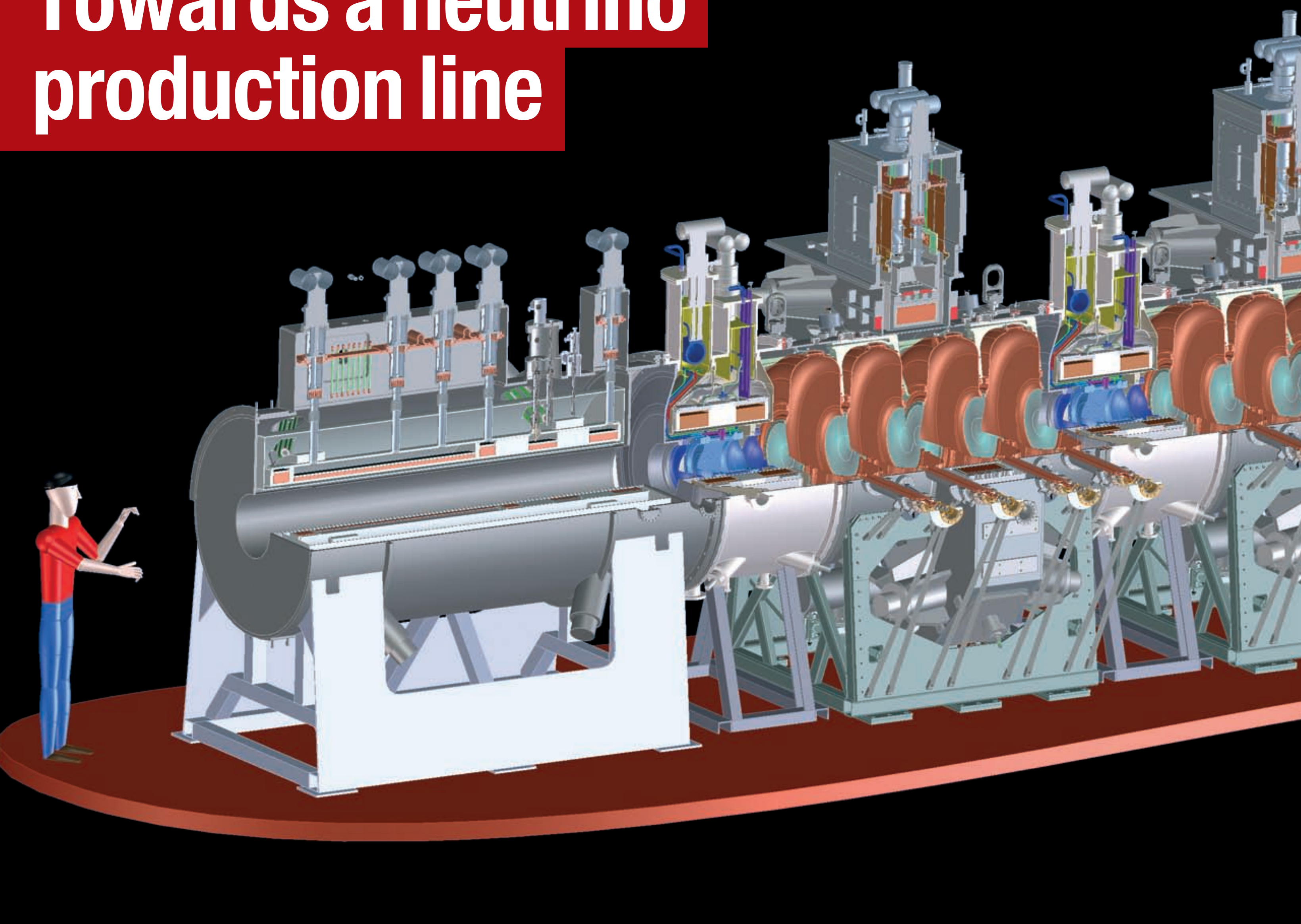
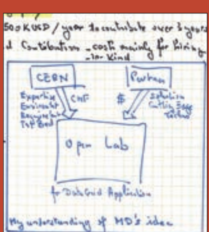
INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 52 NUMBER 4 MAY 2012

Towards a neutrino production line





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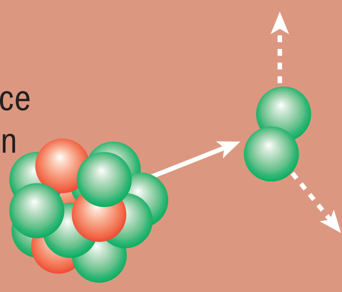

ELECTRONS FOR THE LHC

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

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

Publisher Susan Curtis
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General distribution Courrier Adressage, CERN, 1211 Geneva 23, Switzerland
E-mail: courrier-adressage@cern.ch
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UK Mark Wells, Science and Technology Facilities Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1SZ
E-mail: mark.wells@stfc.ac.uk
US/Canada Published by Cern Courier, 6N246 Willow Drive,
St Charles, IL 60175, US. Periodical postage paid in St Charles, IL, US
Fax 630 377 1569. E-mail: creative_mailing@att.net
POSTMASTER: send address changes to: Creative Mailing Services, PO Box 1147,
St Charles, IL 60174, US

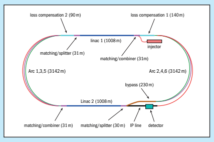
Published by European Organization for Nuclear Research, CERN,
1211 Geneva 23, Switzerland
Tel +41 (0) 22 767 61 11. Telefax +41 (0) 22 767 65 55

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

IOP Publishing

CERNCOURIER

VOLUME 52 NUMBER 4 MAY 2012



On the cover: A cutaway rendering of part of the international Muon Ionization Cooling Experiment (MICE), which is to provide the engineering demonstration of the ionization-cooling technique required for the Neutrino Factory (p17). (Image credit: A DeMello/LBNL.)

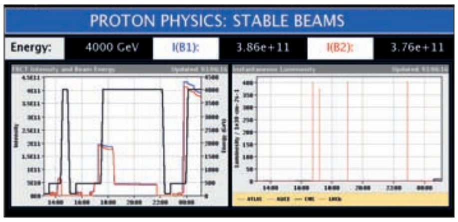
News

CERN

LHC yields data rapidly at new collision energy of 8 TeV

At 12.38 a.m. on 5 April, the LHC shift crew declared "stable beams" as two 4 TeV proton beams were brought into collision at the LHC's four interaction points. This signalled the start of physics data-taking by the LHC experiments for 2012. The collision energy of 8 TeV is a new world record. By 11 April the LHC had already delivered a total integrated luminosity of 0.2 fb^{-1} to the experiments. Last year, it took six weeks achieve the same number.

Although the increase in collision energy is relatively modest, it translates to an increased discovery potential that can be several times higher for certain hypothetical particles. Some, such as those predicted by supersymmetry, would be produced much more copiously at 8 TeV than the 7 TeV of 2011. Larger numbers of Standard Model Higgs bosons, if they exist, will also be produced at 8 TeV but background processes that mimic the Higgs signal will also increase. That means that the full year's running will still be necessary to convert the tantalizing hints seen in 2011 into a discovery – or to rule out the Standard Model Higgs particle altogether.



The LHC started physics again on 5 April, at a new record energy of 4 TeV per beam.

Protons were accelerated to 4 TeV for the first time on the evening 16 March just two days after beam returned to the machine for 2012. A period of beam commissioning followed, during which the teams checked that the various systems are working flawlessly with beam. The optics measurements included setting the β^* of the squeezed beam at the interaction regions. The aim this year is to have a smaller β^* of 60 cm for the ATLAS and CMS experiments. The smaller β^* is then the thinner and more squeezed the beams are at the collision points, but it also requires that the collimators are positioned closer to the beam. The collimation system is therefore carefully set up in different machine modes: injection energy; full energy; full energy with squeezed bunches; and full energy with collisions. By provoking beam losses and making "loss maps", the operators verify that the beam is lost in the collimation region and not in places where it can cause damage. All of these checks take place with a few, often low-intensity, bunches.

The LHC is now scheduled to run until the end of 2012, when it will go into its first long shutdown in preparation for running at an energy of 6.5 TeV per beam in late 2014, with the ultimate goal of ramping up to the full design energy of 7 TeV per beam.

● To keep up to date on news from the LHC, see *The Bulletin*, http://cern.ch/bulletin.

SPACE FLIGHT

Edoardo Amaldi ATV launches into space

A leading figure of 20th-century experimental physics, Edoardo Amaldi was one of the main players in the process that turned the dreams of large, transnational scientific projects among European countries into reality (*CERN Courier* December 2008 p13). While his role in the establishment of CERN is the prime example, he was also an active advocate for a European programme for space research and was instrumental in founding the organizations that were the precursors to ESA.

On 23 March ESA's third Automated Transfer Vehicle (ATV), named in honour of Amaldi, was launched on board an Ariane rocket. It successfully docked with the International Space Station six days later, where it will remain for five months. The 20-tonne vessel, flying autonomously while being monitored from the ground, is delivering essential supplies and propellant, as well as reboosting the station's altitude. The ATV docked with the 450-tonne orbital complex with a precision of 6 cm while circling the Earth at more than 28,000 km/h.

Lift off. (Image credit: ESA.)

Sommaire en français

News

NEUTRINOS

Daya Bay collaboration observes a new kind of neutrino oscillation

The Daya Bay reactor antineutrino experiment has observed the disappearance of electron-antineutrinos at a distance of about 2 km from the reactors. As briefly reported earlier (*CERN Courier* April 2012 p8), this provides strong evidence for a new kind of neutrino oscillation through a nonzero neutrino-mixing angle, θ_{13}.

There has been good evidence for more than a decade that the electron-neutrino, muon-neutrino and tau-neutrino can morph into one another. This phenomenon of neutrino oscillation is a consequence of mixing between the three flavours of neutrinos, and oscillations between three neutrinos are described with three mixing angles, two mass-squared differences and one CP-violating phase. Two of the mixing angles, θ_{12} and θ_{23}, have been measured to good precision but the third mixing angle, θ_{13}, was poorly known.

A decade ago, the CHOOZ experiment set a limit of $\sin^2 2\theta_{13} < 0.17$. However, newer analyses of the measurements with solar neutrinos and by the KamLAND experiment – as well as data from the T2K, MINOS and Double Chooz experiments – hinted that θ_{13} could be larger than zero. On 8 March, based on an exposure of 43,000 tonne-GW_{th}-days, the Daya Bay collaboration reported the result of their measurement, $\sin^2 2\theta_{13} = 0.092 \pm 0.016$ (stat.) $\pm$ 0.005 (syst.), concluding that θ_{13} is significantly different from zero.

The Daya Bay experiment is located at the Daya Bay Nuclear Power Complex in China, 55 km northeast of Hong Kong. About 3.6×10^{21} low-energy electron-antineutrinos per second are produced by three pairs of nuclear reactors with a combined maximum thermal-power of 17.4 GW_{th}. Three underground experimental halls connected by horizontal tunnels will eventually house eight antineutrino detectors (two in each near hall and four in the far site).

In each hall, the antineutrino detectors are submerged in a water pool that is partitioned optically into two zones. These two water-Cherenkov detectors tag cosmic-ray muons, which can generate background that mimics antineutrino interactions. The water also shields the detectors from ambient radiation that can generate background. The experiment identified electron-antineutrinos via the inverse beta-decay reaction $\nu_e + p \rightarrow e^+ + n$, with 20 tonnes of 0.1% gadolinium-doped liquid scintillator in each antineutrino detector.

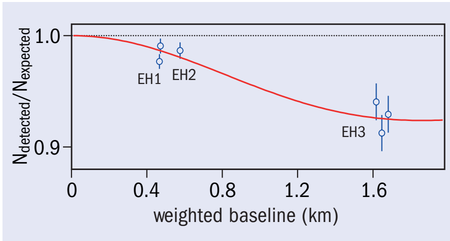


Fig. 1. Ratio of the detected number of electron-antineutrinos versus the number expected, assuming no oscillation in each detector. The expected signal has been corrected with the best-fit normalization parameter. The flux-weighted average baselines were computed using the reactor and survey data. The red curve is the oscillation-survival probability, with the best-fit value of $\sin^2 2\theta_{13}$ = 0.092. The left and right data points of the far hall are displaced by –30 and +30 m for visual clarity.

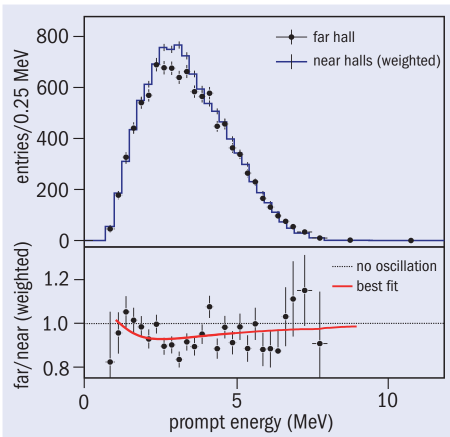


Fig. 2. Top: The measured prompt-energy spectrum at the far hall (sum of three antineutrino detectors) compared with the no-oscillation prediction from the measurements of the two near halls. The spectra were background subtracted. Uncertainties are statistical only. Bottom: The ratio of measured and predicted no-oscillation spectra. The red curve is the best-fit solution with $\sin^2 2\theta_{13}$ = 0.092 obtained from the rate-only analysis. The dashed line is the no-oscillation prediction.

The data used for these first results were obtained with six antineutrino detectors – three deployed in the far hall, two in one of the near halls and one in the other near hall. When the number of detected electron-antineutrino events at the far site was compared with the expected number derived from the measurements in the near sites, a ratio of 0.940 ± 0.011 (stat.) ± 0.004 (syst.) was found, indicating neutrino oscillation through θ_{13}. Using the total number of detected events yielded a value of $\sin^2 2\theta_{13}$ that was 5.2 σ from zero.

Figure 1 shows the disappearance of reactor electron-antineutrinos as a function of flux-weighted distance. Further evidence for this new kind of neutrino oscillation comes from the comparison of the observed and predicted energy spectra of the electron-antineutrinos at the far site. As figure 2 shows, the spectral distortion as a function of the prompt (positron) energy is also consistent with oscillation corresponding to $\sin^2 2\theta_{13} = 0.092$.

Since the announcement of Daya Bay's measurement of a nonzero value for θ_{13}, the RENO collaboration has reported the observation of the disappearance of electron-antineutrinos by their experiment based in Korea. The value that they find for $\sin^2 2\theta_{13}$ is consistent with the results from Daya Bay.

A nonzero θ_{13} is crucial for designing experiments to search for CP-violation in the neutrino sector (p17). These next-generation experiments will explore whether neutrinos oscillate differently from antineutrinos and answer the question of whether neutrinos can explain why matter is predominant in the universe. Furthermore, knowing the value of θ_{13} helps to complete the determination of the neutrino-mixing matrix and constrain models beyond the current Standard Model.

● The Daya Bay collaboration consists of 230 collaborators from 38 institutions worldwide. The experiment is supported by the funding agencies of China, the Czech Republic, Hong Kong, Russia, Taiwan and the US. Daya Bay is currently one of the largest collaborative scientific projects between China and the US.

● Further reading

Daya Bay collaboration 2012, arXiv:1203.1669 [hep-ex], *Phys. Rev. Lett* (in press).

LHC PHYSICS

The rarest B decay ever observed

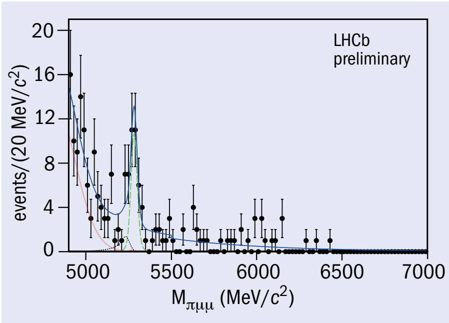
Winter conferences

In this issue, news from the LHC experiments focuses on a few highlights from the "winter conferences", where the latest results in particle physics are traditionally aired for the first time.

As announced at the "Moriond" conference on 10 March, the LHCb collaboration has made the first observation of the decay $B^+ \to \pi^+\mu^+\mu^-$. With a branching ratio of about 2 per 100 million decays, this is the rarest decay of a B hadron ever observed.

The LHCb experiment is designed to search for new physics in the rare decays and CP-violation of particles with heavy flavour, i.e. those containing the c or b quark. Such decays have previously been studied by the B-factory experiments BaBar and Belle, but LHCb is taking the field further as a result of two major advantages: not only are all of the varieties of heavy-flavour hadrons produced in the LHC's high-energy collisions, but they are also produced at an enormous rate.

The B factories relied on the copious production of B^+B^- and $B^0\bar{B}^0$ pairs in the decay of the ϒ(4S) resonance. However, in addition to those particles, collisions at the LHC also produce B_s, B_c and b baryons, which may provide an alternative route to finding new physics. This has been illustrated by recent results from LHCb on the rare decay $B_s \to \mu^+\mu^-$, where the strongest limit yet has been placed on the branching ratio of $< 4.5 \times 10^{-9}$ (at 95% CL), and the first evidence for CP-violation in the B_s system, as well as observation of new decay modes for B_c and the most precise measurements of the mass of a b-flavoured baryon.



Invariant-mass distribution of selected $\pi^+\mu^+\mu^-$ combinations, showing the clear peak corresponding to B^+ decays (green long-dash). Also shown are the components in the fit from partially reconstructed decays (red dotted) and misidentified $K^+\mu^+\mu^-$ (black dashed) and the total (blue solid line). Candidates for which the $\mu^+\mu^-$ pair is consistent with coming from a J/ψ or ψ(2S) decay have been excluded.

However, the large cross-sections and luminosity at the LHC mean that even for B^+ and B^0 decays, LHCb can now overtake the B-factory results. The decay $B^+ \to \pi^+\mu^+\mu^-$ is a good example: it is a flavour-changing neutral-current decay, which is strongly suppressed in the Standard Model as it proceeds via quark diagrams involving loops (box or penguin diagrams). The predicted branching ratio is $(2.0 \pm 0.2) \times 10^{-8}$ in the Standard Model but could be enhanced by new physics. The best previous limit on this mode, from the Belle experiment at KEK, was $< 6.9 \times 10^{-8}$ (at 90% CL) (Belle collaboration 2008). Now LHCb has observed a clear signal for the decay, shown in the figure, with a significance of more than 5 σ. The measured branching ratio of $(2.4 \pm 0.6\,(\text{stat.}) \pm 0.2\,(\text{syst.})) \times 10^{-8}$ is in good agreement with the expectation from the Standard Model. This observation opens the door to more detailed studies of rare $b \to d$ transitions, which will be possible with the increase in data in 2012.

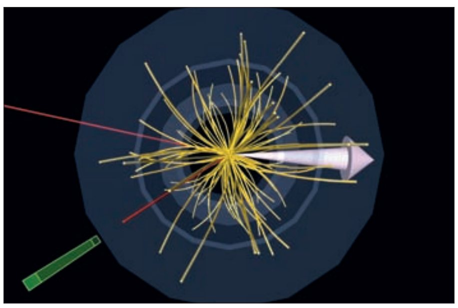
● References

LHCb collaboration 2012 LHCb-CONF-2012–006.
Belle collaboration 2008 *Phys. Rev.* **D78** 011101.
For other results by the LHCb collaboration mentioned here, see: arXiv:1203.4493 ($B_s \to \mu^+\mu^-$); arXiv:1202.6251 (B_s CP-violation); CERN-PH-EP-2012–090 (B_c decay modes); LHCb-CONF-2011-060 (b-baryon mass).

ATLAS experiment's winter round-up

The ATLAS experiment sent the results of more than 40 new analyses to "La Thuille", "Moriond" and other winter conferences. These results covered the full scientific programme of the experiment, from precision measurements of Standard Model processes, through searches for the Higgs boson and new physical phenomena to the study of hot and dense matter probed in heavy-ion collisions.

The collaboration has made a great deal of progress since the seminar on 13 December where preliminary results on the Higgs search in both the ATLAS and CMS experiments were presented (*CERN Courier* January/February 2012 p6). ATLAS has since used the full 2011 data set to search for a Standard Model Higgs boson in 12 different decay channels. Combining all of these results has left only three remaining windows for the Higgs: 115.5–131 GeV, 237–251 GeV and above 520 GeV. The upcoming data at the new centre-of-mass energy of 8 TeV will increase the sensitivity of both CMS and ATLAS, and allow the collaborations to make more definitive statements on the existence and mass of a Standard Model Higgs boson by the end of the year.



Display of a candidate WW diboson event in the "eμ + missing momentum" final state.

At moderate to high masses, the most sensitive searches for the Higgs boson involve its decays to two heavy electroweak bosons, either WW or ZZ. Because this search looks for an excess of events over the background from other diboson production it is important to measure the diboson background as accurately as possible. This measurement is also important in its own right: it depends on the strength of the interaction between the W boson, the Z boson and the photon. This strength is a fundamental parameter of the Standard Model and distinguishes it from other theories. These new measurements use the full 2011 data set and are twice as precise as

News

previous ATLAS measurements.

In the Standard Model, the B_s meson is predicted to decay to a $\mu^+\mu^-$ pair rarely: only 3 or 4 times in a billion. However, in various extensions of the Standard Model this rate can be increased by a factor of 10 or even a 100; it is one of the more sensitive indirect tests for new physics and complements some of the direct searches for new phenomena at the LHC. Other experiments both at Fermilab's Tevatron and at the LHC have set upper limits on this decay in the range of 4.5–51 decays per billion. The ATLAS collaboration has now joined this search and has reported an upper limit of 22 decays per billion.

At the International Conference on High-Energy Physics (ICHEP) in Paris, ATLAS showed the first LHC results with sensitivity beyond that of previous experiments: limits on quark substructure obtained by studying events containing two jets (*CERN Courier* November 2010 p19). ATLAS has continued to investigate this category of events using the full 2011 data set. The additional data have provided extremely energetic events for ATLAS to study: in some cases the two jets have a combined mass above 4 TeV. There is still no evidence that quarks are made of smaller objects – but if they existed and were at least as large as 3×10^{-20} m, ATLAS would have detected them. This lack of observation allows the experiment to set a limit on the size of any quark substructure. In a complementary measurement looking for excited electrons or muons, which would also be an indication of substructure, ATLAS has set limits around 10^{-19} m.

Based on the new results previewed at these conferences, the ATLAS collaboration has sent more than 30 articles to scientific journals, with more in preparation. The next major round of conferences will be in summer and will include ICHEP 2012 in Melbourne. In addition to new results at a total collision energy of 7 TeV, the collaboration intends to show early results from 8 TeV collisions.

Further reading

The following ATLAS conference notes are available at https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/:
ATLAS-CONF-2012–019 (Higgs searches); ATLAS-CONF-2012–025, ATLAS-CONF-2012–026, ATLAS-CONF-2012–027 (dibosons); ATLAS-CONF-2012–010 (B_s); ATLAS-CONF-2012–038 (excited quarks); ATLAS-CONF-2012–008 (excited leptons).

ATLAS and CMS search for new gauge bosons

The ATLAS and CMS collaborations are carrying out a large-scale hunt for hypothetical heavy partners of the Standard Model gauge bosons, the W and the Z. The two experiments were designed to be sensitive to the decays of such particles, which are called, appropriately, W' and Z'. The latest findings presented at the recent winter conferences show that so far these searches probe for W' and Z' particles with masses more than 20 times larger than those of their well known Standard Model counterparts.

The W and Z bosons, mediators of the weak force, are almost 100 times heavier than the proton. Their discovery, which was announced in 1983, had awaited the conversion of CERN's Super Proton Synchrotron into a proton–antiproton collider to form the first machine energetic enough to produce them. Various theories provide motivation for the heavier W' and Z' bosons, and their existence would provide answers to many fundamental questions. For example, the extreme weakness of gravity – when compared with electromagnetism – could be explained by theories that include additional spatial dimensions and in which new heavy particles like a Z' appear.

Strongly motivated by such theoretical arguments, physicists at the LHC have been hunting for these heavy partners of the W and Z since the collider started up. Many theories predict that the new gauge bosons would be similar to their light partners, only with larger masses. For example, the Z' boson could decay to a lepton–antilepton pair, the same channel in which the Z was discovered. ATLAS and CMS have carefully analysed all such events and classified them into mass distributions, such as the one in figure 1 for dimuons in the ATLAS experiment. The black points represent the data and the coloured areas represent contributions expected in the Standard Model. The prominent feature is the Z-boson peak on the left side of the spectrum. If a Z' boson exists, it should peak in a similar manner somewhere on the right, in the mass region around 1500–2000 GeV, as shown by the thin coloured lines.

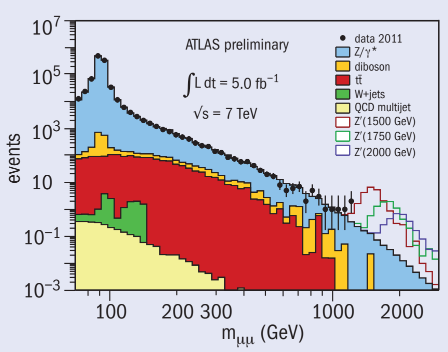


Fig. 1. Dimuon invariant mass distribution after final selection, compared with the sum of all expected Standard Model backgrounds, with three example Z' signals overlaid.

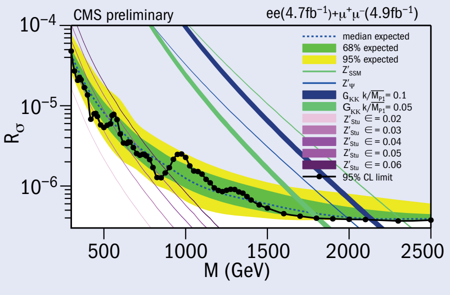


Fig. 2. Limits on the rates of the hypothetical Z' bosons in the dilepton channel. The rates predicted by different theories are overlaid.

No clear evidence of the Z' or W' bosons has yet been observed, so the collaborations calculate the mass range where the existence of a hypothetical W' or Z' boson is excluded with 95% probability. Figure 2 shows the maximum allowed production rate (black points) as a function of the hypothetical Z' boson mass, as allowed by the CMS data. The different theories, shown by continuous coloured lines, are excluded in the low-mass region where they predict a rate larger than that shown with the black line, but are still

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allowed in the high-mass region where they predict a lower rate. For example, the Standard Model-like Z' boson predicted by the Sequential Standard Model is excluded up to 2300 GeV (2.3 TeV).

It might also be the case that the preferred decay channels of the Z' bosons are different from those of the Z boson. For instance, the Z' may prefer to decay into pairs of quarks or even a pair of the lighter partners – the W and Z of the Standard Model. It is therefore critical to explore all of the possible decay channels. These searches are about to be completed by the two collaborations using large data samples collected during the 2010–2011 runs. At the same time they are eagerly awaiting the 2012 data, with larger data samples of even more energetic collisions provided by the LHC. The hunt will then start anew and probe even higher masses

● Further reading:

CMS collaboration 2011 *Phys. Lett.* **B704** 123; https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11019Winter2012.

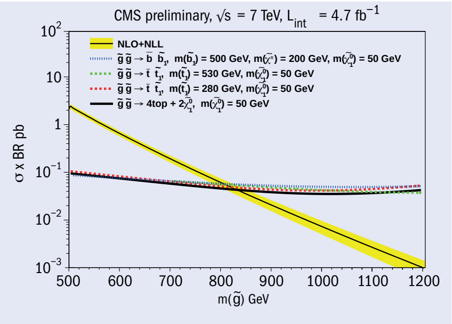
ATLAS collaboration 2011 *Phys. Rev. Lett.* **107** 272002; ATLAS-CONF-2012–007.

New developments in the search for SUSY

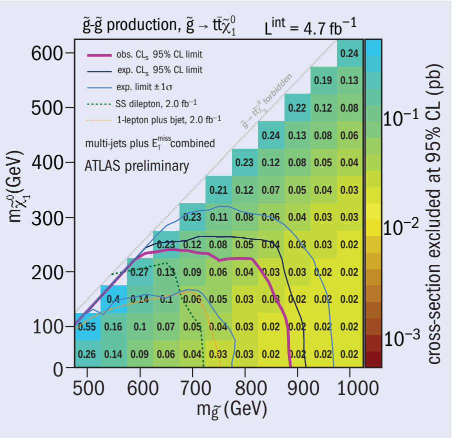
Although no sign of supersymmetry (SUSY) has been observed so far, it is still the front-runner as a signal for new physics that could be discovered at the LHC. Not only does it neatly solve several shortcomings of the Standard Model, it also provides a candidate for the as-yet undiscovered dark-matter particle. Unfortunately, the masses of the SUSY particles are not constrained by theory, but it does provide some interesting hints. For SUSY to solve in a natural way the fine-tuning problems that arise in the Standard Model from the presence of a low-mass Higgs, the lightest of the two supersymmetric partners of the top quark (stop quarks) should have a mass not too much beyond that of the Standard Model counterpart, and the mass of the gluon's superpartner (gluino) should not be too far above that of the stop quarks.

Both the ATLAS and CMS collaborations have made significant progress in searching for possibly light third-generation squarks (stop and sbottom), produced either directly or in the decays of gluinos, and first results based on the full data set recorded in 2011, equivalent to about 5 fb^{-1}, have been released. CMS has presented a search for events containing multiple b-quarks and two leptons of the same charge, thus effectively eliminating most of the Standard Model backgrounds. ATLAS has released a novel interpretation of its updated multi-jet analysis, which explores events with up to nine high-transverse-momentum jets.

The figures show the current constraints that both collaborations are imposing on the gluino, pushing its allowed mass above 850 GeV in some cases. In addition, constraints from experiments at Fermilab's Tevatron on direct sbottom pair-production have been extended by both ATLAS and CMS, and first results constraining direct production of stop in a simplified model of stop decays were recently presented by ATLAS. These are just appetizers for more results that will be released by both collaborations over the next few months.



Upper limits on the cross-section of different models for gluino-mediated production of stop or sbottom with the full 2011 data set from CMS. The lower limits on the gluino mass for the different processes considered are determined by the crossing of the corresponding line with the yellow band, which represents the effective production cross-section of gluino pairs as a function of their mass.



Limits from ATLAS on gluino-mediated stop production as a function of the gluino and the neutralino masses for the multi-jet and missing transverse-momentum analysis. Previous exclusions with b-tagging and same-sign dileptonic searches with a reduced data set are also shown. The coloured boxes with numbers represent the upper limit on the excluded cross-section for the corresponding masses.

The collaborations have also updated the more canonical searches that look for multiple energetic jets, the eventual presence of leptons and large missing transverse momentum – a striking signature for the presence of a dark-matter particle that escapes the detectors. Both collaborations invested a large effort in refining their analysis techniques, thus boosting their sensitivities. In certain SUSY scenarios, gluinos and squarks with masses below 1.4 TeV are now excluded.

Last, the large data set produced by the LHC in 2011 allowed the collaborations to begin exploring the electroweak sector of the SUSY particle spectrum with the study of multilepton final states. New and updated results have been released for many other SUSY decay signatures, including photons and τ leptons, and also in the context of searches for long-lived particles, disappearing tracks, and signatures without missing momentum, which are becoming increasingly interesting as possible ways to discover SUSY.

While no indications for the presence of supersymmetric particles have been found in the LHC collisions so far, the hunt continues and more results from additional search channels will appear in the coming months. Only a small part of the SUSY parameter space has been challenged by direct searches so far. Relatively light stops and gluinos are still allowed by the present data, and more dedicated searches will show if "natural SUSY" prevails. The increase of the LHC centre-of-mass energy to 8 TeV and the foreseen increase of data to be delivered in 2012 will open a new window to search for the presence of SUSY particles. Combined with the collaborations' ever-growing experience and new analyses dedicated to specific signatures, this guarantees exciting developments during the rest of the year.

● Further reading:

ATLAS-CONF-2012–037.

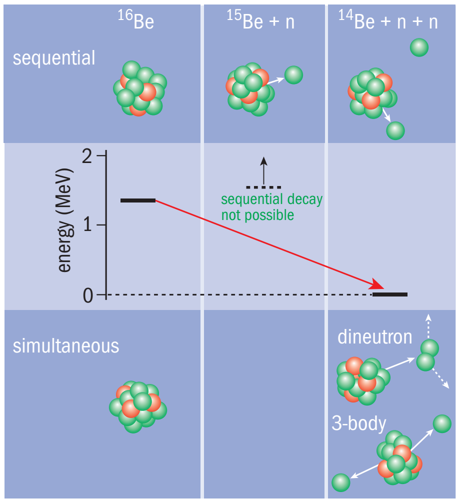
CMS PAS SUS-11–020.

Nuclear physics

MoNA makes first confirmed sighting of dineutron decay

Researchers in the Modular Neutron Array (MoNA) collaboration have found evidence for a new nuclear-decay mode at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. Artemis Spyrou, Zach Kohley and their colleagues have recently published results on the first confirmation of dineutron decay, which has long been hypothesized but never detected directly (A Spyrou *et al.* 2012).

Beginning with a beam of ^{17}B at 53 MeV/*u* produced by the Coupled Cyclotron Facility, the nucleus of interest, ^{16}Be, was created by knocking out a proton from the beam. The ^{16}Be decayed immediately into a ^{14}Be fragment and two neutrons. The charged fragment, ^{14}Be, was deflected by the sweeper-dipole magnet and detected in a suite of position- and energy-sensitive detectors. The neutrons were detected in MoNA.



The different possible neutron decays for ^{16}Be. (Image credit: T Baumann/NSCL.)

There are three decay-modes that the dineutron emission could proceed through: a sequential emission of the two neutrons through the intermediate system ^{15}Be; a simultaneous emission of the two neutrons via a three-body break-up; and a dineutron decay, where the two neutrons are assumed to be clustered together inside the nucleus. Only the latter model was able to reproduce the experimental results and, in particular, the two-neutron correlation parameters. By observing a small angle between the two neutrons the team could demonstrate that these were emitted together as a cluster, and thus as a dineutron. ^{16}Be was found to be a rare case where the two neutrons are emitted simultaneously because the decay through the intermediate system, ^{15}Be, is not energetically favourable.

This experiment showed for the first time that a dineutron decay is possible in these extremely neutron-rich systems. The observation can improve understanding of nuclear binding, especially at the limits of nuclear stability, and help to create more reliable models for describing the astrophysical processes.

● **Further reading:**

A Spyrou *et al.* 2012 *Phys. Rev. Lett.* **108** 102501.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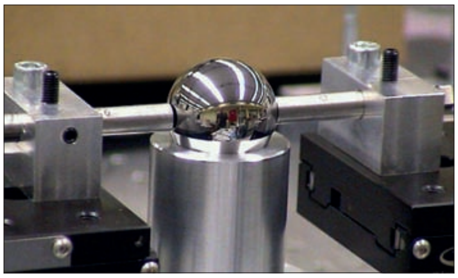
Sciencewatch

Compiled by John Swain, Northeastern University

The ups and down of friction

The exact nature of friction is still somewhat mysterious, despite having long been studied by many physicists and engineers. In the 17th century, Guillaume Amontons and Charles-Augustin de Coulomb attributed friction to tiny surface irregularities that mesh and impede horizontal motion, necessitating frequent vertical motions. These ideas fell somewhat to the wayside in more recent adhesion-based theories of friction but they have recently received renewed support from Farid Al-Bender and colleagues at the Katholieke Universiteit Leuven.

These researchers used nanoscale techniques to measure hysteresis curves in the normal displacement (perpendicular to the surface) of a sliding object as it is pushed along. They tested various materials (paper, plastic and brass) at different speeds, recording the curves of the up-and-down motion of the object as it rises and falls over small irregularities. Remarkably, this phenomenon – known as lift-up hysteresis – does not appear to have been shown before. Its measurement shows the complexity of friction and, say the researchers, confirms the intuition of Amontons and Coulomb.



Nanomeasurement instruments can detect movement to a billionth of a metre. (Image credit: K U Leuven.)

Further reading

F Al-Bender *et al.* 2012 *Tribol. Lett.* **46** 23.

Earthshine and life on other worlds

One way to look for life on other planets is to look at spectroscopic signals of the chemical composition of their atmospheres, searching for compounds such as methane or molecular oxygen, which are likely to be produced by living things. The catch so far has been that the light from exoplanets is faint compared with that emitted by the stars they orbit. Now, Michael Sterzik of the European Southern Observatory in Santiago and colleagues have a clever proposal. Light that comes through an atmosphere becomes polarized, allowing it to be separated from unpolarized background.

The researchers tested this idea with the Focal Reducer/Low-Dispersion Spectrograph at the Very Large Telescope in Chile, looking at earthshine reflected from the Moon. They were able to find signatures of oxygen, ozone and water and indications of vegetation, as well as the fractional contributions of clouds and ocean surface. This technique could offer a new way of studying distant planets and searching for life even before there is a means to go there for a more direct look.

Further reading

M F Sterzik *et al.* 2012 *Nature* **483** 64.

Alcohol helps fruit flies

People who drink a little whisky in the hopes of helping a cold may be surprised to find that fruit flies do something similar. Neil Milan of Emory University in Atlanta and colleagues raised fruit-fly larvae infected with parasites from a wasp that lays eggs in them. As many as 80 per cent of the infected larvae favoured alcohol-laced food, which can kill off the parasites, as opposed to just 30 per cent of the noninfested ones. Even better for the fruit flies, the wasps avoided laying eggs in the alcoholic larvae.

Fruit flies also seem to treat psychological problems with alcohol. Galit Shohat-Ophir and colleagues at the University of California in San Francisco found that male fruit flies are more likely to choose food laced with alcohol after being rejected by a mate (something that might strike a chord in humans). Alcohol seems to raise levels of neuropeptide F, a brain chemical that also rises after mating. The work suggests treatments for human alcoholism and depression by raising levels of neuropeptide Y, the human analogue of neuropeptide F.

Further reading

N F Milan *et al.* 2012 *Current Biology* **22** 488.

G Shohat-Ophir *et al.* 2012 *Science* **335** 1351.

Ice-age plant resurrected

Silene stenophylla *regenerated from tissue of fossil fruit. (Image credit: S Yashina* et al.*)*

It may not be quite the same scenario as in *Jurassic Park*, but Svetlana Yashina and colleagues at the Russian Academy of Sciences in Puschchino managed to resurrect a 30,000-year-old Ice Age flowering plant. They recovered fruit tissue of the plant (*Silene stenophylla*) from a fossilized squirrel burrow 38 m underground near the Kolyma river in Siberia.

By using growth hormones, the team managed to start the cells dividing again and were able to grow viable plants that actually bloomed. This sets a new record, shattering the previous record for a 1200-year-old lotus, which was grown in modern times.

Further reading

S Yashina *et al.* 2012 *Proc. Nat. Acad. Sci.* **109** 4008.

Storing hydrogen in acid

A big challenge in using hydrogen for energy is how to store it. Jonathan Hull of Brookhaven National Laboratory and colleagues have shown that hydrogen can be stored in an aqueous solution of formic acid, the acid that burns in ant stings. At normal temperatures and pressures – a big plus for this technique – an iridium catalyst can make hydrogen react with carbon dioxide to make formic acid under slightly alkaline conditions. Acidifying the solution releases pure hydrogen gas at high pressures.

Further reading

J F Hull 2012 *Nature Chemistry*, doi:10.1038/nchem.1295.

Astrowatch

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

Gamma-ray observations constrain dark matter

Dark matter remains dark. The Fermi Gamma-ray Space Telescope could not detect an annihilation signal from dark-matter reservoirs in nearby dwarf galaxies. This nonetheless constrains the properties of candidate dark-matter particles. The results exclude for the first time weakly interacting massive particles (WIMPs) within a specific range of masses and interaction rates.

That 80 per cent of the matter content in the universe is invisible makes it one of the challenges of modern physics and astronomy. Looking at different wavelengths does not help because the elusive matter seems neither to emit nor absorb electromagnetic radiation. Yet, its gravitational influence is manifest in the orbital speeds of stars inside galaxies and in shaping the structure of clusters of galaxies. The mystery is compounded by the lack of clues as to what this dark matter actually is. It must be non-baryonic – that is, not made of ordinary matter, essentially protons and neutrons – which suggests a new kind of subatomic particle. A favoured class of dark-matter candidates consists of WIMPs, which are presumed not to interact with normal matter or radiation, except through gravitation, but which could mutually annihilate to produce gamma rays. Such a weak-scale annihilation has the advantage that it accounts naturally for the observed cosmological density of dark matter – and this is the prime motivation for favouring WIMP dark matter.

NASA's Fermi satellite is well suited to look for a WIMP-annihilation signal. Launched on 11 June 2008, its payload includes the Large Area Telescope (LAT), which scans the whole sky every three hours in the 100 MeV to 300 GeV energy range

This dwarf spheroidal galaxy, in the constellation Fornax, is a satellite of the Milky Way and one of those included in Fermi's dark-matter search. The presence of dark matter is inferred from the motion of the stars in the galaxy. (Image credit: ESO/Digital Sky Survey 2.)

(*CERN Courier* November 2008 p13). A prime target to look for signs of WIMP annihilation are dwarf spheroidal galaxies. These small galaxies orbit the Milky Way and are characterized by a high ratio of dark to normal matter. Their stellar population is old, making them unlikely to contain supernova remnants or pulsars emitting contaminating gamma rays; they can also be selected at locations in the sky that avoid the gamma-ray-bright Galactic plane.

The Fermi-LAT collaboration has made a study of the gamma-ray emission of dwarf spheroidal galaxies observed over two years and published results based on a joint likelihood analysis that evaluates all of the galaxies at once without merging the data (Ackermann *et al.* 2012). The study also accounts for uncertainties in the actual distribution of dark matter inside the galaxies. The results yield no evidence of a gamma-ray signal from dark matter and thus can strongly constrain the cross-section for dark-matter particle annihilation.

Specifically, the study strongly disfavours the existence of WIMPs with the most generic velocity-averaged cross-section (3×10^{-26} cm^3 s^{-1} for a purely s-wave annihilation cross-section) and masses less than around 30 GeV. A lower cross-section would imply too high a cosmological density of dark matter, whereas a higher cross-section would result in a significant detection of gamma rays. The effective exclusion of the less massive WIMP candidates is confirmed by an independent study reported in the same issue of *Physical Review Letters*. Authored by Alex Geringer-Sameth and Savvas Koushiappas of Brown University, Rhode Island, the second analysis uses another set of Fermi-LAT data and a different statistical method and treatment of the background.

The limits presented in these two papers are among the strongest dark-matter limits obtained to date and suggest that Fermi-LAT has the potential either to discover the WIMP-annihilation signal from dwarf spheroidal galaxies or to rule out that dark matter is made of WIMPs. The next step is the inclusion of more recent gamma-ray measurements that extend to higher energies with an improved LAT sensitivity. It will be interesting to see whether the forthcoming study leads to a further decisive push towards higher energies of the allowed range of WIMP masses, or to a historic discovery.

Further reading

M Ackermann *et al.* The Fermi-LAT collaboration 2011 *Phys. Rev. Lett.* **107** 241302.
A Geringer-Sameth and S M Koushiappas 2011 *Phys. Rev. Lett.* **107** 241303.

Picture of the month

This image from the NASA/ESA Hubble Space Telescope reveals the globular cluster Messier 9 (M9) in unprecedented detail. M9 is one out of 29 globular clusters included in the Messier catalogue of 110 nebulae and star clusters. The French astronomer Charles Messier could certainly not have even dreamt of such an image when he discovered and catalogued this "nebula without star" on 28 May 1764. It was only later in the 18th century that astronomers, notably William Herschel, began to spot stars within the cluster. Hubble's image now resolves about 250,000 stars, even right into the crowded centre of the cluster. The study of the brightness of the stars together with their colours – indicating different surface temperatures – allows astronomers to estimate their age. Stars in M9 have about twice the age of the Sun and are thus among the oldest stars in the Galaxy, born when the universe was only a small fraction of its current age. (Image credit: NASA/ESA.)

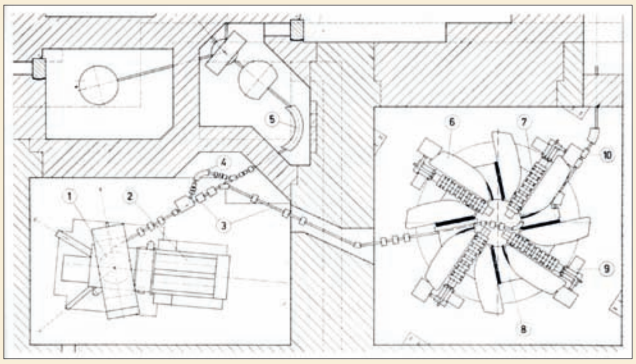
CERN Courier Archive: 1969

A look back to CERN Courier vol. 8, May 1969, compiled by Peggie Rimmer

VILLIGEN

Original SIN

A "meson factory" of novel design is being built by SIN (Schweizerisches Institut für Nuklearforschung – Swiss Institute for Nuclear Research) at Villigen near Zurich. It involves a two-stage machine capable of accelerating intense beams of protons. The first stage is a 70 MeV isochronous cyclotron injecting into an isochronous ring cyclotron which completes acceleration to over 500 MeV, well above the 450 MeV threshold for pi-meson production. The machine will be operating fully from the middle of the 1970s.



A simplified layout of the 500 MeV Villigen accelerator: 1) injector cyclotron; 2) r.f. system; 3) beam-transport system; 4) beam-switch for simultaneous use of the 70 MeV beam; 5) low-energy beam-analysing system; 6) sector magnets of the ring cyclotron; 7) r.f. cavities; 8) free section of the vacuum chamber; 9) vacuum pumping system and r.f. power stages; 10) beam-transport system for the ejected protons.

Evolution of the cyclotron

A cyclotron depends on the fact that, in a uniform magnet field, charged particles take the same time to travel round their orbit regardless of their velocity. A voltage of fixed frequency applied across a gap accelerates protons each time they come round the cyclotron and spiral outwards with increasing energy. This remains efficient up to energies around 20 MeV, when the speed of the protons becomes a significant fraction of that of light, their mass begins to increase noticeably (2%) and they take longer to orbit (2%).

In a synchrocyclotron (such as the CERN 600 MeV machine), particles are accelerated to higher energies with a constant magnetic field by continuously adjusting the frequency of the field in the accelerating gap to keep in step with the changing rotation frequency. However, this means that particles must be injected and accelerated in pulses, many times per second.

To regain a continuous beam, sectors can be placed on the poles of fixed-frequency cyclotrons such that the circular orbits become scalloped. The magnetic field seen by a particle can then increase with radius and the distances travelled can be arranged to compensate for the increase in mass.

High-voltage accelerating cavities can be positioned between magnet sectors at the outer part of the machine but there is no room at the centre. This led SIN to lift the centre portion out of the machine, leaving an (eight-sector) isochronous ring with the removed portion, a conventional isochronous cyclotron, sitting alongside as an injector.

The Swiss goals were for an energy of over 500 MeV with a proton beam intensity of the order of 100 μA. Such intense beams must be ejected with very high efficiency which means that the outermost particle orbits must be well separated radially so that fields applied to the full energy orbit can bend particles out of the machine without affecting neighbouring orbits.

RF cavities in four of the eight gaps between the magnets in the ring will each give up to 500 keV to the protons. The energy gain per turn can be as large as 2 MeV to give an orbit separation at 500 MeV of 8 mm (separation on the CERN synchrocyclotron is currently 0.04 mm). With such a separation a septum extraction system can yield calculated efficiencies of 95%.

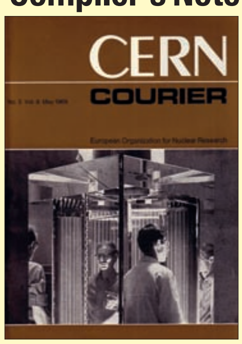
Experimental programme

The machine will be used for intermediate energy physics with pion and muon beams and the experimental programme will be determined by the high beam intensity and the 100% duty-cycle. This opens up new fields of research which until now have barely been touched or have been without prospects. Some of these fields connect different branches of science, such as muonium chemistry and pion-radiation biology. The first acceleration stage will, however, be capable of accelerating many types of particle to different low energies for nuclear-physics research.

There are a number of fundamental problems in classical elementary-particle physics which have not been solved with present accelerators but which can finally be attacked with the beams of a "meson factory", for example, the study of rare decay modes. The abundance of particles will make it possible to use instruments with unprecedented resolution, such as crystal spectrometers.

● Compiled from texts on pp139–141.

Compiler's Note



The SIN machine started operation in 1974. Three years later, candidates for neutrinoless decays of muons into electrons were reported, violating lepton-flavour conservation and causing great excitement. Although later disproved, they launched an ongoing search for such decays, which are forbidden in the Standard Model.

In 1988, SIN merged with the Federal Institute for Reactor Research across the Aare river to form the Paul Scherrer Institute (PSI). In collaboration with several universities, hospitals and industry, future-oriented projects in solid-state physics, biomedicine, renewable energy and environmental sciences were established.

Notably, PSI has become a world-class centre for cancer therapy, pioneering the high-precision spot-scanning technique for proton irradiation of deep-seated tumours. It has recently developed a facility for the irradiation – under anaesthetic – of infants. On a lighter note, thanks to its competence in materials research, PSI made a precise determination of the age of Ötzi, the Ice Mummy found in 1991.

Neutrino production moves to an industrial scale

The Neutrino Factory is designed to generate the intense beams of high-energy neutrinos required to fathom the behaviour of neutrinos and cast light on fundamental questions in particle physics and beyond.

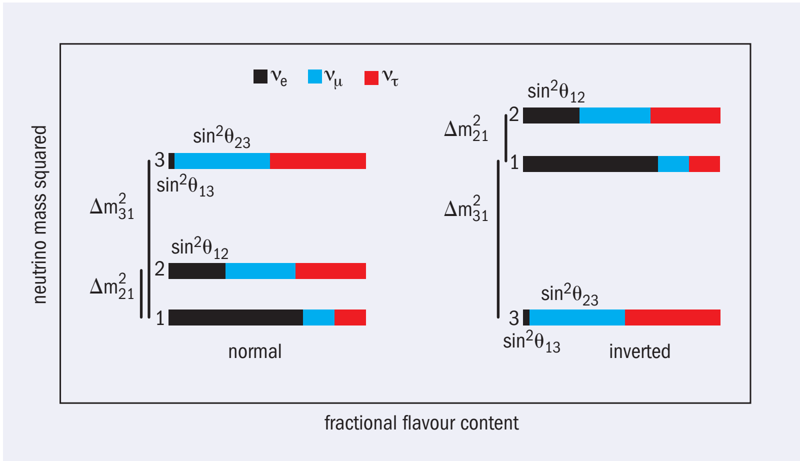


Fig. 1. Diagram of the relationship between the mass eigenstates (labelled 1, 2 and 3) for neutrinos and the flavour eigenstates (ν_e, ν_μ and ν_τ). Neutrinos from the Sun have been used to show that $m_2 > m_1$; m_3 may be greater or less than m_1 and m_2 (the "normal hierarchy") or smaller than m_1 and m_2 (the "inverted hierarchy"). The fractional contribution of each flavour to the mass eigenstates is indicted by the coloured bars. (After a figure by S Parke.)

The measurements of the electron- and muon-neutrino fluxes published by the Super-Kamiokande collaboration in 1998 marked a turning point in the history of particle physics. This team showed that fewer muon-neutrinos arrive at the surface of the Earth than are produced by cosmic-ray interactions in the upper atmosphere (atmospheric neutrinos). This in turn indicated evidence for neutrino oscillations, the phenomenon in which the flavour of the neutrino changes (oscillates) as the neutrino propagates through space and time (*CERN Courier* October 1999 p24). Since the publication of Super-Kamiokande's seminal paper, the phenomenon of neutrino oscillations has been established through further measurements of atmospheric neutrinos, as well as of neutrinos and antineutrinos produced in the Sun, by nuclear reactors and by high-energy particle accelerators. It is arguably the most significant advance in particle physics of the past decade.

Extending the Standard Model

Neutrino oscillations imply that the Standard Model is incomplete and must be extended to include neutrino mass as well as mixing among the three neutrino flavours. The mechanism by which neutrino mass is generated is not known. An intriguing possibility is that the tiny neutrino mass is the result of physics at extremely high energy scales. Such a "see-saw" mechanism might also help to explain why neutrino mixing is so much stronger than the mixing among quarks. Mixing among three massive neutrinos admits the possibility that symmetry between matter and antimatter (CP-symmetry) is violated via the neutrino mixing matrix. Nonzero neutrino mass implies that lepton number must be used to distinguish a neutrino from an antineutrino. If lepton number is not conserved then a neutrino is indistinguishable from an antineutrino, i.e. the neutrino is a Majorana particle – a completely new state of matter. The determination of the properties of the neutrino, therefore, is fundamental to the development of particle physics.

Neutrino oscillations are readily described by extending the Standard Model to include three neutrino-mass eigenstates, ν_1, ν_2 and ν_3, such that the neutrino-flavour eigenstates, ν_e, ν_μ and ν_τ, are quantum-mechanical mixtures of the mass eigenstates (figure 1). Neutrino oscillations arise from the "beating" of the phase of the neutrino-mass eigenstates as a neutrino produced as an eigenstate of flavour propagates through space and time. The matrix by which the mass-basis is rotated into the flavour-basis is parameterized in terms of three mixing angles (θ_{12}, θ_{23} and θ_{13}) and one phase parameter (δ). If δ is nonzero (and not equal to π), then CP-violation in the neutrino sector will occur so long as $\theta_{13} > 0$. Measurements of neutrino oscillations in vacuum can be used to determine the moduli of the mass-squared differences $\Delta m^2_{31} = m^2_3 - m^2_1$ and $\Delta m^2_{21} = m^2_2 - m^2_1$ and, with the aid of interactions with matter, also the sign.

Neutrino oscillation is arguably the most significant advance in particle physics of the past decade.

The bulk of the measurements of neutrino oscillations to date have been collected ▷

Facilities

using the dominant "disappearance" channels $\nu_e \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\mu$. These data have yielded values for the three mixing angles, as well as for the magnitude of the mass-squared differences Δm^2_{31} and Δm^2_{21}, and have shown that $m_2 > m_1$ (i.e. that $\Delta m^2_{21} > 0$). Last year, the T2K, MINOS and Double Chooz experiments presented evidence that θ_{13} may be greater than zero (*CERN Courier* September 2011 p6 and January/February 2012 p10). Then, in March this year, the Daya Bay collaboration reported that $\sin^2 2\theta_{13} = 0.092 \pm 0.016 \text{(stat.)} \pm 0.005 \text{(syst.)}$, i.e. that $\sin^2 2\theta_{13} = 0$ is excluded at $5.2\,\sigma$. The announcement was soon followed by the report of a similar result from the RENO experiment (see p6). These exciting new measurements imply that it may be possible to observe CP-violation in neutrino oscillations. The challenge for the neutrino community, therefore, is to refine the measurement of θ_{13} to determine the sign of Δm^2_{31} (the "mass hierarchy"), to discover CP-violation (if, indeed, it does occur) by measuring δ and to improve the accuracy with which θ_{23} is known.

Over the next few years, several experiments – MINOS, T2K, NOνA, Double Chooz, Daya Bay and RENO – will exploit the $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_e \rightarrow \bar{\nu}_x$ channels to improve significantly the precision with which θ_{13} is known. The NOνA long-baseline experiment might also be able to determine the mass hierarchy. However, it is unlikely that either T2K or NOνA will be able to discover CP-violation, i.e. that $\delta \neq 0$ or π.

The Neutrino Factory

Neutrino oscillations also have implications well beyond the confines of particle physics. The possibility of CP-violation through the neutrino mixing matrix, combined with the possibility that the neutrino is a Majorana particle, makes it conceivable that the interactions of the neutrino led to the observed domination of matter over antimatter in the universe. The abundance of neutrinos in the universe is second only to that of photons. Even with a tiny mass, the neutrino may make a significant contribution to dark matter and thereby play an important role in determining the structure of the universe.

Such a breadth of impact justifies an ambitious, far-reaching experimental programme. Determining the nature of the neutrino – whether Majorana or Dirac – through the search for neutrinoless double-beta decay ($2\beta0\nu$) is an important part of this programme. The absolute neutrino mass must also be determined either through observations of $2\beta0\nu$ decay or from the measurement of the end-point of the electron spectrum in beta decay. Equally important is the accurate determination of the parameters that determine the properties of the neutrino. This requires intense, high-energy neutrino and antineutrino beams – precisely what the Neutrino Factory is designed to produce.

In the Neutrino Factory, beams of ν_e and $\bar{\nu}_\mu$ ($\bar{\nu}_e$,ν_μ) are produced from the decays of μ^+ (μ^-) circulating in a storage ring. High neutrino-energies can readily be achieved because the neutrinos carry away a substantial fraction of the energy of the muon. Time-dilation is beneficial, allowing sufficient time to produce a pure, collimated beam. The table above lists the oscillation channels that are available at the Neutrino Factory. Charged-current interactions induced by $\nu_e \rightarrow \nu_\mu$ oscillations – the "gold channel" – produce muons that are opposite in charge to those produced by the $\bar{\nu}_\mu$ in

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$	$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$	
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	$\nu_\mu \rightarrow \nu_\mu$	disappearance
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_e$	appearance (challenging)
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$	$\nu_\mu \rightarrow \nu_\tau$	appearance
$\nu_e \rightarrow \nu_e$	$\bar{\nu}_e \rightarrow \bar{\nu}_e$	disappearance
$\nu_e \rightarrow \nu_\mu$	$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$	appearance: "golden" channel
$\nu_e \rightarrow \nu_\tau$	$\bar{\nu}_e \rightarrow \bar{\nu}_\tau$	appearance: "silver" channel

Oscillation processes at the Neutrino Factory.

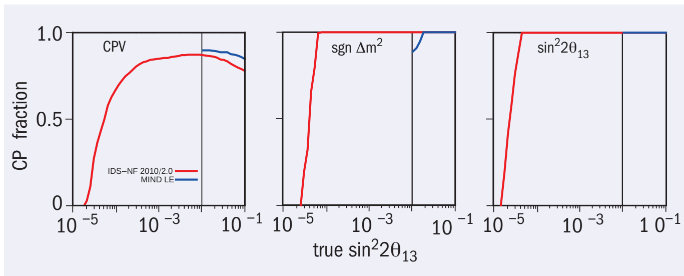


Fig. 2. Left to right: The discovery potential at 3 σ for CP-violation, the mass hierarchy and $\sin^2 2\theta_{13}$. The discovery reach is plotted in terms of the "CP fraction" (the fraction of all possible values of the mixing phase, δ) as a function of $\sin^2 2\theta_{13}$. The red solid line shows the performance of the IDS-NF baseline Neutrino Factory, while the blue line refers to the "low-energy" option, optimized for large $\sin^2 2\theta_{13}$.

the beam, so a magnetized detector is required. The additional capability to investigate the "silver" ($\nu_e \rightarrow \nu_\tau$) and "platinum" ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) channels also makes the Neutrino Factory an excellent place to look for oscillation phenomena that are outside the standard three-neutrino mixing paradigm. It would be the ideal facility to serve the precision-era of neutrino-oscillation measurements.

In 2011, the International Design Study for the Neutrino Factory (the IDS-NF) collaboration presented two options for the facility in its Interim Design Report (IDR) (Choubey *et al.* 2011). The first, optimized for discovery reach at small θ_{13} ($\sin^2 2\theta_{13} < 10^{-2}$), calls for two distant detectors, with baselines of 2500–5000 km and 7000–8000 km, and a stored-muon energy of 25 GeV. The second option, optimized for sensitivity at large θ_{13}, requires a single detector at a distance of around 2000 km and a stored-muon beam with an energy of only 10 GeV. Figure 2 shows the discovery reach of the facility presented in terms of the fraction of all possible values of δ (the "CP fraction") and plotted as a function of $\sin^2 2\theta_{13}$.

The abundance of neutrinos in the universe is second only to that of photons.

In the past few weeks, the Daya Bay and RENO collaborations have announced the first measurements of $\sin^2 2\theta_{13}$ with a value around 0.1 (see p6).

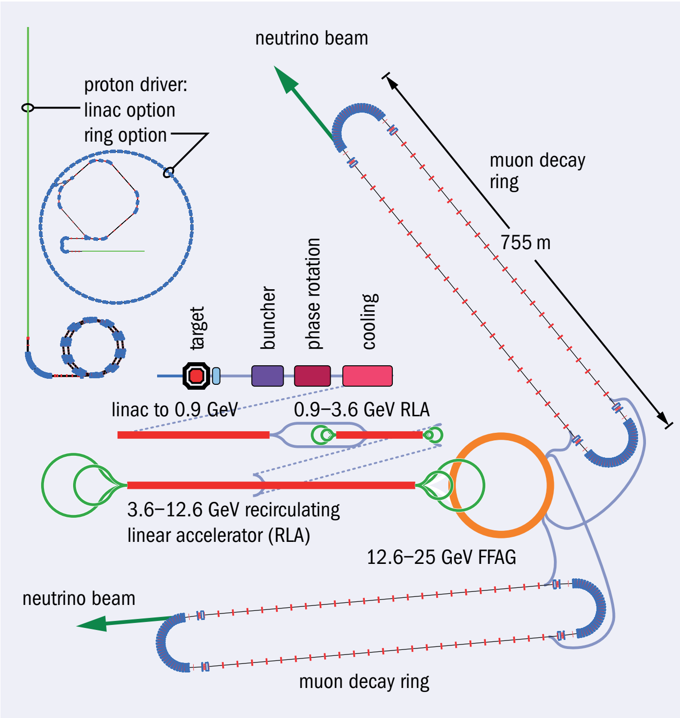


Fig. 3. Schematic diagram of the IDS-NF baseline for the Neutrino Factory accelerator complex (Choubey et al. *2011). The various systems have been drawn to scale.*

Figure 2 shows that at such a large value of θ_{13}, excellent performance can be achieved using the "low-energy" option. At such a large value of θ_{13}, the precision and discovery reach of a "low energy" Neutrino Factory is significantly better than the realistic alternatives (IDS-NF 2011).

Novel techniques

The IDS-NF baseline accelerator facility sketched in figure 3 provides a total of 10^{21} muon decays per year, split between the two distant neutrino detectors. The process of creating the muon beam begins with the bombardment of a pion-production target with a pulsed proton beam. The pions are captured in a solenoidal channel in which they decay to produce the muon beam. A sequence of accelerators is then used to manipulate and reduce (cool) the muon-beam phase space and to accelerate the muons to their final energy.

The muon's short lifetime has required novel techniques to be developed to carry out these steps. Ionization cooling, the technique by which it is proposed to cool the muons, involves passing the beam through a material in which it loses energy through ionization and then re-accelerating it in the longitudinal direction to replace the lost energy. Muon acceleration will be carried out in a series of superconducting linear and recirculating linear accelerators. The final stage of acceleration, from 12.6 GeV to the stored-muon energy of 25 GeV, is provided by a fixed-field alternating-gradient (FFAG) accelerator. The baseline neutrino detector is a MINOS-like iron-scintillator sandwich calorimeter with a sampling fraction optimized for the Neutrino Factory beam. The baseline calls for a fiducial mass of 100 kilotonnes to be placed ▷

Cooling at MICE

MICE is a single-particle experiment in which the position and momentum of each muon is measured before it enters the MICE cooling channel and is measured again after it has left (Gregoire *et al.* 2003 and 2005). Muons with momenta between 140 MeV/*c* and 240 MeV/*c*, with normalized emittance between 2 πmm and 10 πmm, will be provided by a purpose-built beamline at the 800 MeV proton synchrotron, ISIS, at the Rutherford Appleton Laboratory.

The MICE cooling channel, a single lattice cell, comprises three 20-l volumes of liquid hydrogen and two short linac modules each consisting of four 201 MHz cavities. Beam transport is achieved by a series of superconducting solenoids: the "focus coils" focus the beam into the liquid-hydrogen absorbers, while a "coupling coil" surrounds each of the linac modules. A particle-identification system, with scintillator time-of-flight (TOF) hodoscopes and threshold Cherenkov counters, upstream of the cooling channel allows a pure muon beam to be selected. Downstream of the cooling channel, a final hodoscope and a calorimeter system allow muon decays to be identified. The calorimeter is composed of a lead-scintillator section, of a similar design to that of the KLOE detector at DAΦNE but with thinner lead foils, followed by a fully active scintillator detector (the electron-muon ranger) in which the muons are brought to rest.

Charged-particle tracking in MICE is provided by two solenoidal spectrometers that together determine the relative change in transverse emittance of the beam, which is expected to be approximately 10%, with a precision of ±1% (i.e. a 0.1% measurement of the change in absolute emittance). The trackers themselves are required to have high track-finding efficiency in the presence of background that is induced by X-rays produced in the RF cavities.

In the first "step" of the experiment, the muon beam for MICE has been characterized using the beamline instrumentation and the TOF, Cherenkov and lead-scintillator systems (figure 5, p22). The results, which are being prepared for publication, show that the muon beam can provide the range of momentum and emittance required by MICE. The trackers and a prototype of the electron-muon ranger have been tested and shown to perform to specification. The cavities that make up the two short linac sections have been manufactured by Lawrence Berkeley National Laboratory (LBNL). The superconducting magnets required for the cooling channel are all under construction. By the end of 2012, the collaboration will commission the two spectrometer modules and the first liquid-hydrogen absorber and focus-coil module. This will allow preliminary studies of the ionization-cooling effect to be performed. The full MICE cooling cell will be constructed once the initial cooling studies are complete.

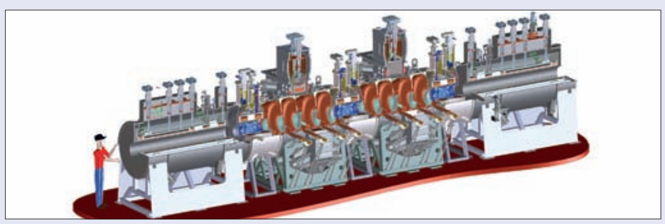


Fig. 4. Cutaway rendering of the international Muon Ionization Cooling Experiment. The muon beam enters from the bottom left of the figure. (Image credit: A DeMello/LBNL.)

Facilities

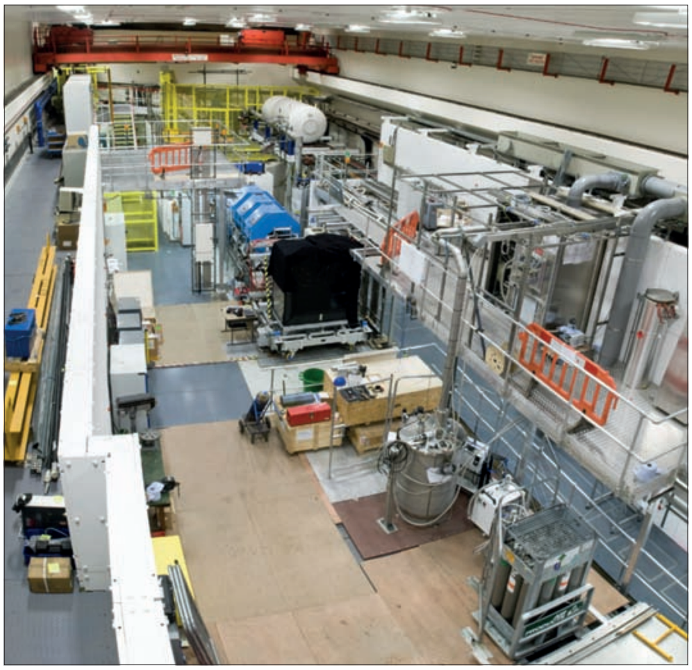


Fig. 5. The MICE Hall in June 2011. The ISIS synchrotron lies behind the wall at the back. The downstream quadrupoles (blue) are visible in front of the concrete shielding (white), with a TOF hodoscope for particle identification immediately after the final quadrupole. This hodoscope is followed by the lead-scintillator section and the prototype electron-muon ranger. In the foreground are the prototype liquid-hydrogen delivery system and R&D cryostat. (Image credit: S Kill/STFC.)

at the intermediate baseline and a detector of 50 kilotonnes at the magic baseline.

Much of the Neutrino Factory facility, the accelerator complex and the neutrino detectors exploit state-of-the-art technologies. To achieve the ultimate performance (10^{21} muon decays per year) the IDS-NF baseline calls for: a proton-beam power of 4 MW, delivered at a repetition rate of 50 Hz in short (around 2 ns) bunches; a pion-production target capable of accepting the high proton-beam power; an ionization-cooling channel that increases the useful muon flux by a factor of around 2; and an FFAG to boost the beam energy rapidly to 25 GeV. R&D programmes that address each of these issues are underway. CERN, along with other proton-accelerator laboratories, is actively developing the technologies necessary to deliver multimega-watt, pulsed proton beams. The principle of a mercury-jet pion-production target was demonstrated by the MERIT experiment in 2008 that ran in the beamline of n_TOF, the neutron time-of-flight facility at CERN. The nonscaling FFAG accelerator EMMA (the Electron Model of Muon Acceleration, also known as the Electron Model of Many Applications) has been commissioned at the Daresbury Laboratory in the UK and used to demonstrate the "serpentine acceleration" characteristic of the nonscaling FFAG. The international Muon Ionization Cooling Experiment (MICE) at the Rutherford Appleton Laboratory will provide the engineering demonstration of the ionization-cooling technique (see box, previous page).

The Neutrino Factory is the facility of choice for the study of neutrino oscillations. It has excellent discovery reach and offers the best precision on the mixing parameters. The ability to vary the stored-muon energy and, perhaps the detector technology, gives the necessary flexibility to respond to developments in understanding neutrino physics and in the discovery of new phenomena. The R&D programme required to make the Neutrino Factory a reality will directly benefit the development of a muon collider and experiments that seek to discover charged lepton-flavour violation. The case for the Neutrino Factory as part of a comprehensive muon-physics programme is compelling indeed.

I gratefully acknowledge the help, advice, and support of my many colleagues within the IDS-NF, EUROnu and MICE collaborations and the Neutrino Factory community who have freely discussed their results with me and from whose work and results I have drawn freely.

Further reading

S Choubey *et al.* IDS-NF collaboration 2011 arXiv:1112.2853 [hep-ex].
G Gregoire *et al.* MICE collaboration 2003 *MICE Note* **21**, www.mice.iit.edu/mnp/MICE0021.pdf.
G Gregoire *et al.* MICE collaboration 2005 MICE-TRD-2005, www.mice.iit.edu/trd/MICE_Tech_ref.html.

Résumé

La production de neutrinos passe à l'échelle industrielle

En 2011, l'étude de conception pour l'usine à neutrinos (IDS-NF) a présenté son rapport de conception préliminaire. Le but est de générer des faisceaux intenses de neutrinos de haute énergie pour étudier le comportement de ces particules et éclairer certaines questions fondamentales de la physique des particules et au-delà. Dans cette installation, les faisceaux de neutrinos sont produits par la désintégration de muons circulant dans un anneau de stockage. Une série d'accélérateurs est utilisée pour maîtriser et refroidir le faisceau de muons et accélérer les muons pour les porter à leur énergie finale. En raison de la durée de vie brève du muon, des techniques innovantes ont dû être mises au point pour réaliser ces différentes étapes.

Ken Long, Imperial College.

Electrons for the LHC

The LHeC project would provide a polarized electron beam of 60 GeV in energy to collide with the intense proton and ion beams of the LHC and allow a rich programme of physics.

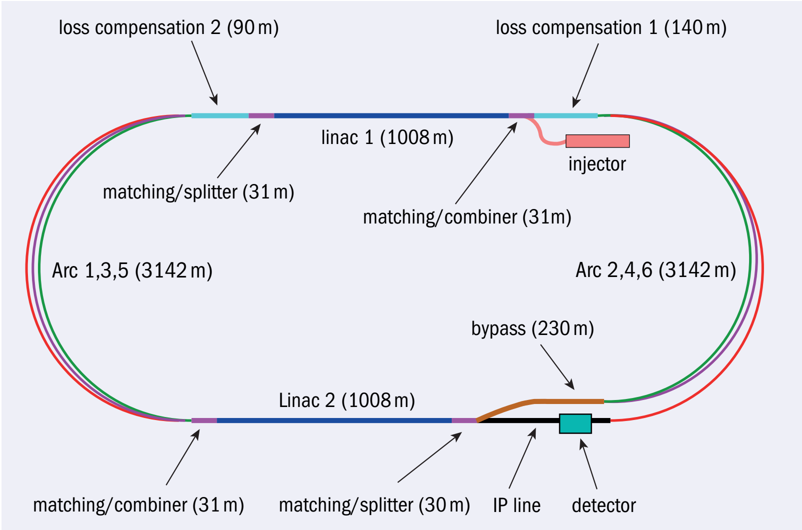


Fig. 1. Schematic layout of the recirculating 60 GeV energy linac with a 500 MeV injector, two 1 km superconducting accelerator structures of 472 cavities each, three return arcs with a total of 3600 dipole magnets, synchrotron energy-loss compensation and further accelerator elements. The electron-beam tunnel has a circumference of about 9 km; it is tentatively arranged to be on the inside of the LHC and tangential to IP2 such that its access shafts may be arranged to be on CERN territory.

This month sees the final touches being made to a detailed, 500-page report on the physics programme, a detector design and the accelerator options for the proposed Large Hadron Electron Collider (LHeC) project (*CERN Courier* April 2009 p22). Following invitations by CERN and the European Committee for Future Accelerators (ECFA) and after three annual workshops, a study group of nearly 200 physicists and engineers from 60 institutes has now laid out the motivation and design concepts for a next-generation collider and a detector to explore the tera-electron-volt energy scale. The technical and particle physics aspects of the report have been refereed by more than 20 world experts, who were invited by CERN last year to scrutinize the design. The design process was monitored by ECFA and the Nuclear Physics European collaboration Committee (NuPECC), as well as by a scientific advisory committee. The potential for electron–ion scattering led NuPECC in 2010 to include the LHeC in its long-range plan for European nuclear physics.

The LHeC project involves extending the capabilities of the LHC with a 60 GeV polarized electron beam, which in collisions with the intense proton (and ion) beams of the LHC would reach luminosities about 100 times larger than at HERA, the world's first electron–proton collider that ran at DESY in the years 1991–2007. The aim would be to exceed HERA's maximum four-momentum-transfer squared, Q^2, by a factor of 20. This would open up a new chapter in the physics of deep inelastic-scattering (DIS), a story that began at SLAC with the discovery of quarks as the smallest constituents of the proton in 1968. More recently it led to the discovery at HERA that at small relative parton momenta, x, the proton is largely determined by gluon interactions, which also give mass to the visible matter of the universe.

The electron beam for the LHeC could be supplied by a new electron storage-ring mounted on top of the LHC, for which new, lighter, high-quality dipole magnets have been successfully developed both at CERN and at the Budker Institute of Nuclear Physics, Novosibirsk, in accordance with the design report. An alternative is to use an electron linac in a "racetrack" configuration of 1/3 the circumference of the LHC. This would consist of some 120 accelerating-cavity cryomodules placed in two linacs, each 1 km long and connected by triple return arcs (figure 1). These superconducting cavities operate in a continuous-wave mode at a gradient of about 20 MV/m, similar to the European XFEL project at DESY, and at a frequency that is likely to be 721 MHz. The limitation of the total power consumption to 100 MW and the necessity to achieve maximum luminosity, in excess of 10^{33} cm^{-2} s^{-1}, led to the linac for the LHeC being designed as an energy-recovery linac (*CERN Courier* June 2005 p26). The concept of energy recovery is growing in popularity and with the LHeC, CERN and its partners would develop the highest-energy application. With a linac length of 2 km, the new accelerator is no longer than SLAC's famous linac; however, the reach in Q^2 is enlarged by a factor of almost 10^5 owing to the collider configuration and the high-energy beams of the LHC.

The design report describes the machine physics, such as optics and beam–beam dynamics, for both options for the LHeC's electron beam, as well as schemes to achieve high positron currents in the linac option. It also gives details for the various elements of the accelerator system, such as the warm dipole and cold interaction-region magnets, the cryogenics and the power supply (RF) components.

To achieve the high integrated luminosity at the LHeC, the design envisages that the LHC would operate synchronously with electron–proton and proton–proton collisions. This would turn the LHC into a novel three-beam facility; it also determines ▷

LHC projects

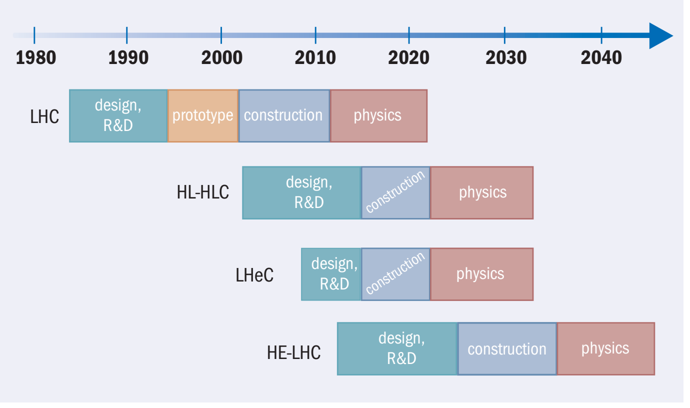


Fig. 2. The LHeC design foresees synchronous operation with the LHC in its high luminosity (HL) phase.

the time schedule for building and operating the LHeC (figure 2).

The report also covers a new collider detector, designed for high acceptance – down to 1° to the beam axis – and for the highest precision. Relying on novel technologies, as used in the ATLAS and CMS experiments and being developed for their upgrades, and based on the experience from the H1 and ZEUS detectors at HERA, the detector could be built in the 10 years or so available. Figure 3 shows the main detector, which is complemented by forward devices to tag protons, neutrons and deuterons for diffractive-scattering studies, and by backward electron and photon calorimeters for tagging events at low Q^2 (photo-production) and for measuring the luminosity with Bethe-Heitler scattering. With the assumption of only one interaction region being available for the LHeC in the 2020s, the report considers only one collider detector, with possibly two analysis collaborations to ensure independent and competing analysis approaches – a novel concept for particle physics

The physics chapters of the design report discuss the rich and unique programme of the LHeC. There exist different and complementary points of view on the interest in such a project:

- *The LHC point of view* sees the LHC as the natural, highest-energy collider for finding physics beyond or complementing the Standard Model. New particles observed in proton–proton collisions may also be produced in electron–proton interactions and their characteristics studied. One example would be the Standard Model scalar boson at 125 GeV, if confirmed; its charge-parity properties and decays to b-quark pairs may be cleanly investigated at the LHeC in the process of WW fusion. If new particles or phenomena are so heavy that they can be seen only at the LHC, the precise understanding of quarks and gluons, mostly at large Bjorken x, could become crucial in distinguishing new observations from instrumental or merely partonic effects.
- *The precision-physics point of view* recognizes the unique potential related to ultraprecise electron–proton measurements. A far-reaching programme of investigations in experimental DIS physics and in perturbative QCD is linked to the possibility of measuring the strong coupling constant $\alpha_s(M_Z^2)$ with tenfold improved precision (to per mille accuracy) as required in supersymmetric grand-unification scenarios of the electromagnetic, weak and strong interactions.
- *The parton-distribution function (PDF) point of view* emphasizes that the LHeC, for the first time, provides a complete foundation based not on fits but on data for the determination of the distributions of the two valence and six sea quarks, including the first mapping of those for the strange and top quarks. The LHeC maps the gluon distribution to unprecedented precision in a range from very low $x > 10^{-6}$ to x close to 1. The complete set of precision PDFs is crucial for extending the ranges of searches at the LHC or for measuring the mass of the W boson.
- *From a QCD point of view,* this precision needs to be matched by calculations of a further order of perturbation theory. New theoretical concepts, such as generalized parton distributions (based on scattering amplitudes), unintegrated parton distributions (that take transverse parton momenta into account) and diffractive parton distributions, are in their infancy. Factorization and resummation may be tested decisively in combining data from the LHC and LHeC. The investigation of high-energy electron–proton scattering can also be important for constructing a non-perturbative approach to QCD based on effective string theory in higher dimensions.
- *From a neutron point of view,* tagging the spectator proton in electron–deuteron collisions leads to a removal of the corrections for Fermi motion. Moreover, the nuclear-shadowing effects may be controlled with diffractive scattering as proposed by Vladimir Gribov. These new methods would put tests of neutron structure, parton-symmetry relations and the evolution of QCD on new, firm ground.
- *The heavy-ion point of view* notes that the LHeC will extend the kinematic range in electron–ion scattering by almost four orders of magnitude and lead to essential innovations in understanding nuclear parton distributions. This is deeply related to the initial state of the quark–gluon plasma and will allow the black-body limit of deep inelastic electron–ion scattering to be established experimentally. Such a possibility would complete the exciting programme of physics with heavy ions at the LHC.
- *From the HERA point of view,* there is a large programme to be performed with higher luminosity. Examples include precision measurements of the longitudinal structure function down to low x, or the solution of the up-to-down quark limit at high x, with data free of both nuclear and power corrections.
- *The photon point of view* recognizes that the most elementary boson yet has a quantum mechanical, partonic (gluon, charm etc.) structure, which could be uniquely investigated at the LHeC. It will allow both new phenomena and classic QCD subjects in photo-production to be studied at much higher energy. The LHeC design with a linear accelerator could also generate a real photon beam, allowing the possibility of the first-ever photon–proton collider .
- *The surprise point of view,* finally, relies on the greatly extended kinematic range and high luminosity for observing fundamentally new phenomena. HERA discovered the marked rise of parton densities towards low x and that in 10% of the events the proton remained intact despite the violence of the interaction – a fact that remains surprising. Known candidates for discovery are: a three-gluon state, the odderon; a topological QCD phenomenon, the instanton; a currently hypothetical substructure of the top quark or weak bosons; and the exclusion of the saturation phenomenon. Top quarks have never been noticeably produced in deep inelastic-

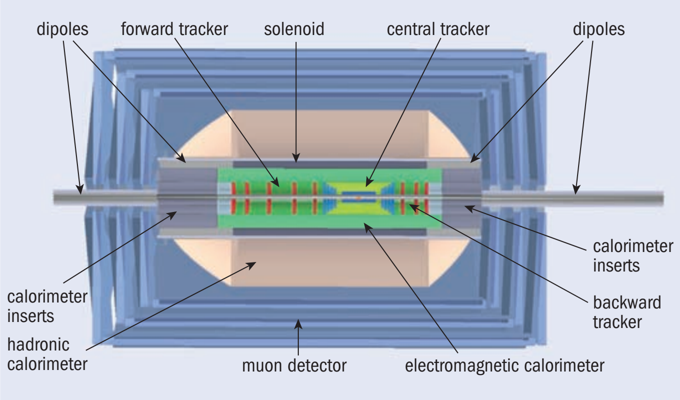


Fig. 3. Sketch of the LHeC main detector. The current design uses an all-silicon tracker and a liquid-argon electromagnetic calorimeter. These are surrounded by a long dipole for head-on collision and separation of the electron and proton beams, a 3.5 T solenoid, a hadronic tile-calorimeter and a muon detector. The apparatus has a length of 14 m and a diameter of 9 m, to be compared with the CMS detector, which extends to 21 m × 15 m.

scattering but they will appear copiously at the LHeC. Steps into an unknown kinematic region have always led to surprises, either through new particles or through their absence.

The design report will provide valuable input to the discussion on the future of European particle physics. The next steps towards the LHeC will be discussed at a workshop near Coppet, near Geneva, on 14–15 June. The project offers the promise for a new multipurpose experiment for particle physics at CERN. It is reminiscent of the time when the Sp$\bar{p}$S operated while CERN was also the centre of DIS with its muon- and neutrino-scattering experiments such as BCDMS and CDHSW. The LHeC builds on the LHC, enriching its physics harvest substantially and continuing the tradition of DIS as part of the exploration of the energy frontier. The accelerator technology and the experimental prospects are fascinating. By increasing the energy or the positron intensity there is also a bright future for further developments, reaching into the time when the LHC could be replaced by a new high-energy proton–proton collider and where the maximum Q^2 could approach 10 TeV^2.

Résumé

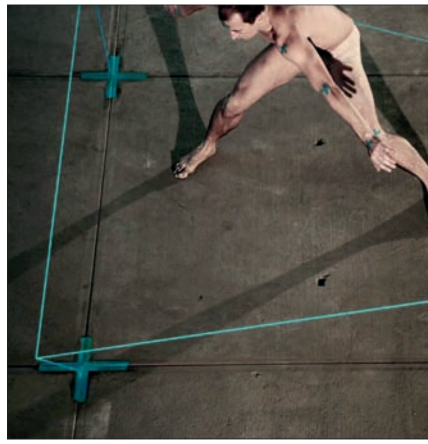
Des électrons pour le LHC

Ce mois-ci est la dernière ligne droite pour la production du rapport de 500 pages sur le programme de physique, les options relatives aux accélérateurs et la conception d'un détecteur pour le projet de Grand collisionneur hadron–électron (LHeC). Le projet LHeC porte sur la construction d'un accélérateur pour la production d'un faisceau d'électrons polarisés de 60 GeV, qui entrerait en collision avec les faisceaux intenses de protons (et d'ions) du LHC. Le riche programme de physique qui deviendrait possible est centré sur des études détaillées de la structure du proton et de QCD, mais il permettrait aussi de mieux comprendre les nouveaux phénomènes découverts au LHC ou au LHeC lui-même.

Oliver Brüning, CERN, and **Max Klein**, University of Liverpool.

The world's two largest Tesla coils at the opening of the 2011 Ars Electronic Festival. (Image credit: A Kolb.)

The Vienna Philharmonic Orchestra play Music for CERN's LHC by Ralph Schutti at the festival (Image credit: Rubra.)



Dancer Lukáš Timulak one of the memb collaboration with CERN. (Courtesy: Ru

How to build a p

Ariane Koek describes what it took to set up Arts@CERN – a creative collision that is now producing exciting results.

Take a 27-km, record-breaking machine, with 10,000 scientists from 100 countries and 630 institutions, throw in selected artists and arts specialists, and what do you get? An experiment to bring about head-on collisions between things that are even more elusive than the Higgs Boson – creativity, imagination and human ingenuity. Without them, science, art and technology would not exist. The name of this experiment is Arts@CERN, and last year saw the switch-on of this new and rather different collider at CERN.

The start-up has seen CERN collaborate in the world's most prestigious digital-arts festival, Ars Electronica, in Linz; feature in the keynote event at the Agenda 2016 conference at Moderna Museet, in Stockholm; supply live footage from the LHC to the US film director David Lynch for the Mathematics exhibition at one of the world's leading contemporary arts museums, Fondation Cartier, in Paris; and have its research into antimatter feature on the centre spread of China's best-selling design magazine.

Other results of the arts switch-on involve specially curated visits to CERN's facilities for leading international artists. Recently these included the Swiss video artist Pipilotti Rist, the Polish conceptual artist Goshka Mocuga and the master of contemporary dance, the US choreographer William Forsythe, as well as up-and-coming young artists, such as performer Niamh Shaw from Ireland. And to cap it all, this year CERN has two artists in residence on the new, three-year international artists' residency programme, Collide@CERN, which is funded and supported by external donors and partners.

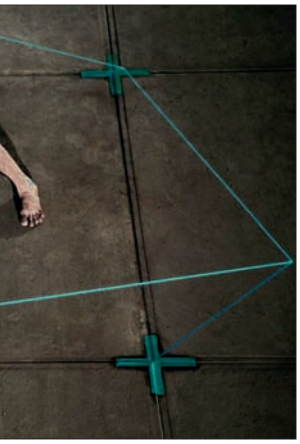
This all seems a long time since 2009, when I was given the opportunity to go anywhere in the world after I received the Clore Fellowship – an award for cultural leadership. Instead of taking the opportunity to work in a famous arts organization, I decided to approach CERN to come for three months, supported by the UK Government who funded my award, to carry out a feasibility study for an artists' residency scheme. Little did I know that I would be hired in the spring of 2010 to build a p(art)icle collider for CERN.

Making us human

So why should CERN engage with the arts? CERN has a mission to engage science in society. The arts reach areas that science and technology alone cannot reach – touching the public who might otherwise be turned off. By joining forces, arts, technology and science make an unbeatable force for change and innovation in the 21st century, as Eric Schmidt, now executive chair of Google, points out. In the words of CERN's director-general, Rolf Heuer: "They are expressions of what makes us human in the world."

This phrase, more than any other, shows what is behind CERN's high-level engagement with the arts and can be summed up in a simple equation: arts + science + technology = culture. For an organization to be truly cultural and innovative in the 21st century, it has to embrace all factors and facets of human experience, engaging with them on the same level of excellence as its institutional values.

Science and the arts are intimately connected in other ways, too. The British sculptor Antony Gormley is one of several leading international artists who are the patrons of the Collide@CERN artist in residence scheme. He recently donated one of his pieces, *Feeling Material*, to CERN in acknowledgement of the inspiration of particle physics on his work; it now hangs in the Main Building (*CERN Courier* January/February 2012 p39). Gormley is clear about the connection between art and science: "My whole philosophy is that art and science are better together than apart. We



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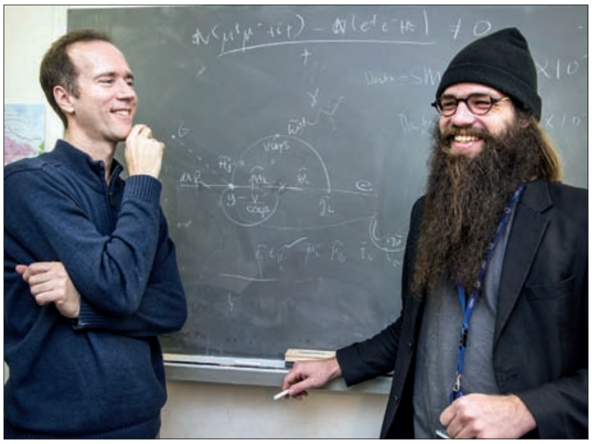
Ruben van Leer.)



CERN's first artist in residence, Julius von Bismarck (right), with inspiration partner, theorist James Wells.

Feeling Material *(2008) by Antony Gormley hangs over the staircase in CERN's Main Building.*

(art)icle collider

have somehow accepted an absolute division between analysis and intuition but I think actually the structures that they both come up with are an intricate mix of the two."

The showpiece event that signalled the switch-on of CERN's arts experiment was the six-day Ars Electronica Festival in Linz in 2011 (*CERN Courier* October 2011 p43). Being the world's leading digital-arts festival, it features spectacular performances in and around its state-of-the-art building and museum in addition to digital-arts exhibitions and interventions throughout the city. In 2011, CERN was the major collaborative partner and inspiration for the festival, which was called "Origin" and attracted more than 70,000 visitors from 33 countries. A symposium explored the importance of fundamental research and CERN's collaborative international organizational structure. Even the logo for the festival was taken from the collisions in the ATLAS detector. CERN's director of research and innovation, Sergio Bertolucci, and the director-general both spoke at the festival, and researchers from the experiments at the LHC gave the public "walk and talk through" guides to the innards of the detectors, with extraordinary high-resolution images.

That was not all. Ars Electronica and CERN also announced at the festival a landmark, three-year international cultural partnership with the launch of the annual Prix Ars Electronica Collide@CERN award for digital artists. The prize is a residency at both institutions lasting three months – two months at CERN for inspiration and one month at Ars Electronica for production. The first competition attracted 395 artists from 40 countries – from Azerbaijan and Uzbekistan, Brazil and Iceland, as well as from across Europe and the US. The winning artist was the 28-year-old Julius von Bismarck – one of the rising stars of the international arts scene, who is currently studying with the celebrated Icelandic Danish artist Olafur Eliasson at the Institute of Spatial Experiments in Berlin (*CERN Courier* January/February 2012 p39).

The arts reach areas that science and technology alone cannot.

It was only after awarding von Bismarck the prize that the jury discovered that he had wanted to be a physicist, and that both his brother and his grandfather are physicists. This only goes to prove the point at the heart of the Arts@CERN initiative – that scientists and artists are inter-related. He has just completed his residency of two months at CERN, being inspired by the science and the environment and having been "matched" with James Wells, a theorist at CERN, as his partner for scientific inspiration.

During his time at the laboratory, von Bismarck carried out interventions in perception among the CERN community and held many informal discussions. He is now at Ars Electronica's transdisciplinary innovation and research facility, Futurelab, producing the ideas generated at CERN. He is working with his production mentor Horst Hoertner – one of the co-founders of the Prix Ars Electronica Collide@CERN. He will showcase the work at this year's Ars Electronica Festival before bringing the piece back to CERN for a lecture on 25 September. However, the ripples of the residency and the ideas will continue long after von Bismarck has left. As he stated after just two weeks at the laboratory: "This experience is changing my life."

A policy for arts

If this arts experiment sounds easy, it isn't. As with any experiment, it needs expertise and knowledge to make it happen and to build it, using foundation and structure. So I created for CERN its first arts policy, "Great Arts for Great Science", putting the arts ▷

Arts

Dance and performance

May sees the start of the first prize in the second strand of the Collide@CERN Artists Residency programme – the Geneva award for dance and performance funded by the City and Canton of Geneva. The Swiss-born choreographer Gilles Jobin received the three-month residency by jury for his proposal to use interventions and dance to explore the relationship between mind and body at CERN. Jobin has an international reputation in contemporary dance, with an increasing interest in science, as shown in one of his seminal works, *The Moebius Strip*.

The Moebius Strip, *Gilles Jobin 2007. (Image credit: Dorothée Thébert.)*

on the same level of selected excellence as the science to create truly meaningful, high impact-quality engagement, mutual understanding and respect between the arts and science. The first CERN Cultural Board was appointed at this high level of knowledge and excellence – to build expertise in the arts into CERN. The board members, honorary appointments for three years, are recognized leaders in their fields. They include the director-general of the Lyon Opera House, Serge Dorny, and the director of Zurich's Kunsthalle, Beatrix Ruf, who is acknowledged as one of the most influential figures in contemporary art today. All of the board members donate their time and, crucially, the board also includes a CERN physicist, Michael Doser. Researchers from CERN are also on the juries for all of the artists' residencies awards.

Every year, the board will select at least one major arts project in which CERN officially collaborates, its stamp of approval enabling the project to find external funding. In 2012–2013, the selected project is the cutting-edge, multimedia/dance/opera/film *Symmetry*, by a truly international team of artists performing across several art forms, including the soprano Claron McFadden and the Nederlands Dans Theater dancer, Lukáš Timulak. The project is the brainchild of the emerging film director, Ruben Van Leer.

So, that is step one of building a p(art)icle collider – create the policy and the structure. The other steps were to: create the flagship Collide@CERN residency scheme; launch a website to make the work, visits and potential involvement with CERN of artists (past, present and future) visible and accessible; and finally give back to the CERN community by advising on home-grown initiatives that have international artistic potential. In 2010, one of my first acts was to carry out a major strategic review of the home-grown, biannual film festival CinéGlobe, created by CERN's Open Your Eyes film club. The review recommended developing the brand, mission, vision and values, as well as substantial organizational restructuring and planning. I also suggested the slogan "Inspired by Science" to sum up the festival's mission.

Two years since being hired by CERN, I am still there. It is the positive spirit of fundamental research – the quest to expand human knowledge and understanding for the good of all, engaging with cutting-edge ideas and technologies – that inspires me to work at CERN, as well as being the source of inspiration for artists. After all, landmark moments of science in the 20th century created some of the most significant arts movements of the modern world. My personal belief is that particle physics combines the twin souls of the artist – the theorist who thinks beyond the paradigms and the experimentalist who tests the new and brings them down to Earth. By building a p(art)icle collider, creative collisions between arts and science have truly begun at CERN.

● For more information see: Arts at CERN website, www.cern.ch/arts; Prix Ars Electronica Collide@CERN Artists blog, www.aec.at/futurelab/en/collide-at-cern/; and the first Prix Ars Electronica Collide@CERN lecture by Julius von Bismarck, http://cdsweb.cern.ch/record/1433816?ln=en.

Résumé

Dans « particules », il y a « art »…

Quand Ariane Koek a bénéficié d'une bourse dans le domaine de l'action culturelle, c'est au CERN qu'elle a choisi de venir, et non dans une institution se consacrant à l'art. Elle s'est ensuite attachée à définir une politique d'action artistique au CERN, qui a conduit à la création du comité culturel du CERN et à l'organisation, grâce au soutien de sponsors, de Arts@CERN – collision créative entre art, science et technique. Cette expérience nouvelle pour le CERN produit déjà des résultats enthousiasmants. Différentes collaborations sont ainsi menées, par exemple avec Ars Electronica, festival de premier plan dans le domaine des arts numérique, et un important programme d'artistes en résidence a été lancé.

Ariane Koek, CERN.

Light work with heavy ions

The fragmentation of heavy nuclei – lead ions – is being put to work at CERN to deliver beams of light ions, such a beryllium and carbon.

Nuclear fragmentation is the name given to the break-up of nuclei. It can happen when a high-energy hadron hits an intact nucleus. This is the process that is used to produce beams of exotic projectiles, such as radioactive nuclei, at CERN's ISOLDE facility, which has served a worldwide community for many years (*CERN Courier* January/February 2012 p33). However, nuclear fragmentation also takes place in inelastic peripheral collisions between heavy ions, a process that is now being put to use to generate beams of light ions in the North Area at CERN.

In a heavy-ion collision, the nuclear matter is unstable outside the region where the interacting nuclei overlap – mainly because of the mismatch between shape and surface-energy – and it disintegrates into a mixture of different nuclei. The composition of the fragments produced, in terms of particle mass (A), charge (Z) and momentum, varies considerably from one collision event to another, even for fixed initial conditions in energy and impact parameter. This type of nuclear fragmentation has been studied extensively and found to occur over a range of incident energies, from as low as 20 MeV per nucleon up to highly relativistic energies. For a given collision system (that is, with specific values of A and Z for the projectile and target), the distributions of mass and charge of the nuclei in the final state are, to a good approximation, independent of the incident energy. The same independence is also true for the momenta of the produced ions in the rest frame of the corresponding parent nucleus. In the laboratory frame, however, the fragments experience an energy-dependent boost, which causes a forward-peaked angular distribution.

Fragmentation of beams of heavy nuclei is used at a variety of facilities, including GANIL, RIKEN, GSI and the National Superconducting Cyclotron Laboratory at Michigan State University (*CERN Courier* July/August 2008 p15). However, a different application of nuclear fragmentation was introduced 12 years ago at CERN, when beams of fragments with energies of 40A GeV/*c* and 158A GeV/*c* were produced in a primary carbon target and delivered to the North Area at the Super Proton Synchrotron (SPS).

Figure 1a shows the production cross-section of ion-fragment projectiles as a function of the fragment's charge that was measured when lead nuclei at an energy of 158 GeV per nucleon collided with the carbon target (Cecchini *et al.* 2002, Thuillier *et al.* 2002). The results were in good agreement with model calculations and confirmed that there is a relatively high probability of producing ions

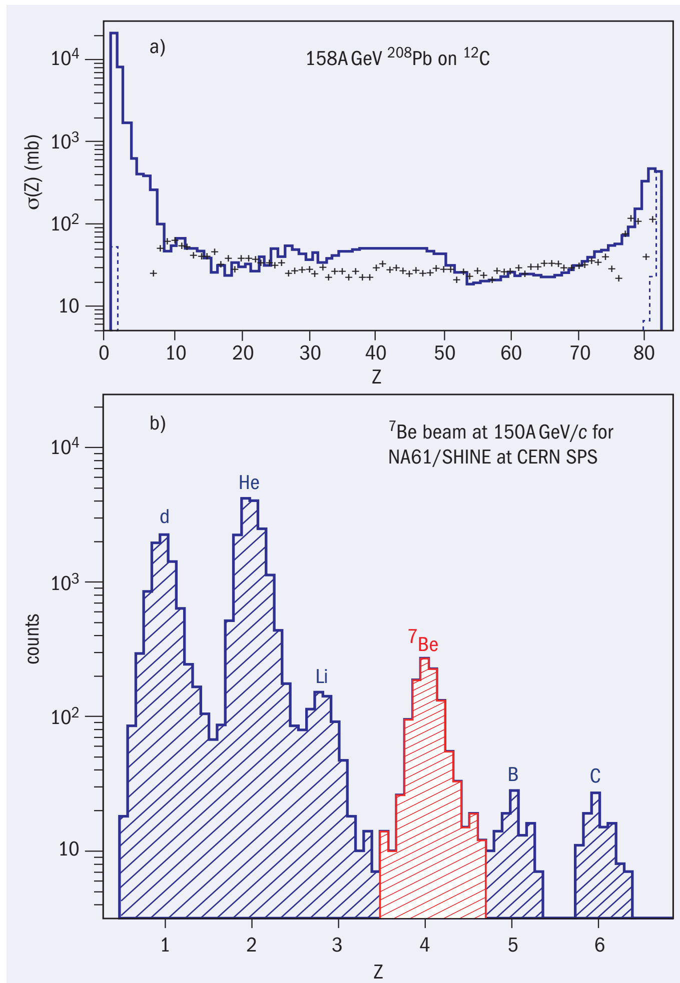


Fig. 1. a) Fragment cross-sections as a function of the charge Z of ions produced at CERN in Pb+C collisions at 158A GeV/c (Cecchini et al.*). b) The measured ion rates in the H2 beamline for a selection in rigidity optimized for the transmission of ^{7}Be.*

with either low or high charge, giving rise to a U-shaped distribution of the kind previously observed at much lower energies (Trautmann *et al.* 1992, Schüttauf *et al.* 1996). At the same time a fragmented lead-ion beam was used by the NA49 experiment for physics, in which fragments with A/Z values close to two were transported to the experimental area. Charge measurements of the beam particles allowed "tagging" of the charge states Z = 6 or 14, corresponding to the ^{12}C and ^{28}Si ions whose interactions with the secondary target in NA49 were recorded and analysed. Fragmentation was also used to produce beams of mixed ions, with a large spread of combinations of A and Z, for the calibration of detectors such as the ring imaging Cherenkov counter for the Alpha Magnetic Spectrometer ▷

Ion beams

experiment in 2002 (Efthymiopoulos and Buenerd 2003).

The NA61/SHINE collaboration has recently revived this method with the aim of producing light-ion beams with increased purity (NA61/SHINE 2009). The work is part of an effort to study the onset of deconfinement in heavy-ion collisions and search for the critical point of hadronic/partonic matter by scanning systematically both in collision energy and in the size of the colliding nuclei (*CERN Courier* January/February 2012 p17). For the light-ion part of the programme, the collaboration decided to begin with a fragment beam, as primary light ions will become available in the North Area only in 2014. To create the light ions, a primary beam of lead ions from the SPS was directed towards a stationary target in the North Area, where a secondary beamline was tuned to transport projectile fragments with an optimized content of ^{7}Be ions to NA61/SHINE, for studying the reaction ^{7}Be + ^{9}Be.

The selection and transport of a specific ion species from a fragmented heavy-ion (^{208}Pb) beam is not straightforward. The secondary beamlines in the North Area are designed to transport particles emerging from the primary targets to the experiments. They basically consist of two large spectrometers, which can select particles with a range in rigidity (momentum-to-charge ratio, $B\rho \approx 3.31\gamma A/Z$) of ±1.5%. The desired ions produced in the fragmentation of the primary beam will be immersed in a variety of other nuclei that have a similar mass-to-charge ratio and, therefore, a rigidity value within the beam acceptance. Moreover, overlaps in rigidity occur not only for ions with the same mass-to-charge ratio but also for neighbouring elements. This is because the momentum of the ions varies as a result of the nuclear Fermi motion of the fragments. Without Fermi motion, the fragments would leave the interaction region almost undisturbed, with the same velocity (or momentum per nucleon) as the incident lead ions. Instead, the Fermi motion, which depends on the masses of the fragment and the projectile, can spread the longitudinal momenta of light nuclear fragments by up to 3–5% – i.e. much, more than the beam acceptance.

The ^{7}Be ion was chosen for the beam for the NA61/SHINE experiment because it has no long-lived near-neighbours, thus allowing the production of a light-ion beam with a large proportion of the desired ions. The near neighbours to ^{7}Be are its isotopes ^{6}Be and ^{8}Be and nuclei with a charge-difference of one and a similar mass-to-charge ratio (e.g. ^{5}Li,^{9}B). Furthermore ^{7}Be has more protons ($Z = 4$) than neutrons ($N = 3$). Such nuclear configurations are disfavoured with increasing nuclear mass because a surplus of protons causes a Coulomb repulsion that cannot be balanced by the attractive potential of the smaller number of neutrons. Figure 1b shows ion rates in the fragment beam delivered to NA61/SHINE. It indicates that ^{7}Be fragments are accompanied mainly by deuterons and helium ions, whose rigidity overlaps with that of the wanted ions because of the Fermi motion. A counter-example for the choice of ion-species would have been a nucleus with a mass-to-charge ratio of two, which would be accompanied by a range of stable or long-lived nuclei from ^{2}D up to ^{56}Ni.

At low energies, the insertion of a "degrader" into the beamline improves the separation of the desired ions (Münzenberg *et al.* 1992, Geissel *et al.* 1995), profiting from the double spectrometer configuration of the secondary beamline. The first spectrometer selects ions within a rigidity range that maximizes the proportion

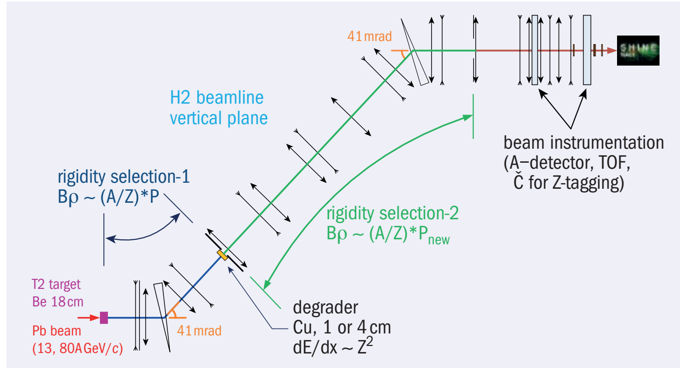


Fig. 2. Schematic view of the vertical plane of the H2 beamline at CERN, as used for ion-fragment separation.

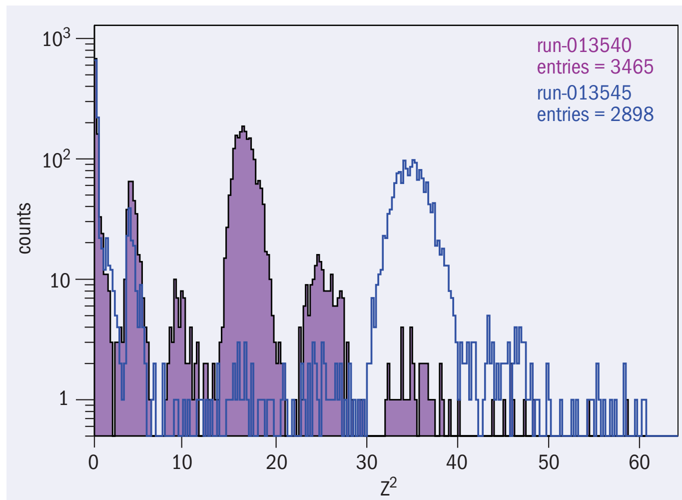


Fig. 3. Charge distributions of fragments measured with the NA61 beamline in fragment-separator mode, with collimator settings optimized for ^{7}Be (solid purple) and ^{11}C (open blue) fragments, for a primary lead beam with energy 13A GeV.

of wanted ions produced by the primary fragmentation target; on passing through the degrader, a piece of material introduced at the spectrometer's focal point, these ions lose energy in a charge-dependent way. The second spectrometer then separates the ions spatially according to their charge so that they can then be selected by using a thin collimator slit.

The drawback of this method is a loss of beam intensity, through both the nuclear interactions and the beam blow-up caused by multiple scattering in the material of the degrader, which rises with increasing thickness. So the high separation power is accompanied by a high loss of intensity. Furthermore, for a given degrader thickness both the nuclear cross-section and the energy loss are energy independent to a large extent. This means that the separation power ($\Delta E/E$) increases with decreasing energy.

NA61/SHINE is located on the H2 beamline in the North Area, where lead ions from the SPS are focused onto a primary beryllium fragmentation target, 180 mm long. In passing through the target the lead beam undergoes collisions, mostly peripheral, with the light target-nuclei. Part of the resulting mixture of nuclear fragments is captured by the beamline, which is tuned to a rigidity that maximizes the ratio of the created ^{7}Be to all ions. Figure 2 shows the layout of the H2 beamline with its two-step spectrometer. The optional degrader (a copper plate either 1 cm or 4 cm in thickness) is located between the two spectrometer sections. The composition of the ion beam can be monitored by scintillation counters that measure the charge (Z^2) and time-of-flight of the ions. The latter allows the determination of the mass (A) of the ions for momenta lower than 20 GeV/*c* per nucleon.

Investigations of fragment separation in the H2 beamline took place during test-beam time in 2010, using a 13A GeV/*c* lead beam incident on the primary target and with the 4 cm degrader in place. Figure 3 shows, for a given rigidity setting, the charge distributions detected with the collimator set to optimize the selection of either ^{7}Be or ^{11}C ions. During running in 2011 the NA61/SHINE collaboration used the configuration without degrader to record a total of 6×10^6 ^{7}Be + ^{9}Be collisions at beam momenta of 158A GeV/*c*, 80A GeV/*c* and 40A GeV/*c*. A typical charge spectrum for a fragment beam selected by the spectrometer is indicated in figure 1b. With an incident beam from the SPS of several 10^8 lead ions per spill, typical beam intensities at NA61/SHINE were 5000 to 10,000 ^{7}Be particles per spill, with 10 to 20 times as many unwanted ions (Efthymiopoulos *et al.* 2011).

A second period with a ^{7}Be beam is scheduled for autumn this year. It will be devoted to data-taking at beam momenta of 30A GeV/*c*, 20A GeV/*c* and 13A GeV/*c*. The latter is close to the lower limit of what is possible given the characteristics of the SPS accelerator and the external beamlines.

Further reading

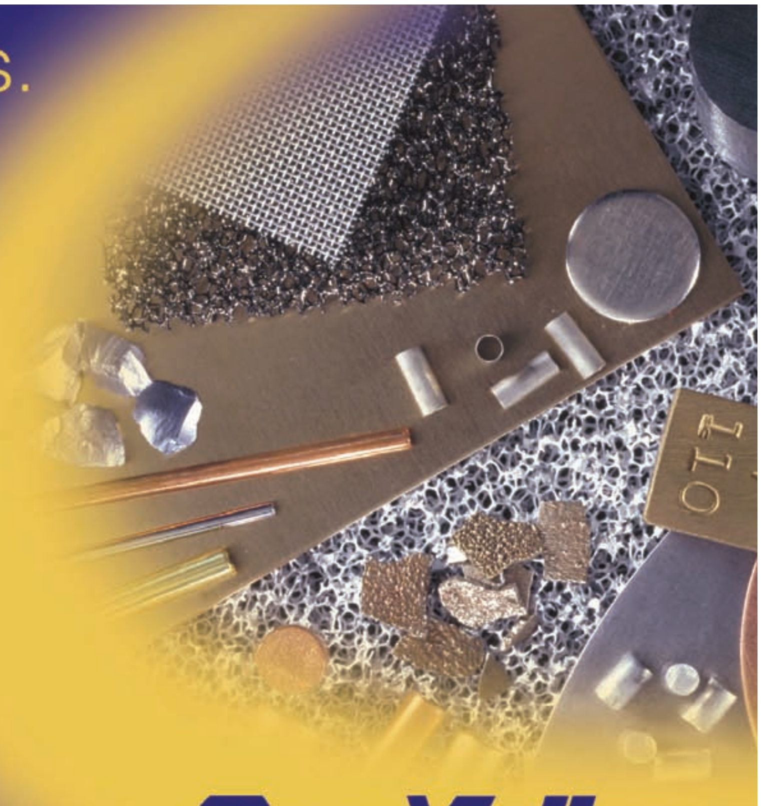
S Cecchini *et al.* 2002 *Nucl. Phys.* **A 707** (2002) 513.
H Geissel *et al.* 1995 *Annu. Rev. Nucl. Part. Sci.* **163**.
I Efthymiopoulos and M Buenerd 2003 CERN-AB-2003–052-ATB.
I Efthymiopoulos *et al.* 2011 IPAC11, CERN-ATS-2011-266.
G Münzenberg *et al.* 1992 *Nucl. Instrum. Meth.* **B70** 265.
NA61/SHINE collaboration 2009 CERN-SPSC-2009–001 and SPSC-P-330-ADD-4, http://cdsweb.cern.ch/record/1155904?ln=en.
A Schüttauf *et al.* 1996 *Nucl. Phys.* **A607** 457.
T Thuillier *et al.* 2002 *Nucl. Inst. and Meth. in Phys.* **A491** 83.
W Trautmann *et al.* 1992 *Nucl. Phys.* **A538** 473c.

Résumé

Faire du léger avec du lourd

La fragmentation nucléaire est ce qui se passe quand les noyaux se divisent, et cela se produit non seulement quand un hadron de haute énergie entre en collision avec un noyau, mais aussi dans les collisions périphériques entre ions lourds. La fragmentation des faisceaux d'ions lourds est utilisée dans plusieurs laboratoires pour produire des faisceaux d'ions légers. Le procédé a été introduit au CERN il y a 12 ans pour produire des ions légers destinés à l'expérience NA40 auprès du Supersynchrotron à protons. À présent, la collaboration NA61/SHINE a repris cette méthode, dans le cadre d'une étude systématique portant sur l'apparition du déconfinement dans les collisions d'ions lourds.

Herbert Stroebele, University of Frankfurt, and **Ilias Efthymiopoulos**, CERN.



The openlab adventure continues to thrive

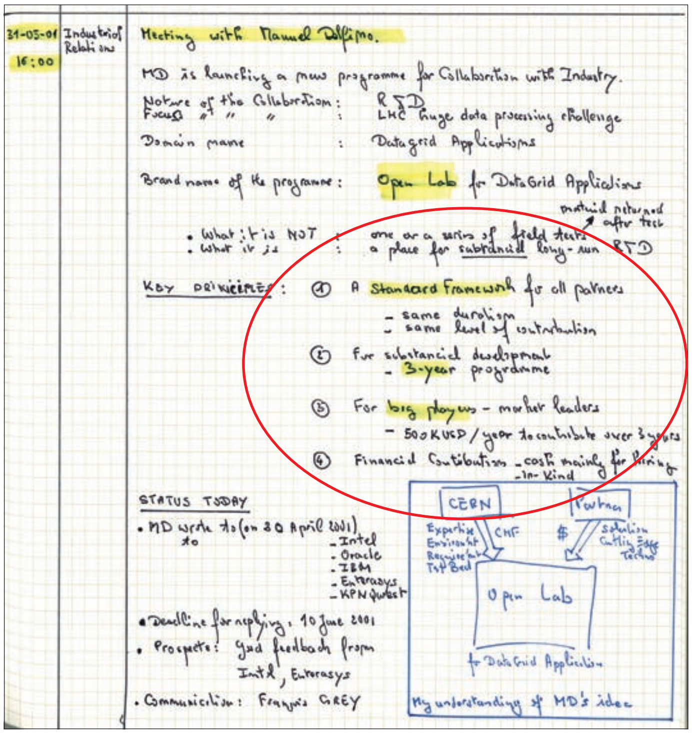
As the CERN openlab enters its second decade, **François Fluckiger** offers a personal account and some of his own recollections of how this bold initiative began and went on to thrive.

Friday, 31 May 2001, 6 p.m. – Back in my office, I open my notebook and write "My understanding of MD's ideas" in blue ink. I draw a box and write the words "Open Lab" in the middle of it. I've just left the office of Manuel Delfino, the head of CERN's IT division. His assistant had called to ask me to go and see Manuel at 4 p.m. to talk about "industrial relations". I've been technology-transfer co-ordinator for a few weeks but I had no idea of what he was going to say to me. An hour later, I need to collect my thoughts. Manuel has just set out one of the most amazing plans I've ever seen. There's nothing like it, no model to go on, and yet the ideas are simple and the vision is clear. He's asked me to take care of it. The CERN openlab adventure is about to begin.

This is how the opening lines of the openlab story could begin if it were ever to be written as a novel. At the start of the millennium, the case was clear for Manuel Delfino: CERN was in the process of developing the computing infrastructure for the LHC; significant research and development was needed; and advanced solutions and technologies had to be evaluated. His idea was that, although CERN had substantial computing resources and a sound R&D tradition, collaborating with industry would make it possible to do more and do it better.

Four basic principles

CERN was no stranger to collaboration with industry, and I pointed out to Manuel that we had always done field tests on the latest systems in conjunction with their developers. He nodded but stressed that here was the difference: what he was proposing was not a random collection of short-term, independent tests governed by various different agreements. Instead, the four basic principles of openlab would be as follows (I jotted them down carefully because Manuel wasn't using notes): first, openlab should use a common framework for all partnerships, meaning that the same duration and the same level of contribution should apply to everyone;



The original, hand-written notes from the first meeting on 31 May 2001 on what was to become openlab. The red circle highlights the four desired characteristics proposed for the new initiative. (Image credit: F Fluckiger.)

second, openlab should focus on long-term partnerships of up to three years; third, openlab should target the major market players, with the minimum contribution threshold set at a significant level; last, in return CERN would contribute its expertise, evaluation capacity and its unique requirements. Industrial partners would contribute in kind – in the form of equipment and support – and in cash by funding young people working on joint projects. Ten years on, openlab is still governed by these same four principles.

Back to May 2001. After paving the way with extensive political discussions over several months, Manuel had written a formal letter to five large companies, Enterasys, IBM, Intel, Oracle and KPN QWest, inviting them to become the founding members of the Open Lab (renamed "openlab" a few months later). These letters, which were adapted to suit each case, are model sales-pitches worthy of a professional fundraiser. They set out the unprecedented computing challenges associated with the LHC, the unique opportunities ▷

Industry

Manuel Delfino, left, and Luciano Maiani, who was then director-general of CERN, at the first meeting of the openlab board in March 2002.

Robert Aymar, then director-general of CERN, and a representative from Intel, sign the openlab-III agreement between CERN and Intel.

of a partnership with CERN in the LHC framework, the potential benefits for each party and proposed clear areas of technical collaboration for each partner. The letters also demanded a rapid response, indicating that replies needed to reach CERN's director-general just six weeks later, by 15 June. A model application letter was also provided. With the director-general's approval, Manuel wrote directly to the top management of the companies concerned, i.e. their chairs and vice-chairs. The letters had the desired effect: three companies gave a positive response by the 15 June deadline, while the other two followed suit a few months later – openlab was ready to go.

The first task was to define the common framework. CERN's legal service was brought in and the guiding principles of openlab, drawn up in the form of a public document and not as a contract, were ready by the end of 2001. The document was designed to serve as the basis for the detailed agreements with individual partners, which now had to be concluded.

Three-year phases

At the start of 2002, after a few months of existence, openlab had three partners: Enterasys, Intel and KPN QWest (which later withdrew when it became a casualty of the bursting of the telecoms and dotcom bubbles). On 11 March, the first meeting of the board of sponsors was held at CERN. Chaired by the then director-general, Luciano Maiani, representatives of the industrial companies were in attendance as well as Manuel, Les Robertson (the head of the LHC Computing Grid project) and me. At the meeting I presented the first openlab annual report, which has since been followed by nine more, each printed in more than 1000 copies. Then, in July, openlab was joined by HP, and subsequently followed by IBM in March 2003 and by Oracle in October 2003.

In the meantime, a steering structure for openlab was set up at CERN in early 2003, headed by the new head of the IT Department, Wolfgang von Rüden, in an *ex officio* capacity. Sverre Jarp was the chief technical officer, while François Grey was in charge of communication and I was to co-ordinate the overall management. January 2003 was also a good opportunity to resynchronize the partnerships. The concept of three-year "openlab phases" was adopted, the first covering the years 2003–2005. Management practices and the technical focus would be reviewed and adapted through the successive phases.

Thus, Phase I began with an innovative and ambitious technical objective: each partnership was to form a building block of a common structure so that all of the projects would be closely linked. This common construction, which we were all building together, was called "opencluster". It was an innovative and ambitious idea – but unfortunately too ambitious. The constraints ultimately proved too restrictive – both for the existing projects and for bringing in new partners. So what of a new unifying structure to replace opencluster? The idea was eventually abandoned when it came to openlab-II: although the search for synergies between individual projects was by no means excluded, it was no longer an obligation.

A further adjustment occurred in the meantime, in the shape of a new and complementary type of partnership: the status of "contributor" was created in January 2004, aimed at tactical, shorter-term collaborations focusing on a specific technology. Voltaire was the first company to acquire the new status on 2 April, to provide CERN with the first high-speed network based on Infiniband technology. A further innovation followed in July. François set up the openlab Student Programme, designed to bring students to CERN from around the world to work on openlab projects. With the discontinuation of the opencluster concept, and with the new contributor status and the student programme, openlab had emphatically demonstrated its ability to adapt and progress. The second phase, openlab-II, began in January 2006, with Intel, Oracle and HP as partners and the security-software companies Stonesoft and F-Secure as contributors. They were joined in March 2007 by EDS, a giant of the IT-services industry, which contributed to the monitoring tools needed for the Grid computing system being developed for the LHC.

The year 2007 also saw a technical development that was to prove crucial for the future of openlab. At the instigation of Jean-Michel Jouanigot of the network group, CERN and HP ProCurve pioneered a new joint-research partnership. So far, projects had essentially focused on the evaluation and integration of technologies proposed by the partners from industry. In this case, CERN and HP ProCurve were to undertake joint design and development work. The openlab's hallmark motto, "You make it, we break it", was joined by a new slogan, "We make it together". Another major event followed in September 2008 when Wolfgang's patient, months-long discussions with Siemens culminated in the company becoming a openlab partner. Thus, by the end of Phase II, openlab had entered the world of control systems.

At the start of openlab-III in 2009, Intel, Oracle and HP were joined by Siemens. EDS also decided to extend its partnership by one year. This third phase was characterized by a marked increase in education and communication efforts. More and more workshops were organized on specific themes – particularly in the framework of collaboration with Intel – and the communication structure was reorganized. The post of openlab communications officer, directly attached to the openlab manager, was created in the summer of 2008. A specific programme was drawn up with each partner and tools for monitoring spin-offs were implemented.

Everything was therefore in place for the next phase, which Wolfgang enthusiastically started to prepare at the end of 2010. In May 2011, in agreement with Frédéric Hemmer, who had taken over as head of the IT Department in 2009, he handed over the reins to Bob Jones. The fourth phase of openlab began in January 2012 with not only HP, Intel and Oracle as partners, but also with Chinese multinational Huawei, whose arrival extended openlab's technical scope to include storage technologies.

After 10 years of existence, the basic principles of openlab still hold true and its long-standing partners are still present. While I, too, passed on the baton at the start of 2012, the openlab adventure is by no means over.

● For a version of this article in French, see https://cern.ch/Fluckiger/Articles/F.Fluckiger-openlab-10_ans_deja.pdf.

Résumé

L'aventure CERN openlab continue

Au printemps 2011, Manuel Delfino, Chef de la Division IT, convoque François Fluckiger et lui présente une idée absolument novatrice, et pourtant limpide : un modèle ambitieux de partenariats nouveaux, de longue durée, utilisant tous un cadre commun, avec les géants industriels de l'informatique. Il lui demande de s'en occuper. Manuel écrit directement aux présidents des entreprises, leur donnant six semaines pour devenir membres fondateurs. Et cela fonctionne. L'openlab est né ! Dans cet article, François Fluckiger, qui a quitté le projet en ce début d'année, apporte un témoignage sur la naissance étonnante et les étapes majeures de cette entreprise unique.

François Fluckiger, CERN, openlab manager (2001–2011).

Faces & Places

Industry

CERN tech catches the power of the Sun

Vacuum technology developed at CERN for particle accelerators is to be put to work in what will be one of Switzerland's largest solar-energy systems. Some 300 high-temperature solar–thermal panels will cover a surface of 1200 m^2 on the roof of the main terminal building at Geneva International Airport. The first panels, from the company SRB Energy, were delivered on 9 March.

The high-temperature solar–thermal panels are the invention of Cristoforo Benvenuti, who came to CERN in 1966 and worked on vacuum technology for the world's first proton–proton collider, the Intersecting Storage Rings. He later proposed getter vacuum technology for the Large Electron–Positron collider, which used 20 km of getter strips – a material that attracts residual gas molecules rather as flypaper attracts insects (*CERN Courier* December 1998 p22). However, it was the combination of thin-film coating techniques with getter technology for the LHC in the 1990s that paved the way for solar-panel applications.

Benvenuti patented the technology of thin-film getter coating and CERN made licences available to commercial companies in its Member States. After retiring from CERN, in 2005 Benvenuti teamed up with the Spanish automotive company Grupo Segura to form SRB Energy, which has production facilities in Spain and R&D activities still based at CERN.

The ultrahigh vacuum provides the panels' heat chambers with exceptional insulation, vastly reducing heat loss and greatly improving efficiency. "We've had temperatures of 80°C inside the panel when the panels were covered in snow," says Benvenuti. The panels also recover the energy produced by diffuse light more efficiently than traditional panels. The two technologies make them particularly suited to colder, less sunny climates where they are more efficient than traditional solar panels.

Cristoforo Benvenuti with one of his innovative solar panels.

Symposium

LeCosPA in focused space–time endeavour

The First LeCosPA Symposium, "Towards Ultimate Understanding of the Universe", took place on 6–9 February in Taipei, in conjunction with the 4th anniversary of the National Taiwan University (NTU) Leung Center for Cosmology and Particle Astrophysics – LeCosPA (*CERN Courier* July/August 2008 p38). Since its founding four years ago, LeCosPA has become an active participant in several experimental programmes: the ARA Neutrino Observatory at South Pole, the balloon-borne ANITA project in Antarctica, and the UFFO GRB Satellite Telescope. It has also developed a vibrant theoretical-research programme.

The opening ceremony was attended by two university presidents – Si-Chen Lee of the NTU and Jonathan Dorfan of the Okinawa Institute of Science and Technology – and the management of three LeCosPA sister institutions (KIPAC-Stanford, KIPMU-Tokyo, ICRA-Rome), as well as the leaders of the ARA, ANITA and UFFO international collaborations.

Attendees of the First LeCosPA Symposium. (Image credit: Chie-Yu Wang.)

Organized by the director, Pisin Chen of LeCosPA, the symposium featured more than 40 lectures, with Shing-Tung Yau of Harvard University opening the scientific part with a lecture on "Mass and Waves in Gravity", describing the momentum vector in a space–time governed by the Einstein equation. In the closing lecture, Gabriele Veneziano of CERN and Collège de France reviewed achievements and challenges in understanding space, time and matter, before wishing LeCosPA a happy future.

The LeCosPA 2012 lectures are available online at http://lecospa.ntu.edu.tw/LeCosPA2012/program.php.

The meeting coincided with the celebration of the Lantern Festival in Pingxi, a small town outside Taipei. The words on this lantern released by the symposium attendees read: "Wishing that everything goes well for LeCosPA." (Image credit: Benjamin Chong.)

Faces & Places

Anniversary

The Ettore Majorana Foundation and Centre for Scientific Culture celebrates 40 years of QCD

The Ettore Majorana Foundation and Centre for Scientific Culture (EMFCSC) is celebrating its 50th anniversary over the period 2011–2013. Why three years? The EMFCSC started in 1961 when I first discussed with John Bell the problem of creating a bridge between university courses and activities in advanced physics laboratories such as CERN. A year later at CERN, Bell, Patrick Blackett, Victor Weisskopf, Isidor Rabi and I formally established the EMFCSC. The centre's first activity was the School of Subnuclear Physics at Erice in June 1963. This is why the celebrations are occurring over three years.

In 2011 the EMFCSC celebrated the discovery of the negative sign of the β-function and of asymptotic freedom. This year it is celebrating 40 years of QCD and in 2013 it will celebrate spontaneous symmetry breaking (SSB) plus instantons, i.e. the current understanding of the mechanisms that are responsible for the breaking of a symmetry law, both the spontaneous one and the direct one.

The celebrations have their roots in the past 50 years of activities of the Subnuclear Physics School in Erice, which has been involved in the analysis of all crucial steps and achievements in high-energy physics, such as: SU(3) flavour and SU(6) (with SU(2)-spin coupled with SU(3) flavour) dismantled by the "no-go theorem"; the battle between S-matrix and field theory; the universality of the weak forces (beginning with the ε-parameter and the non-existence of the flavour-changing neutral currents, which was solved by the existence of charm); the experimental search for the third lepton in the early 1960s before the discovery of CP-breaking; the birth of electroweak unification and the SSB mechanism; the discovery of the negative sign of the β-function and of asymptotic freedom; the triumph of non-Abelian field theories (QCD and QFD) with all of their consequences (including instantons and the "effective energy" in non-perturbative QCD); the theoretical discovery of supersymmetry (many years after the "no-go theorem").

Now, subnuclear physics is engaged with relativistic quantum string theory and the LHC. But, as Enrico Fermi said: "Without memory neither science nor civilization could exist". This is why the memory of past achievements – such as QCD – has to be as correct as possible.

In 1971, William Bardeen, Harald Fritzsch and Murray Gell-Mann discussed the group SU(3) × SU(3), where the second SU(3)-group was assumed to be an exact symmetry. The quarks were triplets of this group. The associated quantum numbers were called "colours" of the quarks (Bardeen *et al.* 1972). A year later, Fritzsch and Gell-Mann proposed that this exact colour group is a gauge group. The quarks were supposed to be confined by this gauge interaction. The observed baryons and mesons were colour singlets. The confined neutral massless gauge bosons were denoted as "gluons". Gell-Mann and Fritzsch also discussed colour-singlet bound states of the gluons, denoted as glue mesons (Fritzsch and Gell-Mann 1972). Finally, this theory was named "quantum chromodynamics" in 1973 and in the same year Fritzsch, Gell-Mann and Heinrich Leutwyler published further details of the theory (Fritzsch *et al.* 1973).

There was one point that needed to be explained: why, at high-energy, protons do not break into quarks, as we proved experimentally at CERN. Some modification of the non-Abelian gauge theory was needed but asymptotic freedom had still to be discovered. Its origin was in the negative sign of the β-function, which Gerardus 't Hooft mentioned in a discussion session at a conference in Marseilles in 1972. A year later, David Gross, Frank Wilczek and David Politzer announced their discovery of the negative sign of the β-function for a non-Abelian force, which was able to describe the interaction between quarks and gluons, i.e. $SU(3)_{colour}$ with asymptotic freedom.

These papers, to my knowledge, gave rise to QCD, but it had not been easy to reach this point – as the earlier work of Oscar Greenberg and others indicates.

In 1964, using the framework of parastatistics of rank three, Greenberg was able to show that there is no problem with Pauli statistics for the baryons. This has been associated with the three colour charges and hence QCD, but the origin of QCD was different. There is no possibility to have a gauge theory of objects described by parastatistics. Nature does not seem to follow parastatistics. Nevertheless there is a problem: the mathematics needed to describe coloured quarks without coloured hadrons is the same as the mathematics that describes parastatistical quarks without parahadrons. But if parahadrons were real particles, then the mathematics needed to describe paraquarks with parahadrons would be different from that needed to describe coloured quarks with coloured hadrons.

Here comes a crucial problem: do coloured hadrons exist? The answer from Fritzsch, Gell-Mann and Leutwyler is "yes". So, how can they be found if only neutral QCD-colour hadrons are allowed to exist in our world? The answer can come only from the QGCW (quark gluon coloured world) project currently being studied at CERN. The coloured hadrons can, in fact, exist only in the subnuclear world, which can be created in heavy-ion collisions at the LHC. The existence of coloured hadrons in this subnuclear world would be a clear-cut answer to the problem of distinguishing colour and parastatistics. Maybe there is some indirect connection between colour and parastatistics, but it would be confusing rather than helpful.

Another line towards QCD was that of Yoichiro Nambu and Moo-Young Han who discussed in 1965 quarks with integral charges. They introduced a second group, SU(3), so the symmetry group of the quarks became SU(3) × SU(3). This group was strongly broken, and the electric-charge operator of the quarks was a generator of this group. The massive gauge bosons had integral electric charges and were identified with the observed vector mesons, far away from the massless QCD-gluons.

The work of Greenberg, Han and Nambu shows how difficult it was to reach the final goal of QCD.

● *Antonino Zichichi, CERN, EMFCSC – Erice, Enrico Fermi Centre – Rome, INFN and University of Bologna.*

● Further reading

W Bardeen, H Fritzsch and M Gell-Mann 1973 *Proceedings of the Conference on Conformal Symmetry, Frascati 1972*, John Wiley Inc.

H Fritzsch and M Gell-Mann 1972 *Proceedings of the XIV Int. Conference on High Energy Physics, Chicago 1972, Vol. 2*.

H Fritzsch, M Gell-Mann and H Leutwyler 1973 *Phys. Letts.* **47B** 365.

A Zichichi 1999 *Subnuclear Physics – The First Fifty Years*, World Scientific.

Faces & Places

Visits

On 14 February **Nikolai Patrushev**, secretary of the Security Council for the Russian Federation, was welcomed to CERN. He visited the ATLAS underground experimental area, the LHC tunnel and ATLAS Visitor Centre before viewing the *Universe of Particles* exhibition at the Globe of Science and Innovation.

Kassym-Jomart Tokayev, director-general of the United Nations Office at Geneva, centre, visited CERN on 15 February. He toured the LHC tunnel with **Maurizio Bona**, CERN's adviser to the director-general, relations with international organizations, left, and **Frédérick Bordry**, CERN's technology department head. He also visited the ATLAS underground experimental area, as well as the exhibition at the Globe of Science and Innovation.

Vice-president of the Senate of the Parliament of the Czech Republic, **Alena Gajduskova**, right, was welcomed to CERN by **Rolf Heuer**, CERN's director-general, on 14 and 15 February. Her time at CERN included the ATLAS Visitor Centre and underground experimental area, the LHC tunnel, the LHC superconducting-magnet test hall and the ALICE underground experimental area. She also heard a presentation on the LHC Computing Grid Project at CERN's Computer Centre.

On 27 February, **Giulio Terzi di Sant' Agata**, the Italian minister of foreign affairs, came to CERN. During his visit he gave an address to CERN's Italian staff and signed the guest book.

Iveta Radicova, the Slovak Republic's prime minister, came to CERN on 28 February. During her visit she was welcomed by Rolf Heuer, CERN's director-general, Emmanuel Tsesmelis, CERN international relations office, and Karel Safarik, of the ALICE collaboration, who all provided a brief introduction to CERN's activities. She also toured the ALICE underground experimental area and the LHC superconducting magnet test hall.

Faces & Places

New products

Amphenol Aerospace has announced a series of rugged, micro-miniature connectors that provide more power throughput and consistent coupling by incorporating more electrical connections in a compact form. Available in shell sizes from 5 to 23, the new high-density 2M series weighs 72% less and is 52% smaller than standard MIL-DTL-38999 connectors, and are intermateable/intermountable with existing micro-miniature high-density connectors. For details, e-mail scurtis@amphenol-aao.com or visit www.amphenol-aerospace.com/circular_2m.asp.

Elsys Instruments has expanded its family of LAN-controlled transient recorders to include high-speed PCE Express data transfer on its data-acquisition modules. The new modules are high-precision and high-resolution digitizers with features such as advanced trigger modes, continuous data-acquisition mode, single-ended and differential inputs and digital input. They can be housed in Elsys' TraNET FE transient recorders that hold 4–32 single-ended channels, or 2–16 differential channels, in the TraNET EPC frame with 16 slots for a total of 64 channels, or in the TraNET PPC portable computer system with six slots, i.e. 24 channels. For further details, contact Peter Wilhelm, tel +41 56 496 01 55, e-mail peter.wilhelm@elsys.ch or see www.elsys-instruments.com.

Keithley Instruments Inc has introduced the Model 2657A High Power System SourceMeter instrument, with a built-in 3000 V, 180 W source. The precision, high-speed measurement engine built into the Model 2657A enables current measurement resolution of 1 fA, to support the low-leakage requirements of next-generation power semiconductor devices. This model is optimized for high-voltage applications such as testing power semiconductor devices, including diodes, FETs and IGBTs, as well as characterizing newer materials such as gallium nitride and silicon carbide. For more information, visit www.keithley.com.

Magna-Power Electronics has recently announced its new generation of DC power supplies, spanning models from 2 kW to 2000 kW+ that address a range of application requirements. New features include enhancements to controls and calibration procedures for accuracy specifications that are now ± 0.075% of full-scale voltage/current programming and ± 0.2% of full-scale voltage/current monitoring. For further details, contact Adam Pitel, tel +1 908 237 2200 ext. 109, e-mail apitel@magna-power.com or see www.magna-power.com.

Teijin Aramid has introduced Twaron Tape, an improved way of protecting fibreoptic cables. Twaron Tape is an aramid-fibre matrix construction that enables the production of fibreoptic cables with a diameter as small as 1.2 mm. It also provides three to five times better crush resistance compared with currently used aramid-fibre protection. The tape's flexibility enables quicker and more convenient installation and handling of the cables. For more information, contact Peter Coolen, tel +31 652 594 314, e-mail peter.coolen@ketchum.com or visit www.teijinaramid.com.

Transtec has announced new servers and workstations in its range of high-quality and high-performance computing solutions. The systems are based on new Intel Xeon E5 processor technology, code name Sandy Bridge. The computing and data transfer performance of the servers has been improved by up to 118%. They provide the results of processor-intense modelling and analysis applications much faster and have relevant certification such as Windows, RedHat, Solaris, WMware, Microsoft SQL/Exchange and Oracle. For further details, contact Markus Jastroch, tel +49 7071 703 775, fax +49 7071 703 90775 or e-mail markus.jastroch@transtec.de.

Visits

On 24 February **Nuno Crato**, the Portuguese minister for education and science, left, toured the LHC superconducting-magnet test hall accompanied by **Frédérick Bordry**, CERN's technology department head. He also took the opportunity to visit the underground experimental areas of ATLAS and CMS, and heard about the LHC Computing Grid Project before meeting Portuguese scientists working at CERN.

On February 27 **Plodprasop Suraswadi**, minister of science and technology for the Kingdom of Thailand, centre right, visited CERN. He toured the CMS underground experimental area with (from left to right) former CMS collaboration deputy-spokesperson, **Albert De Roeck**, Thai deputy permanent secretary, **Weerapong Pairsuwan**, CERN international relations office adviser for the Kingdom of Thailand, **Emmanuel Tsesmelis**, CMS deputy spokesperson, **Joao Varela**, and secretary to the minister of science and technology, **Kamol Bundaipetch**. His visit included the LHC superconducting-magnet test hall, the ALICE surface exhibit and ALICE underground experimental area.

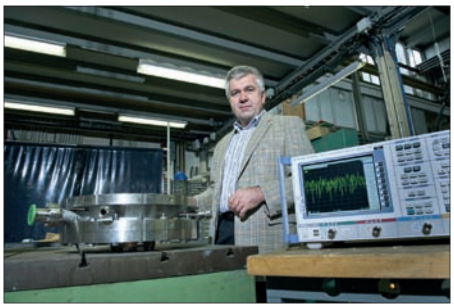
On 29 February **Erato Kozakou-Marcoullis**, the Cypriot minister of foreign affairs, came to CERN for discussions on Cyprus's application for Associate Membership. She is seen here during a tour of the CMS underground experimental area. She also made a visit to the LHC superconducting-magnet test hall.

Awards

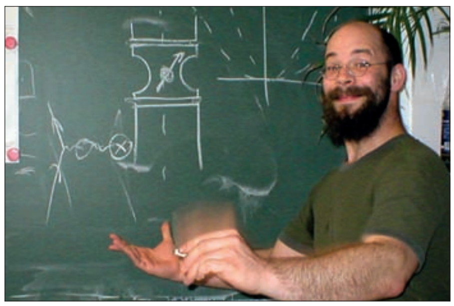
ASACUSA's antihydrogen research attracts grants

Eberhard Widmann, director of the Stefan Meyer Institute for Subatomic Physics of the Austrian Academy of Sciences, has received a European Research Council Advanced Grant for his research on antihydrogen within the ASACUSA collaboration at the Antimatter Decelerator (AD) at CERN. The grant focuses on ASACUSA's primary future direction, the measurement of the ground-state hyperfine structure of antihydrogen. It builds on the collaboration's success one year ago when they made antihydrogen for the first time in their cusp trap (*CERN Courier* March 2011 p17).

Collaboration member Stefan Ulmer, of RIKEN and CERN, has been awarded a RIKEN Initiative Research Unit Grant to continue research on the high-precision measurement of the magnetic moment of the proton and the antiproton. Before joining ASACUSA, Ulmer did his PhD at the universities of Heidelberg and Mainz, where he observed for the first time spin-flips with a single trapped proton. The magnetic moment of the antiproton is currently known with a relative precision of only 10^{-3}. By applying the measuring principle that Ulmer developed for the proton, an improvement of at least a factor of 100 is possible.



Eberhard Widmann with some of the apparatus used in ASACUSA.



Stefan Ulmer explains his observation technique. (Image credit: S W Kreim.)

Becky Parker wins medal for inspirational physics teaching

It was a visit to CERN that sparked an idea for Becky Parker, head of physics at Simon Langton Grammar School in the UK, to raise £60,000 to build a detector. This detector – the Langton Ultimate Cosmic Ray Detector (LUCID) – is just one example of how Parker has enabled her students to join international scientific collaborations. This enthusiasm has led to her winning the first Royal Astronomical Society Patrick Moore Medal in recognition for her outstanding work as a teacher of astronomy.

Since her arrival at the school in 2005, Parker has established, and directs, the Langton Star Centre, a specialist facility with laboratories, classrooms and an astronomical observatory. Her students collaborate with NASA and ESA, as well as with international schools including the Dr Obote College in northern Uganda. When LUCID begins operation later this year, both Ugandan and UK students will be able to analyse the results. Her motivation to innovate and collaborate, coupled with her success in inspiring young people to pursue careers in science, underlie this award of the Patrick Moore Medal.

Becky Parker – "an inspiration". (Image credit: Langton Star Centre.)

Recruitment

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

University of Zurich[UZH]

Faculty of Science

The Faculty of Science invites applications for a

Professorship in Theoretical Physics

in particle physics or adjacent fields. Applications from outstanding candidates from other research areas will also be considered.

The new professor is expected to pursue vigorous research and to contribute to teaching at both undergraduate (English or German) and graduate (English) level. She or he will find a very stimulating environment including major experimental activities in particle and astroparticle physics.

It is anticipated that the position will be filled at the Assistant Professor (tenure track) level, however exceptional candidates at any level will be considered.

Candidates are invited to submit by May 31, 2012 an application package including curriculum vitae, publication list, outline of current and future research interests, teaching philosophy and names and addresses of three potential referees. Documents should be addressed to
Prof. Dr. Michael Hengartner, Dean of the Faculty of Science, University of Zurich, and submitted as a single PDF file at www.mnf.uzh.ch/tp. For further information, please contact Prof. Dr. Thomas Gehrmann at thomas.gehrmann@uzh.ch.

The University of Zurich is an equal opportunity employer. Applications from female candidates are particularly encouraged.

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UNIVERSITY OF Cincinnati

Postdoctoral Fellow Belle and Belle II

The experimental particle physics group seeks a recent Ph.D. physicist to join us as a Postdoctoral Fellow in the development and construction of the "Imaging Time-of-Propagation" (iTOP) particle identification detector for Belle II and exploitation of Belle's tremendous data sample in the Upsilon energy region. Possible analysis topic include CP violation in Beauty and Charm, as well as studies at the Υ(5S) of bottomonia and B_S.

Details on applying may be found at http://homepages.uc.edu/physics/facultyStaff/jobs.html.

We will begin reviewing applications immediately and continue until the position is filled.

The University of Cincinnati is an equal opportunity/affirmative action employer. Women, people of color, people with disabilities and veterans are encouraged to apply.

ÖAW
Austrian Academy of Sciences

HBAR-HFS

The ERC Advanced Grant project

HBAR-HFS – Hyperfine Structure of Antihydrogen

(PI: Prof. E. Widmann)

is to be performed at the Antiproton Decelerator of CERN, Geneva, Switzerland.

We are looking for two highly qualified postdocs interested in studies of fundamental symmetries using antimatter.

Tasks:
- Enhancements of the HFS spectroscopy beamline for the ASACUSA experiment.
- Development of an ultra slow antihydrogen beam for HFS spectroscopy in the AEgIS experiment.

Experience with low-energy precision experiments in atomic or particle physics is required.

Detailed job descriptions can be found at:
www.antihydrogen.at/jobs

Prof. Dr. Eberhard Widmann

Stefan Meyer Institute for Subatomic Physics

Austrian Academy of Sciences
Vienna, Austria

eberhard.widmann@oeaw.ac.at
www.antihydrogen.at

Science & Technology Facilities Council

The Science and Technology Facilities Council will bring strategic leadership and an integrated approach to UK investments in large national and international research facilities, whilst continuing to deliver world-class science, technology and people for the UK. The Council is involved in some of the world's most exciting research projects – like the Diamond Light Source Synchrotron and the Large Hadron Collider – and will develop new areas of science and technology – with your help.

Executive Director, Programmes

Swindon, Wiltshire – Ref:IRC50945

Attractive salary and benefits

Our new Chief Executive is bringing together a new senior management team for the Science and Technology Facilities Council to ensure our continued ability to make a substantial impact on science, technology and the UK economy. We are seeking an Executive Director of Programmes to provide visible leadership and excellence in delivering this vision by guiding and shaping our world-class science and technology programme.

Reporting to the Chief Executive, key responsibilities will be:-

- Visible leadership of the organisation as a Member of the Executive Board, sharing corporate accountability for the delivery of our Vision, Strategy and Delivery Plan;
- Stewardship of the United Kingdom's astronomy, particle physics and nuclear physics disciplines and of accelerator R&D;
- Visionary leadership of our world-class science and technology programme, commissioning a comprehensive programme with our external partners and our national laboratories including thematic programmes, external innovation, public engagement activities, and an education, fellowships and training programme;
- Leadership and oversight of STFC's peer review processes, science advisory structure and science and technology strategy;
- Highly effective management of strategic stakeholder relationships with key universities, the other research councils plus national and international scientific organisations including CERN, ESO, ESRF, ILL and Diamond Light Source to deliver shared strategies and objectives;
- Leadership of a highly committed team of staff in the Programmes Directorate, spread across 3 UK sites and of our observatory sites in Hawaii and La Palma;

Our successful candidate will:-

- Have excellent leadership, team working, influencing and communication skills, and the ability to build highly effective relationships and collaborations;
- Demonstrate significant knowledge and ability at senior management level in areas relating to our science and technology programme as well as a track record in managing people, finance and resources;
- Possess a broad based understanding of STFC's science and technology areas together with familiarity with our science communities and the ability to gain their respect;
- Be able to make a substantial contribution at a strategic level, both corporately and for the Programmes Directorate;
- Be focused on excellence, achievement, innovation and improvement.

For further information about this role, please contact Professor John Womersley by email: John.Womersley@stfc.ac.uk

Applications are handled by the RCUK Shared Services Centre; to apply please visit our job board at https://ext.ssc.rcuk.ac.uk and attach a CV, covering letter and vision statement. Applicants who would like to receive this advert in an alternative format (e.g. large print, Braille, audio or hard copy), or who are unable to apply online should contact us by telephone on 01793 867003, please quote reference number IRC50945.

Closing date for applications: 11 May 2012

Interview dates: 7 & 8 June 2012

www.scitech.ac.uk

POSITIVE ABOUT DISABLED PEOPLE

LA³NET

Open positions within the LA³NET project

Lasers have become increasingly important for the successful operation and continuous optimization of particle accelerators.

Laser-based particle sources are well suited for delivering the highest quality ion and electron beams, laser acceleration has demonstrated unprecedented accelerating gradients and might be an alternative for conventional particle accelerators in the future, and without laser-based beam diagnostics it would not be possible to unravel the characteristics of many complex particle beams. Within LA³NET, laser applications for particle accelerators will be developed within an international network.

The network is currently aiming to recruit a pool of talented, energetic, strongly motivated, early stage researchers with a degree in physics, electrical engineering or a closely related field. Possibilities for enrolling into a PhD program exist. Women are especially encouraged to apply.

Each researcher will benefit from a wide ranging training program that will take advantage of both local and network-wide activities, as well as of schools, conferences, and workshops. Excellent salaries will be offered.

Application deadline:

May 30th 2012

You will find more information about LA³NET, all research projects and application details at:

http://www.liv.ac.uk/la3net

Contact and further detail:

Prof. Dr. Carsten P. Welsch
Associate Director

Cockcroft Institute of Accelerator Science and Technology
University of Liverpool
Department of Physics
L69 7ZE Liverpool, UK
carsten.welsch@quasar-group.org

This project is funded by the European Union under contract PITN-GA-2011-289191

OPEN POSITIONS WITHIN THE OPAC PROJECT

The optimization of the performance of any particle accelerator critically depends on an in-depth understanding of the beam dynamics in the machine and the availability of simulation tools to study and continuously improve all accelerator components.
It also requires a complete set of beam diagnostics methods to monitor all important machine and beam parameters with high precision and a powerful control and data acquisition system.

Within the oPAC project these aspects will be closely linked with the aim to optimize the performance of present and future accelerators that lie at the heart of many research infrastructures.

The network is currently aiming to recruit a pool of talented, energetic, strongly motivated, early stage researchers with a degree in physics, electrical engineering or a closely related field. Possibilities for enrolling into a PhD program exist. Women are especially encouraged to apply.

Deadline for applications:

May 31st 2012

Each researcher will benefit from a wide ranging training program that will take advantage of both local and network-wide activities, as well as of schools, conferences, and workshops. Excellent salaries will be offered. Most positions are for starting in summer 2012. You will find more information about oPAC, all research projects and the application details at:

http://www.liv.ac.uk/opac

Contact and further detail:

Prof. Dr. Carsten P. Welsch
Associate Director
Cockcroft Institute of Accelerator Science and Technology
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L69 7ZE Liverpool, UK
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This project is funded by the European Union under contract PITN-GA-2011-289485

Bookshelf

L'enigma dei raggi cosmici. Le più grandi energie dell' universo

By Alessandro De Angelis
Springer
Paperback: £19.99 €24.44

In telling the story of "the enigma of cosmic rays", physicist and enthusiastic communicator Alessandro De Angelis traces the fascinating adventure of cosmic rays since their discovery a century ago. Today, the exploration of the mysteries of cosmic rays continues with even more powerful tools in a range of energies that extends 20 orders of magnitude.

Cosmic rays have always been puzzling. In the first decade of the 20th century, physicists were seeking a solution to the problem of why gold-leaf electroscopes – instruments that are still common in laboratories in schools today – discharge spontaneously. Many scientists faced this problem, including an Italian, Domenico Pacini, who made some important measurements by immersing his instruments under water at different depths and observing a marked decrease in the discharge rate. Indeed, Pacini was the first to give a clear indication that part of the natural radiation he detected came from the atmosphere and from the cosmos. However, his results were published only in Italian and had no great prominence – although Viktor Hess did mention Pacini several times in his speech when he obtained the Nobel Prize in Physics for the discovery of cosmic rays. Pacini's work is yet another glaring example of a discovery that has not obtained the international recognition it deserves.

The riddles of cosmic rays do not end there. We still do not know for sure where they come from. They are deflected by the interstellar magnetic field so their direction of arrival cannot be connected to their starting point. Above all, we still struggle to understand what mechanism provides them with an energy that can in extreme cases reach the energy of a tennis ball concentrated in a single atomic nucleus. Enrico Fermi proposed a theory for the acceleration of cosmic rays that explains in part what is observed. However, there is still much to understand and we hope that recent and future results in high-energy astrophysics will be able to answer this fundamental question.

What is sure is that cosmic rays bring to the Earth pieces of the far-away universe. Furthermore, their high energy makes them interact with the atmosphere, producing secondary particles – as in powerful particle

accelerators. For this reason, in the first half of the past century cosmic rays revealed the first particle of antimatter – the positron – and many new particles that led to the birth of elementary particle physics before accelerators made by humans turned it into a mature science. Even today, in the LHC era, the study of high-energy cosmic rays and the precision testing of their composition at intermediate energies are active fields of research, with experiments on Earth and in space. In particular the first evidence of neutrino oscillations – and thus of their mass – was observed by studying the secondary neutrinos produced by cosmic rays in the atmosphere.

This book by De Angelis traces the history of the study of cosmic rays in a documented, comprehensive way, often providing details both interesting and little known. It is easily readable and an excellent reference for anyone interested in fundamental physics and contemporary astrophysics.

● *Roberto Battiston, University of Perugia.*

Books received

The Universe: A Challenge to the Mind

By Jacques Vanier
Imperial College Press
Hardback: £74 $120
Paperback: £33 $54

In this book, Jacques Vanier gives a comprehensive picture of the physical laws that appear to regulate the functioning of the universe, from the atomic to the cosmic world. It offers a description of the main fields of physics as applied to the atomic world and the cosmos, to describe how the universe evolved to its present state. This is done without equations, except for a few, although there is a short annexe for readers who wish to see how the principles and laws expressed in words can be visualized in the language of mathematics. The author also occasionally uses two young people placed in various situations to explain aspects of physics through their observations.

An Introduction to String Theory and D-Brane Dynamics: With Problems and Solutions (2nd Edition)

By Richard J Szabo
Imperial College Press
Hardback: £42 $68
E-book: $88

Originally published in 2004, this book provides a quick introduction to the rudiments of perturbative string theory and a detailed introduction to the more current topic of D-brane dynamics. The presentation is pedagogical, with much of the technical detail streamlined. The rapid but coherent introduction to the subject is perhaps what distinguishes this book from other string-theory or D-brane books. This second edition includes an additional appendix with solutions to the exercises, thus expanding the technical material and making the book more appealing for use in lecture courses. The material is based on mini-courses in theoretical high-energy physics delivered by the author at various summer schools, so its level has been appropriately tested.

Adventures in Cosmology

By David Goodstein (eds.)
World Scientific
Hardback: £57 $86
E-book: $112

This up-to-date collection of review articles offers a general introduction to cosmology by experts in various fields. It starts with "Galaxy Formation from Start to Finish" and ends with "The First Supermassive Black Holes in the Universe", exploring in between the grand themes of galaxies, the early universe, the expansion of the universe, neutrino masses, dark matter and dark energy. Together the chapters provide a detailed view of what is known about the universe as well as what remains unknown. Students, researchers and academics interested in cosmology should find this book useful.

Viewpoint

It's good to blog

Norbert Holtkamp extols the virtues of blogging as a way to encourage dialogue on important issues.

It all started a year ago over dinner with a good bottle of wine in front of us. Steve Gourlay of Lawrence Berkeley National Laboratory, Stuart Henderson of Fermilab and myself talked about the future of accelerator R&D in the US and what could be done to promote it.

We had no idea that an opportunity would present itself so quickly, that it would require such fast action or that blogging would be a central part of carrying out our mission.

A 2009 symposium called "Accelerators for America's Future" had laid out some of the issues and obstacles, and in September 2011 the US Senate Committee on Appropriations asked the US Department of Energy (DOE) to submit a strategic plan for accelerator R&D by June 2012.

The DOE asked me to lead a task force to develop ideas about this important matter: what should the DOE do, over the next 10 years, to streamline the transfer of accelerator R&D so that its benefits could spread out into the larger society?

We were ready to go by October. The task force would have until 1 February 2012 – just four months – to identify research opportunities targeted to applications, estimate their costs and outline the possible impediments to carrying out such a plan. Based on this information, DOE officials would draw up their strategic plan in time for the congressional deadline.

It was a huge job. The 15 members of the task force, who hailed from six DOE national laboratories, industry, universities, DOE headquarters and the National Science Foundation, would need to gather facts, opinions and ideas from a range of people with a stake in this issue – from basic researchers at the national laboratories to university and industry scientists, entrepreneurs, inventors, regulators, industry leaders, defence agencies and owners of

Norbert Holtkamp. (Image credit: SLAC.)

businesses both small and large.

We quickly held a workshop in Washington, DC, followed by others at the Argonne and Lawrence Berkeley National Laboratories, where we presented some of the major ideas. And to gather the most feedback from the most people in the shortest amount of time, I did something that I like to do: I started a blog.

Now, anyone who has been around high-energy physics for a while knows that blogs and other forms of cutting-edge social media are nothing new. We particle physicists, after all, started the World Wide Web as a way to share our ideas, and what became known as the arXiv to distribute preprints of our research results. Many physicists are avid bloggers, and a number of laboratories – from CERN to Fermilab and KEK – operate blogs of their own; you can see a sample of these blogs at www.quantumdiaries.org. But it's not as usual to incorporate a blog into the work of a task force – although, for the life of me, I don't know why you would not want to do it.

One of the first things that I did when I came to SLAC two years ago was to start a blog aimed at fostering communication among people in the Accelerator Directorate. A blog is a great way to talk about topics that are burning under our fingernails – although sometimes one needs to overcome a certain amount of cultural resistance to get people talking freely. Instead of filling various inboxes with chains of e-mails, "electronic blackboards" are easy to read and easy to post on, and they even have the added convenience of notifying you when a new post goes up.

In the good old days you could have everyone come to one place and have a panel discussion or an all-hands meeting – an easy, free-flowing exchange of ideas. A blog can be just such a thing: open and inviting.

Our task force invited literally thousands of people to comment on the issues at hand. What can be done to move the fruits of basic accelerator research and development more quickly into medicine, energy development, environmental cleanup, industry, defence and national security? What good could flow from such a movement? What are the barriers – especially between the national laboratories, where most of this research is done, and the industries that could develop it into products – and how can they be overcome?

Not everyone answered, but many did. More than half of the responses that we got came in through the blog rather than as e-mail messages. Within a couple of days it became clear just from the people who blogged that the medical community is starving for facilities and infrastructure to develop radiation therapy further, mainly with heavy-ion beams. The people talked to us and among themselves. So it's no surprise that the report we write will describe opportunities for the DOE to make its infrastructure available for researchers who want to pursue this line of work.

Others talked about the difficulties that they had in working with government agencies or national laboratories and how this could be made easier – a worthwhile read during an easy afternoon.

So, blogging is not just fun; it's a great way to gather information and encourage dialogue. Once our task force finalizes its report, the site will be up for a while, and then, when the next issue arises, the blackboard will get cleaned and I will start a new one.

● To see the blog, go to https://slacportal.slac.stanford.edu/sites/ad_public/committees/Acc_RandD_TF_Blog/default.aspx.

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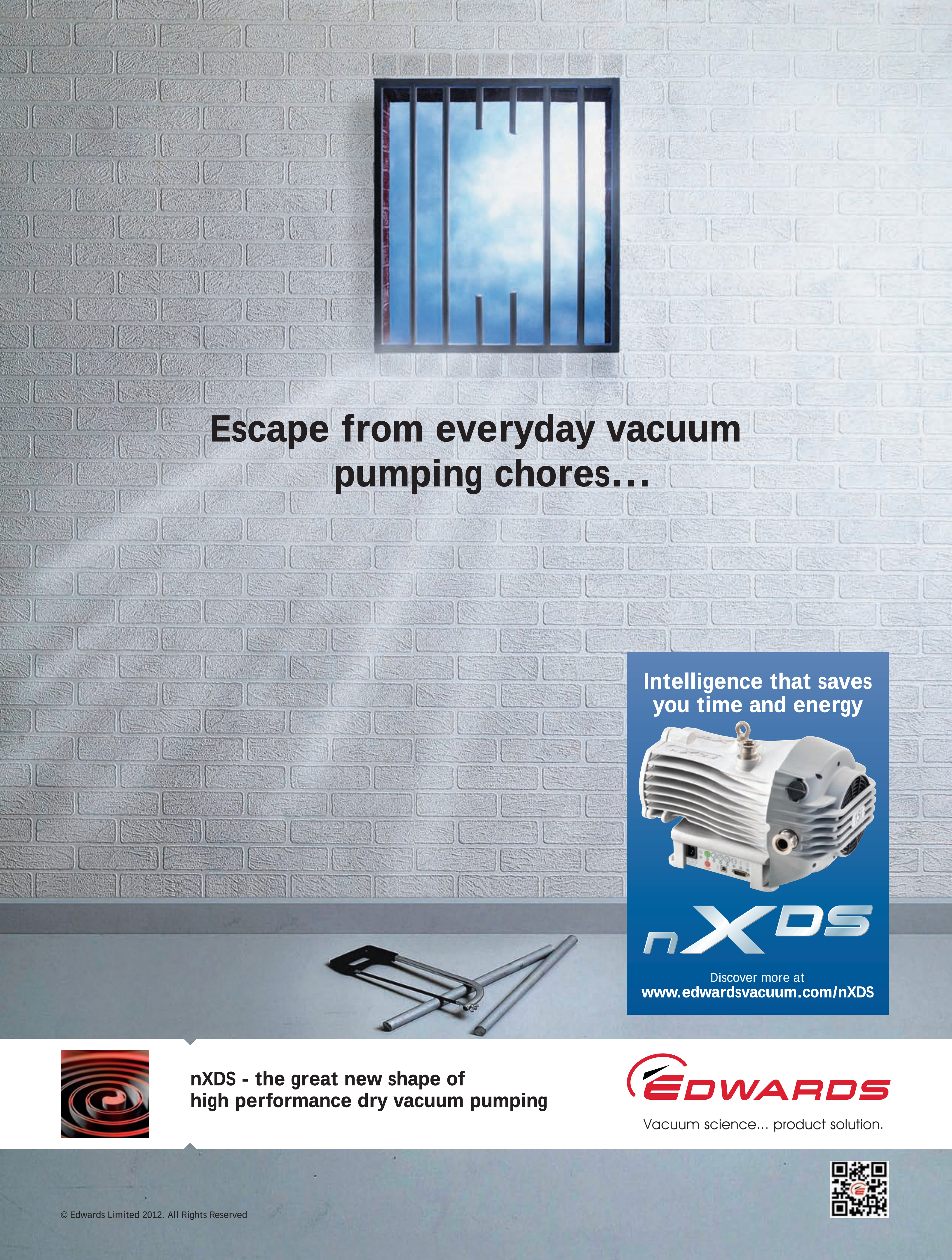
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