WELCOME

CERN Courier – digital edition

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

Smashing particles into one another at high energies has been crucial in establishing the Standard Model of particle physics, leading to discoveries such as the W and Z bosons, the top quark and, most recently, the Higgs boson. In pursuit of this strategy, one of CERN's options for a post-LHC collider is a high-energy electron–positron machine called the Compact Linear Collider (CLIC), which has recently been redesigned to focus on an optimal initial energy stage of 380 GeV before being boosted in stages to 1.5 and 3 TeV. Other collider projects, meanwhile, are being pursued within the Future Circular Collider (FCC) study. But colliders are just one way to address fundamental physics questions, and in September CERN hosted a kick-off meeting to explore opportunities for physics beyond colliders based on the laboratory's existing accelerator infrastructure. This issue of the *Courier* also describes the scintillating activities of CERN's Crystal Clear collaboration, which this month celebrates 25 years of developing detectors for physics and medicine, and we catch up with Kip Thorne – the visionary theorist who correctly predicted that a pair of coalescing black holes can produce a detectable burst of gravitational waves.

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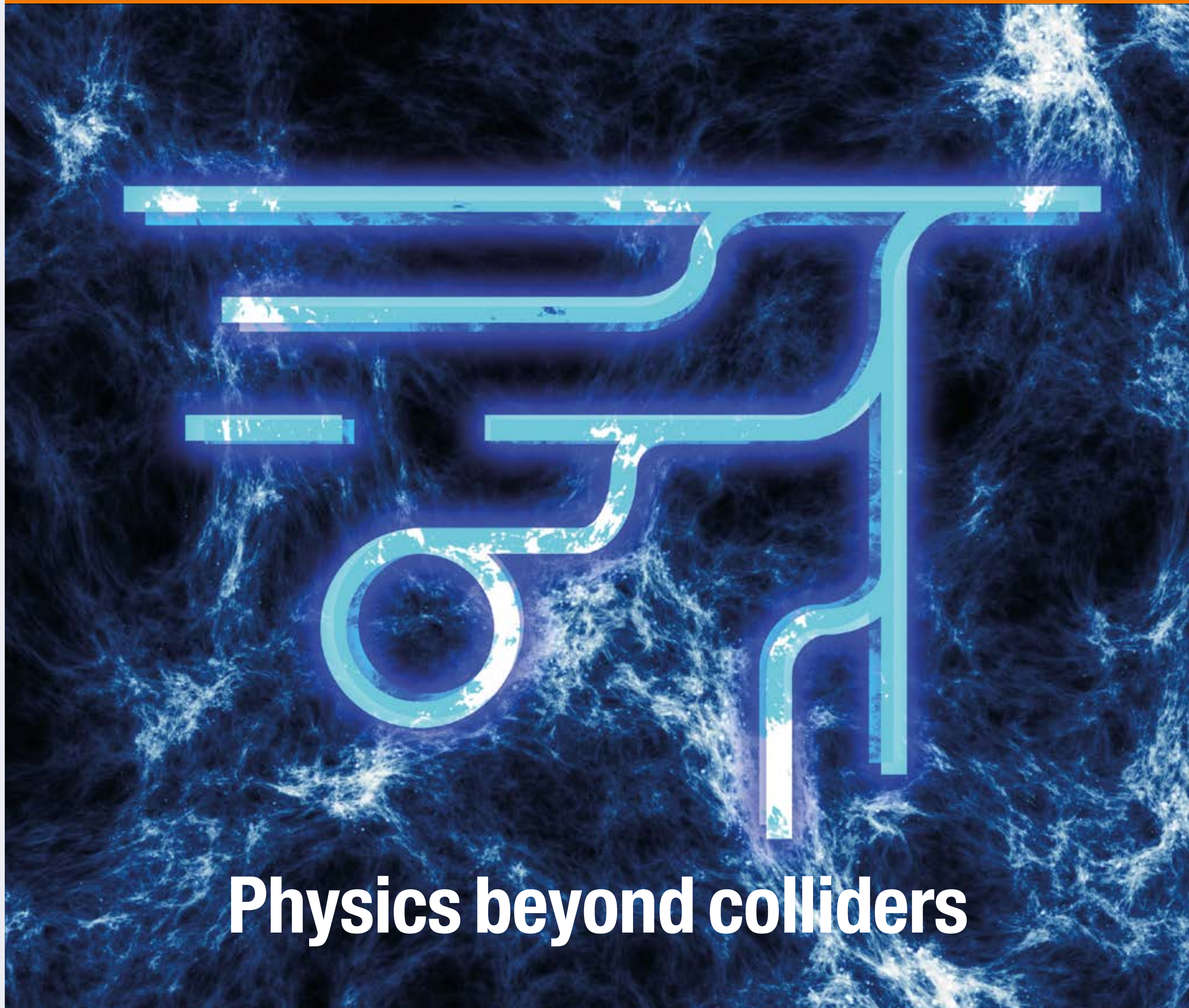
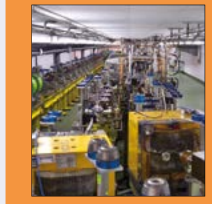
EDITOR: MATTHEW CHALMERS
DIGITAL EDITION CREATED BY DESIGN STUDIO/IOP PUBLISHING, UK

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERNCOURIER
VOLUME 56 NUMBER 9 NOVEMBER 2016





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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
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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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PO Box 918, Beijing 100049, People's Republic of China
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UK Mark Wells, Science and Technology Facilities Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1SZ
E-mail: mark.wells@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 56 Number 9 November 2016

On the cover: The Physics Beyond Colliders workshop logo, set against a simulation of cosmic structure. (Image credit: Daniel Dominguez, for background image, with graphic treatment by Tim Cooper.)

CERNCOURIER
Volume 56 Number 9 November 2016
IOP Publishing

Viewpoint

The usefulness of 'useless' knowledge

The pursuit of basic scientific knowledge will help the UN to meet its Agenda 2030 goals.

Jeff Wiener

Nurturing young minds is one of CERN's core goals. Here, students build their own cloud chambers at CERN's S'Cool LAB, a new particle-physics learning laboratory that enables high-school children to conduct experiments.

By Fabiola Gianotti

As far back as 1939, the US educator Abraham Flexner penned a stirring paean to basic research in *Harper's Magazine* under the title "The usefulness of useless knowledge." Flexner, perhaps being intentionally provocative, pointed out that Marconi's contribution to the radio and wireless had been practically negligible. He went on to argue that the 1865 work of James Clerk Maxwell on the theoretical underpinnings of electricity and magnetism, and the subsequent experimental work of Heinrich Hertz on the detection of electromagnetic waves, was done with no concern about the practical utility of the work. The knowledge they sought, in other words, was never targeted to a specific application. Without it, however, there could have been no radio, no television and no mobile phones.

The history of innovation is full of such examples. It is practically impossible to find a piece of technology that cannot be traced back to the work of scientists motivated purely by a desire to understand the world. But basic research goes further. There is something primordial about it. Every child is a natural scientist imbued with curiosity, vivid imagination and a desire to learn. It is what sets us apart from any other species, and it is what has provided the wellspring of innovation since the harnessing of fire and the invention of the wheel. Children are always asking questions: why is the sky blue? What are we made of? It is by investigating questions like these that science has advanced, and because it can inspire children to grow up into future scientists or scientifically aware citizens.

Education and training are among CERN's core missions. Over the years we have developed programmes that reach everyone from primary-school children to professional physicists, accelerator scientists and computer scientists. We also keep tabs on the whereabouts of young people passing through CERN, and it is enriching to follow their progress. Around 1000 people per year receive higher degrees from universities around the world for work carried out at CERN. Basic research therefore not only inspires young people to study science, it also provides a steady stream of qualified people for business and industry, where their high-tech, international experience allows them to make a positive impact.

Turning to the UN's admirably ambitious Global Goals for Sustainable Development, which officially came into force on 1 January 2016 and will last for 15 years as part of the Agenda 2030 programme, the focus on science and technology is positive and encouraging. It testifies to a deeper understanding of the importance of science in driving progress that benefits all peoples and helps to overcome today's most pressing development challenges. But Agenda 2030's potential can only be fulfilled through sustained commitment and funding by governments. If we are to tackle issues ranging from eliminating poverty and hunger to providing clean and affordable energy, we need science and we need people to be scientifically aware.

Places like CERN are a vitally important ingredient in the innovation chain. We contribute to the kind of knowledge that not only enriches humanity, but also provides ideas that become the technologies of the future. Some of CERN's technology has immediate impact on society, such as the World Wide Web and the application of particle accelerators to cancer therapy and many other fields. We also train young people. All this is possible because governments support science, technology, engineering and mathematics (STEM) education and basic research, but we should do more. The scientific community, including CERN, urged Agenda 2030 to consider a minimum GDP percentage devoted by every nation to STEM education and basic research. This is particularly important in times of economic downturn, when private funding naturally concentrates on short-term payback and governments focus on domains that offer immediate economic return, at the expense of longer-term investment in fundamental science.

Useless knowledge, as Flexner called it, is at the basis of human development. Humankind's continuing pursuit of it will make the UN's development goals achievable.

Fabiola Gianotti is Director-General of CERN. A longer version of this article appears in the book 17 Big Bets for a Better World (Historika, 2016), published as part of the UN's Agenda 2030 initiative. (Image credit: Maximilien Brice.)

News

HL-LHC

All systems go for the High-Luminosity LHC

On 19 September, the European Investment Bank (EIB) signed a 250 million Swiss francs (€230 million) credit facility with CERN in order to finance the High-Luminosity Large Hadron Collider (HL-LHC) project. The finance contract follows recent approval from CERN Council, and will allow CERN to carry out the work necessary for the HL-LHC within a constant CERN budget.

The HL-LHC is expected to produce data from 2026 onwards, with the overall goal of increasing the integrated luminosity recorded by the LHC by a factor 10. Following approval of the HL-LHC as a priority project in the European Strategy Report for Particle Physics, this major upgrade is now gathering speed together with companion upgrade programmes of the LHC injectors and detectors. Engineers are currently putting the finishing touches to a full working model of an HL-LHC quadrupole, which will eventually be installed in the insertion regions close to the ATLAS and CMS experiments in order to focus the HL-LHC beam. Built in partnership with Fermilab, the magnets are based on an innovative niobium-tin superconductor (Nb_3Sn) that can produce higher magnetic fields than the niobium-titanium magnets used in the LHC.

The contract signed between CERN and EIB falls under the InnovFin Large Projects facility, which is part of the new generation of financial instruments developed and supported under the European Union's Horizon 2020 scheme. It's the second EIB financing for CERN, following a loan of €300 million in 2002 for the LHC. "This loan under Horizon 2020, the EU's research-funding programme, will help keep CERN and Europe at the forefront of particle-physics research," says the European commissioner for research, science and innovation, Carlos Moedas. "It's an example of how EU funding helps extend frontiers of human knowledge."

Maximilien Brice

A model quadrupole magnet for the HL-LHC being prepared for cryogenic tests at CERN's SM18 facility in late September.

NUCLEAR PHYSICS

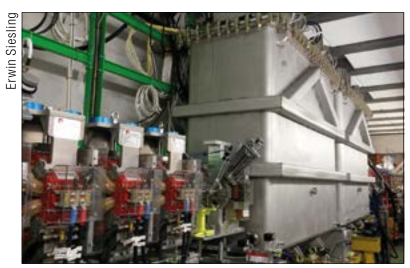
First physics at HIE-ISOLDE begins

In early September, the first physics experiment using radioactive beams from the newly upgraded ISOLDE facility got under way: a study of tin, which is a special element because it has two double magic isotopes. ISOLDE is CERN's long-running nuclear research facility, which for the past 50 years has allowed many different studies of the properties of atomic nuclei. The upgrade means the machine can now reach an energy of 5.5 MeV per nucleon, making ISOLDE the only Isotope Separator On-Line (ISOL) facility in the world capable of investigating heavy and super-heavy radioactive nuclei.

HIE-ISOLDE (High Intensity Energy-ISOLDE) is a major upgrade of the ISOLDE facility that will increase the energy, intensity and quality of the beams delivered to scientific users. "Our success is the result of eight years of development and manufacturing," explains HIE-ISOLDE project-leader Yacine Kadi. "The community around ISOLDE has grown a lot recently, as more scientists are attracted by the possibilities that new higher energies bring. It's an energy domain that's not explored much, since no other facility in the world can deliver pure beams at these energies."

The first run of the facility took place in October last year, but because the machine only had one cryomodule, it operated at an energy of 4.3 MeV per nucleon. Now, with the second cryomodule in place, the machine is capable of reaching up to 5.5 MeV per nucleon and therefore can investigate the structure of heavier isotopes. The rest of 2016 will be a busy time for HIE-ISOLDE, with scheduled experiments studying nuclei over a wide range of mass numbers – from ^{9}Li to ^{142}Xe. When two additional cryomodules are installed in 2017 and 2018, the facility will operate at 10 MeV per nucleon and be capable of investigating nuclei of all masses.

HIE-ISOLDE will run until mid-November, and all but one of the seven different experiments planned during this time will use the Miniball detection station.



Erwin Siesling

The tunnel at HIE-ISOLDE now contains two cryomodules – a unique set-up that marks the end of phase one for the HIE-ISOLDE installation.

Sommaire en français

CERNCOURIER

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IOP Publishing

Making research results freely available to everyone is in the spirit of CERN's Convention.

PUBLISHING

Three-year extension for open-access initiative

In September, following three years of successful operation and growth, CERN announced the continuation of the global SCOAP³ open-access initiative for at least three more years. SCOAP³ (Sponsoring Consortium for Open Access Publishing in Particle Physics) is a partnership of more than 3000 libraries, funding agencies and research organisations from 44 countries that has made tens of thousands of high-energy physics articles publicly available at no cost to individual authors. Inspired by the collaborative model of the LHC, SCOAP³ is hosted at CERN under the oversight of international governance. It is primarily funded through the redirection of budgets previously used by libraries to purchase journal subscriptions.

Since 2014, in co-operation with 11 leading scientific publishers and learned societies, SCOAP³ has supported the transition to open access of many long-standing titles in the community. During this time, 20,000 scientists from 100 countries have benefited from the opportunity to publish more than 13,000 open-access articles free of charge.

With strong consensus of the growing SCOAP³ partnership, and supported by the increasing policy requirements for and global commitment to open access in its Member States, CERN has now signed contracts with 10 scientific publishers and learned societies for a three-year extension of the initiative. "With its success, SCOAP³ has shown that its model of global co-operation is sustainable, in the same broad and participative way we build and operate large collaborations in particle physics," says CERN's director for research and computing, Eckhard Elsen.

DARK MATTER

LUX-ZEPLIN passes approval milestone

A next-generation dark-matter detector in the US called LUX-ZEPLIN (LZ), which will be at least 100 times more sensitive than its predecessor, is on schedule to begin its deep-underground hunt for WIMPs in 2020. In August, LZ received a US Department of Energy approval ("Critical Decision 2 and 3b") concerning the project's overall scope, cost and schedule. The latest approval step sets in motion the building of major components and the preparation of its nearly mile-deep cavern at the Sanford Underground Research Facility (SURF) in Lead, South Dakota.

The experiment, which is supported by a collaboration of more than 30 institutions and about 200 scientists worldwide, is designed to search for dark-matter signals from within a chamber filled with 10 tonnes of purified liquid xenon. LZ is named for the merger of two dark-matter-detection experiments: the Large Underground Xenon experiment (LUX) and the UK-based ZonEd Proportional scintillation in LIquid Noble gases (ZEPLIN) experiment. LUX, a smaller liquid-xenon-based underground experiment at SURF that earlier this year ruled out a significant region of WIMP parameter space, will be dismantled to make way for the new project.

"Nobody looking for dark-matter interactions with matter has so far convincingly seen anything, anywhere, which makes LZ more important than ever," says LZ project-director Murdock Gilchriese of the University of California at Berkeley.

SLAC National Accelerator Laboratory

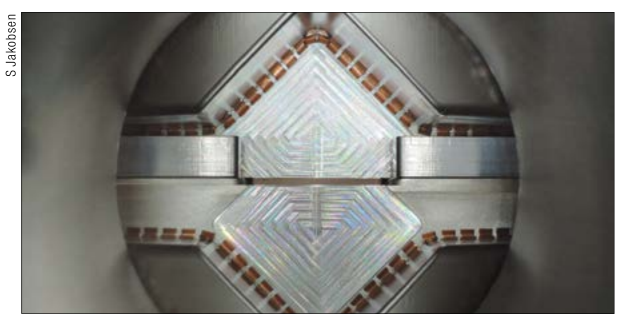
A mini version of the future LZ dark-matter detector at a test stand at the SLAC National Accelerator Laboratory, showing the detector TPC core (white container).

LHC NEWS

Large beams take LHC physics forward

Usually, the motto of the LHC operations team is "maximum luminosity". For a few days per year, however, this motto is put aside to run the machine at very low luminosity. The aim is to provide data for the broad physics programme of the LHC's "forward physics" experiments – TOTEM and ATLAS/ALFA. By running the LHC with larger beam sizes at the interaction points, corresponding to a lower luminosity, the dedicated TOTEM and ATLAS/ALFA detectors can probe the proton–proton elastic-scattering regime at small angles.

In elastic scattering, two protons survive their encounter intact and only change direction by exchanging momentum. TOTEM, which is located in the straight sections of the LHC on either side of CMS at Point 5, and ATLAS/ALFA at Point 1, are not able to study this process during normal operation. To facilitate the special run, which took place in the third week of September, the LHC team has developed a special machine configuration that delivers exceptionally large beams at the interaction points (IP) of ATLAS and CMS. The focusing at the IP is normally parameterised by β^*: the higher the value of β^*, the bigger the beams and, importantly, the lower the angular divergence. For this year's high-β^* run, its value had to be raised to 2.5 km compared with around 1 km during LHC Run 1 at an energy of 8 TeV, because the higher energy of LHC Run 2 causes the two incoming protons to scatter at smaller angles. The measurements were carried out with very low-intensity beams, allowing TOTEM and ALFA to bring their "Roman Pot" detectors remarkably close to the beam.



S Jakobsen

Looking into the LHC beam pipe, showing ATLAS/ALFA Roman Pots in their data-taking position with a gap of just 0.9 mm.

In addition to the precise determination of the total proton–proton interaction probability at 13 TeV, TOTEM will focus on a detailed study of elastic scattering in the low-transferred momentum regime. The experiment will investigate how Coulomb scattering interferes with the nuclear component of the elastic interaction, which can shed light on the internal structure of the protons. TOTEM will also search for special states formed by three gluons.

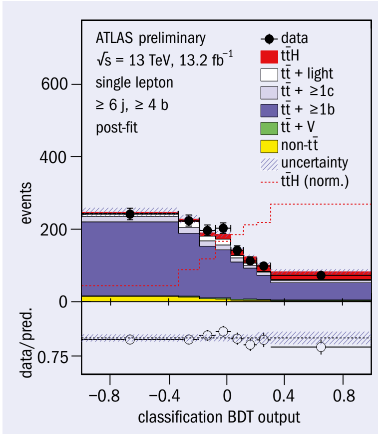
ATLAS/ALFA also intends to carry out a precision measurement of the proton–proton total cross-section, and will use this to determine the absolute LHC luminosity at Point 1. For ATLAS/ALFA, the interesting part of the spectrum is at low values of transferred momentum, where Coulomb scattering is dominant. Since the Coulomb scattering cross-section is theoretically known, its measurement provides an independent estimate of the absolute luminosity of the LHC. This would provide an important cross-check of the luminosity calibration measurements performed via van der Meer scans during dedicated LHC fills.

LHC EXPERIMENTS

ATLAS homes in on Higgs-quark couplings

The Higgs boson has been observed via its decays to photons, tau leptons, and Z and W bosons, which has allowed ATLAS to glean much information about the particle's properties. So far, these properties agree with the predictions of the Standard Model (SM). However, there are several aspects of the Higgs boson that are still largely unexplored, most notably the coupling of the Higgs boson to quarks. The two heaviest quarks, the bottom and top, are particularly interesting because they have the largest couplings to the Higgs boson. If these couplings differ from the SM predictions, it could provide a first hint of new physics.

Observing the coupling of the Higgs boson to these two quark flavours is challenging, however. Despite the Higgs decaying to a pair of bottom quarks around 58% of the time, this decay has not yet been observed because such decays manifest themselves as jets in the detector and this signature is overwhelmed by the SM production of multi-jets. As a result, physicists search for this decay by looking for the production of the Higgs in association with a vector boson (W or Z) or a top-quark pair. The additional particles have a more distinctive decay signature, but this comes at the price of a much lower signal-production rate.



The boosted-decision-tree output used to separate the small Higgs boson signal (solid red histogram) from the large background processes (stacked coloured histograms), for the case of the Higgs boson decaying to a pair of bottom quarks when produced in association with a pair of top quarks.

Regarding the top quark, the only way to directly measure the coupling of the Higgs to the top quark at the LHC is to study events where a Higgs is produced in association with a top-quark pair. Like the situation with bottom quarks, this process has not yet been observed. Indeed, even with the more distinct decays, the background processes that mimic these signals are large, complex and difficult to model. In both the top and bottom production channels, the backgrounds are controlled by using advanced machine-learning techniques to separate signal events from background (see figure).

Both searches have now been carried out by ATLAS with data from LHC Run 2, revealing a sensitivity to the Higgs boson couplings to top and bottom quarks that is competitive with searches at Run 1. However, they are still not precise enough to identify if there are any deviations from SM behaviour. With further improvements to the analyses, better understanding of the backgrounds and the unprecedented performance of the LHC, we should finally observe both of these processes at a high statistical significance later during Run 2. This will tell us if the Higgs boson is indeed responsible for the masses of the quarks as predicted in the SM, or if there is new physics beyond it.

Further reading

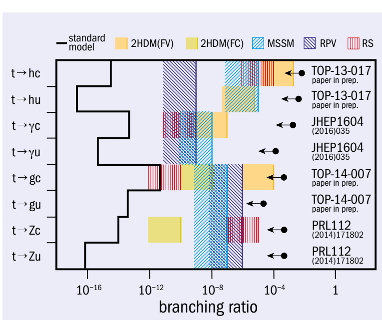
ATLAS Collaboration 2016 ATLAS-CONF-2016-058.
ATLAS Collaboration 2016 ATLAS-CONF-2016-068.
ATLAS Collaboration 2016 ATLAS-CONF-2016-080.
ATLAS Collaboration 2016 ATLAS-CONF-2016-091.

CMS investigates the width of the top quark

Twenty years after its discovery at the Tevatron collider at Fermilab, interest in studying the top quark at the LHC is higher than ever. This was illustrated by the plethora of new results presented by the CMS collaboration at the ICHEP conference in August and at TOP 2016, which took place in the Czech Republic from 19 to 23 September.

The top quark is the only fermion heavier than the W boson and which has weak decays that do not involve a virtual particle. This leads to an unusually short lifetime (5×10^{-24} s) for a weak-mediated process, and provides a unique opportunity to probe the properties and couplings of a bare quark. In particular, the width of the top quark (which, like for all quantum resonances, is inversely proportional to its lifetime) may be easily affected by new-physics processes.

In a series of recent publications, the CMS collaboration has explored the width of the top quark in a model-independent way and searched for contributions from extremely rare processes mediated by so-called flavour-changing neutral currents (FCNCs).



Summary of the upper limits at 95% confidence level on flavour-changing neutral-current processes in the top sector, as set by different CMS analyses using the LHC Run I data set. Predictions of the Standard Model and different new-physics models are included.

The top-quark width is too narrow compared with the experimental resolution of the CMS detector to allow a precision measurement directly from the shape of the top's invariant-mass distribution. CMS therefore considers alternative observables that provide complementary information on the top's mass and width.

One of those observables is the invariant-mass distribution of lepton and b-jet systems produced after top-quark pair decays, which has allowed the collaboration to place new bounds on a Standard Model-like top-quark width of $0.6 \le \Gamma_t \le 2.4$ GeV, based on the first 13 fb^{-1} of data collected in 2016 at a collision energy of 13 TeV. In parallel, based on the LHC Run 1 data set recorded at lower energies, a set of dedicated searches for FCNC processes involving top quarks has been carried out. This analysis focuses on the couplings of the top-quark to other up-type quarks (up, charm) and different neutral bosons: the gluon, the photon, the Z boson and the Higgs boson.

Another approach adopted by CMS was to search for the rare production of a single top quark in association with a photon and a Z boson with the 8 TeV data set. These channels exploit the large up-quark density in the proton, and to a lesser extent the charm-quark density, therefore compensating for the smallness of the FCNC couplings. Finally, events with the conventional signature of t-channel production (resulting in a single top-quark decay and a light-quark jet) were used to set constraints on FCNC and other anomalous couplings by simultaneously considering their effects on the production and the decay of the top quark with both the 7 and 8 TeV data sets.

Although no deviation from the background-only expectations has been observed in any of the analyses so far, the CMS collaboration is fast approaching sensitivity to the FCNC signals expected by some models with just Run 1 data (see figure). All the analyses are limited in statistics and therefore will only benefit from more data to start effectively probing beyond-the-Standard-Model effects in the top quark sector.

Further reading

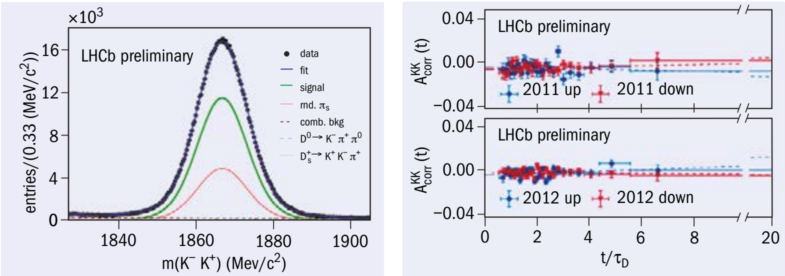
CMS Collaboration 2016 CMS PAS-TOP-16-019.
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP.

LHCb targets new source of CP violation

The LHCb collaboration presented new results at the 8th International Workshop on Charm Physics (Charm 2016), which took place in Bologna on 5 to 9 September. Among various novelties, the collaboration reported the most precise measurements of the asymmetry between the effective lifetime of the D^0 meson (composed of a $\bar{c}$ u quark pair) and that of its anti-partner, the $\bar{D}^0$ meson, decaying to final states composed of two charged pions or kaons. Such an asymmetry, referred to as A_Γ, differs from zero if and only if the effective lifetimes of these particular D^0 and $\bar{D}^0$ decays are different, signalling the existence of CP-violating effects.

CP violation is still unobserved in the charm-quark sector, and its effects here are predicted to be very tiny by the Standard Model (well below the 10^{-3} level in this specific case). Thanks to the unprecedented sample sizes that LHCb is accumulating, it is only now that such a level of precision on these CP-violating observables with charm-meson decays is starting to be accessible.

Charm mesons are produced copiously at the LHC, either directly in the proton–proton collisions or in the decays of heavier beauty particles. Only the former production mechanism was used in this analysis. To determine whether the decaying meson is a D^0 or a $\bar{D}^0$ (since they cannot be distinguished by the $\pi^+\pi^-$ or K^+K^- common final state), LHCb reconstructed the decay chains $D^{*+} \to D^0\pi^+$ and $D^{*-} \to \bar{D}^0\pi^-$ so that the sign of the charged pion could be exploited to identify which D meson was involved in the decay. Two distinct analysis techniques were developed (see figure). The results of the two analyses are in excellent agreement and are consistent with no CP violation within about three parts in 10^4. These constitute the most precise measurements of CP violation ever made in the charm sector, with the full Run 2 data set expected to reduce the uncertainties even further.



The invariant-mass distribution of $D^0 \to K^+K^-$ decays from one of the two analyses (left), and the decay-time asymmetries (right) from the other analysis, distinguishing data taken with the two possible magnet polarities of the LHCb spectrometer.

Further reading

LHCb Collaboration 2016 LHCb-CONF-2016-009.
LHCb Collaboration 2016 LHCb-CONF-2016-010.

ALICE explores shear viscosity in QCD matter

One of the key goals in exploring the properties of QCD matter is to pin down the temperature dependence of the shear-viscosity to entropy-density ratio (η/s). In the limit of a weakly interacting gas, kinetic theory indicates that this ratio is proportional to the mean free path. Many different fluids exhibit a similar temperature dependence for η/s around a critical temperature T_c associated with a phase transition.

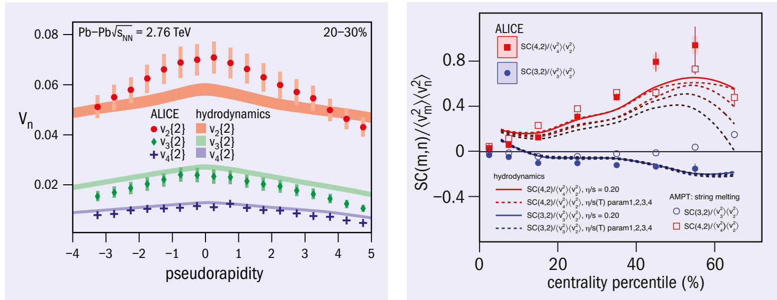
Heavy-ion collisions at the LHC create a state of hot and dense matter where quarks and gluons become deconfined (the quark gluon plasma, QGP). It exists within the initial instants of the collision, then as the system cools, the quarks and gluons form a hadronic gas at T_c. The temperature dependence of η/s is expected to follow the trend of other fluids, with a minimum at T_c. The minimum value of η/s is of particular interest because weakly coupled QCD and AdS/CFT models predict different values.

The ALICE collaboration has recently released results from anisotropic-flow measurements, which provide new constraints for $\eta/s(T)$. Anisotropic flow results from spatial anisotropies in the initial state that are converted to momentum anisotropies via pressure gradients during the evolution of the system. The magnitudes of momentum anisotropies are quantified by the so-called v_n coefficients, where v_2 is generated by initial states with an elliptic shape, v_3 a triangular shape, etc. The shape of the initial state fluctuates on an event-by-event basis.

Our results show that the average ▷

temperature of the system decreases with the pseudo-rapidity magnitude (figure, left), which means that measurements at forward rapidities are more sensitive to the hadronic phase. Although the model calculations reproduce the general trends of the data, it is clear that other parameterisations of η/s(T) could be explored to better describe the RHIC and LHC data simultaneously.

We also measured event-by-event correlations of different v_n coefficients in lead–lead collisions (figure, right). It is clear that the v_2 and v_4 correlations are rather sensitive to different parameterisations. By contrast, the correlation between v_2 and v_3 is not, and is largely sensitive to how the initial state is modelled. Subsequently, it was found that the agreement improved as the number of degrees of freedom in the initial model was increased. Whether the deviations between data and model for the v_2 and v_4 correlation are due to the η/s(T) parameterisations or the initial-state modelling will be the subject of future study.



(Left) Measurements of v_n versus the pseudorapidity of produced charged particles, with lines indicating hydrodynamical calculations tuned with RHIC data. (Right) The correlation of v_n as a function of centrality, which is related to the amount of overlap of both lead ions at the time of the collision: solid red points are positive, while negative correlations are shown in blue.

● **Further reading**

ALICE Collaboration 2016: arXiv:1604.07663 and arXiv:1605.02035.

***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.*

CERN Courier welcomes contributions from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

Sciencewatch

Compiled by John Swain, Northeastern University

Beer guides yeast evolution

Humans have a long relationship with the yeasts that make beer. Genetic and phenotypic analysis of 157 strains of *Saccharomyces cerevisiae* yeast used by the fermentation industry now reveal that they all originate from a few common ancestors and evolved in ways to make brewers happy. The work, led by Kevin J Verstrepen and Steve Maere of the Flemish Institute for Biotechnology in Belgium, also found that beer yeast possesses, in contrast to wild yeast, duplicated genes that help to break down maltotriose, a sugar in beer mash. Many also evolved a mutation that prevents production of 4-vinylguaiacol, which is known to taint the flavour of beer. Beer yeast has also lost its ability to reproduce sexually, which would be needed to survive in a wild environment. On the other hand, wine yeast can still reproduce sexually, presumably because wine-making only happens in the autumn and the yeasts therefore have to get by without human support during the rest of the year.

Shutterstock/fujji

Beer provides insight into the domestication origin of industrial yeasts, and may also help to select and breed new superior strains.

● **Further reading**

B Gallone *et al.* 2016 *Cell* **166** 1397.

Hawking effect in water

An analogue of the Hawking effect, whereby black-body radiation is emitted by black holes, can be seen in general wave phenomena when analogue horizons are present as waves propagating on a stationary counter-flowing medium. When the flow matches the speed of the wave, the wave is blocked and converted into other branches of the dispersion relation. L-P Euvé of CNRS-Université de Poitiers in France and colleagues have now observed this phenomenon in the power spectrum and two-point correlation function in surface waves on a countercurrent of water in a linear tank. Furthermore, because the flow velocity near the blocking point decreases along the direction of flow, the system is in fact an analogue of a white hole (a time-reversed black hole).

● **Further reading**

L-P Euvé *et al.* 2016 *Phys. Rev. Lett.* **117** 121301.

Weather bombs and earthquakes

The atmosphere–ocean system can drive the Earth to produce seismic signals called "microseisms". These can be produced by large slow-moving storms but also by smaller storms, and in particular small extratropical storms dubbed "weather bombs", in which the central pressure drops rapidly. Using a seismic array in Japan, Kiwamu Nishida of the University of Tokyo and Ryota Takagi of Tohoku University report both P-wave and previously unobserved S-wave microseisms produced under a weather bomb between Greenland and Iceland. Non-linear forcing of an ocean swell with a 1D Earth model can explain P waves and vertically polarised S waves, but not horizontally polarised S waves. This makes weather bombs a possible new probe of the Earth's interior.

● **Further reading**

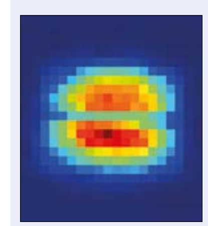
K Nishida and R Takagi 2016 *Science* **353** 919.

Ghost imaging with X-rays

Ghost imaging constructs images of objects using information from light detected at two detectors. The idea is to use correlations in intensities between an object beam that strikes the object and a reference beam that doesn't, similar to the use of intensity correlations from starlight to determine the diameter of a star. Now, two papers, one by Hong Yu from the Chinese Academy of Sciences, Shanghai, and colleagues and another by Daniele Pelliccia from RMIT University, Australia, and colleagues, report achieving this for the first time using synchrotron X-rays. Both use a multi-pixel detector for the reference beam and a single-pixel "bucket" detector for the object beam, but one group takes data in Fourier space and the other in real space. The work is of particular interest for medical imaging because the imaged object is subjected to a much lower dose of radiation than in conventional imaging.

● **Further reading**

D Pelliccia *et al.* 2016 *Phys. Rev. Lett.* **117** 113902.
H Yu *et al.* 2016 *Phys. Rev. Lett.* **117** 113901.



Ghost images of a copper wire produced by X-rays at the European Synchrotron Radiation Facility in Grenoble, France.

Record light squeeze

A new record has been set in squeezing of the quantum state of light, which could be important for improving the sensitivity of gravitational-wave detectors and for more precise calibrations of photoelectric detectors. Henning Vahlbruch of Leibniz Universität Hannover and the Max-Planck-Insitut für Gravitationsphysik and colleagues used degenerate parametric down-conversion in a doubly resonant optical parametric amplifier to reduce amplitude fluctuations by a factor of 32 (15 dB) relative to classical noise. The result was demonstrated at a wavelength of 1064 nm, which is the wavelength used in all current interferometric gravitational-wave observatories. With this squeezed light, the team was also able to measure the quantum efficiency of a customised InGaAs PIN diode with a 0.5% uncertainty.

● **Further reading**

H Vahlbruch *et al.* 2016 *Phys. Rev. Lett.* **117** 110801.

Astrowatch

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

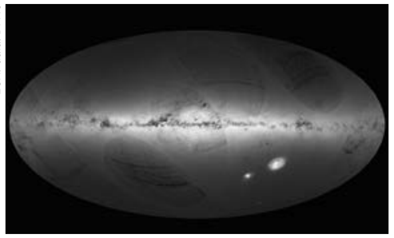
Gaia compiles largest ever stellar survey

The largest all-sky survey of celestial objects has been compiled by ESA's Gaia mission. On 13 September, 1000 days after the satellite's launch, the Gaia team published a preliminary catalogue of more than a billion stars, far exceeding the reach of ESA's Hipparcos mission completed two decades ago.

Astrometry – the science of charting the sky – has undergone tremendous progress over the centuries, from naked-eye observations in antiquity to Gaia's sophisticated space instrumentation today. The oldest known comprehensive catalogue of stellar positions was compiled by Hipparchus of Nicaea in the 2nd century BC. His work, which was based on even earlier observations by Assyro-Babylonian astronomers, was handed down 300 years later by Ptolemy in his 2nd century treatise known as the *Almagest*. Although it listed the positions of 850 stars with a precision of less than one degree, which is about twice the diameter of the Moon, this work was significantly surpassed only in 1627 with the publication of a catalogue of about 1000 stars by the Danish astronomer Tycho Brahe, who achieved a precision of about 1 arcminute by using large quadrants and sextants.

The first stellar catalogue compiled with the aid of a telescope was published in 1725 by English astronomer John Flamsteed, listing the positions of almost 3000 stars with a precision of 10–20 arcseconds. The precision increased significantly

ESA/Gaia/DPAC



An all-sky view of stars in the first Gaia catalogue. With a dot for each star, the map outlines the Milky Way (horizontally) and the Magellanic Clouds (lower right). The curved features are artifacts due to Gaia's scanning procedure.

during the following centuries, with the use of photographic plates by the *Yale Trigonometric Parallax Catalogue* reaching 0.01 arcsecond in 1995. ESA's Hipparcos mission, which operated from 1989 to 1993, was the first space telescope devoted to measuring stellar positions. The Hipparcos catalogue, released in 1997, provides the position, parallax and proper motion of 117,955 stars with a precision of 0.001 arcsecond. The "parallax" is a small displacement of the star's position after a six-month interval, offering a different viewpoint from Earth's annual orbit around the Sun and allowing the star's distance to be derived.

While Hipparcos could probe the stars to distances of about 300 light-years, Gaia's objective is to extend this to a significant fraction of the size of our Galaxy, which spans about 100,000 light-years. To achieve this, Gaia has an astrometric accuracy about 100 times better than Hipparcos. As a comparison, if Hipparcos could measure the angle that corresponds to the height of an astronaut standing on the Moon, Gaia would be able to measure the astronaut's thumbnail.

Gaia was launched on 19 December 2013 towards the Lagrangian point L2, which is a prime location to look at the sky away from disturbances from the Sun, Earth and Moon. Although the first data release already comprises about a billion stars observed during the first 14 months of the mission, there was not enough time to disentangle the proper motion from the parallax. This could only be computed with higher precision for about two million stars previously observed by Hipparcos.

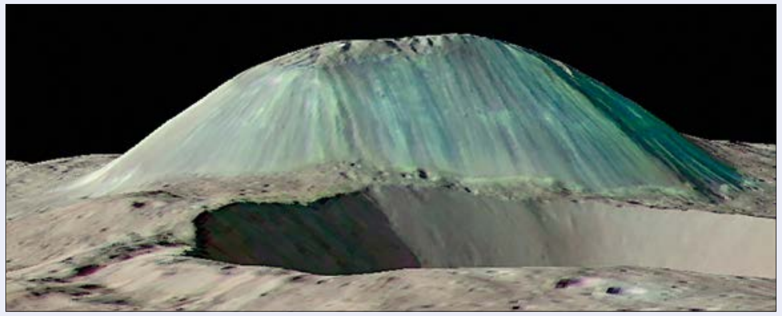
The new catalogue gives an impression of the great capabilities of Gaia. More observations are needed to make a dynamic 3D map of the Milky Way and to find and characterise possible brightness variations of all these stars. Gaia will then be able to provide the parallax distance of many periodic stars such as Cepheids, which are crucial in the accurate determination of the cosmic-distance ladder.

Further reading

Gaia Collaboration 2016 *Astronomy & Astrophysics* (in press).

Picture of the month

Dawn Science Team and NASA/JPL-Caltech/GSFC



This impressive alien view shows the mountain Ahuna Mons rising behind an impact crater on the dwarf-planet Ceres, which is the largest body among the thousands of asteroids that are located between the orbits of Mars and Jupiter. The image is a reconstructed perspective view without vertical exaggeration based on data collected by NASA's Dawn spacecraft, which is currently in orbit around Ceres (*CERN Courier* March 2016 p19). The mountain is 4 km high and 17 km wide and is thought to be a cryovolcano – a low-temperature volcanic activity, where molten ice replaces the molten silicate rock erupted by terrestrial volcanoes. The volcanic dome was likely built from repeated eruptions of salty, muddy water freezing on the surface, which has an average temperature of –40 °C. A study recently published in *Science* constrains the age of the most recent activity on Ahuna Mons to be within the past 210±30 million years, but scientists still have to elucidate the nature of the central heat source at the origin of the eruptions.

Crystal Clear celebrates 25 years of success

CERN's Crystal Clear collaboration marks a quarter-century of developing advanced scintillators for applications in physics and medicine, describes **Etiennette Auffray**.

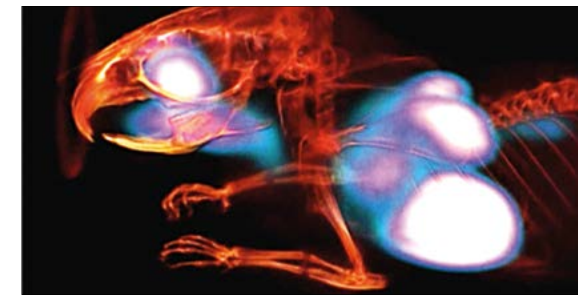
The Crystal Clear (CC) collaboration was approved by CERN's Detector Research and Development Committee in April 1991 as experiment RD18. Its objective was to develop new inorganic scintillators that would be suitable for electromagnetic calorimeters in future LHC detectors. The main goal was to find dense and radiation-hard scintillating material with a fast light emission that can be produced in large quantities. This challenge required a large multidisciplinary effort involving world experts in different aspects of material sciences – including crystallography, solid-state physics, luminescence and defects in solids.

From 1991 to 1994, the CC collaboration carried out intensive studies to identify the most adequate scintillator material for the LHC experiments. Three candidates were identified and extensively studied: cerium fluoride (CeF_3), lead tungstate ($PbWO_4$) and heavy scintillating glass. In 1994, lead tungstate was chosen by the CMS and ALICE experiments as the most cost-effective crystal compliant with the operational conditions at the LHC. Today, 75,848 lead-tungstate crystals are installed in CMS electromagnetic calorimeters and 17,920 in ALICE. The former contributed to the discovery of the Higgs boson, which was identified in 2012 by CMS and the ATLAS experiment via its decay, among others, into two photons. The CC collaboration's generic R&D on scintillating materials has brought a deep understanding of cerium ions for scintillating activators and seen the development of lutetium and yttrium aluminium perovskite crystals for both physics and medical applications.

From physics to medicine

In 1997, the CC collaboration made its expertise in scintillators available to industry and society at large. Among the most promising sectors were medical functional imaging and, in particular, positron emission tomography (PET), due to its growing importance in cancer diagnostics and similarities with the functionality of electromagnetic calorimeters (the principle of detecting gamma rays in a PET scanner is identical to that in high-energy physics detectors).

Following this, CC collaboration members developed and constructed several dedicated PET prototypes. The first, which was later commercialised by Raytest GmbH in Germany under the trademark ClearPET, was a small-animal PET machine used for radiopharmaceutical research. At the turn of the millennium, five ClearPET prototypes characterised by a spatial resolution of 1.5 mm were built by the CC collaboration, which represented a major breakthrough in functional imaging at that time (*CERN Courier* July/August 2005 p27). The same crystal modules were also developed by the CC team at Forschungszentrum Jülich, Germany, to image plants in order to study carbon transport. A modified ClearPET geometry was also combined with X-ray single-photon detectors by CC researchers at CPPM Marseille, offering simultaneous PET and computed-tomography (CT) acquisition, and providing the first PET/CT simultaneous images of a mouse in 2015 (see image above). The simultaneous use of CT and PET allows the excellent position resolution of anatomic imaging (providing detailed images of the structure of tissues) to be combined with functional imaging, which is sensitive to the tissue's metabolic activity.



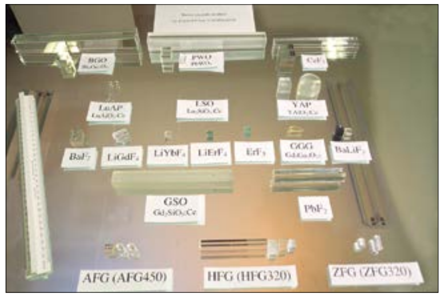
M. Hamonet (CPPM) & Luc Bidaut (Lincoln Univ. UK)

3D PET/CT image of a mouse labelled with FDG acquired with the ClearPET/XPAD prototype developed at CPPM Marseille.

The activities of the CC collaboration have resulted in more than 650 publications and 72 PhD theses.

After the success of ClearPET, in 2002, CC developed a dedicated PET camera for breast imaging called ClearPEM. This system had a spatial resolution of 1.3 mm and represented the first PET imaging based on avalanche photodiodes, which were initially developed for the CMS electromagnetic calorimeter. The machine was installed in ▷

Scintillators



(Above) Various scintillating inorganic crystals investigated by CC and (above right) LuAG crystal fibres developed for future detectors.

(Below left) ClearPET cassettes used in the PLANTIS project at Jülich. (Right) View inside ClearPET Neuro in Jülich, which was based on technology from CC and uses 20 cassettes containing crystal modules to image small animals.

Coimbra, Portugal, where clinical trials were performed. In 2005, a second ClearPEM machine combined with 3D ultrasound and elastography was developed with the aim of providing anatomical and metabolic information to allow better identification of tumours (*CERN Courier* July/August 2013 p23). This machine was installed in Hôpital Nord in Marseille, France, in December 2010 for clinical evaluations of 10 patients, and three years later it was moved to the San Girardo hospital in Monza, Italy, to undertake larger clinical trials, which are ongoing.

In 2011, a European FP7 project called EndoTOFPET-US, which was a consortium of three hospitals, three companies and six institutes, began the development of a prototype for a novel bi-modal time-of-flight PET and ultrasound endoscope with a spatial resolution better than 1 mm and a time resolution of 200 ps. This was aimed at the detection of early stage pancreatic or prostatic tumours and the development of new biomarkers for pancreatic and prostatic cancers. Two prototypes have been produced (one for pancreatic and one for prostate cancers) and the first tests on a phantom-prostate prototype were performed in spring 2015 at the CERIMED centre in Marseille. Work is now ongoing to improve the two prototypes, in view of pre-clinical and clinical operation.

In addition to the development of ClearPET detectors, members of the collaboration have initiated the development of the Monte Carlo simulation software-package GATE, a GEANT4-based simulation tool allowing the simulation of full PET detector systems (*CERN Courier* January/February 2005 p27).

Clear impact

In 1992, the CC collaboration organised the first international conference on inorganic scintillators and their applications, which led to a global scientific community of around 300 people. Today, this community comes together every two years at the SCINT conferences, the next instalment of which will take place in Chamonix, France, from 18 to 22 September 2017.

To this day, the CC collaboration continues its investigations into new scintillators and understanding their underlying scintillation mechanisms and radiation-hardness characteristics – in addition to the development of detectors. Among its most recent activities is the investigation of key parameters in scintillating detectors that enable very precise timing information for various applications. These include mitigating the effect of "pile-up" caused by the high event rate at particle accelerators operating at high peak luminosities, and also medical applications in time-of-flight PET imaging. This research requires the study of new materials and processes to identify ultrafast scintillation mechanisms such as "hot intraband luminescence" or quantum-confined excitonic emission with sub-picosecond rise time and sub-nanosecond decay time. It also involves investigating the enhancement of the scintillator light collection by using various surface treatments, such as nano-patterning with photonic crystals. CC recently initiated a European COST Action called Fast Advanced Scintillator Timing (FAST) to bring together European experts from academia and industry to ultimately achieve scintillator-based detectors with a time precision better than 100 ps, which provides an excellent training opportunity for researchers interested in this domain.

Among other recent activities of the CC collaboration are new crystal-production methods. Micro-pulling-down techniques, which allow inorganic scintillating crystals to be grown in the shape of fibres with diameters ranging from 0.3 to 3 mm, open the way to attractive detector designs for future high-energy physics experiments by replacing a block of crystals with a bundle of fibres. A Horizon 2020 European RISE Marie Skłodowska-Curie project called Intelum has been set up by the CC collaboration to explore the cost-effective production of large quantities of fibres. More recently, the development of new PET crystal modules has been launched by CC collaborators. These make use of new photodetector silicon photomultipliers and have a high spatial resolution (1.5 mm), depth-of-interaction capability (better than 3 mm) and a fast timing resolution (better than 200 ps).

Future directions

For the past 25 years, the CC collaboration has actively carried out R&D on scintillating materials, and investigated their use in novel ionising radiation-detecting devices (including read-out electronics and data acquisition) for use in particle-physics and medical-imaging applications. In addition to significant progress made in the understanding of scintillation mechanisms and radiation hardness of different materials, the choice of lead tungstate for the CMS electromagnetic calorimeter and the realisation of various prototypes for medical imaging are among the CC collaboration's highlights so far. It is now making important contributions to understanding the key parameters for fast-timing detectors.

Scintillators

ClearPEM-Sonic installed at Hôpital Nord in Marseille, showing the ultrasound system (left) and ClearPEM system (right).

The various activities of the CC collaboration, which today has 29 institutional members, have resulted in more than 650 publications and 72 PhD theses. The motivation of CC collaboration members and the momentum generated throughout its many projects open up promising perspectives for the future of inorganic scintillators and their use in HEP and other applications.

● An event to celebrate the 25th anniversary of the CC collaboration will take place at CERN on 24 November.

● Further reading

N Aubry *et al.* 2013 *JINST* **8** C04002.
E Auffray *et al.* 1996 *Nucl. Instrum. Methods Phys. Res. A* **380** 524.
E Auffray *et al.* 1996 *Nucl. Instrum. Methods Phys. Res. A* **383** 367.
Crystal Clear Collaboration 1991 CERN/DRDC/91-15/DRDC/P27
M Hamonet *et al.* 2015 *Conf. Rec. IEEE NSS/MIC'2015* (IEEE Press)
A Knapitsch and P Lecoq 2014 *Int. J. Mod. Phy. A* **29** 1430070.
P Lecoq *et al.* 1995 *Nucl. Instrum. Methods Phys. Res. A* **365** 291.
M Lucchini *et al.* 2016 *NIM A* **816** 176.
K Pauwels *et al.* 2013 *JINST* **8** P09019.
M Pizzichemi *et al.* 2016 *Phys. Med. Biol.* **61** 4679.

Résumé

Crystal Clear fête ses 25 ans

Cela fait à présent un quart de siècle que la collaboration Crystal Clear du CERN effectue des travaux de R&D sur les matériaux scintillants de pointe, en vue de leur utilisation dans des dispositifs novateurs de détection des rayonnements ionisants destinés à la physique des particules et à l'imagerie médicale. En plus d'une avancée notable dans la compréhension des mécanismes de scintillation et de la résistance aux radiations de différents matériaux, la collaboration a aussi à son actif une contribution importante dans le choix du tungstate de plomb comme matériau de base pour le calorimètre électromagnétique de CMS et la réalisation de divers prototypes pour l'imagerie médicale. Il faut à présent ajouter à cela des contributions importantes à la compréhension des paramètres-clés pour les détecteurs à très haute résolution temporelle.

Etiennette Auffray, CERN, and spokesperson of the Crystal Clear collaboration.

The CTF3 test facility at CERN, which has demonstrated CLIC's novel two-beam acceleration technology.
Image credit: Maximilien Brice.

CLIC steps up to the TeV challenge

An updated baseline-staging scenario for CERN's Compact Linear Collider (CLIC) focuses on an optimised initial-energy stage at 380 GeV that will be significantly cheaper than the original design, say **Philipp Roloff** and **Daniel Schulte**.

One of CERN's main options for a flagship accelerator in the post-LHC era is an electron–positron collider at the high-energy frontier. The Compact Linear Collider (CLIC) is a multi-TeV high-luminosity linear collider that has been under development since 1985 and currently involves 75 institutes around the world. Being linear, such a machine does not suffer energy losses from synchrotron radiation, which increases strongly with the beam energy in circular machines. Another option for CERN is a very high-energy circular proton–proton collider, which is currently being considered as the core of the Future Circular Collider (FCC) programme. So far, CLIC R&D has principally focused on collider technology that's able to reach collision energies in the multi-TeV range. Based on this technology, a conceptual design report (CDR) including a feasibility study for a 3 TeV collider was completed in 2012.

With the discovery of the Higgs boson in July of that year, and the fact that the particle turned out to be relatively light with a mass of 125 GeV, it became evident that there is a compelling physics case for operating CLIC at a lower centre-of-mass energy. The optimal collision energy is 380 GeV because it simultaneously allows physicists to study two Higgs-production processes in addition to top-quark pair production. Therefore, to fully exploit CLIC's scientific potential, the collider is foreseen to be constructed in several stages corresponding to different centre-of-mass energies: the first at 380 GeV would be followed by stages at 1.5 and 3 TeV, allowing powerful searches for phenomena beyond the Standard Model (SM).

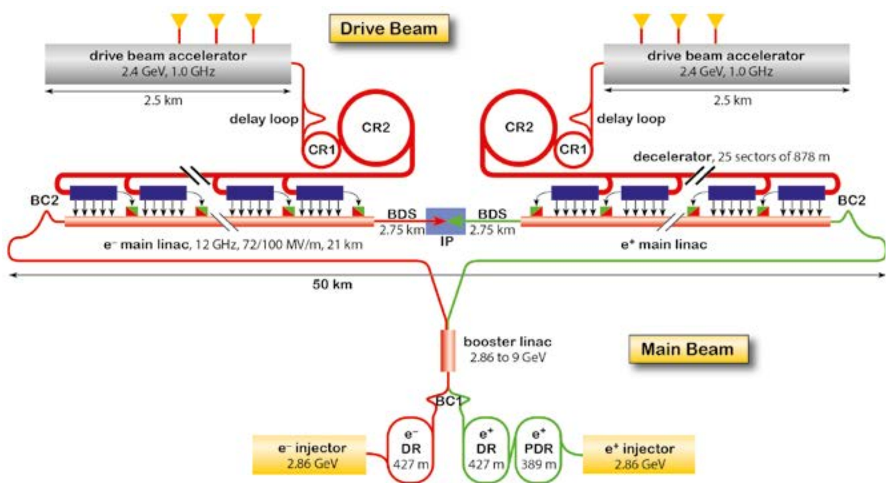
While a fully optimised collider at 3 TeV was described in the CDR in 2012, the lower-energy stages were not presented at the same level of detail. In August this year, however, the CLIC and CLICdp (CLIC detector and physics study) collaborations published an updated baseline-staging scenario that places emphasis on an optimised first-energy stage compatible with an extension to high energies. The performance, cost and power consumption of the CLIC accelerator as a function of the centre-of-mass energy were addressed, building on experience from technology R&D and system tests. The resulting first-energy stage is based on already demonstrated performances of CLIC's novel acceleration technology and will be significantly cheaper than the initial CDR design.

CLIC physics

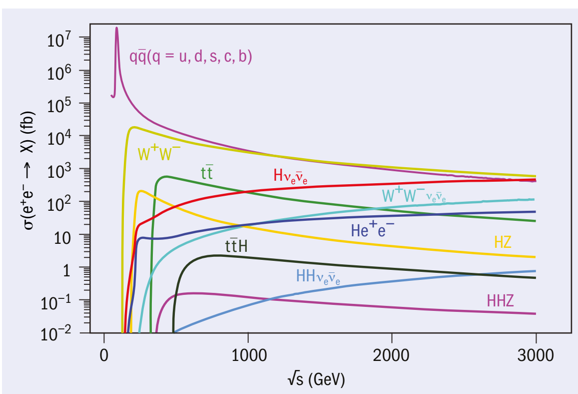
An electron–positron collider provides unique opportunities to make precision measurements of the two heaviest particles in the SM: the Higgs boson (125 GeV) and the top quark (173 GeV). Deviations in the way the Higgs couples to the fermions, the electroweak bosons and itself are predicted in many extensions of the SM, such as supersymmetry or composite Higgs models. Different scenarios lead to specific patterns of deviations, which means that precision measurements of the Higgs couplings can potentially discriminate between different new-physics scenarios. The same is true of the couplings of the top quark to the Z boson and photon. CLIC would offer such measurements as the first step of its physics programme, and full simulations of realistic CLIC detector concepts have been used to evaluate the expected precision and to guide the choice of collision energy.

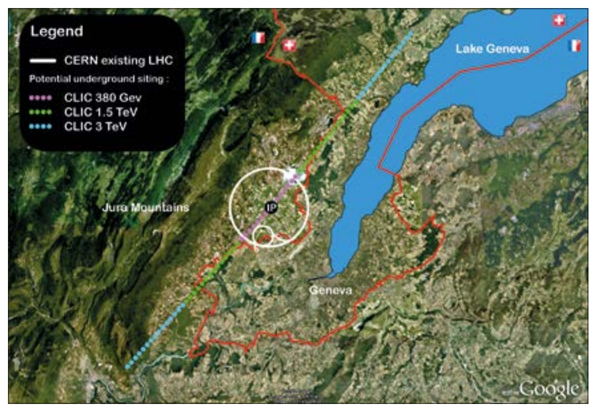
The principal Higgs production channel, Higgsstrahlung ($e^+e^- \rightarrow ZH$), requires the centre-of-mass energy to be equal to the sum of the Higgs- and Z-boson masses plus a few tens of GeV. For an electron–positron collider such as CLIC, Higgsstrahlung has a maximum cross-section at a centre-of-mass energy of around 240 GeV and decreases as a function of energy. Because the colliding electrons and positrons are elementary particles with a precisely known energy, Higgsstrahlung events can be identified by detecting the Z boson alone as it recoils against the Higgs boson. This can be done without looking at the decay of the Higgs boson, and hence the measurement is completely independent of possible unknown Higgs decays. This is a unique capability of a lepton collider and the reason why the first energy stage of CLIC is so important. The most powerful method with which to measure the Higgsstrahlung cross-section in this way is based on events where a Z boson decays into hadrons, ▷

Combining all available knowledge led to the choice of 380 GeV for the first energy stage.



(Left) Overview of the CLIC layout at 3 TeV, showing combiner rings (CR), delay loop, damping ring (DR), pre-damping ring (PDR), bunch compressor (BC) and beam delivery system (BDS). The red and green squares represent beam dumps. (Below) CLIC footprints in the vicinity of CERN, showing the three implementation stages. (Below left) The centre-of-mass energy dependencies of important SM processes in electron–positron collisions.





and the best precision is expected at centre-of-mass energies around 350 GeV. (At lower energies it is more difficult to separate signal and background events, while at higher energies the measurement is limited by the smaller signal cross-section and worse recoil mass resolution.)

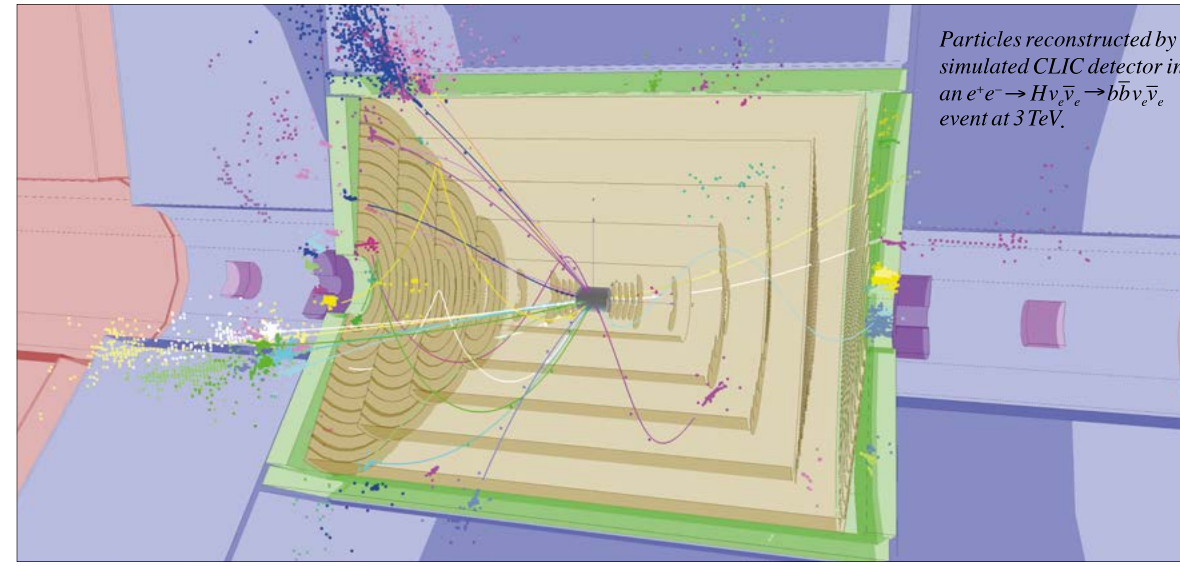
The other main Higgs-production channel is WW fusion ($e^+e^- \to H\nu_e\bar{\nu}_e$). In contrast to Higgsstrahlung, the cross-section for this process rises quickly with centre-of-mass energy. By measuring the rates for the same Higgs decay, such as $H \to b\bar{b}$, in both Higgsstrahlung and WW-fusion events, researchers can significantly improve their knowledge of the Higgs decay width – which is a challenging measurement at hadron colliders such as the LHC. A centre-of-mass energy of 380 GeV at the first CLIC energy stage is ideal for achieving a sizable contribution of WW-fusion events.

So far, the energy of electron–positron colliders has not been high enough to allow direct measurements of the top quark. At the first CLIC energy stage, however, properties of the top quark can be obtained via pair-production events ($e^+e^- \to t\bar{t}$). A small fraction of the collider's running time would be used to scan the top pair-production cross-section in the threshold region around 350 GeV. This would allow us to extract the top-quark mass in a theoretically well-defined scheme, which is not possible at hadron colliders. The value of the top-quark mass has an important impact on the stability of the electroweak vacuum at very high energies.

With current knowledge, the achievable precision on the top-quark mass is expected to be in the order of 50 MeV, including systematic and theoretical uncertainties. This is about an order of magnitude better than the precision expected at the High-Luminosity LHC (HL-LHC).

The couplings of the top quark to the Z boson and photon can be probed using the top-production cross-sections and "forward-backward" asymmetries for different electron-beam polarisation configurations available at CLIC. These observables lead to expected precisions on the couplings which are substantially better than those achievable at the HL-LHC. Deviations of these couplings from their SM expectations are predicted in many new physics scenarios, such as composite-Higgs scenarios or extra-dimension models. It was recently shown, using detailed detector simulations, that although higher energies are preferred, this measurement is already feasible at an energy of 380 GeV, provided the theoretical uncertainties improve in the coming years. The expected precisions depend on our ability to reconstruct $t\bar{t}$ events correctly, which is more challenging at 380 GeV compared to higher energies because both top quarks decay almost isotropically.

Combining all available knowledge therefore led to the choice of 380 GeV for the first-energy stage of the CLIC programme in



Particles reconstructed by a simulated CLIC detector in an $e^+e^- \to H\nu_e\bar{\nu}_e \to b\bar{b}\nu_e\bar{\nu}_e$ event at 3 TeV.

the new staging baseline. Not only is this close to the optimal value for Higgs physics around 350 GeV but it would also enable substantial measurements of the top quark. An integrated luminosity of 500 fb^{-1} is required for the Higgs and top-physics programmes, which could take roughly five years. The top cross-section threshold scan, meanwhile, would be feasible with 100 fb^{-1} collected at several energy points near the production threshold.

Stepping up

After the initial phase of CLIC operation at 380 GeV, the aim is to operate CLIC above 1 TeV at the earliest possible time. In the current baseline, two stages at 1.5 TeV and 3 TeV are planned, although the exact energies of these stages can be revised as new input from the LHC and HL-LHC becomes available. Searches for beyond-the-SM phenomena are the main goal of high-energy CLIC operation. Furthermore, additional unique measurements of Higgs and top properties are possible, including studies of double Higgs production to extract the Higgs self-coupling. This is crucial to probe the Higgs potential experimentally and its measurement is extremely challenging in hadron collisions, even at the HL-LHC. In addition, the full data sample with three million Higgs events would lead to very tight constraints on the Higgs couplings to vector bosons and fermions. In contrast to hadron colliders, all events can be used for physics and there are no QCD backgrounds.

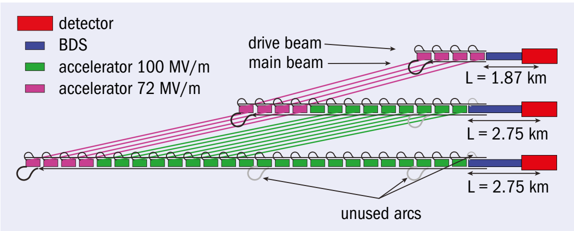
Two fundamentally different approaches are possible to search for phenomena beyond the SM. The first is to search directly for the production of new particles, which in electron–positron collisions can take place almost up to the kinematic limit. Due to the clean experimental conditions and low backgrounds compared to hadron colliders, CLIC is particularly well suited for measuring new and existing weakly interacting states. Because the beam energies are tunable, it is also possible to study the production thresholds of new particles in detail. Searches for dark-matter candidates, meanwhile, can be performed using single-photon events with missing energy. Because lepton colliders probe the coupling of dark-matter particles to leptons, searches at CLIC are complementary to those at hadron colliders, which are sensitive to the couplings to quarks and gluons.

The second analysis approach at CLIC, which is sensitive to even higher mass scales, is to search for unexpected signals in precision measurements of SM observables. For example, measurements of two-fermion processes provide discovery potential for Z′ bosons with masses up to tens of TeV. Another important example is the search for additional resonances or anomalous couplings in vector-boson scattering. For both indirect and direct searches, the discovery reach improves significantly with increasing centre-of-mass energy. If new phenomena are found, beam polarisation might help to constrain the underlying theory through observables such as polarisation asymmetries.

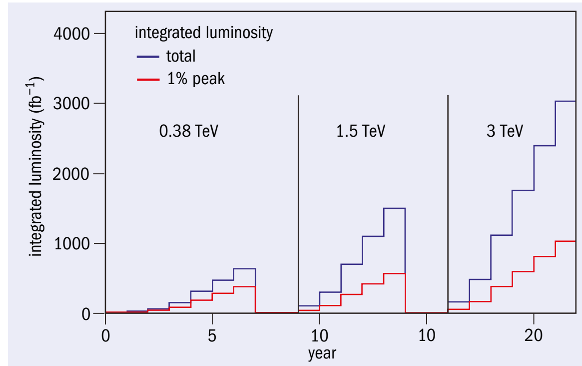
The CLIC concept

CLIC will collide beams of electrons and positrons at a single interaction point, with the main beams generated in a central facility that would fit on the CERN site. To increase the brilliance of the beams, the particles are "cooled" (slowed down and reaccelerated continuously) in damping rings before they are sent to the two high-gradient main linacs, which face each other. Here, the beams are accelerated to the full collision energy in a single pass and a magnetic telescope consisting of quadrupoles and different multipoles is used to focus the beams to nanometre sizes in the collision point inside of the detector. Two additional complexes produce high-current (100 A) electron beams to drive the main linacs – this novel two-beam acceleration technique is unique to CLIC.

The CLIC accelerator R&D is focused on several core challenges. First, strong accelerating fields are required in the main linac to limit its length and cost. Outstanding beam quality is also essential to achieve a high rate of physics events in the detectors. In addition, the power consumption of the CLIC accelerator complex has to be limited to about 500 MW for the highest-energy stage; hence a high efficiency to generate RF power and transfer ▷



The different energy stages of the CLIC design. In the first stage, a different accelerating structure design is used, which can be moved to the beginning of the linacs and reused for the following stages.



Integrated luminosity in the considered staging scenario (years are counted from the start of beam commissioning).

it into the beams is mandatory. CLIC will use high-frequency (X-band) normal-conducting accelerating structures (copper) to achieve accelerating gradients at the level of 100 MV/m. A centre-of-mass energy of 3 TeV can be reached with a collider of about 50 km length, while 380 GeV for CLIC's first stage would require a site length of 11 km, which is slightly larger than the diameter of the LHC. The accelerator is operated using 50 RF pulses of 244 ns length per second. During each pulse, a train of 312 bunches is accelerated, which are separated by just 0.5 ns. To generate the accelerating field, each CLIC main-linac accelerating structure needs to be fed with an RF power of 60 MW. With a total of 140,000 structures in the 3 TeV collider, this adds up to more than 8 TW.

Because it is not possible to generate this peak power at reasonable cost with conventional klystrons (even for the short pulse length of 244 ns), a novel power-production scheme has been developed for CLIC. The idea is to operate a drive beam with a current of 100 A that runs parallel to the main beam via power extraction and transfer structures. In these structures, the beam induces electric fields, thereby losing energy and generating RF power, that is transferred to the main-linac accelerating structures. The drive beam is produced as a long (146 µs) high-current (4 A) train of bunches and is accelerated to an energy of about 2.4 GeV and then sent into a delay loop and combiner-ring complex where sets of 24 consecutive sub-pulses are used to form 25 trains of 244 ns length with a current of about 100 A. Each of these bunch-trains is then used to power one of the 25 drive-beam sectors, which means that the initial 146 µs-long pulse is effectively compressed in time by a factor of 600, and therefore its power is increased by the same factor.

To demonstrate this novel scheme, a test facility (CTF3) was constructed at CERN since 2001 that reused the LEP pre-injector building and components as well as adding many more. The facility now consists of a drive-beam accelerator, the delay loop and one combiner ring. CTF3 can produce a drive-beam pulse of about 30 A and accelerate the main beam with a gradient of up to 145 MV/m. A large range of components, feedback systems and operational procedures needed to be developed to make the facility a success, and by the end of 2016 it will have finished its mission. Further beam tests at SLAC, KEK and various light sources remain important. The CALIFES electron beam facility at CERN, which is currently being evaluated for operation from 2017, can provide a testing ground for high-gradient structures and main-beam studies. More prototypes for CLIC's main-beam and drive-beam components are being developed and characterised in dedicated test facilities at CERN and collaborating institutes. The resulting progress in X-band acceleration technology also generated important interest in the Free Electron Laser (FEL) community, where it may allow for more compact facilities.

The overall three-stage CLIC physics programme would last for 22 years.

To achieve the required luminosities ($6\times10^{34}\,\mathrm{cm^{-2}s^{-1}}$ at 3 TeV), nanometre beam sizes are required at CLIC's interaction point. This is several hundred times smaller than at the SLC, which operated at SLAC in the 1990s and was the first and only operational linear collider, and therefore requires novel hardware and sophisticated beam-based alignment algorithms. A precision pre-alignment system has been developed and tested that can achieve an alignment accuracy in the range of 10 µm, while beam-based tuning algorithms have been successfully tested at SLAC and other facilities. These algorithms use beams of different energies to diagnose and correct the offset of the beam-position monitors, reducing the effective misalignments to a fraction of a micron. Because the motion of the ground due to natural and technical sources can cause the beam-guiding quadrupole magnets to move, knocking the beams out of focus, the magnets will be stabilised with an active feedback system that has been developed by a collaboration of several institutes, and which has already been demonstrated experimentally.

CLIC's physics potential has been illustrated through the simulation and reconstruction of benchmark physics processes in two dedicated detector concepts. These are based on the SiD and ILD detector concepts developed for the International Linear Collider (ILC), an alternative machine currently under consideration for construction in Japan, and have been adapted to the experimental environment at the higher-energy CLIC. Because the high centre-of-mass energies and CLIC's accelerator technology lead to relatively high beam-induced background levels for a lepton collider, the CLIC detector design and the event-reconstruction techniques are both optimised to suppress the influence of these backgrounds. A main driver for the ILC and CLIC detector concepts is the required jet-energy resolution. To achieve the required precision, the CLIC detector concepts are based on fine-grained electromagnetic and hadronic calorimeters optimised for particle-flow analysis techniques. A new study is almost complete, which defines a single optimised CLIC detector for use in future CLIC physics benchmark studies. The work by CLICdp was crucial for the new staging baseline (especially for the choice of 380 GeV) because the physics potential as a function of energy can only be estimated with the required accuracy using detailed simulations of realistic detector concepts.

The new staged design

To optimise the CLIC accelerator, a systematic design approach has been developed and used to explore a large range of configurations for the RF structures of the main linac. For each structure design, the luminosity performance, power consumption and total cost of the CLIC complex are calculated. For the first stage, different accelerating structures operated at a somewhat lower accelerating gradient of 72 MV/m will be used to reach the luminosity goal at a cost and power consumption similar to earlier projects at CERN – while also not inflating the cost of the higher-energy stages. The design should also be flexible enough to take advantage of projected improvements in RF technology during the construction and operation of the first stage.

When upgrading to higher energies, the structures optimised for 380 GeV will be moved to the beginning of the new linear accelerator and the remaining space filled with structures optimised for 3 TeV operation. The RF pulse length of 244 ns is kept the same at all stages to avoid major modifications to the drive-beam generation scheme. Data taking at the three energy stages is expected to last for a period of seven, five and six years, respectively. The stages are interrupted by two upgrade periods each lasting two years, which means that the overall three-stage CLIC programme will last for 22 years from the start of operation. The duration of each stage is derived from integrated luminosity targets of $500\,\mathrm{fb^{-1}}$ at 380 GeV, $1.5\,\mathrm{ab^{-1}}$ at 1.5 TeV and $3\,\mathrm{ab^{-1}}$ at 3 TeV.

An intense R&D programme is yielding other important improvements. For instance, the CLIC study recently proposed a novel design for klystrons that can increase the efficiency significantly. To reduce the power consumption further, permanent magnets are also being developed that are tunable enough to be able to replace the normal conducting magnets. The goal is to develop a detailed design of both the accelerator and detector in time for the update of the European Strategy for Particle Physics towards the end of the decade.

Mature option

With the discovery of the Higgs boson, a great physics case exists for CLIC at a centre-of-mass energy of 380 GeV. Hence particular emphasis is being placed on the first stage of the accelerator, for which the focus is on reducing costs and power consumption. The new accelerating structure design will be improved and more statistics on the structure performance will be obtained. The detector design will continue to be optimised, driven by the requirements of the physics programme. Technology demonstrators for the most challenging detector elements, including the vertex detector and main tracker, are being developed in parallel.

Common studies with the ILC, which is currently being considered for implementation in Japan, are also important, both for accelerator and detector elements, in particular for the initial stage of CLIC. Both the accelerator and detector parameters and designs, in particular for the second- and third-energy stages, will evolve according to new LHC results and studies as they emerge.

CLIC is the only mature option for a future multi-TeV high-luminosity linear electron–positron collider. The two-beam technology has been demonstrated in large-scale tests and no show stoppers were identified. CLIC is therefore an attractive option for CERN after the LHC. Once the European particle-physics community decides to move forward, a technical design will be developed and construction could begin in 2025.

• Further reading

H Abramowicz *et al.* 2016 arXiv:1608.07538.
CLIC and CLICdp Collaborations 2016 arXiv:1608.07537.

Résumé

Le CLIC s'attaque au défi des TeV

Le collisionneur linéaire compact (CLIC) est un collisionneur linéaire à haute luminosité de plusieurs TeV, en développement depuis 1985, pour lequel un rapport préliminaire de conception a été achevé en 2012. Avec la découverte du boson de Higgs en juillet de la même année, l'intérêt indiscutable d'une exploitation du CLIC à une énergie dans le centre de masse plus faible (380 GeV) est devenu évident. Récemment, CLIC a publié une mise à jour de son scénario de base, étape par étape ; il met l'accent sur une première étape d'énergie optimisée. Cette première étape est basée sur des performances déjà démontrées de la technologie d'accélération novatrice du CLIC, et elle sera nettement moins onéreuse que celle figurant dans le rapport préliminaire de conception initial.

Philipp Roloff and **Daniel Schulte**, CERN.

Factory Acceptance Testing at Buckley Systems

Mobile "Roamer" CMM used to confirm dimensions are within tolerance on a quadrupole magnet.

General

Buckley Systems manufactures sophisticated magnets, and it is certified ISO 9001:2008 for the following scope: the design and manufacture of precision electromagnets, ion-beam physics hardware, and ultra-high vacuum equipment used in the semiconductor - ion implant industry, laboratory research and particle accelerators. Nevertheless, from the customer's point of view, the manufacturing job is not complete until the Factory Acceptance Test (FAT) is successfully completed. Buckley System "FATs" are described in the Coils, and Magnets sections.

A Quality Control (QC) programme is in place to ensure that machined parts and assemblies meet dimensional tolerances (and other specified customer constraints) throughout the manufacturing process. Several high-accuracy Coordinate Measuring Machines (CMM) measure dimensions to 10 µm including a "roamer" which has "touchscan" capability meaning that its finger can be drawn along a surface rather than just touching a surface at several points. Ceramic gauge blocks measure magnet gaps to 1 µm accuracy.

Coils

Buckley Systems achieves FATs for National Laboratories that are comprehensive and stringent. All measurements within the temperature controlled test building must be within a set tolerance to achieve a pass. A sample list of typical measurements follows:

(i) electrical resistance tests,
(ii) inductance tests,
(iii) pressure and flow rate tests of the cooling water,
(iv) insulation resistance and high electric potential tests with coils immersed in salted water ($<1{,}000\ \Omega$-m) and leakage currents $<50\ \mu$A,
(v) impulse-tested for turn-to-turn integrity over a range of voltages with rejection based on frequency shifts or damping rates changing as a function of voltage, or non-conformance to customer supplied waveforms
(vi) thermal-switch open/close testing as a function of temperature.

Magnets

Buckley Systems accommodates magnets with apertures ranging from 8 mm to 2000 mm, and has Hall probes with 3.5 m of travel at its disposal. Completed magnets must also undergo FATs and a sampling of what these entail follows:

(i) the nominal mechanical resonant frequency orthogonal to the magnet axis,
(ii) Magnetic measurements for dipole magnets through a range of excitation-currents include for example:
(a) integrated field homogeneity to one part in 10^6 over a "good field" range in the mid-plane, (b) integrated dipole field over length of yoke and including fringe field region, (c) end field maps and chamfer adjustments to minimize integrated field errors, and (d) B/I curve at the midpoint,
(iii) Magnetic measurements for quadrupole, sextupole, and octupole magnets over a range of excitation-currents include:
(a) integrated field harmonics up to a maximum-pole (42-pole in some cases) at a set radius, (b) integrated field measurements over length of yoke and including fringe field region, (c) end chamfer adjustments to minimize integrated harmonic terms of the customer's choice, (d) magnetic centre measurement to better than ± 50 microns, (e) magnetic length, and (f) field angle,
(iv) Leak rate tests for high vacuum and ultra high vacuum chambers with the appropriate bake-out procedures observed.

Lastly, Buckley Systems can model particle trajectories through the measured magnetic fields and compare the magnet's performance based on the measured fields to the simulated performance. This has been particularly useful in ascertaining whether magnetic spectrometer systems have achieved their design resolution or not.

Magnetic Field Measurements on a Dipole Magnet.

BUCKLEY SYSTEMS

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CERN Courier November 2016

Physics beyond colliders

CERN explores opportunities for physics beyond colliders

CERN has established a study group to explore how its accelerator complex can be used to target fundamental-physics questions similar to those addressed by high-energy colliders but based on different types of beams and experiments, report **Joerg Jaeckel**, **Mike Lamont** and **Claude Vallée**.

Our understanding of nature's fundamental constituents owes much to particle colliders. Notable discoveries include the W and Z bosons at CERN's Super Proton Synchrotron in the 1980s, the top quark at Fermilab's Tevatron collider in the 1990s and the Higgs boson at CERN's LHC in 2012. While colliding particles at ever higher energies is still one of the best ways to search for new phenomena, experiments at lower energies can also address fundamental-physics questions.

The Physics Beyond Colliders kick-off workshop, which was held at CERN on 6–7 September, brought together a wide range of physicists from the theory, experiment and accelerator communities to explore the full range of research opportunities presented by the CERN complex. The considered timescale for such activities reaches as far as 2040, corresponding roughly to the operational lifetime of the LHC and its high-luminosity upgrade. The study group has been charged with pulling together interested parties and exploring the options in appropriate depth, with the aim of providing input to the next update to the European Strategy for Particle Physics towards the end of the decade.

As the name of the workshop and study group suggests, a lot of interesting physics can be tested in experiments that are complementary to colliders. Ideas discussed at the September event ranged from searching for particles with masses far below an eV up to more than 10^{15} eV, to prospects for dark matter and even dark-energy studies.

Theoretical motivation

Searches for electric and magnetic dipole moments in elementary particles are a rich experimental playground, and the enormous precision of such experiments allows a wide range of new physics to be tested. The long-standing deviation of the muon magnetic moment (g-2) from the Standard Model prediction could indicate the presence of relatively heavy supersymmetric particles, but also the presence of relatively light "dark photons", which are also a possible messenger to the dark-matter sector. A confirmation, or not, of the original g-2 measurement and experimental tests of other models will provide important input to this issue.

Electric dipole moments are inherently linked to the violation of charge–parity (CP) symmetry, which is a necessary ingredient to explain the origin of the baryon asymmetry of the universe. While CP violation has been observed in weak interactions, it is notably absent in strong interactions. For example, no electric dipole moment of the neutron has been observed so far. Eliminating this so-called strong-CP problem gives significant motivation for hypothesising the existence of a new elementary particle called the axion. Indeed, axion-like particles are not only natural dark-matter candidates but they turn out to be one of the features that are abundant in well-motivated extensions of the Standard Model, such as string theory. Axions could help to explain a number of astrophysical puzzles such as dark matter. They may also be connected to inflation in the very early universe and to the generation of neutrino masses, and potentially are even involved with the hierarchy problem.

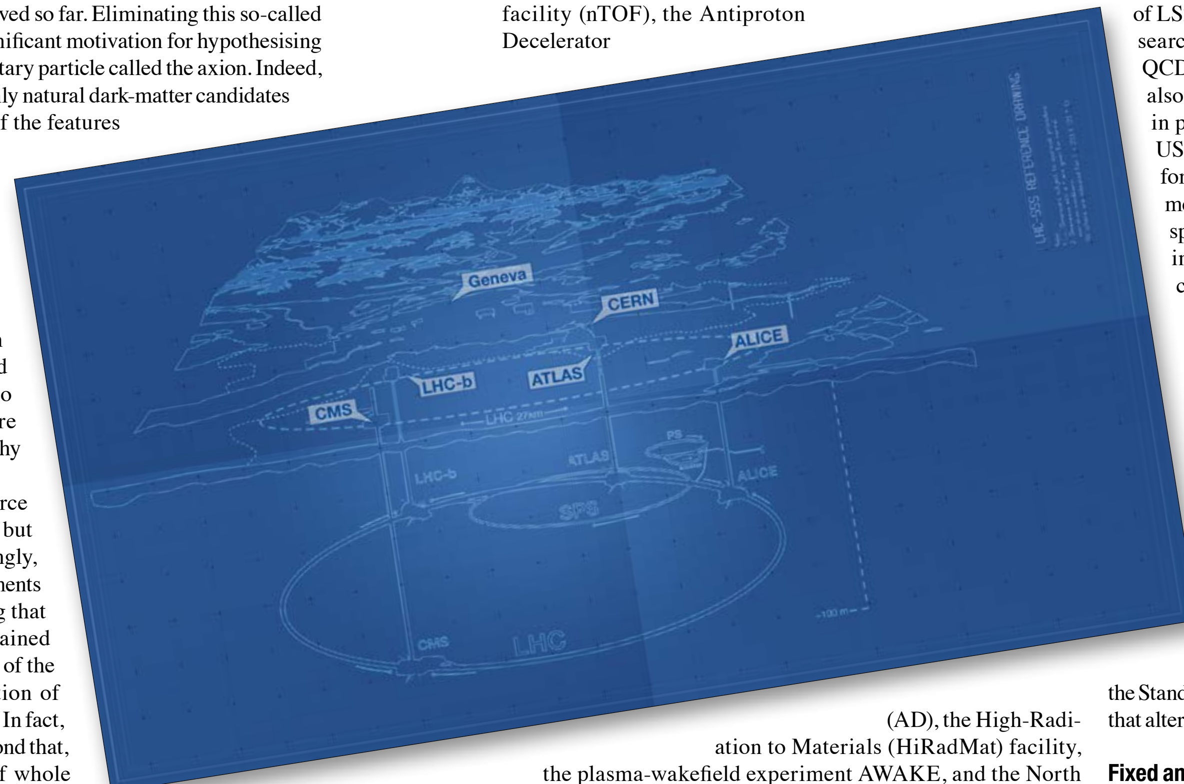
Neutrinos are also the source of a large range of puzzles, but also opportunities. Interestingly, essentially all current experiments and observations – including that of dark matter – can be explained by a very minimal extension of the Standard Model: the addition of three right-handed neutrinos. In fact, theorists' ideas range far beyond that, motivating the existence of whole sectors of weakly coupled particles below the Fermi scale.

Ambitions may even lead to tackling one of the most challenging of questions: dark energy. While the effective couplings between ordinary matter and dark energy must be quite small, there is still significant room for observable effects in low-energy experiments, for example using atom interferometry.

Experimental opportunities

It is clear that CERN's priority over the coming years is the full exploitation of the LHC – first in its present guise and then, from 2026, as the High-Luminosity LHC (HL-LHC). The HL-LHC places stringent demands on intensity and related characteristics, and a major upgrade of the LHC injectors is planned during Long Shutdown 2 (LS2) beginning in 2019 to provide beams in the HL-LHC era. Despite this, the LHC doesn't actually use many protons. This leaves the other facilities at CERN open to exploit the considerable beam-production capabilities of the accelerator complex.

CERN already has a diverse and far-sighted experimental programme based on the LHC injectors. This spans the ISOLDE radioactive beam facility, the neutron time-of-flight facility (nTOF), the Antiproton Decelerator (AD), the High-Radiation to Materials (HiRadMat) facility, the plasma-wakefield experiment AWAKE, and the North and East experimental areas. CERN's proton-production capabilities are already heavily used and will continue to be well-solicited in the coming years. A preliminary forecast shows that there is potential capacity to support one more major SPS experiment after the injector upgrade.



The AD is a classic example of CERN's existing non-collider-based facilities. This unique antimatter factory has several experiments studying the properties of antiprotons and anti-hydrogen atoms in detail. Here, in the experimental domain, the time constant for technological evolution is much shorter than it is for large high-energy detectors. The AD is currently being upgraded with the ELENA ring, which will increase by two orders of magnitude the trapping efficiency of anti-hydrogen atoms and will allow different experiments to operate in parallel. After LS2, ELENA will serve all AD experiments and will secure CERN's antimatter research into the next decade. The ISOLDE and nTOF facilities also offer opportunities to investigate fundamental questions such as the unitarity of the quark-mixing matrix, parity violation or the masses of the neutrinos.

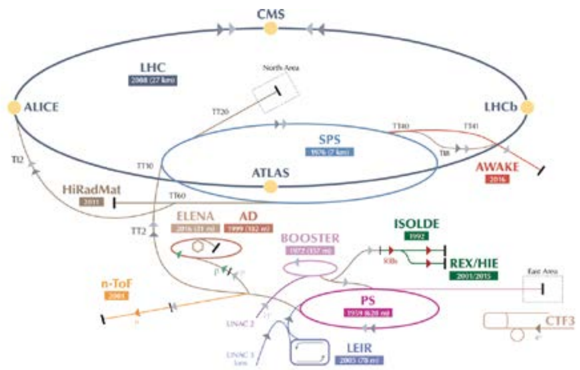
The three main experiments of the North Area – NA61, COMPASS and NA62 – have well-defined programmes until the time of LS2 and all have longer term plans. After completion of its search for a QCD critical point, NA61 plans to further study QCD deconfinement with emphasis on charm signals. It will also remain a unique facility to constrain hadron production in primary proton targets for future neutrino beams in the US and Japan. The Common Muon and Proton Apparatus for Structure and Spectroscopy (COMPASS) experiment, meanwhile, intends to further study the hadron structure and spectroscopy with RF-separated beams of higher intensity in order to study fundamental physics linked to quantum chromodynamics.

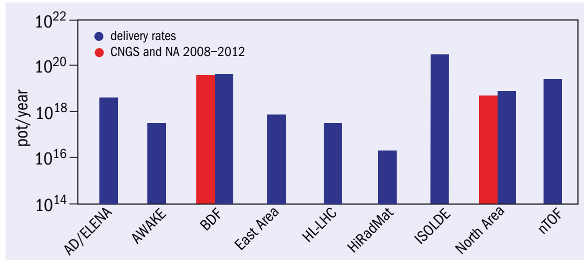
An independent proposal submitted to the workshop involved using muon beams from the SPS to make precision measurements of μ–e elastic scattering, which could reduce by a factor of two the present theoretical hadronic uncertainty on g-2 for future precision experiments. Once NA62 reaches its intended precision on its measurement of the rare decay $K^+ \rightarrow \pi^+ \nu\nu$, the collaboration plans comprehensive measurements in the K sector in addition to one year of operation in beam-dump mode to search for heavy neutral leptons such as massive right-handed neutrinos. In the longer term, NA62 aims to study the rare decay $K^0 \rightarrow \pi^0 \nu\nu$, which would require a similar but expanded apparatus and a high-intensity K^0 beam. In general, rare decays might reveal deviations from the Standard Model that indicate the presence of new heavy particles that alter the decay rate.

Fixed ambitions

The September workshop heard proposals for new ambitious fixed-target facilities that would complement existing experiments at CERN. A completely new development at CERN's North Area is the proposed SPS beam-dump facility (BDF). Beam dump in this context implies a target that absorbs all incident protons and contains most of the cascade generated by the primary-beam interaction. The aim is for a general-purpose fixed-target facility, which in the initial phase will facilitate a general search for weakly interacting "hidden" particles. The Search for HIdden Particles (SHiP) experiment plans to exploit the unique high-energy, high-intensity features of the SPS beam to perform a comprehensive investigation of the dark sector in the few-GeV mass range (*CERN Courier* March 2016 p25). A complementary approach, based on observing missing energy in the products of high-energy interactions, is currently being explored by NA64 on an electron test beam, and the ▷

Physics beyond colliders





Giovanni Rumolo

(Left) CERN's accelerator complex offers broad opportunities for new non-accelerator and fixed-target experiments. (Above) Foreseen proton-production capabilities of the complex.

experiment team has proposed to extend its programme to muon and hadron beams in the future.

From an accelerator perspective, the BDF is a challenging undertaking and will involve the development of a new extraction line and a sophisticated target and target complex with due regard to radiation-protection issues. More generally, the foreseen North Area programme requires high intensity and slow extraction from the SPS, and this poses some serious accelerator challenges. A closer look at these reveals the need for a concerted programme of studies and improvements to minimise extraction beam loss and associated activation of hardware with its attendant risks.

Fixed-target experiments with LHC beams could be carried out using either crystal extraction or an internal gas jet, and initially these might operate in parasitic mode upstream from existing detectors (LHCb or ALICE). Combined with the high LHC beam energy, an internal gas target would open up a new kinematic range to hadron and heavy-ion measurements, while beam extraction using crystals was proposed to measure the magnetic moments of short-lived baryons.

New facilities to complement fixed-target experiments are also under consideration. A small all-electric storage ring would provide a precision measurement of the proton electric dipole moment (EDM) and could test for new physics at the 100 TeV scale, while a mixed electric/magnetic ring would extend such measurements to the deuteron EDM. The physics motivation for these facilities is strong, and from an accelerator standpoint such storage rings are an interesting challenge in their own right (*CERN Courier* September 2016 p27).

A dedicated gamma factory is another exciting option being explored. Partially stripped ions interacting with photons from a laser have the potential to provide a powerful source of gamma rays. Driven by the LHC, such a facility would increase by seven orders of magnitude the intensity currently achievable in electron-driven gamma-ray beams. The proposed nuSTORM project, meanwhile, would provide well-defined neutrino beams for precise measurements of the neutrino cross-sections and represent an intermediate step towards a neutrino factory or a muon collider.

Last but not least, there are several non-accelerator projects that stand to benefit from CERN's technological expertise and infrastructure, in line with the existing CAST and OSQAR experiments. CAST (CERN Axion Solar Telescope) uses one of the LHC dipole magnets to search for axions produced in the Sun, while OSQAR attempts to produce axions in the laboratory. Researchers working on IAXO, the next-generation axion helioscope foreseen as a significantly more powerful successor to CAST, have expressed great interest in co-operating with CERN on the design and running of the experiment's large toroidal magnet. The high-field magnets developed at CERN would also increase the reach of future axion searches in the laboratory as a follow-up of OSQAR at CERN or ALPS at DESY. DARKSIDE, a flagship dark-matter search to be sited in Gran Sasso, also has technological synergies with CERN in the cryogenics, liquid-argon and silicon-photomultiplier domains.

Next steps

Working groups are now being set up to assess the physics case of the proposed projects in a global context, and also their feasibility and possible implementation at CERN or elsewhere. A follow-up Physics Beyond Colliders workshop is foreseen in 2017, and the final deliverable is due towards the end of 2018. It will consist of a summary document that will help the European Strategy update group to define its orientations for non-collider fundamental-particle-physics research in the next decade.

• Further reading

Physics Beyond Colliders workshop https://indico.cern.ch/event/523655.

Résumé

Le CERN étudie des perspectives pour la physique au-delà des collisionneurs

L'atelier de lancement sur la physique au-delà des collisionneurs, qui a eu lieu au CERN les 6 et 7 septembre, a réuni des physiciens de divers domaines; leur objectif était d'explorer toutes les possibilités de recherche présentées par le complexe du CERN pour les expériences hors collisionneurs. Le calendrier envisagé pour ces activités va jusqu'en 2040, ce qui correspond approximativement à la durée de vie opérationnelle du LHC et de son amélioration à haute luminosité. Le groupe d'étude est chargé de fournir des informations pour la prochaine mise à jour de la stratégie européenne pour la physique des particules, à la fin de la décennie actuelle.

Joerg Jaeckel, University of Heidelberg, **Mike Lamont**, CERN, and **Claude Vallée**, CPPM Marseille and DESY Hamburg.

Interview: Kip Thorne

Secrets of discovery

Kip Thorne is the visionary theorist who predicted the observation of gravitational waves from colliding black holes, as detected recently by LIGO. **Paola Catapano** spoke with him in September as he received the 2016 Tomalla Prize at the University of Geneva.

Caltech

Theoretical physicist Kip Thorne is emeritus professor at Caltech.

Did you expect that gravitational waves would be discovered during your lifetime?

Yes, and I thought it quite likely it would come from two colliding black holes of just the sort that we did see. I wrote a popular book called *Black Holes and Time Warps: Einstein's Outrageous Legacy*, published in 1994, and I wrote a prologue to this book during my honeymoon in Chile in 1984. In that prologue, I described the observation of two black holes, both weighing 25 solar masses, spiralling together and merging and producing three solar masses of energy and gravitational waves, and that's very close to what we've seen. So I was already in the 1980s targeting black holes as the most likely kind of source; for me this was not a surprise, it was a great satisfaction that everything came out the way I thought it probably would.

Can you summarise how an instrument such as LIGO could observe such a weak and rare phenomenon?

The primary inventor of this kind of gravitational-wave detector is Ray Weiss at MIT. He not only conceived the idea, in parallel with several other people, but he, unlike anybody else, identified all of the major sources of noise that would have to be dealt with in the initial detector and he invented ways to deal with each of those. He estimated how much noise would remain after the experiment did what he proposed to limit each noise source, and concluded that the sensitivity that could be reached would be good enough. There was a real possibility of seeing the waves that I as a theorist and colleagues were predicting. Weiss wrote a paper in 1972 describing all of this and it is one of the most powerful papers I've ever read, perhaps the most powerful experiment-related paper. Before I read it, I had heard about his idea and concluded it was very unlikely to succeed because the required sensitivities were so great. I didn't have time to really study it in depth, but it turned out I was wrong. I was sceptical until I had discussions with Weiss and others in Moscow. I then became convinced, and decided that I should devote most of the rest of my career to helping them succeed in the detection of gravitational waves.

How will the new tool of "multi-messenger astronomy" impact on our understanding of the universe?

Concerning the colliding black hole that we've seen so far, astronomers who rely on electromagnetic signals have not seen anything coming from them. It's conceivable that in the future something may be seen because disturbances caused when two black holes collide and merge can lead to X-ray or perhaps optical emissions. We also expect to see many other sources of gravitational waves. Neutron stars orbiting each other are expected to collide and merge, which is thought to be a source of gamma-ray bursts that have already been seen. We will see black holes tear apart and destroy a companion neutron star, again producing a very strong electromagnetic emission as well as neutrino emission. So the co-ordinated gravitational and electromagnetic observation and neutrino observations will be very powerful. With all of these working together in "multi-messenger" astronomy, there's a great richness of information. That really is the future of a large portion of this field. But part of this field will be things like black holes, where we see only gravitational waves.

Do gravitational waves give us a bearing on gravitons?

Although we are quite sure gravitational waves are carried by gravitons, there is no chance to see individual gravitons based on the known laws of physics. Just as we do not see individual photons in a radio wave because there are so many photons working together to produce the radio wave, there are even more gravitons working together to produce gravitational waves. In technical terms, the mean occupation number of the gravitational-wave field that is seen is absolutely enormous, close to 10^{40}. With so many gravitons there is no hope, unfortunately, to see individual gravitons. ▷

Interview: Kip Thorne

Will we ever reconcile gravity with the three other forces?
I am quite sure gravity will be reconciled with the other three forces. I think it is quite likely this will be done through some version of string theory or M theory, which many theorists are now working on. When it does happen, the resulting laws of quantum gravity will allow us to address questions related to the nature of the birth of the universe. It would also tell us whether or not it is possible to build time machines to go backward in time, what is the nature of the interior of a black hole, and address many other interesting questions. This is a tremendously important effort, by far the most important research direction in theoretical physics today and recent decades. There's no way I could contribute very much there.

Regarding future large-scale research infrastructures, such as those proposed within CERN's Future Circular Collider programme, what are the lessons to be learnt from LIGO?
Maybe the best thing to learn is having superb management of large physics budgets, which is essential to make the project succeed. We've had excellent management, particularly with Barry Barish, who transformed LIGO and took over as director when we were just about ready to begin construction (Robbie Waught, who had helped us write a proposal to get the funding from the NSF and Congress, also got two research teams at Caltech and MIT to work together in an effective manner). Barry created the modern LIGO and he is an absolutely fantastic project director. Having him lead us through that transition into the modern LIGO was absolutely essential to our success, plus a very good experiment idea and a superb team, of course.

You were an adviser to the blockbuster film *Interstellar*. Do you have any more science and arts projects ahead?
I am 76. I was a conventional professor for almost 50 years, and I decided for my next 50 years that I want to do something different. So I have several different collaborations: one on a second film; collaborations in a multimedia concert about sources of gravitational waves with Hans Zimmer and Paul Franckman, who did the music and visual effects for *Interstellar*; and collaborations with Chapman University art professor Lia Halloran on a book with her paintings and my poetry about the warped side of the universe. I am having great fun entering collaborations between scientists and artists and I think, at this point of my life, if I have a total failure with trying to write poetry, well that's alright: I've had enough success elsewhere.

Résumé
Les secrets d'une découverte

Kip Thorne est l'un des fondateurs de l'expérience LIGO, qui a annoncé la découverte des ondes gravitationnelles au début de l'année. Paula Catapano l'a rencontré en septembre, à l'Université de Genève, où devait lui être remis le prix Tomalla 2016, qui est décerné tous les trois ans pour des recherches exceptionnelles dans le domaine de la gravitation ou de la cosmologie.

Paola Catapano, CERN.

Faces & Places

APPOINTMENTS

Paolo Giubellino to lead FAIR and GSI

Gaby Otto/GSI

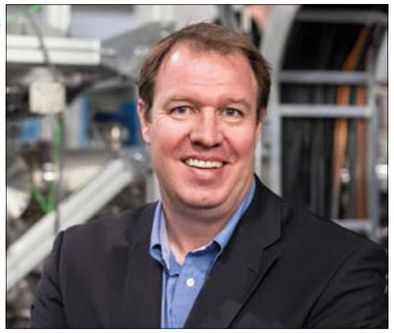
ALICE spokesperson Paolo Giubellino will be the first joint scientific managing-director of FAIR and GSI.

Italian physicist Paolo Giubellino, who is currently spokesperson for the ALICE experiment at the LHC, has been appointed the first joint scientific managing-director and spokesperson of the directorate of the Facility for Antiproton and Ion Research in Europe GmbH (FAIR GmbH) and GSI Helmholtzzentrum für Schwerionenforschung GmbH in Darmstadt, Germany. Giubellino will take up his new position on 1 January, succeeding Boris Sharkov of FAIR and Karlheinz Langanke of GSI.

Giubellino has participated in many heavy-ion experiments at CERN and has been ALICE spokesperson since 2011. He has worked at the Torino section of the Italian National Institute for Nuclear Physics since 1985 and has served as research director since 2006.

"With the extensive international experience Paolo Giubellino gained at CERN in Switzerland, he has ideal prerequisites to tackle the assignment in Darmstadt," says Otmar Wiestler, president of Germany's Helmholtz Association. "Being able to attract people like Paolo Giubellino to FAIR shows the worldwide appeal of Helmholtz research. We have chosen the right path with our strategy to pursue a more international course."

TRIUMF appoints new science associate director



TRIUMF

Jens Dilling took up the ALD position on 1 September.

Jens Dilling has been appointed TRIUMF's new associate laboratory director (ALD) for its physical-sciences division, effective from 1 September. Dilling was recruited to TRIUMF in 2001 as a research scientist and has since served as deputy and department head for nuclear physics and deputy division head of the science division.

Dilling received both his diploma and PhD in physics from the University of Heidelberg, Germany. An expert on ion traps, his research interests include precision atomic-physics techniques applied to nuclear physics at accelerators. He led the design, construction and operation of TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) facility.

As ALD of physical sciences, Dilling will provide leadership and direction for TRIUMF's local and international scientific programme in particle and nuclear physics and molecular and material sciences. He will also work closely with TRIUMF's accelerator division to foster isotope delivery and prepare the lab for upcoming facilities including the Advanced Rare IsotopE Laboratory (ARIEL).

AWARDS

LHCb recognises young scientists

LHCb spokesperson Guy Wilkinson (left), with Agnieszka Dziurda, Daniel Craik and award-chair George Lafferty.

The LHCb collaboration has announced the winners of its inaugural thesis prize, which recognises students who have produced the best theses and made exceptional contributions to the LHCb experiment. The recipients of the first awards for theses defended during 2015 are Lucio Anderlini of the University of Florence for his thesis "Measurement of the B_c^+ meson lifetime using $B_c^+ \to J/\psi \mu^+ \nu_\mu X$ decays with the LHCb experiment at CERN"; Daniel Craik of the University of Warwick for "A measurement of the CKM angle γ from studies of $D K \pi$ Dalitz plots"; and Agnieszka Dziurda of the Institute of Nuclear Physics PAN in Krakow for "Studies of time dependent CP violation in charm decays of B_s^0 mesons".

CERNCOURIER
VOLUME 56 NUMBER 9 NOVEMBER 2016
IOP Publishing

CHIPP prize for neutrino researcher


Mohamed Rameez.

The annual prize of the Swiss Institute of Particle Physics (CHIPP) 2016 goes to Mohamed Rameez, a 27 year old neutrino physicist who recently completed his PhD at the University of Geneva, for his leadership in searches for dark-matter annihilation in the Sun with the IceCube Neutrino Observatory and his contribution to their theoretical interpretation.

Perimeter physicist wins early researcher award


Asimina Arvanitaki during a visit to CERN in July.

Samuel Rubio for *Quanta Magazine*

Perimeter Institute faculty member Asimina Arvanitaki has received a grant of $140,000 to advance her research. The Early Researcher Awards are administered by Ontario's Ministry of Research, Innovation and Science to help promising young faculty members build research teams. Arvanitaki, who holds the inaugural Stravros Niarchos Foundation Aristarchus Chair at the Perimeter Institute, is exploring novel experimental approaches to particle physics that may be done with small-scale experiments rather than large colliders.

FACILITIES

DESY inaugurates new research halls

Ada Yonath in front of the building that bears her name.

DESY/G Born

On 14 September, the DESY laboratory in Hamburg, Germany, celebrated the opening of two new experimental halls at its synchrotron X-ray facility PETRA III. The halls, which will provide highly specialised experimental stations that allow synchrotron users to examine materials and structures on the atomic scale, were named after two prominent scientists and X-ray users: Israeli Nobel laureate Ada Yonath, who conducted important research at DESY and other European light sources for her structural examination of ribosomes, and the late Paul P Ewald, who was one of the pioneers of structural analysis using X-rays.

CERN Courier November 2016

Faces & Places

CONFERENCES

CERN event links particles to astrophysics

The annual TeV Particle Astrophysics (TeVPA) conference series discusses the most recent advances in the booming field of astroparticle physics. This year's event took place on 12–16 September and for the first time was hosted by CERN. It was a fitting location, given the well-established implications of particle physics for astrophysics and cosmology, as well as the long-standing commitment of CERN on related activities such as the CAST solar-axion experiment.

The five-day-long event was attended by almost 300 people, with topics including gamma rays, gravitational waves and cosmology, indirect and direct dark-matter searches, and links with particle physics. The highlight of discussions was the Advanced LIGO discovery of gravitational waves from two binary black-hole mergers, which opens a new astrophysical window on the universe. Equally exciting were the broader perspectives of this field, including the mind-boggling reach of the space-based gravitational-wave detector LISA, which will target phenomena ranging from supermassive black-hole mergers to physics in the early universe.

During the conference, the POLAR gamma-ray burst polarimeter on board the Chinese TG-2 space lab was launched, and delegates also heard a report on preliminary observations made by the space-based DAMPE detector, which was launched at the beginning of the year. Whereas POLAR will focus on gamma-ray bursts, DAMPE targets cosmic-ray observations with an excellent energy resolution at TeV energies.

The field of charged cosmic rays also saw the presentation of the first scientific results of CALET, which is located on the Japanese module of the International Space Station. Launched 13 months ago,

Word cloud of terms used in the 247 abstracts that were presented at TeVPA 2016.

CALET has a very deep calorimeter and excellent nuclear-identification capabilities. Energetic electron candidates above the TeV have been identified and the experiment has also placed upper limits on the gamma-ray counterparts of the gravitational-wave merger event of last December. An update on AMS-02 results was also presented, hinting that the positron spectrum "turns off" at sub-TeV energies. The conference also brought physicists up to date with the latest positive progress of the innovative cosmic-ray anti-deuteron experiment GAPS – a high-altitude balloon experiment that aims to stop and capture anti-nuclei and identify them spectroscopically.

The maturity of gamma-ray astrophysics thanks to space-based instruments like Fermi and ground-based Cherenkov telescopes, both for galactic and extragalactic objects, was manifest. There was also a report on the first results from HAWC, which is the latest realisation of a "Cherenkov water pool" to detect byproducts of gamma-ray showers on the ground. In its first year of operation, HAWC already found around 40 galactic sources in the multi-TeV range, about 10 of which were unknown until now, and the instrument is ideally placed to study possible gamma counterparts to IceCube neutrino events.

Even fields in which no direct discoveries have yet been made have experienced a remarkable boost in sensitivity in recent years: the latest limits from LUX and PandaX, for example, are around 10 times better than those set by Xenon in 2012 for spin-independent cross-sections. The still puzzling interpretation of astrophysical neutrinos, which have now been detected up to energies of several PeV by IceCube, was another discussion point at TeVPA 2016. Plans to increase the performance of MeV–GeV neutrino detectors such as SuperKamiokande via gadolinium doping, which are important for diffuse supernova neutrino detection, are also proceeding well.

The path towards further key measurements from cosmology to particle physics, notably in the neutrino sector, was highlighted – as were some of the current difficulties of the cold dark-matter model and possible strategies to address them. The importance of the forward-physics programme at the LHC for cosmic-ray shower simulations, the role of effective field theories and simplified theories for dark-matter searches at the LHC, and the role of ongoing LHCb measurements of proton–helium cross-sections for cosmic-ray antiproton calculations were just a few examples of the numerous links between particle physics and the astroparticle field.

The next TeVPA meeting will be held next summer at Ohio State University, Columbus, in the US.

Netherlands focus for 2016 ENLIGHT meeting

The annual meeting of the ENLIGHT network, which gathers experts working on particle therapy for cancer treatment, was hosted by Nikhef and held at the University of Utrecht in the Netherlands on 15–17 September. Around 100 participants from 15 countries attended, and one of the key discussion topics was the design and realisation of four new centres for proton therapy in the Netherlands, following the recent approval by the Dutch government to make proton therapy available nationwide.

The new Dutch centres for proton therapy are distributed across the entire country. The Holland Proton Therapy Centre (PTC) in Delft and the UMC Groningen PTC are already under construction and foresee first patient treatments in autumn–winter 2017. The PTC in Maastricht is heading towards the construction phase and expects treatments to start in 2018, while the fourth PTC in Amsterdam is currently tendering for technical equipment and plans to enter into operation at the end of 2018. All four centres will have one or two treatment rooms equipped with gantries that allow a complete rotation of the beam axis to better target ▷

the tumour, and together are expected to treat more than 1000 patients each year.

The institutions involved in establishing the new centres are members of the ENLIGHT network, which was created in 2002 to co-ordinate and accelerate the activities of European centres (including CERN) and research groups working on particle therapy. A major achievement of ENLIGHT has been the blending of traditionally separate communities to allow clinicians, physicists, biologists and engineers to work towards a common goal. The flourishing of new centres such as those in the Netherlands is both an achievement and a *raison d'être* for the network.

In addition to the collaborative and interactive model of the new Dutch centres, many other hot topics were discussed, including recent breakthroughs in medical imaging. This is vital to deliver effective treatment while avoiding side effects caused by damage to healthy cells. Positron emission tomography (PET), magnetic resonance imaging (MRI) and computed tomography (CT) scans are used alone or in combination (multi-modal imaging) to assess the volume and the position of the tumour before, after and during treatment, whenever possible. In the case of moving organs such as the lungs, the situation is more complicated because it is necessary to monitor the patient during treatment. The integration of MRI with a linear accelerator, for example, can provide image-guidance concurrent with treatment, reducing the patient exposure to the additional ionising radiation of CT scans.


Hanne Nijhuis

Participants of this year's ENLIGHT meeting included leading radio-oncologists and directors of major European radiotherapy clinics.

Image-guided proton therapy (IGPT) is an instance of the shift to more personalised and precise oncology, where treatments are tailor-made for each patient. Another strand of this paradigm shift in medicine is informatics based on past cases to assist doctors in selecting the best combination of treatments. Such systems can be built only if clinical data are accessible. This is controversial due to privacy concerns, but important changes in society are taking place towards massive data gathering and sharing.

Since its establishment, ENLIGHT has given primary importance to the training of young researchers and physicians in this specialised field. PTCs require highly trained staff comprising medical doctors, physicists, radiobiologists and technicians, yet few experts exist in this emerging field. Therefore, in a first for the ENLIGHT consortium, this year's meeting included a one-day training event devoted to key aspects of particle therapy, including radiobiology, medical imaging and data sharing.

The next annual ENLIGHT meeting will be held in June 2017 in Aarhus, where Denmark's first particle-therapy centre is under construction.

Higgs Hunting 2016

The seventh Higgs Hunting workshop took place in Paris between 31 August and 2 September, attracting 130 physicists for lively discussions about recent results in the Higgs sector. ATLAS and CMS presented results based on more than 13 fb^{-1} of data recorded at an energy of 13 TeV, which corresponds to around half of the data that has been taken so far at the LHC. The uncertainty on some measured properties of the Higgs boson discovered at CERN in 2012, such as the production cross-section, is already smaller with the 13 TeV data than it was after LHC Run 1 at 7 and 8 TeV – especially in cases where the measurement is dominated by statistical errors.


C Nellist

Participants at the September Higgs event held in Paris.

Several searches for phenomena beyond the Standard Model, in particular for additional Higgs bosons, were presented. In particular, ATLAS and CMS did not confirm with the 2016 data the small excess around a mass of 750 GeV in the diphoton invariant mass spectrum that was present in the 2015 data, which was thought by many theorists to be a spin-0 Higgs-like object. At the end of the 2016 run, which is expected to increase the recorded luminosity at 13 TeV by a factor of three, searches for heavier Higgs-like objects will be possible. The increased luminosity will also decrease the statistical errors by almost a factor of two, demanding that the experiments work hard to reduce systematic uncertainties.

The next Higgs Hunting workshop will be held in Orsay and Paris on 17–19 July 2017.

African school goes from strength to strength

The fourth biennial African School of Fundamental Physics and Applications took place on 1–19 August in Kigali, Rwanda. The event saw 75 students, who were chosen from 439 applicants from around the African continent, spend three weeks at the University of Rwanda's College of Sciences and Technology, during which 40 lecturers from different fields in physics flew in from CERN and many parts of the world to teach and mentor the students.

"What makes this programme unique is that we tailor-make each programme according to what area of physics is interesting to the host country," says Ketevi Assamagan, a physicist at Brookhaven National Laboratory in New York and member of the International Organising Committee of the school. "The ultimate goal is to host the school in as many countries on the continent as possible, with the help of host-country governments."

The biennial summer school, which was launched in South Africa in 2010, has previously been hosted by Ghana in 2012 and by Senegal in 2014. This year, the school received financial support from CERN and 19 other institutions, including the International Centre for Theoretical Physics (ICTP), Brookhaven National Laboratory, the South African National Research Foundation and Department of Technology, the Rwandan Ministry of Education, INFN and other major particle-physics laboratories.

The next event will be hosted by Namibia in 2018, and promises to attract an even greater number of applications from students across Africa. Visit www.africanschoolofphysics.org for more information.


Delegates at the 2016 African school in Rwanda.

Visits

Sophia Bennett


Around 70 participants in the Virgin Galactic space programme were joined by **Richard Branson** (third from left), founder of the Virgin group, on 31 August for a tour of CERN, which took in the SM18 hall.

Jules Ordan


On 13 September, Canadian rock group **Nickelback** took a day out of their European tour to visit CERN, which included a trip to the CMS building.

Event spotlight

FCC hh ee he

The first **Future Circular Collider (FCC) physics workshop** will take place at CERN on **16–20 January 2017**, focusing on the broad physics opportunities offered by the FCC programme. The workshop will also address experimental requirements and machine–detector interface issues that are directly relevant to the physics programme. All sessions will be plenary, with an emphasis on the complementarity of the different components of the programme (ee, hh and eh). Original ideas and contributions on alternative experimental approaches in the global context of the FCC – also including physics with beam dumps and the injector complex, and physics in the forward region – are strongly encouraged. The event will precede the 2017 FCC week due to take place in Berlin from 29 May to 2 June (fccw2017.web.cern.ch).

OBITUARIES

Siegmund Brandt 1936–2016

Siegmund Brandt was born on 17 July 1936 in Berlin and studied physics at Bonn University in Germany. In his diploma work, which was carried out under the supervision of Wolfgang Paul, he constructed a small bubble chamber for experiments at the Bonn 500 MeV electron synchrotron. As early as 1961, Brandt worked at CERN on bubble-chamber physics studying pion–proton interactions, which became the topic of his PhD thesis.

After his habilitation in 1966, he became associate professor at Heidelberg University, and in 1972 he became professor, founding senator of physics and vice rector at the newly founded University of Siegen. At Siegen, Brandt's interest turned to electronic detectors and he worked at DESY on the PLUTO experiment at DORIS and PETRA. He contributed to the three-jet analysis with the "triplicity" method, which led to the discovery of gluons in 1979. After PLUTO, Brandt continued with the PETRA experiments by joining TASSO. During this time, Brandt was also member of the Scientific Council of DESY, which he chaired from 1990 to 1993, and he was later elected to the Polish Academy of Arts and Sciences.

Sven Faller

Siegmund Brandt was a member of the ALEPH experiment.

Brandt left DESY for CERN in the late 1980s, where he joined the ALEPH experiment at LEP and contributed to the ALEPH forward detectors and the analysis of Bhabha scattering and jet production.

Brandt was an extremely creative author – his books include *Data Analysis: Statistical and Computational Methods for Scientists and Engineers* (1975) and *The Harvest of a Century: Discoveries of Modern Physics* (2013). He is also well known by many students as one of the authors of the general-physics textbook series he wrote with his theory colleague Hans Dieter Dahmen.

Brandt was a versatile physicist. His work spanned the operation of now-historic detectors such as bubble chambers and the construction and analysis of modern electronic high-resolution instruments, and his successes will live on in his books on basic science. Brandt passed away peacefully in Munich on 28 August after a long period of illness, leaving behind his son and his grandchildren. He will be dearly missed by his friends and colleagues.

● *Hans Dieter Dahmen, Claus Grupen and Thomas Mannel, Siegen University.*

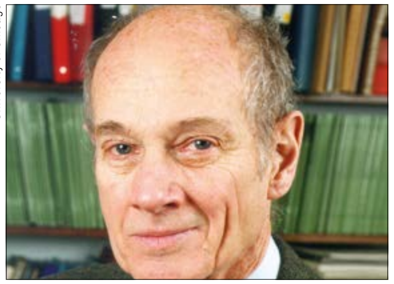
James Cronin 1931–2016

Jim Cronin, who shared the 1980 Nobel Prize in Physics with Val Fitch for the discovery of CP violation, died on 25 August 2016. He was a brilliant experimentalist and data analyst who had remarkable careers in both particle and cosmic-ray physics.

Jim was a man of extraordinary drive. Born in Chicago, he was raised in Dallas where his father was a classics professor. In 1953 he moved to Brookhaven and then Princeton, where he honed the spark-chamber technique before returning to the University of Chicago in 1971. He was appointed to head the colliding-beams division at Fermilab in 1977, but he soon resigned: a largely administrative role was not for him. In 1982, while on leave at CERN, he led a small team to make the best direct measurement of the lifetime of the π^0.

In 1986, to the surprise of many, Jim turned to cosmic rays and started to discuss his design for an air-shower array that could search for PeV gamma rays from the binary source Cygnus X-3. His visit to Leeds, UK, in November 1986 led to a lasting friendship, and in 1991 we embarked on an effort to build a collaboration and raise money to construct an instrument of unprecedented size to study cosmic rays with energies up to 10^{20} eV. Thirteen years later, the Pierre Auger Observatory, which covers 3000 km^2 of Western Argentina, began data-taking, and continues to do so with a team of more than 400 scientists from 16 countries.

University of Chicago



Nobel laureate Jim Cronin.

The route to this achievement was strewn with difficulties, which were largely overcome through Jim's formidable drive and his discrete and modest use of his status. He obtained $100,000 from UNESCO to bring scientists from developing countries to Fermilab for a six-month-long design study, won support for us to tour the Far East to raise interest, and prised $1 million from the University of Chicago to build a new centre at the site. Evaluation of our plans by an international body proved impossible, so Jim invited a panel of experts, including CERN's Jack Steinberger, to assess us. Their report helped to raise $50 million, although one agency commented "Of course it is a favourable report: you chose the committee."

The success of the Auger project has greatly enhanced the profile of fundamental physics in Argentina, Brazil, Mexico and Vietnam, while the host town of Malargüe is home to the James Cronin School. Despite the large size of the collaboration, Jim stimulated young people while carrying out key analyses alone using FORTRAN 77 and "TopDrawer" – an ancient graphics package hosted on a dedicated Chicago computer.

Jim will be sorely missed by all who knew him. Without his strong sense of direction and his persuasive skills, the Pierre Auger Observatory and many other projects would never have succeeded. He is survived by his second wife, Carol, and by a daughter, a son and six grandchildren. His first wife, Annette, and an older daughter pre-deceased him.

● *Alan Watson, University of Leeds, UK.*

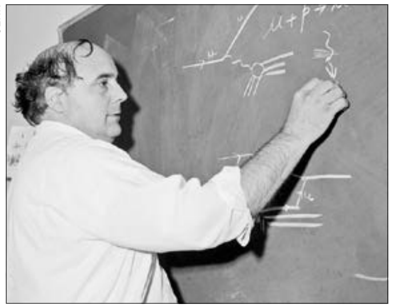
Erwin Gabathuler 1933–2016

Erwin Gabathuler, a highly respected experimental physicist and former CERN research director, passed away on 29 August 2016. Gabathuler was born in 1933 in Maghera, Northern Ireland, the son of the manager of an embroidery factory. He graduated in physics from Queen's University Belfast in 1956 and was awarded his PhD from the University of Glasgow in 1961. After a postdoc at Cornell University he returned to the UK in 1964 to work on the NINA electron synchrotron at the Daresbury Laboratory, where, among a number of experiments, he made a pivotal measurement of "ρ–ω interference" in wide-angle electron–positron pair production.

In 1974, Gabathuler moved to CERN and led the European Muon collaboration, which was aimed at understanding the quark structure of nucleons and nuclei. He became head of the CERN experimental division in 1978 and CERN research director in 1981, guiding CERN's programme in the years leading to the discovery of the W and Z bosons.

In 1983, Gabathuler was appointed to a chair at the University of Liverpool and to the position of head of the particle-physics group, taking charge of the leadership of the group's programme as it entered the collider era. He initiated major Liverpool involvement in the H1 and HERMES experiments at the HERA electron–proton collider at DESY, while also nurturing Liverpool's contribution to the DELPHI experiment at LEP. At the same time, his interest in the role of fundamental symmetries in physics led him to also conceive and establish CERN's unique CPLEAR experiment to study kaon decay. While continuing his interest in deeply inelastic lepton–hadron physics with colleagues on H1, and following the completion of CPLEAR, Gabathuler took Liverpool into the BaBar experiment at SLAC, California.

CERN



Erwin Gabathuler discussing the NA2 experiment in 1977.

His appointment to Liverpool led Gabathuler to have a substantial influence on the development of high-energy physics in the UK, at a time when the then UK government was considering possible withdrawal from CERN. His commitment contributed greatly to the success of his colleagues in physics and in other fields. He helped to secure funding for the Liverpool Surface Science Centre, and initiated new undergraduate courses with the Astrophysics Research Institute at Liverpool John Moores University.

In 1990, Gabathuler was elected to the fellowship of the Royal Society. He was also a fellow of the UK Institute of Physics, received the institute's Rutherford Medal and Prize in 1992, and was awarded the Order of the British Empire in 2001 for services to physics. He received two honorary doctorates in science, and during his emeritus years continued to contribute as a member of national and international scientific advisory committees.

As a colleague in Liverpool, he was widely admired and respected. He was a friend and mentor who exhibited unswerving support and concern for his colleagues' individual well-being and career advancement, while demanding in return delivery of physics of the very highest standard.

● *John Dainton and Themis Bowcock, University of Liverpool.*

Werner Kienzle 1936–2016

Experimental particle-physicist Werner Kienzle was born in Wiernsheim, a small town in Baden-Württemberg close to Stuttgart. His childhood was profoundly marked by the war and the death of his father on the German eastern front. Despite life after the war being difficult for his family, he was very successful in his academic studies and earned a fellowship at the University of Göttingen, where he did his PhD in solid-state physics.

Werner joined CERN in 1964 as a postdoc fellow and he remained at the Organization for his entire career. Concerned and eager for peace in the tense context of the Cold War, he was deeply involved in collaboration with Russian colleagues and participated in experiments in Serpukhov from 1968 to 1972. Back at CERN, his work concentrated on searching for evidence of the presence of quarks in hadrons. He was among the main initiators of the NA3 experiment at the Super Proton Synchrotron (SPS), which allowed measurements of the structure functions of pions. The results indicated a cross-section about twice as high as anticipated, corresponding to QCD high-order corrections, and this enhancement was named the "K" factor by the collaboration, as recognition of Werner's contribution.

Maria Kienzle

Werner Kienzle spent most of his career at CERN.

Werner was appointed SPS co-ordinator at the beginning of the 1980s and participated in the discovery of the W and Z bosons. In parallel, he became involved in new outreach programmes: in particular, he was promoter of the Microcosm in 1988 and editor of the *Hadrons for Health* reference booklet in 1996. While reaching his retirement age, Werner participated in the development of the total cross-section measurement set-ups that initiated the TOTEM experiment at the LHC.

Werner was a fantastic and enthusiastic storyteller, an adventurer and an innovator. His wife, Maria, and his sons, Francesco and Marco, can be proud of everything he did for CERN.

● *His colleagues and friends.*

Stanley Mandelstam 1928–2016

The great theoretician Stanley Mandelstam passed away in June, aged 87. He was born in Johannesburg, South Africa, from a Jewish family originating in Latvia, and studied in the UK under doctoral adviser Richard Dalitz. He became a professor at the University of Birmingham in 1960, then at the University of California at Berkeley in 1963.

His initial reputation came from his 1958 proposal of what is called the Mandelstam representation, which implies that the scattering amplitude is the boundary value of an analytic function in a 2D domain in which the only singularities are cuts. Some people could say, now that we have the Standard Model of particle physics, that all this was useless. This is not the case historically, however, since it supported the idea that interesting results could be obtained from the combination of analyticity and unitarity.

The main example is the "Froissart

Stanley Mandelstam.

Bound" obtained in 1961, which says that the cross-section cannot increase faster than the square of the logarithm of the energy. In 1966, a proof of the Froissart bound was obtained without the Mandelstam representation. Around that time, V N Gribov also used the Mandelstam representation to predict that the scattering amplitude does not behave as was expected at high energies. It is also clear that the Veneziano amplitude, which was proposed in 1968 and led to dual models in which particles interact via "strings", was inspired by the Mandelstam representation. The surprise was that theoreticians proposed that particles themselves be strings or superstrings. It is precisely in this domain that Mandelstam made further fundamental contributions.

It's not possible to list all of his papers here, but let me single out his proof that N = 4 supersymmetry is finite, an important result for which he sought absolutely no publicity. Mandelstam was a fellow of the Royal Society and of the American Academy of Arts and Sciences. He received the Dirac Medal in1991 and the Dannie Heineman Prize in 1992. Testimonies from students say that he was an excellent lecturer, including in undergraduate courses. Stanley Mandelstam was an affable person and incredibly modest. We shall miss him.

● *André Martin, CERN.*

Recruitment

POST-DOCTORAL POSITIONS AT THE INTERNATIONAL INSTITUTE OF PHYSICS

The International Institute of Physics of the Federal University of Rio Grande do Norte (IIP-UFRN) is opening new post-doctoral research positions.

Successful candidates should demonstrate a high level of expertise and a strong academic record in the areas of Foundations of Quantum Mechanics, Quantum Information, Statistical Field Theory and Engineering of Quantum Devices; Strongly Correlated Electronic Systems; Classical Gravity and Gravitational Wave Physics, String Theory and Mathematical Physics. A candidate's strong ability to conduct interdisciplinary research in those fields will be considered as an additional asset by the Selection Committee.

The appointments will start between October 2016 and March 2017 and have a two year's duration (extensible to two more years depending on agreement) with a tax-free monthly salary of R$7.000,00 (seven thousand Brazilian Reais).

Candidates should send their CV with a list of publications, research proposal and at least two letters of reference (in English) to **postdocpositions@iip.ufrn.br**. Priority shall be given to applications received by October 1, 2016.

The IIP-UFRN is located in the city of Natal, the capital of the State of Rio Grande do Norte, in Northeastern Brazil.

The IIP-UFRN is a research institute with an international character, focused on theoretical research in frontier topics of physics. Intent on attaining a leading role in the region, the Institute promotes several visitor's, exchange, and workshop programs.

Quintessa Scientific Software Developer

Quintessa (**www.quintessa.org**) is an employee-owned company that undertakes high-quality scientifically-based consultancy, research and software development for industry and governments in the UK and around the world, primarily in the energy and environment sectors.

We are looking for a bright and enthusiastic graduate to join our team developing scientific software applications. The role will involve working on a range of software development projects, including web-based systems, data visualisation and modelling tools developed both internally and for our clients. Working in a small team of scientific developers, you will become competent in how different software applications are designed and developed, and in how they are used both within the company and by external clients.

Applicants are invited with a strong mathematical or numerate scientific background, and practical experience of software development, ideally in an object-oriented language such as C# or/and C++. Energy and environment domain knowledge is not required as full training will be provided. Practical experience of developing desktop and web-based software applications is not essential but would be an advantage, as would experience in languages such as PHP/SQL/HTML/Java.

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Please send a CV with a covering letter by e-mail to Richard Little at **RichardLittle@quintessa.org**.

INTERNATIONAL SELECTION PROCESS FOR ELI BEAMLINES FACILITY IN CZECH REPUBLIC

LEADER OF RESEARCH PROGRAMME 2

X-ray sources driven by ultrashort laser pulses

The suitable candidate will be responsible for the delivery of X-ray sources driven by ultrashort laser pulses and their integration into the ELI Beamlines facility.

The candidates are expected to comply with the following requirements:

1. PhD in the field of laser plasma physics
2. Post-doc in laser driven X-ray sources would be a plus
3. Working experience of minimum 5 years in the field of laser driven X-ray sources with an excellent record of publications in this field in international peer-reviewed journals
4. Working experience in management of a larger research group
5. Willing to travel and English language on a very good level (written and spoken)

Location: ELI Beamlines, Institute of Physics ASCR, Dolní Břežany, Czech Republic

Applicants should provide their CV and cover letter (in English) along with a complete list of publications. They should single out 5 most important publications with the description of their contribution. All these materials should be sent to hr@eli-beams.eu. The deadline for applications is open.

Please include the following text in your cover letter, to allow us to process your personal details:

I agree that, according to the decree 101/2000 coll. (Czech Republic), my personal details sent to FZU AV CR, v.v.i., Na Slovance 2, 18221 Praha 8, Czech Republic can be used for the purpose of obtaining employment and management of database of employment candidates. This permission is given for the period of one year and can be at any time withdrawn by giving a notice in writing.

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The Institute for Nuclear Physics at the University of Münster invites applications for a tenured

Full Professorship in Experimental Physics (salary scale W3)

starting in October 2017.

Candidates are expected to have a strong track record in the field of heavy-ion physics.

The research programme should strengthen the current research activities of the Institute for Nuclear Physics (Involvement in the experiments ALICE/CERN and CBM/FAIR) as well as develop further the main research field Particle Physics. Detector development, well established in the institute should play an important role. Close cooperation is expected with the theoretical and experimental groups, especially within coordinated programmes like the existing graduate school "Strong and weak interactions – from hadrons to dark matter". Teaching obligations cover the whole area of Experimental Physics. Candidates are also expected to participate in the academic administration of the faculty.

Prerequisite for the application are a PhD and outstanding teaching skills, as well as academic achievements made as a Juniorprofessor (assistant professor), in a Habilitation (postdoctoral qualification), as a member of the academic staff of a university or non-university research institute, or in a research position in business, administration or other relevant fields in Germany or abroad.

The University of Münster is an equal opportunity employer and is committed to increasing the proportion of senior women academics. Consequently, we actively encourage applications by women. Female candidates with equivalent qualifications and academic achievements will be preferentially considered within the framework of the legal possibilities. We also welcome applications from candidates with severe disabilities. Disabled candidates with equivalent qualifications will be preferentially considered.

Applications with a CV, including teaching experience and publication list, copies of degree certificates, and a statement of research interests, shall be submitted in written form until **November 14, 2016** to the

Dean of the Faculty of Physics
Wilhelm-Klemm-Str. 9
48149 Münster, Germany

www.uni-muenster.de

Universität Heidelberg Zukunft seit 1386

The **Heidelberg Graduate School of Fundamental Physics (HGSFP)** at the Department of Physics and Astronomy at Heidelberg University, a School funded by the German Excellence Initiative, invites applications for

DOCTORAL FELLOWSHIPS

in the following areas of modern fundamental physics: (a) Astronomy and Cosmic Physics, (b) Quantum Dynamics and Complex Quantum Systems, (c) Fundamental Interactions and Cosmology, (d) Complex Classical Systems, (e) Mathematical Physics, and (f) Environmental Physics. Thesis research topics cover areas such as experimental and theoretical astrophysics, cosmology, accelerator based particle physics, precision measurements in physics, study of quantum systems – many body as well as small systems, low as well as high temperature physics, atomic, molecular and optical physics, mathematical physics and string theory. In addition, fundamental problems in biophysics, e.g. in materials science aspects of cell biology, and in environmental physics are studied. The HGSFP combines doctoral projects at the forefront of international research in the areas mentioned above with a rich and thorough teaching programme. Further information can be found on the School's web site: **http://www.fundamental-physics.uni-hd.de**.

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

Highly qualified and motivated national and international students are invited to apply. Applicants should preferably hold a Master of Science or equivalent degree in physics. Excellent candidates holding a four year bachelor degree and proof of research experience may also be considered. At equal level of qualification, preference will be given to disabled candidates. Female students are particularly encouraged to apply.

Applicants have to initiate their application registering via a web form available at **http://www.fundamental-physics.uni-hd.de/fellowships**. Applications should be completed by November 22, 2016.

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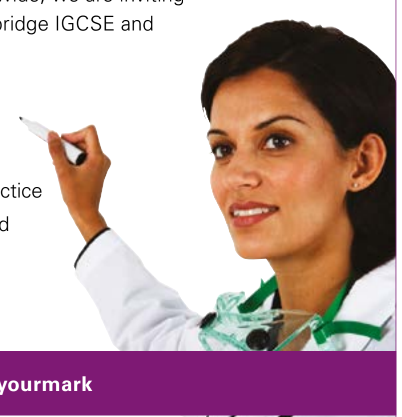

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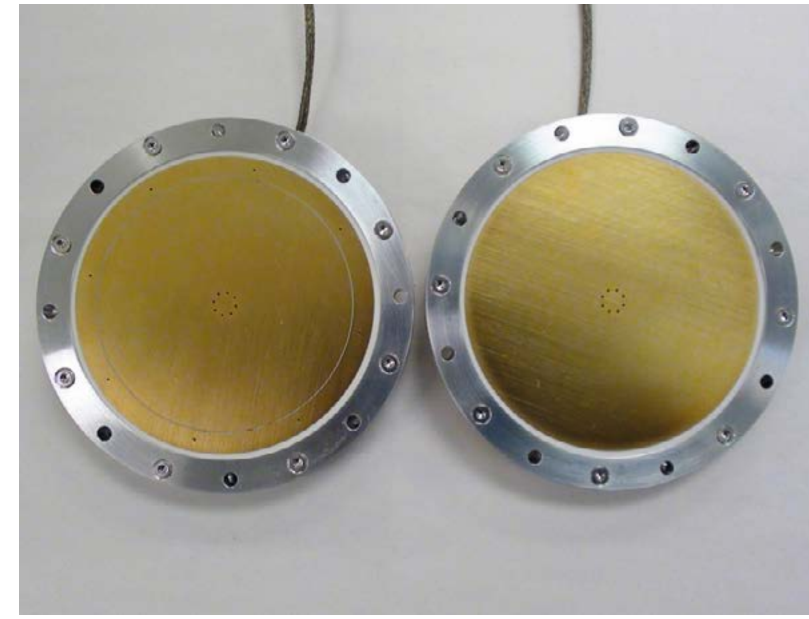
Advertising feature

Subnanometre positioning in a vacuum

Queensgate Instruments, an Elektron Technology brand, specialize in creating nanopositioning and sensing solutions for high-tech industries, with variants for precision measurement in vacuum, radiation and cryogenic environments. The company was founded in 1978 as a spin-off from Imperial College, London, and pioneered the use of capacitive metrology for nanopositioning. With deep roots in academia, Queensgate has stayed firmly involved in cutting-edge research and development, and has a range of market-leading products.



NCG-1-AL-UHV capacitive sensors.

The Nanosensor® is a non-contact measuring system based on the principle of capacitance micrometry. Two nanosensor plates (the probe and target) are mounted facing each other. The nominal gap is usually equivalent to the measurement range and the sensors operate from 50% nominal to 150% nominal. One plate is usually secured to a fixed position and the other moves. Short-range sensors generally offer the best resolution, with less than 10 pm possible for a 20 µm range. Longer range sensors of 11 mm can still offer high resolutions of a few tens of nanometres.

Our standard range of capacitive sensors, the NX series, are metal plate sensors. The standard models are constructed in aluminium, with the option of Super Invar for superior thermal stability. They are available in a variety of shapes and sizes to suit the application.

Image: NX capacitive sensor.

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- secondary EMI shielding – the NC series incorporates a primary driven screen and a secondary grounded screen.

Queensgate also produce a range of piezo actuators, available for UHV. The Digital Piezo Translators (DPT) are a family of preloaded closed-loop piezoelectric actuators that incorporate capacitive feedback. This guarantees ultimate positioning performance. Their Super Invar construction provides high thermal stability and low drift. They are available with ranges from 20 µm to 110 µm, and can move loads up to 60 kg.

Our engineers, scientists and manufacturing experts provide the best solution for challenging problems. We can advise on the best use of standard products and are specialists in delivering custom systems. Products are engineered to last, with many systems in continuous operation in excess of 20 years. Queensgate offer a number of products, including flexure-guided stages, closed-loop actuators, nanopositioning sensors, as well as high-quality control electronics.

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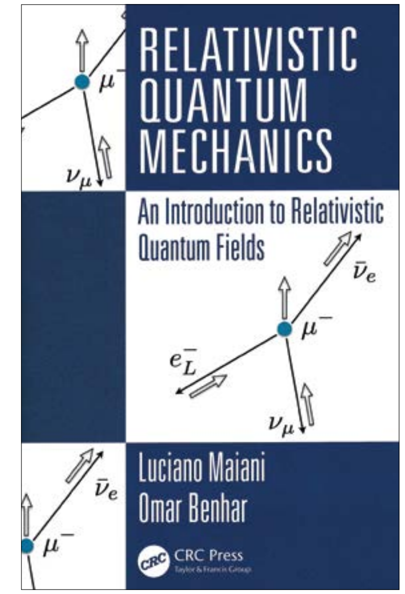
Bookshelf

Compiled by Virginia Greco, CERN

Relativistic Quantum Mechanics: An Introduction to Relativistic Quantum Fields
By Luciano Maiani and Omar Benhar
CRC Press



Quantum field theory (QFT) is the mathematical framework that forms the basis of our current understanding of the fundamental laws of nature. Its present formulation is the achievement of almost a century of theoretical efforts, first initiated by the necessity of reconciling quantum mechanics with special relativity. Its success is exemplified by the Standard Model, a specific QFT that spectacularly accounts for all of the observations performed so far in particle-physics experiments over many orders of magnitude in energy. Learning and mastering QFT is therefore essential for anyone who wants to understand how nature works on the smallest scales.

This book gives a concise and self-contained introduction to the basic concepts of QFT. As mentioned in the preface, it is mainly addressed to students with different interests who are approaching the subject for the first time, and is based on a series of lecture courses taught by the authors over the course of a decade at the University of Rome La Sapienza. Topics are selected and presented following their historical development and constant reference is made to those experiments that marked key advances, and sometimes breakthroughs, on the theoretical front. Some important subjects were not included, but they can be reconsidered later for more in-depth study.

The book is conceived as the first of a series that comprises two other texts on the more advanced topics of gauge theories and electroweak interactions (in collaboration with the late Nicola Cabibbo). The authors do not indulge in technical discussions of more formal aspects but try to derive the main physics results with the minimum amount of mathematical machinery. Although some concepts would have benefitted from a more systematic discussion, such as the scattering matrix and its definition through asymptotic states, the goal of giving an essential introduction to QFT and providing a solid foundation in this for the reader is achieved overall. The experience of the authors as both proficient teachers of the subject and main players is crucial to finding a good balance in establishing the QFT framework.

The first part of the book (chapters 1–3) is dedicated to a short review of classical dynamics in the relativistic limit. Starting from the principles of relativity and minimal action, the motion of point-like particles and the evolution of fields are described in their Lagrangian and Hamiltonian formulations. Special emphasis is given to symmetries and conservation laws. Quantisation is introduced in chapter 4 through the example of the scalar field by replacing the Poisson brackets with commutators of operators. Equal-time commutation rules are then used to define creation and destruction operators and the Fock space. Chapter 5 deals with the quantisation of the electromagnetic field. The approach is that of canonical formalism in the Coulomb gauge, but no mention is made of the complication due to the presence of constraints on fields. Chapters 6 and 7 are dedicated to the Dirac equation and the quantisation of the Dirac field. Besides introducing the usual machinery of spinors and gamma matrices, they include a detailed analysis of the relativistic hydrogen atom as well as concise though important discussions about Wigner's method of induced representations as applied to the Lorentz group, micro-causality and the relation between spin and statistics. The propagation of free fields is analysed in chapter 8, while the three chapters that follow introduce the reader to relativistic perturbation theory. Chapter 12 discusses discrete symmetries (C, P and T) in QFT, gives a proof of the CPT theorem and illustrates its consequences. The last part of the book is dedicated to applications of QFT formalism to phenomenology. The authors give a detailed account of QED in chapter 14 by discussing a variety of physical processes. The reader is here introduced to the method of Feynman diagrams through explicit examples following a pragmatic approach. The following chapter deals with Fermi's theory of weak interactions, again making use of several explicit examples of physical processes. Finally, chapters 13 and 16 are devoted to the theory and phenomenology of neutrinos. In particular, the last section discusses neutrino oscillations (both in a vacuum and through matter) and presents a thorough analysis of current experimental results. There is also a useful set of exercises at the end of each chapter.

Both the pragmatic approach and choice of topics make this book particularly suited for readers who want a concise and self-contained introduction to QFT and its physical consequences. Students will find it a valuable companion in their journey into the subject, and expert practitioners will enjoy the various advanced arguments that are scattered throughout the chapters and not commonly found in other textbooks.

● *Roberto Contino, Scuola Normale Superiore of Pisa, Italy.*

Learning Scientific Programming With Python
By Christian Hill
Cambridge University Press

Science cannot be accomplished nowadays without the help of computers to produce, analyse, treat and visualise large experimental data sets. Scientists are called to code their programs using a programming language such as Python, which in recent times has become very popular among researchers in different scientific domains. It is a high-level language that is relatively easy to learn, rich in functionality and fairly compact. It includes many additional modules, in particular scientific and visualisation tools covering a vast area in numerical computation, which make it very handy for scientists and engineers.

In this book, the author covers basic programming concepts – such as numbers, variables, strings, lists, basic data structures, control flow, and functions. It also deals with advanced concepts and idioms of the Python language and of the tools that are ▷

Bookshelf

presented, enabling readers to quickly gain proficiency. The most advanced topics and functionalities are clearly marked, so they can be skipped in the first reading.

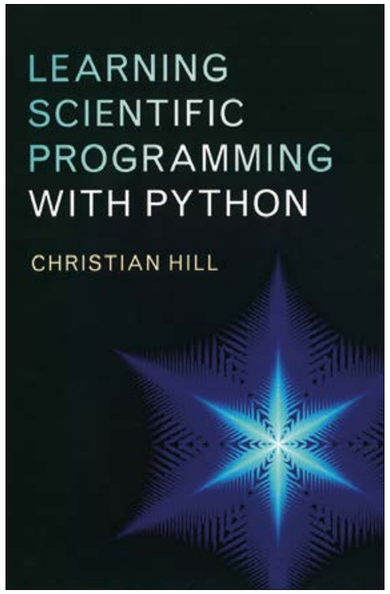
While discussing Python structures, the author explains the differences with respect to other languages, in particular C, which can be useful for readers migrating from these languages to Python. The book focuses on version 3 of Python, but when needed exposes the differences with version 2, which is still widely in use among the scientific community.

Once the basic concepts of the language are in place, the book passes to the NumPy, SciPy and Matplotlib libraries for numerical programming and data visualisation. These modules are open source, commonly used by scientists and easy to obtain and install. The functionality of each is well introduced with lots of examples, which is clearly an advantage with respect to the terse reference documentation of the modules that are available from the web. NumPy is the de facto standard for general scientific programming that deals very efficiently with data structures such as unidimensional arrays, while the SciPy library complements NumPy with more specific functionalities for scientific computing, including the evaluation of special functions frequently used in science and engineering, minimisation, integration, interpolation and equation solving.

Essential for any scientific work is the plotting of the data. This is achieved with the Matplotlib module, which is probably the most popular one that exists for Python. Many kinds of graphics are nicely introduced in the book, starting from the most basic ones, such as 1D plots, to fairly complex 3D and contour plots. The book also discusses the use of IPython notebooks to build rich-media documents, interleaving text and formulas with code and images into shareable documents for scientific analysis.

The book has many relevant examples, with their development traced from both science and engineering points of view. Each chapter concludes with a series of well-selected exercises, the complete step-by-step solutions of which are reported at the end of the volume. In addition, a nice collection of problems without solutions are also added to each section.

The book is a very complete reference of the major features of the Python language and of the most common scientific libraries. It is written in a clear, precise and didactical style that would appeal to those who, even if they are already familiar with the Python programming language, would like to develop their proficiency in numerical and



scientific programming with the standard tools of the Python system.

● *Pere Mato Vila, CERN.*

Books received

Reviews of Accelerator Science and Technology: Volume 7
By Alexander W Chao and Weiren Chou (eds)
World Scientific
Also available at the CERN bookshop

Volume 7 of *Reviews of Accelerator Science and Technology* is dedicated to colliders and provides an in-depth panorama of the different technologies developed since the construction in the 1960s of the first three: AdA in Italy, CBX in the US, and VEP-1 in the then Soviet Union.

Colliders have been crucial for proving the validity of the Standard Model, and they still define the energy frontier in particle physics because at present no machine can overcome the current LHC limit of 13 TeV in the centre of mass.

The book opens with an article by Burton Richter, a pioneer of high-energy colliders, who shares his viewpoint about their future. This is followed by contributions from leading experts worldwide, who discuss the characteristics, advantages and limits of machines that collide different types of particles. Proton–proton and proton–antiproton colliders are reviewed by Walter Scandale, electron–positron circular colliders by Katsunobu Oide, ion colliders by Wolfram Fischer and John M Jowett, and electron–proton and electron–ion colliders by Ilan Ben-zvi and Vadim Ptitsyn. Akira Yamamoto and Kaoru Yokoya then discuss linear colliders, Robert B Palmer muon colliders, and Jeffrey Gronberg photon colliders.

A section of the book is dedicated to the accelerator physics that form the basis of the design of these machines. In particular, Frank Zimmermann provides a general overview of collider-beam physics, while Eugene Levichev goes into more detail discussing the technologies for circular colliders.

The volume concludes with an article by Kwang-Je Kim, Robert J Budnitz and Herman Winick on the life of Andy Sessler, an accelerator physicist considered by his colleagues as an inspiring figure.

Comprehensive and containing contributions by high-profile experts, this book will be a good resource for students, physicists and engineers willing to learn about colliders and accelerator physics.

Colour: How We See It and How We Use It
By Michael Mark Woolfson
World Scientific

In this book, the author discusses the scientific nature of light and colours, how we see them and how we use them in a variety of applications.

Colours are the way that our vision system and – ultimately – our brain translate the different wavelengths of a part of the light spectrum. Other living things are sensitive in different ways to light and not all of them can see colours.

After presenting the science behind colours and our vision, the book discusses the use that mankind has made of colours. Ever since the time that humans lived in caves, we have used pigments to make graffiti on walls, which evolved into paintings and, lately, graphic art. Here, as is the case when designing decorations and dyes for clothing, the colours are not natural but man-made.

In the chapters that follow, the author reviews three technologies integrated in our everyday life that emerged as black-and-white and evolved into colour by way of photography, cinematography and television. The final part of the book is dedicated to describing various forms of light displays, mostly used for entertainment purposes, and to the application of colours as a code in many contexts – including road safety, hospital emergencies and industry.

Readers attracted by this mixture of science, art and culture will find the book easily readable.

CERN Courier Archive: 1973

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

CERN News

Computers

After a running-in period which was expected to last about a year, the new central computer, the CDC 7600, can now handle more work than all the other computers at CERN put together.

A sector now giving cause for concern is that of magnetic tapes. Difficulties arise because they are so numerous and differ in format. The large quantity poses problems in machine operation, because the mass of information they transmit can saturate the information transfer channels. The diversity of format creates software problems, since each type has to be processed in a different way.

CERN 246.9.73

This is just part of the stock of 40,000 tapes which has been moved to CERN's new computer building. It illustrates the problem of data storage, one of the present headaches in high-energy physics.

However, a solution seems to be emerging. Magnetic discs will help to deal with the tape bottleneck. At the end of October a third large capacity disc was connected to the 7600. It will be used to store the data from several tapes in frequent use and will considerably lighten the operators' task. Furthermore, the load on the channel linking the tape units and central memory is considerably reduced.

● Compiled from texts on p333.

DESY

Meeting on Storage Rings

In Spring 1974 the first experiments are scheduled to start at DORIS (DOppel-RIng-Speicher), the electron–positron double storage ring at DESY. While the last preparations for the 3 GeV storage rings were still in progress, some of its initiators discussed further possibilities for developing the machine's physics potential. They concluded that the amount of money needed for a normal high-energy physics experiment would be sufficient to add the ability to carry out electron–proton collisions within the rings.

The original plans were to have a 1 GeV proton booster but it has now been decided to do the main acceleration of the protons in the DESY electron synchrotron. Protons will be injected into the synchrotron at 4 MeV by a Van de Graaff accelerator. In one second about 10^{11} protons will be accelerated to an energy of 2 to 4.5 GeV and stacked in the storage ring. It should be possible to accumulate up to 3×10^{13} protons. At the two intersecting regions they will collide with 5×10^{12} electrons circulating in the second storage ring, resulting in luminosities as high as 10^{31} per cm^2 per s.

This will be an excellent opportunity to study machine physics problems which will be important for the next generation of e–p storage rings. Given the importance of these topics, from 8 to 12 October experts were invited to DESY from all of the laboratories in Europe and the United States where storage rings are being planned, are under construction, or are already operating.

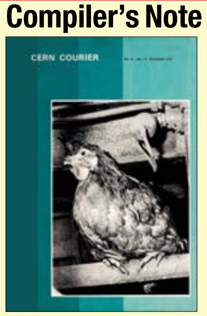
The meeting confirmed that multi-laboratory discussions on the different machine problems are a necessary and stimulating exercise to exchange information and to check the practicability of future projects. The local stimulation at DESY may have been responsible, a few days after the meeting, for bringing the first electrons and positrons from the DESY synchrotron to the injection points of DORIS.

● Compiled from texts on pp314–342.

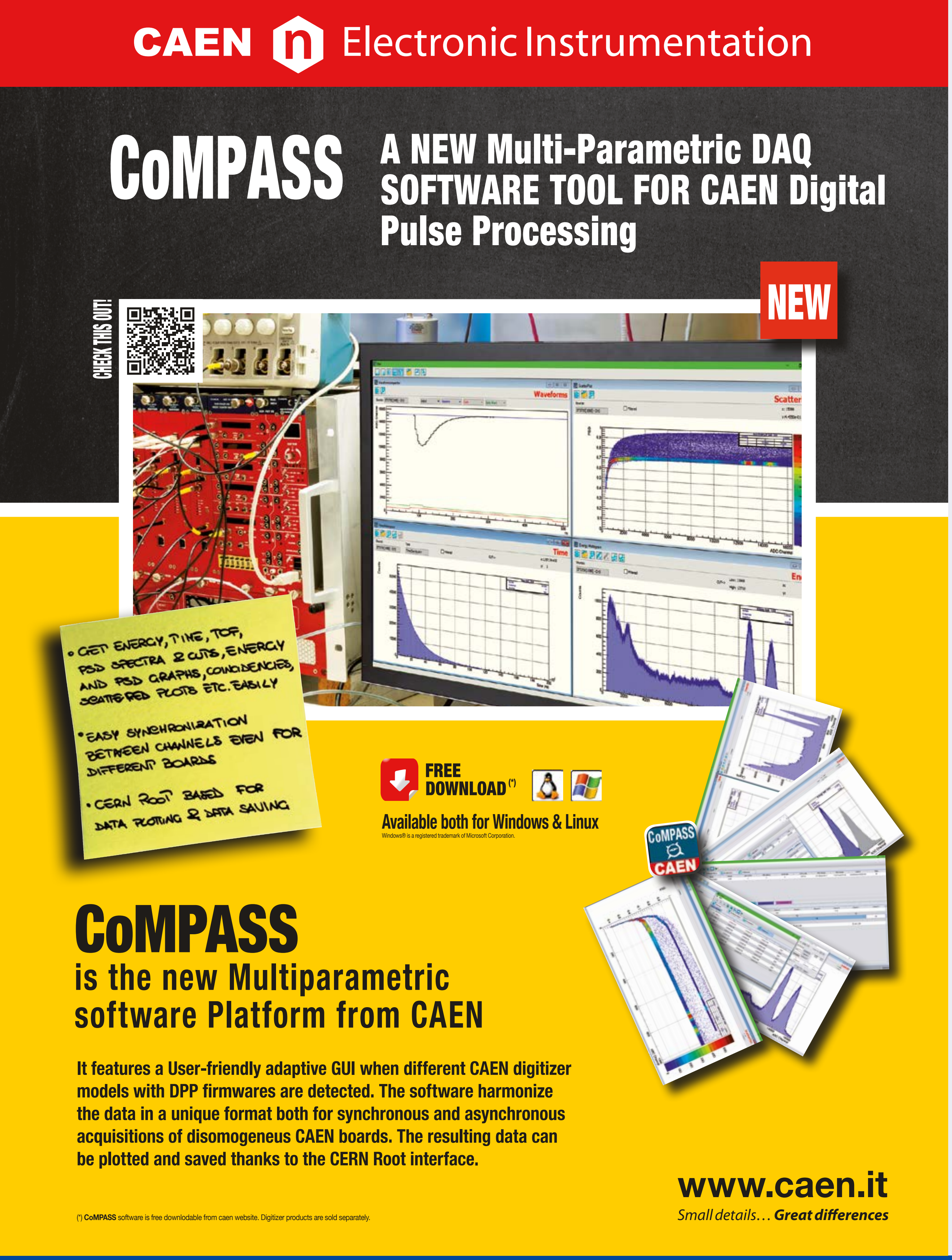
Some well-known faces from the accelerator world, brought together by the DESY meeting (clockwise from top left): Gustav Weber (DESY), Wolfgang Panofsky (SLAC), Bjørn Wiik (DESY), Kjell Johnsen (CERN), Herwig Schopper (CERN), Burton Richter (SLAC), and Kurt Hübner (CERN).

Image credits: DESY

Compiler's Note



Each nine-track magtape used for data storage in the 1970s could hold about 100 MB, so CERN's 40,000-tape headache measured around 4 on the TB (10^{12} bytes) scale. Today's LHC experiments produce more than 3 GB of data per second, creating that headache every 20 minutes. Together, they generate more than 30 PB (30×10^{15} bytes) per year, which are distributed to 170 computing centres in 42 countries connected by the Worldwide LHC Computing Grid. The centres are ranked in tiers, from 0 (largest) to 4 (smallest). The two Tier-0 centres, the CERN Data Centre in Meyrin and the Wigner Data Centre in Budapest, are responsible for the long-term safekeeping of the first copy of the raw data. While all centres store a fraction of the data on disc for fast access during analysis, the archiving medium is still magtape. It is inexpensive and durable, and one of today's compact cartridges can hold up to 5 TB, exceeding CERN's 1970s data headache.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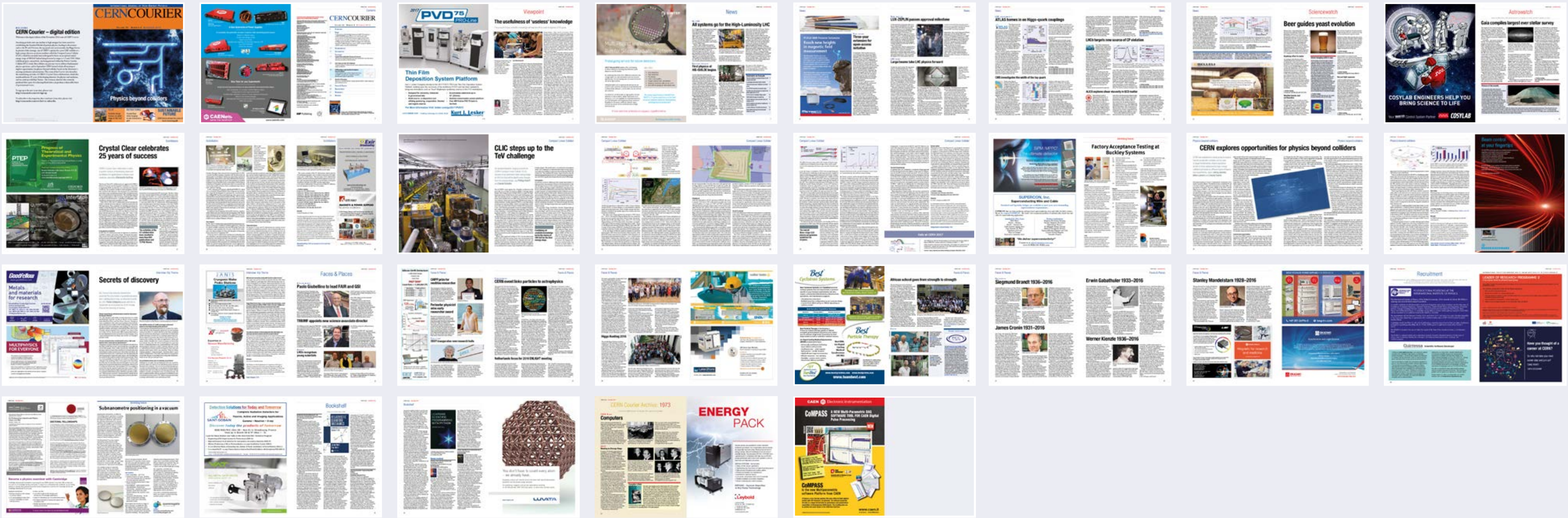
(*) CoMPASS software is free downloadable from caen website. Digitizer products are sold separately.
www.caen.it
Small details… Great differences



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VOLUME 56 NUMBER 9 NOVEMBER 2016

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