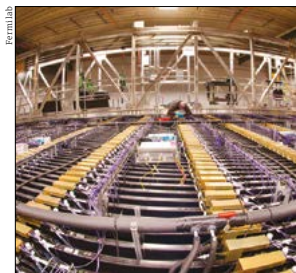


NEWS DIGEST



The NOvA far detector.

NOvA joins supernova watch

The NOvA experiment in the US, designed to study neutrino oscillations in a beam produced at Fermilab, has joined the Supernova Early Warning System (SNEWS). SNEWS is a global network of neutrino experiments that has been running in automated mode since 2005 to catch core-collapse supernovae in our galaxy – which occur a handful of times each century. NOvA joins other detectors including Super-K in Japan, IceCube at the South Pole, Borexino in Italy, Daya Bay in China, and HALO in Canada. The next step for SNEWS is to embrace the world of multi-messenger astronomy by linking with the LIGO and VIRGO gravitational-wave detectors. Potential collaborators are invited to join a SNEWS workshop at SNOLAB, Canada, in June.

ϕ boson where art thou

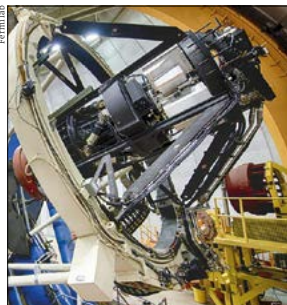
The CDF collaboration at Fermilab in the US has set the most stringent limits to date on the existence of a spin-zero particle called the ϕ boson. Such bosons arise, for example, in minimal supersymmetric extensions of the Standard Model and would be expected to decay predominantly into a pair of b quarks. A previous CDF analysis observed a 3 σ excess of events with respect to the expected background at a ϕ mass of 150 GeV/c². The new CDF search excludes such a signal at 95% confidence, setting upper limits ranging from 20 to 2 pb for the product of production cross-sections times branching fraction for a ϕ boson with mass between 100 and 300 GeV/c² (arXiv.org/1902.04683).

ADMX Sidecar explores ALPs

The Axion Dark Matter Experiment (ADMX) at the University of Washington in the US has reported results from a pathfinder experiment, ADMX “Sidecar”, which is designed to pave the way for future, higher mass, searches. Axions are cold dark-matter candidates that were originally postulated to solve the strong CP problem of the Standard Model. ADMX searches for them by looking for the resonant conversion of dark-matter axions to microwave photons in a strong magnetic field (known as the inverse Primakoff effect). The experiment has already excluded axion masses near 3 μ eV, and its Sidecar pathfinder has now demonstrated that the same technique can be used to search for axion-like particles with masses up to 30 μ eV (arXiv:1901.00920).

DES completes data-taking

The Dark Energy Survey (DES) – which began mapping a 5000-square-degree area of the sky in August 2013 – completed taking data on 9 January. Using the 520-megapixel Dark Energy Camera (below) mounted on the 4-metre Blanco telescope at the Cerro Tololo Inter-American Observatory in Chile, the Fermilab-hosted project took data on 758 nights over six years, recording data from more than 300 million distant galaxies. The DES collaboration has already released a full range of papers based on its first year of data, and will now focus on producing results from its six years of data.



The Dark Energy Camera is mounted on the 4-metre Blanco telescope.

BESIII amasses record J/ψ dataset

On 11 February, the BESIII experiment at the Beijing Electron Positron Collider in China finished accumulating a sample of 10 billion J/ψ events – the world’s largest dataset produced directly from electron-positron annihilations. Decays of the J/ψ particle offer a clean laboratory for studying exotic hadrons composed of light quarks and gluons, including those composed of pure gluons. With 1.3 billion J/ψ events collected in 2009 and 2012, BESIII has reported many such studies. The record J/ψ -event data sample – which adds the 8.7 billion events collected in 2017, 2018 and 2019 – will improve the precision of such studies.

New kaon decay observed

The NA48/2 experiment at CERN’s North Area has reported the first observation of the decay $K^+ \rightarrow \pi^+ \pi^0 e^+ e^-$, based on data recorded in 2003–2004. This radiative decay proceeds via a virtual photon which converts into an electron-positron pair, where the photon can be produced either by inner bremsstrahlung, where it is emitted by one of the charged mesons, or by direct emission at the weak vertex. The experimenters observed decays in a 60 GeV/c kaon beam passing through a 114 m tank, and used 4919 candidates to measure the branching ratio to be $4.24 \pm 0.14 \times 10^{-6}$. Several CP-violating asymmetries were investigated and found to be consistent with zero (arXiv:1809.02873).

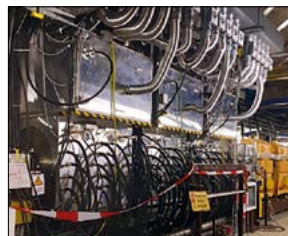
Skyrmion model revised

The skyrmion model in nuclear physics offers a way to determine the properties of nuclei from QCD, by describing the nucleus in terms of pions and linking the number of twists – or skyrmions – in the quantum field that the pions create with the number of nucleons. But the model yields nuclear binding energies that are an order of magnitude larger than nuclear data, and predicts shapes for nuclei that don’t match the clustering structure of light nuclei. Carlos Naya and Paul

Sutcliffe of Durham University in the UK have now shown that a modified version of the model that includes rho mesons, the next lightest subatomic mesons, can improve both of these features (Phys. Rev. Lett. **121** 232002).

FAIR progress with heavy ions

After a two-year-long shut down, the SIS18 heavy-ion synchrotron is back in action at GSI, Darmstadt, with upgraded cavities (below), power converters and shielding. SIS18 is the new fast-cycling booster synchrotron for FAIR, the international Facility for Antiproton and Ion Research (CERN Courier July/August 2017 p41). FAIR will use beams from protons up to uranium ions with a wide range of intensities and energies to garner insights into the nuclear reactions that underpin the synthesis of heavy elements and other processes.



Three new radio-frequency cavities enable the acceleration of intermediate-charge-state heavy ions.

Dark photon search begins

A new dark-matter experiment, the Heavy Photon Search at Jefferson Lab in Virginia, is preparing to take first data. If dark matter is part of a hidden sector, it could couple to ordinary matter via so-called heavy photons. During a two-month run this summer, the collaboration hopes to create dark photons in bremsstrahlung radiation from 4.5 GeV electrons impinging on a heavy target. The experiment will search for bumps in the invariant mass spectrum of electron-positron pairs with vertices separated from the target, with sensitivity to masses of the order of a few hundred MeV.



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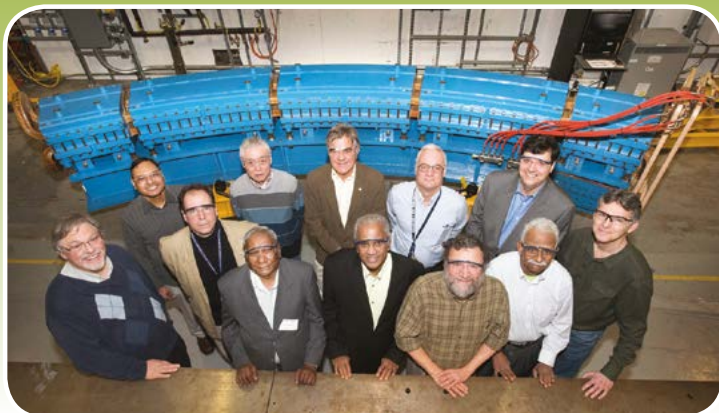
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Cyclotron	Energy (MeV)	Isotopes Produced
Best 15	15	¹⁸ F, ^{99m} Tc, ¹¹ C, ¹³ N, ¹⁵ O, ⁶⁴ Cu, ⁶⁷ Ga, ¹²⁴ I, ¹⁰³ Pd
Best 20u/25	20, 25–15	Best 15 + ¹²³ I, ¹¹¹ In, ⁶⁸ Ge/ ⁶⁸ Ga
Best 30u (Upgradeable)	30	Best 15 + ¹²³ I, ¹¹¹ In, ⁶⁸ Ge/ ⁶⁸ Ga
Best 35	35–15	Greater production of Best 15, 20u/25 isotopes plus ²⁰¹ Tl, ⁸¹ Rb/ ⁸¹ Kr
Best 70	70–35	⁸² Sr/ ⁸² Rb, ¹²³ I, ⁶⁷ Cu, ⁸¹ Kr + research

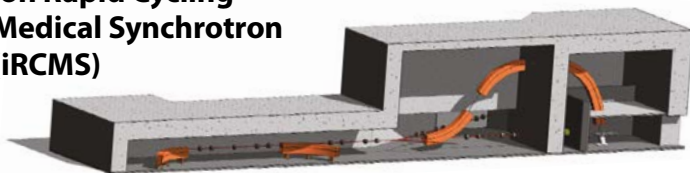


Proton-to-Carbon High Energy Particle Delivery System:

- Intrinsically small beams facilitating beam delivery with precision
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- Highly efficient single turn extraction
- Efficient extraction – less shielding
- Flexibility – protons and/or carbon, future beam delivery modalities



ion Rapid Cycling Medical Synchrotron (iRCMS)



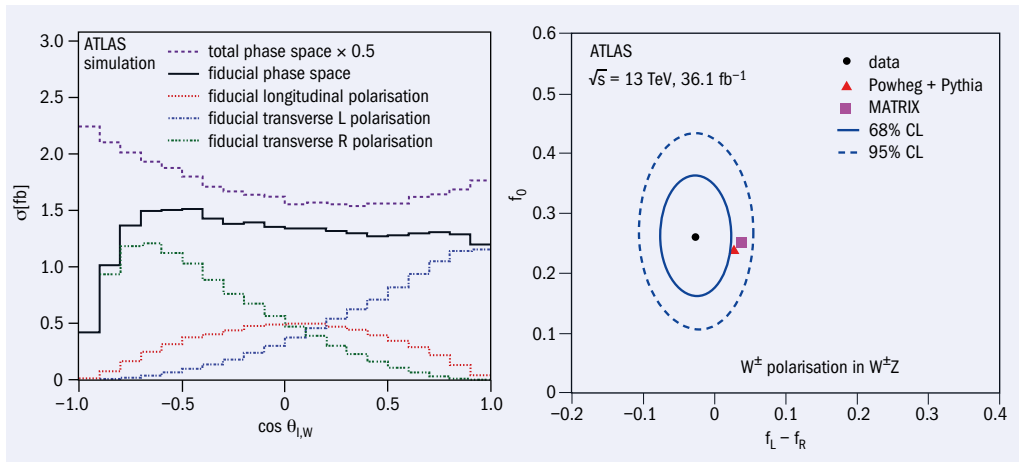
ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

ATLAS

Probing gauge–boson polarisation

Fig. 1. Left: simulated distributions of the cosine of the angle between the momentum of the W boson and that of its decay lepton for each W -boson polarisation state in WZ -production events. Right: new ATLAS measurements of longitudinal versus left minus right polarisation fractions of W bosons in WZ -production events.



Precision measurements of diboson processes at the LHC are powerful probes of the gauge structure of the Standard Model at the multi-TeV energy scale. Among the most interesting directions in the diboson physics programme is the study of gauge–boson polarisation. The existence of three polarisation states is predicted by the Standard Model. The transverse polarisation is composed of right- and left-handed states, with spin either parallel or antiparallel to the momentum vector of the boson. The third state, a longitudinally-polarised component, is generated when the W and Z bosons acquire mass through electroweak symmetry breaking, and is therefore under particular scrutiny.

New phenomena can alter the polarisation predicted by the Standard Model due to interference between new-physics amplitudes and diagrams with gauge–boson self-interactions. WZ production, with its clean experimental signature, offers a sensitive way to search for such anomalies by providing a direct probe of the WWZ gauge coupling, due to the s -channel “ Z -strahlung” contribution, where the W radiates a Z .

Building on precision WZ measurements previously reported by the ATLAS and CMS collaborations, a recent ATLAS result constitutes the most precise WZ measurement at a centre-of-mass energy of 13 TeV, and provides the first measurement of the polarisation of pair-produced vector bosons in hadron collisions. Based on 36.1 fb^{-1} of data collected in 2015 and 2016 by the ATLAS detector, and using leptonic decay modes of the gauge bosons to electrons or muons, ATLAS has achieved a precision of 4.5% for the WZ cross section measured in a fiducial phase space closely matching the detector acceptance. The kinematics of WZ events, including the underlying dynamics of accompanying hadronic jets, has been studied in detail by measuring the cross section as a function of several observables.

The polarisation states for W and Z bosons can be probed through distributions of the angle of the leptons relative to the bosons from which they decayed (figure 1, left). A binned profile-likelihood fit of templates describing the three helicity states allowed ATLAS to extract the W and Z polarisations in the fiducial measurement region. Because of the incomplete

The longitudinally-polarised component is generated when the W and Z bosons acquire mass through electroweak symmetry breaking

knowledge of the neutrino momentum originating from the W -boson decay, it is more difficult to measure the helicity fractions of the W than of the Z . The fraction of a longitudinally-polarised W boson in WZ events is found to be 0.26 ± 0.06 (figure 1, right), while the longitudinal fraction of the Z boson is found to be 0.24 ± 0.04 . The analysis leads to an observed significance of 4.2 standard deviations for the presence of longitudinally-polarised W bosons, and 6.5 standard deviations for longitudinally-polarised Z bosons.

Improved precision

The measurements are dominated by statistical uncertainties, but future datasets will improve precision and allow the collaboration to probe new-physics effects in events where both the Z and the W are longitudinally polarised. The ultimate target is to measure the scattering of longitudinally polarised vector bosons: this would be a direct test of electroweak symmetry breaking.

Further reading

ATLAS Collaboration 2019 arXiv 1902.05759 (submitted to *Eur. Phys. J. C*).

LHCb

Charm mixing tests the Standard Model

The Standard Model (SM) allows neutral flavoured mesons such as the D^0 to oscillate into their antiparticles. Having first observed this process in 2012, the LHCb collaboration has recently made some of the world's most precise measurements of this behaviour, which is potentially sensitive to new physics. The oscillation of the D^0 ($c\bar{u}$) into its antiparticle, the $\bar{D}^0$ ($\bar{c}u$), occurs through the exchange of massive virtual particles. These might include as-yet undiscovered particles, so the measurements are sensitive to non-Standard Model dynamics at large energy scales. By examining D^0 and $\bar{D}^0$ mesons separately, it is also possible to search for the violation of charge-parity (CP) symmetry in the charm sector. Such effects are predicted to be very small. Therefore, given LHCb's current level of experimental precision, any sign of CP violation would be a clear indication of physics beyond the Standard Model.

Due to quantum-mechanical mixing between the neutral charm meson's mass and flavour eigenstates, the probabilities of observing either it or its antiparticle vary as a function of time. This mixing can be described by two parameters, x and y , which relate the properties of the mass eigenstates: x is the normalised difference in mass, and y is the normalised difference in width, or inverse lifetime. The mixing rate is very slow, making these parameters difficult to measure. Isolating the differences between the D^0 and $\bar{D}^0$ mesons is an even greater challenge. For these two papers, LHCb was

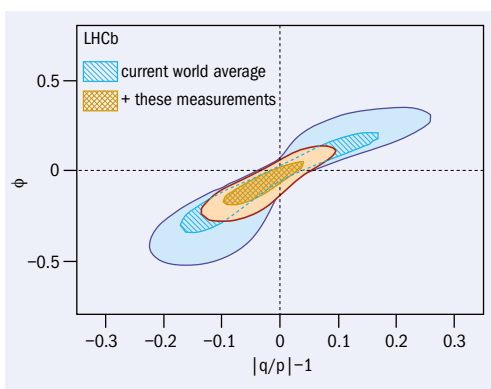


Fig. 1. Constraints on the parameters describing CP violation in charm mixing, showing the impact of LHCb measurements (orange). The 68% and 95% confidence regions are shown. Under the hypothesis of CP conservation, the expected value is (0,0).

able to achieve small statistical uncertainties thanks to the large samples of charm mesons collected during Run 1, and minimised systematic uncertainties by measuring ratios of yields to cancel detector effects.

In the first paper, LHCb physicists studied the effective lifetime of the mesons. As a consequence of mixing, the effective decay width to CP-even final states, such as K^+K^- and $\pi^+\pi^-$, differs from the average width measured in decays such as $D^0 \rightarrow K^- \pi^+$. The parameter y_{CP} , which in the limit of CP symmetry is equal to y , can be deduced from the ratio of decay rates to these two final states as a function of time. LHCb measured y_{CP} with the same

precision as all previous measurements combined, obtaining a value consistent with the world-average value of y .

In the second analysis, LHCb reconstructed D^0 decays into the final state $K_S^0 \pi^+ \pi^-$ to measure the parameter x , which had not previously been shown to differ from zero. In this mode, mixing manifests as small variations in the decay rate in different parts of phase space as a function of time. Measuring it requires good control over experimental effects as a function of both phase space and decay time. LHCb achieved this by measuring the ratios of the yields in complementary regions of phase space (mirrored in the Dalitz plane) as a function of time. The measured value of x is the world's most precise, and in combination with previous measurements there is now evidence that it differs from zero.

As well as the mixing itself, both analyses are also sensitive to mixing-induced CP violation. While CP violation was not observed, the limits on its parameters were greatly improved (figure 1). This is a good example of how different decay modes give complementary information and, when taken together, can have a big impact. LHCb will continue to perform measurements with additional modes and the larger samples collected in Run 2.

Further reading

LHCb Collaboration 2019 *Phys. Rev. Lett.* **122** 011802.

LHCb Collaboration 2019 LHCb-PAPER-2019-001 (in preparation).

CMS

CASTOR calorimetry delves into gluon saturation

The fundamental structure of nucleons is described by the properties and dynamics of their constituent quarks and gluons, as described by QCD. The gluon's self-interaction complicates this picture considerably. Non-linear recombination reactions, where two gluons fuse, are predicted to lead to a saturation of the gluon density. This largely unexplored phenomenon is expected to occur when the gluons in a hadron overlap transversally, and is enhanced for hadrons with high atomic numbers. Gluon saturation may be studied in lead-proton collisions at the LHC in the kinematic region where the gluon density is high and the gluons have siz-

able transverse dimensions.

Gluon saturation has been at the focal point of the heavy-ion community for decades. Precision measurements at HERA, RHIC and previously at the LHC agree with the predictions made by saturation models, however, the measurements do not allow an unambiguous interpretation of whether gluon saturation occurs in nature. This is a strong motivation both for the LHC experiments and for the planned Electron Ion Collider (CERN Courier October 2018 p31).

The CMS collaboration recently submitted a paper on gluon saturation in proton-lead collisions to the *Journal of High Energy Physics (JHEP)*. The collisions

Non-linear recombination reactions, where two gluons fuse, are predicted to lead to a saturation of the gluon density

that were used for this analysis occurred in 2013 at a centre-of-mass energy of 5 TeV and were detected using the CMS experiment's CASTOR calorimeter. This is a very forward calorimeter of CMS, where "forward" refers to regions of the detector that are close to the beam pipe. Therefore, unlike any other LHC experiment, CMS can measure jets at very forward angles ($-6.6 < \eta < -5.2$) and with transverse momenta (p_T) as low as 3 GeV. This is the first time that a jet-energy spectrum measurement from the CASTOR calorimeter has been submitted to a journal.

Forward jets with a small p_T can target high-density-regime gluons with ample transverse dimensions, making

CASTOR ideal for a study of gluon saturation. By colliding protons with lead ions, the sensitivity of the CASTOR jet spectra to saturation effects was further enhanced. This enabled CASTOR to overcome the ambiguity associated with the interpretation of the previous measurements.

The jet-energy spectrum obtained using CASTOR was compared to two saturation models (figure 1, left). These were the “Katie KS” model and predictions from the AAMQS collaboration; the latter are based on the colour-glass-condensate model. In the Katie KS model, the strength of the non-linear gluon recombination reactions can be varied. Upon comparison with the model, it was seen that the linear and non-linear predictions differed by an order of magnitude for the lowest energy bins of the spectrum, which correspond to low- p_T jets. Meanwhile, they converged at the highest energies, confirming the high sensitivity of the measurement to gluon saturation. The AAMQS predictions underestimated the data progressively, up to an order of magnitude, in the region most strongly affected by saturation. Overall, neither model described the spectrum correctly.

The spectrum was also compared to two cosmic ray models (EPOS-LHC and QGSJETII-04) and to the HIJING event

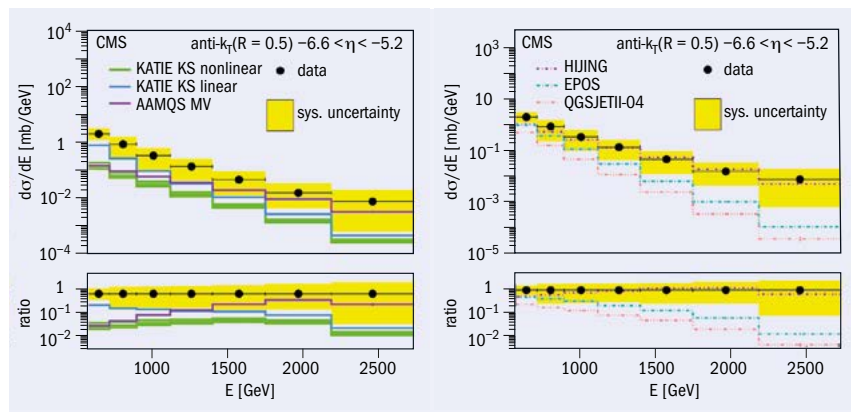


Fig. 1. Left: The differential jet cross section as a function of jet energy as measured in the CASTOR calorimeter, for data, the Katie KS model and AAMQS predictions. Right: The differential jet cross section as a function of jet energy as measured in the CASTOR calorimeter, for data, cosmic ray models and HIJING.

generator (figure 1, right). The former models underestimated the data by over two orders of magnitude while HIJING, which incorporates an implementation of nuclear shadowing, agreed well with the data. Nuclear shadowing is an interference effect between the nucleons of a heavy ion. Like gluon saturation, it is expected to lead to a decrease in the probability for a proton-lead collision to occur, however further data analysis is

required for more definite conclusions on nuclear shadowing.

These results establish CASTOR jets as an experimental reality and their sensitivity to saturation effects is encouragement for further, more refined CASTOR jet studies.

Further reading

CMS Collaboration 2018 arXiv 1812.01691 (submitted to *JHEP*).

ALICE

Bottomonium suppression in lead-lead collisions

The study of the production of quarkonia, the bound states of heavy quark-antiquark pairs, is an important goal of the ALICE physics programme. The quarkonium yield is suppressed in heavy-ion collisions when compared with proton-proton collisions because the binding force is screened by the hot and dense medium. This suppression is expected to be greatest for events with high “centrality”, when the heavy ions collide head-on.

The ALICE collaboration has recently analysed the suppression of inclusive bottomonium ($b\bar{b}$) production in lead-lead collisions relative to proton-proton collisions. This reduction is quantified in terms of the nuclear modification factor R_{AA} , which is the ratio of the measured yield in lead-lead to proton-proton collisions corrected by the number of binary nucleon-nucleon collisions. An R_{AA} value of unity would indicate no suppression whereas zero indicates full suppression. The bottomonium states $\Upsilon(1S)$ and $\Upsilon(2S)$ were measured via their decays to muon pairs at a centre-of-mass energy

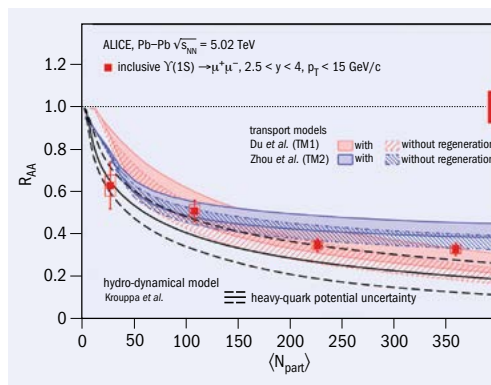


Fig. 1. Inclusive $\Upsilon(1S)$ R_{AA} as a function of centrality. The vertical error bars and the boxes represent the statistical and uncorrelated systematic uncertainties, respectively. The relative correlated uncertainty is shown as a red box at unity. The results are compared with predictions from two transport models and a hydrodynamical model.

per nucleon-nucleon pair of 5.02 TeV, in the rapidity range $2.5 < \eta < 4$, with a maximum transverse momentum of

15 GeV/c. No significant variation of R_{AA} is observed as a function of transverse momentum and rapidity, however, production is suppressed with increasing centrality (figure 1). A decrease in R_{AA} from $0.60 \pm 0.10(\text{stat}) \pm 0.04(\text{syst})$ for the peripheral 50–90% of collisions to $0.34 \pm 0.03(\text{stat}) \pm 0.02(\text{syst})$ for the 0–10% most central collisions was observed.

Theoretical models must deal with the competing effects of melting and (re)generation of the Υ within the quark-gluon plasma, the shadowing of parton densities in the initial state and “feed-down” from higher resonance states. Due to uncertainties on the parton density, is not yet known whether the direct production of $\Upsilon(1S)$ is suppressed, or merely the feed-down from $\Upsilon(2S)$ and other higher-mass states. Nevertheless, the precision of these measurements imposes significant new constraints on the modelling of Υ production in lead-lead collisions.

Further reading

ALICE Collab. 2019 *Phys. Lett. B* **790** 89.

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FIELD NOTES

Reports from events, conferences and meetings

BaBAR COLLABORATION

BaBar celebrates its 25th anniversary

On 11 December 2018, 25 years after its inaugural meeting, the BaBar collaboration came together at the SLAC National Accelerator Laboratory in California to celebrate its many successes. David Hitlin, BaBar's first spokesperson, described the inaugural meeting of what was then called the Detector Collaboration for the PEP-II "asymmetric" electron-positron collider, which took place at SLAC at the end of 1993. By May 1994 the collaboration had chosen the name BaBar in recognition of its primary goal to study CP violation in the neutral $B-\bar{B}$ meson system. Jonathan Dorfan, PEP-II project director, recounted how PEP-II was constructed by SLAC, LBL and LLNL. Less than six years later, PEP-II and the BaBar detector were built and the first collision events were collected on 26 May 1999. Twenty-five years on, and BaBar has now chalked up more than 580 papers on CP violation and many other topics.

The "asymmetric" descriptor of the collider refers to Pier Oddone's concept of using unequal electron and positron beam energies – tuned to 10.58 GeV, the mass of the $Y(4S)$ meson and just above the threshold for producing a pair of B mesons. This relativistic boost enabled measurements of the distance between the points where the mesons decay, which is critical for the study of CP violation. Equally critical was the entanglement of the B meson and anti-B meson produced in the $Y(4S)$ decay, as it marked whether it was the B^0 or $\bar{B}^0$ that decayed to the same CP final state by tagging the flavour of the other meson.

By October 2000 PEP-II had achieved its design luminosity of $3 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ and less than a year later BaBar published its observation of CP violation in the B^0 meson system based on a sample of 32×10^6 pairs of $B^0-\bar{B}^0$ mesons – on the same day that Belle, its competitor at Japan's KEK laboratory, published the same observation. These results led to Makoto Kobayashi and Toshihide Maskawa sharing the 2008 Nobel Prize in Physics. The ultimate luminosity achieved by PEP-II, in 2006, was $1.2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. BaBar continued to



Collegial team
Participants of the BaBar 25th anniversary event.

collect data on or near the $Y(4S)$ meson until 2007 and in 2008 collected large samples of $Y(2S)$ and $Y(3S)$ mesons before PEP-II was shut down. In total, PEP-II produced 471×10^6 $B-\bar{B}$ pairs for BaBar studies – as well as a myriad of other for other investigations.

The anniversary event also celebrated technical innovations, including "trickle injection" of beam particles into PEP-II, which provided a nearly 40% increase in integrated luminosity; BaBar's impressive particle identification, made possible by the DIRC detector; and the implementation of a computing model – spurred by PEP-II delivering significantly more than design luminosity – whereby countries provided in-kind computing support via large "Tier-A" centres. This innovation paved the way for CERN's Worldwide LHC Computing Grid.

Notable physics results from BaBar include the first observation in 2007 of $D-\bar{D}$ mixing, while in 2008 the collaboration discovered the long-sought η_c , the lowest energy particle of the bottomonium family. The team also searched for lepton-flavour violation in tau-lepton decays, publishing in 2010 what remain the most stringent limits on $\tau \rightarrow \mu \gamma$ and $\tau \rightarrow e \gamma$ branching fractions. In 2012, making it onto *Physics World*'s top-ten physics results of the year, the BaBar collabora-

tion made the first direct observation of time-reversal violation by measuring the rates at which the B^0 meson changes quantum states. Also published in 2012 was evidence for an excess of $\bar{B} \rightarrow D^{(*)} \tau^- \bar{\nu}_\tau$ decays, which challenges lepton universality and is an important part of the current Belle II and LHCb physics programmes. Several years after data-taking ended, it was recognised that BaBar's data could also be mined for evidence of dark-sector objects such as dark photons, leading to the publication of two significant papers in 2014 and 2017. Another highlight, published last year, is a joint BaBar-Belle paper that resolved an ambiguity concerning the quark-mixing unitarity triangle.

Although BaBar stopped collecting data in 2008, this highly collegial team of researchers continues to publish impactful results. Moreover, BaBar alumni continue to bring their experience and expertise to subsequent experiments, ranging from ATLAS, CMS and LHCb at the LHC, Belle II at SuperKEKB, and long-baseline neutrino experiments (T2K, DUNE, HyperK) to dark-matter (LZ, SCDMS) and dark-energy (LSST) experiments in particle astrophysics.

J Michael Roney University of Victoria
and **David MacFarlane** SLAC.

The BaBar collaboration made the first direct observation of time-reversal violation

FIELD NOTES

PHYSICS BEYOND COLLIDERS

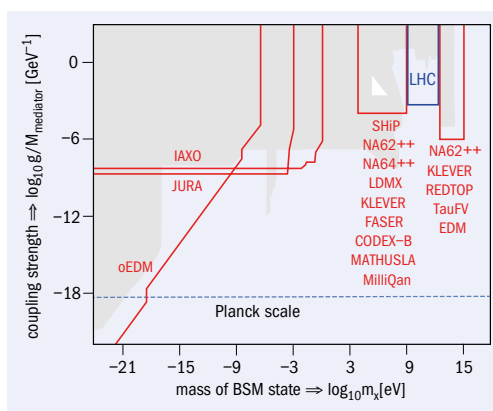
PBC initiative presents main findings

In a workshop held at CERN on 16–17 January, researchers presented the findings of the Physics Beyond Colliders (PBC) initiative, which was launched in 2016 to explore the opportunities at CERN via projects complementary to the LHC and future colliders (CERN Courier November 2016 p28). PBC members have weighed up the potential for such experiments to explore open questions in QCD and the existence of physics beyond the Standard Model (BSM), in particular including searches for signatures of hidden-sector models in which the conjectured dark matter does not couple directly to Standard Model particles.

The BSM and QCD groups of the PBC initiative have developed detailed studies of CERN's options and compared them to other worldwide possibilities. The results show the international competitiveness of the PBC options.

The Super Proton Synchrotron (SPS) remains a clear attraction, offering the world's highest-energy beams to fixed-target experiments in the North Area (see p34). The SPS high-intensity muon beam could allow a better understanding of the theoretical prediction of the muon anomalous magnetic moment (MuonE project), and a significant contribution to the resolution of the proton radius puzzle by COMPASS(R_p). The NA61 experiment could explore QCD in the interesting region of “criticality”, while upgrades of NA64, and a few months of NA62 operation in beam-dump mode (whereby a target absorbs most of the incident protons and contains most of the particles generated by the primary beam interactions) would explore the hidden-sector parameter space. In the longer term, the KLEVER experiment could probe rare decays of neutral kaons, and NA60 and DIRAC could enhance our understanding of QCD.

A novel North Area proposal is the SPS Beam Dump Facility (BDF). Such a



New domains The new-physics domains explored by PBC-proposed projects as a function of mass scale and coupling strength, showing full complementarity between precision measurements and rare decays at high mass, SPS beam-dump-like experiments at intermediate mass, and non-accelerator axion experiments at low mass.

facility could, in the first instance, serve the SHiP experiment, which would perform a comprehensive investigation of the hidden sector with discovery potential in the MeV–GeV mass range, and the TauV experiment, which would search for forbidden τ decays. The BDF team has made excellent progress with the facility design and is preparing a comprehensive design study report. Options for more novel exploitation of the SPS have also been considered: proton-driven plasma-wakefield acceleration of electrons for a dark-matter experiment (AWAKE++); the acceleration and slow extraction of electrons to light-dark-matter experiments (eSPS); and the production of well-calibrated neutrinos via a muon decay ring (nuSTORM).

Fixed-target studies at the LHC are also considered within PBC, and these could improve our understanding of QCD in regions where it is relevant

for new-physics searches at the high-luminosity LHC upgrade. The LHC could also be supplemented with new experiments to search for long-lived particles, and PBC support for a small experiment called FASER has helped pave the way for its installation in the ongoing long shutdown of CERN's accelerator complex.

2018 was a notable year for the gamma factory, a novel concept that would use the LHC to produce intense gamma-ray beams for precision measurements and searches (CERN Courier November 2017 p7). The team has already demonstrated the acceleration of partially stripped ions in the LHC, and is now working towards a proof-of-principle experiment in the SPS. Meanwhile, the Electric Dipole Moment (CPEDM) collaboration has continued studies, supported by experiments at the COSY synchrotron in Germany (CERN Courier September 2016 p27), towards a prototype storage ring to measure the proton EDM.

The PBC technology team has also been working to leverage CERN's skills base to novel experiments, for example by exploring synergies across experiments and collaboration in technologies – in particular, concerning light-shining-through-walls experiments and QED vacuum-birefringence measurements.

Finally, some PBC projects are likely to flourish outside CERN: the IAXO axion helioscope, now under consideration at DESY; the proton EDM ring, which could be prototyped at the Jülich laboratory, also in Germany; and the REDTOP experiment devoted to η meson rare decays, for which Fermilab in the US seems better suited.

The PBC groups have submitted their full findings to the European Particle Physics Strategy Update (<http://pbc.web.cern.ch/>).

Joerg Jaeckel Heidelberg University, **Mike Lamont** CERN and **Claude Vallée** CPPM Marseille.

The Super Proton Synchrotron remains a clear attraction

COMHEP

Colombian students analyse LHC data

The annual Colombian national high-energy physics conference (COMHEP), held this year in the city of Cali, provided an opportunity for youngsters from the Tecnocentro “Somos Pacifico”, an out-of-school activity centre, to participate in a



Masterclass The students from the Cali Tecnocentro with coordinator Carlos Sandoval of ATLAS (fifth from right).

one-off masterclass analysing data from the LHC. The masterclass used the tools and setup from the International Particle Physics Outreach Group (IPPOG) international masterclasses, and was coordinated by ATLAS member Carlos Sandoval from the Universidad Antonio Nariño in Bogotá, and included a virtual visit to the ATLAS control room. The Tecnocentro is in a disadvantaged area of Cali, many of whose inhabitants have been displaced from the countryside by civil conflict.

CLIC WORKSHOP

CLIC collaboration considers collider's potential

The annual workshop of the Compact Linear Collider (CLIC), a proposed multi-TeV linear electron-positron collider at CERN, attracted more than 200 participants to CERN on 21–25 January. CLIC occupies a unique position in both the precision and energy frontiers, combining the benefits of electron-positron collisions with the possibility of multi-TeV collision energies. It uses a two-beam acceleration scheme based on novel, high-gradient X-band accelerating structures, and envisions a three-stage implementation with a collision energy stepping from 380 GeV to 3 TeV and a diverse physics programme spanning 30 years (CERN Courier November 2016 p21).

Key CLIC concepts such as drive-beam production and operation of high-efficiency radio-frequency cavities have all been demonstrated, reported Steinar Stapnes, CLIC project leader. “The CLIC project offers a cost-effective and innovative technology, and is ready to proceed towards a Technical Design Report, enabling the start of construction for the first stage by 2026 and realising electron-positron collisions at 380 GeV as soon as 2035,” he said.

A major focus for the CLIC collaboration during 2018 was the completion of a project implementation plan, as well as several comprehensive CERN Yellow Reports describing the accelerator, detector and detailed physics studies. A central point was an updated cost and power estimate, which for the 380 GeV stage amount to around 5.9 billion Swiss francs and 168 MW. Workshop participants also discussed



Facing the future
Participants of the CLIC workshop in January 2019.

the next important step for CLIC: a preparatory phase focusing on large-scale tests, industrial production and civil-engineering aspects including siting and infrastructure.

An overview of potential industrial involvement in CLIC's core technologies is also being compiled. Several partner agreements support technical developments for smaller X-band accelerators, including the European Commission's CompactLight study and the recently proposed eSPS project that would see a 3.5 GeV X-band electron linac feeding the Super Proton Synchrotron for further acceleration, followed by slow extraction to study dark-sector physics. The linear tunnel of CLIC also provides a natural infrastructure for long-term future projects based on plasma-wakefield and other acceleration techniques.

Concerning CLIC detector R&D, the latest test-beam analysis and simulation results show promise for meeting the challenging CLIC vertex and tracker

requirements. The next generation of detector assemblies will be tested at DESY in Hamburg, where the CLICdp vertex and tracker group will be welcomed for several weeks during the current long shutdown of CERN's accelerators.

CLIC's physics programme generated rich discussions at the January workshop. In particular the Higgs self-coupling, which determines the shape of the Higgs potential, can be directly accessed at the multi-TeV collisions at CLIC via double-Higgs production. A dedicated mini-workshop jointly set up by theorists and experimentalists covered CLIC's potential to extend our knowledge of physics beyond the Standard Model, including possible compositeness of the Higgs boson and dark-matter candidates such as the thermal Higgsino and axion-like particles. The full physics case, designs, costs and timescales for CLIC were submitted to the European Strategy for Particle Physics Update in December.

Rickard Ström CERN.

CUWiP

Supporting future female physicists

The Conferences for Undergraduate Women in Physics (CUWiP) are three-day regional events for undergraduate physics students run by the American Physical Society and many volunteers. Their goal is to provide female students with resources and motivation to support their pursuit of a degree and a career in physics, and is addressed in many ways, including inspirational talks by female physicists and workshops and panel discussions on graduate school and physics careers. This year's CUWiP took place on 18–20 January at 12



universities across the US and Canada, which collectively hosted a record number of attendees. The keynote speaker, CERN Director-General Fabiola Gianotti, delivered her talk from CERN titled “Why a Professional Life in Physics?” She gave details of her path to becoming a physicist – which included her study

Thirst for knowledge
Attendees of the 2019 CUWiP conference for women in physics.

of humanities, constant curiosity as a child, and continuous thirst for knowledge – and expressed that it does not matter if you had a late start in physics as long as you have a passion.

Kai Wright and Theodore Hodapp
American Physical Society.

FIELD NOTES

HIGGS COUPLINGS

Higgs workshop returns to Tokyo

The seventh in the series of Higgs Couplings workshops, which began in Tokyo in 2012, returned to the Japanese capital on 26–30 November 2018. Lively discussions between experimentalists and theorists have been a strength of the meeting since the beginning. The 2018 workshop attracted more than 130 participants and included 49 plenary talks, 35 parallel talks and 18 talks by young scientists, covering a broad range of Higgs–boson physics.

On the experiments side, measurements of the Higgs–boson mass, width, couplings, spin and parity were discussed. In particular, the recent confirmation of the top and bottom Yukawa couplings was presented, and effective field theory was described as the next phenomenological framework for parametrising measurements of the couplings. Additional Higgs–boson searches including dark-matter aspects were discussed, as were new data-analysis techniques such

Higgs highlights

Participants of Higgs Couplings 2018.



as boosted topology and machine learning. On the theory side, recent advances in higher-order calculations in precision Higgs phenomenology were presented.

The importance of future colliders for the measurement of Higgs–boson properties, including its self-coupling, was also highlighted. The high-luminosity LHC, the high-energy LHC, linear colliders such as the ILC, as well as future circular colliders, were discussed. Many prospective results from these colliders were documented in CERN Yellow Reports submitted to the European Strategy for Particle Physics Update, and were reported for the first time at the workshop.

There was also a special session on “beyond collider” studies, which

underlined the synergies with collider experiments and featured recent results from gravitational-wave observatories and cosmic-microwave-background experiments.

The conference also included a young scientists’ forum, which saw many excellent talks. Finally, the Japanese traditional ceremony of Kagami biraki, in which a cask of sake is opened at a party or ceremony, celebrated the measurement of the top and bottom Yukawa couplings and of a new era in Higgs measurements.

The next Higgs Couplings workshop will be held in Oxford in the UK from 30 September to 4 October 2019.

Yuji Enari chair of the local organising committee of Higgs Couplings 2018.

HISTORY OF THE NEUTRINO

Paris event reflects on the history of the neutrino

Neutrinos, discovered in 1956, play an exceptional role in particle and nuclear physics, as well as astrophysics, and their study has led to the award of several Nobel prizes. In recognition of their importance, the first International Conference on the History of the Neutrino took place at the Université Paris Diderot in Paris on 5–7 September 2018.

The purpose of the conference, which drew 120 participants, was to cover the main steps in the history of the neutrino since 1930, when Wolfgang Pauli postulated its existence to explain the continuous energy spectrum of the electrons emitted in beta decay. Specifically, for each topic in neutrino physics, the aim was to pursue an historical approach and follow as closely as possible the discovery or pioneering papers. Speakers were chosen as much as possible for their roles as authors or direct witnesses, or as players in the main events.

The first session, “Invention of a new particle”, started with the prehistory of the neutrino – that is, the establishment of the continuous energy spectrum in beta



decay – before moving into the discoveries of the three flavour neutrinos. The second session, “Neutrinos in nature”, was devoted to solar and atmospheric neutrinos, as well as neutrinos from supernovae and Earth. The third session covered neutrinos from reactors and beams including the discovery of neutral-current neutrino interactions, in which the neutrino is not transformed into another particle like a muon or an electron. This discovery was made in 1973 by the Gargamelle bubble chamber team at CERN after a race with the HPWF experiment team at Fermilab.

The major theme of neutrino oscillations from the first theoretical ideas of Bruno Pontecorvo (1957) to the Mikheyev–Smirnov–Wolfenstein effect (1985), which can modify the oscillations when neutrinos travel through matter, was complemented by talks on the discovery of neutrino oscillations by Nobel laureates Takaaki Kajita and Art McDonald. In 1998, the Super-Kamiokande exper-

History makers

Participants of the first International Conference on the History of the Neutrino.

iment, led by Kajita, observed the oscillation of atmospheric neutrinos, and in 2001 the Sudbury Neutrino Observatory experiment, led by McDonald, observed the oscillation of solar neutrinos.

The role of the neutrino in the Standard Model was discussed, as was its intrinsic nature. Although physicists have observed the rare process of double beta decay with neutrinos in the final state, neutrinoless double beta decay with no neutrinos produced has been searched for for more than 30 years because its observation would prove that the neutrino is Majorana-type (its own antiparticle) and not Dirac-type.

To complete the panorama, the conference discussed neutrinos as messengers from the wider universe, from the Big Bang to violent phenomena such as gamma-ray bursts or active galactic nuclei. Delegates also discussed wrong hints and tracks, which play a positive role in the development of science, and the peculiar sociological aspects that are common to particle physics and astrophysics.

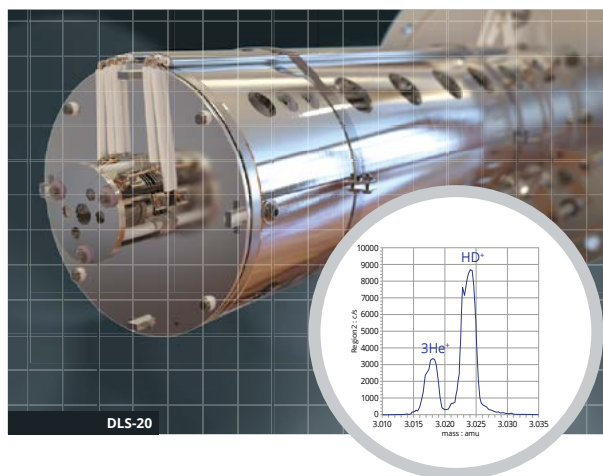
Following the conference, a website dedicated to the history of this fascinating particle was created: <https://neutrino-history.in2p3.fr>.

Michel Cribier APC Laboratory, Paris and CEA-Saclay, and **Daniel Vignaud** APC Laboratory, Paris.

Mass spectrometers for vacuum, gas, plasma and surface science

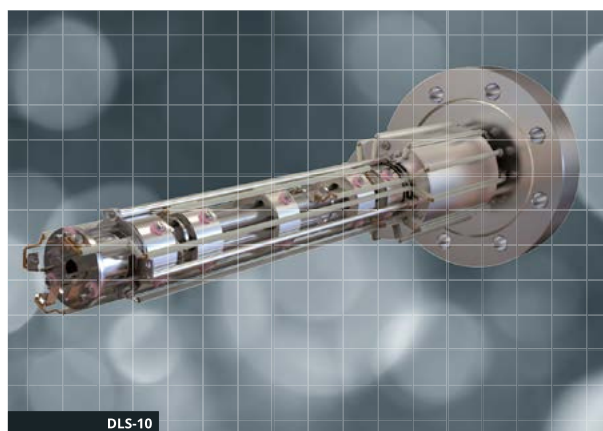


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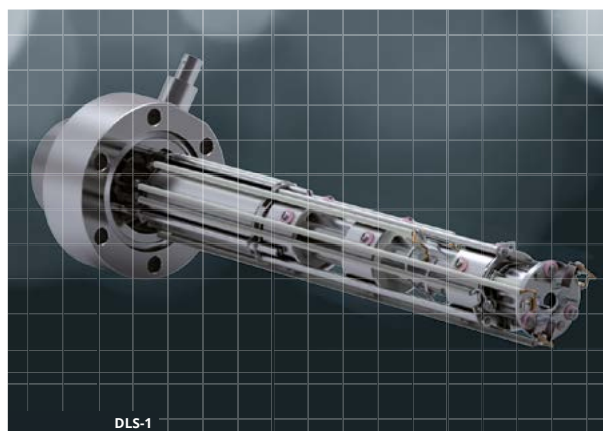
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OPEN SCIENCE

A vision for collaborative, reproducible and reusable research

Solving the challenges of sharing, reproducing and reusing results in particle physics seems more feasible than ever thanks to recent technological developments.

The goal of practising science in such a way that others can collaborate, question and contribute – known as “open science” – long predates the web. One could even argue that it began with the first academic journal 350 years ago, which enabled scientists to share knowledge and resources to foster progress. But the web offered opportunities way beyond anything before it, quickly transforming academic publishing and giving rise to greater sharing in areas such as software. Alongside the open-source (p27), open-access (p29) and open-data (p31) movements grew the era of open science, which aims to encompass the scientific process as a whole.

Today, numerous research communities, political circles and funding bodies view open science and reproducible research as vital to accelerate future discoveries.

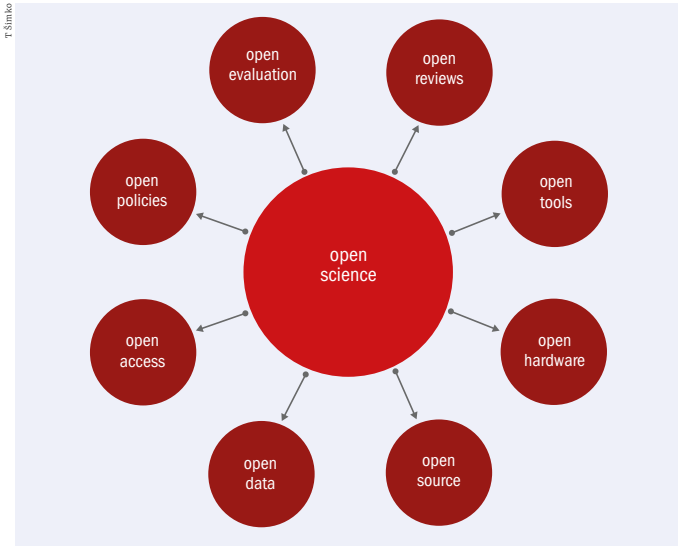
THE AUTHORS

**Sünje Dallmeier-Tiessen and
Tibor Šimko**
CERN.

Yet, to fully reap the benefits of open and reproducible research, it is necessary to start implementing tools to power a more profound change in the way we conduct and perceive research. This poses both sociological and technological challenges, starting from the conceptualisation of research projects, through conducting research, to how we ensure peer review and assess the results of projects and grants. New technologies have brought open science within our reach, and it is now up to scientific communities to agree on the extent to which they want to embrace this vision.

Particle physicists were among the first to embrace the open-science movement, sharing preprints and building a deep culture of using and sharing open-source software. The cost and complexity of experimental particle physics,

FEATURE OPEN SCIENCE

**Open movements**

Open science encompasses all aspects of how scientific research is governed, performed, shared, published and evaluated.

making complete replication of measurements unfeasible, presents unique challenges in terms of open data and scientific reproducibility. It may even be considered that openness itself, in the sense of having an unfettered access to data from its inception, is not particularly advantageous.

Take the existing data-management policies of the LHC collaborations: while physicists generally strive to be open in their research, the complexity of the data and analysis procedures means that data become publicly open only after a certain embargo period that is used to assess its correctness. The science is thus born “closed”. Instead of thinking about “open data” from its inception, it is more useful to speak about FAIR (findable, accessible, interoperable and reusable) data, a term coined by the FORCE11 community. The data should be FAIR throughout the scientific process, from being initially closed to being made meaningfully open later to those outside the experimental collaborations.

True open science demands more than simply making data available: it needs to concern itself with providing information on how to repeat or verify an analysis performed over given datasets, producing results that can be reused by others for comparison, confirmation or simply for deeper understanding and inspiration. This requires runnable examples of how the research was performed, accompanied by software, documentation, runnable scripts, notebooks, workflows and compute environments. It is often too late to try to document research in such detail once it has been published.

FAIR data repositories for particle physics, the “closed” CERN Analysis Preservation portal and the “open” CERN Open Data portal emerged five years ago to address the community’s open-science needs. These digital repositories enable physicists to preserve, document, organise and share datasets, code and tools used during analyses. A flexible metadata structure helps researchers to define everything from experimental configurations to data samples, from

analysis code to software libraries and environments used to analyse the data, accompanied by documentation and links to presentations and publications. The result is a standard way to describe and document an analysis for the purposes of discoverability and reproducibility.

Recent advancements in the IT industry allow us to encapsulate the compute environments where the analysis was conducted. Capturing information about how the analysis was carried out can be achieved via a set of runnable scripts, notebooks, structured workflows and “containerised” pipelines. Complementary to data repositories, a third service named REANA (reusable analyses) allows researchers to submit parameterised computational workflows to run on remote compute clouds. It can be used to reinterpret preserved analyses but also to run “active” analyses before they are published and preserved, with the underlying philosophy that physics analyses should be automated from inception so that they can be executed without manual intervention. Future reuse and reinterpretation starts with the first commit of the analysis code; altering an already-finished analysis to facilitate its eventual reuse after publication is often too late.

Full control

The key guiding principle of the analysis preservation and reuse framework is to leave the decision as to when a dataset or a complete analysis is shared, privately or publicly, in the hands of the researchers. This gives the experiment collaborations full control over the release procedures, and thus fully supports internal processing and review protocols before the results are published on community services, such as arXiv, HEPData and INSPIRE.

The CERN Open Data portal was launched in 2014 amid a discussion as to whether primary particle-physics data would find any use outside of the LHC collaborations. Within a few years, the first paper based on open data from the CMS experiment was published (see p31).

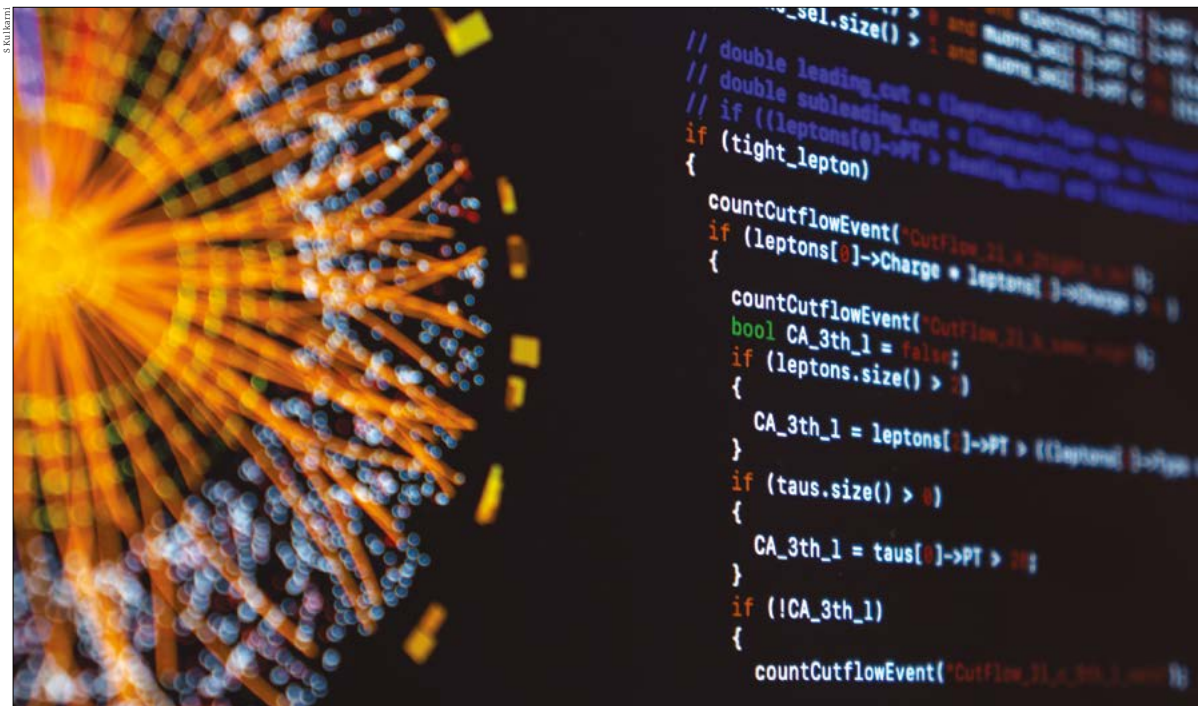
Three decades after the web was born, science is being shared more openly than ever and particle physics is at the forefront of this movement. As we have seen, however, simple compliance with data and software openness is not enough: we also need to capture, from the start of the research process, runnable recipes, software environments, computational workflows and notebooks. The increasing demand from funding agencies and policymakers for open data-management plans, coupled with technological progress in information technology, leads us to believe that the time is ripe for this change.

Sharing research in an easily reproducible and reusable manner will facilitate knowledge transfer within and between research teams, accelerating the scientific process. This fills us with hope that three decades from now, even if future generations may not be able to run our current code on their futuristic hardware platforms, they will be at least well equipped to understand the processes behind today’s published research in sufficient detail to be able to check our results and potentially reveal something new. ●

Further reading

X Chen *et al.* 2019 *Nat. Phys.* 15 113.

True open science demands more than simply making data available



The well-established governance, licensing and collaborative mechanisms of open-source software set a standard for open-science movements.

Open-source has its roots in the free software movement, which grew in the 1980s in response to monopolising corporations and restrictions on proprietary software. The underlying ideal is open collaboration: peers freely, collectively and publicly build software solutions. A second ideal is recognition, in which credit for the contributions made by individuals and organisations worldwide is openly acknowledged. A third ideal concerns rights, specifically the so-called four freedoms granted to users: to use the software for any purpose; to study the source code to understand how it works; to share and redistribute the software; and to improve the software and share the improvements with the community. Users and developers therefore contribute to a virtuous circle in which software is continuously improved and shared towards a common

Today, 20 years after the term “open source” was coined, and despite initial resistance from traditional software companies, many successful open-source business models exist. These mainly involve consultancy and support services for software released under an open-source licence and extend beyond science to suppliers of everyday tools such as the WordPress platform, Firefox browser and the Android operating system. A more recent and unfortunate business model adopted by some companies is “open core”, whereby essential features are deemed premium and sold as proprietary software on top of existing open-source components.

Open collaboration is one of CERN's founding principles, so it was natural to extend the principle into its software. The web's invention brought this into sharp focus. Having experienced first-hand its potential to connect physicists around the globe, in 1993 CERN released the web software into the public domain so that developers could collaborate and improve on it (see p39). The following year, CERN released the next web-server version under an open-source licence with the explicit goal of preventing private compa-

Giacomo Tenaglia
and **Tim Smith**
CERN.

FEATURE OPEN-SOURCE SOFTWARE

Being a scientist in the digital age means being a software producer and a software consumer

nies from turning it into proprietary software. These were crucial steps in nurturing the universal adoption of the web as a way to share digital information, and exemplars of CERN's best practice in open-source software.

Nowadays, open-source software can be found in pretty much every corner of CERN, as in other sciences and industry. Indico and Invenio – two of the largest open-source projects developed at CERN to promote open collaboration – rely on the open-source framework Python Flask. Experimental data are stored in CERN's Exascale Open Storage system, and most of the servers in the CERN computing centre are running on Openstack – an open-source cloud infrastructure to which CERN is an active contributor. Of course, CERN also relies heavily on open-source GNU/Linux as both a server and desktop operating system. On the accelerator and physics analysis side, it's all about open source. From C2MON, a system at the heart of accelerator monitoring and data acquisition, to ROOT, the main data-analysis framework used to analyse experimental data, the vast majority of the software components behind the science done at CERN are released under an open-source licence.

Open hardware

The success of the open-source model for software has inspired CERN engineers to create an analogous "open hardware" licence, enabling electronics designers to collaborate and use, study, share and improve the designs of hardware

components used for physics experiments. This approach has become popular in many sciences, and has become a lifeline for teaching and research in developing countries.

Being a scientist in the digital age means being a software producer and a software consumer. As a result, collaborative software-development platforms such as GitHub and GitLab have become as important to the physics department as they are to the IT department. Until recently, the software underlying an analysis has not been easily shared. CERN has therefore been developing research data-management tools to enable the publication of software and data, forming the basis of an open-data portal (see p31). Naturally, this software itself is open source and has also been used to create the worldwide open-data service Zenodo, which is connected to GitHub to make the publication of open-source software a standard part of the research cycle.

Interestingly, as with the early days of open source, many corners of the scientific community are hesitant about open science. Some people are concerned that their software and data are not of sufficient quality or interest to be shared, or that they will be helping others to the next discovery before them. To triumph over the sceptics, open science can learn from the open-source movement, adopting standard licences, credit systems, collaborative development techniques and shared governance. In this way, it too will be able to reap the benefits of open collaboration: transparency, efficiency, perpetuity and flexibility. ●



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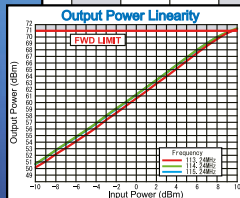
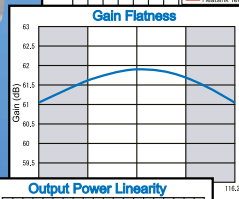
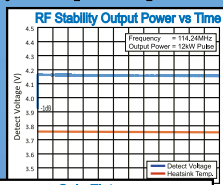
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CA114BW2-6171RP	114MHz ± 1MHz	12kW	30 ~ 100µs	0.50%	Water
CA186BW3-7878R-LB	185.7MHz ± 1.5MHz	60kW	CW	100%	Water
CA200BW0.4-7383RP	200MHz ± 0.2MHz	200kW	~ 1.1ms	3.30%	Water
CA324BW10-7181RP	324MHz ± 5MHz	120kW	210 ~ 600µs	3.00%	Air
CA358BW2-6878RP	358.54MHz ± 1MHz	64kW	10ms	10.00%	Water&Air
CA509MBW6-7373R	509MHz ± 3MHz	20kW	CW	100%	Water&Air
CA571BW2-6070RP	571MHz ± 1MHz	10kW	10 ~ 100µs	0.50%	Water
CA1300BW10-6372R	1300MHz ± 5MHz	16kW	CW	100%	Water
CA2856BW20-5861RP	2856MHz ± 10MHz	1.2kW	5µs	0.05%	Air
CA5712BW20-6157RB	5712MHz ± 10MHz	450W	1µs ~ 5µs	0.05%	Water
GA11424BW200-5757RP	11.424GHz ± 100MHz	500W	1.5µs	1.00%	Air

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A009K251 Series	9kHz ~ 250MHz	25W ~ 12kW CW	Air
A009K401 Series	10kHz ~ 400MHz	25W ~ 500W CW	Air
A101K501 Series	100kHz ~ 505MHz	40W ~ 200W CW	Air
A001M102 Series	1MHz ~ 1000MHz	10W ~ 250W CW	Air
A080M102 Series	80MHz ~ 1000MHz	75W ~ 4kW CW	Air
GA002M122-5757R-CE	2MHz ~ 1250MHz	500W CW	Air
A501M272 Series	500MHz ~ 2700MHz	5W ~ 120W CW	Air
A801M202 Series	800MHz ~ 2000MHz	50W ~ 600W CW	Air
GA102M252 Series	1000MHz ~ 2500MHz	50W ~ 2kW CW	Air
A202M402 Series	2000MHz ~ 4000MHz	10W ~ 50W CW	Air
GA701M402 Series	690MHz ~ 4000MHz	5W ~ 800W CW	Air
GA701M602 Series	700MHz ~ 6000MHz	10W ~ 200W CW	Air
GA252M602 Series	2500MHz ~ 6000MHz	10W ~ 300W CW	Air





A TURNING POINT FOR OPEN-ACCESS PUBLISHING

The European Commission is embarking on an ambitious project called Plan S to make all scientific publications open access from 2020, but particle physics is ahead of the game.

THE AUTHOR

Cristina Agrigoroae
CERN.

High-energy physics (HEP) has been at the forefront of open-access publishing, the long-sought ideal to make scientific literature freely available. An early precursor to the open-access movement in the late 1960s was the database management system SPIRES (Stanford Physics Information Retrieval System), which aggregated all available (paper-copy) preprints that were sent between different institutions. SPIRES grew to become the first database accessible through the web in 1991 and later evolved into INSPIRE-HEP, hosted and managed by CERN in collaboration with other research laboratories.

The electronic era

The birth of the web in 1989 changed the publishing scene irreversibly. Vast sums were invested to take the industry from paper to online and to digitise old content, resulting in a migration from the sale of printed copies of journals to electronic subscriptions. From 1991, helped by the early adoption by particle physicists, the self-archiving repository arXiv.org allowed rapid distribution of electronic preprints in physics and, later, mathematics, astronomy and other sciences. The first open-access journals then began to sprout up and in early 2000 three major international events – the Budapest Open Access Initiative, Bethesda Statement on Open Access Publishing and the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities – set about leveraging the new technology to grant universal free access to the results of scientific research.

Today, roughly one quarter of all scholarly literature in sciences and humanities is open access. In HEP, the figure is almost 90%. The Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP³), a global

partnership between libraries, national funding agencies and publishers of HEP journals, has played an important role in HEP's success. Designed at CERN, SCOAP³ started operation in 2014 and removes subscription fees for journals and any expenses scientists might incur to publish their articles open access by paying publishers directly. Some 3000 institutions from 43 countries (figure 1) contribute financially according to their scientific output in the field, re-using funds previously spent on subscription fees for journals that are now open access.

"SCOAP³ has demonstrated how open access can increase the visibility of research and ease the dissemination of scientific results for the benefit of everyone," says SCOAP³ operations manager Alex Kohls of CERN. "This initiative was made possible by a strong collaboration of the worldwide library community, researchers, as well as commercial and society publishers, and it can certainly serve as an inspiration for open access in other fields."

Plan S

On 4 September 2018, a group of national funding agencies, the European Commission (EC) and the European Research Council – under the name "coAlition S" – launched a radical initiative called Plan S. Its aim is to ensure that, by 2020, all scientific publications that result from research funded by public grants must be published in compliant open-access journals or platforms. Robert-Jan Smits, the EC's open-access envoy and one of the architects of Plan S, cites SCOAP³ as an inspiration for the project and says that momentum for Plan S has been building for two decades. "During those years many declarations, such as the Budapest and Berlin ones, were adopted, calling for a rapid transition to full and immediate open access. Even

FEATURE OPEN-ACCESS PUBLISHING

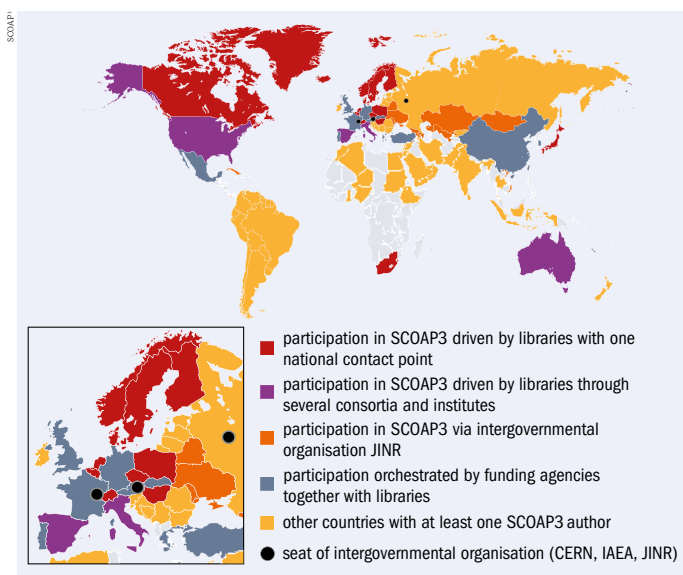


Fig. 1. Participating countries in SCOAP3, which has helped take the percentage of particle-physics articles that are published open access to 90%.

the 28 science ministers of the European Union issued a joint statement in 2016 that open access to scientific publications should be a reality by 2020,” says Smits. “The current situation shows, however, that there is still a long way to go.”

Recently, China released position papers supporting the efforts of Plan S, which could mark a key moment for the project. But the reaction of scientists around the world has been mixed. An open letter published in September by biochemist Lynn Kamerlin of Uppsala University in Sweden, attracting more than 1600 signatures at the time of writing, argues that Plan S should strongly reduce the possibilities to publish in suitable scientific journals of high quality, possibly splitting the global scientific community into two separate systems. Another open letter, published in November by biologist Michael Eisen at University of California Berkeley with around 2000 signatures, backs the principles of Plan S and supports its commitment “to continue working with funders, universities, research institutions and other stakeholders until we have created a stable, fair, effective and open system of scholarly communication.”

Challenges ahead

High-energy physics is already aligned to the Plan S vision thanks to SCOAP3, says Salvatore Mele of CERN, who is one of SCOAP3’s architects. But for other disciplines “the road ahead is likely to be bumpy”. “Funders, libraries and publishers have cooperated through CERN to make SCOAP3 possible. As most of the tens of thousands of scholarly journals today operate on a different model, with access mostly limited to readers paying subscription fees, this vision implies systemic challenges for all players: funders, libraries, publishers and, crucially, the wider research community,” he says.

It is publishers who are likely to face the biggest impact

from Plan S. However, the Open Access Scholarly Publishers Association (OASPA) – which includes, among others, the American Physical Society, IOP Publishing (which publishes *CERN Courier*) and The Royal Society – recently published a statement of support, claiming OASPA “would welcome the opportunity to provide guidance and recommendations for how the funding of open-access publications should be implemented within Plan S”, while emphasising that smaller publishers, scholarly societies and new publishing platforms need to be included in the decision-making process.

Responding to an EC request for Plan S feedback that was open until 8 February, however, publishers have expressed major concerns about the pace of implementation and about the consequences of Plan S for hybrid journals. In a statement on 12 February, the European Physical Society, while supportive of the Plan S rationale, wrote that “several of the governing principles proposed for its implementation are not conducive to a transition to open access that preserves the important assets of today’s scientific publication system”. In another statement, the world’s largest open-access publisher, Springer Nature, released a list of six recommendations for funding bodies worldwide to adopt in order for full open-access to become a reality, highlighting the differences between “geographic, funder and disciplinary needs”. In parallel, a group of learned societies in mathematics and science in Germany has reacted with a statement citing a “precipitous process” that infringes the freedom of science, and urged cOAlition S to “slow down and consider all stakeholders”.

Global growth

Smits thinks traditional publishers, which are a critical element in quality control and rigorous peer review in scholarly literature, should adopt a fresh look, for example by implementing more transparent metrics. “It is obvious that the big publishers that run the subscription journals and make enormous profits prefer to keep the current publishing model. Furthermore, the dream of each scientist is to publish in a so-called prestigious high-impact journal, which shows that the journal impact factor is still very present in the academic world,” says Smits. “To arrive at the necessary change in academic culture, new metrics need to be developed to assess scientific output. The big challenge for cOAlition S is to grow globally, by having more funders signing up.”

Undoubtedly we are at a turning point between the old and new publishing worlds. The EC already requires that all publications from projects receiving its funding be made open access. But Plan S goes further, proposing an outright shift in scholarly publication. It is therefore crucial to ensure a smooth shift that takes into account all the actors, says Mele. “Thanks to SCOAP3, which has so far supported the publication of more than 26,000 articles, the high-energy physics community is fortunate to meet the vision of Plan S, while retaining researcher choice of the most appropriate place to publish their results.” ●

Further reading

www.coalition-s.org
scoap3.org.

The reaction of scientists around the world has been mixed



Through the looking glass A student studying ALICE data during a particle-physics masterclass in 2011.

PRESERVING THE LEGACY OF PARTICLE PHYSICS

While poring over increasingly voluminous datasets, the LHC collaborations are making sure that students and scientists of tomorrow can revisit the ground-breaking analyses of today.

In the 17th century, Galileo Galilei looked at the moons of Jupiter through a telescope and recorded his observations in his now-famous notebooks. Galileo's notes – his data – survive to this day and can be reviewed by anyone around the world. Students, amateurs and professionals can replicate Galileo's data and results – a tenet of the scientific method.

In particle physics, with its unique and expensive experiments, it is practically impossible for others to attempt to reproduce the original work. When it is impractical to gather fresh data to replicate an analysis, we settle for reproducing the analysis with the originally obtained data. However, a 2013 study by researchers at the University of British Columbia, Canada, estimates that the odds of scientific data existing in an analysable form reduce by about 17% each year.

Indeed, just a few years down the line it might not even be possible for researchers to revisit their own data due to changes in formats, software or operating systems. This has led to growing calls for scientists to release and archive their data openly. One motivation is moral: society funds research and so should have access to all of its outputs. Another is practical: a fresh look at data could enable novel research and lead to discoveries that may have eluded earlier searches.

FEATURE OPEN DATA

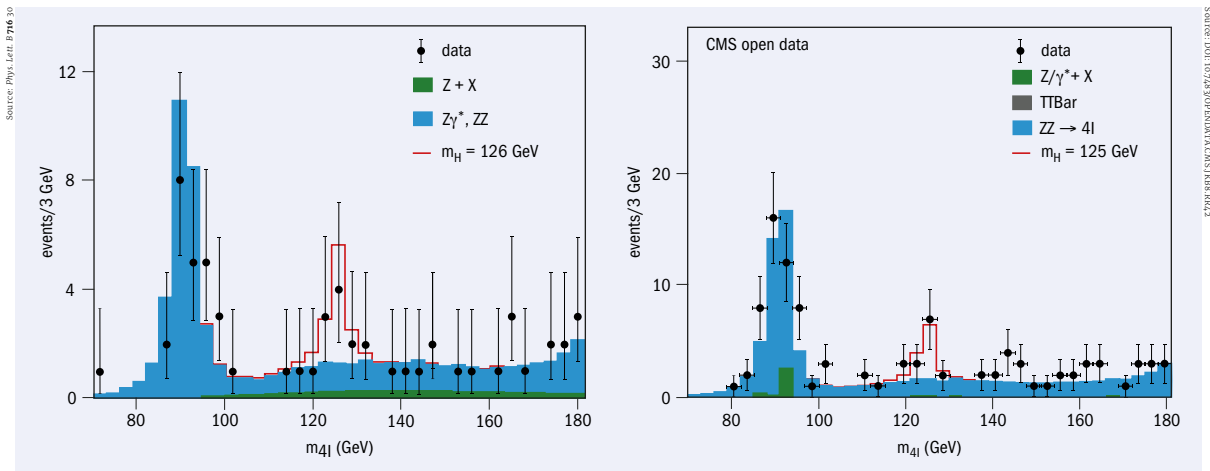


Fig. 1. The official CMS plot for the Higgs-to-four-lepton channel shown during the Higgs-boson discovery announcement (left), and a similar plot (right) produced using CMS open data that contains more data but has not been scrutinised by CMS experts.

Like open-access publishing (see p29), governments have started to impose demands on scientists regarding the availability and long-term preservation of research data. The European Commission, for example, has piloted the mandatory release of open data as part of its Horizon 2020 programme and plans to invest heavily in open data in the future. An increasing number of data repositories have been established for life and medical sciences as well as for social sciences and meteorology, and the idea is gaining traction across disciplines. Only days after they announced the first observation of gravitational waves, the LIGO and VIRGO collaborations made public their data. NASA also releases data from many of its missions via open databases, such as exoplanet catalogues. The Natural History Museum in London makes data from millions of specimens available via a website and, in the world of art, the Rijksmuseum in Amsterdam provides an interface for developers to build apps featuring historic artworks.

Data levels

The open-data movement is of special interest to particle physics, owing to the uniqueness and large volume of datasets involved in discoveries such as that of the Higgs boson at the Large Hadron Collider (LHC). The four main LHC experiments have started to periodically release their data in an open manner, and these data can be classified into four levels. The first consists of the data shown in final publications, such as plots and tables, while the second concerns datasets in a simplified format that are suitable for “lightweight” analyses in educational or similar contexts. The third level involves the data being used for analysis by the researchers themselves, requiring specialised code and dedicated computing resources, and the final level with the highest complexity is the raw data generated by the detectors, which requires petabytes of storage and, uncalibrated, is not of much use without being fed to the third tier.

In late 2014, CERN launched an open-data portal and released research data from the LHC for the first time. The

data, collected by the CMS experiment, represented half the level-three data recorded in 2010. The ALICE experiment has also released level-three data from proton-proton as well as lead-lead collisions, while all four collaborations – including ATLAS and LHCb – have released subsets of level-two data for education and outreach purposes.

Proactive policy

The story of open data at CMS goes back to 2011. “We started drafting an open-data policy, not because of pressure from funding agencies but because defining our own policy proactively meant we did not have an external body defining it for us,” explains Kati Lassila-Perini, who leads the collaboration’s data-preservation project. CMS aims to release half of each year’s level-three data three years after data taking, and 100% of the data within a ten-year window. By guaranteeing that people outside CMS can use these data, says Lassila-Perini, the collaboration can ensure that the knowledge of how to analyse the data is not lost, while allowing people outside CMS to look for things the collaboration might not have time for. To allow external re-use of the data, CMS released appropriate metadata as well as analysis examples. The datasets soon found takers and, in 2017, a group of theoretical physicists not affiliated with the collaboration published two papers using them. CMS has since released half its 2011 data (corresponding to around 200 TB) and half its 2012 data (1 PB), with the first releases of level-three data from the LHC’s Run 2 in the pipeline.

The LHC collaborations have been releasing simpler datasets for educational activities from as early as 2011, for example for the International Physics Masterclasses that involve thousands of high-school students around the globe each year. In addition, CMS has made available several Jupyter notebooks – a browser-based analysis platform named with a nod to Galileo – in assorted languages (programming and human) that allow anyone with an internet connection to perform a basic analysis. “The real impact of open data in terms of numbers of users is in schools,”

Governments have started to impose demands on scientists regarding the availability of research data

FEATURE OPEN DATA

says Lassila-Perini. “It makes it possible for young people with no previous contact with coding to learn about data analysis and maybe discover how fascinating it can be.” Also available from CMS are more complex examples aimed at university-level students.

Open-data endeavours by ATLAS are very much focused on education, and the collaboration has provided curated datasets for teaching in places that may not have substantial computing resources or internet access. “Not even the documentation can rely on online content, so everything we produce needs to be self-contained,” remarks Arturo Sánchez Pineda, who coordinates ATLAS’s open-data programme. ATLAS datasets and analysis tools, which also rely on Jupyter notebooks, have been optimised to fit on a USB memory stick and allow simplified ATLAS analyses to be conducted just about anywhere in the world. In 2016, ATLAS released simplified open data corresponding to 1 fb^{-1} at 8 TeV, with the aim of giving university students a feel for what a real particle-physics analysis involves.

ATLAS open data have already found their way into university theses and have been used by people outside the collaboration to develop their own educational tools. Indeed, within ATLAS, new members can now choose to work on preparing open data as their qualification task to become an ATLAS co-author, says Sánchez Pineda. This summer, ATLAS will release 10 fb^{-1} of level-two data from Run 2, with more than 100 simulated physics processes and related resources. ATLAS does not provide level-three data openly and researchers interested in analysing these can do so through a tailored association programme, which 80 people have taken advantage of so far. “This allows external scientists to rely on ATLAS software, computing and analysis expertise for their project,” says Sánchez Pineda.

The real impact of open data in terms of numbers of users is in schools

Fundamental motivation

CERN’s open-data portal hosts and serves data from the four big LHC experiments, also providing many of the software tools including virtual machines to run the analysis code. The OPERA collaboration recently started sharing its research data via CERN and other particle-physics collaborations are interested in joining the project.

Although high-energy physics has made great strides in providing open access to research publications, we are still in the very early days of open data. Theorist Jesse Thaler of MIT, who led the first independent analysis using CMS open data, acknowledges that it is possible for people to get their hands on coveted data by joining an experimental collaboration, but sees a much brighter future with open data. “What about more exploratory studies where the theory hasn’t yet been invented? What about engaging undergraduate students? What about examining old data for signs of new physics?” he asks. These provocative questions serve as fundamental motivations for making all data in high-energy physics as open as possible. ●

Further reading
opendata.cern.ch.

THE AUTHOR
 Achintya Rao CERN.

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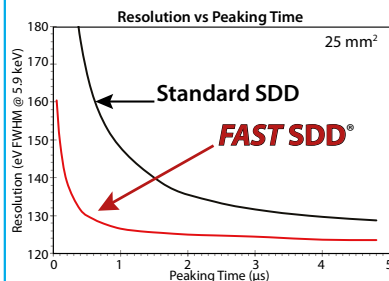
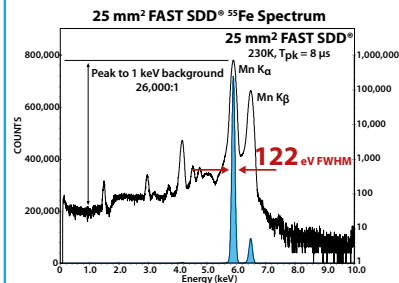
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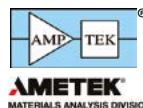


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FIXED TARGET, ST

A strong tradition of innovation and ingenuity shows that, for CERN's North Area, life really does begin at 40.

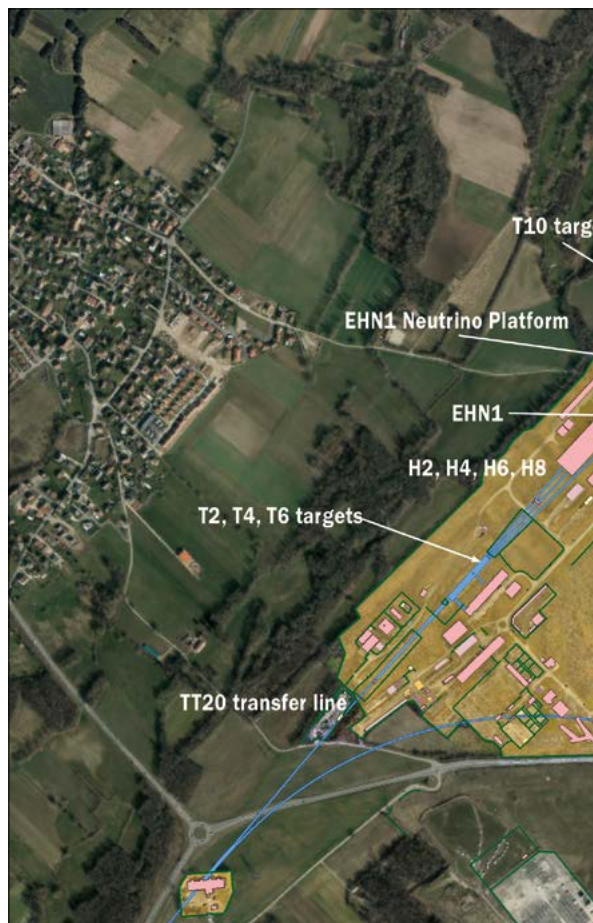
As generations of particle colliders have come and gone, CERN's fixed-target experiments have remained a backbone of the lab's physics activities. Notable among them are those fed by the Super Proton Synchrotron (SPS). Throughout its long service to CERN's accelerator complex, the 7 km-circumference SPS has provided a steady stream of high-energy proton beams to the North Area at the Prévessin site, feeding a wide variety of experiments. Sequentially named, they range from the pioneering NA1, which measured the photoproduction of vector and scalar bosons, to today's NA64, which studies the dark sector. As the North Area marks 40 years since its first physics result, this hub of experiments large and small is as lively and productive as ever. Its users continue to drive developments in detector design, while reaping a rich harvest of fundamental physics results.

Specialised and precise

In fixed-target experiments, a particle beam collides with a target that is stationary in the laboratory frame, in most cases producing secondary particles for specific studies. High-energy machines like the SPS, which produces proton beams with a momentum up to 450 GeV/c, give the secondary products a large forward boost, providing intense sources of secondary and tertiary particles such as electrons, muons and hadrons. With respect to collider experiments, fixed-target experiments tend to be more specialised and focus on precision measurements that demand very high statistics, such as those involving ultra-rare decays.

Fixed-target experiments have a long history at CERN, forming essential building blocks in the physics landscape in parallel to collider facilities. Among these were the first studies of the quark-gluon plasma, the first evidence of direct CP violation and a detailed understanding of how nucleon spin arises from quarks and gluons. The first muons in CERN's North Area were reported at the start of the commissioning run in March 1978, and the first physics publication – a measurement of the production rate of muon pairs by quark-antiquark annihilation as predicted by Drell and Yan – was published in 1979 by the NA3 experiment. Today, the North Area's physics programme is as vibrant as ever.

The longevity of the North Area programme is explained by the unique complex of proton accelerators at CERN, where each machine is not only used to inject the protons



North Area Protons leaving the SPS enter a target station (bottom left), leading

into the next one but also serves its own research programme (for example, the Proton Synchrotron Booster serves the ISOLDE facility, while the Proton Synchrotron serves the Antiproton Decelerator and the n_TOF experiment). Fixed-target experiments using protons from the SPS started taking data while the ISR collider was already in operation in the late 1970s, continued during SPS operation as a proton-antiproton collider in the early 1980s, and again during the LEP and now LHC eras. As has been the case with collider experiments, physics puzzles and unexpected results were often at the origin of unique collaborations and experiments, pushing limits in several technology areas such as the first use of silicon-microstrip detectors.

THE AUTHORS

Augusto Ceccucci,
Gerhard Mallot
and Lau Gatignon
CERN.

STRIKING PHYSICS



g to 6 km of secondary beamlines for experiments in three halls.



Past times

The ECN3 underground hall today, showing experiment NA62 (top) and the same scene superimposed with a view from 1980 (bottom) showing experiments NA10 (left) and NA14 (right).

The initial experimental programme in the North Area involved two large experimental halls: EHN1 for hadronic studies and EHN2 for muon experiments. The first round of experiments in EHN1 concerned studies of: meson photoproduction (NA1); electromagnetic form factors of pions and kaons (NA7); hadronic production of particles with large transverse momentum (NA3); inelastic hadron scattering (NA5); and neutron scattering (NA6). In EHN2 there were experiments devoted to studies with high-intensity muon beams (NA2 and NA4). A third, underground, area called ECN3 was added in 1980 to host experiments requiring primary proton beams and secondary beams of the highest intensity (up to 10^{10} particles per cycle).

Experiments in the North Area started a bit later than those in CERN's West Area, which started operation in 1971 with 28 GeV/c protons supplied by the PS. Built to serve the last stage of the PS neutrino programme and the Omega spectrometer, the West Area zone was transformed into an SPS area in 1975 and is best known for seminal neutrino experiments (by the CDHS and CHARM collaborations, later CHORUS and NOMAD) and hadron-spectroscopy experiments with Omega. We are now used to identifying experimental collaborations by means of fancy acronyms such as ATLAS or ALICE, to mention two of the large LHC collaborations. But in the 1970s and the 1980s, one could distinguish between the experiments (identified by a sequential number)

FEATURE NORTH AREA AT 40

Forty years of fixed-target physics at CERN's North Area



Probing nucleon structure with high-energy muons

High-energy muons are excellent probes with which to investigate the structure of the nucleon. The North Area's EHN2 hall was built to house two sets of muon experiments: the sequential NA2/NA9/NA28 (also known as the European Muon Collaboration, EMC), which made the observation that nucleons bound in nuclei are different from free nucleons; and NA4 (pictured above), which confirmed the electroweak effects between the weak and electromagnetic interactions. A particular success of the North Area's muon experiments concerned the famous "proton spin crisis". In the late-1980s, contrary to the expectation by the otherwise successful quark-parton model, data showed that the proton's spin is not carried by the quark spins. This puzzle interested the community for decades, compelling CERN to further investigate by building the NA47 Spin Muon collaboration experiment in the early 1990s (which established the same result for the neutron) and, subsequently, the COMPASS experiment (which studied the contribution of the gluon spins to the nucleon spin). A second phase of COMPASS still ongoing today, is devoted to nucleon tomography using deeply virtual Compton scattering and, for the first time, polarised Drell-Yan reactions. Hadron spectroscopy is another area of research at the North Area, and among recent important results from COMPASS is the measurement of pion polarisability, which is an important test of low-energy QCD.

Hadroproduction and photoproduction at high energy



Following the first experiment to publish data in the North Area (NA3) concerning the production of $\mu^+\mu^-$ pairs from hadron collisions, the ingenuity to combine bubble chambers and electronic detectors led to a series of experiments. The European Hybrid Spectrometer facility housed NA13, NA16, NA22, NA23 and NA27, and studied charm production and many aspects

of hadronic physics, while photoproduction of heavy bosons was the primary aim of NA1. A measurement of the charm lifetime using the first ever microstrip silicon detectors was pioneered by the ACCMOR collaboration (NA11/NA32; see image of Robert Klanner next to the ACCMOR spectrometer in 1977), and hadron spectroscopy with neutral final states was studied by NA12 (GAMS), which employed a large array of lead glass counters, in particular a search for glueballs. To study $\mu^+\mu^-$ pairs from pion interactions at the highest possible intensities, the toroidal spectrometer NA10 was housed in the ECN3 underground cavern. Nearby in the same cavern, NA14 used a silicon active target and the first big microstrip silicon detectors (10,000 channels) to study charm photoproduction at high intensity. Later, experiment NA30 enabled a direct measurement of the π^0 lifetime by employing thin gold foils to convert the photons from the π^0 decays. Today, electron beams are used by NA64 to look for dark photons while hadron spectroscopy is still actively pursued, in particular at COMPASS.

CP violation and very rare decays



The discovery of CP violation in the decay of the long-lived neutral kaon to two pions at Brookhaven National Laboratory in 1964 was unexpected. To understand its origin, physicists needed to make a subtle comparison (in the form of a double ratio) between long- and short-lived neutral kaon decays in pairs of neutral and charged kaons. In 1987 an ambitious experiment (NA31) showed a deviation from one of the double ratios, providing the first evidence of direct CP violation (that is, it happens in the decay of the neutral mesons, not only in the mixing between neutral kaons). A second-generation experiment (NA48, pictured above in 1996), located in ECN3 to accept a much higher primary-proton intensity, was able to measure the four decay modes concurrently thanks to the deflection of a tiny fraction of the primary proton beam into a downstream target via channelling in a "bent" crystal. NA48 was approved in 1991 when it became evident that more precision was needed to confirm the original observation (a competing programme at Fermilab called E731 did not find a significant deviation from the unity of the double ratio). Both KTeV (the

follow-up Fermilab experiment) and NA48 confirmed NA31's results, firmly establishing direct CP violation. Continuations of the NA48 experiments studied rare decays of the short-lived neutral kaon and searched for direct CP violation in charged kaons. Nowadays the kaon programme continues with NA62, which is dedicated to the study of very rare $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decays and is complementary to the B-meson studies performed by the LHCb experiment.

Heavy-ion experiments



In the mid-1980s, with a view to reproduce in the laboratory the plasma of free quarks and gluons predicted by QCD and believed to have existed in the early universe, the SPS was modified to accelerate beams of heavy ions and collide them with nuclei. The lack of a single striking signature of the formation of the plasma demands that researchers look for as many final states as possible, exploiting the evolution of standard observables (such as the yield of muon pairs from the Drell-Yan process or the production rate of strange quarks) as a function of the degree of overlap of the nuclei that participate in the collision (centrality). By 2000 several experiments had, according to *CERN Courier* in March that year, found "tantalising glimpses of mechanisms that shaped our universe". The experiments included NA44, NA45, NA49, NA50, NA52 and NA57, as well as WA97 and WA98 in the West Area. Among the most popular signatures observed was the suppression of the J/ψ yield in ion-nucleus collisions with respect to proton-proton collisions, which was seen by NA50. Improved sensitivity to muon pairs was provided by the successor experiment NA60. The current heavy-ion programme at the North Area includes NA61/SHINE (see image above), the successor of NA49, which is studying the onset of phase transitions in dense quark-gluon matter at different beam energies and for different beam species. Studies of the quark-gluon plasma continue today, in particular at the LHC and at RHIC in the US. At the same time, NA61/SHINE is measuring the yield of mesons from replica targets for neutrino experiments worldwide and particle production for cosmic-ray studies.



Then and now EHN1, the largest of the North Area's halls, photographed in 1980 (left) and today (right) showing the NA64 experiment.

and the collaborations (identified by the list of the cities hosting the collaborating institutes). For instance CDHS stood for the CERN–Dortmund–Heidelberg–Saclay collaboration that operated the WA1 experiment in the West Area.

Los Alamos, SLAC, Fermilab and Brookhaven National Laboratory in the US, JINR and the Institute for High Energy Physics in Russia, and KEK in Japan, for example, also all had fixed-target programmes, some of which date back to the 1960s. As fixed-target programmes got into their stride, however, colliders were commanding the energy frontier. In 1980 the CERN North Area experimental programme was reviewed in a special meeting held in Cogne, Italy, and it was not completely obvious that there was a compelling physics case ahead. But it also led to highly optimised installations thanks to strong collaborations and continuous support from the CERN management. Advances in detectors and innovations such as silicon detectors and aerogel Cherenkov counters, plus the hybrid integration of bubble chambers with electronic detectors, led to a revamp in the study of hadron interactions at fixed-target experiments, especially for charmed mesons.

Physics landscape

Experiments at CERN's North Area began shortly after the Standard Model had been established, when the scale of experiments was smaller than it is today. According to the 1979 CERN annual report, there were 34 active experiments at the SPS (West and North areas combined) and 14 were completed in 1978. This article cannot do justice to all of them, not even to those in the North Area. But over the past 40 years the experimental programme has clearly evolved into at least four main themes: probing nucleon structure with high-energy muons; hadroproduction and photoproduction at high energy; CP violation in very rare decays; and heavy-ion experiments (see page left).

Aside from seminal physics results, fixed-target experiments at the North Area have driven numerous detector innovations. This is largely a result of their simple geometry and ease of access, which allows more adventurous technical solutions than might be possible with collider experiments. Examples of detector technologies perfected at the North Area include: silicon microstrips and active targets (NA11, NA14); rapid-cycling bubble chambers (NA27); holographic bubble chambers (NA25); Cherenkov detectors (CEDAR, RICH); liquid-krypton calorimeters (NA48);



Nucleon tomography

The COMPASS experiment in EHN2 pictured in late 2018 (see panel, left).

micromegas gas detectors (COMPASS); silicon pixels with 100 ps time resolution (NA62); time-projection chambers with dE/dx measurement (ISIS, NA49); and many more. The sheer amount of data to be recorded in these experiments also led to the very early adoption of PC farms for the online systems of the NA48 and COMPASS experiments.

Another key function of the North Area has been to test and calibrate detectors. These range from the fixed-target experiments themselves to experiments at colliders (such as LHC, ILC and CLIC), space and balloon experiments, and bent-crystal applications (such as UA9 and NA63). New detector concepts such as dual-readout calorimetry (DREAM) and particle-flow calorimetry (CALICE) have also been developed and optimised. Recently the huge EHN1 hall was extended by 60 m to house two very large liquid-argon prototype detectors to be tested for the Deep Underground Neutrino Experiment under construction in the US.

If there is an overall theme concerning the development of the fixed-target programme in the North Area, one could say that it was to be able to quickly evolve and adapt to address the compelling questions of the day. This looks set to remain true, with many proposals for new experiments appearing on the horizon, ranging from the study of very rare decays and light dark matter to the study of QCD with hadron and heavy-ion beams. There is even a study under way to possibly extend the North Area with an additional very-high-intensity proton beam serving a beam dump facility. These initiatives are being investigated by the Physics Beyond Collider study (see p20), and many of the proposals explore the high-intensity frontier complementary to the high-energy frontier at large colliders. Here's to the next 40 years of North Area physics! ●

As fixed-target programmes got into their stride, colliders were commanding the energy frontier



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