missed for both his academic and human qualities.

● *Shasanka Roy, Tata Institute of Fundamental Research, with input from André Martin and Sigrid Kupsch-Losereit.*



Joachim Kupsch made wide-ranging contributions to scattering theory.

Bert Diddens 1928–2018

On 28 August, following a short period of sickness, our friend and colleague Bert Diddens passed away at the respectable age of 90. He was one of the veterans in CERN's proud history of particle physics and the first scientific director of the Dutch high-energy physics institute Nikhef.

Bert was born in the province of Groningen, in the north of the Netherlands. It is a region where people tend to be straightforward and down-to-earth, and Bert fitted that description very well, even up to his last days when telling his family that he didn't want flowers at his funeral, as the money could be better spent on science. But behind this demeanour he was a gentle and sensitive person, loyal to his friends and colleagues. He remained interested in the sciences throughout his life, regularly visiting the Nikhef library to stay informed. This was illustrated by his always to-the-point comments when the jury consisting of him and all other former Nikhef directors deliberated on what was the best PhD thesis of the past year.

Bert studied physics at the University of Groningen, where he also received his PhD. The experimental work that led to it, however, was done in Leiden, where he studied gamma radiation from oriented cobalt and manganese nuclei using low-temperature techniques. After his PhD he joined the small group of physicists at the University of Liverpool in the UK, which served as a warm-up for CERN's first experimental programme. He worked on proton–proton scattering at the university's synchrotron, a topic that remained a thread throughout his early career.


Diddens family

Bert Diddens was the first scientific director of Nikhef.

In 1963 with Giuseppe Cocconi and Alan Wetherell, later joined by Jim Allaby, he formed a group to study proton–proton scattering at the Proton Synchrotron. The experiment revealed that the slope of the diffraction peak shrinks with increasing energy. A few years later, with Alan and Jim, he initiated an experiment at Serpukhov to study particle production and the total hadron–hadron cross section at the then-highest proton energy of 70 GeV. In 1970, with CERN's Intersecting Storage Rings being constructed, Bert with his CERN colleagues joined Ugo Amaldi and Giorgio Matthiae of the Rome-ISS group to design an experiment to study small-angle proton–proton scattering, introducing a novel technique that later became known as "Roman Pots". Just before he was asked in 1975 to become the first scientific director of the high-energy physics section of Nikhef, Bert turned to neutrino physics when his CERN team joined Klaus Winter in the CHARM (CERN–Heidelberg–Amsterdam–Rome–Moscow) experiment.

As a director at Nikhef he was responsible for shaping its first experimental programme, of which CHARM became a valuable part. As Nikhef did not yet have its own building, Bert had the responsibility to make sure that the design and construction of a new laboratory fitted the ambitions of the Dutch high-energy physics community. The success of today's Nikhef is to a large extent determined by these first developments. When Nikhef had to decide which experiments to join at the Large Electron Positron collider (LEP), it was obvious that DELPHI would be one of them, extending into the LEP era the amicable bonds with his former CERN colleagues. He actively participated in the experiment after his directorship came to an end in 1983 and was the thesis supervisor for many PhD students of both DELPHI and CHARM.

We will all remember Bert Diddens with the greatest respect as a wonderful person, an excellent physicist and a key figure in establishing Nikhef as an important player in the international community of high-energy physics institutes.

● *His friends and colleagues.*

Francis Farley 1920–2018

Francis Farley, who played a pivotal role in experiments to measure the anomalous magnetic moment of the muon, passed away on 16 July at his home in the south of France at the age of 97.

The son of a British Army engineering officer, Francis was born in India and educated in England. Before he could complete his education, he transferred to military research and worked on radar, developing his knowledge of electronics and demonstrating his abilities in innovation. Following a secondment to Chalk River Laboratories in Ontario, Canada, he resumed his formal education with a PhD in 1950 from the University of Cambridge, before starting his academic career at Auckland University in New Zealand. During his time at Auckland, he studied cosmic rays; represented New Zealand at a United Nations conference on atomic energy for peaceful purposes; measured neutron yields from plutonium fission (whilst on secondment to Harwell, UK); and wrote his first book *Elements of Pulse Circuits*.

In 1957 Francis joined CERN, where he started his long and remarkable journey on experiments to measure the anomalous magnetic moment of the muon (muon g-2). This endeavour would span nearly five decades and four major experiments, three at CERN and one at Brookhaven National Laboratory (BNL) in the US. The initial result from the first experiment had an accuracy of just 2%, whereas

the final result from the last experiment reached 0.5 parts per million. Each experiment was at the time seen as a tour de force, and the measurement added an important restraint on the imaginations of theorists. It was also striking that each new measurement was within the error limits of the previous ones.

Many other people, including various highly renowned physicists, contributed to this long effort, but Francis is the sole common author, making seminal contributions to all of the experiments. The first experiment was performed on the initiative of Leon Lederman, a CERN visitor at the time, at CERN's first accelerator, the 600 MeV Synchrocyclotron. The other members of the noteworthy team on this experiment were Georges Charpak, Richard Garwin, Theo Muller, Hans Sens and Antonino Zichichi. By the time of the second experiment, CERN's Proton Synchrotron was operating and the second and third experiments were performed there – taking advantage of the higher-energy muons that the accelerator provided. Francis alone continued onto these experiments, but among others joining the experiments was Emilio Picasso. Later Francis, again alone, continued as a member of the most recently completed g-2 experiment at BNL. In the spirit of always looking for major improvements, it is noteworthy that in his review paper "The 47 years of muon g-2", written with Yannis Semertzidis, a totally new structure for a muon storage ring is suggested, should greater accuracy be justified for a future experiment.

The first experiment showed that the muon was a "heavy electron", the second validated electron loops in the photon propagator, and the third showed the contribution from virtual hadron loops. Each measurement has spurred theoretical physicists to include more and more effects in their calculations of the muon magnetic moment: higher-order corrections in quantum electrodynamics, first-order and then higher-order hadronic and electroweak contributions. These advances in the theoretical prediction in turn justified the next generation of experiment, to give an even more stringent test of theory. The muon storage rings also allowed tests of relativistic time dilation, with the third experiment achieving an accuracy of 0.1% for a "muon clock" moving at a speed of 0.9994c and the most accurate test of the "twin paradox".

During the 1970s, when he was again based in the UK and Dean of The Royal Military College of Science, Francis also started to do research in wave energy. This work continued through his retirement, in parallel to the work on g-2. In this area too, he established a formidable reputation, with many papers written and patents produced over a period of 40 years. Indeed, his most recent paper on wave energy was published just a few days after his death.


OPEN-PHO-LIFE-2013-002-1

Farley made seminal contributions to the measurement of the muon magnetic moment.

Early in his retirement, he designed the beam transport system for a proton-therapy system at a cancer hospital, which was still being used more than 20 years later. He also published a special-relativistic single-parameter analysis of data on redshifts of type 1A supernovae that showed no evidence for acceleration or deceleration effects. Even more recently, he worked on other tests of relativity based on analysis of data from the muon g-2 experiments.

He received many honours, including election to a fellow of the Royal Society and the Hughes Medal for his work at CERN on g-2.

Outside of work, Francis had a passion for flying gliders, was a keen skier and windsurfer, a regular swimmer, and liked large American cars. All of these befitted a hardworking but somewhat playboy image, that years later formed much of the basis of his novel *Catalysed Fusion*.

Francis was a wonderful source of new ideas and insights, with a prodigious output. He was always enthusiastic, and he could be charming but forceful, and a stickler for precision.

He will be much missed.

● *His friends and colleagues.*

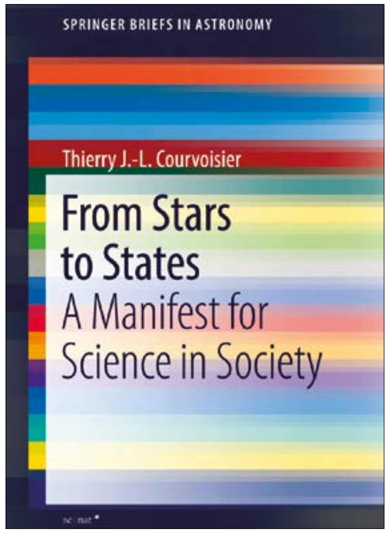
Bookshelf

Compiled by Virginia Greco, CERN

From Stars to States: A Manifest for Science in Society

By Thierry Courvoisier

Springer



This book is a curiosity, but like many curiosities, well worth stumbling across. It is the product of a curious, roving mind with a long and illustrious career dedicated to the exploration of nature and the betterment of society. Pieced together with cool scientific logic, it takes the reader from a whistle-stop tour of modern astronomy through the poetry collection of Jocelyn Bell-Burnell, to a science-inspired manifesto for the future of our planet. After an opening chapter tracing the development of astronomy from the 1950s to now, subsequent chapters show how gazing at the stars, and learning from doing so, has brought benefit to people from antiquity to modern times across a wide range of disciplines.

Astronomy helped our ancestors to master time, plant crops at the right moment, and navigate their way across wide oceans. There's humour in the form of speculation about the powers of persuasion of those who convinced the authorities of the day to build the great stone circles that dot the ancient world, allowing people to take time down from the heavens. These were perhaps the Large Hadron Colliders of their time, and, in Courvoisier's view, probably took up a considerably larger fraction of ancient GDP (gross domestic product) than modern scientific instruments. John Harrison's remarkable clocks are given pride of place in the author's discussion of time, though the perhaps even more remarkable Antikythera mechanism is strangely absent.

By the time we reach chapter three, the beginnings of a virtuous circle linking basic science to technology and society are beginning to appear, and we can start to guess where Courvoisier is taking us. The author is not only an emeritus professor of astronomy at the University of Geneva, but also a former president of the Swiss Academy of Sciences and current president of EASAC, the European Academies Science Advisory Council. For good measure, he is also president of the H Dudley Wright Foundation, a charitable organisation that supports science communication activities, mainly in French-speaking Switzerland. He is, in short, a living, breathing link between science and society.

In chapter four, we enjoy the cultural benefits of science and the pleasure of knowledge for its own sake. We have a glimpse of what in Swiss German is delightfully referred to as Aha Erlebnis – that eureka moment when ideas just fall into place. It reminded me of the passage in another curious book, Kary Mullis's *Dancing Naked in the Mindfield*, in which Mullis describes the Aha Erlebnis that led to him receiving the Nobel Prize in Chemistry in 1993. It apparently came to him so strongly out of the blue on a night drive along a California freeway that he had to pull off the road and write it down. Einstein's famous 1% inspiration may be rare, but what a wonderful thing it is when it happens.

CERN is the resulting evidence for the good that comes when science and policy come together.

Chapter five begins the call to action for scientists to take up the role that their field demands of them in society. "We still need to generate the culture required to […] bring existing knowledge to places where it can and must contribute to actions fashioning the world." Courvoisier examines the gulf between the rational world of science and the rather different world of policy – a gulf once memorably described by Lew Korwarski in his description of the alliance between scientists and diplomats that led to the creation of CERN. "It was a pleasure to watch the diplomats grapple with the difference between a cyclotron and a plutonium atom," he said. "We had to compensate by learning how to tell a subcommittee from a working party, and how – in the heat of a discussion – to address people by their titles rather than their names. Each side began to understand the other's problems and techniques; a mutual respect grew in place of the traditional mistrust between egg-headed pedants and pettifogging hair-splitters." CERN is the resulting evidence for the good that comes when science and policy come together.

As we reach the business end of the book, we find a rallying call for strengthening our global institutions, and here another of Courvoisier's influences comes to the fore. He's Swiss, and a scientist. Scientists have long understood the benefits of collaboration, and if there is one country in the world that has managed to reconcile the nationalism of its regions with the greater need of the supra-cantonal entity of the country as a whole, it is Switzerland. It would be a gross oversimplification to say that Courvoisier's manifesto is to apply the Swiss model to global governance, but you get the idea.

Originally published in French by the Geneva publisher Georg, if there's one criticism I have of the book, it's the translation. It made Catherine Bréchignac, who speaks with fluidity in French, come across as rather clunky in her introduction, and on more than one occasion I found myself wondering if the words I was reading were really expressing what the author wanted to say. Springer and the Swiss Academy of Sciences are to be lauded for bringing this manifesto to an Anglophone audience, but for those who read French, I'd recommend the original.

● *James Gillies, CERN.*

Third Thoughts

By Steven Weinberg

The Belknap Press of Harvard University Press

When Nobel laureates offer their point of view, people generally are curious to listen. Self-described rationalist, realist, reductionist and devoutly secular, Steven Weinberg has published a new book reflecting on current affairs in science and beyond. In *Third Thoughts*, he addresses themes that are of interest for both laypeople and researchers, such as the public funding of science.

Weinberg shared the Nobel Prize in Physics in 1979 for unifying the weak interaction and electromagnetism into the electroweak theory, the core of the Standard Model, and has made many other significant contributions to physics. At the same time, Weinberg has been and remains a keen science populariser. Probably his most famous work is the popular-science book *The First Three Minutes*, where he recounts the evolution of the universe immediately following the Big Bang.

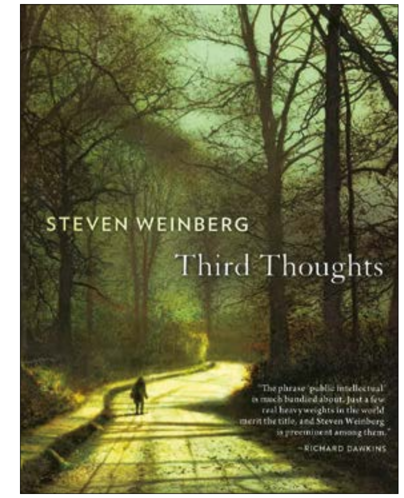
Third Thoughts is his third collection of essays for non-specialist readers, following *Lake Views* (2009) and *Facing Up* (2001). In it are 25 essays divided into four themes: science history, physics and cosmology, public matters, and personal matters. Some are the texts of speeches, some were published previously in *The New York Review of Books*, and others are released for the first time.

The essays span subjects from quantum mechanics to climate change, from broken symmetry to cemeteries in Texas, and are pleasantly interspersed with his personal life stories. Like his previous collections, Weinberg deals with topics that are dear to him: the history of science, science spending, and the big questions about the future of science and humanity.

The author defines himself as an enthusiastic amateur in the history of science, albeit a "Whig interpreter" (meaning that he evaluates past scientific discoveries by comparing them to the current advancements – a method that irks some historians). Beyond that, his taste for controversy encourages him to cogitate over Einstein's lapses, Hawking's views, the weaknesses of quantum mechanics and the US government's financing choices, among others.

Readers who are interested in US politics will find the section "Public matters" very thought-provoking. In particular, the essay "The crisis of big science" is based on a talk he gave at the World Science Festival in 2011 and later published in the *New York Review of Books*. He explains the need for big scientific projects, and describes how both cosmology and particle physics are struggling for governmental support. Though still disappointed by the cut of the Superconducting Super Collider (SSC) in the early 1990s, he is excited by the new endeavours at CERN. He reiterates his frank opinions against manned space flight, and emphasises how some scientific obstacles are intertwined in the historical panorama. In this way, Weinberg sets the cancellation of the SSC in a wider problematic context, where education, healthcare, transportation and law enforcement are under threat.

The author condenses the essence of what physicists have learnt so far about the laws of nature and why science is important. This is a book about asking the right questions, when time is ripened to look for the answers. He explains that the question



"What is the world made of?" needed to wait for chemistry advances at the end of the 18th century. "What is the structure of the electron?" needed to wait for quantum mechanics. While "What is an elementary particle?" is still waiting for an answer.

The essays vary in difficulty, and some concepts and views are repeated in several essays, thus each of them can be read independently. While most are digestible for readers without any background knowledge in particle physics, a general understanding of the Standard Model would help with grasping the content of some of the paragraphs. Having said that, the general reader can still follow the big picture and logically-arranged thoughts.

Several essays talk about CERN. More specifically, the "The Higgs, and beyond" article was written before the announcement of the Higgs boson discovery in 2011, and briefly presents the possibility of technicolour forces. The following essay, "Why the Higgs?", was commissioned just after the announcement in 2012 to explain "what all the fuss is about".

One of the most curious essays to explore is number 24. Citing Weinberg: "Essay 24 has not been published until now because everyone who read it disagreed with it, but I am fond of it so bring it out here." There, he draws parallels between his job as a theoretical physicist and the one of creative artists.

Not all scientists are able to write in such an unconstrained and accessible way. Despair, sorrow, frustration, doubt, uneasiness and wishes all emerge page after page, offering the reader the privilege of coming closer to one of the sharpest scientific minds of our era.

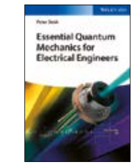
● *Letizia Diamante, CERN.*

Books received

Essential Quantum Mechanics for Electrical Engineers

By Peter Deák

Wiley–VCH



The most recent and upcoming developments of electronic devices for information technology are increasingly being based on physical phenomena that cannot be understood without some knowledge of quantum mechanics (QM). In the new hardware, switching happens at the level of single electrons and tunnelling effects are frequently used; in addition, the superposition of electron states is the foundation of quantum information processing. As a consequence, the study of QM, as well as informatics, is now being introduced in undergraduate electric and electronic engineering courses. However, there is still a lack of textbooks on this subject written specifically for such courses.

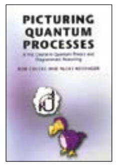
The aim of the author was to fill this gap and provide a concise book in which both the basic concepts of QM and its most relevant applications to electronics and information technologies are covered, making use of only the very essential mathematics.

The book starts off with classical electromagnetism and shows its limitations when it comes to describing the phenomena involved in modern electronics. More advanced concepts are then gradually introduced, from wave–particle duality to the mathematical construction used to describe the state of a particle and to predict its properties. The quantum well and tunnelling through a potential barrier are explained, followed by a few applications, including light-emitting diodes, infrared detectors, quantum cascade lasers, Zener diodes, flash memories and the scanning tunnelling microscope. Finally, the author discusses some of the consequences of QM for the chemical properties of atoms and other many-electron systems, such as semiconductors, as well as the potential hardware for quantum information processing.

Even though the mathematical formulation of basic concepts is introduced when required, the author's approach is oriented at limiting calculations and abstraction in favour of practical applications. Applets, accessible on the internet, are also used as a support, to ease the computational work and quickly visualise the results.

Bookshelf

Picturing Quantum Processes: A First Course in Quantum Theory and Diagrammatic Reasoning
By Bob Coecke and Aleks Kissinger
Cambridge University Press

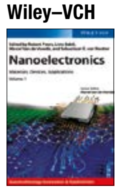


"This book is about telling the story of quantum theory entirely in terms of pictures," declare the authors of this unusual book, in which quantum processes are explained using diagrams and an innovative method for presenting complex theories is set up. The book employs a unique formalism developed by the authors, which allows a more intuitive understanding of quantum features and eliminates complex calculations. As a result, knowledge of advanced mathematics is not required.

The entirely diagrammatic presentation of quantum theory proposed in this (bulky) volume is the result of 10 years of work and research carried out by the authors and their collaborators, uniting classical techniques in linear algebra and Hilbert spaces with cutting-edge developments in quantum computation and foundational QM.

An informal and entertaining style is adopted, which makes this book easily approachable by students at their first encounter with quantum theory. That said, it will probably appeal more to PhD students and researchers who are already familiar with the subject and are interested in looking at a different treatment of this matter. The text is also accompanied by a rich set of exercises.

Nanoelectronics: Materials, Devices, Applications (2 volumes)
By R Puers, L Baldi, M Van de Voorde and S E van Nooten (editors)
Wiley–VCH



This book aims to provide an overview of both present and emerging nanoelectronics devices, focusing on their numerous applications such as memories, logic circuits, power devices and sensors. It is one unit (in two volumes) of a complete series of books that are dedicated to nanoscience and nanotechnology, and their penetration in many different fields, ranging from human health, agriculture and food science, to energy production, environmental protection and metrology.

After an introduction about the semiconductor industry and its development, different kinds of devices are discussed. Specific chapters are also dedicated to new materials, device-characterisation techniques, smart manufacturing and advanced circuit design. Then, the many applications are covered, which also shows the emerging trends and economic factors influencing the progress of the nanoelectronics industry.

Since nanoelectronics is nowadays fundamental for any science and technology that requires communication and information processing, this book can be of interest to electronic engineers and applied physicists working with sensors and data-processing systems.

Recruitment

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Please send all material by e-mail in a single pdf file until October 31, 2018 to: **dekanat@physik.uni-bielefeld.de**
or by regular mail to:
Prof. Dr. Jürgen Schnack,
Dean of the Faculty of Physics,
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The two positions will be in the framework of our multi-disciplinary activities on novel radioisotopes for theranostics. We aim at producing Positron Emission Tomography (PET) isotopes by proton irradiation and alpha/beta emitters for therapy by photonuclear reactions. Most of the investigations will be performed at the Bern medical cyclotron laboratory. Thanks to its characteristic beam transport line, our group is currently developing new particle accelerator and detector methodologies for medical and other applications. Photonuclear reactions will be studied using electron accelerators.

The successful Postdoctoral candidate is expected to play a leading role in our scientific activities, in particular in the development of targets and irradiation methodologies. This will involve hardware work, data analysis and computer simulations. Applicants must have a PhD in physics or engineering and an excellent knowledge in the field of nuclear and particle physics applied to medicine. Experience with particle accelerators and detectors, targets, radiation protection and computer simulation codes will be highly considered in the selection procedure. The initial duration of the contract is for two years, extendable.

The successful PhD candidate is expected to play an active role in our scientific activities, which will involve both hardware work and data analysis. He/She must have a Master degree (or equivalent) in physics and good knowledge in the field of nuclear and particle physics applied to medicine. Experience with radiation physics, hardware, data analysis as well as knowledge of programming will be positively considered in the selection procedure. The position has a duration of up to 4 years.

Applications will be reviewed starting September 15th 2018 and accepted until the positions are filled.

Interested candidates for these roles are requested to send by e-mail a letter of application, CV, list of publications and the names and addresses of three references (no letters, these will be requested at a later stage) to:

PD Dr. Saverio Braccini
Laboratorium für Hochenergiephysik
Universität Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
Saverio.Braccini@lhep.unibe.ch

CERN Courier Archive: 1975

A look back to CERN Courier vol. 15, October 1975, compiled by Peggie Rimmer

CERN News

Iron in the neutrino line

Inside the tunnel that will house the iron shielding for the neutrino beam-line. The photograph shows a 14-ton disc which has been carried to its position in the tunnel by a trolley on rails.

Work has started on the installation of shielding designed to filter out all particles other than neutrinos en route from the 400 GeV proton synchrotron to the 3.7 m European Bubble Chamber, BEBC, ready for the neutrino experiments which will be an important part of the SPS programme.

To produce neutrinos, protons from the SPS are directed onto a target near the accelerator ring, producing pions and kaons with an average energy around 40 GeV/c. A magnet will concentrate these particles into a 13 mrad cone and a second magnet, 90 m downstream, will further focus the beam. The pions and kaons will then enter a vacuum tube 1.20 m in diameter and 300 m long, in which most of them will decay, giving muons and neutrinos.

Once the neutrinos have been produced, all other particles, in particular the muons, have to be eliminated from the beam. This will be the task of shielding, comprising 170 m of iron (followed by 180 m of earth). Calculations show that this will reduce the muon flux from 10^{13} to 10 in each machine pulse.

The shielding is being erected in an underground tunnel with a 4% slope, since the neutrino beam climbs up from the underground SPS to BEBC at ground level. It consists of 425 iron discs, each 2.50 m in diameter, 40 cm thick and weighing about 14 tons. They are lowered down a shaft and run on a rail-mounted trolley to their desired location, at a rate of 10 per day. Positioning of the shielding will be complete by the end of the year.

● Compiled from text on p314.

Further contacts with China

Hsinhua News Agency

In conversation at the National People's Congress Palace, left to right, Mme Charpak, Mrs Weisskopf, G Charpak, Mrs Jentschke, V F Weisskopf, W K Jentschke, Wu Lein-Fu, two Chinese interpreters, L Van Hove and Mme Van Hove.

In the summer of 1973 a delegation of physicists from the People's Republic of China, headed by Professor Chang Wen-Yu, made an extensive tour of high-energy physics laboratories in the USA, concluding with a week's visit to CERN. In September 1975 there was a return visit by W K Jentschke (Director General of Laboratory I), G Charpak, L Van Hove and V F Weisskopf from CERN. The invitation for this visit proved to be much more than reciprocal hospitality. Discussions were wide-ranging and thorough, carrying contacts between the scientific communities a stage further.

The tour of the CERN group centred on Peking and Shanghai. The visitors saw work on controlled thermonuclear fusion at the Institute of Physics at Peking (involving laser technology and a mini-Tokomak), on computers at the University of Peking, on lasers, thin films and integrated circuits at Tsing Hua University, on reactor technology at the Institute of Atomic Energy in Peking, on nuclear physics involving the use of a cyclotron (including isotope production) at the Institute of Atomic Energy Shanghai, …

Some very fine work was seen in instrumentation. This included integrated circuits, many electronic instruments, and multiwire chambers (a follow-up from a chamber passed by Charpak to the Chinese delegation in 1973).

Despite their achievements, the hosts insisted that China is a "developing" country in need of scientific and technical input from "developed" countries. However, they also insist that it must be the Chinese people themselves that do the work and apply the knowledge.

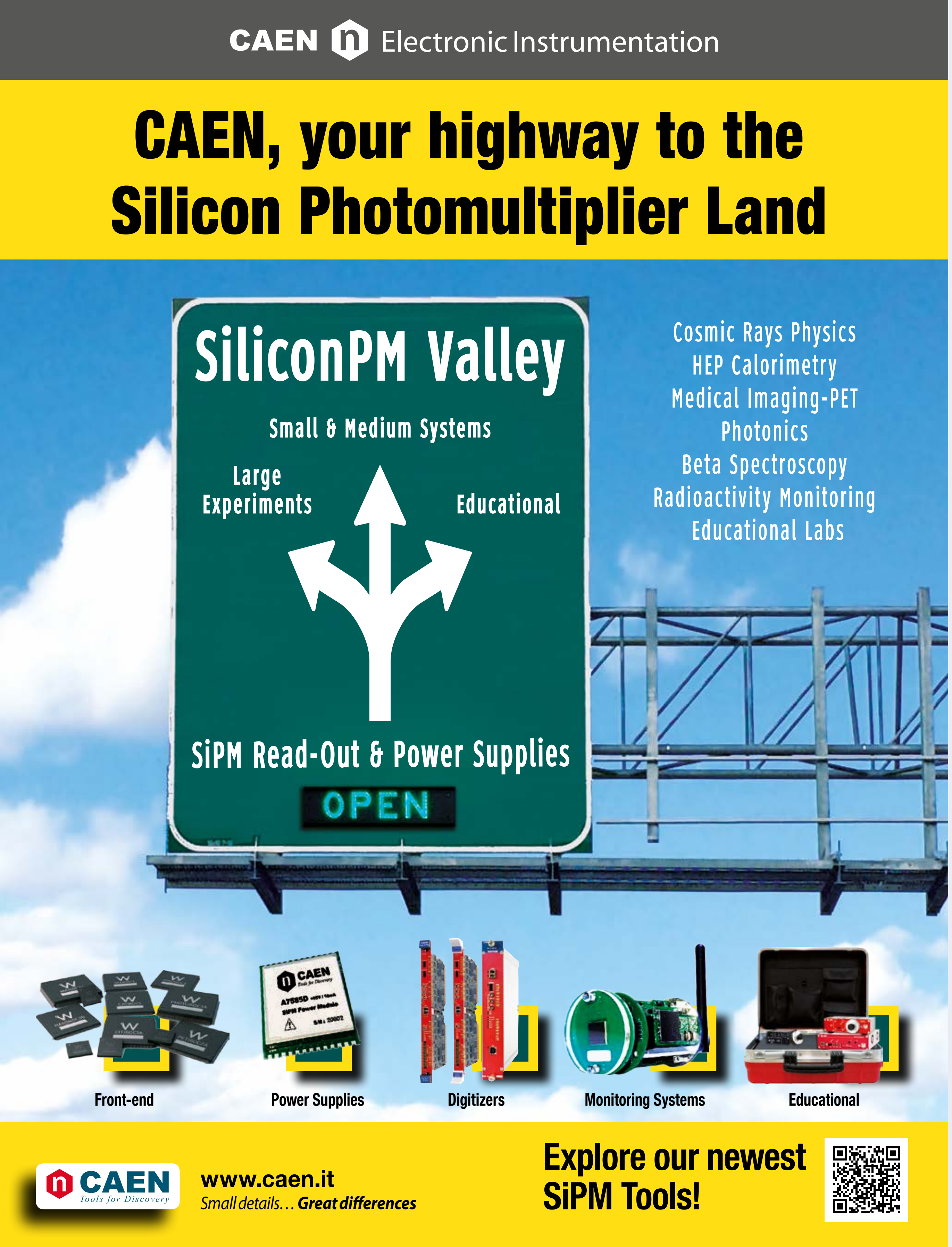
The highlight of the tour was a meeting with Wu Lein-Fu, Vice-Chairman of the Standing Committee of the National People's Congress. He said that China wishes to see contacts and exchanges with high energy physicists extended, particularly of CERN, and again stressed the readiness of China to learn from experience elsewhere. Concerning the exchange of people, we can finish with a typical Chinese proverb quoted by Wu Lein-fu – "One eye is better than a hundred ears".

● Compiled from text on p303.

Compiler's note

Whether or not China now considers itself to be developed or developing, the wishes expressed by Vice-Chairman Wu have already been amply fulfilled. By 2017, CERN had 12,236 users, 4322 coming from non-member states. Of these, 456 were from China, behind the US with 1143 and Russia with 1095. Between the years 2013–2017, the participation of the US and Russia in CERN's programmes and projects increased by 21% and 14% respectively, while that of China increased by 78%.

Looking to the future, China has recently completed a conceptual design report for a 100 km-circumference ring, initially to house a circular electron–positron collider, CEPC, and later a super proton–proton collider, SppC (*CERN Courier* June 2018 p21). To be built in China, this is foreseen as a facility for worldwide collaboration.



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