EP Newsletter of the EP department

A word from the Head of the EP department - September 2016

Editorial

*by **Manfred Krammer***

Dear Colleagues, Members of the EP Department and CERN Users,

Welcome to the 3rd edition of the EP Newsletter this year. Many of you have certainly followed the ICHEP 2016 conference, either in Chicago directly or from remote. An amazing wealth of results have been shown, notably but not only by the LHC experiments. These results in many areas of our field should comfort us over the disappointment of the disappearance of the “bump”. The LHC is and will remain for a long time the only machine on earth where we can study the heaviest objects of the Standard Model. The accelerator and the excellent experiments will allow us to explore and test with increasing precision the electroweak symmetry breaking mechanism, heavy quark physics and the Higgs particle, to name only a few physics topics, for many years to come.

Further in this newsletter is the announcement of a new group in the Experimental Physics Department. EP-NU, the Neutrino Group has become the 12th group in EP as of September 1st. As the interim Group Leader I will make sure that the activities of this group will be well integrated in the department and that a close connection is built with the Neutrino Platform and the activities in the CERN Theory Department.

Enjoy reading this newsletter and take your time to read about experiments at the Antiproton Decelerator, a summary from the Physics Beyond Collider Workshop, the latest news from SESAME, an inspiring interview with Guido Tonelli, etc., etc.

With best regards,

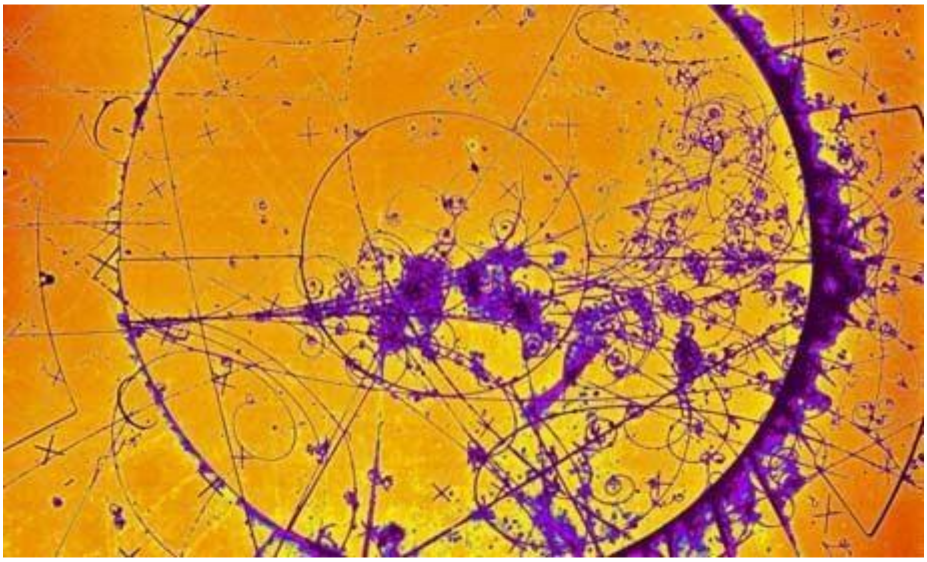
Manfred Krammer

EP Department Head

EP department announces new neutrino group

Neutrino *by* ***Panos Charitos***

To meet the challenges of the neutrino programme at CERN, the EP department recently announced the establishment of a neutrino group in the department. The group will act as a focal point for the activities of the accelerator-based experimental neutrino community in Europe and world-wide, and will work in close connection also with the CERN neutrino Platform and the neutrino related activity in the TH Department. Manfred Krammer and Albert De Roeck will coordinate the activities of the new group and hence will ensure that the Organization continues to play a key role in neutrino research.



Albert De Roeck explains: “The formation of the new group is a result of the progress made in the past years and CERN’s effort to be a key part of worldwide activities for neutrino physics. As a response to the 2013 European Strategy for Particle Physics, CERN launched the neutrino platform with the aim of fostering and contributing to fundamental research in neutrino physics at particle accelerators worldwide. The EP neutrino group will contribute towards this direction and assist European physicists interested in neutrino projects.”

Presently, a number of projects at CERN are connected directly with experiments planned to take place both at Fermilab and in Japan. “We are just in the beginning, but the new group will act as a hub for the large community of neutrino experts around Europe, enabling them to develop their ideas, work on simulations and various experimental aspects in preparation for their participation in the large neutrino experiments.”

The new group aims to offer CERN scientists and visitors that will come and spend some time at CERN to connect with ongoing R&D efforts, as well as provide opportunities to young researchers who could apply for a fellowship or staff position and work in one of the future accelerator based neutrino experiments. Planned activities range from simulations of physics processes to detector data reconstruction and performance studies, while future work may focus further on e.g. trigger and data acquisition, as well as in analysing test beam data. “We are also open to discuss new areas in which EP could engage,” adds Albert. “Opportunities for CERN activities in both long and short baseline experiments will be explored.”

The neutrino group will also work closely with the support groups under the umbrella of the EP department, namely the electronics systems group (ESE), the detector technologies group (DT) and the software design group (SFT). A wide range of possibilities could be explored, from improvements in Geant4 to the development of new micro-electronics or detector concepts, while the upgrades of the LHC detectors may offer synergies. In addition, the neutrino group will work closely with colleagues from the TH department where a neutrino task force has already been set up, and confront experimental with theoretical ideas that can be tested in the foreseen experiments.

Albert De Roeck concludes: “We will collaborate very closely with CERN’s neutrino platform and other EP groups, such as the support groups (DT, ESE, SFT) to deliver the best possible outcome and facilitate new projects that will attract physicists interested in neutrino from all over Europe. It is important to show that there is a coherent effort to strengthen the connections between CERN and the worldwide community and help promote research in neutrino physics at CERN.

Physics Beyond Colliders kickoff workshop

by ***Panos Charitos, Mike Lamont, Claude Valee, Joerg Jaeckel***

Recent results from the LHC shows that that the Standard Model works with a remarkable accuracy within the presently accessible energy range. However there is now overwhelming evidence for the existence of Dark Matter; a component of our Universe not described by the Standard Model. On the other hand, the fact that there we haven’t yet found signs of new physics at the LHC means that physicists may have to look more carefully in the lower energy cracks. As the renowned cosmologist Mikhail Shaposhnikov mentioned in his talk: "Whatever the LHC will bring us, we are in a “no lose” situation: New physics at the LHC - study it! No new physics at the LHC - a number of new experiments at high energy, precision, and high intensity frontiers, in cosmology and astrophysics will be needed - a lot to explore!"

CERN’s management has set up a study group to explore what else could be done with CERN’s accelerator complex to target fundamental physics questions, similar in nature to those addressed by high-energy colliders, but based on different types of beams and experiments. The given timescale is out to around 2040. The study group is charged with pulling together interested parties, exploring the options at an appropriate depth with the aim of providing input to the next update to the European Strategy for Particle Physics in around 2019.

The kickoff meeting took place on 6th and 7th of September 2016 at CERN. For this meeting the team adopted a fairly loose bottom-up approach to survey the theoretical challenges along with the plans for upgrading the existing accelerator complex – including the PS and SPS - and experimental facilities. The next step was to invite proposals from the community, a selection of which were presented at the workshop. The meeting was well attended – registration was closed when the total passed 300!

From a theoretical perspective there are many prospects for new physics below the Fermi scale. One of them is based on the measurement of the electric dipole moment that could open a window on new physics and help to identify the energy scale where new physics may lie. The hunt for axions and axion-like particles, heavy neutral leptons, dark energy detection and searches for ultralight dark matter are among the options that physicists consider in order to answer some of the open questions related to the “dark” component of our Universe.

It is clear that CERN’s priority over the coming years will be the full exploitation of the LHC firstly in its present guise and then from 2026 as the High Luminosity upgrade (HL-LHC). The LHC places stringent demands on intensity and related characteristics and a major upgrade of the injectors is planned to provide the requisite beams of the HL era. Despite this the LHC doesn’t actually use many protons. This leaves the other facilities open to exploit the considerable beam production capabilities of the accelerators and indeed the already diverse and far-sighted program spans ISOLDE, AD, nTOF, East Area, HiRadMat, AWAKE and the North Area.

A number of interesting ideas concern the North Area and the numerous beams on offer/available there. Some proposals target novel measurements at existing facilities such as precise measurements of the branching ratios (BRs) for the flavor-changing neutral current decays $K \rightarrow \pi\nu\nu bar$ at NA62.

Others foresee completely new developments. Notable among these is the proposed SPS beam dump facility (BDF), a fixed-target facility foreseen to be situated at the North Area of the SPS. Beam dump in this context implies a target aimed at absorbing all incident protons and containing most of the cascade generated by the primary beam interaction. The aim is a general purpose fixed target facility, which in the initial phase is aimed at a general Search for Hidden Particles (SHiP) including heavy neutral leptons, as well as tau neutrino physics.

Precision measurement of the proton electric dipole moment (EDM) can be envisaged using a small 500 m circumference all electric storage ring. The physics motivation is strong, and from an accelerator standpoint challengingly interesting. Other options discussed included the search for dark photons using an electron beam dump and the exploration of fixed target possibilities at the LHC based either on crystal extraction or an internal gas jet. Partially stripped ions interacting with a LASER have the potential to provide a powerful gamma source.

On the non-accelerator side of things, axion and dark matter searches span an impressive range of possibilities. At one extreme are the plans for an international axion observatory (IAXO) based on a large superconducting toroid magnet, at the other are sensitive measurements on the short range interactions between macroscopic bodies that potentially provide a window on possible physics beyond the standard model.

"I think Nature is smarter than physicists. We should have the courage to say: "Let Nature tell us what is going on." to quote Carlo Rubbia. “Our experience of the past has demonstrated that in the world of the infinitely small, it is extremely silly to make predictions as to where the next physics discovery will come from and what it will be. In a variety of ways, this world will always surprise us all. The next breakthrough might come from beta decay, or from underground experiments, or from accelerators. We have to leave all this spectrum of possibilities open and just enjoy this extremely fascinating science."

The workshop threw up a wide range of possibilities at various stages of development. The study team's next challenge will be develop a strategy to harness the available resources to explore at an appropriate depth those proposals that meet the given criteria of exploiting the unique opportunities offered by CERN's accelerator complex and scientific infrastructure, and being complementary to other initiatives in the world.

First call for proposals for the SESAME light source

SESAME *by* ***Kathryn Coldham***

Allan, Jordan, and Manchester, UK, 27 July 2016. SESAME, the pioneering new regional laboratory for the Middle East and neighbouring countries, announced last month its first call for proposals for experiments.

A third generation light source with a research capacity ranging from medicine to cultural heritage, SESAME's first beams will be circulating this autumn, with the experimental programme getting under way in 2017. SESAME is already host to a growing user community of some 300 scientists from across the region and, as is standard in the light source community, is open to proposals for good science, wherever they may come from.

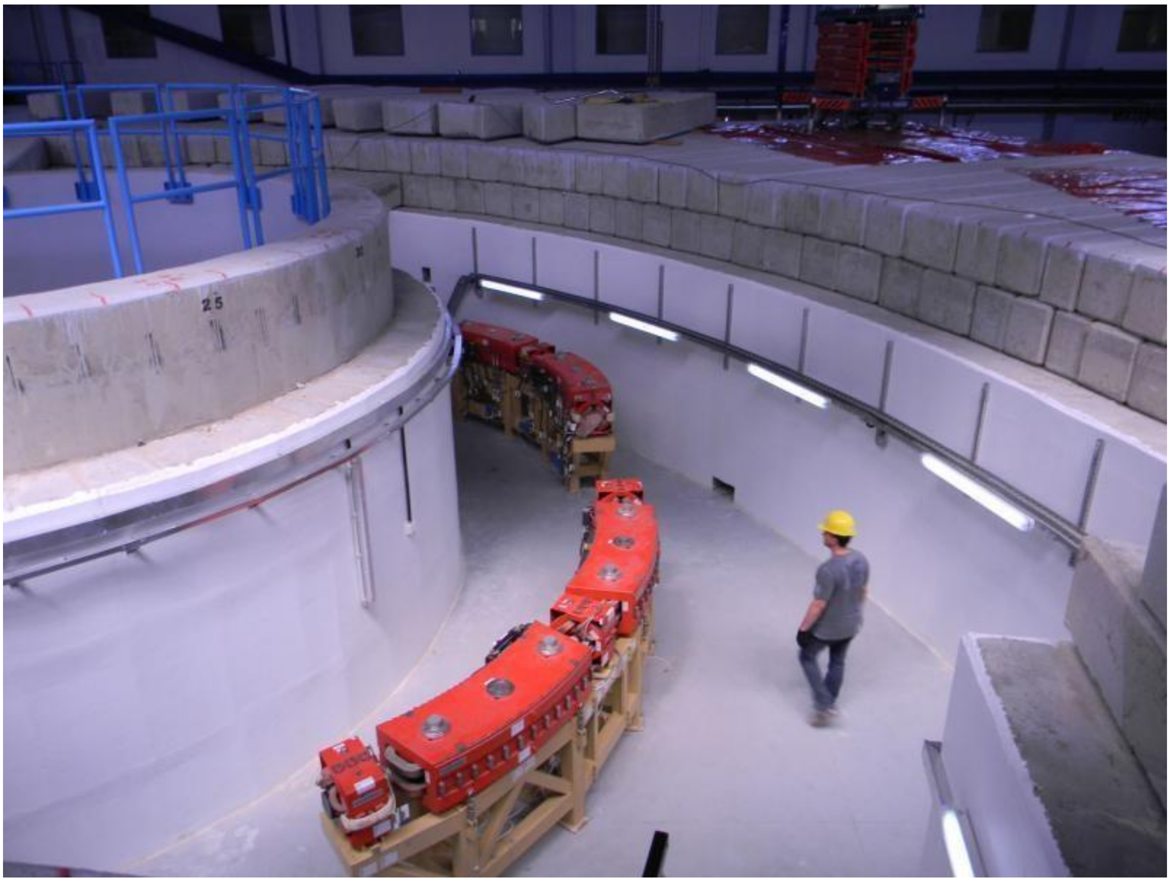


Image Credit@CERN(link sends e-mail)

“This is a very big moment for SESAME,” said Dr Khaled Toukan, SESAME’s Director General. “It signals the start of the research programme at the first international synchrotron research facility in our region.”

“I am a string physicist, we study potential parallel universes,” said Eliezer Rabinovici, Professor at the Hebrew University of Jerusalem and former Vice-President of the SESAME Council. “At Sesame I can actually be in such a parallel universe, one where scientists of the region work together for the benefit of humanity and the benefit of their own people.”

SESAME is a unique intergovernmental venture created bottom-up by scientists from its Members: Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey. It will foster dialogue and better understanding between scientists of all ages with diverse cultural, political and religious backgrounds, who will work side-by-side at SESAME. Strong links already exist between SESAME and light sources around the world, which have supported SESAME’s growing user community as the laboratory has been taking shape.

SESAME will start up with two beam lines, one delivering infrared light, the other X-rays. The laboratory’s full scientific programme will span fields ranging from medicine and biology, through materials science, physics and chemistry to healthcare, the environment, agriculture and archaeology.

“It has been a real thrill over recent months to see the SESAME main ring being installed,” said Gihan Kamel, SESAME’s infrared beam line scientist. “The infra red beam line is also ready for installation.”

SESAME’s maintenance and operation are financed by its Members. Capital investment has come from special contributions from three Members: Israel, Jordan and Turkey, who will be joined by Iran now that sanctions have been lifted. The European Commission financed the design and construction of key components, the main-ring magnets and power supplies, through a project coordinated by CERN. Italy provided the main-ring accelerating structures. Various other countries have made contributions, including Germany, which donated the BESSY1 synchrotron, which has now been converted into the injector for the SESAME main ring.

“Europe has made a very important contribution to SESAME,” said Chris Llewellyn-Smith, President of the SESAME Council, “helping to build scientific and technical capacity through training and knowledge transfer through the main-ring project.”

Proposals for SESAME’s opening call may be submitted through the SESAME website(link is external) from August 2016. They will be examined by the SESAME Proposal Review Committee, which will recommend SESAME’s opening research programme to the SESAME Directorate.

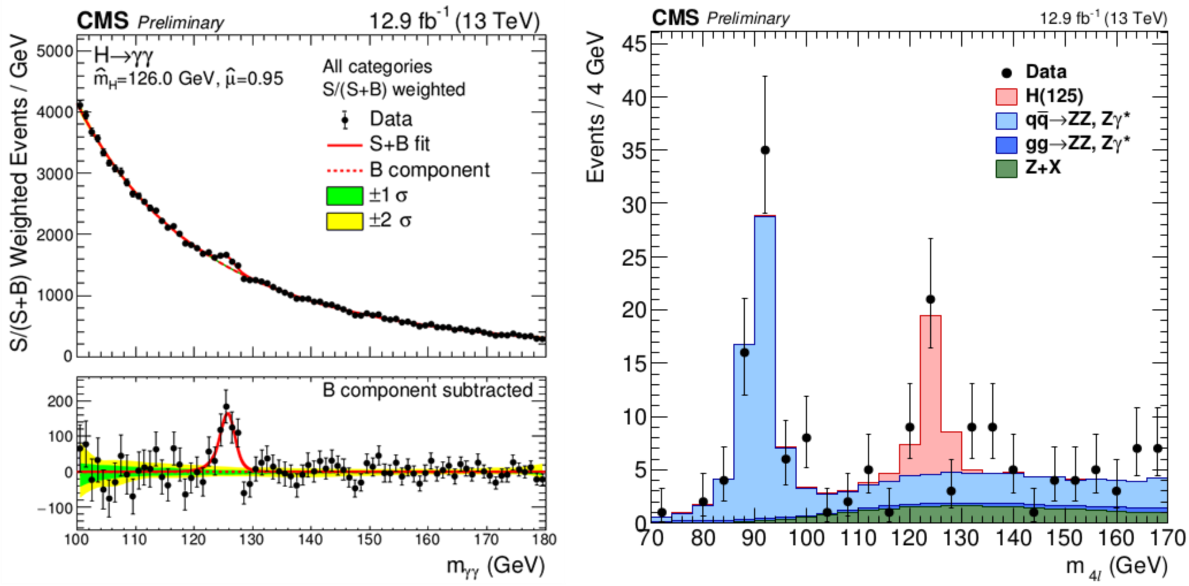
LHC experiments present latest results in ICHEP16 *by Panos Charitos*

New results from the LHC experiments were presented during the 38th International Conference on High Energy Physics (ICHEP 2016) that took place in Chicago, USA. The collaborations of the LHC experiments can now dive in and explore at the new energy frontier of 13 TeV, following last year’s first glimpse of physics at this unprecedented energy level. LHC collaborations are presenting more than 100 different new results, including many analyses based on newly taken 2016 data.

Thanks to the outstanding performances of the LHC, experiments have already recorded about 5 times more data in 2016 than in 2015, in just a few months of operations. The LHC surpassed its

design luminosity in June reaching a peak luminosity of 1 billion collisions per second so that even the rarest processes at the highest effective energy could occur. The LHC is thus running beyond expectations and the objective of 25 inverse femtobarn[3] of proton–proton collisions delivered to experiments for the whole of 2016 is within sight. *“The LHC really entered a new regime by reaching its nominal luminosity, now exceeded by 20%,”* said CERN Director for Accelerators and Technology, Frédérick Bordry. *“It’s a major achievement and we can be confident that we will go beyond our goals for the full second run of the LHC.”*
Physicists have been hard at work in the past months dealing with the huge amount of data recorded by the LHC experiments. With a larger data set now analysed, more precise measurements of the Standard Model processes and more sensitive searches for the direct production of new particles at the highest energy are possible. As an example, the 125 GeV Higgs boson, discovered in 2012, has now also been observed at the new energy of 13 TeV with higher statistical significance. In addition, both ATLAS and CMS experiments have made new precise measurements of Standard Model processes, especially looking for anomalous particle interactions at high mass, a very sensitive but indirect test for physics beyond the Standard Model.

CMS is significantly increasing its physics reach with respect to Run 1, especially in studies of the Higgs sector and in searches for new physics.One of the highlights from CMS for ICHEP is the full re-discovery programme around the Higgs boson with a mass of 125 GeV, providing independent observations in the H→γγ and H→ZZ*→4l channels well above 5 standard deviations. The analyses are completed with dedicated measurements of the cross-section in the fiducial volume, mass and spin-parity studies, and searches for additional Higgs bosons at higher masses. All results were found to be consistent with Standard Model expectations and with previous CMS results from Run 1.



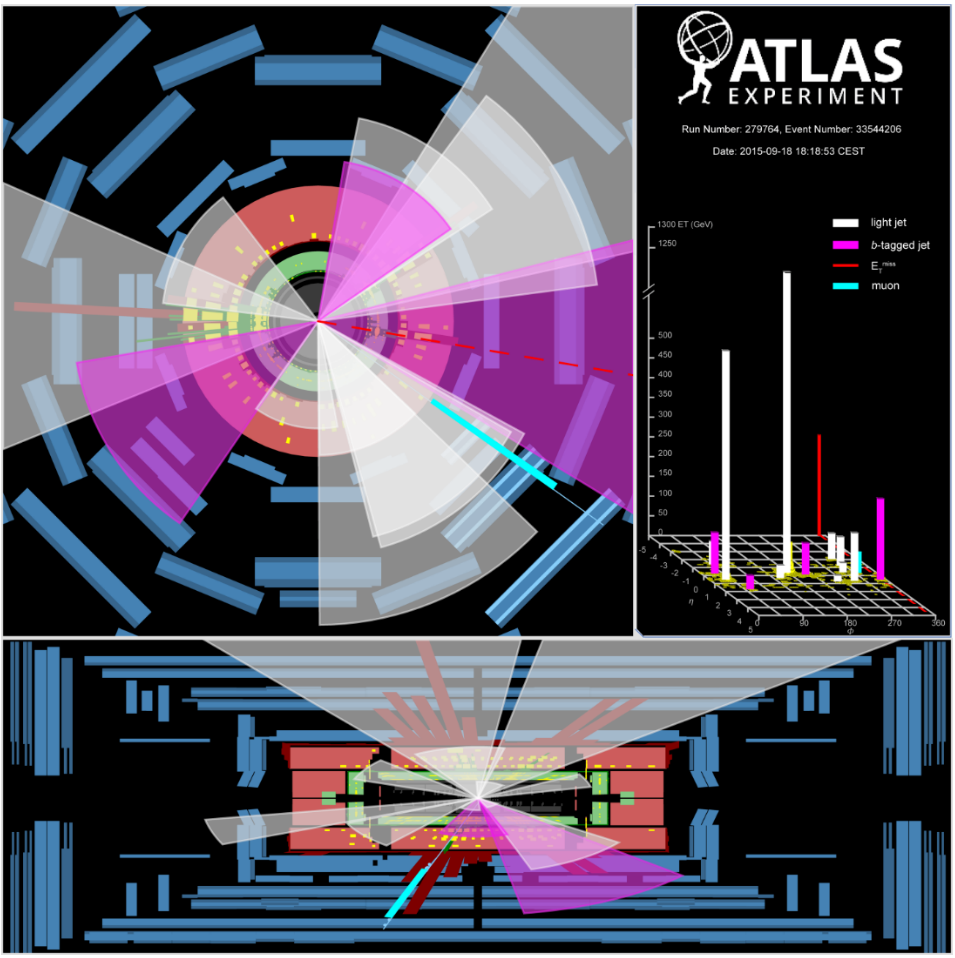
Mass spectra obtained in the 2016 CMS Higgs search using the di-photon (left) and fourlepton (right) decays channels. The significance of the observed signals around 125 GeV is larger than 5 standard deviations in both channels. The analysed data correspond to an integrated luminosity of 13 fb^{-1}, collected with the CMS detector at a centre-of-mass energy of 13 TeV.

SUSY searches are also taking full advantage of the increased statistics. While no significant excesses were observed in the new data, mass limits increased by a few hundreds of GeV on almost all fronts. That is the case of gluino and top-squark (or stop) searches in high-multiplicity

states associated to missing transverse energy. Updated analyses in photonic or leptonic final state also led to improved limits. Finally, a new generation of SUSY analyses is targeting complicated scenarios like compressed spectra or particles exclusively produced via electroweak interactions.
CMS keeps an intensive, comprehensive dark-matter search programme in the so-called “monoX” final states, where high-mass mediators decay into invisible particles (dark matter) and recoil against high-pT X visible objects. The most sensitive “mono-jet” analysis is now excluding mediator masses up to 2 TeV in several standard scenarios for low masses of the dark-matter candidate.

CMS continues to perform precise measurements of Standard Model processes, with a special focus on high-mass final states, where Run 2 is particularly advantageous. CMS is also presenting new heavy-ion results from the most recent pp, pPb and PbPb runs taken at 5 TeV centre-of-mass per nucleon. Last but not least, data from Run 1 keep providing extremely interesting physics results, like a first high-statistics study of Z+charm production at the LHC. An investigation of the $B^0_s\pi$ spectrum did not show any evidence for resonant structures around 5568 MeV, leading to a conservative limit of about half the rate claimed by the D0 experiment at the 95% CL. More information about the CMS results can be found at http://cern.ch/cms-results/publicresults/preliminary-results/ICHEP-2016.

ATLAS released results with 12 inverse femtobarns of data recorded at 13 TeV in 2016. This is nearly four times larger than the 2015 dataset – and the year is not yet over.



Preparations for ICHEP have kept everyone at ATLAS on their toes. From detector operations and trigger to computing and analysis, ATLAS teams have worked tirelessly to collect and analyse this new wealth of data. Thanks to their efforts, 50 new conference notes have been prepared especially for ICHEP.

Along with detailed studies of Standard Model processes and searches for new physics, new studies of the Higgs boson will be shown, including searches for SUSY particles. ATLAS physicists have been eagerly searching the collected data for evidence of the production of the supersymmetric top quark (squark). Theory predicts that the top squark would decay to ordinary quarks, a dark matter particle and possibly leptons (electrons or muons). Recent ATLAS results feature five separate searches for this elusive particle. Each search differs in the number of leptons in the final state, covering all the possible decay modes. Four searches require respectively zero, one, two, or three light leptons (electrons or muons) and the fifth targets decays to tau leptons.

Overall, the data gathered have been found to be consistent with the production of only known particles. You can read more about the key results presented during ICHEP16 in ATLAS Physics Briefings(link is external),

For both experiments, the analysis of the di-photon spectrum near 750 GeV with the new 2016 data became one of the priorities, The new results including more data from the 2016 run, show no significant excess in the relevant region and do not confirm the previously observed evidence of an excess. Additional searches in related channels (like $X \rightarrow Z\gamma$) have not shown any significant excess around 750 GeV mass either.

Searches for any signs of the direct production of new particles predicted by Supersymmetry and other exotic theories of physics beyond the Standard Model, but no compelling evidence of new physics has appeared yet. *“This is one of the most exciting times in recent years for physicists, as we dig into the unknown in earnest: the particle physics at an energy never explored before,”* said CERN Director for Research and Computing, Eckhard Elsen.

LHCb are presenting many interesting new results as well, in the domain of flavour physics. A particular highlight is the discovery of the decay mode B^0->K^+K^-, the rarest B-meson decay into a hadronic final state ever observed, as well as studies of unprecedented sensitivity of CP violation, a very subtle phenomenon explaining nature’s “preference” for matter over antimatter. LHCb have also conducted measurements that could help to reveal some new phenomena such as the first measurement of the photon polarisation in radiative decays of $B_s$mesons and determinations of the production cross-sections of several key processes at a collision energy of 13 TeV – some of which, at first sight, are at variance with current predictions.

Results from heavy-ion collisions were also presented from ALICE - the dedicated heavy-ion LHC experiment- and the other LHC experiments. The wealth of results marks a bright future for the rich research programme in heavy-ions. The new energy regime reached at the LHC allows both pursuing discovery of new phenomena and improving our knowledge about the quark-gluon plasma..

“We're just at the beginning of the journey,” said CERN Director-General, Fabiola Gianotti. *“The superb performance of the LHC accelerator, experiments and computing bodes extremely well for a detailed and comprehensive exploration of the several TeV energy scale, and significant progress in our understanding of fundamental physics.”*

ASACUSA Collaboration at CERN AD

SME

by ***Ryugo Hayano on behalf of the ASACUSA collaboration***

ASACUSA (atomic spectroscopy and collisions using slow antiprotons) now works mainly on two subjects, 1) antihydrogen ground-state hyperfine splitting measurement, and 2) antiprotonic helium laser spectroscopy. Both of these aim at CPT tests.

ASACUSA collaboration has a unique infrastructure called the RFQD (radiofrequency quadrupole decelerator), an *inverse linac*, which decelerates the 5.3 MeV antiprotons extracted from the AD (antiproton decelerator) to 100 keV with a deceleration efficiency of some 30%. This post deceleration increases the trapping fraction of antiprotons into the “MUSASHI” catching trap by about two orders of magnitude, as compared to the conventional degrader method. Antiprotons captured and cooled in the “MUSASHI” trap are being used in our attempt to produce an antihydrogen beam, and to measure the ground-state hyperfine splitting, as detailed in Section 1. The ground-state hyperfine splitting of antihydrogen will be measured by passing the beam through a microwave cavity (1.4 GHz), and by collecting the spin-flipped antihydrogens with a sextupole magnet. The method has now been perfected by testing the whole setup using an ordinary hydrogen source. This is discussed in Section 2.

The RFQD beam is also used to produce “antiprotonic helium”, a three-body atom composed of a normal helium nucleus with an antiproton, by stopping the slow antiprotons in a cold, dilute, helium gas. We have been working on the precision laser spectroscopy of antiprotonic helium, with which we can deduce the antiproton-to-electron mass ratio, as discussed in Section 3.

Antihydrogen and antiprotonic helium experiments will both benefit very much when the ELENA ring is completed, which can deliver electron-cooled 100 keV antiprotons with high brightness. We are contributing beam monitors, which we have developed and have been using to monitor the RFQD-decelerated antiprotons, to the ELENA projects.

§1 Hyperfine Spectroscopy of Antihydrogen Beam

The ASACUSA-CUSP group comprises about 30 scientists from various institutes in Japan (RIKEN, Univ. Tokyo, and Hiroshima Univ.) and in Europe (SMI and Brescia Univ.). It aims to measure a property of antihydrogen called the “hyperfine structure” precisely and compare it to the well-known value for hydrogen in order to detect any tiny difference for stringent test of the CPT symmetry between matter and antimatter. Since this measurement is very sensitive to magnetic fields, ASACUSA-CUSP aims to create a beam of antihydrogen atoms that can fly to a region where no disturbing fields are present, and to apply a Rabi-type hyperfine spectroscopy scheme (Spectroscopy results using a polarized hydrogen beam are described below).

The experiment is renewed in 2014 with a completely new set-up, which includes a superconducting double cusp magnet, a 3D tracking detector and an upgraded antihydrogen detector. Figure 1 schematically shows the whole setup. Antiprotons from the AD (Antiproton Decelerator) are transported to MUSASHI via the RFQD. MUSASHI then traps, cools, and compresses antiprotons, which are adiabatically transported to the double cusp magnet, and softlanded on a pre-loaded cold positron cloud to synthesize cold antihydrogen atoms. Positrons emitted from ^{22}Na are moderated by a thin layer of Ne ice and continuously stored in the positron accumulator. Positrons are then pulse-extracted, transported to the double cusp magnet, and stacked in the double cusp magnet, compressed/de-compressed before the injection of antiprotons. Antihydrogen atoms in the low field seeking states are extracted downstream, pass the MW (Micro Wave) cavity to induce hyperfine transitions, the Sextupole magnet for spin analysis, and are finally detected by the antihydrogen detector.

Double cusp magnet: The double cusp magnet consists of a pair of two anti-Helmholz coils, which has a strong focusing capability for antihydrogen atoms in low field seeking states, and yields a spin-polarised beam of antihydrogen atoms.

3D Micromegas Tracker: In the bore of the double cusp magnet, a semi-cylindrical tracker is installed to extract detailed information on the formation processes of antihydrogen atoms. The tracker is a precision three-dimensional annihilation Micromegas detector with the curvature of ~100mm that implements very thin flexible insulator films on which metallic patterns are printed, immersed in a gas mixture to follow the particle trajectory precisely.

Antihydrogen beam detector: At the most downstream, the antihydrogen detector is installed. It consists of a BGO crystal disc in a vacuum and two-layer hodoscope, 32 bars per layer surrounding it. This is essential to allow the experiment to distinguish accurately between antihydrogen particles coming from the beam (which are therefore to be measured and studied) and spurious particles coming from unshielded cosmic rays and from antiproton annihilations upstream of the antihydrogen detector primarily in the cusp magnet.

We are continuously improving the antihydrogen synthesis scheme for the ground state hyperfine spectroscopy. The completion and operation of ELENA will benefit the experiment by further increasing the intensity of antihydrogen beam.

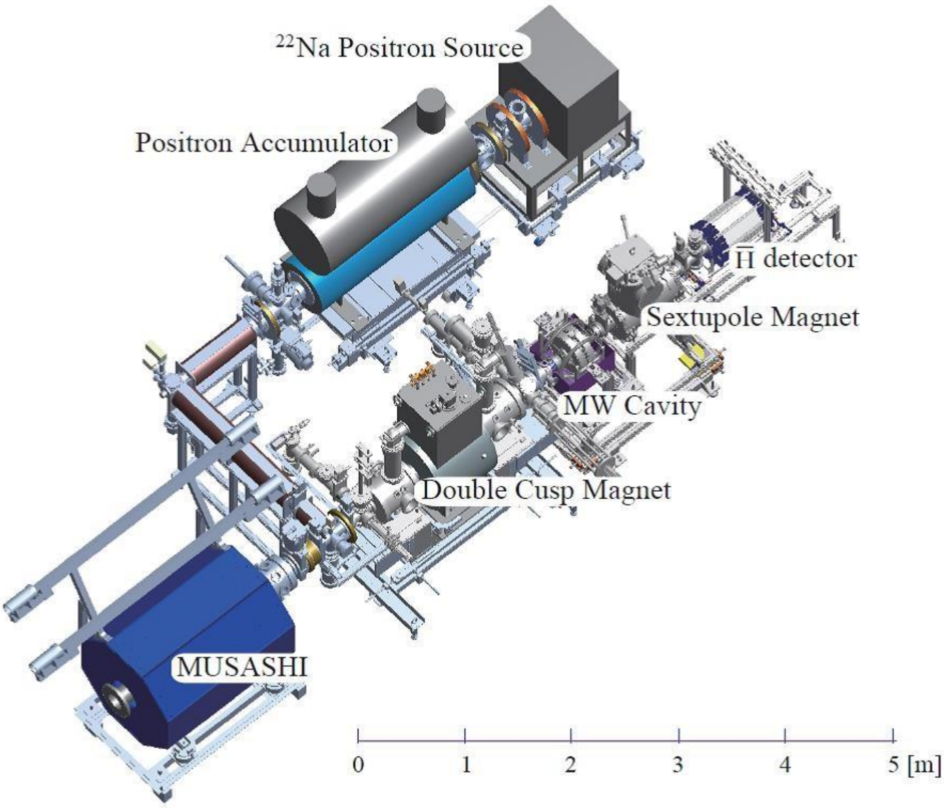


Fig.1: A schematic drawing of the experimental setup for the hyperfine spectroscopy of antihydrogen beam

§2 Polarised hydrogen beam

In order to characterize the Rabi-type hyperfine spectroscopy apparatus (a microwave cavity oscillating at ~ 1.42 GHz and a superconducting sextupole acting as spin selector) developed for antihydrogen spectroscopy, a source of polarized cold atomic hydrogen was built at Stefan Meyer Institute. It consists of a radio frequency discharge to create atomic hydrogen, two permanent sextupoles to polarize the beam and to narrow the velocity distribution, as well as a commercial quadrupole mass spectrometer to detect hydrogen atoms.

The setup was first installed in the CERN cryolab and later in Bldg. 275. In a first series of measurements, one of two possible hyperfine transitions, the so-called σ_1 transition, was studied and its value has been determined with an accuracy of 3 ppb by applying a small static magnetic field and extrapolating to zero external magnetic field. This proves that the apparatus is capable of achieving a high precision provided an intense enough antihydrogen beam becomes available.
The next step is to measure the second transition (π_1) which is more sensitive to magnetic field inhomogeneity. New Helmholtz coils with additional correction coils have been built and an improved magnetic shielding has been designed. Measurements will commence in September. Using this setup, it will also be possible to determine some coefficients of the Standard Model Extension SME by Alan Kostelecky et al. which are sensitive on Lorentz Invariance Violation.

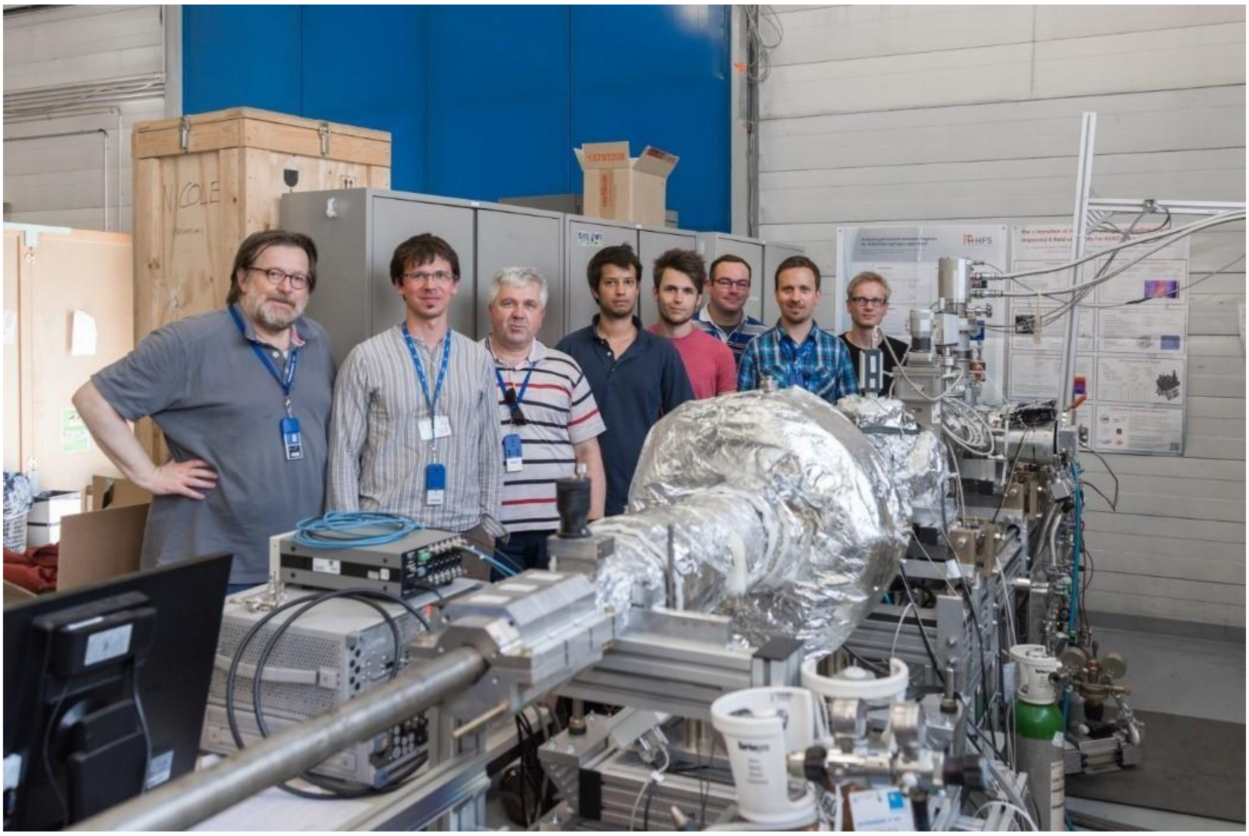


Fig. 2: Members of Stefan Meyer Institute in front of the polarized hydrogen beam at CERN.
source: CERN

3 Determination of the antiproton-to-electron mass ratio by laser spectroscopy of antiprotonic helium

Antiprotonic helium is a three-body atom composed of a normal helium nucleus with an antiproton orbiting a highly-excited state, and an electron orbiting the ground state. The ASACUSA collaboration synthesizes large numbers (10^9) of these atoms and shoots powerful laser beams with a high degree of monochromaticity on them, which causes the antiproton in each atom to transfer from one quantum orbital to another. The characteristic transition frequencies of the atom are measured by detecting the resonance condition between the laser beam and the atom. By comparing these experimental results with theoretical quantum-electrodynamics calculations, the antiproton-to-electron mass ratio M_{p^-}/m_e is determined to sub-parts-per-billion scale precision. This ratio derived by ASACUSA has so far agreed with the proton-to-electron values obtained by other experimental groups to an even higher level of precision.

In past experiments carried out by ASACUSA, the thermal motions of the atoms in the experimental apparatus caused an uncertainty (called the Doppler broadening) in the determination of the antiproton-to-electron mass ratio. We have spent the last few years perfecting two techniques to improve the experimental precision beyond this limit. The first involves irradiating the atom with two counterpropagating laser beams to cancel the effect of this Doppler broadening, and observe narrow spectral lines. The second technique involves the cooling down of our samples of atoms to cryogenic temperatures below T=2 K. The collaboration will soon publish an improved value on the antiproton-to-electron mass ratio. For these experiments, we relied on valuable help provided by the CERN cryogenics laboratory.

Further large improvements in the experimental precision of M_{p^-}/m_e are expected once the ELENA storage ring comes into operation. New higher-precision lasers and experimental targets are being developed for these future experiments.

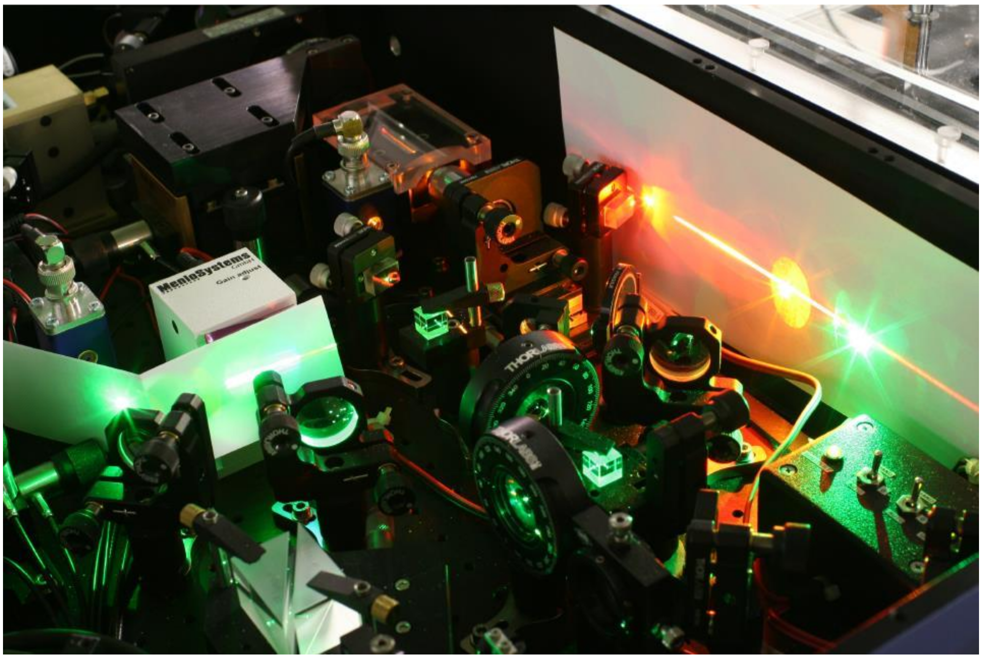


Fig 3: Detail of laser system used for experiments on antiprotonic helium.

The author would like to thank Y. Yamazaki, E. Widmann and M. Hori for their invaluable contributions to this article.

The BASE Experiment

*by **Stefan Ulmer on behalf of the BASE Experiment***

BASE is a Japanese / German collaboration at the antiproton decelerator facility which was approved in 2013. The goal of the effort is to conduct Penning trap based high-precision investigations of the fundamental properties of protons and antiprotons. These type of experiments provide stringent tests of the fundamental charge, parity, time invariance, which is the most fundamental symmetry in the relativistic quantum field theories of the Standard Model.

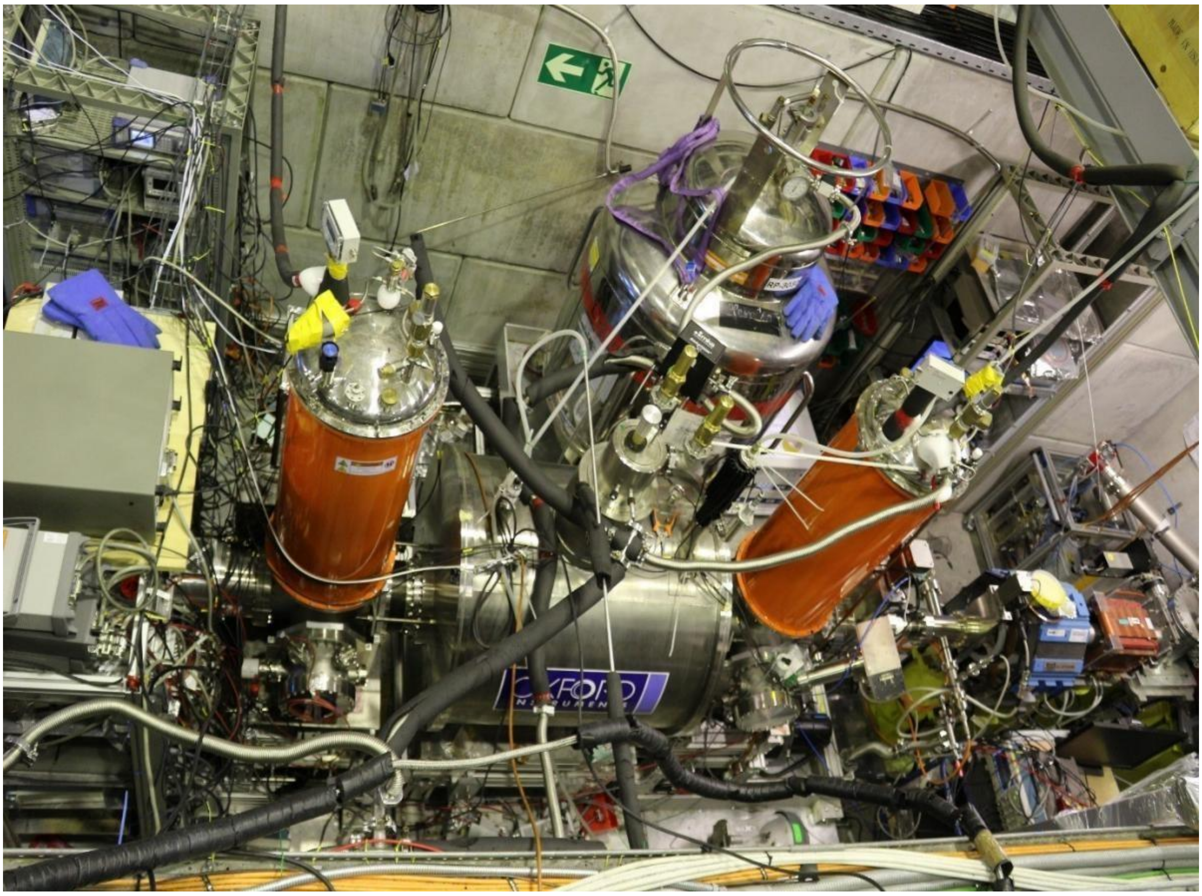
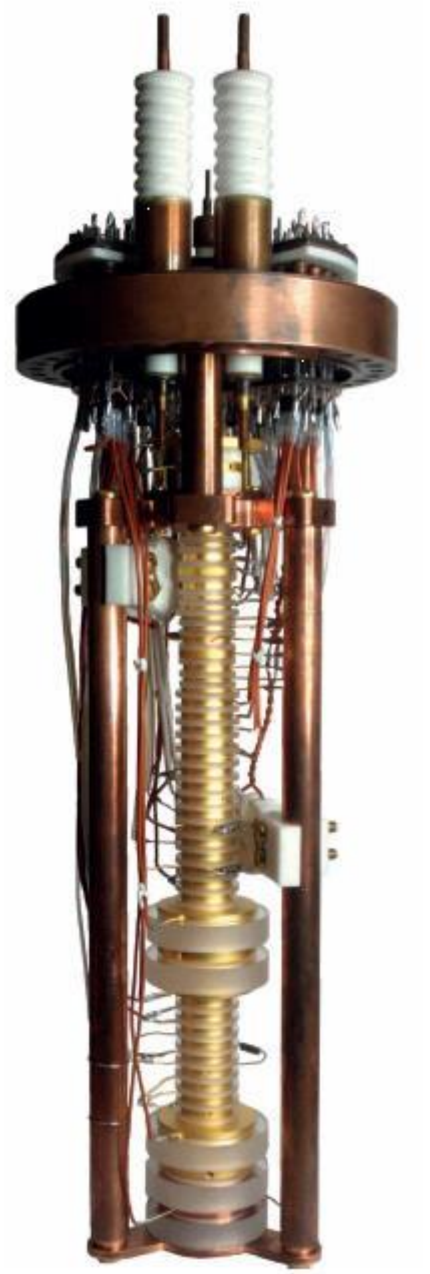


Fig. 1: BASE apparatus as installed in the antiproton decelerator facility. The central vessel is a superconducting magnet in persistent mode which provides the stable magnetic field for the Penning trap. The orange vessels are cryostats which cool the Penning trap apparatus. Cryopumping produces in the central trap volume background pressures of order 1e-18 mbar.

The BASE collaboration developed from an effort which started at the University of Mainz, Germany, around 2007. The goal of this campaign was to use the elegant continuous Stern Gerlach effect, a method which was previously applied with great success to measure the magnetic moments of electrons and positrons, to perform the most precise measurement of the magnetic moment of the bare proton. This is a rather challenging task since, compared to the electron/positron system, the magnetic moment of the proton is by 660 times smaller. Thus, an apparatus had to be developed with an orders of magnitude higher sensitivity with respect to magnetic moments than any Penning trap experiment which has been built before. After years of development work – in 2011 – the group was able to report on a major milestone towards their physics goal; the first observation of spin flips with a single trapped proton. Based on this success and after considerable improvements of the experimental apparatus the team reported on the observation of singleproton spin-quantum transitions and the first demonstration of the double-Penning-trap technique with a single proton. The sequence of achievements culminated in the most precise measurement of the magnetic moment of the proton with a fractional precision of 3.3 parts in a billion.

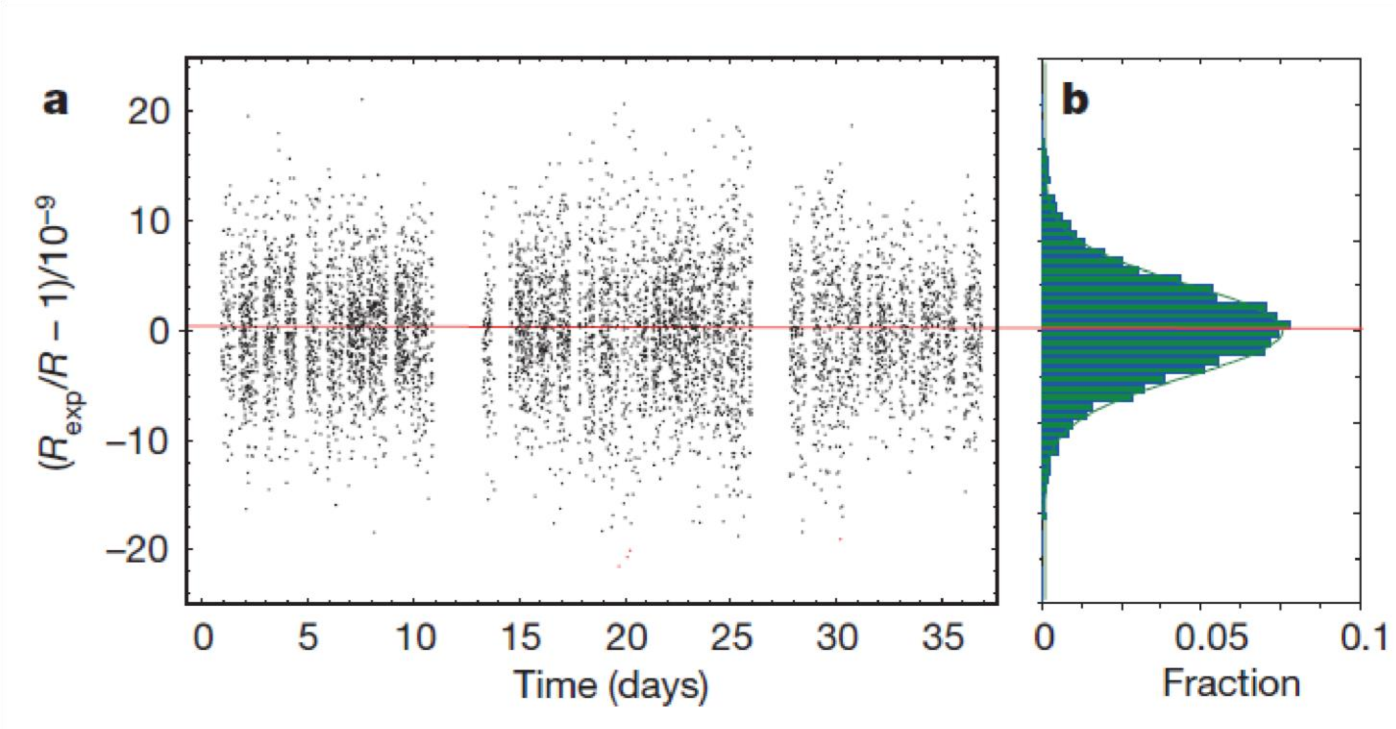


What's highly topical: the double-Penning-trap method which was used to achieve this goal for the proton can directly be applied to measure the magnetic moment of the antiproton with comparable precision. To date the most precise value of this fundamental antiparticle property comes from a 2013 ATRAP measurement. Using a single Penning trap method a fractional precision of 4.4 parts in a million was achieved. The double Penning trap technique developed by the Mainz scientists has the potential to improve this measurement by more than a factor of thousand. To apply this method to the antiproton the BASE collaboration was formed. Led by the Japanese RIKEN institute a novel type of precision Penning trap was developed – the four Penning-trap system shown in Fig. 2.

Fig. 2: BASE Penning trap stack which consists of four Penning traps, a reservoir trap, a double Penning trap for precision frequency measurements and a cooling trap for efficient mode cooling of the individual degrees of freedom.

It consists of a double Penning trap, a precision Penning trap for frequency measurements and an inhomogeneous analysis trap for spin state analysis. What's new is that the BASE scientist added two additional traps, a small cooling trap for highly efficient single particle cooling and a reservoir trap. This unique device – invented by BASE – traps a cloud of antiprotons from the antiproton decelerator and stores them under background pressures of order 1e-18 mbars for arbitrarily long time. Methods were developed to extract single particles from this reservoir and to supply them to the precision Penning trap cycle. This enables BASE to conduct experiments almost independently from accelerator cycles, even during the winter shut-down when magnetic background noise in the accelerator hall is much lower than during the antiproton run. Currently, September 2016, the experiment is being operated with antiprotons which were trapped in November 2015, which constitutes a new record in antiproton trapping time.

Apart from magnetic moment measurements the BASE Penning trap techniques incorporate another highly exciting possibility – the comparison of the antiproton-to-proton charge-to-mass ratios. Such comparisons are based on cyclotron frequency comparisons of antiprotons and negatively charged hydrogen ions which serve as perfect proxies for protons. A scheme was implemented which enables such frequency comparisons in experiment cycle times of only 4



minutes, which is by about 50 times faster than in previous experiments. This fast measurement technique enables thus measurements at much higher statistics. By using this fast comparison technique BASE performed in the 2014 antiproton run the most precise comparison of the protonto-antiproton charge-to-mass ratio with a fractional precision of 69 parts in a trillion, results are shown in Fig. 3. The measurement constitutes the to-date most precise test of CPT invariance with baryons, the measured result being consistent with CPT invariance.

Fig. 3: Results of the high precision cyclotron frequency comparisons of antiprotons and negatively charged hydrogen ions. In total 6500 frequency ratios were measured within a sampling time of about one month

Apart from a stringent test of CPT symmetry the data provide an interesting interpretation: By assuming that CPT invariance holds the proton/antiproton cyclotron frequency comparisons set a stringent constraint on hypothetically different gravitational red-shifts experienced by matter and antimatter particles, respectively. Given this assumption the BASE data set most stringent limits on the weak equivalence principle of general relativity.

The BASE effort has just started and is currently in the middle of the third antiproton run. A first benchmark measurement with 69 p.p.t. fractional uncertainty has been performed in a very first step. Further optimization of the apparatus will allow for a further improved comparison of the antiproton-to-proton charge-to-mass ratios as well as a thousand-fold improved measurement of the magnetic moment of the antiproton. This experiment – considerably more challenging than the charge-to-mass comparison – is currently being commissioned.

Interview with Guido Tonelli

by ***Panos Charitos***

Guido Tonelli, former spokesperson of the CMS experiment and one of the protagonists of the Higgs boson discovery, discusses the meaning of one of the major breakthroughs of the century, as well as the importance of pushing beyond the current limits of knowledge. He reflects on the present situation in particle physics and the significance of having a vision for the future.

How do you see the present situation in particle physics following the recent findings of the LHC?

We are living a truly magic moment in physics. With the discovery of the Higgs boson we have closed a chapter that was opened approximately 50 years ago. We have found the last missing piece and the Standard Model of fundamental interactions is now complete. Still, while we celebrate another triumph of this successful theory, we are left with a long list of open questions, whose answer would probably require the emergence of new paradigms.

Why the discovery of the Higgs boson was so important?

We have understood the specific mechanism chosen by nature to break the perfect symmetry between electromagnetic and weak interactions. We can now reconstruct the very special moment, in the early life of our Universe, 10-11 seconds after the Big-Bang, when a new scalar field occupied every corner of the immense object originated from a tiny fluctuation of the vacuum. The mechanism with which the Higgs boson forever separated electromagnetic and weak interactions and assigned a well-defined mass to elementary particles is now understood. It allows light quarks and gluons to form stable protons and attract electrons, therefore generating the first atoms. The current shape of everything, including us, was somehow determined in those moments. The evolution of matter eventually led to the formation of galaxies, stars and planets, including a very special planet located in a comfortable corner of our solar system, where several forms of life became possible.

Do you think that we have reasons to search beyond the Standard Model of particle physics?

We are very proud of the success of the Standard Model, but we are also aware that it does not include particles or forces responsible for dark matter and dark energy. It does not explain the dynamics of inflation, neither is it able to consistently unify the major interactions. Last but not least, it does not include gravity. We already know that sooner or later we shall be forced to abandon the Standard Model as a general theory in favor of a new, more complete description of nature. The beauty of our job is that this could happen anytime. It could happen tomorrow, if the analysis of the current LHC data unveils new states of matter, but it could also take years of efforts or perhaps a completely new generation of accelerators.

How should one proceed in trying to address today's open questions in high-energy physics?

We have to follow two independent routes: direct searches and precision measurements. With the LHC running at 13TeV, we are going to explore a completely new region that could hide very heavy particles. So far, we have explored the region up to ~1TeV and within the next twenty years we could extend this reach by factors. Furthermore, in the high luminosity regime, the LHC will produce a huge amount of Higgs bosons that could be studied in great detail. For the moment, we have only measured the major characteristics of the newly discovered particle and the errors are still large. The Higgs boson is a unique object that couples to all particles, including, possibly, some of the very massive ones foreseen in supersymmetry or extra dimensions models. If they exist, and they will be too heavy to be produced directly, they can be "seen" indirectly, by measuring deviations from the expected properties of the new scalar boson. Statistics matter a lot, since we will need to produce tens of millions of Higgs bosons to improve precision and study very rare decays that could hide anomalies. It must be noted that the heavier the unknown particle interacting with the Higgs, the smaller the effect on its properties. This is why now is the time to start looking beyond the LHC.

FCC is the right project to coherently address these issues. I consider it a sort of dream machine. Imagine first the FCC-ee option, where we could perform the most precise measurements of all parameters of the Standard Model, stressing it to the extreme limit. Consider, then, the 100TeV pp collider. For the first time, we could study the Higgs away from the stable equilibrium in which it has been for 13.8 billion years. With the new machine, the electroweak phase transition could be studied in detail and we could measure the Higgs self-coupling, one of the most important parameters for checking the evolution of its potential. We would also have the opportunity to directly explore new states of matter, up to masses of tens of TeV. Nature might have surprises for us in this new energy regime, but this is not granted. It is certain, however, that after FCC our conception of matter will not be the same as today.

Is it timely to think ahead and design future colliders that could extend the present intensity and energy frontier?

It is urgent to start thinking forward to the next generation of colliders. The very first discussions on the LHC started in the mid-1980s and the accelerator was completed in 2008. If we want a new machine at the end of the high luminosity phase of the LHC, the time to act is *now*. The CERN management has been very wise in launching the FCC study group. Since 2014, we have been attracting a growing interest in this initiative. Hundreds of scientists are making enormous progress, both in addressing the most important physics cases and in finding solutions to many technological challenges.

How would you describe the relation between scientific and technological developments?

Without fundamental physics, there can be no serious technological developments. Think for a moment of laser or microelectronics technology. Do you think they would have been possible without Maxwell's equations and quantum mechanics? When interviewed by journalists on this subject, I sometimes joke about the BRB, the Big Red Button. Let's suppose that we could have it somewhere, say at CERN. Its function would be to switch off all major physics discoveries of the last 150 years, erasing therefore their applications in modern society. Whenever politicians or the general public would start questioning the economic impact of investments in research, it would be enough to switch off the BRB for a few moments. I am sure that, within hours, the entire world would line up in front of CERN's doors offering money and asking physicists to continue their research.

Guido Tonelli was one of the speakers of the public event "Macchine per scoprire dal Bosone di Higgs alla Nuovo Fisica" that was held in Rome during the 2016 FCC Week.

Do you think that recent data from the LHC and experiments in other fields, i.e. astrophysics, cosmology, could offer a new understanding of the fundamental theories of particle physics?

We are a lucky generation of scientists: in a very short period of time, we have witnessed two major breakthroughs in physics. They will probably influence our field for decades. The first was the discovery of the Higgs boson at the LHC in 2012. The second was the recent detection of gravitational waves by the LIGO interferometer. It looks like we now have two new powerful tools to better understand the fine structure of our Universe. The Higgs boson could be the portal to discovering new particles or new interactions at the microscopic scale, but it could also provide hints about cosmic inflation. It is well known that a scalar particle could produce the very special potential that could lead to inflation. The Higgs is the first fundamental scalar particle observed in nature so far. Did it play a role in the very early stage of the evolution of the Universe? To carefully answer this question, we would probably need better measurements of the Higgs and a new round of precision astrophysics measurements. The recently discovered gravitational waves could be a fantastic new tool to explore these very first instants of our Universe.

Could we be in the middle of a revolution in physics that calls for a change of scientific paradigm?

This is the secret hope of every scientist. I am particularly puzzled by gravity. It is frankly embarrassing that the most popular of the major interactions is still such a mysterious subject. The extreme weakness of gravity makes the effort to unify it with the other interactions very difficult, not to mention the long-lasting attempts of building a convincing quantum description of it. The in-depth understanding of gravity will likely be the target of the next generation of gravitational waves experiments. The challenge will be to improve, by orders of magnitude, the sensitivity of the current interferometers. High-energy physics at accelerators could also play a role in carefully testing the theoretical models based on additional spatial dimensions or in discovering new behaviors of gravity at a very small scale. I am sure that a breakthrough in understanding gravity would imply a change of paradigms in physics similar to the ones that marked the beginning of the 20-th century.

Why did you choose to study particle physics and what would be your advice to young scientists?

Curiosity and passion were my main driving forces. I studied in Pisa and I still remember the feeling of entering rooms on whose the walls hang original drawings of Galilei or the front page of Fermi's thesis. Each student in Pisa feels the strength of a powerful tradition that has continued through strong personalities, like Bruno Pontecorvo or Carlo Rubbia. I have been very lucky, when I was student, in having met some incredible professors. I remember, in particular, Adriano di Giacomo and Lorenzo Foà. They were excellent mentors, with the special gift of widening the horizons of each young student interacting with them. Furthermore, they both showed a huge confidence in young people. I entered the field, as many other colleagues, thanks to their encouragement. The advice I can give to the new generation of young scientists is very simple: follow your passion and try to make your dreams come true. I don't know if you will succeed, but I am sure that you'll never regret it.

In an age of turbulence like the present one, why do you think it is important to continue investing in fundamental research?

Investments in fundamental research are the answer to the current economic crisis. In the new order that will emerge from this turbulent period, the hierarchy will be defined by the role of each country in producing knowledge and innovation. Countries taking the lead in these areas will guide the world for the whole century. If Europe wants to continue playing an important role in a planet that is becoming more and more competitive, it should secure its current leadership in high-energy physics. The right move would be to soon launch FCC as a new, global project. With new actors, like China and Japan, trying to take center stage, every delay or hesitation could be extremely dangerous.

Finally, I would like to ask you about your new book and what motivated you to write it? I have written the book *The imperfect origin of everything* mostly to tell our story to young people, with the secret hope that some of the readers will discover the same passion in them. It is the story of my generation, of people that were young scientists in their 30s when they started discussing the idea of building the LHC, the new, fantastic accelerator that would discover the Higgs boson. The book describes the many crises we have faced to build this marvelous machine and its challenging detectors, but also the deep emotions of the last months of this long-lasting hunt. The last part deals with the many open questions in physics and the new challenges facing our field today, including the FCC initiative. Quite surprisingly, the book has become a best seller in Italy. Actually, in the last two years, several physics books written for the general public have become very popular in our country. This has therefore generated serious attention by the media, which regularly cover all major events and report on the most significant scientific results. It is a sort of magic moment for physics that has already translated into a significant increase of physics students in Universities. Since I am always optimistic, I do hope that this trend will continue to grow and involve the government, yielding new resources to the field.

Guido Tonelli is professor of Physics at the University of Pisa, former spokesperson of the CMS experiment and the author of "LA NASCITA IMPERFETTA DELLE COSE – THE IMPERFECT BIRTH OF THINGS" (Rizzoli Publications).

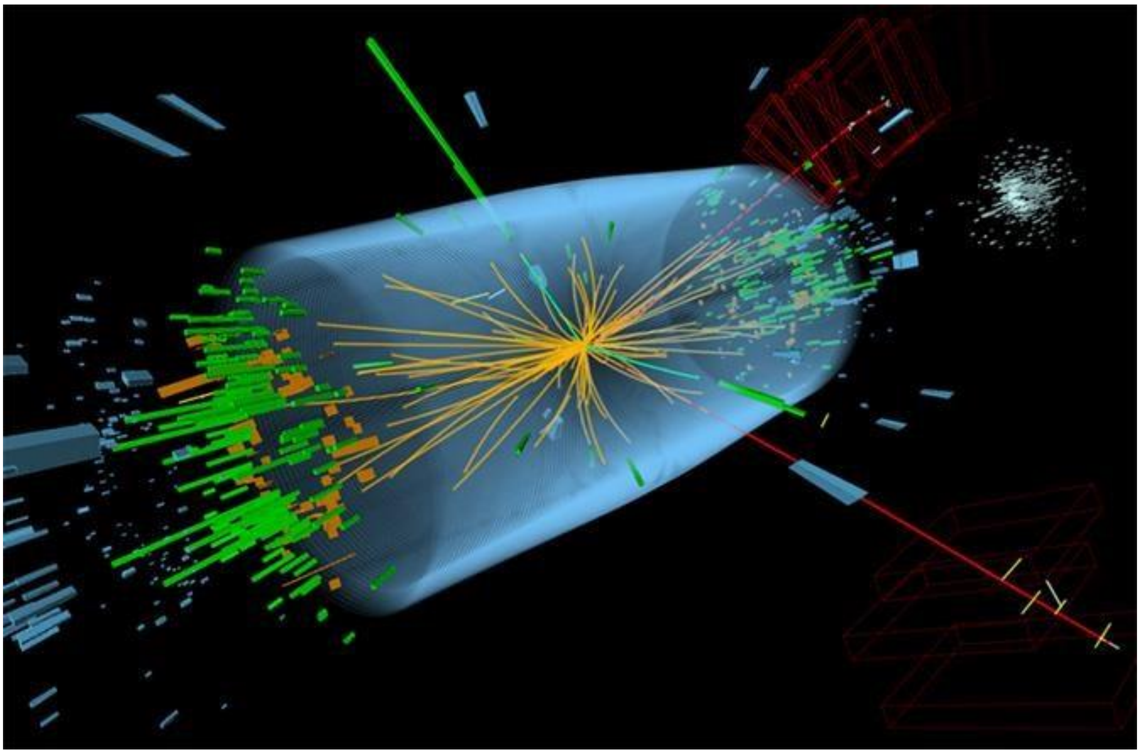
The big rush to the God Particle and the new Physics that will change the world. The discovery of the Higgs boson as told by one of its protagonists. An accomplishment that will revolutionize the idea that we have of ourselves and of the world around us. "Everything is precarious. The human condition is as fragile as the gigantic structures of the universe, even those that seem immortal." At that precise moment, a hundredth of a billionth of a second after the Big Bang, our destiny was decided. In a universe where matter and antimatter were equivalent, and that therefore could have gone back any moment to being pure energy, a slight preference of the Higgs boson for matter instead of antimatter can have been enough for the world as we know it to be produced. "Here is the flaw, the subtle imperfection that gave birth to everything. An anomaly that gives rise to a universe that can evolve for billions of years." If everything comes from there, we need to understand in each detail that crucial moment, rebuild it frame by frame, in slow motion and from different angles. For this reason, at CERN in Geneva, LHC was created: the most powerful particle *collider in the world, the place most similar to the first moment of life of the universe that man has been able to build. For this, for years, the world's best physicists have been working day and night, at the four corners of the planet. This is how the "God particle" was captured. And this is why the studies continue, to better understand how all this was born and how our story will end: if in the cold and in the dark, or in a cosmic catastrophe that would give us the privilege of a much more spectacular exit. Guido Tonelli is one of the protagonists of this great adventure, one of the leaders of this army of visionaries. Here, with the attitude of an explorer, he tells what it means to push beyond the extreme limit of knowledge, what it means to make the discovery of the century on the day of one's birthday, what it means to understand how it all began and will probably end.*

Charting the Unknown: interpreting LHC data from the energy frontier

by ***Panos Charitos***

PDF version

The LHC has started its Run2, exploring for the first time the high-energy frontier at 13 TeV. Collected data will give decisive information on the dynamics behind electroweak symmetry breaking, testing weak-scale naturalness. A TH Institute "Charting the Unknown: Interpreting LHC data from the energy frontier" focused on the interpretation of the new data in the context of theories beyond the Standard Model. From 25 July to 12 August, world-leading experts came together for an in-depth discussion towards revealing the final clues of the underlying theory of the electroweak scale. The organizers aimed to have the latest data presented during the workshop in order to trigger interesting discussions. The TH institute partially coincided with ICHEP16, the world's largest event in particle physics, where the experimental collaborations presented their latest results.



In the past months, there was a lot of excitement about the 750 GeV diphoton excess that could have signified a new fundamental particle. This exciting hint generated many theory papers attempting to explain the origin of the 750 GeV signal. However, with more data included in the analysis, the bump disappeared, suggesting that it was a statistical fluctuation; thus refuting theories for new physics. The story of the 750 GeV bump is an example of how new data can completely shift the focus of the scientific community. Theorists are ready to embrace new ideas. The discovery of the Higgs boson has been a crucial chapter in our understanding of the electroweak breaking sector. But our understanding is not complete. There are still many open questions.

For most theorists it is clear that we enter a moment of transition. Most of the models build so far to explain some of the open questions relied on the argument of naturalness to predict new physics at the LHC. However, today many of them have been excluded with more data from the LHC and it seems that we are reaching a crossroad regarding the open questions about our nature. Given the latest results from the 13TeV run of the LHC, the TH workshop focused on some of the open questions about the electroweak symmetry breaking; namely the existence of dark matter and the potential candidate particles, the role of naturalness and finally plans for future colliders that will push back further the energy frontier. The programme also included review talks by the LHC experimental collaborations to report on their latest results (including searches for symmetry and exotic particles as well as Higgs studies) and highlight future projections.

It is worth mentioning a novel idea that Savas Dimopoulos presented during the TH workshop on very light particles that can accumulate around a black hole altering the dynamics of the space time. The characteristic radiation (superradiance) from these particles could allow probing axions between 10^{-20} and 10^{-10} eV independent of the abundance of dark matter. Dimopoulos suggested that if this is the case then they could be directly observed by analysing the gravitational waves emitted from the collision of two black holes. His talk generated an intense discussion as it is clearly linked to the recent discovery of gravitational waves.

Another inspiring talk pointing to possible new directions in our research was given by David Kaplan. In his talk “The Lifetime Frontier” he suggested that we should search for particles with very long lifetimes (LLPs) that can be one way to go beyond the naturalness paradigm. To detect these particles one should consider building detectors on top of the LHC – and outside the cavern – as these very weakly particles could live long and travel up to the surface. In other words, this calls to enlarge the parameter space of the present experiments by several order of magnitude.

The last talk was dedicated about physics in future colliders. LianTao Wan discussed the different options for lepton-lepton, hadron-hadron and lepton-hadron colliders and reviewed the physics potential of these machines. It is evident that future colliders can cover significant ground beyond the LHC and by extending the energy and luminosity frontiers give answers to many of the questions that remain open. The importance of lepton machines was also emphasized during the talk as they can provide a powerful and complementary probe about the energy scale where new physics might lie. In addition it will also shed more light on the nature and the properties of the Higgs boson as it seems to be a very special particle of the Standard Model.

Finally, during the TH institute three colloquia were given on ”Fundamental Physics beyond Colliders” by Mina Arvanitaki, on “New ideas in dark matter direct detection” by Kathryn Zurek and finally on “Spacetime, Quantum Mechanics and the LHC” by Nima Arkani Hamed. Arvanitaki discussed how existing and well-established techniques can improve by several orders of magnitude searches for scalar Dark Matter and the QCD axions. Zurek offered a detailed overview of past indirect and direct searches. In his presentation he shown the interplay between highenergy physics and condensed matter while he also discussed new ideas for the detection of dark matter that could pave the way forward. Finally, Arkani Hamed, in an inspirational talk, discussed the effort to go beyond the quantum field theory in order to get a breakthrough in our present understanding of quantum mechanics and general relativity. This may sound like a simple statement but the maths in doing this step are very complicated. In fact, an interesting suggestion is that we may be missing a more fundamental part of our theory – having models that offer a more complicated description of reality. For Arkani Hamed, complexity stems from the fact that we try to maintain locality in our theories (while conservation of energy & momentum is manifest in all steps).

Read more about this workshop: https://indico.cern.ch/event/466926/

The CERN School of Computing 2016

SFT

*by **Danilo Piparo, Enric Tejedor***

The CERN School of Computing (CSC) fosters the dissemination of knowledge and learning in the field of scientific computing. Its mission is to create a common culture in scientific computing among young scientists and engineers involved in particle physics and other sciences as a strategic direction to facilitate the development of large computing-oriented transnational projects. The CSC is composed of up to three schools per year, each one characterized by its own flavour and specific goals.

The Main School, the CSC, is held every year and lasts for two weeks in summer. It is a veritable "Summer University", which offers both formal lectures and hands-on exercises. The practical part is an important component of the school, and may include projects carried out by groups of students. The supporting computing infrastructure is configured on the site of the school. Attendance usually ranges from 50 to 80 students. Upon successful completion of the CSC exam an official CERN School of Computing Diploma is delivered to the students and, thanks to the hosting universities, ETCS credits are recognized, six for the 2016 edition of the CSC.

In addition there is the Thematic School, tCSC, which is characterised by being shorter, smaller and focused on a specific technical "theme". It lasts for one week and is dedicated to advanced lectures and practical exercises on a specific topic that can change from edition to edition. Students typically have either a computing or a science background, but with a strong interest in applications designed to solve demanding and sophisticated scientific computing problems.

The Inverted School, iCSC, is a place where "Students turn into lecturers". This school involves former attendees of the tCSC and CSC as lecturers. This event lasts one to three days, is held at CERN and comprises only talks. In fact, several of the lecturers at the CSC have previously presented talks at the iCSC. Attendance to this event is open to anyone at CERN who is interested to attend.

This year the Main School was organised in Mol, Belgium at the SCK-CEN research centre and took place from August 28th to September 10th. Forty-nine students from twenty-five different countries attended the School.

The SCK-CEN "Lakehouse" where the restaurant and lecture room were located.

The scientific programme consisted of fifty-two hours of tuition organised in three tracks: *Data Technologies*, addressing the broad domain of data storage and management technologies, *Physics Computing*, covering tools and techniques for scientific software design and data analysis and *Base Technologies*, presenting a selection of advanced computing technologies especially relevant in the context of scientific computing.

Also this year SFT group contributed to the Base Technologies track with four hours of lectures and three hours of exercises covering the topic of *Software Design in the Many-Core Era*. This lecture series gave an introduction to the architecture of large parallel applications and treated the cornerstones of the design and development of parallel scientific software. Theoretical concepts such as implicit and explicit parallelism, task scheduling, thread safety and protection of resources have been discussed in depth also examining examples coming from High Energy Physics and High Performance Computing.

SFT is not only involved in the Main School but is also present at the Thematic School, where it is responsible for one third of the scientific program, and also plays a role at the iCSC, contributing to the mentoring of the student-lecturers.

A presentation at SCK-CEN. During the CSC, ex-cathedra lessons are always complemented by hands-on sessions.

However, the CSC is not only made of lectures and exercises but students are also given the opportunity to socialise and establish relationships that last for a lifetime. Exchange of ideas and points of view is encouraged with an outstanding social program that foresees many opportunities such as dinner outings and other activities. Among these activities, an optional sport programme is offered. It usually consists in two to three hours of sport during several afternoons. Often more than 90% of the students participate and the possibility to discover new sports or to improve new skills, through lessons given by school lecturers or by external instructors, is appreciated. The sport programme helps maintaining a healthy work-life balance offering additional opportunities for interactions between students, lecturers and organisers. This year students were given the possibility of canoeing, trekking, cycling and playing tennis, football, basketball, badminton and volley.

A beach volleyball game during an afternoon of sports

Preparation of the 2017 edition of the Main School has already started. It will be held in Madrid and the hosting institution is the Universidad Politécnica de Madrid (UPM). You are all invited to submit your application!

Playing with Protons: Engaging Teachers to Engage K-6 Students with Science, Technology and Innovation

CMS

by ***Angelos Alexopoulos***

PDF version

There is widespread consensus among science education researchers that learning science should begin early in every child's schooling. Among many good reasons, one stands out clearly: "Children naturally enjoy observing and thinking about nature"[1]. Several studies have shown that the public also wants science to be taught early. For example, in a recent public opinion research conducted for the Center for the Future of Teaching and Learning at WestEd(link is external), seven in ten Californians expressed the view that learning science in primary school is likely to increase the chances of students to perform well in high school[2].

In line with the above, several initiatives to engage primary school students have taken place in collaboration with CERN. These include the "Mains dans la pate(link is external)" initiative of Georges Charpak in France, and the "Dans la peau d'un chercheur(link is external)" project that is aimed at K-6 students from local schools.

Playing with Protons(link is external) (PwP) is a new science education initiative led by the CMS Experiment(link is external) that contributes to this effort by encouraging primary school teachers to engage in professional development (PD) opportunities. These are designed specifically to enrich teachers' pedagogical practice with creative, hands-on methodologies by which K-6 students can, in turn, get engaged effectively with science, technology and innovation.

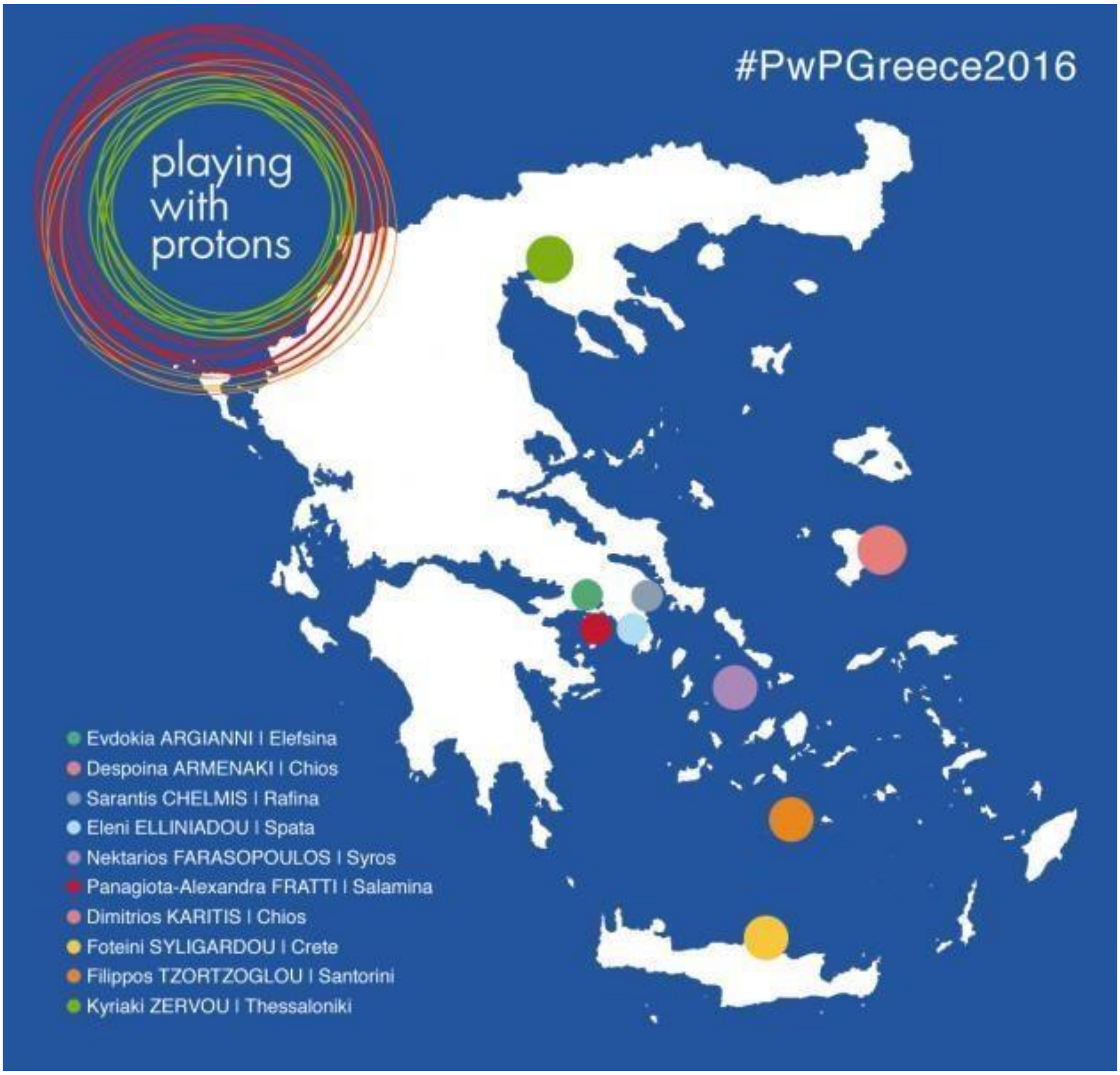
PwP was born out of the passion, dynamism and determination of Tina Nantsou, a physics educator at Hill Memorial School(link is external) in Athens, Greece. Established in 1831, this is the oldest operating primary school in the country. In 2013, Tina visited

CERN as a participant in the Greek Teacher Programme, and upon her return to Athens started a project in collaboration with CERN that involved forty-five 11-12 year old students at Hill Memorial School. And as you may have already guessed, the title Tina gave to her project was *Playing with Protons.* You can read more about it here(link is external) and here(link is external).

Tina's work attracted a lot of interest by the educational community and the media in Greece. The results of the project were also shared with prominent physicists, including Distinguished Professor of Physics and holder of the Mitchell/Heep Chair in High Energy Physics at Texas A&M University, and former President of the Academy of Athens, Dimitri Nanopoulos, and Clerk Maxwell Professor of Theoretical Physics at King's College London, John Ellis. Over the last three years, both Prof. Nanopoulos and Prof. Ellis visited Hill Memorial School, met the students, answered their advanced questions and witnessed first-hand what effective engagement with physics looks like.

Prof. John Ellis at his recent visit to Hill Memorial School in Athens, Greece. Image credit – Christina dePian

In response to this interest, it was considered meaningful to design a pilot PD course that would enable more teachers from public primary schools, and especially those schools located in islands and relatively underprivileged urban areas in Greece, to get familiar with the unique culture of science, technology and innovation at CERN, and to embrace creative approaches for passing on their newly acquired knowledge and enthusiasm to their pupils.



The names and the geographical distribution of PwP Greece 2016 participants are shown on this map.

Thanks to synergies built between nonprofit organisation New Wrinkle, the industry[3], the Greek Ministry of Education and the European Commission Office in Athens(link is external), and under the umbrella of EU project CREATIONS(link is external), a fully self-fundedPwP course(link is external) became a reality this year for a small number of Greek primary school teachers. The 10 finalist teachers were selected by a committee at CERN from a total of 151 applications.

The course was hosted by CERN's IdeaSquare from 17 to 22 August 2016, and based on participants' written feedback we may securely say that it has been successful. This, of course, wouldn't be possible without the support, enthusiasm and expertise of many colleagues from CMS and the wider CERN community. A big thank you to each and everyone of you! You know who you are!

And now, what better way to learn about this experience than from the teachers themselves? So, here is an interview I did with Elena Elliniadou and Filippos Tzortzoglou, two of the participants of PwP Greece 2016, soon after their return home from CERN.

PwP Greece 2016 participant Elena Elliniadou. Image credit – Sophia Bennett/CERN

PwP Greece 2016 participant Filippos Tzortzoglou. Image credit – Sophia Bennett/CERN

Can you tell me a few words about yourself and your school?

Elena Elliniadou: I'm the principal of the 6th Primary School of Artemis. This is a typical suburban school located at the east of Attica region in Greece. My school is under the same roof with the 2nd Primary School of Artemis, the principal of which is Mrs. Kassiani Katsiouli. Both schools have in total more than 400 K-6 students. Kassiani and I work closely together, which means that the two schools are effectively run as one. My participation in PwP will therefore have an impact not only on the 135 students of my school, but also on Kassiani's students. I'm also an ICT teacher trainer and a blogger. In my blog(link is external) I express my viewpoints on primary education and the role of ICT in it. I also share resources and materials that I think would help my colleagues learn how to build effective pedagogies for teaching various subjects, including of course science and technology.

Filippos Tzortzoglou: I've been working as a primary school teacher for the last eight years. I've been teaching in many schools across Greece most of which located in islands such as Kefalonia, Crete and Santorini. This September I'm going to teach in a small public primary school in Psinthos, a mountainous village at the island of Rhodes.

I have great interest in ICT applications for education and especially in mobile applications for game-based learning and in augmented reality (AR), with the latter being the topic of my PhD research at the University of the Aegean. My passion for innovative technologies and their role in education have led in several interesting collaborations with companies specialized in this area. My latest passion is blogging. I'm the founder and author of EdTech.gr(link is external), where I share my experience with other teachers, school administrators and parents.

Why did you decide to apply to PwP?

EE: When I read the call for applications that was sent out last April by the Ministry of Education, I thought of PwP as an innovative course that would fill a notable gap in the professional development available to primary school teachers in Greece and, I guess, elsewhere. One extra reason was Tina Nantsou and her key role in the course as pedagogical coordinator. I follow Tina's blog(link is external) for many years now, and I admire the creative, hands-on methodologies through which she introduces her students into the world of physics. Participating in PwP would offer me, and my students as a consequence, a unique opportunity to create new, fun and impactful projects about particle physics and CERN with the aim to make science accessible to students by helping them discover how cutting-edge science actually works at the world's largest particle physics lab. In addition, the course would help me answer my students' questions about the Universe and its mysteries, with the ultimate aim to inspire them, to open their minds and their horizons as far as it concerns science, physics, particle physics and, of course, CERN. I believe that every kid should know how their everyday life is related to scientific discoveries and technological breakthroughs, some of which born at CERN.

FT: Taking part in PwP was an excellent opportunity for me to visit CERN, the *Mecca* of particle physics, to experience first-hand how scientific research is taking place there, and to meet scientists who have, in one way or another, contributed to discoveries such as the recent discovery of the Higgs boson. I also thought it would be a great opportunity to enrich my existing knowledge in the field so that I could update my students with the latest developments at one of the world's greatest scientific experiments. When I applied to the course, I had one goal in mind: to inspire my students about all this, and to encourage them to dream that they can one day become members of the scientific community. In addition, I thought that seeing how all these scientists, engineers and technicians work together at CERN would be beneficial for my own PhD research.

PwP Greece 2016 teachers try out hands-on activities under the guidance of Tina Nantsou during an afternoon workshop at CERN's IdeaSquare. Image credit – Sophia Bennett/CERN

Now that the course is over, what will you bring back to your school, to your students and perhaps to your local community?

EE: I'll try to pass on my passion and enthusiasm to my students and my colleagues, first by describing them my overall experience at CERN and, second, by working with them on various curriculum projects inspired by what I learned during the course. I'll definitely tell everyone that there is a place called CERN, where diversity, equality and peace are not just accepted but celebrated. I'll also tell them that there are no many places in the world that really push forward our understanding of where we come from, what we are made of, and where we are going, also as humanity at large. We, as teachers, have an obligation to help our students open their own paths to knowledge, science and life. What I – and I believe all the other teachers who took part in PwP – will do is to communicate to colleagues, students, parents and the local community what we experienced at CERN and how we can transform this experience into school projects, outreach events for the local community and learning networks, both physical and virtual.

FT: During my time at CERN, I met a lot of interesting people such as the fellow teachers who took part in the course, and a good number of CERN scientists. I definitely learned a lot by visiting remarkable experimental facilities and by experiencing first-hand the multicultural and vibrant culture of collaboration that makes CERN what it is. I'll definitely share this experience with my school and the local community! I'll tell them how enthusiastic and passionate the people I met are about their work in science and technology. I'll then try to pass on my own enthusiasm and the new things I learned during the course to my students. A concrete way to do so is to try to incorporate ICT applications into new educational scenarios inspired by PwP, perhaps by making a mobile game or an AR application in order to motivate and guide my students in the right direction.

From left to right: Elena Elliniadou (PwP teacher), Georgios Karananas (EPFL), Dimitrios Karitis (PwP teacher), Andromachi Tsirou (CERN), Angelos Alexopoulos (CERN), Tina Nantsou (PwP pedagogical coordinator), Filippos Tzortzoglou (PwP teacher), Kyriaki Zervou (PwP teacher), Sarantis Chelmis (PwP teacher), Nektarios Farasopoulos (PwP teacher), Stephanos Cherouvis (Ellinogermaniki Agogi), Despoina Armenaki (PwP teacher), Evdokia Argianni (PwP teacher), Alexandra Fratti (PwP teacher), Foteini Syligardou (PwP teacher). Image credit – Sophia Bennett/CERN.

What are your personal highlights of this course?

EE: Being around brilliant scientists, both young ones and seniors, and feeling their passion and energy for what they are doing was something I hadn't experienced before. John Ellis' "Playing with the Universe" lecture, which was tailored to primary school teachers, was in particular truly amazing. I'll also remember the visits and, of course, the afternoon hands-on workshops at IdeaSquare(link is external). My overall takeaway is that there is a purpose that runs through all that CERN scientists do, and that is to help us understand better the physical world and our place in it.

FT: I have to say that I enjoyed all the presentations and workshops. A personal highlight was François Briard’s talk about the “Dans la peau d’un chercheur(link is external)” project. I think it’s a fantastic way to foster scientific reasoning in primary school students. Meeting applied physicists such as Andromachi Tsirou from CMS, but also theoretical physicists such as Asimina Arvanitaki(link is external) from Perimeter Institute(link is external), was also really useful as it helped me understand where theory and practice meet in particle physics. And, of course, John Ellis’ talk was something else! I was also amazed by the visit to the CMS experiment, which made me realise the amount of human effort and sophisticated materials required to build a particle detector. This can only be possible when passionate and determined individuals work together. And this passion and determination, I think, is what makes CERN what it is.

Finally, if you could describe PwP in three words, what would they be?

EE: Innovative, inspiring, motivational.

FT: Fascinating, innovative, unique.

Word cloud showing the words that teachers used to describe PwP. Words in larger fonts indicate the ones used more frequently across teachers. Image – Angelos Alexopoulos

A new CERN service for web-based data analysis in the cloud: SWAN

SFT

*by **Enric Tejedor, Danilo Piparo EP-SFT***

In the last few years, a clear trend has emerged in the data science industry: the increase of service offerings for data analysis in the cloud, accessible via a web interface. It is precisely this phenomenon that led us, the SFT and IT-ST groups, to the creation of **SWAN**, the CERN Service for Web-based ANalysis.

SWAN offers an integrated environment for data analysis in the CERN cloud where the user can find all the experiment and user data together with rich stacks of scientific software. The interface offered by the service is the one of Jupyter notebooks(link is external). Notebooks have been chosen since they give access to a rich narrative made of code, text and formulas as well as multimedia material, all combined in an HTML page that can be rendered in a browser.
SWAN is not tied in particular to any programming language. Presently it offers the possibility to write notebooks in three languages: C++ (processed by Cling, the interpreter of ROOT(link is external)), Python and R. An innovative element is represented by the fact that, thanks to ROOT(link is external), these languages can be seamlessly mixed: multilanguage notebooks can be created.
As a result of its integration with the Jupyter(link is external) technology, only a web browser is needed to useSWAN: data analysis can be performed without requiring any local software installation. Every computation happens on the server side - in the cloud - while the results are displayed on the client's browser. Regarding the data, both input and output files also reside in the cloud, with EOSacting as a cloud storage backend: the work directory is the user space located on EOS. The exciting part about this solution is that the files in the cloud can be synchronised on local devices and vice-versa thanks to CERNBox. In addition the sharing functionality of CERNBox allow to quickly involve colleagues in the development of notebooks.

CERN Summer Student Program 2016

During the summer the EP department welcomed 230 summer students. They have participated in lectures covering a wide range of topics, and had the chance to visit different sites around CERN and learn more about the diversity of CERN's research programme. Additionally a project was assigned to each student, with subjects that span the entire spectrum of the department's work. In this article we will dive into some of their experiences.

Pourya Vakilipourtakalou is a physics student in University of Tehran (UT). He has been thrilled to work at CERN, as it provided him with an environment full of learning opportunities. His project was Improvement of the ROOT Machine Learning Methods, in EP-SFT group and as implied by the title was in the realm of informatics. Understanding the importance of computing in physics research he took up his project with enthusiasm. With the great coordination and availability demonstrated by his supervisors he managed to complete the project by parallelising some Machine learning methods of TMVA, a ROOT toolkit. When asked what he would take back home he talked about his introduction to advanced computer science, the diverse environment and unique experience he had at CERN.

Niharika Gajam is studying computers science in Institute of Technology, Indore in India. She is passionately pursuing her career in Machine learning, Neural Networks and Software Development. She combined those interest with hard work in order to provide a cloud-based approach to analyzing data files. The new approach will help scientists make use of newly developed technologies like SWAN. In addition to the technical training she acquired over the course of her internship and the great relationships she built with her supervisors and colleagues Niharika will take back home more important lessons. The experience of working and communicating her work in a diverse, international and highly scientific environment like CERN was a cherished experience for her future career.

Marek Matas is a masters graduate from Faculty of Nuclear Sciences and Physical Engineering in Prague, with a focus on QCD and evolution equations. Marek worked for the Future Circular Collider, that might be built in the next 30-40 years. He worked on the electromagnetic calorimeter where he was determining the influence of the magnetic field on the electromagnetic shower development. He learned a lot about how an international collaboration like CERN works and how he should approach his work and physics in general. When asked about his experience he answers: “It was an amazing opportunity to see how it is really done and how amazing machines that most people find miraculous come to life. I loved every second of my stay here. The friends I made is one of the most valuable things that I "take home”.”

Palmerina Gonzalez Izquierdo is a physics graduate from Cantabria, Santander, Spain. This summer just before finishing her studies she did a summer internship at CERN. The project was related to the search of the super-partner of the top quark. This is a particle predicted by the supersymmetry theory, which states that every particle has a super-partner, although not proved yet. The way of achieving this aim was analysing CMS data and using Monte Carlo simulations to search for stop quark pair production and apply different cuts and strategies to distinguish it from the background (mostly top quark pair production). The code to do this was written in C++ and ROOT. During this internship Palmerina improved her coding skills as well as her knowledge about particle physics and supersymmetry. Just like her peers Palmerina recognises another value in her experience: the experience of working in an international research centre.

In conclusion this September has signalled the end of another successful year for the Summer Student Program at CERN. The experience will help the students to presume a bright career in science and promote greater global integration in particle physics, an important CERN policy.

Can ‘useless’ knowledge be useful?

by ***Fabiola Gianotti***

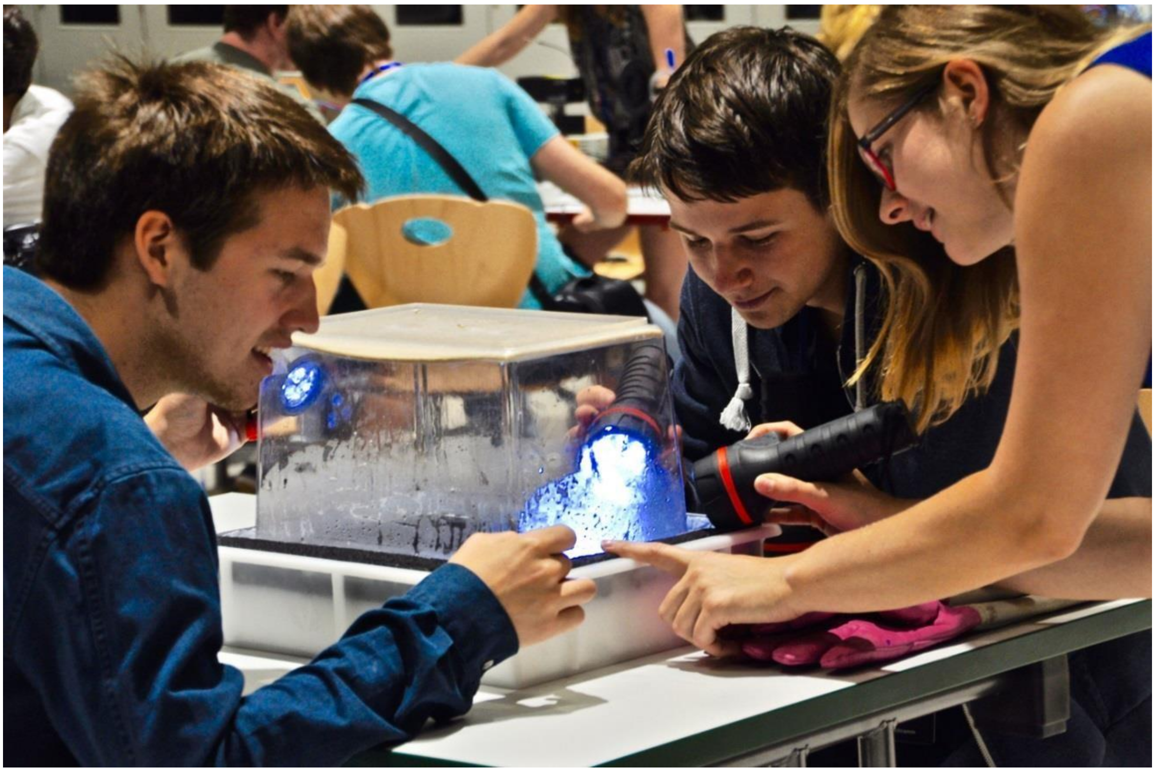
As far back as 1939, Abraham Flexner penned a stirring paean to basic research in Harpers magazine under the title: ‘The Usefulness of Useless Knowledge’. Flexner, perhaps being intentionally provocative, pointed out that Marconi’s contribution to the radio and wireless had been practically negligible. He went on to argue that the 1865 work of James Clerk Maxwell on the theoretical underpinnings of electricity and magnetism, and the subsequent experimental work of Heinrich Hertz on the detection of electromagnetic waves, was done with no concern about the practical utility of the work.

Maxwell and Hertz cared only about the adding to our shared pool of knowledge on the workings of the natural world. The knowledge they sought, in other words, was never targeted to a specific application. Without it, however, there could have been no Marconi, no wireless, no radio, no television and no mobile phones.

Nurturing scientific minds is child’s play

The history of innovation is full of such examples. Indeed, it is practically impossible to find a piece of technology that cannot be traced back to the work of scientists motivated purely by a desire to understand the world we inhabit.

But basic research goes further. There is something primordial about it. Every child is a natural scientist, imbued with curiosity, vivid imagination and a desire to learn. It is what sets us apart from any other species, and it is what has provided the wellspring of innovation since early humans harnessed fire and invented wheels. Children are always asking questions. Why is the sky blue? What are we made of? What are those specks of twinkling light in the night sky? It’s by investigating questions like these that science has advanced, and that we can inspire children to grow up into future scientists or scientifically aware citizens.



(Image: Jeff Wiener/ CERN)

Nurturing curious minds is one of CERN's goals, and education and training are among our core missions. Over the years we have developed programmes that reach everyone from primary school children to professional physicists, accelerator scientists and computer scientists. We also keep tabs on the whereabouts of young people passing through CERN, and it is very enriching to follow their progress. About a thousand people a year receive higher degrees from universities around the world for work carried out at CERN.

Basic research therefore not only inspires young people to study science, it also provides a steady stream of qualified people for business and industry, where their high-tech, international experience allows them to make a positive impact around the world.

Global Goals

Turning to the UN's admirably ambitious Global Goals, the focus on science and technology in Agenda 2030 is positive and encouraging. It testifies to a deeper understanding of the importance of science in driving progress that benefits all peoples and helps to overcome today's most pressing development challenges.

But Agenda 2030's potential can only be fulfilled through sustained commitment and funding by governments. If we are to tackle issues from eliminating poverty and hunger to providing clean and affordable energy, we need science and we need scientifically aware citizens.

Places like CERN are a vitally important ingredient in the innovation chain. We contribute to the kind of knowledge that not only enriches humanity, but also provides the wellspring of ideas that become the technologies of the future. We develop technologies ourselves that have immediate applications for the benefit of society: technologies like the World Wide Web and the application of particle accelerators, one of CERN's core areas of expertise, to fields as diverse as food sterilisation and cancer therapy. And we train the young people.

All this is possible because governments support STEM education and basic research. But we should do more: we should aim to ring-fence a minimum investment in STEM education and basic research in GDP terms for every country in the world. That is the way to long-term development and sustainability.

The scientific community, including CERN, urged Agenda 2030 to ask that there be a minimum GDP percentage devoted by every nation to STEM education (Science, Technology, Engineering and Math education) and basic research. This is particularly important in times of economic downturn, when private funding naturally concentrates on short-term payback and governments focus on domains that offer immediate economic return, at the expense of longer-term investment in fundamental science.

Useless knowledge, as Flexner called it, is at the basis of human development. Humankind's continuing pursuit of it will make the development goals achievable.

A longer version of this article was originally written and will be published as part of the Big Bet Initiative