WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the December 2015 issue of *CERN Courier*.

Eight years after their first visit to ALMA's site in Chile, CERN's Paola Catapano and Mike Struik pay a second visit to the experimental site and its 66 antennas, now in operation. For the past four years, anything ALMA has observed has been a press release, and more is certainly to come for the world's largest astronomical project. Closer to the field of particle physics, in this issue we feature the role of photons as probes to investigate the properties of quark–gluon plasma, and we discover DUNE, the flagship neutrino experiment gaining global interest from an increasingly large community. Finally, we pay tribute to a giant of physics, Nobel laureate Yoichiro Nambu, who passed away in July.

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CERNCOURIER

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Amazing ALMA

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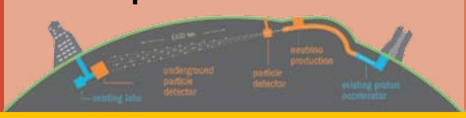
DUNE
The experiment gains global interest **p19**



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

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On the cover: Aerial photograph taken from a drone of the ALMA site in July. (Image credit: Mike Struik, CERN.)

Viewpoint

Our Courier

Whose *Courier* is it? The new editor reflects on the future of the *CERN Courier*.

Cian O'Luanaigh 2015

The communication of science is more effective when it is conveyed in a more visual way.

By Antonella Del Rosso

The *CERN Courier* is not exclusively CERN's. Its subtitle "International Journal of High-Energy Physics" stands as a friendly warning to all those readers who might otherwise think it is an official mouthpiece of the CERN laboratory. As the new editor, I share my predecessor's vision (and hope) of producing a magazine that will interest and stimulate the entire high-energy physics community across the world.

Over the last decade, the community has expanded to encompass physicists from many different areas – not just accelerator physics and not just from CERN. Today, the high-energy frontier is being explored not only by particle physicists but also by astrophysicists, cosmologists, astroparticle physicists and neutrino physicists. We use accelerators such as the unique LHC, but also satellites and detectors installed on the International Space Station. The hard-won results of physicists worldwide are increasingly a collaborative effort, where the boundaries between the various sub-disciplines have faded to nothing.

Our ambition must be to follow the natural evolution of the high-energy physics community and continue to be its magazine for years to come. How will we achieve this? You might have already noticed a few small changes in the November issue. A first visible change is this "Viewpoint". Up until the October issue, it could be found at the end of the issue. Now it has been placed at the start, and its role has changed from that of an opinion piece to being the opening article intended to grab the reader's attention. Is it working? Are you reading it? Please let me know. Although this is probably the first time that we have appealed for feedback directly in these pages, the fact that the *CERN Courier* is open to contributions and feedback from the wider community is far from new. From when the magazine was first published online, the "Contact us" webpage has stated the following, in French and English: "*CERN Courier* welcomes contributions from the international high-energy 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 your proposal to the editor."

In other words, for many years we have been eager to hear from you. And, indeed, you have communicated with us and given your feedback, and we have published your work, your professional ambitions, and your points of view. We have been part of your life and you have been part of ours. Many thanks for that. And what does the future hold? The *CERN Courier* will continue to bring you its authoritative insight into scientific information; it will continue to keep you abreast of developments at CERN and other laboratories worldwide; it will continue to bring you the very best images and, where possible, the very best video clips (yes, purely "sciency" videos, produced exclusively for the *CERN Courier*, see p24 of this issue) and other multimedia material.

Being an editor of a (still) printed publication in 2015 is no easy task. Out there in the world, information flows fast. Here, at the *CERN Courier*, we still take time to do things properly. As Christine Sutton, the previous editor, said in her "Viewpoint" in the November issue (*CERN Courier* November 2015 p5), our ambition is to take you "behind the headlines" and bring you the real protagonists with their full stories. The *CERN Courier* has the space, and that space is for you.

Let me take this opportunity to thank all of our regular contributors. Most of them have collaborated with us on a voluntary basis for many years and are the backbone of the magazine. Their profiles, together with that of our new "Bookshelf" editor, Virginia Greco, are available at cerncourier.com/cws/our-team. Obviously, the magazine would not exist without the hundreds of contributors worldwide who send us their texts, be they a feature article or a short piece for "Faces & Places". A big thank you to everyone.

The *CERN Courier* adventure continues.

With a degree in physics and more than 15 years experience in science communication, Antonella Del Rosso became editor of the CERN Courier *in September 2015. At CERN, she is also in charge of internal communication, and is editor of the* CERN Bulletin.

Advertising feature

Miniaturised precision stages with piezo-based inertia drives

Today, piezo-ceramic drive concepts provide a suitable solution for practically every task in the field of precision positioning. The common factors in all of the concepts are the compact dimensions and the high positioning accuracy, which is substantiated by the functional principle. Piezo actuators convert electrical energy directly into mechanical energy and make motion in the subnanometre range possible, even with short response times and high acceleration.

However, the displacement caused by the piezo effect is only a fraction of 1% of the actual component size. Achieving larger travel ranges can therefore be complex and expensive. PI (Physik Instrumente) has responded accordingly by introducing its Q-Motion range of positioning systems. The Q-Motion range is based on piezoelectric inertia drives and stands for high resolution in the nanometre range with theoretically unlimited travel ranges, miniaturised design and attractive price.

Piezo-based inertia drives utilise the stick-slip effect: the actuator expands slowly and moves a runner, and due to its inertia the runner is unable to follow the fast contraction of the actuator and remains at its position. At rest, the piezo-based inertia drives are self-locking and therefore do not consume any power.

From the linear positioning stage to the six-axis positioning system

The functional principle allows easy configuration of the actuators and the control. The piezo-based drive is deployed as a module. This makes it possible to realise long travel ranges or rotary motion, and individual axes can be easily combined with each other. At the same time, it is also possible to realise very compact designs.

Precise rotation stage with a diameter of only 14 mm. (Image: PI)

Palm-sized, parallel kinematic SpaceFABs have six motion axes and are suitable for applications where samples, detectors or tools need to be moved and rotated. (Image: PI)

The smallest linear positioning stage currently available is only 22 mm wide and 10 mm high. It is suitable for travel ranges of 6.5, 13 or 26 mm and achieves velocities of up to 10 mm/s. At the same time, it develops a feed and holding force of 1 N. When equipped with an incremental encoder, it achieves a resolution of up to 1 nm. There are a large number of typical areas of application for the small precision stage, especially because it is also available as a vacuum version and, if required, can be combined with further linear axes or rotary stages, and this is possible without additional adapters.

The miniature rotation stages (image left) have a diameter of only 14 mm, achieving resolutions in a range of 1 µrad; the holding force of the linear positioning stage is up to 8 N in a de-energized state and the maximum velocity is 10 mm/s, rotationally up to 70 /s. For those applications where samples, detectors, optical components or tools need to be moved and rotated in space, there are six-axis, parallel kinematic positioning systems. These SpaceFABs (image top) are so small that they can be easily placed on the palm of the hand. The design is based on combined linear positioning stages and can be quickly and easily adapted to application requirements, e.g. even for use in a high or an ultra-high vacuum.

The PI Group, with headquarters in Karlsruhe, Germany, is a leading manufacturer of positioning systems with accuracies in the nanometre range. PI miCos GmbH in Eschbach, Germany, has been part of PI since 2011, and is specialised in the integration of positioning components in complex systems such as industrial test and calibration facilities or scientific set-ups in large research facilities. The wide-ranging application know-how of PI miCos guarantees the implementation of technically demanding solutions. The most advanced positioning systems for ultra-high vacuum applications are a good example of this, as are the parallel kinematic hexapods with six degrees of freedom or air-bearing axes for the highest running accuracy.

The PI Group is represented at four locations in Germany and 11 sales and service subsidiaries abroad. With 850 highly qualified employees all over the world, the PI Group is in a position to fulfill almost any requirement in the field of innovative precision motion technology. All key technologies are developed in-house. This allows the company to control every step of the process, from design to shipment, to precision mechanics and electronics as well as position sensors.

PI

Web www.pi.ws

News

LHC UPGRADE

High Luminosity LHC moves forward

October 2015 was a turning point for the High Luminosity LHC (HL-LHC) project, marking the end of the European-funded HiLumi LHC Design Study activities, and the transition to the construction phase, which is also reflected in the redesigned logo that was recently presented.

So far, the LHC has only delivered 10% of the total planned number of collisions. To extend its discovery potential even further, the LHC will go through the HL-LHC major upgrade around 2025, which will increase the luminosity by a factor of 10 beyond the original design value (from 300 to 3000 fb^{-1}). The HL-LHC machine will provide more accurate measurements and will enable the scientific community to study new phenomena discovered by the LHC, as well as new rare processes. The HiLumi upgrade programme relies on a number of key innovative technologies, such as cutting-edge 12 Tesla superconducting magnets, very compact and ultra-precise superconducting cavities for beam rotation, and 100 m-long high-power superconducting links with zero energy dissipation. In addition, the higher luminosities will make new demands on vacuum, cryogenics and machine protection, and will require new concepts for collimation and beam diagnostics, advanced modelling for the intense beam and novel schemes of beam crossing to maximise the physics output of these collisions.

Mike Struik, CERN

Artistic shot of the light show that celebrated the HiLumi LHC milestone and the International Year of Light.

From design to construction

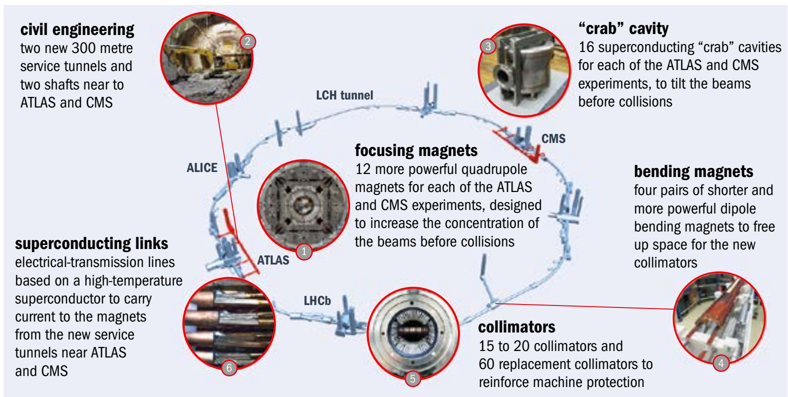
The green light for the beginning of this new HL-LHC phase, marked by main hardware prototyping and industrialisation, was given with the approval of the first version of the Technical Design Report – the document that describes in detail how the LHC upgrade programme will be carried out. This happened at the 5th Joint HiLumi LHC-LARP Annual Meeting, which took place at CERN from 26 to 30 October and saw the participation of more than 200 experts from all over the world to discuss the results and achievements of the HiLumi LHC Design Study. In the final stage of the more than four-year-long design phase, an international board of independent experts worked on an in-depth cost-and-schedule review. As a result, the total cost of the project – amounting to CHF 950 million – will be included in the CERN budget until 2026.

In addition to the project management work-package (WP), a total of 17 WPs involving more than 200 researchers and engineers addressed the technological and technical challenges related to the upgrade. During the 48 months of the HiLumi Design Study, the accelerator-physics and performance team defined the parameter sets and machine optics that would allow HiLumi LHC to reach the very ambitious performance target of an integrated luminosity of 250 fb^{-1} per year. The study of the beam–beam effects confirmed the feasibility of the nominal scenario based on the baseline β^* levelling mechanism, providing sufficient operational margin for operation with the new ATS (Achromatic Telescopic Scheme) at the nominal levelling luminosity of $5 \times 10^{34} cm^{-2}s^{-1}$, with the possibility to reach up to 50% more. The magnet design activity, focusing on the design of the insertion magnets, launched the hardware fabrication of short models of the Nb_3Sn quadrupoles' triplet (QXF), separation dipole, two-in-one large aperture quadrupole and 11 T dipole for Dispersion Suppressor collimators. Single short coils in the mirror configuration have already been successfully tested for the triplet. The first model of the QXF triplet containing two CERN and two LARP coils was assembled in the US in the summer, and is being tested this autumn, while a short model of the 11 T dipole fabricated at CERN reached 12 T. To protect the magnets from the higher beam currents, the collimation team focused on the design and verification of the new generation of collimators. The team presented a complete technical solution for the collimation in and around the insertions in HL-LHC, providing improved flexibility against optics changes. The crab-cavities activity finalised and launched the manufacturing of the crab-cavity interfaces, including the helium vessels and the cryo-module assembly. All cavity parts stamped in the US will be assembled and surface processed in the US, in addition to electron-beam welding and testing. Last but not least, as part of their efforts to develop a superconducting transmission line, the ▷

Sommaire en français

cold powering activity hit a world-record current of 20 kA at 24 K in a 40 m-long MgB_2 electrical transmission line. The team has finalised the development and launched the procurement of the first MgB_2 PIT round wires. This is an important achievement that will enable the start of large cabling activity in industry, as required for the production of a prototype cold-powering system for the HL-LHC.

In addition to the technological challenges, the HL-LHC project has also seen an important expansion of the civil-engineering and technical infrastructure at P1 (ATLAS) and P5 (CMS), with new tunnels and underground halls needed to house the new cryogenic equipment, the electrical power supply and various plants for electricity, cooling and ventilation.



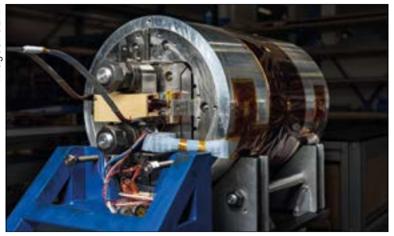
New technologies for the high-luminosity LHC.

A winning combination

Such an extensive technical, technological and civil endeavour would not be possible without collaboration with industry. To address the specific technical and procurement challenges, the HL-LHC project is working in close collaboration with leading companies in the field of superconductivity, cryogenics, electrical power engineering and high-precision mechanics. To enhance the co-operation with industry on the production of key technologies that are not yet considered by commercial partners due to their novelty and low production demand, the newly launched QUACO project, recently funded by the EU, is bringing together several research infrastructures with similar technical requirements in magnet development to act as a single buyer group.

TECHNOLOGY

A new record for the RMC test magnet at CERN



Top: The RMC_03 racetrack test magnet. Above: Samples of the two cables used to wind the RMC_03 coils.

Images: CERN

High magnetic fields are the Holy Grail of high-energy accelerators. The strength of the dipole field determines the maximum energy the beam can achieve on a given orbit, and large-aperture, high-gradient quadrupoles, with high peak field, govern the beam collimation at the interaction points. This is why, this September, members of the CERN Magnet Group in the Technology Department had big grins on their faces when the RMC racetrack test magnet attained a peak field of 16.2 T, twice the nominal field of the LHC dipoles, and the highest field ever reached in this configuration.

This result was achieved thanks to a different superconductor –the intermetallic and brittle compound Nb_3Sn – used for the coils and the new "bladder-and-keys" technology developed at LBNL to withstand the extremely powerful electromagnetic forces.

The beginning of this success story dates back more than 10 years, when experts started to realise that Nb–Ti alloy, the workhorse of the LHC (and of all superconducting accelerators until then), and the conventional collar structure enclosing the superconducting coils in a locked, laminated assembly, would soon run out of steam. A technological quantum leap was needed.

Seeds sown

The first seeds of a European programme were sown in 2004, when a group of seven European laboratories and universities (CCLRC RAL, CEA, CERN, CIEMAT, INFN, Twente University and Wrocław University), under the co-ordination of CEA Saclay, decided to join forces to develop the technologies for the next-generation high-field magnets. Initially conceived to develop a 15 T dipole with a bore of 88 mm, the NED JRA EU-funded programme subsequently became an R&D programme to develop a new conductor. Its main result was an industrial Nb_3Sn powder-in-tube (PIT) conductor with high current densities, designed to reach fields up to 15 T.

Three of the NED JRA partners – CEA, CERN and RAL – saw the importance of exploiting the new technology and continued the R&D beyond the NED JRA programme. Inspired by programmes at neighbouring laboratories, in particular LBNL, they started to develop a sub-scale model magnet with racetrack coils: the short model coil (SMC). This intermediate step led the partners to learn the basic principles of Nb_3Sn coil construction. In fact, the SMC became a fast-turnaround test-bed for medium-sized cables, and is still in use at CERN. In 2011, the second SMC assembly successfully achieved 12.5 T. In a subsequent SMC assembly in 2012, the field went up to 13.5 T. With these results, CERN and its European partners demonstrated that they were on track to master Nb_3Sn magnet technology.

Towards high fields

Since 2009, CERN and CEA have continued work on the technology, initially under the FP7-EuCARD project activities, and today within the scope of the CEA/CERN magnet collaboration. The focus of the FP7-Eucard high-field magnet (HFM) work package became the construction of a 13 T dipole magnet with a 100 mm aperture, which will be used to upgrade the FRESCA facility at CERN: FRESCA2. To achieve the 13 T objective, the CERN-CEA team designed the magnet for a field of 15 T using the state-of-the-art Nb_3Sn technology: a 1 mm wire supplied by the only two manufacturers in the world capable of meeting the critical current specification, one in Germany (powder-in-tube, or PIT wire) and one in the US (rod restack process, or RRP wire). The cable for FRESCA2, was designed to have 40 strands and to carry nearly 20 kA at 1.9 K for a magnetic field of 16 T. This is an impressive set of values compared with the LHC, where the dipole cables can carry 13 kA at 1.9 K for a magnetic field of 9 T.

In spite of the engineering margins in the design, FRESCA2 proved to be a challenging goal. CERN therefore decided to design and construct an intermediate step, consisting of two racetrack, flat coils and no bore, made with the same 40 strand cable and fabrication procedures as for FRESCA2. This magnet was named the "racetrack model coil" (RMC).

Two initial assembly configurations were built using either RRP and PIT cables, and then a third one – called RMC_03 – was trained up to a maximum current of 18.5 kA at a temperature of 1.9 K. Based on the calculation of the field, this current corresponds to peak fields of 16 T in the coil wound with PIT cable and 16.2 T in the coil wound with RRP cable. With this result – a new record in this configuration – CERN has reached LBNL in the domain of high dipole fields.

Nb_3Sn will be used to build the IR QXF quadrupoles and the 11 T dispersion suppressor dipoles for the high-luminosity upgrade of the LHC (*CERN Courier* January/February 2013 p28). The RMC record paves the way for a promising demonstration of this technique for future developments. In particular, cables of the same type as for FRESCA2 are also being considered for the Future Circular Collider (FCC) studies (*CERN Courier* April 2014 p16).

A lot of hard work remains before CERN and its collaborating partners will be able to achieve a 16 T field inside a beam aperture with the required field quality for an accelerator, so the development work on FRESCA2 continues. The coils are under construction and a test station is being built in SM18 to host the giant magnet, which should be ready for testing by next summer.

CERN Courier December 2015

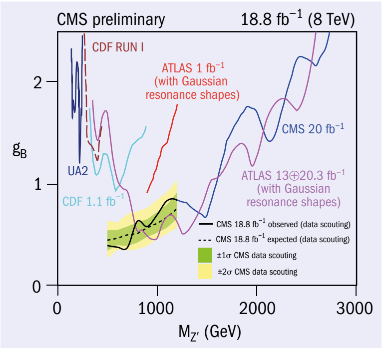
News

LHC EXPERIMENTS

CMS data-scouting and a search for low-mass dijet resonances

Proton beams crossed inside each of the CMS and ATLAS detectors 20 million times a second during the 2012 LHC proton–proton run. However, the physics programme of CMS is based on only a small subset of these crossings, corresponding to about 1000 events per second for the highest beam intensities attained that year. This restriction is due to technological limitations on the speed at which information can be recorded. The CMS detector has around 70 million electronics channels, yielding up to about half-a-million bytes per event. This volume of data makes it impossible to record every event that occurs. A so-called trigger system is used in real time to select which events to retain. Events are typically required to contain at least one object with a large transverse momentum relative to the proton beam axis. This restriction is effective at reducing the event rate but it also reduces sensitivity to new phenomena that might occur at a smaller transverse-momentum scale, and therefore it reduces sensitivity to the production of new particles, or "resonances", below certain mass values. While many important studies have been performed with the standard triggers, the necessary reduction imposed by these triggers seriously limits sensitivity to resonances with masses below around 1 TeV that decay to a two-jet ("dijet") final state, where a "jet" refers to a collimated stream of particles, such as pions and kaons, which is the signature of an underlying quark or gluon.

To recover sensitivity to events that would otherwise be lost, CMS implemented a new triggering scheme, which began in 2011, referred to as "data scouting". A dedicated trigger algorithm was developed to retain events with a sum of jet transverse energies above the relatively low threshold of 250 GeV, at a rate of about 1000 events per second. To compensate for this large rate and to remain within the boundaries imposed by the available bandwidth and disk-writing speed, the event size was reduced by a factor of 1000 by retaining only the jet energies and momenta in an event, reconstructed at a higher-level trigger stage. Because of the minimal amount of information recorded, no subsequent offline data processing was possible, and the scouted data were appropriate for a few studies only, such as the dijet resonance search. The resonance search was implemented directly in the CMS data-quality monitoring system so that, should deviations from the Standard Model expectation be observed, the trigger could be adjusted to collect the events in the full event format.



Upper limit of the coupling of a Z'_B resonance as a function of its mass. The results are compared with results obtained by standard data-taking, as well as with similar searches at different colliders.

The first results to use data-scouting were reported by CMS in 2012. These results were based on 0.13 fb^{-1} of proton–proton collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV, collected during the last 16 hours of the 2011 run. New results on dijet resonances have now been presented, which employ data-scouting in a much larger sample of 18.8 fb^{-1} collected at $\sqrt{s} = 8$ TeV in 2012. The results are summarised in the figure, which shows exclusion limits on the coupling strength (g_B) of a hypothetical baryonic Z'_B boson that decays to a dijet final state, as a function of the Z'_B mass. The CMS results, shown in comparison with previous results, demonstrate the success of the data-scouting method: using very limited disk-writing resources, corresponding to only about 10% of what is typically allocated for a CMS analysis, the exclusion limits for low-mass resonances (below around 1 TeV) are improved by more than a factor of four. Although no evidence for a new particle is found, data-scouting has established itself as a valuable tool in the search for new physics at the LHC.

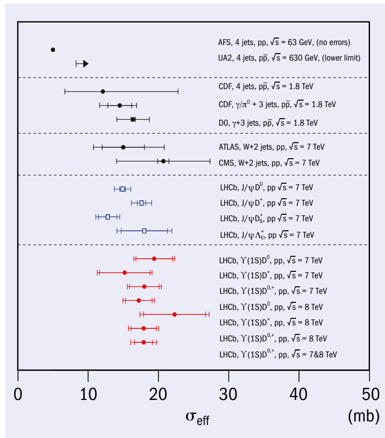
Further reading

cds.cern.ch/record/2063491

LHCb measures the effective double parton scattering cross-section with unprecedented precision

In high-energy hadron–hadron collisions, each incoming hadron behaves as a loosely bound system of massless partons – quarks, antiquarks and gluons. The interaction of incoming hadrons is described as the pair-wise interactions of partons from one incoming hadron with partons from the other hadron. This model agrees well with numerous precise experimental data, in particular with the production of heavy-flavoured particles. Such processes have been studied at the Tevatron and at the LHC. All experimental data agree well with the dominant contribution coming from the single pair-wise collision of gluons, producing a single charm–anticharm ($c\bar{c}$) or bottom–antibottom ($b\bar{b}$) pair, the so-called single parton scattering (SPS) paradigm. However, evidence for the production of multiple $c\bar{c}$ pairs in single hadron–hadron collisions has been reported by the NA3 and WA75 collaborations, who observed J/ψJ/ψ pairs, and three charmed mesons, respectively. Also, B_c meson production requires a $c\bar{c}$ and a $b\bar{b}$ pair. Yet these processes are consistent with a SPS of gluons.

At higher energy, the probability of a second hard parton interaction becomes non-negligible. The evidence for this kind of process, named double parton scattering (DPS), was obtained a long time ago by the AFS and UA2 collaborations. At the LHC where the energies of colliding protons are much larger, the DPS contribution is expected to be more prominent, and even dominant for some processes.



Summary of all available measurements of the σ_{eff} parameter.

Assuming the independence of partons, the rate of DPS processes is proportional to a product of the independent rates for two pair-wise parton collisions. A consequence is that the corresponding proportionality coefficient is universal, independent of the collision energy, and of the considered process. The inverse of this proportionality coefficient has the dimension of an area and is named the "effective DPS cross-section", σ_{eff}.

The significant role of DPS processes at the LHC has been demonstrated by the LHCb collaboration via the measurement of the simultaneous production of J/ψ mesons and charm hadrons. The measured rates are found to be 30 times larger than predicted from the SPS paradigm and in agreement with DPS predictions, showing the dominance of the DPS contribution in these processes. The measured parameter σ_{eff} is found to be in excellent agreement with those determined by the CDF collaboration from the study of jet events, but significantly more precise.

Recently, LHCb has extended this analysis to studying the simultaneous production of Υ mesons and charm hadrons. Such final states rely on the simultaneous production of $c\bar{c}$ and $b\bar{b}$ pairs. The full Run 1 data set has been used in this analysis.

The measured production rates exceed significantly the theory predictions, based on the SPS approach, but agree nicely with the DPS paradigm.

The measured parameter σ_{eff} is in very good agreement with all previous determinations and within the most precise measurements of this important parameter. The current best measurements of the σ_{eff} parameter are summarised in the figure.

● **Further reading**

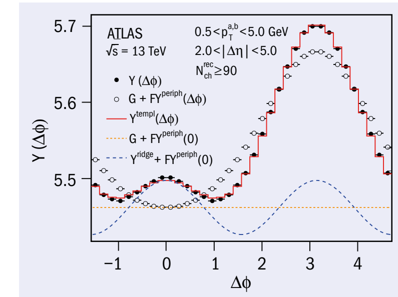
arxiv.org/abs/1510.05949

ATLAS observes long-range elliptic anisotropies in √s = 13 and 2.76 TeV pp collisions

Measurements of two-particle angular correlations in proton–proton (pp) collisions at the LHC have shown a feature commonly called the "ridge": an enhancement in production of particle pairs at small azimuthal angle separation, Δϕ, that extends over a large pseudorapidity separation, Δη. This feature has been demonstrated and the two-particle correlation function has been measured in pp collisions at √s = 13 TeV. The ridge has been observed and studied in more detail in proton–nucleus (p+A) and nucleus–nucleus (A+A) collisions where a long-range correlation is observed on the away-side (Δϕ ~ π) as well. Both the near- and away-side ridges in p+A and A+A collisions have been shown to result from a modulation of the single-particle azimuthal angle distributions, whose convolution produces the observed features in the two-particle Δϕ distribution. However, prior to this measurement, it was not yet known whether the ridge in pp collisions arises from single-particle modulations or even if it is present on the away-side or not.

Recently, ATLAS has performed an analysis of the long-range component of the two-particle correlations in pp collisions at 2.76 TeV and 13 TeV in different intervals of charged-particle multiplicity, N_{ch}^{rec}. The yield, Y(Δϕ), of particles associated with a "trigger" particle, for |Δη| > 2, is shown in the figure. A peak at Δϕ ~ 0 is associated with the ridge while the peak at Δϕ ~ π contains known contributions from dijets and, possibly, contributions from an away-side ridge. To disentangle the ridge and jet contributions, a new template fitting procedure, demonstrated in the figure, was used. The Y(Δϕ) distributions were fitted by a sum (red curve) of two components: Y(Δϕ) measured in low-multiplicity ($0 < N_{ch}^{rec} < 20$) collisions (open points), which accounts for the "jet" contribution, and a sinusoidally modulated component (blue dashed lines) which represents the long-range correlation like that observed in p+A and A+A collisions. These template fits successfully describe the two-particle correlations in all N_{ch}^{rec} intervals at both energies. Furthermore, the sinusoidal component was found to be present at all N_{ch}^{rec} intervals, indicating that the long-range correlation is a feature that is present at all multiplicities and not only in rare high-multiplicity events. The fractional amplitudes of the sinusoidal components are observed to be nearly constant with multiplicity and to be approximately the same at the two centre-of-mass energies.

These results suggest that the ridges in pp, p+A and A+A collisions arise from similar mechanisms. The observed weak dependence of the fractional amplitudes on N_{ch}^{rec} and centre-of-mass energy should provide a strong constraint on the physical mechanism responsible for producing the ridge.



Template fit to the Y(Δϕ) in 13 TeV pp collisions for charged particle pairs with $0.5 < p_T^{a,b} < 5$ GeV and $2 < |\Delta\eta| < 5$. This plot corresponds to the $N_{ch}^{rec} \geq 90$ interval. The open points indicate $FY^{periph}(\Delta\phi) + G$ (where G is the magnitude of the combinatoric component of the yield Y^{ridge}), while the solid and dashed curves show the full template functions and $Y^{ridge}(\Delta\phi) + FY^{periph}(0)$, respectively. The horizontal short-dashed line indicates $G + FY^{periph}(0)$.

● **Further reading**

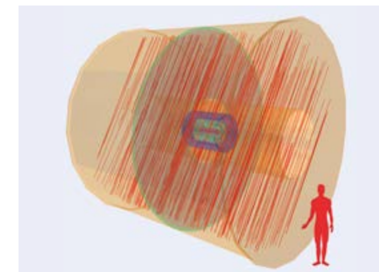
ATLAS Collaboration 2015 arxiv.org/abs/1509.04776, submitted to *Phys. Rev. Lett.*

ALICE looks to the skies (part II)

The ALICE experiment, designed for the LHC heavy-ion programme, is particularly well-suited for the detection and study of very high-energy cosmic events. The apparatus is located in a cavern 52 m underground, with 28 m of overburden rock, offering excellent conditions for the detection of muons produced by the interaction of cosmic rays in the upper atmosphere.

During pauses in the LHC operation (no beam circulating) between 2010 and 2013, the experiment collected cosmic-ray data for 30 days of effective time. Specific triggers were constructed from the information delivered by three detectors: ACORDE (A COsmic Ray DEtector), TOF (Time-Of-Flight) and SPD (Silicon Pixel Detector). The tracks of muons crossing the ALICE apparatus were reconstructed from the signals recorded by the TPC (time projection chamber). The unique ability of the TPC to track events with a large number of muons, unimaginable with standard cosmic-ray apparatus, has opened up the opportunity of studying the muon multiplicity distribution (MMD), and in particular rare events with extremely high muon density.

Atmospheric muons are created in extensive air showers that originate from the interaction of primary cosmic rays with nuclei in the upper atmosphere. The MMD has been measured by several experiments in the past, in particular by the ALEPH and DELPHI detectors at LEP. Neither of these two experiments was able to identify the origin of the high-multiplicity events observed. In particular, ALEPH concluded that the bulk of the data can be described using standard hadronic production mechanisms, but not the highest-multiplicity events, for which the measured rate exceeds the model predictions by over an order of magnitude, even when assuming that the primary cosmic rays are solely composed of iron nuclei.



Event display of a multi-muon event with 276 reconstructed muons crossing the TPC.

The MMD measured from the data set collected by ALICE exhibits a smooth distribution up to a muon multiplicity of around 70. At larger multiplicities, five events have been detected with more than 100 muons, confirming the detection of similar events by ALEPH and DELPHI. The event with the highest multiplicity (276 muons) shown in the figure corresponds to a density of around 18 muons/m².

These particular events triggered the question whether the data can be explained by a standard cosmic-ray composition, with usual hadronic-interaction models, or whether more exotic mechanisms are required. To answer these questions, as a first step, the MMD has been reproduced at low-to-intermediate multiplicities using the standard event generator CORSIKA, associated with QGSJET as the hadronic-interaction model. CORSIKA simulates the development of extensive air showers following the collision of a cosmic ray with the nuclei in the atmosphere. The shower particles are tracked through the atmosphere until they reach the ground.

These simulations successfully described the magnitude and shape of the measured MMD in the low-to-intermediate multiplicity, so the same model was then used to explore the origin of the five high-multiplicity events. This investigation revealed that these rare events can only be produced by primary cosmic rays with energies higher than 10,000 TeV. More importantly, the observed detection rate of one event every 6.2 days can be reproduced quite well by the simulations, assuming that all cosmic rays were due to iron nuclei (heavy composition). For proton nuclei (light composition) the expected rate would be of one event every 11.6 days.

Hence, for the first time, the rate of these rare events has been satisfactorily reproduced using conventional hadronic-interaction models. However, the large error in the measured rate (50%) prevents us from drawing a firm conclusion on the exact composition of these events, with heavy nuclei being, on average, the most likely candidates. This conclusion is in agreement with the deduced energy of these primaries being higher than 10,000 TeV, a range in which the heavy component of cosmic rays prevails.

The data collected this year will be extremely valuable in performing more detailed analysis using all of the measured variables and different hadronic-interaction models, and will therefore allow further progress in comprehending the origin of high-muon-multiplicity events.

● **Further reading**

CERN Courier July/August 2012 p26, see cerncourier.com/cws/article/cern/50219.

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Sciencewatch

Compiled by John Swain, Northeastern University

Wasp venom targets cancer

If you have an aversion to wasps, it might help to know that the venom from one of them, *Polybia paulista*, offers new hope for cancer treatment. Natália Bueno Leite of São Paolo State University in Brazil and colleagues have found that a peptide in the venom, Polybia-MP1, targets cancer cells selectively while leaving normal ones alone. It acts specifically on an atypical lipid composition in cancer-cell membranes, making holes, which kill the cell. These holes form in seconds, and the general strategy of going after cancer cells based on this difference in lipid structure could form the basis for a completely new class of anticancer drugs.


Attila Fodemesi/Shutterstock

Venom from Polybia paulista *could offer new hope for cancer treatment.*

Further reading

N Bueno Leite *et al.* 2015 *Biophys. J.* **109** 936.

Disappearing circuits

Carbon atoms deposited on graphene via focussed electron-beam-induced deposition (FEBD), making patterns that change with time, enable the creation of circuits that do something one day and something else the next. Songkil Kim of the Georgia Institute of Technology in Atlanta and colleagues were trying initially to clean hydrocarbons from graphene surfaces, when they realised that amorphous carbon created where the beam struck acted as a dopant, making n-type graphene on an initially p-type surface and forming a p–n junction. The patterns that are made change over a timescale of tens of hours. Carbon atoms can also be "frozen" in place by using a laser to turn them into graphite – yet another form of carbon. Potential applications include security, allowing a circuit or data to disappear after a while, or timing the release of pharmaceuticals in medicine.

Further reading

S Kim *et al.* 2015 *Nanoscale* **7** 14946.

Gravity-induced decoherence

In quantum mechanics, you can put an object into a superposition of states for "here" and "there", but we never seem to see those. And we say that there is decoherence, but what causes it? This has been a topic of much debate since the beginning of quantum mechanics.

Now, Igor Pikovksi of the University of Vienna and colleagues offer an idea based on time dilation due to general relativity. The amplitudes for "here" and "there" will, in general, evolve in time at different rates, due the local variations in the gravitational field. Put in the numbers close to Earth, and perhaps surprisingly, the effect is not small, and varies with the square root of the number of particles in an object and inversely with both the temperature and the distance between "here" and "there". For a gram-scale object, and a distance of 1 μm vertically, one gets about a millisecond. The idea could be tested in the near-zero-gravity environment of space.

Further reading

I Pikovski *et al.* 2015 *Nature Phys.* **11** 668.

Cosmology by radio

Measurements of cosmological distance are of great importance, and any new ways of obtaining information other than via redshift analyses would be very welcome. Kiyoshi Wesely Masui and Kris Sigurdson of the University of British Columbia in Vancouver, Canada, have shown that "standard pings" – short broadband radio impulses such as fast radio bursts (FRBs) – could be used to study the 3D clustering of matter in the universe, even without redshift information, using their dispersion as they travel through plasma in space. Dispersion is an imperfect measure of distance, but it is used routinely for pulsars, and redshifts have their own sources of bias. They show that the distortions due to inhomogeneities are calculable, making this new approach promising, and it could be done using forthcoming wide-field radio telescopes.

Further reading

K W Masui and K Sigurdson 2015 *Phys. Rev. Lett.* **115** 121301.

Skintight invisibility cloak

Attempts to produce a Harry Potter-style invisibility cloak have been improving, but they have so far tended to be too bulky to really compare to clothing. Now, Xingjie Ni of the University of California in Berkely and colleagues have shown that they can be made a mere 80 nm thick – just a tenth of the wavelength of the light for which it works – using nano antennas (gold squares on an insulator) to make a metamaterial that bends light around whatever is to be concealed, rendering it invisible. The current device has to be tailored to the structure it hides and cannot conceal all wavelengths, but is a major step towards turning a storybook idea into reality.

Further reading

X Ni *et al.* 2015 *Science* **349** 1310.

Astrowatch

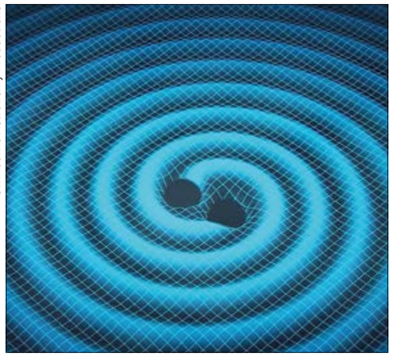
Compiled by Marc Türler, ISDC and Observatory of the University of Geneva, and CHIPP, University of Zurich

Eleven-year search misses gravitational waves

A pair of supermassive black holes (SMBHs) in close orbit around each other are expected to produce gravitational waves. The background "rumble" of gravitational waves resulting from many such systems in the universe should be detectable via precise timing of radio pulsars. But an 11 year search has now failed to detect the predicted signal, suggesting the need to revise current models of black-hole binaries in merging galaxies.

There is observational evidence of the presence of a SMBH – a black hole with a mass of at least one-million solar masses – in almost every spiral galaxy. Therefore, when two galaxies merge, their black holes are thought to be drawn together and to form an orbiting pair (*CERN Courier* November 2015 p17). The separation of the two black holes would then decrease with time, first via interaction with nearby stars and gas, and finally via the emission of gravitational waves.

According to the general theory of relativity, gravitational waves are space–time distortions moving with the speed of light. Precisely 100 years after Einstein's publication, they have not yet been directly detected. Millisecond pulsars offer an indirect way to detect them. Such neutron stars rotate on themselves hundreds of times per second, and produce extremely regular trains of radio pulses (*CERN Courier* November 2013 p11). A gravitational wave passing between the Earth and a millisecond pulsar squeezes and stretches space, changing the distance between them by about 10 m. This changes, very slightly, the time when the pulsar's signals arrive on Earth on a timescale of ~0.1 to 30 years. The method requires precision in the pulse arrival time of the order of 10 ns.


Swinburne Astronomy Productions

Artist's conception of a pair of supermassive black holes in close orbit, sending out gravitational waves as space–time ripples.

Using the 64 m Parkes radio telescope in Australia, scientists monitored 24 millisecond pulsars during 11 years. They focused on four of them having the highest timing precision, but could not find any sign of gravitational waves. The study, published in *Science*, was led by Ryan Shannon from the Commonwealth Science and Industrial Research Organization and the International Centre for Radio Astronomy Research, Australia. It aimed at detecting the stochastic background of gravitational waves resulting from merging galaxies throughout the universe.

The obtained upper limit on the amplitude of the gravitational wave background is below the expectations of current models. A possible explanation of the discrepancy is linked to the environment of the black-hole pairs at the centre of merging galaxies. In the presence of more surrounding gas, the black holes would lose more rotational energy via friction. Their orbit would shrink quicker, therefore shortening the time when gravitational waves are emitted. Another possibility is that the galaxy merger rate is lower than expected.

Whatever the explanation, it means that the detection of gravitational waves by timing pulsars will require more intense monitoring. This has, however, no implications for ground-based gravitational-wave detectors such as Advanced LIGO (the Laser Interferometer Gravitational-Wave Observatory), which look for higher-frequency signals generated by other sources, such as coalescing neutron stars.

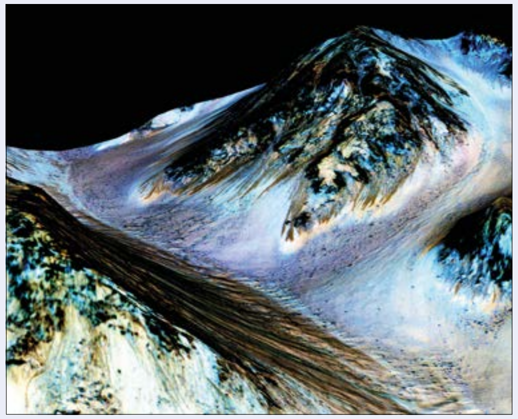
Further reading and weblink

R M Shannon *et al.* 2015 *Science* **349** 1522

www.csiro.au/en/News/News-releases/2015/Eleven-year-cosmic-search-leads-to-black-hole-rethink

Picture of the month

You might already have seen this image in a newspaper or magazine. It illustrated NASA's announcement on 28 September of liquid-water flows on Mars. The evidence comes from dark, narrow streaks on slopes appearing in the Martian summer season, before they fade away during the winter. These "recurring slope lineae" are seen here at the Hale crater as the dark features some 100 m long. The detection of hydrated salts on these slopes corroborates the idea that the streaks are indeed formed by liquid water. The unreal look of the picture betrays a particular processing. Indeed, the image was produced by draping a false colour image – combining infrared, red, and blue/green channels – onto a digital-terrain model of the same site with vertical exaggeration by a factor of 1.5. It is based on observations by the High Resolution Imaging Science Experiment (HiRES) camera on the Mars Reconnaissance Orbiter (Picture of the month, *CERN Courier* November 2013 p11, March 2010 p9, December 2009 p11).


NASA/JPL-Caltech/Univ. of Arizona

Weblink

https://www.nasa.gov/press-release/nasa-confirms-evidence-that-liquid-water-flows-on-today-s-mars

CERN Courier Archive: 1972

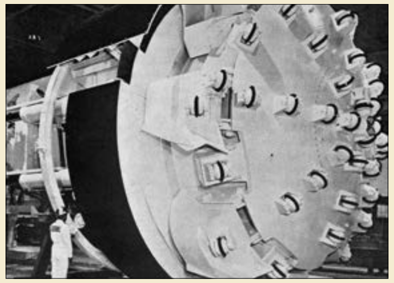
A look back to CERN Courier vol. 12, December 1972, compiled by Peggie Rimmer

Laboratory II

Two years on

Almost two years ago, CERN Council approved the "Programme for the Construction and Bringing into Operation of the CERN 300 GeV Laboratory". The SPS [Super Proton Synchrotron] project has now reached the stage where most of the design work on the accelerator components is complete. Many of the big contracts have been placed. The laboratory buildings are almost ready for occupation. Several of the access shafts to the machine level underground have been dug to their full depth and the boring machine, which will chew its way around the 7 km circumference of the accelerator, is on site ready for action early next year.

● Compiled from texts on pp411–413.


Robbins

A Robbins rotary tunnelling machine, "the mole", of the type that will bore the SPS tunnel.

CERN–France contract signed

On 9 December, after many months of careful preparation, the CERN Directors-General and representatives of the French government once again signed a formal piece of paper. In June […there was…] the signature of an agreement concerning the legal status of the organization in France, referring to a contract concerning land made available to CERN for the development of Laboratory II. It is this contract that was signed at the beginning of December.

A ceremony took place at the Sousprefecture at Gex in the presence of representatives of the government, local authorities and CERN. The Directors-General of CERN thanked the French authorities and spoke about CERN's policy in the region. It is hoped to avoid becoming a foreign enclave and, on the contrary, to become integrated in the life of the region.

The Laboratory II site is largely an open one and a scheme has been worked out for its management. This will involve regular contact with representatives of the local community to determine, for example, the conditions under which farming will be carried out on the site, and care will be taken to preserve the forests with the help of the Office des Forêts.

Another section of the contract concerns linking the two laboratories without passing via the customs posts. A tunnel will be dug underneath the RN 84 to be used by CERN personnel and for transporting equipment.

The contract makes 412 hectares available to CERN at a nominal rent of 100 French francs per year for 92 years. It is linked to the one concerning the use of the ISR site, which came in effect in 1965 and runs for a hundred years.

A contract concerning CERN's use of 412 hectares of land in France was signed at Gex on 9 December by A Alline (Ministère des Affaires Etrangères) on behalf of the French government and, behind him, CERN Directors-General W K Jentschke and J B Adams.

● Compiled from texts on pp417–418.

Rutherford

Computing by telephone

After the "instant commissioning" of the Rutherford Laboratory's large new computer – an IBM 360/195 – at the end of last year, the machine has continued to operate reliably. Most of the software was taken direct from IBM, the laboratory adding a message-transfer system and an interactive terminal file-handling system.

The computer runs on a 24 hour, five-days-a-week schedule with two eight-hour periods at the weekend. About 20% of the computing time is assigned to the Atlas Computer Laboratory, the rest by other than high-energy physicists. The computing load is climbing, however, and round-the-clock operation seven days a week is about to start.

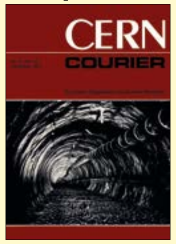
Five satellite computers control a variety of automatic measuring machines, graphics terminals and typewriters, connected through IBM 2701 interfaces by fast data links. In addition, remote workstations (small computer, card reader, line printer) are connected via 2400 baud Post Office-leased telephone lines to a Memorex interface that can handle 24 bisynchronous lines and 72 asynchronous lines. The latter can also be accessed through the PO-switched public telephone network. Centres now connected are Glasgow, Birmingham, Oxford, Imperial College, Durham, Westfield College, CERN, RSRS Slough [Radio and Space Research Station], ATLAS Laboratory and the Institute of Computer Science London.

UK-leased lines at 2400 bits per second cost between £1400 and £3250 per year; the CERN link is of the order of £4000 per year.

"Dial a computer" seems to be with us.

● Compiled from texts on pp421–422.

Compiler's Note



One reason often given for the World Wide Web having been invented at CERN around 1990 was the burgeoning need for the widely scattered high-energy physics community to share information and computing resources; LEP was operational and the LHC was just below the horizon. In fact, the community had been engaged in distributed computing for 20-odd years, employing (and is still employing) a medley of local, regional, research, academic, national and international networks, with communications protocols ranging from the home-grown to (eventually) the internet suite that underpins the web today.

The Sanford Underground Research Facility, where DUNE will study neutrinos produced 1300 km away at Fermilab.

DUNE and its CERN connection

With almost 800 scientists and engineers from 145 institutes in 26 nations, the DUNE experiment is gaining global interest from the neutrino-physics community.

André Rubbia and **Mark Thomson**, co-spokespersons of the DUNE collaboration.

The Deep Underground Neutrino Experiment (DUNE) is a next-generation long-baseline neutrino-oscillation experiment, currently under review by the US Department of Energy (DOE). DUNE has a potentially game-changing scientific programme for neutrino physics.

The DUNE collaboration came together in response to the US P5 report on the "Strategic Plan for US Particle Physics in the Global Context", published in 2014, and the recommendations of the European Strategy for Particle Physics to freeze the development of neutrino beams at CERN. The P5 report called for the previously US-dominated LBNE experiment to be reformulated as a truly international scientific endeavour, incorporating the scientific goals and expertise of the worldwide neutrino-physics community, in particular those developed by LBNO in Europe. As a result, the international DUNE collaboration was formed and structured following a model that was successfully adopted by the LHC experiments.

The DUNE collaboration currently consists of almost 800 scientists and engineers from 145 institutes in 26 nations. The rapid development of this large collaboration is indicative of the global interest in neutrino physics and the innovative science made possible with the DUNE near and far detectors and the proposed Long-Baseline Neutrino Facility (LBNF) at Fermilab. The strong partnership between the US DOE and CERN already established in the LHC programme is also one of the essential components for the success of DUNE/LBNF. Construction of the CERN facility that will host two large-scale DUNE prototype detectors and a test beam has already begun.

So what is DUNE/LBNF? LBNF is a new 60–120 GeV beamline at Fermilab that can produce either an intense beam of muon neutrinos or antineutrinos. The initial beam power will be 1.2 MW (compared with the maximum planned for Fermilab's existing NuMI beam of 700 kW for the NOvA experiment). This is just the first step for LBNF and the beam is being designed to be upgradable to at least 2.4 MW.

The neutrino beam will be directed towards a near and a far detector. DUNE's far detector will be located 1.5 km underground at the Sanford Underground Research Facility (SURF) in South Dakota. Neutrinos will travel a distance of 1300 km through the Earth's crust, therefore allowing the neutrino flavours to oscillate. The DUNE far detector consists of four 10 kton (fiducial) liquid-argon time projection chambers (LAr-TPCs). ▷

DUNE Collaboration

Some of the almost 800 members of the DUNE collaboration.

These detectors are very large – each will be approximately 62 × 15 × 14 m. The advantage of the LAr-TPC technology is that it allows 3D bubble-chamber-like imaging of neutrino interactions (or proton decay) in the vast detector volume. The DUNE near detector on the Fermilab site will observe the unoscillated neutrino beam, providing constraints on experimental uncertainties. By the standards of neutrino physics, the near-detector event rates are incredible – it will detect hundreds of millions of neutrino interactions. This will enable a diverse and world-leading neutrino-physics programme.

DUNE/LBNF has a broad and comprehensive scientific programme – it aims to make groundbreaking discoveries such as CP violation in the neutrino sector and measuring the corresponding CP phase. Because of the long baseline, DUNE will also conclusively determine the neutrino-mass ordering (normal versus inverted hierarchy). The sensitivity to the mass hierarchy arises because the neutrinos traverse 1300 km of matter (as opposed to antimatter). These "matter effects" imply that the oscillations of muon neutrinos to electron neutrinos are expected to differ from those of the corresponding process for antineutrinos, independent of CP violation. DUNE will measure both CP violation and the mass hierarchy in a single experiment by utilising a wide-band beam so that the oscillations can be measured as a function of neutrino energy (covering both first- and second-oscillation maxima). One of the advantages of a LAr-TPC is that it acts as a totally active calorimeter where the energy deposits from all final-state particles are detectable, resulting in an excellent neutrino-energy measurement over the broad range of energies needed to study the first- and second-oscillation maxima. In general, the large event samples of muon neutrino/antineutrino interactions (in the disappearance channel) and electron neutrino/antineutrino interactions (in the appearance channel) will enable neutrino oscillations to be probed with unprecedented precision, providing a test of the current three-flavour neutrino paradigm – there may yet be surprises lurking in the neutrino sector.

CERN is playing a crucial role in prototyping the DUNE far detector.

DUNE is not only about neutrinos. The large far detector with bubble-chamber-like imaging capability, located deep underground, provides an opportunity to search for proton decay. In particular, DUNE is able to search for proton-decay modes with kaons (such as the $p \to K^+$ antineutrino), which are favoured in many SUSY scenarios. The clear topological and ionisation (dE/dx) signature of these decay modes allows for a near-background-free search – a significant advantage in capability over large water Cherenkov detectors. Furthermore, DUNE will provide unique capabilities for the observation of neutrinos from core-collapse supernova bursts (SNBs). While water Cherenkov detectors are primarily sensitive to electron antineutrinos from SNBs, DUNE is mostly sensitive to the electron neutrinos. This would enable DUNE to directly observe the neutron-star-formation stage ($p + e^- \to n + \nu_e$) in "real time", albeit delayed by the time that it takes for neutrinos to reach the Earth – this would be a truly remarkable observation. There is even the possibility to observe the formation of a black hole as a sharp cut-off in the time spectrum of the SNB neutrinos, if the black hole were to form a few seconds after the stellar-core collapse.

CERN's role

CERN is playing a crucial role in prototyping the DUNE far detector and in the detailed understanding of its performance. Following the recommendations of the European Strategy document, CERN has set up a programme to fulfil the needs of large-scale neutrino-detector prototyping. In the framework of this programme, a new neutrino "platform" is being brought to light in the North Area. The new CERN facility will be available for experiments in the autumn of 2016 and will include a 70 m extension of the EHN1 experimental hall, which will host the large experimental apparatus and expose them to charged-particle test beams. The plan is to operate the first charged-particle beams in 2017 after the civil engineering and infrastructure work needed to upgrade the experimental hall has been completed.

To deliver the DUNE far detector requires the LAr-TPC technology to be scaled up to an industrial scale. The CERN platform will support the development of the single-phase and dual-phase liquid-argon technologies that are being considered on a large scale for the DUNE far detectors. In the single-phase approach, the ionisation electrons produced by charged particles are drifted towards read-out wire planes in the liquid-argon volume. In the dual-phase approach, the ionisation electrons are amplified in gaseous argon above the liquid surface and then read out. The

CERN

The 70 m extension of the EHN1 experimental hall, which will host the experimental apparatus.

CERN platform will host two large-scale prototypes for the DUNE far detector – ProtoDUNE and WA105.

ProtoDUNE is the engineering prototype for the single-phase far-detector design currently planned for the first 10 kton far-detector module. ProtoDUNE is based on the pioneering work carried out for the ICARUS detector operated at the Gran Sasso underground laboratory. The ICARUS detector, with its 600 tonnes of liquid argon, took data from 2010 to 2012. It demonstrated that a liquid-argon TPC detector can provide detailed images of charged particles and electromagnetic showers, with excellent spatial and calorimetric resolution. ICARUS also demonstrated the long-term stability of the LAr-TPC concept.

The WA105 demonstrator will be based on the novel dual-phase liquid-argon time projection chamber that was developed by the European LAGUNA-LBNO consortium, with R&D efforts located at CERN for more than a decade. The dual-phase approach, which offers potential advantages over the single-phase read-out, is being considered by DUNE for one or more of the DUNE far-detector 10 kton modules. The WA105 collaboration is currently building a smaller-scale 25 tonne prototype at CERN, to be operated in 2016. The larger 300 tonne WA105 demonstrator should be ready for test beam by 2018 in the EHN1 extension of the North Area at CERN.

The goal of these prototypes is to validate the construction techniques that will be adopted for the deep-underground installation at SURF, and to measure the performance of full-scale modules. In addition, the EHN1 test beams will provide the unique capability to collect and analyse charged-particle data necessary to understand the response of these detectors, with the high precision required for the DUNE science programme. The CERN neutrino platform will also serve additional R&D efforts, in particular for the DUNE near detector, where the current design utilises a straw-tube tracking chamber (inspired by the earlier NOMAD experiment at CERN), but other options, such as a high-pressure gaseous-argon TPC, are being studied.

The DUNE/LBNF scientific programme has broad support from partners in the Americas, Asia and Europe, and the collaboration is expected to grow. Progress in the last year has been rapid; DUNE/LBNF produced a four-volume Conceptual Design Report (CDR) in July 2015, detailing the design of the DUNE near and far detectors and the design of LBNF, which encompasses both the new neutrino beamline at Fermilab and civil facilities for the DUNE detectors. The CDR was a crucial element of the DOE CD-1 review of the cost range for the project. DUNE/LBNF is currently seeking DOE CD-3a approval for the underground excavation of the far-site facility that would host the four far-detector modules. The timescales are relatively short, with the start of the excavation project planned for 2017 and installation of the first far-detector module planned to start in 2021, with first commissioning for physics starting soon after. The strong role of CERN in this programme is crucial to its success.

- For further details, see lbnf.fnal.gov and www.dunescience.org.

Résumé

DUNE : un partenariat avec le CERN

Forte de près de 800 scientifiques et ingénieurs issus de 145 instituts dans 26 pays, l'expérience DUNE suscite un grand intérêt au niveau mondial dans la communauté de la physique des neutrinos. Le développement rapide de cette grande collaboration manifeste l'intérêt au niveau mondial pour la physique des neutrinos et pour la science innovante qui sera réalisée par les détecteurs proches et lointains de DUNE, et par l'installation neutrino longue distance (LBNF) au Fermilab. Le partenariat entre le ministère de l'énergie des États-Unis et le CERN, déjà solidement établi dans le cadre du programme LHC, est un aspect essentiel du succès de DUNE/LBNF.

Penetrating and puzzling: photons shed light on heavy-ion collisions

The light shining from high-energy collisions of heavy nuclei reveals unique information on quark–gluon plasma. However, several puzzling questions remain.

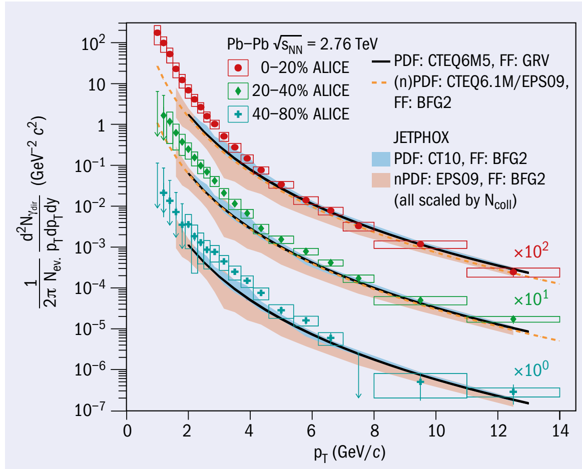
Klaus Reygers, Physikalisches Institut, Universität Heidelberg.

Quark–gluon plasma (QGP) is a thermalised state of matter at extreme temperatures consisting of deconfined quarks and gluons. Because the mean free path length of energetic photons is much larger than the size of the hot nuclear medium in which they are produced, they provide unscathed and direct information on the thermodynamic state of the QGP. In contrast to photons, hadrons that are produced after the QGP has cooled off to a temperature of about 1.8×10^{12} K ($k_B T = 155$ MeV) mostly reflect the properties of the hadronic phase and carry only indirect information about the preceding QGP phase.

The role of direct photons

Photons are emitted over the entire duration of a heavy-ion collision via various production mechanisms. First, direct photons are distinguished from photons originating from the decay of neutral mesons, which constitute the background in the direct-photon measurement. Prompt direct photons are produced in initial hard-parton scatterings, prior to the formation of a QGP, and dominate the photon spectrum at large values of the transverse momentum (p_T), beyond 4 GeV/c. Because photons do not interact with the medium, their yield, well described by perturbative quantum chromodynamics (pQCD), directly reflects the rate of initial hard-scattering processes. By contrast, the yield of high-p_T hadrons is suppressed, an observation interpreted as the result of the energy lost in the QGP by quarks and gluons produced in hard-scattering processes. The interpretation of this effect, known as "jet quenching", strongly relies on the observation that direct photons at high p_T are not suppressed.

Thermal direct photons are produced in the QGP and in the subsequent hadron gas. They are expected to give a significant contribution at low p_T ($1 < p_T < 3$ GeV/c), convey information about the QGP temperature, and provide a test for models of the space–time evolution of a heavy-ion collision. For a given temperature, the spectrum of thermal photons falls off exponentially with transverse momentum, so that the temperature of the photon source can be read off from the slope. This is similar to the determination of the temperature of a red-hot heating element, or the surface of the Sun, based on the emitted thermal photon radiation. Note, however, that unlike in these examples, the photons from the QGP and the hadron gas are not in thermal equilibrium with the surrounding medium. In heavy-ion collisions, the thermal photon spectrum is an effective average over the different volume elements in the QGP and the hadron gas at different temperatures. However, during the latter stages of the collision, volume elements move with considerable velocity towards the detector. The resulting blue-shift of the spectrum leads to an apparent temperature that can be as large as twice the actual temperature of the source. Determining the initial QGP temperature therefore relies on comparison with models such as the hydrodynamic description of the evolution of heavy-ion collisions, which has proved to be very successful for hadrons. Being produced at all stages of the collisions, low-p_T direct photons therefore provide an independent constraint for these models.



Direct-photon spectra in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for three centrality classes (0–20%, scaled by a factor 100; 20–40%, scaled by a factor 10; and 40–80%) measured by the ALICE collaboration. For $p_T > 4$ GeV/c, the data agree with direct-photon production from initial hard parton–parton scatterings, as calculated by perturbative QCD calculations. At lower p_T, most notably in central collisions (0–20%), there seems to be a direct-photon signal that is not accounted for by the perturbative QCD calculation. These extra photons might be related to thermal photons from the QGP and the subsequent hadron gas.

The ALICE experiment and experiments at RHIC have measured two distinct features of direct photons: their yield and their azimuthal anisotropy as a function of p_T. ALICE has measured the direct-photon spectrum in central-to-peripheral Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV (see figure opposite). For $p_T > 4$ GeV/c, the spectrum agrees with the expectation for direct-photon production in initial hard-parton scatterings, as calculated by pQCD. At lower p_T, most notably in central Pb–Pb collisions, there appears to be an additional source of (most likely) thermal photons from the QGP and the hadron gas. State-of-the-art hydrodynamic models agree with the measured direct-photon spectra within uncertainties; however, they tend to under-predict the central values of the measurement. For the direct-photon spectrum measured in central Au–Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC, the differences between measurements and predictions become more prominent.

Anisotropies as puzzling as yields

Even more surprising, azimuthal anisotropies of low-p_T direct photons measured in heavy-ion collisions were found to be much larger than predicted by hydrodynamic models. The anisotropies are a consequence of the approximately almond-shaped overlap zone of the two nuclei in non-central collisions. This gives rise to a variation of pressure gradients as a function of the azimuthal angle. As a consequence, azimuthally dependent collective flow velocities develop as the system expands, and give rise to the experimentally observed elliptic flow, an azimuthal variation of hadron yields. This is quantified by a Fourier coefficient, $v_2(p_T)$. Taking into account the fact that collective flow fields take time to build up, and that photon production is dominated by photons from the early hot QGP phase, the azimuthal anisotropy v_2 of direct photons at low p_T was expected to be smaller than that of hadrons. The PHENIX experiment at RHIC, however, measured v_2 values similar to the values of hadrons. ALICE seems to confirm this observation. These measurements could indicate that thermal photons from the late hadron gas phase outshine photons from the early QGP.

The observation that models under-predict both the thermal photon spectrum and the v_2 is puzzling, and is one of the most pressing challenges for our understanding of heavy-ion collisions. The puzzle is currently more apparent in Au–Au collisions at RHIC, with much less of a tension in Pb–Pb collisions at the LHC. Its solution could be related to the hydrodynamic modelling of the space–time evolution of heavy-ion collisions, or to the theoretical description of photon production. It could also point to so-far-unknown photon production mechanisms. Many new theoretical ideas have recently been put forward in this direction. Until this puzzle is solved, the question about the role of thermal photons remains open: are they messengers of the QGP, or are thermal photons from the QGP only a small contribution buried under photons produced much later in the hadron gas? An answer is eagerly awaited.

● For further details, see arxiv.org/abs/1509.07324 and arxiv.org/abs/1212.3995, ALICE Collaboration; arxiv.org/abs/1405.3940 and arxiv.org/abs/1509.07758, PHENIX Collaboration.

Résumé

Les émissions de photons éclairent les collisions d'ions lourds

La lumière émise dans des collisions à haute énergie de noyaux lourds révèle des informations uniques sur le plasma quark-gluon.

CERN Courier December 2015
Astrophysics

A close look at the world's largest astronomical project

Eight years after their first visit to ALMA's site in Chile, CERN's **Paola Catapano** and **Mike Struik** pay a second visit to the experimental site and its 66 antennas, now in operation.

Paola Catapano, with photos and videos by **Mike Struik**, CERN.

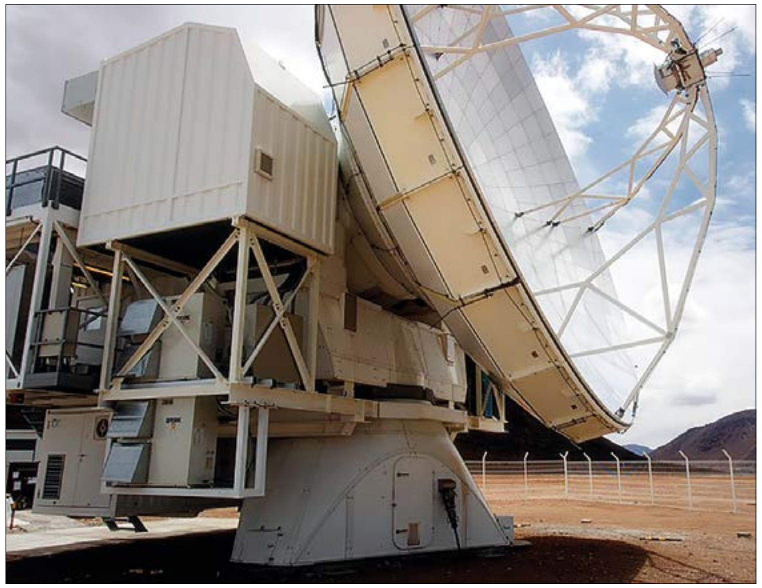
Chajnantor highlands, Chile, 5100 m above sea level. Winding up through the *Echinopsis atacamensis* – a rare species of centennial cacti that grows only at altitudes between 3200 and 3800 m – the 12 m-wide road to the top has not changed since my last visit to the plateau eight years ago, nor has the magnificent backdrop of the snow-capped Andean volcanoes. It's only at the last checkpoint, at 41 km, that I catch the first glimpse of the shiny white discs of the ALMA array. What an extraordinary emotion. The once flat, huge and literally desert site is now studded with 66 giant parabolic antennas surrounding the point once marked as the Centre of Array (COFA, see photo bottom right). The mark is still there, but ALMA today is no longer just a video animation, although its 66 antennas still look unreal against the backdrop of the thin transparent air at 5100 m. Currently in an intermediate configuration, the antennas are designed to be moved from compact to long baseline, with a maximum extension of 16 km.

Reconciliation with the cosmos

Chajnantor is probably the only place on the planet that could offer such a vast, flat and dry space at this altitude. In the indigenous "kunza" language, still spoken by the Atacameños population in the San Pedro area, Chajnantor means "the place of departure, of reconciliation with the cosmos." No better name could have been chosen for the site that now hosts this revolutionary astronomical observatory, the most advanced and powerful array of high-precision antennas searching for our cosmic origins from their solid feet on the planet. ALMA is the only instrument offering the high sensitivity and spectral resolution – 10 times better than the Hubble Space Telescope's – needed to catch the faint radio waves emitted by the cold and so-far-invisible regions of our universe. These submillimetre and millimetre radio waves are impossible to observe with optical telescopes. "These signals come from multiple physical processes," explains Daniel Espada, shift leader at the time of my visit to the observatory in July. "One of these is molecules, originating from molecular transitions in the cold area of the universe, which have a little bit of energy. In some regions, we can see this primordial material, essential to life, which enables us to understand their composition. These molecules travel and

All images: Mike Struik, CERN



Left, from top to bottom: Echinopsis atacamensis*, the protected cacti species that grows at altitudes between 3200 and 3800 m; physicist David Rabanus by the "cold heart" of one of ALMA's antennas; Apex, the first ALMA antenna to be installed. Right, from top to bottom: Aerial photograph of the ALMA site today; the ALMA Operations Support Facility, at 2900 m, under construction in 2007; Laura Ventura, ESO communications, and Paola Catapano stand by the COFA (Centre Of Array), as it is today.*

radiate, and we can observe them and learn about some of their properties, including temperature density. ALMA allows us to perform high-precision studies on the properties of the interstellar dust, which is key to understanding how the energy of a galaxy is emitted." "Nobody had ever observed those frequencies with such sensitivity," adds astronomer Gianni Marconi, one of the permanent ESO staff on the project. "Since four years, anything ALMA has observed is a press release, because nobody had ever observed those things before. They're all firsts."

Amazing performance

Indeed, all of the objectives set for ALMA are being achieved, one after the other, since it began operation for science in 2011, while the array was still under completion. Among its most striking "firsts", we all remember the discovery, in 2012, of glycolaldehyde, in the vicinity of a sun-like star (*CERN Courier* October 2012 p13). This simple sugar molecule is one of the ingredients in the formation of ribonucleic acid. Its discovery showed that some of the building blocks of life existed in this system at the time of planet formation. The high sensitivity of ALMA — even at the technically challenging shortest wavelengths at which it operates — was instrumental for these observations, which were made with a partial array of antennas during the observatory's science-verification phase.

Another primary scientific goal of ALMA was the observation of primordial galaxies, and it did so with just a bunch of antennas, in its compact configuration. The discovery was announced on the day of its official inauguration in March 2013. "By using the gravitational lensing technique," explains Marconi, "we could shed light on 26 of the universe's most primordial galaxies, where vast reservoirs of dust and gas are converted into new stars, at the pace of 10,000 per year." The study concluded that these starburst galaxies are much more abundant, much further (about 12 billion light-years) and quite older (one-billion years) than previously assumed. Astronomers observed their formation as it started, two-billion years after the Big Bang. One of the galaxies discovered was already in existence a mere one-billion years after the birth of the universe, its light travelling the length of the cosmos since that time.

Since late 2014, ALMA has been experimenting with its very-long-baseline interferometry, using 22–36 antennas arranged with a baseline of up to the maximum 16 km. The resolution ▷

The ALMA Control Room in 2007.

Sunset over ALMA's Operations Support Facility, at 2900 m.

obtained with such an extended configuration is equivalent to that of a telescope as large as 15 km in diameter. Such a resolution enabled ALMA, among other things, to observe, for the first time, the existence of an incredibly powerful magnetic field in the close vicinity of the event horizon of a supermassive black hole in the centre of a distant galaxy (*CERN Courier* June 2015 p12). "Up to now, only weak magnetic fields several light-years (and not days) far from black holes had been probed," confirms Marconi. Daniel Espada's favourite record among such an impressive series of "firsts" is another recent one, made by ALMA in its almost final configuration (54 antennas). "The most spectacular result, for me, is the unprecedented observation of proto-planetary systems," says Espada. "Seeing the formation of a planet-forming disc around a young star, basically a solar system like ours, live, as it happens, was an incredible breakthrough and left all of us astounded."

In the recently published images of the discovery of a proto-planetary system in our Galaxy, about 450 light-years away, astronomers could clearly identify dust and gas gradually forming into planets and asteroids, in the same way as it happened to Saturn's rings or even to our own solar system, a few billion years ago. The picture (*CERN Courier* January/February 2015 p15) is so far the sharpest ever made at submillimetre wavelengths, with a resolution exceeding Hubble's, and started "a new era in our exploration of the formation of stars and planets, and could revolutionise theories of planetary formation", as Tim de Zeeuw, Director-General of ESO, declared in the press release. "We now know for sure our solar system is not alone," comments Daniel.

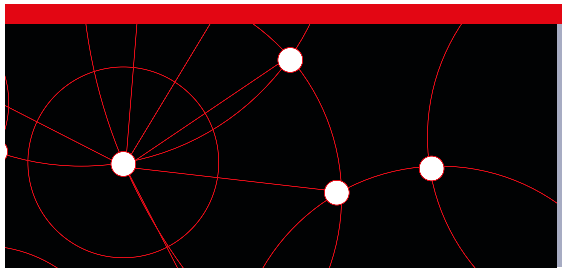
What does this dream instrument have in store for the near future? Astronomers agree that with ALMA's capacity, everything is possible – the expected and the unexpected. "ALMA can observe the entire sky, we can follow the ecliptic of our solar system, we can observe our Galaxy, we see the Santiago trail, we can observe beyond our Galaxy and anywhere else in the sky. We can also observe the composition of the atmosphere of planets and satellites near Earth. Together with optical telescopes, we're looking for planets similar to Earth. We might not encounter other forms of life on these other planets, but we can observe their main characteristics and the atmosphere," concludes Espada, before getting ready for his night shift, while I remain speechless in the extraterrestrial light of yet another out-of-this-world sunset over the Atacama desert.

Watch the video interviews with David Rabanus at cds.cern.ch/record/2062981 and cds.cern.ch/record/2062982.

Résumé

Pleins feux sur le plus grand projet astronomique du monde

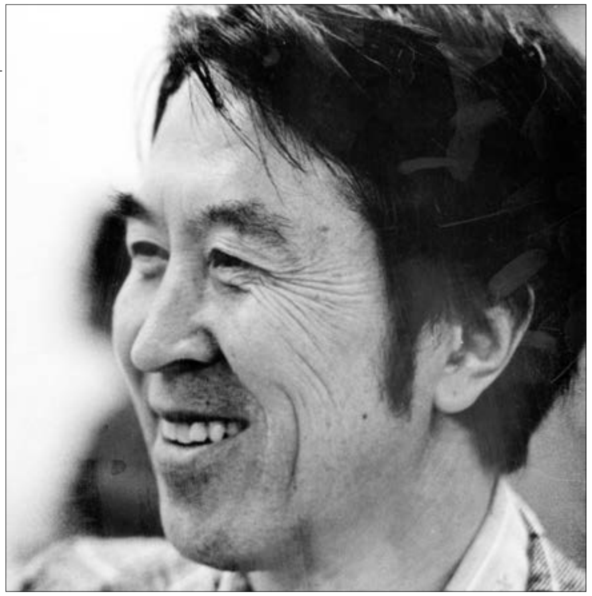
Huit ans après leur première visite sur le site d'ALMA, au Chili, Paola Catapano et Mike Struik, du CERN, reviennent sur les lieux pour découvrir les 66 antennes désormais en service. La résolution obtenue, grâce à l'ampleur de l'installation, est équivalente à celle d'un télescope de 15 km de diamètre. Tous les objectifs fixés pour ALMA sont en train d'être atteints, l'un après l'autre. L'installation a commencé à être exploitée pour la science en 2011, avant son achèvement. Que peut-on attendre de cet instrument exceptionnel ? Pour les astronomes, étant donné les capacités d'ALMA, tout est possible : le prévu, et l'imprévu.



Yoichiro Nambu: breaking the symmetry

Two prominent scientists mentored by him recall the work and personality of Nobel laureate Yoichiro Nambu, who passed away in July this year.

Sumit R Das, university research professor and chair of physics and astronomy, the University of Kentucky, US, and **Spenta R Wadia**, founding director and professor emeritus, the International Centre for Theoretical Sciences of TIFR, Bangalore, India.



Spenta Wadia

Yoichiro Nambu.

Yoichiro Nambu passed away on 5 July 2015 in Osaka. He was awarded the Nobel Prize in Physics in 2008 "for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics". Nambu's work in theoretical physics spanning more than half a century is prophetic, and played a key role in the development of one of the great accomplishments of 20th century physics – the Standard Model of particle physics. He was also among those who laid the foundations of string theory.

The early years

When Nambu graduated from the University of Tokyo in 1943, Japan was in the midst of the Second World War – but at the same time, Japanese physics was extremely vibrant. Among other things, a group of superb Japanese physicists were developing the framework of quantum field theory. This spark came from the work of Hideki Yukawa in the 1930s, who laid the foundations of modern particle physics by his prediction that the force between nucleons inside a nucleus is caused by the exchange of a particle (today called the pion) that, unlike the photon, had a mass. Yukawa showed that this results in a force that dies out quickly as the distance between the nucleons is increased, as opposed to electromagnetic forces, caused by a massless photon, which have infinite range. Yukawa was Japan's first Nobel laureate, in 1949. Soon afterwards, Japan became a powerhouse of particle physics and quantum field theory. In 1965, Sin-Itiro Tomonaga received the Nobel prize (shared with Richard Feynman and Julian Schwinger) for his work on the quantum field theory of electromagnetism.

In 1948, Nambu joined a select group of theoretical physicists at the newly formed department at Osaka City University. He spent three formative years there: "I had never felt and enjoyed so much the sense of freedom." Much of his early work dealt with quantum field theory. One influential paper dealt with the derivation of the precise force laws in nuclear physics. In the process, he derived the equation that describes how particles can bind with each other – an equation that was later derived independently by Bethe and Salpeter, and is now known commonly as the Bethe–Salpeter equation.

Nambu always felt that his work in physics was guided by a philosophy – one that was uniquely his own. During his years in Osaka, he was deeply influenced by the philosophy of Sakata and Taketani. Sakata was yet another prominent theoretical physicist in Japan at that time: he later became well known for the Sakata model, which was a precursor to the quark model of nuclear constituents. Sakata was influenced by Marxist philosophy, and together with Taketani developed a "three-stage methodology" in physics. As Nambu recalled later, Taketani used to visit the young group of theorists at Osaka and "spoke against our preoccupation with theoretical ideas, emphasised to pay attention to experimental physics. I believe that this advice has come to make a big influence on my attitude towards physics". Together with colleagues Nishijima and Miyazawa, he immersed himself in understanding the properties of the newly discovered elementary particles called mesons. ▷

Spenta Wadia

Nambu at the Belur temple, Bangalore, in 1983.

In 1952, J R Oppenheimer invited Nambu to spend a couple of years at the Institute of Advanced Study in Princeton. By his own account, this was not a particularly fruitful period: "I was not very happy." After a summer at Caltech, he finally came to the University of Chicago at the invitation of Marvin Goldberger. There he became exposed to a remarkably stimulating intellectual atmosphere, which epitomised Fermi's style of "physics without boundaries". There was no "particle physics" or "physics of metals" or "nuclear physics": everything was discussed in a unified manner. Nambu soon achieved a landmark in the history of 20th century physics: the discovery that a vacuum can break symmetries spontaneously. And he came up with the idea while working in a rather different area of physics: superconductivity.

Symmetries of the laws of nature often provide guiding principles in physics. An example is "rotational symmetry". Imagine yourself to be in deep space, so far away from any star or galaxy that all you can see in any direction is empty space. Things look completely identical in all directions – in particular, if you are performing an experiment, the results would not depend on if you rotated your lab slowly and did the same thing. It is this symmetry that leads to the conservation of angular momentum. Of course, the rotational symmetry is only approximate, because there are stars and galaxies that break this symmetry explicitly.

There are other situations, however, where a symmetry is broken spontaneously. One example is a magnet. The molecules inside a magnet are themselves little magnetic dipoles. If we switch on a small magnetic field, then the rotational symmetry is broken explicitly and all of the dipoles align themselves in the direction of the magnetic field. That is simple. The interesting phenomenon is that the dipoles continue to be aligned in the same direction, even after the external magnetic field is switched off. Here the rotational symmetry is broken spontaneously.

Nevertheless, the fact that the underlying laws respect rotational symmetry has a consequence: if we gently disturb one of the dipoles from its perfectly aligned position, it gently nudges its neighbours and they nudge their neighbours, and the result is a wave that propagates through the magnet. Such a wave has very low energy and is called a spin wave. This is a special case of a general phenomenon where a spontaneously broken symmetry has an associated low-energy mode, or in quantum theory an associated massless particle.

Breaking symmetry

Nambu took the concept of spontaneous symmetry breaking to a new level. He came up with this idea while trying to understand the Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity. Superconductors are materials that conduct electric current without any resistance. Superconductors also repel external magnetic fields – an effect called the Meissner effect. Inside a superconductor, electromagnetic fields are short-ranged rather than long-ranged: as if the photon has acquired a mass, like Yukawa's mesons. However, a massive photon appears to be inconsistent with gauge invariance – a basic property of electromagnetism.

It was Nambu in 1959, and independently Philip Anderson a little earlier in 1958, who understood what was going on. They realised that (in the absence of electromagnetic interactions) the superconducting state broke the symmetry spontaneously. This symmetry is unlike the rotation symmetry that is spontaneously broken in magnets or crystals. It is a symmetry associated with the fact that electric charge is conserved. Also, if we imagine switching off the electromagnetic interaction, this symmetry breaking would also result in very low-energy waves, like spin waves in a magnet – a massless particle. Now comes a great discovery: if we switch on the electromagnetic interaction, which is there, we can undo the apparent symmetry breaking by a gauge transformation, which is local in space (and time), without any energy cost. Hence, there is no massless particle, and in fact the photon becomes massive together with a massive neutral particle, which explains the Meissner effect. The neutral scalar excitation in superconductors was discovered 20 years after it was predicted. This effortless excursion across traditional boundaries of physics characterised Nambu's work throughout his career.

Soon after finishing his work on superconductivity, Nambu returned to particle physics. The first thing he noticed was that the Bogoliubov equations describing excitations near the Fermi surface in a superconductor are very similar to the Dirac equation that describes nucleons. The energy gap in a superconductor translates to the mass of nucleons. The charge symmetry that is spontaneously broken in a superconductor (electromagnetism switched off) also has an analogue – chiral symmetry. If the energy gap in a superconductor is a result of spontaneous symmetry breaking of charge symmetry, could it be that the mass of a nucleon is the result of spontaneous symmetry breaking of chiral symmetry? Unlike the charge symmetry in a superconductor, chiral symmetry is a global symmetry that can be truly spontaneously broken, leading to a massless particle – which Nambu identified with the pion. This is exactly what Nambu proposed in a short paper in 1960, soon followed by two papers with Jona-Lasinio.

There are situations where spontaneous symmetry breaking can happen in the vacuum of the world.

This was a revolutionary step. In all previous examples, spontaneous symmetry breaking happened in situations where there were constituents (the molecular dipoles in a magnet, for example) and the underlying laws did not permit them to arrange themselves maintaining the symmetry. Nambu, however, proposed that there are situations where spontaneous symmetry breaking can happen in the vacuum of the world.

In physics, vacuum is the name given to "nothing". How can a symmetry be broken – even spontaneously – when there is nothing around? The radical nature of this idea has been best described by Phil Anderson: "To me – and perhaps more to his fellow particle theorists – this seemed like a fantastic stretch of imagination. The vacuum, to us, was and always had been a vacuum – it had, since Einstein got rid of the aether, been the epitome of emptiness…I, at least, had my mind encumbered with the idea that if there was a condensate, there was something there…This is why it took a Nambu to break the first symmetry."

Nambu was proposing that the masses of elementary particles have an origin – something we can calculate. The revolutionary nature of this idea cannot be overstated. Soon after the papers of Nambu and Jona-Lasinio, Goldstone came up with a simpler renormalisable model of superconductivity, which also illustrates the phenomenon of spontaneous symmetry breaking by construction and provided a general proof that such symmetry breaking always leads to a massless particle.

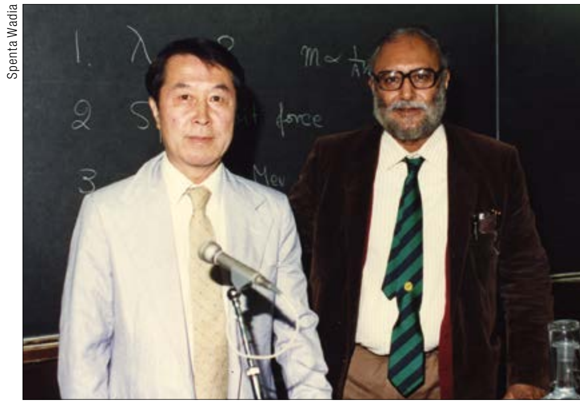
Meanwhile, in 1963 Anderson realised that the mechanism of generating masses for gauge particles that was discovered in superconductivity could be useful in elementary particle physics in the context of the nature of "vacuum of the world". The mechanism was subsequently worked out in full generality by three independent groups, Higgs, Englert and Brout, and Guralnik, Hagen and Kibble, and is called the "Higgs mechanism". It became the key to formulating the Standard Model of particle physics by Weinberg and Salam, building on the earlier work of Glashow, and resulting in our current understanding of electromagnetic and weak forces. The analogue of the special massive state in a superconductor is the Higgs particle, discovered at CERN in 2012.

We now know, for certain, that chiral symmetry is spontaneously broken in strong interactions. However, the final realisation of this idea had to wait until another work by Nambu.

The idea that all hadrons (particles that experience strong forces) are made of quarks was proposed by Gell-Mann, and independently Zweig, in 1964. However, the idea soon ran into serious trouble.

Now, the quarks that make up nucleons have spin ½. According to the spin-statistics theorem, they should be fermions obeying the exclusion principle. However, it appeared that if quarks are indeed the constituents of all hadrons, they cannot at the same time be fermions. To resolve this contradiction, Nambu proposed that quarks possess an attribute that he called "charm" and is now called colour. In his first proposal, quarks have two such colours. Subsequently, in a paper with M Y Han, he proposed a model with three colours. Two quarks may appear identical (and therefore cannot be on top of each other) if their colour is ignored. However, once it is recognised that their colours are different, they cease to be identical, and the usual "exclusion" of fermions does not apply. A little earlier, O Greenberg came up with another resolution: he postulated that quarks are not really fermions but something called "para-fermions", which have unconventional properties that are just right to solve the problem.

Spenta Wadia



Nambu and Abdus Salam at ICTP (Trieste, Italy) in 1986.

However, it was Nambu's proposal that turned out to be more fruitful. This is because he made another remarkable one: colour is like another kind of electric charge. A quark not only produced an ordinary electric field, but a new kind of generalised electric field. This new kind of electric field causes a new kind of force between quarks, and the energy is minimum when the quarks form a colour singlet. This force, Nambu claimed, is the basic strong force that holds the quarks together inside a nucleon. This proposal turned out to be essentially correct, and is now known as quantum chromodynamics (QCD). In the model of Han and Nambu, quarks carry integer charges, which we now know is incorrect. In 1972, Fritzsch and Gell-Mann wrote down the model with correct charge assignments and proposed that only colour singlets occur in the spectrum, which would ensure that fractionally charged quarks remain unobserved. However, it was only after the discovery by David Gross, Frank Wilczek, and David Politzer in 1973 of "asymptotic freedom" for the generalised electric field that QCD became a candidate theory of the strong interactions. It explained the observed scaling properties of the strong interactions at high energies (which probe short distances) and indicated that the force between quarks had a tendency to grow as they were pulled apart.

Simple dynamical principle

String theory, which is recognised today as the most promising framework of fundamental physics including gravity, had its origins in making sense of strongly interacting elementary particles in the days before the discovery of asymptotic freedom. To make a long story short, Nambu, Nielsen and Susskind proposed that many mathematical formulae of the day, which originated from Veneziano's prescient formula, could be explained by the hypothesis that the underlying physical objects were strings (one-dimensional objects) rather than point particles. This was a radical departure from the "Newtonian" viewpoint that elementary laws of nature are formulated in terms of "particles" or point-like constituents. ▷

CERNCOURIER

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IOP Publishing

Obituary

Nambu (and independently Goto) also provided a simple dynamical principle with a large local symmetry for consistent string propagation. His famous paper on the string model entitled "Duality and hadrodynamics" was submitted to the Copenhagen High Energy Physics Symposium in 1970. In a letter dated 4 September 1986, to one of us (SRW), Nambu wrote: "In August 1970, there was a symposium to be held in Copenhagen just before a High Energy Physics Conference in Kiev, and I was planning to attend both. But before leaving for Europe, I set out to California with my family so that they could stay with our friends during my absence. Unfortunately our car broke down as we were crossing the Great Salt Lake Desert, and we were stranded in a tiny settlement called Wendover for the three days. Having missed the flight and the meeting schedules, I cancelled the trip in disgust and had a vacation in California instead. The manuscript, however had been sent out to Copenhagen, and survived."

It is quite common for scientists to become excessively attached to their own creations. In contrast, Nambu was remarkably open-minded. To him, his work was like placing a few pieces into a giant jigsaw puzzle: he never thought that he had discovered the "ultimate truth". This deep sense of modesty was also a part of his personality. To the entire community of physicists, he was this shy, unassuming man, often difficult to understand, coming up with one original idea after another. There was a sense of play in the way that he did science: maybe that is why his ideas were sometimes incomprehensible when they first appeared.

Nambu's legacy, "physics without boundaries", must have had a subconscious influence on some of us in India involved in setting up the International Centre for Theoretical Sciences (ICTS), a centre of TIFR in Bangalore, where "science is without boundaries".

We end with a quote from Nambu's speech at the Nobel presentation ceremony at the University of Chicago on 10 December 2008, which clearly shows his view of nature: "Nowadays, the principle of spontaneous symmetry breaking is the key concept in understanding why the world is so complex as it is, in spite of the many symmetry properties in the basic laws that are supposed to govern it. The basic laws are very simple, yet this world is not boring; that is, I think, an ideal combination."

● An earlier version of the article appeared in *Frontline* magazine, see www.frontline.in/other/obituary/a-giant-of-physics/article7593580.ece.

Résumé

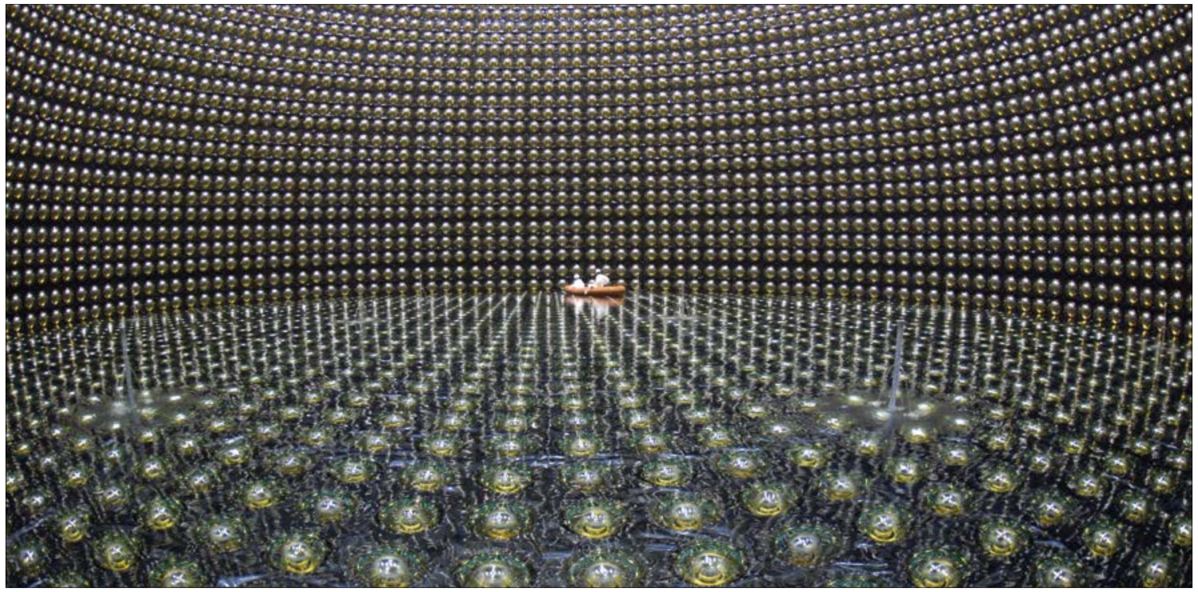
Yoichiro Nambu et la brisure de symétrie

Deux éminents physiciens, anciens étudiants de Yoichiro Nambu, évoquent les travaux et la personnalité du prix Nobel de physique, décédé en juillet dernier. Yoichiro Nambu a reçu le prix Nobel de physique en 2008 « pour la découverte du mécanisme de brisure spontanée de la symétrie en physique subatomique ». Les travaux de Nambu en physique théorique, sur plus d'un demi-siècle, ont été prophétiques ; ils ont joué un rôle majeur dans le développement d'un des grands acquis de la physique du XX^e siècle : le Modèle standard de la physique des particules. Nambu a également été l'un des fondateurs de la théorie des cordes.

Faces & Places

Nobel prize

A new Nobel prize for neutrino physics

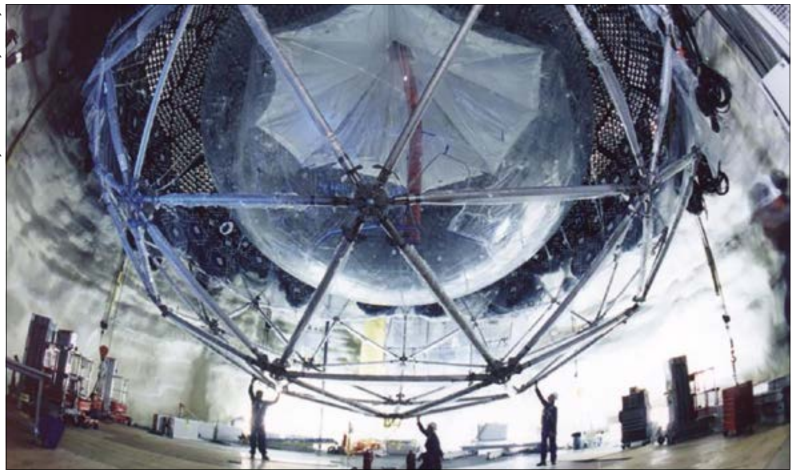


SNO

Takaaki Kajita, from the Super-Kamiokande collaboration in Japan, and Arthur B McDonald, from the Sudbury Neutrino Observatory (SNO) in Canada, were awarded the 2015 Nobel Prize in Physics for "the discovery of neutrino oscillations, which shows that neutrinos have mass". The two experiments independently demonstrated that neutrinos can change or "oscillate" from one type to another. This discovery at the turn of the millennium, more than 40 years after the prediction of the phenomenon by Italian physicist Bruno Pontecorvo, has had a profound impact on our understanding of the universe. This is the fourth time that neutrino studies have been rewarded with the prestigious prize.

Nearly 90 years after their prediction by Wolfgang Pauli, and almost 60 years after their experimental discovery, neutrinos remain among the most mysterious particles known in nature, and they are subject to a vigorous experimental programme around the world. As part of the European Strategy for Particle Physics, CERN inaugurated a new facility at the end of 2014. The CERN Neutrino Platform provides a focal point for Europe's contribution to global neutrino research, developing and prototyping the next generation of neutrino detectors.

Kamioka Observatory/ICRR/University of Tokyo



Top: The Super-Kamiokande Detector. Above: View of the SNO detector under construction.

In December 2014, the CERN Neutrino Platform took delivery of the ICARUS detector, shipped from the Gran Sasso National Laboratory where it studied the neutrino beam from CERN until 2012. The 760 tonne detector is now being refurbished at CERN, and in 2017 it will be shipped to Fermilab in the US to become part of a dedicated neutrino programme there. Scientists from the CERN Neutrino Platform are also involved in R&D for experiments at Fermilab's Long-Baseline Neutrino Facility.

● For more information, see www.nobelprize.org/nobel_prizes/physics/laureates/2015/.

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The Middle East

First shipment of magnets from CERN to SESAME

On 19 October, CERN bade a fond farewell to two containers of magnets. Their destination: SESAME, the synchrotron light source under construction in Jordan.

The containers held 31 sextupoles, produced in Cyprus and France, and 32 quadrupoles, produced in Spain and Turkey. The magnets have rejoined eight dipoles (from the UK), which are already at SESAME. The quadrupoles and sextupoles were checked and measured at CERN before this shipment, while the dipoles went via the ALBA synchrotron, near Barcelona, where magnetic measurements were carried out.

With this shipment, around 50% of the magnets for the SESAME storage ring will have been delivered. The containers are expected to arrive just in time for the SESAME Council meeting at the end of November. The rest of the magnets – as well as all of the power supplies and related control modules – have been produced and will be delivered to SESAME at the beginning of 2016, in time for first beams in the machine in summer 2016.

● For more details, visit www.sesame.org.jo/sesame/events/385-13th-sesame-users-meeting.html.

CERN

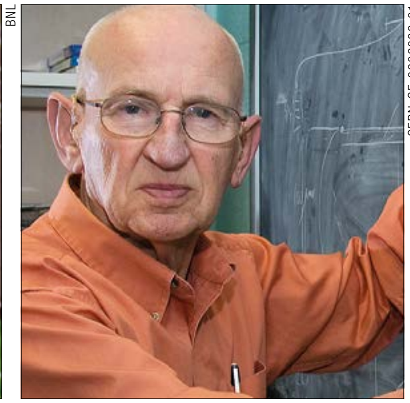
Top: Inside the SESAME hall, May 2012. Above: Magnets ready for shipment from CERN to SESAME.

Honours

Nygren, Radeka, and Witten receive new awards from the American Physical Society

Jerry Przybylski

BNL



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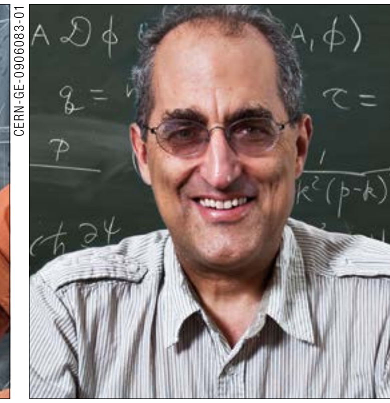


From left to right: David Nygren, Veljko Radeka and Edward Witten.

The inaugural American Physical Society (APS) Division of Particles and Fields Instrumentation Award has been presented jointly to David Nygren of the University of Texas at Arlington and Veljko Radeka of Brookhaven National Laboratory (BNL). Nygren and Radeka received the award during the APS New Technologies for Discovery Workshop on 5 October, at the University of Texas at Arlington. The two renowned scientists are honoured for their "widespread contributions and leadership in the development of new detector technologies and low-noise electronics instrumentation in particle physics as well as other fields".

In particular, David Nygren is recognised for the invention of the time projection chamber (TPC), developed during his 40 years at Lawrence Berkeley National Laboratory. Measuring the tracks of charged particles with exquisite precision has long been, and continues to be, one of the challenges for particle-physics detectors. Nygren developed the TPC for the PEP-4 detector to study 29 GeV electron–positron collisions at the PEP storage ring at SLAC. Over the past 40 years, the TPC has found use in diverse applications, including particle physics, relativistic heavy-ion collisions (including the ALICE experiment), neutrinoless double-beta decay and dark-matter searches.

Veljko Radeka and his colleagues developed the liquid-argon calorimeter, which has been used in many high-energy physics experiments, first at the Intersecting Storage Rings at CERN and now in the ATLAS experiment at the LHC (*CERN Courier* March 2011 p43). He also developed the highly sensitive low-noise electronics needed for the read-out of the small signals from these detectors.

In addition, Edward Witten, of the Institute for Advanced Study, is the first person to win the APS Medal for Exceptional Achievement in Research. The 2016 APS medal citation honours Witten for "discoveries in the mathematical structure of quantum field theory that have opened new paths in all areas of quantum physics". Witten is widely regarded as one of the world's leading theorists in a number of areas, including string theory and quantum gravity. He is also the originator of M-theory, which resolved perceived conflicts between five competing string theories and sparked a resurgence of research widely known as the second superstring revolution.

Swiss Physical Society honours Herwig Schopper

Herwig Schopper, CERN's former Director-General (1981–1988), has been appointed an honorary member of the Swiss Physical Society for his outstanding contributions to the field of particle physics, in particular for the realisation of the Large Electron–Positron Collider (LEP) at CERN, for his engagement in promoting international scientific collaboration at CERN and for the SESAME project in Jordan, and for his vision of "science without borders". He was recently also elected a foreign member of the Polish Academy of Arts and Sciences.

Schopper's outstanding scientific career started with his PhD at Hamburg University in 1951, followed by positions at prestigious institutions: he was research assistant at the Stockholm Technical University (with Lise Meitner), at the Cavendish Laboratory, UK (with O R Frisch), and at Cornell University (with R R Wilson). From 1973 until his retirement in 1989 he was professor at Hamburg University.

From the early days of his career, Schopper had a strong interest in shaping the future of particle physics. He realised that its success would rely on building strong links between scientists from various countries in an atmosphere of freedom, and joining together human and financial resources for a common scientific goal – a vision that he successfully implemented ▷

as Director-General of CERN. His ability to bring scientific groups together and enable discussion and decision-making on equal grounds shaped the way that CERN operates today. His vision of science without borders in other research fields led Schopper to become involved with the SESAME project in Jordan (*CERN Courier* July/August 2015 p19), of which he became the first president of Council and its honorary member for life.

Schopper has served and still serves as a member – often as chairman – on many high-level international scientific boards. Among other functions, he chaired the Scientific Council of the UNESCO International Basic Science Program (2003–2011), is a member of the Board of Trustees of the Cyprus Institute, and chaired its Scientific Council (2002–2014). He was a member of the Scientific Council of the Joint Institute for Nuclear Research in Dubna, Russia (1993–2002), president of the

Swiss Physical Society

Herwig Schopper.

German Physical Society (1992–1994) and president of the European Physical Society (1994–1996).

Schopper has received numerous prestigious distinctions and awards. To mention just a few, he received the UNESCO Albert Einstein Gold Medal and the UNESCO Niels Bohr Gold Medal for his pivotal role in building international scientific co-operation, and the American Institute of Physics (AIP) presented him with the Tate Medal for International Leadership in Physics. Schopper has also been honoured by various academies for his remarkable contributions to science and society. He is elected member of Leopoldina, the German National Academy for Natural Sciences, the European Academy, the Academia Scientiarium et Artium Europea and the World Academy of Arts and Sciences WAAS, where he is also on the Board of Trustees. He is also a corresponding member of the Bavarian Academy of Sciences, honorary member of the Hungarian Academy of Sciences, fellow of the American Physical Society and member of the Portuguese Academy of Sciences.

● See cerncourier.com/cws/article/cern/56613.

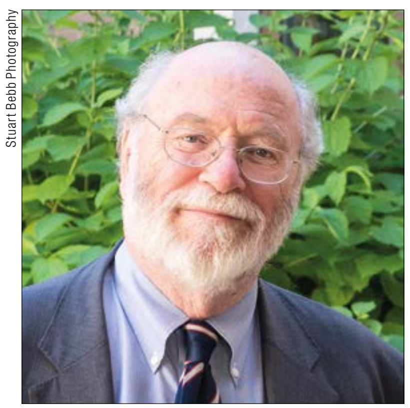
CELEBRATION

Roger Cashmore turns 70

Colleagues and friends gathered in Oxford on 30 June to celebrate the achievements of Roger Cashmore, former research director and deputy Director-General of CERN from 1999 to 2004. After CERN, he became principal of Brasenose College, Oxford, and is currently chair of the UK Atomic Energy Authority, whose responsibilities include the UK's fusion programme.

The day reflected both Roger's distinguished past in particle physics and his current interests. His influence stretches from contributions to understanding baryon structure in the quark model while he was at SLAC in the early 1970s, through pioneering studies of charm lifetimes at CERN, to the important role he played in the discovery of the gluon with the TASSO experiment at the PETRA collider at DESY in 1979. He subsequently led the construction in the UK of the central tracking detector for the ZEUS experiment, studying lepton–proton physics at HERA in the 1990s. He also made his

Stuart Bebb Photography



Roger Cashmore.

mark at Fermilab on the CDF experiment. He has advised many organisations; his role at the Gran Sasso National Laboratory was recalled by former director Eugenio Coccia.

The breadth of Roger's interests and accomplishments was apparent from the talks. His work in the field of energy policy resulted in an influential report by the Royal Society, of which Roger is a distinguished fellow, on strategy for nuclear energy. This, and progress in fusion, were highlighted by Steven Cowley, director of Culham Laboratory. As research director of CERN, Roger played a key role in the construction of the LHC detectors, recalled by speakers from the four big collaborations. He continues to have trenchant views on future facilities, reflected in forward-looking talks from Ian Hinchliffe and Halina Abramowicz, currently chair of the European Committee for Future Accelerators. Finally, Chris Llewellyn Smith, former Director-General of CERN and currently also involved in energy policy, gave his own commentary on Roger's career, drawing together contributions from members of the audience.

In a particular highlight for Roger and his wife Annie, their son Hrothgar, daughter-in-law Emily and granddaughter Lili were able to participate from Australia via video link. The day concluded with a banquet at Balliol College, where Roger is an emeritus fellow, the occasion enlivened by after-dinner speeches containing anecdotes of his Oxford career. In summary, in addition to past achievements, the day highlighted that Roger is still contributing strongly to science and society, and all participants joined in wishing him well for the future.

NEW APPOINTMENT

Pierluigi Campana is new director of the Frascati National Laboratory

Pierluigi Campana has been appointed director of INFN's Laboratori Nazionali di Frascati (LNF) for a four-year term as of 1 August 2015. He succeeds Umberto Dosselli.

Campana graduated in physics in 1981 at Rome's "La Sapienza" University, and quickly became a staff member at INFN-LNF. His first research activities related to the NUSEX experiment at Monte Bianco and the MACRO experiment at INFN's Gran Sasso Laboratory. He later worked at the ALEPH experiment at CERN's LEP collider, participating in the construction of the hadron calorimeter with streamer tubes.

In the mid 1990s, he joined the KLOE experiment at Frascati's DAFNE machine to study CP violation in K mesons. During the construction of the detector, he led the team in charge of building the lead-scintillating fibre calorimeter. Between 2001 and 2004, he was technical manager of the KLOE experiment. Since 2002, he has been working on the LHCb experiment at the LHC, searching for CP violation and new physics effects in the decay of beauty quarks, leading the Frascati group in the construction of the muon system. From 2011 to 2014, he was spokesperson of the LHCb collaboration. His main research interests have been in particle detectors, with a particular emphasis on calorimetry, gas-detector technology and, more recently, scintillating fibres for tracking.

INFN-LNF

Pierluigi Campana.

VISITS

The Spanish vice-president visits CERN

CERN-PHOTO-201509-194-9

CERN's Director-General Rolf Heuer, right, with a gift from CERN for the vice-president of the Government of Spain, Soraya Sáenz de Santamaría, left.

On 29 September, CERN welcomed the vice-president of the government of Spain, Soraya Sáenz de Santamaría, for a visit to the laboratory. The vice-president was accompanied by Carmen Vela, Spanish secretary of state for research, development and innovation, Bernardo de Sicart Escoda, ambassador of Spain to Switzerland, and Ana Menéndez Pérez, permanent representative of Spain to the United Nations and international organizations in Geneva. Their tour started at LHC Point 1, where CERN's Director-General, Rolf Heuer, welcomed them and gave them an introduction to CERN's activities. Their visit ended at the LHC superconducting-magnet assembly hall, where they met with CERN scientists from Spain.

CERN-PHOTO-201509-187-19

Gao Xingjian, winner of the Nobel Prize in Literature in 2000, was invited to visit CERN as part of European Researchers' Night activities organised by the POPScience EU funded project. At a conference given at the University of Geneva, he presented "Made of shadows and light", an anthology of seven short texts he wrote in Chinese between 1990 and 2012, and extracted from a work entitled Youshen Yu Xuansi (Earthbound Spirit and Meditative Thought)*. The texts have been translated for the first time, exclusively for CERN, into French, English, Spanish and Italian in the framework of POPScience for the 2015 European Researchers' Night. The ebook format, which is the first digital publication for the Nobel prizewinner, is distributed worldwide by POPScience Poetry. From left to right: Didier Bertet (CERN, IdeaSquare), Nobel laureate Gai Xingjian, and Susana Wong, POPScience poetry project manager.*

● *For Gao Xingjian's ebook, see www.jsd-portfolio.com/Gao_xingjian.epub.*

Event

TEDxCERN breaks the rules

CERN-PHOTO-201510-198-13

Around 600 people in the audience and 4000 online took part in TEDxCERN.

On 9 October, TEDxCERN brought together 15 "rule-breakers" to explore ideas that push beyond the boundaries of academia. They addressed a full house of 600 audience members, as well as thousands watching the event online.

TEDxCERN broke all of the rules this year – starting with its choice of venue. The CMS construction hall at Point 5 was converted into a gala centre, complete with sound stage and dance floor. It was a stunning transformation that also brought to life the hall's to-scale photo of the CMS detector. The image served as the backdrop to a light-projection show entitled "Turbulence", by artist François Moncarey.

From singer-songwriter Imogen Heap to CERN's own Edda Gschwendtner, the line-up of speakers was as diverse as it was educational. They discussed using tangible interfaces that allow human interaction via e-devices, the potential of 3D technology to revolutionise education and product fabrication, and even explored transformation of matter into habitable structures.

● You can find the full programme of speakers on the TEDxCERN website, see tedxcern.web.cern.ch/.

Workshops

Life in extreme environments discussed at the LSC

LSC

DULIA-bio participants visiting the underground laboratory at Canfranc (Spain).

The Deep Underground Laboratory Integrated Activity in biology (DULIA-bio) workshop was held on 13 and 14 October at the Canfranc Underground Laboratory (LSC), in Spain. The LSC (*CERN Courier* November 2015 p29) is one of the four deep-underground laboratories (DULs) in Europe, together with Boulby (UK), Gran Sasso (Italy) and Modane (France). Twenty-eight scientists, physicists and biologists, gathered at the LSC and others participated remotely from SNOlab, in Canada. The aim of the workshop, supported by DULs, the Astroparticle Physics European Consortium (ApPEC) and the Istituto de Fisica Corpuscular in Valencia, was to establish a common framework for DULs in deep-life studies and their applications in astrobiology.

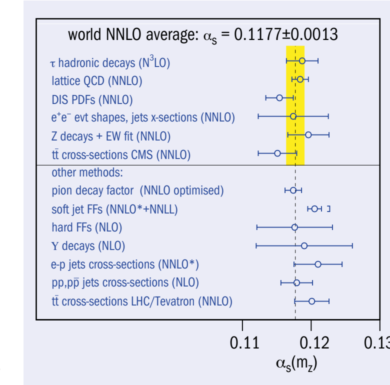
In the 1990s it became apparent that life is also possible in subsurface and extreme environments, and could actually have originated in the subsurface of the Earth. Today, many questions remain. What factors control the maximum depth limit where life is still possible? What are the sources of carbon for deep-seated life? And what processes regulate the energy flux for deep-seated life? Micro-organisms living under extreme conditions on Earth could shed light on the question of life on other planets because subsurface ecosystems are functioning independently of the surface environment and this could be similar for subsurface life on other planets. In this respect, the search for life in the universe could be pursued through studies in deep-underground facilities on Earth, which offer a unique opportunity to investigate the subject and to answer these fundamental questions. The different geological locations of the DULs enhance the possibility and variability of investigations.

One of the subjects discussed at DULIA-bio was the effects on biological systems of prolonged exposure to ionising radiation levels below natural background. Studies on how natural-background radiation is essential for life to maintain genomic stability in living organisms were presented from research carried out at Gran Sasso and SNOlab. Micro-organisms inhabiting the inside of rocks are studied at Canfranc by the GOLLUM project, due to the fact that underground spaces are the perfect site for extremophile ecology studies. Ongoing work at the Boulby underground laboratory includes studies of microbial life found in salt layers, and on the development of instrumentation to look for life on other planets.

DULIA-bio has been the first of a number of workshops organised by DULs in Europe to strengthen the integrated activities and the multidisciplinary features of these unique facilities.

● For more information, see https://indico.cern.ch/event/436589/.

Strong coupling: a workshop at CERN reviews latest advances



David d'Enterria (CERN)

Summary of the strong coupling extractions discussed in the workshop.

The latest progress in measurement of the strong interaction coupling was discussed in a recent workshop on "High precision measurements of α_s: from LHC to FCC-ee", held at CERN on 12–13 October. The meeting brought together leading experts in the field to explore in-depth recent theoretical and experimental developments on the determination of α_s, new ways to measure this coupling in lepton–lepton, lepton–hadron and hadron–hadron collisions and, in particular, the improvements expected at the proposed Future Circular Collider e^+e^- (FCC-ee) facility.

In quantum chromodynamics (QCD), the coupling constant α_s sets the scale of the strength of the interaction at a given reference scale (usually taken at the Z boson mass), and it is one of the fundamental parameters of the Standard Model (SM). The α_s coupling, known up to now with $\delta\alpha_s \approx \pm 0.5\%$ uncertainty, is the least precisely known of all fundamental constants in nature, orders-of-magnitude less well known than the gravitational ($\delta G \approx \pm 10^{-5}$), Fermi's ($\delta G_F \approx \pm 10^{-8}$), and fine-structure ($\delta\alpha \approx \pm 10^{-10}$) constants. Improving our knowledge of α_s is a prerequisite to reduce the theoretical uncertainties in the calculations of all perturbative QCD (pQCD) processes whose cross-sections or decay rates depend on higher-order powers of α_s, as is the case for virtually all of those measured at the LHC. In the introductory session, S Bethke presented the preliminary 2015 update of the Particle-Data-Group (PDG) world-average α_s, obtained from comparison of next-to-next-to-leading-order (NNLO) pQCD calculations with a set of six groups of experimental data. Enlarged uncertainties from lattice QCD and tau–lepton decays, as well as the first NNLO extraction from top-pair cross-sections at the LHC, have doubled the uncertainty on α_s, which will move from $\alpha_s = 0.1185 \pm 0.0006$ to $\alpha_s = 0.1177 \pm 0.0013$. L Mihaila reviewed the impact on Higgs physics of α_s, which is the second major contributor – after the bottom mass – to the parametric uncertainties of its dominant $H \rightarrow b\bar{b}$ partial decay, and the largest source of uncertainty for the $c\bar{c}$ and gg decay modes. An accurate knowledge of the running of α_s at TeV energy scales is also crucial for physics searches beyond the SM. F Sannino presented generic exclusion bounds on masses of new coloured particles based on LHC data.

The second session of the workshop was devoted to low-energy studies of the QCD coupling, such as from lattice QCD (covered by P Mackenzie and X Garcia i Tormo), pion (J-L Kneur), τ (A Pich) and Υ (J Soto) decays, and soft parton-to-hadron fragmentation functions (FFs) (R Perez-Ramos). The comparison of pQCD predictions with computational lattice-QCD "data", yielding $\alpha_s = 0.1184 \pm 0.0012$, still provides the most precise α_s extraction with a $\delta\alpha_s \approx \pm 1\%$ uncertainty. Hadronic decays of the tau lepton yield $\alpha_s = 0.1187 \pm 0.0023$ (i.e. $\delta\alpha_s = \pm 1.9\%$), although the results of different theoretical approaches are still a matter of debate. The pion decay factor was proposed as a new observable to extract $\alpha_s = 0.1174 \pm 0.0017$, notwithstanding the low scales involved, which challenge the pQCD applicability. Decays of the b–$\bar{b}$ bound state (Υ) used to constrain the QCD coupling until a few years ago ($\alpha_s = 0.1190 \pm 0.0070$), but their lower degree of (NLO) theoretical accuracy should be improved to be included in future PDG updates. Similarly, the energy evolution of the distribution of hadrons in jets has proven to be a novel robust method to extract $\alpha_s = 0.1205 \pm 0.0022$, but the calculations need to go beyond their current approximate-NNLO accuracy.

Future measurements

Determinations of α_s at higher energy scales – including global fits of parton distribution functions (PDFs) (reviewed by J Bluemlein), hard parton-to-hadron FFs (B Kniehl), jets in $e^{\pm}p$ (M Klasen), e^+e^- event shapes (S Kluth, A Hoang), jet cross-sections in e^+e^- (A Banfi), Z and W decays (K Moenig, M Srebre), and the $e^+e^- \rightarrow$ hadrons cross-section (J Kuehn) – were covered in the third workshop section. The NNLO analyses of PDFs have good precision ($\delta\alpha_s = \pm 1.7\%$), albeit yielding a central value lower than the rest of the methods: $\alpha_s = 0.1154 \pm 0.0020$.

Upcoming NNLO fits of the jet FFs will provide a QCD coupling that is more accurate than the current one at NLO ($\alpha_s = 0.1176 \pm 0.0055$). Similarly, a full-NNLO analysis of jet production in $e^{\pm}p$ is needed to improve the current $\alpha_s = 0.121 \pm 0.003$ extraction from these observables. Electron–positron event shapes and jet rates yield $\alpha_s = 0.1174 \pm 0.0051$ with a $\delta\alpha_s = \pm 4.3\%$ uncertainty, but new e^+e^- data at lower and higher energies than LEP are required for better control of hadronisation corrections. The hadronic decays of electroweak bosons are high-precision observables for extraction of the strong coupling. The current Z data provide $\alpha_s = 0.1196 \pm 0.0030$, i.e. $\delta\alpha_s = \pm 2.5\%$, which can be reduced to below ±0.3% with the huge statistical data sets expected at the FCC-ee. The W hadronic decay data are not as precise today, but promise the same α_s sensitivity with measurements at the FCC-ee. The final session was dedicated to α_s extractions at hadron colliders. Important NNLO theoretical developments for top-quark pair and jet cross-sections were reviewed by A Mitov, G Salam and J Pires. A lowish $\alpha_s = 0.1151 \pm 0.0028$ value with $\delta\alpha_s = \pm 2.5\%$ uncertainty is obtained using the only $t\bar{t}$ cross-sections published so far by CMS, although inclusion of all preliminary data increases it to $\alpha_s \approx 0.1201 \pm 0.0025$. The imminent release of the NNLO calculation for jets will provide a huge boost for PDFs, FFs and cross-section studies in pp, $e^{\pm}p$ and γp collisions. To date, the NLO combination of ATLAS, CMS and Tevatron jet results yields $\alpha_s = 0.1179 \pm 0.0023$. Existing and planned measurements of α_s at the LHC were also reviewed by B Malaescu (ATLAS) and K Rabbertz (CMS), clearly confirming asymptotic freedom at multi-TeV scales. The results of the workshop will be incorporated into the FCC Conceptual Design Report under preparation. Whereas the strong force decreases with energy, scientific interest in the QCD interaction clearly proves constant, if not increasing, with time.

● For more information, see indico.cern.ch/e/alphas2015.

SCHOOL

CAS course on Advanced Accelerator Physics held in Warsaw, Poland

The CERN Accelerator School (CAS) and the National Centre for Nuclear Research (NCBJ) recently organised a course on advanced accelerator physics, which took place in Warsaw, Poland, from 27 September to 9 October.

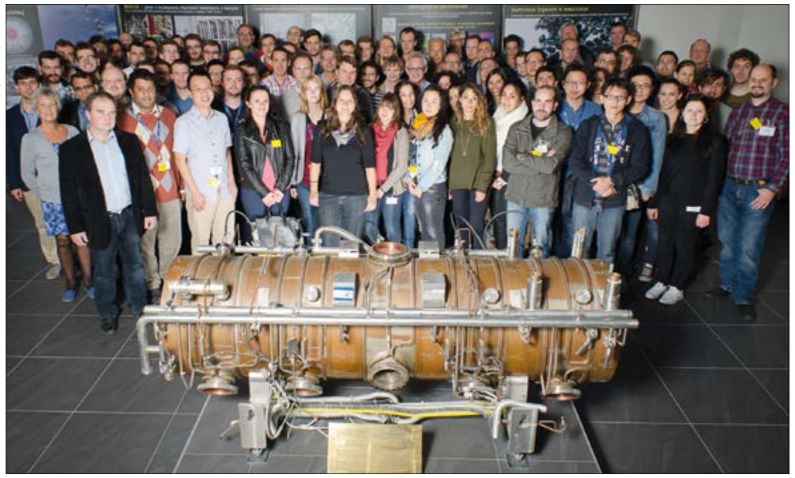
The course followed an established format with lectures in the mornings and practical courses in the afternoons. The lecture programme consisted of 34 talks, supplemented by private study, tutorials and seminars. The practical courses provided "hands-on" experience in three topics: beam instrumentation and diagnostics; RF measurement techniques; and optics design and corrections. Participants selected one of the three courses and followed the chosen topic throughout the school.

Sixty-six students representing 18 nationalities attended the course, with most participants coming from European counties, but also from Korea, Taiwan and Russia. Feedback from the participants was positive, reflecting the high standard of the lectures and teaching.

NCBJ provided excellent facilities and invaluable support for the highly technical courses, which are a key feature of the advanced school. They also organised an optional visit to their reactor, which is used for research and industrial purposes, and provided live beam facilities through electron linacs for "hands-on" experience.

Forthcoming CAS courses will be a specialised school on free electron lasers and energy-recovery linacs (FELs and ERLs) (Hamburg, Germany, 31 May–10 June 2016), an introduction to accelerator physics (Istanbul, Turkey, September 2016) and a specialised school on beam injection, extraction and transfer to be held at CERN in November 2016.

● See www.cern.ch/schools/CAS.



Marcin Jakubowski, NCBJ, Poland

Group photo of the 66 students at the recent CAS in Poland.

OUTREACH

Science pops in Geneva

This year, CERN celebrated European Researchers' Night with a series of events and activities organised in the framework of the EU-funded project POPScience. The day was jam-packed with activities that presented science through comic strips, games, cinema and television. Around 500 children attended the sessions for schools organised at Balexert, Geneva's popular multiplex cinema, and 600 spectators flocked to the public screenings.

Using the big screen, scientists, directors and authors were on hand to disentangle truth from untruths and science from science fiction. The guests, some of whom appeared in person and others via video link, included Jorge Cham, author of *PhD Comics* and the spin-off film; David Saltzberg, physicist at CMS and scientific consultant for the television series *The Big Bang Theory*; Kip Thorne, scientific consultant for the film *Interstellar*; Lawrence Krauss, author of *The Physics of Star Trek*; and Italian astronaut Roberto Vittori, who gave a commentary on the film *Gravity*.

In the main area of the shopping centre, CERN scientists performed experiments for the public. In the multimedia shop FNAC, authors signed books, customers enjoyed virtual tours of the CMS experiment via television screens, physicists answered numerous questions, and children built Lego detectors.

CERN/Bennett, Sophia Elizabeth

Left: Researchers explain the properties of matter using liquid nitrogen during a "Fun with Physics" session organised by POPScience. Right: Jorge Cham, author of the popular PhD Comics *signs his latest book for the visitors.*

AFRICA

HEPMAD 15 brings high-energy physics to Madagascar

Association Gasy Miara-Mandroso (AGMM)

HEPMAD 15 participants at the École Normale Supérieure, where the conference sessions were held.

HEPMAD 15, the 7th High-Energy Physics International Conference, was held in Antananarivo, the capital of Madagascar, on 17–22 September, with the official opening ceremony taking place at the National Malagasy Academy and sessions at the École Normale Supérieure.

The conference, initiated by Stephan Narison of the Laboratoire Univers et Particules of Montpellier in 2001, alternates with the series of QCD-Montpellier conferences that he started in 1985. It aims both to be pedagogical – Narison presented his book for the general public, *Particles and the Universe* (World Scientific, in press) to a large audience – and to report on the latest experimental and theoretical results. There were around 50 participants with 15 invited speakers from abroad.

Recent results were presented from ATLAS and CMS on tests of the Standard Model, improved measurements of the Higgs couplings, searches for new physics beyond the Standard Model, top-quark properties and B-meson physics. The ALICE collaboration reported results on heavy quarkonia in quark–gluon plasma, while results on kaon and B-meson physics, CP-violation and the Cabibbo–Kobayashi–Maskawa matrix were presented by NA48/NA62 and BELLE. BELLE has also reviewed searches for exotic XYZ hadrons, which have been complemented by preliminary predictions of their masses and couplings from QCD spectral sum rules, including next-to-next-to-leading-order perturbative corrections. Other reports covered some aspects of astrophysics and the new HAWC gamma-ray observatory in Mexico. The conference also included poster presentations by national researchers on other areas of physics: climatology, physics of the atmosphere, the environment and nuclear physics.

There were also discussions on the organisation of the next conference, HEPMAD 17, the possibility of holding the African School of Physics in Madagascar in the near future and, in general, the development of physical sciences in Africa and in the Indian Ocean area. Here, Narison emphasised his wish for the creation of an International Physics Centre in Madagascar for African Sub-Saharan, Indian Ocean, South Asian and Australian physicists.

Finally, the conference provided an opportunity for foreign participants to discover the natural richness and traditions of Madagascar, as well as its social poverty, exemplified by the "exotic" bus used for the excursions.

● HEPMAD 15 was co-organised by the HEPMAD Research Institute of Antananarivo and the Association Gasy Miara-Mandroso (AGMM). Visit www.lupm.univ-montp2.fr/users/qcd/hepmad15/.

Obituaries

Guido Altarelli 1941–2015

Guido Altarelli passed away on 30 September in his 74th year. A great theoretical physicist, Guido spent most of his scientific carrier in Rome and at CERN. He received the Julius Wess Prize in 2011, the Sakurai Prize in 2012 and the EPS Prize in 2015, but these very celebrated awards only partially reflect the richness of his contributions: his deep and long-lasting influence is ubiquitous in the field of high-energy physics.

Guido was born on 12 July 1941. He studied physics at the University of Rome, and in 1963 he graduated under the supervision of Raul Gatto (who was in Florence) with a thesis in collaboration with Franco Buccella on single-photon emission in e^+e^- collisions. In 1964, he joined the very lively and large group of young researchers (known as "*gattini*", which means "young cats" in Italian) that were working together under the careful and inspiring supervision of Gatto ("cat", in Italian). In Florence, where he remained until 1968, Guido worked with Gatto and the other gattini (among them Franco Buccella, Luciano Maiani and Giuliano Preparata), primarily on topics that were fashionable at the time (e.g. SU(6) symmetries, Regge poles). After two years in New York, he returned to Rome as professor, initially at La Sapienza until 1992 and later at the University of Roma Tre. During this period, he was a senior staff physicist in the CERN Theory Division (1987–2006) and theory division leader from 2000 to 2004.

After his return to Rome, his scientific interests veered towards the parton model and QCD. Many of these works were written with Nicola Cabibbo, Luciano Maiani, Guido Martinelli, Roberto Petronzio and myself. Among the most important ones are the papers on octet enhancement of non-leptonic weak interactions in asymptotically free gauge theories – a crucial and seminal

Altarelli family

Guido Altarelli.

step towards understanding the interplay between QCD strong interactions and weak interactions – as well as his paper on the discovery of large QCD correction to the naïve parton model prediction in $\mu^+\mu^-$ production, and the paper where we derived the so-called Altarelli–Parisi equation. This last paper stemmed from one of his ideas, which was to make previously obtained results on scale violation clearer and more exploitable. It was written while both of us were in Paris, and Guido liked to remark that it is the most cited French paper.

New interests

In the 1980s he became more interested in deriving predictions for future CERN experiments, e.g. the production of jets, heavy-vector mesons, and other exotic objects like Higgs and supersymmetric particles. In the same period, he continued his deep analysis of the consequences of QCD on weak-interactions theory, e.g. computing, for the first time, the two-loop contributions. He also wrote seminal papers on the decay of heavy quarks. During this period, he became deeply interested in polarised proton structure function, where he discovered, together with Graham Ross, the crucial interplay among the gluon anomaly and polarisation effects.

Later on, after he went to CERN, Guido worked on the construction of a model independent analysis of electroweak data (with Riccardo Barbieri as a precious collaborator), on the Higgs mesons (theoretical predictions on the mass and the cross-section at colliders), and on many other problems. In the new millennium, Guido went on to work on a new subject without neglecting any of the old ones: he became fascinated by the elegance of tri-bimaximal neutrino mixing. Many of his papers (mostly written with Ferruccio Feruglio) are dedicated to the search for the possible origins of this baffling symmetry.

As often happens, his scientific success was inseparable from his human qualities, and was not only due to his technical capabilities. Perhaps his most characteristic features were his great kindness and intellectual honesty, coupled with a rather ironic view of himself and of life in general. His great inquisitiveness, the enjoyment he derived from learning new things and putting together the pieces of a puzzle, allowed him to make summaries of topical subjects. These were crucial, not only because they allowed us to take stock of the current state of a field of research, but also because they indicated new directions to take. He liked clear, precise formulations that could be understood by all.

He was not a reclusive or selfish scientist, only interested in the personal prestige that could be gained from his research. Guido was also a researcher who worked with others within a large community – that of CERN, and the high-energy particle-physics community in general. Many of Guido's works, from the most famous to the lesser known, were conceived in a spirit not only of research, but of service to the community to which he belonged. It is difficult to imagine what the status of the field would be without his contributions.

We all miss him very much, not only as an invaluable scientist, but also as a dear friend.

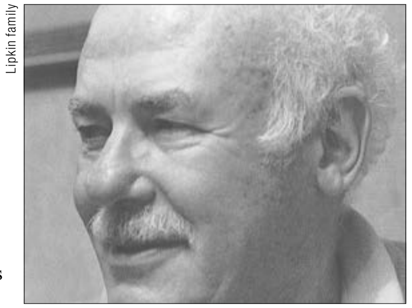
● *Giorgio Parisi.*

Harry (Zvi) Lipkin 1921–2015

Harry (Zvi) Lipkin passed away on 15 September. He was one of the leading theoretical physicists of Israel, one of the founders of the Physics Department of the Weizmann Institute, and a major contributor to a broad spectrum of topics. Unlike most theoretical physicists, his originality and creativity continued for many decades; he was the prolific author of excellent new ideas at an age when others retire and most have forgotten their last important contribution.

Lipkin was born in New York City in 1921 and grew up in Rochester, New York. His life was very rich: he graduated in engineering; contributed to the crucial WWII anti U-boat

microwave radar project at MIT; undertook an experimental-physics PhD thesis at Princeton; immigrated to Israel with his wife Malka to start a pioneering life in an agricultural kibbutz on the Lebanese border; was sent to France to study nuclear reactors; joined an early R&D unit of the Israeli army; co-founded and moved into the newly created Department of Nuclear Physics at the Weizmann Institute; became a theoretical nuclear physicist… and we have only reached 1955 in his history. For the remaining 60 years of his life, he also contributed to theoretical condensed-matter physics, particularly the Mössbauer effect; basic problems in quantum mechanics; and, especially, particle physics, with an emphasis on symmetries, quark-model analysis, applications of group theory and a wide variety of other topics. His book *Lie Groups for Pedestrians* introduced many generations of physicists to the subject. He received several major prizes, including the Wigner Medal, the Emet Prize and the Rothschild Prize. He spent long periods of research in the US, especially at Argonne National Lab and, for decades, was a frequently invited speaker at just about every major physics department and conference.



Lipkin family

Harry Lipkin.

But his original contributions to physics research were only one aspect of his incredible career. He always felt that one should never take oneself too seriously, even as a scientist. Together with virologist Alexander Kohn, he founded the *Journal of Irreproducible Results*, in which no allegedly serious scientific topic remained immune to parodies, jokes and ridicule. Lipkin was also passionate about the teaching of reading in elementary schools, a subject about which he held strong, well-informed views, often arguing his case in widely distributed written contributions. He did the same on his own interpretations regarding events in the Middle East, and was essentially a prolific blogger, decades before the word "blog" was coined. In the 1980s, Lipkin corresponded with the exiled Andrei Sakharov, and was instrumental in keeping Sakharov's fate in the focus of public opinion.

His research, as well as his attitude to everything else, was enriched by a unique ability to provide simple descriptions and explanations, often using analogies to better understood topics. His physics work always stood on several basic, solid legs: maximal contact with experiments, both already performed and newly proposed; a rare intuition for complex quantum-mechanical paradoxes and dilemmas, a feature that most great physicists understand but have no intuition for; and an ability to see through a myriad of irrelevant details, straight to the heart of the matter.

Lipkin was an excellent scientist, great mind and a wonderful tour guide through many labyrinths. We are proud to have been his friends and collaborators.

● *Haim Harari, Weizmann Institute and Marek Karliner, Tel Aviv University.*

Recruitment

For advertising enquiries, contact *CERN Courier* recruitment/classified, IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK.
Tel +44 (0)117 930 1264 Fax +44 (0)117 930 1178 E-mail sales@cerncourier.com
Please contact us for information about rates, colour options, publication dates and deadlines.

UNIVERSITY OF BIRMINGHAM

School of Physics and Astronomy
College of Engineering and Physical Sciences

Lecturer/Senior Lecturer/Reader in Particle Physics Instrumentation– reference 52934

Level of appointment will depend on the skills/experience of the candidate

Starting salary of appointment at Lecturer level £38,511 to £51,702. Starting Salary at Senior Lecturer or Reader level £47,328 to £71,509

The School of Physics and Astronomy at the University of Birmingham has over 100 academic and research staff covering a broad range of research interests, along with 120 graduate students and 35 technical staff. It takes in around 180 undergraduates per year. As part of a major new strategic investment by the University in particle physics instrumentation, Birmingham has appointed a new professor (Allport) to lead this activity and is making rolling appointments of 3 new academic positions. The second post, having the role to support the ATLAS Tracker Upgrade programme is available with immediate effect at a level dependent on the experience and qualifications of the successful candidate.

Applicants are invited to obtain more information and submit their application online to us, via www.hr.bham.ac.uk/jobs. Informal inquiries to Prof Phil Allport (allport@cern.ch; tel: +44-1214144717) or Prof Paul Newman (paul.newman@cern.ch; tel: +44-1214144617).

Closing date: 11th December 2015

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IceCube WinterOver Experiments Operator

WIPAC is a research center at the UW-Madison responsible for the IceCube Neutrino Observatory at the South Pole.

Working as a team with one additional IceCube winter-over personnel, this position will be responsible for all winter-over operations of this state-of-the-art neutrino observatory.
This position is located at the Amundsen-Scott South Pole Station and reports to the Winter-over Manager in Madison, WI.

Training for two candidates is anticipated to begin in Madison, WI at the beginning of August 2016. Deployment to the South Pole is expected to be in early October 2016 for 12-13 months with no possibility of leaving during the winter months from mid-February to mid-October.

Successful candidates will attend the NSF contractor orientation program and will be expected to pass physical and psychological evaluations to work at polar and high altitude sites for one year, as required by the National Science Foundation (NSF) Office of Polar Programs.

M.S. in Computer Science, Physics, Electrical Engineering or related field is required. B.S. in Computer Science, Electrical Engineering, or related field and substantial (equivalent to a Masters degree) experience will be considered.

For instructions to apply
https://icecube.wisc.edu/jobs

To ensure consideration, application materials must be received by January 15, 2015.

POSTDOCTORAL FELLOWS
Kavli Institute for the Physics and Mathematics of the Universe, The University of Tokyo, Japan

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

The "Kavli Institute for the Physics and Mathematics of the Universe" (Kavli IPMU) is an international research institute with English as its official language established in October 2007. The goal of the institute is to discover the fundamental laws of nature and to understand the universe from the synergistic perspectives of mathematics, statistics, theoretical and experimental physics, and astronomy. We are particularly interested in candidates with broad interests and a willingness to interact with people across disciplines.

We intend to offer more than a dozen postdocs with three-year terms. We seek to build a diverse, highly interactive membership, and female and international applicants are strongly encouraged. We have generous travel support for our postdocs, and encourage full-time members to be away from the Institute for between 1 and 3 months every year.

The focus of Kavli IPMU includes but is not limited to: all areas of mathematics (e.g. algebra, geometry, analysis, and statistics); string theory and mathematical physics; particle theory, collider phenomenology, beyond the standard model physics phenomenology; cosmology and astrophysics theory; astronomy and observational cosmology; and particle and underground experiments. We are leading efforts on the XMASS dark matter experiment, the KamLAND-Zen neutrino experiment, the Hyper Suprime-Cam (HSC) project for weak lensing surveys and Prime Focus Spectrograph (PFS) for the dark energy at the Subaru Telescope, GADZOOKS! at Super-Kamiokande, the Belle II experiment, T2K long baseline neutrino experiment, SDSS-IV for a survey of galaxies, POLARBEAR CMB B-mode polarization measurement, and R&D for future large neutrino detectors and the LiteBIRD satellite.

We have embarked on a new frontier field of statistical computational cosmology. We plan to develop applications to statistically extract cosmological parameters from a huge dataset from the Subaru wide field survey. We have a few positions for this project which is supported by CREST from Japan Science and Technology Agency (JST).

The search is open until filled, but for full considerations please submit the applications and letters on the application form by Dec 1, 2015

Further information can be found here:
http://www.ipmu.jp/job-opportunities
For inquiries please contact: **application-inquiry@ipmu.jp**

Universität Bielefeld

The **Faculty of Physics of Bielefeld University** invites applications for

1. Junior Professorship (W1) with tenure track (W3) in Theoretical Physics

We are looking for an outstanding junior scientist with international reputation who complements and extends the local research activities in theoretical high energy physics. Current research topics include heavy ion physics, particle cosmology, thermal field theory, lattice gauge theory, and mathematical physics. We are interested in applicants who have demonstrated research abilities in the field of strong-interaction matter. The junior professor is expected to contribute to our international coordinated research activities.
Employment prerequisites are a university degree, teaching ability and specialized skills for scientific work, in general documented by an excellent doctoral thesis.

2. Professorship (W3) in Theoretical Physics

We are looking for an outstanding scientist with international reputation who complements and extends the local research activities in theoretical high energy physics. Current research topics include heavy ion physics, particle cosmology, thermal field theory, lattice gauge theory, and mathematical physics. We are interested in applicants who have expertise in strong-interaction matter. The professor is expected to contribute to our international coordinated research activities.
Employment prerequisites are a university degree, teaching ability, specialized skills for scientific work, in general documented by an excellent doctoral thesis, and additional scientific achievements which will be evaluated in the hiring procedure.

All applicants should demonstrate commitment to excellence in teaching Theoretical Physics both at the undergraduate and graduate level.

Applications from suitably qualified handicapped and severely handicapped persons are explicitly encouraged.
Bielefeld University has been repeatedly awarded for succeeding in equal opportunities and has been certified as a family friendly university. Applications of women are appreciated. This especially applies to the scientific sector as well as to those of technology, IT and crafts.
Applications are treated according to the regulations of the Landesgleichstellungsgesetz (North-Rhine-Westphalian Equal Opportunities Act).

We ask the candidates to send a single application and to indicate if they apply for the W1 or W3 level. Only one position will be filled. The expected date of appointment is Jan 1st, 2017.

Applications including CV, list of publications, research and teaching proposals, information on previous research and teaching experience as well as third-party funding should be submitted until **January 4th 2016** to:

Bielefeld University
Dean of the Faculty of Physics
Postfach 100131, D-33501 Bielefeld, Germany
e-mail: dekanat@physik.uni-bielefeld.de

Please send in your application via e-mail rather than hard copy. All application data will be deleted or destroyed permanently after the recruitment process has been completed.

→ www.uni-bielefeld.de

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A Research Centre of the Helmholtz Association

FLASH EXPERIMENTS.

DESY, Hamburg location, is seeking:
Scientist (f/m)

DESY
DESY is one of the world's leading research centres for photon science, particle and astroparticle physics as well as accelerator physics.

DESY operates the free electron laser FLASH whose GW level, femtosecond pulses offer unique opportunities for multidisciplinary research in the vacuum ultraviolet and soft X-ray (XUV) range. The combination with synchronised optical laser systems and strong-field phase locked THz pulses allows exploring ultrafast timescales using pump-probe techniques. The facility is currently extended and will double its capacity for experiments. We have an immediate opening for a PostDoc who is willing to join the team responsible for the THz beamlines at FLASH.

The position
- Participation in development and commissioning of the high-field THz sources at FLASH1 (in operation) and FLASH2 (under construction), with particular emphasis on diagnostics instrumentation and development of novel XUV/THz pump-probe techniques
- Support of the international user groups during experiment campaigns involving XUV/THz pump-probe experiments at FLASH, and possible participation in the experiments
- Contribution to the in-house research program at FLASH, preferentially utilizing THz beamlines

Requirements
- PhD in experimental physics or a related field
- Hands-on experience with THz (infrared) sources and optics; experience with combining THz with visible and/or UV-soft X-ray sources is an advantage
- Experience with ultrafast radiation sources, preferentially with ultrafast accelerator-based sources
- Background in short-pulse interactions with matter is desirable
- Team player with good communication skills
- Good knowledge of the English language

For further information please contact Nikola Stojanovic +49-40-8998-4526.

The position is limited to 3 years.
Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. DESY operates flexible work schemes. Handicapped persons will be given preference to other equally qualified applicants. DESY is an equal opportunity, affirmative action employer and encourages applications from women. There is a bilingual kindergarten on the DESY site.

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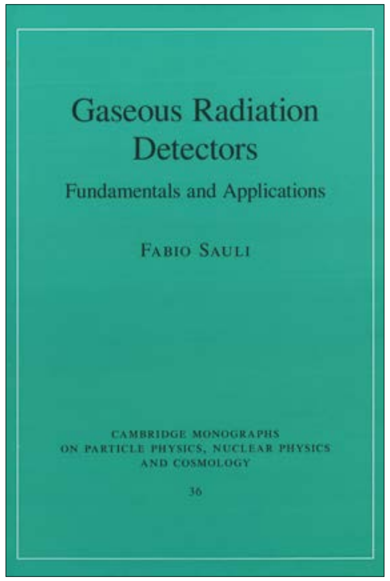
Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: EP046/2014
Notkestraße 85 | 22607 Hamburg | Germany | Phone: +49 40 8998-3392
Deadline for applications: until the position is filled
www.desy.de

The Helmholtz Association is Germany's largest scientific organisation.
www.helmholtz.de
HELMHOLTZ ASSOCIATION

Bookshelf

Compiled by Virginia Greco, CERN

Gaseous Radiation Detectors: Fundamentals and Applications (Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology)
By Fabio Sauli
Cambridge University Press
Also available at the CERN bookshop



In the last few decades, fast revolutionary developments have taken place in the field of gaseous detectors. At the start of the 1970s, multiwire proportional chambers were invented. These detectors and their descendants (drift chambers, time-projection chambers, ring-imaging Cherenkov detectors, etc) rapidly replaced cloud and bubble chambers, as well as spark counters, in many high-energy physics experiments. At the end of the last century, resistive-plate chambers and micropattern detectors were introduced, which opened up new avenues in applications.

Ironically, for a long time, no books had been published on gaseous detectors and their fast evolution. For this reason, in spite of thousands of scientific publications covering the rapid and exciting developments in the field of gaseous detectors, no simple and analytical description has been made available for a wide audience of non-professionals, including, for example, students.

Suddenly "an explosion" took place: several books dedicated to modern gaseous detectors and their applications appeared on the market, almost all at the same time.

Sauli's book is certainly one of the best of these. The author, a leading figure in the field, has succeeded in writing a remarkable and charming book, which I strongly recommend to anyone interested in learning about recent progress, open questions and future perspectives of gaseous detectors. Throughout its 490 pages, it offers a broad coverage of the subject.

The first five chapters focus on fundamentals: the interaction of charged particles and photons with matter, the drift and diffusion of electrons and ions, and avalanche multiplications. This first part of the book offers a refreshing mix of basic facts and up-to-date research, but avoids giving too much space to formulas and complicated mathematics, so non-specialists can also gain from the reading.

The remaining eight chapters are dedicated to specific detectors, from single-wire proportional counters to state-of-the-art micro-pattern gaseous detectors. This latter part of the book gives exhaustive detail and describes the design and operational features, including signal development, time and position resolutions, and other important characteristics. The last chapter deals with degeneracy and ageing – serious problems that detectors can experience if the gas composition and construction materials are not chosen carefully.

This fascinating book is easy to read, so it is suitable for everyone, and in particular, I believe, for young people. I was especially impressed by the care with which the author prepared many figures, which in some cases include details that I have not seen in previous texts of this kind. The high-quality figures and photographs contribute significantly to making this book well worth reading. In my opinion, it is not only remarkably complementary to other recently published monographs, but it can also serve as a main textbook for those who are new to the field.

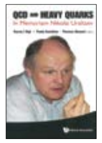
The only omission I have observed in this otherwise wide-ranging and well-researched book, is the lack of discussion on secondary processes and ion back flows, which are very important in the operation of some modern photosensitive detectors, including, for example, ALICE and COMPASS ring-imaging detectors.

There could be a few other improvements in a future edition. For instance, it would be useful to expand the description of the growing applications of gaseous detectors, especially resistive-plate chambers and micropattern detectors.

All in all, this is a highly recommendable book, which provides an interesting guided tour from the past to present day of gaseous detectors and the physics behind their operation.
● *Vladimir Peskov, CERN.*

Books received

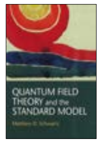
QCD and Heavy Quarks: In Memoriam Nikolai Uraltsev
By I I Bigi, P Gambino and T Mannel (eds)
World Scientific



The book collects together articles on QCD and heavy-quark physics written in memory of Nikolai Uraltsev, who passed away unexpectedly in February 2013. Uraltsev was an excellent theorist with acute intuition, who dedicated his career to the study of phenomenological particle physics, in particular quantum chromodynamics and its non-perturbative properties. He is also considered one of the fathers of heavy-quark expansion. By writing this book, Uraltsev's closest colleagues and friends intended to honour his groundbreaking work, as well as give testimonies of their personal relationships with him.

The text gives an overview of some aspects of QCD, including CP violation in hadronic processes and hadronic matrix elements in weak decays. Three selected works by Uraltsev are also reproduced in the appendix.

Quantum Field Theory and the Standard Model
By Matthew D Schwartz
Cambridge University Press
Also available at the CERN bookshop



Providing a comprehensive and modern introduction to quantum field theory, this textbook covers the development of particle physics from its foundations to the recent discovery of the Brout–Englert–Higgs boson. Based on a course taught by the author at Harvard University for many years, the text starts from the principle that quantum field theory (QFT) is primarily a theory of physics and, as such, it provides a set of tools for performing practical calculations. The book develops field theory, quantum electrodynamics, renormalisation and the Standard Model, including modern approaches and state-of-the-art calculation techniques.

Bookshelf

With a combination of intuitive explanations of abstract concepts, experimental data and mathematical rigour, the author makes the subject accessible to students with different backgrounds and interests.

Particle and Astroparticle Physics, Gravitation and Cosmology: Predictions, Observation and New Projects – Proceedings of the XXXth International Workshop on High Energy Physics

By V Petrov and R Ryutin (eds)

World Scientific

The most interesting talks delivered at the XXXth International Workshop on High Energy Physics, held in Protvino, Russia, in June 2014, are collected in this volume, along with the minutes of the six panel discussions. As the full title suggests, this conference not only focused on high-energy physics, but addressed a wide range of fundamental issues of modern particle and astroparticle physics, gravitation and cosmology.

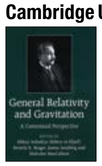
The major subjects presented included the discovery and interpretation of the Brout–Englert–Higgs boson at the LHC, heavy-quark physics, quark–gluon plasma studies, diffractive scattering at high energies, neutrino oscillations, and theoretical interpretations of cosmological data on the evolution of the universe.

The panel discussions, in turn, highlighted difficult points in the various domains of modern physics, and identified possible research paths.

General Relativity and Gravitation: A Centennial Perspective

By A Ashtekar et al (eds)

Cambridge University Press



On the occasion of the centennial of Einstein's discovery of general relativity, the International Society on General Relativity and Gravitation commissioned a team of leading international researchers to write about the advances that have occurred in all of the branches of physics during the last three decades. Through 12 comprehensive chapters, the volume gives an overview of key topics in relativistic astrophysics, cosmology and gravitational-wave theories, as well as mathematics and computational science. The book in intended both for beginners, who could use it as an introduction to the entire field, and for more advanced researchers, especially if they are interested in subjects that are outside of their field of expertise. Organised in four parts, each of about five chapters, the book guides the reader on a journey from the triumph of Einstein's theory of relativity through the phenomenon of gravitational waves, to quantum gravity.

Nuclear and Particle Physics

By Claude Amsler

IOP Publishing

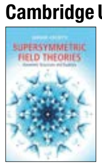
This textbook provides an introductory course on nuclear and particle physics for undergraduate and early graduate students. It originated from a series of lectures given at the Physics Institute of the University of Zurich by the author. The subjects are presented following their historical development. The explanations are experimentally and phenomenologically orientated, and often make use of intuitive arguments. In addition, many concepts and phenomena are derived with inductive rather than deductive thinking.

Originally published in German, this new version in English has been enriched with several modern topics, such as the Higgs boson, updates on neutrinos, the top quark and bottom-quark physics.

Supersymmetric Field Theories: Geometric Structures and Dualities

By Sergio Cecotti

Cambridge University Press



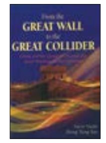
An unconventional and elegant geometrical approach is adopted in this book to explain supersymmetric field theories, and describe intuitive methods for understanding the logic underlying such concepts. Aimed at graduate students and researchers, the collection of lectures provides an advanced course in supergravity and supersymmetry, which requires knowledge of the basic concepts and fundamental tools of these fields. The author shows how complex results and formulae obtained from the more classical approaches to SUSY can be simplified dramatically when translated to a geometric setting.

Covering a wide range of topics and offering rigorous, in-depth explanations, this text would be an extremely valuable resource for theoretical physicists.

From the Great Wall to the Great Collider: China and the Quest to Uncover the Inner Workings of the Universe

By S Nadis and S T Yau

International Press of Boston



The volume presents the reasons behind the ambitious project pursued by a group of distinguished Chinese scientists, led by Shing-Tung Yau, professor of mathematics and physics at Harvard University, to build the next biggest particle collider in China, to continue the quest to identify the fundamental building blocks of nature.

The discovery of the Brout–Englert–Higgs boson put in place the long-sought-after missing piece of the Standard Model of particle physics. Although this model can describe the behaviour of particles with remarkable accuracy, it is actually incomplete, because it is not able to explain a range of phenomena.

Several centuries ago, Chinese emperors erected a majestic ring of fortification – the Great Wall. Today, Chinese researchers are contributing to particle physics with a project of almost comparable magnificence: the building of a giant accelerator, the Great Collider.

The book explains the scientific issues at stake, discusses the history of particle physics, and tells the story of the birth and development of the Great Collider project.

Inflation and String Theory

By D Baumann and L McAllister

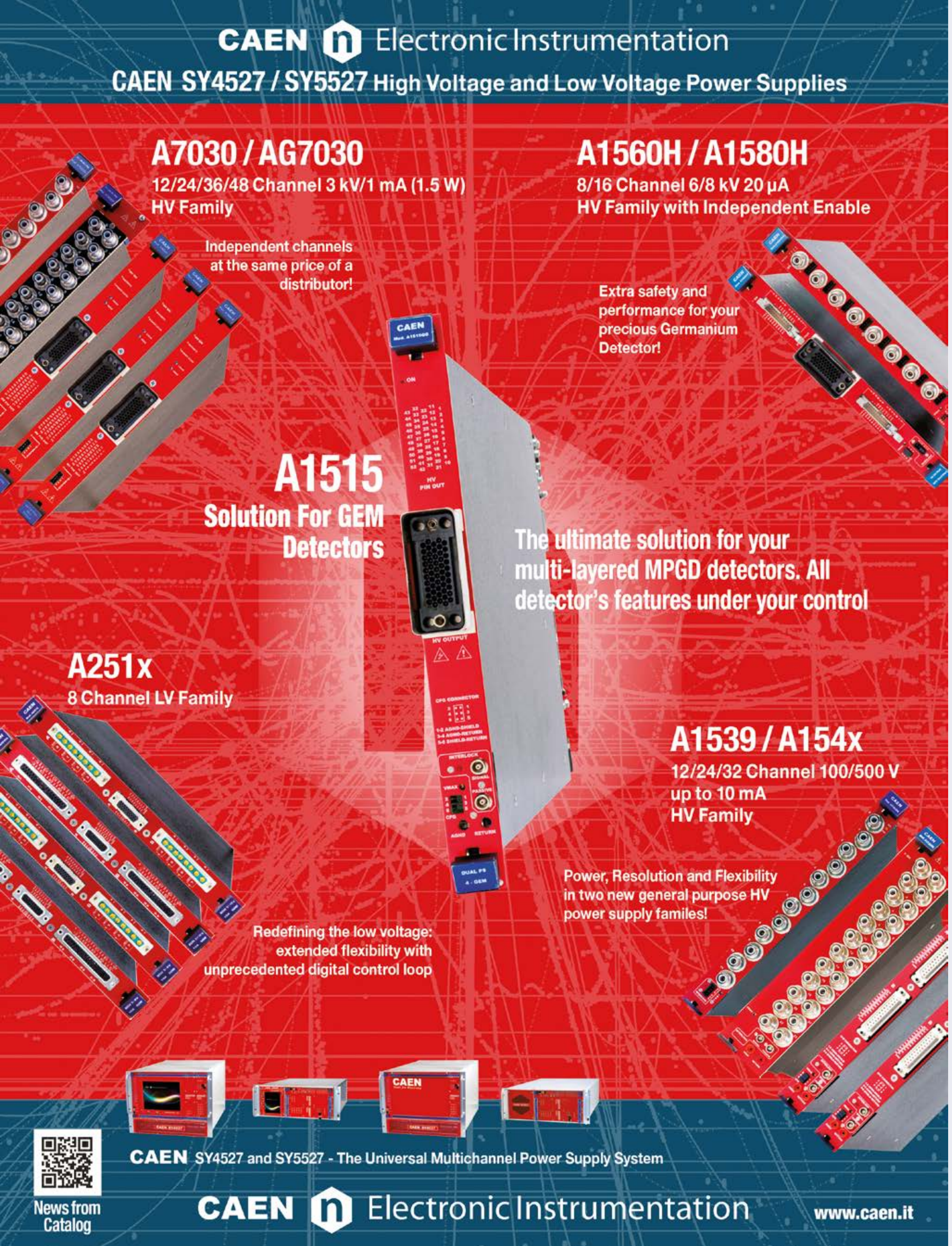
Cambridge University Press

This complete and accessible text, written by two of the leading researchers in the field, provides a modern treatment of inflationary cosmology and its connection to string theory and elementary particle theory.

The past two decades of advances in observational cosmology have brought about a revolution in our understanding of the universe. In particular, deeper studies of the cosmic microwave background have revealed strong evidence for a period of inflationary expansion in the very early universe. At the same time, new developments in string theory have led to a better understanding of inflation in a framework that unifies quantum mechanics and general relativity.

After a brief introduction about observations in favour of the inflationary hypothesis, the volume provides an overview of effective field theory, string theory, and string compactifications. Finally, several classes of models of inflation in string theory are examined in detail.

The background material in geometry and cosmological perturbation theory included in the appendices makes the book self-contained and accessible not only to experienced researchers, but also to graduate students and readers who are new to the field.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