

WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the June 2017 issue of *CERN Courier*.

Fifty years ago, Robert Wilson and his deputy Edwin Goldwasser set up temporary offices in Oak Brook, Illinois, and immediately started staffing a new laboratory for fundamental physics centred around a 200 GeV accelerator. This issue of *CERN Courier* revisits the beginnings of Fermilab, now the principal laboratory in the US devoted to particle physics, and looks at some of its contributions over the decades. Three elementary particles were discovered there: the bottom quark, the top quark and the tau neutrino. Together with CERN's discovery of the W, Z and Higgs bosons, these two titans of the high-energy frontier have put the Standard Model on solid foundations. The evolving relationship between Fermilab and CERN, one of collaboration and competition, has seen records broken on both sides of the Atlantic, most recently with CERN's LHC surpassing the energy of Fermilab's Tevatron collider. Today, the two labs enjoy a closer partnership than ever, with Fermilab contributing to the LHC and CERN contributing to the short- and long-baseline neutrino programmes at Fermilab. Both facilities have demonstrated the benefits of carrying out high-energy physics on large scales, and now serve as models for how to achieve global collaboration. Meanwhile, two other major physics facilities celebrate anniversaries this month: the Baksan Neutrino Observatory in Russia, which also turns 50, and the Gran Sasso National Laboratory in Italy, for which construction was completed 30 years ago. Happy birthday to all!

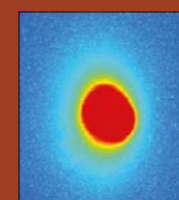
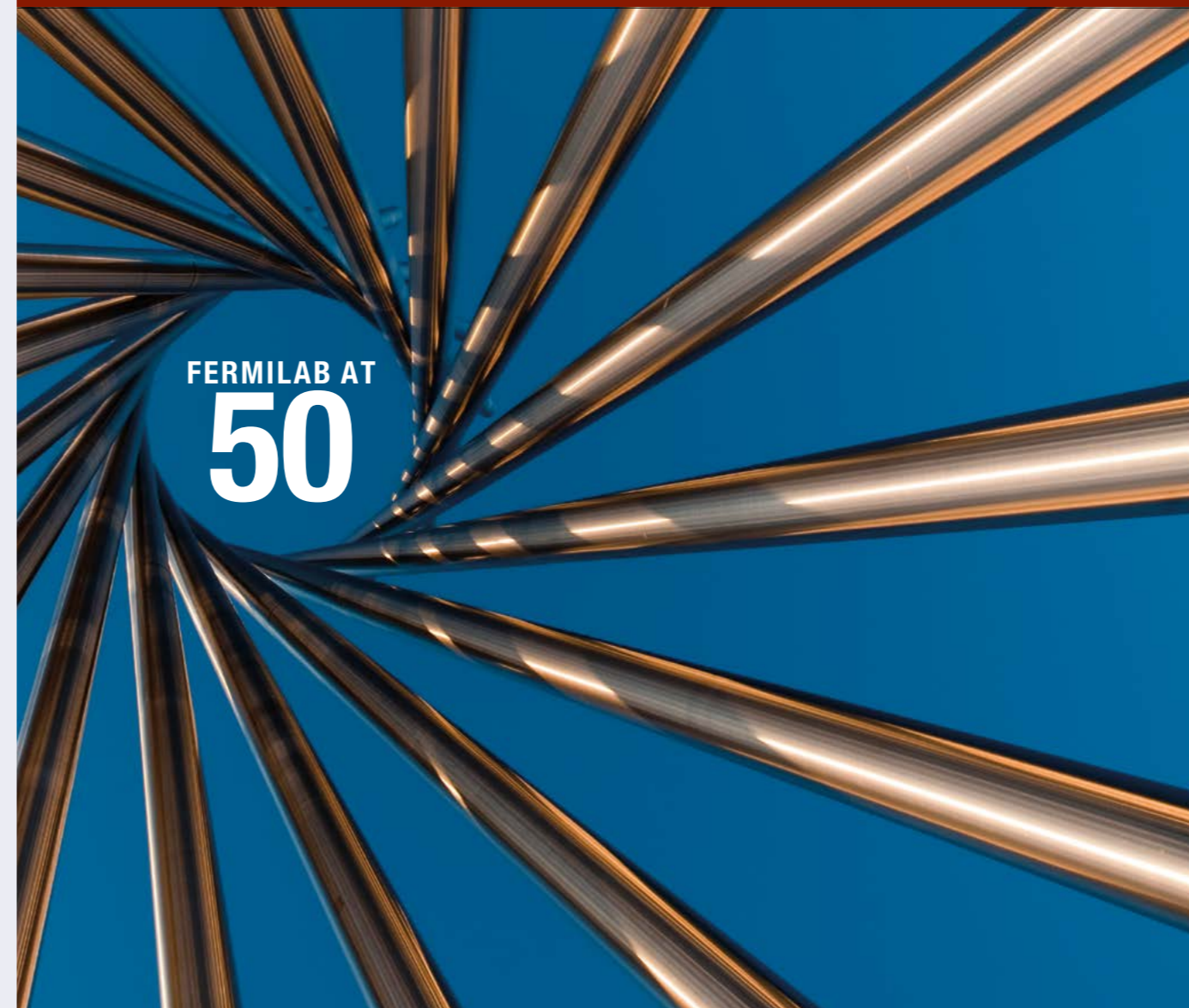
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EDITOR: MATTHEW CHALMERS, CERN
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**BEAM BACK**

LHC Run 2 resumes with high-energy proton operations
p7

NEUTRINOS

Baksan Neutrino Observatory on the rise
p39

**ADVANCED ACCELERATORS**

Workshop calls for international co-ordination
p7



HAPPY BIRTHDAY, FERMILAB!

W-IE-NE-R AND ISEG - POWERING NEUTRINO DETECTORS

DUNE / LBNF
 Deep Underground Neutrino Experiment
 Long-Baseline Neutrino Facility (LBNF)

THANKS FOR MANY YEARS OF SUCCESSFUL COLLABORATION

50 YEARS FERMILAB

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CERN COURIER

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5	VIEWPOINT
7	NEWS • LHC back with a splash • Workshop puts advanced accelerators on track • CAST experiment constrains solar axions • Belle II rolls in • CERN on the road • LHCb finds new hints of Standard Model discrepancy • Proton-proton collisions become stranger • ATLAS explores the energy frontier • SUSY searches in the electroweak sector • CERN and APS sign open access agreement
15	SCIENCEWATCH
17	ASTROWATCH
18	FEATURES The founding of Fermilab <i>Fifty years ago, physicists in the US established a new laboratory and with it a new approach to carrying out frontier research.</i>
25	Search for sterile neutrinos triples up <i>Fermilab's short-baseline neutrino programme targets sterile neutrinos.</i>
32	A selection of Fermilab's greatest hits <i>Timeline showing Fermilab's major experimental achievements.</i>
35	Revisiting the b revolution <i>A look back at the Fermilab experiment that unearthed the b quark.</i>
39	Baksan scales new neutrino heights <i>The Baksan Neutrino Observatory celebrates 50 years of success.</i>
45	FACES & PLACES
55	RECRUITMENT
59	BOOKSHELF
61	INSIDE (PHOTO)STORY
62	ARCHIVE



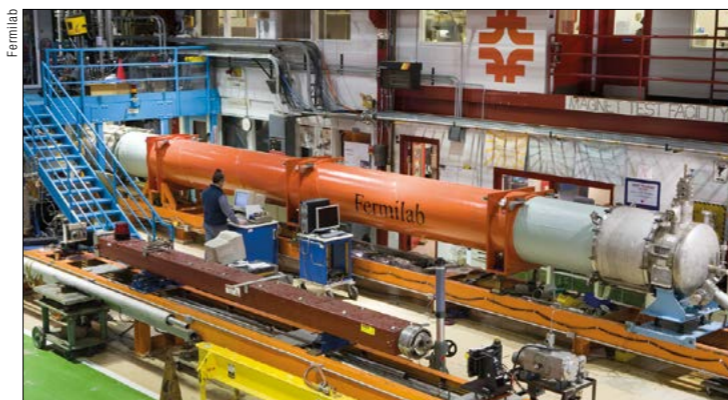
On the cover: Detail from the "Tractitious" sculpture at Fermilab, designed by founding director Robert Wilson. (Image credit: Fermilab.)



Viewpoint

A new era for particle physics

The next 50 years will be shaped by greater partnerships between labs and a capacity to innovate.



Fermilab developed the superconducting quadrupole magnets that focus the LHC's proton beams prior to collisions at each interaction point.

By Nigel Lockyer

Driven by technology, scale, geopolitical reform, and even surprising discoveries, the field of particle physics is changing dramatically. This evolution is welcomed by some and decried by others, but ultimately is crucial for the survival of the field. The next 50 years of particle physics will be shaped not only by the number, character and partnerships of labs around the world and their ability to deliver exciting science, but also by their capacity to innovate.

Increasingly, the science we wish to pursue as a field has demanded large, even mega-facilities. CERN's LHC is the largest, but the International Linear Collider (ILC) project and plans for a large circular collider in China are not far behind, and could even be new mega-science facilities. The main centres of particle physics around the world have changed significantly in the last several decades due to this trend. But a new picture is emerging, one where co-ordination among and participation in these mega-efforts is required at an international level. A more co-ordinated global playing field is developing, but "in transition" would best describe the situation at present.

Europe and North America have clear directions of travel. CERN has emerged as the leader of particle physics in Europe; the US has only Fermilab devoted entirely to particle physics. Other national labs in the US and Europe have diversified into other areas of science and some have found a niche for particle physics while also connecting strongly to the research programmes at Fermilab and CERN. Indeed, in the US a network of laboratories has emerged involving SLAC, Brookhaven, Argonne

and Berkeley. Once quite separate, now these labs contribute to the LHC and to the neutrino programme based at Fermilab. Furthermore, each lab is becoming specialised in certain science and technology areas, while their collective talents are being developed and protected by the Department of Energy. As a result, CERN and Fermilab are stronger partners than ever before. Likewise, several European labs are now engaged or planning to engage in the ambitious neutrino programme being hosted by Fermilab, for which CERN continues to be the largest partner.

Will this trend continue, with laboratories worldwide functioning more like a network, or will competition slow down the inevitable end game? There are at least a couple of wild cards in the deck at the moment. Chief issues for the future are how aggressively and at what scale will China enter the field with its Circular Electron Positron Collider and Super Proton-Proton Collider projects, and whether Japan will move forward to build the ILC. The two projects have obvious science overlap and some differences, and if either project moves forward, Europe and the US will want to be involved and the impact could be large.

The global political environment is also fast evolving, and science is not immune from fiscal cuts or other changes taking place. While it is difficult to predict the future, fiscal austerity is here to stay for the near term. The consequences may be dramatic or could continue the trend of the last few decades, shrinking and consolidating our field. Rising above this trend will take focus, co-ordination and hard work. More importantly than ever, the worldwide community needs to demonstrate the value of basic science to funding stakeholders and the public, and to propose compelling reasons why the pursuit of particle physics deserves its share of funding.

Top-quality, world-leading science should be the primary theme, but it is not enough. The importance of social and economic impact will loom ever larger, and the usual rhetoric about it taking 40 years to reap the benefits from basic research – even if true – will no longer suffice. Innovation, more specifically the role of science in fuelling economic growth, is the favourite word of many governments around the world. Particle physics needs to be engaged in this discussion and contribute its talent. Is this a laboratory effort, a network of laboratories effort, or a global effort? For the moment, innovation is local, sometimes national, but our field is used to thinking even bigger. The opportunity to lead in globalisation is on our doorstep once again.

Nigel Lockyer is an experimental particle physicist who has been director of Fermilab since 2013, having served at the US lab in a variety of roles during the past 25 years.



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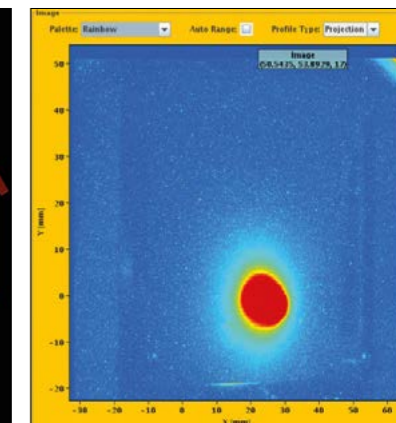
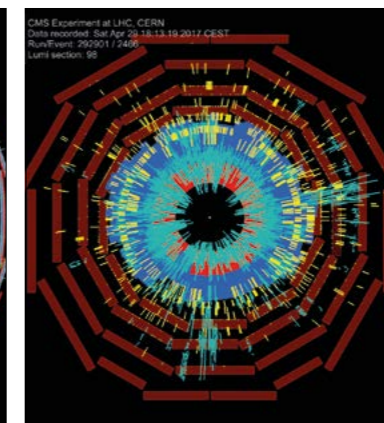
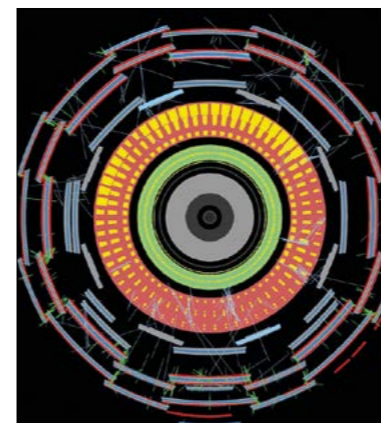
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LHC NEWS

LHC back with a splash



On 29 April, just after 8.00 p.m., the Large Hadron Collider (LHC) began circulating beams of protons for the first time this year. Extensive technical and maintenance work was undertaken since its end-of-year shutdown in early December, yet the restart of the 27 km-circumference superconducting collider has proceeded smoothly.

Magnet powering tests, which ensured the machine can be operated at an energy of 6.5 TeV per beam, were completed during the last week of April. This was followed by the machine-checkout phase, during which all equipment is placed in its operational state and the four LHC experiment caverns are patrolled and closed.

In the meantime, the crew of the Super Proton Synchrotron (SPS), which feeds protons to the LHC, worked hard to extract the single-bunch beam so that the LHC could be commissioned with beam. By the end of the afternoon on Friday 28 April, protons had been sent successfully down both transfer lines and were knocking at the LHC's door. The following day, at

6.00 p.m., beam 1 (clockwise direction) was injected and threaded through the LHC's eight sectors one at a time, circulating the entire machine after a period of 45 minutes. Beam 2 (anticlockwise direction) then went through the same process, and at 8.12 p.m. both beams were circulating. On Sunday 30 April, the single-bunch, low-intensity beams were successfully ramped to an energy of 6.5 TeV.

The next task, which was well under way as the *Courier* went to press, was to continue with detailed setting up of the machine while stepping up to higher bunch intensities and then multiple bunches. Each step in the intensity ramp up that follows has to be validated by circulating the beams from three fills for up to 20 hours, and the team is aiming for a configuration of 2550 bunches per beam, with each bunch containing of the order 1.2×10^{11} protons. Once stable beams have been declared, expected in the second half of May, the beams will be brought into collision and the second chapter of LHC Run 2 will be under way.

"Splash" events, whereby protons that have scattered off a collimator in the LHC beam pipe spray debris into the detectors, were recorded by ATLAS (left) and CMS (middle) at the end of April. (Right) A single low-intensity proton bunch strikes a screen in the LHC twice, signifying that it has made one full turn of the collider.

ACCELERATORS

Workshop puts advanced accelerators on track

Researchers working on advanced and novel accelerator technologies met at CERN on 25–28 April to draw up an international roadmap for future high-energy particle accelerators. Organised by the International

Committee for Future Accelerators (ICFA) to trigger a community effort, the Advanced and Novel Accelerator for High Energy Physics Roadmap Workshop saw 80 experts from 11 countries discuss the steps needed to include these new technologies in strategies for future machines in Asia, Europe and the US. It follows recent discussions of national roadmaps in the US and elsewhere, and was timed so that

Sommaire en français

Le LHC fait son retour	7
Un atelier pour faire décoller les futurs accélérateurs	7
L'expérience CAST fixe de nouvelles limites pour les axions solaires	8
Tout roule pour Belle II	9
Un nouveau visage pour le CERN	9
LHCb trouve des nouveaux indices d'un écart par rapport au Modèle standard	10
Les collisions proton-proton deviennent plus 10 étranges	10
ATLAS explore la physique aux plus hautes énergies	11
SUSY recherchée dans le secteur électrofaible	12
Le CERN et l'APS signent un accord pour le libre accès	12
La physique et l'inégalité des richesses	15
Une étude lève le voile sur l'orée des halos de matière noire	17



advanced accelerator development can be taken into account in the coming update of the European Strategy for Particle Physics in 2020.

Given the scale of the cost of traditional accelerator technologies, which require large circular or long linear accelerators to reach the highest energies, the past two decades have seen significant progress to find alternative approaches. These include dielectrics and plasmas driven by laser pulses or particle beams, which are able to accelerate particles 1000 times more than the radio-frequency structures used in today's accelerators. Major laboratories including CERN, SLAC, Argonne, DESY and INFN-Frascati are working on various techniques. CERN has recently started the AWAKE experiment, demonstrating that high-energy protons from the SPS can drive large accelerating fields in a plasma.

The next step is to apply these methods to high-energy physics. For example, the acceleration schemes must be tuned to determine their real potential for producing high-energy and high-quality particle bunches; the former has been demonstrated, but the latter remains a challenge. This requires experimental facilities that can only be hosted by international laboratories and a strong, united and co-ordinated community that merges the advanced and traditional accelerator communities.

The April event has now set this process



M. Bricchi/CERN

CERN's AWAKE experiment. A possible application of this technology would be to use a proton beam from the LHC to accelerate electrons in a few-hundred-metre-long plasma for electron-proton collisions.

in motion, focusing on the technical milestones that are needed to progress towards an intermediate-size particle accelerator and on the strategies needed to bring communities together. A new working group dedicated to the development of a roadmap will be included in the European Advanced Accelerators Concept Workshop in September 2017 in Elba, Italy.

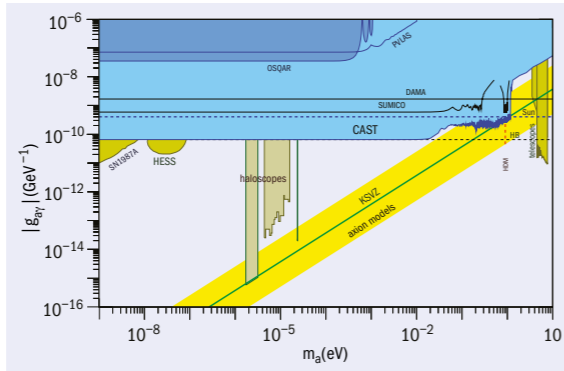
"This is the first time that the advanced accelerator field is co-ordinated at the international level, and will pull the community together towards the first great challenge ahead, i.e. the achievement of reliable and high-quality particle bunches," says workshop chair Brigitte Cros. "Further workshops will be organised to strengthen and sustain this co-ordination."

AXION SEARCH

CAST experiment constrains solar axions

In a paper published in *Nature Physics*, the CERN Axion Solar Telescope (CAST) has reported important new exclusion limits on coupling of axions to photons. Axions are hypothetical particles that interact very weakly with ordinary matter and therefore are candidates to explain dark matter. They were postulated decades ago to solve the "strong CP" problem in the Standard Model (SM), which concerns an unexpected time-reversal symmetry of the nuclear forces. Axion-like particles, unrelated to the strong-CP problem but still viable dark-matter candidates, are also predicted by several theories of physics beyond the SM, notably string theory.

A variety of Earth- and space-based observatories are searching possible locations where axions could be produced, ranging from the inner Earth to the galactic centre and



The latest constraints on the two-photon coupling, $g_{a\gamma}$, of axions and other similar particles as a function of mass, showing the new CAST limits.

right back to the Big Bang. CAST looks for solar axions using a "helioscope" constructed from a test magnet originally built for the Large Hadron Collider. The 10 m-long superconducting magnet acts like a viewing tube and is pointed directly at the Sun: solar axions entering the tube would be converted by its strong magnetic field into X-ray photons, which would be detected at either end of the magnet. Starting in 2003, the CAST helioscope, mounted on a movable platform

and aligned with the Sun with a precision of about 1/100th of a degree, has tracked the movement of the Sun for an hour and a half at dawn and an hour and a half at dusk, over several months each year.

In the latest work, based on data recorded between 2012 and 2015, CAST finds no evidence for solar axions. This has allowed the collaboration to set the best limits to date on the strength of the coupling between axions and photons for all possible axion

masses to which CAST is sensitive. The limits concern a part of the axion parameter space that is still favoured by current theoretical predictions and is very difficult to explore experimentally, allowing CAST to encroach on more restrictive constraints set by astrophysical observations. "Even though we have not been able to observe the ubiquitous axion yet, CAST has surpassed

even the sensitivity originally expected, thanks to CERN's support and unrelenting work by CASTers," says CAST spokesperson Konstantin Zioutas. "CAST's results are still a point of reference in our field."

The experience gained by CAST over the past 15 years will help physicists to define the detection technologies suitable for a proposed, much larger, next-generation axion helioscope

called IAXO. Since 2015, CAST has also broadened its research at the low-energy frontier to include searches for dark-matter axions and candidates for dark energy, such as solar chameleons.

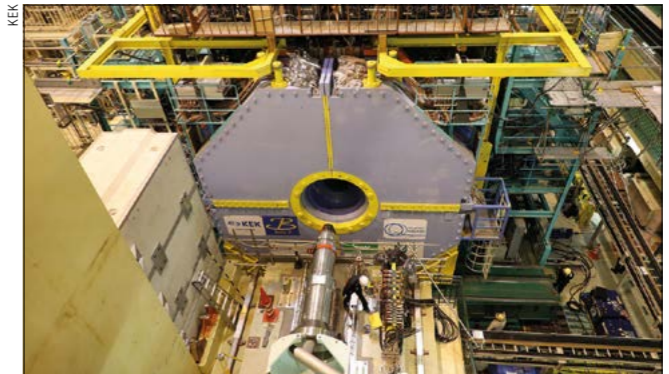
• **Further reading**
CAST Collaboration 2017 *Nature Physics* doi:10.1038/nphys4109.

FACILITIES

Belle II rolls in

On 11 April, the Belle II detector at the KEK laboratory in Japan was successfully "rolled-in" to the collision point of the upgraded SuperKEKB accelerator, marking an important milestone for the international B-physics community. The Belle II experiment is an international collaboration hosted by KEK in Tsukuba, Japan, with related physics goals to those of the LHCb experiment at CERN but in the pristine environment of electron-positron collisions. It will analyse copious quantities of B mesons to study CP violation and signs of physics beyond the Standard Model (*CERN Courier* September 2016 p32).

"Roll-in" involves moving the entire 8 m-tall, 1400 tonne Belle II detector system from its assembly area to the beam-collision point 13 m away. The detector is now integrated with SuperKEKB and all its seven subdetectors, except for the innermost vertex detector, are in place. The next step is to



The Belle II detector is now in place at the SuperKEKB facility in Japan.

install the complex focusing magnets around the Belle II interaction point. SuperKEKB achieved its first turns in February 2016, with operation of the main rings scheduled for early spring and phase-III "physics" operation by the end of 2018.

Compared to the previous Belle experiment, and thanks to major upgrades made to the former KEKB collider, Belle II will allow much larger data samples to be

collected with much improved precision. "After six years of gruelling work with many unexpected twists and turns, it was a moving and gratifying experience for everyone on the team to watch the Belle II detector move to the interaction point," says Belle II spokesperson Tom Browder. "Flavour physics is now the focus of much attention and interest in the community and Belle II will play a critical role in the years to come."

CERN

CERN on the road

CERN has begun major work to create a new visitor space called Esplanade des Particules, to welcome the ever-growing numbers of visitors to the laboratory each year. The project, undertaken in conjunction with the Etat de Genève, will integrate the laboratory better into the local urban landscape, making it more open and easily accessible, with work to last until summer 2018.

A competition was launched in 2011 to showcase the public entrance to CERN. Landscape-architects Studio Paolo Bürgi won with a design for a large space dedicated to pedestrians that connects CERN's reception to the Globe of Science and Innovation. The Esplanade des Particules will see the current "Flags Car Park" replaced by a blue pedestrianised area in which the flags of CERN Member States will cross the main road to the laboratory.



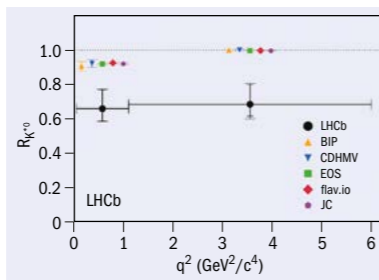
The speed limit will be reduced to 50 km h⁻¹ at the point where the Esplanade des Particules crosses the pedestrianised area.

LHC EXPERIMENTS

LHCb finds new hints of Standard Model discrepancy

At a seminar at CERN on 18 April, the LHCb collaboration presented new results in flavour physics that show an interesting departure from Standard Model (SM) predictions. The new measurement concerns a parameter called R_{K^*0} , which is the ratio of the probabilities that a B^0 meson decays to $K^*0\mu^+\mu^-$ and to $K^*0e^+e^-$ (where the K^*0 meson was reconstructed through its decay into a charged kaon K^+ and a pion π^-).

Lepton universality – a cornerstone of the SM – states that leptons have the same couplings to gauge bosons and therefore that R_{K^*0} is expected to be close to unity (apart from well-understood effects related to the different masses of the leptons, which change this value slightly). Any conclusive observation of a violation of this rule would indicate the existence of physics beyond the SM. Based on analysis of data from Run 1, the LHCb measurement differs from the prediction with a significance between



The measured value (black) of R_{K^*0} in two regions of the $\mu^+\mu^-$ or e^+e^- invariant mass squared, q^2 , and various independent SM theoretical predictions (colours).

2.1 and 2.5 standard deviations in the two regions of q^2 (the $\mu^+\mu^-$ or e^+e^- invariant mass squared) in which the measurement is performed.

Three years ago, LHCb found a similar discrepancy for the quantity R_K – in which the B^0 meson is replaced by a B^+ and the

K^*0 meson by a K^+ . In addition, another class of measurements concerning different ratios of B-meson decay rates involving τ and muon leptons also exhibit some tensions with predictions. While intriguing, none of the differences are yet at the level where they can be claimed to exhibit evidence for physics beyond the SM.

The LHCb collaboration has a wide programme of lepton-universality tests based on different R measurements in which other particles replace the K^*0 or K^+ mesons in the ratios. The R_{K^*0} and R_K measurements so far were obtained using the entire Run 1 data sample, corresponding to an integrated luminosity of 3 fb^{-1} at an energy of 7 and 8 TeV. Data collected in Run 2 already provide a sample more than twice as large, and it is therefore of great importance to see whether updates of the present analysis will confirm or rule out the discrepancies.

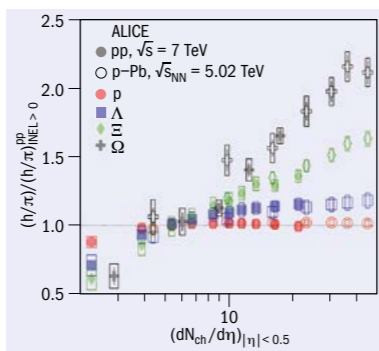
• **Further reading**
LHCb Collaboration 2017 LHCb-PAPER-2017-013.

Proton–proton collisions become stranger

Recreating the intense fireball of quarks and gluons that existed immediately after the Big Bang, the quark–gluon plasma (QGP), traditionally requires high-energy collisions between heavy ions such as lead–lead. Recently, however, the ALICE experiment has seen tentative evidence that the extreme QGP state is created in much smaller systems generated by selected proton–proton collisions.

In a paper published in *Nature Physics*, the collaboration reports an enhanced production of strange and multi-strange hadrons in high-multiplicity proton–proton (pp) interactions at a centre-of-mass energy of 7 TeV. This phenomenon was one of the earliest proposed indicators for the formation of a QGP, and is very similar to that found in lead–lead (Pb–Pb) collisions and proton–lead (p–Pb) collisions. Measured at mid-rapidity, the production rate of strange particles increases with the event “activity” (quantified by the charged-particle multiplicity density) faster than that of non-strange ones, leading to an enhancement relative to pions.

The enhancement in strangeness is expected to be more pronounced for multi-strange baryons, and this was



Particle-to-pion ratios versus the number of charged particles produced in an event, normalised to the average values measured in proton–proton collisions.

confirmed in collisions of heavy nuclei at the SPS, RHIC and the LHC. The remarkable similarity between strange particle production in pp, p–Pb and Pb–Pb collisions is complemented by other pp and p–Pb measurements. All exhibit characteristic features from high-energy heavy-ion collisions that are understood to be connected to the formation of a deconfined QCD phase

at high temperature and energy density.

The observed multiplicity-dependent enhancement (see figure) follows a hierarchy connected to the strangeness in the hadron. No enhancement is observed for protons (which have no valence strange quarks), demonstrating that the observed increase is strangeness rather than mass related. The results have been compared with Monte Carlo models commonly used at the LHC, of which none can reproduce satisfactorily the observations.

It is not yet clear if the ALICE data truly signal the progressive onset of a QGP medium in small systems. On the other hand, these measurements unveil another remarkable similarity with phenomena known from high-energy nuclear reactions, opening up new possibilities to investigate the underlying dynamical mechanisms of the QGP. Either way, the ability to isolate QGP-like phenomena in a smaller and simpler system opens up an entirely new dimension for the study of the properties of the fundamental state that our universe emerged from.

• **Further reading**
ALICE Collaboration 2017 *Nature Physics* doi:10.1038/nphys4111.

ATLAS explores the energy frontier



The start of LHC Run 2 in 2015 saw the centre-of-mass energy of proton–

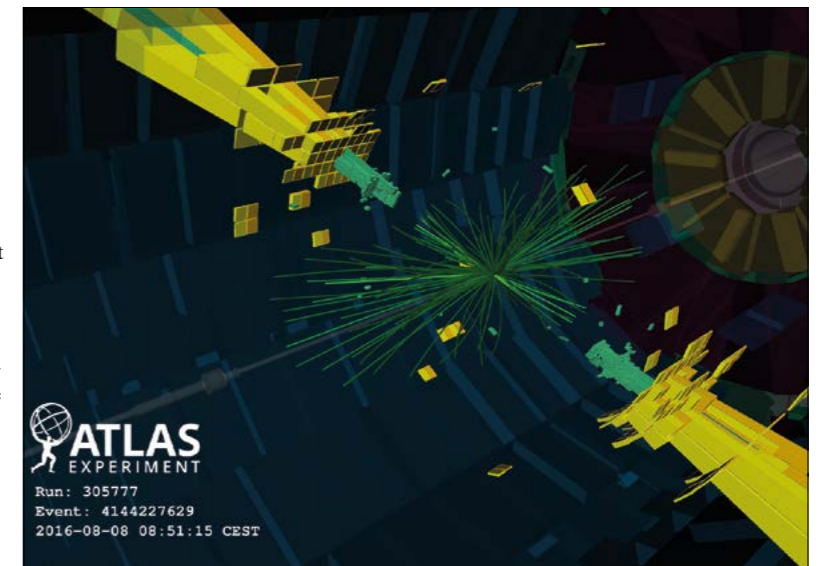
proton collisions increase from 8 to 13 TeV, dramatically increasing the possibility to create heavy particles predicted by many models of new physics. The ATLAS collaboration has recently released the first search results from its analysis of the full 2015 and 2016 data sets, providing the largest combined LHC data set analysed so far.

New heavy particles are likely to decay immediately inside the detector into known objects such as pairs of jets, leptons or bosons. These decay products will typically have large transverse momentum, due to the high mass of the parent particle, and this raises challenges both for the detector and the algorithms used to identify the decay products.

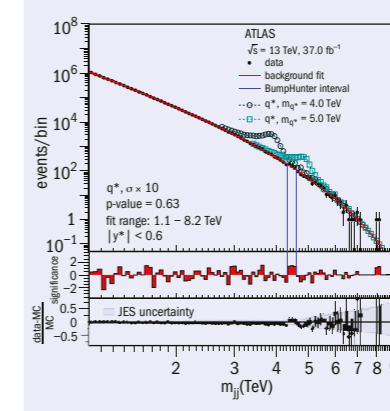
Utilising pairs of jets (dijets), a recent ATLAS search was able to probe the highest invariant mass of any of its searches, measuring events with energies as high as 8.1 TeV and thereby pushing up the experiment’s sensitivity to hypothetical new resonances. Additionally, ATLAS has released the results of searches in events containing pairs of muons or electrons or single muons/electrons plus a neutrino, which extend the sensitivity to new resonance masses up to 4.5 and 5.1 TeV, respectively. Heavy particles with an affinity for coupling to the Higgs boson were also examined up to a mass of 3.7 TeV.

ATLAS has also searched for vector-like top-quark partners, which are strongly interacting particles invoked by models with new high-scale symmetries and which may be produced at the LHC. The final states sought in these analyses are a single high-transverse-momentum electron or muon, plus either several jets and a large component of missing transverse momentum or a large-radius jet consistent with a W or Z boson plus some missing transverse momentum and one b-tagged jet. The presence of vector-like top quarks is excluded for particle masses of up to 1.35 TeV, depending on the physics model chosen.

Finally, ATLAS has performed direct



(Above) The highest mass dijet event selected by ATLAS in its dijet resonance search, corresponding to a mass of 8.1 TeV. (Left) New resonances would reveal themselves as excesses of events (open circles and squares) in the dijet mass spectrum. ATLAS searches for them by comparing the data (black) to an estimate of the spectrum produced if no new particles are present (red). The most significant excess (vertical blue lines) is compatible with a statistical fluctuation.



searches for dark matter by looking for single energetic photons plus missing transverse momentum and for a Higgs boson plus missing transverse momentum. These are potential signatures of the production and decay of a pair of weakly interacting massive particles (with the photon arising from initial-state radiation and the Higgs boson being produced in the decay of a Z' dark-matter mediator). The data are found to be consistent with

Standard Model predictions for all of the searches conducted thus far. The second phase of Run 2 is about to begin and is scheduled to continue until the end of 2018, roughly tripling the integrated luminosity collected so far. This huge amount of data yet to be recorded will further extend the reach of these searches for new physics.

• **Further reading**
ATLAS Collaboration 2017 arXiv:1703.09127.
ATLAS Collaboration 2017 ATLAS-CONF-2017-027.
ATLAS Collaboration 2017 ATLAS-CONF-2017-016.
ATLAS Collaboration 2017 ATLAS-CONF-2017-018.
ATLAS Collaboration 2017 ATLAS-CONF-2017-015.
ATLAS Collaboration 2017 arXiv:1704.03848.
ATLAS Collaboration 2017 ATLAS-CONF-2017-028.

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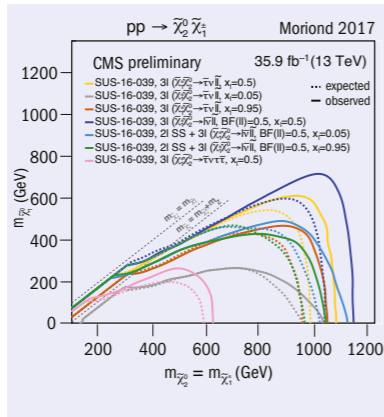
SUSY searches in the electroweak sector



The sensitivity of searches for supersymmetry (SUSY) has been boosted by the increased centre-of-mass energy of LHC Run 2. Analyses of the first Run 2 data recorded in 2015 and early 2016 focused on the production of strongly interacting SUSY particles – the partners of Standard Model (SM) gluons (“gluinos”) and quarks (“squarks”).

With the large data set accumulated during the rest of 2016, attention now turns to a more challenging but equally important part of the SUSY particle spectrum: the supersymmetric partners of SM electroweak gauge (“winos”, “binos”) and Higgs (“higgsinos”) bosons. The spectrum of the minimal supersymmetric extension of the SM contains six of these particles: two charged (“charginos”) and four neutral (“neutralinos”) ones. The cross-sections for the direct production of pairs of these particles are typically three to five orders of magnitude lower than that for gluino pair production, but such events might be the only indication of supersymmetry at the LHC if the partners of gluons, quarks and leptons are heavy.

CMS has recently reported searches for electroweak production of neutralinos and charginos in different final states. Decays of these particles to the lightest SUSY particle (LSP) – which are candidates for dark matter – are expected to produce Z, W and H bosons, or photons. If the SUSY partners of leptons (sleptons) are sufficiently light they can also be part of the decay chain. In all of these cases, since final states with two or more leptons constitute a large fraction

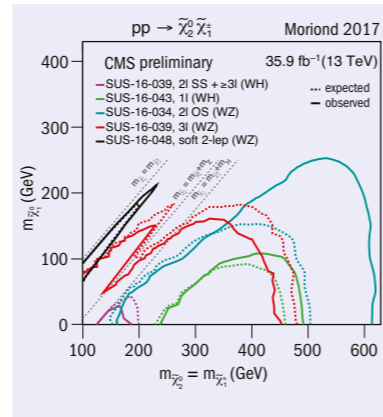


SUSY exclusion limits for the production of chargino-neutralino pairs for decays with intermediate sleptons (left) and decays involving W, Z or H bosons (right).

of the signal events, CMS has searched for supersymmetry in final states with multiple leptons. These searches are complemented by analyses targeting hadronic decays of Higgs bosons in these events.

None of the searches performed by CMS show any significant deviation of the observed event counts from the estimated yields for SM processes. In benchmark models with reduced SUSY particle content, the strongest constraints on the electroweak production of pairs of the lightest chargino and the second-lightest neutralino are obtained by assuming their decay chains involve sleptons, with mass limits reaching up to 1.15 TeV, depending on the slepton’s mass and flavour. For direct decays of the chargino (neutralino) to a W (Z) boson and the lightest neutralino, the excluded regions reach up to 0.61 TeV.

A particularly interesting case, favoured by “natural” supersymmetry, are models with small mass differences between the lightest chargino and neutralino states. In these models, the transverse momenta of the leptons can be significantly lower than



the typical thresholds of 10–20 GeV used in most analyses. CMS has designed a specific search to enhance the sensitivity to final states with two low-momentum leptons of opposite charge that includes a dedicated online selection for muons with transverse momenta as low as 3 GeV. The search reaches an unprecedented sensitivity: for a mass difference of 20 GeV, the exclusion reaches a mass of 230 GeV.

Based on data recorded in 2016, CMS has covered models of electroweak production of “wino”-like charginos and neutralinos with searches in different final states. More results are expected soon, and the sensitivity of the searches will largely profit from the extension of the data set in the remaining two years of LHC Run 2.

Further reading

- CMS Collaboration 2017 CMS-PAS-SUS-16-034.
- CMS Collaboration 2017 CMS-PAS-SUS-16-039.
- CMS Collaboration 2017 CMS-PAS-SUS-16-043.
- CMS Collaboration 2017 CMS-PAS-SUS-16-044.
- CMS Collaboration 2017 CMS-PAS-SUS-16-046.
- CMS Collaboration 2016 CMS-PAS-SUS-16-048.

in *Physical Review C*, *Physical Review D* and *Physical Review Letters* at no direct cost. The aim is to allow free and unrestricted exchange of scientific information within the global scientific community and beyond. As a result of the agreement, SCOAP³ will cover about 90 per cent of all the journal literature in high-energy physics.

Convened and managed by CERN and launched in 2014, SCOAP³ is the largest-scale global open access initiative ever built, involving 3000 libraries and research institutes from 44 countries. The initiative is possible through funds made available from

the redirection of former subscription monies: publishers reduce subscription prices for journals participating in the initiative, and those savings are pooled by SCOAP³ partners to pay for the open access costs.

“Open access reflects values and goals that have been enshrined in CERN’s Convention for more than 60 years, such as the widest dissemination of scientific results. We are very pleased that the APS is joining SCOAP³ and we look forward to welcoming more partners for the long-term success of this initiative,” says CERN Director-General Fabiola Gianotti.

PUBLISHING CERN and APS sign open access agreement

On 27 April, CERN and the American Physical Society (APS) signed an agreement for the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP³). Under the agreement, high-energy physics articles published in three leading journals of the APS will be open access from January 2018 onwards. All authors worldwide will be able to publish their articles



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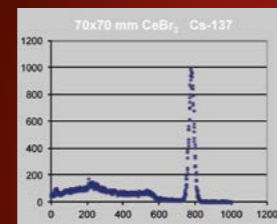
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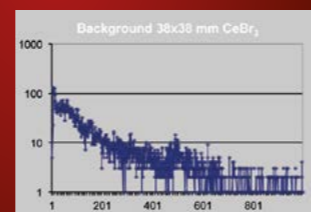


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Physics and wealth inequality

Wealth inequality, a topic of much current concern, is an inevitable consequence of the laws of physics. That's the conclusion of a study by Adrian Bejan of Duke University in the US and Marcelo Errera of the Federal University of Paraná in Curitiba, Brazil, who have related the distribution of wealth to what they call "the movement of all streams" of a live society. This corresponds to the actual physical movement of masses over distances and can be defined in various ways, such as the amount of fuel consumed annually, all of which lead to the same



The new study reveals why inequality is so difficult to erase.

scaling behaviour. This naturally produces a hierarchical distribution of wealth that becomes more accentuated as the economy develops, and predicts the Lorenz-type distribution of wealth that has been adopted empirically for the last century.

• **Further reading**
A Bejan and M Errera 2017 *J. Appl. Phys.* **121** 124903.

Negative mass

Push most objects and they will accelerate in the direction they were pushed. Not so for objects with a negative effective mass, which do the exact opposite by accelerating against an applied force. This counter-intuitive behaviour has now been realised experimentally in an expanding Bose–Einstein condensate made from rubidium atoms. Mohammad Khamehchi of Washington State University and colleagues engineered a specific dispersion relation in the system using Raman dressing techniques to open a gap at the crossing of two parabolic free-particle dispersion curves. For suitable parameters this leads to a branch with a region of negative curvature, and thus a negative effective mass. The team reports a range of interesting dynamics in the system, including breaking of parity and Galilean covariance, dynamical instabilities and self-trapping.

• **Further reading**
M Khamehchi *et al.* 2017 *Phys. Rev. Lett.* **118** 155301.

Big chemistry

Expensive, large-scale projects are familiar in physics, astronomy, space exploration and, more recently, genetics. Now chemistry may join the ranks of big science. Martin Burke of the University of Illinois, Urbana-Champaign, has proposed a \$1 billion, 20 year-long project to extend an automated synthesis machine such that it can synthesise most of the hundreds of thousands of known organic small molecules made by plants, animals and microbes – many of

Blood in amber

In what seems like a step closer to Jurassic Park, combined with some good fortune, a blood-engorged tick trapped in amber 15–45 million years ago has turned out to contain perfectly preserved mammalian blood cells, likely from a monkey. George Poinar Jr of Oregon State University in Corvallis also found numerous single-celled parasites in different parts of their life cycle in the fossil, which comes from the Cordillera Septentrional mountain range of the Dominican Republic. Two small holes on the tick's back suggest that it was picked off during its meal, perhaps by another monkey, and fell immediately into tree sap. As an added bonus, the amber stained the red blood cells and parasites differently, making each stand out clearly.

• **Further reading**
G Poinar Jr 2017 *J. Med. Entomol.* doi:10.1093/jme/tjw247.



The preserved tick, measuring roughly 2 mm across, with two broken areas visible in the body wall.

which are of medical interest. The odds of funding for such a project at present are not clear, but it is certainly a bold new idea.

• **Further reading**
R Service 2017 *Science* **356** 231.

AI identifies bias

Machine learning applied to ordinary English can identify content corresponding to human biases, according to a new study. Aylin Caliskan of Princeton University and colleagues used a word-embedding method that represents each word in a 2.2 million-word case-sensitive vocabulary as a vector with 300 semantic dimensions, derived from 840 billion "tokens" obtained from crawling the web. The method was able to distinguish human attitudes including likes, dislikes and stereotypes, potentially adding a new "comprehension" skill to computers. The result could lead to new understanding and detection of (perhaps unintended) discrimination based on factors such as race, gender, age or ethnicity.

• **Further reading**
A Caliskan *et al.* 2017 *Science* **356** 183.

Condensed-matter SUSY

While supersymmetry has not yet appeared at the Large Hadron Collider, a new analysis predicts that it should appear as an emergent phenomenon in condensed-matter physics. Shao-Kai Jian of Tsinghua University in China and colleagues have shown that a supersymmetric gauge theory with dynamical gauge bosons and fermionic gauginos emerges under certain conditions on the surface of a correlated topological insulator, such as SmB_6 .

• **Further reading**
S-K Jian *et al.* 2017 *Phys. Rev. Lett.* **118** 166802.



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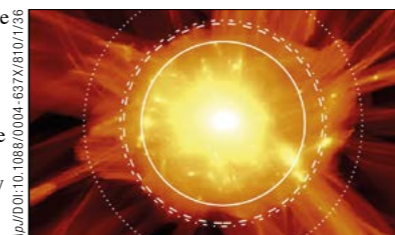
COMPILED BY MERLIN KOLE, DEPARTMENT OF PARTICLE PHYSICS, UNIVERSITY OF GENEVA

Survey reveals edge of dark-matter halos

Gravitational-lensing measurements indicate that clusters of galaxies are surrounded by large halos of dark matter. By studying the distribution and colour of galaxies inside galaxy clusters using data from the Sloan Digital Sky Survey (SDSS), researchers have now measured a new feature of the shape of these halos. The results show that the density of dark matter in a halo does not gradually fall off with distance, as might be expected, but instead exhibits a sharp edge.

According to the standard cosmological model, dark-matter halos are the result of small perturbations in the density of the early universe. Over time, and under the influence of gravity, these perturbations grew into large dense clumps that affect surrounding matter: galaxies in the vicinity of a halo will initially all move away due to the expansion of the universe, but gravity eventually causes the matter to fall towards and then orbit the halo. Studying the movements of the matter inside halos therefore provides an indirect measurement of the interaction between normal and dark matter, allowing researchers to probe new physics such as dark-matter interactions, dark energy and modifications to gravity.

Using the SDSS galaxy survey, Bhuvnesh Jain and Eric Baxter from the University of Pennsylvania and colleagues at other



Simulation showing the density of a galaxy cluster, with a clear edge in the density (dashed line) induced by the process of "splash back".

institutes report new evidence for an edge-like feature in the density profile of galaxies within a halo. The large amount of SDSS data available allowed a joint analysis of thousands of galaxy clusters each containing thousands of galaxies, revealing an edge inside clusters in agreement with simulations based on "splash-back" models. The edge is associated with newly accreted matter which, after falling into the halo, slows down as it reaches the extremity of its elliptical orbit before falling back towards the halo centre. As the matter "splashes back" it slows down, which leads to a build-up of matter at the edge of the halo and a steep fall-off in the amount of matter right outside this radius.

The authors found additional evidence for the edge by studying the colour of the galaxies. Since new stars that formed in hydrogen-rich regions are more bright in the blue part of the spectrum, galaxies with large amounts of new-star formation are more blue than those with little star formation. As a galaxy travels through a cluster, different mechanisms can strip it of the gasses required to form new blue stars, reducing star formation and making the galaxy appear more red. Models therefore predict galaxies still in the process of falling into the halo to be more blue, while those which already passed the edge and are in orbit have started to become red - exactly as data from the SDSS galaxy survey showed.

A range of ongoing and new galaxy surveys - such as Hyper Suprime-Cam, Dark Energy Survey, Kilo-Degree Survey and the Large Synoptic Survey Telescope - will measure the galaxy clusters in more detail. Using additional information on the shape of the clusters, says the team, it is possible to study both the standard physics of how galaxies interact with the cluster and the possible unknown physics of what the nature of dark matter and gravity is.

• **Further reading**
E Baxter *et al.* 2017 arXiv:1702.01722.

Picture of the month

In this Hubble Space Telescope image, which was released as part of the telescope's 27th anniversary this year, two very different looking spiral galaxies - NGC 4302 on the bottom and NGC 4298 on the top - are located next to each other 55 million light-years away and were discovered by astronomer William Herschel in 1784. The galaxies, which are among around 2000 that form the Virgo Cluster, are separated at their closest point by approximately 7000 light-years. Yet despite their close proximity, they apparently lack any significant gravitational interaction. No tidal tails or large deformations, typical for galaxies in close proximity, are observed for this pair, only a faint bridge of neutral hydrogen gas (not visible in the image) appears to stretch between them.



NASA, ESA and M. Mutchler



The founding of Fermilab



Wilson Hall, the central laboratory building, is the heart of the Fermilab site. (All image credits: Fermilab.)

Fifty years ago, physicists in the US established a new laboratory and with it a new approach to carrying out frontier research in high-energy physics.

In 1960, two high-energy physics laboratories were competing for scientific discoveries. The first was Brookhaven National Laboratory on Long Island in New York, US, with its 33 GeV Alternating Gradient Synchrotron (AGS). The second was CERN in Switzerland, with its 28 GeV Proton Synchrotron (PS). That year, the US Atomic Energy Commission (AEC) received several proposals to boost the country's research programme focusing on the construction of new accelerators with energies between 100–1000 GeV. A joint panel of president Kennedy's Presidential Science Advisory Committee and the AEC's General Advisory Committee was formed to consider

the submissions, chaired by Harvard physicist and Manhattan Project veteran Norman Ramsey. By May 1963, the panel had decided to have Ernest Lawrence's Radiation Laboratory in Berkeley, California, design a several-hundred GeV accelerator. The result was a 200 GeV synchrotron costing approximately \$340 million.

When Cornell physicist Robert Rathbun Wilson, a student of Lawrence's who also worked on the Manhattan Project, saw Berkeley's plans he considered them too conservative, unimaginative and too expensive. Wilson, being a modest yet proud man, thought he could design a better accelerator for less money and let his thoughts be known. By September 1965, Wilson had proposed an alternative, innovative, less costly (approximately \$250 million) design for the 200 GeV accelerator to the AEC. The Joint Committee on Atomic Energy, the congressional body responsible for AEC projects and budgets, approved of his plan.

During this period, coinciding with the Vietnam war, the US Congress hoped to contain costs. Yet physicists hoped to make breakthrough discoveries, and thought it important to appeal to national interests. The discovery of the Ω^- particle at Brookhaven

in 1964 led high-energy physicists to conclude that "an accelerator 'in the range of 200–1000 BeV' would 'certainly be crucial' in exploring the 'detailed dynamics of this strong SU(3) symmetrical interaction'." Simultaneously, physicists were expressing frustration with the geographic situation of US high-energy physics facilities. East and West Coast laboratories like Lawrence Berkeley Laboratory and Brookhaven did not offer sufficient opportunity for the nation's experimental physicists to pursue their research.

Physicists were expressing frustration with the geographic situation of US high-energy physics facilities.

Managed by regional boards, the programmes at these two labs were directed by and accessible to physicists from nearby universities. Without substantial federal support, other major research universities struggled to compete with these regional laboratories.

Against this backdrop arose a major movement to accommodate physicists in the centre of the country and offer more equal access. Columbia University experimental physicist Leon Lederman championed "the truly national laboratory" that would allow any qualifying proposal to be conducted at a national, rather than a regional, facility. In 1965, a consortium of major US research universities, Universities Research Association (URA), Inc., was established to manage and operate the 200 GeV accelerator laboratory for the AEC (and its successor agencies the Energy Research and Development Administration (ERDA) and the Department of Energy (DOE)) and address the need for a more national laboratory. Ramsey was president of URA for most of the period 1966 to 1981.

Following a nationwide competition organised by the National Academy of Sciences, in December 1966 a 6800 acre site in Weston, Illinois, around 50 km west of Chicago, was selected. Another suburban Chicago site, north of Weston in affluent South Barrington, had withdrawn when local residents "feared that the influx of physicists would 'disturb the moral fibre of their community'". Robert Wilson was selected to direct the new 200 GeV accelerator, named \triangleright

History

History



Ground-breaking for the 200 GeV Synchrotron/Main Ring at the National Accelerator Laboratory in October 1969.



Deputy director Edwin Goldwasser (left) and director Robert Wilson at the controls of the Main Ring in 1972.

the National Accelerator Laboratory (NAL). Wilson asked Edwin Goldwasser, an experimental physicist from the University of Illinois, Urbana-Champaign, and member of Ramsey's panel, to be his deputy director and the pair set up temporary offices in Oak Brook, Illinois, on 15 June 1967. They began to recruit physicists from around the country to staff the new facility and design the 200 GeV accelerator, also attracting personnel from Chicago and its suburbs. President Lyndon Johnson signed the bill authorising funding for the National Accelerator Laboratory on 21 November 1967.

Chicago calling

It wasn't easy to recruit scientific staff to the new laboratory in open cornfields and farmland with few cultural amenities. That picture lies in stark contrast to today, with the lab encircled by suburban sprawl encouraged by highway construction and development of a high-tech corridor with neighbours including Bell Labs/AT&T and Amoco. Wilson encouraged people to join him in his challenge, promising higher energy and more experimental capability than originally planned. He and his wife, Jane, imbued the new laboratory with enthusiasm and hospitality, just as they had experienced in the isolated setting of wartime-era Los Alamos while Wilson carried out his work on the Manhattan Project.

Wilson and Goldwasser worked on the social conscience of the laboratory and in March 1968, a time of racial unrest in the US, they released a policy statement on human rights. They intended to: "seek the achievement of its scientific goals within a framework of equal employment opportunity and of a deep dedication to the fundamental tenets of human rights and dignity... The formation of the Laboratory shall be a positive force... toward open housing... [and] make a real contribution toward

providing employment opportunities for minority groups... Special opportunity must be provided to the educationally deprived... to exploit their inherent potential to contribute to and to benefit from the development of our Laboratory. Prejudice has no place in the pursuit of knowledge... It is essential that the Laboratory provide an environment in which both its staff and its visitors can live and work with pride and dignity. In any conflict between technical expediency and human rights we shall stand firmly on the side of human rights. This stand is taken because of, rather than in spite of, a dedication to science." Wilson and Goldwasser brought inner-city youth out to the suburbs for employment, training them for many technical jobs. Congress supported this effort and was pleased to recognise it during the civil-rights movement of the late 1960s. Its affirmative spirit endures today.

When asked by a congressional committee authorising funding for NAL in April 1969 about the value of the research to be conducted at NAL, and if it would contribute to national defence, Wilson famously answered: "It has only to do with the respect with which we regard one another, the dignity of men, our love of culture... It has to do with, are we good painters, good sculptors, great poets? I mean all the things we really venerate and honour in our country and are patriotic about. It has nothing to do directly with defending our country except to help make it worth defending."

A harmonious whole

Wilson, who had promised to complete his project on time and under budget, perceived of the new laboratory as a beautiful, harmonious whole. He felt that science, technology, and art are importantly connected, and brought a graphic artist, Angela Gonzales, with him from Cornell to give the laboratory site and its publications a distinctive aesthetic. He had his engineers work with a Berkeley colleague, William Brobeck, and an architectural-engineering group, DUSAF, to make designs and cost estimates for early submissions to the AEC, in time for their submissions to the congressional committees that controlled NAL's budget. Wilson appreciated frugality and minimal design, but also tried to leave room for improvements and innovation. He thought design should



The interior of the Main Ring, 1973.

be ongoing, with changes implemented as they are demonstrated, before they became conservative.

There were many decisions to be made in creating the laboratory Wilson envisioned. Many had to be modified, but this was part of his approach: "I came to understand that a poor decision was usually better than no decision at all, for if a necessary decision was not made, then the whole effort would just wallow – and, after all, a bad decision could be corrected later on," he wrote in 1987. An example was the magnets in the Main Ring, the first name of the 200 GeV synchrotron accelerator, which had to be redesigned as did the plans for the layout of the experimental areas. Even the design of the distinctive Central Laboratory building, constructed after the accelerator achieved its design energy and renamed Robert Rathbun Wilson Hall in 1980, had to have certain adjustments from its initial concepts. Wilson said that "a building does not have to be ugly to be inexpensive" and he orchestrated a competition among his selected architects to create the final design of this visually striking structure. To save money he set up competitions between contractors so that the fastest to finish a satisfactory project were rewarded with more jobs. Consequently, the Main Ring was completed on time by 30 March 1972 and under the \$250 million budget. NAL was dedicated and renamed Fermilab on 11 May 1974.

International attraction

Experimentalists from Europe and Asia flocked to propose research at the new frontier facility in the US, forging larger collaborations with American colleagues. Its forefront position and philosophy attracted the top physicists of the world, with Russian physicists making news working on the first approved experiment at Fermilab in the height of the Cold War. Congress was pleased and the scientists were overjoyed with more experimental areas than originally planned and with higher energy, as the magnets were improved to attain 400 GeV and 500 GeV within two years. The higher energy in a fixed-target accelerator complex allowed more innovative experiments, in particular enabling the discovery of the bottom quark in 1977 (see p35).



(Top to bottom) The dedication of Fermilab, 11 May 1974. The interior of the energy doubler/saver with a ring of superconducting magnets underneath the original Main Ring, 1983. Incoming and outgoing directors John Peoples (left) and Leon Lederman, respectively, in April 1989.

History



(Top left) Aerial view of Weston, the Illinois site for the National Accelerator Laboratory, in 1966. (Bottom left) Aerial view of Fermilab showing fixed-target areas (foreground), the Main Ring accelerator (top) and Wilson Hall (top, right) in 1977. (Above) Aerial view of the Tevatron complex in 2003.

Fermilab's early intellectual environment was influenced by theoretical physicists Robert Serber, Sam Trieman, J D Jackson and Ben Lee, who later brought Chris Quigg and Bill Bardeen, who in turn invited many distinguished visitors to add to the creative milieu of the laboratory. Already on Wilson's mind was a colliding-beams accelerator he called an "energy doubler", which would employ superconductivity, and he had established working groups to study the idea. But Wilson encountered budget conflicts with the AEC's successor, the new Department of Energy, which led to his resignation in 1978. He joined the faculties of the University of Chicago and Columbia University briefly before returning to Cornell in 1982.

Fermilab's future was destined to move forward with Wilson's ideas of superconducting-magnet technology, and a new director was sought. Lederman, who was spokesperson of the Fermilab study that discovered the bottom quark, accepted the position in late 1978 and immediately set out to win support for Wilson's energy doubler. An accomplished scientific spokesman, Lederman achieved the necessary funding by 1979 and promoted the energy-enhancing idea of introducing an antiproton source to the accelerator complex to enable proton-antiproton collisions. Experts from Brookhaven and CERN, as well as the former USSR, shared ideas with Fermilab physicists to bring superconducting-magnet technology to fruition at Fermilab. Under the leadership of Helen Edwards, Richard Lundy, Rich Orr and Alvin Tollestrup, the Main Ring evolved into the energy doubler/saver in 1983 with a new ring of superconducting magnets installed below the early Main Ring magnets. This led to a trailblazing era during which Fermilab's accelerator complex, now called the Tevatron, would lead the world in high-energy physics experiments. By 1985 the Tevatron had achieved 800 GeV in fixed-

target experiments and 1.6 TeV in colliding-beam experiments, and by the time of its closure in 2011 it had reached 1.96 TeV in the centre of mass – just shy of its original goal of 2 TeV.

Theory also thrived at Fermilab in this period. Lederman had brought James Bjorken to Fermilab's theoretical physics group in 1980 and a theoretical astrophysics group founded by Rocky Kolb and Michael Turner was added to Fermilab's research division in 1983 to address research at the intersection of particle physics and cosmology. Lederman also expanded the laboratory's mission to include science education, offering programmes to local high-school students and teachers, and in 1980 opened the first children's centre for employees of any DOE facility. He founded the Illinois Mathematics and Science Academy in 1985 and the Chicago Teachers Academy for Mathematics and Science in 1990, and the Lederman Science Education Center on the Fermilab site is named after him. Lederman also reached out to many regions including Latin America and partnered with businesses to support the lab's research and encourage technology transfer. The latter included Wilson's early Fermilab initiative of neutron therapy for certain cancers, which later would see Fermilab build the 70–250 MeV proton synchrotron for the Loma Linda Medical Center in California.

Scientifically, the target in this period was the top quark. Fermilab and CERN had planned for a decade to detect the elusive top, with Fermilab deploying two large international experimental teams at the Tevatron – CDF (founded by Tollestrup) and DZero (founded by Paul Grannis) – from 1976 to 1995. In 1988 Lederman shared the Nobel prize for the discovery of the muon neutrino at Brookhaven 25 years previously, and in 1989 he stepped down as Fermilab director and joined the faculty of the University

of Chicago and later the Illinois Institute of Technology.

Lederman was succeeded by John Peoples, a machine builder and Fermilab experimentalist since 1970, and leader of the Fermilab antiproton source from 1981 to 1985. Peoples had his hands full not only with Fermilab and its research programme but also with the Superconducting Super Collider (SSC) laboratory in Texas. In 1993 the SSC was cancelled and Peoples was asked by the DOE to close down the project and its many contracts. The only person to direct two national laboratories at the same time, Peoples successfully managed both tasks and returned to Fermilab to see the discovery of the top quark in 1995. He had also launched the luminosity-enhancing upgrade to the Tevatron, the Main Injector, in 1999. Peoples stepped down as laboratory director that summer and became director of the Sloan Digital Sky Survey (SDSS) – Fermilab's first astrophysics experiment. He later directed the Dark Energy Survey and in 2010 he retired, continuing to serve as director emeritus of the laboratory.

Intense future

In 1999, experimentalist and former Fermilab user Michael Witherell of the University of California at Santa Barbara became Fermilab's fourth director. Ongoing fixed-target and colliding-beam experiments continued under Witherell, as did the SDSS and the Pierre Auger cosmic ray experiments, and the neutrino programme with the Main Injector. Mirroring the spirit of US-European competition of the 1960s, this period saw CERN begin construction of the Large Hadron Collider (LHC) to search for the Higgs boson at a lower energy than the cancelled SSC. Accordingly, the luminosity of the Tevatron became a priority, as did discussions about a possible future international linear collider. After launching the Neutrinos at the Main Injector (NuMI) research programme, including sending the underground particle beam off-site to the MINOS detector in Minnesota, Witherell returned to Santa Barbara in 2005 and in 2016 he became director of the Lawrence Berkeley Laboratory.

Physicist Piermaria Oddone from Lawrence Berkeley Laboratory became Fermilab's fifth director in 2005. He pursued the renewal of the Tevatron in order to exploit the intensity frontier and explore new physics with a plan called "Project X", part of the "Proton Improvement Plan". Yet the last decade has been a challenging time for Fermilab, with budget cuts, reductions in staff and a redefinition of its mission. The CDF and DZero collaborations continued their search for the Higgs boson, narrowing the region where it could exist, but the more energetic LHC always had the upper hand. In the aftermath of the global economic crisis of 2008, as the LHC approached switch-on, Oddone oversaw the shutdown of the Tevatron in 2011. A Remote Operations Center in Wilson Hall and a special US Observer agreement allowed Fermilab

physicists to co-operate with CERN on LHC research and participate in the CMS experiment. The Higgs boson was duly discovered at CERN in 2012 and Oddone retired the following year.

Under its sixth director, former Fermilab user and director of TRIUMF laboratory in Vancouver, Nigel Lockyer, Fermilab now looks ahead to shine once more through continued exploration of the intensity frontier and understanding the properties of neutrinos. In the next few years, Fermilab's Long-Baseline Neutrino Facility (LBNF) will send neutrinos to the underground DUNE experiment 1300 km away in South Dakota, prototype detectors for which are currently being built at CERN. Meanwhile, Fermilab's Short-Baseline Neutrino programme has just taken delivery of the 760 tonne cryostat for its ICARUS experiment after its recent refurbishment at CERN (see p25), while a major experiment called Muon g-2 is about to take its first results. This suite of experiments, with co-operation with CERN and other international labs, puts Fermilab at the leading edge of the intensity frontier and continues Wilson's dreams of exploration and discovery.

Further reading

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Résumé

La fondation du Fermilab

Il y a cinquante ans, des physiciens ont créé aux États-Unis un nouveau laboratoire, et dans la foulée une nouvelle manière de mener des recherches de pointe en physique des hautes énergies. Appelé initialement National Accelerator Laboratory et rebaptisé Fermilab quelques années plus tard, le laboratoire a eu comme première grande installation un accélérateur de 200 GeV, lequel a ouvert la voie au collisionneur Tevatron et aux grandes découvertes telles que celle du quark t. Aujourd'hui, le Fermilab se consacre principalement aux études à la frontière des hautes intensités et à la compréhension des propriétés des neutrinos, perpétuant ainsi les rêves d'exploration et de découverte de son premier directeur, Robert Wilson.

Adrienne Kolb, Fermilab archivist-historian 1983 to 2015.



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Remote handling for hostile environments

Oxford Technologies is a world-leading developer of remote-handling systems, providing innovative solutions in sectors including high-energy physics, nuclear fusion and nuclear decommissioning.

Leading-edge capabilities

The company, now part of Veolia Nuclear Solutions, was formed in 2000 as a high-technology spin-off from EFDA/JET, where the company's team of specialist engineers was responsible for delivering the world's first remote-handling operation inside a nuclear fusion reactor.

Typically, remote-handling projects combine many diverse leading-edge engineering technologies, including vision and image processing, human-machine interfacing and virtual and augmented reality and simulation, together with mechanical, mechatronic, electronic and electrical engineering – all of which skills and capabilities are brought together by Oxford Technologies and their growing team of engineers.

Global reach

With extensive expertise in the development of remote-handling solutions from conceptualisation through to implementation and operation, the company provides clients with services ranging from feasibility assessments and short-term peer reviews up to and including the supply and installation of fully operational remote-handling facilities – with projects varying from the provision of small hand tools up to large-capacity manipulators operating in super-hostile environments.

The international nature of many of its projects has meant that Oxford Technologies has developed into an organisation that is truly global in its outlook and philosophy. Because technology and science at this level cross national boundaries, neither the geographic location nor the multinational nature of customers and their engineering



Control Room at Oxford Technologies



Prototype robotic arm developed as part of the remote handling solution for nuclear waste retrieval from the Dounreay Shaft

teams pose a barrier to Oxford Technologies, which, in addition to working in the UK and France, has also participated in commissions in Belgium, Spain, Italy, Finland, Germany Switzerland and the Netherlands.

Poised for future growth

As Global Access Marketing & Business Development Director, Stephen Sanders, explains: "Oxford Technologies is strategically positioned to meet the rapidly increasing demand for remote-handling solutions, which is being driven by the growth of commercial and

academic engineering projects in hostile environments, from CERN to deep-sea mining and space exploration."

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Tackling engineering challenges at ITER

Oxford Technologies is currently working on one of the many detailed engineering challenges that will turn the science of fusion energy into engineering reality: developing a compliant wrench to tighten and loosen the bolts, which hold the blanket modules that shield the walls of the tokamak.

The 440 blanket modules covering the inner walls of the vessel protect the structure from the heat flux generated by the plasma. Each 1 m² module weighs 3.5 tonnes and consists of a detachable, plasma-facing panel and a shield block, which forms the structure of the blanket module and houses the cooling water channels.

Due to the complex geometry of the interior face of the vessel, the exact alignment of the holding bolts will vary on each panel and the wrench must therefore be able not only to locate, engage and tighten/loosen the bolts, but also to cope with vertical, lateral and angular misalignments.

The engineering challenge has been to create a test rig to test two types of wrench design that can overcome the anticipated misalignments while continuing to function effectively.

Because the blanket will be installed in what may be one of the most hazardous environments on Earth, the tools to remove and replace damaged blankets need to be operated using remote-handling technology – Oxford Technologies' core expertise.

Search for sterile neutrinos triples up



The cryostat for the ICARUS detector, one of three detectors that will make up Fermilab's short-baseline neutrino programme, being moved between buildings at CERN in late 2016 as part of its refurbishment programme, before being shipped to the US this summer.

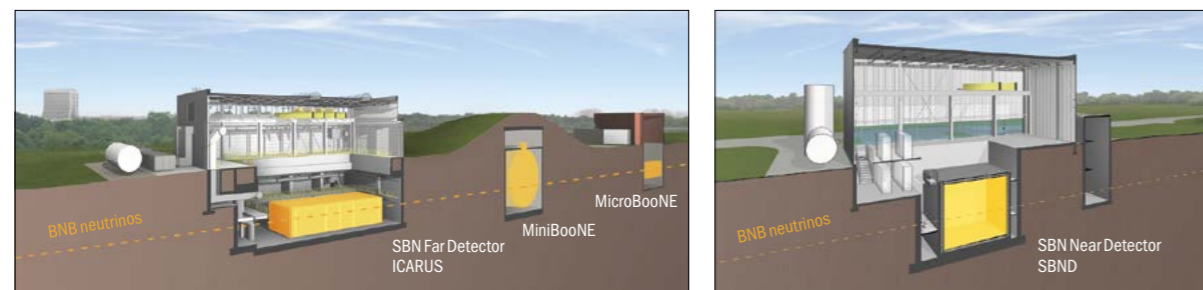
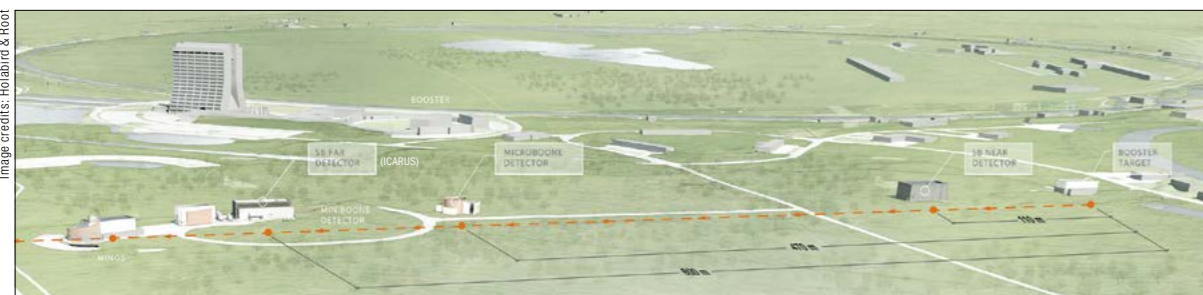
Fermilab's short-baseline neutrino programme sites three detectors in a single high-intensity neutrino beam to address the possible existence of eV-scale sterile neutrinos.

This summer, two 270 m³ steel containment vessels are making their way by land, sea and river from CERN in Europe to Fermilab in the US, a journey that will take five weeks. Each vessel houses one of the 27,000-channel precision wire chambers of the ICARUS detector, which uses advanced liquid-argon technology to detect neutrinos. Having already operated successfully in the CERN to Gran Sasso neutrino beam from 2010 to 2012, and spent the past two years being refurbished at CERN, ICARUS will team up with two similar detectors at Fermilab to deliver a new physics opportunity: the ability to resolve some intriguing experimental anomalies

lies in neutrino physics and perform the most sensitive search to date for eV-scale sterile neutrinos. This new endeavour, comprised of three large liquid-argon detectors (SBND, MicroBooNE and ICARUS) sitting in a single intense neutrino beam at Fermilab, is known as the Short-Baseline Neutrino (SBN) programme.

The sterile neutrino is a hypothetical particle, originally introduced by Bruno Pontecorvo in 1967, which doesn't experience any of the known forces of the Standard Model. Sterile-neutrino states, if they exist, are not directly observable since they don't interact with ordinary matter, but the phenomenon of neutrino oscillations provides us with a powerful probe of physics beyond the Standard Model. Active-sterile mixing, just like standard three-neutrino mixing, could generate additional oscillations among the standard neutrino flavours but at wavelengths that are distinct from the now well-measured "solar" and "atmospheric" oscillation effects. Anomalies exist in the data of past neutrino experiments that present intriguing hints of possible new physics. We now require precise follow-up experiments to either confirm or rule out the existence of additional, sterile-neutrino states.

Fermilab neutrino programme



An aerial view depicting the layout of the SBN programme beamline (top), and detectors at the Fermilab site.

On the scent of sterile states

The discovery nearly two decades ago of neutrino-flavour oscillations led to the realisation that each of the familiar flavours (ν_e, ν_μ, ν_τ) is actually a linear superposition of states of distinct masses (ν_1, ν_2, ν_3). The wavelength of an oscillation is determined by the difference in the squared masses of the participating mass states, $m_1^2 - m_2^2$. The discoveries that were awarded the 2015 Nobel Prize in Physics correspond to the atmospheric mass-splitting $\Delta m_{ATM}^2 = m_3^2 - m_2^2 = 2.5 \times 10^{-3} \text{ eV}^2$ and the solar mass-splitting $\Delta m_{SOLAR}^2 = m_2^2 - m_1^2 = 7.5 \times 10^{-5} \text{ eV}^2$, so-named because of how they were first observed. Any additional and mostly sterile mass states, therefore, could generate a unique oscillation driven by a new mass scale in the neutrino sector: $m_{\text{mostly sterile}}^2 - m_{\text{mostly active}}^2$.

The most significant experimental hint of new physics comes from the LSND experiment performed at the Los Alamos National Laboratory in the 1990s, which observed a 3.8σ excess of electron antineutrinos appearing in a mostly muon antineutrino beam in a region where standard mixing would predict no significant effect. Later, in the 2000s, the MiniBooNE experiment at Fermilab found excesses of both electron neutrinos and electron antineutrinos, although there is some tension with the original LSND observation. Other hints come from the apparent anomalous disappearance of electron antineutrinos over baselines less than a few hundred metres at nuclear-power reactors (the “reactor anomaly”), and the lower than expected rate in radioactive-source calibration data from the gallium-based solar-neutrino experiments GALLEX and SAGE (the “gallium anomaly”). Numerous other searches in appearance and disappearance channels have been conducted at various neutrino experiments with null results (including ICARUS when it operated in the CERN to Gran Sasso beam), and these have thus constrained the parameter space where light sterile neutrinos could still be hiding. A global analysis of the available data

now limits the possible sterile-active mass-splitting, $m_{\text{mostly sterile}}^2 - m_{\text{mostly active}}^2$ to a small region around $1-2 \text{ eV}^2$.

Long-baseline accelerator-based neutrino experiments such as NOvA at Fermilab, T2K in Japan, and the future Deep Underground Neutrino Experiment (DUNE) in the US, which will involve detectors located 1300 km from the source, are tuned to observe oscillations related to the atmospheric mass-splitting, $\Delta m_{ATM}^2 \sim 10^{-3} \text{ eV}^2$. Since the mass-squared difference between the participating states and the length scale of the oscillation they generate are inversely proportional to one another, a short-baseline accelerator experiment such as SBN, with detector distances of the order 1 km, is most sensitive to an oscillation generated by a mass-squared difference of order 1 eV^2 – exactly the region we want to search.

Three detectors, one beam

The SBN programme has been designed to definitively address this question of short-baseline neutrino oscillations and test the existence of light sterile neutrinos with unprecedented sensitivity. The key to SBN’s reach is the deployment of multiple high-precision neutrino detectors, all of the same technology, at different distances along a single high-intensity neutrino beam. Use of an accelerator-based neutrino source has the bonus that

SBN was conceived to unravel the physics of light sterile neutrinos.

both electron-neutrino appearance and muon-neutrino disappearance oscillation channels can be investigated simultaneously.

The neutrino source is Fermilab’s Booster Neutrino Beam (BNB), which has been operating at high rates since 2002 and providing beam

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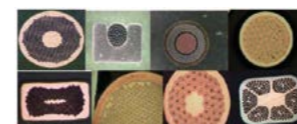
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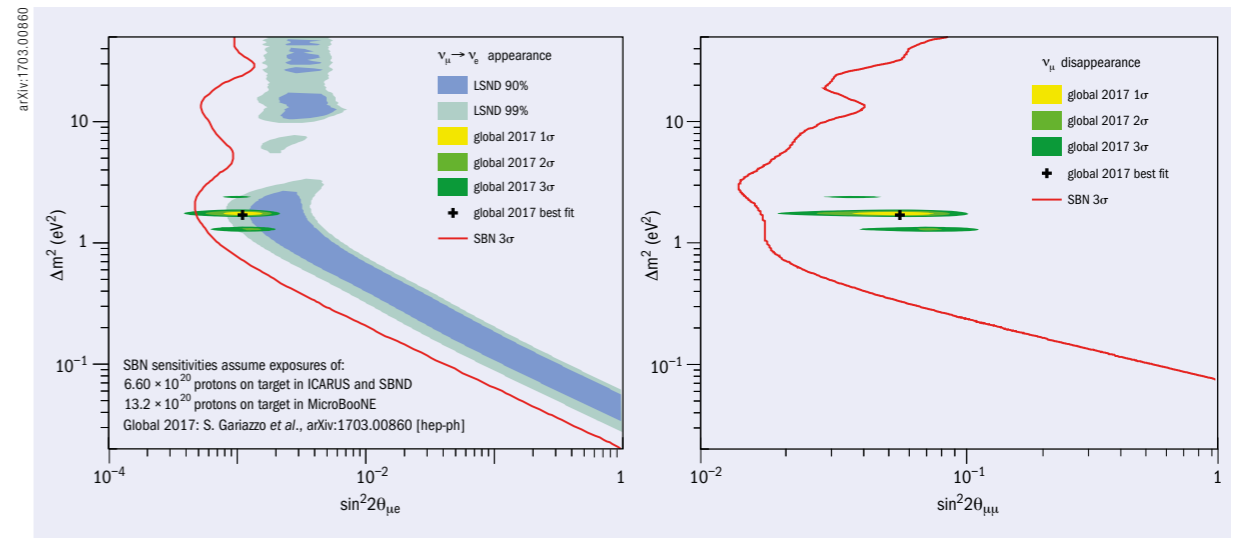
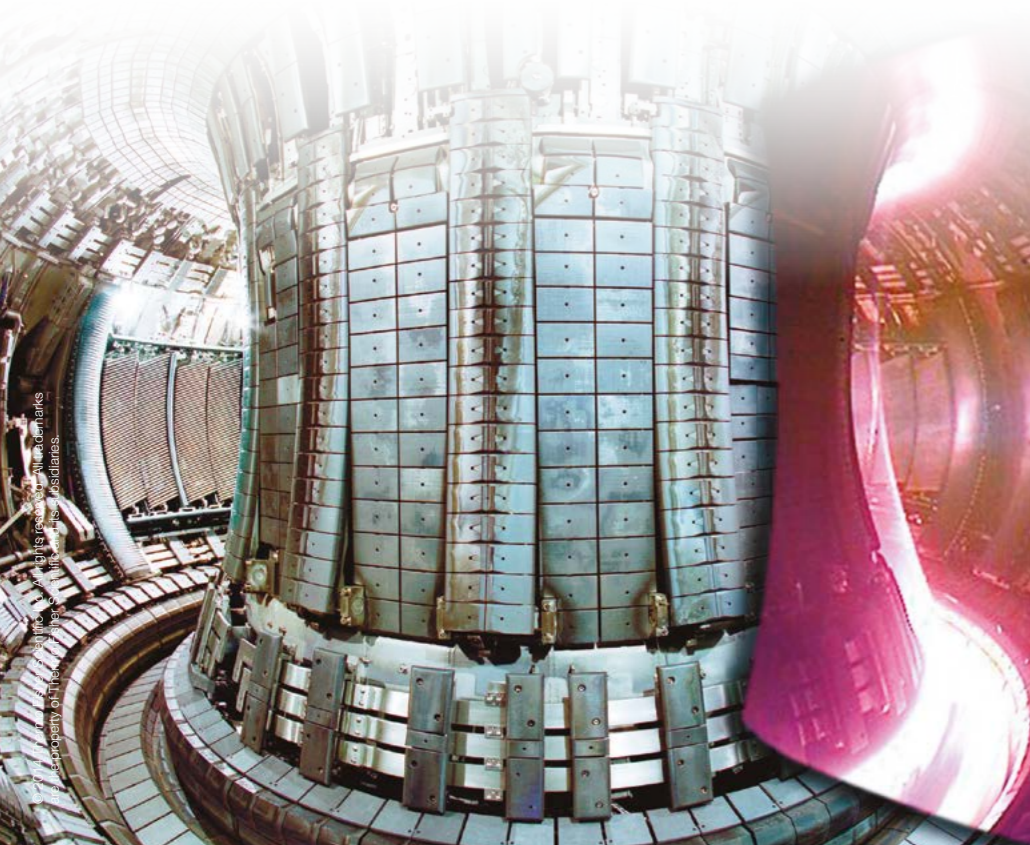


Fig. 1. The sensitivity of the SBN programme to electron-neutrino appearance (left) and muon-neutrino disappearance (right) compared to the allowed oscillation parameter regions coming from a recent global analysis of sterile-neutrino search data. For ν_e appearance, the parameter values allowed by the original LSND data on its own are also shown for comparison.

to multiple experiments. The BNB is generated by impinging 8 GeV protons from the Booster onto a beryllium target and magnetically focusing the resulting hadrons, which decay to produce a broad-energy neutrino beam peaked around 700 MeV that is made up of roughly 99.5% muon neutrinos and 0.5% electron neutrinos.

The three SBN detectors are each liquid-argon time projection chambers (LArTPCs) located along the BNB neutrino path (see images on p26). MicroBooNE, an 87 tonne active-mass LArTPC, is located 470 m from the neutrino production target and has been collecting data since October 2015. The Short-Baseline Near Detector (SBND), a 112 tonne active-mass LArTPC to be sited 110 m from the target, is currently under construction and will provide the high-statistics characterisation of the un-oscillated BNB neutrino fluxes that is needed to control systematic uncertainties in searches for oscillations at the downstream locations. Finally, ICARUS, with 476 tonnes of active mass and located 600 m from the BNB target, will achieve a sufficient event rate at the downstream location where a potential oscillation signal may be present. Many of the upgrades to ICARUS implemented during its time at CERN over the past few years are in response to unique challenges presented by operating a LArTPC detector near the surface, as opposed to the underground Gran Sasso laboratory where it operated previously. The SBN programme is being realised by a large international collaboration of researchers with major detector contributions from CERN, the Italian INFN, Swiss NSF, UK STFC, and US DOE and NSF. At Fermilab, new experimental halls to house the ICARUS and SBND detectors were constructed in 2016 and are now awaiting the LArTPCs. ICARUS and SBND are expected to begin operation in 2018 and 2019, respectively, with approximately three years of ICARUS data needed to reach the programme's design sensitivity.

A rich physics programme

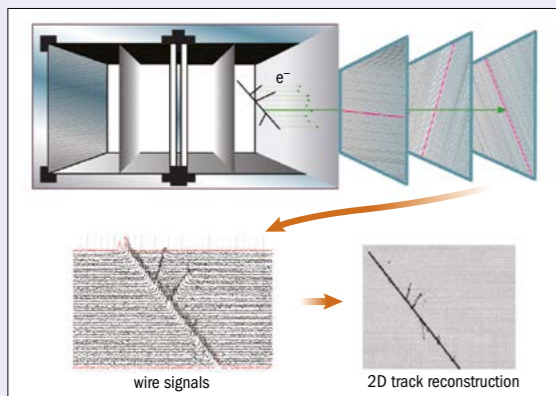
In a combined analysis, the three SBN detectors allow for the cancellation of common systematics and can therefore test the $\nu_\mu \rightarrow \nu_e$ oscillation hypothesis at a level of 5σ or better over the full range of parameter space originally allowed at 99% C.L. by the LSND data. Recent measurements, especially from the NEOS, IceCube and MINOS experiments, have constrained the possible sterile-neutrino parameters significantly and the sensitivity of the SBN programme is highest near the most favoured values of Δm^2 . In addition to ν_e appearance, SBN also has the sensitivity to ν_μ disappearance needed to confirm an oscillation interpretation of any observed appearance signal, thus providing a more robust result on sterile-neutrino-induced oscillations (figure 1).

SBN was conceived to unravel the physics of light sterile neutrinos, but the scientific reach of the programme is broader than just the searches for short-baseline neutrino oscillations. The SBN detectors will record millions of neutrino interactions that can be used to make precise measurements of neutrino-argon interaction cross-sections and perform detailed studies of the rather complicated physics involved when neutrinos scatter off a large nucleus such as argon. The SBND detector, for example, will see of the order 100,000 muon-neutrino interactions and 1000 electron-neutrino interactions per month. For comparison, existing muon-neutrino measurements of these interactions are based on only a few thousand total events and there are no measurements at all with electron neutrinos. The position of the ICARUS detector also allows it to see interactions from two neutrino beams running concurrently at Fermilab (the Booster and Main Injector neutrino beams), allowing for a large-statistics measurement of muon and electron neutrinos in a higher-energy regime that is important for future experiments.

In fact, the science programme of SBN has several important connections to the future long-baseline neutrino experiment ▷

Fermilab neutrino programme

LArTPCs rule the neutrino-oscillation waves



A schematic diagram of the ICARUS liquid-argon time projection chamber (LArTPC) detector, where electrons create signals on three rotated wire planes. The concept of the LArTPC for neutrino detection was first conceived by Carlo Rubbia in 1977, followed by many years of pioneering R&D activity and the successful operation of the ICARUS detector in the CNGS beam from 2010 to 2012, which demonstrated the effectiveness of single-phase LArTPC technology for neutrino physics. A LArTPC provides both precise calorimetric sampling and 3D tracking similar to the extraordinary imaging features of a bubble chamber, and is also fully electronic and therefore potentially scalable to large, several-kilotonne masses. Charged particles propagating in the liquid argon ionise argon atoms and free electrons drift under the influence of a strong, uniform electric field applied across the detector volume. The drifted ionisation electrons induce signals or are collected on planes of closely spaced sense wires located on one side of the detector boundary, with the wire signals proportional to the amount of energy deposited in a small cell. The very low electron drift speeds, in the range of 1.6 mm/μs, require a continuous read-out time of 1–2 milliseconds for a detector a few metres across. This creates a challenge when operating these detectors at the surface, as the SBN detectors will be at Fermilab, so photon-detection systems will be used to collect fast scintillation light and time each event.

Closing in on a resolution

The hunt for light sterile neutrinos has continued for several decades now, and global analyses are regularly updated with new results. The original LSND data still contain the most significant signal, but the resolution on Δm^2 was poor and so the range of values allowed at 99% C.L. spans more than three orders of magnitude. Today, only a small region of mass-squared values remain compatible with all of the available data, and a new generation of improved experiments, including the SBN programme, are under way or have been proposed that can rule on sterile-neutrino oscillations in exactly this region.

There is currently a lot of activity in the sterile-neutrino area. The nuPRISM and JSNS² proposals in Japan could also test for $\nu_\mu \rightarrow \nu_e$ appearance, while new proposals like the KPipe experiment, also in Japan, can contribute to the search for ν_μ disappearance. The MINOS+ and IceCube detectors, both of which have already set strong limits on ν_μ disappearance, still have additional data to analyse. A suite of experiments is already currently under way (NEOS, DANSS, Neutrino-4) or in the planning stages (PROSPECT, SoLid, STEREO) to test for electron-antineutrino disappearance over short baselines at reactors, and others are being planned that will use powerful radioactive sources (CeSOX, BEST). These electron-neutrino and -antineutrino disappearance searches are highly complementary to the search modes being explored at SBN.

The Fermilab SBN programme offers world-leading sensitivity to oscillations in two different search modes at the most relevant mass-splitting scale as indicated by previous data. We will soon have critical new information regarding the possible existence of eV-scale sterile neutrinos, resulting in either one of the most exciting discoveries across particle physics in recent years or the welcome resolution of a long-standing unresolved puzzle in neutrino physics.

Further reading

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Résumé

La quête des neutrinos stériles s'intensifie

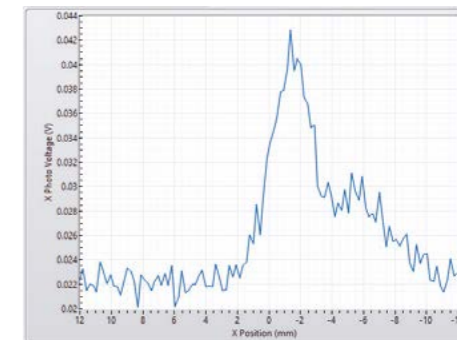
Le programme neutrino courte distance du Fermilab dispose de trois détecteurs (SBND, ICARUS et MicroBooNE) situés sur la trajectoire d'un faisceau de neutrinos de haute intensité. Il vise à comprendre certaines anomalies intrigantes issues des expériences en physique des neutrinos et à traquer à l'échelle des eV, une sensibilité inédite, les neutrinos stériles – des particules hypothétiques n'interagissant pas via les forces du Modèle standard. Le détecteur ICARUS, déjà utilisé avec le faisceau de neutrinos CERN-Gran Sasso, a été envoyé au Fermilab en mai après sa rénovation au CERN. Les physiciens disposeront donc bientôt de nouvelles informations cruciales pour s'attaquer à certains grands mystères de la physique des neutrinos.

David Schmitz, University of Chicago, US, and **Matt Bass**, University of Oxford, UK.

at Fermilab, DUNE. DUNE will deploy multiple 10 kt LArTPCs 1.5 km underground in South Dakota, 1300 km from Fermilab. The three detectors of SBN present an R&D platform for advancing this exciting technology and are providing direct experimental activity for the global DUNE community. In addition, the challenging multi-detector oscillation analyses at SBN will be an excellent proving ground for sophisticated event reconstruction and data-analysis techniques designed to maximally exploit the excellent tracking and calorimetric capabilities of the LArTPC. From the physics point of view, discovering or excluding sterile neutrinos plays an important role in the ability of DUNE to untangle the effects of charge-parity violation in neutrino oscillations, a primary physics goal of the experiment. Also, precise studies of neutrino-argon cross-sections at SBN will help control one of the largest sources of systematic uncertainties facing long-baseline oscillation measurements.

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UniBEaM is a new non-disruptive particle beam profiling system using optical sensor fibers rather than traditional wires. It is used to measure the beam intensity profile of charged particles with kinetic energies from keV to GeV and sensitive to beam currents from pA to mA.

Software displays the beam intensity distribution in the horizontal and vertical planes, and calculates the beam location and integrated profile area, which correlates well with total beam current.



UniBEaM Profile with 200 micron Ce³⁺ doped quartz fiber, on AEC-LHEP's IBA Cyclotron cyclotron. Beam: H⁺, 18 MeV, 62 pA. Priced to compete with conventional wire scanners.

A selection of Fermilab's greatest hits

1967
National Accelerator Laboratory (NAL) approved

1972
Main Ring achieves 200 GeV design energy



High-energy neutrino interactions observed (enabling technologies: neutrino beam creation; massive detectors)

1977
E288 discovers b quark (high-luminosity 400 GeV accelerator)
Neutron therapy used in cancer treatment (secondary neutron beams; use of medical radiology)

1981
Charm observed in hadronic production (high-energy proton beams; silicon-vertex detectors; and trigger processors)

1991
Fixed-target experiment detects b decays (emulsion targets; downstream particle detectors)

1990
Proton therapy demonstrated at Loma Linda University Medical Center (cyclotron design and extraction of proton beams)



1985
First proton-antiproton collisions in the Tevatron (lithium lenses; antiproton cooling techniques; low-beta focusing quadrupoles)

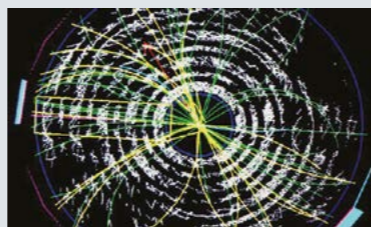
Measurement of the magnetic moments of strange hyperons (creation of charged and neutral hyperon beams)

CP violation in K decays (intense neutral kaon beams; precision electromagnetic calorimetry)

1983
Tevatron sets 512 GeV energy record (superconducting cable and magnet manufacture; world's largest cryogenic facilities)



1995
CDF and D0 discover top quark (scintillating-fibre and silicon-vertex detectors; Tevatron technology)



1996
US agrees to contribute to LHC accelerator and detectors

1998
Discovery and measurements of the B_s meson (first silicon-vertex detector in a hadron collider)
Sloan Digital Sky Survey sees first light (Fermilab built data acquisition and other systems)

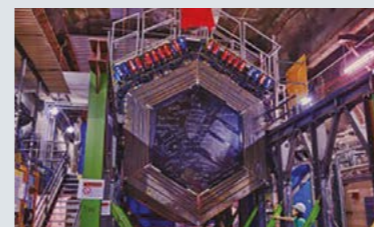


1999
Dedication of the Main Injector

2000
DONUT directly observes tau neutrino (emulsion-vertex detector; very short-baseline neutrino beam)



2010
MINERvA begins operations (fine-grained scintillator; short-baseline neutrino beam)



2009
Single-top production at Tevatron (multivariate techniques; computer farms)

2008
The LHC starts up at CERN (low-beta quadrupoles; detector expertise provided by Fermilab)

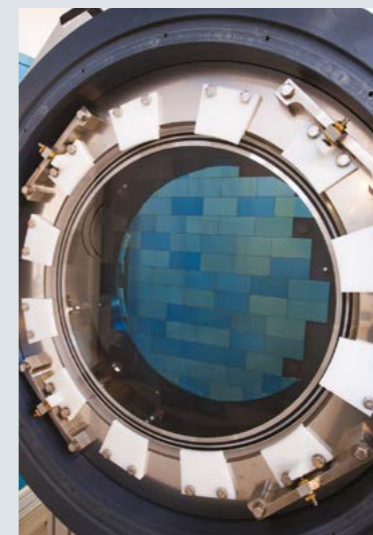
First dark-matter search with Chicagoland Observatory for Underground Particle Physics (bubble-chamber technology)

2007 CMS Remote Operations Center and LHC Physics Center at Fermilab dedicated



2006
Cryogenic Dark Matter Search sets new limits on dark matter (Fermilab provided detector technology and project management)
MINOS begins neutrino observations (long-baseline neutrino beam from Main Injector; near and far detectors)

2012
Dark Energy Survey begins (Fermilab led construction of DECam, the world's largest CCD camera for astrophysics)



Precise W and top-mass measurements by CDF and D0 (world's first permanent magnet accelerator; slip-stacking techniques; electron lens; antiproton recycler)

Fermilab shares in the LHC's discovery of the Higgs boson

2013
Magnet for Muon g-2 experiment arrives from Brookhaven



2017
ICARUS cryostat arrives from CERN (joining SBND and Micro-BooNE for the short-baseline neutrino programme)

Neutrino-beam power record of 700 W set by Main Injector

2016
South Pole Telescope launches improved CMB study (Fermilab responsible for detector cryostat)

2015
CERN and US sign co-operation agreement for the HL-LHC and neutrino programmes (powerful low-beta quadrupoles; large liquid-argon neutrino detectors)



MicroBooNE begins operations (large liquid-argon neutrino detectors)

2014
Mu2e experiment approved (superconducting solenoids operating within a strong radiation field)

NOvA experiment begins data-taking (powerful long-baseline neutrino beamline; liquid-scintillator detector)

US CMS upgrade programme approved (project management; technical infrastructure; and detector expertise)

Timeline representing a subset of Fermilab's milestones (a full list of Fermilab achievements can be found at 50.fnal.gov/timeline). All image credits: Fermilab.

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Revisiting the b revolution

June 2017 marks 40 years since a bump in fixed-target data at the E288 experiment led to Fermilab's first major discovery: the b quark.

Scientists summoned from all parts of Fermilab had gathered in the auditorium on the afternoon of 30 June 1977. Murmurs of speculation ran through the crowd about the reason for the hastily scheduled colloquium. In fact, word of a discovery had begun to leak out [long before the age of blogs], but no one had yet made an official announcement. Then, Steve Herb, a postdoc from Columbia University, stepped to the microphone and ended the speculation: Herb announced that scientists at Fermilab Experiment 288 had discovered the upsilon particle. A new generation of quarks was born. The upsilon had made its first and famous appearance at the Proton Center at Fermilab. The particle, a b quark and an anti-b quark bound together, meant that the collaboration had made Fermilab's first major discovery. Leon Lederman, spokesman for the original experiment, described the upsilon discovery as "one of the most expected surprises in particle physics".

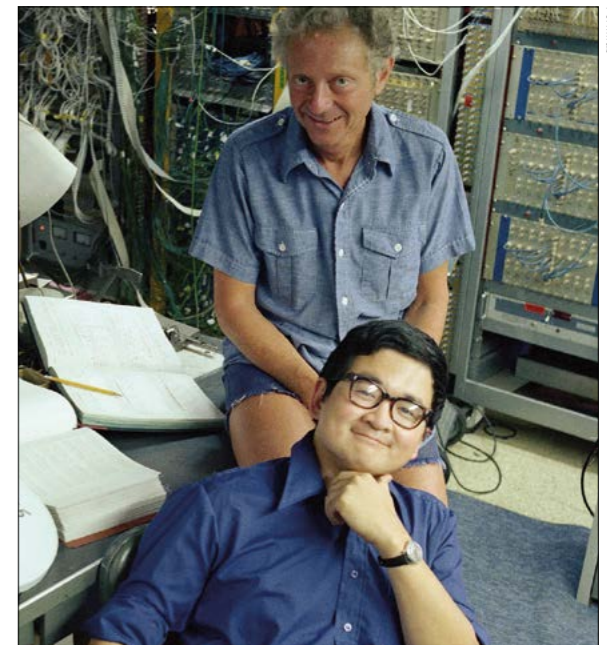
The story had begun in 1970, when the Standard Model of particle interactions was a much thinner version of its later form. Four leptons had been discovered, while only three quarks had been observed – up, down and strange. The charm quark had been predicted, but was yet to be discovered, and the top and bottom quarks were not much more than a jotting on a theorist's bedside table.

In June of that year, Lederman and a group of scientists proposed an experiment at Fermilab (then the National Accelerator Laboratory) to measure lepton production in a series of experimental phases that began with the study of single leptons emitted in proton collisions. This experiment, E70, laid the groundwork for what would become the collaboration that discovered the upsilon.

The original E70 detector design included a two-arm spectrometer [for the detection of lepton pairs, or di-leptons], but the group

After what Wilson jocularly refers to as "horsing around," the group tightened its goals in the spring of 1977.

first experimented with a single arm [searching for single leptons that could come, for example, from the decay of the W, which was still to be discovered]. E70 began running in March of 1973, pursuing direct lepton production. Fermilab director Robert Wilson asked for an update from the experiment, so the collaborators extended their ambitions, planned for the addition of the



John Yoh (front), experimental co-ordinator, and Leon Lederman, spokesman for the Fermilab experiment.

second spectrometer arm and submitted a new proposal, number 288, in February 1974 – a single-page, six-point paper in which the group promised to get results, "publish these and become famous". This two-arm experiment would be called E288.

The charm dimension

Meanwhile, experiments at Brookhaven National Laboratory and at the Stanford Linear Accelerator Center were searching for the charm quark. These two experiments led to what is known as the "November Revolution" in physics. In November of 1974, both groups announced they had found a new particle, which was later proven to be a bound state of the charm quark: the J/psi particle.

Some semblance of symmetry had returned to the Standard Model with the discovery of charm. But in 1975, an experiment at SLAC revealed the existence of a new lepton, called tau. This brought a third generation of matter to the Standard Model, and was a solid indication that there were more third-generation particles to be found.

The Fermilab experiment E288 continued the work of E70 so much of the hardware was already in place waiting for upgrades. By the summer of 1975, collaborators completed construction on ▸

Fermilab

Upsilon discovery

Upsilon discovery

Bumps on the particle-physics road

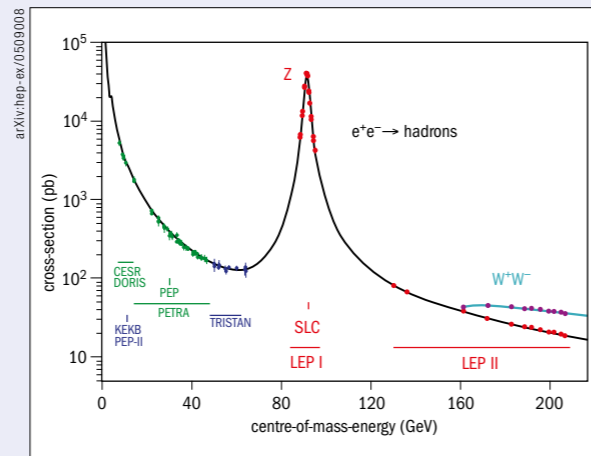
The story of “bumps” in particle physics dates back to an experiment at the Chicago Cyclotron in 1952, when Herbert Anderson, Enrico Fermi and colleagues found that the πp cross-section rose rapidly at pion energies of 80–150 MeV, with the effect about three times larger in $\pi^+ p$ than in $\pi^- p$. This observation had all the hallmarks of the resonance phenomena that was well known in nuclear physics, and could be explained by a state with spin 3/2, isospin 3/2. With higher energies available at the Carnegie Synchro-cyclotron, in 1954 Julius Ashkin and colleagues were able to report that the πp cross-section fell above about 180 MeV, revealing a characteristic resonance peak. Through the uncertainty principle, the peak’s width of some 100 MeV is consistent with a lifetime of around 10^{-23} s. Further studies confirmed the resonance, later called Δ , with a mass of 1232 MeV in four charge states: Δ^{++} , Δ^+ , Δ^0 and Δ^- .

The Δ remained an isolated case until 1960, when a team led by Luis Alvarez began studies of $K^+ p$ interactions using the 15 inch hydrogen bubble chamber at the Berkeley Bevatron. Graduate students Stan Wojcicki and Bill Marciano studied plots of the invariant mass of pairs of particles produced, and found bumps corresponding to three resonances now known as the Σ (1385), the Λ (1405) and the K^* (892). These discoveries opened a golden age for bubble chambers, and set in motion the industry of “bump hunting” and the field of hadron spectroscopy. Four years later, the Δ , together with Σ and Ξ resonances, figured in the famous decuplet of spin-3/2 particles in Murray Gell-Mann’s quark model. These resonances and others could now be understood as excited states of the constituents – quarks – of more familiar longer-lived particles.

By the early 1970s, the number of broad resonances had grown into the hundreds. Then came the shock of the “November Revolution” of 1974. Teams at Brookhaven and SLAC discovered a new, much narrower resonance in experiments studying, respectively, $pBe \rightarrow e^+e^-X$ and e^+e^- annihilation. This was the famous J/ψ , which after the dust had settled was recognised as the bound state of a predicted fourth quark, charm, and its antiquark. The discovery of the upsilon, again as a narrow resonance formed from a bottom quark and antiquark, followed three years later (see main article). By the end of the decade, bumps in appropriate channels were revealing a new spectroscopy of charm and bottom particles at energies around 4 GeV and 10 GeV, respectively.

This left the predicted top quark, and in the absence of any clear idea of its mass, over the following years searches at increasingly high energies looked for a bump that could indicate its quark–antiquark bound state. The effort moved from e^+e^- colliders to the higher energies of $p\bar{p}$ machines, and it was experimental groups at Fermilab’s Tevatron that eventually claimed the first observation of top quarks in 1995, not in a resonance, but through their individual decays.

However, important bumps did appear in $p\bar{p}$ collisions, this time at



The Z boson is the most precisely measured resonance in particle physics, with the LEP collider in particular confirming its mass and width.

CERN’s SPS, in the experiments that discovered the W and Z bosons in 1983. The bumps allowed the first precise measurements of the masses of the bosons. The Z later became famous as an e^+e^- resonance, in particular at CERN’s LEP collider. The most precisely measured resonance yet, the Z has a mass of 91.1876 ± 0.0021 GeV and a width of 2.4952 ± 0.0023 GeV.

However, a more recent bump is probably still more famous – the Higgs boson as observed in 2012. In data from the ATLAS and CMS experiments, small bumps around 125 GeV in the mass spectrum in the four-lepton and two-photon channels, respectively, revealed the long-sought scalar boson (CERN Courier September 2012 p43 and p49).

Today, bump-hunting continues at machines spanning a huge range in energy, from the BEPC-II e^+e^- collider, with a beam energy of 1–2.3 GeV in China, to the CERN’s LHC, operating at 6.5 TeV per beam. Only recently, LHC experiments spotted a modest excess of events at an energy of 750 GeV; although the researchers cautioned that it was not statistically significant, it still prompted hundreds of publications on the arXiv preprint server. Alas indeed, on this occasion as on others over the decades, the bump faded away once larger data sets were recorded.

Nevertheless, with the continuing searches for new high-mass particles, now as messengers for physics beyond the Standard Model, and searches at lower energies providing many intriguing bumps (CERN Courier April 2017 p31), who knows where the next exciting “bump” might appear?

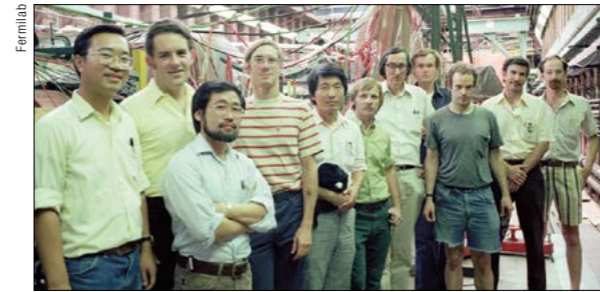
• Christine Sutton, formerly CERN.

the detector. Lederman invited a group from the State University of New York at Stony Brook to join the project, which began taking data in the autumn of 1975.

One of the many legends in the saga of the b quark describes a false peak in E288’s data. In the process of taking data, several events at an energy level between 5.8 and 6.2 GeV were observed, suggesting the existence of a new particle. The name upsilon

was suggested for this new particle. Unfortunately, the signals at that particular energy turned out to be mere fluctuations, and the eagerly anticipated upsilon became known as “oopsLeon”.

What happened next is perhaps best described in a 1977 issue of *The Village Crier* (FermiNews’s predecessor): “After what Dr R R Wilson jocularly refers to as ‘horsing around,’ the group tightened its goals in the spring of 1977.” The tightening of goals



Members of the E288 experiment in 1977: (left to right) Dave Hom, Chuck Brown, Al Ito, Bob Kephart, Koiji Ueno, Ken Gray, Hans Sens, H D Snyder, Steve Herb, Jeff Appel and Dan Kaplan.

came with a more specific proposal for E288 and a revamping of the detector. The collaborators, honed by their experiences with the Fermilab beam, used the detectors and electronics from E70 and the early days of E288, and added two steel magnets and two wire-chamber detectors borrowed from the Brookhaven J/psi experiment.

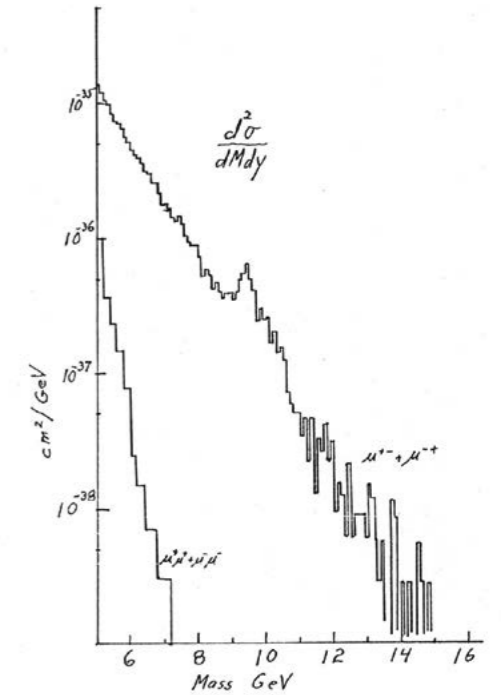
The simultaneous detection of two muons from upsilon decay characterised the particle’s expected signature. To improve the experiment’s muon-detection capability, collaborators called for the addition to their detector of 12 cubic feet – about two metric tonnes – of beryllium, a light element that would act as an absorber for particles such as protons and pions, but would have little effect on the sought-for muons. When the collaborators had problems finding enough of the scarce and expensive material, an almost forgotten supply of beryllium in a warehouse at Oak Ridge National Laboratory came to the rescue. By April 1977, construction was complete.

Six weeks to fame

The experiment began taking data on 15 May 1977, and saw quick results. After one week of taking data, a “bump” appeared at 9.5 GeV. John Yoh, sure but not overconfident, put a bottle of champagne labelled “9.5” in the Proton Center’s refrigerator.

But champagne corks did not fly right away. On 21 May, fire broke out in a device that measures current in a magnet, and the fire spread to the wiring. The electrical fire created chlorine gas, which when doused with water to put out the fire, created acid. The acid began to eat away at the electronics, threatening the future of E288. At 2.00 a.m. Lederman was on the phone searching for a salvage expert. He found his expert: a Dutchman who lived in Spain and worked for a German company. The expert agreed to come, but needed 10 days to get a US visa. Lederman called the US embassy, asking for an exception. Not possible, said the embassy official. Just as it began to look hopeless, Lederman mentioned that he was a Columbia University professor. The official turned out to be a Columbia graduate, class of 1956. The salvage expert was at Fermilab two days later. Collaborators used the expert’s “secret formulas” to treat some 900 electronic circuit boards, and E288 was back online by 27 May.

By 15 June, the collaborators had collected enough data to prove the existence of the bump at 9.5 GeV – evidence for a new particle, the upsilon. On 30 June, Steve Herb gave the official announcement of the discovery at the seminar at Fermilab, and on 1 July the collaborators submitted a paper to *Physics Review Letters*. It was



The plot showing an excess of events around 9.50 GeV, marking the discovery of the upsilon particle. “There was no known object that could explain that bump,” said Leon Lederman, E288 spokesman and Fermilab director emeritus, at the time.

published without review on 1 August.

Since the discovery of the upsilon, physicists have found several levels of upsilon states. Not only was the upsilon the first major discovery for Fermilab, it was also the first indication of a third generation of quarks. A bottom quark meant there ought to be a top quark. Sure enough, Fermilab found the top quark in 1995.

• Further reading

S Herb et al. 1977 *Phys. Rev. Lett.* **39** 252.

Résumé

Retour sur la révolution des b

Le mois de juin 2017 marque les quarante ans de l’apparition d’une bosse dans des données enregistrées avec cible fixe par l’expérience E288 du Fermilab. Cette bosse allait mener à la première grande découverte du laboratoire, le méson upsilon. Composé d’un quark b et d’un antiquark b liés ensemble, l’upsilon a permis d’établir l’existence d’une troisième génération de quarks. Depuis cette découverte, les physiciens ont trouvé plusieurs niveaux d’états upsilon et la physique des b est devenue l’un des domaines les plus actifs de la physique des hautes énergies moderne.

Based on an article (FermiNews, vol. 20, no.14) by Katherine Arnold, Fermilab, written at the time of the 20th anniversary of the discovery.



A new Large Research Infrastructure based on a linac with unprecedented reliability requirements



Since 1998 SCK•CEN is developing the MYRRHA project as an **accelerator driven system (ADS)** based on the lead-bismuth eutectic (LBE) as a coolant of the reactor and a material for its spallation target. MYRRHA is a flexible fast-spectrum pool-type research irradiation facility, also serving since the FP5 EURATOM framework as the backbone of the **Partitioning & Transmutation (P&T) strategy** of the European Commission concerning the ADS development in the third pillar of this strategy. MYRRHA is proposed to the international community of nuclear energy and nuclear physics as a pan-European large research infrastructure in ESFRI to serve as a multipurpose fast spectrum irradiation facility for various fields of research.

The subcritical core of the MYRRHA reactor (~100 MW_{th}) has to be driven by a **600 MeV proton beam** with a maximum **intensity of 4 mA**. The ADS application requires this beam to be delivered in a continuous regime — the resulting beam power of 2.4 MW classifies the driver machine as a High Power Proton Accelerator.

Already in the early design phase of MYRRHA the choice for linac has been endorsed, motivated to a large extent by the **unprecedented reliability requirements**.

The design of the MYRRHA linac has been conducted through an intense European

collaborative effort and supported by several consecutive Euratom FP's. Today the design effort is pursued under the H2020 MYRTE project complemented by several bilateral collaboration agreements.

The MYRRHA linac consists of 2 fundamental entities: (i) the injector and (ii) the main linac. The injector is fully normal conducting and brings the proton beam from the source through a 4-rod RFQ followed by a series of CH-type multigap cavities to 17 MeV.

A MEBT line matches the beam into the main linac, which is fully superconducting and operated at 2K.

2 families of spoke cavities prepare the beam for final acceleration in a sequence of 5-cell elliptical cavities. The 600 MeV proton beam is then transported through an achromatic line for vertical injection from above into the reactor. A beam window centered in the subcritical core closes the line.

A specific requirement for ADS application is the high level of the proton beam reliability, in other words the absence of unwanted beam trips. In the case of MYRRHA it is defined as follows: during a 3-months operational period the number of beam trips longer than 3s should be limited to 10. Shorter beam trips, on the other hand, are tolerated in large numbers. It has been

acknowledged from the early design stage that such a level of availability/reliability clearly requires a coherent approach to all accelerator components, but also that it compels to implement a global fault tolerant concept.

This has since been confirmed by extensive reliability modeling. The final design of the linac introduces the possibility of fault tolerance at the level of the superconducting cavities through conservative nominal conditions on beam dynamics and on cavity set points.

A similar fault tolerant concept is applied in the solid state RF amplifiers, which may therefore continue feeding the accelerating cavities even in case of failing components. However, such a scheme, based on redundancy from modularity, may not be applied in the injector. Fault tolerance is then recovered by a mere duplication of the injector: 1 active, 1 hot standby.

The phased approach of MYRRHA will primarily concentrate on its linac limited to 100 MeV (first spoke family), albeit with 1 injector only. This installation will be a relevantly sized test platform of various fault tolerance mechanisms, and thereby it will allow for a thorough investigation and extrapolation of the realistic capabilities of the full size 600 MeV linac.

Baksan Neutrino Observatory



View of the Andyrchi mountain near Mount Elbrus in the Northern Caucasus and the Neutrino village, from across the valley.

Baksan scales new neutrino heights

On its 50th anniversary, the world's first underground lab built exclusively for science, the Baksan Neutrino Observatory in Russia, remains at the forefront of neutrino research.

On 29 June 1967, the Soviet government issued a document that gave the go-ahead to build a brand new underground facility for neutrino physics in the Baksan valley in the mountainous region of the Northern Caucasus. Construction work began straight away on the tunnels under the 4000 m-high peak of Mount Andyrchi that would contain the experimental halls, and 10 years later, the laboratory's first neutrino telescope started operation. Today, a varied

experimental programme continues at the Baksan Neutrino Observatory, which is operated by the Institute for Nuclear Research (INR) of the Russian Academy of Sciences (RAS). And there is the promise of more to come.

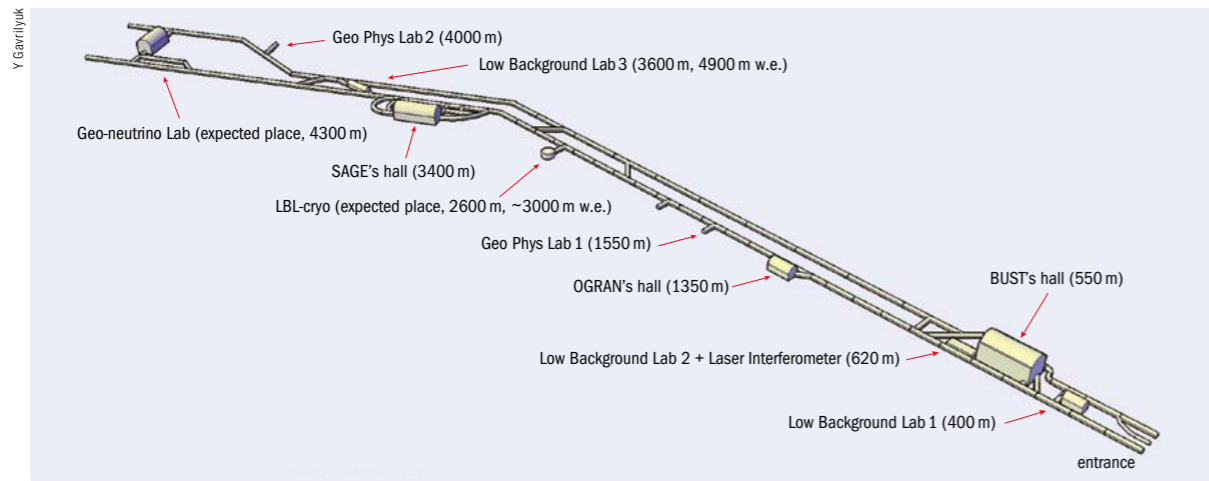
The detailed proposal for the Baksan Neutrino Observatory was put together by "the father of neutrino astronomy", Moisei Markov, and his younger colleagues, Alexander Chudakov, George ▾



www.sckcen.be/MYRRHA



Baksan Neutrino Observatory



Underground laboratories of the Baksan Neutrino Observatory, at increasing distances from the tunnel entrance (right). Being under a mountain the shielding increases with distance along the tunnel.

Zatsepin and Alexander Pomansky, together with many others. The decision to construct a dedicated underground facility rather than use an existing mine – something that had never been done before – gave the scientists the freedom to choose the location and the structure of their future laboratory to maximise its scientific output. Their proposal to house it in an almost horizontal tunnel under a steep mountain decreased the construction costs by a factor of six with respect to a mine, while maintaining higher safety standards. They selected Andyrchi – one of a series of peaks dominated by Europe's highest mountain, Mount Elbrus (5642 m) – from many potential sites. The entrance to the laboratory tunnel is located in the valley below the peaks, which is well known to mountaineers, hikers and skiers, at an altitude of 1700 m. A small village called Neutrino was built to accommodate scientists and engineers working for the observatory, with office and laboratory buildings, some surface installations, living quarters and related infrastructure.

The basic idea of underground neutrino detection is to use soil and rock to shield the installations from muons produced in cosmic-ray interactions with the atmosphere – the main background for neutrino detection. The underground complex at Baksan contains two interconnected tunnels (having two is a safety requirement) with laboratory halls situated at various distances along the tunnels, corresponding to different shielding conditions below the mountain. At the end of the 4 km-long tunnels, the flux of the muons is suppressed by almost 10 million times with respect to the surface.

Experiments past

The first experiment to start at Baksan, back in 1973, was not however underground. The Carpet air-shower experiment completely covered an area of around 200 m² with 400 liquid-scintillator detectors, identical to those of the first neutrino telescope "BUST" (see below). Its key task was a detailed study of the central part of air showers produced by cosmic particles in the atmosphere. One of its first results, based on the interpretation of shower sub-cores as imprints of jets with high transverse-momenta – born in the

primary interactions of the cosmic rays – was on the production cross-section of these jets for leading-particle energies up to 500 GeV. This result was published earlier than the corresponding measurement at CERN's Super Proton Synchrotron and confirmed predictions of quantum chromodynamics. Carpet's discoveries of astrophysical importance included a puzzling giant flare in the Crab Nebula in 1989.

The Baksan Underground Scintillator Telescope (BUST) started operation in 1977. A multipurpose detector, it is located in an artificial cavern with a volume of 12,000 m³ located 550 m from the tunnel entrance. The telescope is a four-level underground building 11.1 m high with a base area of 280 m². The building, made of low-radioactivity concrete, houses 3180 detectors containing 330 tonnes of liquid scintillator. Sensitive to cosmic neutrinos with energies of dozens of MeV, the detector is well suited to the search for supernova neutrinos, and on 23 February 1987 it was one of four detectors in the world that registered the renowned neutrino signal from the supernova 1987A in the Large Magellanic Cloud. The results obtained with the telescope have been used for cosmic-ray studies, searches for exotic particles (notably, magnetic monopoles) and neutrino bursts.

Neutrinos with lower energies were the target of the Gallium-Germanium Neutrino Telescope, a pioneering device to search for solar neutrinos in the SAGE (Soviet-American Gallium Experiment) project. The first experiments to detect neutrinos from the Sun – Homestake in the US and Kamiokande II in Japan – registered neutrinos with energies of a few MeV, which are mainly produced in the decay of boron-8 and constitute less than 1% of the total solar-neutrino flux. These Nobel-prize-winning experiments revealed the solar-neutrino deficit, subsequently interpreted in terms of neutrino oscillations, the only firm laboratory indication so far for the incompleteness of the Standard Model of particle physics. However, to assess the problem fully, it was necessary to find out what happens with the bulk (86% of the total flux) of the solar neutrinos, which come from proton-proton (pp) fusion

reactions and have energies below about 0.4 MeV.

In 1965, Vadim Kuzmin proposed using the reaction $^{71}\text{Ga} + \nu_e \rightarrow ^{71}\text{Ge} + e^-$ to detect the low-energy solar neutrinos. This idea was implemented in two experiments: GALLEX in the Gran Sasso National Laboratory and SAGE at Baksan. SAGE, which has been in operation since 1986 and is led by Vladimir Gavrin, is located 3.5 km from the tunnel entrance, where the cosmic-ray muon flux is suppressed by a factor of several million. About 50 tonnes of liquid gallium are used as a target; amazingly, a special factory was built to produce this amount of gallium, which exceeded the total consumed by the Soviet Union at the time. A unique chemical technology was developed to allow about 15 germanium atoms to be extracted from the 50 tonnes of gallium every month.

SAGE and GALLEX were the first experiments to detect solar pp neutrinos and to confirm the solar-neutrino deficit for the bulk of the flux. Combined with results from other experiments to subtract sub-leading contributions from other channels, SAGE found the solar pp neutrino flux to be $6.0 \pm 0.8 \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$. This agrees nicely with the solar-model prediction (taking into account neutrino oscillations) of $5.98 \pm 0.04 \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$ and the result has been confirmed by the 2014 measurement by Borexino, using a different method, which gives $6.6 \pm 0.7 \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$.

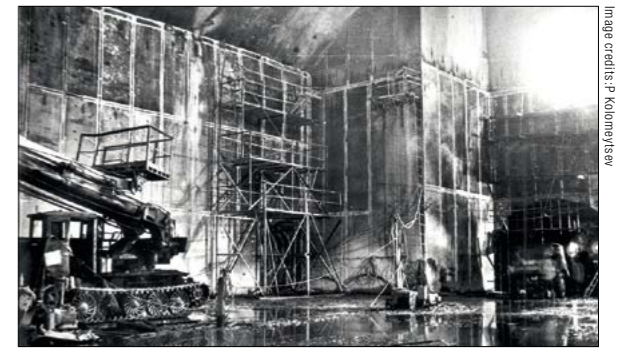
The unique underground conditions at Baksan also allowed the creation of several ultra-low-background laboratories where, in addition to the natural shielding, materials with extremely low radioactivity were used in construction. There are three shielded chambers at different depths where rare nuclear processes have been searched for and a number of low-background experiments performed, including a precise measurement of the isotopic composition of the lunar soil delivered by the Luna-16, Luna-20 and Luna-24 spacecraft.

Current experiments

Now 50, the Baksan Neutrino Observatory continues to probe the neutrino frontier. The scintillator telescope is still monitoring the universe for neutrino bursts, its almost 40 year exposure time setting stringent constraints on the rate of core-collapse supernova in the Milky Way. The non-observation of neutrinos associated with the gravitational-wave event of 15 September 2015, detected by the LIGO Observatory, puts a unique constraint on the associated flux of neutrinos with energies of 1–100 GeV, complementary to constraints from larger experiments at different energies.

Calibration of the gallium solar-neutrino experiments, SAGE and GALLEX, with artificial neutrino sources has revealed the so-called gallium anomaly, which can be understood in terms of a new, sterile-neutrino state. A new experiment called the Baksan Experiment on Sterile Transitions (BEST), has been instigated to check the anomaly and thus test the sterile-neutrino hypothesis. This will be based on a ^{51}Cr artificial neutrino source with an intensity of around 100 PBq, placed in the centre of a spherical gallium target of two concentric zones with equal neutrino mean-free-paths; any significant difference in the rate of neutrino capture in the inner and outer zones would indicate the existence of a sterile neutrino. CrSOX, a similar experiment with the Borexino detector at Gran Sasso, might become competitive with BEST but only in its full-scale configuration with the 400 PBq neutrino source. Reactor experiments would provide

Baksan Neutrino Observatory



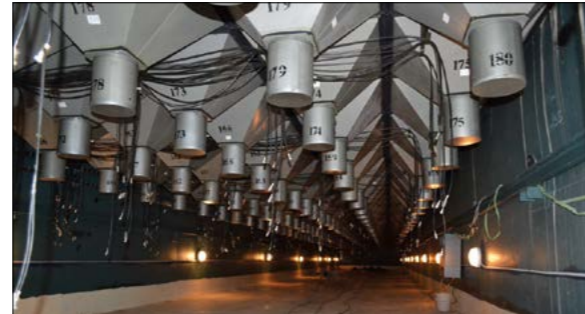
Construction and early days of the Baksan Neutrino Observatory. (Top to bottom) Constructing the BUST cave in 1976; Semen Gershtein, Bruno Pontecorvo and Alexander Chudakov inspect the construction of the observatory in 1977 (in the background are Vitaly Kaftanov and Alexander Pomansky); Evgeny Alexeyev, Georgiy Zatsepin, Moisey Markov and Vadim Kuzmin at the Neutrino-77 conference held at Baksan.

complementary information about a sterile antineutrino.

BEST is now fully constructed and is awaiting the artificial neutrino source. Meanwhile, ultra-pure gallium is still used in the SAGE experiment, confirming the stability of the solar-neutrino flux over decades: fortunately, the Sun is not about to change its power output.

Numerous experiments are being carried out in the low-background laboratory, thanks to a new experimental hall – Low Background Lab 3 on the figure on previous page – located 3.67 km from the tunnel entrance (providing shielding equivalent of 4900 m of water). One of them searches for solar axions via their resonant \triangleright

Baksan Neutrino Observatory



(Clockwise from top left) One of the layers of the Baksan Underground Scintillator Telescope; the reactor hall of the Ga–Ge solar-neutrino experiment (SAGE); the new muon detector of the Carpet-3 air-shower experiment; the assembled gallium sterile-neutrino experiment (BEST).

reconversion on ^{83}Kr , and this experiment has already resulted in the world's best constraint on certain couplings of the hadronic axion.

Among the surface-based experiments, the Carpet air-shower array is undergoing the most intense development. Equipped with a brand new muon detector with an area of 410 m^2 , this old cosmic-ray installation is starting a new life as a sophisticated sub-PeV gamma-ray telescope. A world-best sensitivity to the diffuse gamma-ray flux above 100 TeV , which could be achieved by the end of 2017, would be sufficient to decide between the galactic and extragalactic origin of the high-energy astrophysical neutrinos detected by the IceCube neutrino observatory at the South Pole.

Other experiments are also ready to produce interesting results. The Andyrchi air-shower array located on the slope of the mountain above BUST works in coincidence with the telescope, which serves as a muon detector with a 120 GeV threshold. A small gravitational-wave detector, OGRAN, capable of registering a galactic supernova, makes Baksan a true multi-messenger observatory. In addition, important interdisciplinary studies are taking place at the border with geophysics. They include not only deep-underground precise monitoring of seismic and magnetic parameters close to the sleeping volcano Elbrus, but also, for example, studies of atmospheric electricity and its relation to the cosmic-ray muon flux.

Future prospects

Looking ahead, the Baksan Neutrino Observatory could host new breakthrough experiments. The many planned projects include a further upgrade of the Carpet array with the increase in both the

surface-array and muon-detector areas for the purposes of sub-PeV gamma-ray astronomy; a new resonant-reconversion solar axion experiment with a sensitivity an order of magnitude better than the present one; and a circular laser interferometer – or Sagnac gyroscope – for geophysics and fundamental-physics measurements.

However, the main project for the observatory is the Baksan Large-Volume Scintillator Detector (BLVSD, although the name of the experiment is yet to be fixed). This detector, currently at the R&D stage, should contain $10\text{--}20$ kilotonnes of ultra-pure liquid scintillator and could be located at the end of the observatory tunnel. There, unused artificial caverns exist in which a $\text{Cl}\text{--}\text{Ar}$ solar-neutrino experiment was originally planned, but was replaced by the SAGE Ga–Ge detector in a different cave. This large-volume detector should be able to detect not only neutrinos from a galactic core-collapse supernova, but also the composite neutrino background of numerous distant explosions, thus making it possible to study supernova neutrinos in the unlucky, but probable, case that no galactic explosion happens in the coming decades. In the opposite case, the large neutrino statistics from a nearby explosion would open up possibilities for a detailed study.

For solar neutrinos, BLVSD would be capable of measuring the neutrino flux from the carbon–nitrogen–oxygen (CNO) fusion cycle in the Sun with a precision sufficient to discriminate between various solar models and therefore solve experimentally the present-day contradiction between results from helioseismology and those from chemical-composition studies of the solar surface. A primary target for BLVSD would be the study of geoneutrinos, which are produced

Baksan Neutrino Observatory

in nuclear decays in the Earth's interior. Clearly, the detector could also be used for a precise study of neutrino oscillations, in particular with a dedicated long-distance accelerator beam.

BLVSD would join a global network of large-scale neutrino detectors, if created. Such joint operation would open possibilities to solve many interesting problems. It would allow, for instance, the inclusion of effects of the inhomogeneous structure of the Earth's crust in geoneutrino studies, or the determination of the direction of a supernova that is obscured and visible only in neutrinos. The unique conditions at the Baksan observatory would also make the solo operation of BLVSD efficient. Not only do the existing infrastructure and experience allow for ultra-low-background experiments, but the geographical position in the Northern Caucasus guarantees a large distance from nuclear reactors. For geoneutrinos, estimates of the ratio of the signal counting-rate to the background from artificial reactors give a value around 5 for Baksan, compared to around 1.1 for Borexino and around 0.15 for KamLand. It is the low background that would allow a precise measurement of the solar CNO flux, which is barely possible in any of the currently operating experiments.

The large-scale BLVSD project is still in its infancy, and numerous efforts in R&D, fundraising and construction are still to be made. The Baksan Neutrino Observatory is fully open for worldwide collaboration and co-operation, both in this and in other scientific projects. Happy birthday, Baksan.

Further reading

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Résumé

Baksan : des sommets pour les neutrinos

L'observatoire de neutrinos de la Baksan, en Russie, premier laboratoire souterrain du monde construit exclusivement à des fins scientifiques, fête en juin son cinquantième anniversaire. L'idée à l'origine de sa création, reprise ensuite par de nombreux autres laboratoires, était d'utiliser le sol et les roches pour protéger les installations des muons produits par les interactions des rayons cosmiques avec l'atmosphère, qui constituent le principal bruit de fond lors de la détection de neutrinos. L'expérience SAGE de Baksan et l'expérience GALLEX du Laboratoire national de Gran Sasso ont été les premières à détecter des neutrinos solaires et à confirmer le problème du déficit de neutrinos solaires. Aujourd'hui, l'observatoire de la Baksan demeure à la pointe en physique des neutrinos. De nouvelles expériences doivent bientôt être lancées, notamment BEST et le détecteur à scintillateur de grand volume de Baksan.

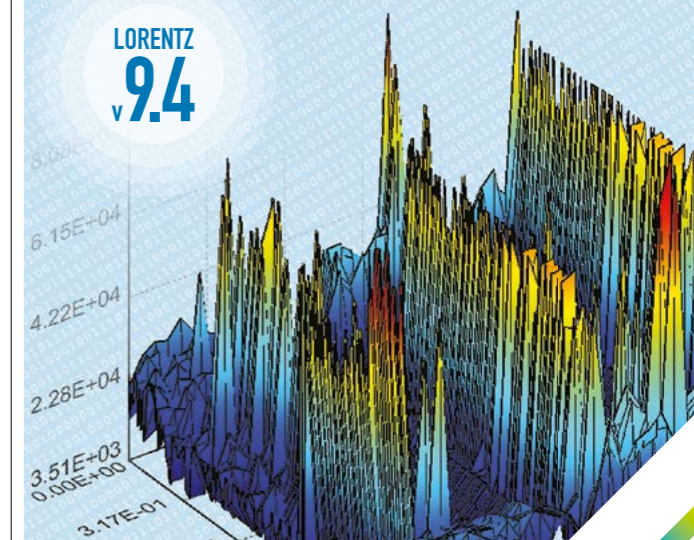
Valery Kuzminov, BNO director, and Sergey Troitsky, lead researcher, INR RAS.

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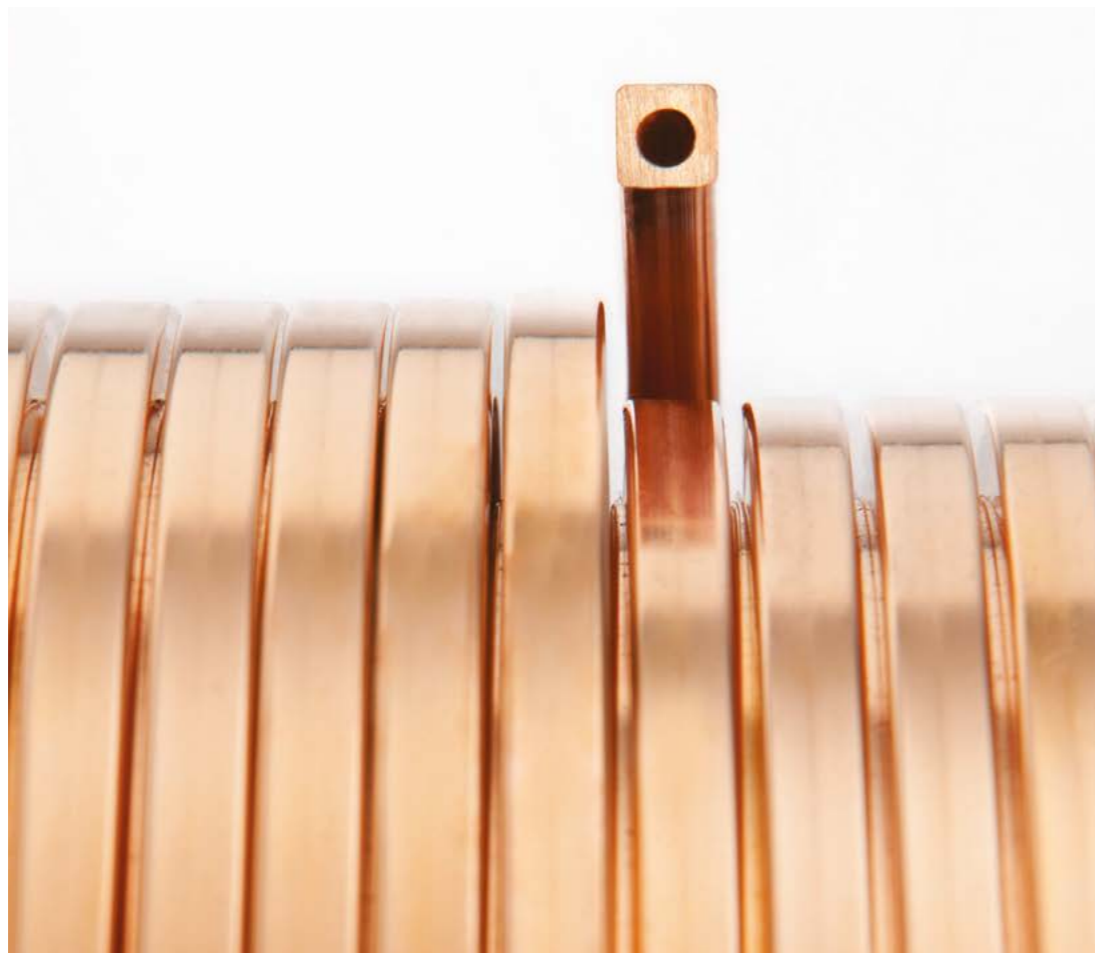
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AWARDS

Tim Berners-Lee receives Turing Award

On 4 April, CERN alumnus Tim Berners-Lee received the 2016 A M Turing Award for his invention of the World Wide Web, the first web browser, and the fundamental protocols and algorithms allowing the web to scale. Named in honour of British mathematician and computer scientist Alan Turing, and often referred to as the Nobel prize of computing, the annual award of \$1 million is given by the Association for Computing Machinery. In 1989, while working at CERN, Berners-Lee wrote a proposal for a new information-management system for the laboratory, and by the end of the following year he had invented one of the most influential computing innovations in history – the World Wide Web. Berners-Lee is now a professor at Massachusetts Institute of Technology and the University of Oxford, and director of the World Wide Web Consortium and the World Wide Web Foundation.



Berners-Lee created the first web-serving software in open-source fashion, catalysing the web's development.

ICTP Dirac medallists 2016

The International Centre for Theoretical Physics 2016 Dirac Medal has been awarded to Nathan Seiberg of the Institute for Advanced Study in Princeton, and Mikhail Shifman and Arkady Vainshtein of the University of Minnesota. The award recognises the trio's important contributions to field theories in the non-perturbative regime and in particular for exact results obtained in supersymmetric field theories.

Nathan Seiberg (left), Mikhail Shifman (middle) and Arkady Vainshtein (right) have made important contributions to supersymmetric field theories.



Guido Altarelli Award 2017

The second edition of the Guido Altarelli Award, given to young scientists in the field of deep inelastic scattering and related subjects, was awarded to two researchers during the 2017 Deep Inelastic Scattering workshop held in Birmingham, UK, on 3 April. Maria Ubiali of Cambridge University in the UK was recognised for her theoretical contributions in the field



Paolo Gunnellini and Maria Ubiali receive the prize, which was established in 2016 to honour the memory of CERN theorist Guido Altarelli.

of proton parton density functions, and in particular for her seminal contributions to the understanding of heavy-quark dynamics. Experimentalist Paolo Gunnellini of DESY, who is a member of the CMS collaboration, received the award for his innovative ideas in the study of double parton scattering and in Monte Carlo tuning.

Prizes galore for IceCube members

Four members of the IceCube neutrino observatory, based at the South Pole, have independently won awards recognising their contributions to the field. Aya Ishihara of Chiba University in Japan was awarded the 37th annual Saruhashi Prize, given each year to a female scientist under the age of 50 for exceptional research accomplishments. This year's prize, presented in Tokyo on 27 May, cites Ishihara's contributions to high-energy astronomy with the IceCube detector.

Fellow IceCube collaborator Subir Sarkar of the University of Oxford, UK, and the Niels Bohr Institute in Denmark has won the 4th Homi Bhabha prize. Awarded since 2010 by the Tata Institute of Fundamental Research (TIFR) in India and the International Union of Pure and Applied Physics, the prize recognises an active scientist who has made distinguished contributions in the field of high-energy cosmic-ray and astroparticle physics over an extended academic career. Sarkar has also worked on the Pierre Auger Observatory and is a member of the Cherenkov Telescope Array collaboration.

Meanwhile, former IceCube spokesperson Christian Spiering from DESY has won the O'Ceallaigh Medal for astroparticle physics, awarded every second year by the Dublin Institute for Advanced Studies. Spiering, who led the collaboration from 2005 to 2007 and also played a key role in the Lake Baikal Neutrino Telescope, was honoured "for his



(Clockwise from top left) Aya Ishihara, Subir Sarkar, Christian Spiering and Ben Jones.

outstanding contributions to cosmic-ray physics and to the newly emerging field of neutrino astronomy in particular". Both he and Sarkar will receive their awards at the 35th International Cosmic Ray Conference in Busan, South Korea, on 13 July.

Finally, IceCube member Ben Jones of the University of Texas at Arlington has won the APS 2017 Mitsuyoshi Tanaka Dissertation Award in Experimental Particle Physics, for his thesis "Sterile Neutrinos in Cold Climates".

Firms to begin prototyping the science cloud

An awards ceremony took place at CERN on 3 April recognising companies that have won contracts to start building the prototype phase of the Helix Nebula Science Cloud (HNSciCloud). Initiated by CERN in 2016, HNSciCloud is a €5.3 million pre-commercial procurement tender driven by 10 leading research organisations and funded by the European Commission. Its aim is to establish a European cloud platform to support high-performance computing and big-data capabilities for scientific research. The April event marked the official beginning of the prototype phase, which covers the procurement of R&D services for the



Award winners and participants at the ceremony, which marks the official beginning of the prototype phase of the pre-commercial procurement process for the Helix Nebula Science Cloud.

design, prototype development and pilot use of innovative cloud services. The three winning consortia are: T-Systems, Huawei, Cyfronet and Divia; IBM; and RHEA Group, T-Systems, Exoscale and

SixSq. Each presented its plans to build the HNSciCloud prototype and the first deliverables are expected by the end of the year, after which two consortia will proceed to the pilot phase in 2018.



CONFERENCES Beam gymnastics in Sicily

The CERN Accelerator School (CAS) organised a specialised course devoted to beam injection, extraction and transfer in Erice, Sicily, from 10 to 19 March. The course was held in the Ettore Majorana Foundation and Centre, and was attended by 72 participants from 25 countries including China, Iran, Russia and the US.

The intensive programme comprised 32 lectures and two seminars, with 10 hours of case studies allowing students to apply their knowledge to real problems. Following introductory talks on electromagnetism, relativity and the basics of beam dynamics, different injection and extraction schemes were presented. Detailed lectures about the special magnetic and electrostatic elements for the case of lepton and hadron beams followed. State-of-the-art kicker and septa designs were discussed, as were issues related to stripping-injection and resonant extraction as used in medical settings. An overview of optics measurements in storage rings and non-periodic structures completed the programme, with talks about the production of secondary and radioactive beams and exotic injection methods.

The next CAS course, focusing on advanced accelerator physics, will take place at Royal Holloway University in the UK from 3–15 September. Later in the year, CAS is participating in a joint venture in collaboration with the accelerator schools of the US, Japan and Russia. This school is devoted to RF technologies and will be held in Japan from 16–26 October. Looking further ahead, schools are currently planned in 2018 on accelerator physics at the introductory level, on future colliders and on beam instrumentation and diagnostics. See <https://www.cern.ch/schools/CAS>.

(Above) Participants at the CAS event, which was devoted to beam injection, extraction and transfer.

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Testing gravity in Vancouver

Around 100 participants from 15 countries attended the 2017 Testing Gravity Conference at the Simon Fraser University, Harbour Centre, in Vancouver, Canada, on 25 to 28 January. The conference, the second such meeting following the success of the 2015 event, brought together experts exploring new ways to test general relativity (GR).

GR, and its Newtonian limit, work very well in most circumstances. But gaps in our understanding appear when the theory is applied to extremely small distances, where quantum mechanics reigns, or extremely large distances, when we try to describe the universe. Advancing technologies across all areas of physics open up opportunities for testing gravity in new ways, thus helping to fill these gaps.

The conference brought together renowned cosmologists, astrophysicists, and atomic, nuclear and particle physicists to share their specific approaches to test GR and to explore ways to address long-standing mysteries, such as the unexplained nature



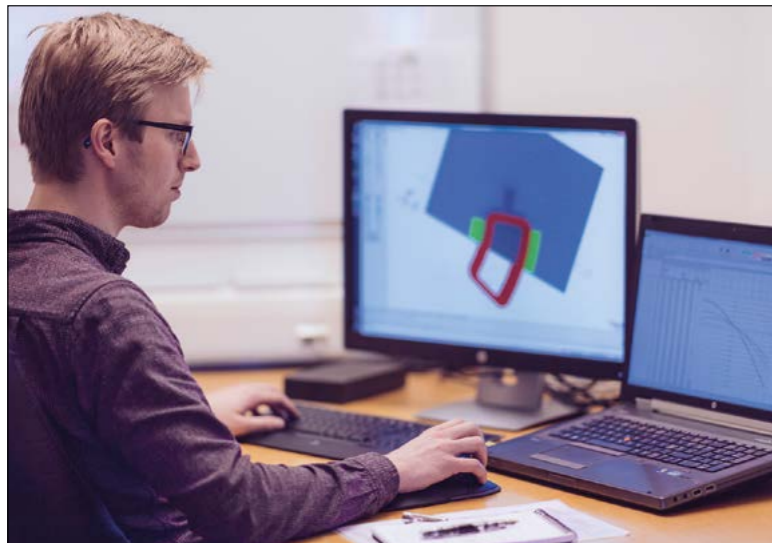
Testing Gravity is a new conference series held every two years.

of dark matter and dark energy. Among the actively discussed topics were the breakthrough discovery in February 2016 of gravitational waves by the LIGO observatory, which has opened up exciting opportunities for testing GR in detail (*CERN Courier* January/February 2017 p34), and the growing interest in gravity tests among the CERN physics community – specifically

regarding attempting to measure the gravitational force on antihydrogen with three experiments at CERN's Antiproton Decelerator (*CERN Courier* January/February 2017 p39).

Among other highlights there were fascinating talks from pioneers in their fields, including cosmologist Misao Sasaki, one of the fathers of inflationary theory; Eric Adelberger, a leader in gravity tests at short distances; and Frans Pretorius, who created the first successful computer simulations of black-hole collisions.

This is an exciting time for the field of gravity research. The LIGO–Virgo collaboration is expected to detect many more gravitational-wave events from binary black holes and neutron stars. Meanwhile, a new generation of cosmological probes currently under development, such as Euclid, LSST and SKA, are stimulating theoretical research in their respective domains (*CERN Courier* May 2017 p19). We are already looking forward to the next Testing Gravity in Vancouver in 2019.



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VISITS



On 12 April, CERN hosted the seven-member high-level group of scientific advisers to the European Commission, which provides independent scientific advice on specific policy issues. Led by former CERN Director-General Rolf Heuer, the group toured ATLAS and the AMS Payload Operations Control Centre.



Minister for higher education and science in Denmark **Søren Pind** visited CERN on 25 April, touring the synchrocyclotron, the Antiproton Decelerator, ALICE and ATLAS. Here he is pictured (centre) meeting ATLAS spokesperson Karl Jakobs.



On 18 April, Czech minister of health **Miloslav Ludvik** visited CERN, during which he toured the ALICE experiment and signed the guestbook with head of Member State relations Pippa Wells.



Dr **Viktoras Pranckietis** MP and speaker of the Seimas, Republic of Lithuania, visited CERN on 26 April, taking in CMS, ISOLDE and MEDICIS. He signed the guestbook with senior adviser for Lithuania Tadeusz Kurtyka (left) and director for finance and human resources Martin Steinacher.

LETTERS

Two loops in context

The article “The two-loop explosion” (*CERN Courier* April 2017 p18) summarises the current status of precision theory predictions for scattering processes at the LHC, driven by the impressive performance of the LHC experiments. While this is a new situation at CERN, it is not without precedent at a hadron collider. In fact, it had already been apparent in the late 1990s at the electron–proton collider HERA, then operated at DESY, that two- and even three-loop computations in QCD were needed to match the high accuracy of the data. Since then the theory community has made steady advances by achieving

two-loop predictions also for electron–positron collisions and, in some cases, pushing as far as the five-loop level.

This progress is based on a number of developments. Factorisation of physics from different length scales has been used systematically to establish effective theories in the soft and collinear limits, helping to organise the sometimes tedious process of cancelling infrared divergences in physical cross-sections. Deeper insight into the analytical structure of scattering amplitudes and new research in mathematics on iterated integrals, hyper-logarithms and periods have also revealed the algebraic structure encoded in Feynman diagrams. Finally,

there has been constant progress in computer algebra as the key technology in multi-loop calculations. The computational challenge to set up and solve large systems of equations, even of terabyte size, can be overcome with symbolic manipulation systems such as FORM. It is only during recent years that suitable open-source software and relatively inexpensive hardware have become widely available.

Thus, continuous efforts and investments in theory research during the past decades are bearing fruit, allowing theory predictions in 2017 to indeed match the precision required by many LHC measurements.

● *Sven-Olaf Moch, University of Hamburg.*

Faces & Places

OBITUARIES

Pierre Binétruy 1955–2017

One of the most brilliant theorists of his time, Pierre Binétruy, passed away on 1 April. Binétruy received his doctorate on gauge theories in 1980 under the direction of Mary K Gaillard, and held several positions including a CERN fellowship and postdocs in the US. In 1986, he was recruited as a researcher at LAPP in Annecy-le-Vieux and, four years later, he moved to the University of Paris XI. Since 2003 he was a professor at Paris Diderot University. He helped to found the Astroparticle and Cosmology Laboratory (APC) in 2005 and was its director until 2013. We also owe to him the involvement of the APC in space sciences, Earth sciences, and the realisation of the importance of data science.

Binétruy's research interests evolved from high-energy physics (notably supersymmetry) to cosmology and gravitation, and in particular the intersection between the primordial universe and fundamental theories. His recent interests included inflation models, dark energy and gravitational-wave cosmological backgrounds. During his prolific career, he published seminal papers that approached 1000 citations each and received several awards, including the Thibaud Prize and the Paul Langevin Award.

But he will also be remembered for his spirit and courage. He knew that it was necessary not only to seek scientific truth



Binétruy's research interests included supersymmetry, cosmology and gravitation.

but also to have the courage to prepare the community for the scientific goals that this truth demands and to fight to defend them. Older members of IN2P3 remember the extraordinary intellectual atmosphere that animated the Supersymmetry Research Group, which he proposed and directed from 1997 to 2004, transforming it into an unprecedented crossroads for experimenters and theorists. By that time, when the detection of gravitational waves was for many a distant dream, he also had the intuition to involve France in the field of gravitational-wave detection via the LISA Pathfinder programme – a scientific choice to which he devoted great dynamism right up to his death.

Binétruy was also an inspiration to hundreds of students. Through the MOOC Gravity project, which he developed in collaboration with George Smoot, his courses reached tens of thousands of students. He viewed MOOC not just as a simple way to improve the visibility of the university, but as a revolution in the way knowledge is diffused. In parallel with these activities, Binétruy found time to be president of the Fundamental Physics Advisory Group (2008–2010) and the Fundamental Physics Roadmap Committee (2009–2010) of ESA; the French consortium of the LISA space mission; the theory division of the French Physical Society (1995–2003); and the theory section of CNRS (2005–2008). He was also a member of the IN2P3 Scientific Committee (1996–2000) and numerous other panels.

Alongside his scientific activities, which he pursued with enthusiasm and unflinching rigor, Binétruy had a deep appreciation and knowledge of broader culture. He had a profound knowledge of the arts, where he was the driving force behind several interactions between art and science. As one of his eminent colleagues said of him: "Pierre was one of those very exceptional people who was at the top of the game and, at the same time, a remarkably pleasant colleague."

• Stavros Katsanevas.

Gösta Ekspong 1922–2017

Our mentor, colleague and close friend Gösta Ekspong passed away peacefully on 24 February at the age of 95. His life as a particle physicist covered the nuclear-emulsion epoch, the bubble-chamber years, experiments at CERN's Large Electron-Positron (LEP) and Super Proton Synchrotron colliders. In his retirement he closely followed the results from the LHC, in particular the search for the Higgs boson.

In 1950 Ekspong was working with Cecil Powell's group in Bristol, UK, which had become a world-leading centre for cosmic-ray emulsion work. In a brilliant experiment with Hooper and King he identified the decay $\pi^0 \rightarrow \gamma\gamma$. By observing e^+e^- pairs from the conversion of the photons close to cosmic-ray interactions, it was



possible to determine the mass of the π^0 and set an upper limit for its lifetime.

Ekspong obtained his doctorate at Uppsala University, Sweden, in 1955, and immediately took up a postdoc position in Emilio Segré's group at Berkeley where

Ekspong once served as Sweden's delegate to CERN Council.

he was involved in the discovery of the antiproton at the Bevatron. Scanning emulsions one evening, he found the first evidence for an annihilation interaction in an emulsion, and on the 50th anniversary of the discovery of the antiproton he was invited to Berkeley to talk about the discovery.

Ekspong was appointed to the first chair in particle physics in Sweden, at Stockholm University, in 1960. There he founded a large particle-physics group that over the years made important contributions to many experiments with data mostly from CERN. He strongly supported the use of CERN, where he was a member and chair of the Emulsion

Faces & Places

Committee in the early 1960s and a member of the Scientific Policy Committee from 1969 to 1975. He was Swedish delegate to CERN Council for many years and was a catalyst for the development of Swedish particle physics. He was elected to the Royal Swedish Academy of Sciences in 1969 and was a member of its Nobel Committee for physics from 1975 to 1988, chairing the committee from 1987 to 1988.

His deep knowledge of statistics allowed Ekspong to clarify general features of high-energy interactions. Data from CERN's Proton Synchrotron and bubble chambers had suggested that the multiplicity distributions of charged particles obeyed so-called "KNO" scaling, but this relationship was found not to be valid in later collider data recorded at higher energies with the UA5 experiment. In a discovery

reported and discussed by him at many conferences, Ekspong showed that the distributions instead followed a negative binomial distribution.

In the early studies of physics possibilities at the planned LEP collider, Ekspong also made a convincing contribution to the search strategy for observing the Higgs boson by carefully examining the experimental mass resolution. This strategy was later employed by the LEP experiments to exclude the Higgs mass up to about 115 GeV. He also took part in the technical development of one of the LEP experiments, DELPHI.

Gösta Ekspong inspired many with his lectures, discussions, and stories about Nobel-prize discoveries. In many articles in Swedish he made physics available and understandable for the general public.

• Per Carlson and Sven-Olof Holmgren.

Gareth Hughes 1943–2017

Gareth Hughes joined the high-energy physics group at Lancaster University in 1970, following his undergraduate and postgraduate studies at Oxford University. He was born in Wales and was a proud supporter of the Welsh Rugby Union team, although he had never played the game. He used to say that he was among the few Welshmen who never played rugby, who could not sing and who did not like leeks. Ironically, he died on the feast day of St David, the patron saint of Wales.

Following his appointment in Lancaster, Gareth played a central role in the work of the Manchester-Lancaster experiment (dubbed "Manchester") at Daresbury Laboratory to study the electro-production of nucleon resonances (by which the components of the nucleon are converted to more highly energetic states). He subsequently went on to work on the JADE experiment at DESY, the ALEPH and then ATLAS experiments at CERN – all of which have been key in establishing the Standard Model of particle physics.

Gareth's main strength was computing. In the 1990s, as well as being a member of the CERN Central Computing Committee, he was chairman of the committee that produced the policy on computing for UK particle physics. This was a very rapidly changing field at the time but a subject in which Gareth's insight and guidance was to prove invaluable. He was also a prominent member of the Particle Physics Grants Committee and other bodies that manage funding for UK particle physics.



Gareth Hughes was a member of the ALEPH and ATLAS collaborations.

He was an excellent teacher, his gentle sense of humour and infinite patience making him a much sought after member of staff by both undergraduate and postgraduate students. He eventually became director of undergraduate courses within the physics department at Lancaster.

Gareth's quick grasp of a situation and clear insight made him an extremely valuable colleague with whom to discuss problems. He was widely known and, in turn, seemed to know everyone. This proved to be a great help on numerous occasions. He retired from the physics department in 2007 but continued his involvement with the ATLAS experiment as an emeritus staff member until his death following a short illness. He will be sorely missed by us all but especially by his wife Jane, daughter Siân and son Owain, and his four grandchildren.

• His friends and colleagues.

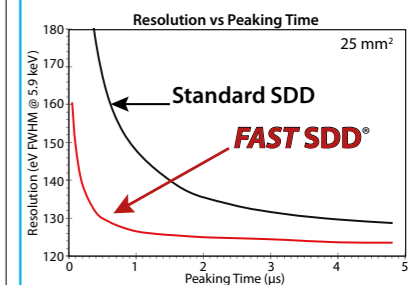
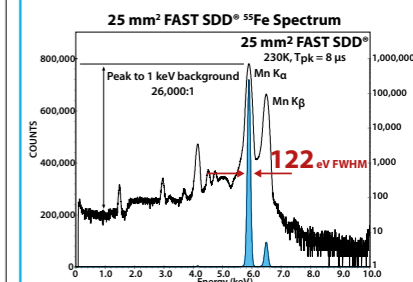
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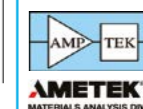


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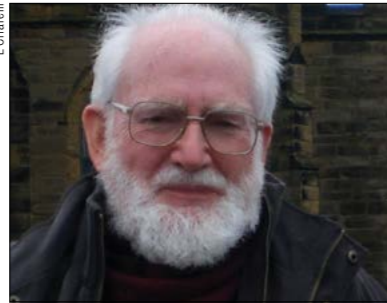


Thomas Massam 1936–2016

Thomas Massam received his undergraduate degree in physics in 1956 at the Chadwick Laboratory, Cambridge, and his PhD at the University of Liverpool in 1960. Jovial but very serious and tireless at work, Tom devoted his life to experimental-physics research and to his family.

I had the privilege of meeting Tom at the Fermi Summer School of Physics in Varenna, Italy, in 1962. The topics discussed at the school were the results of the Blackett group on the unexpected V particles, later called “strange” by Gell-Mann, and the effects of “virtual physics” in properties of the elementary particles and the experimental-plus-theoretical research needed. Tom was the most active student of the school, and soon afterwards he joined my group at Bologna University and remained there until his retirement in 2002. Together we performed experiments in all of the important laboratories in Europe, including CERN, DESY, ADONE and Gran Sasso.

Tom had an extraordinary intelligence, work capacity and “scientific fidelity”. He



Tom Massam helped to set up the first large-scale non-bubble-chamber facility at CERN.

is also one of the founders of the Ettore Majorana International Centre for Scientific Culture, established at CERN in the early 1960s with its headquarters in Erice, Sicily. In 1972, Tom initiated an International School of Theory Application of Computers.

Tom played a major role, contributing with his extraordinary experimental talents,

in experiments that established evidence for the Standard Model during the 1960s and afterwards. He helped to set up the first large-scale non-bubble-chamber facility at CERN, and was a close collaborator in our adoption of electromagnetic calorimeters as a tool to separate leptons from hadrons to allow searches for new particle states. Together, we started the first heavy-lepton search and developed a new technology to measure the time-of-flight of particles with a very high precision, leading to the first experimental observation of anti-deuteron production.

Tom, research director in the INFN unit of Bologna, was also giving regular physics courses to the students at the ISSP International School of Subnuclear Physics in Erice, established in 1963.

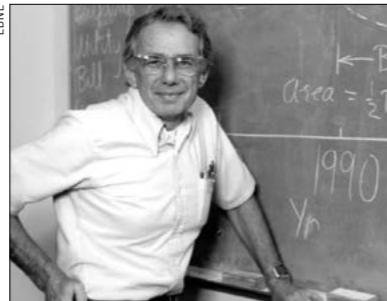
Tom is no longer with us. On 1 December 2016 he left his beloved family, Veronica with three children Peter, Steven, Paul, and his friends and colleagues with the unforgettable memory of his extraordinary life.

● Antonino Zichichi.

Arthur Rosenfeld 1926–2017

Arthur H Rosenfeld, a long-time member of the faculty at the University of California, Berkeley, and distinguished senior scientist at the Lawrence Berkeley National Laboratory, passed away in Berkeley on 27 January at the age of 90. A student of Enrico Fermi, he was a leading participant in the revolutionary advances in particle physics in the 1950s and 1960s before striking out in a new direction, where he became legendary. A fitting tribute to Art was the award in 2006 of the Enrico Fermi Award of the US Department of Energy “for a lifetime of achievements ranging from pioneering scientific discoveries in experimental nuclear and particle physics to innovations in science, technology, and public policy for energy conservation that continue to benefit humanity. His vision not only underpins national policy but has helped launch an industry in energy efficiency”.

Art’s first impact on the physics community was with Jay Orear and Robert Schluter, when the three of them produced the book *Nuclear Physics* consisting of the notes from Fermi’s course at the University of Chicago. Art came to Berkeley from Chicago and was part of Luis Alvarez’s



Art Rosenfeld helped establish the Particle Data Group among his many achievements.

team, which used bubble chambers to discover many of the meson and baryon resonances, including the omega meson and the $\Sigma^*(1385)$, which led to the recognition of SU(3) flavour symmetry. Art co-authored papers not only with experimenters, but also with Murray Gell-Mann, Shelly Glashow, and Sam Treiman. The 1957 *Annual Review of Nuclear Science* paper with Gell-Mann, “Hyperons and Heavy Mesons (Systematics and Decay)”, was the beginning of the

Particle Data Group. Today’s Particle Data Group and the *Review of Particle Physics* are, 60 years later, Art’s legacy to the physics community.

Much greater still is Art’s legacy to the US and international communities, which benefit today from his relentless pursuit of increased efficiency in the use of energy through both technological advances and political advocacy. The oil embargo of 1973 led Art to wonder why he saw so many obviously wasteful practices in the use of energy. He devoted the rest of his career to rectifying this. That per-capita usage of energy in California remained essentially constant from 1973 to 2006, while it rose by 50% elsewhere in the US, was given the name “The Rosenfeld Effect,” because of Art’s success in getting the state to adopt policies encouraging efficient use of energy.

Art, together with a number of nuclear and particle physicists, and with the backing of Andrew Sessler, the director of the Lawrence Berkeley Laboratory in the mid-1970s, developed programmes in energy efficiency for buildings, appliances and lighting, which became a major part of the Laboratory’s

programme. Art’s efforts extended beyond the laboratory. He was a founder of the American Council for an Energy-Efficient Economy, a non-profit organisation that continues today to push for policies that increase energy efficiency. Art served in the Clinton administration from 1994 to 1999 as senior adviser to the DOE’s assistant secretary for energy efficiency and renewable energy, and subsequently as commissioner at the

California Energy Commission under two state administrations.

Among the numerous honours Art received was the National Medal of Science and of Technology and Innovation presented by president Barack Obama in 2011 for “extraordinary leadership in the development of energy-efficient building technologies and related standards and policies”.

Art showed that the analytical skills and

pragmatism the physics community values could be put to use on practical problems facing humanity. The result of his dedication was profound and lasting contributions to energy efficiency. Despite Art’s ever growing fame, he remained an unassuming colleague, and we remember him as a friend whose achievements transcended the scope of our ordinary research endeavours.

● Robert N Cahn.

Durga Prasad Roy 1941–2017

Durga Prasad Roy, or DP as he was popularly known, passed away on 17 March in Cuttack, India, after a brief illness. He was active until his last days, having posted a review on the arXiv preprint server in August 2016, participated in conferences in 2017 and having given a series of lectures on the Standard Model at the University of Hyderabad just a few days before he fell ill.

DP completed his PhD in particle physics in 1966 at the Tata Institute of Fundamental Research (TIFR), Mumbai, and was a postdoctoral fellow at the University of California (1966–1968), CERN (1968–1969) and the University of Toronto (1969–1970). He moved to the Rutherford Laboratory in the UK (1970–1974), and was a reader at Visva Bharati University, India, from 1974 to 1976. He joined TIFR in 1976 and retired 30 years later in 2006. He then became a member of the Homi Bhabha Centre of Science Education.

Scientifically, DP had an instinct for recognising what is important. He made pioneering contributions in particle- and astroparticle-physics phenomenology. His early research work was in the area of “Regge phenomenology and duality”, which addresses the dominant part of cross-sections for hadron–hadron collision processes. Using these ideas, DP predicted exotic mesons called baryonium (now termed tetraquarks) as well as exotic pentaquark baryons – robust predictions that continue to attract the attention of experimentalists and lattice-QCD experts. Along with his collaborators, he suggested to look for a hard isolated lepton and jets as



DP made pioneering contributions in particle and astroparticle physics.

a signature of the top quark, a methodology widely adopted at the CERN and Tevatron proton–antiproton colliders.

He also worked extensively on many popular theories of physics beyond the Standard Model, such as supersymmetry. He suggested a promising signature with which to search for charged Higgs bosons using tau decays and the distinctive polarisation of these particles, which is currently being used in the ongoing search for charged Higgs boson at the LHC. Likewise, the missing transverse-momentum signature for supersymmetric particles suggested by DP is being widely used in the ongoing collider searches for these particles.

DP and collaborators, and other groups, employed global fits of the solar-neutrino data, including the SNO neutral-current data from 2002, to pin down the large-mixing-angle (LMA)

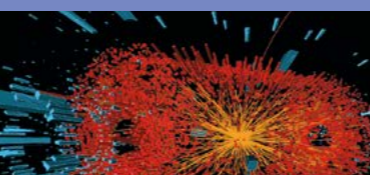
Mikheyev–Smirnov–Wolfenstein (MSW) solution to the solar-neutrino problem. This was tested by two impressive sets of neutrino-spectrum results published by the KamLAND experiment in 2003 and 2004. Incorporating these data further in their analysis, and focussing on the LMA–MSW solution in the two-neutrino framework, DP and collaborators ruled out the high-mass-squared-difference LMA solution by more than three standard deviations and converged on the low-mass-squared-difference LMA as the unique solution.

His scientific achievements were recognised by the Meghnad Saha Award and the SN Bose Medal. He was elected fellow of the Indian Academy of Sciences, Indian National Science Academy and National Academy of Sciences.

Along with his colleague Probir Roy, DP started a series of workshops in high-energy physics phenomenology called WHEPP that still initiate a lot of collaborative work today. He was passionate about undergraduate teaching, but also had many interests outside science. He was a weightlifting champion of Orissa, an expert swimmer, and a connoisseur of Indian classical music and dance. His passion for adventure always showed up in the after-work evening activities at WHEPP workshops. He also had strong views on the lack of experimental investigations in ancient India, and published them in an article in the *Indian Journal of History of Science* in 2016.

DP leaves behind a loving wife, Monika, and a daughter, Kalyani.

● Rajiv V Gavai.



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The candidate should also indicate the names and e-mail addresses of not less than three renowned physicists. These physicists will receive an e-mail message from us with instructions on how to submit a recommendation letter on the candidate's behalf.

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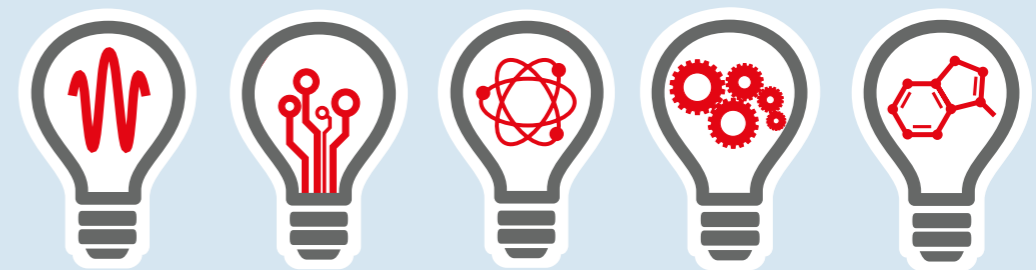
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For more information and prompt consideration, visit our website at www.jlab.org/careers. To receive full consideration, please apply by June 30, 2017. Confidential inquiries and questions concerning this search may be directed to Stuart Henderson, Jefferson Lab Director, at stuart@jlab.org, or Rhonda Barbosa, Human Resources Director, at rbarbosa@jlab.org.

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Northern Illinois
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OPPORTUNITY FOR TENURE-TRACK ASSOCIATE and ASSISTANT PROFESSORSHIP APPOINTMENTS IN ACCELERATOR PHYSICS (JOINTLY WITH FERMILAB)

The Physics Department of Northern Illinois University is home to world-class faculty in accelerator, detector and particle physics. In a joint initiative with Fermi National Accelerator Laboratory (Fermilab), it has established a Cluster of Research Excellence in accelerator science and beam physics since 2014. Faculty members have national and international research and educational collaborations with Fermilab, Argonne National Laboratory (ANL), SLAC, CERN, DESY and USPAS/ CERN Accelerator Schools. Funded by the National Science Foundation, the Department of Energy and other institutional and national agencies, the Accelerator and Beam Physics faculty members in the cluster work at the theoretical and experimental frontiers, with full access to special purpose laboratories and advanced accelerator test facilities at NIU and Fermilab (e.g. NIU High Brightness Electron Source laboratory in IARC and Fermilab FAST/IOTA testbed). The research cluster aims at enabling "discovery-class" science driven by charged particle beams and associated advanced techniques/ technologies of lasers, bright electron and ion sources, nano-material structures, superconductivity, microwave cavity electrodynamics, nonlinear dynamics, electrodynamic and optical control of intense charged particle, atomic and molecular beams. The R&D is directed towards developments in particle physics and related disciplines of cosmology, material and life sciences and their applications to societal grand challenges of energy, environment, health and security.

Working seamlessly with the outstanding accelerator and technology research staff at Fermilab and Northern Illinois Centre for Accelerator and Detector Development (NICADD), unique collaborative research opportunities exist to contribute to large scale national and international accelerator activities such as the PIP-II at Fermilab for the development of the long-baseline neutrino facility in support of the international DUNE experiment, TeV-scale collider developments world-wide including the LHC and its upgrade and the FCC at CERN, "precision" experiments e.g. "g-2", "Mu-2-e" etc. at Fermilab, anti-matter related experiments at CERN, as well as cutting edge innovative research in laboratory-scale experiments to investigate the "dark" sector of the vacuum.

The cluster seeks appointment of two tenure-track faculty members in accelerator physics, jointly with Fermilab, at Associate/Assistant Professor levels as soon as possible. Aspiring candidates, with a PhD degree in Physics or equivalent and relevant post-doctoral experience beyond, should contact Professor Swapan Chattopadhyay, President's Professor and Director of Accelerator Research, NIU (schaterji@niu.edu) and Distinguished Scientist, Director's Senior Leadership Team, Fermilab (swapan@fnal.gov) for further details and send early expressions of interest and professional background information in advance before August 15, 2017. Candidates from historically underrepresented communities are especially encouraged to apply. A detailed job posting with specific directions for applications will be announced online and selected journals soon.

Chair for Experimental nuclear and particle physics at Vilnius University, Lithuania

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Vilnius University has joined CERN RD collaborations in 2002 and the CMS experiment in 2007. Previous participation in one of the major experiments at the Large Hadron Collider at CERN (ALICE, ATLAS, CMS or LHCb) will be considered an advantage.

Vilnius University is the oldest and most comprehensive university in Lithuania. According to "QS World University Rankings 2016-2017", it is among top 500 universities in the world. The academic staff consists of 1350 employees (250 of them are professors) and around 20,000 students, including 3,600 graduate and 900 doctoral students.

The research laboratories of the Faculty of Physics have premises in the National Centre of Physical and Technological Sciences in Sunrise Valley ("Saulėtekis") since 2016. The Valley is the largest and most advanced base for physical, chemical and life sciences and for technology in Lithuania and the Baltic states. The lecture rooms and the educational laboratories at the Faculty of Physics, the largest center of physics studies in Lithuania, are situated nearby.

A Chair position is equivalent to a full professor position. The incumbent is expected to fulfill the requirements corresponding to the recommended European competences for a leading (R4) or, at least, an established (R3) researcher.

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Applications are invited from candidates of any nationality and gender. Citizens of non-EU countries will need to fulfil the requirements for obtaining a work permit in Lithuania. The successful candidate must take residence in Vilnius.

Chair's mission: • Coordinate Lithuania's research activities in theoretical and experimental high energy physics, and in materials and computer sciences and medical applications relevant to CERN research fields; • facilitate the involvement of researchers at Vilnius University into the programmes and experiments conducted at CERN; • organize teaching and training of students and young researchers in particle physics, particle detector techniques, data processing and related fields; • raise the public awareness for fundamental physics such as the current understanding of the Universe and its origin in a form that is suitable for a broad audience.

Full details of the Chair's duties will be provided upon request.

The successful candidate will be entitled to: • a separate office; • premises to establish her/his own laboratory, if the existing infrastructure does not match the needs, within the limits of the Centre's financial possibilities; • Salary Range: negotiable and depending on experience.

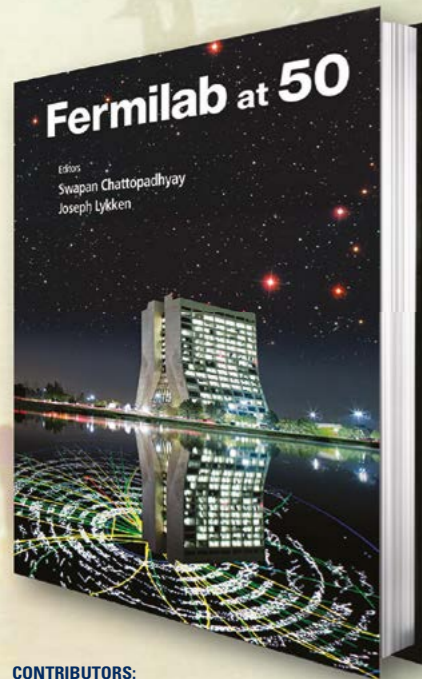
The applications should be sent to VU Directorate of Personnel zis@cr.vu.lt **The deadline: 10 September, 2017.**

A cover letter should include a request to participate in the contest and should be addressed to the Rector of Vilnius University.

Also, a description of academic activities together with a list of scientific publications, curriculum vitae, an outline of the research plan and any other additional documents allowing to objectively evaluate the qualifications of the applicant.

The letters of support from senior scientists with an established track record in high-energy nuclear and particle physics (min 3, max 6) should be sent directly to Vilnius university (zis@cr.vu.lt).





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— A. McDonald, Nobel Laureate and N. Smith, SNOLAB Director

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— Burton Richter, Nobel Laureate

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— J. Steinberger, Nobel Laureate

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— Ed Witten, Princeton University

CONTRIBUTORS:

- T. D. Lee (Nobel Laureate, Columbia University, Emeritus)
- Art McDonald (Nobel Laureate, Queens University/SNOLAB)
- Burton Richter (Nobel Laureate, Director Emeritus, SLAC)
- Nigel Smith (Director, SNOLAB)
- Jack Steinberger (Nobel Laureate, CERN, Emeritus)
- Ed Witten (Princeton University)
- Mike Witherell (Director, Berkeley Lab)
- Lyndon Evans (Director, Linear Collider Collaboration, CERN)
- Fabiola Gianotti (Director-General, CERN)
- Yifang Wang (Director, IHEP, China)
- James Siegrist (Director, DOE OHEP)
- Mike Turner (Director, KICP, U. Chicago)
- Sau Lan Wu (University of Wisconsin, Madison)
- and many others.



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About the editors



Swapan Chattopadhyay is a Distinguished Scientist in the Senior Leadership of Fermilab and President's Professor for Research, Scholarship and Artistry and Director of Accelerator Research at Northern Illinois University. Chattopadhyay received his Ph.D. from University of California at Berkeley which started his association with Fermilab and CERN proton-antiproton colliders in search of the W and Z bosons and the top quark. Since then Chattopadhyay has held major scientific leadership positions in the USA and UK at Berkeley Lab, Jefferson lab and Cockcroft Institute. Recognized internationally for pioneering contributions to particle accelerators and colliders, he has contributed to the US and European particle physics strategies. He is a Fellow of the APS, AAAS, IoP (UK), RSA (UK), a visiting professor at Oxford and honorary scientific associate at CERN.



Joe Lykken is the Deputy Director for Research and Chief Research Officer at Fermilab. A Distinguished Scientist at the laboratory, Lykken received his Ph.D. from the Massachusetts Institute of Technology, and has previously worked for the Santa Cruz Institute for Particle Physics and the University of Chicago. He is known for theoretical research in a variety of areas including supersymmetry, superstrings, and extra dimensions, applying his research to the Large Hadron Collider at CERN as a member of the CMS collaboration, including the characterization of the properties of the newly discovered Higgs boson. He is a Fellow of the APS and AAAS.

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Making Sense of Quantum Mechanics

By Jean Bricmont

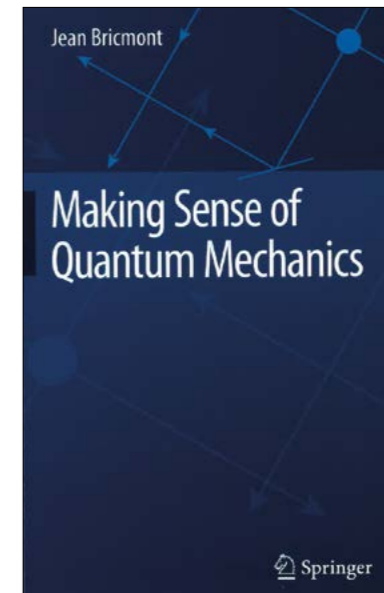
Springer

In this book, Jean Bricmont aims to challenge Richard Feynman's famous statement that "nobody understands quantum mechanics" and discusses some of the issues that have surrounded this field of theoretical physics since its inception.

Bricmont starts by strongly criticising the "establishment" view of quantum mechanics (QM), known as the Copenhagen interpretation, which attributes a key role to the observer in a quantum measurement. The quantum-mechanical wavefunction, indeed, predicts the possible outcomes of a quantum measurement, but not which one of these actually occurs. The author opposes the idea that a conscious human mind is an essential part of the process of determining what outcome is obtained. This interpretation was proposed by some of the early thinkers on the subject, although I believe Bricmont is wrong to associate it with Niels Bohr, who relates the measurement with irreversible changes in the measuring apparatus, rather than in the mind of the human observer.

The second chapter deals with the nature of the quantum state, illustrated with discussions of the Stern–Gerlach experiment to measure spin and the Mach–Zender interferometer to emphasise the importance of interference. During the last 20 years or so, much work has been done on "decoherence". This has shown that the interaction of the quantum system with its environment, which may include the measuring apparatus, prevents any detectable interference between the states associated with different possible measurement outcomes. Bricmont correctly emphasises that this still does not result in a particular outcome being realised.

The author's central argument is presented in chapter five, where he discusses the de Broglie–Bohm hidden-variable theory. At its simplest, it proposes that there are two components to the quantum-mechanical state: the wavefunction and an actual point particle that always has a definite position, although this is hidden from observation until its position is measured. This model claims to resolve many of the conceptual problems thrown up by orthodox QM: in particular, the outcome of a measurement is determined by the position of the particle being measured, while the other possibilities implied by the wavefunction can be ignored because they are associated with "empty waves". Bricmont shows how all the results of standard QM – particularly the statistical



probabilities of different measurement outcomes – are faithfully reproduced by the de Broglie–Bohm theory.

This is probably the clearest account of this theorem that I have come across. So why is the de Broglie–Bohm theory not generally accepted as the correct way to understand quantum physics? One reason follows from the work of John Bell, who showed that no hidden-variable theory can reproduce the quantum predictions (now thoroughly verified by experiment) for systems consisting of two or more particles in an entangled state unless the theory includes non-locality – i.e. a faster-than-light communication between the component particles and/or their associated wavefunctions. As this is clearly inconsistent with special relativity, many thinkers (including Bell himself) have looked elsewhere for a realistic interpretation of quantum phenomena. Not so Jean Bricmont: along with other contemporary supporters of the de Broglie–Bohm theory, he embraces non-locality and looks to use the idea to enhance our understanding of the reality he believes underlies quantum physics. In fact he devotes a whole chapter to this topic and claims that non-locality is an essential feature of quantum physics and not just of models based on hidden variables.

Other problems with the de Broglie–Bohm theory are discussed and resolved – to the author's satisfaction at least. These

include how the de Broglie–Bohm model can be consistent with the Heisenberg uncertainty principle when it appears to assume that the particle always has a definite position and momentum; he points out that the statistical results of a large number of measurements always agree with conventional predictions, and these include the uncertainty principle.

Alternative ways to interpret QM are presented, but the author does not find in them the same advantages as in the de Broglie–Bohm theory. In particular, he discusses the many-worlds interpretation, which assumes that the only reality is the wavefunction and that, rather than collapsing at a measurement, this produces branches that correspond to all measurement outcomes. One of the consequences of decoherence is that there can be no interaction between the possible measurements, and this means that no branch can be aware of any other. It follows that, even if a human observer is involved, each branch can contain a copy of him or her who is unaware of the others' presence. From this point of view, all the possible measurement outcomes co-exist – hence the term "many worlds". Apart from its ontological extravagance, the main difficulty with many-worlds theory is that it is very hard to see how the separate outcomes can have different probabilities when they all occur simultaneously. Many-worlds supporters have proposed solutions to this problem, which do not satisfy Bricmont (and, indeed, myself), who emphasises that this is not a problem for the de Broglie–Bohm theory.

A chapter is also dedicated to a brief discussion of philosophy, concentrating on the concept of realism and how it contrasts with idealism. Unsurprisingly, it concludes that realists want a theory describing what happens at the micro scale that accounts for predictions made at the macro scale – and that de Broglie–Bohm provide just such a theory.

The book concludes with an interesting account of the history of QM, including the famous Bohr–Einstein debate, the struggle of de Broglie and Bohm for recognition, and the influence of the politics of the time.

This is a clearly written and interesting book. It has been very well researched, containing more than 500 references, and I would thoroughly recommend it to anyone who has an undergraduate knowledge of physics and mathematics and an interest in foundational questions. Whether it actually lives up to its title is for each reader to judge.

● Alastair Rae, University of Birmingham, UK.



Bookshelf

Bose–Einstein Condensation and Superfluidity

By *L. Pitaevskii and S Stringari*

Oxford University Press

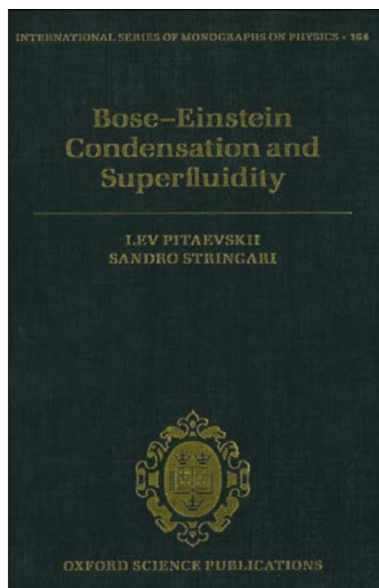
This book deals with the fascinating topics of Bose–Einstein condensation (BEC) and superfluidity. The main emphasis is on providing the formalism to describe these phases of matter as observed in the laboratory. This is far from the idealised studies that originally predicted BEC and are essential to interpret the experimental observations.

BEC was predicted in 1925 by Einstein, based on the ideas of Satyendra Nath Bose. It corresponds to a new phase of matter where bosons accumulate at the lowest energy level and develop coherent quantum properties at a macroscopic scale. These properties may correspond to phenomena that seem impossible from an everyday perspective. In particular, BEC lies behind the theory of superfluids, which are fluids that flow without dissipating energy and rotate without generating vorticity – if we except quantised vortices, which are a sort of topological defect.

Experimentally, the first BEC from dilute gases was observed in the laboratory in 1995, recognised by the 2001 Nobel Prize in Physics. Since then, there has been an explosion of interest and new results in the field. It is thus timely that two of its leading experts have updated and extended their volume on BEC to summarise the theoretical aspects of this phase of matter. The authors also describe in detail how superfluid phenomena can occur for Fermi gases in the presence of interactions.

The book is relatively heavy in formalism, which is justified by the wide range of phenomena covered in a relatively concise volume. It starts with some basics about correlation functions, condensation and statistical mechanics. Next, it delves into the simplest systems for which BEC can occur: weakly coupled dilute gases of bosonic particles. The authors describe different approaches to the BEC phase, including the works of Landau and Bogoliubov. They also introduce the Gross–Pitaevskii equation and show its importance in the description of superfluids. Superfluidity is explained in great detail, in particular the occurrence of quantised vortices.

The second part describes how to adapt the theoretical formalism introduced in the first part to realistic traps where BEC is observed. This is very important to connect theoretical descriptions to laboratory research, for instance to predict in which experimental configurations a BEC will appear and how to characterise it.



Part three deals with BEC in fermionic systems, which is possible if the fermions interact and pair-up into bosonic structures. These fermionic phases exhibit superfluid properties and have been created in the laboratory, and the authors consider fermionic condensates in realistic traps. The final part is devoted to new phenomena appearing in mixed bosonic–fermionic systems.

The book is a good resource for the theoretical description of BEC beyond the idealised configurations that are described in many texts. The concise style and large amount of notation requires constant effort from the reader, but seems inevitable to explain many of the surprising phenomena appearing in BECs. The book, perhaps combined with others, will provide the reader with a clear overview of the topic and latest theoretical developments in the field. The text is enhanced by the many figures and plots presenting experimental data.

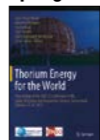
● *Diego Blas Temino, CERN.*

Books received

Thorium Energy for the World

By *J.-P Revol, M Bourquin, Y Kadi, E Lillestol, J.-C de Mestral and K Samec (eds)*

Springer



This book contains the proceedings of the Thorium Energy Conference (TheEC13), held in October 2013 at CERN, which brought together some of the world's leading experts on

thorium technologies. According to them, nuclear energy based on a thorium fuel cycle is safer and cleaner than the one generated from uranium. In addition, long-lived waste from existing power plants could be retrieved and integrated into the thorium fuel cycle to be transformed into a stable material while generating electricity.

The technology required to implement this type of fuel cycle is already being developed, nevertheless much effort and time is still needed.

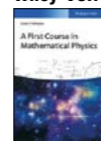
The TheEC13 conference saw the participation of high-level speakers from 30 countries, such as the Nobel prize laureates Carlo Rubbia and Jack Steinberger, the then CERN Director-General Rolf Heuer, and Hans Blix, former director-general of the International Atomic Energy Agency (IAEA), to name a few.

Collecting the contributions of the speakers, this book offers a detailed technical review of thorium-energy technologies from basic R&D to industrial developments, and is thus a tool for informed debates on the future of energy production and, in particular, on the advantages and disadvantages of different nuclear technologies.

A First Course in Mathematical Physics

By *Colm T Whelan*

Wiley-VCH



The aim of this book is to provide undergraduate students taking classes in the physical sciences with the fundamental mathematics tools they need to proceed with their studies.

In the first part the author introduces core mathematics, starting from basic concepts such as functions of one variable and complex numbers, and moving to more advanced topics including vector spaces, fields and operators, and functions of a complex variable.

The second part shows some of the copious applications of these mathematics tools to physics. When introducing complex physics laws and theories, including Maxwell's equations, special relativity and quantum theory, the author tries to present the material in an easily intelligible way. The author also emphasises the direct connection between the conceptual basis of these physics topics and the mathematical tools provided in the first part of the text.

Two appendices of formulas conclude the book. A large number of problems are included but the solutions are only made available on a password-protected website for lecturers.

Inside (Photo)story

Iconic Fermilab

Fermilab's founding director, Robert Wilson, wanted his new facility to look different from stereotypical government labs.



Broken Symmetry, painted black on one side and orange on the other, appears perfectly symmetrical when viewed directly from below.

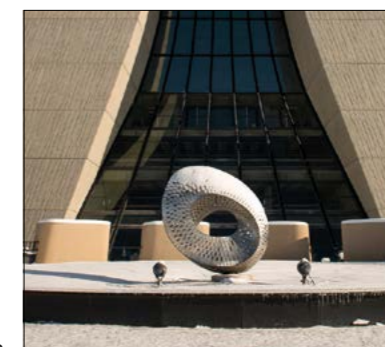
Fermilab's Wilson Hall, which is purposely reminiscent of the Beauvais Cathedral in France, is a striking landmark in the Chicago area. But it is not the only visual milestone the laboratory's first director left behind. While on sabbatical in 1961, Wilson studied sculpture at the Accademia di Belle Arti di Firenze in Italy. He did not want Fermilab to look like a standard government facility, and Fermilab has celebrated Wilson's role as an artist by featuring several of his sculptures.

Straddling the Pine Street entrance is Broken Symmetry (top right), a three-span arch, painted black on one side and orange on the other, appearing perfectly symmetrical when viewed from below, but with carefully calculated asymmetry visible from its other views.

Atop Ramsey Auditorium stands Wilson's Mobius Strip, which is made of three-by-five-inch pieces of stainless steel welded on a tubular form eight-feet tall (above right).

Gracing the expansive grassy area in front of the laboratory's Industrial Building Complex is Tractricious (above far right). This array of six-and-a-half-inch-diameter stainless-steel cryostat pipes, which were left over from construction of the Tevatron's magnets, is bunched together in the form of a paraboloid. Wilson derived the name Tractricious from tracktrix: a curve such that any tangent segment from the tangent point on the curve to the curve's asymptote has constant length.

Close to the Users' Center is The Tree, a sculpture Wilson created with Fermilab welders around 1970. But perhaps the most well known of Wilson's works of art is the



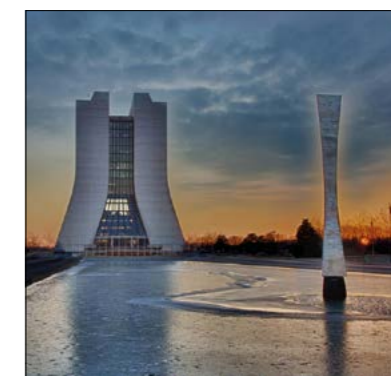
The Mobius Strip is mounted outside Ramsey Auditorium and is eight-feet tall.



Hyperbolic Obelisk (right), which stands at the foot of the reflecting pond in front of Wilson Hall. It is 32-feet high, fabricated from three stainless-steel plates each one-quarter-inch thick.

In the early 1990s, Wilson drew upon Frank Lloyd Wright's Prairie school of architecture for the design of the building for the Leon M Lederman Science Education Center. Other architectural landmarks at Fermilab include: the Feynman Computing Center, originally built as the lab's central computing facility; a concrete Archimedes Spiral covering the pumping stations at Casey's Pond; and Wilson's distinctive series of power-transmission-line poles, which resemble the Greek letter pi.

● *Paola Catapano, CERN.*



(Top) Tractricious is made from the scraps of Tevatron magnets. (Above) The Obelisk is made from three stainless steel plates.

CERN Courier Archive: 1974

A LOOK BACK TO CERN COURIER VOL. 14, JUNE 1974, COMPILED BY PEGGIE RIMMER

SUPERCONDUCTIVITY

Stanford Accelerator Conference

The sessions on superconductivity at the IXth International Conference on High Energy Accelerators, held at the Stanford Linear Accelerator Centre from 2–7 May, were somehow rather frustrating. For many years, the potential of superconductivity, both in radio-frequency and magnet applications, has seemed on the brink of opening new doors. A lot has been achieved in practical realisation and in increasing basic understanding but, for many factors important for the future big projects, it is extremely difficult to get convincing answers. There was a woolliness about many of the discussions which needs to be cleared up.

On the r.f. side, superconducting cavities could give high accelerating voltage gradients and low power absorption, allowing cavities to be operated for longer times resulting in high duty cycle linacs and separators. In r.f. conditions the losses do not disappear completely but fall exponentially with temperature near absolute zero. Hence there is interest in pushing temperatures lower than

is adequate for superconducting magnets. The currents flow in the surface layer of superconductors and the major problems have been concerned with achieving good quality surfaces in large r.f. structures and retaining their properties in operation.

The news of the work on superconducting magnets was equally frustrating. On the one hand, the past few years have seen d.c. superconducting magnets being brought into reliable operation at accelerators (for example, the Optique à Grande Acceptance OGA quadrupoles at Saclay and beam-line magnets at Berkeley and Brookhaven). These magnets have thousands of hours of physics use under their belts. Also many pulsed magnets have been through their paces in the laboratory with reasonable success.

On the other hand, all the magnets have exhibited training to some degree. In other words, we still do not manage to avoid small mechanical movements of the superconductor and because of this, a multi-magnet project would need to design

the machine for a field considerably lower than the optimum, since we would not be sure to what fields the magnets would “train”.

Among other factors which could lead to accepting lower performance figures is the temperature sensitivity of the superconductor. Under usual operating conditions, with niobium-titanium superconductor at liquid helium temperature of 4.2 K giving fields of about 4.5 T, fluctuations of a few tenths of a degree can flip the magnets out of their superconducting state. There is a need to develop other superconducting materials, such as vanadium-gallium or niobium-tin. These materials have a much higher critical temperature (about 17 K) and could be operated at higher current densities to give fields of 6 T or above with comfortable temperature stability. The materials are however extremely brittle and the metallurgical problems of using them are not yet solved.

● Compiled from texts on pp202–204.

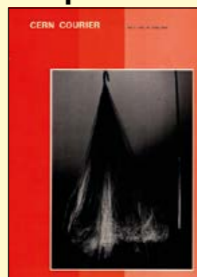
CERN NEWS

Not by physics alone doth man live...

(Top) The CERN rugby team won the final of the Swiss Cup on 26 May, having already taken the Swiss league championship for 1973–74. It was a strong year for CERN rugby – the reserve team also won their championship and the junior team won all the matches in its category.

(Bottom) Professor Jentschke, Director-General of CERN Lab I, fires the starting pistol for the annual team race around the CERN site. Forty-five teams raced on 29 May 1974. A Theory Division team won in 12 minutes 5 seconds, comfortably beating the track record.

Compiler's Note



Notwithstanding the somewhat pessimistic note struck at the Stanford Conference, in 1983 the first superconducting particle accelerator went into operation. The Tevatron at Fermilab was a 6.3 km circular synchrotron with 990 magnets at 4.4 K giving fields of 4.4 T. In 1995, the first large-scale superconducting r.f. accelerator came on air. The Continuous Electron Beam Accelerator Facility (CEBAF) at the Jefferson Lab consisted of two linacs with 1.5 GHz Nb cavities operating at 2 K. And in 2008, CERN's Large Hadron Collider (LHC) became the largest scientific instrument in the world. Around the 27 km circumference, 1706 main superconducting magnets cooled to 1.9 K provided fields of 8.3 T.

The CERN Rugby Club – now the Rugby Club of CERN, Meyrin and St Genis (RC CMSG) – is one of the oldest in Switzerland and today it has male and female teams across all ages who take part in the Swiss leagues. Players span 23 nationalities, representing almost a quarter of the 100 or so countries that play the game worldwide. The CERN annual relay race also remains a popular social event, organised by the Running Club and Staff Association. In May 2016, 127 teams competed, with the winners scoring a record time of 10 minutes 19 seconds.



● Compiled from text on p212.

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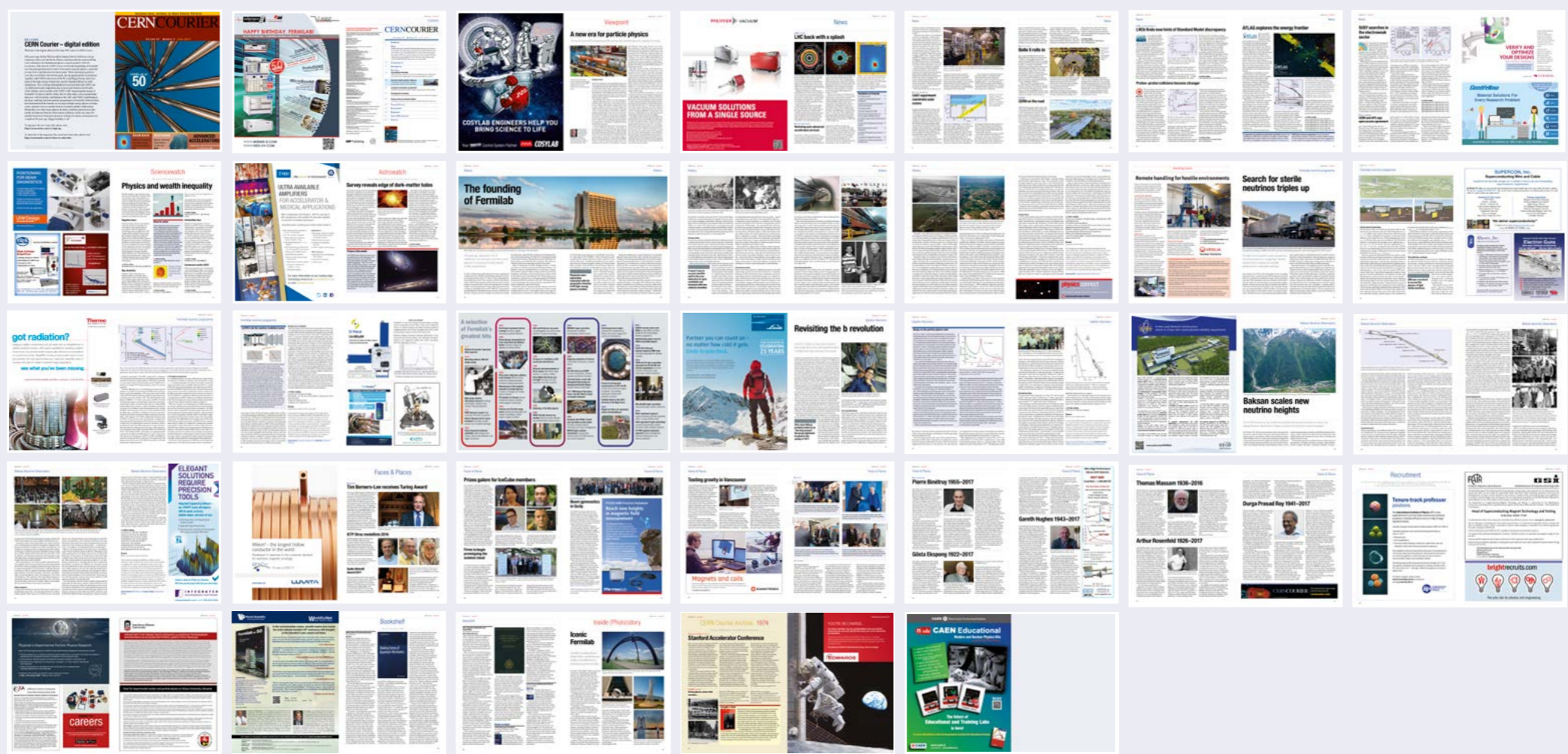


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VOLUME 57 NUMBER 5 JUNE 2017

Contents

5 **VIEWPOINT**

7 **NEWS**

• LHC back with a splash • Workshop puts advanced accelerators on track • CAST experiment constrains solar axions • Belle II rolls in • CERN on the road • LHCb finds new hints of Standard Model discrepancy • Proton–proton collisions become stranger • ATLAS explores the energy frontier • SUSY searches in the electroweak sector • CERN and APS sign open access agreement

15 **SCIENCEWATCH**

17 **ASTROWATCH**

18 **FEATURES**

The founding of Fermilab

Fifty years ago, physicists in the US established a new laboratory and with it a new approach to carrying out frontier research.

Search for sterile neutrinos triples up

Fermilab's short-baseline neutrino programme targets sterile neutrinos.

A selection of Fermilab's greatest hits

Timeline showing Fermilab's major experimental achievements.

Revisiting the b revolution

A look back at the Fermilab experiment that unearthed the b quark.

39 **Baksan scales new neutrino heights**

The Baksan Neutrino Observatory celebrates 50 years of success.

45 **FACES & PLACES**

55 **RECRUITMENT**

59 **BOOKSHELF**

61 **INSIDE (PHOTO)STORY**

62 **ARCHIVE**

CERN COURIER

VOLUME 57 NUMBER 5 JUNE 2017



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