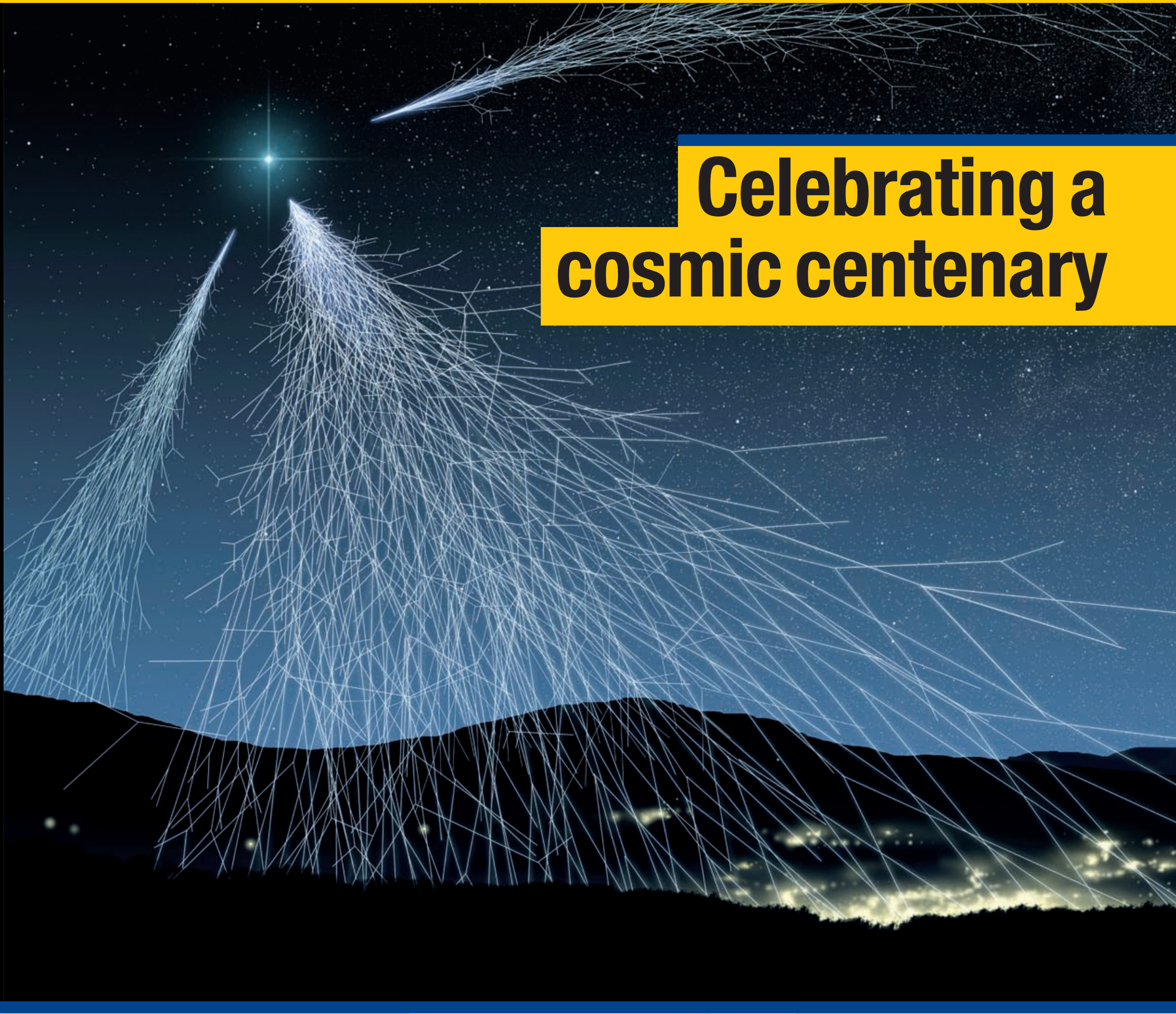
INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERNCOURIER

VOLUME 52 NUMBER 6 JULY/AUGUST 2012



Celebrating a cosmic centenary

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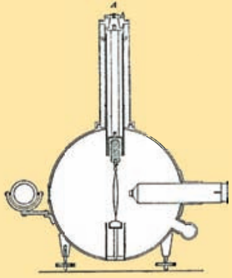
The early days of cosmic-ray research **p15**



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

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

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

Publisher Susan Curtis
Production editor Jesse Karjalainen
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or +44 (0)117 930 1164 (for recruitment advertising);
E-mail: sales@cerncourier.com; fax +44 (0)117 930 1178

General distribution Courrier Adressage, CERN, 1211 Geneva 23, Switzerland
E-mail: courrier-adressage@cern.ch
In certain countries, to request copies or to make address changes, contact:
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PO Box 918, Beijing 100049, People's Republic of China
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UK Mark Wells, Science and Technology Facilities Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1SZ
E-mail: mark.wells@stfc.ac.uk
US/Canada Published by Cern Courier, 6N246 Willow Drive,
St Charles, IL 60175, US. Periodical postage paid in St Charles, IL, US
Fax 630 377 1569. E-mail: creative_mailing@att.net
POSTMASTER: send address changes to: Creative Mailing Services, PO Box 1147,
St Charles, IL 60174, US

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

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

IOP Publishing

CERNCOURIER

VOLUME 52 NUMBER 6 JULY/AUGUST 2012

On the cover: An artist's impression of a cosmic-ray shower created when a high-energy primary interacts in the Earth's atmosphere. (Image credit L Bret/Novapix/ASPERA.)


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News

LHC NEWS

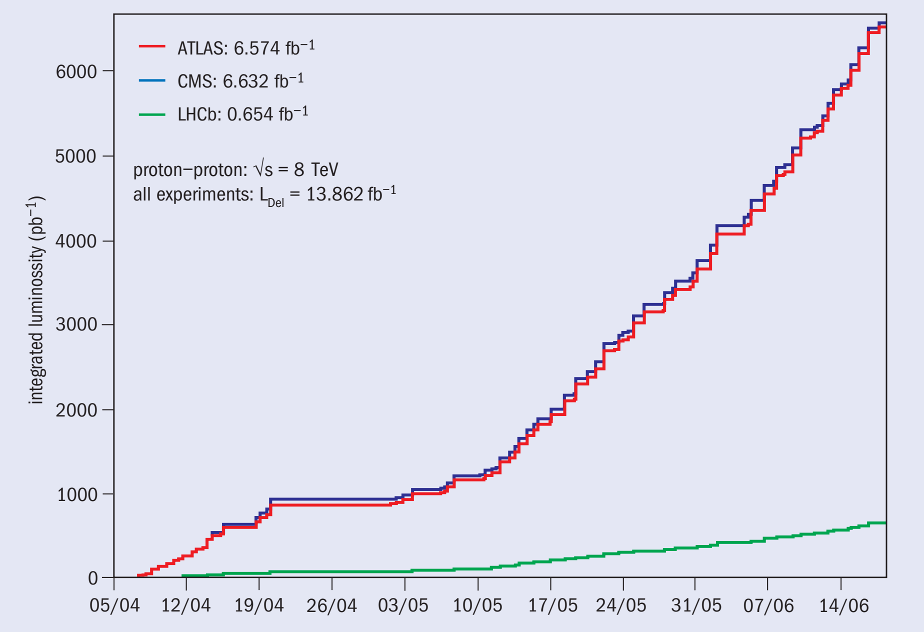
LHC delivers for the summer conferences

With more luminosity delivered by the LHC between April and June 2012 than in the whole of 2011, the experiments had just what the collaborations wanted: as much data as possible before the summer conferences. By the time that a six-day period of machine development began on 18 June, the integrated luminosity for 2012 had reached about 6.6 fb^{-1}, compared with around 5.6 fb^{-1} delivered in 2011.

The LHC's performance over the preceding week had become so efficient that the injection kicker magnets – which heat up while beams continue to pass through them as they circulate – did not have time to cool down between fills. The kickers lose their magnetic properties when the ferrites at their centres become too hot, so on some occasions a few hours of cool-down time had to be included before beam for the next fill could be injected.

As the time constants for warming up and cooling down are both of the order of many hours, the temperature of the magnets turns out to provide a good indicator of the LHC's running efficiency. The record for luminosity production of more than 1.3 fb^{-1} in a single week corresponds well with the highest measured kicker-magnet temperature of 70° C. A programme is now under way to reduce further the beam impedance of the injection kickers, which should substantially reduce the heating effect in future.

Routine operation of the LHC for physics is set to continue over the summer, with the machine operating with 1380 proton bunches in each beam – the maximum value for this year – and around 1.5×10^{11} protons a bunch. The higher beam energy of 4 TeV (compared with 3.5 TeV in 2011) and the higher number of collisions are expected to enhance the machine's discovery potential considerably, opening new possibilities in the searches for new and heavier particles.



The steady rise in integrated luminosity bodes well for physics at the LHC.

Stop press: Higgs update

A seminar at CERN presented highly anticipated news on the search for the Higgs boson at the LHC as this edition of the *CERN Courier* was going to press. The September edition will contain a full report on the significance of the latest results from ATLAS and CMS.

100 years of cosmic rays

On 7 August 1912, Victor Hess took a now famous balloon flight in which he observed a "clearly perceptible rise in radiation with increasing height" and concluded that "radiation of very high penetrating power enters our atmosphere from above".

This issue of the *CERN Courier* marks this discovery of cosmic rays with a look at cosmic-ray research in the past as well as at its future directions.

The experiments – and the results – have always been challenging, as a look at those before Hess shows (p15). Nevertheless, they led to new techniques, such as the detection of Cherenkov radiation produced in the atmosphere (p34), now fundamental for high-energy gamma-ray astronomy (p28). Large-scale experiments detect the highest-energy cosmic rays (p22) and have their sights on cosmic neutrinos (p31) in a quest to discover the cosmic accelerators that surpass the highest energies attained in the laboratory. Meanwhile, the LHC contributes with useful data (p19) and some intriguing results (p26).

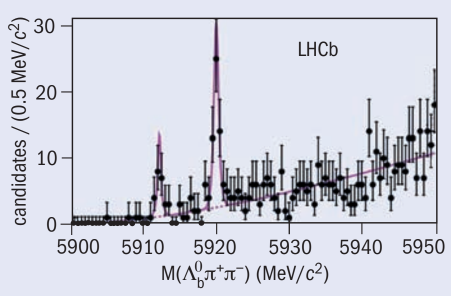
Sommaire en français

LHC EXPERIMENTS

A surprising asymmetry and more excited states

The flavour-changing neutral-current decays B → K(K*)μ$^+$μ$^-$ provide important channels in searching for new physics, as they are highly suppressed in the Standard Model. The predictions in these channels suffer from relatively large theoretical uncertainties but these can be overcome by measuring asymmetries in which the uncertainties cancel. One example is the isospin asymmetry A_I, which compares the decays: $B^0 \rightarrow K^0(K^{*0})\mu^+\mu^-$ and $B^+ \rightarrow K^+(K^{*+})\mu^+\mu^-$. In the Standard Model, A_I is predicted to be small, around –1%, for the decays to the excited K*, and while there is no precise prediction for the decays to the K, a similar value is expected.

LHCb has measured A_I for these decays as a function of the dimuon mass (q^2), using data corresponding to an integrated luminosity of 1.0 fb^{-1}, with a surprising result. While the measurements for $B \rightarrow K^*\mu^+\mu^-$ are consistent with the prediction of negligible isospin asymmetry, the value for $B \rightarrow K\mu^+\mu^-$ is non zero. In particular, in the two q^2 bins below 4.3 GeV/c^2 and in the highest bin above 16 GeV/c^2 the isospin asymmetry is negative in the $B \rightarrow K\mu^+\mu^-$ channel. These q^2 regions are furthest from the charmonium regions and cleanly predicted theoretically. The measured asymmetry is dominated by the deficit observed in $B^0 \rightarrow K^0\mu^+\mu^-$. Integrated over the dimuon mass range, the result for A_I deviates from zero by more than 4σ.



Enhancements corresponding to Λ_b excited states with masses of 5912 and 5920 MeV.

These results were obtained with the full data sample for 2011, which should more than double by the end of 2012. In the meantime, theorists will analyse this puzzling result to establish whether this effect can be accommodated in the framework of the Standard Model – or whether its explanation requires new physics.

In a different study, LHCb observed two Λ_b excited states for the first time, as predicted within the context of the quark model. The excited states (see figure) were reconstructed in three steps. First, Λ_c^+ particles were reconstructed through their decay $\Lambda_c^+ \rightarrow pK^-\pi^+$; then the Λ_c particles were combined with π^- to look for Λ_b particles; finally the Λ_b particles were combined with $\pi^+\pi^-$ pairs. In this way the team found about 16 $\Lambda_b(5912) \rightarrow \Lambda_b\pi^+\pi^-$ decays (4.9σ significance) and about 50 $\Lambda_b(5920) \rightarrow \Lambda_b\pi^+\pi^-$ decays (10.1σ) among some 6×10^{13} proton–proton collisions detected during 2011.

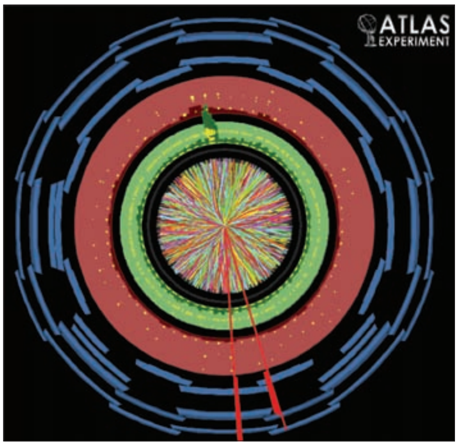
- **Further reading**

LHCb collaboration 2012 arXiv:1205.3422 [hep-ex]
LHCb collaboration 2012 arXiv:1205.3452 [hep-ex]

Seeing bosons in heavy-ion collisions

Studies of heavy-ion collisions at the LHC are challenging and refining ideas on how to probe QCD – the theory of the strong interaction – at high temperature and density. From precision analyses of particle "flow" that clearly distinguish pre-collision effects from post-collision effects, to the observation of jet quenching, the ATLAS collaboration is releasing many new results. Several of these observations are surprising and unexpected, such as the occurrence of strong jet quenching with almost no jet broadening; and complete explanations are currently lacking. One new set of results, however, spectacularly confirms expectations: photons and the heavy W and Z bosons are unaffected by the hot dense QCD medium.

Direct measurements of energetic photon production released by the collaboration recently show that the number of photons produced is just as would be expected from ordinary proton–proton collisions when extrapolated to the multiple collisions within the heavy-ion interactions. This effect is truly independent of the "centrality" of the collision, the parameter that distinguishes head-on (central) collisions from grazing collisions. Similar observations have been made at much lower energies. However, by taking advantage not only of the LHC beam energy but also the capacity of the ATLAS calorimeters to make precision measurements and reject background events, this new study extends the results to energies 10 times higher for central collisions.



A candidate $Z \rightarrow \mu^+\mu^-$ (red lines) in a heavy-ion collision in ATLAS, in association with an extra jet (green calorimeter deposit).

ATLAS has also released new measurements of Z-boson production, which show that, like photons, Zs are unaffected by the heavy-ion environment; the number produced is exactly what would be expected from "binary scaling", i.e. scaling up to the number of nucleon collisions. The Z bosons were measured through their decays both to two muons, using the ATLAS muon spectrometer, and to electron–positron pairs, with the ATLAS calorimeters. The observation of binary scaling not only shows that the Zs are unaffected by the medium, but it reveals that the electrons, positrons and muons produced are also unaffected, as expected.

These results open up a long dreamt of possibility in this field: the study of jet-boson correlations. Because the bosons are unaffected by the hot dense medium, they can be used as a "control" to study precisely the suppression of jets. ATLAS is already making prototype measurements of this kind and high precision should be attainable in future LHC runs.

- For more information, see https://twiki.cern.ch/twiki/bin/view/AtlasPublic.

NEUTRINOS

EXO, MINOS and OPERA reveal new results

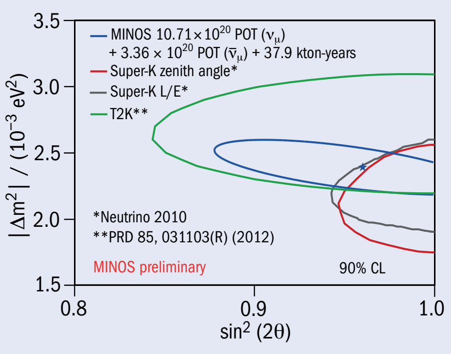
The first results from the Enriched Xenon Observatory 200 (EXO-200) on the search for neutrinoless double beta decay show no evidence for this hypothesised process, which would shed new light on the nature of the neutrino. Located in the US Department of Energy's Waste Isolation Pilot Plant in New Mexico, EXO-200 is a large beta-decay detector. In 2011 it was the first to measure two-neutrino double beta decay in ^{136}Xe; now it has set a lower limit for neutrinoless double beta decay for the same isotope.

Double beta decay, first observed in 1986, occurs when a nucleus is energetically unable to decay via single beta decay, but can instead lose energy through the conversion of two neutrons to protons, with the emission of two electrons and two antineutrinos. The related process without the emission of antineutrinos is theoretically possible but only if the neutrino is a "Majorana" particle, i.e. it is its own antiparticle.

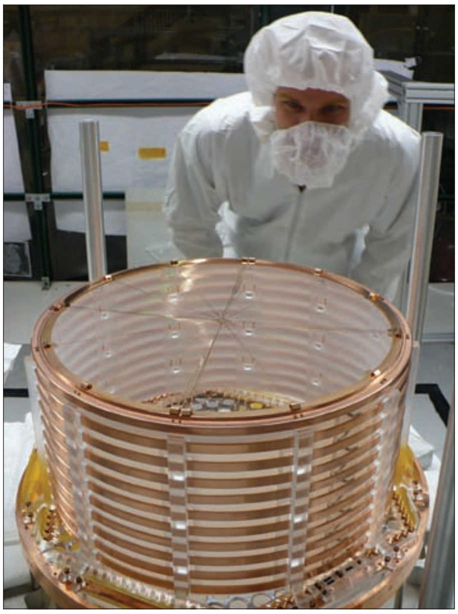
EXO-200 uses 200 kg of ^{136}Xe to search for double beta decay. Xenon can be easily purified and reused, and it can be enriched in the ^{136}Xe isotope using Russian centrifuges, which makes processing large quantities feasible. It also has a decay energy – Q-value – of 2.48 MeV, high enough to be above many of the uranium emission lines. Using ^{136}Xe as a scintillator gives excellent energy resolution through the collection both of ionization electrons and of scintillation light. Finally, using xenon allows for complete background elimination through tagging of the daughter barium ion. This tagging, combined with the detector's location more than 650 m underground and the use of materials selected and screened for radiopurity, ensures that other traces of radioactivity and cosmic radiation are eliminated or kept to a minimum. The latest results reflect this low background activity and high sensitivity – as only one event was recorded in the region where neutrinoless double beta decay was expected.

In the latest result, no signal for neutrinoless double beta decay was observed for an exposure of 32.5 kg/y, with a background of about 1.5×10^{-3} kg^{-1}y^{-1}keV^{-1}. This sets a lower limit on the half-life of neutrinoless double beta decay in ^{136}Xe to greater than 1.6×10^{25} y, corresponding to effective Majorana masses of less than 140–380 meV, depending on details of the calculation (Auger *et al.* 2012).

The EXO collaboration announced the results at Neutrino 2012, the 25th International Conference on Neutrino Physics and Astrophysics, held in Kyoto, on 3–9 June. This dedicated conference for the neutrino community provided the occasion for many neutrino experiments to publicize their latest results. In the case of the MINOS collaboration, these included the final results from the first phase of the experiment, which studies oscillations between neutrino types.



Graph showing the parameters for muon-neutrino mixing, with the latest values from MINOS compared with measurements from other experiments. The latest MINOS results provide a region of allowed values for the mixing parameters, with the blue star representing the set of parameters preferred by the MINOS data, specifically $\Delta m^2 = 2.39\times10^{-3}$ eV^2 and a value for $\sin^2 2\theta = 0.96$. This result uses all neutrino beam and antineutrino beam data and also includes data from atmospheric neutrinos collected at the MINOS detector.



One half of the EXO time projection chamber in a clean room during construction. (Image credit: EXO collaboration.)

In 2010 the MINOS collaboration caused a stir when it announced the observation of a surprising difference between neutrinos and antineutrinos. Measurements of a key parameter used in the study of oscillations – Δm^2, the difference in the squares of the masses of two oscillating types – gave different values for neutrinos and antineutrinos. In 2011, additional statistics brought the values closer together and, with twice as much antineutrino data collected since then, the gap has now closed. From a total exposure of 2.95×10^{20} protons on target, a value was found for muon antineutrinos of $\Delta\bar{m}^2 = 2.62{+0.31}{-0.28}$(stat.)±0.09(syst.) and the antineutrino "atmospheric" mixing angle was constrained with $\sin^2 2\theta$ greater than 0.75 at 90% confidence level (Adamson *et al*, 2012). These values are in agreement with those measured for muon neutrinos.

Since its debut in 2006, the OPERA experiment in the Gran Sasso National Laboratory has been searching for neutrino oscillations in which muon-neutrinos transform into τ-neutrinos as they travel the 730 km of rock between CERN, where they originate, and the laboratory in Italy. At the conference, the OPERA collaboration announced the observation of their second τ-neutrino, after the first observation two years ago (*CERN Courier* July/August 2010 p5). This new event is an important step towards the accomplishment of the final goal of the experiment.

Results on the time of flight of neutrinos from CERN to the Gran Sasso were also presented by CERN's director for research and scientific computing, Sergio Bertolucci, on behalf of four experiments. All four – Borexino, ICARUS, LVD and OPERA – measure a neutrino time of flight that is consistent with the speed of light. The indications are that a measurement by OPERA announced last September can be attributed to a faulty element of the experiment's fibre-optic timing system (*CERN Courier* November 2011 p6).

● Further reading

M Auger *et al.* EXO collaboration 2012 arXiv:1205.5608v1 [hep-ex].
P Adamson *et al.* MINOS collaboration 2012 arXiv:1202.2772v1 [hep-ex].

IUPAC

Elements 114 and 116 receive official names

IUPAC has officially approved the names “flerovium” (Fl) for the element with atomic number 114 and “livermorium” (Lv), for the one with atomic number 116. The names were proposed by the collaboration from the Joint Institute for Nuclear Research (JINR), Dubna, and the Lawrence Livermore National Laboratory in California, led by JINR’s Yuri Oganessian. Scientists from the two laboratories share the priority for the discovery of these new elements at the facilities in Dubna.

The name flerovium is in honour of the Flerov Laboratory of Nuclear Reactions, where these superheavy elements were synthesized. Georgy Flerov (1913–1990) was a pioneer in heavy-ion physics and founder of the JINR Laboratory of Nuclear Reactions in 1957, which has borne his name since 1991. Flerov is also known for his fundamental work in fields of physics that resulted in the discovery of new phenomena in properties and interactions of atomic nuclei.

The name livermorium honours the Lawrence Livermore National Laboratory. A group of researchers from Livermore took part in the work carried out in Dubna on the synthesis of superheavy elements, including element 116. Over the years, researchers at the laboratory have been involved in many areas of nuclear science and investigation of chemical properties of the heaviest elements.

The discoverers of flerovium and livermorium have submitted their claims for the discovery of further heavy elements, with atomic numbers 113, 115, 117 and 118 to the Joint Working Party of independent experts drawn from the International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Pure and Applied Physics.

- **Further reading**

The recommendations are published in the July issue of the IUPAC journal *Pure and Applied Chemistry*, which is available online: 2012 *Pure Appl. Chem.* **no. 7** 84 (doi: 10.1351/PAC-REC-11-12-03).

HEAVY IONS

Lead collisions in the LHC top the bill in Cagliari

Hard Probes 2012 – the 5th International Conference on Hard and Electromagnetic Probes of Nuclear Collisions – took place in Cagliari on 27 May – 1 June. The most important topical meeting to focus on the study of hard processes in ultra-relativistic heavy-ion collisions, this was the first time that the LHC collaborations presented their results based on lead–lead data. The main focus was undoubtedly on the wealth of new high-quality results from ALICE, ATLAS and CMS, complemented with significant contributions from the PHENIX and STAR experiments at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven.

Quoting from the inspired opening talk given by Berndt Mueller of Duke University, the hard probes “manifesto” can be summarized as follows: hard probes are essential to resolve and study a medium of deconfined quarks and gluons at short spatial scales, and they have to be developed into as precise a tool as possible. This is accomplished by the study of the production and the propagation in the deconfined medium of heavy quarks, particles with high momentum transfer (p_T), jets and quarkonia.

Jet quenching can be addressed by studying the suppression of leading hadrons in nuclear collisions with respect to the proton–proton case. The ALICE and CMS collaborations reported results on the production of open charm and beauty, and results were also presented from the STAR experiment. An important aspect of parton energy-loss in the medium is its mass dependence: the energy loss is expected to be strongest for light hadrons and smaller for heavy quarks. The LHC data shown at the conference are suggestive of such hierarchy, although more statistics are still needed to reach a firm conclusion.

In addition, the high-precision LHC data on light charged hadrons are significantly expanding the kinematic reach. This is fundamental to discriminating among theoretical models, which have been tuned at the lower energy of RHIC.

At the LHC, full reconstruction of high-energy jets has become possible for the first time, allowing ATLAS and CMS to present high-statistics results on jet–jet correlations. The emerging picture is consistent with one in which partons lose a large fraction of their energy while traversing the hot QCD medium – before fragmenting essentially in vacuum. First results on γ-jet correlations were also presented by the CMS and PHENIX collaborations; these allow the tagging of quark jets and give a better estimation of the initial parton energy. During the conference, an intense debate developed on how to exploit fully the information provided by full jet reconstruction.

Quarkonia suppression was another of the striking observables, for which results from LHC had been eagerly awaited. CMS presented the first exciting precision results on the suppression of the Υ states. These reveal a clear indication of a much larger suppression for more weakly bound $\Upsilon(2S)$ and $\Upsilon(3S)$ with respect to the strongly bound $\Upsilon(1S)$ states, in accordance with the predictions for the observation of colour screening. The ALICE collaboration presented new data on the rapidity and p_T dependence of J/ψ suppression. The results show that, despite the higher initial temperatures reached at LHC, the size of the suppression remains significantly smaller than at RHIC. This is an intriguing hint that a regeneration mechanism from the large number of charm quarks present in the deconfined medium may take place at LHC energies.

Part of the conference was devoted to the study of initial-state phenomena. In particular, at high energy peculiar features related to the saturation of the gluon

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

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

phase-space should emerge, leading to a state called "colour glass condensate". A discussion took place on the how the existence of this state could be proved or disproved at LHC. The study of initial-state phenomena also came under debate because of its importance in disentangling the effects of cold nuclear matter from genuine final-state effects in hot matter.

With the advent of high-precision data, theory is being increasingly challenged, since the understanding of the bulk properties of the medium produced in heavy-ion collisions is rapidly advancing. As several speakers discussed, significant advances are being made both in the understanding of the parton energy-loss mechanism and in the quarkonia production, for which a quantitative picture is emerging.

Still, as CERN's Jürgen Schukraft pointed out in his summary talk, there is a need for measurements of even higher precision, as well as a wish list for new measurements: for example, in the heavy-flavour sector, lowering the p_T reach to measure the total charm cross-section; and reconstructing charmed and beauty baryons to gain further insight into thermalization of the medium.

On a shorter time scale, the next crucial step is the measurement of effects in cold nuclear matter, which will be possible in the forthcoming proton–nucleus run at the LHC. Based on the experience from the past lower energy measurements, new surprises might be just behind the corner.

The conference was preceded by introductory student lectures covering aspects of quarkonia production and jet quenching. About 40 students were supported by the organization, thanks to generous contributions by several international laboratories (CERN, EMMI, INFN) and, in particular, by the University of Cagliari and by the government of Sardinia. The conference was broadcast to a wider audience worldwide as a webcast.

- For more information, see the conference website www.ca.infn.it/hp12/.

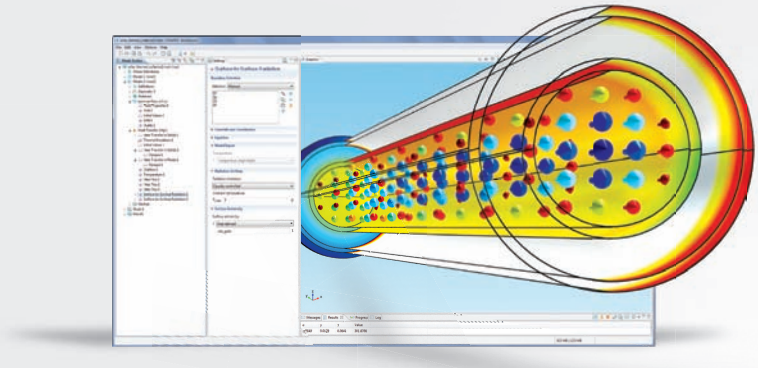
BEPCII

One billion J/ψ events in Beijing

In a 40-day run ending on 22 May, the Institute of High-Energy Physics in China accumulated a total of 1.3 billion J/ψ events at the upgraded Beijing Electron Positron Collider (BEPCII) and Beijing Spectrometer (BESIII).

In a two-year run from 1999 until 2001, the earlier incarnations of BEPC and BESII had accumulated a highly impressive 58 million J/ψs (*CERN Courier* December 2001 p6). By analysing these and 220 million events at BESIII, important results such as the discovery of X(1835) have already been produced. Now, thanks to the upgrades, data-acquisition efficiency is 120 times higher, and as many as 40 million J/ψs were being collected daily towards the end of the latest run.

BEPCII is a two-ring electron–positron collider with beam energy of 1.89 GeV (*CERN Courier* March 2006 p23). With a design luminosity of $1 \times 10^{33}\,\mathrm{cm^{-2}s^{-1}}$, it reached a peak of $2.93 \times 10^{32}\,\mathrm{cm^{-2}s^{-1}}$ in the latest run, 59 times higher than that of its predecessor, BEPC.



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Alan Jackson, former Technical Director of the Project (ASP)

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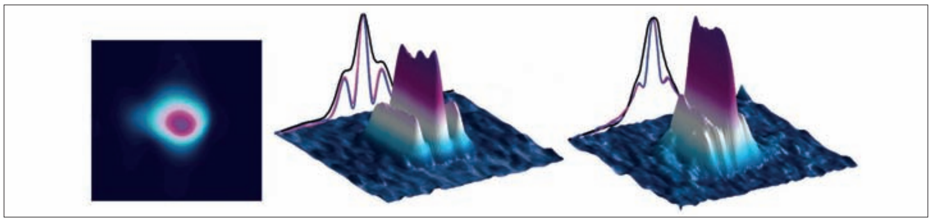
COMPILED BY JOHN SWAIN, NORTHEASTERN UNIVERSITY

An X-ray laser for the table top



The X-ray beam profile generated in helium, left, and diffraction patterns formed by illuminating two 5-μm slits, separated by 10 μm, with X-rays generated in neon, centre, and helium, right, spanning 7.7–43Å and 14–43Å, respectively.

Tenio Popmintchev and colleagues at JILA in Boulder have reported the first table-top X-ray laser. The team drives pressurized helium gas with an infrared laser, producing a strong electric field that pulls electrons off the helium and energizes them. The electrons release this extra energy as radiation (at shorter wavelengths) when they smash back into the helium atoms – in close analogy with how standard Röntgen X-ray tubes work, but in this case coherently.

The technique involves high-harmonic generation where frequency upconversions of more than a factor of 5000 greatly exceed typical high factors of around 100. The result is a bright continuum in which the photons produced have energies that range from extreme UV to 1.6 keV. They also come in brief pulses – around 2.5×10^{-18} s is possible. This is shorter than from traditional sources but the intensity is also lower. The system consumes only about 1 W and provides some 10^5 photons per shot. Nevertheless, the simplicity and low cost make this an attractive alternative to synchrotrons or free-electron lasers for applications in time-resolved nanoscale chemistry.

● **Further reading**

T Popmintchev *et al.* 2012 *Science* **336** 1287.

The shape of stalactites

Anyone who has seen a stalactite or stalagmite will have noticed the presence of crenulations, or ripples along the surface. Carlo Camporeale and Luca Ridolfi of the Politecnico di Torino now have an explanation of where they come from. The researchers have shown that coupling the fluid dynamics of falling films of liquid with the geochemistry that governs how minerals precipitate onto these structures, or how water dissolves them, produces universal shapes that match well with observations down to the wavelengths of the crenulations. In addition to its intrinsic interest, the work makes it possible to determine past film-flow rates from measurements on stalactites, which can be used for palaeoclimate analyses.

● **Further reading**

C Camporeale and L Ridolfi 2012 *Phys. Rev. Lett.* **108** 238501.

Gamma-ray optics

The difference between the index of refraction of a material and 1 can be written as the sum of real and imaginary parts, describing refraction and absorption. While making measurements of the refractive index of silicon in the region 0.18–2 MeV using gamma rays from an in-pile target at the neutron high-flux reactor at Institut Laue-Langevin in Grenoble, D Habs of Ludwig Maximilians University in Munich and colleagues have found that the real part changes sign at around 0.7 MeV and is much larger than expected. The result can be understood in terms of Delbrück scattering and virtual-pair creation in the large nuclear electric field. Extrapolation to atoms of higher Z, such as gold, suggests that the real part could be as large as 10^{-5} – big enough to open a new field of gamma-ray optics based on refraction.

● **Further reading**

D Habs *et al.* 2012 *Phys. Rev. Lett.* **108** 184802.

Quantum information stored for 3 minutes

Two recent results put nuclear spins as front-runners to store quantum information. M Steger of Simon Fraser University and colleagues stored spins on an ensemble of dilute ^{31}P nuclei in ultrapure ^{28}Si using a combination of hyperfine-resolved optical transitions, Auger photoionization and nuclear magnetic resonance and were able to store quantum information for 180 s. The ultrapure silicon acts as an effective "vacuum" for the data, insulating it from decoherence.

In work published in the same issue of *Science*, P C Maurer of Harvard University and colleagues stored qubits on a single ^{13}C nuclear spin near a nitrogen-vacancy colour centre in isotopically pure diamond. This gave coherence lifetimes of more than 1 s at room temperature and the team suggests it could be extended to 1.5 days. Long-lived quantum information could revolutionize information security by providing intrinsically unforgeable and non-copyable forms of data.

● **Further reading**

M Steger *et al.* 2012 *Science* **336** 1280.
P C Maurer *et al.* ibid. 1283.

Majorana quasiparticles

Majorana fermions – should they exist – would be their own antiparticles, much as the photon is. While the jury is still out on whether or not neutrinos are Majorana particles, V Mourik of the Kavli Institute of Nanoscience at Delft University of Technology in the Netherlands and colleagues report on making them in the laboratory as quasiparticles. The team used a wire made of InSb, a semiconductor with a large spin-orbit coupling, coated with superconducting NbTiN and placed in a magnetic field along its axis. The number of electrons in the wire was controlled by capacitatively coupled gates and for certain electron densities the magnetic field and spin-orbit coupling produced a novel superconducting state with Majorana bound states at its ends. This may be exotic condensed matter, but arrays of such wires could form the basis of a quantum computer.

● **Further reading**

V Mourik *et al.* 2012 *Science* 336 1003.

Astrowatch

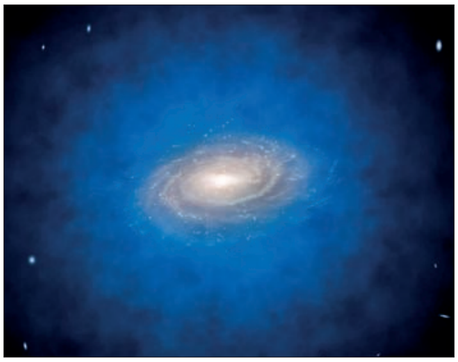
COMPILED BY MARC TÜRLER, ISDC AND OBSERVATORY OF THE UNIVERSITY OF GENEVA

The Milky Way's dark-matter halo reappears

Back in April, a study of the motion of hundreds of stars in the Milky Way found no evidence of a massive dark-matter halo (*CERN Courier* June 2012 p11). The finding came as a surprise and did not long withstand the assault of sceptical scientists questioning the results. A new study based on the same data set, but proposing a different underlying assumption, now reconciles the observations with the presence of a dark-matter halo in line with expectations.

One of the first pieces of evidence for dark matter was that the rotation velocity of stars in the Milky Way remains constant instead of decreasing with distance from the Galactic centre. This flat rotation curve implies the presence of an extended distribution of dark matter, whose mass compensates the decreasing stellar density in the outer regions of the Galaxy. The presence of a similar dark-matter halo is implied by the flat rotation curve observed in almost every spiral galaxy but its actual shape and density distribution is difficult to predict.

To determine the amount of dark matter in the vicinity of the Sun, a team of Chilean astronomers measured the motions of more than 400 red giant stars up to 13,000 light-years from the Sun, in a volume that is four times larger than ever previously considered. Visible matter in the form of stars and gas is dominant in the plane of the Galaxy but at higher elevation above the Galactic disc, dark matter should dominate. The rotational velocity of stars at different Galactic heights should thus result in a measure of the local density of dark matter in the solar neighbourhood.



This artist's impression depicts our home Galaxy, the Milky Way, embedded in a spherical halo of dark matter (shown in blue). (Image credit: ESO/L Calçada.)

To their surprise, Christian Moni Bidin of the Universidad de Concepción and colleagues found no evidence at all for a dark-matter halo. They obtained an upper limit of 0.07 kg of dark matter in a volume the size of the Earth, whereas theories predict a mass in the range of 0.4–1.0 kg. This difference of about an order of magnitude led some astronomers to query the validity of the analysis.

Jo Bovy and Scott Tremaine of the Institute for Advanced Study, Princeton, claim that they found a fault in one of the assumptions made by Moni Bidin and colleagues. The problematic assumption is that the average rotational velocity <V> is constant with distance from the Galactic centre at all heights above the plane of the Galaxy. For Bovy and Tremaine, this assumption applies to the circular velocity V_c but not to <V>. The difference is rather subtle, but it is a well identified effect known as the "asymmetric drift", which arises from a sub-population of stars with elliptical orbits that have on average a lower velocity than V_c. The result is a difference between <V> and V_c that evolves with the height above the Galactic plane and would have led the Chilean researchers to underestimate the density of dark matter.

With their modified assumption that the circular velocity curve is flat in the mid-plane, Bovy and Tremaine obtain a local dark-matter density of 0.3±0.1 GeV/cm^3, fully consistent with estimates from the usual models. They also claim to demonstrate that this assumption is motivated by observations, while the previous one was implausible.

As with the OPERA result on the faster-than-light neutrinos (p7), this is another example of an unexpected result being later disproved. It seems that submitting the problem to the scientific community in the form of a paper is an efficient way to identify quickly the origin of the disagreement. The strength of the scientific community as a whole is to be able to solve major issues more effectively than a single research group.

● Further reading

C Moni Bidin *et al.* 2012 *ApJ* **751** 30.
J Bovy and S Tremaine 2012, *ApJ*, in press arXiv:1205.4033 [astro-ph].

Picture of the month

This stunning image by ESA's Herschel observatory offers an unprecedented view of the Carina Nebula. With a mirror of 3.5 m, Herschel is the largest space telescope and provides impressive images and results from the far-infrared sky (*CERN Courier* September 2010 p11). The Carina Nebula is a very active star-forming nursery some 7500 light-years away (*CERN Courier* April 2009 p12).The colour coding of this infrared image is such that warmer gas and dust is shown in blue and cooler structures in red. Dust pillars point towards the central blue area from where they are eroded by powerful stellar winds and intense radiation produced by giant stars, most notably Eta Carinae (*CERN Courier* July/August 2008 p12). (Image credit: ESA/PACS/SPIRE/Thomas Preibisch, Universitäts-Sternwarte München, Ludwig-Maximilians-Universität München.)

CERN Courier Archive: 1969

A look back to CERN Courier vol. 8, July/August 1969, compiled by Peggie Rimmer

CERN

Do-it-yourself CERN Courier writing kit

At certain times of the year, such as when everyone is on holiday, the volume of material which is covered in *CERN Courier* is likely to fall. However, to compensate our more eager readers for the sparser issue this month [July 1969], we present a 'writing kit' from which the reader himself [sic] may construct a large variety of penetrating statements, such as he [sic] is accustomed to draw from our pages. It is based on the SIMP (Simplified Modular Prose) system developed in the Honeywell computer's jargon kit.

Take any four-digit number – try 1969, for example – and compose your statement by selecting the corresponding phrases from the following tables (1 from TABLE A, 9 from TABLE B, etc ...).

Table A

1	It has to be admitted that
2	As a consequence of inter-related factors,
3	Despite appearances to the contrary,
4	Until such time as fresh insight reverses the present trend,
5	Using the principle of cause and effect,
6	Presuming the validity of the present extrapolation,
7	Without wishing to open Pandora's box,
8	It is now proven beyond a shadow of a doubt that,
9	Worrying though the present situation may be,

Table B

1	willy-nilly determination to achieve success
2	construction of a high-energy accelerator
3	access to greater financial resources
4	pursuit of a Nobel prize
5	bubble chamber physics
6	a recent computation involving non semi-simple algebra
7	over-concern with the problems of administration
8	new measurements of eta zero zero
9	information presented in CERN COURIER

Table C

1	should only serve to add weight to
2	will inevitably lead to a refutation of
3	can yield conclusive information on
4	might usefully take issue with
5	must take into consideration
6	will sadly mean the end of
7	ought to stir up enthusiasm for
8	could result in a confirmation of
9	deflates the current thinking regarding

Table D

1	the need to acquire further computing capacity.
2	humanitarian concern with the personnel ceiling.
3	the Veneziano model.
4	a design which produces collisions at a later stage.
5	Macbeth's instruction 'Throw physic to the dogs'.
6	divergencies in weak interaction theory.
7	the desire to ensure that certain scientists go far.
8	bootstraps, conspiracies, poles and dips.
9	the future of physics in Europe.

Compiler's Note

This jargon-juggling game can generate some quite amusing assertions. Despite the blatant bias in the introduction, readers of any gender are invited to submit a 2012 version of the writing kit. To help, the original 1969 text can be copied from the *CERN Courier* website: http://cern.ch/go/couriercompetition.

Your offering should be sent to the editor: cern.courier@cern.ch before 30 September 2012. She (yes!) will choose a winner, based on a random 4-digit number; her decision will be completely subjective and final. The prize will be to see your name in print (sorry no lights) in the December 2012 issue of *CERN Courier*.

● The August 1969 cover featured an Aeroflot plane, seen at Geneva airport for the first time in July, chartered by CERN to carry equipment to and from the CERN-Serpukhov experiments in the then Soviet Union. The *CERN Courier* was exactly 10 years old that month and had 10 laboratory correspondents. Now there are 26, reflecting the impressive growth in the number of CERN users, from below 1000 in the late 1960s to more than 10,000 today.

100 years of cosmic rays

A discovery of cosmic proportions

In August 2012, Victor Hess made the historic balloon flight that was set to open a new window on matter in the universe.

"We took off at 6.12 a.m. from Aussig on the Elbe. We flew over the Saxony border by Peterswalde, Struppen near Pirna, Birchofswerda and Kottbus. The height of 5350 m was reached in the region of Schwielochsee. At 12.15 p.m. we landed near Pieskow, 50 km east of Berlin."

The flight on 7 August 1912 was the last in a series of balloon flights that Victor Hess, an Austrian physicist, undertook in 1912 with the aid of a grant from what is now the Austrian Academy of Sciences in Vienna. The previous year, he had taken two flights to investigate the penetrating radiation that had been found to discharge electroscopes above the Earth's surface. He had reached an altitude of around 1100 m and found "no essential change" in the amount of radiation compared with observations near the ground. This indicated the existence of some source of radiation in addition to γ-rays emitted by radioactive decays in the Earth's crust.

For the flights in 1912 he equipped himself with two electroscopes of the kind designed by Wulf (p17), which were "perfectly airtight" and could withstand the pressure changes with altitude. The containers were electrolytically galvanized on the inside to reduce the radiation from the walls. To improve accuracy the instruments were equipped with a new "sliding lens" that allowed Hess to focus on the electroscopes' fibres as they discharged without moving the eyepiece and hence changing the magnification.

Hess undertook the first six flights from his base in Vienna, beginning on 17 April 1912, during a partial solar eclipse. Reaching 2750 m, he found no reduction in the penetrating radiation during the eclipse but indications of an increase around 2000 m. However, on the following flights he found that "the weak lifting power of the local gas, as well as the meteorological conditions" did not allow him to ascend higher.

So, on 7 August he took off instead from Aussig [today Ústí nad Labem in the Czech Republic], several hundred kilometres north of Vienna. Although cumulus clouds appeared during the day, the balloon with Hess and the electrometers were never close to them; there was only a thin layer above him, at around 6000 m. The results of this flight were more conclusive. "In both γ-ray detectors the values at the greatest altitude are about 22–24 ions higher than at the ground."

Hess in the basket of his balloon, sometime in 1912.

Before reporting these results, Hess combined all of the data from his various balloon flights. At altitudes above 2000 m the measured radiation levels began to rise. "By 3000 to 4000 m the increase amounts to 4 ions, and at 4000 to 5200 m fully to 16 to 18 ions, in both detectors."

He concludes: "The results of the present observations seem to be most readily explained by the assumption that a radiation of very high penetrating power enters our atmosphere from above … Since I found a reduction … neither by night nor at a solar eclipse, one can hardly consider the Sun as the origin."

Although continuing research discovered more about the particles involved, the exact location of the source remains a mystery that continues to drive adventurous research in astroparticle physics.

● The extracts are from a translation of the original paper by Hess, taken from *Cosmic Rays* by A M Hillas, in the series "Selected readings in physics", Pergamon Press 1972.

Domenico Pacini making a measurement in 1910. (Image credit: Pacini family.)

Domenico Pacini and the origin of cosmic rays

Physicists were reluctant to abandon the hypothesis of a terrestrial origin for a mystery penetrating radiation, even when experiments above water showed a clear independence from radioactivity in the Earth's crust.

In 1785 Charles-Augustin de Coulomb presented three reports on electricity and magnetism to France's Royal Academy of Sciences. In the third of these he described his experiments showing that isolated electrified bodies can spontaneously discharge and that this phenomenon was not a result of defective insulation. After dedicated studies by Michael Faraday around 1835, William Crookes observed in 1879 that the speed of discharge decreased when the pressure was reduced: the ionization of air was thus the direct cause. But what was ionizing air? Trying to answer this question paved the way in the early 20th century towards a revolutionary scientific discovery – that of cosmic rays.

Spontaneous radioactivity had been discovered at the end of the 19th century and researchers observed that a charged electroscope promptly discharges in the presence of radioactive material. The discharge rate of an electroscope could then be used to gauge the level of radioactivity. A new era of research into discharge physics opened up, this period being strongly influenced by the discoveries of the electron and positive ions.

During the first decade of the 20th century, results on ionization phenomena came from several researchers in Europe and North America. Around 1900, Charles Wilson in Scotland and, independently two high-school teachers and good friends in Germany, ▷

Julius Elster and Hans Geitel, improved the technique for the careful insulation of electroscopes in a closed vessel, thus improving the sensitivity of the electroscope itself (figure 1). As a result, they could make measurements of the rate of spontaneous discharge. They concluded that ionizing agents were coming from outside the vessel and that part of this radioactivity was highly penetrating: it could ionize the air in an electroscope shielded by metal walls a few centimetres thick. This was confirmed in 1902 by quantitative measurements performed by Ernest Rutherford and Henry Cooke, as well as by John McLennan and F Burton, who immersed an electroscope in a tank filled with water.

The obvious questions concerned the nature of such radiation and whether it was of terrestrial or extra-terrestrial origin. The simplest hypothesis was that its origin was related to radioactive materials in the Earth's crust, which were known to exist following the studies by Marie and Pierre Curie on natural radioactivity. A terrestrial origin was thus a commonplace assumption – an experimental proof, however, seemed difficult to achieve. In 1901, Wilson made the visionary suggestion that the origin of this ionization could be an extremely penetrating extra-terrestrial radiation. Nikola Tesla in the US even patented in 1901 a power generator based on the fact that "the Sun, as well as other sources of radiant energy, throws off minute particles of matter […which] communicate an electrical charge". However, Wilson's investigations in tunnels with solid rock overhead showed no reduction in ionization and so did not support an extra-terrestrial origin. The hypothesis was dropped for many years.

New heights

A review by Karl Kurz summarizes the situation in 1909. The spontaneous discharge observed was consistent with the hypothesis that background radiation did exist even in insulated environments and that this radiation had a penetrating component. There were three possible sources for the penetrating radiation: an extra-terrestrial radiation, perhaps from the Sun; radioactivity from the crust of the Earth; and radioactivity in the atmosphere. Kurz concluded from ionization measurements made in the lower part of the atmosphere that an extra-terrestrial radiation was unlikely and that (almost all of) the radiation came from radioactive material in the crust. Calculations were made of how such radiation should decrease with height but measurements were not easy to perform because the electroscope was a difficult instrument to transport and the accuracy was not sufficient.

Although a large effort to build a transportable electroscope was made by the meteorology group in Vienna (leaders in measurements of air ionization at the time), the final realization of such an instrument was made by Father Theodor Wulf (figure 2, left), a German scientist and Jesuit priest serving in the Netherlands and later in Rome. In Wulf's electroscope, the two metal leaves were replaced by metalized silicon-glass wires, with a tension spring in between, also made of glass. The instrument could be read by a microscope (figure 2, right). To test the origin of the radiation causing the spontaneous discharge, Wulf checked the variation of radioactivity with height: in 1909 he measured the rate of ionization at the top of the Eiffel Tower in Paris (300 m above ground). Supporting the hypothesis of the terrestrial origin of most of the radiation, he expected to find less ionization at the top of the tower than at ground level. However, the rate of ionization showed too small a decrease to confirm this hypothesis. Instead, he found that the amount of radiation "at nearly 300 m [altitude] was not even half of its ground value", while with the assumption that radiation emerges from the ground there would remain at the top of the tower "just a few per cent of the ground radiation".

Fig. 1. The school-teacher friends, Julius Elster and Hans Geitel, improved the technique for the insulation of electroscopes in a closed vessel. (Image credit: www.elster-geitel.de.)

Wulf's observations were puzzling and demanded an explanation. One possible way to solve this puzzle was to make measurements at altitudes higher than the 300 m of the Eiffel tower. Balloon experiments had been widely used for studies of atmospheric electricity for more than a century and it became evident that they might give an answer to the problem of the origin of the penetrating radiation. In a flight in 1909, Karl Bergwitz, a former pupil of Elster and Geitel, found that the ionization at 1300 m altitude had decreased to about 24% of the value on the ground. However, Bergwitz's results were questioned because his electrometer was damaged during the flight. He later investigated electrometers on the ground and at 80 m, reporting that no significant decrease of the ionization was observed. Other measurements with similar results were obtained around the same time by Alfred Gockel, from Fribourg, Switzerland, who flew up to 3000 m (and first introduced the term "kosmische Strahlung", or "cosmic radiation"). The general interpretation was that radioactivity was coming mostly from the Earth's surface, although the balloon results were puzzling.

The meteorologist Franz Linke had, in fact, made 12 balloon flights in 1900–1903 during his PhD studies at Berlin University, carrying an electroscope built by Elster and Geitel to a height of 5500 m. The thesis was not published, but a published report concludes: "Were one to compare the presented values with those on ground, one must say that at 1000 m altitude [...] the ionization is smaller than on the ground, between 1 and 3 km the same amount,

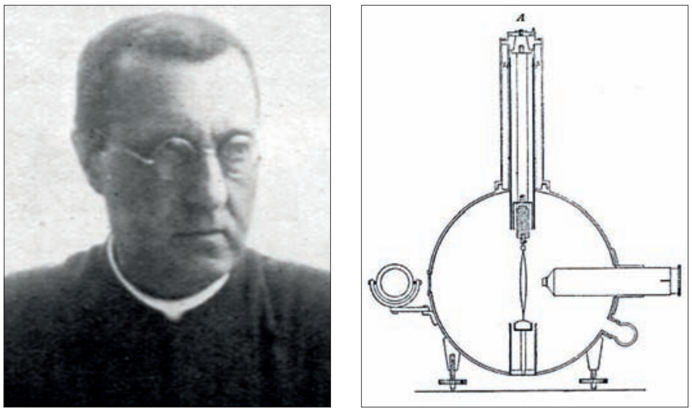


Fig. 2. Left: Theodor Wulf pictured around 1910. (Image credit: Archiv der Norddeutschen Provinz SJ, Munich). Right: Wulf's electroscope, from his own drawing. (Image credit: T Wulf 1909 Phys. Zeit. ***1*** *152.)*

and above it is larger ... with values increasing up to a factor of 4 (at 5500 m). [...] The uncertainties in the observations [...] only allow the conclusion that the reason for the ionization has to be found first in the Earth." Nobody later quoted Linke and although he had made the right measurement, he had reached the wrong conclusions.

Underwater measurements

One person to question the conclusion that radioactivity came mostly from the Earth's crust was an Italian, Domenico Pacini. An assistant meteorologist in Rome, he made systematic studies of ionization on mountains, on the shoreline and at sea between 1906 and 1910. Pacini's supervisor was the Austrian-born Pietro Blaserna, who had graduated in physics within the electrology group at the University of Vienna. The instruments used in Rome were state of the art and Pacini could reach a sensitivity of one third of a volt.

In 1910 he placed one electroscope on the ground and one out at sea, a few kilometres off the coast, and made simultaneous measurements. He observed a hint of a correlation and concluded that "in the hypothesis that the origin of penetrating radiations is in the soil [. . .] it is not possible to explain the results obtained". That same year he looked for a possible increase in radioactivity during a passage of Halley's comet and found no effect.

Pacini later developed an experimental technique for underwater measurements and in June 1911 compared the rate of ionization at sea level and at 3 m below water, at a distance of 300 m from the shore of the Naval Academy of Livorno. He repeated the measurements in October on the Lake of Bracciano. He reported on his measurements, the results – and their interpretation – in a note entitled, "Penetrating radiation at the surface of and in water", published in Italian in *Nuovo Cimento* in February 1912. In that paper, Pacini wrote: "Observations carried out on the sea during the year 1910 led me to conclude that a significant proportion of the pervasive radiation that is found in air had an origin that was independent of the direct action of active substances in the upper layers of the Earth's surface. ... [To prove this conclusion] the apparatus ... was enclosed in a copper box so that it could be immersed at depth. ... Observations were performed with the instrument at the surface, and with the instrument immersed in water, at a depth of 3 m".

Pacini measured the discharge rate of the electroscope seven times over three hours. The ionization underwater was 20% lower than at the surface, consistent with absorption by water of radiation coming from outside; the significance was larger than $4\,\sigma$. He wrote: "With an absorption coefficient of 0.034 for water, it is easy to deduce from the known equation $I/I_0 = \exp(-d/\lambda)$, where d is the thickness of the matter crossed, that, in the conditions of my experiments, the activities of the sea-bed and of the surface were both negligible. The explanation appears to be that, owing to the absorbing power of water and the minimum amount of radioactive substances in the sea, absorption of radiation coming from the outside indeed happens, when the apparatus is immersed." Pacini concluded: "[It] appears from the results of the work described in this note that a sizable cause of ionization exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the crust."

Despite Pacini's conclusions – and the puzzling results of Wulf and Gockel on the dependence of radioactivity on altitude – physicists were reluctant to abandon the hypothesis of a terrestrial origin for the mystery penetrating radiation. The situation was resolved in 1911 an 1912 with the long series of balloon flights by Victor Hess, who established the extra-terrestrial origin of at least part of the radiation causing the observed ionization. However, it was not until 1936 that Hess was rewarded with the Nobel Prize for the discovery of cosmic radiation. By then the importance of this "natural laboratory" was clear, and he shared the prize with Carl Anderson, who had discovered the positron in cosmic radiation four years earlier. Meanwhile, Pacini had died in 1934 – his contributions mainly forgotten through a combination of historical and political circumstances.

● Further reading

For a detailed account of the early studies of cosmic rays and the work of Domenico Pacini, with references to original papers, see:

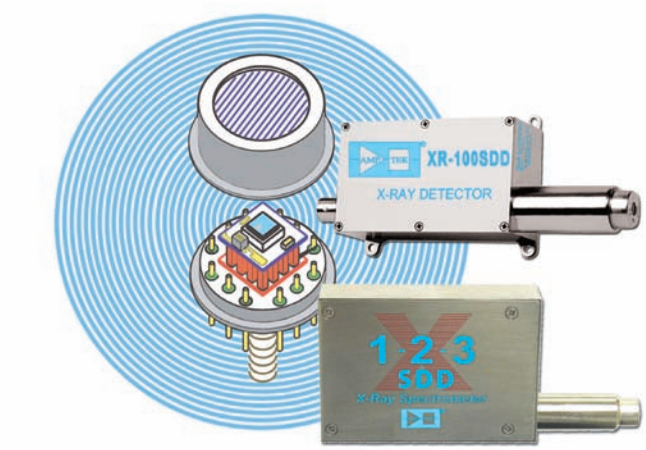
A De Angelis 2010 *Riv. Nuovo Cim.* **33** 713.
P Carlson and A De Angelis 2011 *Eur. Phys. J. H* 309.

Résumé

Domenico Pacini et la découverte des rayonnements cosmiques

Le phénomène de décharge spontanée de corps électrisés semble indiquer que l'air est ionisé – mais par quoi ? Pour tenter de répondre à cette question, des expériences furent menées au début du XX^{e} siècle au sommet de la Tour Eiffel et dans des ballons. Ces expériences montrèrent que le degré d'ionisation ne diminuait pas avec l'altitude comme ce serait le cas si cette ionisation provenait des radiations émises par les matières radioactives de la croûte terrestre. Cependant, les physiciens ont eu du mal à abandonner l'hypothèse d'une origine terrestre de cette mystérieuse radiation ionisant l'air, alors même que Domenico Pacini avait réalisé des expériences dans l'eau démontrant qu'elle était indépendante de la radioactivité de la croûte terrestre.

Alessandro De Angelis, University of Udine, INFN and LIP, and author of *L'enigma dei raggi cosmici. Le più grandi energie dell' universo* Springer 2012 (*CERN Courier* May 2012 p 52).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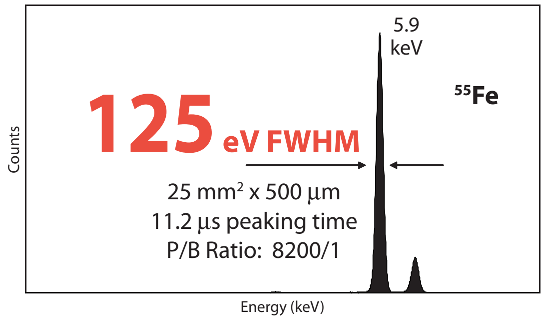
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LHCf: bringing cosmic collisions down to Earth

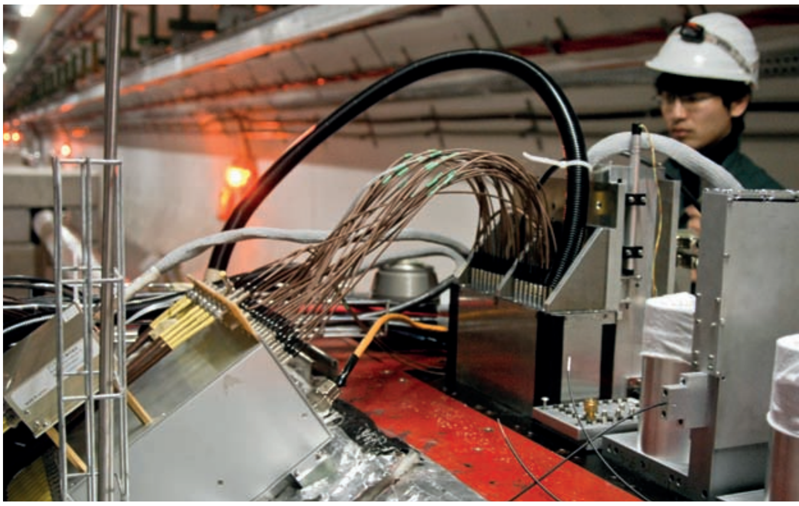
The high-energy proton collisions in the LHC are providing valuable input for models used in measuring extensive air showers from ultrahigh-energy cosmic rays.

Recent observations of ultra-high-energy cosmic rays (UHECRs) by extensive air-shower arrays have revealed a clear cut-off in the energy spectrum at $10^{19.5}$ eV. The results are consistent with the predictions made in the mid-1960s that interactions with the cosmic microwave background would suppress the flux of particles at high energies (Greisen 1966, Zatsepin and Kuz'min 1966). Nevertheless, as the article on page 22 explains, the nature of the cut-off – and, indeed, the origin of the UHECRs – remains unknown.

UHECRs are observed in the large showers of particles created when a high-energy particle (proton or nucleus) interacts in the atmosphere. This means that information about the primary cosmic ray has to be estimated by "interpreting" the observed extensive air shower. Both longitudinal and lateral shower structures measured by the fluorescence and surface detectors, respectively, are used in the interpretation of the energy and species of the primary particle through comparison with the predictions of Monte Carlo simulations. In high-energy hadronic collisions, the energy flow is dominated by the very-forward-emitted particles in which the shower development is determined by the energy balance of baryonic and mesonic particle production. However, the lack of knowledge about hadronic interactions at such high energies, especially in the forward region, means that the interpretations tend to be model-dependent. To constrain the models used in the simulations, measurements of the forward production of particles relevant to air-shower development are indispensable at the highest energies possible.

Into the lab

The most important cross-section for cosmic-ray shower development is for the forward production in hadron collisions of neutral pions (π^0), which immediately decay to two forward photons. The highest energies accessed in the laboratory are reached in particle colliders, and until the start-up of the LHC, the only experiment dedicated to forward particle production at a collider was carried out at UA7 at CERN's Sp$\bar{\text{p}}$S collider (Paré *et al.* 1990). Now, two decades later, members of the UA7 team have formed a new collaboration for the Large Hadron Collider forward (LHCf) experiment (LHCf 2006). This is dedicated to measuring very-forward particle production at the LHC, where running with proton–proton collisions at the full design energy of 14 TeV will correspond to 10^{17} eV in the laboratory frame and so will be in touch with the UHECR region.



LHCf's detectors are located in the target neutral absorbs at 140 m either side of the ATLAS interaction point. Here the upper part of the infrastructure and cabling for the Arm1 detector is visible on the centre right. (Image credit: LHCf.)

The LHCf experiment consists of two independent calorimeters (Arm1 and Arm2) installed 140 m on either side of the interaction point in the ATLAS experiment. The detectors fit in the instrumentation slots of the target neutral absorbers (TANs), which are located where the vacuum chamber for the beam makes a Y-shaped transition from the single beam pipe that passes through the interaction point to the two separate beam tubes that continue into the arcs of the LHC. Charged particles produced in the collision region in the direction of the TAN are swept aside by an inner beam-separation magnet before they reach it. Consequently, only neutral particles produced at the interaction point enter the TAN and the detectors. This location allows the observation of particles at nearly 0° to the proton beam direction.

Both LHCf detectors contain two sampling and imaging calorimeters, each consisting of 44 radiation lengths of tungsten and 16 sampling layers of 3 mm-thick plastic scintillator for the initial runs. ▷

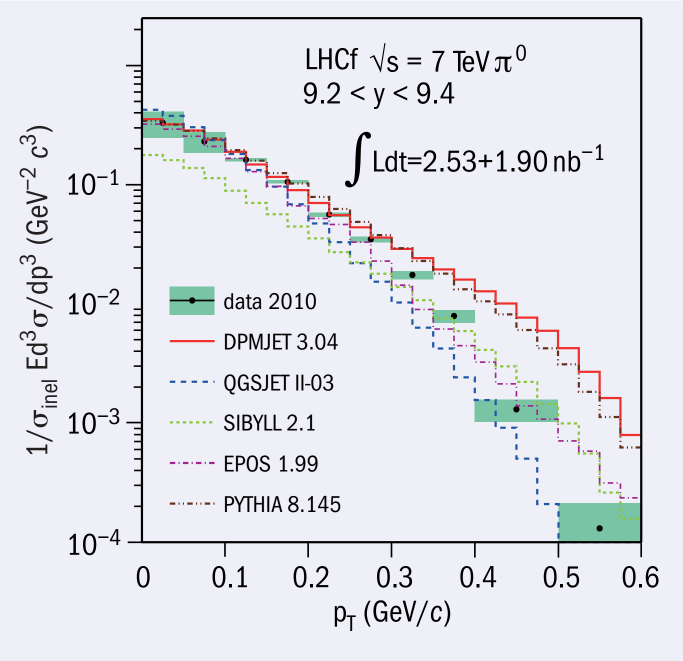


Fig. 1. An example of combined p_T spectra of the LHCf-Arm1 and Arm2 detectors (black dots) and the total uncertainties (shaded rectangles) compared with the predicted spectra by hadronic interaction models.

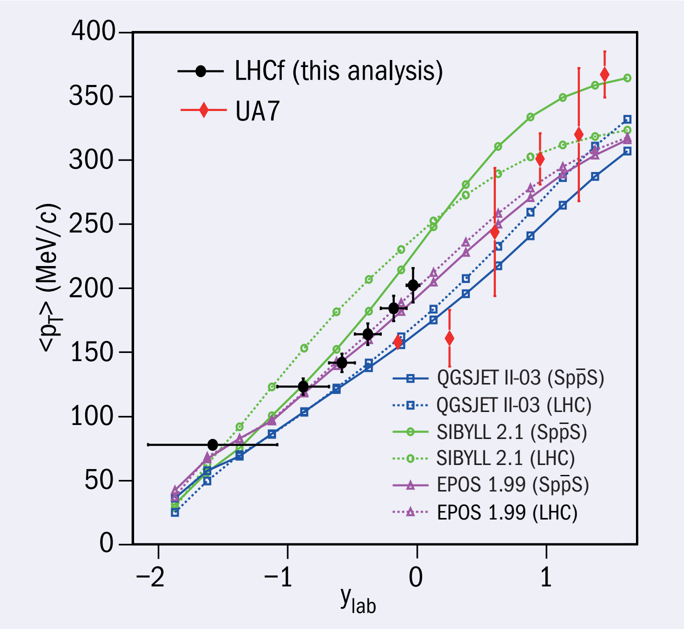


Fig. 2. Average p_T as a function of y_{lab}, showing data from LHCf and UA7, together with predictions from three hadronic interaction models, SIBYLL 2.1, QGSJETII-03 and EPOS 1.99. In all three cases, solid and dashed curves indicate the collision energy at LHC and Sp$\bar{p}$S, respectively.

The calorimeters in Arm1 have an area transverse to the beam direction of 20 × 20 mm² and 40 × 40 mm², while those in Arm2 have areas of 25 × 25 mm² and 32 × 32 mm². Four X-Y layers of position-sensitive sensors are interleaved with the tungsten and scintillator to provide the transverse positions of the showers generated in the calorimeters, employing different technologies in the two detectors: Arm1 uses scintillating fibres and multi-anode photomultiplier tubes (MAPMTs); Arm2 uses silicon-strip sensors. In each case, the sensors are installed in pairs in such a way that two pairs are optimized to detect the maximum of gamma-ray-induced showers, while the other two are for hadronic showers developed deep within the calorimeters. Although the lateral dimensions of these calorimeters are small, the energy resolution is expected to be better than 6% and the position resolution better than 0.2 mm for gamma-rays with energy between 100 GeV and 7 TeV. This has been confirmed by test-beam results at CERN's Super Proton Synchrotron.

LHCf successfully took data right from the first collision at the LHC in 2009 and finished its first phase of data-taking in mid-July 2010, after collecting enough data in proton–proton collisions at both 900 GeV and 7 TeV in the centre of mass. In 2011, the collaboration reported its measurements of inclusive photon spectra at 7 TeV (Adriani *et al.* 2011 and *CERN Courier* June 2011 p6). A comparison of the data with predictions from the hadron-interaction models used in the study of air showers and from PYTHIA 8.145, which is popular in the high-energy-physics community, revealed various discrepancies, with none of the models showing perfect agreement with the data.

Now, LHCf has results for the inclusive π^0 production rate at rapidities greater than 8.9 in proton–proton data at 7 TeV in the centre of mass. Using data collected in two runs in May 2010, corresponding to integrated luminosities of 2.53 nb^{-1} in Arm1 and 1.90 nb^{-1} in Arm2, the collaboration measured instances where two photons emitted into the very-forward regions could be attributed to π^0 decays and obtained the transverse momentum (p_T) distributions of the π^0s. The criteria for the selection of π^0 events were based on the position of the incident photons (within 2 mm of the edge of the calorimeter), the photon energy (above 100 GeV), the number of hits (one in each calorimeter), photon-like particle identification using the energy deposition and, last, an invariant mass corresponding to the π^0 mass.

The p_T spectra were derived in independent analyses of the two detectors, Arm1 and Arm2, in six rapidity intervals covering the range 8.9–11.0. These spectra, which agree within statistical and systematic errors, were then combined and compared with the predictions from various hadronic interaction models: DPMJET 3.04, QGSJET II-03, SIBYLL 2.1, EPOS 1.99 and PYTHIA 8.145 (default parameter set).

Data from LHCf can now be used in models to constrain the air-shower development.

Figure 1 shows the combined spectrum for one rapidity interval, $9.2 < y < 9.4$, compared with the outcome from these models (Adriani *et al.* 2012). It is clear that DPMJET 3.04 and PYTHIA 8.145 predict the π^0 production rates to be higher than the data from LHCf as p_T increases. SIBYLL 2.1 also predicts harder pion spectra than are observed in the experimental data, although the expected π^0 yield is generally small. On the other hand, QGSJET II-03 predicts π^0 spectra that are softer than both the LHCf data and the other model predictions. Among the hadronic interaction models, EPOS 1.99 shows the best overall agreement with the LHCf data.

In figure 2 the values of average p_T ($\langle p_T\rangle$) obtained in this analysis are compared as a function of $y_{lab} = y_{beam} - y$ with the results from UA7 and with the model predictions. Although the LHCf and UA7 data have limited overlap and the systematic errors for UA7 are relatively large, the values of $\langle p_T\rangle$ from the two experiments lie mainly along a common curve and there is no evidence of a dependence on collision energy. EPOS 1.99 shows the smallest dependence of $\langle p_T\rangle$ on the two collision energies among three of the models, and this tendency is consistent with the results from LHCf and UA7. It is also evident from figure 2 that the best agreement with the LHCf data are obtained by EPOS 1.99.

The photon and π^0 data from the LHCf experiment can now be used in models to constrain the mesonic part (or electromagnetic part via π^0s) of the air-shower development. The collaboration, meanwhile, is turning to analysis of baryon production, which will provide complementary information on the hadronic interaction. At the same time, work is ongoing towards taking data on proton–lead collisions at the LHC, planned for the end of 2012. Such nuclear collision data are important for understanding the interaction between cosmic rays and the atmosphere. Also other work is under way on replacing the plastic scintillator in the calorimeters – which were removed after the runs in July 2010 – with more radiation-resistant crystal scintillator, so as to be ready for 2014 when the LHC will run at 7 TeV per beam. There are also plans to change the position of the silicon sensors to improve the performance of the experiment in measuring the energy of the interacting particles.

Further reading

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Résumé

LHCf ramène les collisions cosmiques sur Terre

Pour augmenter nos connaissances expérimentales sur les rayonnements cosmiques à très haute énergie, les chercheurs utilisent entre autres des simulations des gigantesques gerbes atmosphériques de particules que ces rayonnements produisent dans l'atmosphère terrestre. Afin de déterminer les limites des modèles utilisés pour les simulations, il est indispensable de mesurer la production à petits angles de certaines particules, à l'énergie la plus haute possible. L'expérience LHCf auprès du LHC fournit à présent des informations précieuses, grâce à des mesures prises aux énergies de collision de protons les plus élevées accessibles en laboratoire.

Takasi Sako and **Gaku Mitsuka**, Nagoya University, LHCf collaboration.

Studies of ultra-high-energy cosmic rays look to the future

Cosmic rays with energies of 10^{20} eV and above have puzzled scientists since they were first detected 50 years ago. A symposium held at CERN in February looked at the latest developments in attempts to understand these extreme events.

One of the 1660 surface-detector stations (foreground) and one of the four fluorescence-detector sites that make up the Pierre Auger Observatory in Argentina. Each surface-detector station contains 12,000 litres of water and is powered by a solar panel. Each of the fluorescence-detector sites houses six telescopes and a communications tower. (Image credit: Auger collaboration.)

"Analysis of a cosmic-ray air shower recorded at the MIT Volcano Ranch station in February 1962 indicates that the total number of particles in the shower was 5×10^{10}. The total energy of the primary particle that produced the shower was 1.0×10^{20} eV." Thus begins the 1963 paper in which John Linsley described the first detection of a cosmic ray with a surprisingly high energy. Such ultra-high-energy cosmic rays (UHECRs), which arrive at Earth at rates of less than 1 km^{-2} a century, have since proved challenging both experimentally and theoretically. The International Symposium on Future Directions in UHECR Physics, which took place at CERN on 13–16 February, aimed to discuss these challenges and look to the next step in terms of a future large-scale detector. Originally planned as a meeting of about 100 experts from the particle- and astroparticle-physics communities, the symposium ended up attracting more than 230 participants from 24 countries, reflecting the strong interest in the current and future prospects for cosmic rays at the highest energies.

Soon after Linsley's discovery, UHECRs became even more baffling when Arno Penzias and Robert Wilson discovered the cosmic microwave background (CMB) radiation in 1965. The reason for this is twofold: first, astrophysical sources delivering particle energies of 10 to 100 million times the beam energy of the LHC are hard to conceive of; and, second, the universe becomes opaque for protons and nuclei at energies above 5×10^{19} eV because of their interaction with the CMB radiation. In 1966, Kenneth Greisen, and independently Georgy Zatsepin and Vadim Kuz'min, pointed out that protons would suffer pion photoproduction and nuclei photodisintegration in the CMB. These processes limit the cosmic-ray horizon above the so-called "GZK" threshold to less than about 100 Mpc, resulting in strongly suppressed fluxes of protons and nuclei from distant sources.

The HiRes, Pierre Auger and Telescope Array (TA) collaborations recently reported a suppression of just this type at about the expected threshold. Does this mark the long awaited discovery of the GZK effect? At the symposium, not all participants were convinced because the break in the energy spectrum could also be caused by the sources running out of steam. To shed more light on this most important question of astroparticle physics, information about the mass composition and arrival directions, as well as the precise energy spectrum of the highest-energy cosmic rays, is now paramount.

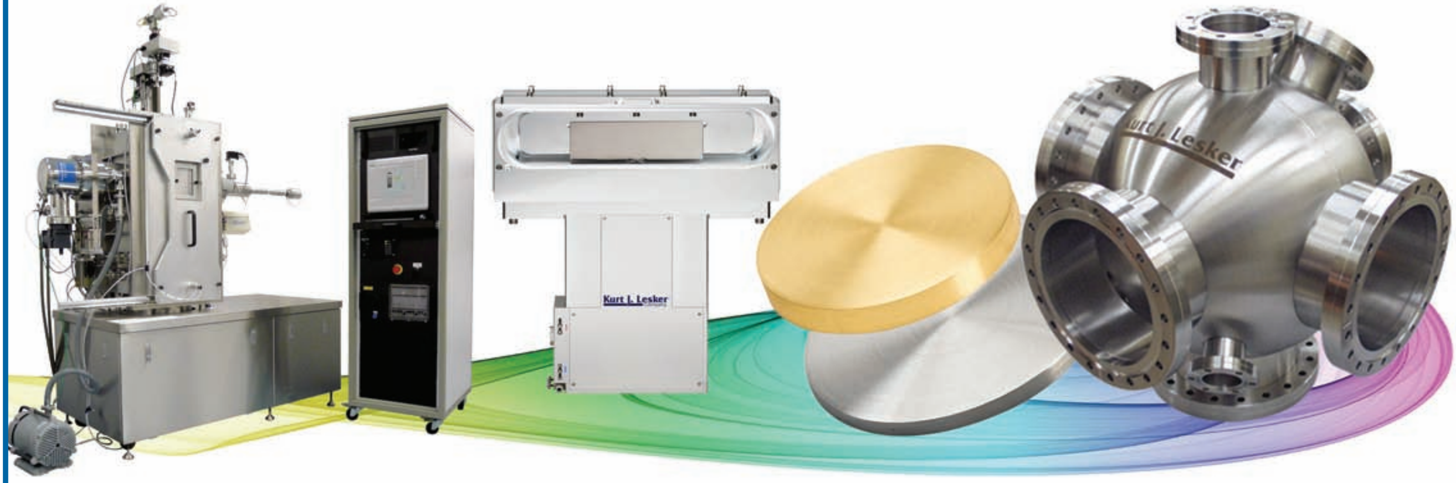
Searching for answers

Three large-scale observatories, each operated by international collaborations, are currently taking data and trying to provide answers: the Pierre Auger Observatory in Argentina, the flagship in the field, which covers 3000 km^2; the more recently commissioned TA in Utah, which samples an area of 700 km^2; and the smaller Yakutsk Array in Siberia, which now covers about 10 km^2. To make progress in understanding the data from these three different observatories new ground was broken in preparing for the symposium. Before the meeting, five topical working groups were formed comprising members from each collaboration. They were given the task of addressing differences between the respective approaches in the measurement and analysis methods, studying their impact on the physics results and delivering a report at the symposium. These working-group reports – on the energy spectrum, mass composition, arrival directions, multimessenger studies and comparisons of air-shower data to simulations – were complemented by invited overview talks, contributed papers and a large number of posters addressing various topics of analyses, new technologies and concepts for future experiments.

In opening the symposium and welcoming the participants, CERN's director of research, Sergio Bertolucci, emphasized the organization's interest in astroparticle physics in general and in cosmic rays in particular – the latter being explicitly named in the CERN convention. Indeed, many major astroparticle experiments have been given the status of "recognized experiment" by CERN. Pierre Sokolsky, a key figure in the legendary Fly's Eye experiment and its successor HiRes, followed with the first talk, a historical review of the research on the most energetic particles in nature. Paolo Privitera of the University of Chicago then reviewed the current status of measurements, highlighting differences in observations and the understanding of systematic uncertainties. Theoretical aspects of acceleration and propagation were also discussed, as well as predictions of the energy and mass spectrum, by Pasquale Blasi of Istituto Nazionale di Astrofisica/Arcetri Astrophysical Observatory and Venya Berezinsky of Gran Sasso National Laboratory.

Some of the detector stations in the Yakutsk Array in Siberia. (Image credit: Yakutsk collaboration.)

Data from the LHC, particularly those measured in the very forward region, are of prime interest for verifying and optimizing hadronic-interaction event-generators that are employed in the Monte Carlo simulations of extensive air showers (EAS), which are generated by the primary UHECRs. Overviews of recent LHC data by Yoshikata Itow of Nagoya University and, more generally, the connection between accelerator physics and EAS were therefore given prominence at the meeting. Tanguy Pierog of Karlsruhe Institute of Technology demonstrated that the standard repertoire of interaction models employed in EAS simulations not only cover the LHC data reasonably well but also the predicted LHC data better than high-energy physics models, such as PYTHIA or HERWIG. Nonetheless, no perfect model exists and significant muon ▷



Participants at the symposium on Future Directions in UHECR Physics, outside CERN's Main Building.

deficits in the models are seen at the highest air-shower energies. In a keynote talk, John Ellis, now of King's College London, highlighted UHECRs as being the most extreme environment for studying particle physics – at a production energy of around 10^{11} GeV and more than 100 TeV in the centre-of-mass – and discussed the potential for exotic physics. In a related talk, Paolo Lipari of INFN Rome La Sapienza discussed the interplay of cross-sections, cosmic-ray composition and interaction properties, highlighting the mutual benefits provided by cosmic rays and accelerator physics.

High-energy photons and neutrinos are directly related to cosmic rays and are different observational probes of the high-energy non-thermal universe. Tom Gaisser of the University of Delaware, Günter Sigl of the University of Hamburg and others addressed this multimessenger aspect and argued that current neutrino limits from IceCube begin to disfavour a UHECR origin inside relativistic gamma-ray bursts and active galactic-nuclei (AGN) jets, and that cosmogenic neutrinos would provide a smoking-gun signal of the GZK effect. However, as Sigl noted, fluxes of diffuse cosmogenic neutrinos and photons depend strongly on the chemical composition, maximal acceleration energy and redshift evolution of sources.

Future options

Looking towards the future, the symposium discussed potentially attractive new technologies for cosmic-ray detection. Radio observations of EAS at frequencies of some tens of megahertz are being performed at the prototype level by a couple of groups and the underlying physical emission processes are being understood in greater detail. Ad van den Berg of the University of Groningen described the status of the largest antenna array under construction, the Auger Engineering Radio Array (AERA). More recently, microwave emission by molecular bremsstrahlung was suggested as another potentially interesting emission process. Unlike megahertz-radiation, gigahertz-emission would occur isotropically, opening the opportunity to observe showers sideways from large distances, a technique known from the powerful EAS fluorescence observations. Thus, huge volumes could be surveyed with minimal equipment available off the shelf. Pedro Facal of the University of Chicago and Radomir Smida of the Karlsruhe Institute of Technology reported preliminary observations of such radiation, with signals being much weaker than expected from laboratory measurements.

The TA collaboration is pursuing forward-scattered radar detection of EAS, as John Belz of the University of Utah reported; this again potentially allows huge volumes to be monitored for reflected signals. However, the method still needs to be proved to work. Interesting concepts for future giant ground-based observatories based on current and novel technologies were presented by Antoine Letessier-Selvon of the CNRS, Paolo Privitera and Shoichi Ogio of Osaka City University. The goal is to reach huge apertures with particle-physics capability at cost levels of €100 million.

One of three fluorescence sites in the Telescope Array, Utah, which has a ground array of 507 detectors. (Image credit: TA collaboration.)

Parallel to pushing for a new giant ground-based observatory, space-based approaches, most notably by JEM-EUSO – the Extreme Universe Space Observatory aboard the Japanese Experiment Module – to be mounted on the International Space Station, were discussed by Toshikazu Ebizusaki of RIKEN, Andrea Santangelo of the Institut für Astronomie und Astrophysik Tübingen and Mario Bertaina of Torino University/INFN. Depending on the effective duty cycle, apertures of almost 10 times that of the Auger Observatory with a uniform coverage of northern and southern hemispheres may be reached. However, the most important weakness as compared with ground-based experiments is the poor sensitivity to the primary mass and the inability to perform particle-physics-related measurements.

The true highlights of the symposium were reports given by the joint working groups. This type of co-operation, inspired by the former working groups for CERN's Large Electron–Positron Collider, marked a new direction for the community. Yoshiki Tsunesada of the Tokyo Institute of Technology reported detailed comparisons of the energy spectra measured by the different observatories. All spectra are in agreement within the given energy-scale uncertainties of around 20%.

The goal is to reach huge apertures with particle-physics capability.

Accounting for these overall differences, spectral shapes and positions of the spectral features are in good agreement. Nevertheless, the differences are not understood in detail and studies of the fluorescence yield and photometric calibration – treated differently by the TA and Auger collaborations – are to be pursued.

The studies of the mass-composition working group, presented by Jose Bellido of the University of Adelaide, addressed whether the composition measured by HiRes and TA is compatible with proton-dominated spectra while Auger suggests a significant fraction of heavy nuclei above 10^{19} eV. Following many cross-checks and cross-correlations between the experiments, differences could not be attributed to issues in the data analysis. Even after taking into account the shifts in the energy scale, the results are not fully consistent within quoted uncertainties, assuming no differences existed between the northern and southern hemispheres.

The anisotropy working group discussed large-scale anisotropies and directional correlations to sources in various catalogues and concluded that there is no major departure from anisotropy in any of the data sets, although some hints at the 10–20° scale might be have been seen by Auger and TA. Directional correlations to AGN and to the overall nearby matter-distribution are found by Auger at the highest energies, but the HiRes collaboration could not confirm this finding. Recent TA data agree with the latest signal strength of Auger but, owing to the lack of statistics, they are also compatible with isotropy at the 2% level.

Studies by the photon and neutrino working group, presented by Markus Risse of the University of Siegen and Grisha Rubtsov from the Russian Academy of Sciences, addressed the pros and cons of different search techniques and concluded that the results are similar. No photons and neutrinos have been observed yet but prospects for the coming years seem promising for reaching sensitivities for optimistic GZK fluxes.

Lastly, considerations of the hadronic-interaction and EAS-simulation working group, presented by Ralph Engel of Karlsruhe Institute of Technology, acknowledged the many constraints – so far without surprises – that are provided by the LHC. Despite the good overall description of showers, significant deficits in the muon densities at ground level are observed in the water Cherenkov tanks of Auger. The energy obtained by the plastic scintillator array of TA is around 30% higher than the energies measured by fluorescence telescopes. These differences are difficult to understand and deserve further attention. Nevertheless, proton–air and proton–proton inelastic cross-sections up to $\sqrt{s} = 57$ TeV have been extracted from Auger, HiRes and Yakutsk data, demonstrating the particle-physics potential of high-energy cosmic rays.

The intense and lively meeting was summarized enthusiastically by Angela Olinto of the University of Chicago and Masaki Fukushima of the University of Tokyo. A round-table discussion, chaired by Alan Watson of the University of Leeds, iterated the most pressing questions to be addressed and the future challenges to be worked on towards a next-generation giant observatory. Clearly, important steps were made at this symposium, marking the start of a coherent worldwide effort towards reaching these goals. The open and vibrant atmosphere of CERN contributed much to the meeting's success and was highly appreciated by all participants, who agreed to continue the joint working groups and discuss progress at future symposia.

Air fluorescence

The study of the highest-energy cosmic rays owes a great deal to the faint glow emitted when high-energy ionizing particles excite molecular nitrogen in the atmosphere. Detecting this light allows the atmosphere to be used as a giant calorimeter, enabling the energy of the primary cosmic ray to be measured, in principle, without depending on assumptions about hadronic physics at ultra-high energies.

A key to the importance of this technique lies in the isotropic emission of the radiation, which allows showers to be observed as a streak of light from a distance and makes it feasible to monitor large volumes of the atmosphere. The total amount of light depends on the number of particles in the shower and, in turn, on the energy. The shape and direction of the streak provide information about the direction and nature of the primary cosmic ray.

Edward Teller in the US was probably the first person to have the idea of using air-fluorescence – for detecting X-rays from nuclear explosions. The idea of applying it to detect high-energy cosmic rays seems to have emerged independently a little later, in the late 1950s. Aleksandr Chudakov, a pioneer of the air-Cherenkov technique (p34) made measurements in the years 1955–1957 but did not publish until a decade later. Discussions of the idea had also begun at the Institute of Nuclear Science in Tokyo in the mid-1950s, initiated by Koichi Suga, who with Goro Tanhashi led the effort to make the first successful detection in 1969. At the same time, Kenneth Greisen's group at Cornell University addressed many of the key issues, although their work was to end in 1972 after unsuccessful attempts to detect the faint light, mainly because of the local climate.

A group at the University of Utah eventually developed the technique, in their "Fly's Eye" detector, observing the highest-energy cosmic ray (3.2×10^{20} eV) to date on 15 October 1991. Now, the detection of air fluorescence is a key feature of the Auger and TA arrays.

- For more information about the symposium, see http://2012.uhecr.org.

Résumé

Recherches sur les rayonnements cosmiques d'ultra-haute énergie : cap vers le futur

Depuis leur découverte il y a 50 ans, les rayonnements cosmiques, avec des énergies atteignant 10^{20} eV et plus, n'en finissent pas de rendre les scientifiques perplexes. Un colloque international, tenu au CERN en février, a été l'occasion d'évoquer les défis que représentent ces particules d'ultra-haute énergie, ainsi que les prochaines étapes à franchir pour mettre au point un futur détecteur de grande échelle. Trois observatoires de grande échelle sont actuellement en fonctionnement, et pour améliorer la compréhension des données recueillies, cinq groupes de travail avaient été formés avant la conférence avec pour mission d'étudier les différences méthodologiques entre les observatoires et leurs conséquences sur les résultats obtenus. Les contributions de ces groupes ont constitué le moment fort du colloque.

Karl-Heinz Kampert, University of Wuppertal, and **Masaki Fukushima**, University of Tokyo.

ALICE looks to the skies

The ALICE experiment uses special triggers to keep an eye on high-multiplicity atmospheric muon events – and has made some intriguing observations.

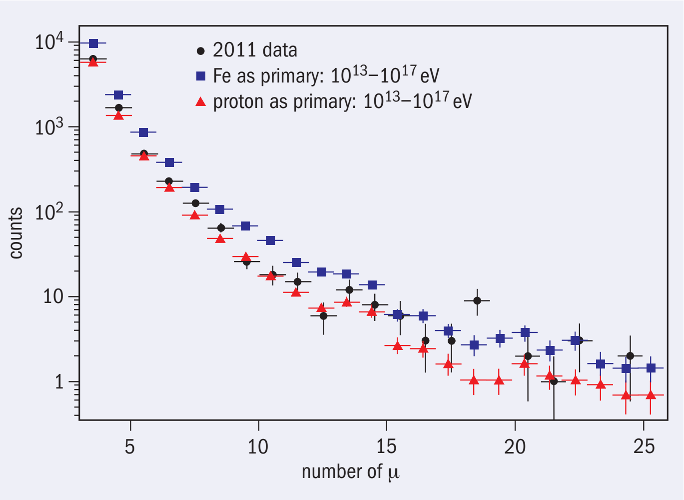


Fig. 1. Atmospheric muon multiplicity distribution for the data taken in 2011. The red triangles are the predictions assuming a pure proton primary composition while the blue squares are the predictions for pure iron.

ALICE is one of the four big experiments at CERN's LHC. It is devoted mainly to the study of a new phase of matter, the quark–gluon plasma, which is created in heavy-ion collisions at very high energies. However, located in a cavern 52 m underground with 28 m overburden of rock, it can also detect muons produced by the interactions of cosmic rays with the Earth's atmosphere.

The use of high-energy collider detectors for cosmic-ray physics was pioneered during the era of the Large Electron–Positron (LEP) collider at CERN by the L3, ALEPH and DELPHI collaborations. An evolution of these programmes is now possible at the LHC, where the experiments are expected to operate for many years, with the possibility of recording a large amount of cosmic data. In this context, ALICE began a programme of cosmic data-taking, collecting data for physics for 10 days over 2010 and 2011 during pauses in LHC operations. In 2012, in addition to this standard cosmic data-taking, a special trigger now allows the detection of cosmic events during proton–proton collision runs.

A different approach

In a typical cosmic-ray experiment, the detection of atmospheric muons is usually done using large-area arrays at the surface of the Earth or with detectors deep underground. The main purpose of such experiments is to study the mass composition and energy spectrum of primary cosmic rays in an energy range above 10^{14} eV, which is not available through direct measurements using satellites or balloons. The big advantages of these apparatuses are the large size and, for the surface experiments, the possibilities for measuring different particles, such as electrons, muons and hadrons, created in extensive air showers. Because the detectors involved in collider experiments are tiny compared with the large-area arrays, the approach and the studies have to be different so that the remarkable performances of the detectors can be exploited.

The first different characteristic for experiments at LEP or the LHC is the location, being some 50–140 m underground. These are in an intermediate situation between surface arrays – where all of the components of the shower can be detected – and detectors deep underground, where only the highest-energy muons (usually of the order of 1 TeV at the surface) are recorded. In particular for ALICE, all of the electromagnetic and hadronic components are absorbed by the rock overburden and apart from neutrinos only muons with an energy greater than 15 GeV reach the detectors. The special features that are brought by ALICE are the ability to detect a clean muon component with a low-energy cut-off, allowing a larger number of detected events compared with deep underground sites, combined with the ability to measure a greater number of variables, such as momentum, arrival time, density and direction, than was ever achieved by earlier experiments.

The tradition in collider experiments, and also in ALICE, is to use these muons mainly for the calibration and alignment of the detectors. However, during the commissioning of ALICE, specific triggers were implemented to develop a programme of cosmic-ray physics. These employ three detectors: A COsmic Ray DEtector (ACORDE), time-of-flight (TOF) and the silicon pixel detector (SPD).

For ALICE, apart from neutrinos only muons with an energy greater than 15 GeV reach the detectors.

ACORDE is an array of 60 scintillator modules located on the three upper faces of the ALICE magnet yoke, covering 10% of its area. The trigger is given by the coincidence of the signals in at least two different modules. The TOF is a cylindrical array of multi-gap resistive-plate chambers, with a large area that completely surrounds the time-projection chamber (TPC), which is 5 m long and has a diameter of 5 m. The cosmic trigger requires a signal in a read-out channel (a pad) in the upper part of the TOF and another in a pad in the opposite lower part. The SPD consists of two layers of silicon pixel modules located close to the interaction point. The cosmic trigger is given by the coincidence of two signals in the top and bottom halves of the outer layer.

The track of an atmospheric muon crossing the apparatus can be reconstructed by the TPC. This detector's excellent tracking performance can be exploited to measure the main characteristics of the muon – such as momentum, charge, direction and spatial distribution – with good resolution, while the arrival time can be measured with a precision of 100 ps with the TOF. In particular the ability to track a high density of muons – unimaginable with a standard cosmic-ray apparatus – together with the measurement of all of these observables at the same time, permits a new approach to the analysis of cosmic events, which has so far not been exploited. For these reasons, the main research related to the physics of cosmic rays with the ALICE experiment has centred on the study of the muon-multiplicity distribution and in particular high-density events.

The analysis of the data taken in 2010 and 2011 revealed a muon multiplicity distribution that can be reproduced only by a mixed composition. Figure 1 (previous page) shows the multiplicity distribution for real data taken in 2011, together with the points predicted for pure-proton and pure-iron composition for the primaries. It is clear from the simulation that the lower multiplicities are closer to the pure-proton points, while at higher multiplicities the data tend to approach the iron points. This behaviour is expected from a mixed composition that on average increases the mass of the primary when its energy increases, a result confirmed by several previous experiments.

High-multiplicity events

However, a few events found both in 2010 and in 2011 (beyond the scale of figure 1) have an unexpectedly large number of muons. In particular, the highest multiplicity reconstructed by the TPC has a muon density of 18 muons/m^2. Figure 2 shows the display of this event and gives an idea of the TPC's capabilities in tracking such high particle densities without problems of saturation, a performance never achieved in previous experiments.

The estimated energy of the primary cosmic ray for this event is at least 3×10^{16} eV, assuming that the core of the air shower is inside ALICE and that the primary particle is an iron nucleus. Recalling that the rate of cosmic rays is 1 m^{-2} year^{-1} at the energy of the knee in the spectrum (3×10^{15} eV), and that over one decade in energy the flux decreases by a factor of 100, an event with this muon density is expected in ALICE in 4–5 years of data. Since other events of high multiplicity have been found in only 10 days of data-taking, further investigation and detection will be necessary to understand whether they are caused by standard cosmic rays – and if the high multiplicity is simply a statistical fluctuation – or whether they have a different production mechanism. A detailed study of these events has not shown any unusual behaviour in the other measured variables.

For all of these reasons it is important to see whether other unexpected high-multiplicity events are detected in future and at what rate. To this end, in addition to standard cosmic runs, a special trigger requiring the coincidence of at least four ACORDE modules has been implemented this year to record cosmic events during proton–proton collisions, and so increase the time for data-taking to more than 10 times that of the existing data.

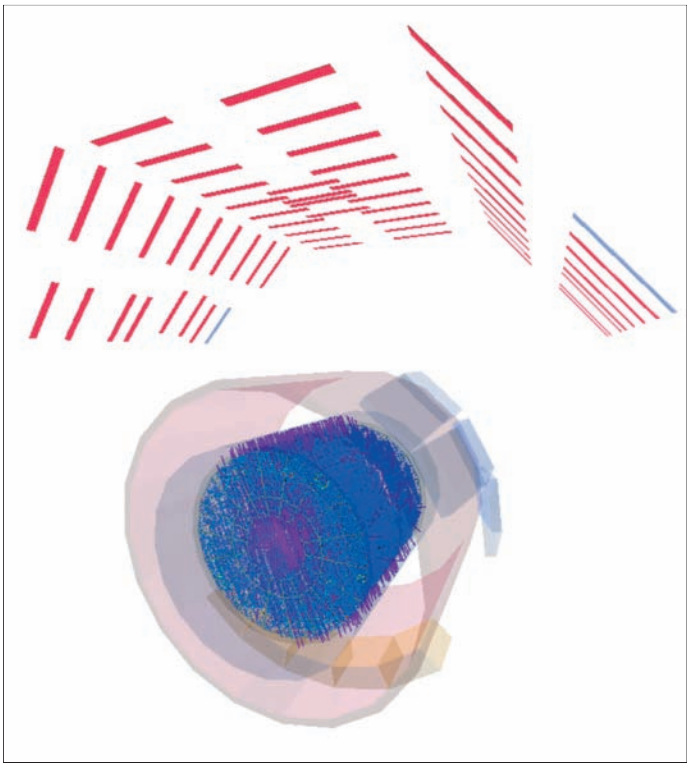


Fig. 2. Display of a very high muon-multiplicity event. The event produced a signal in 58 ACORDE modules (red rectangles above the cylinder of the TPC).

It is interesting to note that the three LEP experiments – L3, ALEPH and DELPHI – also found an excess of high-multiplicity events that were not explained by Monte Carlo models. The hope with ALICE is to find and study a large number of these events in a more quantitative way to understand properly their nature.

Résumé

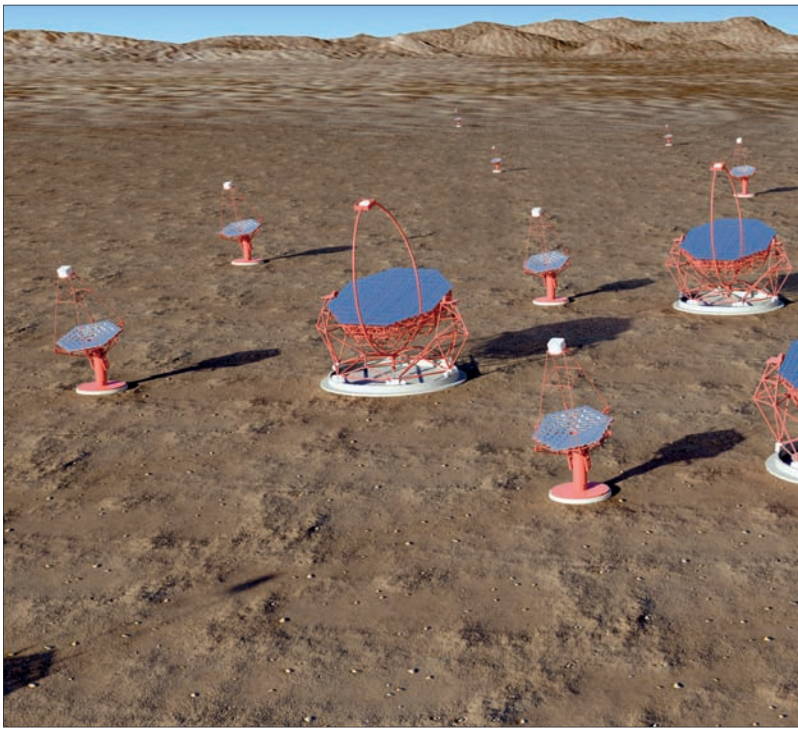
ALICE lève les yeux au ciel

ALICE est l'une des quatre grandes expériences LHC du CERN. Le détecteur est principalement dédié à l'étude d'un nouvel état de la matière, le plasma quark–gluon, créé lors de collisions entre ions lourds à de très grandes énergies. Cependant, bien que situé dans une caverne à 52 m de profondeur et recouvert de 28 m de roche, il peut aussi détecter les muons produits par les interactions des rayonnements cosmiques avec l'atmosphère. L'expérience utilise un déclencheur spécifique pour surveiller les événements muoniques atmosphériques de haute multiplicité et a déjà réalisé quelques observations intéressantes.

Bruno Alessandro, INFN Torino, and **Mario Rodriguez**, Autonomous University of Puebla, Mexico.

Cherenkov Telescope Array i

A new window into astroparticle physics has been unlocked over the past decade, with very high-energy gamma-ray astronomy based on the detection of air Cherenkov radiation having become a reality. In the next few years, the Cherenkov Telescope Array is set to fling this window wide open.



An artist's impression of the Cherenkov Telescope Array (CTA), which will b southern hemisphere. It will include telescopes of different sizes to capture t extended energy range. The largest telescopes, detecting the lowest energies

In 2004, as the telescopes of the High Energy Stereoscopic System (HESS) were starting to point towards the skies (*CERN Courier* January/February 2005 p30), there were perhaps 10 astronomical objects that were known to produce very high-energy (VHE) gamma rays – and exactly which 10 was subject to debate. Now, in 2012, well in excess of 100 VHE gamma-ray objects are known and plans are under way to take observations to a new level with the much larger Cherenkov Telescope Array.

VHE gamma-ray astronomy covers three decades in energy, from a few tens of giga-electron-volts to a few tens of tera-electron-volts. At these high energies, even the brightest astronomical objects have fluxes of only around 10^{-11} photons $cm^{-2} s^{-1}$, and the inevitably limited detector-area available to satellite-based instruments means that their detection from space requires unfeasibly long exposure times. The solution is to use ground-based telescopes, although at first sight this seems improbable, given that no radiation with energies above a few electron-volts can penetrate the Earth's atmosphere.

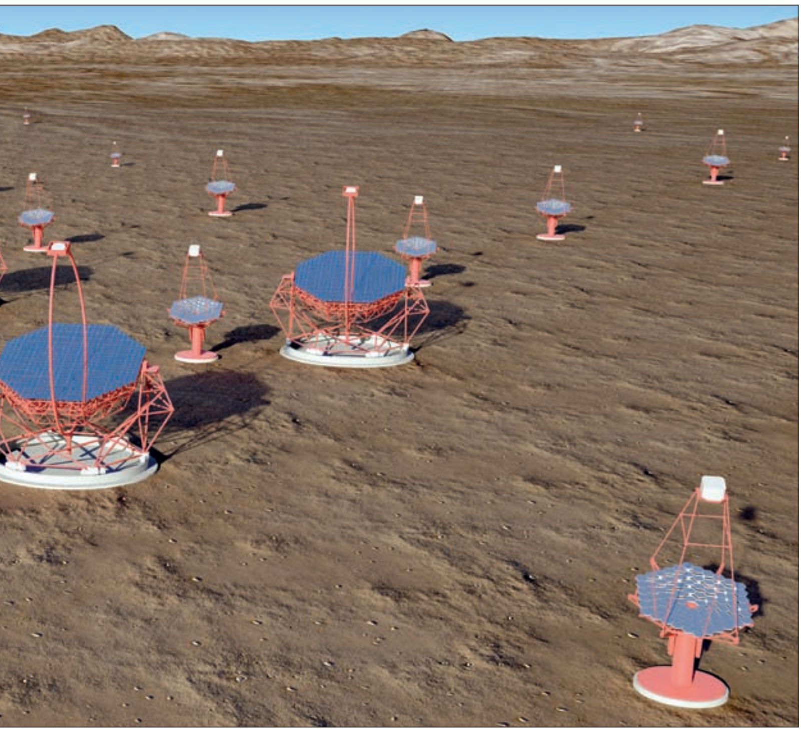
The possibility of doing ground-based gamma-ray astronomy was opened up in 1952 when John Jelley and Bill Galbraith measured brief flashes of light in the night sky using basic equipment sited at the UK Atomic Energy Research Establishment in Oxfordshire – then, as now, not famed for its clear skies (p34). This confirmed Blackett's suggestion that cosmic rays, and hence also gamma rays, contribute to the light intensity of the night sky via the Cherenkov radiation produced by the air showers that they induce in the atmosphere. The radiation is faint – constituting about one ten-thousandth of the night-sky background – and each flash is only a few nanoseconds in duration. However, it is readily detectable with suitable high-speed photodetectors and large reflectors. The great advantage of this technique is that the effective area of such a telescope is equivalent to the area of the pool of light on the ground, some 10^4 m^2.

Early measurements of astronomical gamma rays using this method were difficult to make because there was no method of distinguishing the gamma-ray-induced Cherenkov radiation from that produced by the more numerous cosmic-ray hadrons. However, in 1985 Michael Hillas at Leeds University showed that fundamental differences in the hadron- and photon-initiated air showers would lead to differences in the shapes of the observed flashes of Cherenkov light. Applying this technique, the Whipple telescope team in Arizona made the first robust detection of a VHE gamma-ray source – the Crab Nebula – in 1989. When his technique was combined with the arrays of telescopes developed by the HEGRA collaboration and the high-resolution cameras of the Cherenkov Array at Themis, the imaging atmospheric Cherenkov technique was well and truly born.

The current generation of projects based on this technique includes not only HESS, in Namibia, but also the Major Atmospheric Gamma-Ray Imaging Cherenkov (MAGIC) project in the Canary Islands (*CERN Courier* June 2009 p20), the Very Energetic Radiation Imaging Telescope Array System (VERITAS) in Arizona (*CERN Courier* July/August 2007 p19) and CANGAROO, a collaborative project between Australia and Japan, which has now ceased operation.

These telescopes have revealed a wealth of phenomena to be studied. They have detected the remains of supernovae, binary star systems, highly energetic jets around black holes in distant galaxies, star-formation regions in our own and other galaxies, as well as many other objects. These observations can help not only with

is set to open new windows



be built at two sites – one in the northern hemisphere and one in the
the Cherenkov light from showers produced by gamma rays across an
es, will be 23 m in diameter. (Image credit: G Pérez/IAC/SMM.)

understanding more about what is going on inside these objects but also in answering fundamental physics questions concerning, for example, the nature of both dark matter and gravity.

The field is now reaching the limit of what can be done with the current instruments, yet the community knows that it is observing only the "tip of the iceberg" in terms of the number of gamma-ray sources that are out there. For this reason, some 1000 scientists from 27 countries around the world have come together to build a new instrument – the Cherenkov Telescope Array (CTA).

The Cherenkov Telescope Array

The aim of the CTA consortium is to build two arrays of telescopes – one in the northern hemisphere and one in the southern hemisphere – that will outperform current telescope systems in a number of ways. First, the sensitivity will be a factor of around 10 better than any current array, particularly in the "core" energy range around 1 TeV. Second, it will provide an extended energy range, from a few tens of giga-electron-volts to a few hundred tera-electron-volts. Third, its angular resolution at tera-electron-volt energies will be of the order of one arc minute – an improvement of around a factor of four on the current telescope arrays. Last, its wider field of view will allow the array to survey the sky some 200 times faster at 1 TeV.

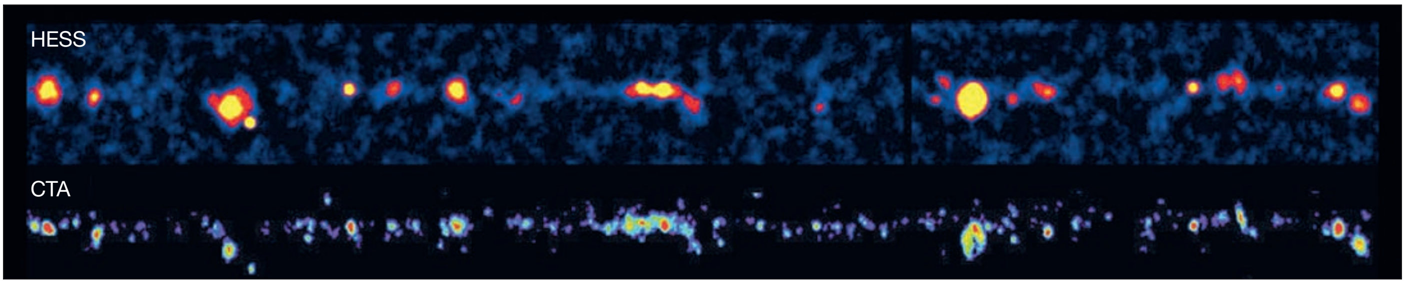
This unprecedented performance will be achieved using three different telescope sizes, covering the low-, intermediate- and high-energy regimes, respectively. The larger southern-hemisphere array is designed to make observations across the whole energy range. The lowest-energy photons (20–200 GeV) will be detected with a few large telescopes of 23 m diameter. Intermediate energies, from about 200 GeV to 1 TeV, will be covered with some 25 medium-size telescopes of 12 m diameter. Gamma rays at the highest energies (1–300 TeV) produce so many Cherenkov photons that they can be easily seen with small (4–6 m diameter) telescopes. These extremely energetic photons are rare, however, so a large area must be covered on the ground (up to 10 km^2), needing as many as 30 to 70 small telescopes to achieve the required sensitivity. The northern-hemisphere array will cover only the low and intermediate energy ranges and will focus on observations of extragalactic objects.

Being both an astroparticle-physics experiment and a true astronomical observatory, with access for the community at large, the CTA's science remit is exceptionally broad. The unifying principle is that gamma rays at giga- to tera-electron-volt energies cannot be produced thermally and therefore the CTA will probe the "non-thermal" universe.

Gamma rays can be generated when highly relativistic particles – accelerated, for example, in supernova shock waves – collide with ambient gas or interact with photons and magnetic fields. The flux and energy spectrum of the gamma rays reflects the flux and spectrum of the high-energy particles. They can therefore be used to trace these cosmic rays and electrons in distant regions of the Galaxy or, indeed, other galaxies. In this way, VHE gamma rays can be used to probe the emission mechanisms of some of the most powerful astronomical objects known and to probe the origin of cosmic rays.

VHE gamma rays can also be produced in a top-down fashion by decays of heavy particles such as cosmic strings or the hypothetical dark-matter particles. Large dark-matter densities that arise from the accumulation of the particles in potential wells, such as near the centres of galaxies, might lead to detectable fluxes of gamma rays, especially given that the annihilation rate – and therefore the gamma-ray flux – is proportional to the square of the density. Slow-moving dark-matter particles could give rise to a striking, almost mono-energetic photon emission.

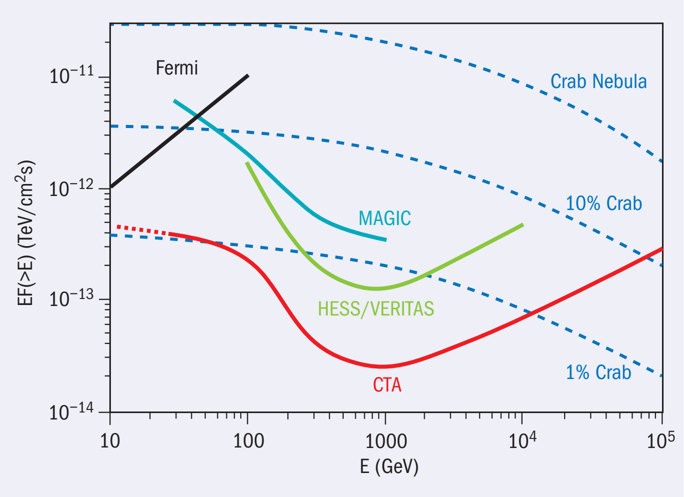
The discovery of such line emission would be conclusive evidence for dark matter, and the CTA could have the capability to detect gamma-ray lines even if the cross-section is "loop-suppressed", which is the case for the most popular candidates of dark matter, i.e. those inspired by the minimal supersymmetric extensions to the Standard Model and models with extra dimensions, such as Kaluza-Klein theory. Line radiation from these candidates is not detectable by current telescopes unless optimistic assumptions about the dark-matter density distribution are made. The more generic continuum contribution (arising from pion ▷



The inner Galaxy (within ±30° of the Galactic centre) seen in TeV gamma-rays. Top: HESS survey 2004–2006. Bottom: simulated image for the first 100 hours of CTA data, based on a population model for galactic TeV sources. Such models suggest that the CTA will detect some 1000 new gamma-ray sources over the whole sky. (Image credit: Funk et al. *AIP Conf. Proc.* ***1085*** *886.)*

production) is more ambiguous but with its curved shape it is potentially distinguishable from the usual power-law spectra produced by known astrophysical sources.

It is not only the mechanisms by which gamma rays are produced that can provide useful scientific insights. The effects of propagation of gamma rays over cosmological distances can also lead to important discoveries in astrophysics and fundamental physics. VHE gamma rays are prone to photon–photon absorption on the extragalactic background light (EBL) over long distances, and the imprint of this absorption process is expected to be particularly evident in the gamma-ray spectra from active galactic nuclei (AGN) and gamma-ray bursts. The EBL is difficult to measure because of the presence of foreground sources of radiation – yet its spectrum reveals information about the history of star formation in the universe. Already, current telescopes detect more gamma rays from AGN than might have been expected in some models of the EBL, but understanding of the intrinsic spectra of AGN is limited and more measurements are needed.



Sensitivity of the CTA compared with other air-Cherenkov telescopes (HESS, VERITAS and MAGIC) and the Fermi Gamma-ray Space Telescope.

Building the CTA

How to build this magnificent observatory? This is the question currently preoccupying the members of the CTA consortium. There is much experience and know-how within the consortium of building VHE gamma-ray telescopes around the world but nonetheless challenges remain. Foremost is driving down the costs of components while also ensuring reliability. It is relatively easy to repair and maintain four or five telescopes, such as those found in the current arrays, but maintaining 60, 70 or even 100 presents difficulties on a different scale. Technology is also ever changing, particularly in light detection. The detector of choice for VHE gamma-ray telescopes has until now been the photomultiplier tube – but these are bulky, relatively expensive and have low quantum-efficiency. Innovative telescope designs, such as dual-mirror systems, might allow the exploitation of newer, smaller detectors such as silicon photodiodes, at least on some of the telescopes. Mirror technologies are another area of active research because the CTA will require a large area of robust, easily reproducible mirrors.

The CTA is currently in its preparatory phase, funded by the European Union Seventh Framework Programme and by national funding agencies. Not only are many different approaches to telescope engineering and electronics being prototyped to enable the consortium to choose the best possible solution, but organizational issues, such as the operation of the CTA as an observatory, are also under development. It is hoped that building of the array will commence in 2014 and that it will become the premier instrument in gamma-ray astronomy for decades to come. Many of its discoveries will no doubt bring surprises, as have the discoveries of the current generation of telescopes. There are exciting times ahead.

- For more about the CTA project, see www.cta-observatory.org.

Résumé

Le réseau de télescopes Tcherenkov (CTA)

Ces dix dernières années, un nouveau domaine est apparu en physique des astroparticules, grâce aux observations sur l'effet Tcherenkov dans l'air qui ont contribué à donner corps à l'astronomie des rayons gamma de très haute énergie. Dans les années à venir, le réseau de télescopes Tcherenkov (CTA) élargira encore la perspective. Il s'agira de deux réseaux de télescopes, l'un dans l'hémisphère nord, l'autre dans l'hémisphère sud, d'une sensibilité environ 10 fois supérieure à celle des réseaux actuels. Les télescopes auront trois diamètres différents possibles, et couvriront une gamme d'énergies très vaste allant de quelques dizaines de giga-électronvolts à quelques centaines de tera-électronvolts.

Paula Chadwick, Durham University.

A neutrino telescope deep in the Mediterranean Sea

A near decade of technical design work and preparatory efforts are paying off as the construction of a first stage of the KM3NeT neutrino telescope is now imminent.

Particle physicists – like many other scientists – are used to working under well controlled laboratory conditions, with constant temperature, controlled humidity and perhaps even a clean-room environment. They would consider crazy anyone who tried to install an experiment in the field outside the lab environment, without shelter against wind and weather. So what must they think of a group of physicists and engineers planning to install a huge, highly complex detector on the bottom of the open sea?

This is exactly what the KM3NeT project is about: a neutrino telescope that will consist of an array of photo-sensors instrumenting several cubic kilometres of water deep in the Mediterranean Sea (figure 1). The aim is to detect the faint Cherenkov light produced as charged particles emerge from the reactions of high-energy neutrinos in the instrumented volume of ocean or the rock beneath it. Most of the neutrinos that are detected will be "atmospheric neutrinos", originating from the interactions of charged cosmic rays in the Earth's atmosphere. Hiding among these events will be a few that have been induced by neutrinos of cosmic origin, and these are the prime objects that the experimenters desire.

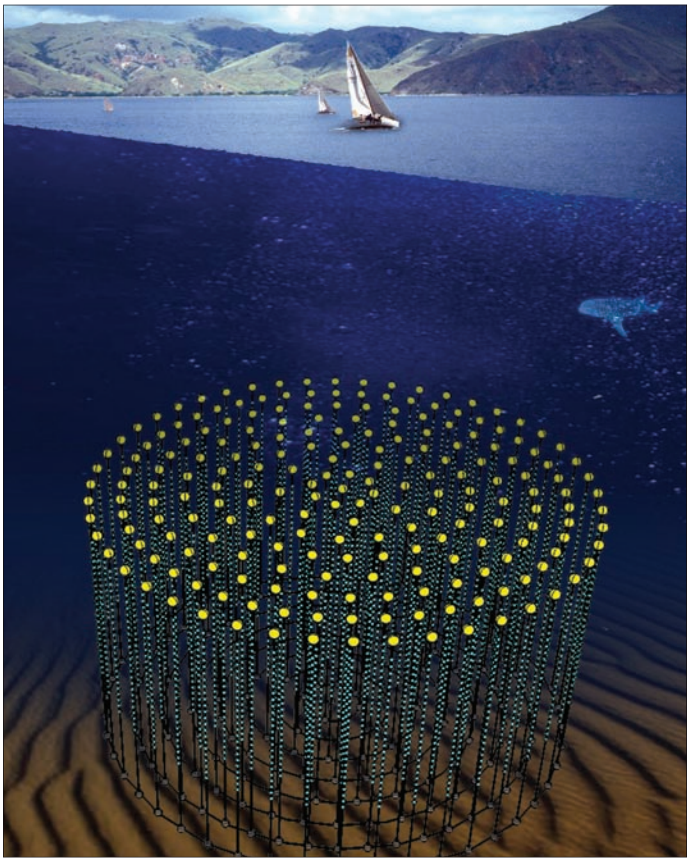


Fig. 1. Artist's impression of the KM3NeT neutrino telescope. Note that the drawing is not to scale and that KM3NeT is most likely going to be constructed in two or more large blocks that can be close to each other at the same site, or distributed across different sites. (Image credit: KM3NeT collaboration.)

Ideal messengers

Why are a few cosmic neutrinos worth the huge effort to construct and operate such an instrument? A century after the discovery of cosmic rays, the start of construction of the KM3NeT neutrino telescope marks a big step forwards in understanding their origin and solving the mystery of the astrophysical processes in which they acquire energies that are many orders of magnitude beyond the reach of terrestrial particle accelerators. This is because neutrinos are ideal messengers from the universe: they are neither absorbed nor deflected, i.e. they can escape from dense environments that would absorb all other particles; they point back to their origin; and they are produced inevitably if protons or heavier nuclei with the energies typical of cosmic rays – up to eight orders of magnitude above the LHC beam energy – scatter on other nuclei or on photons and thereby signal astrophysical acceleration of nuclei.

Only a handful of neutrinos assigned to an astrophysical source would convey the unambiguous message that this source accelerates nuclei – a finding that can not be achieved any other way. Of course, much more can be studied with neutrino telescopes. Cosmic neutrinos might signal annihilations of dark-matter particles, and their isotropic flux provides information about sources that cannot be resolved individually. Moreover, atmospheric neutrinos could be used to make measurements of unique importance for particle physics, such as the determination of the neutrino-mass hierarchy.

Driven by the fundamental significance of neutrino astronomy, a first generation of neutrino telescopes with instrumented ▷

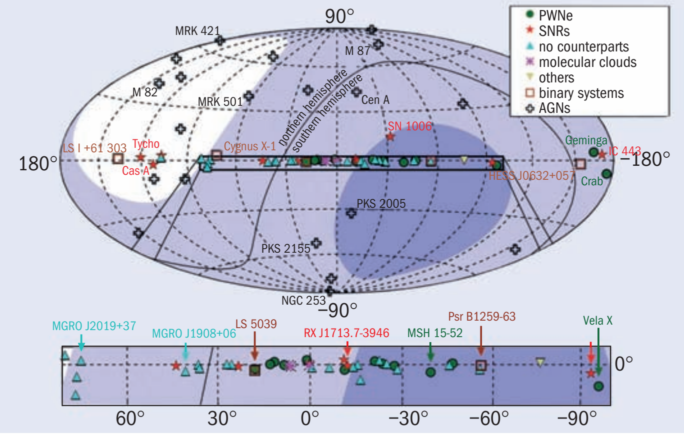


Fig. 2. Sky coverage in Galactic co-ordinates for neutrino telescopes at the South Pole and in the Mediterranean Sea, assuming a 2π downward sensitivity. The shades of blue indicate the fraction of time a given source is visible from the Mediterranean. Also indicated are potential neutrino sources observed with high-energy gamma-ray telescopes. (Image credit: Alexander Kappes/Univ. Erlangen & HU Berlin.)

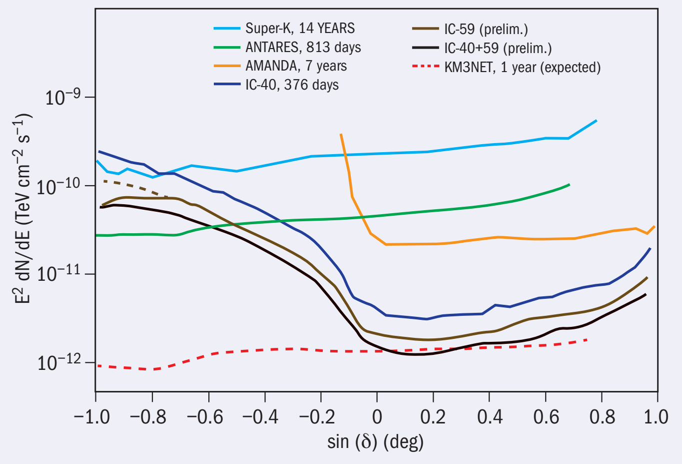


Fig. 3. Point-source neutrino-flux sensitivities (median expected limits at 90% CL) from various experiments. The expected sensitivity for KM3NeT is for one year of data in the full detector configuration. The assumptions underlying this analysis are conservative. (Image credit: U Katz and C Spiering 2012 Prog. Part. Nucl. Phys. ***67*** *651)*

volumes up to about a per cent of a cubic kilometre was constructed over the past two decades: Baikal, in the homonymous lake in Siberia; AMANDA, in the deep ice at the South Pole; and ANTARES, off the French Mediterranean coast. These detectors have proved the feasibility of neutrino detection in the respective media and provided a wealth of experience on which to build. However, they have not – yet – identified any neutrinos of cosmic origin.

These results and the evolution of astrophysical models of potential classes of neutrino sources over the past few years indicate that, in fact, much larger target volumes are necessary for neutrino astronomy. The first neutrino telescope of cubic-kilometre size, the IceCube observatory at the South Pole, was completed in December 2010 (*CERN Courier* March 2011 p28). Its integrated exposure is growing rapidly and the discovery of a first source may be just round the corner.

Why then start constructing another large neutrino telescope? Would it not be better to wait and see what IceCube finds? To answer this question it is important to understand in somewhat more detail the way in which neutrinos are actually measured.

The key reaction is the charged-current (mostly deep-inelastic) scattering of a muon-neutrino or muon-antineutrino on a target nucleus. In such a reaction, an outgoing muon is produced that, on average, carries a large fraction of the neutrino energy and is emitted with only a small angular deflection from the neutrino direction. The muon trajectory – and thus the neutrino direction – is reconstructed from the arrival times of the Cherenkov light in the photo-sensors and the positions of the sensors. This method is suitable for the identification of neutrinos if they come from the opposite hemisphere, i.e. through the Earth. If they come from above, then the resulting muons are barely distinguishable from “atmospheric” muons that penetrate to the detector and are much more numerous. Neutrino telescopes therefore look predominantly “downwards” and do not cover the full sky. IceCube, being at the South Pole, can thus observe the Northern sky but not the Galactic centre and the largest part of the Galactic plane (figure 2).

The KM3NeT telescope will have the Galactic centre and central plane of the Galaxy in its field of view and will be optimized to discover and investigate the neutrino flux from Galactic sources. Shell-type supernova remnants are a particularly interesting kind of candidate source. In these objects the supernova ejecta hit interstellar material, such as molecular clouds, and form shock fronts. Gamma-ray observations show that these are places where particles are accelerated to very high energies – but there is an intense debate as to whether these gamma rays stem from accelerated electrons and positrons or hadrons. The only way to give a conclusive answer is through observing neutrinos. Figure 3 shows the sensitivity of KM3NeT and other different experiments to neutrino point sources. According to simulations based on model calculations using gamma-ray measurements by the High Energy Stereoscopic System (HESS) – an air Cherenkov telescope – KM3NeT could make an observation of the supernova remnant RX J1713.7-3946 (figure 4) with a significance of 5σ within 5 years, if the emission process is purely hadronic.

The construction of a neutrino telescope of this sensitivity within a realistic budget faces a number of challenges. The components have to withstand the hostile environment with several hundred bar of static pressure and extremely aggressive salt water. That limits the choice of materials, in particular as maintenance is difficult or even impossible. In addition, background light from the radioactive decay of potassium-40 and bioluminescence causes high rates of photomultiplier hits, while the deployment of the detector requires tricky sea operations and the use of unmanned

The collaboration is confident that it can construct a detector of 5–6 km³ for €220–250 million.

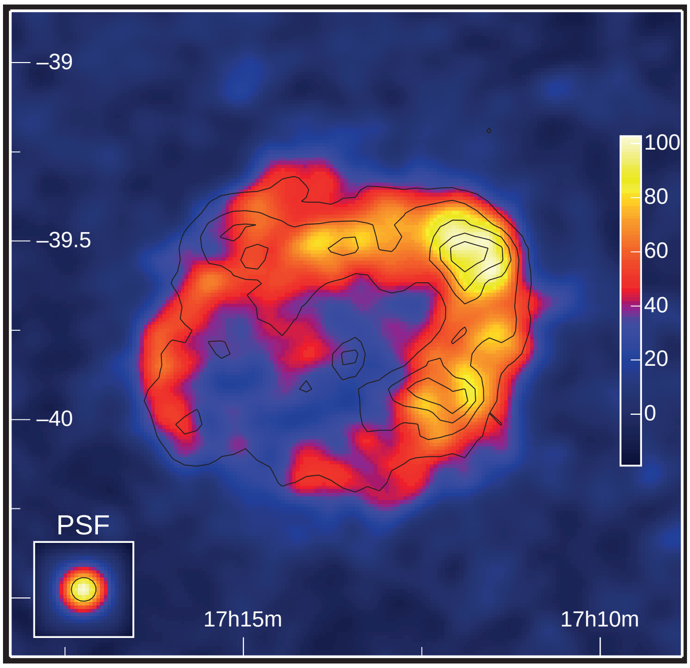


Fig. 4. Gamma-ray image of the supernova remnant RX J1713.7 –3946, from the HESS telescope; superimposed are contours of X-ray surface brightness from the ASCA satellite. (Image credit: HESS collaboration F Aharonian et al. A&A ***464*** *235.)*

Fig. 5. A prototype of the KM3NeT digital optical module. (Image credit: Marco Kraan/Nikhef.)

submersibles to make cable connections.

When the KM3NeT design effort started out with an EU-funded Design Study (2006–2009), a target cost of € 200 million for a cubic-kilometre detector was defined. At the time, this was considered utterly optimistic in view of the investment cost for ANTARES of about €20 million. Now, in 2012, the collaboration is confident that it can construct a detector of 5–6 km^3 for € 220–250 million. This enormous development is partly a result of optimizing the neutrino telescope for slightly higher energies, which implies larger horizontal and vertical distances between the photosensors. The main progress, however, has been in the technical design. Almost all of the components have been newly designed, in many cases pursuing completely new approaches.

The design of the optical module is a prime example. Instead of a large, hemispherical photomultiplier (8- or 10-inch diameter) in a glass sphere (17-inch diameter), the design now uses as many as 31 photomultipliers of 3-inch diameter per sphere (figure 5). This triples the photocathode area for each optical module, allows for a clean separation of hits with one or two photo-electrons and adds some directional sensitivity.

All data, i.e. all photomultiplier hits, will be digitized in the optical modules and sent to shore via optical fibres. At the shore station, a data filter will run on a computer cluster and select the hit combinations in which the hit pattern and timing are compatible with particle-induced events.

Three countries (France, Italy and the Netherlands) have committed major contributions to an overall funding of € 40 million for a first construction phase; others (Germany, Greece, Romania and Spain) are contributing at a smaller level or have not yet made final decisions. It is expected that final prototyping and validation activities will be concluded by 2013 and that construction will begin in 2013–2014. The installation will soon substantially exceed any existing northern-hemisphere instruments in sensitivity, thus providing discovery potential from an early stage.

Last, astroparticle physicists are not alone in looking forward to KM3NeT. For scientists from various areas of underwater research, the detectors will provide access to long-term, continuous measurements in the deep sea. It will provide nodes in a global network of deep-ocean observatories and thus be a truly multidisciplinary research infrastructure.

- For more information, see the *KM3NeT Technical Design Report* at www.km3net.org.

Résumé

KM3NeT : un télescope à neutrinos au fond de la Méditerranée

Dix ans de conception technique et de travaux préparatoires sont sur le point de porter leurs fruits, avec le début imminent de la première étape de la construction du télescope à neutrino KM3NeT, dans la Méditerranée. KM3NeT sera composé d'un réseau de photomultiplicateurs couvrant plusieurs kilomètres cube d'eaux profondes, et cherchera à détecter la lumière Tcherenkov émise lors des interactions des neutrinos de haute énergie. Ce détecteur qui, comme tous les télescopes à neutrinos, regardera « vers le bas », sera complémentaire du détecteur IceCube (au Pôle sud). Le centre et le plan de notre galaxie étant dans son champ de vision, KM3NeT sera optimisé pour découvrir et étudier les flux de neutrinos provenant de sources galactiques.

Uli Katz, University of Erlangen-Nürnberg, and KM3NeT collaboration.

100 years of cosmic rays

The discovery of air-Cherenkov radiation

In 1952 a simple and audacious experiment allowed the first observation of Cherenkov light produced by cosmic rays passing through the atmosphere, giving birth to a new field of astronomy.

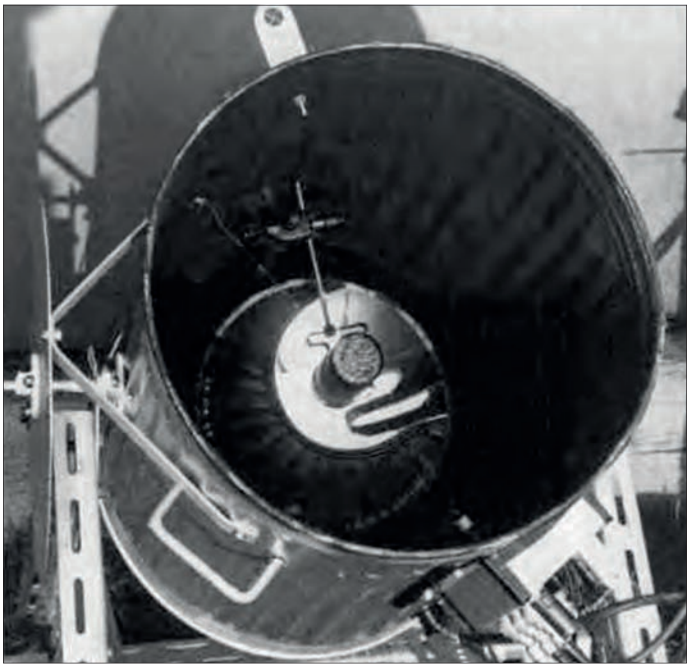
Sixty years ago, in September 1952, two young researchers at the UK's Atomic Energy Research Establishment went out on a moonless night into a field next to the Harwell facility equipped with little more than a standard-issue dustbin containing a Second World War parabolic signalling mirror only 25 cm in diameter, with a 5 cm diameter photomultiplier tube (PMT) at its focus, along with an amplifier and an oscilloscope. They pointed the mirror at the night sky, adjusted the thresholds on the apparatus and for the first time detected Cherenkov radiation produced in the Earth's atmosphere by cosmic rays (Galbraith and Jelley 1953).

William (Bill) Galbraith and John Jelley were members of Harwell's cosmic-ray group, which operated an array of 16 large-area Geiger-Müller counters for studying extensive air showers (EAS) – the huge cascades of particles produced when a primary cosmic particle interacts in the upper atmosphere. Over several nights, by forming suitable coincidences between the Geiger-Müller array and their PMT, Jelley and Galbraith demonstrated – unambiguously – a correlation between signals from the array and light pulses of short duration (<200 ns) with amplitudes exceeding 2–3 times that of the night-sky noise. By cross-calibrating with alpha particles from a ^{239}Pu source, they were further able to estimate that they were detecting three photons per square centimetre per light flash in the wavelength range of 300–550 nm. A new age of Cherenkov astronomy was born.

The sky at night

Five years before this observation, at a meeting of the Royal Society's Gassiot Committee in July 1947 on "The emission spectra of the night sky and aurorae", Patrick Blackett had presented a paper in which he suggested, for the first time, that Cherenkov radiation emitted by high-energy cosmic rays should contribute to the light in the night sky. Blackett estimated the contribution of cosmic-ray-induced Cherenkov light to be 0.01% of the total intensity, concluding: "Presumably such a small intensity of light could not be detected by normal methods." Blackett's work went largely unnoticed until a chance meeting at Harwell in 1952, which Jelley later recounted (Jelley 1986): "… hearing of our work on Cherenkov light in water, [Blackett] quite casually mentioned that … he had shown that there should be a contribution to the light of the night sky, amounting to about 10^{-4} of the total, due to Cherenkov radiation produced in the upper atmosphere from the general flux of cosmic rays." Jelley continued: "Blackett was only with us a few hours, and neither he nor any of us ever mentioned the possibility of pulses of Cherenkov light, from EAS. It was a few days later that it occurred to Galbraith and myself that such pulses might exist and be detectable."

The work of 1952 demonstrated the presence of short-


The detector used for the first observations of atmospheric-Cherenkov radiation: a dustbin with a small parabolic mirror and phototube. (Image credit: Courtesy G Hallewell.)

They pointed the mirror at the sky and detected Cherenkov radiation produced in the atmosphere by cosmic rays.

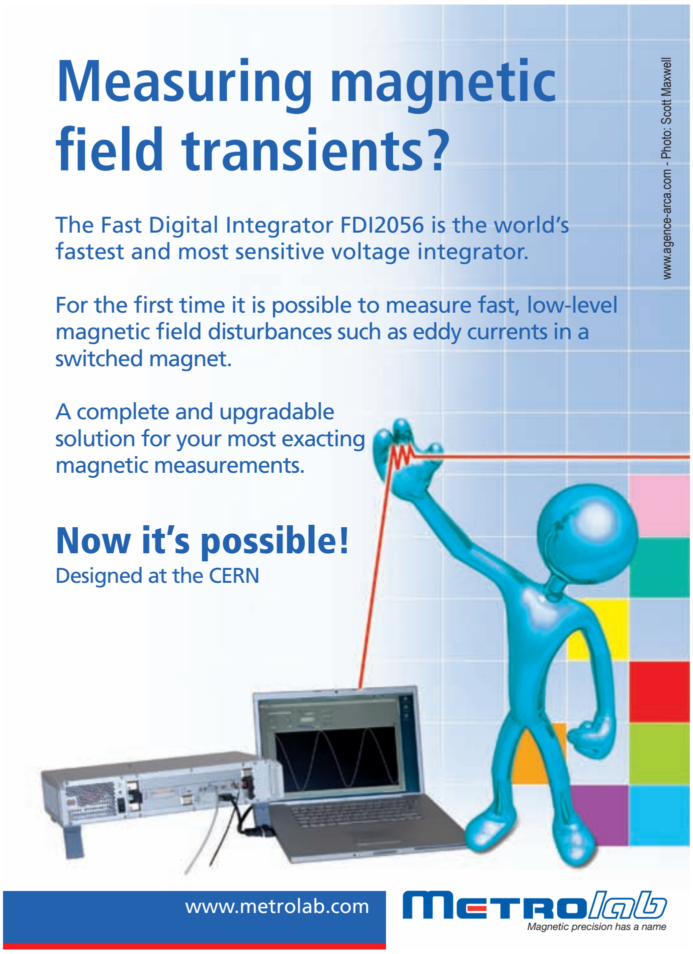
duration pulses of light in coincidence with EAS but it did not prove that the light was, indeed, Cherenkov radiation. In particular, Galbraith and Jelley were aware that the light that they had observed could be also be produced either by bremsstrahlung or by recombination following ionization in the atmosphere. Thus, in the summer of 1953, they set out to establish the Cherenkov nature of the light pulses that they had observed.

Daunted by the vagaries of the British weather, they headed to the Pic du Midi observatory in France where, over six moonless weeks in July to September 1953, they carried out a series of experiments to determine the polarization and directionality of the light and also performed a rudimentary wavelength determination. This time they were equipped with four mirrors and two types of PMT. Conscious that the light-pulse counting rate would change with the noise level of the night sky, which in turn would depend on which part of the sky they were looking at, they devised a method of keeping the mean PMT current and, hence the noise, constant by using a small lamp next to the mirror.

Experimental conditions at the top of the mountain were challenging. EAS correlations were provided by requiring coincidences of signals from the PMTs with those from a linear array of five trays of Geiger-Müller counters, each tray 800 cm^2 in area and aligned over almost 75 m – the positioning of these units was somewhat limited by the available space on the mountain (Galbraith and Jelley 1955). PMT pulses were recorded on an oscilloscope and subsequently photographed. Evidence for polarization of the observed light, a known characteristic of Cherenkov radiation, was clearly established by taking readings of a PMT with a polarizer placed over the PMT's photocathode and calculating the ratio of the number of events seen when the polarizer was aligned parallel or perpendicular to the Geiger-Müller array. The result was a ratio of 3.0±0.5 to 1 for events seen in coincidence with two Geiger-Müller counter trays (Jelley and Galbraith 1955).

The two researchers also investigated the directionality of the observed light by plotting the coincidence rate of pulses seen in two light receivers (normalized accordingly) as a function of the angle between the two receivers. This experiment was done using pairs of receivers 1 m apart and was repeated with mirrors having different fields of view. The results fell between the two theoretical curves for Cherenkov and ionization light but they gave additional support for the premise that the light being observed was, indeed, Cherenkov light. In addition, the use of wide-band filters enabled Galbraith and Jelley to demonstrate that the light contained more blue light than green, which was another expected feature of Cherenkov radiation.

During their studies on the Pic du Midi, Jelley and Galbraith went on to explore the relationship between the light yield in the atmosphere and the energy of the shower, confirming, as expected, that larger light pulses were correlated with showers with higher particle densities. Finally, aware that their light receivers had ▷



both a considerable effective area and good angular resolution, they went on to search for possible point sources of cosmic rays in the night sky. The search yielded no statistically significant variations, and Galbraith and Jelley subsequently estimated that the receiver was sensitive to showers of energies of 10^{14} eV and above.

Following these studies in the early 1950s, it soon became apparent that use of the atmosphere as a Cherenkov radiator was a viable experimental technique. By the end of the decade, Cherenkov radiation in the atmosphere had been developed further as a means for studying cosmic rays – far away from the generally unsuitable British climate. In the Soviet Union, Aleksandr Chudakov and N M Nesterova of the Lebedev Physical Institute deployed a series of large-area Geiger counters along with eight light receivers at 3800 m in the Pamir Mountains to detect the lateral distribution of the Cherenkov light and thereby study the vertical structure of cosmic-ray showers. In Australia, around the same time, Max Brennan and colleagues of the University of Sydney used two or more mis-aligned light receivers to demonstrate the effects of Coulomb scattering of the charged particles in the cosmic-ray shower.

Meanwhile, at the International Cosmic Ray Conference in Moscow in 1959, Giuseppe Cocconi made a key theoretical prediction – that the Crab Nebula should be a strong emitter of gamma rays at tera-electron-volt energies (*CERN Courier* July/August 2009 p19). This stimulated further work, both by a British–Irish collaboration that included Jelley, and by Chudakov and his colleagues. The work at the Lebedev Physical Institute led in the early 1960s to the construction of the first air-Cherenkov telescope, with 12 searchlight mirrors, each 1.5 m in diameter and mounted on railway cars at a site in the Crimea close to the Black Sea.

The legacy

So, just a decade after the initial pioneering steps by Galbraith and Jelley, the first operational air-Cherenkov telescope had been built, setting in motion a chain of events that would ultimately lead in 1989 to the observation of gamma rays from the Crab Nebula by Trevor Weekes and colleagues at the Whipple telescope in the US. This breakthrough came nearly 25 years after Weekes had worked with Jelley in a collaboration between AERE and the University of Dublin, making the first attempts to detect gamma rays from quasars – a feat achieved only recently by the MAGIC air-Cherenkov telescope in the Canary Islands (*CERN Courier* June 2009 p20). Now, researchers around the world are teaming up to build the most sensitive telescope of this kind yet – the Cherenkov Telescope Array (p28).

In writing only a few years ago about the work at Harwell, Weekes stated: “The account of these elegant experiments is a must-read for all newcomers to the field” (Weekes 2006). He also summed up well that first experiment by Galbraith and Jelley: “It is not often that a new phenomenon can be discovered with such simple equipment and in such a short time, but it may also be true that it is not often that one finds experimental physicists with this adventurous spirit!”

Heaviside, Mallet and Vavilov

The first experimental observations of Cherenkov radiation took place around the beginning of the 20th Century. In her diaries documenting her pioneering work on radium, Marie Curie makes a reference to Cherenkov light, writing: “Nor was this the end of the wonders of radium: it also gave phosphorescence to a large number of bodies incapable of emitting light by their own means.” The Curies chose not follow up these observations and it was left to a French scientist, Leon Mallet, to make the first dedicated study of the phenomenon in 1922.

A decade later, Pavel Cherenkov, working with Sergei Vavilov in the Lebedev Physical Institute, made detailed experimental studies of the radiation that was to take his name, and the effects he observed were described theoretically by colleagues at Lebedev, Il’ja Frank and Igor Tamm (*CERN Courier* November 2004 p37). In 1958, Cherenkov, Frank and Tamm received the Nobel Prize in Physics. In his Nobel lecture in 1958, Tamm explained that the name “Vavilov-Cherenkov radiation” was generally used in the Soviet Union to emphasize the decisive role of Vavilov, who had died seven years earlier.

However, it was arguably Oliver Heaviside who first predicted the phenomenon in the 1880s. In a paper published in *The Electrician* in 1888, Heaviside considered the electromagnetic effects of a moving charge, concluding: “Returning to the case of a charge q at a point moving through a dielectric, if the speed of motion exceeds that of light, the disturbances are wholly left behind the charge, and are confined within a cone.”

Heaviside’s work appears to have gone largely unnoticed until 1974, when Tom Kaiser, professor of space physics and a colleague of Galbraith, who was then at the University of Sheffield, brought it to the world’s attention in a one-page letter to *Nature*, in which he proposed that the phenomenon be renamed as “Heaviside radiation”. The following letter was from Jelley, suggesting that the name “Heaviside-Mallet radiation” might be more appropriate.

● Further reading

W Galbraith and J V Jelley 1953 *Nature* **171** 349.
W Galbraith and J V Jelley 1955 *J Atmos. Terr. Phys.* **6** 250.
J V Jelley and W Galbraith 1955 *J Atmos. Terr. Phys.* **6** 304.
J V Jelley 1986 *NATO ASI Proc.* **199** 27.
T Weekes 2006 *Proc. Int. Workshop*, “Energy Budget in the High Energy universe” 22–24 February 2006, Kashiwa, Japan, 282; arXiv:astro-ph/0606130v2.

Résumé

La découverte de l’effet Tcherenkov dans l’air

Il y a 60 ans, au Royaume-Uni, deux jeunes chercheurs partaient en expédition, une nuit sans lune, avec pour seul bagage une poubelle dans laquelle se trouvaient un petit miroir parabolique à signaux, un tube photomultiplicateur, un amplificateur et un oscilloscope. Il orientèrent leur miroir vers le ciel, ajustèrent le niveau de sensibilité de l’appareil et détectèrent pour la première fois un rayonnement Tcherenkov, produit dans l’atmosphère terrestre par des rayonnements cosmiques. Cette expérience simple mais audacieuse donna naissance à un nouveau domaine de l’astronomie.

Lee Thompson, University of Sheffield.

Faces & Places

APPOINTMENT

Lyn Evans becomes Linear Collider director

On 20 June the International Committee for Future Accelerators (ICFA) announced the appointment of Lyn Evans as Linear Collider director. Evans is the first to hold this new position, which is to lead the Linear Collider organization, created to bring the two existing large-scale linear collider programmes under one governance.

For several years the world's particle-physics community has been developing proposals for two different accelerators – the International Linear Collider (ILC) and the Compact Linear Collider (CLIC). Evans will lead the effort to unify these programmes and will represent this combined effort to the worldwide science community and funding agencies.

The two projects have recently been collaborating on technological issues that are common to both (*CERN Courier* December 2010 p7). The new leadership role unifies the two efforts, providing direction for research and development on both accelerator technologies.

Evans brings a wealth of technology and leadership experience to the position, most recently leading the construction of the LHC. In his new role, based at CERN, he will work with three associate directors, one for each of the ILC, CLIC and the associated detectors.

The appointment of the Linear Collider director followed an ICFA review of candidates nominated by members of the American, Asian and European particle-physics communities. Evans and ICFA members will discuss the appointments of the associate directors at the ICHEP 2012 meeting in Melbourne.

Lyn Evans: from LHC project leader to Linear Collider director.

FACILITIES

Davis Campus brings new life to the Homestake mine

On 30 May the Sanford Underground Research Facility introduced more than 60 government, scientific and media visitors to the new laboratories of its Davis Campus, 1478 m deep in the former Homestake gold mine in South Dakota.

The official dedication was a tribute to the decision taken by the US Department of Energy (DOE) in July 2011 to support operations and existing experiments under the Sanford name and to pursue options for additional experiments, including Fermilab's Long Baseline Neutrino Experiment. In December 2010, the National Science Board, which oversees the US National Science Foundation, had decided to stop funding development of the Deep Underground Science and Engineering Laboratory (DUSEL) in the mine (*CERN Courier* September 2009 p29).

Two major experiments occupy the Davis Campus. LUX is a dark-matter search in the cavern where Ray Davis began looking for solar neutrinos in the mid-1960s. The solar neutrino problem he uncovered precipitated the modern era of neutrino physics, which led eventually to his 2002 Nobel Prize. Davis' widow, Anna, was on hand for the campus dedication and was given a mounted piece of the tank that held her husband's experiment, where LUX now stands.

The MAJORANA DEMONSTRATOR occupies a nearby laboratory, testing a design for achieving the absence of background essential for detecting neutrinoless double beta decay, the signal that neutrinos are their own antiparticles. Shielding from cosmic-ray debris – plus the nature of radioactivity from surrounding rock – are what make the Davis Campus one of the world's best locations for such exquisitely sensitive experiments.

Guests at the dedication of the Davis Campus assemble in the cavern that houses the LUX experiment. (Image credit: Roy Kaltschmidt, LBNL.)

Kevin Lesko of Lawrence Berkeley National Laboratory, who led the DUSEL proposal for over a decade, now leads DOE's effort. "Each of these experiments foresees something like five years of operation, establishing world leadership in their respective searches for dark matter and neutrinoless double beta decay," he explains.

For South Dakota, represented by Governor Dennis Daugaard, former Governor Mike Rounds, and philanthropist T Denny Sanford (after whom the Sanford Lab is named), the dedication confirmed that tens of millions of dollars of public and private investment, plus the donation of the retired mine itself, had not been in vain. James Siegrist, DOE's associate director of science for high-energy physics, stood in for Office of Science director, Bill Brinkman, who was turned back by thunderstorms on his way to South Dakota. Siegrist acknowledged South Dakota's patience while awaiting the federal government's decision on the correct course and he noted the commitment and enthusiasm of Brinkman, himself and staff in the Office of Science staff for the Sanford Laboratory's promising programme.

Work is complete on tunnel network for European X-Ray Free-Electron Laser

With a length of nearly 6 km, the tunnel network for the European X-Ray Free-Electron Laser (European XFEL) in northern Germany was completed according to plan on 14 June. This new international research facility, with its 11 underground sectors, is one of the largest scientific projects in Germany.

Due to open in 2015, European XFEL will fire electrons from DESY in Hamburg to Osdorf, where high-intensity X-ray flashes will be generated and used in the experiment hall in neighbouring Schenefeld. The facility will support researchers worldwide in life sciences, materials sciences and nanotechnology. The aim is to produce up to 27,000 X-ray flashes a second, less than 100 fs long, at wavelengths of 0.05–6 nm. The next step is to equip the tunnels with the necessary infrastructure and safety devices, before installing the main components: the superconducting linear electron accelerator and the photon tunnels, undulator lines and experiment hall.

The European XFEL tunnel construction, which began in July 2010, is now complete. (Image credit: European XFEL.)

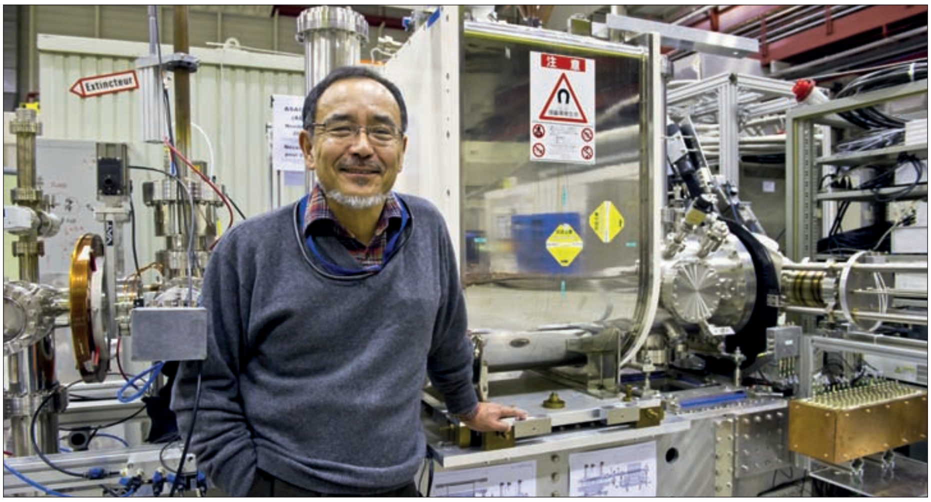
ANTIMATTER

Japanese recognition for ASACUSA's antihydrogen research

Research proposed by the cusp trap group in the ASACUSA collaboration working at CERN's Antiproton Decelerator has been approved for a further five years by the Japan Society for the Promotion of Science. The leader of the cusp group, Yasunori Yamazaki of the RIKEN research institute in Japan, has received grant-in-aid in the category of Specially Promoted Research, which is "internationally appraised research that is expected to produce outstanding results".

The grant will support ASACUSA's efforts to make high-precision microwave spectroscopy of ground-state hyperfine transitions of antihydrogen atoms extracted from the cusp trap. The trap was first successfully demonstrated in December 2010 (*CERN Courier* March 2011 p17). The work had already received a grant of around € 3 million in the same category to support the work up to March this year. It is rare in Japan that funding at this level is approved successively to the same subject and to the same person.

It has been a good 12 months for Yamazaki, who has also received several personal awards for his research. He has been honoured with the 15th Matsuo Foundation Hiroshi Takuma Memorial Award, the 52nd Toray Science and Technology Prize and the 2012 Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology.



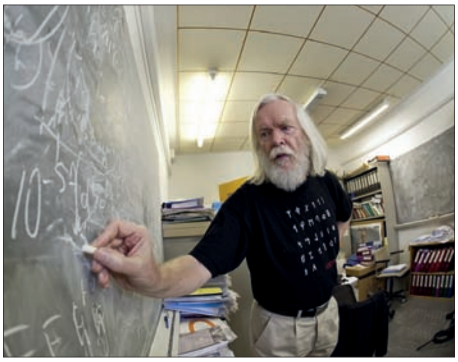
Yamazaki at the ASACUSA experiment at CERN. Behind him is the cusp magnet, which is one of the most important components of the cusp trap used in synthesizing antihydrogen.

AWARDS

John Ellis is honoured by the Queen

John Ellis, now Clerk Maxwell Professor of Theoretical Physics at King's College London, is to become a Commander of the Order of the British Empire (CBE) for services to science and technology, announced in the Queen's Birthday Honours list for 2012. Well known throughout the particle-physics community, John has been a familiar face at CERN, where he worked for 33 years before retiring in 2011. One of the UK's most influential and eminent particle physicists, he provides an important bridge between theoretical and experimental domains and is also widely admired for his efforts to involve non-European nations in CERN's scientific activities.

Also honoured this year is Michael Sterling, chair of the UK's Science and Technology Facilities Council, who has been awarded a knighthood for his services to higher education, science and engineering.



John Ellis at CERN before his move to King's College London in 2011.

Leon Lederman receives the Vannevar Bush award

In a ceremony on 3 May, the National Science Board of the US National Science Foundation (NSF) awarded Leon Lederman the 2012 Vannevar Bush award. This award, established in 1980, is named after the presidential science adviser who helped create the NSF. It honours exceptional, lifelong leaders in science and technology who have made substantial contributions to science, technology and public policy.

Lederman is currently director emeritus of Fermilab, having been director from 1979 to 1989. In 1988 he received the Nobel Prize in Physics, together with Melvin Schwartz and Jack Steinberger, for their work that led to the discovery of the muon-neutrino. He has also made many contributions to the public understanding of science and the development of scientific talent, for example as a founder and the inaugural resident scholar at the Illinois Mathematics and Science Academy, a three-year residential high school for the gifted.

Nobel laureate Leon M Lederman receives the 2012 Vannevar Bush Award for his contributions to science. (Image credit: Visual Media Services, Fermilab.)

Wim Leemans wins Advanced Accelerator Concepts prize

Wim Leemans of the Lawrence Berkeley National Laboratory received the 2012 Advanced Accelerator Concepts (AAC) prize at the 15th meeting of the AAC Workshop, held in Austin on 10–15 June. He was awarded the prize for "outstanding contributions to the science and technology of laser-plasma accelerators".

Leemans, who heads the Laser Optical Systems Integrated Studies (LOASIS) programme at Berkeley, is a pioneer in the field of laser wakefield acceleration. He has also demonstrated that laser-plasma accelerator technology is practical, through a series of key advances. He now leads the project to build a compact, laser-plasma wakefield accelerator, BELLA, which in a single stage only 1 m long will accelerate an electron beam to 10 GeV (*CERN Courier* January/February 2010 p8). The award is well timed to coincide with the imminent completion of the project.

The prize, which has been awarded three times since its inception six years ago, was made possible by a donation from Bergoz Instrumentation of St Genis-Pouilly, France, manufacturers of electronic instruments for high-energy particle accelerators.

Wim Leemans holds the 3.3-cm sapphire accelerator module with which the LOASIS team accelerated electrons to 1 GeV in 2006. (Image credit: Roy Kaltschmidt, LBNL.)

INR awards the 2012 Markov prizes

The Institute for Nuclear Research (INR) of the Russian Academy of Sciences in Moscow has awarded the 2012 M A Markov Prize to Nikolai Krasnikov and Boris Zhuikov, both of the INR. They received the awards at the 10th Markov Readings in Moscow on 12 May.

Krasnikov, one of the Russian leaders in quantum field theory and particle physics, is recognized for his contribution to the development of the theory of particles and quantum fields and elaboration of the research programme at the LHC. Zhuikov, who is head of the radioisotope complex at INR, is honoured for his elaboration of methods for producing special isotopes for medicine and new hardware.

Left to right: INR deputy director Leonid Kravchuk, academician Valery Rubakov, Markov Prize 2012 laureates Nikolai Krasnikov and Boris Zhuikov, and academician Victor Matveev. (Image credit: INR RAS.)

The M A Markov Prize, which is awarded for essential contributions to theoretical and experimental studies in the field of elementary particle physics, nuclear physics and neutrino astrophysics, was established by INR in memory of Moizey Alexandrovich Markov (1908–1994), who was one of the founders of the institute. The Markov Readings are held on 13 May each year to commemorate his birthday.

CONFERENCE

Quantum theory under scrutiny in Malta

On 24–27 April the University of Malta hosted Quantum Malta 2012, the first international conference on quantum mechanics organized by the newly established EU COST Action "Fundamental Problems in Quantum Physics" (*CERN Courier* June 2011 p32). The aim of the Action is to co-ordinate and promote research in the foundations of quantum theory throughout Europe and the rest of the world. Quantum Malta 2012 was dedicated to exploring the most recent achievements in the field, in which four research topics characterize current research.

- Quantum theory without observers. This line of research explores how to formulate an observer-free quantum theory, describing measurements as they should be: physical processes having the same nature as all other physical processes, without any extra ad hoc assumptions. In this way, all puzzles with the standard quantum theory – such as the measurement problem and Schrödinger's Cat paradox – naturally go away. The most famous proposals are Bohmian mechanics, collapse models and the many-worlds interpretation.
- Effective descriptions of complex systems. Here, investigations focus on the process by which phenomenological classical equations describing macroscopic phenomena – such as heat or charge transfer – emerge from the underlying microscopic quantum dynamics. There have been major advances in recent years, partly in trying to assess to what extent quantum features remain important, when moving from the microscopic to the macroscopic domain, before giving way to classical behaviour. This could revolutionize understanding of charge transfer in photosynthetic systems, with possible technological breakthroughs in finding more efficient ways for energy production.
- Quantum theory meets relativity. This is one of the most fascinating – and at the same time difficult – research topics in theoretical physics. People believe in the correctness of both quantum theory and special relativity, yet there is a deep, unresolved tension between the two theories. The problem is how quantum effects such as non-locality and the instantaneous collapse of the wave function can cope with a relativistic universe. So far, no satisfactory solution has been found. In addition, it is still unclear how quantum mechanics and gravity can be combined in a unified description of the universe.
- From theory to experiments. Recent experimental investigations have been particularly active in exploring the limits of validity of quantum theory. Perhaps the most important issue is to assess if the superposition principle breaks down in the mesoscopic/macroscopic domain. Experiments are proliferating, using different techniques, to create macroscopic quantum superpositions. Research is also active in testing symmetry principles in quantum mechanics, such as the Pauli exclusion principle, CP violation, CTP violation and the like.

Quantum Malta 2012 was held in conjunction with the conference, "Black Holes: From Quantum To Gravity", organized by another COST Action, "Black Holes in a violent universe". Three joint sessions, each hosting two keynote speakers, were organized to foster synergies between the community working on quantum mechanics and its foundations, and the community working on black holes and astrophysics in general.

The cosmological implications of black holes were described by Joe Silk of Oxford University. In particular, he looked at the effect black holes might have had, for example, on the cosmic microwave background, and also considered how much further observations can take the current understanding of how black holes work in reality. Markus Arndt of the University of Vienna gave an overview of matter-wave experiments with molecules and nanoparticles, which aim at testing the superposition principle of quantum mechanics. He covered the roles of coherence, decoherence and of gravity in these experiments. Gian-Carlo Ghirardi of the University of Trieste reviewed spontaneous wave-function collapse models, as well as the issues related to non-locality and the tension between quantum mechanics and relativity.

Experiments at CERN's LHC are searching for "micro" black holes; Greg Landsberg of Brown University gave a detailed update of these searches as well as a report on the progress in finding the Higgs boson. Peter Biermann of the University of Alabama discussed possible avenues forward in quantum gravitation, with a focus on how different foundational principles affect the resulting theory. The transition from the microscopic to the macroscopic world was the subject of an overview by Jean Bricmont of the University of Leuven. In particular, he focused on explaining how macroscopic irreversibility can be explained starting from the underlying reversible microscopic dynamics.

● Quantum Malta 2012 was organized by Angelo Bassi (University of Trieste), Detlef Duerr (Ludwig-Maximilian University, Munich) and Jackson Said (University of Malta). The event was entirely sponsored by COST. The next meeting of the COST Action "Fundamental Problems in Quantum Physics" will be help in Bielefeld on 22–26 April 2013. For further information about Quantum Malta 2012, see: www.um.edu.mt/science/physics/astro-ph/quantummalta2012.

SPACE

Return of the neutralino

ESA astronaut and former CERN physicist Christer Fuglesang returned a special neutralino particle to CERN's director for research, Sergio Bertolucci, during a colloquium on 24 May. In 2009 CERN presented Fuglesang with the neutralino (yellow toy pictured) to accompany him on a mission to the International Space Station (ISS) (*CERN Courier* October 2009 p27). Fuglesang had returned to CERN to present an overview of the physics research at the ISS (see https://indico.cern.ch/conferenceDisplay.py?confId=187351).

Bertolucci, left, Fuglesang and a neutralino.

PUBLICATIONS

More ways to access the 'bible' of particle physics

Often referred to as the "bible" of particle physics, *The Review of Particle Physics* has been issued every two years since 1957 by the international Particle Data Group (PDG). The 2012 edition, just released, summarizes 2658 new measurements from 644 papers, with 112 comprehensive review articles covering every important subject in particle physics and cosmology.

The publication, called the PDG for short, is now more than 1400 pages in print, hence an online version available at http://pdg.lbl.gov. This version includes an interactive web application, pdgLive, to browse the PDG database. There is also a new beta-version of pdgLive, featuring print-quality displays of mathematical expressions and equations and improved cross-links with the INSPIRE information management system for high-energy physics (*CERN Courier* April 2010 p19).

A condensed 320-page *Particle Physics Booklet* will follow in September, but for those who cannot wait the 2010 booklet is now available as an Android phone app, thanks to the efforts of Igor Kreslo, a physicist at the University of Bern. Although not supported by the PDG, this application is published with their permission and includes added search functionality, making it a useful resource for researchers and teachers. Kreslo has also developed an Android application called "Particle Properties", with an interactive table of elementary particles with their main properties, including decay modes and branching ratios. Both applications are available free from Google Play http://play.google.com/store.

Peter Higgs, left, recently returned to Bristol some 70 years after he attended Cotham School, where he was inspired to study physics by the work of a former pupil, Paul Dirac. On 16 May he took part in the city's Festival of Ideas, discussing "The Higgs Boson and Paul Dirac", together with Graham Farmelo, right, author of The Strangest Man: The Life of Paul Dirac (CERN Courier *September 2009 p39). The following day, Higgs went back to his old school and unveiled a plaque in the new Dirac-Higgs science centre, and met current pupils. He also gave a talk at the University of Bristol. (Image credit: Jesse Karjalainen.)*

OBITUARY

Cornelis ‘Kees’ Zilverschoon 1923–2012

Cornelis (“Kees”) Zilverschoon, one of the pioneers of CERN, passed away on 20 April.

Kees joined CERN in May 1954, being one of the first staff to participate in the adventure of the new laboratory; the European Organization for Nuclear Research was formally founded later that year at the end of September. He retired in 1988, having contributed to CERN’s accelerator projects for more than 30 years. Few had such an impact on CERN and its strategy over so many years as he did. Kees was one of the leading personalities who made the laboratory what it is today, with a worldwide reputation.

Coming from the University of Amsterdam as an applied physicist, Kees joined the construction project of the 25 GeV Proton Synchrotron (PS) led by John Adams. He took charge of general engineering, including the organization of machine installation and, later, the setting up of an operations group. With this position, he was also a member of the Parameter Committee, collaborating most closely with Colin Ramm and Gordon Munday, who were in charge, of the magnet and the vacuum systems, respectively.

When the PS was finished, Kees chose to work on developing future projects and joined the Accelerator Research Division. He thus was one of the leading figures preparing the design and cost estimate of future large projects for CERN: the 30 GeV Intersecting Storage Rings (ISR) and the 300 GeV synchrotron, later named Super Proton Synchrotron (SPS). A fierce competition between the two projects continued for several years: substantially increasing the available collision energy with the ISR or constructing a powerful synchrotron that would provide plenty of secondary beams of a higher energy than the PS could provide.

Cornelis Zilverschoon in the Proton Synchrotron Control Room in 1960.

After the CERN Council’s decision in 1965 in favour of the ISR, Kees joined the project as deputy project leader. For several years, he also continued to lead the group examining the proposals from many member states for possible alternative locations for the SPS.

Following the foundation of the European Southern Observatory (ESO) in 1962, he was active in promoting the collaboration between CERN and ESO to provide an engineering basis for ESO. In the early 1970s, this led to the hosting of the design group of the first large telescope (3.6 m) at CERN, which provided support services and infrastructure, with Kees a devoted counsellor to the project.

While the construction of the ISR was being finished in 1970 and commissioning started, Kees succeeded Pierre Germain as director of the PS Department, where a new 50 MeV linac and the 800 MeV Booster were added to the PS. At the same time he became director of programme and budget from 1973 to 1975. After this, he returned to long-term studies, where he was co-leader of the study of the Large Electron–Positron Collider (LEP), together with Eberhard Keil and Wolfgang Schnell.

He was a member of the ISR Division until 1982 and of the LEP Division until 1988, when he reached retirement. During these years, and for a few more years during his retirement, he was chair of the CERN Council’s committee in charge of an urgent reform of the CERN pension fund.

Kees was always appreciated as being a frank, friendly and unassuming senior colleague, combining cheerfulness with a natural authority. Many will remember his wholehearted laughter resounding through some of CERN’s corridors, as well as his broad view and fast grip of the salient points when unexpected problems arose.

● *His colleagues and friends.*

MEETING

PCaPAC-2012, the **9th biennial International Workshop on Personal Computers and Particle Accelerator Controls** will take place on 4–7 December at the Variable Energy Cyclotron Centre, Kolkata. The workshop focuses on low-cost control and data-acquisition systems using PC technology, as well as on emerging technologies including the web, GUI, middleware, FPGAs, embedded systems, use of commercial off-the-shelf systems and modern rapid-development environments. The programme will include tutorials on selected topics, invited and contributed talks, as well as poster presentations. For registration and abstract submission, go to http://indico.vecc.gov.in/indico/internalPage.py?pageId=4&confId=13; for more about the conference, see www.vecc.gov.in/pcapac2012.

NEW PRODUCTS

Alibava Systems has announced the Alibava trigger card for silicon radiation detectors, based on silicon-diode sensors with one or two diode coincidence triggers. The card has a high rate of 20 kHz with inputs of 5 V, a sensor bias of 20–30 V and an output of TTL trigger pulse. The Alibava compact tracker telescope has also been launched for tracking high-energy particles with fine resolution. There are up to 16 planes (more on request) for x-y positioning. The telescope is based on Alibava boards with synchronous read-out and standard $1 \times 1\ \text{cm}^2$ silicon microstrip detectors at each station (other sizes and shapes on request). For further details, e-mail info@alibavasystems.com or see www.alibavasystems.com.

Goodfellow Cambridge Ltd has introduced wire as thin as 0.6 µm, readily available from stock in lengths ranging from just a small fraction of a metre to large production runs. The ultrathin wire is ideal for use in microfabricated devices such as integrated circuits, microelectromechanical systems, solar cells and thermal probes for biomedical applications. For more information, tel +44 1480 424 800, fax +44 1480 424 900, e-mail info@goodfellow.com, or visit www.goodfellow.com.

National Instruments has announced NI LabVIEW software and NI hardware-compatible mobile apps for iPhone, iPad and Android devices. These combine the portability, ease of use, faster start-up time and longer battery longevity of mobile devices with the power of LabVIEW. The Data Dashboard for LabVIEW and Data Dashboard Mobile for LabVIEW apps can be used to visualize measurement data using smartphone and tablet devices. For further details, tel +44 1635 523 545, fax +44 1635 523 154, e-mail info.uk@ni.com or see http://uk.ni.com.

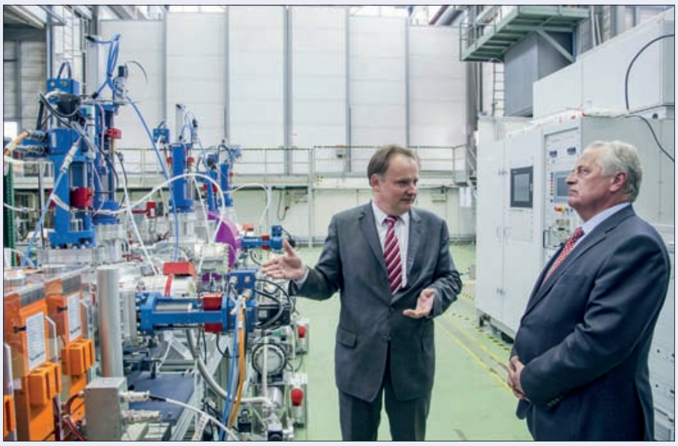
Hiden Analytical Ltd has introduced the EQ/PS Series of mass spectrometers. These provide direct real-time plasma monitoring for analysis of both process ion and process neutral species, addressing a pressure range from 10^{-3} mbar to atmosphere and featuring Hiden's Series 8 PC interface. The pulse ion counting detector gives a continuous dynamic range of a full seven decades. Atomic mass range is up to 1000 amu with energy ranges of +/– 100 eV and +/– 1000 eV. For more information, tel +44 1925 445 225, e-mail info@hiden.co.uk or visit www.hidenanalytical.com.

Specialised Imaging Ltd has announced the SIM-D, a compact ultrafast framing camera system, capable of scanning up to 1 billion frames per second. A new auxiliary viewpoint option enables users to interface high-speed video, streak cameras or time-resolve spectrometers with the SIM-D. The optical design of the SIM-D provides the choice of up to 16 separate optical channels. Effects such as parallax and shading are eliminated and the high spatial resolution is the same from frame to frame and in both axes. For further details, tel +44 1442 827 728, fax +44 1442 827 830, e-mail info@specialised-imaging.com or see www.specialised-imaging.com.

VISITS

The Turkish minister of health, **Recep Akdağ**, right, was welcomed to CERN on 22 May by **Felicitas Pauss**, CERN's head of international relations, here presenting a gift of a temperature-sensitive mug that depicts the history of the universe. While at CERN the minister also toured the ATLAS Visitor Centre.

On 23 May, **Nadia Eskndar Zkhary**, minister of scientific research for the Arab Republic of Egypt, centre, met with **Rolf Heuer**, CERN's director-general, right. **Hisham Badr**, left, permanent representative of the Arab Republic of Egypt to the United Nations Office and specialized institutions in Geneva and other international organizations in Switzerland, accompanied the minister. During the visit they attended an informal meeting with the Egyptian community at CERN.



Rudolph Hundstorfer, Austrian federal minister of labour, social affairs and consumer protection, right, visited the *Med*Austron facility at CERN on 11 July, with **Michael Benedikt**, *Med*Austron spokesperson. The minister also toured the CMS control room and the LHC superconducting-magnet test hall.

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.

IAEA
International Atomic Energy Agency

Laboratory Head

The International Atomic Energy Agency (IAEA), an independent United Nations organization headquartered in Vienna, Austria, with more than 150 Member States and a staff of 2300, serving as the global focal point for international cooperation in the safe and peaceful use of nuclear technology, is seeking a Laboratory Head for its Physics Section. **This individual will be**: (1) a *team leader* ensuring the efficient and effective development and implementation of the Nuclear Spectrometry and Applications Laboratory's (NSAL) research, training and service activities; (2) a *scientific leader* of the NSAL's research and development activities; (3) a *manager* of human resources and key activities of the NSAL; (4) an *advisor* to the Head of the Physics Section and the Director of the Division in programmatic, scientific and technical matters.

The successful candidate should have at the minimum:

- PhD in nuclear physics or a closely related field
- Minimum of 10 years of postdoctorate experience in experimental nuclear physics research and in the development of nuclear instrumentation or radiation detectors
- Strong publication record in peer reviewed journals and at international conference
- Experience with accelerator-based experiments, specifically experiments at synchrotrons and/or experiments at ion beam accelerators.

To apply for this position, **please submit an on-line application** at http://www.iaea.org/About/Jobs ***before August 17th 2012***, selecting vacancy notice no. 2012/0697.

Benefits: The IAEA offers a stimulating multicultural working environment. The post offers: **tax free remuneration; diplomatic status; rental subsidy; 6 weeks annual leave**; medical insurance coverage; a staff retirement plan; full coverage of removal expenses for staff member, family, and personal effects; additional allowance for installation expenses; assistance with finding housing and schools in the local area; financial assistance with the education of dependent children; and paid travel to the home country for the staff member and family every other year.

IAEA

Our Goal: *to facilitate the safe contribution of nuclear technologies to peace, health and prosperity throughout the world, while ensuring that no technology or material under our oversight or provided with our assistance is used to further any military purpose.*

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High Energy Physics Group
Dept of Physics & Astronomy

UCL

Lectureship in Particle Physics (UCL Reference: 1260289)

Applications are invited for a lecturer post in the High Energy Physics Group in the Department of Physics and Astronomy at UCL.

The successful candidate will be expected to take a leading role in the ATLAS upgrade project, to publish research from the current ATLAS data and to raise the funds to support their research programme. They will also be expected to participate in the Department's teaching programme at undergraduate and graduate level including: lecturing, problem-solving tutorials, laboratory demonstrating and dissertation supervision.

Depending on experience, the salary will be in the Lecturer Grade 8 range: £39,818 to £46,972 per annum inclusive of London Allowance.

More details about the application procedure, the position, the UCL ATLAS group, the High Energy Physics Group, the Department of Physics and Astronomy, and UCL can be found at **http://www.hep.ucl.ac.uk/positions/lectureship_2012.shtml**

The closing date for applications is 5pm on Monday, 3 September 2012.

The Excellence Cluster for Fundamental Physics

'Origin and Structure of the Universe'

RESEARCH FELLOWS in

Astrophysics, Cosmology, Nuclear and Particle Physics

The Excellence Cluster “Origin and Structure of the Universe” was established at the Technische Universität München (TUM) in October 2006 within the framework of the Excellence Initiative. The interdisciplinary research project unifies the physics faculties of TUM and Ludwig-Maximilians-Universität (LMU) as well as University Observatory of the LMU, several Max-Planck-Institutes (MPA, MPE, MPP, IPP) and the European Southern Observatory (ESO). The main goal of the Universe Cluster is to solve fundamental questions of physics, astrophysics, cosmology as well as nuclear and particle physics.

As part of our **FELLOWSHIP PROGRAM** we are looking for excellent young scientists on the postdoc level. Fellows will have the opportunity to work independently and potentially pursue an interdisciplinary research program in any research area of the Universe Cluster (theoretical or experimental). Fellowship appointments will be for a 3-year term and come with a budget of EUR 5K/year.

APPLICATION

Candidates should send a cover letter, a complete curriculum vitae, a list of publications, a PhD certificate, a brief statement of research accomplishments and a research plan. Please upload these separate documents in the job section of the Cluster website **www.universe-cluster.de**. Please also arrange for 3 letters of recommendation to be sent to **job@universe-cluster.de**.

Applications from women and candidates with disabilities are especially encouraged and will be given preference to other applicants with equal qualifications. The application deadline is **October 31, 2012**.

CONTACT

Technische Universität München · Excellence Cluster Universe
Dr. Andreas Müller · Boltzmannstrasse 2
85748 Garching · Germany

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ibs Institute for Basic Science

Thinking about the Future of Basic Science.

IBS/RISP has openings for:

Accelerator Scientists/Engineers

The Institute for Basic Science (IBS) was established by the Korean government in November 2011 with the goal to create a world-class research institute in the basic sciences. IBS/RISP is to develop scientific and technical expertise and capabilities for the construction of a rare isotope accelerator complex (Rare Isotope Science Project, RISP) for nuclear physics, and medical and material science and applications.

The IBS/RISP is seeking for qualified applicants to work for Rare Isotope Science Project (RISP) at its headquarters office in Daejeon, Republic of Korea. The positions are at the level of research fellow, and postdoctoral research associates and accelerator engineers. Persons with high-level research achievement, extensive experience in large scale accelerator facility construction are given higher priority. The starting date is as soon as possible.

The successful candidates will participate in the R&D and construction of accelerator systems for RISP.

If you have the appropriate skills and are looking for a diverse and interesting employment opportunity we encourage you to apply. IBS/RISP is an equal opportunity employer; all applicants will be considered on their merit. Salary and benefits will be decided upon negotiations with the Director of RISP and will become effective upon signing the contract.

Please send your application including CV and introduction to

Ms. Y.H. LEE, RISP Director’s Office at the Institute for Basic Science, 70 Yuseong-daero 1689-gil Yusung-gu, Daejeon, Korea, 305-811

or e-mail to **leeyh@ibs.re.kr.**

Applicants should arrange to have three letters of references sent to address or e-mail.

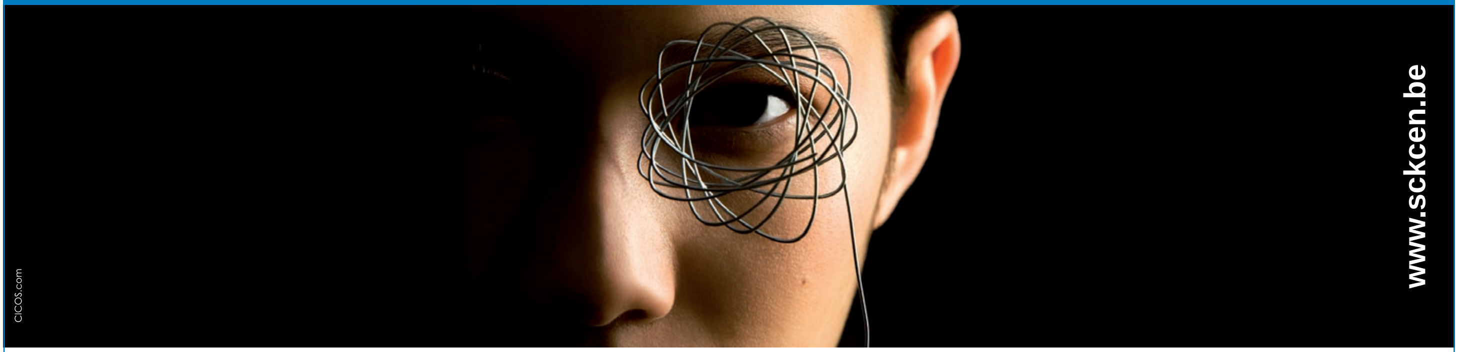
Application deadline is August 31, 2012.

Further information can be obtained by sending mail to **leeyh@ibs.re.kr.**

Deadline for applications: 31 August 2012

http://risp.ibs.re.kr

Create the technology of the future at the Belgian Nuclear Research Centre



Since its foundation in 1952, **the Belgian Nuclear Research Centre (SCK•CEN)** has been playing a pioneering role with unique achievements and groundbreaking work in the area of nuclear science and technology. Today SCK•CEN is one of the largest research centres in Belgium. About 700 people work on the development of peaceful industrial and medical applications of ionising radiation. Our goal: to strive for constant excellence in nuclear expertise and research.
With the MYRRHA project, SCK•CEN is developing an innovative fast spectrum research reactor, conceived as an accelerator driven system (ADS). MYRRHA will be used for the production of radioisotopes and doped silicon for renewable energy applications, the transmutation of radioactive waste and the study of materials for innovative fission reactors and for fusion technology.

Within the framework of this project we are looking for an **Accelerator System Engineer (3 year contract)**

As the Accelerator System Engineer you will have the full ownership of the engineering activities and their integration for the full development cycle (design phase, engineering design, prototyping, production, improvement, maintenance).

A detailed job description and the required qualifications can be found on our website: **www.sckcen.be/jobs**

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Evi Belmans, Human Resources Management, SCK•CEN, Boeretang 200 - 2400 Mol, email: ***jobs@sckcen.be***

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Faculty Positions

SINP invites applications for faculty positions at different levels from scientists having outstanding academic records and research achievements. At present, major research activities of the Institute are in the following broad areas: Atomic, Nuclear and Plasma Physics, Condensed Matter & Surface Physics, High Energy Physics, Theoretical & Mathematical Physics and Biophysical Sciences. SINP is an autonomous organization funded by the Department of Atomic Energy of Government of India to carry out basic research in the above broad areas. SINP has excellent state-of-the-art in-house facilities and also has collaborative access to various high-energy accelerators and synchrotron facilities across the world. We seek applicants, who will complement and extend our current research activities. Prospective applicants should also have interest in graduate teaching. This is a rolling advertisement (refer **http://www.saha.ac.in/cs/www/position Selection_Procedure.pdf)** and applications may be submitted anytime of the year in plain papers/e-mails with details like cover letter, resume giving entire list of publications, a statement of research plan and contact details of 5 referees. Salary and rank will be commensurate with qualifications and research experience - minimum of two years of postdoctoral experience is required.

Director, Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata 700064, INDIA; director.sinp@saha.ac.in

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Cornell University

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Accelerator Physicist/Engineer Research Associate

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE) has an immediate opening for a PhD level Accelerator Physicist/Engineer to oversee the operation and development of a 300 MeV electron linac and carry out research in accelerator physics, engineering and beam instrumentation. The successful candidate must have an exceptional track record demonstrating a high level of initiative and competence in science or engineering R&D. A strong background in particle accelerator physics or engineering and experience with high power Radio Frequency systems is highly desirable. This is a three-year appointment with expectation for renewal, subject to mutual satisfaction and availability of funds. Requirements: PhD in engineering or physics and at least five years' experience in accelerators or work relevant to accelerators.

Applications should be submitted at http://academicjobsonline.org/ (posting 1542) and should include a cover letter, a CV, a list of publications, a detailed summary of research experience and interests. Applicants must arrange to have at least three letters of recommendation from individuals who have detailed, relevant knowledge of the candidate uploaded, as per instructions on the academicjobsonline website.
For information about the position, contact
David Rice at dhr1@cornell.edu./

Cornell University is an Affirmative Action, Equal Opportunity Employer and Educator

The Deutsches Elektronen-Synchrotron (DESY) and the Humboldt-Universität zu Berlin (HU) invite applications for a joint appointment as

Leading Scientist (m/f)

at the DESY, Zeuthen site and

Full Professor (W3) for Experimental Astroparticle Physics

at the Faculty of Mathematics and Natural Sciences I – Department of Physics of the HU.

DESY, Zeuthen site, is one of the leading centres for astroparticle and particle physics. In astroparticle physics, DESY plays a leading role in gamma-ray astronomy with strong contributions to CTA, VERITAS, MAGIC, H.E.S.S., and Fermi and neutrino astronomy with the IceCube experiment. The research program in particle physics consists of strong contributions to the LHC experiments and detector development. The experimental program is enhanced by collaboration with a strong theory group. DESY collaborates closely with German groups in the framework of the Helmholtz Alliances “Astroparticle Physics” and “Physics at the Terascale” and internationally with major laboratories and institutes in astroparticle and particle physics.

DESY, Zeuthen site, is seeking to intensify and widen its research program in experimental astroparticle physics, including related particle physics research at underground laboratories. The appointee is expected to have an established international reputation in the field of astroparticle physics with a background in particle physics. He/She is expected to play a leading role in shaping the future research program of the laboratory, to foster scientific cooperation with the HU and to actively participate in the common DFG Research Training Group GK1504 “Mass, Spectrum, Symmetry: Particle Physics in the Era of the Large Hadron Collider”. The appointee is expected to contribute to the physics teaching at all levels at the HU and will have the potential to attract external funding for a creative research program.

Applicants must meet the requirements for a university professor as stipulated in § 100 of the “Berliner Hochschulgesetz”. The position will be available as of October 1st 2012. Both DESY and HU are equal opportunity employers. The goal is to enhance the percentage of women in the areas where they are underrepresented. Women, therefore, are particularly encouraged to apply. Applications of disabled persons will be preferred in cases of equal qualifications. Applicants with migration background are highly welcomed.

Deadline for application: August 15th 2012

Applications should be addressed to Prof. Dr. C. Stegmann, DESY, Platanenallee 6, 15738 Zeuthen, including the reference number **PR/018/12**. For further information Prof. Stegmann can be contacted by email (christian.stegmann@desy.de). Application materials will not be returned. Therefore, you are requested to send only copies of all documents.

Applicants are kindly asked to send their application materials both in written form as well as electronically via http://www2.physik.hu-berlin.de/ssl/desy

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HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

The Department of Physics in the Faculty of Science at the University of Helsinki invites applications for a

PROFESSOR IN THEORETICAL PHYSICS

The field of the professorship is elementary particle physics. The position is permanent.

The professor will be responsible for his/her part for teaching of and research in particle physics, especially quantum field theories in particle physics, with focus on weak interactions. The research environment consists of both theoretical research groups and groups in leading experiments in particle physics and cosmology. (Homepage of the Department of Physics: **http://www.physics.helsinki.fi/english/index.html**).

Applications should include: an academic portfolio approved by the Faculty containing a summary of supervision duties of master’s and doctoral theses and a presentation on how the applicant plans to develop his/her field and its teaching; a list of those publications and other relevant documents on competence and merits that the applicant wishes to be taken into account in the selection process; a maximum of 15 publications for experts’ perusal. More information of the application can be found at the Faculty webpages: **http://www.helsinki.fi/facultyofscience/vacancies/index.html**.

An average starting salary for a newly appointed professor is c. 5500 euros per month.

Applications addressed to the Faculty of Science must be delivered to: **Registry of the University of Helsinki. P.O. Box 33 (Yliopistonkatu 4), FI-00014 University of Helsinki, Finland**. The Faculty requests that the application and its enclosures be sent the Registry via email to the address **hy-kirjaamo@helsinki.fi**.

The closing date for applications is 31 August 2012.

More details can be obtained from **Head of Department, Professor Juhani Keinonen, +358 9 191 50005, +358 9 191 50601, juhani.keinonen@helsinki.fi.**

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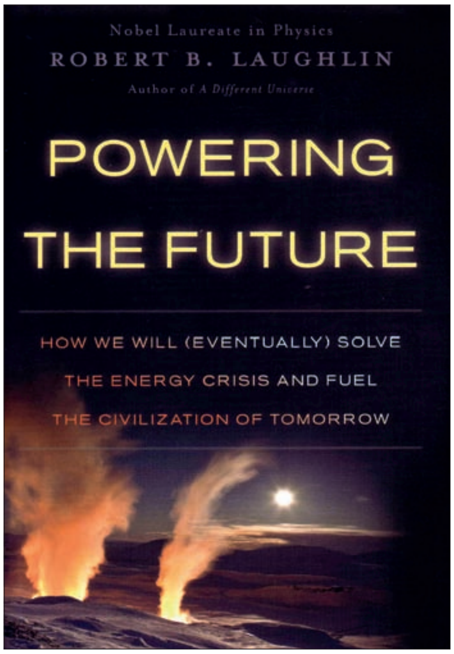
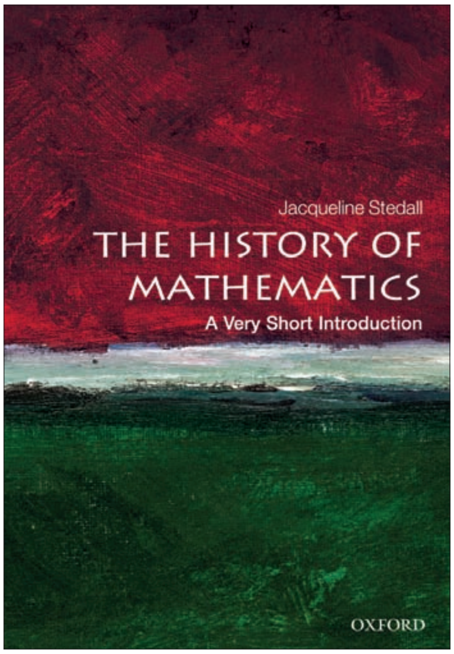
Bookshelf

Summer Bookshelf

Summer is the season of conferences for physicists, with holidays squeezed in where possible. This year many particle physicists have been working hard on preparing the latest results from the LHC, in particular searches for the Higgs boson, based on the bumper crop of data already achieved.

For those with time for reading something other than drafts of their latest papers and preprints with new results, this Bookshelf features a few books for more some different reading – or for recommending to family and friends, while the hard work continues.





Powering the Future: How We Will (Eventually) Solve the Energy Crisis and Fuel the Civilization of Tomorrow

By Robert Laughlin

Basic Books

Hardback: £17.99 $24.99

Nearly 90% of the world's economy is driven by the massive use of fossil fuels. The US spends one-sixth of its gross domestic product on oil alone, without counting the important costs of coal and natural gas, even though its use of oil and the other fossil fuels has progressively decreased since the mid-1970s. While the debate on fossil fuels continues to rage on both sides of the Atlantic, Robert Laughlin, professor of physics at Stanford University and Nobel Laureate for the fractional Hall effect, has written *Powering the Future* – a hypothetical voyage through the future, where the human race will have demands and expectations similar to those of today but where technologies will probably be quite different.

The book is essentially one of two halves. The first half contains the main chapters, where all of the essential statements and the logical lines of the various arguments are developed with an informal style. These are then complemented by the second half, which consists of a delightful set of notes. The notes encourage readers to form their own opinions on specific subjects using a number of tools, which range from assorted references to simplified quantitative estimates.

Treatises on energy problems that are written by political scientists are often scientifically inaccurate; specialized monographs are sometimes excessively technical. This book uses an intermediate register where the quantitative aspects of a problem are discussed but the overall presentation is not pedantic. Of the numerous examples, here are two short ones. What is the total precipitation that falls in one year on the world? The answer is "one metre of rain, the height of a golden retriever" (page 7 and note on page 127). What is the power-carrying capacity for the highest voltage currently used in North America? The answer is "2 billion watts" (page 46 and note on page 156) and is derived with simple mathematical tools.

Laughlin's chain of arguments forms a composite approach to the energy challenge, where fossil fuels will still be needed 200 years from now to fly aeroplanes. Nuclear power plants will inevitably (but cautiously) be exploited and solar energy will offer decisive solutions in limited environments (see chapter nine, "Viva Las Vegas!"). While the author acknowledges that market forces (and not green technology) will be the future driver of energy innovation, the book does not explicitly support any partisan cause but tries to inspect thoroughly the issues at stake.

A few tweets may not suffice to develop informed views on the energy future of the human race. On the other hand, *Powering the Future* will certainly stimulate many readers (including, I hope, physicists) to form their own judgements and to challenge some of the canned statements that proliferate on the internet these days.

● *Massimo Giovannini, CERN and INFN Milan-Bicocca.*

The History of Mathematics: A Very Short Introduction

By Jacqueline Stedall

Oxford University Press

Paperback: £7.99 $11.95

What a wonderful surprise. I was going to review another book before this one but it wasn't to my liking (actually it was pretty bad) and I gave up after the first few

chapters. So I settled instead on this book, mainly because it is short, or "very short" as the subtitle suggests.

Seeing that it was part of a series, I was expecting a typical history starting with Pythagoras and Euclid, then Newton and possibly Leibniz, Euler, Gauss and Riemann, followed by a collection of moderns, depending on how much space was left. I looked in the (excellent) index at the back (opening Q–Z) and was surprised to find no entry for Riemann. Was this British bias? No, Hardy was missing as well – but instead there were other people who I'd never heard of: William Oughtred, for example, (author of the first maths book published in Oxford) and Etienne d'Espagnet (who supplied Fermat with essential earlier works). Samuel Pepys also makes an appearance but more as an example of how little maths educated people knew in the 17th century.

I learnt in this charming book that what I had been expecting is called the "stepping stone" approach to the history of mathematics, focusing on elite mathematicians. This book is refreshingly different. It is actually more about the subject "history of mathematics", i.e. about how we compile and recount a history of mathematics rather than about a sequence of events. However, it does this by focusing on intriguing stories that show the various features that must be considered. In doing so, it fills in the water between the stepping stones, for example, in the story of Fermat's last theorem. It also tells the story of the majority of people who actually do maths – schoolchildren – by discussing the class work in a Babylonian classroom (around 1850 BC), as well as in a Cumbrian classroom around 1800.

After reading this "preview version", I am now going to get the "director's cut" – *The Oxford Handbook of the History of Mathematics*, which is co-authored by the same author with Eleanor Robson.

Happy reading and exploring!

- *Herbert Dreiner, University of Bonn.*

How the hippies saved physics: science, counterculture, and the quantum revival

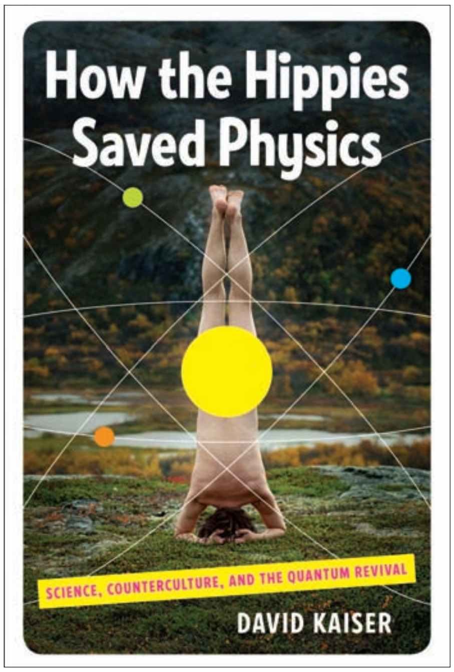
By David Kaiser

W W Norton & Company

Hardback: £17.99 $26.95

Paperback: $17.95

In this curious book, David Kaiser presents a detailed "biography" of a group of young physicists, the "Fundamental Fysics Group", based in Berkeley, California, and their unconventional impact on the development of "the new quantum age". Most of the action takes place in the 1970s and includes a surprising mixture of characters and plots, as suitably summarized in these illuminating words: "Many of the ideas that now occupy the core of quantum information science once found their home amid an anything-goes counterculture frenzy, a mishmash of spoon-bending psychics, Eastern mysticism, LSD trips, CIA spooks chasing mind-reading dreams and comparable 'Age of Aquarius' enthusiasms." These people regularly gathered to discuss all sorts of exotic topics, including telepathy and "remote viewing", as well as faster-than-light communication and the fundamental concepts of quantum theory.



Among many other things, I liked learning about early discussions regarding Bell's theorem, the Einstein-Podolsky-Rosen paradox and the nature of reality, sometimes taking place in workshops with sessions in hot baths, interspersed by drum playing and yoga exercises. I also enjoyed reading about the first experimental tests of Bell's work by John Clauser and about the genesis of the bestseller *The Tao of Physics*, by Fritjof Capra. It was particularly interesting to learn about a paper on superluminal communication (published despite negative reports from referees), which triggered the development of rebuttal arguments that ended up being quite revolutionary and leading to quantum encryption etc. It was thinking outside the "establishment" way that led to a wrong but fruitful idea about implications of Bell's theorem, which forced others to improve the understanding of quantum entanglement and gave rise to a new and highly successful branch of physics: quantum information. Kaiser's basic message is that, sometimes, crazy ideas push the understanding of science beyond the frontiers set by people working in conventional environments, within universities, and by government grants.

I know that we should not judge a book by its cover but with such a title I expected this book to be an interesting summertime read and was surprised to find that it is written in a rather heavy style that is more suitable for historians of science than for physicists relaxing on the beach. The topic of the book is actually quite curious, the language is fluid and the narrative is well presented but the level of detail is such that many readers will often feel like jumping ahead. It is elucidating to note that almost 25% of the book's 400 pages are devoted to listings of notes and of bibliography. Essentially every sentence, every paragraph, is justified by an "end note", which is an overkill for a book targeting a general audience. Writing this dense book must have been a long-term job for Kaiser, who is both a physicist and a historian. The result does not really qualify as an easy read. I enjoy reading biographies if they have a nice rhythm, some suspense and a few anecdotes here and there – which is not exactly the case for this book. I wonder how many readers end up moving it aside after realizing that they have been misled by the spirited title?

- *Carlos Lourenço, CERN.*

Niels Bohr and the Quantum Atom: The Bohr Model of Atomic Structure 1913–1925

By Helge Kragh

Oxford University Press

Hardback: £35

Next year, 2013, is the centenary of the Bohr model of the atom. One hundred years ago, the scene had been set after Max Planck had formulated the need for quanta and Ernest Rutherford had discovered the atomic nucleus. But nobody knew what atoms looked like or how they functioned. In a series of milestone papers, Niels Bohr set atomic understanding on a new path.

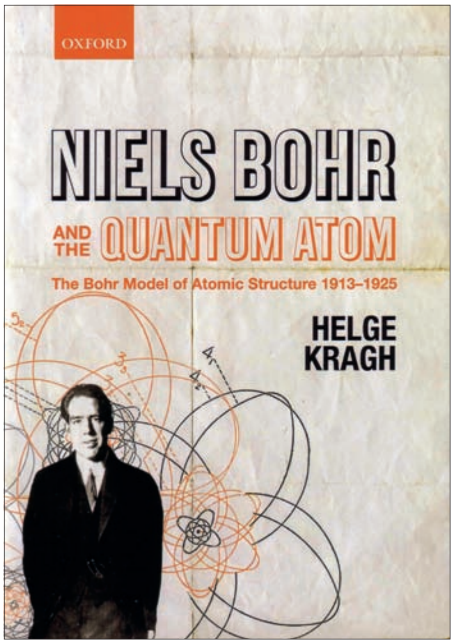
Bohr was influential and led a productive life. The broad lines have been well sketched in *Niels Bohr's Times*, the biography by Abraham Pais. In this new book, Helge Kragh fills in the details of Bohr's early career and how it affected science, not to mention Bohr himself. As befits a science historian, Kragh commendably links Bohr's enduring contributions to the painstaking efforts of the many researchers who found the various tiny pieces of the atomic jigsaw and helped fit them together.

After initial studies in Denmark, the ambitious young Bohr went to Cambridge in 1911 but his motivation was quickly quenched when he realized that his idol, J J Thomson, seemed to have lost the plot. This situation was rapidly rectified when Bohr decided instead to move to Manchester and work with the dynamic Rutherford.

In 1913 Bohr proposed his famous idea of "quantum jumps", which changed the scenery of physics and brought a new phrase into common language. His initial picture was confined to hydrogen atoms with circular electron orbits. Arnold Somerfeld extended it to bigger atoms and elliptical orbits, allowing the empirical model to keep pace with new developments, such as the Stark effect and the fine structure of atomic spectra.

With his reputation made, Bohr returned to Denmark – although the UK later tried to coax him back. Rutherford had cornered the market in nuclear physics but atomic studies were becoming a German speciality. One reason that Bohr preferred to remain in Copenhagen was that he was busy with a new challenge: he was setting up what would become a world centre for atomic physics and a staging post for young researchers from across the world.

Kragh relates how Somerfeld viewed Bohr's new scientific venture: "The Institute … should not only serve the up-and-coming generation of Denmark, it will also be an international place of work for foreign talent whose countries are no longer in a position to [support] scientific work." It sounds like a job description for CERN, written half a century ahead of its time.



Perhaps the most interesting part of this book is its final chapter, "Crisis: the end of the Bohr Model". Experiments were now covering scattering as well as spectroscopy and it was becoming increasingly difficult to reconcile the model with these new results on one hand and with classical phenomena on the other.

In all this, Bohr had temporarily lost his way. The once-attractive idea of electrons revolving round the nucleus in planetary-like orbits were having to be cast aside and replaced with new ideas – less conventional but more productive. The death throes of the Bohr-Somerfeld model are redolent of the "wheels within wheels" contortions of Ptolemaic astronomy right before another scientific revolution – that one Copernican.

According to Kragh, the Bohr model had 'lost credibility' even before the formulation of quantum mechanics in 1925. However, those who formulated this new mechanics had been schooled by Bohr's thinking and many of them had worked in his institute.

Despite the demise of his model, Bohr always kept an open mind. For him, the advent of the quantum era was not a revolution. He preferred to call it a "joyful advancement".

- *Gordon Fraser is author of* Quantum Exodus: Fugitive Jews, the Atomic Bomb, and the Holocaust.

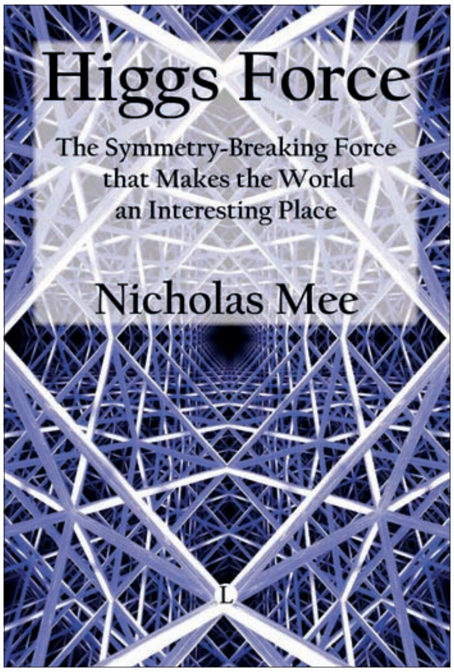
Higgs Force. The Symmetry-Breaking Force that Makes the World an Interesting Place

By Nicholas Mee

Lutterworth
Hardback: £25
Paperback: £15

Almost 30 years ago, ground was broken at CERN for the Large Electron–Positron collider. It was attended by François Mitterand, the last socialist president of France until now – when another François, this time Hollande, has been inaugurated. At the time, the new accelerator and the concomitant physics were described in an unusually readable pamphlet by a Russian, Yefime Zarjevski, who – I found out later – worked at the United Nations High Commission for Refugees. I had occasion to ask him: what do you know about physics? The answer: nothing! He went round CERN, talked to people and then put on paper what he understood, returned to them to check, and that was how it was done. (He was also the author of several books.) It was an intersection of literature and science. Today, we have a replay at CERN with the efforts of Ariane Koek to bring together physics and the arts (*CERN Courier* May 2012 p28).

In reading the *Higgs Force* by Nicholas Mee, I am reminded a little of these events. In about 300 pages, Mee takes us through a history of science from the early beginnings to the present. He is a physicist, but appears – through many analogies that he makes between more complex physical events and modes of vibration of strings and higher-dimensional instruments – to bridge a little the gap between science and art. (Max Planck also went from musician to physicist.) He succeeds in presenting most clearly the physics, from insights into the atom, the nucleus and then into the nucleons – with quark structure, matter and force-mediating particles, as well as symmetries – and finally arrives at the place reserved for the eagerly sought-after (but not yet found) Higgs particle, one of the *raisons d'être* of the LHC.



As an experimentalist, I would have liked to see rather more credit to this side, e.g. the wave nature of the electron, as found by Clinton Davisson and Lester Germer, or the detection of quarks in the scattering experiments of Jerome Friedman, Henry Kendall and Richard Taylor, while the collider has its origins in the proposal by Gerald O'Neill. Other missing persons include: Edward Purcell, Robert Dicke, Arno Penzias and Robert Wilson for the discovery of cosmic background radiation; and earlier, Joseph von Fraunhofer and solar spectroscopy. Is due credit given to László Tisza for his two-fluid theory of liquid helium? And closer to CERN, Isidor I Rabi (who never liked to be called "Isidore" – author, please note the correct spelling!), who was instrumental after the Second World War in the establishment of this multinational laboratory to unify scientists from the previously warring European countries.

However, these should not detract from Mee's book. It reminds me a little of Max Born's *Atomic Physics*, with more narrative in the main part of the book and details in the appendices. The author concludes with the most impressive detectors, the impact of technological development on society, such as the World Wide Web, born at CERN, and finally the physics beyond the Higgs particle. The book is clear and would make good reading for anyone interested in getting an idea of what it is that today's physicists are excited about.

- A new edition of *The Higgs Force* published by Quantum Wave Books is due out on 1 August 2012.
- *H Henry Stroke, New York University and CERN.*

Catalysed Fusion

By Francis Farley

www.smashwords.com/books/view/152272
E-book: £3.84 $5.99–6.03

The author – well known in particle physics for his work on the early muon g-2 experiments at CERN – sent this book to me and to the *CERN Courier* in April noting that it was intended "to sell particle physics to the uninitiated" and was "hot in some places". Before I started reading, some reviews, for example in the *The Telegraph*, a prestigious British newspaper, confirmed its steamy character.

So does it work? Regarding the physics, I worked in muon-catalysed fusion for three years and I find the subject well explained and accessible to non-experts. However, I think that the air of mystery is superfluous in this context. Regarding the "steaminess", although the story includes a large number of love scenes and all of the couples sooner or later mix up, I didn't find it all that erotic, maybe because of the predictable ending, which leaves nothing for the reader to anticipate.

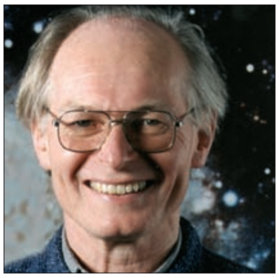
Was this really a necessary exercise? Perhaps not, but it is useful. While I don't agree with the reviewer in *The Telegraph* that the book challenges the serious image of CERN, I do think that it confirms that physicists are normal people and are not disconnected from society or shut in their laboratories. Does the book describe real situations? I would like to reply with the following: if your husband or your wife is a physicist, just consider him/her as any other person with a normal job. The rest is just normal life.

- *Antonella Del Rosso, CERN.*

Viewpoint

From the ionization of air to beyond the LHC

Alan Watson looks at how the links between particle physics and cosmic-ray research have evolved over the past century.



Alan Watson. (Image credit: Fermilab.)

In August, some 100 physicists will gather at Bad Saarow in Germany to celebrate the centenary of the discovery of cosmic rays by the Austrian scientist, Victor Hess. The meeting place is close to where Hess and his companions landed following their flight from Aussig during which they reached 5000 m in a hydrogen-filled balloon; Health and Safety legislation did not restrain them. Finding the rate of ion-production at 5000 m to be about three times that of sea level, Hess speculated that the Earth's atmosphere was bombarded by high-energy radiation. This anniversary might also be regarded as the centenary of the birth of particle physics. The positron, muon, charged pions and the first strange particles were all discovered in cosmic rays between 1932 and 1947; and in 1938 Pierre Auger and colleagues showed, by studying cascade showers produced in air, that the cosmic-ray spectrum extended to at least 10^{15} eV, a claim based on the new ideas of QED.

Reviewing history, one is struck by how reluctant physicists were to contemplate particles other than protons, neutrons, electrons and positrons. The combination of the unexpectedly high energies and uncertainties about the validity of QED meant that flaws in the new theory were often invoked to explain observations that were actually evidence of the muon. Another striking fact is how many giants of theoretical physics, such as Bethe, Bhabha, Born, Fermi, Heisenberg, Landau and Oppenheimer, speculated on the interpretation of cosmic-ray data. However, in 1953, following a famous conference at Bagnères de Bigorre, the focus of work on particle physics moved to accelerator laboratories and despite some isolated discoveries – such as that of a pair of particles with naked charm by Kiyoshi Niu and colleagues in 1971, three years before the discovery of the J/ψ at accelerators – accelerator laboratories were clearly the place to do precision particle physics. This is not surprising because the beams there are more intense and predictable than nature's: the cosmic-ray physicist cannot turn to the accelerator experts for help.

Cosmic rays remained – and remain – at the energy frontier but post-1953 devotees were perhaps over eager to show that particle-physics discoveries could be made with cosmic rays without massive collaborations. Cosmic-ray physicists preferred to march to the beat of their own drums. This led to attitudes that were sometimes insufficiently critical and the field became ignored or even mocked by many particle physicists. In the 30 years after Bagnères de Bigorre, a plethora of observations of dramatic effects were claimed, including Centauros, the Mandela, high-transverse momentum, the free quark, the monopole, the long-flying component and others. Without exception, these effects were never replicated because better cosmic-ray experiments were made or the relevant energies were superseded at machines. That many of the key results – good and bad – were hidden in the proceedings of the biennial International Cosmic Ray Conference did not help. Not that the particle-physics community has never made false claims: older readers will recall that in 1970 the editor of *Physical Review Letters* found it necessary to lay down "bump hunting" rules for those searching for resonances and, of course, the "split A2".

However, another cosmic-ray "discovery" led to a change of scene. In 1983, a group at Kiel reported evidence for gamma rays of around 10^{15} eV from the X-ray binary, Cygnus X-3. Their claim was apparently confirmed by the array at Haverah Park in the UK and at tera-electron-volts energies at the Whipple Telescope in the US. Several particle physicists of the highest class were sucked into the field by the excitement. This led to the construction of the VERITAS, HESS and MAGIC instruments that have now created a new field of gamma-ray astronomy at tera-electron-volt energies. The construction of the Auger Observatory, the largest cosmic-ray detector ever built, is another major consequence. In addition to important astrophysics results, the instrument has provided information relevant to particle physics. Specifically, the Auger Collaboration has reported a proton–proton cross-section measurement at a centre-of mass energy of 57 TeV.

When the LHC began to explore the tera-electron-volt energy region, some models used by cosmic-ray physicists were found to fit the first rapidity-data as well as, if not better than, those from the particle-physics theorists. It is clear that there is more to be learnt about features of hadronic physics through studying the highest-energy particles, which reach around 10^{20} eV. Estimates of the primary energy that are made using hadronic models are significantly higher than those from the measurements of the fluorescence-light from air-showers, which give a calorimetric estimate of the energy that is almost independent of assumptions about particle physics beyond the LHC. Furthermore, the number of muons found in high-energy showers is about 30% greater than predicted by the models. The Auger Collaboration plans to enhance their instrument to extend these observations.

Towards the end of operations of the Large Electron–Positron collider at CERN, projects such as L3-Cosmics used the high-resolution muon detectors to measure muon multiplicities in showers. Now there are plans to do something similar through the ACME project, part of the outreach programme related to the ATLAS experiment at the LHC, but with a new twist. The aim is for cheap shower detectors of innovative design, paid for by schools, to be built above ATLAS – with students monitoring performance and analysing data. Overall, we are seeing another union of cosmic-ray and particle physics, different from that of pre-1953 but nonetheless one that promises to be as rich and fascinating.

● *Alan Watson is a spokesperson emeritus of the Pierre Auger Observatory.*

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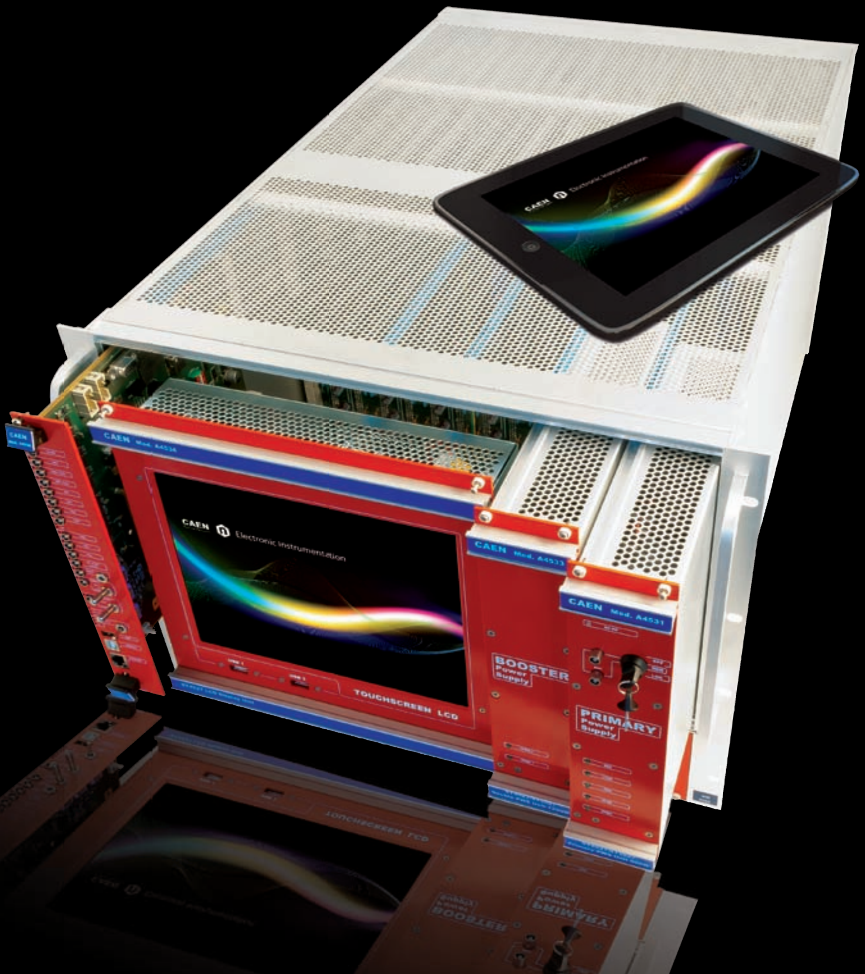

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