WELCOME

CERN Courier – digital edition

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

From the first 3.5 TeV collisions in March 2010 to the start of the first long shutdown earlier this year, the LHC has gone through three years of improving performance. This issue takes a look behind the scenes at what underpinned the successful operation of the LHC during this first long run. A reliable cryogenics system and robust, sophisticated systems to prevent uncontrolled losses of the huge energies stored in both the beam and the magnets have allowed the machine to deliver plenty of collisions, leading to the long-awaited discovery of a Higgs boson. Meanwhile, results continue to pour from the LHC experiments, including the observation of an extremely rare decay in B mesons by CMS and LHCb – news that was among the highlights of the recent summer conferences.

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

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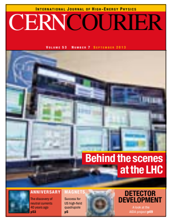


On the cover: Screens indicate 1092 buches in each proton beam in the LHC, well on the way to 1380 bunches, which marked one of the key steps in the LHC's improving performance in 2011 (p25)

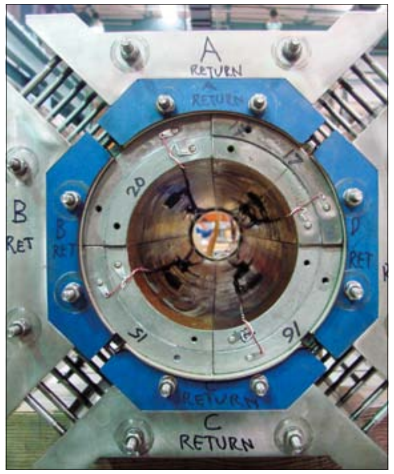
LHC UPGRADE

US high-field quadrupole magnet passes test

The US LHC Accelerator Program (LARP) has successfully tested a powerful superconducting quadrupole magnet that will play a key role in developing a new beam-focusing system for the LHC. This advanced system – with other major upgrades to be implemented over the next decade – will allow the LHC to deliver a luminosity up to 10 times higher than in the original design.

Dubbed HQ02a, the latest in LARP's series of high-field quadrupole magnets is wound with cables of the brittle but high-performance niobium-tin superconductor (Nb_3Sn). Like all LHC magnets, HQ02a is designed to operate in superfluid helium at temperatures that are close to absolute zero. However, it has a larger beam aperture than the current focusing magnets – 120 mm in diameter compared to 70 mm – and the magnetic field in the superconducting coils reaches 12 T – 50% higher than the current 8 T. The corresponding field gradient – the rate of increase of field strength over the aperture – is 170 T/m. In a recent test at Fermilab, HQ02a achieved all of its challenging objectives.

One of LARP's primary goals is to support CERN's plan to replace the quadrupole magnets in the interaction regions in about 10 years from now as part of the High Luminosity LHC project (*CERN Courier* January/February 2013 p28). Not only must the magnets produce a stronger field, they will also require a larger temperature margin and have to cope with the intense radiation, which comes hand in hand with the planned increase in the rate of energetic collisions. These requirements go beyond the capabilities of the niobium-titanium currently used in the LHC and in all previous superconducting magnets for particle accelerators.



The new Nb_3Sn HQ02a quadrupole has a larger aperture and is designed to operate at a higher magnetic field than previous final-focusing magnets. (Image: Berkeley Lab.)

Modern niobium-tin can operate at a higher magnetic field and with a wider temperature margin than niobium-titanium. However, it is brittle and sensitive to strain – critical factors where intense electrical currents and strong magnetic fields create enormous forces as the magnets are energized. Large forces can damage the fragile conductor or cause sudden displacements of the superconducting coils, releasing energy as heat and possibly resulting in a loss of the superconducting state – that is, a quench.

To address these challenges, LARP has adopted a mechanical support structure that is based on a thick aluminum shell, pre-tensioned at room temperature using water-pressurized bladders and interference keys. This design concept – developed at Berkeley under the US Department of Energy's General Accelerator Development programme – was compared with the traditional collar-based clamping system used in Fermilab's Tevatron and all of the subsequent high-energy accelerators and scaled up to 4 m in length in the LARP long "racetrack" and long quadrupoles. The HQ models further refined this mechanical design approach, in particular by incorporating full coil alignment.

The success of these tests not only establishes high-performance niobium tin as a powerful superconductor for use in accelerator magnets, it also marks a shift from R&D to development of the LARP magnets that will be installed for the LHC luminosity upgrade.

● LARP is a collaboration involving Berkeley, Brookhaven, Fermilab and SLAC, working in close partnership with CERN. It is now led by Giorgio Apollinari (see p57).

The LHC's first long run

From the first 3.5 TeV collisions in March 2010 to the start of the first long shutdown in March 2013, the LHC went through three years of improving performance. This led in 2012 to the discovery of a Higgs boson, which made headlines around the world and brought many accolades to CERN, including the 2013 EPS-HEPP prize (p7). This issue takes a look behind the scenes at what underpinned the successful operation of the LHC during this first long run. With thanks to Theresa Harrison, Warwick University, for her editorial work with the authors of these articles. Thanks also to Jesse Karjalainen, IOP Publishing, for his work on the design of what will be his last issue of *CERN Courier* as he heads for pastures new after six years.

Sommaire en français

Conference

ALICE goes to Stockholm and Birmingham

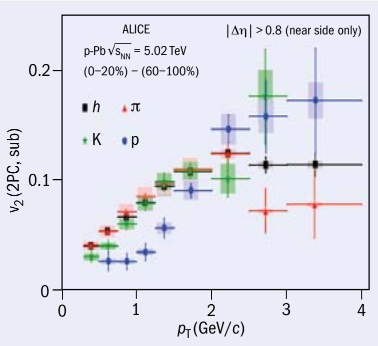
The ALICE collaboration had a significant presence at two recent major conferences, the 2013 European Physical Society Conference on High-Energy Physics (EPSHEP 2013), in Stockholm (p7), and the 14th Topical Conference on Strangeness in Heavy Flavour Production in Heavy-Ion Collisions – Strangeness in Quark Matter 2013 (SQM2013) – that took place on 22–27 July at Birmingham University in the UK.

The many contributed talks and plenary presentations, in particular at SQM2013, highlighted new results from the proton–lead (pPb) data recorded in early 2013. While this run was initially intended to provide control data sets, several unexpected, and currently unexplained, results have been observed.

Most intriguingly, both the spectra of identified particles and charged-hadron correlations in high-multiplicity pPb events reveal signals suggestive of collective flow, which are similar to those observed in heavy-ion collisions, as the figure shows. These mass-dependent phenomena do not arise trivially in either the colour glass condensate or in the gluon saturation framework that describes the initial state of the colliding nuclei at the relevant small values of Bjorken-x.

Also in pPb collisions, ALICE's measurements of minimum-bias spectra for a variety of hadronic species and jets, reveal no strong deviations from the expectations of the scaled number of nucleon–nucleon (binary) collisions. This confirms that the striking suppressions observed so far for all final-state hadrons in lead–lead (PbPb) collisions are a specific feature of quark and/or gluon energy loss via interactions with the quark–gluon plasma (QGP).

Presentations also covered updates on both soft (low p_T) and hard (high p_T and heavy flavour) probes of PbPb collisions. Higher precision results on nuclear-modification factors and elliptic flow – including measurements on heavy quarks – as a function of the event centrality gave the most detailed picture to date of partonic interactions with the QGP. The measurements of D mesons also indicate that the initial density and temperature of the QGP are so high that the heavy, charm quarks thermalize with the QGP before hadronization. Interestingly, the J/ψ results reveal much less suppression than at Brookhaven's Relativistic Heavy-Ion Collider, suggesting that significant late-stage regeneration of these quarkonia states occurs as a result of the initial copious production of charm quarks in the heavy-ion collisions at the LHC.



The remaining second fourier coefficient, v_2, of the $\Delta\phi$ two particle correlations at large $\Delta\eta$ as a function of p_T for π (red triangles) K (green stars), p (blue cirlces), and charged particles (black squares) in 0–20% centrality pPb collisions after subtraction of the correlations measured in the 60–10% centrality class. (ALICE collaboration 2013 arXiv :1307.3237 [nucl-ex], submitted for publication.)

Last, the high-precision soft physics results from the PbPb data underscored the potential significance of a hadronic re-scattering phase at the end of the produced medium's evolution at the LHC. This phase has not previously been considered important when predicting signatures of the QGP, but it must now be accounted for to model accurately the full dynamics of a heavy-ion collision at the LHC.

There was lively debate at both conferences about the possible interpretations of all of these interesting new results, continuing well after the talks were over. Future studies were proposed that should help to unravel the origin of these intriguing phenomena observed in both pPb and PbPb collisions.

EPS-HEP2013: these are good times for physics

Stockholm, with its many stretches of water, islands and old town, provided an attractive setting for the 2013 International Europhysics Conference on High-Energy Physics, EPS-HEP2013 on 18–24 July. Hosted by the KTH (Royal Institute of Technology) and Stockholm University, the conference centres on a busy programme of parallel and plenary sessions.

Like particle physics itself, EPS-HEP has a global reach, with people attending from Asia and the Americas, as well as from Europe. This year there were some 750 participants, including many young people who presented results in both parallel and poster sessions. As many as 440 speakers and more than 100 presenters of posters brought news from a host of experiments around the world, ranging from those at particle accelerators and colliders to others deep underground and in space.

Coming just one year after the announcement of the discovery of a new boson at CERN's LHC, the conference provided a showcase for the latest results from the ATLAS and CMS experiments, as well as from Fermilab's Tevatron. Together, they confirm the new particle as a Higgs boson, compatible with the Standard Model, and are making progress in pinning down its properties. Other measurements from the LHC and the Tevatron continue to test the Standard Model, as in the search for rare decay modes. The CMS and LHCb collaborations presented results on the decay $B_s \to \mu\mu$, two years after the CDF collaboration reported a first measurement, in slight tension with the Standard Model, at EPS-HEP2011 in Grenoble (*CERN Courier* September 2011 p11). CMS and LHCb now observe this decay at more than 4σ, with a branching fraction that is in good agreement with the Standard Model, therefore closing a potential window on new physics (p19).

All four of the large LHC collaborations – ALICE, ATLAS, CMS and LHCb – presented results in the dedicated sessions on ultrarelativistic heavy ions, which also featured presentions of measurements from the Relativistic Heavy-Ion Collider at Brookhaven. First results from the proton–lead run at the LHC are yielding surprises, including some intriguing similarities with findings in lead–lead collisions (p9).

Left: Paris Sphicas, chair of the international organizing committee, centre, with the winners of the 2013 EPS-HEPP prize, left to right, Peter Jenni, Tejinder Virdee, Dave Charlton and Joe Incandela. (Image credit: Abha Eli Phoboo.) Right: François Englert and Peter Higgs, on either side of CERN's director-general, Rolf Heuer, at the press conference. (Image credit: Terry Pritchard.)

Beyond the Standard Model, the worldwide search for dark matter has progressed with experiments that are becoming increasingly precise, gaining a factor of 10 in sensitivity every two years. There are also improved results from experiments at the intensity frontier, in the study of neutrinos and in particle astrophysics. Highlights here included the T2K collaboration's updated measurement with improved background rejection, which now indicates electron-neutrino appearance at a significance of 7σ (p8). Other news included results from the GERDA experiment, which sets a new lower limit on the half-life for neutrinoless double-beta decay of 2.1×10^{25} years.

Other sessions looked to the continuing health of the field, with presentations of studies on novel ideas for future particle accelerators and detection techniques. These topics also featured in the special session for the European Committee for Future Accelerators, which looked at future developments in the context of the update of the European Strategy for Particle Physics.

An important highlight of the conference was the awarding of the European Physical Society High Energy and Particle Physics Prize to the ATLAS and CMS collaborations "for the discovery of a Higgs boson, as predicted by the Brout-Englert-Higgs mechanism", and to Michel Della Negra, Peter Jenni and Tejinder Virdee, "for their pioneering and outstanding leadership roles in the making of the ATLAS and CMS experiments". François Englert and Peter Higgs were there in person to present the prizes and to take part in a press conference together with the prizewinners. Spokespersons Dave Charlton and Joe Incandela accepted the prizes on behalf of ATLAS and CMS, respectively.

Wrapping up the conference in a summary talk, Sergio Bertolucci, CERN's director for research and computing, noted that it had brought together many beautiful experimental results for comparison with precise theoretical predictions. "These are lucky times for physics," he concluded, with experiments and theory providing an "unprecedented convergence of the extremes of scales around a common set of questions".

● For details on all the talks see http://eps-hep2013.eu. A longer report will appear in a future edition of the *CERN Courier*.

***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.*

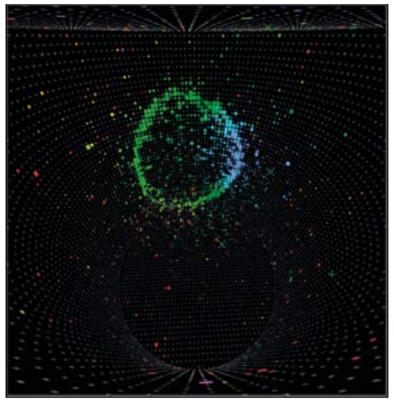
CERN Courier welcomes contributions from the international particle-physics community. These can be written in English or French, and will be published in the same language. If you have a suggestion for an article, please send proposals to the editor at cern.courier@cern.ch.

T2K observes $\nu_\mu \to \nu_e$ definitively

The international T2K collaboration chose the EPSHEP2013 meeting in Stockholm as the forum to announce its definitive observation of the transformation of muon-neutrinos to electron-neutrinos, $\nu_\mu \to \nu_e$.

In 2011, the collaboration announced the first signs of this process – at the time a new type of neutrino oscillation (*CERN Courier* September 2011 p6). Now with 3.5 times more data, T2K has firmly established the transformation at a 7.5σ significance level.

In the T2K experiment, a ν_μ beam is produced in the Japan Proton Accelerator Research Complex (J-PARC) in Tokai on the east coast of Japan. The beam – monitored by a near detector in Tokai – is aimed at the Super-Kamiokande detector, which lies underground in Kamioka near the west coast, 295 km away. Analysis of the data from Super-Kamiokande reveals that there are more ν_e (a total of 28 events) than would be expected (4.6 events) without the transformation process.



The first candidate ν_e event observed in Super-Kamiokande after recovery from the earthquake on the east coast of Japan in 2011. The detector has recorded a ring of light, attributed to Cherenkov radiation associated with the fast electron produced in the reaction $\nu_e + n \to p + e$. (Image credit: T2K collaboration.)

Observation of this type of neutrino oscillation opens the way to new studies of charge-parity (CP) violation in neutrinos, which may be linked to the domination of matter over antimatter in the present-day universe. The T2K collaboration expects to collect 10 times more data in the near future, including data with an antineutrino beam for studies of CP violation.

In announcing the discovery, the collaboration paid tribute to the unyielding and tireless effort by the J-PARC staff and management to deliver high-quality beam to T2K after the devastating earthquake in eastern Japan in March 2011. The earthquake caused severe damage to the accelerator complex and abruptly halted the data-taking run of the T2K experiment.

- The T2K experiment was constructed and is operated by an international collaboration, which currently consists of more than 400 physicists from 59 institutions in 11 countries: Canada, France, Germany, Italy, Japan, Poland, Russia, Switzerland, Spain, UK and the US.

GERDA sets new limits on neutrinoless double beta decay

The GERDA collaboration has obtained new strong limits for neutrinoless double beta decay, which tests if neutrinos are their own antiparticles.

The GERDA (GERmanium Detector Array) experiment, which is operated at the underground INFN Laboratori Nazionali del Gran Sasso, is looking for double beta decay processes in the germanium isotope ^{76}Ge, both with and without the emission of neutrinos. For ^{76}Ge, normal beta decay is energetically forbidden, but the simultaneous conversion of two neutrons with the emission of two neutrinos is possible. This has been measured by GERDA with unprecedented precision with a half-life of about 2×10^{21} years, making it one of the rarest decays ever observed. However, if neutrinos are Majorana particles, neutrinoless double beta decay should also occur, at an even lower rate. In this case, the antineutrino from one beta decay is absorbed as a neutrino by the second beta-decaying neutron, which is possible if the neutrino is its own antiparticle.

In GERDA germanium crystals are both source and detector. ^{76}Ge has an abundance of about 8% in natural germanium and its fraction was therefore enriched more than 10-fold before the special detector crystals were grown. To help to minimize the backgrounds from environmental radioactivity, the GERDA detector crystals and the surrounding detector parts have been carefully selected and processed. In addition, the detectors are located in the centre of a huge vessel filled with extremely clean liquid argon, lined by ultrapure copper, which in turn is surrounded by a 10-m diameter tank filled with high purity water. Last, but not least, it is all located underground below 1400 m of rock. The combination of all of these techniques has made it possible to reduce the background to unprecedented levels.

Data taking started in autumn 2011 using eight detectors if 2 kg each. Subsequently, five additional detectors were commissioned. Until recently, the signal region was blinded and the researchers focused on the optimization of the data analysis procedures. The experiment has now completed its first phase, with 21 kg years of accumulated data. The analysis, in which all calibrations and cuts had been defined before the data in the signal region were processed, revealed no signal of neutrinoless double beta decay in ^{76}Ge, which leads to the world's best lower limit for the half-life of 2.1×10^{25} years. Combined with information from other experiments, this result rules out an earlier claim for a signal by others.

The next steps for GERDA will be to add new detectors, effectively doubling the amount of ^{76}Ge. Data taking will then continue in a second phase after some further improvements are implemented to achieve even stronger background suppression.

- GERDA is a European collaboration with scientists from 19 research institutes or universities in Germany, Italy, Russia, Switzerland, Poland and Belgium.

LHC PHYSICS

Charmless baryonic B decays

The LHCb collaboration has made the first sightings of the decay of B mesons into two baryons containing no charm quarks. While the collaboration has previously reported on multibody baryonic B decays, these are its first results on the rare two-body charmless modes and will help to address open questions concerning baryon formation in B decays.

Baryonic decays of B mesons were studied extensively by the BaBar and Belle experiments at SLAC and KEK, respectively. The measured branching fractions are typically in the range 10^{-6}–10^{-4}, with charmless modes at the low end of this range and those with charm having larger branching fractions. Decays with double-charm final states have branching fractions up to 10^{-3} in some cases, which is a surprisingly large value. The channel $B^+ \to p\bar{p}K^+$ was the first charmless baryonic B-meson decay mode to be seen, in 2002 (Belle collaboration 2002). Soon after, Belle struck gold again with the first observation of a two-body baryonic B decay, $B^0 \to \Lambda c\bar{p}$, which manifestly has charm (Belle collaboration 2003). However, there were no signs of charmless two-body baryonic decays of B mesons until now.

The suppression of low-multiplicity compared with higher-multiplicity decay modes is a striking feature of B decays to baryons that is not replicated by their two-body and three-body decays to mesons. It is also a key to the theoretical understanding of the dynamics behind these types of decays.

The LHCb collaboration used the 1.0 fb^{-1} data sample collected in 2011 to study the proton–antiproton spectra with or without an extra light meson – a pion or a kaon. Figure 1 shows the invariant mass distribution of $p\bar{p}K^+$ candidates in the $\bar{p}K^+$ mass window 1.44–1.585 GeV/c^2, where a $B^+ \to p\bar{p}K^+$ signal is visible. The inset shows the $\bar{p}K^+$ invariant mass distribution near the threshold for B-signal candidates weighted to remove the non-$B^+ \to p\bar{p}K^+$ decay background.

The analysis reveals a clear $\bar{\Lambda}(1520)$ resonance, with the branching fraction for the decay chain $B^+ \to p\bar{\Lambda}(1520) \to p\bar{p}K^+$ measured to be close to 4×10^{-7} (LHCb collaboration 2013a). With a statistical significance exceeding 5σ, the result constitutes the first observation of a two-body charmless baryonic B decay, $B^+ \to p\bar{\Lambda}(1520)$.

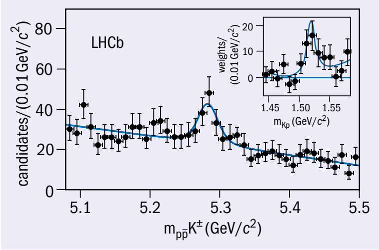


Fig. 1. Invariant mass distribution of $p\bar{p}K^+$ candidates in the $\bar{p}K^+$ mass window between 1.44 and 1.585 GeV/c^2 after full selection. The inset shows the $\bar{\Lambda}(1520) \to \bar{p}K^+$ resonance near threshold (B-signal weighted $\bar{p}K^+$ invariant mass distribution).

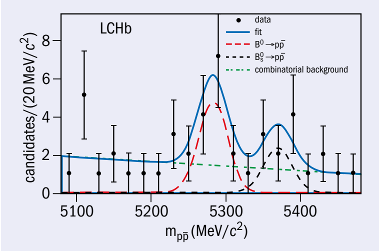
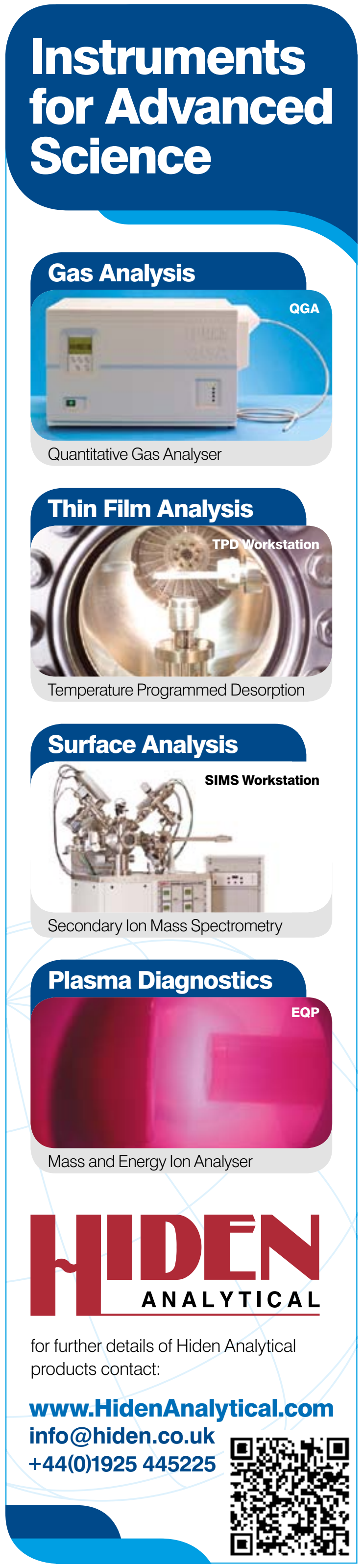


Fig. 2. Invariant mass distribution of $p\bar{p}$ candidates after full selection. The fit result (blue line) is superposed with each fit model component.

Figure 2 shows a fit from a related analysis, searching for $B \to p\bar{p}$ decay (LHCb collaboration 2013b). An excess of $B^0 \to p\bar{p}$ candidates with respect to background expectations is observed with a statistical significance of 3.3σ, giving a measurement of the branching fraction for $B^0 \to p\bar{p} = (1.47^{+0.71}_{-0.53}) \times 10^{-8}$. No significant signal is observed for $B^0_s \to p\bar{p}$ but the current analysis improves the previous bound on the branching fraction by three orders of magnitude.

Further reading

Belle collaboration 2002 *PRL* **88** 181803.
Belle collaboration 2003 *PRL* **90** 121802.
LHCb collaboration 2013a LHCb-PAPER-2013-031 arXiv:1307.6165 [hep-ex].
LHCb collaboration 2013b LHCb-PAPER-2013-038, arXiv:1308.0961 [hep-ex].



Surprising studies in multiplicity

One of the key ways of looking into what happens when high-energy hadrons collide is to measure the relationship between the number, or multiplicity, of particles produced and their momentum transverse to the direction of the colliding beams. The results cast light on processes ranging from the interactions of individual partons (quarks and gluons) to the collective motion of hot, dense matter containing hundreds of partons. The ALICE experiment is investigating effects across the range of possibilities, using data collected with proton–proton (pp), proton–lead (pPb) and lead–lead collisions (PbPb) in the LHC – and the results are showing some surprises.

A correlation between the average transverse momentum $\langle p_T \rangle$ and the charged particle multiplicity N_{ch} was first observed at CERN's Sp$\bar{p}$S collider and has since been measured in pp($\bar{p}$) collisions over a range of centre-of-mass energies, culminating recently at the LHC. The strong correlation observed led to a change in paradigm in the modelling of such collisions, with the proposal of mechanisms that go beyond independent parton–parton collisions.

In pp collisions, one way to understand the production of high multiplicities is through multiple parton interactions, but the incoherent superposition of such interactions would lead to the same $\langle p_T \rangle$ for different values of multiplicity. The observation of a strong correlation thus led to the introduction, within the models of the PYTHIA event simulator, of colour reconnections between hadronizing strings. In this mechanism, which can be interpreted as a collective final-state effect, strings from independent parton interactions do not independently produce hadrons, but fuse before hadronization. This leads to fewer, but more energetic, hadrons. Other models that employ similar mechanisms of collective behaviour also describe the data.

In PbPb collisions, high-multiplicity events are the result of a superposition of (single) parton interactions taking place in a large number of nucleon–nucleon collisions. In this case, substantial rescattering of constituents is thought to lead to a redistribution of the particle spectrum, with most particles being part of a locally thermalized medium that exhibits collective, hydrodynamic-type, behaviour. The moderate increase of $\langle p_T \rangle$ seen in PbPb collisions (shown in figure 1 for N_{ch} around 10 or larger) is thus usually attributed to collective flow.

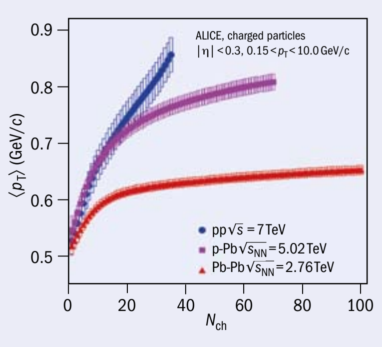


Fig. 1. Average transverse momentum $\langle p_T \rangle$ *versus charged-particle multiplicity* N_{ch} *in pp, pPb, and PbPb collisions for* $|\eta| < 0.3$. *The boxes represent the systematic uncertainties. The statistical errors are negligible.*

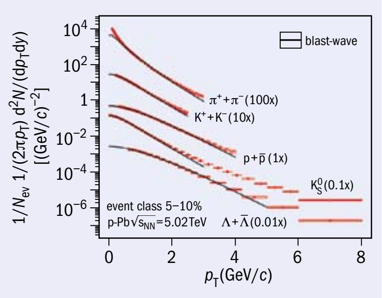


Fig. 2. $\pi^\pm$, $K^\pm$, K^0_S, p, $\bar{p}$, Λ *and* $\bar{\Lambda}$ *spectra in pPb collisions at* $\sqrt{s_{NN}} = 5.02$ *TeV compared with a blast-wave parameterization.*

Now, the first measurements by ALICE of two-particle correlations in the intermediary system of pPb collisions have sparked an intense debate about the role of initial- and final-state effects. The pPb data on $\langle p_T \rangle$ indeed exhibit features of both pp and PbPb collisions, at low and high multiplicities, respectively. However, the saturation trend of $\langle p_T \rangle$ versus N_{ch} is less pronounced in pPb collisions than in PbPb and at high multiplicities leads to a much higher value of $\langle p_T \rangle$ than in PbPb. Is this nevertheless a fingerprint of collective effects in pPb collisions? Predictions that incorporate collective effects within the hadron interaction model EPOS describe the data well, but alternative explanations, based on initial-state effects (gluon saturation), have also been put forward and are being tested by these data (ALICE collaboration 2013 a).

Other recent measurements of particle production in proton–nucleus collisions have shown unexpected behaviour that is reminiscent of quark–gluon plasma (QGP) signatures. But what could cause such behaviour and is a QGP the only possible explanation? To answer this in more detail, it is important to separate particle species, as collective phenomena should follow an ordering in mass. To this end, ALICE has measured the transverse-momentum spectra of identified particles in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and their dependence on multiplicity (ALICE collaboration 2013b).

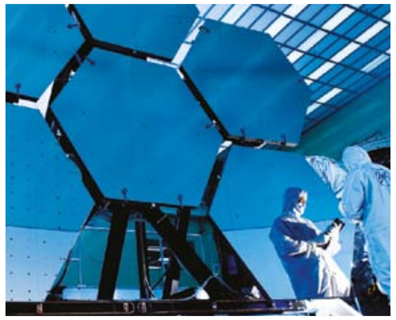
The measurements show that the identified particle spectra become progressively harder with multiplicity, just as in PbPb collisions, where the hardening is more pronounced for particles of higher mass. In heavy-ion collisions, this mass ordering is interpreted as a sign of a collective radial expansion of the system. To check if such an idea describes the observations, a blast-wave parameterization can be used. This assumes a locally thermalized medium that undergoes a collective expansion in a common velocity field, followed by an instantaneous common freeze-out.

As figure 2 shows, the blast-wave fit describes the spectra well at low p_T, where hydrodynamics-like behaviour should dominate. The description fails at higher momenta, however, where the non-thermal components should contribute significantly. But are QGP-like interpretations such as this one unique in describing these measurements? The colour-recombination mechanism present in PYTHIA, discussed above, leads qualitatively to similar features to those observed in the data.

The presence of flow and of a QGP in high multiplicity pPb collisions is thus not ruled out, but since other non-QGP effects could mimic collective phenomena, further investigation is needed. Nevertheless, these results are certainly a crucial step towards a better comprehension not only of pPb collisions but also of high-energy collisions involving nuclei in general.

● Further reading

ALICE collaboration 2013a arXiv:1307.1094 [nucl-ex].
ALICE collaboration 2013b arXiv:1307.6796 [nucl-ex].



Sciencewatch

Compiled by John Swain, Northeastern University

The incredible lightness of … electronics

Electronics has just become much lighter. Researchers at the University of Tokyo and Johannes Kepler University (JKU) in Linz have demonstrated a new fabrication technique based on organic transistors supported by 1-µm-thick polymer foils that are some 10 times thinner than plastic food wrap. They weigh just 3 g/m^2 – the paper weight of this page 65 g/m^2 – and can be repeatedly bent to radii of 5 µm. They can be stretched by 230% and crumpled up like a sheet of paper without being damaged. The approach is low cost and in their *Nature* paper, the authors speculate that these "imperceptible" electronic foils may soon become as common as plastic wrap is today.

The list of applications includes matrix-addressed tactile-sensor foils for health care and monitoring, thin-film heaters, temperature and infrared sensors, displays and organic solar cells. In a second paper, in *Nature Communications*, the researchers report on their ultrathin organic solar cells, which are more than 10 times thinner again and more flexible than any other solar cell of any technology to date. A third paper, this time in *Nature Photonics*, reports on work on highly flexible and stretchable red and orange polymer light-emitting diodes, which the authors write constitute "an important step towards integration with malleable materials like textiles and artificial skin".


The electronics sheets float to the ground more slowly than a feather and are therefore virtually unbreakable. (Image credit: JKU.)

● **Further reading**
M Kaltenbrunner *et al.* 2013 *Nature* **499** 458.
M Kaltenbrunner *et al.* 2013 *Nature Communications* **3**; doi:10.1038/ncomms1772.
M A White *et al.* 2013 *Nature Photonics*; doi:10.1038/nphoton.2013.188.

Weird water

Water confined to scales of around 20 Å has different transport and thermodynamics properties. It now also turns out that even the ground state of electrons is weird. George Reiter of the University of Houston in Texas and colleagues used X-ray Compton scattering to show that the electronic structure of nanoconfined water in hydrated Nafion (a plastic) is not only different from that of regular water but also cannot be explained by conventional *ab initio* calculations. Cells must make use of water in a distinct quantum state from bulk water, so this is likely to have important implications for biology, as well as being of intrinsic interest in physics.

● **Further reading**
G F Reiter *et al.* 2013 *Phys. Rev. Letts.* **111** 036803.

Measuring k_B

A new method to determine Boltzmann's constant, k_B, could lead to a new definition of the kelvin. At present, the kelvin is defined in terms of the temperature of water at its triple point – where liquid, solid and vapour phases co-exist. Now, Michael de Podesta of the National Physical Laboratory in Teddington in the UK has made a new determination of k_B, in terms of which the kelvin can be re-defined.

The idea is to take a known volume of argon gas in a copper container held at the triple point and use measurements of the speed of sound (which depends on temperature) to obtain k_B. The new value is $k_B = 1.38065156\,(98) \times 10^{-23}$ J/K, with a relative standard uncertainty of just 0.71 parts per million.

● **Further reading**
M de Podesta *et al.* 2013 *Metrologia* **50** 354.

Perfect mirror

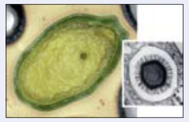
It is common knowledge that any mirror absorbs some of the light incident on it – but this "rule" turns out to have an exception. Chia Wei Hsu of Massachusetts Institute of Technology and colleagues have shown that a patterned dielectric, which acts as a photonic crystal, can exhibit a perfect cancellation between light waves both inside and outside it, leading to perfect reflection. This happens only for a specific frequency and angle, but can be used to trap light indefinitely, bouncing between photonic crystals.

The researchers not only predict this, they also demonstrate it experimentally with silicon nitride patterned with holes, submerged in a liquid and mounted on a silicon-dioxide substrate. The liquid matches the index of refraction of the substrate and reflection can be 100%.

● **Further reading**
C W Hsu *et al.* 2013 *Nature* **499** 188.

Giant viruses

Viruses are usually thought of as tiny compared with eukaryotes, both in size and in the amount of DNA they contain. Giant DNA viruses, such as the Mimivirus with 1.18 million base pairs, have been known for a decade but now Jean-Michel Claverie and Chantal Abergel of Aix-Marseilles University and colleagues have found two new record-breakers.


Pandoraviruses have a bigger genome, atypical shape and different genes from megaviruses (inset). (Image credit: IGS CNRS-AMU/Chantal Abergel.)

The new viruses have at least 2.5 and 1.9 megabases, one from off the coast of Chile and the other from a freshwater pond near Melbourne. They are neither morphologically nor genomically similar to any previously known virus families and appear to be members of a new genus, which the researchers called Pandoravirus to reflect the "surprises expected from their future study". Their difference is so great that they may represent a fourth primitive cell lineage distinct from bacteria, archea and eukarya.

● **Further reading**
N Philippe *et al.* 2013 *Science* **341** 281.

Astrowatch

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

Do fast radio bursts signal black-hole formation?

Astronomers using the 64-m Parkes radio telescope in Australia have detected radio transients with a duration of only 4 ms. These fast radio bursts (FRBs) are a recently discovered class of mysterious sources that are found at cosmological distances. Now, two theorists suggest that FRBs are the last signal emitted by neutron stars as they collapse to form black holes.

In 2007, Duncan Lorimer and colleagues reported finding an unexpected burst of radio emission in archival observations of the Parkes telescope (*CERN Courier* November 2007 p10). The distance to the burst was calculated to be far outside the Galaxy at cosmological distances and hence the inferred luminosity was huge – similar to that of a quasar. This first radio "hyperburst" is now called the Lorimer burst, or FRB 010724.

Now, an international team led by Dan Thornton of the University of Manchester and the Australia Telescope National Facility has identified four additional FRBs. All bursts are found to be at cosmological distances as inferred by their dispersion measure, which is related to the integrated density of free electrons along the line of sight to the source. The free electrons in an ionized medium scatter the radio waves and cause a time delay in the arrival of the burst that increases towards longer wavelengths. The measured delays for the four FRBs suggest a strong contribution from the intergalactic medium and that the sources are several thousand-million light-years away, corresponding to cosmological redshifts, z, of between 0.45 and 0.96. This is significantly more than for the Lorimer burst (z ~ 0.12) and confirms the cosmological origin of these events.

CSIRO's Parkes radio telescope with an image of the distribution of gas in the Galaxy. An artist's impression of an FRB is shown away from the Galactic plane emission. (Image credit: Swinburne Astronomy Productions / http://astrometry.fas.harvard.edu/skymaps/halpha.)

The detection of these bursts at a great distance implies a strong instantaneous luminosity. However, because the FRBs last only for milliseconds, the total energy released in radio waves is relatively modest – of the order of 10^{31}–10^{33} J. While this is about the energy output of the Sun in days to months, it is more than 10 orders of magnitude less than the energy released by a gamma-ray burst (GRB) or a supernova explosion (~10^{44} J). With four FRBs detected in the same survey it is also possible to estimate the event rate. Thornton and colleagues find a rate of about 10,000 per day for the full sky – about one burst every 10 s. Given the number of galaxies in the probed volume, they find an event rate of one burst per thousand years per galaxy. This is about 10 times less frequent than core-collapse supernovae (*CERN Courier* January/February 2006 p10) but a thousand times more frequent than GRBs.

With only these characteristics and the fact that there is no known transient detected simultaneously at other wavelengths, it is challenging to speculate on the nature of the objects producing FRBs. The brevity of the emission indicates small objects, typically neutron stars. A possible candidate is a magnetar – a highly magnetized neutron star that can emit powerful gamma-ray flashes (*CERN Courier* June 2005 p12).

Another interesting scenario has recently been proposed by Heino Falcke and Luciano Rezzolla, affiliated to institutes in the Netherlands and Germany. They claim that there should be a population of neutron stars that are stable with respect to gravitational collapse only because they are spinning quickly. Because of magnetic breaking, their spin rate must decrease slowly during several thousands to millions of years until reaching a critical value when the star collapses into a black hole. According to the "no hair" theorem, black holes cannot keep the strong magnetic field of the neutron star. The magnetosphere would be released during the collapse and result in a radio burst. FRBs would therefore be the last "cry" of neutron stars succumbing to their own gravitational pull.

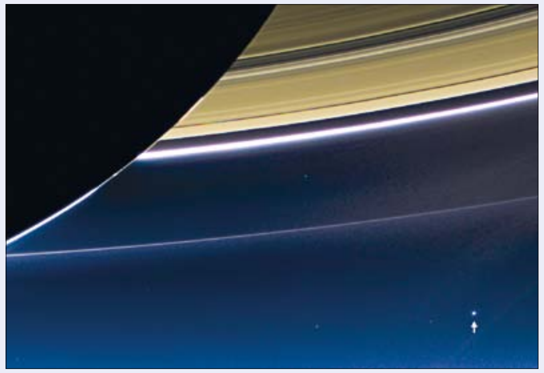
● Further reading

D Thornton *et al.* 2013 *Science* **341** 53.

H Falcke and L Rezzolla 2013 arXiv 1307.1409 [astro-ph.HE].

Picture of the month

In this majestic view of Saturn's rings, the little blue dot at the lower right is the Earth. This humbling view of our planet was taken on 19 July by NASA's Cassini spacecraft, which has been orbiting the ringed planet since 2004 (*CERN Courier* September 2004 p13). This is only the third time that an image of the Earth has been obtained from the outer solar system. The first was taken by NASA's Voyager 1 spacecraft in 1990 and famously titled "Pale Blue Dot". The Earth was also part of a stunning image of Saturn eclipsing the Sun that was taken on 15 September 2006. In this wide-field view from Cassini, the Earth–Moon system – at a distance of 1.446 × 10^9 km – is not resolved spatially. However, the Earth and Moon are clearly separated in another image that was taken on the same day by NASA's MESSENGER spacecraft, which is currently orbiting Mercury, the innermost planet of the solar system. (Image credit: NASA/JPL-Caltech/Space Science Institute.)



CERN Courier Archive: 1970

A LOOK BACK TO CERN COURIER VOL. 8, SEPTEMBER 1970, COMPILED BY PEGGIE RIMMER

NEWS FROM ABROAD

Conference in Kiev

The XVth International Conference on High Energy Physics was held in Kiev, the lively capital of the Soviet Ukraine, from 26 August to 4 September. This series of conferences, known as the Rochester Conferences, is the most important in our field.

The Conference was sponsored by the International Union of Pure and Applied Physics, the USSR Academy of Sciences, the USSR State Committee on the Use of Atomic Energy and the Ukrainian Academy of Sciences. Dubna and the Kiev Institute of Theoretical Physics participated in the organization. It was held in the October Palace of Culture where a huge auditorium was amply capable of absorbing the 800 participating scientists. The multitude of services so important to the smooth running of a conference, projection and sound services, catering facilities, etc., functioned very well and the Organizing Committee, chaired by N N Bogolubov with A N Tavkhelidze as Deputy Chairman, deserve special praise for their efficiency. (There was a strong feeling among many participants that the Committee could most usefully take over Intourist.)

Though there were many beautiful experiments reported, and much elegant theoretical work, there was little that crystallized out in terms of trends, highly promising approaches, or very exciting new results. A decade ago the Rochester Conferences were the scene of high excitement as access to higher energies broke new ground in our knowledge of particles and their behaviour. Now it looks as if, with the research facilities available, the plums have been picked and we are in the hard grind of trying to understand the detail. This does not carry the glory of ten years ago, but it is nothing new in science that periods of dramatic discovery are followed by periods of much slower advance, as more detail is uncovered. High energy physics is in a complex phase at the moment.

● Compiled from text on p271.

Dubna Instrumentation Conference

As is by now traditional, the Rochester Conference was followed by an "International Conference on Instrumentation for High Energy Physics"; this year it was held from 8 to 12 September at Dubna.

The bulk of the Conference was given to reporting further refinements brought to established techniques for particle detection. On the bubble chamber side there is, in addition to the trend to much larger sensitive volumes, growing interest in rapid cycling techniques to take more pictures per accelerator pulse. At the Stanford Linear Accelerator Center (SLAC), for example, work is under way to pulse a 1 m bubble chamber at a rate as high as 20 times per second. Related topics are the ultrasonic bubble chamber research at CERN and Dubna, and the use of counters to fire the chambers or cameras only when an event of interest is known to have occurred (done, for example, at Argonne).

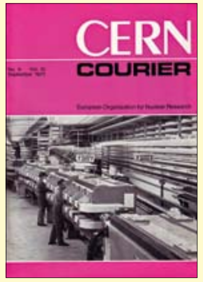
N N Bogolubov speaking at the opening ceremony of the Instrumentation Conference at Dubna. (Image credit: Yu Tumanov).

V P Dzhelepov (left), Director of the Laboratory of Nuclear Problems at Dubna and Chairman of the Organizing Committee, in conversation during the Conference with G Charpak who has led the work on multiwire proportional chambers. (Image credit: Yu Tumanov.)

On the electronics experiments side, multiwire proportional chambers developed at CERN are now an accepted choice for a wide range of applications - if you can afford them. On-line computers have, within a few years, moved from being an innovation to being something we cannot live without. A computer-controlled CAMAC system ACE, to Automatically set up and Calibrate electronics for Experiments, has been developed at Daresbury. Spectrometer systems are growing bigger, more accurate and more versatile. There is growing mastery of streamer chambers (half way between the bubble chamber and electronics techniques); there was a particularly nice report on the operation of the chamber at DESY.

● Compiled from texts on pp275–276.

Compiler's Note



By the mid-1960s, a baffling variety of so-called elementary particles, mostly hadrons, had been discovered. In 1964, Murray Gell-Mann and George Zweig independently proposed that a small number of quarks could suffice as fundamental building blocks of the hadrons, an idea that began to gain traction only after 1968, when evidence for the possible physical existence of quarks had shown up in the deep inelastic scattering of electrons on nucleons at SLAC. In fact, quarks were not mentioned in the citation of the 1969 Nobel Prize awarded to Gell-Mann "for his overall contributions and discoveries concerning the classification of elementary particles and their interactions". High-energy physics was indeed in a complex phase at the beginning of the 1970s.

For the record, the XXXVth Rochester Conference will be held in Valencia, Spain, in 2014.

Strangely beautiful dimuons

A key observation at the LHC marks a major milestone in a 30-year-long journey.

Since its birth, the Standard Model of particle physics has proved to be remarkably successful at describing experimental measurements. Through the prediction and discovery of the W and Z bosons, as well as the gluon, it continues to reign. The recent discovery of a Higgs boson with a mass of 126 GeV by the ATLAS and CMS experiments indicates that the last piece of this jigsaw puzzle has been put into place (*CERN Courier* May 2013 p21). Yet, despite its incredible accuracy, the Standard Model must be incomplete: it offers no explanation for the cosmological evidence of dark matter, nor does it account for the dominance of matter over antimatter in the universe. The quest for what might lie beyond the Standard Model forms the core of the LHC physics programme, with ATLAS and CMS systematically searching for the direct production of a plethora of new particles that have been predicted by various proposed extensions to the model.

Complementary methods

As a consequence of its excellent performance – including collisions at much higher energies than previously achieved and record integrated luminosities – the LHC also provides complementary and elegant approaches to finding evidence of physics beyond the Standard Model, namely precision measurements and studies of rare decays. Through Heisenberg's uncertainty principle, quantum loops can appear in the diagrams that describe Standard Model decays, which are influenced by particles that are absent from both the initial and final states. This experimentally well established general concept opens a window to observe the effects of undiscovered particles or of other new physics in well known Standard Model processes. Because these effects are predicted to be small, the proposed new-physics extensions remain consistent with existing observations. Now, the high luminosity of the LHC and the unprecedented precision of the experiments are allowing these putative effects to be probed at levels never before reached in previous measurements. Indeed, this is the prime field of study of the LHCb experiment, which is dedicated to the precision measurement of decays involving heavy quarks, beauty (b) and charm (c). The general-purpose LHC experiments can also compete in these studies, especially where the final states involve muons.

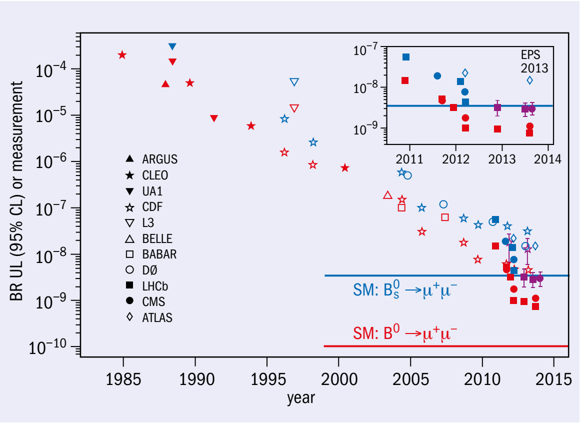


Fig. 1. Results of $B_s \rightarrow \mu\mu$ and $B^0 \rightarrow \mu\mu$ searches at current and past colliders: the violet points are measurements (with error bars) and the other points are upper limits, for the B_s (blue) and for the B^0 (red). The inset zooms in on the LHC results.

A rare confluence of factors makes the decay of beauty mesons into dimuon ($\mu^+\mu^-$) final states an ideal place to search for this sort of evidence for physics beyond the Standard Model. The decays of B^0 (a beauty antiquark, $\bar{b}$, and a down quark, d) and B_s (a $\bar{b}$ and a strange quark, s) to $\mu^+\mu^-$ are suppressed in the Standard Model yet several proposed extensions predict a significant enhancement (or an even stronger suppression) of their branching fractions. A measurement of the branching fraction for either of these decays that is inconsistent with the Standard Model's prediction would be a clear sign of new physics – a realization that sparked off a long history of searches. For the past 30 years, a dozen experiments at nearly as many particle colliders have looked for these elusive decays and established limits that have improved by five orders of magnitude as the sensitivities approach the values predicted by the Standard Model (figure 1). Last November, LHCb found the first clear evidence for the decay $B_s \rightarrow \mu\mu$, at the 3.5σ level (*CERN Courier* January/February 2013 p8). Now both the CMS and ▷

The decay of beauty mesons into dimuon final states is an ideal place to search beyond the Standard Model.

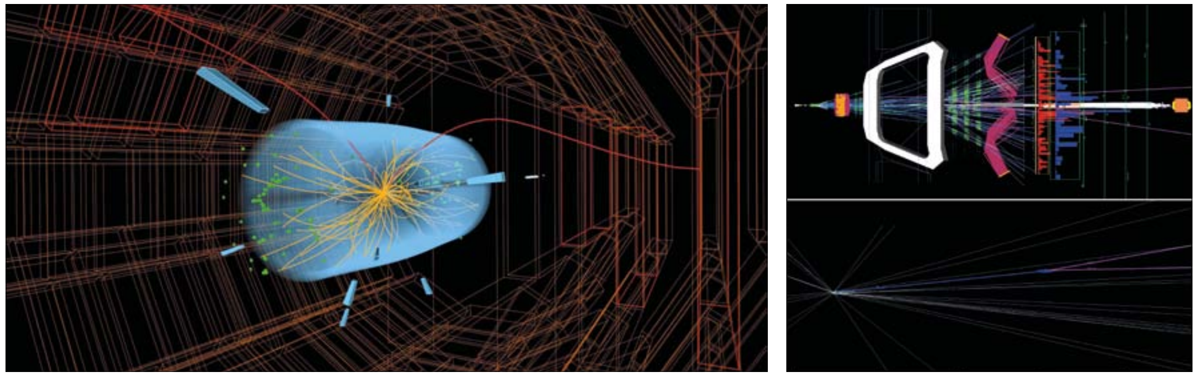


Fig. 2. Display of a $B_s \to \mu\mu$ candidate in each of the experiments: (left) CMS, where the two muon tracks are red. (right) LHCb, where the two muon tracks are purple; the lower image zooms in on the decay vertex and shows a region 100 mm across. The different geometry of the two detectors can be seen: CMS is central and LHCb is a forward spectrometer.

LHCb collaborations have updated their results for these decays.

Behind the seemingly simple decay topology hides a tricky experimental search aimed at finding a few signal events in an overwhelming background: only three out of every thousand million B_s mesons are expected to decay to μμ, with the rate being even lower for the B^0. The challenge is therefore to collect a huge data sample while efficiently retaining the signal and filtering out the background.

Several sources contribute to the large background. B hadrons decay semi-leptonically to final states with one genuine muon, a neutrino and additional charged tracks that could be misidentified as muons, therefore mimicking the signal's topology. Because the emitted neutrino escapes with some energy, these decays create a dimuon peak that is shifted to a lower mass than that of the parent particle. The decays $\Lambda_b \to p\mu\nu$ form a dangerous background of this kind because the Λ_b is heavier than the B mesons, so these decays can contribute to the signal region. Two-track hadronic decays of B^0 or B_s mesons also add to the background if both tracks are mistaken for muons. This "peaking background" – fortunately rare – is tricky because it exhibits a shape that is similar to that which is expected for the signal events. The third major background contribution arises from events with two genuine muons produced by unrelated sources. This "combinatorial" background leads to a continuous dimuon invariant-mass distribution, overlapping with the B^0 and B_s mass windows, which is reduced by various means as discussed below.

The first hurdle to cross in finding the rare signal events is to identify potential candidates during the bursts of proton–proton collisions in the detectors. Given the peak luminosities reached in 2012 (up to $8 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$), the challenge for CMS was to select by fast trigger the most interesting 400 events a second for recording on permanent storage and prompt reconstruction, with around 10 per second reserved for the $B \to \mu\mu$ searches. With its smaller event size, LHCb could afford a higher output rate from its trigger, recording several kilohertz with a significant fraction dedicated to dimuon signatures.

The events selected by the trigger are then filtered according to the properties of the two reconstructed muons to reject as much background as possible while retaining as many signal events as possible. In particular, hadrons misidentified as muons are suppressed strongly through stringent selection criteria applied on the number of hits recorded in the tracking and muon systems, on the quality of the track fit and on the kinematics of the muons. In LHCb, information from the ring-imaging Cherenkov detectors further suppresses misidentification rates. Additional requirements ensure that the two oppositely charged muons have a common origin that is consistent with being the decay point of a (long-lived) B meson. The events are also required to have candidate tracks that are well isolated from other tracks in the detector, which are likely to have originated from unrelated particles or other proton–proton collisions (pile-up). This selection is made possible by the precise measurements of the momentum and impact parameter provided by the tracking detectors in both experiments. The good dimuon-mass resolution (0.6% at mid-rapidity for CMS and 0.4% for LHCb) limits the amount of combinatorial background that remains under the signal peaks. Figure 2 shows event displays from the two experiments, each including a displaced dimuon compatible with being a $B \to \mu\mu$ decay.

The final selection of events in both experiments is made with a multivariate "boosted decision tree" (BDT) algorithm, which discriminates signal events from background by considering many variables. Instead of applying selection criteria independently on the measured value of each variable, the BDT combines the full information, accounting for all of the correlations to maximize the separation of signal from background. CMS applies a loose selection on the BDT discriminant to ensure a powerful background rejection at the expense of a small loss in signal efficiency. Both experiments categorize events in bins of the BDT discriminant. LHCb has a higher overall efficiency, which together with the larger B cross-section in the forward region compensates for the lower integrated luminosity, so the final sensitivity is similar for both experiments.

The observable that is sensitive to potential new-physics contributions is the rate at which the B^0 or B_s mesons decay to μμ, which requires a knowledge of the total numbers of B^0 and B_s mesons that are produced. To minimize measurement uncertainties, these numbers are evaluated by reconstructing events where B mesons decay through the J/ψK channel, with the J/ψ decaying to two muons. This signature has many features in common with the signal being sought but has a much higher and well known branching fraction. The last ingredient required is the fraction of B_s produced relative to B^+ or B^0 mesons, which LHCb has determined in independent analyses. This procedure provides the necessary "normalization" without using the total integrated luminosity or the beauty production cross-section. LHCb also uses events with the decay $B^0 \to K^+\pi^-$ to provide another handle on the normalization.

Results

Both collaborations use unbinned maximum-likelihood fits to the dimuon-mass distribution to measure the branching fractions. The combinatorial background shape in the signal region is evaluated from events observed in the dimuon-mass sidebands, while the shapes of the semileptonic and peaking backgrounds are based on Monte Carlo simulation and are validated with data. The magnitude of the peaking background is constrained from measurements of the fake muon rate using data control samples, while the levels of semileptonic and combinatorial backgrounds are determined from the fit together with the signal yields.

Both collaborations use all good data collected in 2011 and 2012. For CMS, this corresponds to samples of 5 fb^{-1} and 20 fb^{-1}, respectively, while for LHCb the corresponding luminosities are 1 fb^{-1} and 2 fb^{-1}. The data are divided into categories based on the BDT discriminant, where the more signal-like categories provide the highest sensitivity. In the fit to the CMS data, events with both muons in the central region of the detector (the "barrel") are separated from the others (the "forward" regions). Given their excellent dimuon-mass resolution, the barrel samples are particularly sensitive to the signal. All of the resulting mass distributions (12 in total for CMS and eight for LHCb) are then simultaneously fit to measure the $B^0 \to \mu\mu$ and $B_s \to \mu\mu$ branching fractions, yielding the results that are shown in figure 3.

For both experiments, the fits reveal an excess of $B_s \to \mu\mu$ events over the background-only expectation, corresponding to a branching fraction $\mathrm{BF}(B_s \to \mu\mu) = 3.0^{+1.0}_{-0.9} \times 10^{-9}$ in CMS and $2.9^{+1.1}_{-1.0} \times 10^{-9}$ in LHCb, where the uncertainties reflect statistical and systematic effects. These measurements have significances of 4.3σ and 4.0σ, respectively, evaluated as the ratio between the likelihood obtained with a free $B_s \to \mu\mu$ branching fraction and that obtained by fixing $\mathrm{BF}(B_s \to \mu\mu) = 0$. The results have been combined to give $\mathrm{BF}(B_s \to \mu\mu) = 2.9 \pm 0.7 \times 10^{-9}$ (CMS+LHCb).

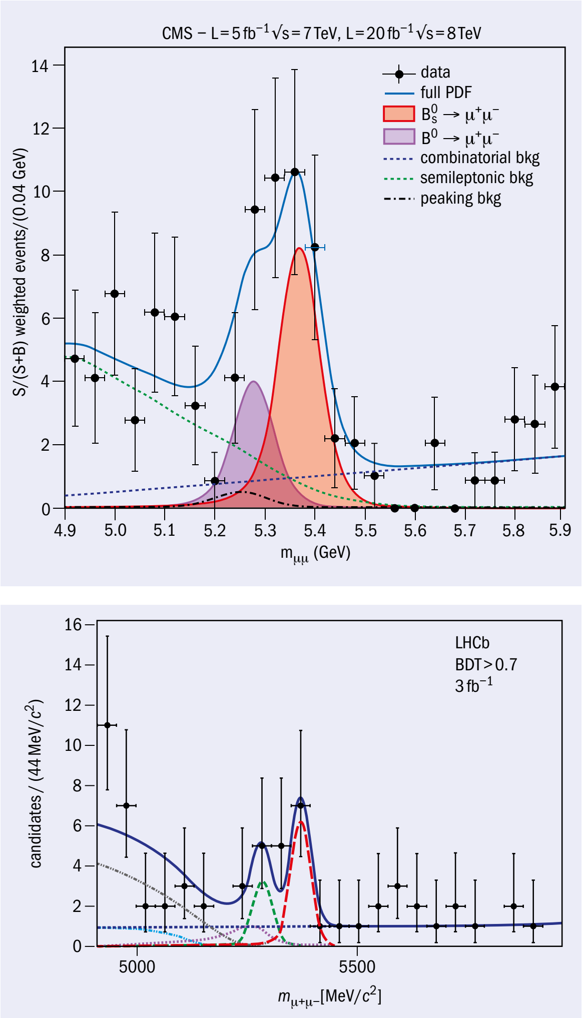


Fig. 3. (top) Result of the simultaneous fit to the 12 dimuon-mass distributions from CMS: the purple and red curves show the B^0 and B_s signals, respectively, while the blue dashed line and the green and black shapes show the combinatorial, semileptonic and peaking backgrounds, respectively. The solid curve shows the sum of the components. (bottom) Dimuon mass distribution for BDT > 0.7 from LHCb with superimposed fit: the green and red curves show the B^0 and B_s signals, respectively, while the other contributions show the backgrounds. The solid blue curve shows the sum of the components.

Both CMS and LHCb reported this long-sought observation at the EPS-HEP conference in Stockholm in July and in back-to-back publications submitted to *Physical Review Letters* (CMS collaboration 2013, LHCb collaboration 2013).

The combined measurement of $B_s \to \mu\mu$ by CMS and LHCb is consistent with the Standard Model's prediction, ▷

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$\mathrm{BF}(B_s \to \mu\mu) = 3.6 \pm 0.3 \times 10^{-9}$, showing that the model continues to resist attempts to see through its thick veil. The same fits also measure the $B^0 \to \mu\mu$ branching fraction. They reveal no significant evidence of this decay and set upper limits at the 95% confidence level of 1.1×10^{-9} (CMS) and 0.74×10^{-9} (LHCb). These limits are also consistent with the Standard Model, although the measurement fails to reach the precision required to probe the prediction.

While the observation of a decay that has been sought for so long and by so many experiments is a thrilling discovery, it is also a bittersweet outcome. Much of the appeal of the $B_s \to \mu\mu$ decay-channel was in its potential to reveal cracks in the Standard Model – something that the measurement has so far failed to provide. However, the story is far from over. As the LHC continues to provide additional data, the precision with which its experiments can measure these key branching fractions will improve steadily and increased precision means more stringent tests of the Standard Model. While these results show that deviations from the expectations cannot be large, even a small deviation – if measured with sufficient precision – could reveal physics beyond the Standard Model.

Additionally, the next LHC run will provide the increase in sensitivity that the experiments need to measure $B^0 \to \mu\mu$ rates at the level of the Standard Model's prediction. New physics could be lurking in that channel. Indeed, the prediction for the ratio of the $B_s \to \mu\mu$ and $B^0 \to \mu\mu$ decay rates is well known, so a precise measurement of this quantity is a long-term goal of the LHC experiments. And even in the scenario where the Standard Model continues its undefeated triumphant path, theories that go beyond it must still describe the existing data. Tighter experimental constraints on these branching fractions would be powerful in limiting the viable extensions to the Standard Model and could point towards what might lie beyond today's horizon in high-energy physics. With the indisputable observation of $B_s \to \mu\mu$ decays, experimental particle physics has reached a major milestone in a 30-year-long journey. This refreshing news motivates the LHC experimental teams to continue forward into the unknown.

● Further reading:

CMS collaboration 2013 CMS 1307.5025, to appear in *Phys. Rev. Letts*.
LHCb collaboration 2013 LHCb 1307.5024, to appear in *Phys. Rev. Letts*.

Résumé

Des dimuons d'une étrange beauté

Dans le Modèle standard, les désintégrations de mésons B^0 et B_s en paires de muons ($\mu\mu$) sont fortement réduites. Une mesure du rapport d'embranchement de l'une ou l'autre de ces désintégrations qui serait incompatible avec les prédictions du Modèle standard indiquerait clairement l'existence d'une nouvelle physique. Durant les 30 dernières années, une douzaine d'expériences, dans presque autant de collisionneurs de particules, ont recherché ces désintégrations si insaisissables. En novembre dernier, LHCb a pour la première fois montré clairement l'existence de la désintégration $B_s \to \mu\mu$ à un niveau de $3{,}5\sigma$. Les collaborations CMS et LHCb ont ainsi pu actualiser leurs résultats.

The LHCb and CMS collaborations.

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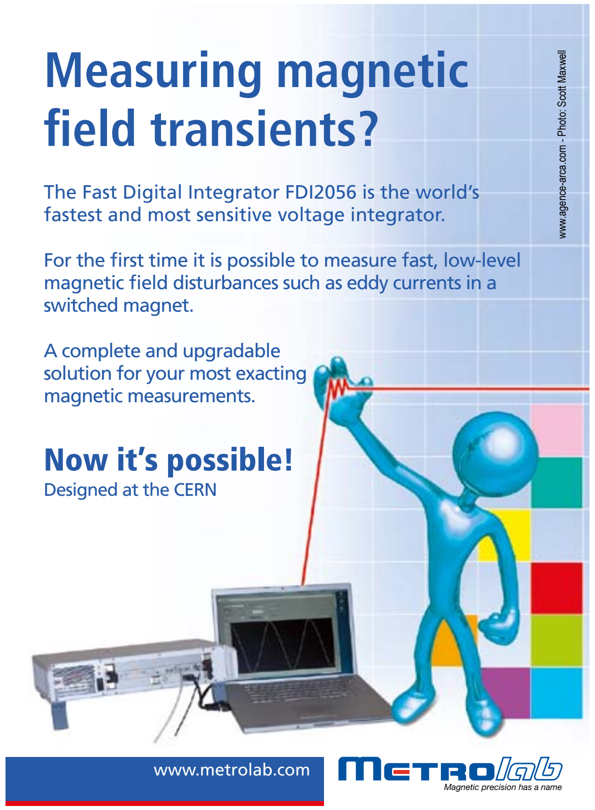

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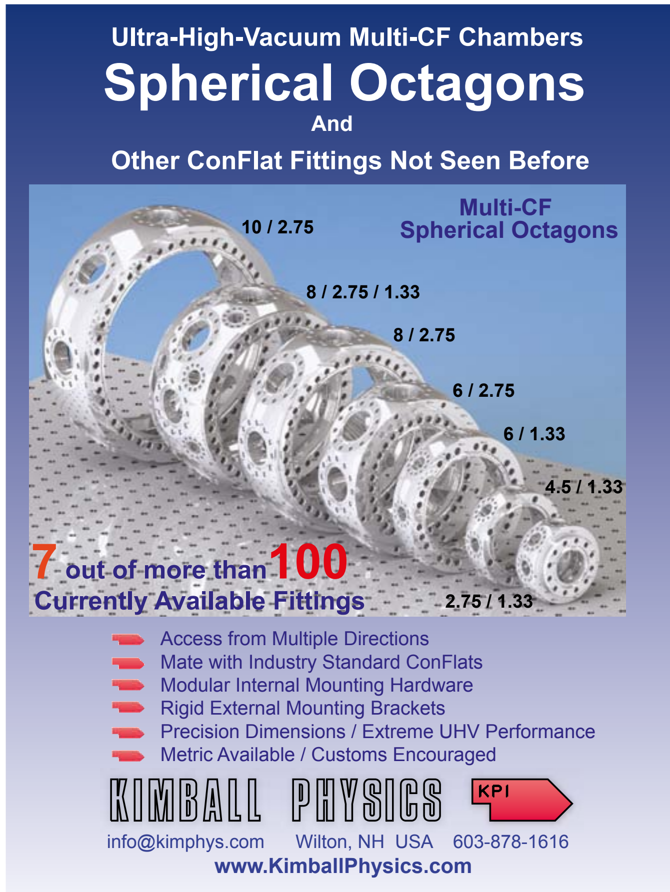

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The LHC's first long run

High-quality beam from the injectors and full exploitation of options in the collider underpinned the LHC's performance in 2010–2013.

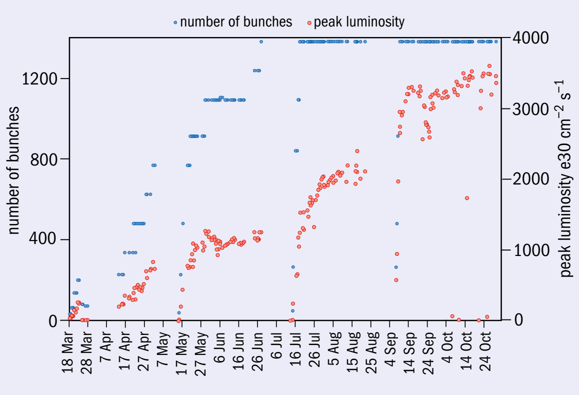
Since the first 3.5 TeV collisions in March 2010, the LHC has had three years of improving integrated luminosity. By the time that the first proton physics run ended in December 2012, the total integrated proton–proton luminosity delivered to each of the two general-purpose experiments – ATLAS and CMS – had reached nearly 30 fb^{-1} and enabled the discovery of a Higgs boson. ALICE, LHCb and TOTEM had also operated successfully and the LHC team was able to fulfil other objectives, including productive lead–lead and proton–lead runs.

Establishing good luminosity depends on several factors but the goal is to have the largest number of particles potentially colliding in the smallest possible area at a given interaction point (IP). Following injection of the two beams into the LHC, there are three main steps to collisions. First, the beam energy is ramped to the required level. Then comes the squeeze. This second step involves decreasing the beam size at the IP using quadrupole magnets on both sides of a given experiment. In the LHC, the squeeze process is usually parameterized by β* (the beam size at the IP is proportional to the square root of β*). The third step is to remove the separation bumps that are formed by local corrector magnets. These bumps keep the beams separated at the IPs during the ramp and squeeze.

High luminosity translates into having many high-intensity particle bunches, an optimally focused beam size at the interaction point and a small emittance (a measure of the spread of the beam in transverse phase space). The three-year run saw relatively distinct phases in the increase of proton–proton luminosity, starting with basic commissioning then moving on through exploration of the limits to full physics production running in 2012.

The first year in 2010 was devoted to commissioning and establishing confidence in operational procedures and the machine protection system, laying the foundations for what was to follow. Commissioning of the ramp to 3.5 TeV went smoothly and the first (unsqueezed) collisions were established on 30 March. Squeeze commissioning then successfully reduced β* to 2 m in all four IPs.

With June came the decision to go for bunches of nominal intensity, i.e. around 10^{11} protons per bunch (see table, p27). This involved an extended commissioning period and subsequent operation with beams of up to 50 or so widely separated bunches. The next step was to increase the number of bunches further. This required the move to bunch trains with 150 ns between bunches and the introduction of well defined beam-crossing angles in the interaction regions to avoid parasitic collisions. There was also a judicious back-off in the squeeze to a β* of 3.5 m. These changes necessitated setting up the tertiary collimators again and recommissioning the process of injection, ramp and squeeze – but provided a good opportunity to bed-in the operational sequence.



Performance 2011 – in red the peak luminosity, in blue the number of bunches. The plot tracks the switch to 50 ns bunch spacing; the subsequent increase in number of bunches to 1380; smaller emittances from the injectors; and finally the reduction in β from 1.5 to 1 m. (The gaps and following ramp-up are the schedule technical stops.)*

A phased increase in total intensity followed, with operational and machine protection validation performed before each step up in the number of bunches. Each increase was followed by a few days of running to check system performance. The proton run for the year finished with beams of 368 bunches of around 1.2×10^{11} protons per bunch and a peak luminosity of 2.1×10^{32} cm^{-2} s^{-1}. The total integrated luminosity for both ATLAS and CMS in 2010 was around 0.04 fb^{-1}.

The beam energy remained at 3.5 TeV in 2011 and the year saw exploitation combined with exploration of the LHC's performance limits. The campaign to increase the number of bunches in the machine continued with tests with a 50 ns bunch spacing. An encouraging performance led to the decision to run with 50 ns. A staged ramp-up in the number of bunches ensued, reaching 1380 – the maximum possible with a bunch spacing of 50 ns – by the end of June. The LHC's performance was increased further by reducing the emittances of the beams that were delivered by the injectors and by gently increasing the bunch intensity. The result was a peak luminosity of 2.4×10^{33} cm^{-2} s^{-1} and some healthy delivery rates that topped 90 pb^{-1} in 24 hours.

The next step up in peak luminosity in 2011 followed a reduction in β* in ATLAS and CMS from 1.5 m to 1 m. Smaller beam size at an IP implies bigger beam sizes in the neighbouring inner triplet magnets. However, careful measurements had revealed ▷

a better-than-expected aperture in the interaction regions, opening the way for this further reduction in β^*. The lower β^* and increases in bunch intensity eventually produced a peak luminosity of $3.7 \times 10^{33}\,\mathrm{cm^{-2}\,s^{-1}}$, beyond expectations at the start of the year. ATLAS and CMS had each received around 5.6 fb^{-1} by the end of proton–proton running for 2011.

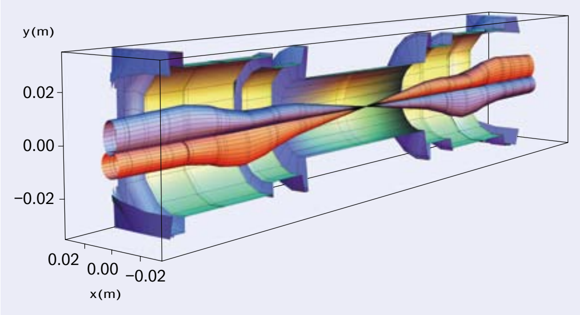
An increase in beam energy to 4 TeV marked the start of operations in 2012 and the decision was made to stay at a 50 ns bunch spacing with around 1380 bunches. The aperture in the interaction regions, together with the use of tight collimator settings, allowed a more aggressive squeeze to β^* of 0.6 m. The tighter collimator settings shadow the inner triplet magnets more effectively and allow the measured aperture to be exploited fully. The price to pay was increased sensitivity to orbit movements – particularly in the squeeze – together with increased impedance, which as expected had a clear effect on beam stability.

Peak luminosity soon came close to its highest for the year, although there were determined and long-running attempts to further improve performance. These were successful to a certain extent and revealed some interesting issues at high bunch and total beam intensity. Although never debilitating, instabilities were a recurring problem and there were phases when they cut into operational efficiency. Integrated luminosity rates, however, were generally healthy at around 1 fb^{-1} per week. This allowed a total of about 23 fb^{-1} to be delivered to both ATLAS and CMS during a long operational year with the proton–proton run extended until December.

Apart from the delivery of high instantaneous and integrated proton–proton luminosity to ATLAS and CMS, the LHC team also satisfied other physics requirements. These included lead–lead runs in 2010 and 2011, which delivered 9.7 and 166 μb^{-1}, respectively, at an energy of 3.5Z TeV (where Z is the atomic number of lead). Here the clients were ALICE, ATLAS and CMS. A process of luminosity levelling at around $4 \times 10^{32}\,\mathrm{cm^{-2}\,s^{-1}}$ via transverse separation with a tilted crossing angle enabled LHCb to collect 1.2 fb^{-1} and 2.2 fb^{-1} of proton–proton data in 2011 and 2012, respectively. ALICE enjoyed some sustained proton–proton running in 2012 at around $5 \times 10^{30}\,\mathrm{cm^{-2}\,s^{-1}}$, with collisions between enhanced satellite bunches and the main bunches. There was also a successful $\beta^* = 1$ km run for TOTEM and the ATLAS forward detectors. This allowed the first LHC measurement in the Coulomb-nuclear interference region. Last, the three-year operational period culminated in a successful proton–lead run at the start of 2013, with ALICE, ATLAS, CMS and LHCb all taking data.

One of the main features of operation in 2011 and 2012 was the high bunch intensity and lower-than-nominal emittances offered by the excellent performance of the injector chain of Booster, Proton Synchrotron and Super Proton Synchrotron. The bunch intensity had been up to 150% of nominal with 50 ns bunch spacing, while the normalized emittance going into collisions had been around 2.5 mm mrad, i.e. 67% of nominal. Happily, the LHC proved to be capable of absorbing these brighter beams, notably in terms of beam–beam effects. The cost to the experiments was high pile-up, an issue that was handled successfully.

The table shows the values for the main luminosity-related parameters at peak performance of the LHC from 2010 to 2012 and the design values. It shows that, even though the beam size is naturally larger at lower energy, the LHC has achieved 77% of design luminosity at four-sevenths of the design energy with a β^* of 0.6 m (compared with the design value of 0.55 m) with half of the nominal number of bunches.



Beam envelopes in the interaction region around point 1 (ATLAS) showing how the beam sizes are reduced in the last 60 m on each side of the interaction point following the squeeze. Note the different transverse scale: the radius of the cut-away beam pipe is just 18 mm at the collision point. The clockwise beam is in blue and the anti-clockwise beam is in red. (Credit: Courtesy J Jowett.)

Operational efficiency has been good with the integrated luminosity per week record reaching 1.3 fb^{-1}. This is the result of outstanding system performance combined with fundamental characteristics of the LHC. The machine has a healthy single-beam lifetime before collisions of more than 300 hours and on the whole enjoys good vacuum conditions in both warm and cold regions. With a peak luminosity of around $7 \times 10^{33}\,\mathrm{cm^{-2}\,s^{-1}}$ at the start of a fill, the luminosity lifetime is initially in the range of 6–8 hours, increasing as the fill develops. There is minimal drift in beam overlap during physics data-taking and the beams are generally stable.

At the same time, a profound understanding of the beam physics and a good level of operational control have been established. The magnetic aspects of the machine are well understood thanks to modelling with FiDel (the Field Description for the LHC). A long and thorough magnet-measurement and analysis campaign meant that the deployed settings produced a machine with a linear optics that is close to the nominal model. Measurement and correction of the optics has aligned machine and model to an unprecedented level.

A robust operational cycle is now well established, with the steps of pre-cycle, injection, 450 GeV machine, ramp, squeeze and collide mostly sequencer-driven. A strict pre-cycling regime means that the magnetic machine is remarkably reproducible. Importantly, the resulting orbit stability – or the ability to correct back consistently to a reference – means that the collimator set-up remains good for a year's run.

Considering the size, complexity and operating principles of the LHC, its availability has generally been good. The 257-day run in 2012 included around 200 days dedicated to proton–proton physics, with 36.5% of the time being spent in stable beams. This is encouraging for a machine that is only three years into its operational lifetime. Of note is the high availability of the critical LHC cryogenics system. In addition, many other systems also have crucial roles in ensuring that the LHC can run safely and efficiently.

Parameter	2010	2011	2012	design value
Beam energy	3.5	3.5	4	7
β^* in IP 1 and 5 (m)	2.0/3.5	1.5/1.0	0.6	0.55
Bunch spacing (ns)	150	75/50	50	25
Max. number of bunches	368	1380	1380	2808
Max. bunch intensity (protons per bunch)	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}	1.15×10^{11}
Normalized emittance at start of fill (mm mrad)	≈2.0	≈2.4	≈2.5	3.75
Peak luminosity ($\mathrm{cm^{-2}s^{-1}}$)	2.1×10^{32}	3.7×10^{33}	7.7×10^{33}	1×10^{34}
Max. mean number of events per bunch crossing	4	17	37	19
Stored beam energy (MJ)	≈28	≈110	≈140	362

An overview of performance-related parameters during LHC operations in 2010–2013.

In general the LHC beam-dump system (LBDS) worked impeccably, causing no major operational problems or long downtime. Beam-based set-up and checks are performed at the start of the operational year. The downstream protection devices form part of the collimator hierarchy and their proper positioning is verified periodically. The collimation system maintained a high proton-cleaning efficiency and semi-automatic tools have improved collimator set-up times during alignment.

The overall protection of the machine is ensured by rigorous follow-up, qualification and monitoring. The beam drives a subtle interplay of the LBDS, the collimation system and protection devices, which rely on a well defined aperture, orbit and optics for guaranteed safe operation. The beam dump, injection and collimation teams pursued well organized programmes of set-up and validation tests, permitting routine collimation of 140 MJ beams without a single quench of superconducting magnets from stored beams.

The beam instrumentation had great performance overall. Facilitating a deep understanding of the machine, it paved the way for the impressive improvement in performance during the three-year run. The power converters performed superbly, with good tracking between reference and measured currents and between the converters around the ring. There was good performance from the key RF systems. Software and controls benefited from a coherent approach, early deployment and tests on the injectors and transfer lines.

There have inevitably been issues arising during the exploitation of the LHC. Initially, single-event upsets caused by beam-induced radiation to electronics in the tunnel were a serious cause of inefficiency. This problem had been foreseen and a sustained programme of mitigation measures, which included relocation of equipment, additional shielding and further equipment upgrades, resulted in a reduction of premature beam dumps from 12 per fb^{-1} to 3 per fb^{-1} in 2012. By contrast, an unforeseen problem concerned unidentified falling objects (UFOs) – dust particles falling into the beam causing fast, localized beam-loss events. These have now been studied and simulated but might still cause difficulties after the move to higher energy and a bunch spacing of 25 ns following the current long shutdown.

Beam-induced heating has been an issue. Essentially, all cases turned out to be localized and connected with nonconformities, either in design or installation. Design problems have affected the injection-protection devices and the mirror assemblies of the synchrotron-radiation telescopes, while installation problems have occurred in a low number of vacuum assemblies.

Beam instabilities dogged operations during 2012. The problems came with the push in bunch intensity, with the peak going into stable beams reaching around 1.7×10^{11} protons per bunch, i.e. ultimate bunch intensity. Other contributory factors included increased impedance from the tight collimator settings, smaller than nominal emittance and operation with low chromaticity during the first half of the run.

A final beam issue concerns the electron cloud. Here, electrons emitted from the vacuum chamber are accelerated by the electromagnetic fields of the circulating bunches. On impacting the vacuum chamber they cause further emission of one or more electrons and there is a potential avalanche effect. The effect is strongly bunch-spacing dependent and although it has not been a serious issue with the 50 ns beam, there are potential problems with 25 ns .

In summary, the LHC is performing well and a huge amount of experience and understanding has been gained during the past three years. There is good system performance, excellent tools and reasonable availability following targeted consolidation. Good luminosity performance has been achieved by harnessing the beam quality from injectors and fully exploiting the options in the LHC. This overall performance is the result of a remarkable amount of effort from all of the teams involved.

This article is based on "The first years of LHC operation for luminosity production", which was presented at IPAC13.

Résumé

La première longue exploitation du LHC

Depuis les premières collisions à 3,5 Tev en mars 2010, la luminosité intégrée du LHC n'a cessé d'augmenter. Au terme de la première exploitation pour la physique avec protons, en décembre 2012, la luminosité intégrée totale des collisions proton-proton avait atteint environ 30 fb^{-1} dans les expériences ATLAS et CMS, ce qui a permis la découverte d'un boson de Higgs. ALICE, LHCb et TOTEM ont également fonctionné avec succès, et l'équipe du LHC a atteint plusieurs autres objectifs, notamment de fructueuses exploitations plomb-plomb et proton-plomb. Cette bonne performance générale a été possible grâce à la haute qualité des faisceaux produits par les injecteurs et à une exploitation complète des possibilités offertes par le collisionneur.

Mike Lamont, CERN, on behalf of the LHC team.

The challenge of keeping cool

The reliability of the LHC cryogenics system has been central to the collider's successful operation and provision of high integrated luminosity.

The LHC is one of the coldest places on Earth, with superconducting magnets – the key defining feature – that operate at 1.9 K. While there might be colder places in other laboratories, none compares to the LHC's scale and complexity. The cryogenic system that provides the cooling for the superconducting magnets, with their total cold mass of 36,000 tonnes, is the largest and most advanced of its kind. It has been running continuously at some level since January 2007, providing stalwart service and achieving an availability equivalent to more than 99% per cryogenic plant.

The task of keeping the 27-km-long collider at 1.9 K is performed by helium that is cooled to its superfluid state in a huge refrigeration system. While the niobium-titanium alloy in the magnet coils would be superconducting if normal liquid helium were used as the coolant, the performance of the magnets is greatly enhanced by lowering their operating temperature and by taking advantage of the unique properties of superfluid helium. At atmospheric pressure, helium gas liquefies at around 4.2 K but on further cooling it undergoes a second phase change at about 2.17 K and becomes a superfluid. Among many remarkable properties, superfluid helium has a high thermal conductivity, which makes it the coolant of choice for the refrigeration and stabilization of large superconducting systems.

The LHC consists of eight 3.3-km-long sectors with sites for access shafts to services on the surface at the ends of each sector. Five of these sites are used to locate the eight separate cryogenic plants, each dedicated to serving one sector (figure 1). An individual cryoplant consists of a pair of refrigeration units: one, the 4.5 K refrigerator, provides a cooling-capacity equivalent to 18 kW at 4.5 K; while the other, the 1.8 K refrigeration unit, provides a further cooling capacity of 2.4 kW at 1.8 K. Therefore, each of the eight cryoplants must distribute and recover kilowatts of refrigeration across a distance of 3.3 km, to be achieved with a temperature change of less than 0.1 K.

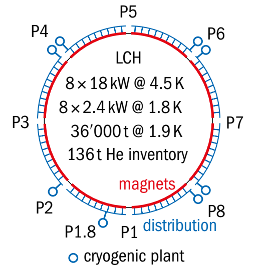


Fig. 1. Distribution of the cryoplants around the LHC ring.

Four of the 4.5 K refrigerators were recovered from the second phase of the Large Electron–Positron collider (LEP2), where they were used to cool its superconducting radiofrequency cavities. These "recycled" units have been upgraded to operate on the LHC sectors that have a lower demand for refrigeration. The four high-load sectors are instead cooled by new 4.5 K refrigerators. The refrigeration capacity needed to cool the 4500 tonnes of material in each sector of the LHC is enormous and can be produced only by using liquid nitrogen. Consequently, each 4.5 K refrigerator is equipped with a 600-kW liquid-nitrogen pre-cooler. This is used to cool a flow of helium down to 80 K while the corresponding sector is cooled before being filled with helium – a procedure that takes just under a month. Using only helium in the tunnel considerably reduces the risk of oxygen deficiency in the case of an accidental release.

The 4.5 K refrigeration system works by first compressing the helium gas and then allowing it to expand. During expansion it cools by losing energy through mechanical turbo-expanders that run at up to 140,000 rpm on helium-gas bearings. Each of the refrigerators consists of a helium-compressor station equipped with systems to remove oil and water, as well as a vacuum-insulated cold box (60 tonnes) where the helium is cooled, purified and liquefied. The compressor station supplies compressed helium gas at 20 bar and room temperature. The cold box houses the heat exchangers and turbo-expanders that provide the cooling capacities necessary to liquefy the helium at 4.5 K. The liquid helium then passes to the 1.8 K refrigeration unit, where the cold-compressor train decreases its saturation pressure and consequently its saturation temperature down to 1.8 K. Each cryoplant is equipped with a fully automatic process-control system that manages about 1000 inlets and outlets per plant. The system takes a total electrical input power of 32 MW and reaches an equivalent cooling capacity of 144 kW at 4.5 K – enough to provide almost 40,000 litres of liquid helium per hour.

In the LHC tunnel, a cryogenic distribution line runs alongside the machine. It consists of eight continuous cryostats, each about 3.2 km long and housing four (or five) headers to supply and recover helium, with temperatures ranging from 4 K to 75 K. A total of 310 service modules, of 44 different types feed the machine. These contain sub-cooling heat exchangers, all of the cryogenic control valves for the local cooling loops and 1–2 cold pressure-relief ▷

Fig. 2. The compressor unit of the 4.5 K refrigerator at Point 6. The unit provides 18 kW cooling capacity. There are eight of these units in the complete system.

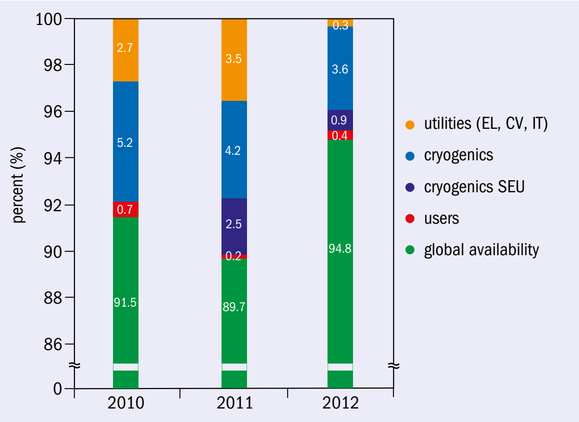


Fig. 3. The global availability of the cryogenic system 2010–2012. The cause of every unavailability is identified and grouped according to its source – utilities (electricity, cooling water and instrument air), cryogenics, cryogenics involving SEUs and user requests.

valves that protect the magnet cold masses, as well as monitoring and control instrumentation. Overall, the LHC cryogenic system contains about 60,000 inlets and outlets, which are managed by 120 industrial-process logic controllers that implement more than 4000 PID control loops.

Operational aspects

The structure of the group involved with the operation of the LHC's cryogenics has evolved naturally since the installation phase, so maintaining experience and expertise. Each cryogenically independent sector of the LHC and its pair of refrigerators is managed by its own dedicated team for process control and operational procedures. In addition, there are three support teams for mechanics, electricity-instrumentation controls and metrology instrumentation. A further team handles scheduling, maintenance and logistics, including cryogen distribution. Continuous monitoring and technical support is provided by personnel who are on shift "24/7" in the CERN Control Centre and on standby duties. This constant supervision is necessary because any loss of availability for the cryogenic system impacts directly on the availability of the accelerator. Furthermore, the response to cryogenic failures must be rapid to mitigate the consequences of loss of cooling.

In developing a strategy for operating the LHC it was necessary to define the overall availability criteria. Rather than using every temperature sensor or liquid-helium level as a separate interlock to the magnet powering and therefore the beam permit, it made more sense to organize the information according to the modularity of the magnet-powering system. As a result, each magnet-powering subsector is attributed a pair of cryogenic signals: "cryo-maintain" (CM) and "cryo-start" (CS). The CM signal corresponds to any condition that requires a slow discharge of the magnets concerned, while the CS signal has more stringent conditions to enable powering to take place with sufficient margins for a smooth transition to the CM threshold. A global CM signal is defined as the combination of all of the required conditions for the eight sectors. This determines the overall availability of the LHC cryogenics.

During the first LHC beams in 2009, the system immediately delivered availability of 90% despite there being no means of dealing quickly with identified faults. These were corrected whenever possible during the routine technical stops of the accelerator and the end-of-year stops. The main issues resolved during this phase were the elimination of two air leaks in sub-atmospheric circuits, the consolidation of all of the 1200 cooling valves for current leads and the 1200 electronic cards for temperature sensors that were particularly affected by energetic neutron impacts, so-called single-event upsets (SEUs).

Since early operation for physics began in November 2009, the availability has been above 90% for more than 260 days per year. A substantial improvement occurred in 2012–2013 because of progress in the operation of the cryogenic system. The operation team undertook appropriate training that included the evaluation and optimization of operation settings. There were major improvements in handling utilities-induced failures. In particular, in the case of electrical-network glitches, fine-tuning the tolerance thresholds for the helium compressors and cooling-water stations represented half of the gain. A reduction in the time taken to recover nominal cryogenic conditions after failures also led to improved availability. The progress made during the past three years led to a reduction in the number of short stops, i.e. less than eight hours, from 140 to 81 per year. By 2012, the efforts of the operation and support teams had resulted in a global availability of 94.8%, corresponding to an equivalent availability of more than 99.3% for each of the eight cryogenically independent sectors.

During first LHC beams in 2009 the system immediately delivered availability of 90%.

In addition, the requirement to undertake an energy-saving programme contributed significantly to the improved availability and efficiency of the cryogenic system – and resulted in a direct saving of SwFr3 million a year. Efforts to improve efficiency have also focused on the consumption of helium. The overall LHC inventory comes to 136 tonnes of helium, with an additional 15 tonnes held as strategic storage to cope with urgent situations during operation. For 2010 and 2011, the overall losses remained high because of increased losses from the newly commissioned storage tanks during the first end-of-year technical stop. However, the operational losses were substantially reduced in 2011. Then, in 2012, the combination of a massive campaign to localize all detectable leaks – combined with the reduced operational losses – led to a dramatic improvement in the overall figure, nearly halving the losses.

Towards the next run

Thanks to the early consolidation work already performed while ramping up the LHC luminosity, no significant changes are being implemented to the cryogenic system during the first long shutdown (LS1) of the LHC. However, because it has been operating continuously since 2007, a full preventive-maintenance plan is taking place. A major overhaul of helium compressors and motors is being undertaken at the manufacturers' premises. The acquisition of important spares for critical rotating machinery is already completed. Specific electronic units will be upgraded or relocated to cope with future radiation levels. In addition, identified leaks in the system must be repaired. The consolidation of the magnet interconnections – including the interface with the current leads – together with relocation of electronics to limit SEUs, will require a complete re-commissioning effort before cool-down for the next run.

The scheduled consolidation work – together with lessons learnt from the operational experience so far – will be key factors for the cryogenic system to maintain its high level of performance under future conditions at the LHC. The successful systematic approach to operations will continue when the LHC restarts at close to nominal beam energy and intensity. With greater heat loads corresponding to increased beam parameters and magnet currents, expectations are high that the cryogenic system will meet the challenge.

Résumé

Rester au frais : un défi

Le LHC est l'un des endroits les plus froids de la planète, avec ses aimants supraconducteurs, qui en sont l'élément-clé et qui fonctionnent à une température de 1,9 K. S'il peut exister des lieux plus froids dans d'autres laboratoires, aucun n'est comparable, en ampleur et en complexité, au LHC. Le système cryogénique, qui produit le froid nécessaire aux aimants supraconducteurs – lesquels représentent une masse froide totale de 36 000 tonnes – est le plus grand et le plus complexe qui soit. Il fonctionne en continu à un certain niveau depuis janvier 2007, de façon exemplaire et avec une disponibilité opérationnelle de plus de 99% pour chacune des installations cryogéniques.

Laurent Tavian, CERN, on behalf of the Cryogenics Group, Technology Department.

Advertising feature

Look deep into nature

"Measure what is measurable, and make measurable what is not so."
Galileo Galilei

The world's largest and most complex scientific instrument, the Large Hadron Collider at CERN, was built for fundamental research into elementary particles by recreating the energies and conditions that existed just billionths of a second into the Big Bang. The machine has been operating over the past two years, during which time it has confirmed the existence of the Higgs boson and yielded many other results.

By virtue of its diamond detectors, CIVIDEC Instrumentation is proud to be one of the companies that has contributed to the successful Higgs search by providing a beam loss and analysis system for the LHC which has more than proven its worth for the surveillance of high quality beams. This system sets itself apart from others by its ability to detect a wide spectrum of charged particles and photons and by recording loss data from Hz down to GHz frequencies while enduring the harsh radiation environment. The size and detail of the recorded data sets are ideal for single-bunch tune measurements, for example. This technology holds major prospects and contributes largely to the essential field of machine protection.

A Diamond Detector as provided by CIVIDEC Instrumentation, Austria

The main factors that make this system one of a kind are its ability to provide a view over a wide spectrum of charged particles and photons, to record detailed nanosecond time structures and, most importantly, the capability to endure in the harsh radiation environment.

Cutting-edge technology
Born from the cutting-edge technology of CERN, CIVIDEC Instrumentation is an internationally operating R&D company situated in the center of Vienna. Their focus lies on the fabrication of radiation monitors based on CVD diamond detectors and, in particular, on low-noise high-speed electronics that fully exploit the intrinsic properties of the diamond material. The Company's practical experience is firmly rooted in custom-tailored solutions for beam instrumentation for particle accelerators and dedicated readout systems.

Examples include

- **A beam loss monitoring system for the LHC beams.** This task is performed with a 1 ns time resolution, 5ns double-pulse resolution, 25 ns bunch-to-bunch loss detection, single particle sensitivity and 160 dB dynamic range. The patented AC+DC measurement system affords AC measurement from 25 kHz to 2 GHz and DC loss measurement with a bandwidth of 1 Hz. The diamond material and the electronics are radiation tolerant up to 1 MGy and have been tested in the cryogenic environment at 1.9 K.
- **ROSY, a dedicated readout system.** This system has been installed at the LHC and has been up and running for over a year. ROSY provides 4 channels, 5 GSPS and a bandwidth of 250 MHz. It has on-line dead-time-free FPGA signal processing and an Ethernet connection to control systems.
- **Neutron spectroscopy system.** This system affords a 3. 5 keV energy resolution and a dynamic range of 20 MeV, direct neutron detection above 6 MeV, and indirect neutron detection via the n → α reaction for neutron energies below 6 MeV.
- **A high-radiation monitor for LHC beam dump studies.** This system can operate under extreme radiation conditions with up to 1E9 MIP particles per pulse on the detector for 144 consecutive pulses. Beam losses are recorded as well as the beam position with a four-quadrant beam position monitor.

CIVIDEC Instrumentation is pleased to offer the sCVD and pCVD diamond diodes from 50 µm to 500 µm thickness. Standard transverse diamond sizes are 10 mm x 10 mm with 8 mm x 8 mm electrodes for pCVD diamonds and 4.5 mm x 4.5 mm with 4 mm x 4 mm electrodes for sCVD diamonds. Custom elements can be made up to a maximum of 80 mm diameter for pCVD. Strip and mosaic detectors can be specified.

Off-the-shelf electronics
Off-the-shelf electronics include: Broadband Current Amplifier: 40 dB, 20 dB, 1 MHz–2 GHz, low noise (3.5dB). Fast Charge Amplifier: 10 ns FWHM, gain = 4 mV/fC, 1000 electrons noise. Spectroscopy Shaping Amplifier: 180 ns FWHM, gain = 8 mV/fC, 300 electrons noise.

Erich Griesmayer is CEO of CIVIDEC Instrumentation and has been working at CERN for more than 20 years. He is associated professor at the Vienna University of Technology and Member of RD42, ATLAS, n_TOF at CERN.

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Safeguarding the superconducting magnets

The LHC employs a sophisticated magnet-protection system against the quench phenomenon, both to safeguard the magnetic circuits and to maximize beam availability.

The total electromagnetic energy stored in the LHC superconducting magnets is about 10,000 MJ, which is more than an order of magnitude greater than in the nominal stored beams (see p45). Any uncontrolled release of this energy presents a danger to the machine. One way in which this can occur is through a magnet quench, so the LHC employs a sophisticated system to detect quenches and protect against their harmful effects.

The magnets of the LHC are superconducting if the temperature, the applied magnetic induction and the current density are below a critical set of interdependent values – the critical surface (figure 1). A quench occurs if the limits of the critical surface are exceeded locally and the affected section of magnet coil changes from a superconducting to a normal conducting state. The resulting drastic increase in electrical resistivity causes Joule heating, further increasing the temperature and spreading the normal conducting zone through the magnet.

An uncontrolled quench poses a number of threats to a superconducting magnet and its surroundings. High temperatures can destroy the insulation material or even result in a meltdown of superconducting cable: the energy stored in one dipole magnet can melt up to 14 kg of cable. The excessive voltages can cause electric discharges that could further destroy the magnet. In addition, high Lorentz forces and temperature gradients can cause large variations in stress and irreversible degradation of the superconducting material, resulting in a permanent reduction of its current-carrying capability.

The LHC main superconducting dipole magnets achieve magnetic fields of more than 8 T. There are 1232 main bending dipole magnets, each 15 m long, that produce the required curvature for proton beams with energies up to 7 TeV. Both the main dipole and the quadrupole magnets in each of the eight sectors of the LHC are powered in series. Each main dipole circuit includes 154 magnets, while the quadrupole circuits consist of 47 or 51 magnets, depending on the sector. All superconducting components, including bus- bars and current leads as well as the magnet coils, are vulnerable to quenching under adverse conditions.

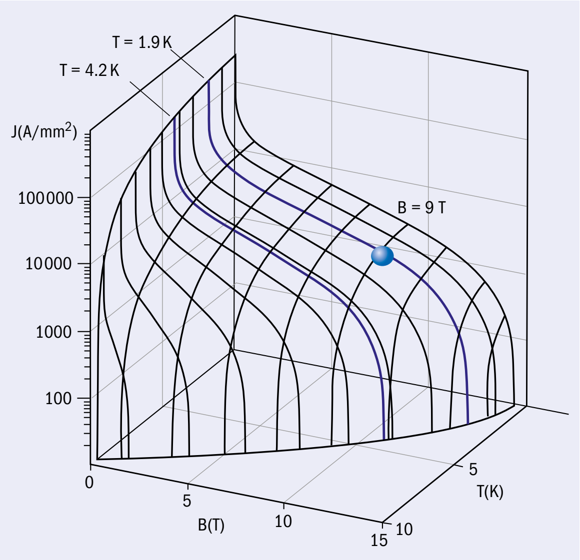


Fig. 1. The critical surface of the niobium-titanium alloy used in the LHC superconducting magnets, which operate at 1.9 K. Points below the surface correspond to superconducting behaviour for the material.

The LHC employs sophisticated magnet protection, the so-called quench-protection system (QPS), both to safeguard the magnetic circuits and to maximize beam availability. The effectiveness of the magnet-protection system is dependent on the timely detection of a quench, followed by a beam dump and rapid disconnection of the power converter and current extraction from the affected magnetic circuit. The current decay rate is determined by the inductance, L, and resistance, R, of the resulting isolated circuit, with a discharge time constant of $\tau = L/R$. For the purposes of magnet protection, reducing the current discharge time can be viewed as equivalent to the extraction and dissipation of stored magnetic energy. This is achieved by increasing the resistance of both the magnet and its associated circuit.

Additional resistance in the magnet is created by using quench heaters to heat up large fractions of the coil and spread the quench over the entire magnet. This dissipates the stored magnetic energy over a larger volume and results in lower hot-spot temperatures. ▷

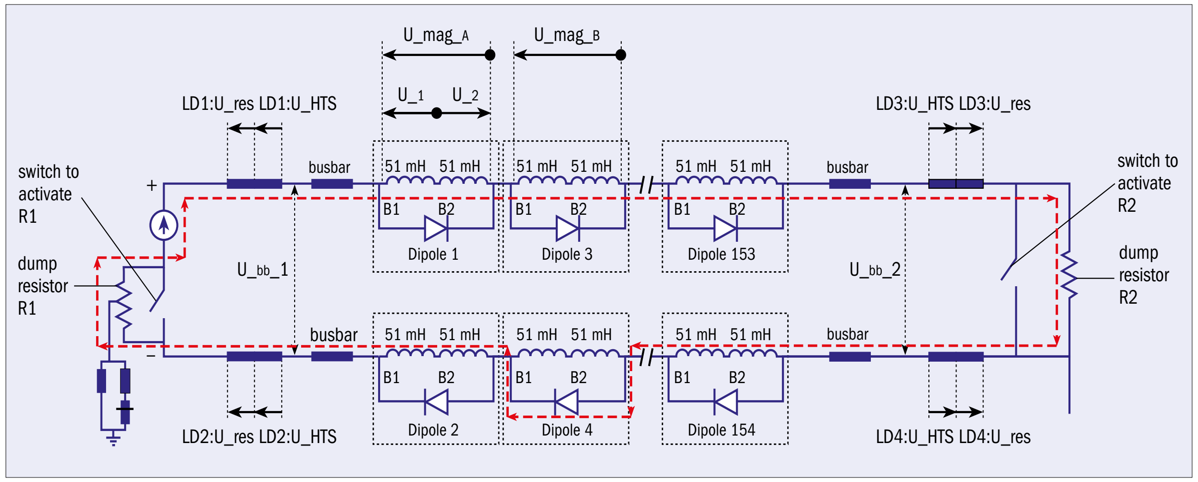


Fig. 2. Schematic of the main LHC dipole circuit in one sector. Magnet coils are connected in series and bypassed by a diode if there is a voltage rise. The path of the current (in red) is shown for the case of one magnet quench (dipole 4 in this picture) after less than 1 s, when all current has bypassed the quenched coil. At this stage the current passes through the dump resistors (R1 and R2), but in the circuit as a whole it is still close to its initial high value. (This diagram does not include the snubber capacitors added following experience in 2010.)

The resistance in the circuit is increased by switching-in a dump resistor, which extracts energy from the circuit (figure 2). As soon as one magnet quenches, the dump resistor is used to extract the current from the chain. The size of the resistor is chosen such that the current does not decrease so quickly as to induce large eddy-current losses, which would cause further magnets in the chain to quench.

Detection and mitigation

A quench in the LHC is detected by monitoring the resistive voltage across the magnet, which rises as the quench appears and propagates. However, the total measured voltage also includes the inductive-voltage component, which is driven by the magnet current ramping up or down. Reliably extracting the resistive-voltage signal from the total voltage-measurement is done using detection systems with inductive-voltage compensation. In the case of fast-ramping corrector magnets with large inductive voltages, it is more difficult to detect a resistive voltage because of the low signal-to-noise ratio; higher threshold voltages have to be used and a quench is therefore detected later. Following the detection and validation of a quench, the beam is aborted and the power converter is switched off. The time between the start of a quench and quench validation (i.e. activating the beam and powering interlocks) must be independent of the selected method of protection.

Creating a parallel path to the magnet via a diode allows the circuit current to by-pass the quenching magnet (figure 2). As soon as the increasing voltage over the quenched coil reaches the threshold voltage of the diode, the current starts to transfer into the diode. The magnet is by-passed by its diode and discharges independently. The diode must withstand the radiation environment, carry the current of the magnet chain for a sufficient time and provide sufficiently high turn-on voltage, to hold during the ramp up of the current. The LHC's main magnets use cold diodes, which are mounted within the cryostat. These have a significantly larger threshold voltage than diodes that operate at room temperature – but the threshold can be reached sooner if quench heaters are fired.

The sequence of events following quench detection and validation can be summarized as follows:

- 1. The beam is dumped and the power converter turned off.
- 2. The quench-heaters are triggered and the dump-resistor is switched-in.
- 3. The current transfers into the dump resistor and starts to decrease.
- 4. Once the quench heaters take effect, the voltage over the quenched magnet rises and switches on the cold diode.
- 5. The magnet starts now to be by-passed in the chain and discharges over the internal resistance.
- 6. The cold diode heats up and the forward voltage decreases.
- 7. The current decrease induces eddy-current losses in the magnet windings yielding enhanced quench propagation.
- 8. The current of the quenched magnet transfers fully into the cold diode.
- 9. The magnet chain is completely switched off a few hundred seconds after the quench detection.

QPS in practice

The QPS must perform with high reliability and high LHC beam availability. Satisfying these contradictory requirements requires careful design to optimize the sensitivity of the system. While failure to detect and control a quench can clearly have a significant impact on the integrity of the accelerator, QPS settings that are too tight may increase the number of false triggers significantly. As well as causing additional downtime of the machine, false triggers – which can result from electromagnetic perturbations, such as network glitches and thunderstorms – can contribute to the deterioration of the magnets and quench heaters by subjecting them to unnecessary spurious quenches and fast de-excitation.

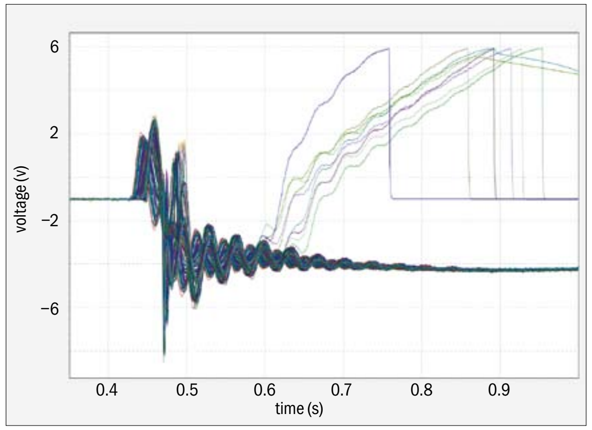


Fig. 3. Evolution of voltage during a multiple dipole magnet quench on 11 March 2010.

One of the important challenges for the QPS is coping with the conditions experienced during a fast power abort (FPA) following quench validation. Switching off the power converter and activating the energy extraction to the dump resistors causes electromagnetic transients and high voltages. The sensitivity of the QPS to spurious triggers from electromagnetic transients caused a number of multiple-magnet quench events in 2010 (figure 3). Following simulation studies of transient behaviour, a series of modifications were implemented to reduce the transient signals from a FPA. A delay was introduced between switching off the power converter and switching-in the dump resistors, with "snubber" capacitors installed in parallel to the switches to reduce electrical arcing and related transient voltage waves in the circuit (these are not shown in figure 2). These improvements resulted in a radically reduced number of spurious quenches in 2011 – only one such quench was recorded, in a single magnet, and this was probably due to an energetic neutron, a so-called "single-event upset" (SEU). The reduction in falsely triggered quenches between 2010 and 2011 was the most significant improvement in the QPS performance and impacted directly on the decision to increase the beam energy to 4 TeV in 2012.

To date, there have been no beam-induced quenches with circulating beams above injection current. This operational experience shows that the beam-loss monitor thresholds are low enough to cause a beam dump before beam losses cause a quench. However, the QPS had to act on several occasions in the event of real quenches in the bus-bars and current leads, demonstrating real protection in operation. The robustness of the system was evident on 18 August 2011 when the LHC experienced a total loss of power at a critical moment for the magnet circuits. At the time, the machine was ramping up and close to maximum magnet current with high beam intensity: no magnet tripped and no quenches occurred.

The reduction in falsely triggered quenches impacted directly on the decision to increase the beam energy to 4 TeV in 2012.

A persistent issue for the vast and complex electronics systems used in the QPS is exposure to radiation. In 2012 some of the radiation-to-electronics problems were partly mitigated by the development of electronics more tolerant to radiation. The number of trips per inverse femtobarn owing to SEUs was reduced by about 60% from 2011 to 2012 thanks to additional shielding and firmware upgrades. The downtime from trips is also being addressed by automating the power cycling to reset electronics after a SEU. While most of the radiation-induced faults are transparent to LHC operation, the number of beam dumps caused by false triggers remains an issue. Future LHC operation will require improvements in radiation-tolerant electronics, coupled with a programme of replacement where necessary.

Future operation

During the LHC run in 2010 and 2011 with a beam energy of 3.5 TeV, the normal operational parameters of the dipole magnets were well below the critical surface required for superconductivity. The main dipoles operated at about 6 kA and 4.2 T, while the critical current at this field is about 35 kA, resulting in a safe temperature margin of 4.9 K. However, this value will become 1.4 K for future LHC operation at 7 TeV per beam. The QPS must therefore be prepared for operation with tighter margins. Moreover, at higher beam energy quench events will be considerably larger, involving up to 10 times more magnetic energy. This will result in longer recuperation times for the cryogenic system. There is also a higher likelihood of beam-induced quench events and quenches induced by conditions such as faster ramp rates and FPAs.

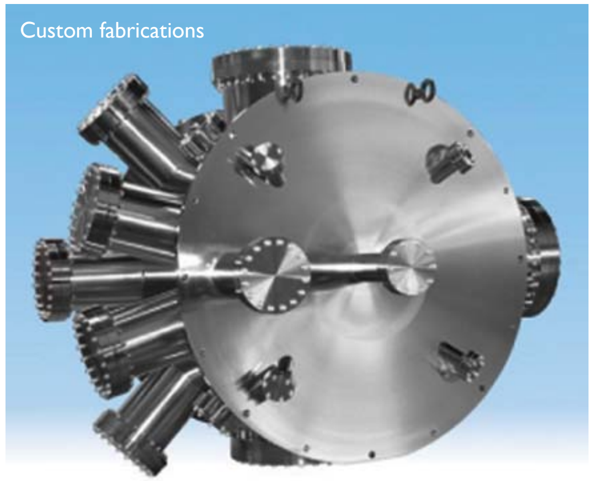
The successful implementation of magnet protection depends on a high-performance control and data acquisition system, automated software analysis tools and highly trained personnel for technical interventions. These have all contributed to the very good performance during 2010–2013. The operational experience gained during this first long run will allow the QPS to meet the challenges of the next run.

Résumé

Protéger les aimants supraconducteurs

L'énergie électromagnétique totale stockée dans les aimants supraconducteurs du LHC s'élève à environ 10 000 MJ, soit un ordre de grandeur de plus que l'énergie nominale stockée dans le faisceau. Toute libération incontrôlée de cette énergie représente un danger pour la machine. Cette situation peut se produire lors d'une transition résistive : l'aimant perd alors très rapidement ses propriétés supraconductrices pour revenir à l'état conducteur normal. Le LHC utilise un système complexe de protection contre ces transitions résistives, autant pour protéger les circuits magnétiques que pour assurer une disponibilité maximale du faisceau.

Andrzej Siemko on behalf of the MPE group.



The collimation system: defence against beam loss

The LHC employs the largest and most advanced cleaning system ever built for a particle accelerator.

Ideally, a storage ring like the LHC would never lose particles: the beam lifetime would be infinite. However, a number of processes will always lead to losses from the beam. The manipulations needed to prepare the beams for collision – such as injection, the energy ramp and "squeeze" – all entail unavoidable beam losses, as do the all-important collisions for physics. These losses generally become greater as the beam current and the luminosity are increased. In addition, the LHC's superconducting environment demands an efficient beam-loss cleaning to avoid quenches from uncontrolled losses – the nominal stored beam energy of 362 MJ is more than a billion times larger than the typical quench limits.

The tight control of beam losses is the main purpose of the collimation system. Movable collimators define aperture restrictions for the circulating beam and should intercept particles on large-amplitude trajectories that could otherwise be lost in the magnets. Therefore, the collimators represent the LHC's defence against unavoidable beam losses. Their primary role is to clean away the beam halo while maintaining losses at sensitive locations below safe limits. The current system is designed to ensure that peak losses below a few 0.01% of the energy lost from the beam is deposited in the cold magnets. As the closest elements to the circulating beams, the collimators provide passive machine protection against irregular fast losses and failures. They also control the distribution of losses around the ring by ensuring that the largest activation occurs at optimized locations. Collimators are also used to minimize background in the experiments.

The LHC collimation system provides multi-stage cleaning where primary, secondary and tertiary collimators and absorbers are used to reduce the population of halo particles to tolerable levels (figure 1). Robust carbon-based and non-robust but high-absorption metallic materials are used for different purposes. Collimators are installed around the LHC in seven out of the eight insertion regions (between the arcs), at optimal longitudinal positions and for various transverse rotation angles. The collimator jaws are set at different distances from the circulating beams, respecting the optimum setting hierarchy required to ensure that the system provides the required cleaning and protection functionalities.

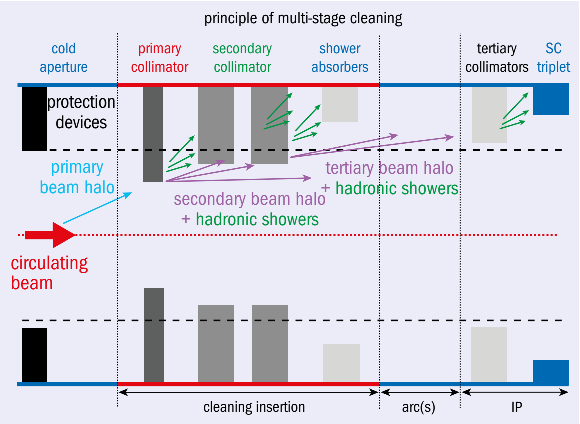


Fig. 1. An illustration of multi-stage cleaning in the transverse beam planes. Primary collimators intercept the protons that are lost from the beam core. The leakage from this single-stage cleaning would be well above the quench limit of superconducting magnets. Secondary collimators and absorbers are used in insertion regions IR3 and IR7 to intercept halo protons and hadronic showers produced by beam particles interacting with the collimator jaws during the multi-turn process. Additional tertiary collimators ensure further protection close to the experiments.

The detailed system design was the outcome of a multi-parameter optimization that took into account nuclear-physics processes in the jaws, robustness against the worst anticipated beam accidents, collimation-cleaning efficiency, radiation impact and machine impedance. The result is the largest and most advanced cleaning system ever built for a particle accelerator. It consists of 84 two-sided movable collimators of various designs and materials. Including injection protection collimators, there are a total of 396 degrees-of-freedom, because each collimator jaw has two stepping motors. By contrast, the collimation system of the Tevatron at Fermilab had less than 30 degrees-of-freedom for collimator positions.

The tight control of beam losses is the main purpose of the collimation system.

The design was optimized using numerical-simulation programs. These were based on a ▷

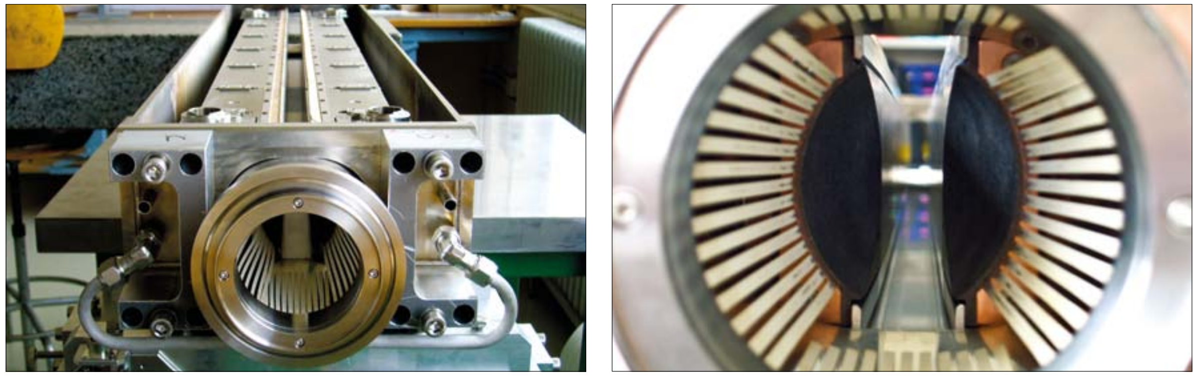


Fig. 2. An LHC collimator with the vacuum tank open, left, and a "beam's eye-view" of the collimator aperture, right. Most collimators consist of two 1-m-long jaws of different materials. The smallest operational gap is 2.1 mm.

detailed model of all of the magnetic elements for particle tracking and the vacuum pipe apertures, with a longitudinal resolution of 0.1 m along the 27-km-long rings. They also involved routines for proton-halo generation and transport, as well as aperture checks and proton–matter interactions. These simulations require high statistics to achieve accurate estimates of collimation cleaning. A typical simulation run involves tracking some 20–60 million primary halo protons for 200 LHC turns – equivalent to monitoring a single proton travelling a distance of 0.03 light-years. Several runs are needed to study the system in different conditions. Additional complex energy- deposition and thermo-mechanical finite-element computations are then used to establish heat loads in magnets, radiation doses and collimator structural behaviour for various loss scenarios. Such a highly demanding simulation process was possible only as a result of computing power developed over recent years.

The backbone of the collimation system is located at two warm insertion regions (IRs): the momentum cleaning at IR3 and betatron cleaning at IR7, which comprise 9 and 19 movable collimators per beam, respectively. Robust primary and secondary collimators made of a carbon-fibre composite define the momentum and betatron cuts for the beam halo. In 2012, in IR7 they were at ± 4.3–6.3σ (with σ being the nominal standard deviation of the beam profile in the transverse plane) from the circulating 140 MJ beams, which passed through collimator apertures as small as 2.1 mm at a rate of around 11,000 times per second.

Additional tungsten absorbers protect the superconducting magnets downstream of the warm insertions. While these are more efficient in catching hadronic and electromagnetic showers, they are also more fragile against beam losses, so they are retracted further from the beam orbit. Further local protection is provided for the experiments in IR1, IR2, IR5 and IR8: tungsten collimators shield the inner triplet magnets that otherwise would be exposed to beam losses because they are the magnets with the tightest aperture restrictions in the LHC in collision conditions. Injection and dump protection elements are installed in IR2, IR8 and IR6. The collimation system must provide continuous cleaning and protection during all stages of beam operation: injection, ramp, squeeze and physics.

An LHC collimator consists of two jaws that define a slit for the beam, effectively constraining the beam halo from both sides (figure 2). These jaws are enclosed in a vacuum tank that can be rotated in the transverse plane to intercept the halo, whether it is horizontal, vertical or skew. Precise sensors monitor the jaw positions and collimator gaps. Temperature sensors are also mounted on the jaws. All of these critical parameters are connected to the beam-interlock system and trigger a beam dump if potentially dangerous conditions are detected.

At the LHC's top energy, a beam size of less than 200 μm requires that the collimators act as high-precision devices. The correct system functionality relies on establishing the collimator hierarchy with position accuracies to within a fraction of the beam size. Collimator movements around the ring must also be synchronized to within better than 20 ms to achieve good relative positioning of devices during transient phases of the operational cycle. A unique feature of the control system is that the stepping motors can be driven according to arbitrary functions of time, synchronously with other accelerator systems such as power converters and radio-frequency cavities during ramp and squeeze.

These requirements place unprecedented constraints on the mechanical design, which is optimized to ensure good flatness along the 1-m-long jaw, even under extreme conditions. Extensive measurements were performed during prototyping and production, both for quality assurance and to obtain all of the required position calibrations. The collimator design has the critical feature that it is possible to measure a gap outside the beam vacuum that is directly related to the collimation gap seen by the beam. Some non-conformities in jaw flatness could not be avoided and were addressed by installing the affected jaws at locations of larger β functions (therefore larger beam size), in a way that is not critical for the overall performance.

Set-up and performance

The first step in collimation set-up is to adjust the collimators to the stored beam position. There are unavoidable uncertainties in the beam orbit and collimator alignment in the tunnel, so a beam-based alignment procedure has been established to set the jaws precisely around the beam orbit. The primary collimators are used to create reference cuts in phase space. Then all other jaws are moved symmetrically round the beam until they touch the reference beam halo. The results of this halo-based set-up provide information on the beam positions and sizes at each collimator. The theoretical target settings for the various collimators are determined from simulations to protect the available machine aperture. The beam-based alignment results are then used to generate appropriate setting functions for the collimator positions throughout the operational cycle. For each LHC fill, the system requires some 450 setting functions versus time, 1200 discrete set points and about 10,000 critical threshold settings versus time. Another 600 functions are used as redundant gap thresholds for different beam energies and optics configurations.

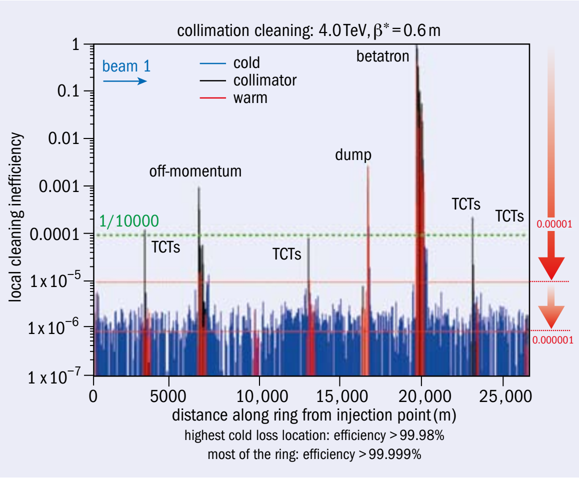


Fig. 3. Beam losses measured during a validation of collimation system performance at 4 TeV in 2012. The losses are normalized by the largest loss measured at the primary collimators in IR7, to illustrate that in most of the cold magnets (blue peaks) the losses are less than 10^{-5} of the peak loss. Collimator losses are shown in black and those in warm regions – less critical for the machine performance – are in red. (Image credit: B Salvachua BE/ABP.)

This complex system worked well during the first LHC operation with a minimum number of false errors and failures, showing that the choice of hardware and controls are fully appropriate for the challenging accelerator environment at the LHC. Collimator alignment and the handling of complex settings have always been major concerns for the operation of the large and distributed LHC collimation system. The experience accumulated in the first run indicates that these critical aspects have been addressed successfully.

The result of the cleaning mechanism from the LHC collimation process is always visible in the control room. Unavoidable beam losses occur continuously at the primary collimators and can be observed online by the operations team as the largest loss spikes on the fixed display showing the beam losses around the ring. The local leakage to cold magnets is in most cases below 0.00001 of the peak losses, with a few isolated loss locations around IR7 where the cleaning reaches levels up to a few 0.0001 (figure 3). So far, this excellent performance has ensured a quench-free operation, even in cases of extreme beam losses from circulating beams. Moreover, this was achieved throughout the year with only one collimator alignment in IR3 and IR7, thanks to the remarkable stability of the machine and of the collimator settings.

However, collimators in the interaction regions required regular setting up for each new machine configuration that was requested for the experiments. Eighteen of these collimators are being upgraded in the current long shutdown to reduce the time spent on alignment: the new tertiary collimator design has integrated beam-position monitors to enable a fast alignment without dedicated beam-based alignment fills. This upgrade will also eventually contribute to improving the peak luminosity performance by reducing further the colliding beam sizes, thanks to better control of the beam orbit next to the inner triplet.

The LHC collimation system performance is validated after set-up with provoked beam losses, which are artificially induced by deliberately driving transverse beam instabilities. Beam-loss monitors then record data at 3600 locations around the ring. As these losses occur under controlled conditions they can be compared in detail with simulations. As predicted, performance is limited by a few isolated loss locations, namely the IR7 dispersion-suppressor magnets, which catch particles that have lost energy in single diffractive scattering at the primary collimator. This limitation of the system will be addressed in future upgrades, in particular in the High Luminosity LHC era.

The first three-year operational run has shown that the LHC's precise and complex collimation system works at the expected high performance, reaching unprecedented levels of cleaning efficiency. The system has shown excellent stability: the machine was regularly operated with stored beam energies of more than 140 MJ, with no loss-induced quenches of superconducting magnets. This excellent performance was among the major contributors to the rapid commissioning of high-intensity beams at the LHC as well as to the squeezing of 4 TeV beams to 60 cm at collision points – a crucial aspect of the successful operation in 2012 that led to the discovery of a Higgs boson.

● The success of the collimation system during the first years of LHC operation was the result of the efforts of the many motivated people involved in this project from different CERN departments and from external collaborators. All of these people, and Ralph Assmann who led the project until 2012, are gratefully acknowledged.

Résumé

Le système de collimation : une arme contre les pertes de faisceaux

Les collimateurs du LHC offrent une protection contre les inévitables pertes de faisceaux. Ces structures mobiles définissent des limites d'ouverture pour le faisceau et interceptent les particules qui pourraient dévier de leur trajectoire. Situés au plus près des faisceaux, les collimateurs assurent une protection passive de la machine contre les pertes et les pannes se produisant subitement. Leur principale fonction est de supprimer le halo du faisceau et de maintenir les pertes de faisceau dans les limites de sécurité données aux points névralgiques de l'accélérateur. Le système actuel à trois niveaux est conçu pour que moins de 0,01 % de l'énergie perdue par le faisceau ne se dépose sur les aimants.

Stefano Redaelli, CERN, on behalf of the LHC collimation project team.

Steve Myers and the LHC: an unexpected journey

As one of the first proponents for the LHC, **Steve Myers** has experienced the highs – and lows – that led to its superb performance 30 years later.

The origins of the LHC trace from the early 1980s, in the days when construction of the tunnel for the Large Electron–Positron (LEP) collider was just getting under way. In 1983, Steve Myers was given an unexpected opportunity to travel to the US and participate in discussions on future proton colliders. He recalls: “None of the more senior accelerator physicists was available, so I got the job.” This journey, it turned out, was to be the start of his long relationship with the LHC.

Myers appreciated the significance for CERN of the discussions in the US: “We knew this was going to be the future competition and I wanted to understand it extremely well.” So he readied himself thoroughly by studying everything on the subject that he could. “With the catalyst that I had to prepare myself for the meeting, I looked at all aspects of it,” he adds. After returning to CERN, he thought about the concept of a proton collider in the LEP tunnel and wrote up his calculations, together with Wolfgang Schnell. “Wolfgang and I had many discussions and then we had a very good paper,” he says.

The paper (*LEP Note* 440) provided estimates for the design of a proton collider in the LEP tunnel and was the first document to bring all of the ideas together. It raised many of the points that were subsequently part of the LHC design: 8 TeV beam energy, beam–beam limitation (arguing the case for a twin-ring accelerator), twin-bore magnets and the need for magnet development, problems with pile-up (multiple collisions per bunch-crossing) and impedance limitations.

After Myers’ initial investigations, the time was ripe to develop active interest in a future hadron collider at CERN. A dedicated study group was established in late 1983 and the significant Lausanne workshop took place the following year, bringing experimental physicists together with accelerator experts to discuss the feasibility of the potential LHC (*CERN Courier* October 2008 p9). Then began the detailed preparation of the project design.

In the meantime in the US, the Superconducting Super Collider (SSC) project had been approved. Myers was on the accelerator physics subcommittee for both of the major US Department of Energy reviews of the SSC, in 1986 and 1990. He recalls that the committee recommended a number of essential improvements to the proposed design specification, which ultimately resulted in spiralling costs, contributing to the eventual cancellation of the project. “The project parameters got changed, the budget went up and they got scrapped in the end.”

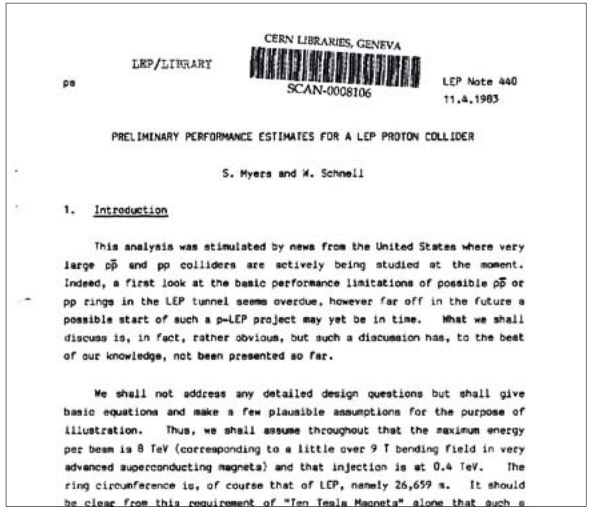
Happiness as the LHC ramps up to a record-breaking energy of 1.18 TeV on the night of 29–30 November 2009.

The LHC design, being constrained by the size of the LEP tunnel, could not compete with the SSC in terms of energy. Strategically, however, the LHC proposal compensated for the energy difference between the machines by claiming a factor-10 higher luminosity – an argument that was pushed hard by Carlo Rubbia. “We went for 10^{34} and nobody thought we could do it, including ourselves! But we had to say it, otherwise we weren’t competitive,” Myers says, looking back. It now gives Myers enormous satisfaction to see that the LHC performance in the first run achieved a peak stable luminosity of $7.73 \times 10^{33}\,\mathrm{cm^{-2}\,s^{-1}}$, while running at low energy. He adds confidently: “We will do 10^{34} and much more.”

The decision to use a twin-ring construction for the LHC was of central importance because separate rings allow the number of bunches in the beam to be increased dramatically. To date, the LHC has been running with 1380 bunches and is designed to use twice that number. For comparison, Myers adds: “The best we ever did with LEP was 16 bunches. The ratio of the number of bunches is effectively the ratio of the luminosities.”

Design details

At CERN, it was difficult to make significant progress with the LHC design while manpower and resources were focused on running LEP. Things took off after the closure of LEP in 2000, when there was a major redeployment of staff onto the LHC project and detailed operational design of the machine got under way. The LHC team, led by Lyn Evans, had three departments headed by Philippe Lebrun (magnets, cryogenics and vacuum), Paulo Ciriani (infrastructure and technical services) and Myers (accelerator physics, beam diagnostics, controls, injection, extraction and beam dump, machine protection, radio frequency and power supplies).



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LEP Note 440
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PRELIMINARY PERFORMANCE ESTIMATES FOR A LEP PROTON COLLIDER

S. Myers and W. Schnell

1. Introduction

This analysis was stimulated by news from the United States where very large $p\bar{p}$ and pp colliders are actively being studied at the moment. Indeed, a first look at the basic performance limitations of possible $p\bar{p}$ or pp rings in the LEP tunnel seems overdue, however far off in the future a possible start of such a p-LEP project may yet be in time. What we shall discuss is, in fact, rather obvious, but such a discussion has, to the best of our knowledge, not been presented so far.

We shall not address any detailed design questions but shall give basic equations and make a few plausible assumptions for the purpose of illustration. Thus, we shall assume throughout that the maximum energy per beam is 8 TeV (corresponding to a little over 9 T bending field in very advanced superconducting magnets) and that injection is at 0.4 TeV. The ring circumference is, of course that of LEP, namely 26,659 m. It should be clear from this requirement of "Ten Tesla Magnets" alone that such a

LEP Note *440, where Myers and Wolfgang Schnell put forward ideas for a hadron collider with 8 TeV beams in the LEP tunnel.*

Myers makes a typical understatement when asked about the challenges of managing a project of this size: “You do your planning on a regular basis.” This attitude provides the flexibility to exploit delays in the project in a positive way. “Every cloud has a silver lining,” he comments, illustrating his point with the stark image of thousands of magnets sitting in car parks around CERN. A delay that was caused by bad welds in the cryogenic system gave the magnet evaluation group the benefit of extra time to analyse individual magnet characteristics in detail. The magnets were then situated around the ring so that any higher-order field component in one is compensated by its neighbour, therefore minimizing nonlinear dynamic effects. Myers believes that is one of the reasons the machine has been so forgiving with the beam optics: “You spend millions getting the higher-order fields down, so you don’t have nonlinear motion and what was done by the magnet sorting gained us a significant factor on top of that.”

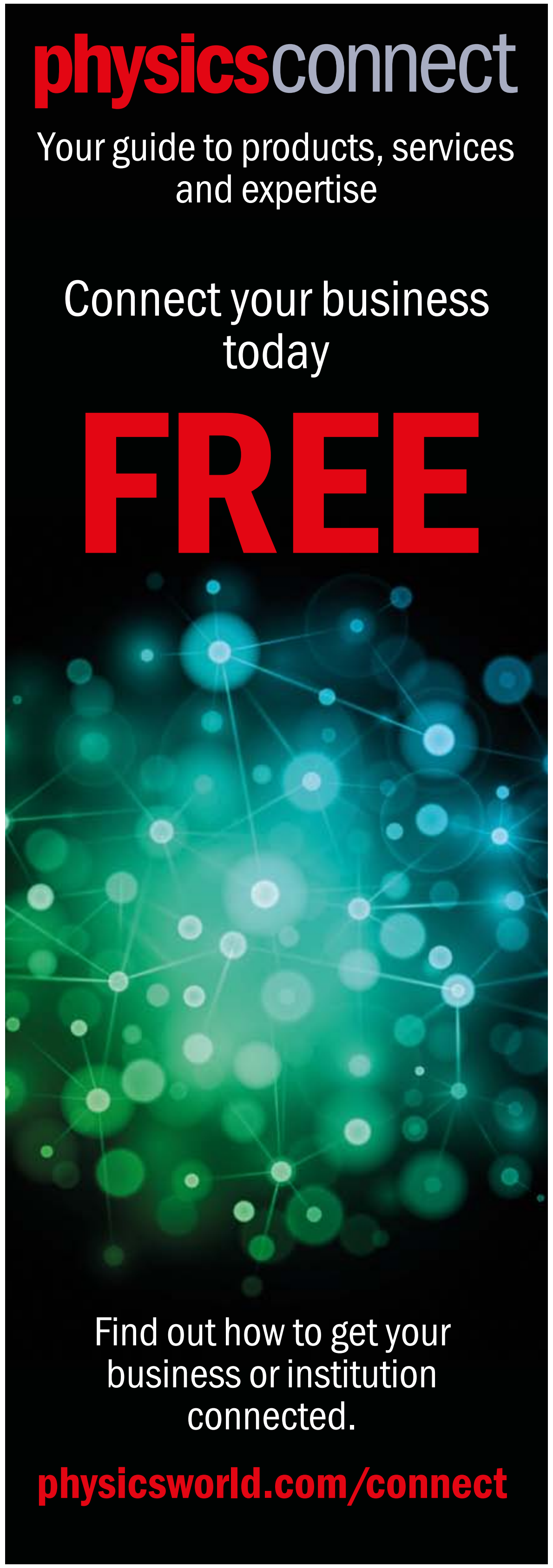
We went for 10^{34} and nobody thought we could do it, including ourselves!

When asked about the key moments in his journey with the LHC, he is clear: “The big highlight for us is when the beam goes all of the way round both rings. Then you know you’re in business; you know you can do things.” To that end, he paid close attention to the potential showstoppers: “The polarities of thousands of magnets and power supplies had to be checked and we had to make sure there were no obstacles in the path of the beam.” During the phase of systematically evaluating the polarities, it turned out that only about half were right first time. There were systematic problems to correct and even differing wiring conventions to address. In addition, a design fault in more than 3000 plug-in modules meant that they did not expand correctly when the LHC was warmed up. This was a potential source of beam-path obstacles and was methodically fixed. These stories illustrate the high level of attention to detail that was necessary for the successful switch-on of the LHC on 10 September 2008.

The low point of Myers’ experience was, of course, the LHC accident on 19 September 2008, which occurred only a matter of hours after he was nominated director of accelerators and technology. The incident triggered a shutdown of more than a year for repairs and an exhaustive analysis of what had gone wrong. During this time, an unprecedented amount of effort was invested in improvements to quality assurance and machine protection. One of the most important consequences was the development of the state-of-the-art magnet protection system, which is more technically advanced than was possible at the time of the LHC design (see this edition of the *Courier*, p25). The outcome is a machine that is extremely robust and whose behaviour is understood by the operations team.

In November 2009 the LHC was ready for testing once again. The first task was to ramp up the beam energy from the injection energy from the Super Proton Synchrotron of 0.45 TeV per beam. The process is complicated in the early stages by the behaviour of the superconducting magnets but the operations team succeeded in achieving 1.18 TeV per beam and established the LHC as the highest-energy collider ever built. By the end of March 2010, the first collisions at 7 TeV were made and from that point on the aim was to increase the collision rate by introducing more bunches with more protons per bunch and by squeezing the beam tighter at the interaction points. Every stage of this process was meticulously planned and carefully introduced, only going ahead when the machine protection team were completely satisfied.

In November 2009, when the LHC was ready to start up, both the machine and its experiments were thoroughly prepared for the physics programme ahead. The result was a spectacular level of productivity, leading to the series of announcements that culminated in the discovery of a Higgs boson. By the end of 2011 the LHC had surpassed its design luminosity for running with 3.5 TeV beams and the ATLAS and CMS experiments had seen the first hints of a new particle. The excitement was mounting and so was the pressure to generate as much data as possible. At the start of 2012, given that no magnet quenches had occurred while running with 3.5 TeV beams, it was considered safe to increase the beam ▷



Steve Myers – passionate about particle accelerators.

energy to 4 TeV. With a collision rate of 20 MHz and levels of pile-up reaching 45, the experiments were successfully handling an almost overwhelming amount of data. Myers finds this an amazing achievement, as he says, "nobody thought we could handle the pile-up," when the LHC was first proposed. He views the subsequent discovery announcement at CERN on 4 July 2012 as one of the most exciting moments of his career and, indeed, in the history of particle physics.

Reflecting on his journey with the LHC, Myers is keen to emphasize the importance of the people involved in its development, as well as the historical context in which it happened. In his early days at CERN in the 1970s, he was working with the Intersecting Storage Rings (ISR), which he calls "one of the best machines of its time". As a result, "I knew protons extremely well," he says. The experience he gained in those years has, in turn, contributed to his work on the LHC.

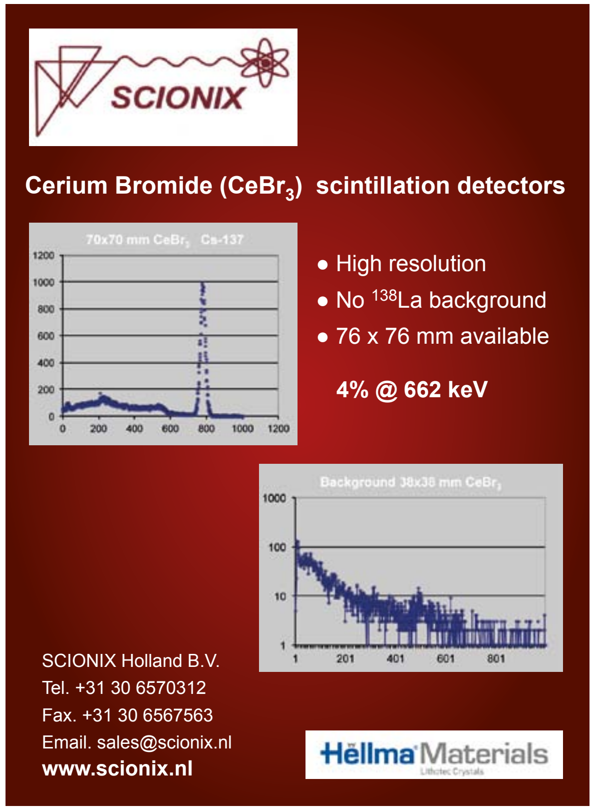
In the following years of building and operating LEP – as the world's largest accelerator – many young engineers developed their expertise, just as Myers had on the ISR. "I think that's why it worked so well," he says, "because these guys came in as young graduates, not knowing anything about accelerators and we trained them all and they became the real experts, in the same way as I did on the ISR." He sums up the value of this continuum of young people coming into CERN and becoming the next generation of experts: "That for me is what CERN is all about."

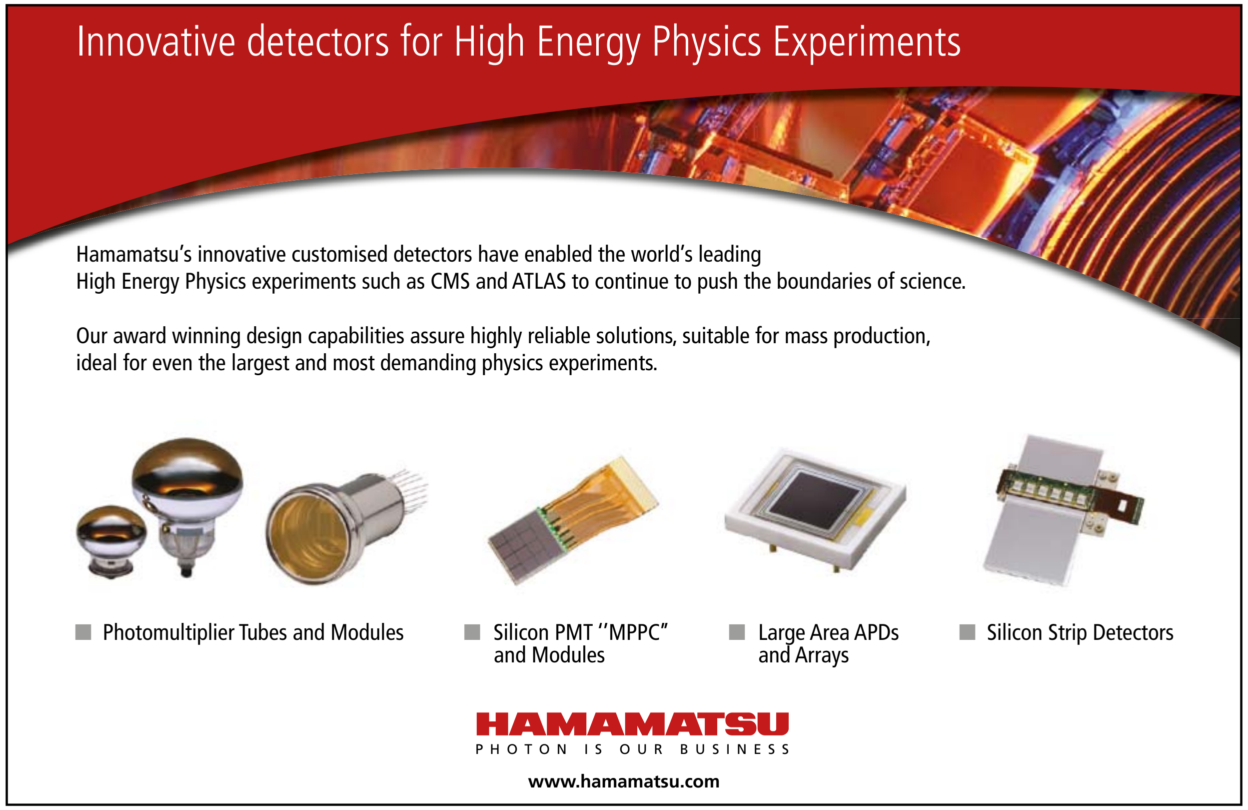
Résumé

Steve Myers et le LHC : une longue amitié

Steve Myers, l'un des initiateurs du LHC, est actuellement directeur des accélérateurs et de la technologie au CERN, et c'est lui qui a supervisé la première longue exploitation du LHC, de 2010 à 2013. En 1983, Steve Myers et Wolfgang Schnell écrivirent un article présentant des estimations pour la conception d'un collisionneur de protons dans le tunnel du Grand collisionneur électron-positon. Depuis, Steve Myers a pu suivre la grande aventure du LHC, qui a conduit aux formidables résultats obtenus en 2012. Dans cette interview, Steve Myers revient sur les moments forts de cette aventure et souligne l'importance des personnes qui y ont pris part.

Theresa Harrison, University of Warwick.

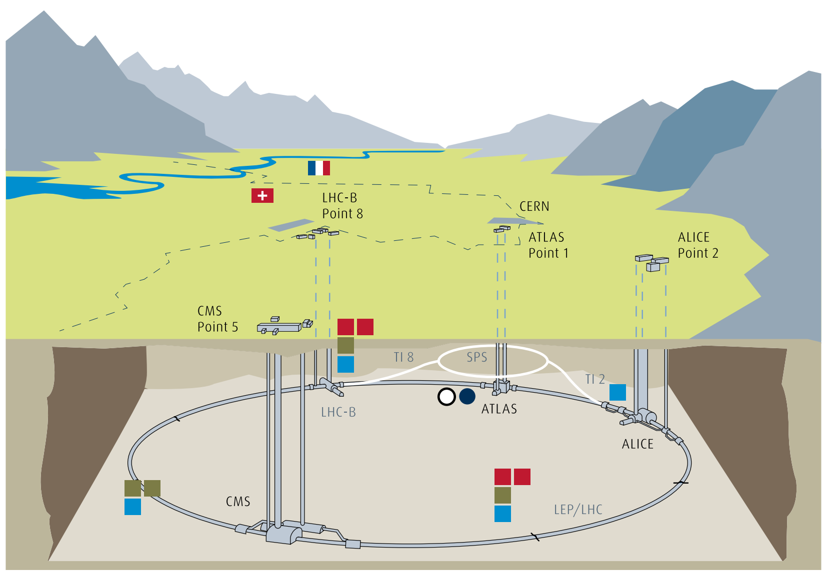




A Giant Fridge for Tiny Particles

Almost 60 years ago, the first few shovels of dirt were cleared for the construction of what will become man's largest and most complex technical feat. As the decades passed, CERN and its machinery grew larger. New and longer accelerator rings were added, detectors became more precise and many unknown phenomena were discovered along the way. The cryogenic experts of Linde Kryotechnik in Switzerland have been on board since the starting days.

Scope of Delivery Linde Kryotechnik:



🟦 pre-cooling unit
🟩 refrigeration system 4.5K
🟥 cold compressor system 1.8K
● cooling of heat shield
○ refrigeration system of magnet test facility

The largest machine of all time

Linde Kryotechnik's participation at the CERN facility dates back to the 1960's, when it delivered the very first cryogenic system to Geneva. The company went on to supply the cooling rigs for the Large Electron-Positron Collider (LEP) and today its technology also ensures the smooth operation of LEP's successor, the Large Hadron Collider (LHC). "The LHC is not only the largest machine of all time – it is also the biggest refrigerator in the world", notes Linde Kryotechnik's Head of Sales, Dr. Lars Blum. Because only a few centimeters away from the blazing hot proton beams, which race around the 27 kilometer accelerator ring, it is bitterly cold: To keep the excited particles on their circular path, some 1,800 superconducting magnets have to generate a field strength of more than eight tesla – equivalent to 200,000 times the earth's magnetic field.

For this to work, the cryo-team at CERN cools the magnet coils down to as far as 1.8 Kelvin (K). In other words: minus 271.35 degrees Celsius – almost absolute zero. "This is only possible by means of helium. It is the only substance that remains liquid at this temperature", explains Blum. Cooling the gigantic mass of over 37,000 tonnes – the weight of all magnets added together – requires 10,000 tonnes of liquid nitrogen and 130 tonnes of helium. It is a complex process that occurs simultaneously at different points in the facility and requires multiple steps. "When seen through the eyes of a cryogenic specialist, the LHC is also an enormous helium distribution system", says Blum. It is organized into eight 3.3-kilometer long sectors. Once a year, for maintenance activities, the LHC is warmed up and cooled down again. The closed helium network is then pre-cooled to 80K by liquid nitrogen units each supplying 600 kilowatts (kW). Linde Kryotechnik supplied four of these machines for the sectors four and six as well as for the sectors two and eight containing the Alice and LHCb detectors. Once this first cooling step is achieved and the facilities helium cycle is at 80K, the actual refrigeration begins: Each sector has a second helium refrigeration stage with a cooling capacity of 18kW at 4.5K. The second stage system works by first compressing the gas and then expanding it. In doing so, the helium cools and loses energy in turbo-expanders that run at up to 216,000 rotations per minute.

Four of these units were already in use during LEP-times. To meet the requirements needed to operate the much larger LHC, the original refrigerators had to be upgraded: "We supplied additional compressors and turbines for two of them in sectors four and six", says Blum. Linde Kryotechnik also delivered two brand new 18kW devices that are installed in sector six and in sector eight, which houses the LHCb detector. Finally, all of the sectors are equipped with a third cooling stage – the cold compressor system (CCS). These 2.4kW super-refrigerators cool the helium down to the ultimate temperature of 1.8K in multi-stage turbo compressors equipped with active magnetic bearings, variable speed and a sophisticated control system – pumping down the cooling bath to 14mbar. Their precision guarantees a temperature variability of under 0.1K in each of the LHC's three-kilometer long sections. Linde Kryotechnik delivered four CC-systems housed in sectors four and eight of the LHC. "The LHC is an incredible machine and its cooling system makes any cryogenic expert's heart beat faster", Blum summarizes.

After the successful discovery of the famed Higgs Boson, the LHC is now being modified: as of 2015 the particle beam's intensity will be doubled. This may lead to more groundbreaking data and expand the boundaries of known physics even further. Blum and his colleagues at Linde Kryotechnik are ready: "We look forward to continue supporting CERN and its facilities for many more years to come", he says.

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Machine protection: the key to safe operation

The LHC's high-intensity beams pose unprecedented challenges to master their energy content. Protecting the machine relies on several interdependent systems.

The combination of high intensity and high energy that characterizes the nominal beam in the LHC leads to a stored energy of 362 MJ in each ring. This is more than two orders of magnitude larger than in any previous accelerator – a large step that is highlighted in the comparisons shown in figure 1. An uncontrolled beam loss at the LHC could cause major damage to accelerator equipment. Indeed, recent simulations that couple energy-deposition and hydrodynamic simulation codes show that the nominal LHC beam can drill a hole through the full length of a copper block that is 20 m long.

Safe operation of the LHC relies on a complex system of equipment protection – the machine protection system (MPS). Early detection of failures within the equipment and active monitoring of the beam parameters with fast and reliable beam instrumentation is required throughout the entire cycle, from injection to collisions. Once a failure is detected the information is transmitted to the beam-interlock system that triggers the LHC beam-dumping system. It is essential that the beams are always properly extracted from the accelerator via a 700-m-long transfer line into large graphite dump blocks, because these are the only elements of the LHC that can withstand the impact of the full beam. Figure 2 on p46 shows the simulated impact of a 7 TeV beam on the dump block.

A variety of systems

There are several general requirements for the MPS. Its top priority is to protect the accelerator equipment from beam damage, while its second priority is to prevent the superconducting magnets from quenching. At the same time, it should also protect the beam – that is, the protection systems should dump the beam only when necessary so that the LHC's availability is not compromised. Last, the MPS must provide evidence from beam aborts. When there are failures, the so-called post-mortem system provides complete and coherent diagnostics data. These are needed to reconstruct the sequence of events accurately, to understand the root cause of the failure and to assess whether the protection systems functioned correctly.

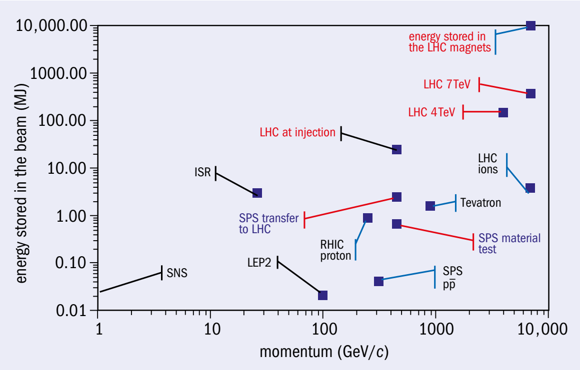


Fig. 1. The stored beam energy in various past and present accelerators. Note that both axes have logarithmic scales.

Protection of the LHC relies on a variety of systems with strong interdependency – these include the collimators and beam-loss monitors (BLMs) and the beam controls, as well as the beam injection, extraction and dumping systems. The strategy for machine protection, which involves all of these, rests on several basic principles:

- Definition of the machine aperture by the collimator jaws, with BLMs close to the collimators and the superconducting magnets. In general, particles lost from the beam will hit collimators first and not delicate equipment such as superconducting magnets or the LHC experiments.
- Early detection of failures within the equipment that controls the beams, to generate a beam-dump request before the beam is affected.
- Active monitoring with fast and reliable beam instrumentation, to detect abnormal beam conditions and rapidly generate a beam-dump request. This can happen within as little as half a turn of the beam round the machine (40 μs).
- Reliable transmission of a beam-dump request to the beam-dumping system by a distributed interlock system. Fail-safe logic is used for all interlocks, therefore an active signal is required for operation. The absence of the signal is considered as a beam-dump request or injection inhibit.
- Reliable operation of the beam-dumping system on receipt of a dump request or internal-fault detection, to extract the beams safely onto the external dump blocks.
- Passive protection by beam absorbers and collimators for specific failure cases.
- Redundancy in the protection system so that failures can be detected by more than one system. Particularly high standards ▷

for safety and reliability are applied in the design of the core protection systems.

Many types of failure are possible with a system as large and complex as the LHC. From the point of view of machine protection, the timescale is one of the most important characteristics of a failure because it determines how the MPS responds.

The fastest and most dangerous failures occur on the timescale of a single turn or less. These events may occur, for example, because of failures during beam injection or beam extraction. The probability for such failures is minimized by designing the systems for high reliability and by interlocking the kicker magnets as soon as they are not needed. However, despite all of these design precautions, failures such as incorrect firing of the kicker magnets at injection or extraction cannot be excluded. In these cases, active protection based on the detection of a fault and an appropriate reaction is not possible because the failure occurs on a timescale that is smaller than the minimum time that it would take to detect it and dump the beam. Protection from these specific failures therefore relies on passive protection with beam absorbers and collimators that must be correctly positioned close to the beam to capture the particles that are deflected accidentally.

Since the injection process is one of the most delicate procedures, a great deal of care has been taken to ensure that only a beam with low intensity – which is highly unlikely to damage equipment – can be injected into an LHC ring where no beam is already circulating. High-intensity beam can be injected only into a ring where a minimum amount of beam is present. This is a guarantee that conditions are acceptable for injection.

The majority of equipment failures, however, lead to beam "instabilities" – i.e. fast movements of the orbit or growth in beam size – that must be detected on a timescale of 1 ms or more. Protection against such events relies on fast monitoring of the beam's position and of beam loss. The LHC is equipped with around 4000 BLMs distributed along its circumference to protect all elements against excessive beam loss (*CERN Courier* October 2007 p6). Equipment monitoring – e.g. quench detectors and monitors for failures of magnet powering – provides redundancy for the most critical failure scenarios.

Last, on the longest timescale there will be unavoidable beam losses around the LHC machine during all of the phases of normal operation. Most of these losses will be captured in the collimation sections, where the beam losses and heat load at collimators are monitored. If the losses or the heat load become unacceptably high, the beam is dumped.

Operational experience

Figure 3 shows the evolution of the peak energy stored in each LHC beam between 2010 and 2012. The 2010 run was the main commissioning and learning year for the LHC and the associated MPSs. Experience had to be gained with all of the MPS sub-systems and thresholds for failure detection – e.g. beam-loss thresholds – had to be adjusted based on operational experience. In the summer of 2010, the LHC was operated at a stored energy of around 1–2 MJ – similar to the level of CERN's Super Proton Synchrotron and Fermilab's Tevatron – to gain experience with beams that could already create significant damage. A core team of MPS experts monitored the subsequent intensity ramps closely, with bunch spacings of 150 ns, 75 ns and 50 ns. Checklists were completed for each intensity level to document the subsystem status and to record observations. Approval to proceed to the next intensity stage was given only when all of the issues had been resolved. As experience was gained, the increments in intensity became larger and faster to execute. By mid-2012, a maximum stored energy of 140 MJ had been reached at 4 TeV per beam.

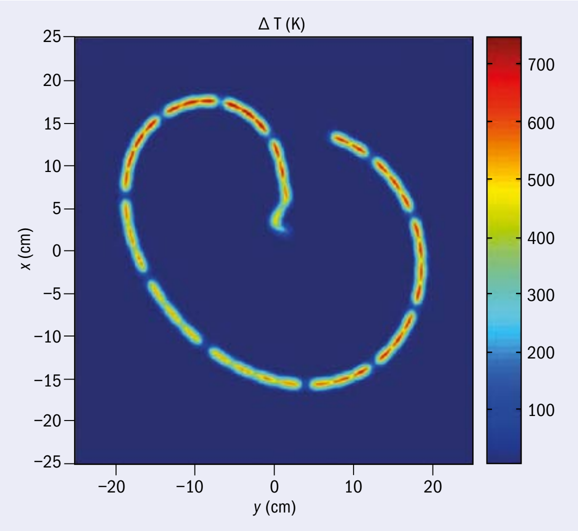


Fig. 2. Map of the calculated temperature increase in the central part of the beam-dump block after impact of a nominal beam at 7 TeV, with a stored energy of 362 MJ. The maximum temperature rise is about 750 K. (The block is a cylinder of graphite with a diameter of 70 cm.)

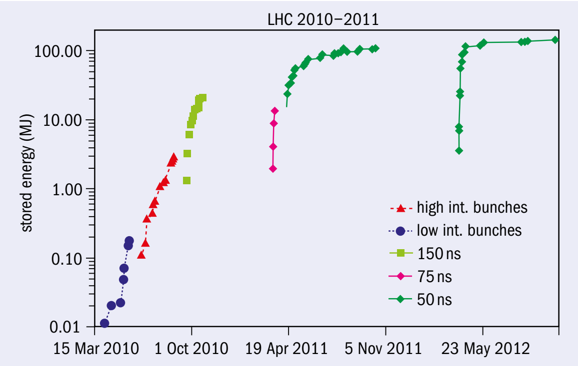


Fig. 3. The peak energy stored in each LHC beam as a function of time and bunch separation/type, from 2010 until late 2012. Note that the vertical axis has a logarithmic scale.

One worry with so many superconducting magnets in the LHC concerned quenches induced by uncontrolled beam losses. However, the rate was difficult to estimate before the machine began operation because it depended on a number of factors, including the performance of the large and complex collimation system. Fortunately, not a single magnet quench was observed during normal operation with circulating beams of 3.5 TeV and 4 TeV. This is a result of the excellent performance of the MPS, the collimation system and the outstanding stability and reproducibility of the machine.

Nevertheless, there were other – unexpected – effects. In the summer of 2010, during the intensity ramp-up to stored energies of 1 MJ, fast beam-loss events with timescales of 1 ms or less were observed for the first time in the LHC's arcs. When it became rapidly evident that dust particles were interacting with the beam they were nicknamed unidentified falling objects (UFOs). The rate of these UFOs increased steadily with beam intensity. Each year, the beams were dumped about 20 times when the losses induced by the interaction of the beams with the dust particles exceeded the loss thresholds. For the LHC injection kickers – where an important number of UFOs were observed – the dust particles could clearly be identified on the surface of the ceramic vacuum chamber. Kickers with better surface cleanliness will replace the existing kickers during the present long shutdown. Nevertheless, UFOs remain a potential threat to the operational efficiency of the LHC at 7 TeV per beam.

The LHC's MPS performed remarkably well from 2010 to 2013, thanks to the thoroughness and commitment of the operation crews and the MPS experts. Around 1500 beam dumps were executed correctly above the injection energy. All of the beam-dump events were meticulously analysed and validated by the operation crews and experts. This information has been stored in a knowledge database to assess possible long-term improvements of the machine protection and equipment systems. As experience grew, an increasing number of failures were captured before their effects on the particle beams became visible – i.e. before the beam position changed or beam losses were observed.

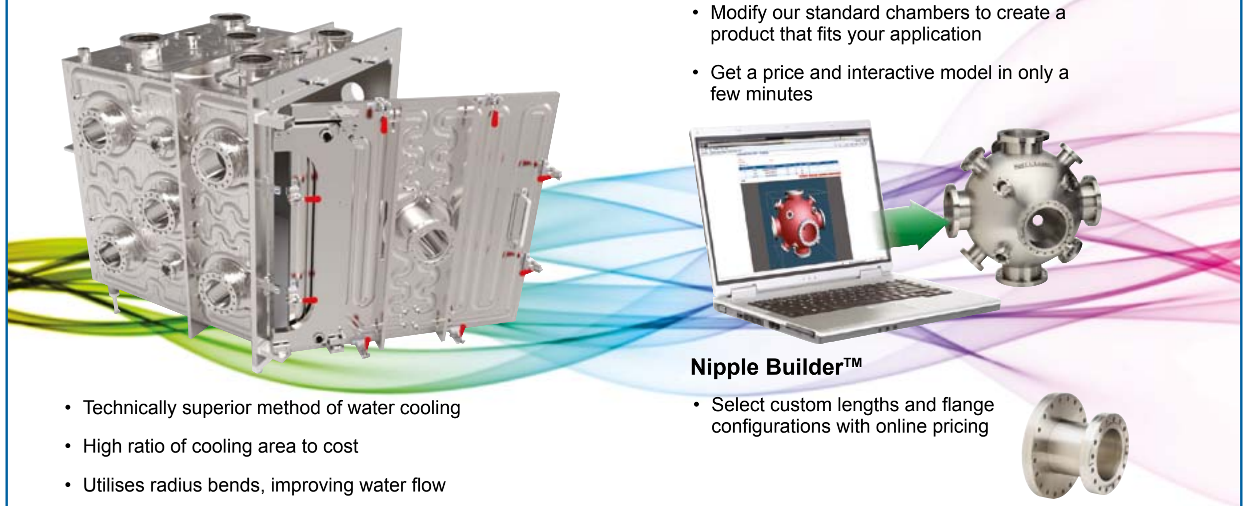
During the whole period, no evidence of a major loophole or uncovered risk in the protection architecture was identified, although sometimes unexpected failure modes were identified and mitigated. However, approximately 14% of the 1500 beam dumps were initiated by the failure of an element of the MPS – a "false" dump. So, despite the high dependability of the MPS during these first operational years, it will be essential to remain vigilant in the future as more emphasis is placed on increasing the LHC's availability for physics.

Résumé

Protéger la machine : la garantie d'un fonctionnement sûr

Les faisceaux de haute intensité du LHC représentent un défi sans précédent en matière de maîtrise de l'énergie. Un fonctionnement sûr du LHC repose sur un système complexe de protection de la machine, dont l'objectif premier est de protéger les équipements contre les dommages que le faisceau pourrait leur causer. Ce système ne doit toutefois arrêter le faisceau que lorsque cela est nécessaire, afin de ne pas compromettre la disponibilité opérationnelle du LHC. Une détection précoce des défaillances, de même qu'une surveillance active du faisceau à l'aide d'instruments très réactifs et fiables est nécessaire tout au long du cycle, de l'injection aux collisions. Les systèmes d'extraction et d'arrêt du faisceau doivent également être d'une grande fiabilité.

Jörg Wenninger, **Rüdiger Schmidt** and **Markus Zerlauth**, CERN.



AIDA boosts detector development

Bringing institutes together to work on shared problems, the AIDA project is enabling detector solutions for the exacting conditions of upgraded and future accelerators.

Research in high-energy physics at particle accelerators requires highly complex detectors to observe the particles and study their behaviour. In the EU-supported project on Advanced European Infrastructure for Detectors at Accelerators (AIDA), more than 80 institutes from 23 European countries have joined forces to boost detector development for future particle accelerators in line with the European Strategy for Particle Physics. These include the planned upgrade of the LHC, as well as new linear colliders and facilities for neutrino and flavour physics. To fulfil its aims, AIDA is divided into three main activities: networking, joint research and transnational access, all of which are progressing well two years after the project's launch (*CERN Courier* March 2011 p7).

Networking

AIDA's networking activities fall into three work packages (WPs): the development of common software tools (WP2); microelectronics and detector/electronics integration (WP3); and relations with industry (WP4).

Building on and extending existing software and tools, the WP2 network is creating a generic geometry toolkit for particle physics together with tools for detector-independent reconstruction and alignment. The design of the toolkit is shaped by the experience gained with detector-description systems implemented for the LHC experiments – in particular LHCb – as well as by lessons learnt from various implementations of geometry-description tools that have been developed for the linear-collider community. In this context, the Software Development for Experiments and LHCb Computing groups at CERN have been working together to develop a new generation of software for geometry modellers. These are used to describe the geometry and material composition of the detectors and as the basis for tracking particles through the various detector layers.

This work uses the geometrical models in Geant4 and ROOT to describe the experimental set-ups in simulation or reconstruction programmes and involves the implementation of geometrical solid primitives as building blocks for the description of complex detector arrangements. These include a large collection of 3D primitives, ranging from simple shapes such as boxes, tubes or cones to more complex ones, as well as their Boolean combinations. Some 70–80% of the effort spent on code maintenance in the geometry modeller is devoted to improving the implementation of these primitives. To reduce the effort required for support and maintenance and to converge on a unique solution based on high-quality code, the AIDA initiative has started a project to create a "unified-solids library" of the geometrical primitives.

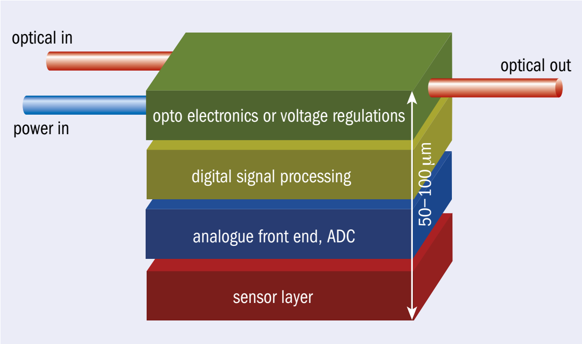


Fig. 1. Conceptual structure of a pixel detector based on 3D integration.

Enabling the community to access the most advanced semiconductor technologies – from nanoscale CMOS to innovative interconnection processes – is an important aim for AIDA. One new technique is 3D integration, which has been developed by the microelectronic industry to overcome limitations of high-frequency microprocessors and high-capacity memories. It involves fabricating devices based on two or more active layers that are bonded together, with vertical interconnections ensuring the communication between them and the external world. The WP3 networking activity is studying 3D integration to design novel tracking and vertexing detectors based on high-granularity pixel sensors.

Interesting results have already emerged from studies with the FE-Ix series of CMOS chips that the ATLAS collaboration has developed for the read-out of high-resistivity pixel sensors – 3D processing is currently in progress on FE-I4 chips (*CERN Courier* June 2012 p19). Now, some groups are evaluating the possibility of developing new electronic read-out chips in advanced ▷

CMOS technologies, such as 65 nm and of using these chips in a 3D process with high-density interconnections at the pixel level. Once the feasibility of such a device is demonstrated, physicists should be able to design a pixel detector with highly aggressive and intelligent architectures for sensing, analogue and digital processing, storage and data transmission (figure 1, p49).

The development of detectors using breakthrough technologies calls for the involvement of hi-tech industry. The WP4 networking activity aims to increase industrial involvement in key detector-developments in AIDA and to provide follow-up long after completion of the project. To this end, it has developed the concept of workshops tailored to maximize the attendees' benefits while also strengthening relations with European industry, including small and medium-sized enterprises (SMEs). The approach is to organize "matching events" that address technologies of high relevance for detector systems and gather key experts from industry and academia with a view to establish high-quality partnerships. WP4 is also developing a tool called "collaboration spotting", which aims to monitor through publications and patents the industrial and academic organizations that are active in the technologies under focus at a workshop and to identify the key players. The tool was used successfully to invite European companies – including SMEs – to attend the workshop on advanced interconnections for chip packaging in future detectors that took place in April at the Laboratori Nazionali di Frascati of INFN.

Test beams and telescopes

The development, design and construction of detectors for particle-physics experiments are closely linked with the availability of test beams where prototypes can be validated under realistic conditions or production modules can undergo calibration. Through its transnational access and joint research activities, AIDA is not only supporting test-beam facilities and corresponding infrastructures at CERN, DESY and Frascati but is also extending them with new infrastructures. Various sub-tasks cover the detector activities for the LHC and linear collider, as well as a neutrino activity, where a new low-energy beam is being designed at CERN, together with prototype detectors.

One of the highlights of WP8 is the excellent progress made towards two new major irradiation facilities at CERN. These are essential for the selection and qualification of materials, components and full detectors operating in the harsh radiation environments of future experiments. AIDA has strongly supported the initiatives to construct GIF++ – a powerful γ irradiation facility combined with a test beam in the North Area – and EAIRRAD, which will be a powerful proton and mixed-field irradiation facility in the East Area. AIDA is contributing to both projects with common user-infrastructure as well as design and construction support. The aim is to start commissioning and operation of both facilities following the LS1 shutdown of CERN's accelerator complex.

The current shutdown of the test beams at CERN during LS1 has resulted in a huge increase in demand for test beams at the DESY laboratory. The DESY II synchrotron is used mainly as a pre-accelerator for the X-ray source PETRA III but it also delivers electron or positron beams produced at a fixed carbon-fibre target to as many as three test-beam areas. Its ease of use makes the DESY test beam an excellent facility for prototype testing because this typically requires frequent access to the beam area. In 2013 alone, 45 groups from more than 30 countries with about 200 users have already accessed the DESY test beams. Many of them received travel support from the AIDA Transnational Access Funds and so far AIDA funding has enabled a total of 130 people to participate in test-beam campaigns. The many groups using the beams include those from the ALICE, ATLAS, Belle II, CALICE, CLIC, CMS, Compass, LHCb, LCTPC and Mu3e collaborations.

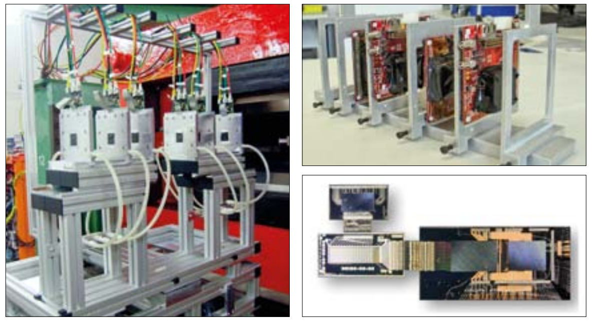


Fig. 2. Clockwise from left: Components of the combined beam-telescope in the test beam at DESY: the MIMOSA telescope, the ATLAS-FEI4 arm and the DEPFET device under test. (Image credit: DESY.)

About half of the groups using the test beam at DESY have taken advantage of a beam telescope to provide precise measurements of particle tracks. The EUDET project – AIDA's predecessor in the previous EU framework programme (FP6) – provided the first beam telescope to serve a large user community, which was aimed at detector R&D for an international linear collider. For more than five years, this telescope, which was based on Minimum Ionizing Monolithic Active pixel Sensors (MIMOSA), served a large number of groups. Several copies were made – a good indication of success – and AIDA is now providing continued support for the community that uses these telescopes. It is also extending its support to the TimePix telescope developed by institutes involved in the LHCb experiment.

The core of AIDA's involvement lies in the upgrade and extension of the telescope. For many users who work on LHC applications, a precise reference position is not enough. They also need to know the exact time of arrival of the particle but it is difficult to find a single system that can provide both position and time at the required precision. Devices with a fast response tend to be less precise in the spatial domain or put too much material in the path of the particle. So AIDA combines two technologies: the thin MIMOSA sensors with their spatial resolution provide the position; while the ATLAS FEI4 detectors provide time information with the desired LHC structure.

The first beam test in 2012 with a combined MIMOSA-FEI4 telescope was an important breakthrough. Figure 2 shows the components involved in the set-up in the DESY beam. Charged particles from the accelerator – electrons in this case – first traverse three read-out planes of the MIMOSA telescope, followed by the device under test, then the second triplet of MIMOSA planes and then the ATLAS-FEI4 arm. The DEPFET pixel-detector international collaboration was the first group to use the telescope, so bringing together within a metre pixel detectors from three major R&D collaborations.

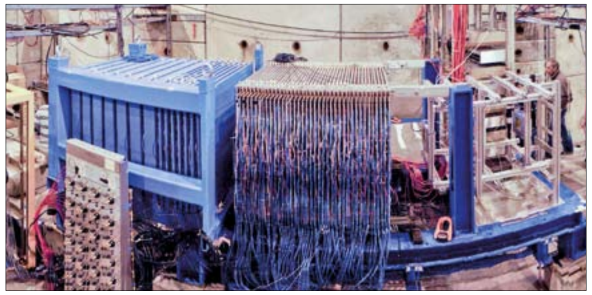


Fig. 3. The CALICE tungsten calorimeter prototype under test at CERN. This cubic-metre hadron calorimeter prototype has almost 500,000 channels that are read out individually – more than all of the calorimeters of the ATLAS and CMS experiments combined.

While combining the precise time information from the ATLAS-FEI4 detector with the excellent spatial resolution of MIMOSA provides the best of both worlds, there is an additional advantage: the FEI4 chip has a self-triggering capability because it can issue a trigger signal based on the response of the pixels. Overlaying the response of the FEI4 pixel matrix with a programmable mask and feeding the resulting signal into the trigger logic allows triggering on a small area and is more flexible than a traditional trigger based on scintillators. To change the trigger definition, all that is needed is to upload a new mask to the device. This turns out to be a useful feature if the prototypes under test cover a small area.

Calorimeter development in AIDA WP9 is mainly motivated by experiments at possible future electron–positron colliders, as defined in the International Linear Collider and Compact Linear Collider studies. These will demand extremely high-performance calorimetry, which is best achieved using a finely segmented system that reconstructs events using the so-called particle-flow approach to allow the precise reconstruction of jet energies. The technique works best with an optimal combination of tracking and calorimeter information and has already been applied successfully in the CMS experiment. Reconstructing each particle individually requires fine cell granularity in 3D and has spurred the development of novel detection technologies, such as silicon photomultipliers (SiPMs) mounted on small scintillator tiles or strips, gaseous detectors (micro mesh or resistive plate chambers) with 2D read-out segmentation and large-area arrays of silicon pads.

After tests of sensors developed by the CALICE collaboration in a tungsten stack at CERN (figure 3) – in particular to verify the neutron and timing response at high energy – the focus is now on the realization of fully technological prototypes. These include power-pulsed embedded data-acquisition chips requested for the particle-flow-optimized detectors for a future linear collider and they address all of the practical challenges of highly granular devices – compactness, integration, cooling and *in situ* calibration. Six layers (256 channels each) of a fine granularity ($5 \times 5\ \text{mm}^2$) silicon-tungsten electromagnetic calorimeter are being tested in electron beams at DESY this July (figure 4). At the same time, the commissioning of full-featured scintillator hadron calorimeter units (140 channels each) is progressing at a steady pace. A precision tungsten structure and read-out chips are also being prepared for the forward calorimeters to test the radiation-hard sensors produced by the FCAL R&D collaboration.

Fig. 4. Five scintillator HCAL units in the test-beam area at DESY. (Image credit: DESY.)

The philosophy behind AIDA is to bring together institutes to solve common problems so that once the problem is solved, the solution can be made available to the entire community. Two years on from the project's start – and halfway through its four-year lifetime – the highlights described here, from software toolkits to a beam-telescope infrastructure to academia-industry matching, illustrate well the progress that is being made. Ensuring the user support of all equipment in the long term will be the main task in a new proposal to be submitted next year to the EC's Horizon 2020 programme. New innovative activities to be included will be discussed during the autumn within the community at large.

● Further reading

For more details, see the AIDA website at aida.web.cern.ch. For more about the CALICE collaboration, see https://twiki.cern.ch/twiki/bin/view/CALICE, and for more about the DEPFET collaboration, see www.depfet.org.

Résumé

AIDA soutient le développement des détecteurs

Le projet AIDA (Advanced European Infrastructure for detectors at Accelerators)*, cofinancé par l'Union européenne, rassemble plus de 80 institutions de 23 pays européens, qui ont uni leurs forces pour encourager le développement des détecteurs destinés aux futurs accélérateurs de particules. Sont notamment visés l'amélioration prévue du LHC et le développement de nouveaux collisionneurs linéaires et de nouvelles installations pour la physique sur les neutrinos et la physique des saveurs. Deux ans après le lancement du projet, qui doit durer quatre ans, les résultats obtenus, allant d'outils logiciels à des équipements de télescope à faisceaux, en passant par la collaboration entre le milieu universitaire et l'industrie, illustrent bien les progrès réalisés.*

Agnes Szeberenyi, CERN, on behalf of the AIDA consortium.

Image courtesy of: National High Magnetic Field Laboratory (NHMFL), Florida State University, Tallahassee, FL

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Neutral currents: A perfect experimental discovery

Forty years after the observation of weak neutral currents at CERN, **Luciano Maiani** reflects on their impact.

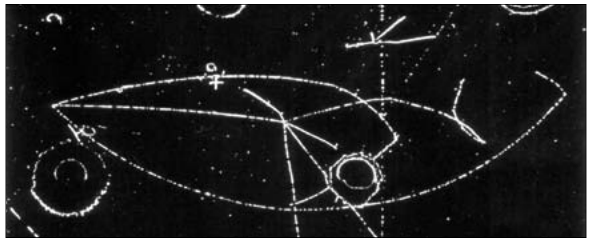


Fig. 1. A hadronic neutral current event, where the interaction of the neutrino from the left produces three secondary particles, all clearly identifiable as hadrons, as they interact with other nuclei in the liquid. There is no charged lepton.

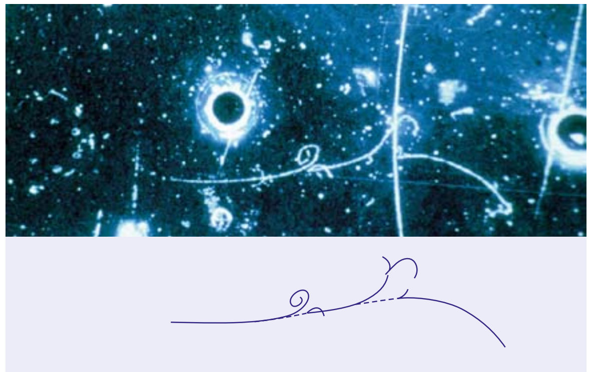


Fig. 2. The first leptonic neutral current event. An antineutrino coming from the left knocks an electron forwards, creating a characteristic shower of electron–positron pairs.

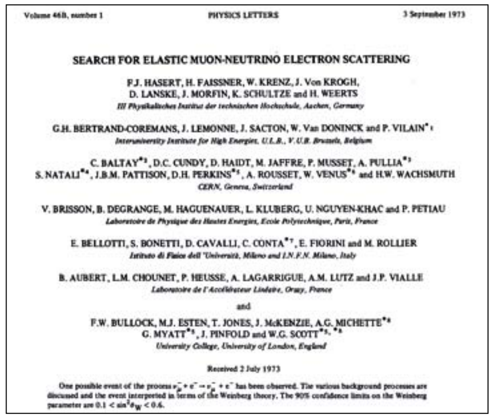
In a seminar at CERN on 19 July 1973, Paul Musset of the Gargamelle collaboration presented the first direct evidence of weak neutral currents. They had discovered events in which a neutrino scattered from a hadron (proton or neutron) without turning into a muon (figure 1) – the signature of a hadronic weak neutral current. In addition they had one leptonic event characterized by a single electron track (figure 2). A month later, Gerald Myatt presented the results on a global stage at the 6th International Symposium on Electron and Photon Interactions at High Energies in Bonn. By then, two papers detailing the discovery were in the offices of *Physics Letters* and were published together on 3 September. A few days later, the results were presented in Aix-en-Provence at the International Europhysics Conference on High-Energy Particle Physics, where they were aired as part of a large programme of events for the public.

Earlier in May, Luciano Maiani was with Nicola Cabibbo at their university in Rome when Ettore Fiorini visited, bringing news of what the Gargamelle collaboration had found in photographs of neutrino interactions in the huge heavy-liquid bubble chamber at CERN. The main problem facing the collaboration was to be certain that the events were from neutrinos and not from neutrons that were liberated in interactions in the material surrounding the bubble chamber (*CERN Courier* September 2009 p25). Fiorini described how the researchers had overcome this in their analysis, one of the important factors being the size of Gargamelle. "He explained that the secret was the volume," Maiani recalls, "which could kill the neutron background." Maiani at least was convinced that the collaboration had observed neutral currents. It was a turning point along the road to today's Standard Model of particles and their interactions, he says.

Weak neutral currents, which involve no exchange of electric charge between the particles concerned, are the manifestation of the exchange of the neutral vector boson, Z, which mediates the weak interaction together with the charged bosons, $W^{\pm}$. The discovery of these neutral currents in 1973 was crucial experimental support for the unification of electromagnetic and weak interactions in electroweak theory. This theory – for which Sheldon Glashow, Abdus Salam and Steven Weinberg received the Nobel Prize in Physics in 1979 – became one of the pillars of the Standard Model.

For Maiani, the theoretical steps began in 1962 with his colleague Cabibbo's work that restored universality in weak interactions. The problem that Cabibbo had resolved concerned an observed difference in the strength of weak decays of strange particles compared with muons and neutrons. His solution, formulated before the proposal of quarks, was based on a weak current parameterized by a single angle – later known as the Cabibbo angle.

During the next 10 years, not only did the concept of quarks as fundamental particles emerge but other elements of today's Standard Model developed, too. In 1970, for example, Maiani, Glashow and Iliopoulos put forward a model that involved a fourth quark, charm, to deal correctly with divergences in weak-interaction ▷



Volume 46B, number 1 PHYSICS LETTERS 3 September 1973

SEARCH FOR ELASTIC MUON-NEUTRINO ELECTRON SCATTERING

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Received 2 July 1973

One possible event of the process $\bar{\nu}_\mu + e^- \to \bar{\nu}_\mu + e^-$ has been observed. The various background processes are discussed and the event interpreted in terms of the Weinberg theory. The 90% confidence limits on the Weinberg parameter are $0.1 < \sin^2\theta_W < 0.6$.

Volume 46B, number 1 PHYSICS LETTERS 3 September 1973

OBSERVATION OF NEUTRINO-LIKE INTERACTIONS WITHOUT MUON
OR ELECTRON IN THE GARGAMELLE NEUTRINO EXPERIMENT

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Received 25 July 1973

Events induced by neutral particles and producing hadrons, but no muon or electron, have been observed in the CERN neutrino experiment. These events behave as expected if they arise from neutral current induced processes. The rates relative to the corresponding charged current processes are evaluated.

The two papers from the 23 September 1973 issue of Physics Letters *together showed that Gargamelle had discovered weak neutral currents.*

theory. Their idea was based on a simple analogy between the weak hadronic and leptonic currents. As their paper stated, the model featured "a remarkable symmetry between leptons and quarks" – and this brought the neutral currents of the electroweak unification of Weinberg and Salam into play in the quark sector. One important implication was a large suppression of strangeness-changing neutral currents through what became known as the GIM mechanism.

Maiani now says that at this point no one was talking in terms of a standard theory, even though many of the elements were there – charm, intermediate vector bosons and the Brout-Englert-Higgs mechanism for electroweak-symmetry breaking. However, perceptions began to change around 1972 with the work of Gerardus 't Hooft and Martinus Veltman, who showed that electroweak theory could be self-consistent through renormalization (*CERN Courier* December 2009 p30). After this leap forward in theory, the observations in Gargamelle provided a similar breakthrough on the experimental front. "At the start of the decade, people did not generally believe in a standard theory even though theory had done everything. The neutral-current signals changed that," Maiani recalls. "From then on, particle physics had to test the standard theory."

A cascade of discoveries followed the observation of neutral currents, with the J/ψ in 1974 and open charm in 1976 through to the W and Z vector bosons in 1983. The discovery of a Higgs boson in 2012 at CERN finally closed the cycle, providing observation of the key player in the Brout-Englert-Higgs mechanism, which gives mass to the W and Z bosons of the weak interactions, while leaving the photon of electromagnetism massless. In a happy symmetry, the latest results on this first fundamental scalar boson were recent highlights at the 2013 Lepton–Photon Conference and at the International Europhysics Conference on High-Energy Particle Physics, EPS-HEP 2013 – the direct descendants of the meetings in Bonn and Aix-en-Provence where the discovery of neutral currents was first aired 40 years ago.

"We are now stressing the discovery of a Higgs boson," says Maiani, "but in 1973 the mystery was: will it all work?" Looking back to the first observation of neutral currents, he describes it as "a perfect experimental discovery". "It was a beautiful experimental development, totally independent of theory," he continues. "It arrived at exactly the right moment, when people realized that there was a respectable theory." That summer 40 years ago also saw the emergence of quantum chromodynamics (*CERN Courier* January/February 2013 p24), which set up the theory for strong interactions. The Standard Model had arrived.

Physicists meet the public at Aix

During the week of the Aix Conference more attention than usual was given to the need for communication with non-physicists. A plenary session was held on "Popularizing High Energy Physics" and on several evenings "La Physique dans la Rue" events were organized in the town centre.

One evening saw a more classical presentation of information with talks by Louis Leprince-Ringuet (on the beauties of pure research), Bernard Gregory (on the role of fundamental science and its pioneering role in international collaboration) and Valentine Telegdi (on the intricate subject of neutral currents). More than 600 people heard these talks, no doubt attracted particularly by the well known television personality of Leprince-Ringuet.

- *CERN Courier* October 1973 pp297–298 (extract).

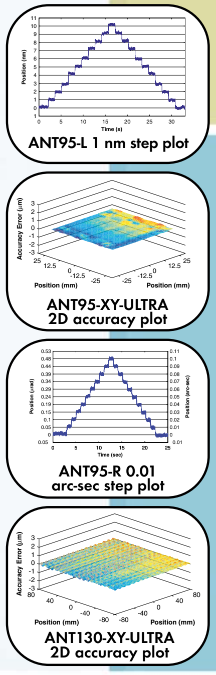
- For more detailed accounts by key members of the Gargamelle collaboration, see the articles by Don Perkins (in the commemorative issue for Willibald Jentschke 2003 p15) and Dieter Haidt (*CERN Courier* October 2004 p21).

Résumé

Les courants neutres : une découverte expérimentale parfaite

Le 3 septembre 1973, deux articles publiés dos à dos dans la revue Physics Letters *décrivaient la découverte des courants neutres faibles dans la chambre à bulles Gargamelle au CERN. Dans cette interview, Luciano Maiani revient sur l'impact qu'a eu cette « découverte expérimentale parfaite » sur la physique des particules. Cette découverte marque le début d'une décennie extraordinaire, à une époque où il n'existait pas encore de théorie uniforme sur les particules et leurs interactions, même si tous les éléments existaient déjà. Dix ans plus tard, après une série de découvertes expérimentales et d'avancées sur le plan théorique, le Modèle standard était constitué.*

Luciano Maiani, University of Rome La Sapienza, talked to **Christine Sutton** at CERN.



Faces & Places

APPOINTMENT

Giorgio Apollinari selected as new head of LARP

Giorgio Apollinari is the new director of LARP. (Image credit: Reidar Hahn/ Fermilab.)

With extensive leadership experience in accelerator research and development, Giorgio Apollinari will be the next director of the US LHC Accelerator Research Program (LARP), which co-ordinates US activities related to the LHC accelerator. He replaces Eric Prebys, who successfully led LARP for the past five years.

Apollinari's responsibilities will include leading the US LARP collaboration to define, develop and construct US contributions to the LHC High Luminosity accelerator upgrades early in the next decade, as well as maintaining the intellectual involvement of US accelerator scientists in improving LHC performance.

For the past six years Apollinari has led the technical division at Fermilab, developing world-class capabilities in superconducting radio frequency accelerator technology and materials science. The division has continued to play a central role in the development of superconducting accelerator magnets and materials, while supporting the operating accelerator complex, as well as construction project activities.

- US LARP is centred on Fermilab, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory and SLAC.

COLLABORATION

New institute hosts programmes in astro- and particle-physics

The newly founded Munich Institute for Astro- and Particle-Physics (MIAPP) will launch its first scientific programme in May 2014. Located on the Garching research campus near the two Munich universities, several Max-Planck institutes and the European Southern Observatory, the institute aims to foster creative thinking in an informal working atmosphere and encourage exchange between scientists from all around the world.

Bridging the fields of particle physics and astrophysics, MIAPP has two directors. Martin Beneke is a theoretical particle physicist at the Technische Universität München (TUM), where MIAPP is part of the Excellence Cluster "Universe". Rolf Kudritzki is of the Institute for Astronomy at the University of Hawaii and the Ludwig-Maximilians-Universität in Munich.

The new institute will host up to six four-week programmes a year on current subjects in astrophysics, cosmology, nuclear and particle physics. In 2014 these will focus on the extragalactic distance scale, the role of neutrinos in astro- and particle-physics, the challenges, innovations and developments in precision calculations for the LHC, as well as cosmology with the Planck satellite. Each programme will be organized by four co-ordinators, one or two of whom will come from the local scientific community to guarantee networking with scientists in the Munich area. A total of 45 scientists can participate in a programme.

The application deadlines for the 2014 workshop series are between August and November 2013, and proposals for the 2015 programme series can be submitted until 30 September 2013.

- To register, see the MIAPP website http://munich-iapp.de.

Lisa Raitt, left, Canadian minister of labour, visited CERN on 18 June. She was welcomed by CERN's director-general, Rolf Heuer, before touring the ATLAS underground experimental area. Her visit concluded with a round-table discussion with Canadian scientists working at CERN.

AWARDS

Aymar and ten Kate honoured for contributions to superconductivity

The Institute of Electrical and Electronics Engineers (IEEE) has honoured Robert Aymar, former director-general of CERN, and Herman ten Kate, project leader for the ATLAS magnet system, for their contributions to the field of applied superconductivity. They received the awards at the 23rd International Conference on Magnet Technology, held in Boston in July.

Aymar, of the French Alternative Energies and Atomic Energy Commission (CEA) and formerly of the ITER fusion project, was awarded the 2013 Max Swerdlow Award for Sustained Service to the Applied Superconductivity Community for his promotion and leadership in the development of large-scale superconducting magnet systems and for promoting academic research related to applied superconductivity.

ten Kate, of CERN and the University of Twente, was a recipient of the 2013 Award for Continuing and Significant Contributions in the Field of Applied Superconductivity in the area of large-scale applications. He is recognized by the IEEE for his pioneering work in the construction of the first full-size accelerator dipole magnet employing Nb_3Sn wire and operating above 11 T, for his managerial leadership in the ATLAS superconducting magnet system and for training young engineers and scientists in superconductor technology.

Joseph Minervini, of the Plasma Science and Fusion Center, Massachusetts Institute of Technology, was also a recipient of the 2013 Award for Continuing and Significant Contributions in the Field of Applied Superconductivity in the area of large-scale applications.

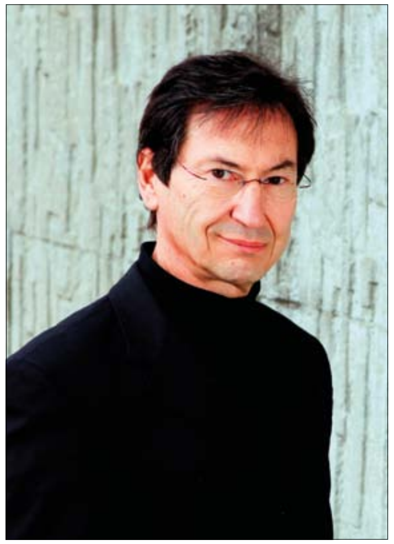
Left to right: Martin Nisenoff, vice president, awards and recognition, IEEE Council on Superconductivity; award winners, Robert Aymar, Joseph Minervini and Herman ten Kate; and Elie Track, president of IEEE Council on Superconductivity. (Image credit: Frank Monkiewicz/IEEE.)

François Flückiger joins Internet Hall of Fame

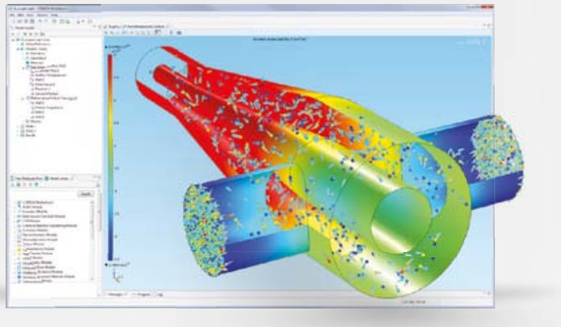
A computer scientist at CERN, François Flückiger, is one of the 32 new inductees to the Internet Hall of Fame, which annually celebrates individuals selected by the Internet Society (ISOC) for their significant contribution to developing and advancing the internet.

CERN is known for its invention of the World Wide Web but its contribution to the internet infrastructure – central for the internet's development – is less well known. Flückiger helped lead the struggle to promote the internet in Europe, at a time when most governments opposed internet technology and instead backed nascent ISO networking standards.

In 1988 he convened the founding meeting that led to the creation of Réseaux IP Européens (RIPE), a non-profit European organization to provide technical co-ordination of the internet infrastructure. He contributed in 1992 to the creation of Ebone (the pan-European internet backbone) by drafting the memorandum of understanding that laid down its basic principles and arranged in the same year for CERN to become a founding member of ISOC. Today, he is CERN's knowledge transfer officer for information technologies and director of its School of Computing. He is also a member of the ISOC Advisory Council and of the W3C Advisory Committee.



François Flückiger is now alongside CERN's web pioneers Tim Berners-Lee and Robert Cailliau in the innovator category of the Internet Hall of Fame. (Image credit : Claudia Marcelloni/CERN.)



Carlile honoured for bringing the ESS to Sweden

The Swedish minister for education, Jan Björklund, presented Colin Carlile with the Royal Order of the Polar Star at a ceremony in Stockholm on 27 June. The distinction marked Carlile's significant contributions to the European Spallation Source (ESS) project, a facility for materials research and life sciences that will be built in Lund in Sweden.

Colin Carlile. (Image credit: Science Village Scandinavia.)

British-born Carlile moved to Sweden in 2006 as a visiting professor at Lund University, following his directorship at the Institut Laue-Langevin in Grenoble. His aim to bring the ESS to Sweden was achieved in May 2009, after a long and determined campaign with Allan Larsson. After seven years as ESS director-general, Carlile stepped down in February this year with the delivery of all promised pre-construction documentation to the 17 ESS partner countries. He continues to develop a strong scientific environment around ESS, while also driving scientific development at Science Village Scandinavia.

The Royal Swedish Order of the Polar Star was established in 1748 by King Fredrik I and is now only awarded to foreign nationals or stateless persons who have made personal efforts for Sweden or for Swedish interests.

Honorary degrees for Johannes Blümer and Carlos Pajares

The close connection between the Universidad Nacional de San Martín (UNSAM) in Buenos Aires and the Karlsruhe Institute of Technology (KIT) is reflected in the award of Doctor Honoris Causa to Johannes Blümer, a senior member of the Pierre Auger Observatory and spokesperson of the KIT Center Elementary Particle and Astroparticle Physics (KCETA).

Blümer was honoured for his "outstanding support and dedication to the development of astroparticle physics in the country, where he participated in major joint projects, and the training of international young researchers" He received the award from Carlos Ruta, rector of UNSAM. UNSAM and KIT set up a dual degree PhD programme that began in May.

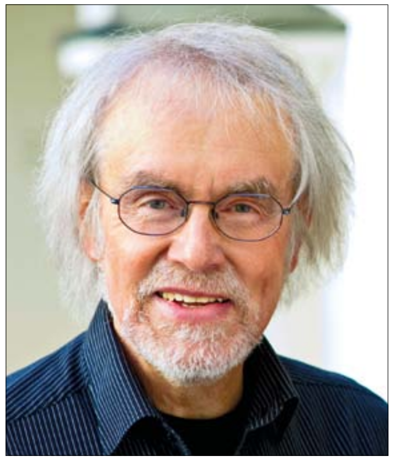
The ceremony on 11 June in Buenos Aires was followed by a two-day German-Argentinean astroparticle-physics workshop at the Universidad Nacional de La Plata and the Universidad de Buenos Aires.

On the same day, in Russia, Carlos Pajares received an Honorary Doctoral Degree from the University of St Petersburg. He is honoured for his work on high-energy nuclear interactions, for forming a widely known phenomenological group in the University of Santiago de Compostela and for his role in the active collaboration between the two universities for more than two decades. Pajares has been the Spanish scientific delegate to the CERN Council (2008–2012) and was the first dean of the physics faculty (1980–1984) and then rector (1984–1990) of the University Santiago de Compostela.

(Top) Johannes Blümer, left, receiving the award from Carlos Ruta. (Image credit: Pablo Carrera Oser.) (Above) Carlos Pajares receives his honorary degree at the degree ceremony. (Image credit: Grigory Feofilov/University of St Petersburg.)

Buras elected to Warsaw academy

Andrzej Buras, professor of theoretical elementary particle physics at the Technische Universität München (TUM) and the TUM Institute for Advanced Study, has been elected a member of the Polish Academy of Sciences in Warsaw. A leading researcher in applied quantum field theory, he is elected on the basis of his studies of strong-interaction (QCD) effects in deep-inelastic processes, calculations of higher-order QCD effects in weak and rare meson decays and extensive studies of the physics beyond the Standard Model in flavour-changing neutral-current processes.



Andrzej Buras. (Image credit: Astrid Eckert/TUM.)

CONFERENCE

CAQCD: 20 years of developments in QCD

Some 40 experts from around the world descended on Minneapolis on 16–19 May to analyse the latest developments in strongly-coupled gauge theories and to exchange their opinions. They were attending the Continuous Advances in QCD (CAQCD) conference, which was held at the William I Fine Theoretical Physics Institute at the University of Minnesota.

The 2013 CAQCD meeting was special because it was the tenth meeting in the series. The proceedings of the previous conferences – they are held biannually – reveal the developments of QCD and related theories from the early 1990s. Some topics, such as the chiral symmetry breaking – and chiral physics in general – are evergreen: they have been discussed at every meeting during the 20 years since the first conference. It is instructive to trace how new themes came into being and took centre stage: exact results in multi-parton amplitudes, high-temperature and high-density QCD, baryons at large N (1994), heavy-quark theory (1996), supersymmetry-based tools in strongly coupled gauge theories (1998), approaches based on holography (2000), supersymmetric critical solitons (2002), the pentaquark controversy (2004), planar equivalence between supersymmetric and nonsupersymmetric theories (2006), anti-de Sitter/QCD (2008) and – finally – QCD in cylindrical geometry and bions (2011).

Among highlights of the 2013 conference were the talks by Thomas Cohen, Nikita Nekrasov, Mithat Ünsal, Zvi Bern, Maxim Pospelov and others.

Zvi Bern was a speaker at the 2013 CAQCD conference. (Image credit: M Shifman.)

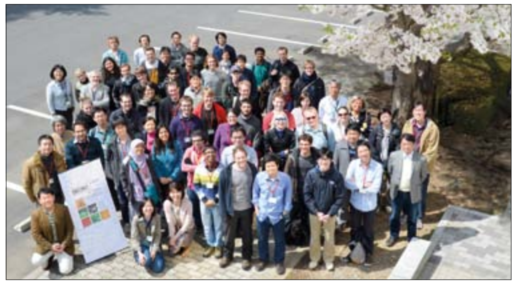
SCHOOL

EDIT goes to Asia for young experimenters to learn more about detectors

The international school Excellence in Detectors and Instrumentation Technologies (EDIT), which aims to provide graduate students and young postdoctoral researchers with in-depth knowledge of major aspects of detectors and instrumentation technologies, started in Europe at CERN in 2011. Having been hosted by Fermilab in North America in 2012, it moved to Asia this year when KEK hosted EDIT 2013.

Forty-nine highly motivated students from 23 countries were selected to participate, about 30% having a background in particle physics. An indication of the school's successful global nature is that half of the participants came from Asia and the other half from the West.

The school's programme consisted of plenary lectures, laboratory courses and facility tours. The morning sessions began with plenary lectures on topics ranging from particle and nuclear physics to astrophysics. Leading researchers from various international physics programmes provided exciting talks. They had time to discuss not only the experimental results but also the structure of the detector system and the ingenuity of its instruments. The lectures were broadcast via a live channel of "Ustream" for those who had not been accepted onto the course.



Cherry blossom celebrated the participants' "graduation" at EDIT 2013. (Image credit: KEK.)

The laboratory courses took place in the afternoons with a variety of "hands-on" exercises, on topics ranging from data acquisition (DAQ) through to various types of detector to work with cosmic rays. In the exercise on FPGA and DAQ systems, for example, the participants learnt how to work with a field-programmable gate array (FPGA) and DAQ, including data-taking software, by constructing a system to measure the muon lifetime using a FPGA training board.

Six of the exercises focused on a specific kind of detector. As an example of a silicon tracking detector, students assembled their own silicon-strip sensors and practised wire-bonding manipulation, before evaluating the sensor's characteristics. They then confirmed their detector's response using pulsed green LED light. Superconducting detectors were represented by the microwave-kinetic-inductance detector (MKID) device. Each student fabricated a device using a photolithography technique and evaluated its performance at a temperature of 0.3 K.

Other exercises provided experience of using a particle detector of a liquid noble liquid gas, by detecting scintillation light and ionization charges in liquid xenon. For gaseous detectors, each student constructed a chamber with a single wire and measured various radiations. After a briefing on micropattern gaseous detectors, they observed the signals from a gas electron multiplier (GEM) and measured how the gain varied with several parameters.

The participants also learnt the basics

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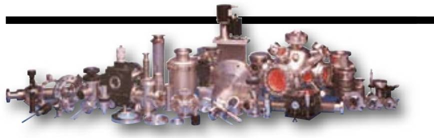
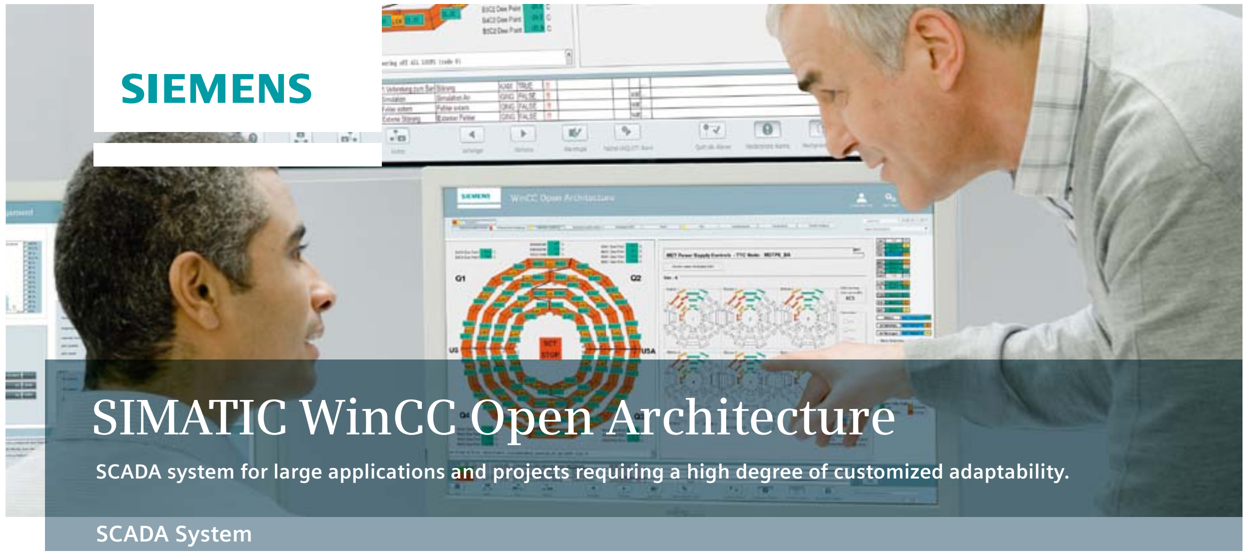




of two typical photon sensors, the photomultiplier and the Geiger-mode avalanche photodiode – the silicon photomultiplier, or multi-pixel photon counter (MPPC) – through measurements to characterize various properties. In another exercise, this time focusing on neutrino detection, the students first learnt how to measure the basic performance of the MPPC, wavelength-shifting fibres and plastic scintillator bars that are used in the T2K neutrino experiment. Then they used cosmic rays to test a small hodoscope.

The participants also had the opportunity for one exercise to stay at the Tokai site of the Japan Proton Accelerator Research Complex (J-PARC). The aim was to gain experience in detector tests using a test beam – but an unfortunate problem with the accelerator meant that the students took data using cosmic rays instead.

On the first and last days, tours took place at KEK'S Tsukuba campus and J-PARC. Before the farewell party, participants received a Japanese-style certificate from KEK's Junji Haba, the director of EDIT 2013. Altogether, the school created a close friendship among participants, which could prove invaluable in their future lives as experimentalists.

● For more information, see the EDIT 2013 website http://edit2013.kek.jp/index.html.

LETTER

Great times in 1982

I was interested to read the article by Lalit Sehgal in the May 2013 issue ("The scent of discovery: a visit to CERN in late 1982", p25). I can well believe that in November 1982 there was great interest at CERN in electroweak interactions. But I doubt that you would have found many UA1 or UA2 team members among the large audience for Sehgal's lectures. In those days, I used to go from home to the UA1 pit and back again about 12 hours later when my sandwiches ran out.

Practically the only times I came to the CERN site were to do shifts at the Megatek event-display facility in Building 2 or to take data tapes to the Computer Centre, when I was on the offline analysis (BOL) shifts. (BOL = Bicycle On Line, but I "cheated" and used my car!). I was also on the calorimeter shift, to look after the read-out chain of the central electromagnetic calorimeter, which our tiny Vienna group (three physicists and one electrical engineer resident at CERN) had constructed. Great times!

● *David Dallman, Vienna/Thoiry.*

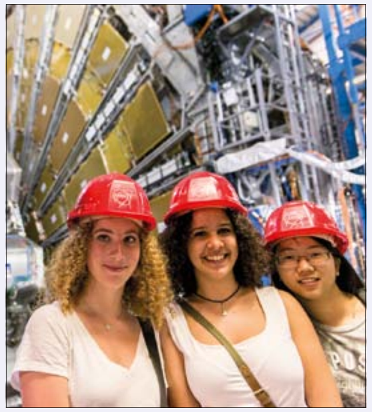
MEETINGS

The 8th International Accelerator School for Linear Colliders will take place at Hotel Rixos Downtown, Antalya, Turkey on 4–15 December. Organized by the Linear Collider Collaboration and the International Committee for Future Accelerators Beam Dynamics Panel, the school is hosted by the Institute of Accelerator Technologies at Ankara University and is sponsored by funding agencies and institutions. The first three days of the 11-day programme will include an introductory course with an overview of proposed future lepton colliders, as well as introductions to linac basics, subjects related to damping rings and circular lepton colliders, and beam instrumentation. This will be followed by two elective courses – one on accelerator physics and the other on accelerator technologies (mainly RF) – to run in parallel for six days. The school will accept a maximum of 60 students from around the world. Students will receive financial aid covering their expenses for attending the school including travel (full or partial). There will be no registration fee. The application deadline is 10 September. For more details and online application, see http://linearcollider.org/school/2013.

VISITS

Now in its fifth year, the CERN-ISEF award of the Intel International Science and Engineering Fair (ISEF) brought 12 winners on a one-week trip to CERN – which included the CMS cavern – at the end of June. The winners – aged 15–20 – came from Canada, Romania, Switzerland and the US, with projects that ranged from using artificial intelligence to creating a low-cost self-driving car to the robotic assessment of seed vitality.

Jonah Kohn, right, brought music to the CMS cavern on 2 July, playing the CMS guitar alongside its owner, physicist **Piotr Traczyk**. As winner of the 13–14 age category of the 2012 Google Science Fair, Kohn's prize included a week as an international particle physicist at both Fermilab and CERN. His winning project involved improving the experience of music for people with hearing loss by creating a device that converts sound into tactile vibrations.



Three French 18 year olds – left to right, **Céline Lay**, **Fanny Risbourg** and **Ophélia Bolmin** – came to see CERN, including the ATLAS cavern, at the start of July through EIROforum's involvement in the European Union Contest for Young Scientists. They won their week-long visit by engineering a hexapedal robot – a lightweight humanitarian robot that imitates a cockroach and can be sent to devastated places to find victims or to evaluate damage.

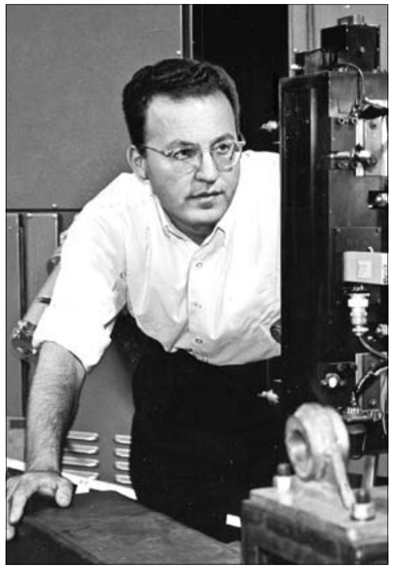
OBITUARIES

Donald Glaser 1926–2013

Donald Arthur Glaser, best known to particle physicists for his invention of the bubble chamber, died on 28 February at his home in Berkeley. He was 86.

Glaser was born in Cleveland, Ohio, on 21 September 1926, the son of Russian immigrant parents. He received his early education in the public schools of Cleveland Heights and completed his BSc degree in physics and mathematics at the Case Institute of Technology in 1946, while playing viola with the Cleveland Orchestra. After serving as a teacher of mathematics at the institute, in 1946 he began his graduate studies at the California Institute of Technology. He obtained his PhD there in 1950 with a thesis on the momentum spectrum of high-energy cosmic rays and mesons at sea level.

In 1949, Glaser joined the physics department of the University of Michigan, where he examined various experimental techniques for visualizing elementary particles, including diffusion cloud chambers and parallel-plate spark counters. He finally hit on the idea of a bubble chamber – in his own words "a pressure cooker with windows" – and built the first one-inch prototype in 1952. The device worked by superheating a liquid above its boiling point so that when a charged particle passed through it left a trail of bubbles that could be photographed. For the following three decades bubble chambers dominated particle physics, especially in the study of strange particles. Only in the mid-1980s did developments in electronics and wire chamber detectors, together with the beginning of a new era of collider physics, bring an end to the use of bubble chambers.



Donald Glaser with a bubble chamber in 1960, the year he won the Nobel Prize. (Image credit: LBNL.)

Glaser moved to the University of California, Berkeley, in 1959 and the following year, at the age of 34, was awarded the Nobel Prize in Physics. With the freedom that accompanies a Nobel Prize, he soon began to explore the new field of molecular biology. He worked in the university's virus lab, conducting experiments with bacteria, bacterial viruses called phages and mammalian cells. He designed automated equipment that made it easier to grow these cells and to study how they grow, repair themselves and reproduce.

In 1971, he joined two friends, Ronald E Cape and Peter Farley, to found the first biotechnology company, Cetus Corp, to exploit new discoveries for the benefit of medicine and agriculture. The company developed interleukin and interferon as cancer therapies but was best known for producing a powerful genetic tool, the polymerase chain reaction, to amplify DNA.

Glaser's experience automating visual tasks in physics and molecular biology eventually led him to an interest in human vision and how the brain processes what is seen. In the 1980s, he spent a semester at The Roland Institute for Science in Cambridge, Massachusetts, where he began psychophysics experiments in vision to understand how humans perceive motion, for example.

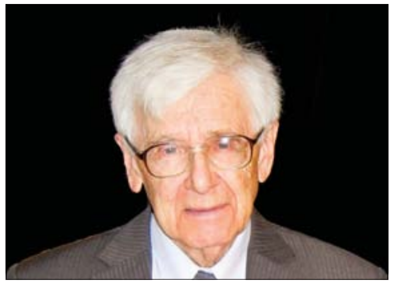
In the years following 1960, Glaser was a consultant and adviser to many governmental organizations, industrial boards of directors, non-profit groups and a member of the editorial boards of several scientific publications. He was also a member of the Life Sciences Division at Lawrence Berkeley National Laboratory.

He is survived by his wife, Lynn Glaser (nee Bercovitz), a musician and painter, two children from his first marriage to Ruth Bonnie Thompson and four granddaughters.

- *Based – with permission – on the obituary by Robert Sanders published on the UC BerkeleyNews Center website, http://newscenter.berkeley.edu/2013/03/01/physics-nobelist-and-biotech-pioneer-donald-glaser-dies-at-86/.*

Aston Antonovich Komar 1931–2013

Aston Komar, a prominent scientist of the Lebedev Physical Institute (LPI) of the Russian Academy of Sciences, died at his home in Moscow on 23 May after battling a difficult illness.



Aston Komar. (Image credit: Komar family.)

Komar received his PhD in 1959 under the direction of Moisei Markov and was fortunate to work in the group of Abdus Salam at Imperial College London in 1959–1960. He then went on to spend his entire research career at the LPI, where he was in charge of the Laboratory of High Energy Electrons for many years and until his last days.

His research in high-energy physics focused on quantum field theory, as well as theoretical and experimental investigations of fundamental particles. He made important and invaluable contributions to the understanding of the quantization of fields with high spin and to the renormalizability of non-Abelian field theories. More recently, inspired by the interdisciplinary potential of modern science, he became interested in the biology of diseases and for a number of years led interdisciplinary research aimed at understanding – with the help of fluorescent spectroscopy of albumin – structural changes in pathology.

Komar had a dynamic personality and played an important role in the popularization and development of science. He was a member of the editorial board of several journals, including *Priroda* (*Nature*), *The Great Russian Encyclopedia*, and *Poverkhnost* (*The Journal of Surface Investigation*).

From the start of his work with the ATLAS experiment at CERN, Komar was an indispensable leader of the LPI team. He made inestimable contributions to the achievements of the institute's liquid-argon group in the production of read-out electrodes for the hadronic endcap and the assembly of the calorimeter.

A theorist with an encyclopedic knowledge, wide and impeccable erudition and a breadth of interests, he trained many generations of young researchers to whom he transmitted his love of science. Komar was a man of great generosity and a true gentleman. He is sorely missed and will be remembered by his family, colleagues and friends.

- *G I Merzon, LPI, on behalf of colleagues of Aston Komar.*

Walter Blum 1937–2013

Walter Blum of the Max Planck Institute of Physics in Munich unexpectedly passed away on 24 March. His death deprives the particle-physics community of one of its prominent members.

Blum was born in Leipzig and grew up in Northern Germany. He studied physics in Munich. For his PhD work, he joined the Max Planck Institute of Physics led by Werner Heisenberg. This institute – and Heisenberg himself – would heavily influence Blum's scientific life.

His first steps into particle physics came through a British-German bubble-chamber collaboration that studied hadronic reactions of kaons. While hadronic reactions were to remain a focus, he soon switched from optical to electronic detection of particles. An early highlight was the demonstration with the CERN-Munich collaboration that the A_2 meson was not split, laying to rest a major controversy. Blum then devoted his time in the following decade to meson spectroscopy and in-depth studies of hadronic reactions, in collaborations led by Bernard Hyams.

The discovery of charm in hadronic reactions led to a change of paradigm in detection techniques: the highest spatial resolution became imperative. Blum focused on understanding the limitations of gaseous detectors in this respect, a theme that would stay with him for the next 20 years. His pioneering work resulted in spatial resolutions in drift chambers in the region of 25 μm. He also worked on experiments using the newly developed silicon-strip detectors, which brought a wealth of results on charm production in hadronic collisions. Soon after the discovery of the Υ meson in the late 1970s at Fermilab and its confirmation at DESY, he joined the DESY-Hamburg-Heidelberg-Munich collaboration, which reported the first measurement of the mass and the width of this particle's first excited state.

Walter Blum. (Image credit: Barbara Blum.)

In 1980, Blum became a founding member of the ALEPH collaboration at the Large Electron–Positron collider. ALEPH's key feature was its time-projection chamber (TPC) but at that time the TPC concept was still beset with flaws and doubts. Blum's capacity for innovation, critical thinking, objective assessment and never-ending curiosity was instrumental in the successful design and construction of the TPC for ALEPH. These years of continuing understanding and development led to Blum's well known textbook *Particle Detection with Drift Chambers*, which appeared first in 1993 with Luigi Rolandi as co-author and after its great success saw a second edition in 2008 (with Werner Riegler as a third author).

In the early 1990s, Blum became pivotal in the design of the ATLAS detector at the LHC, with its large superconducting air-core toroid instrumented with high-precision drift-tube chambers (30 μm spatial resolution). This project matched exactly his dreams of ultimate spatial and timing precision with gaseous detectors.

For many years, Blum was puzzled by a theoretical problem – namely the correct quantum mechanical Lorentz-invariant description of particles with spin and finite lifetime. A publication together with Heinrich Saller showed that unstable particles have an intrinsic spin uncertainty, i.e. the spin spreads across several adjacent spin states. This result was well received and Blum saw further questions in quantum mechanics to be resolved. His untimely death was a severe loss for this endeavour.

Blum lectured on physics for many years at the Ludwig Maximilian University in Munich. In the 1990s, he served for several years as deputy leader of CERN's Experimental Physics Division. Among his lasting achievements were the consolidation of the Users' Office, the oversight of several office construction projects and a highly appreciated review of the CERN Library.

He also had strong interests in matters concerning society. He was concerned particularly about the environment and the impact of greenhouse gases. In the 1990s, he joined the Working Group on Energy Matters of the German Physical Society (DPG), eventually becoming its chair. He was instrumental in organizing sessions on energy matters during the annual meetings of the DPG and was editor and co-author of two major strategy papers on "Energy Supply and Climate Change" in 2005 and 2009.

For both scientific and personal reasons, Blum had the highest respect for Heisenberg's scientific work (Heisenberg was his father-in-law). Together with Hans Peter Dürr and Helmut Rechenberg, he undertook the monumental task of editing three volumes that comprise Heisenberg's entire scientific work in physics and philosophy. At the end of 2012, Blum also saw the fruition of a project that he had pursued for several years, with the inauguration of the Werner Heisenberg Society at the Max Planck Institute of Physics in Munich. Blum acted as the society's deputy president and secretary but sadly he was not to enjoy his dream-come-true for long.

Blum was widely known for his penchant to understand things in depth and to ask pertinent questions, for his intellectual rigor in the pursuit of physics research, his power of innovation, his sense of responsibility for the education of students, his personal integrity and unwavering commitment for what he considered to be just and right. His death is a severe loss for the particle-physics community. He will be greatly missed.

● *His friends and colleagues.*

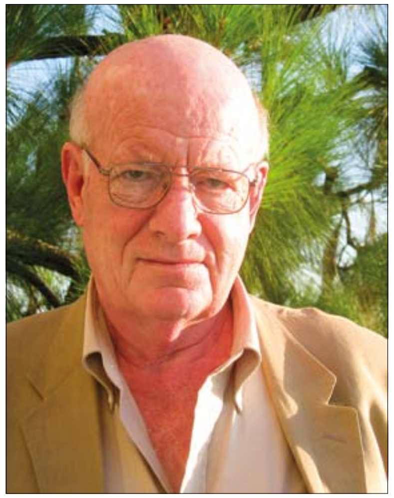
Myron Bander 1937–2012

Myron Bander, professor of physics and astronomy at the University of California, Irvine, died unexpectedly on 19 December during a conference in Fort Lauderdale, Florida.

Myron was born in Belzyce, Poland, on 11 December 1937. The family emigrated to the US in 1949 and they settled in New York City. There, Myron received his bachelor's degree in physics at Columbia College in 1958. He stayed on for graduate work at Columbia University, obtaining his PhD in 1962, studying with Gary Feinberg. His principal field of research was quantum field theory and elementary particle physics.

After a year as a National Science Foundation Postdoctoral Fellow at CERN, the University of Copenhagen and the University of Paris, Myron became the first research associate to be hired at SLAC. In 1966 he joined the faculty of the new Irvine campus of the University of California – UCI – where he and Gordon Shaw built up the elementary particle theory group.

Myron made substantial contributions to particle theory and phenomenology. In collaboration with Dennis Silverman and Amarjit Soni he wrote in 1979 a seminal paper on CP violation in B-meson decay. Other publications covered a range of many subjects, including dispersion relations, lattice gauge theories, statistical mechanics, general relativity, cosmology, nuclear physics, condensed-matter physics and atomic physics. Later he worked extensively with his friend Hector Rubinstein on several topics in astrophysics. A strong advocate for cosmology and its connections to particle physics, Myron was influential in building programmes in cosmology and astroparticle physics at UCI.


Myron Bander. (Image credit: UCI.)

I first met Myron in 1969, when I started to collaborate with Murray Gell-Mann at Caltech. He came to Caltech every Wednesday for the seminar. We met again during many short visits I made to UCI, as well as in 2009, when I visited him for three months and gave lectures at the university. In 2012 he and his wife Carol came to the conference on QCD that I organized in Oberwölz, Austria.

In addition to his research in the elementary particle theory group at UCI, Myron also served as an administrator for his department and school, where he spent the last 46 years of his professional career. He was chair of the Department of Physics and Astronomy for two separate terms and served as the third dean of the School of Physical Sciences from 1980 to 1986. He was instrumental in the creation of the Department of Earth System Science, the only new department added to the school since its founding. After his retirement several years ago, he remained active in teaching and research.

The sparkling intelligence and friendship of Myron Bander will be greatly missed by all his associates, friends and colleagues.

● *Harald Fritzsch, Ludwig Maximilian University, based on the obituary that appeared in* Physics Today's Daily Edition, *www.physicstoday.org/1.2926267.*

New products

FLIR Systems has announced the release of the FLIR A3500sc/A6500sc series of thermal-imaging cameras, which incorporate a cooled 3–5 μm MW-IR detector for applications that need better image quality, more sensitivity and a higher frame rate. Achieving a thermal sensitivity of <25 mK, the cameras capture fine image details and temperature-difference information. Operating in snapshot mode, they register all pixels from a thermal event simultaneously. For more details, visit www.flir.com/cs/emea/en/view/?id=60531, tel +32 3665 5100 or e-mail flir@flir.com.

Goodfellow offers a range of synthetic-sapphire products for research applications, for example in optical design, electronics, mechanical components and medical instrumentation. The products include: sapphire windows, with high strength, scratch resistance, a high operating temperature and good transmission characteristics; precision sapphire spheres, with good corrosion resistance; and precision sapphire bearings, featuring hardness, wear resistance and temperature stability. For more details, tel +44 1480 424 888, e-mail ceramic@goodfellow.com or visit www.goodfellow-ceramics.com.

Trek Inc has introduced a new high-speed, high-voltage amplifier – Model 10/40A-HS. The ±10 kV four-quadrant DC-stable amplifier provides high response speed with a slew rate greater than 900 V/μs, high output current to ±120 mA peak AC and large signal bandwidth of DC to greater than 23 kHz (–3dB). Applications include electrostatic deflection for ion-beam steering, mass spectrometers and particle accelerators. Trek has also announced its new Electrostatic Discharge Audit Kit, Model 511/1501, which includes its ionizer kit (Model 511 electrostatic field meter with charger and charge plate), Model 1501 Surface Resistance Meter and an all-in-one carry case. For more details, contact Brian Carmer, tel +1 585 798 3140 ext 285 or e-mail brian.carmer@trekinc.com.

Recruitment

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

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PSI

The Paul Scherrer Institute, PSI, is with 1500 employees the largest research centre for natural and engineering sciences within Switzerland. We perform world-class research in three main subject areas: Matter and Material; Energy and the Environment; and Human Health. By conducting fundamental and applied research, we work on long-term solutions for major challenges facing society, industry and science.

The Department of Large Research Facilities operates and develops proton and electron accelerators for fundamental and applied research. Our 590 MeV proton cyclotron provides researchers with neutrons and muons produced by the world's most powerful beam of protons. The electron storage ring of the Swiss Light Source is used to generate highly brilliant synchrotron radiation over wavelengths extending from the UV to X-ray region with exceptional stability in position and intensity. PSI also houses a superconducting proton cyclotron used for proton therapy and for developments in that field. We are currently building an X-ray Free Electron Laser, SwissFEL, based on a 6 GeV linear accelerator.

PSI has a long tradition of innovative developments in accelerator science. In keeping with this tradition we are seeking a

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This special postdoctoral fellowship is open to an outstanding doctoral physicist or engineer who is at the start of a promising career. The successful applicant will have the opportunity to work in a stimulating and rich environment at the forefront of accelerator physics. He/she would be expected to perform research in an area of accelerator development corresponding to one or more of the principal programs of the Department. The fellowship is, therefore, awarded in the areas of accelerator physics and technology, beam dynamics and beam diagnostics.

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The successful candidate will have recently completed a PhD, or have an equivalent diploma, in a relevant field of physics or engineering.

For further information please contact Dr Terence Garvey, phone +41 56 310 46 37.

Please submit your application online (including list of publications and addresses of referees) for the position as a Postdoctoral Fellow (index no. 8400-00) under http://www.psi.ch/pa/offenestellen/0615-1.

Paul Scherrer Institute, Human Resources Management, Thomas Erb, 5232 Villigen PSI, Switzerland
www.psi.ch

UNIVERSITÉ DE GENÈVE

The **Faculty of Sciences** of the University of Geneva invites applications for a position as

ASSOCIATE or ASSISTANT PROFESSOR
in experimental particle physics

RESPONSIBILITIES: Full time appointment comprising teaching at undergraduate and postgraduate level, as well as supervising masters' and doctoral theses.
The candidate will develop original research at a national and international level in the field of experimental high energy particle physics and secure external funding. He/she will have important leadership responsibilities for a group, initially on the ATLAS experiment at CERN. He/she will also take on administrative duties at departmental, faculty and university level.

QUALIFICATIONS AND REQUIRED EXPERIENCE:
Ph.D. in physics or equivalent.
Experience in teaching and research, especially as head of a research group.
Publications in international journals.

STARTING DATE : 1st of January 2014 or as agreed

Applications must be completed before **September 30th, 2013** and must be submitted - ***exclusively online*** - to the University website at the address https://jobs.icams.unige.ch/ where a copy of the present advertisement may be found.

Inquiries may be directed to Prof. Giuseppe Iacobucci (giuseppe.iacobucci@unige.ch).

In a perspective of parity, applications by women are particularly encouraged and welcome.

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- ¿Participation in experiments like ALPS and BELLE II
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Requirements

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- Experience in experimental particle physics

DESY-Fellowships are awarded for a duration of 2 years with the possibility of prolongation by one additional year.

Please submit your application including a resume and the usual documents (curriculum vitae, list of publications and copies of university degrees) to the DESY human resources department. Please arrange for three letters of reference to be sent before the application deadline to the DESY human resource department.

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

Please send your application quoting the reference code, also by E-Mail to:
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Human Resources Department | Code: EM100/2013
Notkestraße 85 | 22607 Hamburg | Germany | Phone: +49 40 8998-3392 |
E-Mail: recruitment@desy.de
Deadline for applications: 30 September 2013
www.desy.de

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

HELMHOLTZ | ASSOCIATION

SLAC NATIONAL ACCELERATOR LABORATORY

Associate Laboratory Director
Linac Coherent Light Source

The SLAC National Accelerator Laboratory, at Stanford University, is seeking applications for the position of the Director of its Linac Coherent Light Source, LCLS. As Associate Laboratory Director (ALD) for LCLS, the candidate will report to the SLAC Laboratory Director and is expected to develop the vision and mission objectives to keep LCLS at the international forefront of cutting edge x-ray science while representing LCLS on SLAC's Executive Council.

Tools for Discovery

SLAC, one of the world's leading research laboratories, is a U.S. Department of Energy, Office of Science multi-program laboratory operated by Stanford University. For 50 years, SLAC's linac has produced high-energy electrons for cutting-edge physics experiments. Now, scientists continue this tradition of discovery by using the linac to drive a new kind of laser, creating X-ray pulses of unprecedented brilliance.

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- X-ray laser takes aim at cosmic mystery
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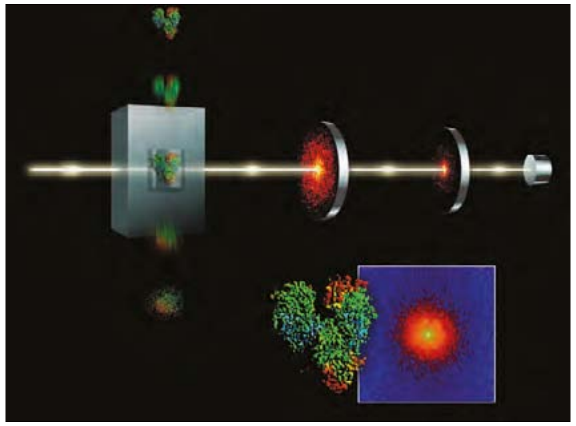
The LCLS Director is expected to be an internationally recognized scientist with established leadership credentials; significant reputation in scientific research; strategic thinking and execution skills; excellent communication skills; commitment to excellence with ability to expand capabilities and capacities of the world's foremost x-ray laser. The successful candidate is expected to assume a tenured position on the SLAC Faculty.



For additional information or to be considered for candidacy please contact/send application materials to:
Lisa Mongetta, Manager, SLAC Staffing Services
2575 Sand Hill Road, Menlo Park, CA 94025
650-926-2733 email: mongetta@slac.stanford.edu

The SLAC National Accelerator Laboratory values diversity and is an Affirmative Action, Equal Opportunity Employer.

The Linac Coherent Light Source at SLAC National Accelerator Laboratory is an Office of Science user facility operated for the Department of Energy by Stanford University.

University of Zurich^UZH

Faculty of Science

The Faculty of Science of the University of Zurich invites applications for a

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In teaching at both undergraduate and graduate level the new professor will stimulate the interest of the students for basic and applied physics research. Undergraduate teaching is in English or German, graduate education is in English.

Candidates are invited to submit an application package including a curriculum vitae, list of publications and personal conference contributions, outline of current and future research interests, teaching philosophy and names and addresses of three potential referees. Documents should be addressed to Prof. Dr. Michael O. Hengartner, Dean of the Faculty of Science, University of Zurich, and uploaded as a single PDF file at www.mnf.uzh.ch/ecmp by September 30, 2013. For further information, please contact Prof. Dr. Jürg Osterwalder via osterwal@physik.uzh.ch, or visit the homepage at http://www.physik.uzh.ch.

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

ESO

European Organization for Astronomical Research in the Southern Hemisphere

The European Organisation for Astronomical Research in the Southern Hemisphere (ESO) is the foremost intergovernmental astronomy organisation in Europe and the world's most productive astronomical observatory. ESO operates three unique world-class observing sites in the Atacama Desert region of Chile: La Silla, Paranal and Chajnantor. For its Headquarters in Garching near Munich, Germany, ESO is advertising the position of

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The Director for Science reports directly to the Director General and assists him in developing the overall strategy for the science programme at ESO. He/she coordinates and administers all aspects of ESO's scientific activities including Outreach and is accountable for their execution. As a member of the ESO senior management team he/she works closely with the Director General and the other Directors in the development of overall policy and strategic planning across the Organisation. He/she reports as required to the ESO Council (main decision making body of ESO) and internal and external advisory bodies and interacts with the astronomical community via membership of strategic committees, participation in conferences and special events. As an active scientist and Full Astronomer of the ESO Astronomy Faculty he/she also maintains personal scientific and technical contacts internationally at the highest level.

Professional requirements:

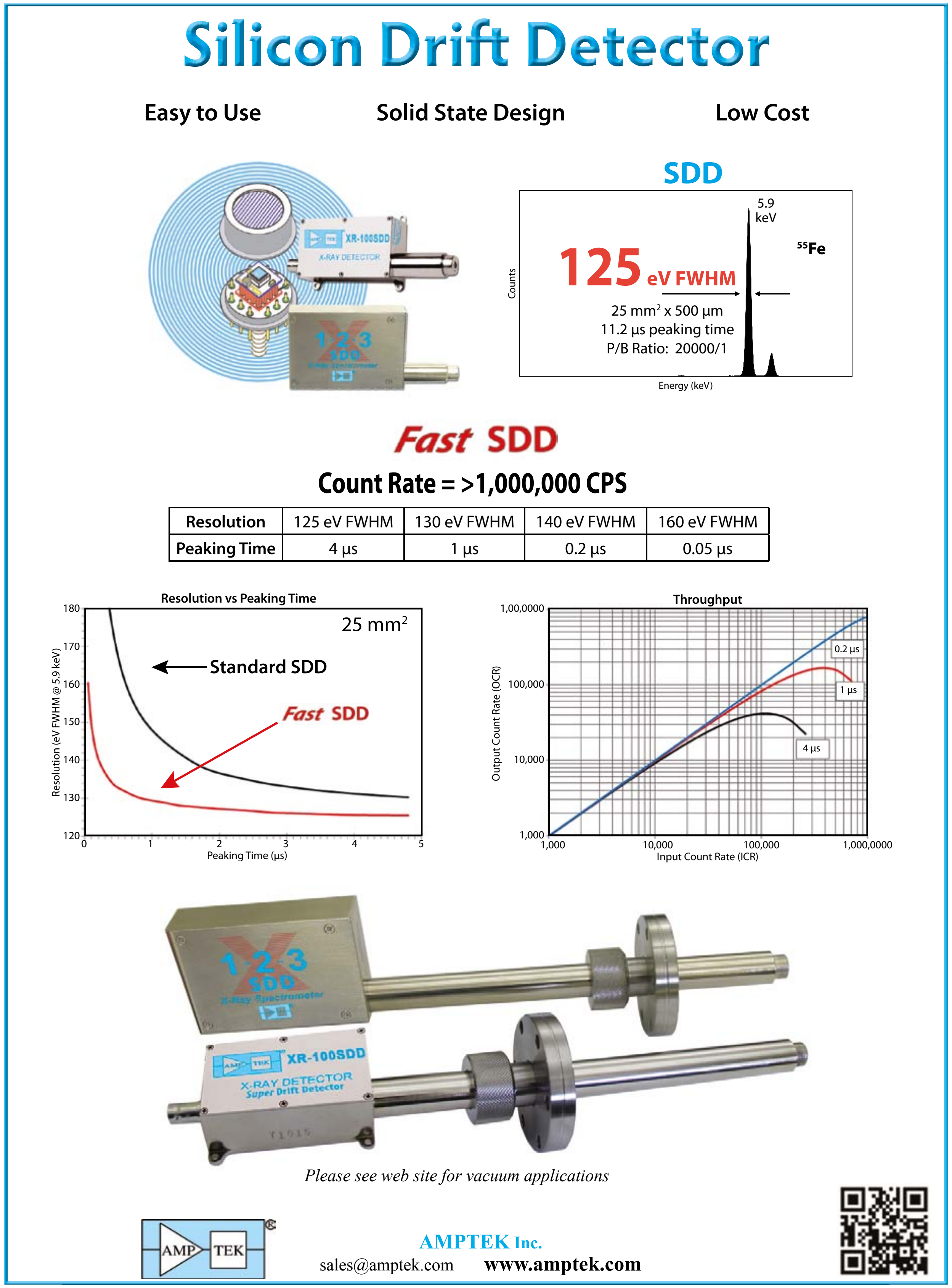
Basic requirements for the position include a PhD in astronomy, astrophysics, physics or related fields; a proven record of scientific leadership and at least 10 years' experience in international scientific collaborations. Substantial management and leadership experience within a scientific organisation, preferably international, is also required.

Starting Date:

1 February 2014 or as soon as possible thereafter.

Closing date for applications is 8 September 2013.

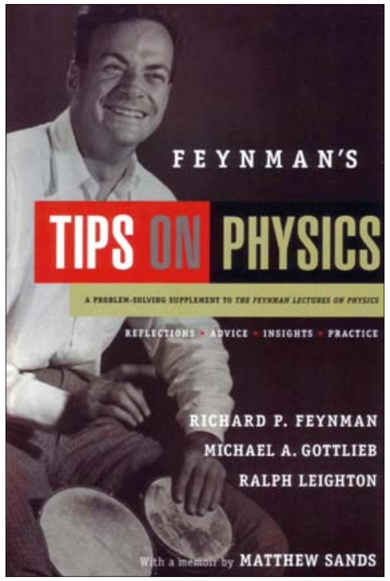
For more information on the position and to apply on-line please visit our recruitment portal (https://recruitment.eso.org/).



Bookshelf

Feynman's Tips on Physics: Problem-Solving Supplement to the Feynman Lectures on Physics

By Richard P Feynman, Michael A Gottlieb and Ralph Leighton
Basic Books
Paperback: £11.99 $16.99



Originally published in hardback not long ago (Addison Wesley 2006), Feynman's *Tips on Physics* is now available as a slim paperback, complete with some additional material. It is essentially a collection of four "lost" lectures and could be thought of as four chapters that somehow didn't make it into *The Feynman Lectures on Physics* – the well known three-volume set by Feynman and colleagues Robert Leighton and Matthew Sands. To complement these, Michael A Gottlieb and Ralph Leighton (Robert's son) have added a fifth chapter with selected problems from *Exercises in Introductory Physics* by Leighton Sr and Rochus Vogt. To set the scene, they also include a "memoir" by Sands on the origins of the famous three books in their distinctive red covers and – new for this edition – three interviews, with Leighton Sr, Vogt and Feynman himself.

The first thing to say is that the scientific level of the four lectures is far below that of the other published lectures. The first lecture, "Prerequisites", is an elementary reminder about the importance of learning basic calculus and vector algebra and it is unlikely that anyone reading this review will find anything new. Perhaps the main point of interest is Feynman's discussion on how to deal with not being the top member of a group comprised of many talented people. This might provide some inspiration to bright high-school students who go from being top of their class to no longer being at the top at a good university.

The second lecture, "Laws and Intuition" attempts to explain to students the importance of having a feel for the material and using physical intuition to back up mathematical calculations. This could help students, who far too often, in my experience, just want to know "what formula to use".

"Problems and Solutions", the third lecture, is pitched at a slightly more advanced level. It would be suitable for a good high school student or first-year university student and covers a range of interesting topics from satellite motion to rockets (including ion and photon propulsion) as well as a couple of simple particle-physics examples: electrostatic deflection of a proton beam and the determination of the charged-pion mass.

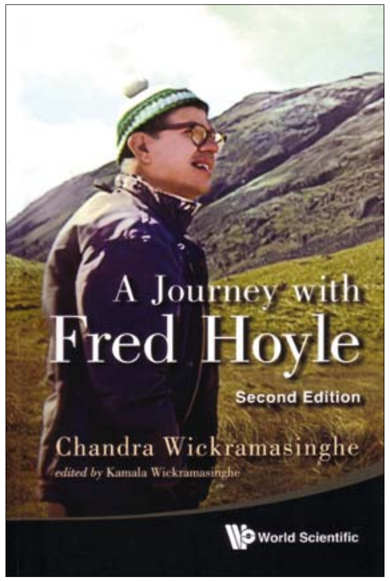
Last, "Dynamical Effects and Their Applications", is essentially about gyroscopes. It contains little mathematics and the technology is quite dated but it is fun to read. In fact, even the datedness of some of the material has its charm. Feynman says: "Computing is mostly analogue at the moment, but it is likely that it'll turn into digital – in a year or two, probably – because that has no errors in it." How things have changed since 1962!

While there is not much here for the practising physicist, it is a quick and easy read and contains many interesting things about the history of *The Feynman Lectures in Physics* in the introduction (and the surprising statement that there are more than 170 errors in the 3 volume set). As such, it is worth the hour or two that it will take to read – and, after all, it is Feynman. While it is unlikely to find much use as a reference work, it would make a nice gift for someone about to start studying physics – but together with the full 3-volume set.

● *John Swain, Northeastern University.*

A Journey with Fred Hoyle (2nd Edition)

By Chandra Wickramasinghe and Kamala Wickramasinghe (ed.)
World Scientific
Paperback: £28
E-book: £21



Fred Hoyle was undoubtedly among the most original thinkers of his time and one of the leading figures of 20th-century physics. From the purely scientific viewpoint, his name is associated with at least three ideas: the synthesis of heavy nuclear elements in the cores of supernovae (developed in collaboration with William Fowler, Margaret and Geoffrey Burbidge); the steady-state model of the universe (formulated together with Hermann Bondi and Thomas Gold); and some of the early applications of anthropic arguments to astrophysics and cosmology. Hoyle also contributed to many other fields – such as stellar structure, planetary formation, galactic dynamics and the origin of large-scale magnetism – where his creative imagination often made the difference.

A Journey with Fred Hoyle – now in a second edition that incorporates relevant developments that have occurred since the original was published in 2005 – is a respectful, lively and at times exciting tribute to an independent thinker, a capable teacher and an inventive scientist. It is an extremely well written collection of scientific memoirs and an intriguing journey in the realm of scientific controversies, which often accompany the achievements of those who like to think a little differently. The author started his PhD under the guidance of Hoyle in the early 1960s and was still collaborating with him in 2001 when Hoyle passed away. His narration begins in Cambridge where, from the mid-1950s to the mid-1960s, three disciplines thrived serendipitously: biology (with the monumental discovery of James Watson and Francis Crick of the famous double helix structure of genetic material); cosmology and astrophysics (with the work of Hoyle at the institute of astronomy and of Martin Ryle with the radio-astronomy group) and particle physics (with the Lucasian professorship of Paul Dirac).

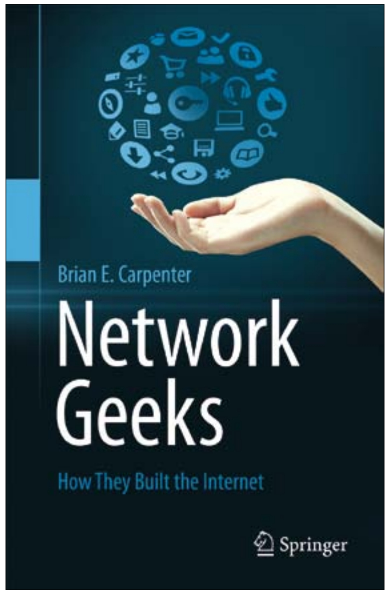
The Cambridge atmosphere probably inspired a quest for the unification between astrophysics and biology – a field that later became known as astrobiology and gained funding and respect from the whole scientific community. The starting observation made by Hoyle and Wickramasinghe was that interstellar clouds are not made of ice, as originally thought in the 1950s and early 1960s, but rather of carbon. By analysing the way that interstellar dust dims starlight the authors proposed, in a crescendo, that the carbon was part of complex organic molecules and, eventually, bacteria or even viruses. This combination of science and inventiveness led to the theory of panspermia, i.e. the hypothesis that life exists throughout the universe distributed in meteorites and asteroids.

Is it really true that life on the Earth came from the cosmos? This is probably not the most relevant question. What matters here is to appreciate that the current success of astrobiology started – amid inevitable controversies – from the analysis of organic compounds in interstellar space. This is an interesting book and worth reading for those who like to follow the complicated fate of successful ideas. Recalling the title of Hoyle's autobiography, we could say that "home" for scientists is, sometimes, "where the wind blows".

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

Networks Geeks: How They Built the Internet

By Brian E Carpenter
Springer
Paperback: £15 €21.09 $19.99
E-book: £11.99 €15.46 $9.99



In *Network Geeks*, Brian Carpenter weaves the history of the early internet into an entertaining personal narrative. As head of CERN's computer-networking group throughout the 1980s, he is well placed to describe the discussions, the splits, the technical specifications and countless acronyms that made up the esoteric world of networking in the early days of the internet in Europe. Just don't expect to be spared the technical details.

Carpenter joined CERN in 1971, at a time when computers filled entire rooms, messages were relayed by paper tape or punched card and numerous local networks ran bespoke software packages around the laboratory. Simplifying the system brought Carpenter into the world of the internet Engineering Task Force – the committee charged with overseeing the development of standards for internet technology.

I enjoyed the fictional account of a meeting of the Task Force in 1996, which gives a vivid idea of the sheer number of technical issues, documents and acronyms that the group tackled. That year, traffic was doubling every 100 days. Keeping up with the pace of change and deciding which standards and protocols to use – TCP/IP or OSI? – were emotive issues. As with any new technology, there was lobbying, competition and elements of luck. Nobody knew where the internet would lead.

Carpenter's enthusiasm is the strength of *Network Geeks*. He recounts his early interest in science – a childhood of Meccano and Sputnik – with an easy nostalgia and his memories of informal meetings with often-bearded computer scientists show genuine warmth. But it is no easy read. The autobiographical narrative jumps jarringly between lyrical descriptions of the author's youth and the rather mundane details of computer networking. At times I felt I was drowning in specifics when I was really hoping for a wider view, for implications rather than specifications.

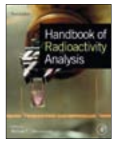
Networks Geeks reminded me that the evolution of technology can be as much down to politics and luck as to scientific advances. It gave me a great overview of the climate in the early days on the internet. At the same, the heavy layers of jargon also reminded me why I'm no computer scientist.

● *Cian O'Luanaigh, CERN.*

Books received

Handbook of Radioactivity Analysis (3rd edition)

By M L'Annunziata (ed.)
Academic Press
Hardback: €120
E-book: €129

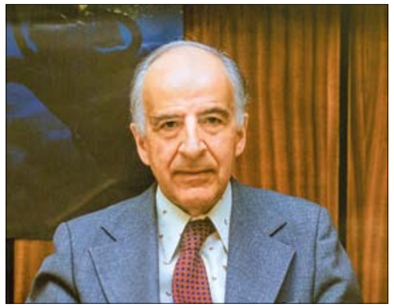


Updated and much expanded, the new edition of this authoritative text provides the principles, practical techniques and procedures for accurately measuring radioactivity, from the low levels encountered in the environment to higher levels measured, for example, in radioisotope research, nuclear medicine and nuclear power. The book describes the basic principles of radiation detection and measurement and the preparation of samples; assists in the selection and use of appropriate radiation detectors; and presents state-of-the-art methods of analysis. Fundamentals of radiation properties, radionuclide decay and methods of detection provide the foundation of the analytical procedures. It is also suitable as a teaching text for university and training courses.

Inside Story

Pontecorvo and neutrino physics

The "father" of neutrino oscillations, born a century ago, had many ground-breaking ideas.



Bruno Pontecorvo in 1983. (Image credit: Yuri Tumanov, JINR.)

Bruno Pontecorvo was born in Pisa on 22 August 1913 to the family of a prosperous manufacturer. As a student in Rome from 1931 to 1936, he was a member of the famous group of "Via Panisperna boys" under Enrico Fermi. By 1943 he had moved to Canada and took part in the design and commissioning of the powerful heavy-water nuclear reactor in Chalk River but also investigated muon decays in experiments with Ted Hincks. These proved that the charged particle produced when a muon decays is an electron, that the muon decays into three particles and that it never decays into an electron and a photon – leading to the notion of "lepton charge". Pontecorvo went on to suggest the existence of a universal μ–e weak interaction in 1947.

At Chalk River he was the first to propose that it should be possible to detect neutrinos. In 1934, Hans Bethe and Rudolf Peierls had calculated that the cross-section for the interaction of a neutrino with matter should be less than 10^{-44} cm^2 and had concluded that it would be impossible to detect neutrinos. Pontecorvo doubted this and realizing that a nuclear reactor would be an intense source of neutrinos (in fact, antineutrinos), in 1946 he suggested detecting them through the extraction of the argon isotope produced in the reaction $\nu + {}^{37}\mathrm{Cl} \rightarrow {}^{37}\mathrm{Ar} + e$. This is the technique that became famous in Raymond Davis's detection of neutrinos from the Sun. Pontecorvo also designed a small proportional counter with high resolution, which he used to detect the nuclear capture of L-electrons in argon for the first time. This allowed him to make the first measurement of the tritium β-spectrum and to obtain a limit on the mass of the electron neutrino of less than 500 eV.

In August 1950, Pontecorvo, his wife and three sons moved to the USSR and he joined JINR, in Dubna. He arrived soon after the start-up of what was then the world's most powerful synchrocyclotron, and joined in research on strong interactions. However, his interest turned again to weak interactions and neutrino physics. In a paper published in 1959, he showed that neutrinos produced in the decays of particles from an accelerator could be observed with big detectors and proposed an experiment to find out if electron and muon neutrinos differ from each other. The successful implementation of such an experiment at Brookhaven in 1962 – independently proposed – was to mark the beginning of high-energy neutrino physics at accelerators. A year earlier, on Pontecorvo's initiative an attempt was made at the JINR synchrophasotron to detect weak neutral currents via the reaction $\nu_\mu + N \rightarrow \nu_\mu + N$. Neutral currents were discovered at CERN a decade later in 1973, with a much more intense neutrino beam.

It was a little earlier, in 1957, that Pontecorvo first suggested the possibility of transitions between muonium (μ^+e^-) and antimuonium (μ^-e^+). (These would be forbidden in the Standard Model because the lepton numbers of the particles both change by two). In discussing these transitions, he proposed that oscillations can occur not only in bosons – neutral kaons and muonia – but also in electrically neutral fermions, i.e. neutrinos. As in the neutral kaon system, this would be possible only if neutrinos possess small, nonzero masses. At a time when the muon neutrino was still unknown, he introduced the notion of the sterile neutrino and considered neutrino oscillations into sterile antineutrinos.

This marked the birth of the hypothesis of neutrino oscillations, which Pontecorvo founded on a close analogy between the weak interactions of leptons and hadrons, long before the idea of quark–lepton symmetry in today's Standard Model. The importance of neutrino oscillations – both for the detection of nonzero neutrino masses and the possible non-conservation of lepton charge – was clear to him. It was to take years of effort by many people for the tiny neutrino masses to become reality. The eventual discovery of neutrino oscillations was a triumph for Pontecorvo's idea. Sadly, it came nearly a decade after his death in 1993 but his name is now enshrined in the title of the neutrino mixing matrix – the Pontecorvo-Maki-Nakagawa-Sakata matrix.

His important ideas on neutrinos did not end with the oscillation hypothesis. In 1959 he was the first to indicate the significance of weak neutral currents between electron neutrinos and electrons for stellar evolution. Then in 1961 – four years before the discovery of the cosmic microwave background radiation – he and Yakov Smorodinsky proposed the possible existence of a "neutrino sea" that must result from the Big Bang. This was in effect the first discussion of dark matter in the form of relic neutrinos. Pontecorvo also stressed in other work the importance of neutrinoless double β-decay in non-accelerator physics, as the process is possible only if the neutrino is a Majorana particle – i.e. identical to its antiparticle. This decay is therefore a unique probe of new physics beyond the Standard Model.

In recognition of Pontecorvo's outstanding service to science, a memorial plaque of the European Physical Society was inaugurated on the doors of his study at JINR in February this year. As a top-rank scientist, he had combined the gift of deep insight into the essence of physical phenomena with the extraordinary talent of an experimenter. His passion for science, his clear and critical mind that was open to new decisions, his talent to see a problem in a new light, his rich knowledge – all left an indelible impression on everyone who knew him. He was also incredibly amiable and his personality brightened the lives of those who were happy to be his friends.

● *Vadim Bednyakov, JINR.*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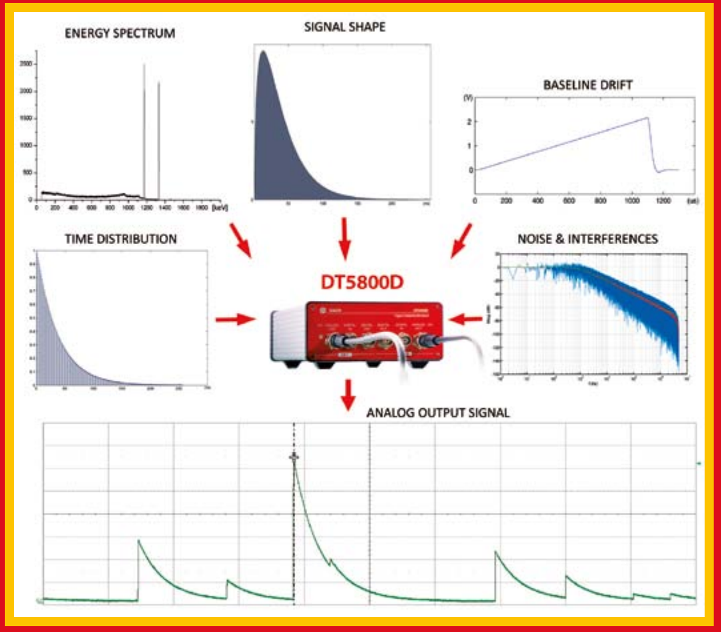
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CERNCOURIER

Volume 53 Number 7 September 2013

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