

WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the November 2013 issue of *CERN Courier*.

For more than 30 years, plasma-based particle accelerators driven by either lasers or particle beams have promised a fast route to high energies – primarily because of the extremely large accelerating electric fields they can support, which are about a thousand times greater than in conventional accelerators. This issue looks at progress in the field, including the start of AWAKE – a new project at CERN to study proton-driven plasma wakefield acceleration – and the latest from the ICAN consortium, which is investigating a possible new fibre-based laser driver operating at high pulse-rate. At CERN, the current long shutdown allowed a great opportunity to visit the LHC and its experiments – and much more – during Open Days at the end of September, while the CLOUD experiment has made the first ever measurements of formation rates of atmospheric aerosol particles.

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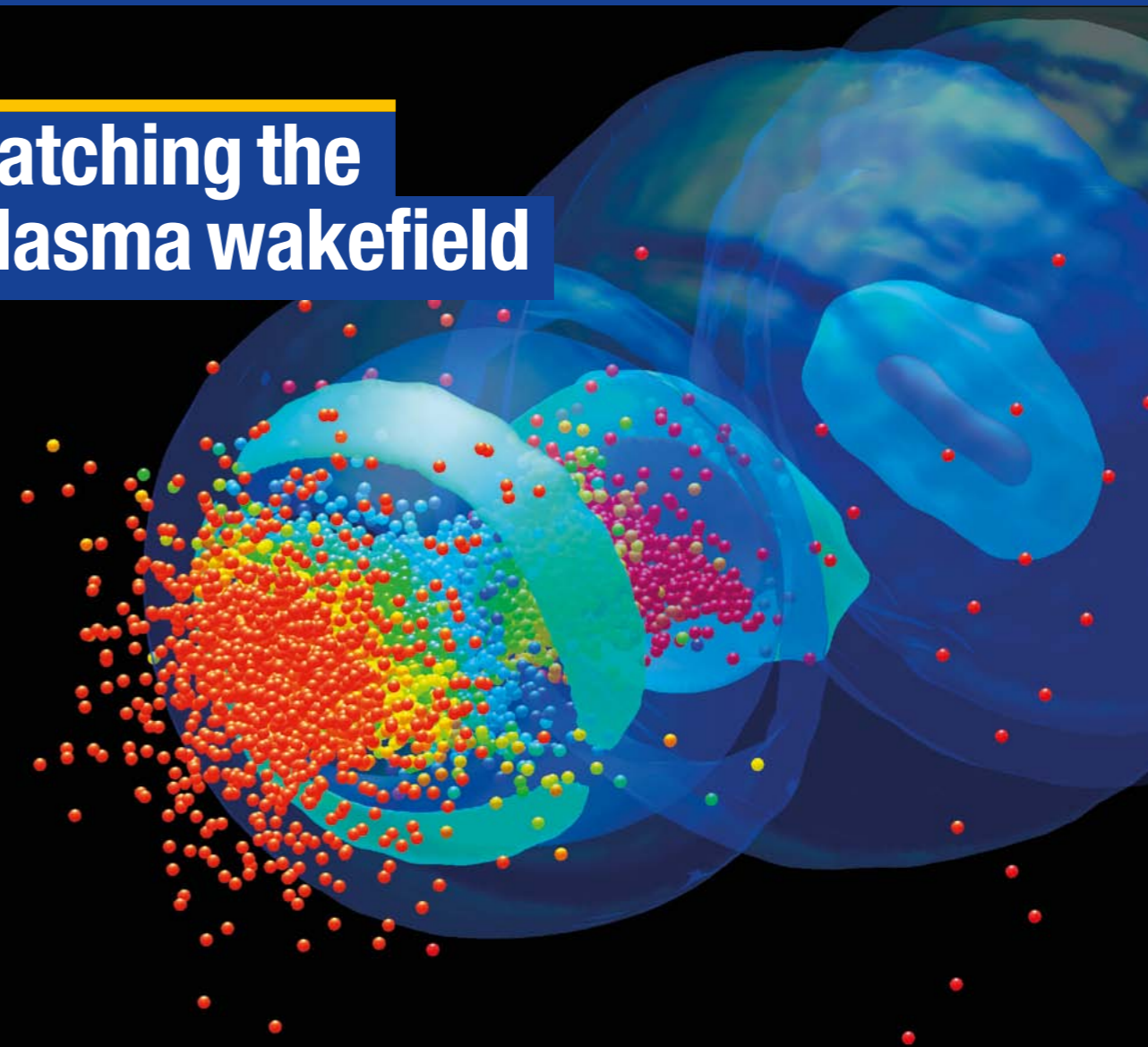
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CERN COURIER

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

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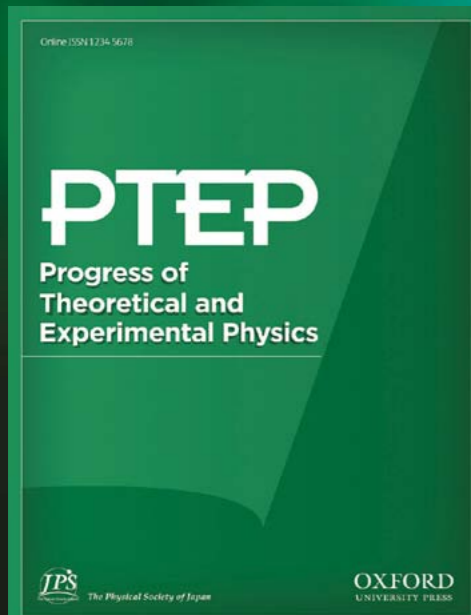
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Anticipate — Accelerate — Achieve



FERMILAB

Neutrinos head off again to Minnesota

In August, after a 16-month shutdown, Fermilab resumed operation of its Neutrinos at the Main Injector (NuMI) beamline and sent the first muon neutrinos to three neutrino experiments: MINERvA, MINOS+ and the new NOvA experiment. Numerous upgrades to the Fermilab accelerator complex have laid the groundwork for increasing the beam power of the NuMI beamline from about 350 kW to 700 kW. In addition, Fermilab has changed the NuMI horn and target configurations to deliver a higher-energy neutrino beam compared with pre-shutdown operation.

The NOvA experiment – still under construction – will study the properties of neutrinos, especially the elusive transition of muon neutrinos into electron neutrinos. The results will help to answer questions about the neutrino-mass hierarchy, neutrino oscillations and the role that neutrinos might have played in the evolution of the universe. The construction of the NOvA near and far detectors, both located 14 milliradians off the NuMI beam axis, is advancing quickly.

The near detector – located 100 m underground in a new cavern that has been excavated at Fermilab – has more than a quarter of its structure in place. Meanwhile, 810 km away in northern Minnesota, technicians have installed more than three quarters of the plastic structure that is the skeleton of the huge, 14,000 tonne far detector. More than 70% of the far detector's plastic modules have been filled with 5.7 million litres of liquid scintillator and the first modules are recording data. The first part of the near detector will turn on before the end of the year.



When completed, the NOvA far detector will comprise 28 detector blocks, each measuring about 15 m tall, 15 m wide and nearly 2 m deep. (Image credit: Fermilab.)

The MINOS+ experiment uses the existing MINOS near and far detectors and takes advantage of the fact that the post-shutdown NuMI neutrino beam differs from earlier operation. The new beam, which is optimized for the NOvA experiment, yields higher-energy neutrinos at the location of the MINOS detector and should not show measurable oscillations. This means that MINOS+ can look for surprises. New types of neutrino interactions could deform the spectrum at the far detector's distance of 735 km and the observation of additional neutrinos would indicate new physics. The experiment can even search for extra dimensions.

MINERvA – located in front of the MINOS near detector – is a dedicated neutrino-interaction experiment designed to study a range of nuclei. These measurements will not only improve understanding of the

nucleus but will also be important inputs to neutrino-oscillation experiments. The MINERvA detector has several targets including helium, carbon, scintillator, water, steel and lead, followed by precise tracking and calorimetry. Previously, MINERvA took data in a beam around 3 GeV, where quasi-elastic, resonance and deep-inelastic scattering processes contribute roughly equally to the event rates. With the new, higher-energy neutrino beam, the event rate is much higher and the events are dominated by deep-inelastic scattering. While MINERvA will study all processes at higher energy, the huge increase in deep-inelastic scattering events in particular will allow precise measurements of the nuclear structure-functions.

Breaking news: The 2013 Nobel Prize in Physics



François Englert, left, and Peter W Higgs have been awarded the 2013 Nobel Prize in Physics "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider". The announcement by the ATLAS and CMS collaborations took place at CERN on 4 July last year (CERN Courier September 2012 p46).

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ATMOSPHERIC PHYSICS

CLOUD shines new light on aerosol formation in atmosphere

The CLOUD experiment at CERN, which is studying whether cosmic rays have a climatically significant effect on aerosols and clouds, is also tackling one of the most challenging and long-standing problems in atmospheric science – understanding how new aerosol particles are formed in the atmosphere and the effect that these particles have on climate. In a major step forward, the CLOUD collaboration has made the first measurements – either in the laboratory or in the atmosphere – of the formation rates of atmospheric aerosol particles that have been identified with clusters of precisely known molecular composition.

Atmospheric aerosol particles cool the climate by reflecting sunlight and by forming smaller but more numerous cloud droplets, which makes clouds brighter and extends their lifetimes. By current estimates, about half of all cloud drops are formed on aerosol particles that were “nucleated” – that is, produced from the clustering of tiny concentrations of atmospheric molecules rather than being emitted directly into the atmosphere, as happens with sea-spray particles. Nucleation is therefore likely to be a key process in climate regulation. However, the physical mechanisms of nucleation are not understood, nor is it known which molecules participate in nucleation and whether they derive from natural sources or are emitted by human activities.

CLOUD has studied the formation of new atmospheric particles in a specially designed chamber under extremely well controlled laboratory conditions of temperature, humidity and concentrations of nucleating vapours (CERN Courier October 2011 p28). This chamber is the first to reach the challenging technical requirements on ultra-low levels of contaminants that are necessary to carry out these experiments in the laboratory. Using state-of-the-art instruments that are connected to the chamber, the experiment can measure extremely low concentrations of atmospheric vapours. It can also study the precise molecular make-up and growth of newly formed molecular clusters from single molecules up to stable aerosol particles.

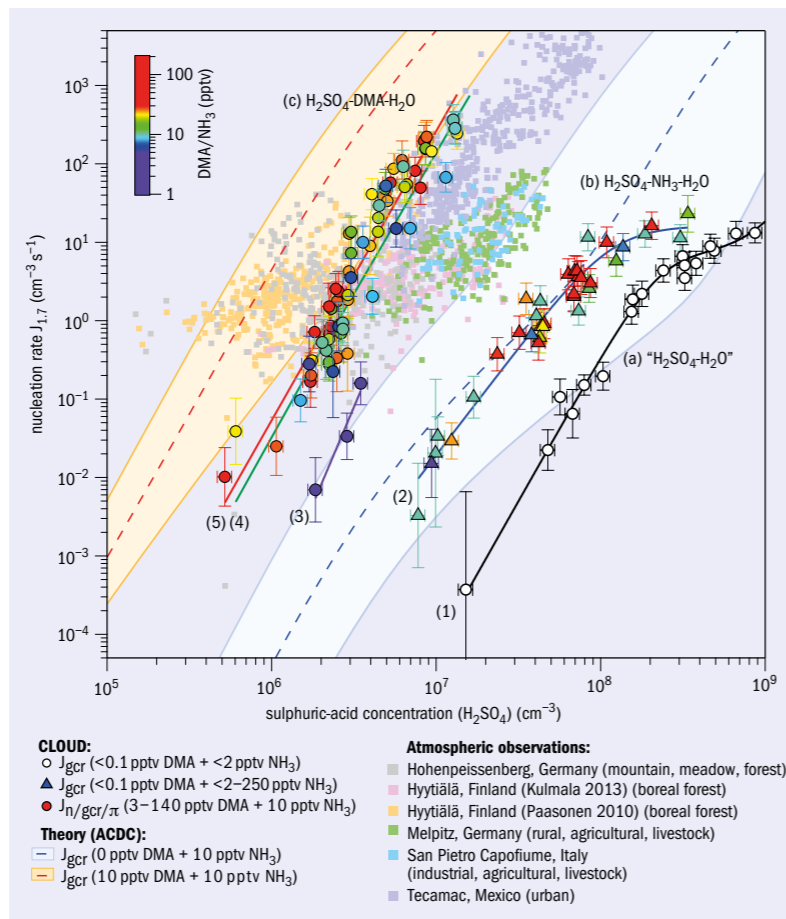


Fig. 1. Atmospheric, experimental and theoretical nucleation rates as a function of sulphuric acid (H_2SO_4) concentration, where 10^7 cm^{-3} is equivalent to a mixing ratio of 0.4 parts per trillion by volume (pptv). The mixing ratios of ammonia (NH_3) or dimethylamine (DMA) in the CLOUD experiment are indicated by the colour scale. Theoretical expectations (the Helsinki ACDC model) are indicated for H_2SO_4 nucleation with 10 pptv NH_3 (dashed blue line), and with 10 pptv DMA plus 10 pptv NH_3 (dashed red line, assuming 0.5 neutral–neutral sticking probability). The bands represent the theoretical uncertainty.

This has enabled CLOUD to measure the formation of particles that are caused by sulphuric acid and tiny concentrations of dimethylamine near the level of 1 molecule per trillion (10^{12}) air molecules.

The measurements, made at 278 K and 38% relative humidity, involved different combinations of sulphuric acid (H_2SO_4) and water (H_2O), with ammonia (NH_3) or dimethylamine (DMA). The figure shows

the results from CLOUD together with various atmospheric measurements and theoretical expectations based on quantum chemical calculations of cluster binding energies. The results indicate that amines at typical atmospheric concentrations of only a few parts per trillion by volume combine with sulphuric acid to form highly stable aerosol particles at rates that are similar to those observed in the lower atmosphere. The figure also shows that these highly detailed measurements allow a fundamental understanding of the nucleation process at the molecular level because they can be reproduced by the theoretical calculations of molecular clustering.

Amines are atmospheric vapours that are closely related to ammonia. Derived largely from anthropogenic activities – mainly animal husbandry – they are also emitted by the oceans, the soil and from biomass burning. The results from CLOUD suggest that natural and anthropogenic sources of amines could influence climate. CLOUD has also found that ionization by cosmic rays has only a small effect on the formation rate of amine–sulphuric-acid particles, suggesting that cosmic rays are unimportant for the generation of these particular aerosol particles in the atmosphere.

• The CLOUD collaboration consists of the California Institute of Technology,

Carnegie Mellon University, CERN, Finnish Meteorological Institute, Helsinki Institute of Physics, Johann Wolfgang Goethe University Frankfurt, Karlsruhe Institute of Technology, Lebedev Physical Institute, Leibniz Institute for Tropospheric Research, Paul Scherrer Institute, University of Beira Interior, University of Eastern Finland, University of Helsinki, University of Innsbruck, University of Leeds, University of Lisbon, University of Manchester, University of Stockholm and University of Vienna.

• Further reading

J Almeida *et al.* (CLOUD collaboration) 2013 *Nature* DOI: 10.1038/nature12663.

LHC EXPERIMENTS

LHCb plans for cool pixel detector

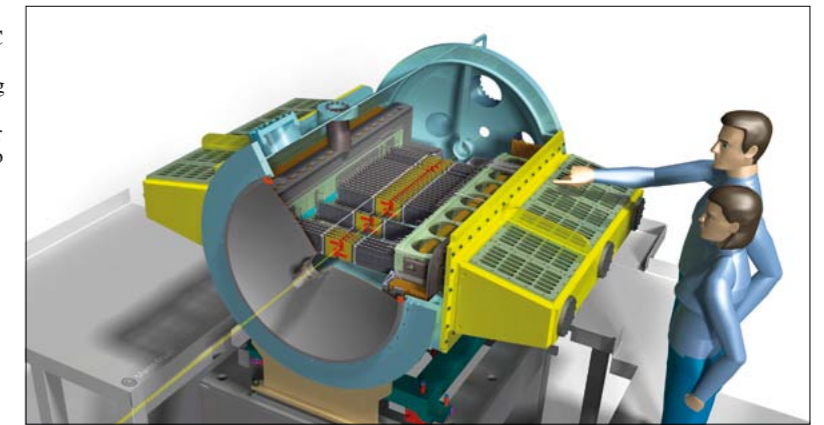
As the first long shutdown since the start-up of the LHC continues, many teams at CERN are already preparing for future improvements in performance that were foreseen when the machine restarts after the second long shutdown, in 2019. The LHCb collaboration, for one, has recently approved the choice of technology for the upgrade of its Vertex Locator (VELO), giving the go-ahead for a new pixel detector to replace the current microstrip device.

The collaboration is working towards a major upgrade of the LHCb experiment for the restart of data-taking in 2019. Most of the subdetectors and electronics will be replaced so that the experiment can read out collision events at the full rate of 40 MHz. The upgrade will also allow LHCb to run at higher luminosity and eventually accumulate an order of magnitude more data than was foreseen with the current set-up.

The job of the VELO is to peer closely at the collision region and reconstruct precisely the primary and secondary interaction vertices. The aim of the upgrade of this detector is to reconstruct events with high speed and precision, allowing LHCb to extend its investigations of CP violation and rare phenomena in the world of beauty and charm mesons.

The new detector will contain 40 million pixels, each measuring $55 \mu\text{m}$ square. The pixels will form 26 planes arranged perpendicularly to the LHC beams over a length of 1 m (see figure). The sensors will come so close to the interaction region that the LHC beams will have to thread their way through an aperture of only 3.5 mm radius.

Operating this close to the beams will expose the VELO to a high flux of particles,



Conceptual design of the new pixel detector for LHCb. (Image credit: Marco Kraan.)

requiring new front-end electronics capable of spitting out data at rates of around 2.5 Tbits/s from the whole VELO. To develop suitable electronics, LHCb has been collaborating closely with the Medipix3 collaboration. The groups involved have recently celebrated the successful submission and delivery of the Timepix3 chip. The VeloPix chip planned for the read-out of LHCb's new pixel detector will use numerous Timepix3 features. The design should be finalized about a year from now.

An additional consequence of the enormous track rate is that the VELO will have to withstand a considerable radiation dose. This means that it requires highly efficient cooling, which must also be extremely lightweight. LHCb has therefore been collaborating with CERN's PH-DT group and the NA62 collaboration to develop the concept of microchannel cooling for

the new pixel detector. Liquid CO_2 will circulate in miniature channels etched into thin silicon plates, evaporating under the sensors and read-out chips to carry the heat away efficiently. The CO_2 will be delivered via novel lightweight connectors that are capable of withstanding the high pressures involved. LHCb will be the first experiment to use evaporative CO_2 cooling in this way, following on from the successful experience with CO_2 cooling delivered via stainless steel pipes in the current VELO (CERN Courier June 2012 p29).

All of these novel concepts combine to make a “cool” pixel detector, well equipped to do the job for the LHCb upgrade.

• For more information, see the LHCb Upgrade Letter of Intent and Framework TDR at the LHCb webpage <https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbUpgrade>.

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

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

News

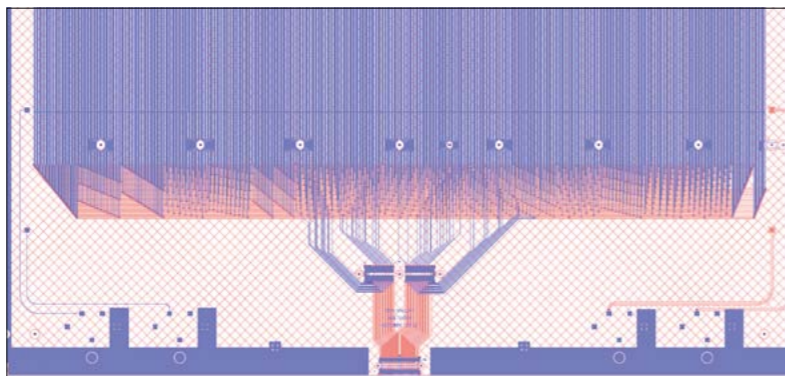
DETECTORS

Genetic multiplexing: how to read more with less electronics

Modern physics experiments often require the detection of particles over large areas with excellent spatial resolution. This inevitably leads to systems equipped with thousands, if not millions, of read-out elements (strips, pixels) and consequently the same number of electronic channels. In most cases, it increases the total cost of a project significantly and can even be prohibitive for some applications.

In general, the size of the electronics can be reduced considerably by connecting several read-out elements to a single channel through an appropriate multiplexing pattern. However any grouping implies a certain loss of information and this means that ambiguities can occur. Sébastien Procureur, Raphaël Dupré and Stéphane Aune at CEA Saclay and INP Orsay have devised a method of multiplexing that overcomes this problem. Starting from the assumption that a particle leaves a signal on at least two neighbouring elements, they built a pattern in which the loss of information coincides exactly with this redundancy of the signal, therefore minimizing the ambiguities of localization. In this pattern, two given channels are connected to several strips in such a way that these strips are consecutive only once in the whole detector. The team has called this pattern "genetic multiplexing" for its analogy with DNA, as a sequence of channels uniquely codes the particle's position.

Combinatorial considerations indicate that, using a prime number p of channels, a detector can be equipped with at most $p(p-1)/2+1$ read-out strips. Furthermore, the degree of multiplexing can be adapted easily



Schematic of the connection between the 61 electronic channels and the 1024 strips of the 50 cm prototype. (Image credit: CEA-Saclay.)

to the incident flux. Simulations show that a reduction in the electronics by a factor of two can still be achieved at rates up to the order of 10 kHz/cm².

The team has successfully built and tested a large, 50 × 50 cm² Micromegas (micro-pattern gaseous detector) with such a pattern, the 1024 strips being read out with only 61 channels. The prototype showed the same spatial resolution as a non-multiplexed detector (Procureur *et al.* 2013). A second prototype that is built from resistive-strip technology will be tested soon, to achieve efficiencies close to 100%.

The possibility of building large micro-pattern detectors with up to 30 times less electronics opens the door for new applications both within and beyond particle physics. In muon tomography, this

multiplexing could be used to image large objects with an unprecedented accuracy, either by deflection (containers, trucks, manufacturing products) or by absorption (geological structures such as volcanoes, large monuments such as a cathedral roof). The reduction of the electronics and power consumption also suggests applications in medical imaging or dosimetry, where light, portable systems are required. Meanwhile, in particle physics this multiplexing could bring a significant reduction in the cost of electronics – after optimizing the number of channels with the incident flux – and simplifications in integration and cooling.

• **Further reading**
S Procureur, R Dupré and S Aune 2013 *Nucl. Instrum. & Meth. A* **729** 888.

NEUTRINOS

LBNE gains new partners from Brazil, Italy and UK

In mid-September, the Long Baseline Neutrino Experiment (LBNE) collaboration, based at Fermilab, welcomed the participation of 16 additional institutions from Brazil, Italy and the UK. The new members represent a significant increase in overall membership of more than 30% compared with a year ago. Now, more than 450 scientists and engineers from more than 75 institutions participate in the LBNE science collaboration (*CERN Courier* April 2012 p12). They come from

universities and national laboratories in the US, India and Japan, as well as Brazil, Italy and the UK.

The swelling numbers strengthen the case to pursue an LBNE design that will maximize its scientific impact. In mid-2012, an external review panel recommended phasing LBNE to meet the budget constraints of the US Department of Energy (DOE). In December the project received the DOE's Critical Decision 1 (CD-1) approval on its

phase 1 design, which excluded both the near detector and an underground location for the far detector. However, the CD-1 approval explicitly allows for an increase in design scope if new partners are able to contribute additional resources. Under this scenario, goals for a new, expanded LBNE phase 1 bring back these excluded design elements, which are crucial to execute a robust and far-reaching neutrino, nucleon-decay and astroparticle-physics programme.

Sciencewatch

COMPILED BY JOHN SWAIN, NORTHEASTERN UNIVERSITY

The frog that hears through its mouth

Gardiner's frogs live in the Seychelles islands and are among the smallest in the world at just 1 cm long. Now they have another claim to fame because they hear in what seems to be a completely distinct way – through their mouths. Other frogs have a tympanic middle ear with a membrane that vibrates on the surface of their heads, while Gardiner's frogs have none and so might seem to be deaf. However, they do croak to communicate and now Renaud Boistel of the Centre de Neurosciences Paris-Sud and colleagues have found that they can hear using their mouths as resonators coupled to an inner ear.

Using X-ray imaging techniques at the European Synchrotron Radiation Facility



A male Gardiner's frog in its natural habitat in the Seychelles. (Image credit: R Boistel/CNRS.)

in Grenoble, the researchers established that the pulmonary system of these frogs could not contribute significantly to the

transmission of sound to the inner ears, so they focused instead on the head. With the aid of numerical simulations the researchers were able to confirm that the mouth acts as a resonator. Hearing via a middle ear is common to all other four-legged animals and seems to have evolved independently in different lineages. The home islands of these unusual frogs have been isolated from other land masses for 47–65 million years, so their hearing mechanism may be a unique survivor of ancestors from the ancient continent of Gondwana.

• **Further reading**
R Boistel *et al.* 2013 *PNAS* **110** 15360.

Nature's pain medicine

While a large fraction of modern medicines are extracted or derived from natural plant sources, medical chemistry has managed to synthesize quite a few that would seem to be human creations. Now Ahcène Boumendjel of Université Joseph Fourier in Grenoble and colleagues have found a synthetic painkiller in a plant used in traditional African medicine to treat pain. They found that the roots – the part used in traditional pain remedies of Cameroon – of the pincushion tree (*Nauclea latifolia*) contain large amounts of tramadol, a synthetic painkiller used since the 1970s. This seems to be the first time a widely used synthetic drug has been found at medically useful levels in a plant. It seems that nature got there first for this one.

• **Further reading**
A Boumendjel *et al.* 2013 *Angewandte Chemie* DOI: 10.1002/anie.201305697.

Cheap and quiet MRI

A new approach to magnetic resonance imaging (MRI) could lead to cheaper devices without the clanging noises and possible nerve stimulation in patients that arise from switching the directions of large magnetic-field gradients in present day devices. Jonathan Sharp at Alberta Innovates Technology Futures in Calgary and colleagues have used a static magnetic field and two resonant RF fields twisting in opposite directions to manipulate nuclear

spins and produce high-resolution images even with a low field of 0.2 T provided by a permanent magnet. In addition to making MRI cheaper and quieter, it opens up new possibilities for MRI imaging and experiments in general because it allows independent simultaneous multi-nuclear or spectrally selective imaging to be done.

• **Further reading**
J C Sharp *et al.* 2013 *NMR in Biomedicine* DOI: 10.1002/nbm.3023.

Perovskites for solar power

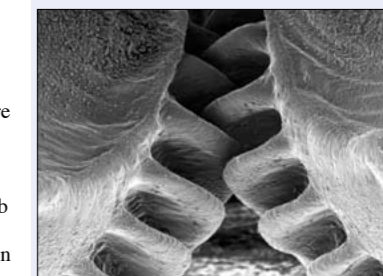
A new, inexpensive approach to making solar cells could beat silicon in price and efficiency. Mingzhen Liu and colleagues at the University of Oxford have shown that vapour-deposited perovskites can provide 15% efficiency at about \$0.15 per watt – a factor of four cheaper than silicon. This efficiency is already close to what has been achieved with silicon and is expected to improve. The fact that the flat layers work has come as something of a surprise, as expectations were that complicated nanostructuring would be needed. An advantage is that the devices produce more than 1 V, which is higher than the 0.7 V from silicon. Moreover, they absorb in a different spectral region, so they could even be printed on top of conventional silicon solar cells, boosting efficiency by 25% with only minor modifications to fabrication.

• **Further reading**
M Liu *et al.* 2013 *Nature* **501** 395.

Insect gears

For the first time, intermeshing gears that function like familiar mechanical gears have been found in an animal. Malcolm Burrows of the University of Cambridge and Gregory Sutton, now at the University of Bristol, have shown that the flightless planthopper insect *Issus* has, in its nymph stage, gears as part of its jumping mechanism. It uses the gears to synchronize motion of the two hind legs, rotating at an amazing 50,000 teeth per second. When the nymph molts to its adult form it seems to no longer need this mechanism and loses it. Once again, nature seems to have got a basic technology first.

• **Further reading**
M Burrows and G Sutton 2013 *Science* **341** 1254.



A scanning electron micrograph shows the gears in the *Issus* nymph. (Image credit: Malcolm Burrows.)



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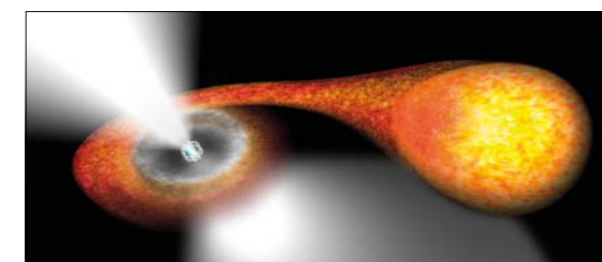
COMPILED BY MARC TÜRLE, ISDC AND OBSERVATORY OF THE UNIVERSITY OF GENEVA

Volatile millisecond pulsar validates theory

For the first time, astronomers have caught a pulsar in a crucial transitional phase that explains the origin of the mysterious millisecond pulsars. The newly found pulsar swings back and forth between accretion-powered X-ray emission and rotation-driven radio emission, bringing conclusive evidence for a 30-year-old model that explains the high spin rate of millisecond pulsars as a result of matter accretion from a companion star.

Pulsars are the highly magnetized, spinning remnants of supernova explosions of massive stars and are primarily observed as pulsating sources of radio waves. The radio emission is powered by the rotating magnetic field and focused in two beams that stem from the magnetic poles. Similarly to a rotating lighthouse beacon, the rotation of the pulsar swings the emission cone through space, resulting in distant observers seeing regular pulses of radio waves (*CERN Courier* March 2013 p12). It is actually the kinetic rotational energy of the neutron star that is radiated away, leading to a gradual slow down of the rotation. While pulsars spin rapidly at birth, they tend to rotate more slowly – with periods of up to a few seconds – as they age. For this reason, astronomers in the 1980s were puzzled by the discovery of millisecond pulsars – old but extremely quickly rotating pulsars with periods of a few thousandths of a second.

The mysterious millisecond pulsars can be explained through a theoretical model known as the “recycling” scenario. If a pulsar is part of a binary system and is accreting matter from a stellar companion via an accretion disc, then it might also



Artist's impression of a bright X-ray millisecond pulsar in a binary system accreting mass and angular momentum from a low-mass companion star. (Image credit: ESA.)

gain angular momentum. This process can “rejuvenate” old pulsars, boosting their rotation and making their periods as short as a few milliseconds. This scenario relies on the existence of accreting pulsars in binary systems, which can be detected through the X rays that are emitted in the accretion process. The discovery in the 1990s of the first X-ray millisecond pulsars was first evidence for this model but, until now, the search for a direct link between X-ray bright millisecond pulsars in binary systems and the radio-emitting millisecond pulsars has been in vain.

Now, the missing link to prove the validity of the scenario has finally been discovered by the wide-field IBIS/ISGRI imager on board ESA's INTEGRAL satellite. A new X-ray source appeared in images taken on 28 March 2013 at the position of the globular cluster M28. Subsequent observations by the XMM-Newton satellite found a modulation of its X-ray emission at a period of 3.9 ms, revealing the incredibly fast spin of the neutron star of more than 250 rotations per second. A very clear modulation of the delay in the pulse arrival time further showed that a low-mass companion star orbits the pulsar

every 11 hours.

These results obtained by an international team led by Alessandro Papitto from the Institute of Space Sciences in Barcelona were then compared with properties of a series of known radio pulsars in M28 and – luckily – they found one with precisely the same values. There is therefore no doubt that the radio and X-ray sources are the same pulsar, providing the missing link that validates the recycling scenario of millisecond pulsars. Follow-up radio observations by several antennae in Australia, the Netherlands and the US showed that the source does not exhibit radio pulsations when active in X-rays and vice-versa. It was only at the end of the X-ray outburst, on 2 May, that radio pulsations resumed.

This bouncing behaviour is caused by the interplay between the pulsar's magnetic field and the pressure of accreted matter. When the accretion dominates, the source emits X rays and radio emission is inhibited by the presence of the accretion disc closing the magnetic field lines.

• **Further reading**
 APapitto *et al.* 2013 *Nature* 501 517.

Picture of the month

While the almost 10-year old *Opportunity* rover starts the ascent of Solander Point on Mars and the *Curiosity* rover has recently found 2% of water in martian surface soil, the red planet is still being continuously scrutinized from orbiting satellites. This picture is an incredibly strange looking landscape revealed by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter (Picture of the month, *CERN Courier* December 2009 p11 and March 2010 p9). This “brain terrain” displays icy lobate features wrapping around a small hill. Researchers have identified them to be made of almost pure ice, but they do not know for sure if these martian ice deposits flow like Earth's glaciers and whether this could induce the mysterious lobate features or not. (Image credit: NASA/JPL/University of Arizona.)



CERN Courier Archive: 1970

A LOOK BACK TO CERN COURIER VOL. 10, NOVEMBER 1970, COMPILED BY PEGGIE RIMMER

CERN

First beams in the ISR



Kjell Johnsen (left) and Klaus Unser gathering beam data.



Wolfgang Schnell (left) tells it like it is to Mervyn Hine and Hildred Blewett (and Stuart Turner).



Bas de Raad announcing the news at 8.34 (20.34) according to his watch, two minutes after the first circulating beam.

Commissioning storage rings is not so clear-cut as commissioning an accelerator, where the day when particles are accelerated to near design energy is fanfare day. For storage rings it is probably the day when sufficient particles are stored in each beam with a long lifetime and collided to give a healthy interaction rate.

At the CERN Intersecting Storage Rings ISR, component installation in one of the rings is incomplete. But we must sound at least a few trumpets to celebrate the remarkable achievements when first injection tests were carried out with the completed ring.

The annual end-of-year shutdown of the 28 GeV proton synchrotron PS was scheduled so that it would be back on the air ready to send beams to the ISR early in 1971. However, when one ISR ring was completed in advance of the shutdown it was decided to have a few preliminary injection runs.

On the night of 29 October, a few PS bunches were assigned to the ISR while the rest were being used for physics. The ISR control room was thronged with people, including Kjell Johnsen, ISR Director, and practically all the design and construction team. Many others were there also: Bernard Gregory (Director General), John Adams (300 GeV project Director), Kees Zilverschoon (now PS Director, who played an important role in the ISR) and Hildred Blewett (without whom it would be presumptuous to attempt to commission a new machine).

Injection tests usually take days or weeks: getting the beam to go in properly, patiently coaxing it around the ring, progressively

correcting and optimizing the magnet fields. At the ISR, it was decided to set up the ring fields and see if the beam would get round.

Comes the moment, buttons are pressed, protons ejected from the PS are guided to the ISR, injected into the ring and the very first pulse sails right round and carries on sailing round. Probably never before has this happened with a ring anything like this size (about 1 km in circumference, second only to the 76 GeV proton synchrotron at Serpukhov) and complexity (the need to store circulating beams for hours make the ISR rings the most complex ever built). The myriad components, for ejection from the PS, transfer to the ISR, injection into the ISR, magnets, power supplies, vacuum system, beam monitoring system... were all working from the word go. The design team had proved themselves complete masters of their craft.

Within an hour beam storage tests had been carried out and protons had circulated

for over twenty minutes. Then came the first stacking test, when successive pulses from the PS were to be added together in the ISR ring to build up a large stored current. Buttons were again pressed and protons stacked at the first attempt, the current climbing steadily to nearly 60 mA.

Did nothing go wrong that night? Yes. The control room clock wasn't reliable and it took an hour to find the key to a locked room, healthy reminders that human beings were involved.

It now remains to bring in the other ring and climb towards a good beamlife, design beam intensities and design interaction rates. In the spring of next year it is hoped to achieve collisions. Experimenters will start installing detectors in the intersection regions and, in the middle of the year, the first experiments with high energy colliding proton beams are scheduled to begin.

● Compiled from texts on pp343–345.

Compiler's Note



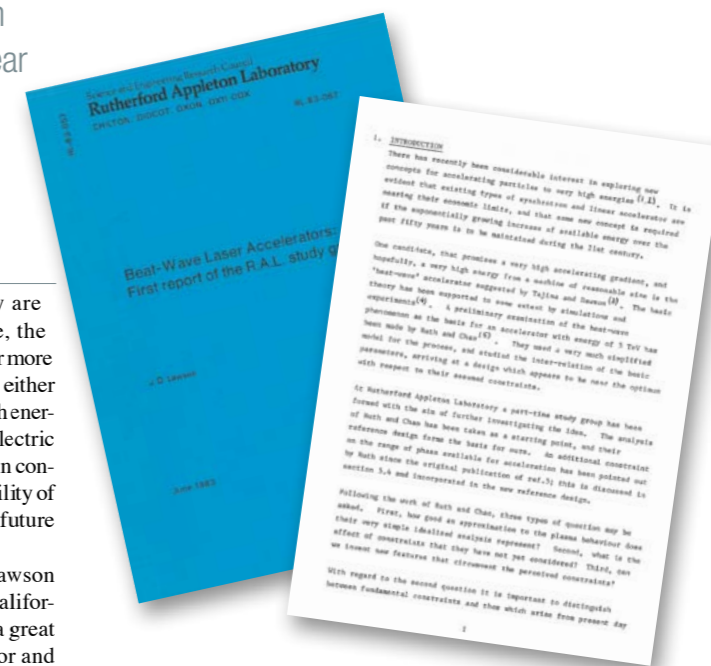
The ISR ran from 1971 until 1984. Its construction broke new ground in accelerator physics and also extended the CERN site beyond Switzerland into France. It produced the first-ever proton-proton collisions and, though the physics output may not have been earth shaking, converted many sceptics who had questioned the utility of a hadron collider. Notably, stochastic cooling was developed at the ISR, making it possible to build the SPS proton-antiproton collider, where the W and Z bosons were discovered 30 years ago.

The ISR tunnel is now used for storage and magnet work and its magnets form part of the LHC beam dump.

Plasma acceleration

To the terascale: catching the plasma wakefield

Thirty years ago, John Lawson led a design study into a laser-driven plasma-based linear accelerator for the 21st century. Study member **Robert Bingham** looks back at those days and the intervening progress.



Particle accelerators developed during the past century are approaching the energy frontier. Today at the terascale, the machines needed are extremely large and costly. However, for more than 30 years, plasma-based particle accelerators driven by either lasers or particle beams have shown promise for a route to high energies, primarily because of the extremely large accelerating electric fields they can support. About a thousand times greater than in conventional accelerators, the high fields would allow the possibility of compact accelerating structures. It is with this in mind that future facilities may incorporate aspects of plasma accelerators.

Plasma-based accelerators – the brainchild of John Dawson (who died in 2001) and his colleagues at the University of California, Los Angeles – are being investigated worldwide with a great deal of success. However, can they be a serious competitor and displace the conventional “dinosaur” variety? This is the question that the late John Lawson at the Rutherford Appleton Laboratory in the UK posed a few years after Dawson and his collaborator Toshi Tajima published their seminal paper on plasma-based accelerators (Tajima and Dawson 1979).

The accelerating fields in plasma are supported by the collective motion of plasma electrons forming a space-charge disturbance that moves close to the speed of light – commonly known as the plasma wakefield accelerator (*CERN Courier* June 2007 p28). The main advantage is that the plasma can support accelerating fields many orders of magnitude greater than conventional devices, which suffer from breakdown of the waveguide structure. In contrast, in a plasma-based system the plasma is already “broken down” and the collective electric field, E , supported by the plasma is determined by the electron density, n , such that $E \sim n^{1/2}$.

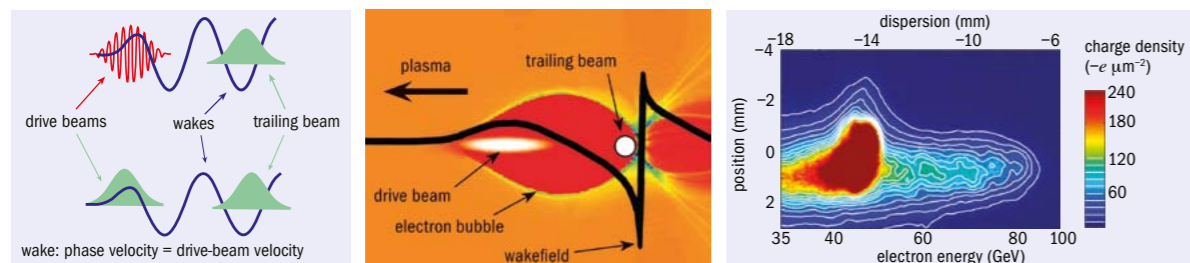
In 1982, Ronald Ruth and Alexander Chao in the US made a first qualitative design based on a simplified model for a linear laser-driven plasma accelerator that could yield electrons at 5 TeV (Ruth and Chao 1982). Spurred on by this, Lawson set up a study group

Lawson's 1983 report aimed at a reference design for a linear electron-positron collider above 1 TeV.

– including Ruth – to investigate the idea further and produce a design based on a more realistic model for a particle collider at the terascale for the 21st century. Published in the summer of 1983, the reference design considered electron energies above 1 TeV and – because of synchrotron radiation losses – a linear collider (Lawson *et al.* 1983). Indeed, it is as components of linear colliders that plasma accelerators continue to be considered.

At the time it was already clear that because of the increased energy advantage of colliding beams, all future high-energy accelerators would work in the colliding-beam mode. Conventional machines were planned that would reach the 1 TeV energy scale for hadrons and the 100 GeV scale for electron-positron colliders. These became the Tevatron at Fermilab, the SLAC Linear Collider and the Large Electron-Positron collider and Large Hadron Collider at CERN, which have made remarkably precise measurements of the W and Z bosons, as well as discoveries of the top \triangleright

Plasma acceleration



Left: A simple 1D schematic of how wakefields are excited by a short-pulse laser (top) or particle-beam (bottom) driver moving left to right in a plasma. Centre: 3D computer simulation of an extremely nonlinear wakefield excited by the drive beam in the “bubble” regime. The wakefield can accelerate an appropriately phased trailing beam at ultra-high gradients. Right: Energy spectrum observed in the experiment at SLAC where electrons at 42 GeV traversed 85 cm of lithium plasma. Particles in the back of the bunch reached 85 GeV.

quark and – most recently – a Higgs boson.

In the RAL report, Lawson writes that “the maximum energies thought ever to be practically achievable are of order 0.4 TeV per beam for e^+e^- and 20 TeV per beam for hadrons” and that these represent “the end of the dinosaurs”. However, radically new techniques such as plasma accelerators demand a long development time, so there is still ongoing development of conventional machines. These include the International Linear Collider for 350–500 GeV electrons and positrons with luminosity of the order of $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ and the more novel Compact Linear Collider for energies up to 3 TeV. In addition, there is the TLEP concept based on a synchrotron, which could also be used for protons (CERN Courier July/August 2013 p26).

The original plasma-accelerator schemes investigated were based on a long-pulse laser. Short-pulse lasers did not exist because chirp pulse amplification had not yet been demonstrated in the optical regime, only in the microwave regime. The Lawson design therefore incorporated the beat-wave mechanism of Tajima and Dawson, where two laser beams with a frequency difference equal to the plasma frequency drive a large-amplitude plasma wave with a phase velocity close to the speed of light. Most laser-driven and particle-driven particle accelerator experiments today are in the so-called bubble regime where the pulse length of the laser or particle beam is of the order of the plasma wavelength. In 2004, three independent groups in three different countries demonstrated mono-energetic electron beams with good emittance using short-pulse lasers and many groups worldwide now routinely produce electron beams at giga-electron-volt energies (CERN Courier November 2004 p5).

As a first attempt at finding a set of consistent parameters appropriate to a linear e^+e^- collider at a few tera-electron-volts, Lawson’s design was optimistic but it laid the groundwork for later studies on the scalings in length of such a machine. For example, Carl Schroeder and colleagues at Lawrence Berkeley National Laboratory (LBNL) recently looked at physics considerations for a 1 TeV machine based on plasma acceleration driven by a short-pulse laser (Schroeder *et al.* 2010).

Despite the difference in the accelerating structure considered in 1983, the outline design of the RAL report is still a good blueprint for a multi-tera-electron-volt device. Its main points are still being investigated. These include the construction of uniform metre-long plasma columns, laser focusing and guiding schemes, the laser

energy and efficiency requirements, staging, particle transport and focusing. There are also requirements on the particle bunch-density and on the beam quality in terms of energy spread, emittance and luminosity. Some of these issues are common to both plasma and conventional accelerators, although Lawson’s design brief was that plasma-based techniques should take particle accelerators to a new level, not easily achievable in a conventional machine.

In particular, in single-pass colliders, bunches are used only once and high densities are required. Self-fields add rather than cancel, causing a pinch that enhances the luminosity – provided the effect is not too strong. However, deflection of particles by the electric fields of the opposite bunch causes strong synchrotron-like radiation, known as beamstrahlung, which reduces the energy of the particles and increases the energy spread. This can be controlled by having fewer particles per bunch and instead having a train of “bunchlets” – a feature that Lawson’s report found to be advantageous.

Since then, researchers have solved many of the issues, an important one – highlighted by Lawson – being creation of a uniform plasma column. In an experiment at SLAC in 2007, Chan Joshi’s group at University of California, Los Angeles, successfully demonstrated acceleration in metre-long plasma columns using lithium vapour that was fully ionized by the head of an electron beam. The resulting wakefield then accelerated particles near the back of the beam pulse. This idea will be incorporated in the group’s latest round of experiments to accelerate electrons and positrons using the electron-beam-driven plasma wakefield facility, FACET, at SLAC (CERN Courier March 2011 p23). It also underpins the proton-beam-driven plasma wakefield experiment, AWAKE, which will use a beam from CERN’s Super Proton Synchrotron and, initially, a 10-m-long plasma column, to produce giga-electron-volt electron beams (see p17).

Today, most experiments such as the Berkeley Lab Laser Experiment (BELLA) at LBNL and FACET at SLAC, as well as other smaller-scale experiments, are aimed at addressing some of the key areas of the underlying physics that still have not been fully resolved. Joshi’s experiment not only showed that metre-length plasma columns can be built with the required density and homogeneity, it also demonstrated energy doubling of an electron beam from 42 GeV to 85 GeV in the lithium plasma – a remarkable result considering that it takes 3 km of the SLAC linac to accelerate electrons to 42 GeV

Plasma acceleration

(CERN Courier April 2007 p5). Laser wakefield experiments already demonstrate mono-energetic electron beams at the giga-electron-volt scale and BELLA, which is nearing completion of a petawatt-class laser, will demonstrate acceleration of electrons to 10 GeV (CERN Courier October 2012 p10).

Despite the successes of these experiments, it is still necessary to demonstrate beam quality – including low-energy spread and low emittance – and focusing of useful beams. In all cases, the experiments are guided by plasma simulations that require the largest computers. Such simulations have already demonstrated that in the range 10–50 GeV electron beams can be created in one stage of a plasma accelerator.

If plasma accelerators are to take over from conventional machines, a great deal of effort still needs to be put into efficient drivers. Suitable laser efficiency and pulse rate are looking likely with diode-pumped lasers or with fibre lasers (see p21), but effort has to be put into these schemes to meet the requirements necessary to drive a wakefield. For beam-driven systems, electron beams at 100 GeV and proton beams with tera-electron-volt energies are required. These exist at the LHC for protons and at the old SLAC linac for electrons. For an e^+e^- system, a key challenge is positron acceleration and some groups are looking at positron acceleration in wakefields. Alternatively an e^-e^- collider or a photon ($\gamma-\gamma$) collider could be built, doing away with the need for positrons and so saving time and effort.

A number of other applications for plasma-based accelerators have been identified such as X-ray generators through betatron radiation, drivers for free-electron lasers, or low-energy proton machines. After more than 30 years it is time to develop the facilities that can answer some of the outstanding issues to demonstrate the full potential of high-energy plasma-based accelerators.

Further reading

J D Lawson 1983 *RL-83-057* <http://purl.org/net/epubs/work/22839>.
R D Ruth and A Chao 1982 *AIP Conference Proceedings* **91** 94; LBL-14332.
C B Schroeder *et al.* 2010 *Phys. Rev. ST. Accel.* **13** 101301.
T Tajima and J M Dawson 1979 *Phys. Rev. Lett.* **43** 267.

Résumé

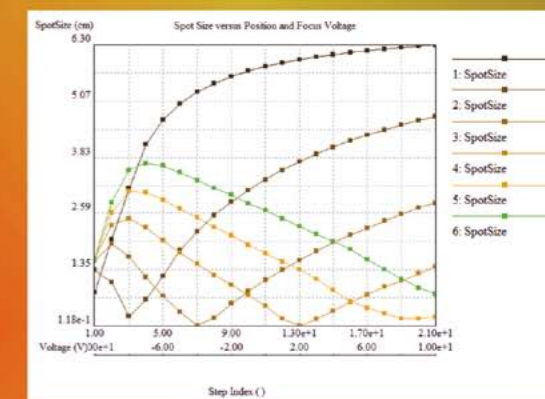
Champs de sillage plasma à l'échelle du téra

Il y a 30 ans, John Lawson, du Laboratoire Rutherford Appleton, menait une étude de conception concernant un accélérateur linéaire à champs de sillage plasma excités par laser pour le XXI^e siècle. Le modèle de conception produit alors reste une référence pour la définition d'une machine de plusieurs TeV, car la plupart des points importants soulevés à l'époque sont encore à l'étude. Certains problèmes majeurs ont été résolus, notamment la production de faisceaux d'électrons à haute énergie avec une bonne émittance, et la formation d'une colonne de plasma uniforme. Cependant, différentes expériences poursuivent les efforts visant à trouver des réponses à des questions essentielles de la physique sous-jacente.

Robert Bingham, Central Laser Facility, Rutherford Appleton Laboratory and University of Strathclyde.

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AWAKE: to high energies in a single leap

Proton-driven plasma wakefield acceleration could accelerate electrons to the terascale in a single plasma stage. The AWAKE project is set to verify this novel technique using proton beams at CERN.

To complement the results that will come from the LHC at CERN, the particle-physics community is looking for options for future lepton colliders at the tera-electron-volt energy scale. These will need to be huge circular or linear colliders. With the accelerating gradients of today's RF cavities or microwave technology limited to about 100 MV/m, the length of the linear machines would be tens of kilometres. However, plasma can sustain much higher gradients and the idea of harnessing them in plasma wakefield acceleration is gathering momentum. One attractive idea is to use a high-energy proton beam as the driver of a wakefield in a single plasma section.

To verify this novel approach, a proof-of-principle R&D experiment – the Advanced Wakefield Experiment (AWAKE) – has been launched at CERN, using 400 GeV proton bunches from the Super Proton Synchrotron (SPS). AWAKE will be the first beam-driven wakefield-acceleration experiment in Europe and the first proton-driven plasma-wakefield-acceleration experiment in the world. The results will have a significant impact on future larger-scale R&D on this technique, for example in accelerating electron bunches to around 100 GeV in 100 m.

Previous research on the potential of plasma as a medium for high-gradient acceleration has focused on injecting a short, intense laser pulse or an electron bunch into a plasma cell. With laser excitation, electrons have been accelerated to 1 GeV in 3 cm, with a gradient of 33 GV/m (CERN Courier November 2006 p5). In other experiments using an electron bunch as driver, the energy of particles in the tail of a bunch was doubled from 42 GeV to 85 GeV in 85 cm – corresponding to a gradient of 52 GV/m (CERN Courier April 2007 p5). However, the energy gain in these studies is limited by the energy carried by the laser or electron drive beam (<100 J) and the propagation length of the driver in the plasma (<1 m). Therefore the staging of a large number of acceleration sections would be required to reach the interesting region of 1 TeV per particle or more.

Proton beams of the kind produced at CERN could overcome the

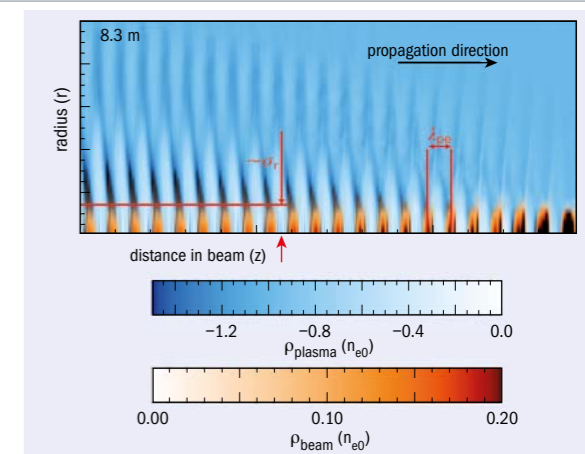


Fig. 1. Simulation of a self-modulated proton bunch resonantly driving plasma wakefields sustained by the plasma-density perturbation. The plasma density is shown increasing from white to blue and the proton density increasing from yellow to dark red.

issue of staging. In the SPS, beams with 3×10^{11} protons per bunch at 400 GeV/c carry much higher energy (19 kJ). This would drive wakefields over much longer plasma lengths than other methods and consequently proton drivers can take a witness beam to the energy frontier in a single plasma cell. Simulations have shown that an LHC-type proton bunch (1 TeV, 10^{11} protons) with an rms bunch length of 100 μm can accelerate an incoming 10 GeV electron bunch to more than 500 GeV in around 500 m of plasma with an average gradient ≥ 1 GV/m (Caldwell *et al.* 2009, Lotov *et al.* 2010).

To reach accelerating gradients of a gigavolt per metre or more requires plasma densities where the number of electrons, n_e , is of the order of 10^{15} cm^{-3} . At these intensities the plasma wavelength, λ_{pe} , is about 1 mm. To achieve the maximum electric field in the plasma, the drive beam requires short, densely packed proton beams with a longitudinal bunch length, σ_z , of the same order as λ_{pe} .

The proton bunches available today are much longer – with σ_z around 10 cm – and producing bunches as short as 1 mm is not possible without major investment. However, the effect known as self-modulation instability (SMI) provides fortuitous opening of the path to an immediate experimental investigation of proton-driven wakefield acceleration with the existing proton bunches at CERN.

A proton beam propagating in plasma produces micro-bunches \triangleright

Plasma acceleration

that are generated by transverse modulation of the bunch density. These micro-bunches are naturally spaced at λ_{pe} and so resonantly excite a strong plasma wave (figure 1, p17). Recent studies have shown that wakefields at high amplitudes – similar to what would be driven if all of the charge were in a single short bunch – can be achieved with a modulated long proton bunch (Kumar *et al.* 2010, Caldwell *et al.* 2011).

The AWAKE experiment

The AWAKE experiment at CERN was proposed by an international collaboration that is today made up of 13 institutes – including the Budker Institute of Nuclear Physics, CERN, MPI Munich and University College London – and numbers more than 50 engineers and physicists. In addition, several more institutes have expressed interest in participating in AWAKE. The collaboration first outlined the proposed experiment in a letter of intent that was presented to the SPS Committee in 2011. This was followed in March 2013 by a technical design report that was submitted to the CERN management and to the SPS Committee (Caldwell *et al.* 2013). A positive review and recommendation of the project led to approval of the AWAKE experiment by the CERN Research Board in August.

The measurement programme of the AWAKE project includes benchmark experiments using proton bunches to drive wakefields and to understand the physics of the proton self-modulation process in the plasma. It will also probe the accelerating wakefields with externally injected electrons, study the injection dynamics and production of multi-giga-electron-volt electron bunches, and develop long, scalable and uniform plasma cells and schemes for the production and acceleration of short proton bunches.

Figure 2 shows the conceptual design of the AWAKE experiment. An LHC-type proton bunch of 400 GeV/c but with higher intensity (around 3×10^{11} protons per bunch) and with a longitudinal rms length, σ_z , of 9–12 cm will be extracted from the SPS and sent to the experiment, where it will be focused to a transverse dimension of 200 μm near the entrance of a plasma cell. A 2 TW laser pulse co-propagating within the proton bunch creates the plasma by ionizing the (initially neutral) gas in the plasma cell. This sudden plasma creation seeds the SMI of the proton bunch. The SMI develops in the proton beam over the first few metres of the plasma, then saturates and the bunch becomes self-modulated. After the SMI saturation, an electron beam with 10^9 electrons, energy of around 16 MeV and with $\sigma_{z, \text{electrons}} > \lambda_{pe}$ will be side-injected at a small angle (a few milliradians). A fraction of the electrons will be trapped in the wakefield and accelerated.

For the first experiments, the plasma cell will be a 10-m-long rubidium vapour source, with the necessary longitudinal density uniformity of around 0.2%. With the current AWAKE baseline parameters, simulations show that the electrons could be accelerated to energies higher than 2 GeV, with an energy spread of a few per cent and achieving a gradient of 0.1–1.2 GV/m along the 10-m-long plasma.

At a later stage the experiment will use two plasma cells and on-axis electron injection. The first cell will preserve the SMI seeding ability and the second will be used for electron acceleration in the wakefields that are resonantly driven by the modulated proton bunch. Introducing a step in plasma density during the growth of

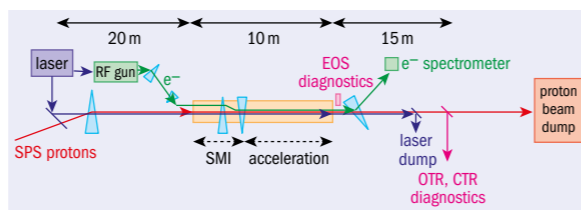


Fig. 2. Baseline design of the AWAKE experiment at CERN.

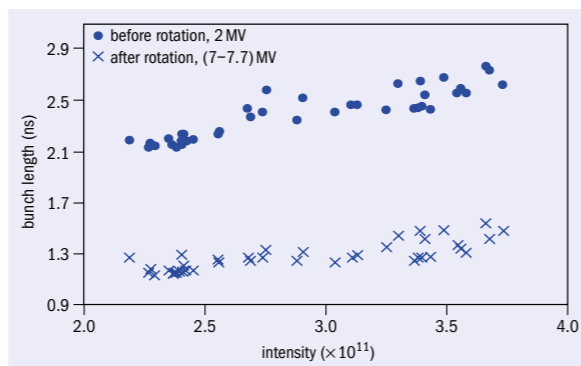


Fig. 3. Flat-top bunch length (4σ Gaussian fit) as a function of intensity, showing the effect of rotation in shortening the bunches in studies at the SPS.

the SMI could maintain the wakefields at the level of gigavolts per metre over distances of several metres.

Short, high-intensity bunches have already been studied at the SPS and the scaling of bunch length and transverse emittance as a function of beam intensity has been identified to guide the design parameters of the AWAKE project (Argyropoulos *et al.* 2013). To obtain a short longitudinal bunch length, the bunches are rotated in longitudinal phase space using the maximum available RF voltage before extraction. Figure 3 shows the bunch length measured before rotation, at 2 MV, and after rotation, at 7–7.7 MV.

The AWAKE experiment will be installed in the existing CERN Neutrinos to Gran Sasso (CNGS) facility (CERN Courier November 2006 p20). This deep underground area, which is designed for running an experiment with a proton beam of high energy and intensity, has a 750-m-long proton beamline that is optimized for a fast extracted beam from the SPS at 400 GeV/c. Figure 4 shows the integration of the AWAKE experiment in the experimental area, with the plasma cell installed in the downstream end of the CNGS proton-beam tunnel and upstream of the CNGS target.

Although the facility already exists, there are several issues that need to be tackled to set up the AWAKE experiment in this area. Essential modifications to the end of the proton beamline include changes to the beam instrumentation and to the final focusing system, in addition to integration of the laser and electron beam with the proton beam. General services such as cooling and ventilation, electricity, radiation monitoring and an access system exist and are operational but some changes will be necessary to adapt them to the AWAKE set-up.

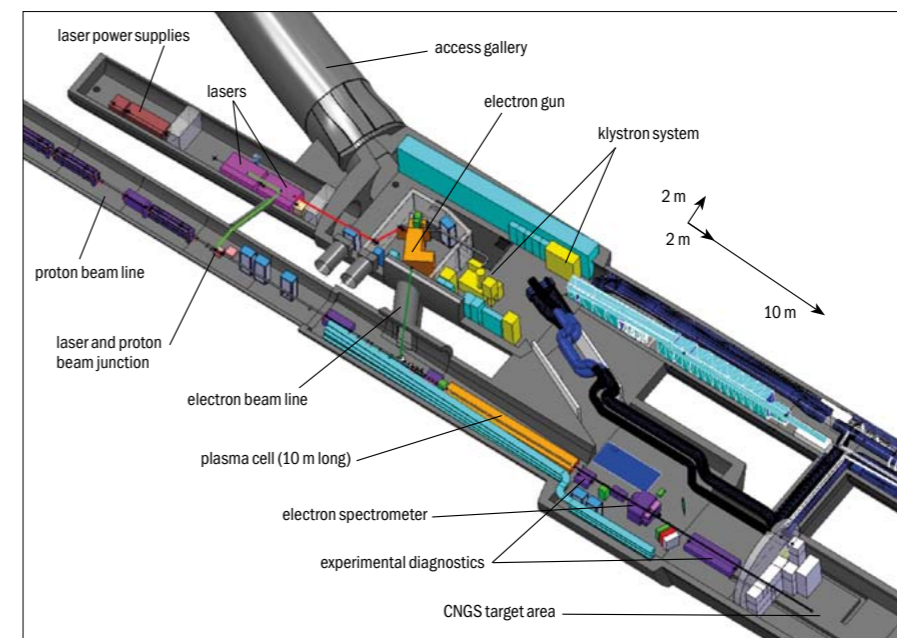


Fig. 4. Integration of the AWAKE experiment in the experimental area at the CNGS facility. Items in dark blue are ventilation ducts. Items in light blue are AWAKE electronic racks. Items in cyan are existing CNGS equipment (cable trays, pipes, etc).

The laser system will be housed in an area that is modified to be dust free and temperature regulated. The high-power laser beam will be transported through a new dedicated tunnel connecting the laser area to the proton-beam tunnel. The area adjacent to the experimental area will be modified to house the electron source and its klystron powering system. The electrons will be transported from the source to the proton-beam tunnel along a beamline through a new 7-m-long liaison tunnel before being injected into the plasma cell. This electron beamline is designed for both side injection (long electron bunches) and on-axis injection (short electron bunches).

The electron source will be driven by a laser pulse that is derived from the same laser system used for the plasma ionization, which will require a synchronization between the laser pulse and the electron beam at a level below 1 ps. The desired synchronization of around 100 ps between the proton beam and the laser beam will be achieved by re-phasing and locking the SPS RF to a stable mode-locker frequency reference from the laser system.

To measure the properties of the electron acceleration, a state-of-the-art magnetic spectrometer with large momentum acceptance (10–5000 MeV) and good momentum resolution will be installed downstream of the plasma cell. A scintillating screen connected to a CCD camera will show the electrons exiting the spectrometer. For the proton beam, various diagnostics will measure the self-modulation effects downstream of the plasma cell. The protons will then be dumped in the existing CNGS beam dump, which is 1100 m downstream of the experimental area, therefore avoiding any radiation into the AWAKE region.

With official approval of the AWAKE experiment in August, the collaboration is now fully “awake” and the first protons can be sent to the plasma cell at the end of 2016. This will be followed by an initial three-to-four-year experimental programme with four

periods of data-taking annually, each lasting two weeks.

Further reading

- For more about AWAKE see <http://awake.web.cern.ch/awake/>.
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Résumé

AWAKE : des hautes énergies en un clin d'œil

L'accélération par champ de sillage plasma entraînée par des protons pourrait permettre l'accélération d'électrons à l'échelle du téra en une seule cellule plasma. C'est pour mettre à l'épreuve cette approche novatrice qu'a été lancée au CERN l'expérience de démonstration du principe AWAKE (accélération par champ de sillage plasma entraînée par des protons). Le projet utilisera des paquets de protons de 400 GeV issus du Supersynchrotron à protons ; ce sera la première expérience d'accélération par champ de sillage entraînée par un faisceau en Europe, et la première expérience de ce type s'appuyant sur un faisceau de protons au monde. Les résultats auront un impact considérable sur les futures expériences de R&D utilisant cette technique, qui seront utilisées à plus grande échelle et qui pourraient consister par exemple en l'accélération de paquets d'électrons à environ 100 GeV sur une centaine de mètres.

Edda Gschwendtner, CERN, for the AWAKE collaboration.

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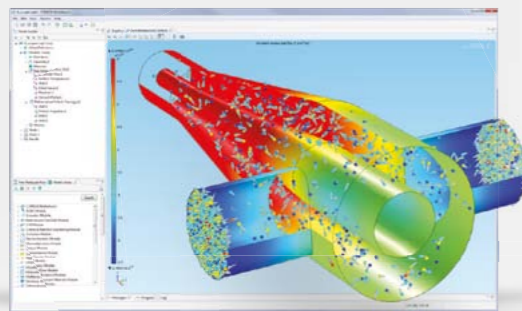
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Can fibre be the future of high-energy physics?

A new laser system that is based on huge arrays of thousands of fibre lasers could provide a way to future laser-driven accelerators, both for fundamental research and for many applications.



Fig. 1. The concept of the CAN fibre laser, in which an initial pulse from a seed laser is stretched and split into many fibre channels. Each channel is amplified in several stages and then combined coherently, compressed and focused to produce a pulse with >10J energy at a repetition rate of around 10kHz. (Image credit: Phil Saunders/spacechannel.org.)

The interaction with plasma of ultra-high-peak-power lasers at the terawatt to petawatt level has the potential to generate large accelerating gradients of giga-electron-volts per metre. Laser-plasma acceleration could therefore be an important replacement for present technology. However, there are two formidable hurdles to overcome: a laser repetition rate that is limited to a few hertz leading to an average power of only a few watts and a dismal wall-plug efficiency of a fraction of a per cent. This twin technological challenge must be resolved if laser wakefield acceleration is to be considered for large-scale applications in science and society.

On 27–28 June, the International Coherent Amplification Network (ICAN) Consortium concluded its EU-supported 18-month feasibility study with a final symposium at CERN that was organized by Ecole Polytechnique, the University of Southampton, Fraunhofer IOF Jena and CERN. A major topic concerned progress with the novel laser architecture known as coherent amplification network (CAN), which could for the first time provide petawatt peak power at a repetition rate as high as 10kHz. This corresponds to an average power in the megawatt range with an efficiency better than 30% and opens the door to many applications.

The symposium also looked at the path towards future laser-driven accelerators and colliders, applications in free-electron lasers and neutron/neutrino sources, as well as the laser search for the “dark fields” of dark matter and dark energy. Other topics included compact proton accelerators that could be used for accelerator-driven systems for nuclear energy or for hadron therapy, as well as the generation of γ -ray beams with a host of applications, from the identification of isotopes in exposed spent nuclear fuel – such as at Fukushima – to nuclear pharmacology.

The main paradigm currently driving fundamental high-energy physics is the high-energy charged-particle collider. To apply laser-acceleration methods to a future collider, the international communities involved in intense lasers and high-energy physics

– in the form of the International Committee on Ultra-High Intensity Lasers (ICUIL) and the International Committee for Future Accelerators (ICFA), respectively – came together in 2009 to form a collaborative working group to study how best to proceed. The ICFA-ICUIL Joint Task Force (JTF) produced a report noting that while the science of laser acceleration has matured, the technology for intense lasers is lagging behind, specifically in the development of systems with a high repetition rate and high efficiency (Leemans *et al.* 2011).

The science of laser acceleration has matured, but the technology for intense lasers is lagging behind.

The possibility of amplifying laser pulses to extreme energy and peak power not only offers a route to a more compact and cheaper way to perform high-energy physics, it could also open the door to a complementary research area that is underpinned by single-shot, high-field laser pulses – a new \triangleright

Plasma acceleration

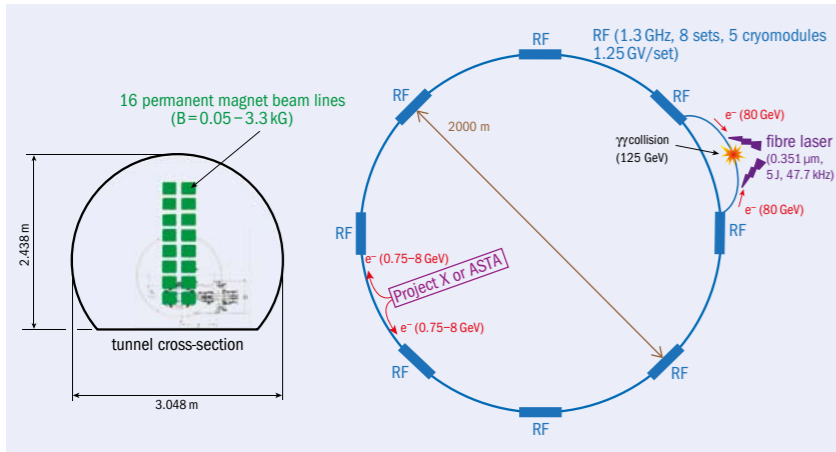


Fig. 2. The photon-collider concept for a Higgs factory in the Tevatron Tunnel (HFITT), where the CAN laser provides a source of low-energy photons to generate high-energy γ rays through inverse Compton scattering from two electron beams travelling in opposite directions. Each beam circulates through eight rings of permanent magnets, while being accelerated to 80 GeV. (Image credit: Chou et al. 2013.)

field of (laser-based) high-field fundamental physics (Tajima and Dawson 1979 and Mourou *et al.* 2006). To muster the support of the scientific community for this vision, the International Center on Zetta-Exawatt Science and Technology (IZEST) was set up in 2011 and now has 23 associated institutes worldwide.

The ICAN project

Stimulated by the JTF's report, members of IZEST set up the ICAN project, which involves a total of 16 institutes including Ecole Polytechnique, the University of Southampton, Fraunhofer IOF Jena and CERN as beneficiaries with a further 13 institutes participating as experts. Starting in October 2011, ICAN began research on the development of the fibre-laser-based CAN concept. Here, pulses from thousands of fibre lasers – built on technology that was originally developed for the telecommunications industry and each capable of producing low-energy pulses efficiently and at a high repetition rate – are coherently added to increase the average power and pulse energy linearly as the number of fibres increases (figure 1, p21). The ICAN project has shown that this architecture can provide a plausible path towards the necessary conditions for a high-energy collider based on a laser accelerator, so answering the challenge that was posed by the JTF report. The fibre laser offers excellent efficiency (>30%) thanks to laser-diode pumping and provides a much larger surface cooling area, therefore making operation at high average power possible.

The most stringent requirement is to phase all of the lasers within a fraction of a wavelength. This originally seemed insurmountable but a preliminary proof of concept that was discussed earlier this year in *Nature Photonics* suggests that tens of thousands of fibres can be controlled to provide a laser output that is powerful enough to accelerate electrons to energies of several giga-electron-volts at a 10 kHz repetition rate. This is an improvement of at least 10,000 times on today's state-of-the-art (Mourou *et al.* 2013). Furthermore, experiments have demonstrated the feedback control of the phase and timing of pulses from each fibre to the attosecond precision necessary for coherent addition. This means that the spatial profile of the overall laser pulse can be delicately controlled to provide a precise beam shape – a highly desirable feature for laser accelerators.

Immediately after the publication of the article in *Nature*

Photonics, the group at Fermilab re-launched the concept of a photon (γ - γ) collider for a Higgs factory, using the CAN laser as the source of low-energy photons to generate high-energy γ rays through inverse Compton scattering from two electron beams (figure 2). Such a collider would have a lower beam energy than the equivalent electron-positron collider and less noise (Chou *et al.* 2013). The required repetition rate is around 50 kHz, within the reach of CAN technology.

Fundamental physics via high fields

While a photon collider would study Higgs physics and other high-energy phenomena, copious coherent photons from the CAN lasers could also provide a new opportunity to look for undetected “dark fields” that are associated with low-energy dark matter (axion-like particles, for example) and dark energy (Tajima and Homma 2012). The use of three distinct parallel lasers with huge numbers of photons could allow sensitive detection of possible dark fields. The basic idea is akin to degenerate four-wave mixing, well known in traditional nonlinear optics but in this case probing the vacuum, whose possible nonlinear constituent is so weak that it has appeared “dark” until now. Since the parallel injection of lasers can make their beat frequency particularly low, the range of detectable masses is extremely low – down to nano-electron-volts – compared with orthodox high-energy physics experiments. The extremely high equivalent luminosity is also unusual. Because of the coherence of the photons, the luminosity of the events is proportional to

The most stringent requirement is to phase all of the lasers within a fraction of a wavelength.

the triple products of the numbers of photons from the three lasers – $N_1 N_2 N_3$. If the laser has 10 kJ energy, the N_i here can each be as large as 10^{23} . On the other hand, the luminosity of a charged-particle collider is proportional to $N_a N_b$, where a and b represent the two beams and these N_j are typically around 10^{10} . The two products that determine the luminosity of each “collider” therefore differ

by as much as 50 orders of magnitude.

Laser-driven acceleration processes, laser wakefield acceleration and the related physical processes might also appear in nature, as demonstrated by the recent realization that the accretion disc of a supermassive black hole and its associated jets could be the theatre for extreme high-energy cosmic-ray acceleration up to 10^{21} eV and accompanying γ -ray emission (Ebisuzaki and Tajima 2013). The disruptive magnetic activities of the disc give rise to the excitation of huge Alfvén waves and the mode-converted electromagnetic waves created in the jet are capable of accelerating ions to extreme energies via a process that is similar to laser acceleration. The coherence of the relativistic waves and particles implies a fundamental similarity between terrestrial and celestial wakefield acceleration processes. It is hoped that one day celestial-type wakefields might be achieved by a similar physical process but on different scales on Earth.

Applications in society

Turning to more earthly issues, the CAN fibre laser opens up many doors to challenging issues in society. With high average power at the same time as high peak power, along with high efficiency and inherent controllability, the CAN source is applicable to many new areas, of which the following are a few examples.

Laser acceleration of protons would provide compact installations compared with conventional accelerators, which could lead to compact proton-therapy accelerators (Habs *et al.* 2011). As the intensity of the laser becomes highly relativistic and the dynamics of proton acceleration become more relativistic, the acceleration mechanism becomes more efficient and the beam quality improves (Esirkepov *et al.* 2004). It then becomes plausible to produce an efficient, compact proton source in the relativistic regime.

Laser-driven compact proton beams could also act as the source of neutrons for accelerator-driven systems and accelerator-driven reactors for nuclear energy (figure 3). The high-fluence CAN laser offers the potential for highly efficient compact neutron sources that would be less expensive than those based on conventional methods (Mourou *et al.* 2013).

Just as in the case of the photon collider but at lower energies, the CAN laser can produce copious γ rays with specified energy in a well defined direction. Such γ -ray sources are useful for detection in nuclear physics, such as in isotopic determination via nuclear resonance fluorescence. Since a CAN-driven γ -ray source could be compact enough to be portable, it could be used for isotopic diagnosis of exposed spent nuclear fuel – as at Fukushima – without contact or proximity. Other industries – auto, chemical, mechanical, medical, energy, etc – have the need for high-fluence, high-efficiency short-pulse lasers. One example is nuclear pharmacology. Since a CAN source produces γ rays (and so neutrons) of specific energy, it can be used to create specific isotopes of nuclei that are known to be useful for medical purposes (Habs *et al.* 2011).

The future looks bright for fibre lasers – not only in high-energy physics but in many applications for society.

Further reading

For more about the IZEST project, see www.izest.polytechnique.edu.

Plasma acceleration

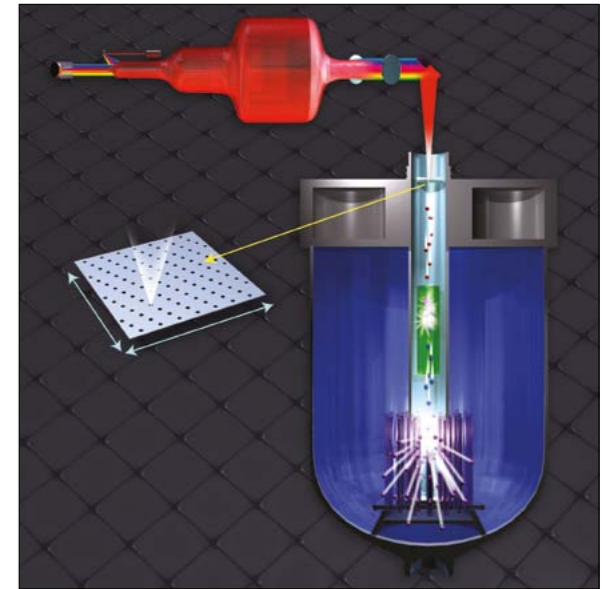


Fig. 3. A concept for an accelerator-driven reactor in which a fibre-based proton accelerator drives a spallation neutron source, which can be used to transmute minor actinides into less toxic elements. (Image credit: Phil Saunders/spacechannel.org.)

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T Esirkepov *et al.* 2004 *Phys. Rev. Lett.* **92** 175003.

D Habs, T Tajima and U Koester 2011 *Current Cancer Treatment: Novel Beyond Conventional Approaches* Öner Özdemir (ed.) InTech chapter 10.

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G Mourou, T Tajima and S Bulanov 2006 *Rev. Mod. Phys.* **78** 309.

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T Tajima and J M Dawson 1979 *Phys. Rev. Lett.* **43** 267.

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Résumé

La fibre est-elle l'avenir de la physique des hautes énergies ?

En juin dernier, le consortium ICAN (International Coherent Amplification Network) a conclu son étude de faisabilité, financée par l'UE, par un colloque au CERN. Les avancées du concept novateur de laser CAN (coherent amplification network) ont été un thème-phare de la conférence. La technique permettrait de commander des dizaines de milliers de fibres afin d'aboutir à une puissance laser suffisante pour accélérer des électrons à une énergie de plusieurs GeV. Ayant le potentiel de fournir une puissance moyenne de l'ordre du mégawatt, le laser CAN aurait également de nombreuses applications au-delà de la physique des particules, s'appuyant sur des accélérateurs de protons compacts.

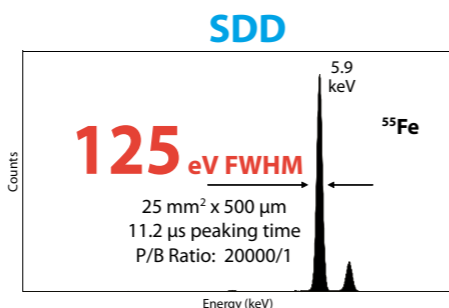
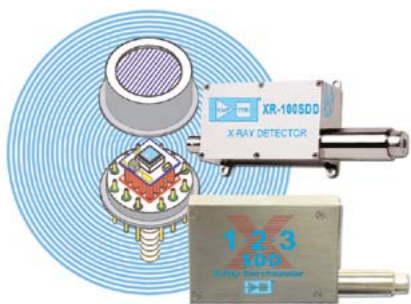
Toshiki Tajima, University of California, Irvine, Gérard Mourou, Ecole Polytechnique, William Brocklesby, University of Southampton, and Jens Limpert, Fraunhofer IOF and Friedrich Schiller University, Jena.

Silicon Drift Detector

Easy to Use

Solid State Design

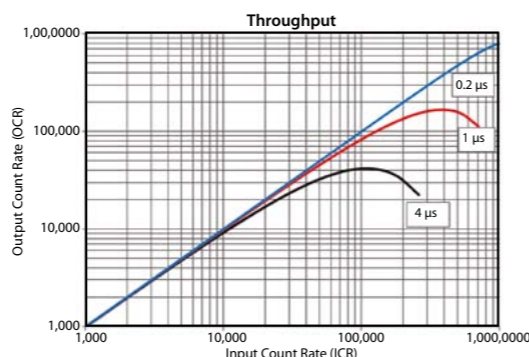
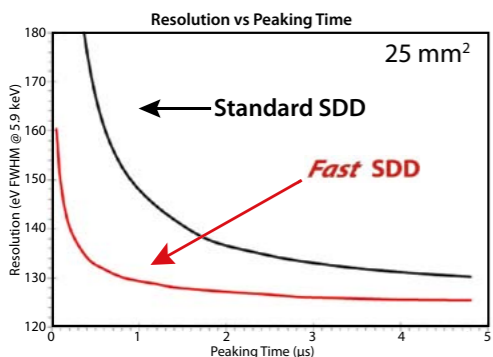
Low Cost



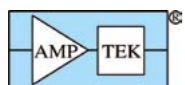
Fast SDD

Count Rate = >1,000,000 CPS

Resolution	125 eV FWHM	130 eV FWHM	140 eV FWHM	160 eV FWHM
Peaking Time	4 µs	1 µs	0.2 µs	0.05 µs



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ICRC 2013: from Earth to the galaxy and beyond

The major conference in the fields of astroparticle and solar physics took place for the first time in South America this year. Exciting results were an important part of a lively time in Rio de Janeiro, as **Ronald Shellard** reports.

At the traditional dinner party they danced to samba music while holding caipirinhas. During the day, the more than 700 physicists who attended the 33rd Cosmic Ray Conference (ICRC 2013) in Rio de Janeiro listened carefully during the 400 scheduled talks in a variety of plenary and parallel sessions on 2–9 July. Instead of caipirinhas, they held laptops and notepads as they focused on the important findings and data presented at the first ICRC to be held in South America.

Organized under the auspices of the International Union of Pure and Applied Physics (IUPAP) and its C4 Commission on Cosmic Rays, ICRC 2013 was hosted by the Centro Brasileiro de Pesquisas Físicas – an institute of the ministry of science, technology and innovation – the Federal University of Rio de Janeiro and the Brazilian Physical Society. It was sponsored by the National Council for Scientific and Technological Development (CNPq), the Coordination for Improvement of Higher Education Personnel (CAPES) and the Research Support Foundation of the state of Rio de Janeiro (FAPERJ).

The location in South America was not the only “first”. The organization of the 33rd ICRC had a scientific programme committee for the first time, consisting of leading experts in solar and heliospheric physics, cosmic-ray physics, gamma-ray astronomy, neutrino astronomy and dark-matter physics. Also for the first time, ICRC included research on dark matter as a main branch of the programme. For this reason, ICRC 2013 adopted the subtitle “The Astroparticle Physics Conference”. This might also become the C4 Commission’s new name,

as Johannes Knapp, the commission’s chair, announced during the closing session. The commission organized a poll during the nine days of the conference in which all registered participants could vote on changing the name from “Cosmic Rays” to “Astroparticle Physics”. The majority voted for the change and the commission is now consulting IUPAP on the matter. To maintain tradition, the conference’s main title – ICRC – will remain unchanged.

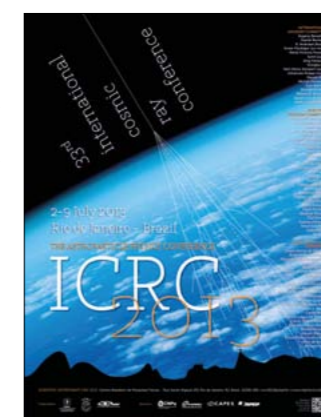
ICRC 2013 was certainly a success. During the plenary session on results from the Pierre Auger Observatory, Antoine Letessier-Selvon of CNRS and Université Pierre et Marie Curie presented evidence of what could be called “the muon problem”. It concerns the conflict between the prediction from Monte Carlo simulations of the number of muons in the surface Cherenkov detectors and the value extracted from the experimental data, which is about a factor of 1.5 higher. Letessier-Selvon argued that a change in composition at higher energies is not sufficient to explain the discrepancy.

The ground-based gamma-ray experiments HESS, MAGIC and VERITAS have added new gamma-ray sources – both in the galaxy and beyond it – to the catalogue, which now totals about 150 sources. Teams at the northern-hemisphere observatories reported flaring of the blazar Mkn 421 in April this year, while MAGIC registered another flare in November 2012, in IC 310 – an extra-galactic source that it had previously discovered. Miguel Mostafa of Colorado State University presented the results of the “first light” – in fact, gamma

rays – in the High Altitude Water Cherenkov Observatory installed at an altitude of 4150 m in Mexico. It is designed to detect ultra-high-energy gamma rays and is sensitive to energies above 300 GeV. With approximately only one third of the detector in operation, the collaboration was still able to present their view of the Mkn 421 flare of April.

In neutrino research, the IceCube experiment has some thrilling results. Spencer Klein of the Lawrence Berkeley National Laboratory and the University of California, Berkeley presented the 28 events that were detected with energies above 50 TeV, which include the previously revealed events above 1 PeV (CERN Courier July/August September 2013 p5). Klein also spoke of the observation of another very-high-energy event in the ongoing analysis of 2012 data – but its characteristics remain “top secret”.

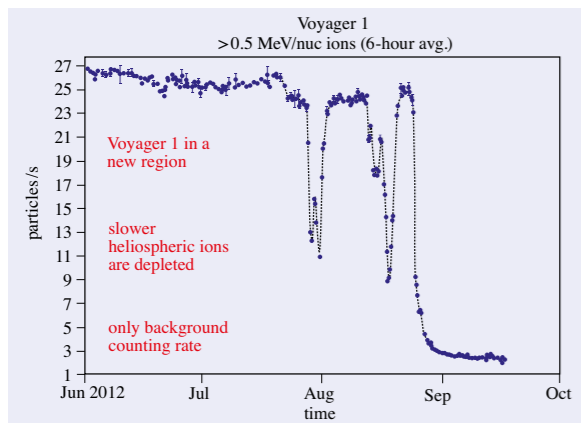
Another highlight of ICRC 2013 was the



With dark matter as a main branch of the programme, ICRC 2013 adopted the subtitle “The Astroparticle Physics Conference”.



Astroparticle physics



Data from Voyager 1 show a clear “wall” characterizing the heliosheath – and indicating that after travelling for 36 years, the spacecraft is at the edge of the solar system.

presentations by Nobel laureate Sam Ting and the Alpha Magnetic Spectrometer (AMS) collaboration of the first results from two years of AMS-02 operation on the International Space Station (ISS). The main goal is to perform a high-precision, large-statistics and long-duration study of cosmic nuclei, elementary charged particles and gamma rays. At the conference the collaboration presented high-precision measurements of the fluxes, ratios and anisotropies of electrons and positrons, as well as first results on proton and helium fluxes (*CERN Courier* October 2013 p22).

Moving further out in space, Ed Stone from Caltech presented the saga of the Voyager 1 spacecraft, launched in 1977, which is now at the edge of the solar system. The data clearly show a “wall” characterizing the heliosheath. It is astonishing that Voyager 1 is still collecting data after all these years – with an on-board computer of the 1970s and a power source that is still very much alive having passed through the harsh environment of Jupiter and Saturn. Stone was seen not only by the conference participants but also by the 40 million viewers who watched an interview with him during a popular programme on Brazilian TV.

The parallel sessions included presentations on a plethora of new projects ranging from next-generation imaging air-Cherenkov telescopes, represented by the Cherenkov Telescope Array, to the Extreme Universe Space Observatory onboard the Japanese Experiment Module (JEM-EUSO). To be installed on the ISS, JEM-EUSO is designed to measure ultra-high-energy cosmic rays through the fluorescence of the extensive air showers that they produce – an expression of optimism in the future of the field.

The 34th ICRC meeting will be held at The Hague, the

Awards for astroparticle physics

Besides the announcements of important findings and experiments, the conference was the occasion for the traditional awards for outstanding contributions in astroparticle physics. Six people were honoured, from more than 30 nominations.

Aya Ishihara, from Shiba University, received an IUPAP Young Scientist Award for her outstanding work on the search for ultra-high-energy neutrinos and the detection of the two neutrino events at >1 PeV with the IceCube detector. A second Young Scientist Award went to Daniel Mazin, from IFAE Barcelona, for his outstanding work on gamma-ray blazars and extragalactic background light, using the MAGIC Cherenkov telescopes.

Rolf Bühler, from DESY Zeuthen, received the Shakti Duggal Award for his outstanding work on the variability of the emission from the Crab nebula and extragalactic background light, using the HESS and Fermi telescopes. The O’Ceallaigh Medal was awarded to Edward Stone, from Caltech, for his contributions to cosmic-ray physics and specifically his leading role in the Voyager mission.

Motohiko Nagano, from ICRR Tokyo and Fukui University, received the Yodh Prize for his pioneering leadership in the experimental study of the highest-energy cosmic rays. Sunil Gupta, from TIFR Mumbai, was awarded the Homi Bhabha Medal and Prize for his contributions to non-thermal astrophysics and his leading role in the development of gamma-ray astronomy.

Netherlands, in July 2015 and will be followed two years later by the 35th meeting in Busan, Korea. Although there will be no samba or caipirinhas, there will surely be the same level of results and commitment from astroparticle physicists worldwide.

Résumé

ICRC 2013 : de la Terre à la galaxie, et au-delà

La Conférence sur les rayons cosmiques s’est tenue pour la première fois en Amérique du sud, à Rio de Janeiro. C’est également la première fois que la conférence avait pour thème principal la matière sombre, et c’est pourquoi le sous-titre retenu pour cette édition était la « Conférence sur la physique des astroparticules ». Parmi les sujets abordés figuraient les actualités de l’Observatoire Pierre Auger, les télescopes HESS d’observation des rayons gamma, MAGIC et VERITAS, les résultats d’IceCube et d’AMS, ainsi que l’histoire de la sonde spatiale Voyager 1, qui a maintenant atteint les confins du système solaire.

Ronald C Shellard, Centro Brasileiro de Pesquisas Físicas, chair of the Local Organizing Committee.

Open days

Our universe was yours

CERN opened its doors for the public on 28 and 29 September, when more than 70,000 people came to visit the CERN sites.

CERN Open Days 2013 saw 70,000 people visit more than 40 activities on the surface across CERN’s Meyrin and Prévessin sites, with 20,000 of them able to see something of the accelerators and detectors underground. Highlights for visitors included seeing one of the large experiments on the LHC – ALICE, ATLAS, CMS or LHCb – or operating robotic arms and forklift trucks, or even making superconducting magnets levitate. A taskforce of 2300 volunteers acted as guides and helpers, explaining the variety of activities at CERN – from particle physics and computing to logistics and fire-fighting – to enthusiasts young and old.

As well as the public open days on Saturday and Sunday, events before and after made this a weekend to remember. On Friday 27 September, CERN welcomed local officials and industrial contacts from throughout its member states for exclusive tours of the laboratory. In the evening – and to celebrate European Researchers’ Night – CERN and the Istituto Nazionale di Astrofisica organized “Origins 2013”, an event that included simultaneous activities at CERN, Paris and Bologna, with participation from UNESCO, ESA, ESO and INFN. During a webcasted event in the Globe of Science and Innovation at CERN, those onstage took questions both from the audience and online.

There was also a flurry of activity on social media. Online events began with a CERN tweetup on Friday, when 12 lucky people visited CERN as citizen journalists to share their exclusive preview of the open days with the world via Twitter.

Lastly, on the following Monday, the whirlwind of events culminated with “Bosons and More” – a celebration for CERN people.

• Max Brice, the CERN photographer, led a team of 26 photographers recording the open-days’ events, with Anna Pantelia, Fons Rademakers, Laurent Egli, Mike Struick, Didier Steyaert, Mathieu Augustin, Pierre Gildemyn, Matthias Schroder, Dmytro Kovalskiy, Lelia Laureyssens, Sylvain Chapeland, Jan Fiete Grosse-Oetringhaus, Antonella Vitale, Jean-Francois Marchand, Neli Ivanova, Olga Driga, Doris Chromek-Burckhart, Sebastian Lopienski, Tomek fotograf, Nicolas Voumard, Erwin van Hove, Stephan Russenschuck, Ilknur Colak, Laura Rossi and Alban Sublet. A selection of photographs is shown here, for many more, see http://cds.cern.ch/collection/Open_Days_2013_Photos.

Kate Kahle, CERN.



The open-days’ poster welcomed the public to the CERN sites with the phrase “Our Universe is Yours”.



The LHC was a key theme for the open days. Here, visitors to Point 6 are lucky enough to have CERN’s director-general explain its workings.



In the “Fun zone!” children played with science, technologies, robots and more, including constructing a miniature LHC.

Open days

Open days



Picture yourself. A visitor to the ALICE cavern captures herself and the experiment on camera.

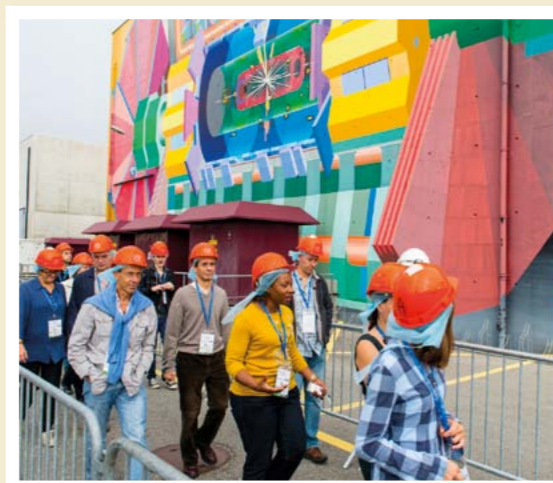


Transport and handling activities provided the opportunity to try out CERN's heavy-lifting equipment, including getting behind the wheel to move a model magnet.

Holder of underground visit tickets were able to descend around 100m to see the different experimental caverns, including that of ATLAS, shown above.



The Synchrocyclotron, now a visitor point, was CERN's first accelerator, commissioned in 1957 and in operation until 1990.

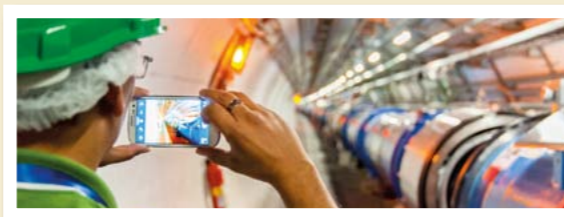


Visitors, next to the ATLAS mural, on their way to the experiment cavern.



(Left) A CERN volunteer demonstrates levitation with superconducting magnets cooled with liquid nitrogen.

(Right) A visitor takes a photo of the LHC tunnel with his smartphone.



Thanks to the fire service – who were also on call – visitors could find out what it takes to be a firefighter.

(Right) A 360° image of the LHCb experiment underground cavern.



Visitors to the CMS cavern gaze in wonder at the huge and complex detector.



There was also the chance to visit the CERN Control Centre, the control room for the accelerators and technical facilities.

On the surface, CMS showcased the dance performance Quantum by former CERN artist-in-residence choreographer Gilles Jobin.



At the CERN Computer Centre, visitors find out about the Worldwide LHC Computing Grid.



Open days

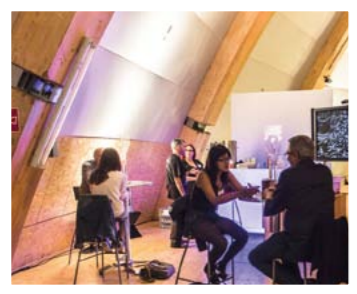
Symmetry



The open-days' control room saw CERN's services working in harmony with French and Swiss authorities to ensure that the event ran smoothly.



At the "CERN tweetup" on Friday, citizen journalists got an exclusive open-days' preview and sent out hundreds of messages on the social network Twitter.



(Left) The "Origins 2013" activities on Friday at CERN included opportunities for "physics speed-dating" – one-to-one informal discussions with researchers.



The "Bosons and More" event on Monday featured concerts from the Orchestre de la Suisse Romande as well as the Alan Parsons Live Project, pictured above.



The "Origins 2013" event included participation from other international organizations, connected via webcast to a live audience at CERN.

(Below) A few of the 2300 volunteers – those from IT, still smiling at the end of a great weekend.



CERN Open Days 2013 is grateful for the support of:



Testing times for relativity

Physicists met in Bloomington to discuss the latest research on possible violations of relativity and CPT symmetry.



Participants at CPT'13 pose for the traditional photo. (Image credit: Jorge S Diaz.)

Albert Einstein's theory of relativity is one of the most successfully tested ideas in physics. Based on the statement that the laws of physics are invariant under rotations and boosts – officially known as Lorentz symmetry – relativity is a cornerstone of the two most successful descriptions of nature: general relativity and the Standard Model. Although experiments to date indicate that relativity provides an accurate description, it became clear in the late 1980s that violations in relativity could appear theoretically as natural features of candidate models of quantum gravity.

During the following decade, a group of theorists led by Alan Kostelecký at Indiana University developed a general framework extending general relativity and the Standard Model to include all possible violations of Lorentz symmetry and CPT symmetry – the combination of charge conjugation, C, parity inversion, P, and time reversal, T – in a realistic field theory. This framework, called the Standard-Model Extension (SME), provides practical methods to compute observable effects for a given experiment. As a result, its advent triggered wide-ranging interest in the features of relativity violations.

Over the past 15 years or so, the experimental community has also enlisted in this challenging enterprise and the search for Lorentz violation has now turned theoretical ideas into a formal field in which theorists and experimentalists worldwide explore possible signals that could reveal that relativity is not exact. Despite the fact that current technology is far from reaching energies that are relevant for quantum gravity, the SME has shown that it is possible to probe well beyond the Planck scale by searching for suppressed effects in low-energy experiments.

In June, the 6th Meeting on CPT and Lorentz Symmetry (CPT'13) took place in Bloomington, Indiana. The latest in a series of unusual conferences that are held every three years, it brought together physicists from a variety of disciplines and global locations to discuss new results and future prospects for studying these fundamental spacetime symmetries. The experiments testing CPT and Lorentz symmetry and the theoretical calculations presented at the meeting together span an impressive set of subfields in physics. Furthermore, the techniques involved cover energies from fractions of an electron-volt to millions of giga-electron-volts.

Given the deep connection between Lorentz invariance and the CPT theorem in local field theory, one of the direct tests of these symmetries involves comparisons between the behaviour of matter

and antimatter systems. The ALPHA collaboration reported on the remarkable progress made along these lines in its experiment at CERN. The collaboration has used antihydrogen traps to store antiatoms for several minutes and to perform basic spectroscopy (CERN Courier July/August 2011 p6). These long timescales for antiatomic systems also offer interesting prospects for studying the effects of gravitational fields.

An important theoretical development in the SME described at the meeting is the study of the effects of relativity violations in couplings of gravity to matter and antimatter. This work has motivated different tests of the equivalence principle as presented by several groups including those at the Max Planck Institute for Nuclear Physics in Heidelberg, the University of California at Berkeley and the University of Pisa. Results of analyses using data from the Gravity Probe B satellite were also presented at the meeting.

Particle physics offers another experimental playground to test Lorentz and CPT invariance. The manner in which Lorentz violation could appear in different systems includes modifications to the kinematics arising from unconventional energy-momentum relations as well as dynamic effects in interactions between different particles. A basic notion in the SME is that breaking Lorentz symmetry must lead the universe to manifest at least one preferred direction. For this reason, one of the key signals to study in Earth-based experiments is the sidereal variation of the relevant experimental observables resulting from the change in the coupling between the system studied and the preferred direction in the universe.

The search for Lorentz violation has now turned theoretical ideas into a formal field.

Sidereal variations are one of the most used techniques for testing Lorentz symmetry. At the meeting, the experimental group at the University of Groningen presented its implementation of such a test in which the researchers search for sidereal variations in the β -decay rate

of sodium atoms. Following a similar approach, a recent proposal formulates the effects of Lorentz violation in the β decay of tritium. The experimental group at the University of Washington reported on the status of the KATRIN experiment and reviewed the use of this detector, which is designed for direct measurement of the mass of the neutrino, as a probe of Lorentz and CPT symmetry using tritium decay. Signals to be tested include the sidereal variation of the endpoint energy and other effects that could mimic a nonzero neutrino mass.

The free propagation of neutrinos has also served as a sensitive probe of Lorentz symmetry. The Double Chooz experiment is designed to measure θ_{13} – the last of the three neutrino-mixing angles, which is responsible for the disappearance of reactor antineutrinos and is key in the possibility of CP violation in neutrinos. Using data from this experiment, a team from Massachusetts Institute of Technology has recently performed a search for sidereal variations of antineutrino oscillations in the context of the SME and also explored the effects of Lorentz violation in the form of possible neutrino-antineutrino oscillations. Other interferometric techniques reported at CPT'13 included sidereal studies performed using the semileptonic decay of B mesons in the DØ experiment at Fermilab and neutral kaons in the KLOE experiment at INFN's Frascati National Laboratory. No compelling evidence of Lorentz violation has appeared but impressive new limits on SME coefficients that control deviations from exact symmetry have been established.

In the past, most studies of Lorentz violation have used the minimal SME as a theoretical framework. The minimal SME extends the Standard Model by incorporating only operators of mass dimension four or less, which guarantee power-counting renormalizability of the theory. One of the most ambitious goals in recent years has been the explicit identification and classification of SME operators of arbitrary mass dimension. The basics of the theory of these so-called non-minimal terms were presented in the photon sector in the previous meeting in this series – CPT'10 (CERN Courier October 2010 p29). In the intervening three years, several experimental searches have demonstrated the advantage of studying high-energy photons from astrophysical sources and the competitive sensitivity of different tabletop experiments.

Using astrophysical observations of sources of X and γ rays at cosmological distances, researchers from Washington University in St Louis reported on a systematic study of non-minimal operators in electrodynamics and provided new limits on photon SME coefficients. Using data from the HESS, MAGIC and VERITAS telescopes, the study searched for the possible energy dependence of the speed of high-energy photons. This is one of the unconventional effects predicted by the SME as a consequence of modified photon dispersion relations. The team now plans to use polarimetry measurements with future space telescopes to explore other effects predicted by the SME.

Despite the great sensitivity of high-energy photons, some Lorentz-violating effects are undetectable in astrophysical measurements. In this case, resonant cavities act as complementary probes of quantum-gravity effects. Microwave cavities and cryogenic sapphire oscillators have allowed scientists at the University of Western Australia to complete the first laboratory study of non-renormalizable operators in the SME. In Berlin, cryogenic optical



Lively discussions: (left) Alan Kostelecký, the meeting organizer, and (right) NASA's Floyd Stecker. (Image credit: Neil Russell.)

resonators and systems of ultracold atomic quantum gases have been developed by researchers at Humboldt University as tools to test relativity, both on Earth and in space.

The remarkable number of experimental studies already performed has led to a vast number of experimental constraints on SME coefficients that control the various ways that Lorentz symmetry can be broken in different sectors of the theory. The results are compiled in a rapidly growing document – *Data Tables for Lorentz and CPT Violation* – which is updated every year. Nonetheless, many more effects remain unexplored. The CPT'13 meeting provided a welcome week-long opportunity to exchange ideas, initiate collaborations and share experimental and theoretical techniques among different sectors. The study of violations of Lorentz and CPT symmetry is a continuing and exciting adventure with many new directions still to be explored.

• Further reading

For more about the meeting, visit www.indiana.edu/~lorentz/cpt13/. For the latest update to the *Data Tables for Lorentz and CPT Violation*, see <http://arxiv.org/abs/arXiv:0801.0287>.

Résumé

La relativité à l'épreuve

La 6^e Rencontre sur les symétries CPT et de Lorentz (CPT'13) a eu lieu en juin à Bloomington, Indiana (États-Unis). Dernière en date d'une série de conférences qui se tiennent tous les trois ans, la rencontre a réuni des physiciens de domaines variés et provenant de différentes parties du globe, qui ont pu discuter des nouveaux résultats et des futures perspectives de l'étude de ces symétries fondamentales de l'espace-temps. Les expériences qui éprouvent la validité des symétries CPT et de Lorentz, ainsi que les calculs théoriques présentés lors de la conférence, couvrent une grande variété de sujets en physique. Par ailleurs, les techniques utilisées couvraient une gamme d'énergie très vaste, allant de fractions d'électron-volt à des millions de GeV.

Jorge S Diaz, Indiana University.

Micropattern-detector experts meet in Zaragoza

There is much on offer in the rapidly growing technology of MPGDs, thanks to the creativity of the research community.

Micropattern gaseous detectors (MPGDs) are the modern heirs of multiwire proportional counter (MWPC) planes, with the wires replaced by microstructures that are engraved on printed-circuit-like substrates. An idea that was first proposed by Anton Oed in 1988, it was the invention of stable amplification structures such as the micromesh gaseous structure (Micromegas) by Ioannis Giomataris in 1996 and the gas electron multiplier (GEM) by Fabio Sauli in 1997 that triggered a boom in the development and applications of these detectors. It was as a consequence of this increasing activity that the series of international conferences on micropattern gaseous detectors was initiated, with the first taking place in Crete in 2009 followed by the second meeting in Kobe in 2011 (CERN Courier March 2012 p27).

The third conference – MPGD2013 – moved to Spain, bringing more than 125 physicists, engineers and students to the Paraninfo building of the Universidad de Zaragoza during the first week of July. The presentations and discussions took place in the same room that, about a century ago, Santiago Ramón y Cajal – the most prominent Spanish winner of a scientific Nobel prize – studied and taught in. The Paraninfo is the university's oldest building and its halls, corridors and stairs provided an impressive setting for the conference. The streets, bars and restaurants of Zaragoza – the capital of Aragon – were further subjects for the conference participants to discover. After an intense day of high-quality science, lively discussions often continued into the evening and sometimes late into the night, helped by a variety of tapas and wines.

The wealth of topics and applications that were reviewed at the conference reflected the current exciting era in the field. Indeed, the large amount of information and number of projects that were presented make it difficult to summarize the most relevant ones in a few lines. The following is a personal selection. Readers who would like more detail can browse the presentations that are posted on the conference website, including the excellent and comprehensive conference-summary talk given by Silvia Dalla Torre of INFN/Treiste on the last day.

The meeting started with talks about experiments in high-energy and nuclear physics that are using (or planning to use) MPGDs.



The three winners of the Charpak Award. (Top) Ioannis Giomataris, left, congratulates Takeshi Fujiwara. (Image credit: F Iguaz.) (Above) Michael Lupberger, left, and Diego González-Díaz with their awards. (Image credit: J Kaminski.)

Since the pioneering implementation of GEM and Micromegas detectors by the COMPASS collaboration at CERN – the first large-scale use of MPGDs in high-energy physics – they have spread to many more experiments. Now all of the LHC experiment collaborations plan to install MPGDs in their future upgrades. The most impressive examples, in terms of detector area, are the 1200 m² of Micromegas modules to be installed in the muon system of ATLAS and the 1000 m² of GEM modules destined for the forward muon spectrometer of CMS. These examples confirm that MPGDs are the technology of choice when large areas need to be covered with high granularity and occupancy in a cost-effective way. These numbers also imply that transferring the fabrication know-how to industry is a must. A good deal of effort is currently devoted to industrialization of MPGDs and this was also an important topic at the conference.

MPGDs have found application in other fields of fundamental research. Some relevant examples that were discussed at ▶

MPGD2013

the conference included their use as X-ray or γ detectors or as polarimeters in astrophysics, as neutron or fission-fragment detectors, or in rare-event experiments. Several groups are exploring the possibility of developing MPPGD-based light detectors – motivated greatly by the desire to replace large photo-multiplier tube (PMT) arrays in the next generation of rare-event experiments. Working at cryogenic temperatures – or even within the cryogenic liquid itself – is sometimes a requirement. Large-area light detectors are also needed for Cherenkov detectors and in this context presentations at the conference included several nice examples of Cherenkov rings registered by MPPGDs. Several talks reported on applications beyond fundamental research, including a review by Fabrizio Murtagh of INFN/Frascati and CERN. MPPGDs are being used or considered in fields as different as medical imaging, radiotherapy, material science, radioactive-waste monitoring and security inspection, among others.

An important part of the effort of the community is to improve the overall performance of current MPPGDs, in particular regarding issues such as ageing or resilience to discharges. This is leading to modified versions of the established amplification structures of Micromegas and GEMs and to new alternative geometries. Some examples that were mentioned at the conference are variations that go under the names of μ -PIC, THGEM, MHSP or COBRA, as well as configurations that combine several different geometries. In particular, a number of varieties of thick GEM-like (THGEM) detectors (also known as large electron multipliers, or LEM) are being actively developed, as Shikma Bressler of the Weizmann Institute of Science described in her review.

Many of the advances that were presented involve the use of new materials – for example, a GEM made out of glass or Teflon – or the implementation of electrodes with resistive materials, the main goal being to limit the size and rate of discharges and their potential damage. Advances on the GridPix idea – the use of a Micromegas mesh post-processed on top of a Timepix chip – also go in the direction of adding a resistive layer to limit discharges and attracted plenty of interest. Completely new approaches were also presented, such as the “piggyback Micromegas” that separates the Micromegas from the actual readout by a ceramic layer, so that the signal is read by capacitive coupling and the readout is immune to discharges.

The presence of CERN’s Rui de Oliveira to review the technical advances in MPPGD fabrication techniques and industrialization is already a tradition at these meetings. Current efforts focus on the challenges presented by projects that require GEM and Micromegas detectors with larger areas. Another tradition is to hear Rob Veenhof of Uludağ University and the RD51 collaboration review the current situation in the simulation of electron diffusion, amplification and signal detection in gas, as well as the corresponding software tools. Current advances are allowing the community to understand progressively the performance of MPPGDs at the microphysics level. Finally, although electronics issues were present in many of the talks, the participants especially enjoyed a pedagogical talk by CERN’s Alessandro Marchioro about the trends in microelectronics and how they might affect future detectors in the field. These topics were studied in more detail in the sessions of the RD-51 collaboration meeting that came after the conference at the same venue. Fortunately, there was the opportunity to



A picnic lunch at the Canfranc Estación village in the Spanish Pyrenees, after having visited the Canfranc Underground Laboratory. (Image credit: S Cebrián.)

relax before this following meeting, with a one-day excursion to the installations of the Canfranc Underground Laboratory in the Spanish Pyrenees and St George’s castle in the town of Jaca.

The vitality of the MPPGD community resides in the relatively large number of young researchers who came to Zaragoza eager to present their work as a talk or as one of the 40 posters that were displayed in the coffee and lunch hall during the week. Three of those young researchers – Michael Lupberger of the University of Bonn, Diego González-Díaz of the University of Zaragoza and Takeshi Fujiwara of the University of Tokyo – received the Charpak Prize to reward their work. This award was first presented at MPPGD2011 in Japan and the hope is that it becomes formally established in the MPPGD community on future occasions.

Time will tell which of the many ideas that are now being put forward will eventually become established but the creativity of the community is remarkable and one of its most important assets. References to this creativity – and to the younger generation of researchers who foster it – were recurrent throughout the conference. At the banquet, by the Ebro riverbank under the shadow of the tall towers of the Basílica del Pilar, several senior members gave advice to the new generation of MPPGD researchers and proposed a toast to them – a blessing for the field.

• Further reading

For more information on the conference and to see the presentations, visit <http://gifna.unizar.es/mpgd13>.

Résumé

Conférence sur les détecteurs gazeux microstructurés à Saragosse

Pour sa troisième édition, MPPGD2013, la Conférence internationale sur les détecteurs gazeux microstructurés (MPPGD) a eu lieu en Espagne. Les détecteurs MPPGD sont de plus en plus utilisés en physique des hautes énergies, car il s’agit d’une technologie optimale pour couvrir de vastes surfaces avec une excellente granularité. Néanmoins, les équipes s’efforcent encore d’améliorer la performance globale des détecteurs, ce qui donne lieu à des versions modifiées des structures existantes et à de nouvelles géométries. Les MPPGD ont par ailleurs trouvé d’autres applications, par exemple comme détecteurs de rayons gamma en astrophysique ou comme détecteurs de neutrons.

Theopisti Dafni and Igor G Irastorza, University of Zaragoza.

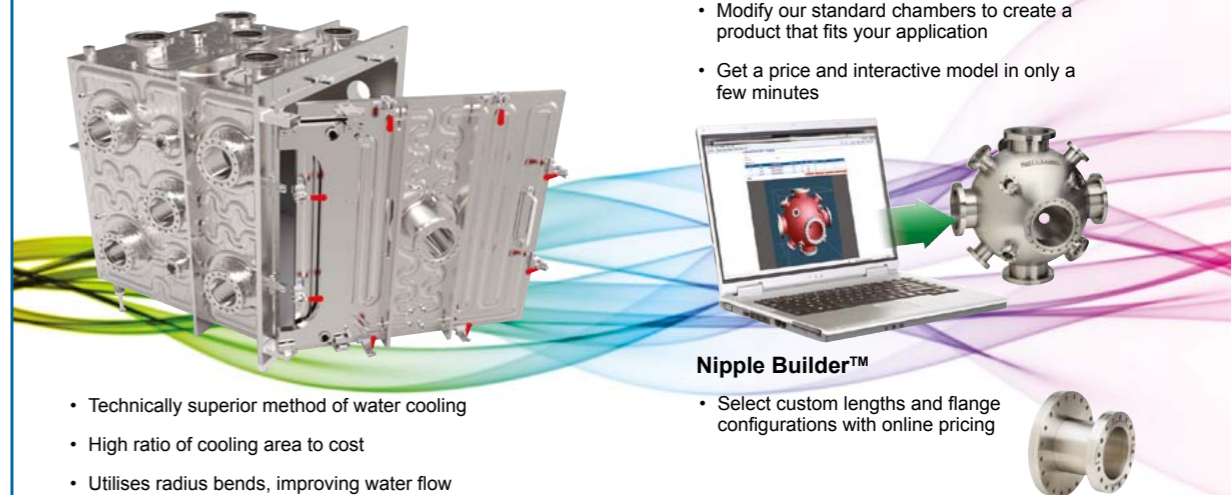
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Faces & Places

MEDICAL PHYSICS

CERN MEDICIS: radioisotopes for health

On 4 September, a ground-breaking ceremony at CERN marked the start of construction of CERN MEDICIS, a research facility that will make radioisotopes for medical applications. The new facility will use the primary proton beam at ISOLDE – CERN's online isotope separator – to produce the isotopes, which initially will be destined for hospitals and research centres in Switzerland. The aim is then to extend the service to a larger network of laboratories in Europe and beyond.

ISOLDE has provided beams of isotopes for experiments at CERN for more than 40 years. Since the 1990s, it has used a 1.4 GeV proton beam from the Proton-Synchrotron Booster, which interacts with a primary target. This beam loses only 10% of its intensity and energy on hitting the target and the particles that pass through can still be used. For CERN MEDICIS, a second target will be placed behind the first to produce the desired radioisotopes. An automated conveyor will then carry this second target to the CERN MEDICIS infrastructure, where the radioisotopes will be extracted.

So far, the Geneva University Hospitals, the Centre hospitalier universitaire vaudois (the University Hospital of Lausanne) and the Swiss Institute for Experimental Cancer



The ground-breaking ceremony for the CERN MEDICIS facility with, left to right, Reto Meuli, department head of medical radiology at the Centre hospitalier universitaire vaudois, Douglas Hanahan, director of the Swiss Institute for Experimental Cancer Research at EPFL, Rolf Heuer, CERN's director-general, Yves Grandjean, secretary general of the Geneva University Hospitals, and Piet Van Duppen, KU Leuven.

Research of the École polytechnique fédérale de Lausanne (EPFL) will use CERN's isotopes. But there is room for expansion.

The project is financed by CERN and counts on financial and in-kind donations from private foundations and

from KU Leuven in Belgium. The civil engineering for the facility should be completed by the end of 2013. Installation of the infrastructure and equipment – including a radiochemical laboratory – is planned for completion in 2015.

AWARDS

Carlo Rubbia appointed senator for life

Four new senators for life were appointed by the Italian president, Giorgio Napolitano, on 30 August. They included Carlo Rubbia, CERN's director-general from 1989 to 1993, together with the music director and conductor Claudio Abbado, the neuroscientist Elena Cattaneo and the architect Renzo Piano.

Before becoming director-general, Rubbia was head of the UA1 collaboration and in 1984 was awarded the Nobel prize in physics together with Simon van der Meer for discovery of the W and Z particles. During his term of office as director-general, the



Italian president, Giorgio Napolitano, left, greets Carlo Rubbia at the Quirinale Palace in Rome on 4 September. (Image credit: Presidenza della Repubblica Italiana.)

Large Electron-Positron (LEP) collider was inaugurated and the four LEP experiments produced their first results. He was also a strong advocate of the case for the next collider in the LEP tunnel – the LHC – first as chair of a long-range planning committee and later as director-general. In 1993, the last year of his mandate, the World Wide Web

protocol and code were declared “free of charge” for all time.

In Italy, the senators for life have the same power as elected senators, including the right to vote. As the term suggests, their mandate lasts for their lifetime. The four new senators for life are worldwide renowned personalities in the fields of music, art and science.

André Lagarrigue prize honours work of Haïssinski

Jacques Haïssinski, professor emeritus of physics at the Université Paris-Sud, has been awarded the 2012 André Lagarrigue Prize. He received the prize on 12 September, during a lively ceremony in which his friends and colleagues acknowledged his scientific achievements, the diversity of his interests – from electron–positron colliders to cosmology – and the depth of his physics understanding.

The award, established in 2006 under the aegis of the French Physical Society, pays tribute to André Lagarrigue, director of the Laboratoire de l'Accélérateur Linéaire (LAL) Orsay from 1969 to 1975, who played a major role in the discovery, 40 years ago, of weak neutral currents with the Gargamelle bubble chamber at CERN, so establishing the validity of the electroweak theory. Co-funded by the CEA, CERN, Ecole Polytechnique, IN2P3-CNRS, LAL and Université Paris-Sud, the prize is awarded every two years.

Having begun his career at LAL when



Jacques Haïssinski at the award ceremony. (Image credit: LAL, Orsay.)

the laboratory had just been created, Haïssinski's work has focused mainly on the physics of electron–positron colliders and on the particle physics accessible

through electron–positron, electron–photon and photon–photon collisions. The subject of his doctoral thesis at the Université Paris-Sud was the operation of AdA – the small collider in which electron–positron collisions were observed in Orsay for the first time, 50 years ago. Combining experimental and theoretical approaches, Haïssinski became a pioneer in the field. Most recently, he has engaged in the design of the ThomX project, a compact source of X rays produced by Compton scattering of an intense laser beam off stored electrons.

Like Lagarrigue, Haïssinski is an outstanding teacher advocating the dissemination of knowledge to the general public. Respected for his integrity and his thorough and rigorous mind, he has participated in many international committees and held major positions. He was notably deputy scientific director of IN2P3-CNRS (1987–1992), led the Dapnia-CEA (1992–1996) and chaired the LEP Committee at CERN (1990–1993).

popular authoritative voice of particle physics for three decades”, praising him for championing physics in the days when “hard science” fought for media attention.

Close has popularized physics through radio, newspaper and magazine articles, several books, and lectures he has given throughout the world. Particle physicists will know his classic introduction to the subject, *The Cosmic Onion*, and his recent work *The Infinity Puzzle*, which tells the story of the quest to find the Higgs boson (*CERN Courier* January/February 2012 p51). At CERN he was co-founder and the first chair of the European Particle Physics Outreach Group.



Frank Close, “popular authoritative voice of particle physics”. (Image credit: F Close.)

Royal Society honours the communication work of Frank Close

Frank Close of Oxford University has been awarded the 2013 Michael Faraday Prize by the Royal Society for excellence in communicating science to UK audiences. The society described Close as “the



Two centuries ago, on 1 November 1813, the Scuola Normale Superiore in Pisa enrolled its first students. Founded two years earlier by Napoleonic decree on 18 October 1810, it was intended as a “carbon copy” of the Ecole Normale Supérieure in Paris. With Napoleon's abdication in 1814, this first institution lasted for only one academic year but it came to life again during the 1840s and went on to become a highly regarded seat of learning. Nobel laureates Enrico Fermi and Carlo Rubbia are probably the best known among the physics students of the 20th century. Others well known in the field of particle physics include Gilberto Bernardini, Gian Carlo Wick, Luigi Radicati, Emilio Picasso, Luigi Di Lella, Italo Mannelli, Giorgio Bellettini, Riccardo Barbieri and Michelangelo Mangano. The Scuola Normale Superiore is at the right of this sketch of the Piazza Dei Cavalieri in Pisa. On the left, is a building where Count Ugolino della Gherardesca was imprisoned with his family and, according to Dante, finally ate the corpses of his children. (Image credit: André Martin.)

CENTENARY

Wolfgang Paul: inspired scientist, Nobel laureate, father figure

Wolfgang Paul was born 100 years ago on 10 August 1913 at Lorenzkirch, a village in Saxony, Germany, as the fourth child of Theodor and Elisabeth Paul. Descended from generations of Lutheran ministers, they preferred a humanistic education for their family, so as a child Paul learnt Latin and Greek and could quote the Bible by heart. However, his father was professor in pharmaceutical chemistry at the university in Munich, where Paul grew up. Although Theodor Paul died when his son was only 15, he had implanted in him a strong interest in sciences – a path that the young Paul decided to follow.

Before Paul began his study of physics in Munich, in 1932 the theoretician Arnold Sommerfeld advised him to start an apprenticeship in practical mechanics. So in 1934 he moved to the Technical Highschool in Berlin. There he joined the group of Hans Kopfermann, who became not only his teacher but also a fatherly friend. In the following years, Paul followed Kopfermann first to Kiel and later to Göttingen, where he worked and taught until 1952. During the 16 years that Paul stayed with Kopfermann, his work concerned mainly the optical measurement of hyperfine-splitting in atomic spectra to determine nuclear magnetic moments. In his PhD thesis – interrupted for a short time by a call to the Luftwaffe at the beginning of the Second World War – Paul improved this method using atomic beams.

By the end of 1952 Paul had accepted a chair at the University of Bonn, where he became director of the Institute of Physics. The institute had suffered war damage and financial means were still scarce. As Paul put it, to perform competitive research in such a situation “one has to have new ideas”. Continuing earlier work, he developed a mass spectrometer using a quadrupole lens with an oscillating field instead of a magnetic field – an interesting example of cross-fertilization between different fields because at the time Paul also became interested in the new idea of strong focusing in particle accelerators. Knowledge of orbit stability in accelerators led him to the “Paul mass filter”, which found many applications.

The mass filter provides stability in two transverse dimensions, but by adding a ring-shaped electrode with an oscillating field, particles are also caught in the longitudinal direction. This is the ingenious idea behind the “Paul trap” or “Ionenkäfig”



Wolfgang Paul, whose “talking was full of content”, in characteristic form outside the Council Chamber at CERN during a Scientific Policy Committee meeting in 1977. He was chair of the committee at the time (1975–1978) and a delegate to Council.

as he called it. The device realized a long-cherished dream – the free suspension of individual atoms or molecules for lengthy periods of time, enabling extremely precise measurements of fundamental constants (e.g. the magnetic moment of an electron), as well as the construction of ultraprecise clocks and other instruments. For this work, Paul shared the Nobel prize with Norman Ramsey and Hans Dehmelt in 1989, followed by many other distinctions.

The second activity that Paul started in Bonn concerned the construction of particle accelerators. A crew of bright young students and assistants – some having followed Paul from Göttingen – but with no experience in accelerator technology, jumped into the adventure of building Europe's first electron synchrotron with strong focusing and an energy of 500 MeV. Even to their own surprise, it worked well. A 2.5 GeV electron synchrotron followed 10 years later and, before retiring, Paul helped to gain approval for a beam-stretcher storage ring – ELSA.

These machines transformed the institute in Bonn to one of the most important laboratories in Europe. More than 100 students were trained there and transferred their knowledge to many universities, countries and industries. The experience gained in Bonn was also essential in the founding of DESY where Paul played a major role.

Active in research even after retiring, Paul had the idea to extend his trap, which was for charged particles, to neutrons. In this case, sextupole rather than quadrupole fields were needed to act on the magnetic moment of the neutron. He built such a trap, NESTOR, which was installed in a neutron beam at the Institut Laue–Langevin, Grenoble. Being

short of manpower, Paul recruited his two sons and they measured the half-life of the neutron with high precision and determined its gravitational mass by seeing the neutrons fall inside the trap.

In addition to his scientific insight, Paul was aware of the responsibility that scientists owe to society. He co-signed the famous Göttingen declaration advising against the nuclear armament of Germany. He also refused a limitation on scientific research, since “scientific knowledge, which means understanding, is no risk. Non-understanding is the risk when acting.”

Paul played important roles as an organizer. Having spent a year as a guest at CERN in 1959, he became director of the Nuclear Physics Division (1964–67) and later served as chair of the Scientific Policy Committee and as a member of the German delegation. He also was director of DESY from 1971 to spring 1973 (where I had the pleasure to succeed him). However, he did not feel “at home” in large organizations, which are necessarily more formal than a university institute, where he could be a paternal boss, following his intuition and taking care of his flock. He was not a polished orator, but his talking was full of content and people listened carefully. In meetings, his pertinent questions, starting with “one should be allowed to ask...”, were feared.

Wolfgang Paul died in Bonn, almost 10 years ago on 7 December. Not only was he an eminent scientist, everyone who had the chance to work with him benefited from his human qualities.

● Herwig Schopper, former CERN director-general and one of the speakers at the Wolfgang Paul Symposium to be held at the University of Bonn on 11–13 November.

Faces & Places

SCHOOL

Advanced accelerator physics in Norway

The CERN Accelerator School (CAS) and the Norwegian University of Science and Technology (NTNU) organized a course on advanced accelerator physics this year, which took place in Trondheim on 18–29 August.

The course followed an established format with lectures in the morning and practical courses in the afternoon. The lecture programme consisted of 32 lectures, supplemented by discussion sessions, private study and tutorials. The practical courses provided “hands-on” experience in three topics: RF measurement techniques, beam instrumentation and diagnostics, and optics design and corrections. Participants selected one of the three courses and followed the chosen topic throughout the school. Seminars and a poster session completed the programme.

The course was attended by 70 students selected from more than 90 applicants.



Participants on the CAS course on advanced accelerator physics in Trondheim. (Image credit: Kaja Bugge Vik.)

Representing 21 nationalities, most of the participants came from European countries with a few from beyond. Their positive feedback reflected the high standard of the lectures and teaching.

CERN, NTNU, the Research Council of Norway and Radiobeam Technologies sponsored the school. NTNU also provided excellent facilities and invaluable support for

the highly technical courses, which are a key feature of the advanced school.

The next CAS courses will be a specialized school on power converters in Switzerland in May 2014 and an introductory course on accelerator physics in the Czech Republic in September 2014.

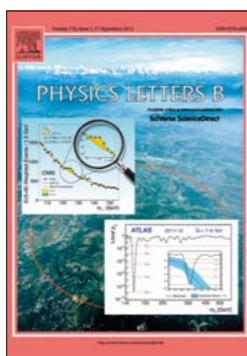
• For more about CAS, visit www.cern.ch/schools/CAS.

PUBLISHING

Elsevier comes on board SCOAP³ open-access initiative

As of January 2014, Elsevier's premier high-energy physics journals *Physics Letters B* and *Nuclear Physics B* will be published under the model of the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP³), which was launched at CERN a year ago (*CERN Courier* November 2012 p6). In a letter of intent that was signed on 8 July, Elsevier and CERN formalized their commitment to move these journals from a subscription model to an open-access model, in which the content is available to anyone who would like to access it free of charge and the open-access article publishing charges are paid by libraries rather than authors.

SCOAP³ was initiated by CERN in 2007, following the report of a task force on open-access publishing in particle physics. In addition, all of the LHC experiments strongly encouraged publishing results in open-access journals. The objective of SCOAP³ is to grant unrestricted access to articles appearing in scientific journals in the field of particle physics. While open dissemination of preprints has been the norm in particle physics for two



The first key findings by ATLAS and CMS on the discovery of a Higgs boson were published in *Physics Letters B* on 17 September 2012.

decades, the SCOAP³ initiative brings the peer-review service that is provided by journals into the open-access domain.

How does the redirecting of funds work? Under the subscription model, libraries purchase journal subscriptions to cover publishing costs and allow their researchers to access articles. In contrast, under SCOAP³, libraries contribute to the consortium, which pays centrally for the publishing charges of the open-access article – freeing the libraries from paying subscriptions.



Tejinder (Jim) Virdee went back to his alma mater, Queen Mary University of London (QMUL), on 18 July to receive an honorary degree at the summer graduation ceremonies. Here he is seen signing the Honorary Graduates Book with the university's principal, Simon Gaskell. Virdee, who is professor of physics at Imperial College, London, played a critical role in the design, research and development, prototyping, construction, installation, commissioning, data taking and physics exploitation of CMS – all leading to the discovery of a Higgs boson in July last year. He has been with the CMS experiment at CERN from the start and was deputy spokesperson (1993–2006) and then spokesperson (2007–2009). (Image credit: QMUL.)

WORKSHOP

From Higgs to black holes: three hot days in Protvino

Experimental and theoretical studies of Higgs bosons, quark–gluon plasma, neutrino oscillations and mass, general problems of the Standard Model and beyond, black holes, dark matter and dark energy, etc. Such was the list of topics for the 29th International Workshop on High Energy Physics – New Results and Actual Problems in Particle & Astroparticle Physics and Cosmology, which was held in Protvino, Moscow region, on 26–28 June, with 35 speakers from institutes and research centres in Australia, Germany, France, India, Poland, Russia, Spain, Switzerland, the UK and the US.

The organizers of the workshop attempted to overcome – as much as possible – the increasing diversification in the different fields in which particle physicists work. The second purpose was to provide an atmosphere of critical discussion to a greater extent than is usually allowed by the brief “question–answer” discussions after a talk. This aim was also helped by the organization of panel discussions after each of the six sessions. Despite being a little overloaded, this proved to be a viable format for future meetings in the series.

The opening talks provided an exhaustive survey of the Higgs searches at the LHC and the Tevatron, followed by presentation on various aspects of possible theoretical interpretations of the observed “Higgs-like” state. The subsequent panel discussion, led by Valery Kiselev of the Institute for High Energy Physics (IHEP), Protvino, revealed the lively interest of the audience and its eagerness to join – and even intervene – in the discussion among the panellists. (The same was true of all of the subsequent panel discussions.) The debate about the elementary or composite nature of the Higgs boson was particularly interesting. The discussion ended with the unanimous, though rather shy, confession of two panellists – both experimentalists – that personally they would, as unbiased researchers, prefer a composite Higgs boson as the more intriguing option.

The second session covered up-to-date experimental results on heavy-ion collisions both from CERN and from the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven. A short account followed on the possible use of the still fashionable anti-de Sitter holographic approach for quark–gluon plasma. The session was completed by a talk from Valentin Zakharov of the Institute for Theoretical and Experimental Physics,



Participants pose in the sunshine for the group photo. (Image credit: Nadezhda Sharykina.)

Moscow, who – instead of the announced talk on quark–gluon plasma – gave an extremely amusing impromptu presentation on the properties of chiral media in magnetic fields. He also led the lively panel discussion on quark–gluon plasma. Among the questions that were discussed, the problem of thermalization in particular was addressed but the discussion did not show a consensus among participants. Reports on heavy-quark physics at the LHC and on the unhappy fate of supersymmetry and other exotica – even at the highest energies achieved so far – completed the first day.

The neutrino session on the second day was marked by recent data from Super-Kamiokande, OPERA, KATRIN and GERDA. The subsequent panel discussion on neutrino problems, led by Vladimir Obraztsov, IHEP, was one of the most lively at the workshop. From the prospects of the long-baseline neutrino experiments to cosmological properties of the hypothetical sterile neutrino, the range of discussion topics riveted the attention of numerous attendees.

The afternoon session covered further results from the LHC on the Standard Model and QCD. There were also short presentations of a phenomenological model of multiple production in deep-inelastic scattering and recent attempts to find a “U-boson” (a dark-matter candidate) at the WASA@COSY experiment. While nuclear collisions at the LHC could be used for checking many unusual observations made with cosmic rays, the LHC energies are arguably not high enough to reveal “genuinely asymptotic” features of strong interactions. The final talks of the day were on current results and future research on the anatomy of spinning nucleons at RHIC and at CEBAF at Jefferson Laboratory.

The second day ended with a panel discussion led by Alexei Prokudin of

Jefferson Lab, which was devoted to the Standard Model and beyond. This revealed, among other interesting issues, that even the familiar Kobayashi–Maskawa matrix – described as a “test-bench” for searches of new physics – might cause embarrassing questions that are uneasy to answer. The subsequent concert of classical music was apt to prepare participants for a peaceful conference dinner.

The last day of the workshop started with a detailed review on observational data accumulated to date on possible candidates for black holes in binary systems and galactic nuclei. Then, while one speaker enthusiastically supported the supposed supermassive black holes in the centre of the Galaxy, others presented both alternative explanations of would-be event-horizon observations and purely theoretical flaws in the black-hole paradigm. They were followed by a presentation on a rigorous exact solution of the metric induced by the point-like source in general relativity. The ensuing panel discussion was quite emotional but could not reconcile “establishment” with “dissidents” and moderator Skiff Sokolov, IHEP, was unable to give a consolidated summary.

The afternoon session started with a talk arguing that quantum cosmology should become a “numerical subject”, which was followed by a talk on cosmological acceleration with arguments that it should not be necessary to invent things like “dark matter” to understand accelerating expansion of the universe. There was then a presentation of data on gamma-ray bursts, core-collapsed supernovae and the global star-formation rate at large redshifts obtained, in particular, at the special astronomical observatory of the Russian academy in the northern Caucasus. High-energy gravitational waves from the early universe and an interesting story about what can be learnt from the study of cosmological perturbations brought the final talk to a close.

The final panel discussion led by Edward Anderson of Université Paris Diderot and the University of Cambridge took place quite late and lasted a while, but the conference hall was filled with people who were by no means experts in cosmology – showing that cosmological problems are accessible and entertaining for particle physicists.

For more information about all of the presentations, see <http://indico.cern.ch/event/hepft2013>.

Faces & Places

VISITS



Dinesh Srivastava, left, the new director of the Variable Energy Cyclotron Centre in Kolkata, came to CERN on 26–30 August. During this time he met with CERN's director-general, **Rolf Heuer**, and gave a talk in CERN's Heavy Ion Forum. He also toured ALICE and other experiments in which Indian scientists participate.



Jaak Aaviksoo, left, Estonian minister of education and research, came to CERN on 17 September. His visit included a tour of the LHC tunnel, accompanied by CERN international relations adviser **Tadeusz Kurtyka**, as well as the TOTEM and CMS experiments.



On 4 September, Polish minister of science and higher education, **Barbara Kudrycka**, centre left, visited CERN. During her tour with **Agnieszka Zalewska**, centre right, president of CERN Council, and **Andrzej Siemko**, left, head of CERN's machine protection and electrical integrity group, she met Polish members of the team working on the protection of the superconducting magnet circuits.

The Italian minister for economic development, **Flavio Zanonato**, right, came to CERN on 10 September. His tour included a visit to the ATLAS experimental cavern, where he was accompanied by **Sergio Bertolucci**, left, CERN's director for research and scientific computing, and is seen enjoying a photo with **Anna Di Ciaccio**, ATLAS-Italy national contact physicist. The visit concluded with meeting Italian members of CERN and Italian teachers.



LETTERS

Lagarrigue and the discovery of neutral currents



André Lagarrigue. (Image credit: Ecole Polytechnique Paris.)

We would like to commend the celebration of the 40th anniversary of the neutral currents discovery by the Gargamelle collaboration through the article “Neutral currents: A perfect experimental discovery” (*CERN Courier* September 2013 p53).

Nevertheless, we believe that the article omits acknowledgement of the overall leader of the project. The Gargamelle detector – a huge heavy-liquid bubble chamber – was conceived, studied and built in France, under the leadership of André Lagarrigue. Until his untimely death in 1975, he led the whole project, including the data analysis that resulted in the discovery of neutral currents by the Gargamelle collaboration. Without his long-term vision and his dedicated tenacity, there would not have been such a discovery at

CERN at that time.

● *Violette Brisson, Anne-Marie Lutz and Guy Wommser, LAL Orsay.*

Progress in double beta decay?

Nuclear double beta ($\beta\beta$) decay is one of the flagships of non-accelerator particle physics, searching underground for physics beyond the Standard Model. For many years (starting in 1992) the Heidelberg-Moscow experiment, using the first enriched high-purity ^{76}Ge detectors, has dominated the field in sensitivity (*CERN Courier* March 2002 p5, March 2012 p34).

However, recently some fresh breeze arose in the field. The EXO and the Kamland experiments looking for $\beta\beta$ decay in ^{136}Xe reached half-life limits of the order of 10^{25} years. They suffer, however, from low-energy resolution (around 30 times less than in germanium detectors). Recently the GERDA experiment at Gran Sasso has yielded its first results. It uses the idea of the GENIUS Project (*CERN Courier* July/August 2003 p9), namely installing naked germanium detectors in liquid nitrogen or liquid argon. Operating 14.6 kg of enriched ^{76}Ge – 10 kg of them from the Heidelberg-Moscow experiment – after

a short exposure, the collaboration derived a lower limit of $T_{1/2} > 2.1 \times 10^{25}$ years at 90% confidence level (1.6 σ) from the pulse-shape selected spectrum (see talk by C Cattadori at EPS-HEP 2013 and *CERN Courier* September 2013 p8).

However, they compared this erroneously with the half-life deduced from the line at $Q_{\beta\beta}$ of the full spectrum recorded by the Heidelberg-Moscow experiment, and found a deviation of less than 2σ , which they say “refutes the Heidelberg-Moscow signal at high probability”. Indeed, they ignored the fact that this line is a double line and that they should have compared their result to the pulse-shape selected spectrum of Heidelberg-Moscow yielding a 6.4 σ signal and $T_{1/2} = (2.2 \pm 0.4) \times 10^{25}$ years (*CERN Courier* March 2012 p34, *Mod. Phys. Lett. A* **21** 1547 and arxiv:1308.2524 [hep-ex]). This means that the limit deduced by GERDA is even less than the half-life determined by the Heidelberg-Moscow experiment, and thus is fully consistent.

The statistics of the GERDA experiment are at present far too low to check the Heidelberg-Moscow result.

● *H V Klapdor-Kleingrothaus, Heidelberg*

OBITUARIES

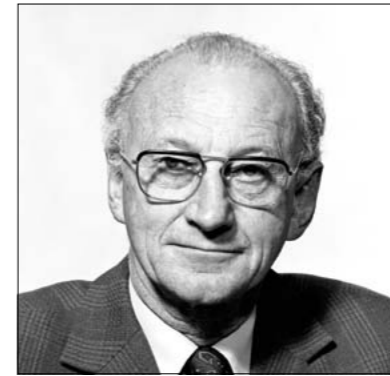
Godfrey Harry Stafford 1920–2013

Godfrey Stafford, who was director of the Rutherford Appleton Laboratory from 1969 to 1981, died on 29 July at the age of 93.

Stafford was one of the international leaders who transformed particle physics in Europe from its early days in modest university facilities to huge international laboratories, such as CERN. This evolution took several decades and the path was strewn with challenges. He worked quietly but with great determination to encourage people to focus on the real issues and to put aside vested interests in support of the bigger picture. His European roles included vice president of the CERN Council (1973–1975), chair of the CERN Scientific Policy Committee (1978–1980) and president of the European Physical Society (1984–1986). His influence continued long after his retirement and in his final years he gave advice to those planning the International Linear Collider, based on his expertise in superconducting RF technology.

Born in England in 1920, Stafford moved to Cape Town aged eight and went on to study at the University of Cape Town under R W James. He completed his MSc in cosmic-ray physics in 1941 but became caught up in the Second World War. He was mainly involved in the development of radar but also did heroic front-line duty of which, with his natural modesty, he would seldom speak.

Stafford did his PhD at Cambridge, spending time at the Atomic Energy Research Establishment, Harwell, under Sir Basil Schonland. In 1950 he returned to South Africa but in 1954 accepted an offer from Gerry Pickavance to join the Cyclotron Group at Harwell. The Rutherford High Energy Laboratory (RHEL) was formed in 1957 with Pickavance as its first director and Stafford as head of the Proton Linear Accelerator (PLA) Group. In a pioneering paper in 1961, he and Tony Banford described how a future superconducting machine would operate continuously, instead of at the 1% duty cycle of the PLA. By 1963, with the PLA operating, Stafford was made the first head of the High Energy Physics Division, with a major responsibility to develop the research programme for Nimrod, the new 7 GeV proton synchrotron. He and Pickavance did a wonderful job of encouraging UK university physicists to form teams and create a unified Nimrod user community. Significant R&D work included the development of twisted filamentary superconducting cable, which was extremely



Godfrey Stafford. (Image credit: RAL Photographic Services.)

resistant to quenches. Known universally as “Rutherford cable”, this is used worldwide in equipment such as accelerator magnets and scanners for magnetic resonance imaging.

Stafford was appointed director of RHEL in 1969, beginning the most challenging and creative phase of his career. Incredibly, it had just been decided to shut down Nimrod prematurely, which would have led to the closure of the laboratory. Therefore Stafford's first job was to convince the relevant authorities that this was scientifically illogical. This he did and then worked to establish diversified activities to ensure the laboratory's long-term future. In 1971 he established the Neutron Beam Research Unit to support the burgeoning community of neutron-beam users and investigate future options. After considering a high-flux reactor on the RHEL site, they subsequently facilitated the UK's entry to the Institut Laue–Langevin in Grenoble.

In 1974 an ambitious accelerator project (EPIC – the Electron–Positron Intersecting Complex) was launched but proved too expensive for the UK alone. In a crucial move, Stafford led an initiative to replace Nimrod by a high-current proton accelerator to serve a pulsed spallation source of neutrons. This was a stroke of genius – it re-used Nimrod's infrastructure and the laboratory's accelerator expertise. Thus was the ISIS facility born. It now has a huge user-community of scientists across the world.

Around the same time, in 1975, the laboratory merged with the ATLAS Computing Laboratory, an Electron Beam Lithography unit was formed and

a high-power laser was approved. Like Nimrod, the laser was beyond a scale that could be accommodated in an individual university. Since then the Central Laser Facility has seen continued dynamic growth.

A second merger with the Appleton Laboratory came in 1979 and the Rutherford Appleton Laboratory (RAL) was created with atmospheric and space sciences as added activities. Stafford had to make a major effort to keep the project for the Infrared Astronomical Satellite on course and on schedule because it was threatened by the move. RAL Space has grown enormously during the past 30 years.

When Stafford resigned as director-general of RAL in 1981, the laboratory was rich with new projects, all developed successfully in the following decades. Nimrod had closed in 1979 after helping to establish the quark model and its users had to broaden their horizons. Stafford had encouraged the development of close links with CERN, DESY and US laboratories. RAL took on the role of a national “staging post” for particle physics, enabling UK physicists to offer equipment and services that made major contributions to experiments elsewhere, taking advantage of the outstanding engineering services at the laboratory.

After leaving RAL, Stafford became the full-time master of St Cross College, Oxford, until his retirement in 1987. He took important initiatives for the development of the college, including moving to permanent accommodation in the heart of Oxford and increasing the number of graduate students.

UK particle physicists – and the communities that emerged with the broader application of accelerators (neutron scattering and synchrotron radiation) – owe a great deal to Stafford. His vision and leadership established the concept of national laboratories with a dual role – partly to provide a service to the university community, partly to carry out their own research – and how to strike the right balance. He will be remembered with great fondness for nurturing a vibrant science culture in the UK and worldwide.

He was a great family man and many who worked at RAL were privileged to get to know his wife Goldy (they married in 1950 and she died in 2003), their son Toby and twin daughters Anne and Liz who survive him and also five grandchildren.

● *His colleagues and friends.*

Frederick Mills 1928–2013

Frederick (Fred) Eugene Mills, an internationally recognized expert in the field of charged-particle beam and accelerator physics, passed away peacefully on 21 June.

Born on 12 November 1928 in Streator, Illinois, Mills received his BS and PhD from the University of Illinois at Urbana-Champaign, where he worked with Al Hanson and Donald Kerst, the inventor of the betatron. He then became a postdoctoral fellow at Cornell University, working on electron synchrotrons under the guidance of Robert Wilson. In 1957, Mills relocated to Madison, Wisconsin, and research on fixed-field alternating gradient accelerators and colliding-beam machines at the Midwestern Universities Research Association (MURA) in Stoughton, Wisconsin.

Following a sabbatical in 1961 at the Centre d'études nucléaires, Saclay, he became director of MURA from 1965 to 1967 and afterwards the first director of the Physical Sciences Laboratory at the University of Wisconsin (UW)-Madison. There, Mills secured funding for and oversaw construction of the first dedicated electron storage ring as a synchrotron light source. That device, soon named Tantalus-I, became the seed for the Synchrotron Radiation Laboratory at UW-Madison.

From 1970 to 1973, Mills served as the chairman of the accelerator department at Brookhaven National Laboratory. He was pulled back to the Midwest in 1973, where his former colleague Wilson was director of the newly formed National Accelerator Laboratory – renamed the Fermi National Accelerator Laboratory in 1974.



Fred Mills. (Image credit: G B Mills.)

At Fermilab, Mills applied his keen insight into accelerator physics to the development of the laboratory's burgeoning accelerator complex. He was one of a small group of innovators who proposed using Fermilab's Main Ring accelerator for very-high-energy proton-antiproton collisions. He helped to bring about a collaboration between Fermilab and the Budker Institute of Nuclear Physics in Novosibirsk, which had developed electron cooling and lithium lenses, and he helped Fermilab to incorporate these techniques into its plans. Thanks to his leadership, the Antiproton Source was completed in 1985 and integrated into the Fermilab accelerator complex. A month later the Tevatron collider produced its first collisions at 1.6 TeV – the highest energy that any collider had achieved.

In addition to his work on Fermilab accelerators, Mills – along with Phil Livdahl, Lee Teng, Don Young and others – designed a synchrotron for proton therapy at the Loma

Linda University Medical Center. Built at Fermilab, it was the first proton-therapy machine to be designed specifically to operate within a hospital setting. Loma Linda began treating patients in 1990 and continues to treat patients to this day.

Mills remained at Fermilab until he retired in 1993. During his 19 years there he took leave to develop a conceptual design for large tokamak fusion-reactors with the University of Wisconsin's Nuclear Engineering Department. In addition, he helped to commission the Advanced Photon Source at Argonne National Laboratory. He also visited the teams at CERN on a number of occasions.

For many years he continued to teach courses on accelerator physics at the University of Wisconsin and – with his daughter – at the University of Illinois, so spawning new generations of accelerator experts. Following his retirement, he continued work on accelerators as a consultant on ion storage rings, muon accelerators and colliders, proton-driver accelerators, antiproton collectors and medical accelerators.

Mills was a skilled handyman, a skier, a hiker, a biker and enjoyed a game of golf. In retirement, at Sun City, Oro Valley, he was president of the Astronomy Club and taught courses on energy and energy sources for the Institute for Learning in Retirement.

● *Based, with permission, on the obituaries in the New York Times ([#fbLoggedOut](http://www.legacy.com/obituaries/nytimes/obituary.aspx?n=Frederick-Mills&pid=165684680)) and Fermilab Today (www.fnal.gov/pub/today/archive/archive_2013/today13-08-15_MillsReadmore.html).*

Francesco Romano 1943–2013

Francesco Romano, a renowned experimental particle physicist, passed away on 16 May. He was 70 years old.

After a brilliant start to his career as a fellow at CERN, Francesco Romano became professor of general physics at the Faculty of Engineering of the University of Bari in 1986. Some years later he moved to the Polytechnic of Bari.

The author of hundreds of publications in the most important international physics journals, he began his research activity by studying the decay of the K^+ in bubble chambers. He joined several experiments at



Francesco Romano. (Image credit: INFN Bari.)

Gargamelle and the Big European Bubble Chamber, mainly contributing to studies of the production of heavy flavours in neutrino interactions. Among the main results that were obtained, the discovery of the Σ_c^+ (a baryon containing the charm quark) was particularly relevant. When the project for the Large Electron-Positron collider at CERN received the green light, Francesco joined the ALEPH experiment, contributing with the Bari INFN group to the construction of the hadron calorimeter.

At the start of the LHC era he joined the CMS collaboration, mainly contributing with the INFN unit of Bari to the design and construction of the resistive-plate-chamber detectors, which play a key role in the first-level muon trigger.

Francesco was a member of the Management Board of the Polytechnic of Bari, director of the Inter-university Department of Physics in Bari and chaired the Italian national board of the co-ordinators of the doctorate in physics from 1983 to 1998. He

was co-ordinator of the Nowcasting project, the local supervisor for the Extreme Energy Events project and a member of several scientific commissions and committees. He founded and directed the Seminario Nazionale di Fisica Nucleare e Subnucleare – an educational initiative for young physicists known as the “School of Otranto”, which took place in September 2013 for the 25th time.

Francesco also promoted many initiatives for scientific communication and, in particular, founded the District of the

Scientific and Technological Information – a spin-off from the School of Otranto that aims to establish a dialogue between physics, society and economy.

He will be greatly missed by all who were lucky to have known him.

● *This is a translation of the obituary that was published on the INFN website on 20 May 2013 and is reproduced with permission. For more about the 25th School of Otranto, see www.ba.infn.it/~otrantofr.html.*

NEW PRODUCTS

AMS Technologies has introduced the new POLARIS family of picosecond lasers. The POLARIS i200 laser delivers 10 ps output pulses over a range of repetition rates of up to 1 MHz, with average output power levels of up to 200 W at the fundamental wavelength of 1064 nm. Developed to respond to the increasing demand from the manufacturing industry for high-power, high-energy picosecond lasers, it is optimized for cost-effective, high-quality and high-speed production. For more details, visit www.amstechnologies.com.

Cobham Technical Services has released a new version of its Opera electromagnetics and multiphysics design software, enabling design engineers to speed up analysis time. Designed for use on standard office-grade PCs, Opera-3d version 16 contains numerous enhancements to take advantage of the multi-core processor architecture offered by many of today's computers. Opera version 16 also extends the multiphysics capabilities of Opera-3d and the Opera-2d circuit editor has been extended to include additional functional components. For more information, e-mail vectorfields.info@cobham.com or visit www.OperaFEA.com.

Edwards Group Limited has updated its range of turbopumping stations to include the newly launched nXDS dry scroll pumps. Edwards' turbopumping stations feature a choice of nEXT turbopumps with speeds from 421/s to 4001/s, enabling the most appropriate pump for the application to be selected. The new nXDS dry scroll pumps extend the range of turbo stations to include dry backing pumps with capacities from 1 m³/hr up to 20 m³/hr and offer an oil-free, robust vacuum solution. For more about the “plug and play” turbopumping system, visit www.edwardsvacuum.com/pumpingstations.

Hidden Analytical has introduced a new gas analyser, the HPR-20 QIC TMS system,

specifically configured for analysis of fast transient pulses and of rapid compositional changes in gaseous processes. Developed for researchers, the system is suited to studies of diverse thermally or chemically triggered reactions. The multi-mode Windows MASSoft Professional software features quantitative analysis and statistical data reduction programs. Operating with sample pressures from near-atmospheric up to 30 bar, the bench-top mass spectrometer uses a fast digital detection system for minimized signal response times. For further information, e-mail info@hidden.co.uk or visit www.HiddenAnalytical.com.

The Numerical Algorithms Group has announced the latest release of its NAG Toolbox for MATLAB to Mark 24. More than 130 new functions have been integrated into the Toolbox, bringing the total number of maths and stats functions to 1500. The NAG Toolbox for MATLAB complements MATLAB by allowing the easy use of NAG and MATLAB functions concurrently, giving increased algorithmic choice. The NAG Toolbox for MATLAB is available for 32-bit and 64-bit Microsoft Windows and 64-bit Linux systems. It will also be made available for Mac OS X. For more information, visit www.nag.co.uk/numeric/MB/start.asp.

The ORTEC Products Group of AMETEK Advanced Measurement Technology (AMT) has introduced the Alpha Mega, a fully integrated, digital alpha spectrometer for environmental laboratories and counting-room applications requiring large-sample-size analysis capabilities. The Alpha Mega can accommodate filter samples up to 4.18 inches (106 mm) in diameter and is designed to easily integrate into the Alpha Ensemble modular system. For more information, download www.ortec-online.com/download/Alpha-Suite.pdf.

PI (Physik Instrumente) LP now offers a new type of positioning stage based on a

miniaturized ceramic inertia drive. The PI miCos LPS-45 linear translation stage is designed to position samples along a precisely guided path with distances up to 2.5 cm. The position of the moving platform is measured by an optical linear encoder with nanometer resolution and controlled in closed-loop operation by a compact electronic motion controller. Several versions are available, for applications in air, vacuum and even for non-magnetic environments. For more details, visit http://www.pi-usa.us/products/Piezo_Motors_Stages/Linear-Motor-Precision-Positioning.php.

Ridgetop Group has announced the RadChek, a 3D software tool for design and shielding optimization of electronic boards and modules exposed to harsh radiation environments, such as in space, near particle accelerators, nuclear power plants, or medical scanners. It allows engineers to determine the best shielding material to use to avoid the damaging effects of radiation. Once the design is generated, the radiation dose and shielding calculation is performed by a ray-tracing module that combines data from the radiation model with data of the radiation environment. For further information, visit www.RidgetopGroup.com or e-mail information@ridgetopgroup.com.

Wind River has released Wind River Open Network Software for the development of next-generation data-centre switches. Open Network Software is a complete, open software environment for the creation of network switches for software-defined networks and infrastructures. It provides the tools and resources to create, modify, and update network layers L1, L2+ and L3+ functionality and is highly extensible, allowing for the seamless addition of third-party applications. It also supports an extensive suite of networking protocols. For more information, visit www.windriver.com/products/linux/open-network-software/.

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.

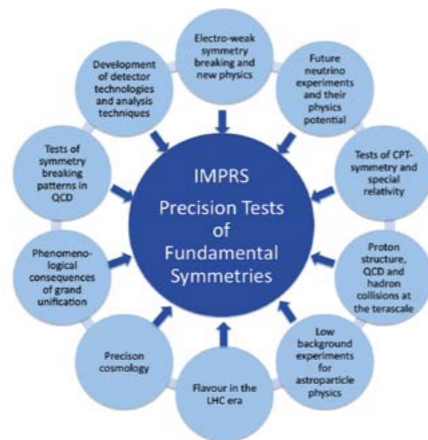
International Max Planck Research School for Precision Tests of Fundamental Symmetries: PhDs in Fundamental Physics

The IMPRS-PTFS is a joint venture of the Max-Planck-Institute for Nuclear Physics and the University of Heidelberg.

Students will work under the supervision of leading scientists on exciting and current topics in the fields of particle and astroparticle physics, cosmology, atomic and nuclear physics. The members of the school can work on both theoretical and experimental aspects. Regular seminars and soft skills courses will add to the broad education of the students.

We invite applications for 3-4 fellowships for PhD positions, with deadline December 1st.

Please refer to <http://www.mpi-hd.mpg.de/imprs-ptfs> for more information and details of the application procedure.



FACULTY POSITION EXPERIMENTAL NUCLEAR PHYSICS UNIVERSITY OF ILLINOIS, URBANA-CHAMPAIGN

The Department of Physics invites applicants for a fulltime tenure or tenure-track faculty position in experimental nuclear physics, beginning in August 2014. The UIUC Department of Physics has strong and broad programs in nuclear physics. Scientists from all subfields of nuclear physics are encouraged to apply. The successful candidate is expected to lead a vigorous research program, teach effectively at both the undergraduate and graduate levels, and to have a strong record of publication.

Qualified senior candidates may also be considered for tenured full Professor positions as part of the Grainger Engineering Breakthroughs Initiative, which is backed by a large gift from the Grainger Foundation. Over the next few years, more than 35 new endowed professorships and chairs will be established. The two main research areas are Big Data and Bioengineering. More information regarding the Grainger Initiative can be found at: <http://graingerinitiative.engineering.illinois.edu>.

To apply for this position, please create a candidate profile at <http://jobs.illinois.edu> and upload a curriculum vitae, a list of publications, a brief description of research and teaching interests and plans, and the names of three people who can provide letters of recommendation. Please contact Margie Gamel at 217-333-3762 or mgamel@illinois.edu for further inquiries or questions. For full consideration, application materials must be received by November 15, 2013. Applications will be accepted until the position is filled. Salary will be competitive and rank will be commensurate with qualifications.

Illinois is an Affirmative Action/Equal Opportunity Employer and welcomes individuals with diverse backgrounds, experiences, and ideas who embrace and value diversity and inclusivity (www.inclusiveillinois.illinois.edu). We have an active and successful dual-career partner placement program and a strong commitment to work-life balance and family-friendly programs for faculty and staff (<http://provost.illinois.edu/worklife/index.html>).



INDIANA UNIVERSITY

FACULTY POSITIONS THEORETICAL NUCLEAR PHYSICS

The Department of Physics at Indiana University invites applications for a position in theoretical nuclear physics, subject to funding and approval for appointment beginning Fall 2014. Applicants must hold a Ph.D. in Theoretical Physics or a related field at the time of appointment (August 1, 2014). Candidates will be evaluated for appointment at the tenure-track assistant professor level at a salary commensurate with qualifications and experience. Members of IU's world-class efforts in nuclear theory are also active within the newly created Center for Exploration of Energy and Matter (CEEM) that provides enhanced support for research and promotes cross-disciplinary research.

The initial position will be a bridge appointment with Thomas Jefferson National Accelerator Facility (Jefferson Lab) for a period of up to six years. During this period, the appointee will spend about half of his/her time at Indiana University and the other half at the Jefferson Lab.

The successful candidate will be expected to develop a world-class research program in any of the forefront areas of theoretical nuclear physics, with particular emphasis on those that support, strengthen and promote collaboration on the Jefferson Lab 12 GeV physics program over the next decade. The areas of specialization include the fields of perturbative and non-perturbative QCD, hadron structure and spectroscopy, hadron reaction theory, electromagnetic and weak interactions and symmetries, effective field theory, and the application of lattice QCD to all aspects of strong interactions.

A commitment to excellence in teaching at the undergraduate and graduate level is essential. Candidates should submit a letter of application, research statement, curriculum vitae including a list of publications, description of teaching interest and a minimum of three letters of reference. Applications should be submitted through the application portal located at <https://indiana.peopleadmin.com/hr/postings/475>. For questions, please contact the Physics Department at 812-855-1247. In addition, a copy of the application package should be mailed to: Dr. Michael Pennington, Associate Director for Theoretical & Computational Physics, Jefferson Laboratory, 12000 Jefferson Avenue, Newport News, VA, USA.

Applications received by January 15, 2014 will be given full consideration. Further information about the IU Physics Department can be found at <http://physics.indiana.edu>.

Indiana University is an Affirmative Action/Equal Opportunity Employer strongly committed to excellence through diversity and is responsive to the needs of dual career couples. The University actively encourages applications of women, minorities, and persons with disabilities.



TRIUMF LABORATORY DIRECTOR

TRIUMF is seeking an individual with an extraordinary combination of scientific vision, accomplishment, and leadership to assume responsibility for directing the laboratory.

TRIUMF is Canada's national laboratory for particle and nuclear physics. Owned and operated as a joint venture by a consortium of 18 Canadian universities, the laboratory enables research that benefits every sector of the Canadian science, technology, and innovation enterprise and leads to major advances in particle and nuclear physics, materials science, nuclear medicine, and accelerator physics. Core financial support for operations is provided through a contribution agreement via the National Research Council of Canada. TRIUMF has a dedicated staff of 350 continuing employees, a user community of 1,000, and provides unique educational experiences and training for undergraduate students, graduate students, and postdoctoral scholars.

The successful candidate will demonstrate his or her ability to advance an organization that is recognized nationally and internationally for excellence:

- Effectively lead overall strategic planning, decision making, and the development of policies and budgets
- Provide leadership in determining the scientific direction of the laboratory;
- Interact closely with relevant funding agencies and with members of the federal and provincial governments to secure financial support;
- Define objectives and approve policies for achieving employee and public safety at TRIUMF;
- Be responsible to the appropriate government agencies for regulatory compliance; and
- Report to the Board of Management on policy and carry out policy decisions.

Position the laboratory to drive societal and economic benefits for Canada

- Encourage interaction between TRIUMF researchers and industry to foster innovation and maximize the economic benefits to Canadians; and
- Promote TRIUMF to the general public.

Interact with Canadian universities and the physics community in formulating plans and in supporting community priorities

- Facilitate the use of TRIUMF's infrastructure to support Canadian-led offshore projects; and
- Develop and maintain contact with other laboratories throughout the world that have common interests.

The position requires broad insight into the research capabilities of TRIUMF and a thorough understanding of how these capabilities can be exploited and further developed. The successful candidate will have leadership experience and a research career of international distinction.

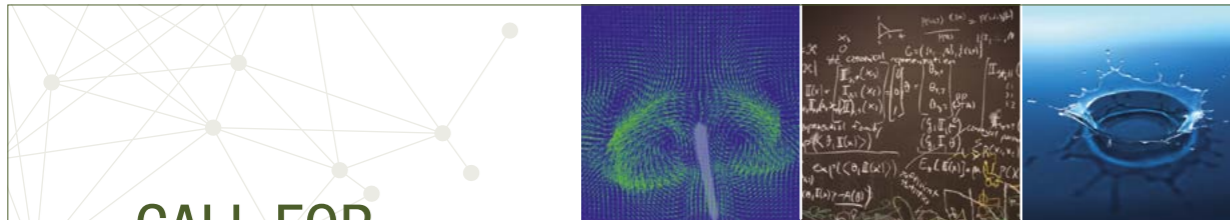
Please note the position is open to all qualified applicants, and in the case of equal qualifications, preference may be given to a Canadian Citizen or Permanent Resident. TRIUMF is an equal opportunity employer. The term of the appointment would be for five years.

Applications should include a full curriculum vitae and a statement on vision for the laboratory. The review of applications will begin on November 4 and continue until an appointment is made. Applications and inquiries should be directed to:

**Professor Robert Kowalewski, University of Victoria
Chair, Search Committee
E-mail: next-director@triumf.ca**

<http://www.triumf.ca/next-director>





CALL FOR Professors and Assistant Professors

IST Austria invites applications for **tenured and tenure-track leaders of independent research groups** in following fields: **Physics | Chemistry | Biology | Neuroscience | Earth Science | Mathematics | Computer Science | Interdisciplinary Areas**

The Institute is dedicated to basic research and graduate education in the natural and formal sciences. The successful candidates will receive a substantial annual research budget, are expected to apply for external research grants and to participate in the Graduate School.

Deadline for receiving Assistant Professor applications: November 15, 2013

Open call for Professor applications

Further information and online application: www.ist.ac.at/professor-applications

IST Austria values diversity and is committed to equality. Female researchers are encouraged to apply.



RF Engineer

Brookhaven National Laboratory is seeking an RF engineer with experience in high power systems. The selected candidate will work closely with a team of RF engineers and technicians in the operations of RF systems in the NSLS-II accelerator complex including the operation and upgrades of 40 Megawatt pulsed S-band klystron systems, a 500 MHz 80kW CW IOT amplifier system and 500 MHz 300 kW CW klystron amplifiers systems powering superconducting RF cavities.

Please apply to Job ID# 16514 at www.bnl.gov/HR/careers



Electronics Engineer

UCL invites applications for an immediate opening for an electronics engineer who will have responsibility for developing, commissioning and maintaining readout/trigger and data acquisitions systems for the HEP group. In the first instance this is an 18-month appointment, but it is anticipated to be a longer-term appointment subject to future grant funding. The successful candidate will have in-depth knowledge in readout and trigger electronics and data acquisition systems for high energy physics detectors and hands-on experience in developing, building and commissioning such systems. Apart from his/her own research work the appointee will liaise closely with other members of the HEP electronics group.

Salary will be in the range from £32,375 to £39,132 per annum inclusive of London Allowance. The closing date for applications is 1 Dec 2013. Further details about the position and the application procedure can be found at http://www.hep.ucl.ac.uk/positions/ee_oct2013.shtml.



Scientific Staff

Postdoctoral Fellows
Assistant Professors
Associate and Full Professors

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

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 make appointments in all three categories of the positions listed above. 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 faculty, 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/MaNGA for a survey of galaxies, POLARBEAR CMB B-mode polarization measurement and R&D for future large neutrino detectors. Kavli IPMU is a full institutional member in SDSS-III.

The search is open until filled, but for full considerations please submit the applications and letters by Dec 1, 2013.

Further information can be found here: <http://www.ipmu.jp/job-opportunities>

For inquiries please contact: application-inquiry@ipmu.jp



The Leung Center for Cosmology and Particle Astrophysics (LeCosPA) of National Taiwan University is pleased to announce the availability of several Post-Doctoral Fellow or Assistant Fellow positions in theoretical and experimental cosmology and particle astrophysics, depending on the seniority and qualification of the candidate. Candidates with exceeding qualification will be further offered as LeCosPA Distinguished Junior Fellows with competitive salary.

LeCosPA was founded in 2007 with the aspiration of contributing to cosmology and particle astrophysics in Asia and the world. Its theoretical studies include dark energy, dark matter, large-scale structure, neutrino cosmology, and quantum gravity. The experimental investigations include the balloon-borne ANITA project in Antarctica and the ground-based ARA Observatory at South Pole in search of GZK neutrinos, and a satellite GRB telescope UFFO that is capable of slewing to the burst event within 1sec.

These positions are available on September 1, 2014. Interested applicant should email his/her application with curriculum vitae, research statement, publication list and three letters of recommendation before December 15, 2013 to Ms. Yen-Ling Lee ntulecospa@ntu.edu.tw

For more information about LeCosPA, please visit its website at <http://lecospa.ntu.edu.tw/>

Three letters of recommendation should be addressed to **Prof. Pisin Chen, Director** Leung Center for Cosmology and Particle Astrophysics National Taiwan University

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron A Research Centre of the Helmholtz Association



PARTICLE PHYSICS.

DESY, Hamburg location, is seeking: Leading 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.

The particle physics programme of DESY comprises strong contributions to the LHC experiments ATLAS and CMS, to BELLE II at SuperKEKB and to the preparation of a future International Linear Collider, as well as the completion of the analyses of the HERA experiments. The experimental programme is performed in close interaction with a strong theory group. DESY is closely collaborating with German groups in the framework of the Helmholtz Alliance Physics at the Terascale and internationally with major laboratories and institutes in particle physics. To strengthen its present and future particle physics programme, DESY seeks a leading scientist equivalent to a full professor (W3) at a German university. The position is embedded in the DESY/ATLAS group.

The position

- Contribute in a leading position to the experimental particle physics programme
- Assume a leading role in DESY's ATLAS activities (data analysis and detector upgrade)
- Contribute in shaping the future programme in particle physics of DESY

Requirements

- Internationally recognised scientist in the field of collider physics
- Demonstrated leadership abilities in high energy physics projects
- Outstanding qualifications in particle physics analyses and detector development

For further information please contact Prof. Dr. Joachim Mnich +49 40 8998-1921, joachim.mnich@desy.de.

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.

Please send your application quoting the reference code, also by E-Mail to:

Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: EM140/2013
Notkestraße 85 | 22607 Hamburg | Germany | Phone: +49 40 8998-3392 | E-Mail: recruitment@desy.de

Deadline for applications: 10 November 2013
www.desy.de

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



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Institute of High Energy Physics, Chinese Academy of Sciences Recruitment of Overseas High-level Talents

Name of Programs:

- National "Thousand Talents Program" (long term & short term programs)
- National "Thousand Young Talents Program"
- "Hundred Talents Program" (overseas outstanding talents) of Chinese Academy of Sciences
- "Outstanding Talents Program" of Institute of High Energy Physics, Chinese Academy of Sciences

Recruitment Objectives:

Based on the needs of the research areas and the disciplines development of the Institute of High Energy Physics Chinese Academy of Sciences (hereafter referred to as "IHEP CAS", we are now publicly recruiting overseas outstanding talents and scholars of relevant disciplines who possess research abilities and innovation awareness.

1. National "Thousand Talents Program"

Research directions: R&D of advanced particle detectors, nuclear electronics, accelerator physics, accelerator technology (including magnet power, high-frequency microwave, vacuum, control, beam measurement, radiation protection, power source, magnets and mechanical technology), cosmic ray physics (including high-energy Gamma-ray astronomy), cosmic ray detection technology, theory and observations of high-energy astrophysics (including compact stars, Gamma ray burst, active galactic nuclei), space astronomical instruments (including detectors, electronics, and X-ray optics), particle physics, nuclear physics, cosmology, astronomy, and accelerator-based light source physics (preferably Higgs physics and other TeV high-energy physics), synchrotron radiation beam line and experiment techniques, relationship of protein structure and function, molecular imaging, medical physics

2. National "Thousand Young Talents Program"

Research directions: pixel detector, offline software, trigger and data acquisition, event reconstruction, data processing, electronics in particle physics experiments, ASIC, radiation-hard devices, accelerator physics, accelerator technology (including magnet power, high-frequency microwave, vacuum, control, beam measurement, radiation protection, power source, magnets and mechanical technology), cosmic ray physics (including high-energy Gamma-ray astronomy), cosmic ray detection technology, theory and observations of high-energy astrophysics (including compact stars, Gamma ray burst, active galactic nuclei), space astronomical instruments (including detectors, electronics, and X-ray optics), particle physics, nuclear physics, cosmology, astronomy, and accelerator-based light source physics (preferably Higgs physics and other TeV high-energy physics), Typical pollutants' environmental behavior and toxicology, Metallomics, synchrotron radiation beam line and experiment techniques, medical imaging (nuclear detection technology, nuclear spectroscopy, nuclear electronics technology, image processing, image reconstruction algorithm) application accelerator (accelerator technology)

3. CAS "Hundred Talents Program"

Research directions: particle physics experiment (detectors R&D, offline software and physical analysis), nuclear electronics, accelerator physics, accelerator technology (including magnet power, high-frequency microwave, vacuum, control, beam measurement, radiation protection, power source, magnets and mechanical technology), accelerator physics, accelerator technology, high intensity proton accelerator technology, low-temperature superconducting technology, cosmic ray physics (including high-energy gamma-ray astronomy), cosmic ray detection technology, theory and observations of high-energy astrophysics (including compact stars, Gamma ray burst, active

galactic nuclei), space astronomical instruments (including detectors, electronics, and X-ray optics), particle physics, nuclear physics, cosmology, astronomy, and accelerator-based light source physics (preferably Higgs physics and other TeV high-energy physics), typical pollutants environmental behavior and toxicology, Metallomics, relationship of protein structure and function, The interaction between nano-materials and organism, the application of nano-materials in cancer diagnosis and treatment, new nano-material synthesis, modification, characterization and application of nano-materials, nuclear structural materials radiation damage effects, synchrotron radiation beam lines and experiment techniques, computer software and theory, distributed computing, network technology, medical imaging (nuclear detection technology, nuclear spectroscopy, nuclear electronics technology, image processing, image reconstruction algorithm) application accelerator (accelerator technology)

4. IHEP "Outstanding Talents Program"

Research directions: pixel detector, offline software, trigger and data acquisition, event reconstruction, data processing, electronics in particle physics experiments, ASIC, radiation-hard devices, sensors and monitoring devices, accelerator physics, accelerator technology (including magnet power, high-frequency microwave, vacuum, control, beam measurement, radiation protection, power source, magnets and mechanical technology), cosmic ray physics (including high-energy gamma-ray astronomy), cosmic ray detection technology, theory and observations of high-energy astrophysics (including compact stars, Gamma ray burst, active galactic nuclei), space astronomical instruments (including detectors, electronics, and X-ray optics), radiation damage effects of nuclear structural materials, typical pollutants' environmental behavior and toxicology, Metallomics, synchrotron radiation beam lines and experiment techniques, medical imaging (nuclear detection technology, nuclear spectroscopy, nuclear electronics technology, image processing, image reconstruction algorithm), application accelerator (accelerator technology)

How to Apply

1. Personal resumes (one in English and one in Chinese preferred)
2. Three letters of recommendation by renowned experts of the field (referees may send the electronic version of the letters of recommendation with their signature to the contact email provided below); At least three renowned overseas referees are required for applicants of National "Thousand Talents Program"/"Thousand Young Talents Program"
3. Chinese Academy of Sciences' "Overseas Outstanding Talents" Candidate Recommendation (Self-recommendation) Form or Institute of High Energy Physics' Outstanding Talent Candidate Recommendation (Self-recommendation) Form

If you are interested, please send your application materials in electronic files to the contacts provided below (please indicate on the subject of the email as: name+job category+where you've obtained the job information)

Means of Contact

Contact Person: Wenli Zheng, Division for Human Resources, Institute of High Energy Physics, Chinese Academy of Sciences

E-mail: zhengwl@ihep.ac.cn

TEL: (86) 010-88235879 Fax: (86) 010-88233102

Address:

No. 19 (B), Yuquan Road, Shijingshan District, Beijing (Postcode: 100049)

For more information please go to <http://english.ihep.cas.cn/>

Are you ready to join our research and collaborations team for Radiation Oncology?

We have two new exciting opportunities within our Research and Collaborations team for Radiation Oncology professionals based out of the United Kingdom and USA.

- 1: **Director of Research and Collaborations, Oncology. Based near Gatwick, West Sussex.**
- 2: **Director of Research and Collaborations, Oncology Based in the USA.**

A highly attractive remuneration package is available for the successful candidate.

Responsibilities

We are looking for someone for both positions to direct, manage and execute departmental objectives responsible for partner management, identifying new collaboration partners and coordinating global Elekta sponsored research activities.

The role is a key driver in ensuring Elekta's continued success in the area of research and clinical partnering.

Elekta are committed to working with our clinical partners on research into the area of Radiation Therapy. Develop and maintain an effective clinical support platform for all oncology solutions and build strong working relationships with Elekta customers and advocates.

Experience

- A Degree in a technical and clinical speciality would be preferable. (Physics, Maths, Engineering).
- A strong knowledge of Elekta's portfolio of products and a successful track record of research is essential.
- You will be required drive forward the already successful collaborations that Elekta have developed.
- Experience of planning, team leadership, negotiating skills, problem solving and senior project management needs to be demonstrated.
- Elekta encourages professional development and offers opportunities for growth within the company. Other benefits include flexible working conditions, 25 days holiday, private medical insurance and pension.

Elekta is a human care company pioneering significant innovations and clinical solutions for treating cancer and brain disorders. The company develops sophisticated tools and treatment planning systems for radiation therapy and radiosurgery, as well as workflow enhancing software systems across the spectrum of cancer care.



For further details and full job description of both positions, please visit the careers section of our website at www.elekta.com or email Lucy.Parsons@elekta.com

Human care makes the future possible



Bookshelf

Bookshelf

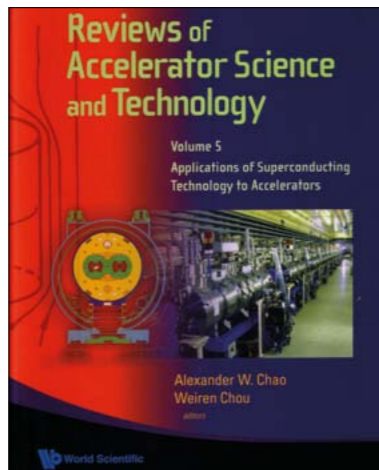
Reviews of Accelerator Science and Technology: Volume 5 – Applications of Superconducting Technology to Accelerators

By Alexander W Chao and Weiren Chou (eds.)
World Scientific
 Hardback: £98
 E-book: £74

Reviews of Accelerator Science and Technology is a journal series that began in 2008 with the stated aim “to provide readers with a comprehensive review of the driving and fascinating field of accelerator science and technology” – in a “journal of the highest quality”. It made an excellent start, with the first volume presenting the history of accelerators, followed by one that focused on medical applications (*CERN Courier* May 2010 p51). With one volume published a year, there are now five in the series, which appears to show no signs of failing in its original goals. Each has communicated a specific topic through the words of highly respected experts in articles that are well illustrated and presented. The books they form hold the promise of becoming an unrivalled encyclopaedia of accelerators.

This latest volume is no exception. It looks at the role of superconductivity in particle accelerators and how this intriguing phenomenon has been harnessed in the pursuit of ever-increasing beam energy or intensity. It also considers the application of superconducting technology beyond the realm of accelerators, for example in medical scanners and fusion devices. As well as containing much technical detail it is also full of fascinating facts.

Exactly 100 years ago, Heike Kamerlingh Onnes speculated that a 10 T superconducting magnet “ought not to be far away” (*CERN Courier* April 2011 p46). The first contributions to this volume, in particular, outline some of the steps to 10 T – and why it took longer than Onnes had originally hoped for the industrial-scale production of high-field superconducting magnets to become reality. A major problem lay in finding superconducting materials with physical properties that allow large-scale fabrication into wires. The first commercially produced wires were of niobium-zirconium, as used in early superconducting magnets for bubble chambers. However, this alloy was soon superseded by niobium-titanium (NbTi) – the material of choice in high-energy physics for the past 40 years, culminating today in the superconducting magnets for the LHC, as well as the huge toroidal and



solenoidal magnets for the ATLAS and CMS detectors. Now, R&D effort is turning to Nb₃Sn, which can allow higher magnetic fields, for example for the High Luminosity LHC project (*CERN Courier* July/August 2013 p41).

In this context, it is worth realizing that the biggest market for superconducting magnets is for nuclear magnetic-resonance spectroscopy – and it is here that a field as high as 23.5 T has been reached in a magnet based on Nb₃Sn. There is also interest in high magnetic fields for magnetic resonance imaging (MRI) in medicine. In MRI the signal strength is related to the polarization of the protons in whatever is being scanned. Increasing the magnetic field from the 1.5 T that is currently used routinely to 10 T results in a polarization that is almost seven times higher, as well as improved signal-to-noise, leading to a clear improvement in image quality. Upcoming developments include 6 T magnets based on Nb₃Sn.

The application of superconductivity in particle accelerators extends of course to the acceleration system, with the use of superconducting RF technology, first proposed in 1961 (*CERN Courier* November 2011 p33). In this case, an important part of the R&D has focused on the physics and materials science of the surface – the surface resistance being a key parameter. So far there are no commercial applications for superconducting RF, but it has a role in many types of particle accelerators, from high-current storage rings at light sources to the high-energy machines of the future, such as the International Linear Collider (ILC).
 Jefferson Lab’s Continuous

Electron-Beam Accelerator Facility (CEBAF) is in a sense the “LHC” of superconducting RF, employing originally 360 five-cell 1.5 GHz cavities. It is currently undergoing an upgrade to 12 GeV (*CERN Courier* November 2012 p30) with cavities that will operate at 19.2 MV/m. The European X-ray free-electron laser project, XFEL at DESY, will use 800 nine-cell 1.3 GHz cavities operating at more than 22 MV/m, but it would be dwarfed by an ILC with more than 15,000 cavities.

Besides the contributions on the major topics of superconducting magnets and RF, others are dedicated to cryogenic technology, industrialization and applications in medicine. In addition, following the journal’s tradition, there are articles that are not related to the overall theme but are of concern to the accelerator community worldwide. In this case, one article discusses the education and training of the next generation of accelerator physicists and engineers, while another reviews the history of the KEK laboratory in Japan. Altogether, this makes for more than a journal volume – in my opinion, it is a book, well worth reading.

• Christine Sutton, CERN.

Doing Physics: How Physicists Take Hold of the World (2nd edition)

By Martin H Krieger
Indiana University Press
 Paperback: £16.99 \$24.00
 E-book: £14.99 \$21.99

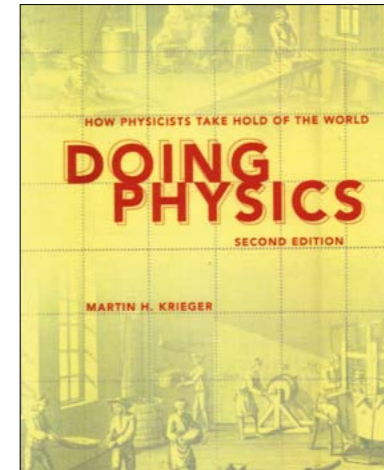
First published over two decades ago, *Doing Physics* has recently been released as a second edition. The book relates the concepts of physics to everyday experiences through a carefully selected series of analogies. It attempts to provide a non-scientific description of the methods employed by physicists to do their work, what motivates them and how they make sense of the world.

Martin Krieger began his academic career in experimental particle physics but quickly realised that he was not suited to working in large groups on experiments. Following his PhD, he moved into the social sciences and began working on computing models for city planning. He uses this experience to reflect on the way science is done from a social science viewpoint. His aim is to explain how doing physics is part of familiar general culture.

Krieger claims that physicists employ a small number of everyday notions to “get a handle on the world” experimentally and

conceptually. He argues further that these models and metaphors describe the way physicists actually view the world and that to see the world in such terms is to be trained as a physicist. The analogies he chooses to support his ideas are drawn from the diverse areas of economics, computing, anthropology, theatre and engineering. Each of the first five chapters of the book is devoted to exploring each of the analogies in detail.

The book begins with a discussion on division of labour according to the economist Adam Smith’s model of a pin factory. The description of physical situations in terms of interdependent particles and fields is analogous to the design of a factory with its division of labour among specialists. The second chapter considers physical degrees of freedom as the parts of a complex model such as a clockwork mechanism or a computer. Chapter three is devoted to the anthropological theory of kinship and marriage, comparing the rules of relationships to the rules of interaction for the families of elementary particles or for chemical species – who can marry whom is like what can interact with what. The conclusion is that anything that is not



forbidden will happen. The theatrical world provides an analogy to creation, where a vacuum is represented by a simple stage setting on which something arises out of nothing. Finally, machine-tool design is used to describe the physicist’s toolkit, where the work of doing physics is like

grasping the world with handles and probes.


In the second edition, Krieger has provided some minor revisions to the text and has added a brief chapter on the role of mathematics and formal models in physics. This additional discussion is based on work from two other books he has written in the intervening years. It is questionable whether the second edition is warranted. In this highly technical chapter Krieger goes so far as to discern an analogy of analogies in physics and mathematics – a so-called syzygy.

Krieger claims that the book is for high-school students and upwards. However, it seems more appropriate for a specialized audience. *Doing Physics* is aimed at sociologists and philosophers of science, rather than at the science community itself. Indeed, for some the experience of reading the book could bring to mind a well known quote by Richard Feynman: “Philosophy of science is about as useful to scientists as ornithology is to birds.” For others, however, the book might provide some useful insights into patterns or relationships between physics and the everyday world that they have not previously considered.

• Theresa Harrison, Warwick University.

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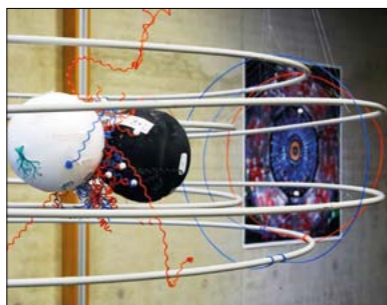




Inside Story

A dialogue between science and art

With an international reach, CMS provides an ideal platform to communicate science through art.



The Incredible Science-Art Collider, one of the students' artworks created during the Science&Art@School event in Graz. (Image credit: M Hoch.)

The Joanneum Universal Museum in Graz is Austria's oldest publicly accessible museum and the largest general museum in central Europe. In June this year, 200 years after its foundation, I was in this inspiring building with a group of students from two local schools. We were participating in an interdisciplinary workshop to bridge art and the scientific world of particle physics. I am a physicist at CERN/CMS but also an artist who tries to express my scientific work in an artistic manner and I want to inspire the younger generation to get in touch with our fascinating scientific world. In my contact with non-science students, I often sense their reservation regarding scientific topics and a fear of being wrong. By getting them involved in a different way via the language of art, they might discover the many beautiful aspects of the scientific universe.

If we want to have a significant impact in reaching out for new science audiences, we need to use extended communication channels. Art is definitely one that gives us the possibility to invite a larger public to get in touch without making them feel excluded from science because they do not understand it. The big advantage of art is that it is subjective, while science is objective. No one can be told that they are wrong if they try to understand the meaning of an artwork.

So, within the CMS collaboration we have set up Art@CMS as a vehicle for dialogue between scientists, artists and the public and to have a sustainable effect on science communication and inspiration. The aim is to tap into the worldwide network of the CMS collaboration and invite artists from all over the world to get in touch and contribute ideas, concepts and artwork.

However, it is not only about professional artists. In CMS we want to inspire young people to think in a different way and we take their thoughts and ideas seriously. Art, like science, is a serious subject, so

the aim was to develop a serious project to bring art and science together at school. In collaboration with the education and outreach groups of both CERN and CMS, together with the Institute for High Energy Physics (HEPHY) in Vienna – the local CMS institute for the event in Graz – we were able to set up the Science&Art@School project within the framework of the PATHWAY European project.

The workshop in Graz was the first of what I hope will be many similar occasions for Science&Art@School. Interdisciplinary in its approach, interactive and flexible in its design and international in its scope, the idea is to promote fruitful dialogue between the arts and the particle-physics community by engaging high-school and university students in the act of creating a work of art, inspired by the big questions that drive scientific work at CMS and CERN. In most school curricula, physics and art are thought of – and taught as – separate subjects. On the other hand, in the Science&Art@School project, as my colleague Angelos Alexopoulos from CERN's Education and Public Outreach Group says, we believe that particle physicists and artists share fertile common ground in their parallel efforts to explore and understand *physis* (the Greek word for nature).

The two-day event in Graz brought together 62 high-school students, art and physics teachers from the Graz International Bilingual school and BORG school, along with particle physicists from HEPHY, to exchange insights, ask and

answer questions and co-create artworks – their visualizations of fundamental concepts in physics. Three months earlier, in preparation, CMS organized an interactive virtual visit to the experiment for the students – a three-to-four-point online video-conference connection with guides both on the surface and underground. Students could ask questions and direct the guides to see various areas of CMS. The workshop had two parts. On the first day, the researchers gave a CMS masterclass, where the students learned to visualize and analyse real LHC data. They then learned about how artists visualize science and technology. On the second day, four groups of students, assisted by the art educators and scientists, created artworks inspired by particle physics, which were then displayed to the public at the museum.

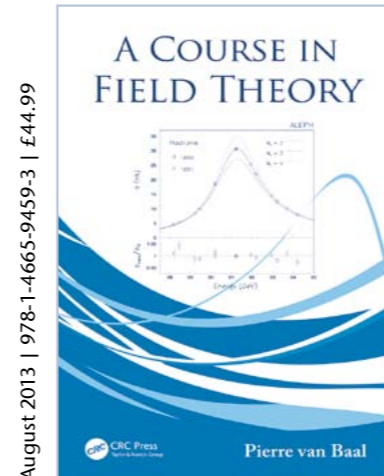
Science&Art@School is part of the bigger project, Art@CMS, which started in 2012 with a collaboration between the Miami artist Xavier Cortada and physicist Pete Markowitz of Florida International University. Cortada's artwork *In search of the Higgs Boson* was shown at CERN during the CMS collaboration week in April 2013. In December, Alison Gill, a sculptural artist from the UK, will present her artwork with "science inspiration partner" Ian Shipsey and in March 2014 it will be the turn of the Italian painter Paco Falco with physicist Pierluigi Paolucci. During the recent open days at CERN, *Quantum*, a co-production of Collide@CERN and the Forum Meyrin by choreographer Gilles Jobin, was presented at CMS Point 5 (see p29).

● Art@CMS upcoming events:
 "Unseen Dimensions" symposium (28 October–1 November) and exhibition (29 October–29 November), City of London School, London;
 "Art of Science, Beauty in Creation" Science Night (8 November) and exhibition (8 November–13 December) RWTH, Aachen;
 "Faszination Ursprung" exhibition (12 November–18 January) Deutsches Museum/Wissenschaftszentrum, Bonn.
 ● Michael Hoch, CMS/Austrian Academy of Sciences. A physicist and artist, he is the founder of Art@CMS (<http://cms.web.cern.ch/content/artcms>). His artwork of the CMS detector was shown in an exhibition at the experiment in July.

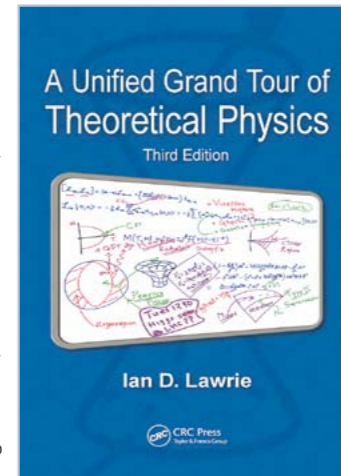
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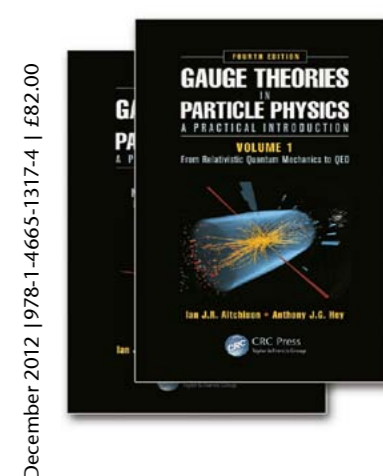
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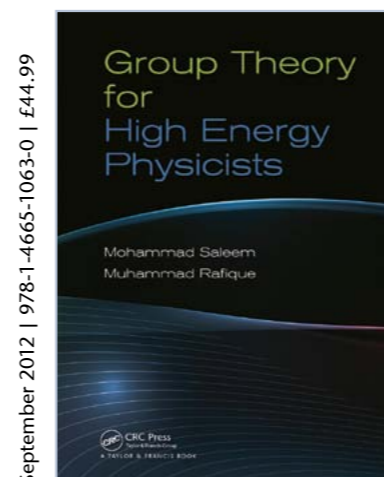
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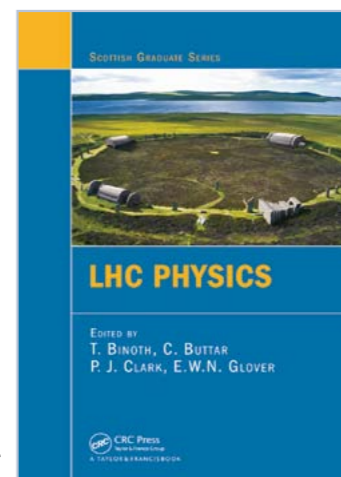
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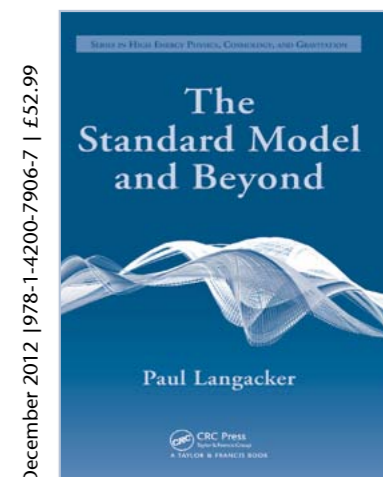
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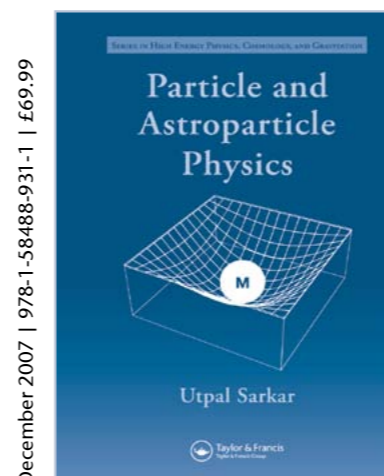
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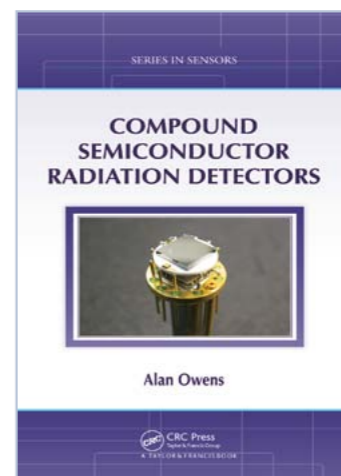
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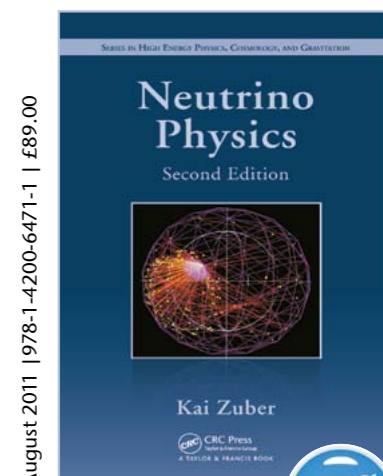
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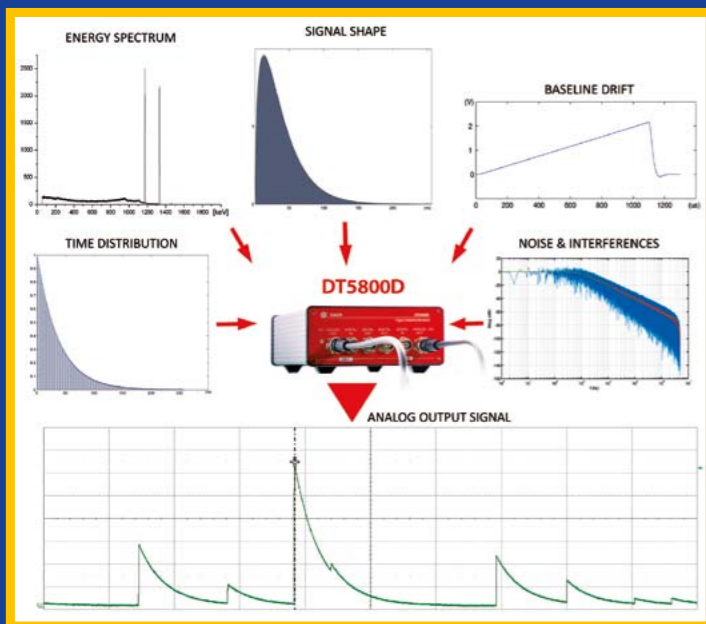
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