LHC experiments present results in Moriond Conference

by ***Panos Charitos***

PDF version

This year saw the 53rd meeting in the series "Les Rencontres de Moriond". ATLAS and CMS presented impressive results (see pictures) of searches for new phenomena, setting boundaries to where the new physics can still exist. These limits severely constrain models for physics beyond the Standard Model including possible candidates for dark matter and searches for supersymmetric particles. It should be noted that the Standard Model processes contribute to the background of many searches for new physics and measuring these processes precisely helps separate the background from a potential signal. In addition, any deviation from the Standard Model's predictions could be the door that leads to new physics.

LHC experiments presented their updates to their measurements of boson (W and Z) and di-boson decays, including the whole 2015 and 2016 dataset of the LHC. These decays appear in typical searches for the Standard Model Higgs and new physics, and thus need to be understood with a high degree of precision. Moreover, ATLAS and CMS also presented a wide range of results that looked at the characteristics of particle jets, including new, detailed measurements of jet and di-jet cross-sections. A high precision understanding of these jets is essential, as they form the basis for most of the measurements made by the experiments.

The ATLAS collaboration examined the Higgs boson decaying into two W bosons ($H \rightarrow W^+W^-$), the charged force carriers of the weak interaction. The analysis uses 36 fb^{-1} of Run 2 data taken in 2015 and 2016 at a collision energy of 13 TeV. With a predicted decay probability (branching fraction) of about 21%, $H \rightarrow W^+W^-$ is the most common decay mode after the decay to b-quark pairs(link is external); yet it required a tour de force to achieve this result.

The present analysis is similar to earlier analyses carried out on the 7 and 8 TeV datasets from Run 1: it focuses on the most ubiquitous Higgs boson production modes, where either two gluons (ggF), or two W or Z bosons (VBF) emitted by the colliding protons fuse to produce the Higgs boson. The W bosons from the Higgs boson decay are unstable and immediately decay to lighter particles. Decays to electrons and muons are considered, which provide a cleaner signal than the more abundant decays to a pair of quarks, but which reduce the exploitable $H \rightarrow W^+W^-$ branching fraction to only 1.1%. An additional challenge is that these W boson decays are accompanied by invisible neutrinos, giving rise to missing energy in the event, thus making the signal reconstruction more challenging.

Data taking conditions are quite a bit harsher in Run 2, with increased beam intensity at the collision point leading to up to 60 simultaneous proton-proton interactions per bunch crossing. This made it much more difficult to distinguish the electrons and muons from W boson decays from other sources, and even from other particles. Refining the analysis proved a challenge – one that has now been met by ATLAS.

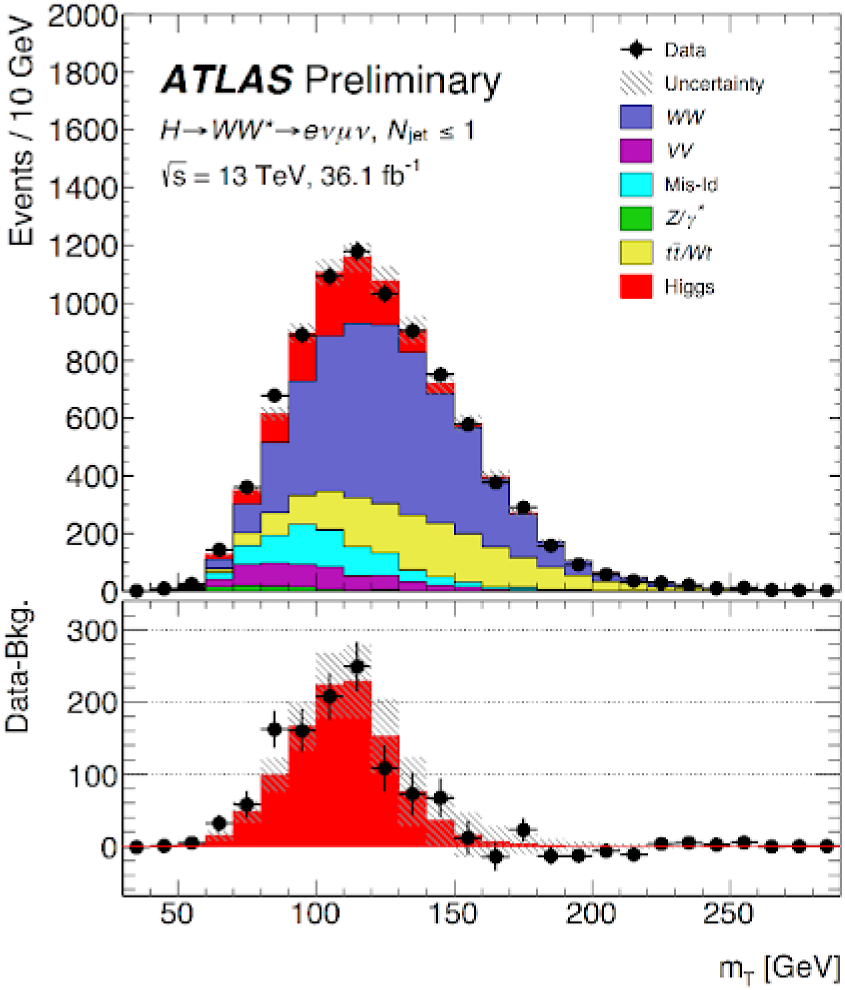


Figure 1: The contribution from the Higgs boson is shown in red, the bottom panel compares the background-subtracted data points to the expected yield from the Higgs boson in the red histogram. (Image: ATLAS Collaboration/CERN)

Figure 1 shows the so-called transverse mass of the events, computed from the visible and invisible decay products of the Higgs boson candidates. The red contribution is the expectation from the Higgs boson, and the other colours represent various background processes. The Higgs-boson signal, which amounts to a significance exceeding six standard deviations, is clearly visible in the figure. Figure 2 shows the measured cross sections times branching fractions for Higgs boson decays to two W bosons for the ggF and VBF production modes.

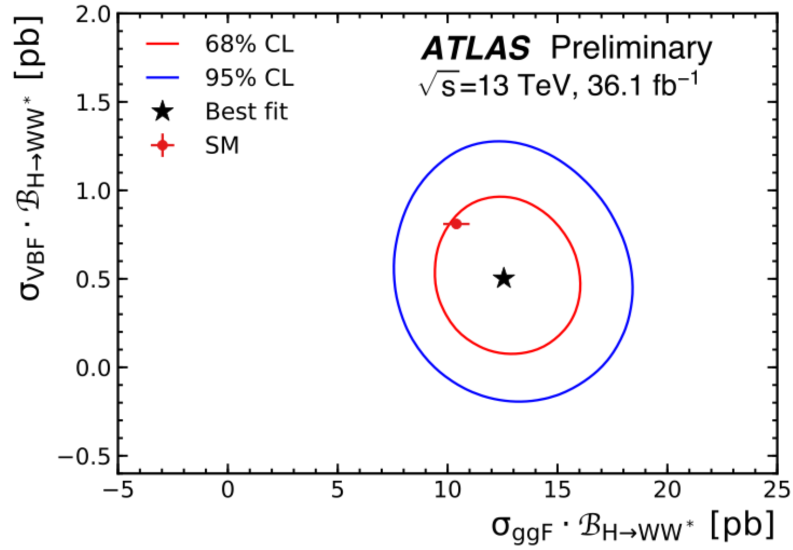


Figure 2: The measured cross sections times branching fractions for Higgs boson decays to two W bosons for the gluon-gluon fusion (ggF) and vector boson fusion (VBF) production modes. The measured values are 12.3 +2.3 / -2.1 pb and 0.5 ± 0.3 pb, respectively, which are in agreement with precise theoretical calculations based on the Standard Model. The contours surrounding the measured values indicate the 68% and 95% confidence intervals, the SM expectations (the red point in the plot) are compatible with the measured values. (Image: ATLAS Collaboration/CERN).

The $H \to W^+W^-$ decay played an important role in the scrutiny of the Higgs boson's nature with Run 1 data, and ATLAS expects it to carry its weight in the even more incisive tests that will be possible with the further Run 2 data.

The CMS collaboration presented more than 25 new results at the 2018 Rencontres de Moriond conference. Most of these results will be published shortly and will add to the growing total of Run 2 CMS publications. Highlights include a set of combined measurements of the production and decay rates of the Higgs boson, as well its couplings to vector bosons and fermions, a first observation of the rare decay $Z \to \psi\, l^+l^-$, and several searches for rare Higgs decays, supersymmetry and other exotic particles. A search for heavy resonances in the di-electron final state with the large data sample collected in 2017 is also presented.

The Higgs measurements use the 2016 data sample for a comprehensive analysis of the production processes gluon fusion, vector boson fusion, and associated production with a W or Z boson or a pair of top quarks, and of the H→ZZ, WW, γγ, ττ, bb and μμ decay modes. Dedicated searches for invisible Higgs boson decays are also considered. The combined signal yield relative to the standard model prediction has been measured to be 1.17 ± 0.10. A significant improvement in the precision of the gluon fusion production rate of around ∼30% has been achieved compared to the previous ATLAS and CMS combined measurement with Run1 data. Results for the Standard Model Higgs boson decaying via the bb channel and produced in association with a top quark-antiquark pair decaying into the all-jet and leptonic final states are also presented.

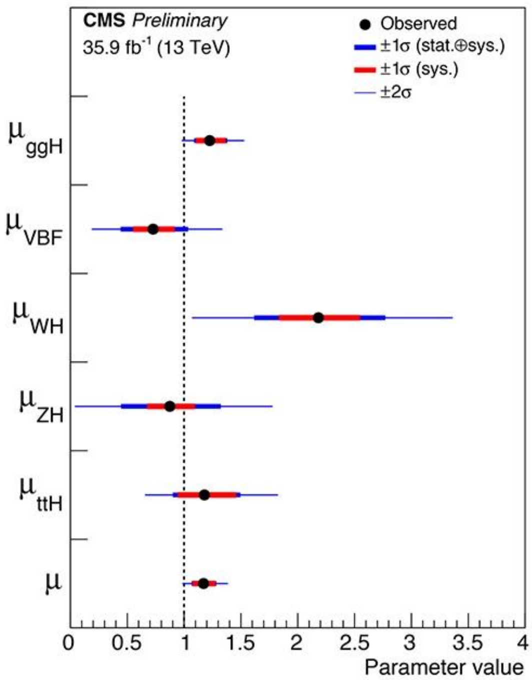


Figure 3: Summary plot of the fit to the per-production mode Higgs signal strength modifiers μi. The thick and thin horizontal bars indicate the ±1σ and ±2σ uncertainties, respectively. Also shown are the ±1σ systematic components of the uncertainties. The last point is taken from a separate fit and indicates the result of the combined overall signal strength μ.The first observation of the Z boson decay to a vector meson and two oppositely charged same-flavour leptons is presented, with a statistical significance of 5.7σ. Using 35.9 fb-1 of data 13.0 ± 3.9 events of the decay Z → ψ μ+μ− and 11.2 ± 3.4 events of the decay Z → ψe+e− have been observed. A measurement of jet substructure observables in top quark events and a study of the properties of the underlying event in top quark events is also presented.

CMS has also released more than 15 direct searches for new physics using the full 2016 dataset. These exotic searches provide new stringent limits on exotic decays of the Higgs boson, dark matter scenarios, hypothetical particles such as leptoquarks, new heavy gauge bosons, long-lived particles and several supersymmetry scenarios. Finally, CMS also presents a search for high mass resonances in the di-electron final state using the 41 fb-1 of data collected during 2017. This is the first result from the analysis of the 2017 dataset and in combination with the analysis of the 2016 data sets stringent limits on the masses of Z' particles that arise in many new physics scenarios. This CMS result is indicative of the high quality of the data collected in 2017 and more results using this dataset are expected to come out later this year.

LHCb presented a wealth of interesting results including the first evidence for the $B_s^0 \rightarrow K^{*0}\mu^+\mu^-$ decay with a statistical significance of 3.4 standard deviations. This decay is predicted to be very rare within the SM, as it occurs only through suppressed loop diagrams. New particles foreseen in extensions of the SM can significantly enhance (or suppress) the rate of this decay. The result presented at the Rencontres de Moriond paves the way to search for new physics using this decay when a larger datasets will be collected by the upgraded LHCb detector during LHC Run 3.

Results of a search for new dimuon resonances were also shown in Moriond. No evidence is found for a signal in the mass range of 5.5 to 15 GeV and upper limits are placed on the product of the production cross-section and the branching fraction to pairs of muons. The limits are competitive with the most stringent ones over most of the mass region considered, and are the first limits set near the Y resonances.

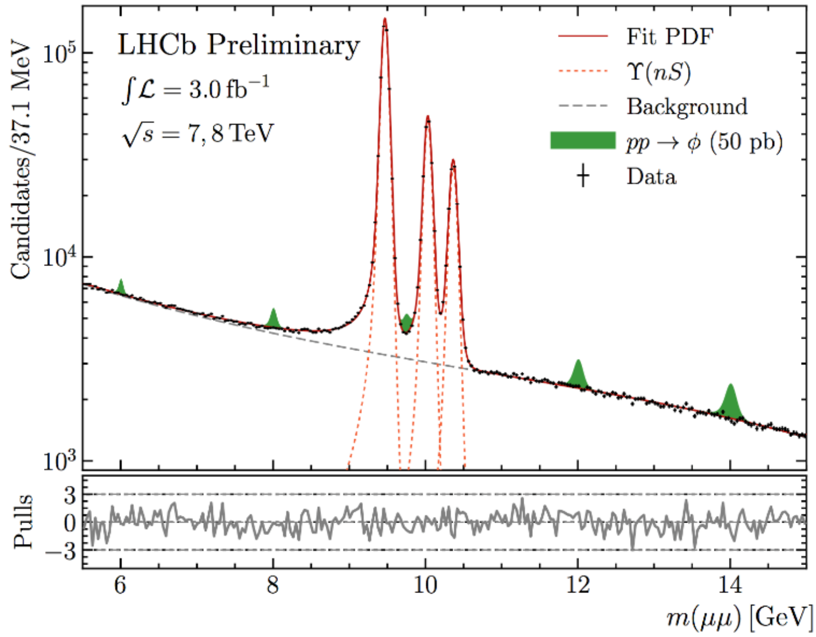


Figure 4: The image shows the mass spectrum of the muon pair in the whole search region. Mass peaks for five hypothetical Φ-boson mass hypotheses are displayed in green.

The LHCb collaboration also presented a number of measurements about CP violation in B decays. Seeing a departure from the value predicted by the Standard Model for rare B decays branching ratios would be a sign of CP violation and could open the door to new physics. First of all, decay-time-dependent CP asymmetries in $B^0 \to D^{\mp}\pi^{\pm}$ decays are measured for the first time in a hadron collider. The image shows an example of the measured asymmetry as a function of the decay time of the B^0.

The parameters describing the difference in behaviour between matter and antimatter, known as CP violation, are constrained in the so called Cabibbo-Kobayashi-Maskawa matrix(link is external) unitarity triangle. The angles of this triangle are denoted α, β and γ, and among them, γ is the least precisely known. The measurement of the asymmetries presented for the first time allow to constrain the angle γ to an interval that is consistent with the current world average. The blue line in the image is the result of this analysis, while the red, dashed line shows the expectation in the absence of CP violation.

Moreover, CP violation in decays of B^0 and of B_s^0 mesons into two charged particles (h) also allow for precise tests of the CKM triangle angle. Results from time-dependent CP asymmetries in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ decays as well as of the time-integrated CP asymmetries in $B^0 \to K^+\pi^-$ and $B_s^0 \to \pi^+K^-$ decays were presented contributing to the determination of the CKM unitarity triangle. Finally, measurements of the time dependent CP-violating asymmetry in the B_s^0 decay to two ϕ mesons was presented and are consistent with the hypothesis of CP conservation.

Following the results presented at the electroweak session of Rencontres de Moriond, the LHC experiments also presented many new results for the following week's quantum chromodynamics (QCD) session. Les Rencontres de Moriond have now ended but the LHC experiments continue working on many fronts. They prepare for recording and analysing new data to probe more precisely as many characteristics of the Higgs boson as possible and push further the experiments' diverse physics programme including new searches.

All presentations from ATLAS and CMS and LHCb, as well as results from ALICE, can be found on the Moriond conference websites: Electroweak physics(link is external) and QCD physics(link is external)

Setting a roadmap for future experimental technologies

PDF version

Today, the scale and technological sophistication of the detectors at the LHC experiments is almost incomprehensible: they include several subdetector systems, contain millions of detecting elements and support a research program for an international community of thousands of scientists. The volume of data that will be produced during the high-luminosity upgrade of the LHC (HL-LHC) and in future colliders call for even more sophisticated technologies that will boost the performance beyond today’s state-of-the-art.

The first workshop on future experimental R&D took place at CERN's main auditorium.

To respond to this challenge, CERN’s Experimental Physics department has launched a process to define its R&D programme on new Experimental Technologies from 2020 onwards. Experts from all over the world have signed up to the eight working groups that were created to define a solid R&D programme in technological key areas and more than 450 physicists and engineers have participated to this workshop.

This initiative initially spans a 5-year period with a foreseen extension beyond this period. It covers detector upgrades beyond LHC phase II and includes concepts developed for CLIC and Future Circular Colliders (FCC). Christian Joram, coordinator of the R&D steering committee and organizer of this meeting, explains: “beyond the high luminosity LHC upgrade the landscape of experiments is only vaguely defined and may evolve in different directions. Therefore we want to launch an R&D programme that concentrates on advancing key technologies rather than developing specialised applications.”

As physics experiments get more ambitious, the detectors they use have to keep pace. Improvements include better electronic readout, better modelling and simulation tools, and better computational techniques for reconstructing the recorded information by the detector. There are certain improvements that will be mutually beneficial for different types of detectors. One example is the increased accuracy in timing. According to Joram: “ultrafast (sub-ns) timing is a promising way to mitigate pile-up in very high luminosity environments and will almost certainly impact the development of all classes of detectors, be it silicon, gas or photodetectors”.

Manfred Krammer, Head of CERN’s EP department and co-organizer of the workshop, emphasized in his opening speech the collaborative spirit of this effort: “We look for synergies, complementarity and cooperation. CERN’s R&D programme is not an isolated path but is carried out thanks to strong partnerships with other laboratories and research institutes” and he added “it is timely to think how the industry can be involved in joint R&D efforts and what we can learn from industrial innovation in fields related to detector technologies”.

Every working group had typically two meetings before the workshop, with up to 70 persons attending, many from external institutes. In their talks the convenors reported about the material and opinions collected during these meetings. The talks covered a variety of topics reflecting the EP department’s diversity and the strong collaboration with partners from all over the world.

In the domain of silicon detectors (WG 1), the depleted CMOS technology attracts a lot of interest, as it allows building low-mass and high-resolution sensors, which have the potential to cover large areas at affordable cost. In the last years, substantial progress was achieved in terms of radiation hardness, obviously a key requirement for almost all future experiments. Another trend are Low Gain Avalanche Detectors (LGAD), which have achieved timing precision in the range of a few tens of picoseconds. Finally, there is also a strong need to continue the development of classic silicon detectors (pixels, strips and pads) and the associated electronics.

Gas detectors (WG 2) will continue to play an important role in future experiments as they can cover very large surfaces at moderate cost. Micro pattern technologies have boosted their performance and a wealth of new ideas exists in terms of materials, production techniques and readout modalities, how this success story can be pursued. An important question is the optimum choices of the gases and their compatibility with environmental standards.

Working group 3 is dealing with calorimetry and light based detectors, two topics often tightly linked. Highly granular calorimeter concepts are in the focus, allowing decomposing jets in their individual particles (‘particle flow calorimetry’). The requirements are manifold and so are the options in terms of active media (e.g. scintillators, noble liquids, silicon), absorbers and readout concepts. Again, fast timing will play a key role. In the last years, we could witness a revolution in the world of photosensors. The so-called Silicon Photomultiplier (SiPM) has matured and is becoming a standard tool for many applications. Still, its high dark count rate and moderate radiation hardness are constraining its use when it comes to the detection of low light levels, e.g. in Cherenkov detectors. This is still the domain of vacuum tubes, where modern finely segmented multi-anode devices, micro-channel plate tubes (for ultra-fast timing) and completely new concepts go far beyond the classic PMT.

The working group on detector mechanics showed an impressive potpourri of advanced materials, design tools and production technologies, which have the potential to change the way we build detectors, but also boost their performance. Ultra-light and precise or also very large-size carbon-fibre components become accessible and lead to solutions which were inconceivable ten years ago. Environment-friendly cooling technologies, combined with advanced 3D printing and microfabrication technologies reduce the material budgets of vertex and tracking detectors. Tight cooperation with high-tech industries is the way to go.

Working groups 5 and 6 gave us insights in the rapidly evolving worlds of electronics and fast data transmission. The numbers of custom-specific chips in the LHC experiments is counted in millions, however and the HEP community is seen as an expert customer with very special requirement. The ever-decreasing feature sizes in the CMOS manufacturing processes lead to benefits (higher functionality), but also to unknowns (radiation hardness) and risks (much higher cost). The main challenges are the strongly increasing ionising doses and the necessity to read and transfer huge amounts of data. Even though the parameter space is complex, the two working groups could already identify promising routes.

At the other end of the data link sit the processing farms with their advanced software for pattern recognition, track reconstruction and other computations. This is the topic of WG 7. The speakers discussed approaches on how to deal with the track reconstruction challenge at an event pile-up of 1000 (FCC-hh scenario) and sketched the potential of machine learning. For a population of more than ten thousand physicist, the EP department is a key provider of software frameworks and toolkits. For the Exabyte era already at the horizon, simple extrapolation of the existing will not be sufficient and fresh concepts for data management will be needed.

Last but not least, WG 8 presented partly already ongoing studies of experimental magnets for LHeC, CLIC and various FCC detector flavours. For FCC-ee a ultra-thin 2T concept is being studied with a free bore of 4.4 m and 6 m length, whose material budget should stay below 1 radiation length. The FCC-hh baseline design foresees a very large main solenoid (a free bore of 10 m and a length of 20 m) and forward solenoids at both ends. All developments require progress in the superconducting cable to meet the increased strength requirements and a multitude of more generic studies.

A second workshop will take place later this autumn, and will start the preparation of a report summarizing the proposed R&D programme. In the meantime, all working groups will filter the proposals discussed during the workshop and agree on roadmaps for future R&D lines. This culminate in a final report on time for the upcoming European Strategy Update.

Finally, it should be noted that developments of detectors for high-energy particle physics benefit many other sectors from healthcare and medical imaging to industrial manufacturing and quality monitoring. The R&D programme on detector technologies shows that there are some big challenges and innovative ideas, and the benefits can be realised by a series of step-by-step improvements that will be documented in the final report due by the end of this year.

You can find more information and a full list of the presentations on the indico page: https://indico.cern.ch/event/696066/

CernVM turns ten!

by ***Jakob Blomer, Gerardo Ganis***

The 3rd CernVM Users Workshop took place at CERN from 30 January to 1 February 2018. As usual, the workshop aimed to bring together users, developers and industry speakers to discuss the current status of the CernVM ecosystem and the future directions, with a fresh look onto the landscape of technology and the evolution in virtualization and cloud computing.
The event has been attended by more than 60 participants, an increase of about 50% with respect to previous editions. Although the majority of attendees and speakers came from HEP, there was a significant presence from other scientific fields, and also from industry.

This edition was also the occasion to celebrate the 10th anniversary of the CernVM project, which started as R&D in EP-SFT in 2008. At this purpose, Predrag Buncic, founder of the CernVM project and now ALICE computing coordinator, was invited to give a keynote address in which he highlighted the main reasons for the success of the project and the lesson learned by this exciting experience.

A set of presentations followed from the CernVM team members about the status of the ecosystem and the short and medium term plans for consolidation and development. Focus was given on the new distributed release manager interface, the support for client cache plug-ins and the plug-in enabling efficient distribution of Docker container images with CernVM-FS.

As in previous editions, one of the key moments was the technology session with invited guest speakers from the industry and academia. Miklos Szeredi, from Red Hat, gave an in-depth presentation of FUSE and Overlay-FS, two key dependencies of CernVM and CernVM-FS, focusing on the different design choices and the future plans. Saeed Noursalehi, from Microsoft, core developer of the Git Virtual File System (GVFS), described the design choices for GVFS and the issues addressed to achieve the required performances; he gave an introduction to stackable file-system driver filters in Windows and to a related open-source library which could open the way to realise a CernVM-FS client for Windows. Michael Bauer, from SyLabs, gave an overview of the feature set of Singularity, a container runtime system designed for HEP/HPC, already in use by several experiments, in particular CMS.

Justin Cormack, from Docker, presented LinuxKit, a toolkit for building secure, portable and lean operating systems for containers, an approach sharing many similarities with the one of CernVM. Finally, Doug Thain, from University of Notre Dame, US, gave a deep insight into the intrinsic complexity of targeting multiple computer environments, and proposed software solutions to tackle this complexity and facilitate complex workflows.

Feedback from the main users confirmed the critical role of CernVM-FS in their continuous integration and production workflows. The usage of CernVM-FS for data distribution, technology previewed at the previous edition of the workshop, is now a reality, providing about 3 petabytes of CMS data to the US science grid.

The remaining sessions of the workshop focused on CernVM-FS integration on High performance Computing (HPC), the evolution of content distribution and integration with container systems. The HPC talks described how a mixture of solutions, including also flexible client cache setups, allow to overcome limitations such as lack of FUSE availability and/or of network connection on the worker nodes. In the session dedicated to content distribution, first investigations on using commercial providers (Cloudfare) or alternative systems (XRootD), have been presented. The main highlight of the container session was the results obtained on the CERN Openstack MAGNUM infrastructure with the Docker graphdriver plug-in for CernVM-FS, showing a spectacular decrease in the container start-up time, in line with expectations.

In conclusion, the workshop confirmed the excellent health of CernVM and CernVM-FS, which are integral parts of many organizations' infrastructures. The current plan of work of the CernVM team is in line with the feedback received from the users. The team is confident that the planned developments will further improve the user experience and increase the attractiveness of the CernVM ecosystem.

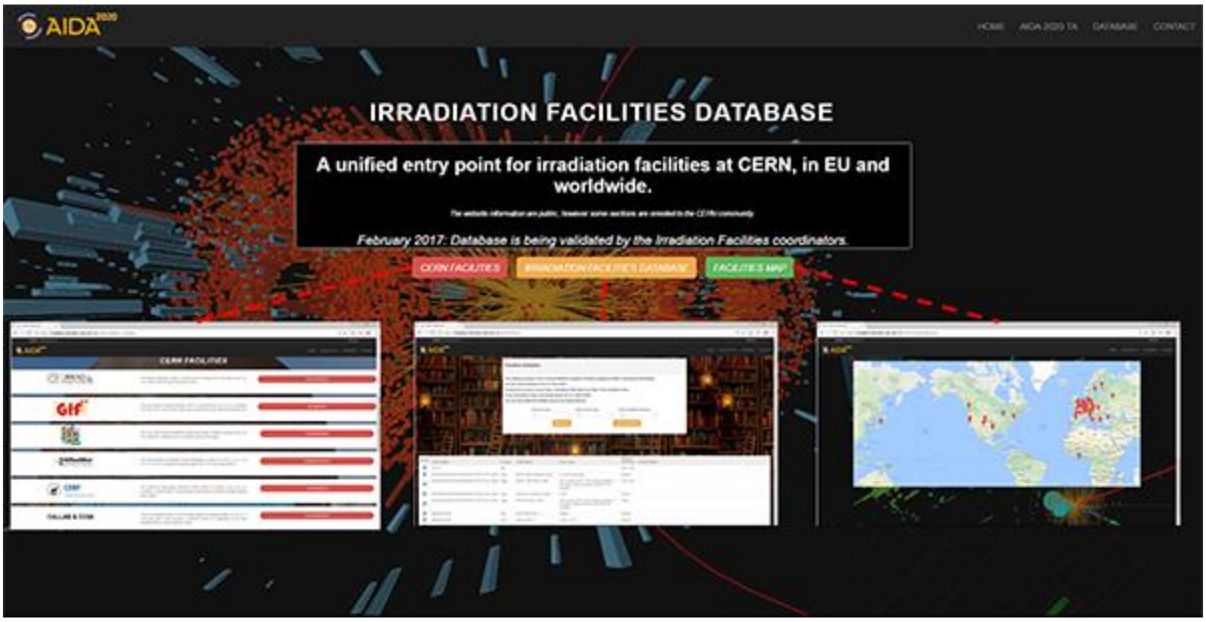
A new database of irradiation facilities

PDF version

Detector and accelerator developers need irradiation facilities to test their components under conditions that are as close as possible to real applications as well as to predict and prevent failures in materials.

The foreseen high-luminosity upgrade of the LHC (HL-LHC) and future accelerator projects like the Future Circular Collider (FCC) where much higher radiation levels are expected call for new and more sophisticated irradiation facilities.

Recently, a new database of irradiation facilities at CERN, in Europe and around the world has been published online as part of the work of AIDA-2020 Work Package 15 and is currently undergoing validation. With a total of 182 entries (as of March 2017) it is the largest and likely most unique database of this kind in the world.



The front page of the irradiation facilities database website (Image: CERN)

"With every validated entry the database gathers more momentum and we are confident that we'll have a largely validated and comprehensive list in the next months," says Federico Ravotti, CERN's irradiation facility spokesperson.

Irradiation experiments will be more important for a successful and safe development of detectors and accelerator systems. As Ravotti notes: "Irradiation facilities, as the one available at CERN, can simulate long-term effects and operational conditions normally occurring over a period of several years within a few days or even hours thus allowing to safely test prototypes and understand how they would behave in the real conditions of a collider". CERN Irradiation team provides support to the EP department and CERN users in planning irradiation experiments at the above mentioned CERN facilities and organizes irradiation campaigns in facilities outside CERN.

The new database was set up by Blerina Gkotse and Georgi Gorine, two PhD students of the irradiation facilities team in the DT-DD section under the supervision of Federico Ravotti. It will help potential users to find the most appropriate irradiation facility for their equipment. "It's a collaborative database," they say.

The database offers a comprehensive list of contact details as well as high level of information. It features a map for a quick overview and several filters allowing a search by country, source type or radiation type. For example, if you are in the UK and looking for a place to irradiate your sample with gamma rays from a Cobalt-60 source, you can very quickly find four entries. Moreover, each database entry shows an exhaustive list of useful information that can ease the choice of the correct facility, such as the minimum and maximum dose/fluence, irradiation conditions, safety rules and the facility's homepage.

Although the database was originally developed for the particle detectors and accelerators community, it also includes facilities that offer services for space, medical, energy fields among many others.

Visit the new Irradiation Facilities Database: http://irradiation-facilities.web.cern.ch

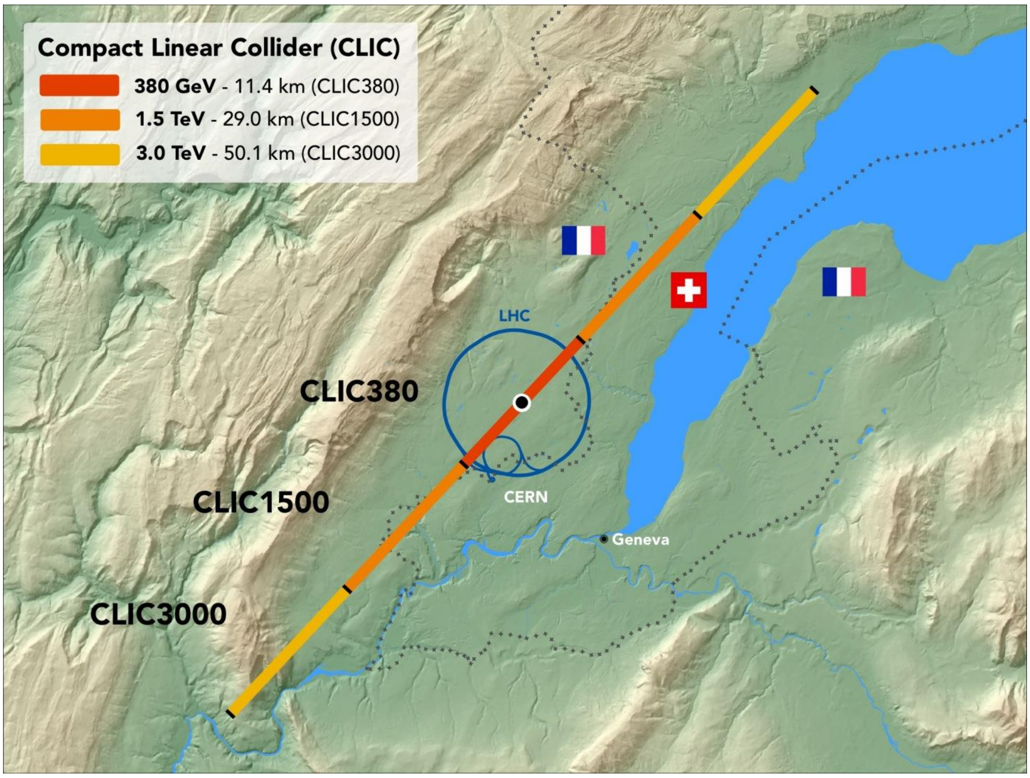
Report from CLIC Week 2018

CLIC

by ***Rickard Ström, Aidan Robson***

PDF version

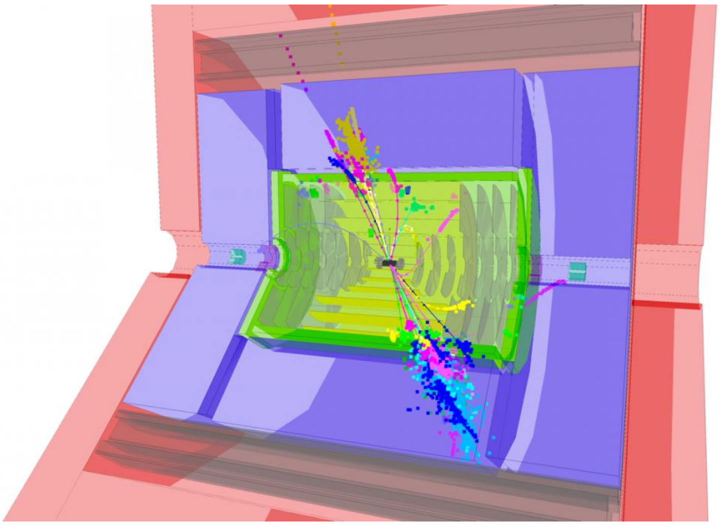
The Compact Linear Collider (CLIC) workshop is the main annual gathering of the CLIC accelerator and detector communities. This year it attracted more than 220 participants to CERN, 22-26 January. CLIC is a proposed electron-positron linear collider, envisaged for the era beyond the High-Luminosity LHC (HL-LHC), that would operate a staged programme over about 25 years with collision energies at 0.38, 1.5, and 3 TeV. This year, the meeting focused on preparations for the update of the European Strategy for Particle Physics.



The footprint of CLIC for the three collision energies considered: 380 GeV, 1.5 TeV, 3 TeV (credit: CLIC)

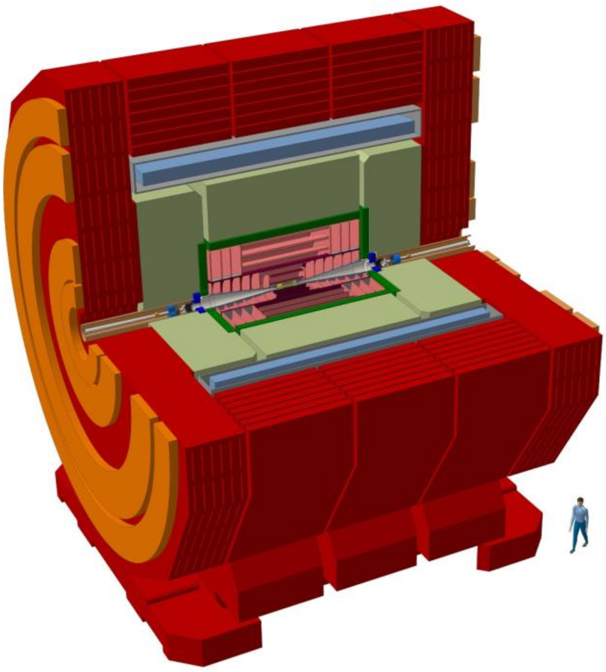
The initial CLIC energy stage is optimised to provide high-precision Higgs boson and top-quark measurements, with the higher-energy stages enhancing sensitivity to effects from beyond-Standard Model (BSM) physics. Following a 2017 publication on Higgs physics, the workshop heard reports on recent developments in top-quark physics and the BSM potential at CLIC, both of which are attracting significant interest from the theory community.

A comprehensive report on top quark physics studies which can be carried out at the three energy stages is nearing completion. It includes studies of top-quark production at threshold and beyond, searches for Flavour Changing Neutral Current (FCNC) top-quark decays, and studies of top-quark pair production in Vector Boson Fusion (VBF) as well as the ttH process. The latter allows the direct extraction of the top Yukawa coupling. Centre-of-mass energies above 1 TeV provide a significant increase in the sensitivity reach for BSM physics. The report includes the phenomenological interpretation of the results from the top-quark production studies for top-philic operators in an Effective Field Theory (EFT), and prospects are given for specific models such as top-quark compositeness, where CLIC has discovery potential to scales far beyond its centre-of-mass energy.



A simulated top-quark pair event at 3 TeV (tt→qqbμvb) – the upper part of the detector features an isolated muon (magenta) along with a b-jet containing an additional muon – the lower part of the detector features a boosted top-quark jet (credit: CLIC)

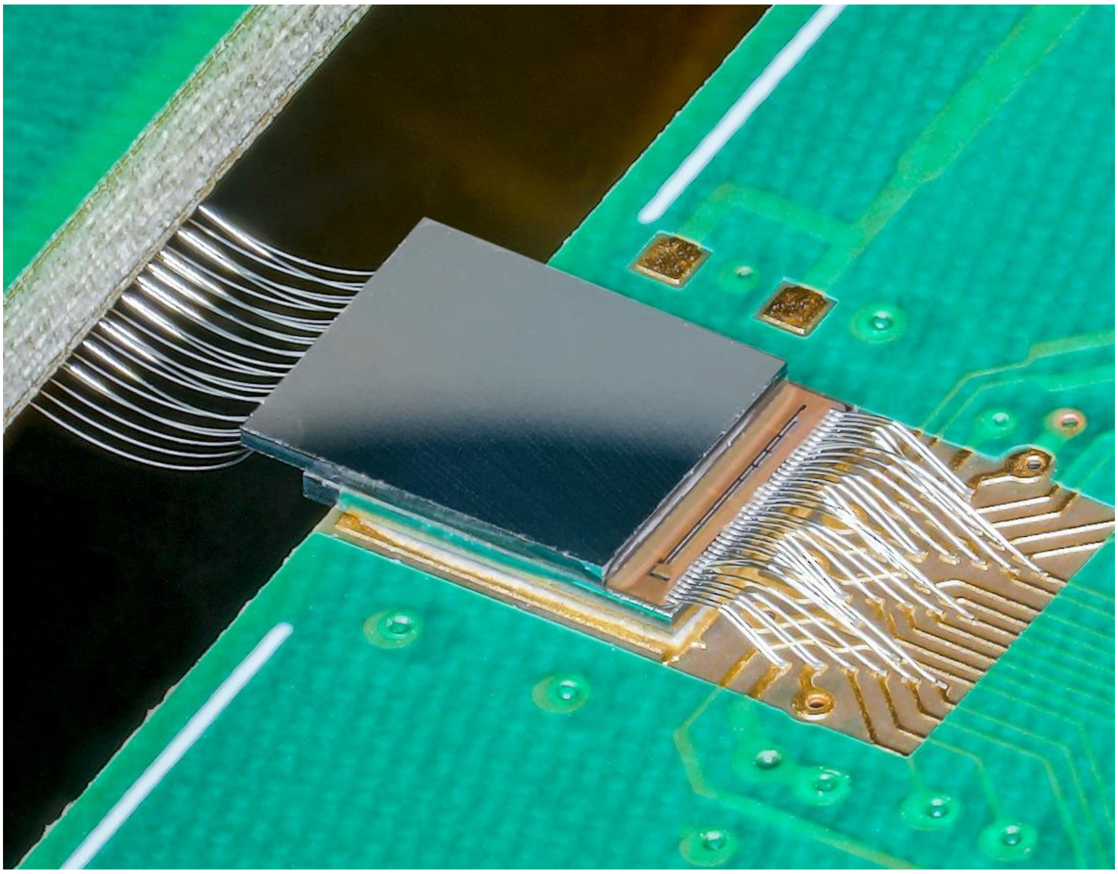
Speakers reported on the progress in the validation and performance of the new CLIC detector model, using a new software suite for event simulation and reconstruction. The software suite is developed in common with ILC and is also used for ongoing FCC-hh tracker optimisation studies and for the design and optimisation of a CLIC-like detector for FCC-ee. To ensure that the detector performance meets the challenging requirements on position resolution, timing capabilities and low-mass features, a new approach to tracking has been commissioned, and the particle flow analysis and flavour-tagging capabilities have been consolidated.



The new CLIC detector model "CLICdet" (credit: CLIC)

Updates were presented on the broad and active R&D programme on the vertex and tracking detectors, which aims to find technologies that simultaneously fulfil all the CLIC requirements.

Several technology options are being pursued, including thin planar sensors, integrated HV-CMOS and HR-CMOS. Detector modules were constructed and tested at the SPS using a dedicated high-precision beam telescope. The silicon pixel R&D is pursued in synergy with the ATLAS and ALICE detector upgrades and the Medipix/Timepix developments. Reports were given on test beam campaigns and on ideas for future developments. Many of the tracking and calorimeter technologies under study for the CLIC detector are also of interest to the HL-LHC, where the high granularity and time-resolution needed for CLIC are equally crucial.



A silicon pixel detector prototype for the CLIC vertex detector (active HV-CMOS + CLICpix2 ASIC) (credit: CLIC)

For the accelerator, studies with the aim of reducing the cost and power have particular priority, in order to present the initial CLIC stage as a project requiring resources comparable to what was needed for LHC. Key activities in this context are high efficiency RF systems, permanent magnet studies, optimised accelerator structures and overall implementation studies related to civil engineering, infrastructure, schedules and tunnel layout.

A key aspect of the ongoing accelerator development is moving towards industrialisation of the component manufacture, by fostering wider applications of the CLIC 12 GHz X-band technology with external partners. As a new initiative, the CLIC Workshop saw the kick-off meeting for the CompactLight project recently funded by the European Commission's Horizon 2020 programme. This three-year project brings together leading European institutions and companies to design an optimised X-ray free-electron laser based on X-band technology, to pave the way for significantly more compact and power-efficient accelerator facilities. 2017 also saw the realisation of the CERN Linear Electron Accelerator for Research (CLEAR), a new user facility for accelerator R&D. Its programme includes CLIC high-gradient and instrumentation studies. Presentations at the

Workshop addressed the programmes for instrumentation and radiation studies, plasma-lensing, wake-field monitors and high-energy electrons for cancer therapy.

As input for the update of the European Strategy for Particle Physics the CLIC accelerator and detector and physics collaborations will prepare summary reports, which will focus on the 380 GeV initial CLIC project implementation, and include plans for the project preparation phase in 2020-2025.

Interview with Pascal Lamy

*by **Panos Charitos***

PDF version

The European Commission is working on a proposal for the framework programme that will succeed Horizon 2020. This is done on the basis of various building blocks including the interim evaluation of Horizon 2020 and the Lab-Fab-App report (informally known as the Lamy report). We met Pascal Lamy, Chairman of the High Level Group on maximising the impact of European research and innovation programmes, and discussed some of the key findings of the Lab-Fab-App report and the group's vision and recommendations for the future.

Last summer, the European Commissioner for Research, Science and Innovation, established a High Level Group to draw clear recommendations for the FP9 programme and prepare a vision for the future. H2020 is one of the world's largest and most successful programmes of investment in scientific research as today more than 1.8 million researchers work in thousands of universities and research centres and industries around Europe. It is remarkable that with just 7% of the world's population and 24% of global GDP, Europe produces around 30% of the world's scientific publications!

However, as research and innovation matter for our future the question raises how we could further maximize its impact. Following an intense 6-month period of consultation with various shareholders and the support of DG research for research, the group published the report "Lab-Fab-App". It is based on data from the Horizon 2020 interim evaluation results, while Lamy acknowledges the great support from the European Commission directorate for Research & Innovation. "It was a very cooperative task and during this period I tried to take into account the opinions of all the members of the group. This was not so trivial as they were all coming from diverse backgrounds, but I felt that this diversity was also our strength and the chance to come up with some meaningful suggestions. The fact that we succeed to follow a consensus based approach in drafting the conclusions that you will read in the Lab-Fab-App report makes me really proud.

Pascal Lamy has a long experience in negotiations that, coupled to his good understanding of how EU functions, made him the ideal choice to chair this group. From 1985 to 1994, he was Chief of staff to the president of EC, Jacques Delors. Between 1999 and 2004, he was appointed Commissioner for Trade of EC under Romano Prodi, and from 2005 to 2013 he served as DG of the World Trade Organization. “I had a long acquaintance with this programme from my previous positions in EC and I always insisted that the EU should invest more of its resources in research and development. I believe that research and development has a strong additional value stemming not only from the new knowledge that is produced but also from the cross-fertilization between different fields and through global collaboration. Investing only a 10% of the total budget always seemed a very small figure to me”.

The first key message of the Lab-Fab-App report is the urgent need to invest more in scientific research to tackle the present societal challenges. The demographic problem that Europe faces, the increasing social inequalities and the challenges posed by emerging economies call for more investment in open science that can trigger faster and fairer growth to address these problems. “To overcome the big societal objectives that today matter across Europe we need to invest in a future based on innovation across all members of the Union”, and he adds “this is why we have suggested increasing the available funds under FP9 from the current H2020 77EUR billion budget to 160EUR billion on a seven year basis”.

Investing in research and innovation is increasingly crucial for shaping a better European future in a globalising world, where success depends ever more on the new knowledge. Innovation can help address some of the most pressing questions while it also opens new markets that can boost European competitiveness.

Today, EU trails well behind many of its trading partners when it comes to innovation. There is an abundance of unexploited ideas and research results with considerable innovation potential, which are not being brought to the markets. “Though Europe invests largely in research and there are many bright minds it still lack behind in innovation compared to other countries including the US, Japan, China and South Korea. We need to pay more attention to the gap we have in Europe between what we produce in science and what we produce in innovation including new products and services”.

The need to address this obstacle in FP9 is more urgent: “This is not new; we have known this for decades. But the rate of technological and economic change and the urgency of global challenges continue to outpace Europe’s response and reforms. This is why we advocate for larger investment in research and innovation while at the same time we try to build stronger industry participation in FP9”. Lamy notes that “EU private intensity to invest in research is smaller compared to other places outside Europe. I believe that we need to do more in this area and specifically to the innovation that presently seems to be left only to small enterprises and startups. In my view we should think how to scale up these businesses and explore new tools to ease their access to funding”, though he adds “it is a complex ecosystem with complicated dynamics and thus there is no simple solution”.

Many of the challenges in society and industry are not Europe-specific but require collaboration as the world gets more interconnected. “Facilitating open innovation would ensure that ideas and knowledge are transformed into socio-economic value for Europe”. Today most researchers and companies based in Europe want to compete in the world and this can be achieved through global cooperation, exploiting the advantages of open science and innovation. The Lab-Fab-App report suggest a more proactive approach that calls for international cooperation to resolve global challenges. For Lamy, “in a competitive environment diverse groups of people win because of the different skills and competencies they bring. This is a requirement to make any progress in science but also in our societies.”

Another innovation of FP9 compared to its predecessors is the concept of R&I missions that should foremost be easy to communicate and capture public imagination and involvement. “Missions should mobilise many actors and investors, including at national level, and induce action across disciplines, sectors and institutional silos”. The report stresses that public financing of science necessitates more public debate and setting research and innovation missions can inspire European citizens to get more involved. “Given the evolution of science that touches borders that are philosophically, ethically or politically sensitive we need to grow more support and build more legitimacy that will also allow to further increase the public investment in science. This means that we need more public debates about the impact of science in people’s daily lives and the types of research that can guarantee a better future. Of course we understand that this concept may be received with some scepticism from scientists or researchers and this is why we have launched a public consultation where everyone is welcome to contribute”.

Another step-change envisioned in the Lab-Fab-App report is to open the EU R&I programme non-EU countries based on the level of excellence in R&I. This will make the EU programme the potential nucleus of a global programme for open science and open innovation, exporting good regulatory practices and improving international trading and investment conditions. It will be an expression of the EU’s ambition to harness globalisation through collaboration in science and innovation, thus helping to address the negative aspects of globalisation that we see today.

Finally, the group makes an important link between the much-needed increased commitment to research and a more efficient use of resources through a simplified programme, with fewer funding schemes and provisions flexible enough to accommodate the diversity of beneficiaries’ interests and backgrounds.

Following the publication of the Lab-Fab-App report there will be a wider public debate on what to do with the next framework programme. After all investing in research and boosting innovation is a complicated issue and has a certain political nature. Lamy says: “The value of this report is whether it becomes an element of political debate with politicians, researchers and the broader society. It should ignite some discussions about the level of investment needed for science and innovation and where do we want to go as a union. This is why we opted for a rather intriguing name while we tried to produce a short report that will possibly reach a wider audience including many non-experts”.

The next months will be crucial for negotiations that will help taking a decision about the FP9 programme, just in time to prepare everything by the end of 2020 when the new framework will take place. “We have shared our results with many European institutions, national governments and other stakeholders including universities, research institutes, non-governmental organisations and industries”. Lamy explains: “Given that the next budget cycle will take place under very specific conditions, that include a gap of about 10 billion caused by Brexit, that necessitate some reshuffling. This opens space for action and if we want EU to grow I think that we should seriously consider the importance of investing more in science and innovation. To leverage the knowledge capacity that we have built in Europe we need bring in the table more resources and help people exploit their ideas and their potential”. Europe is left with clear yet challenging choices.

“The EC should adopt long-term thinking which is needed to understand the impact of research which is different than other parts of European policy. When it comes to research, politicians often can’t show immediate tangible results in their countries. It requires long-term commitment and is more abstract so it needs strong public support”. We need to face up collectively to the immediate challenge of the recovery and to long-term challenges – globalisation, pressure on resources, ageing – so as to make up for the recent losses, regain competitiveness, boost productivity and put the EU on an upward path of prosperity.

BabyMIND records first muon tracks

Neutrino Platform

by ***Etam Noah***

PDF version

Assembled as part of project NP05 at the CERN Neutrino Platform, the Baby MIND muon spectrometer has been recording its first muon tracks from neutrino interactions at J-PARC since 10th March. Baby MIND is designed to determine the momentum and charge of muons that are the product of neutrino interactions in the WAGASCI detector, located in the Neutrino Monitor building that houses the T2K ND280 near detectors, 280 m from the proton target and 295 km from the Super-Kamiokande detector. WAGASCI is exposed to a flux of neutrinos from the T2K neutrino beamline, with a slightly higher mean energy compared with ND280 due to the lower off-axis angle (1.6° vs 2.5°) with respect to the target.

Figure 1. The Baby MIND installation team at J-PARC including Baby MIND collaborators, external contractors Daiichi-Tekko, and KEK facility personnel.

Following project approval by the CERN Research Board in December 2015, the Baby MIND collaboration - comprising CERN, the Institute For Nuclear Research of the Russian Academy of Sciences(RU), and the universities of Geneva(CH), Glasgow(UK), Kyoto (JP), Sofia(BG), Tokyo(JP), Uppsala(SE), Valencia (ES), Yokohama(JP) - developed custom designs for magnet, scintillator and readout electronics modules. Details of the construction and testing at the experimental hall of the Proton Synchrotron in the East Area at CERN were reported in the September 2017 issue of this newsletter.

The logistics for transporting the Baby MIND muon spectrometer from CERN to Japan required the usual planning with several parties and the legal process of the donation of Baby MIND to KEK. The detector left CERN on 17th and 18th October 2017 in 4 special containers, weighing 20 tonnes each. It was delivered to J-PARC on 13th and 14th of December, where it was temporarily stored for a couple of months.


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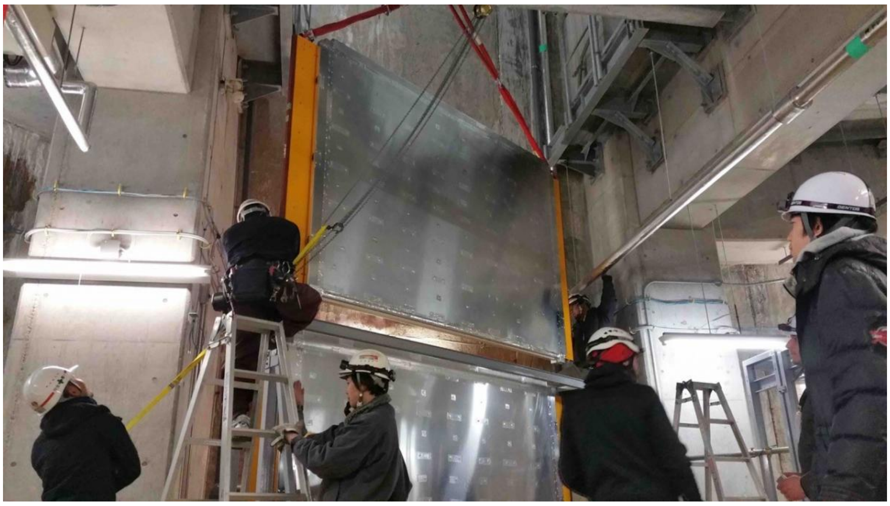
Figure 2. One of 4 20-tonne Baby MIND transport modules being moved to the Neutrino Monitor building at J-PARC from the adjacent temporary storage location at the NA building (left). One of 33 magnet modules being lowered down the access shaft during the installation phase in February 2018 (right).

Specific access and handling constraints had to be taken into account for the installation phase, along with additional requirements to ensure safety at all stages against potential seismic events. Modules had to be lowered from the surface to the lowest floor of the Neutrino Monitor building. The installation phase was completed in 2 weeks in February 2018, with each of the 33 magnet modules, 18 of which are equipped with scintillator modules, lowered down the narrow access shaft one-by-one. KEK facility personnel were instrumental in the planning and supervision of this installation work.



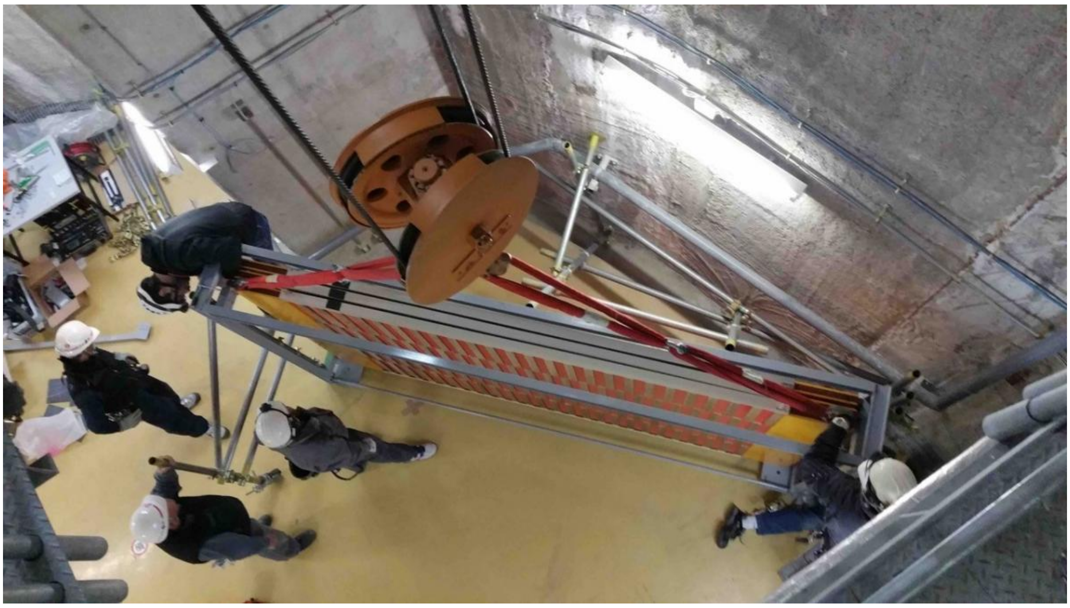
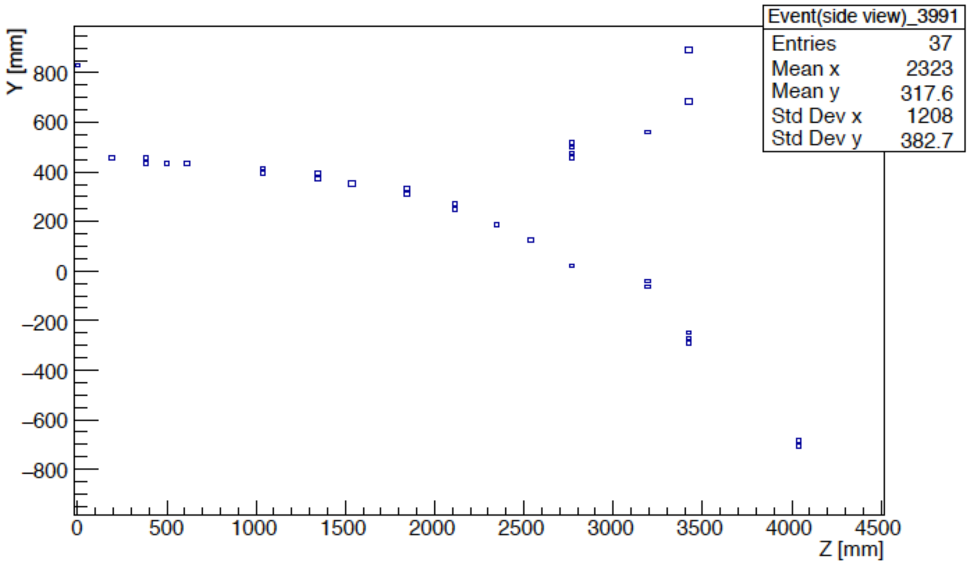


Figure 3. Installation work on the lowest floor of the Neutrino Monitor building at J-PARC.

A new 400 V 3-phase power line was installed on 21st February 2018 to supply 11.5 kW to the magnet. Design optimisation of the magnetic field map led to this relatively low power consumption for the 1.5 T magnet, by constructing a coil on each of the 33 magnet modules. This novel design provided further freedom to increase the acceptance of the central tracking region.

The magnet power supplies were switched ON for the first time at J-PARC on 14th March, with readings for nominal parameters consistent with operation at CERN during summer 2017. These trials were carried out during T2K beam maintenance days. It is planned to run the magnet 24hrs/day from 5th April until end May 2018, the end of the current T2K run 9 this year.

Scintillator detector module and readout electronics commissioning began around the 9th March, a day of trials for the T2K beamline. The electronics were tuned to synchronise to the T2K beamline trigger, and separately to the WAGASCI DAQ Start/Stop signals.



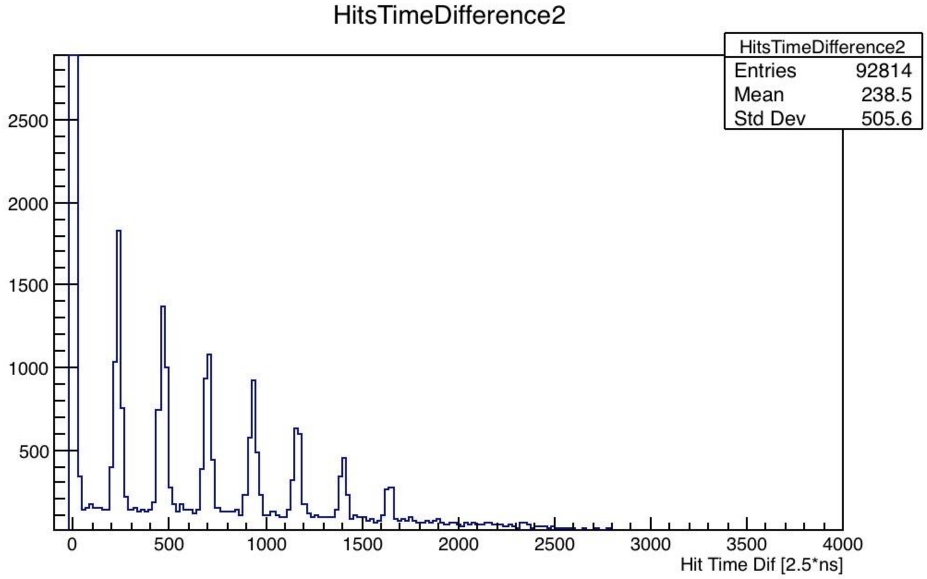


Figure 4. One muon track recorded in Baby MIND from a neutrino interaction in one of three detectors positioned further upstream (to the left in this orientation): INGRID proton module, WAGASCI water module and INGRID proton module. Neutrinos also interact with the Baby MIND, and surrounding cavern structures (top). Plot showing the incidence of events as a function of time in steps of 2.5 ns over several spills. The bunch structure of the T2K beam can clearly be seen, with the 8 bunches each roughly 60 ns wide, separated by roughly 600 ns. One expects the same number of events per bunch, so this early plot highlights the requirement for further work to improve synchronisation with the T2K beamline trigger (bottom).

The current T2K run 9 ending 31st May is a commissioning run for Baby MIND, after which the detector will be ready for physics data taking from January 2019

TLAS further investigates the width of top quark

ATLAS

by ***Panos Charito***

PDF version

The top quark is the heaviest known elementary particle and completes the quark sector of the standard model (SM). Like other fermions in the standard model (SM), it decays through the electroweak interaction. But unlike b and c quarks, which form long-lived hadrons, the top quark has an extremely short lifetime. Hence, its decay width is the largest of all SM fermions and a challenging measurement for many high-energy experiments.

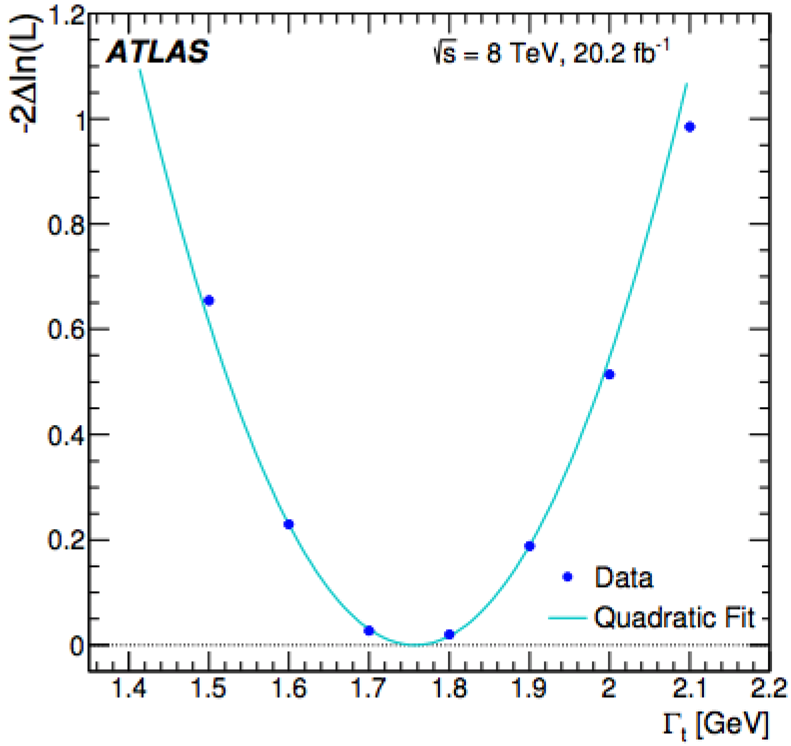
In view of its large mass (almost as heavy as a gold atom) the top quark is an excellent probe of the mechanism that breaks the electroweak gauge symmetry and should therefore play a key role in clarifying the nature of the force(s)/particle(s) responsible for this phenomenon. The top quark is also good probe for possible new parity-violating and non-Standard Model CP violating interactions which could be induced, for instance, by non-standard Higgs bosons. A precise measurement of the top quark width will allow to better estimate the parameters of the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements. A precise measurement is also key for calculating other parameters including the Fermi coupling constant (G_F), the strong coupling constant (α_s) and even in the mass of the W-boson.

Moreover, departures of this value from the Standard Model prediction could be sign of new physics at play as predicted by many beyond the Standard Model theories. For example the top-quark decay can be modified by direct decays to Higgs boson or via flavour-changing neutral currents or radiative corrections coming from other particles beyond the Standard Model. Therefore, precise measurements of top with are important for mapping the parameter space of many BSM models.

Within the SM, the top quark decays almost exclusively into a W boson and a b quark. The total decay width (Γ_t) is expected to be dominated by the partial decay width of the above decay channel, which is consistent with the current experimental data. However, direct measurement of Γ_t that is model-independent can provide useful insights.

The first direct upper bound on the top quark width was set by the CDF collaboration after analysing the invariant mass distribution of $t\bar{t}$ candidate events using 1 fb^{-1} of integrated luminosity. A bound on the decay width of $1.10 < \Gamma_t < 4.05$ GeV for a top-quark mass of 172.5 GeV was set at 68% confidence level. It should be noted that direct measurements are limited by the experimental resolution of the top-quark mass spectrum, and so far are significantly less precise than indirect measurements, but avoid model-dependent assumptions.

Recent results from ATLAS are based on data recorded in 2012 from proton-proton collisions at centre-of-mass energy of $\sqrt{s}$ = 8 TeV corresponding to an integrated luminosity of 20.2 fb^{-1}. The top-quark decay width is extracted using $t\bar{t}$ events in the lepton+jets channel with $t \to Wb$, where one W boson from the two top quarks decays hadronically into a pair of quarks and the other one decays leptonically into a charged lepton and a neutrino.



In a recent paper (Eur. Phys. J. C 78 (2018) 129), ATLAS measured the decay width for a top-quark mass of 172.5 GeV and found that Γ_t = 1.76 (+0.86/ −0.76 GeV). This value agrees with the Standard Model prediction of 1.322 GeV. It should be noted, that the new indirect measurement has a total uncertain smaller by a factor of two compared to previous measurements and thus will help to narrow down searches of BSM physics, excluding sets of models where the top width is affected.

AMS looks at Cosmic Galactic Rays

*by **Panos Charito***

The Alpha Magnetic Spectrometer (AMS) is a state-of-the-art particle physics experiment operating on the International Space Station (ISS) since May 2011. In the first 6 years of missions, AMS has detected over 100 billion cosmic ray (CR) particles. Recently, it has released new results on proton, antiproton, lepton, and nuclei energy spectra at unexplored energies and with an unmatched level of accuracy.

Recent results inaugurate a new era in Cosmic ray (CR) physics driven by high precision. With the latest AMS-02 nuclei data [1] (including the boron-to-carbon ratio, proton flux, helium flux and antiproton-to-proton ratio), the team was able to constrain the primary source and propagation parameters of cosmic rays in the Milky Way by considering three schemes with different data sets (with and without antiproton/proton data) and assuming different propagation models.

Initial discovery of CRs dates back to a century ago (1912). The inexplicable rate of discharge of electroscopes, could be explained by hypothesizing a mysterious source of ionizing radiation in the Galaxy. In 1912, Viktor Hess, an Austrian scientist, showed that this radiation was of extraterrestrial origin, by carrying electrometers on balloon flights and finding that the rate of discharge was increasing with height. For this discovery he was awarded the Nobel Prize in 1936. A similar conclusion had already been reached the year before by the Italian scientist Domenico Pacini, who had carried electrometers on a submarine and performing measurements at different sea depths.

Their identification of CR as particles rather than radiation dates to about 20 years later and in 20 more years also the first suggestion that they were associated with Supernovae Remnants (SNRs) was in place. Highly energetic particles consist of essentially every element ranging from hydrogen, accounting for approximately 89% of the GCR spectrum. The idea that Supernova Remnant (SNR) shocks are the primary sites of CR acceleration in the Galaxy is what is generally referred to as the ”Supernova remnant paradigm for the origin of Cosmic Rays”. This paradigm has been under scrutiny now for about 50 years, but only in the last few years some clear evidence in its favour has been found.

If SNRs are the main sources of CRs, effective amplification of the interstellar magnetic field must take place. The last generation of X-ray telescopes, with their superb spatial resolution, have not only confirmed the presence in SNRs of electrons with TeV energies, but have also finally allowed to highlight the presence of amplified magnetic fields in these sources, likely associated with efficient acceleration of hadrons. Also suggestive of efficient acceleration of protons is the measurement of anomalous widths of Balmer lines in some Hα bright remnants while recently, γ-ray astronomy have led, for the first time, to direct observational evidence of the presence of mildly relativistic protons in few SNRs interacting with molecular clouds.

This fundamental progress deriving from observations of SNRs has been paralleled by discoveries coming from direct observation of CRs. The latter have touched both the hadronic and leptonic component of CRs. As far as nuclei are concerned, the paradigm of a featureless spectrum at energies below the knee in the CR spectrum has been disclaimed by balloon and satellite observations showing a spectral hardening of all species at around 200 GeV/nucleon and a different spectrum for the two most abundant species, protons and He nuclei, with the latter being systematically flatter. These features might be revealing us important clues on the process behind particle acceleration and propagation in the Galaxy.

The long duration of the AMS mission, planned to last for the whole ISS lifetime, will cover a complete solar cycle from the ascending phase of cycle 24, through its maximum, and the descending phase into the next solar minimum. This makes AMS an excellent multichannel CR monitor of solar activity. Precision measurements of the CR time evolution, in connection with the changing solar activity, may give us strong insight on the so-called solar modulation effect.

Along with its connection with solar and CR physics, understanding CR modulation addresses a prerequisite for modeling space weather, which is an increasing concern for space missions and air travelers. The study of these effects has been limited for long time by the scarcity of long-term Cosmic Ray data on different species, and by the poor knowledge of the local interstellar spectra. AMS provides a continuous stream of time-resolved and multichannel Cosmic Ray data that set new objectives, namely: (i) to advance solar modulation observations of Cosmic Ray particles and antiparticles, and (ii) to develop improved and measurement-validated models of Cosmic Ray transport in the heliosphere.

Moreover, the new data allow to understand the puzzling anomalies detected in the energy spectra of CR proton and helium nuclei while also maintaining the universality of the dominant diffusive-shock acceleration mechanism. In this model, the p/He anomaly is explained by a flux transition between two source components that have different injection spectra and composition.

Another important topic is the recent observation of an eight-month time lag in solar modulation of Cosmic Rays. This effect reveals important properties on the dynamics of the formation and changing conditions of the heliospheric plasma. Crucial tests can be performed by AMS via monthly-resolved measurements of these ratios, or even better, by measurements of individual particle fluxes for protons, antiprotons, electrons and positrons under both polarity conditions and across the magnetic reversal. This demonstrates that time-dependent measurements on CR antimatter can provide precious information on the physics of the heliosphere. Finally, understanding the charge-sign dependence of Cosmic Ray modulation is also essential to search for dark matter signatures in Cosmic Ray fluxes.

AMS opens a dedicated, high-precision, multichannel investigation of solar modulation effects in Galactic Cosmic Rays. To develop reliable and data-driven models of CR modulation, however, the availability of time-resolved measurements over the period of interest is crucial and in this respect, monthly-resolved data from AMS will be very precious.

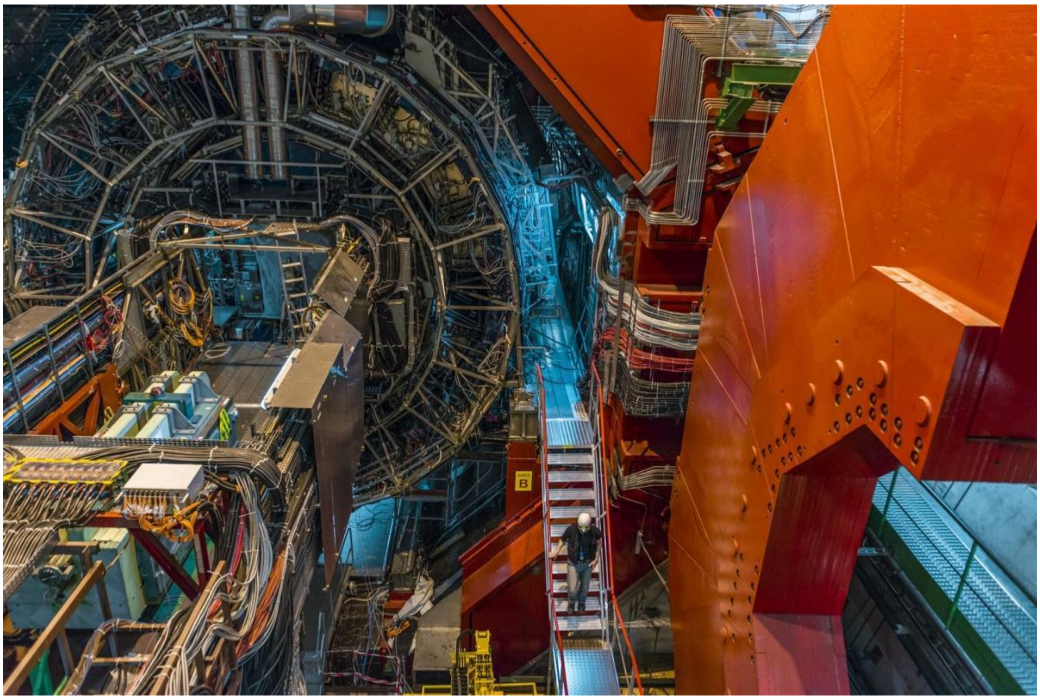
ALICE upgrade plans

by ***Panos Charitos***

PDF version

The ALICE experiment prepares upgrades of several subsystems and the online–offline system for data acquisition and processing during the Long Shutdown 2 (LS2) of the Large Hadron Collider (LHC). This will enable the experiment to do high precision measurements of rare probes from high to very low transverse momentum while also searching for new phenomena in QCD. Two of the key drivers for this upgrade are the high-precision measurements of charm and beauty production in heavy-ion collisions as well as the high-luminosity phase of the LHC (L = 6 ⇥ 10^27 cm^{2}s^{1}) for Pb-Pb.

Excellent tracking efficiency and track resolution down at low transverse momentum and gaining a factor 100 in statistics will boost ALICE's physics programme. In addition, many of the proposed physics topics (heavy flavours, low-mass dileptons, heavy nuclear states) rely on the inspection of high event statistics, without a dedicated trigger. ALICE will be able to inspect practically all heavy-ion collisions.



(Image credits: ALICE Experiment)

The large increase in statistics will be achieved by reading out Pb-Pb interactions at maximum rate of 50 kHz with the goal of integrating a luminosity of ≥13 nb^{-1} after LS2. Moreover, ALICE upgrade will help to improve vertexing and tracking capabilities. This implies building a new Inner Tracking System (ITS), a major upgrade of the TPC detector and a modification of the readout electronics of other detectors to comply with the high readout rate. It implies also a major upgrade of the online and offline systems.

The upgrade of the ALICE ITS will provide excellent tracking capabilities, significantly improve the impact parameter resolution and read out Pb-Pb events at 50 kHz interaction rate. The new, 10 m^2 large silicon detector is entirely based on seven layers of monolithic silicon pixel detectors, based on a 50 μm thick CMOS pixel sensor, and will help to extend the physics reach to new observables and improve the accuracy of existing ones.

The improved impact parameter resolution is achieved by moving the innermost layer (layer 0) closer to the interaction point to 23 mm radius, reducing the beam pipe radius from 29 mm to 18.2 mm, reducing the material budget of the innermost layers by almost a factor 3 to 0.3% X0 and by

reducing the pixel size from presently 50 μm × 425 μm to pixel sizes in the order of 30 μm side length.
Another major upgrade concerns the ALICE Time Projection Chamber. During this winter shutdown period, a delicate intervention has been performed on the TPC in preparation for the Run3 of LHC; endoscopic “cleaning” that will make the TPC more efficient and afford higher collision rates. Furthermore, Operating the TPC at a collision rate of 50 kHz requires to overcome the current limitations imposed by the operation of the gating grid and opt for continuous read out. The present multi-wire proportional chambers (MWPC) based readout chambers will be replaced by GEM detectors which feature intrinsic ion blocking without additional gating and exhibit excellent rate capabilities. The technical implementation of the GEM based upgrade of the ALICE TPC will benefit from new technologies presently being developed for other large upgrade projects like the CMS forward muon system The TPC upgrade also calls for replacing the existing frontend electronics to accommodate for the inverted signal polarity and to provide the full flexibility of a continuous readout.

The current TOF readout can sustain readout rates of tens of kHz so the ALICE upgrade program foresees an upgrade of the TOF readout electronics to further increase the readout rate capability for both Pb-Pb and pp interactions. Similarly, an upgrade of the TRD readout is planned to cope with the new interaction rates. The TRD has originally been designed to cope with a Pb–Pb interaction rate of 10 kHz and a maximum track multiplicity of 8000 charged particles per rapidity unit, which is four times larger than that actually observed. The performance of the TRD readout chain and its potential upgrade depends on two major functional units, the Front-End Electronics (FEE) and the Global Tracking Unit (GTU).

The upgraded ALICE detector will produce more than 1 TByte/s of data. Both collision and data rate impose new challenges on the computing system and software framework. Building on the experience accumulated during the design and operation of the online and offline systems during Run 1 and Run 2, the O2 software framework will implement a distributed, parallel and staged data processing model. The new ALICE Computing Model is designed for a maximal reduction of the data volume read out from the detector as early as possible during the data-flow. It is designed from the start to combine all the computing functionalities needed in a HEP experiment: detector read-out, event building, data recording, detector calibration, data reconstruction, physics simulation and analysis

Finally, the ALICE upgrade programme explores the possibility of upgrade the muon tracking system, including its electronics, as this will offer new possibilities for studying strange and charm quarks production in heavy-ion collisions.

For a full discussion of the ALICE upgrade programme you can read the LoI (link is external)