EP Newsletter of the EP department

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

I am writing this editorial while on telework from home. We are in an unprecedented situation, which would have been unimaginable only one month ago. In this month we have seen the Covid-19 crisis developing at a tearing pace. CERN could not remain an isolated island and we were also forced to take actions, which finally led us to bring CERN into “Safe Mode” and most of us being confined at home. Safety of our personnel was always the highest priority and this should also be retained in the period to come. Please obey all the rules defined by the authorities in the country where you are presently staying.

Despite the difficult situation we are trying to keep as many activities ongoing as possible from remote. Communication becomes even more important and I would like to urge you to keep frequent contacts with your colleagues, be it through video conferences, and even better through frequent chats on the telephone. I noticed with pleasure that many EP teams have introduced virtual coffees. This an excellent idea and I suggest to take it as an example. The isolation may be felt to become more and more difficult to bear and we should take preventive measures.

This EP newsletter should bring a bit of normality back into your life. In it you will find many very interesting articles about work in the EP department, as usual spanning a wide range of activities from hardware work on experiments, new physics analysis, the proposal of a new experiment, etc. At the last moment we have included an article on how high energy physics is contributing to fighting the Covid-19 virus. CERN has set up the “CERN against Covid-19” task force, which coordinates projects initiated by many colleagues, including some very interesting initiatives from EP. Despite CERN being more or less closed, we are still welcoming new Fellows and Staff. You may see their profiles at the bottom of the newsletter and I do hope we will meet them in person in the not so far future.

Finally, I would like to say a special thanks to all our colleagues who, despite the obstacles and potential risks, have to continue to come to CERN to execute crucial activities to keep the laboratory and our equipment in a safe mode and to provide the services necessary for all others teleworking from home.

Enjoy reading the newspaper, take care of your families and stay healthy!

Manfred Krammer

EP Department Head

PUMA: Exploring exotic nuclear phenomena with antimatter

by ***Alexandre Obertelli (TU Darmstadt, PUMA spokesperson) François Butin (CERN, PUMA project manager)***

PDF version

PUMA is a new experiment proposed at both the CERN AD and ISOLDE facilities, that would for the first time transport antiprotons trapped at AD/ELENA to ISOLDE, by carrying them in a trap loaded onto a truck. The antiprotons would then be used for nuclear physics experiments at ISOLDE. The proposed experiment has been favourably reviewed by the SPSC and INTC committees, pending for final approval after a more thorough review of the required CERN resources.

Radioactive isotopes (RI) reveal new many-body phenomena originating in their neutron-to-proton asymmetry or in their low binding energy compared to stable nuclei. Highlight examples of these phenomena are the development of neutron skins at the nuclear surface, neutron halos for weakly bound nuclei close to the so-called neutron dripline, or the nuclear shell evolution as a function of number of protons and neutrons. The investigation of RI is necessary for a global understanding of the nuclear many-body problem and the role of the underlying many-body forces.

In particular, the discovery of halo nuclei was made in 1985 [1]. An effective matter radius of neutron-rich light nuclei was extracted from their reaction cross section when impinging heavy-ion targets. Nuclei such as 6He, 8He and 11Li showed a strong increase of their matter radius compared to lighter isotopes. This increase was later interpreted, first by P. G. Hansen and B. Jonson from ISOLDE at CERN, as a tunnelling effect of loosely bound neutrons whose wave function extends beyond the short range attraction of the rest of the nucleus [2]. This neutron-halo phenomenon was at the origin of RI studies at a large scale, and halos have continued to be an object of fascination and exploration in nuclear physics [3]. Interestingly enough, the term “neutron halo” was first used a decade before this discovery from the interaction of heavy nuclei with… low energy antiprotons to qualify the excess of neutrons at the nuclear surface in stable nuclei [4].

The development of a neutron skin on the nuclear surface along an isotopic chain, i.e. a nucleus with the same number of protons and varying number of neutrons, from stability towards the neutron drip line can be correlated with the bulk properties of the in-medium nucleon-nucleon interaction [5] with a strong connection to the nuclear equation of state that drives, among others, the physics of neutron stars [6].

Antiprotons, as a probe to study short-lived isotopes, remain unexploited despite the pioneering work with stable nuclei, in particular at CERN in the 90s [7]. Indeed, low-energy antiprotons offer a very unique sensitivity to the neutron and proton densities at the annihilation site, in the tail of the nuclear matter density. Experimental techniques such as nucleon removal reactions and elastic scattering are other hadronic probes sensitive to the nuclear surface which are used to extract the matter radius of RI (see [8,9,10] for recent studies). They are complementary to experiments with low-energy antiprotons since they are sensitive to the nuclear surface, typically where the density is half of the saturation density, while the annihilation with low energy antiprotons is sensitive to the tail typically at 2 fm from the surface, where the nuclear density is 10% or less of the saturation density. Such studies with short-lived nuclei and low-energy antiprotons are the motivation of the proposed antiProton Unstable Matter Annihilation (PUMA) experiment [11].

The first objectives of the PUMA experiment are (i) to provide a new observable for radioactive nuclei that characterises the neutron- to-proton asymmetry of their matter density tail, namely the neutron-to-proton annihilation ratio, (ii) to characterise the matter density tail of known halos and neutron skins with this new method, (iii) to evidence new proton and neutron halos, (iv) to understand the development of neutron skins in medium-mass nuclei along isotopic chains.

Today, no facility provides a collider of low-energy radioactive ions and low-energy antiprotons: PUMA aims at transporting antiprotons (the long term goal is 1 billion antiprotons) from CERN/ELENA to CERN/ISOLDE to perform the capture and annihilation of low-energy antiprotons by short-lived nuclei, and probe in this way the so-far unexplored isospin composition of the radial-matter-density tail of radioactive nuclei.

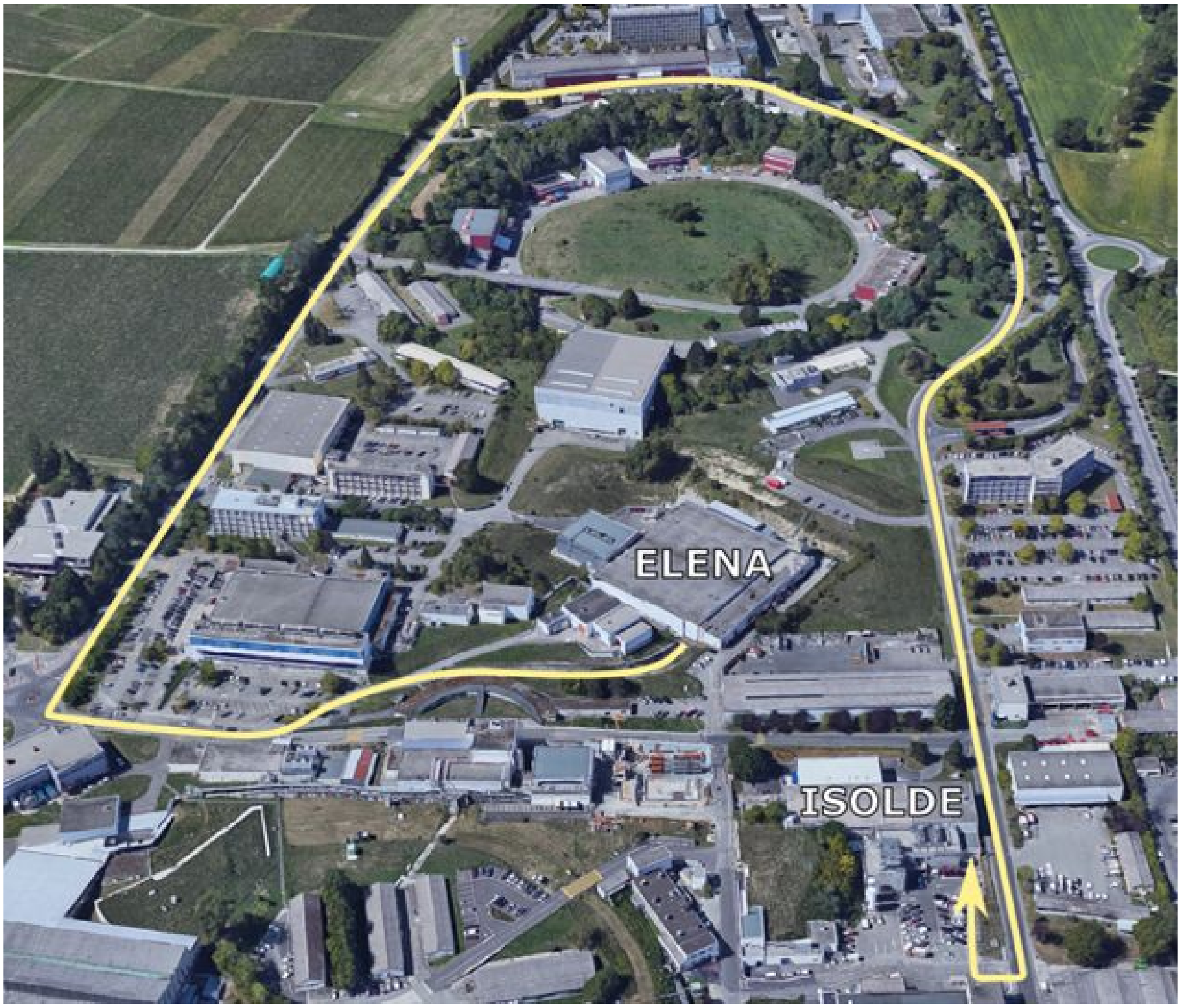

Fig. 1: Itinerary of PUMA from ELENA to ISOLDE.

PUMA will consist of a fully-transportable experimental setup composed of a 28-cm-large bore 4-Tesla solenoid, with active and passive shielding, a 4-K Penning trap for storing antiprotons and ions and charged-particle trackers composed of a time-projection chamber and a plastic scintillator barrel for the detection of annihilation products. Non destructive diagnostics for the antiproton plasma will also be included in the system. The trap will be composed of two zones, a storage zone and a collision zone.

The main challenge of PUMA is related to the extreme high vacuum required for a long term storage of the antiprotons with a half-life of thirty days corresponding to about a hundred of residual gas molecules per cm3 or about 10^{-17} mbar at 4 K. As the objective of PUMA is to inject low-energy ions into the antiproton plasma, the antiproton trap needs to be open to the beam lines at ISOLDE. PUMA has been designed for a vacuum of 10-10 mbar at the interface of the apparatus with both ELENA and ISOLDE beam transfer lines.

Once the antiprotons are trapped, the entire system will be transported in operation from ELENA to ISOLDE. The superconducting wire of the magnet itself as well as the trap electrodes are cooled by pulsed tube cold heads. The full experiment requires 70 kW electrical power during transportation, with the main power consumers being the cold-head compressors and the associated chiller. The system relies on a switchable power source going through an uninterruptible power supply (UPS) and thus batteries. At ELENA and ISOLDE, the system will be powered by the normal electrical network. In case of power outages of a few minutes, the UPS will be able to provide the power to the setup to avoid losing the antiprotons. The full experiment will be moved by crane from the experimental zone to a truck for transportation from ELENA to ISOLDE and vice versa. During the transportation, the experiment will be powered by a generator located on the truck.

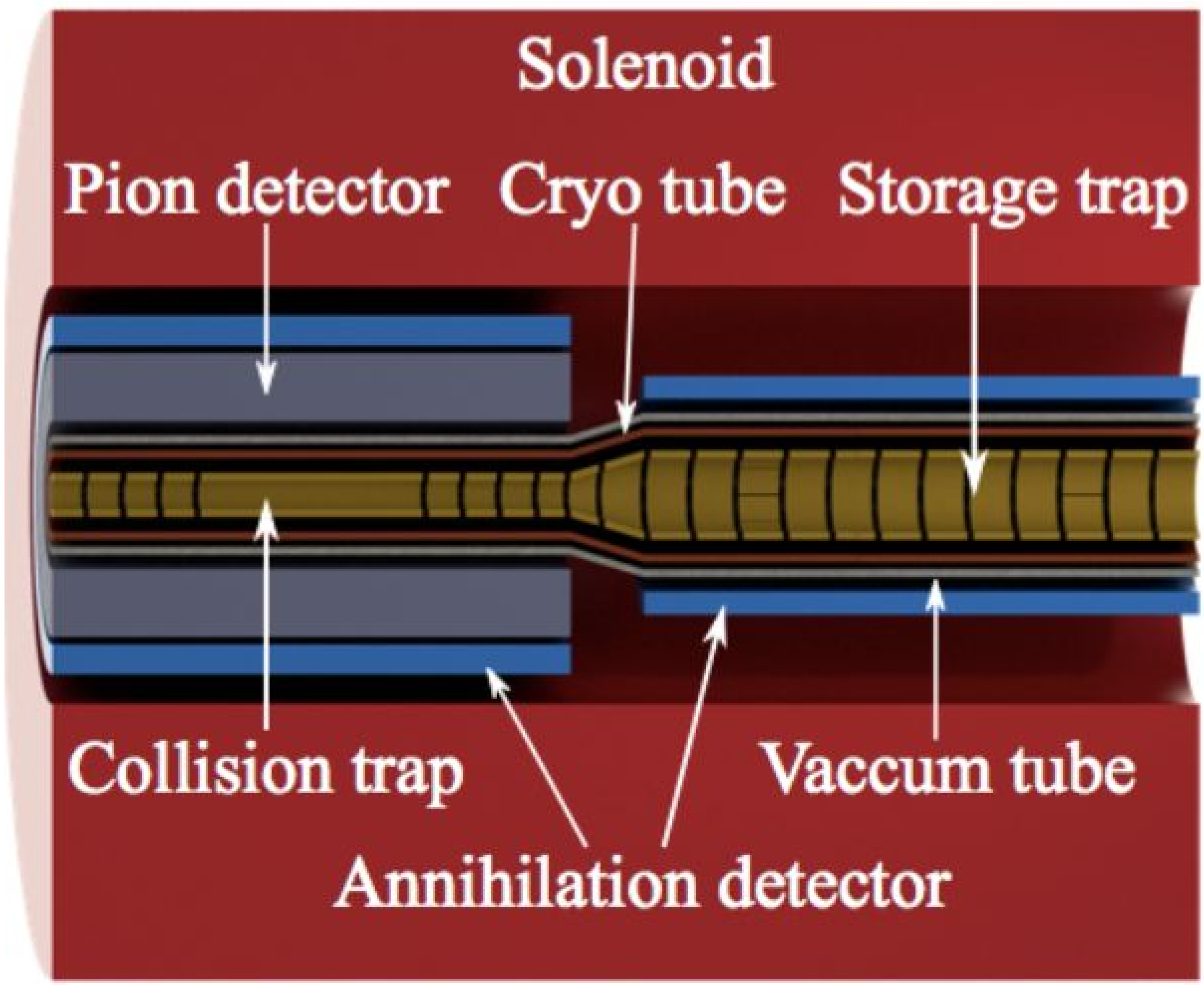

Fig. 2: Schematic side view of the PUMA setup composed of antiproton and ion traps inside a 4K cryostat and pion detection.

At ISOLDE, low-energy Radioactive Ion Beams will be introduced into the PUMA trap and mixed with antiprotons to favour the formation of antiprotonic atoms, followed by the annihilation of the antiprotons with protons or neutrons of the nucleus. The ratio of the number of annihilated neutrons to the number of annihilated protons will be evaluated by measuring the charged pions produced by the annihilation. The basic principle of PUMA relies on the electric charge conservation of the annihilation process: the total charge of the pions is −1 for a neutron annihilation and 0 for a proton annihilation. The determination of this ratio requires a correction of final state interactions, acceptance and detection efficiency. The accuracy of the final state interaction is key to control systematic uncertainties. A precision better than 10% is targeted based on simulations and reference measurements to be performed at CERN/ELENA. Complementary X-ray measurements from the decay of the formed antiprotonic atoms are also considered for future plans.

Today, the PUMA apparatus is under development. The transportable solenoid is being built and should be delivered at TU Darmstadt in 2020. A trap prototype is being assembled and will be soon operated in a test solenoid. The parameters for the trapping, rotating wall technique and sympathetic cooling will be optimised during the test phase in 2020.

Simulations for the vacuum inside the trap were performed in collaboration with CERN TE-VSC. A program of measurements of hydrogen isotherms at low pressure, down to 10-13 mbar, is foreseen. The cryostat of the PUMA trap will be conceived in collaboration with CERN TE-VSC. In addition, R&D for a fast cold-gate valve to limit the amount of residual gas molecules entering the trap has been initiated at TU Darmstadt. The cryostat will be built in 2020 and the full experiment assembled in 2021.

Moreover, the time-projection chamber for the pion detection is being designed and will be built at CERN EP/ESE. while the electronics has been developed at CEA. The goal is to assemble the full detector in 2021.

The PUMA experiment requires a new experimental zone at ELENA. If the experiment is accepted, the ELENA LNE51 beam line will be completed and PUMA will be installed between the existing GBAR and ASACUSA experiments. At ISOLDE, the location of the experiment is still under discussion while beam optics calculations for both ELENA and ISOLDE are ongoing.

The PUMA technical design report (TDR) should be issued at the end of 2020. A first installation at ELENA is foreseen in 2021, while first measurements at ISOLDE in 2022.

The proposed method is indeed first an unambiguous discovery tool for halos: annihilation from a neutron halo nucleus should lead to a neutron-to-proton annihilation ratio exceeding by an order of magnitude the N/Z ratio of the nucleus, annihilation from a proton halo, on the contrary, should lead to a neutron-to-proton annihilation ratio significantly smaller than unity. Neutron skins could be characterised by a neutron- to-proton annihilation ratios larger than N/Z.

The physics cases to be proposed to ISOLDE range from a re-visit of the historical halos 6He and 11Li, the search for proton halos in neutron-deficient nuclei, the search for thick neutron skins or halos in neutron rich Ne and Mg isotopes and a quantitative study of the development of the neutron skin in oxygen and tin isotopes.

Beyond its Nuclear Physics objectives, PUMA will allow to transport a significant amount of antiprotons and to deliver them to experiments outside the AD and, eventually, outside CERN. PUMA will contribute to democratise antiprotons for basic research and, maybe, trigger new ideas.

Further Reading

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POLAR-2 project enters final design stage

by ***Merlin Kole (University of Geneva)***

PDF version

The POLAR-2 project is a follow-up of the POLAR mission that was launched in 2016, mounted on the exterior of the Chinese Spacelab Tiangong-2. Following its application to the Recognized Experiment Committee earlier this year, it has been recommended to be granted CERN Recognized Experiment status.

The POLAR instrument took data successfully for 6 months during 2016 and 2017 during which it studied the emission from astrophysical events called Gamma-Ray Bursts. The main scientific goal of POLAR was to perform the most detailed polarization measurements of the gamma-ray emission from these events. GRBs are the brightest electromagnetic explosions in the Universe since the Big Bang and as such are some of the most studied astrophysical sources. Despite all this research GRBs remain however poorly understood and specifically many open questions remain regarding the origin of their high energy emission. Although polarization measurements have the potential to answer many of these open questions few have been performed successfully in the past due to their complexity. Two important difficulties with the measurements are the low efficiency of event detection for gamma-ray polarization measurements and the requirement to perform such measurements in space. Furthermore, as the polarization is deduced from small asymmetries in the angular distribution of events detected by the instrument, the measurements are very susceptible to systematic errors. Despite all the difficulties involved the POLAR collaboration recently published the first catalogue of detailed polarization measurements of GRBs. These results show an overall low polarization as well as an unexpected complexity in the time evolution of the polarization during a GRB. They therefore indicate that measurements with a significantly improved precision are required in order to gain a full picture of the emission mechanism.

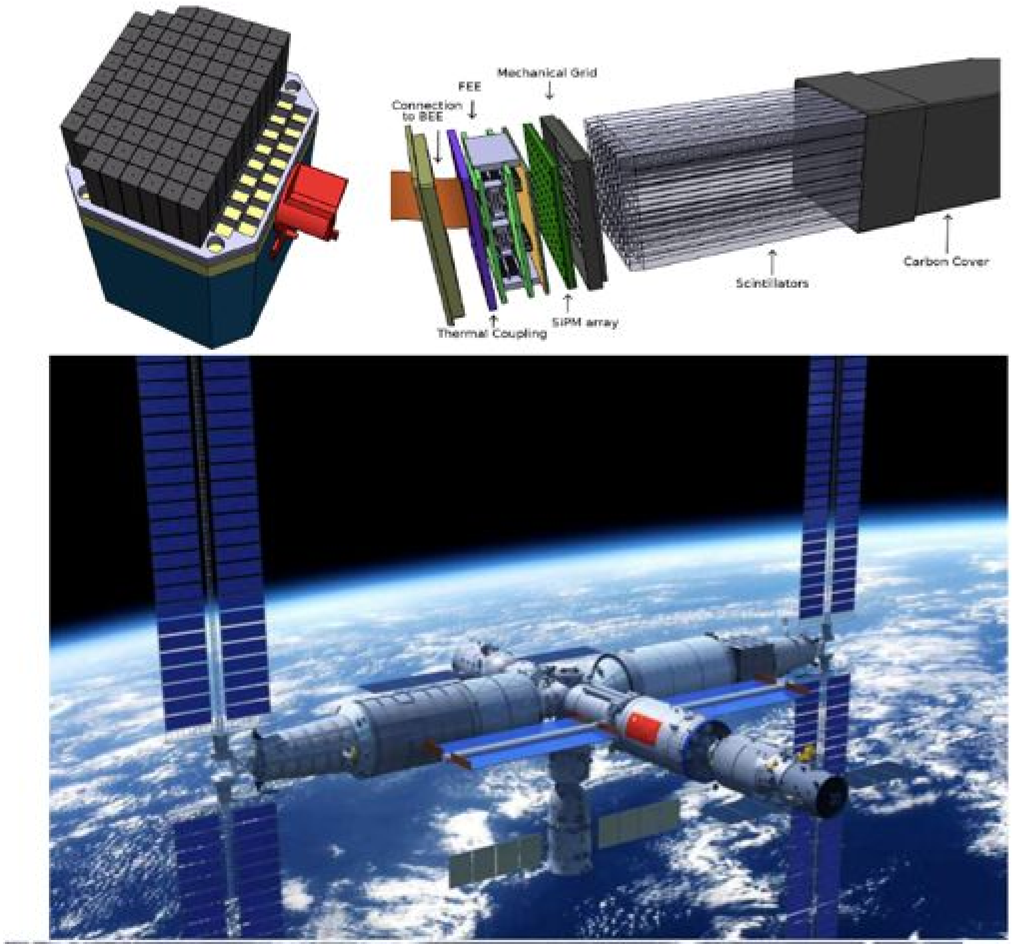

Figure 1: The Chinese Space Station, the design of the full POLAR-2 instrument and the details of a single detector module.

With the recent discovery of gravitational waves and their connection to GRBs, a new era in multi-messenger astrophysics has started. This major advance together with the discoveries made by POLAR warrant a GRB polarimeter with large acceptance capable of both providing high precision polarization measurements as well as detecting very weak GRBs. An international collaboration, led by the University of Geneva and consisting of leading members of the POLAR collaboration and new members from the Max Planck Institute for Extraterrestrial Physics, proposed the POLAR-2 instrument. The instrument will be an order of magnitude more sensitive to the polarization signal from GRBs using recent advances in the field of detector technology. In summer of 2019, the instrument was accepted for launch towards the China Space Station in 2024, from where it will perform polarization measurements for at least 2 years. Furthermore, as the most sensitive instrument in its energy range, POLAR-2 will be capable of detecting weak GRBs invisible to the current generation of gamma-ray detectors. One important feature is that POLAR-2 will be set up to issue alerts with position information for transient events to other instruments, thereby increasing the scientific potential of both POLAR-2 and other instruments.

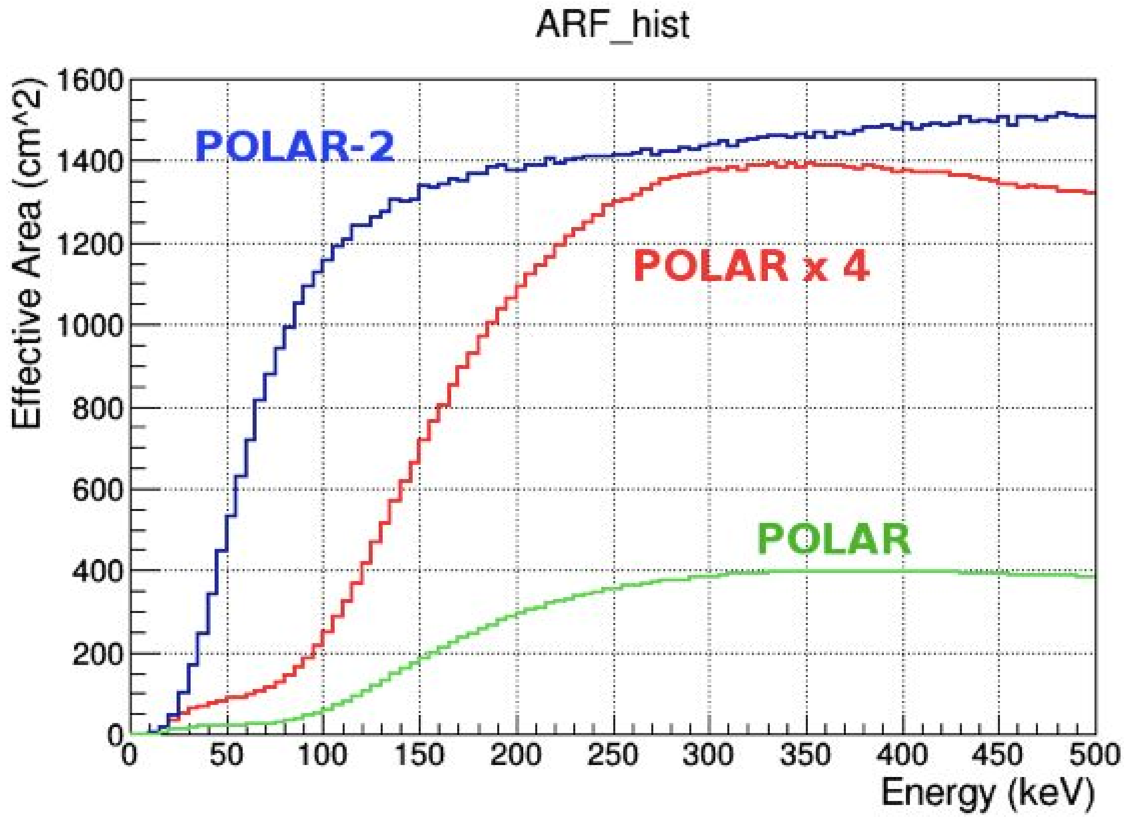

Figure 2: The effective area of POLAR-2 compared to that of POLAR and that of POLAR multiplied by 4. It indicates nicely what we gain by increasing the size of the instrument by a factor 4 illustrating the gain (low energy) through technological R&D improvements.

The instrument design of POLAR-2 is largely based on that of its predecessor POLAR. In the detector the polarization of the incoming gamma-rays is measured using a segmented scintillator array. The design is optimized for gamma-rays which enter the array of 6400 scintillator bars to Compton scatter in one bar and subsequently get photo-absorbed in a second one. Using the relative position of the two bars the Compton scattering angle can be deduced, which in turn can be used to infer the polarization angle of the incoming gamma-ray. Whereas the measurement principle is similar between POLAR and POLAR-2 several improvements to the detector design are made. Firstly the size of the scintillator array is increased by a factor 4, allowing it to detect more gamma-rays per GRB. Secondly, while POLAR used multi-anode photomultipliers to read out the plastic scintillators POLAR-2 will use silicon photomultipliers (SiPMs) instead. The advantages of the SiPMs are not only the higher photo-detection efficiency of these devices but also their larger mechanical resilience. This, as well as their lower operating voltages compared to PMTs, are significant advantages for space based detectors which have to sustain large vibrations and shocks during launch. Many lessons learned from the POLAR mission are used to further improve the design. Examples are optimizations of the scintillator shape and shock dampers, simplifications of the electronics, data compression and improvement of in-orbit to ground communication protocols. Finally, the POLAR-2 instrument will not only consist of the most sensitive space gamma-ray polarimeter, it will also contain spectrometers which can be used to measure both the spectrum and the location of high energy transient events such as GRBs associated with gravitational waves.

The POLAR-2 mission is currently in the final stages of the design. For this purpose studies of different components to be used in the design are being tested for performance, radiation tolerance, shock and vibration resilience and performance in thermal vacuum. Recently seemingly simple components such as reflective foils used to optimize the light yield of the scintillators, were tested. These tests were performed at the CERN EP department with experts who used such materials previously in, for example, LHCb. While the standard material used for this purpose throughout physics experiments around the world, Vikuiti by 3M, was found to be the best reflector, a material produced by Toray in France was found to have a similar performance for POLAR-2, but with the advantage of being significantly thinner. On the other hand the SiPMs are currently undergoing tests at the National Centre for Nuclear Physics in Poland for radiation damage at different temperatures. The first results indicate that while the performance indeed significantly deteriorates with high dose of radiation, at the operating temperatures planned for POLAR-2 no significant issues are expected after operation of 2 years in space. In the near future additional tests are foreseen such as potential irradiation and charge particle response tests at CERN, and detailed instrument calibration tests using synchrotron radiation at the European Synchrotron Radiation Facility (ESRF).

Figure 3: Current measurement setup at CERN showing a single detector module with our first version of the read out electronics.

The POLAR-2 instrument design will continue to be developed during 2020 and early 2021 followed by the instrument construction phase lasting three years. The launch towards the China Space Station is planned for early 2024 after which the instrument will take data for at least 2 years. During these 2 years POLAR-2 will not only be the most sensitive polarimeter ever launched but also one of the most sensitive gamma-ray detectors in space. As such, POLAR-2 will help to unravel many of the mysteries surrounding the most violent explosions in the Universe and play a leading role in the new era of multi-messenger astrophysics.

MUonE experiment gears up to chase whiff of new physics

by ***Clara Matteuzzi & Luca Trentadue (INFN)***

PDF version

A new proposed project, MUonE, was described on the EP Newsletter few months ago [2]. It is an experiment aiming at helping in understanding the long-standing discrepancy between the experimental value and the Standard Model (SM) prediction of the anomalous magnetic moment of the muon, a_μ, which remains one of fundamental parameters in Quantum Field Theory that still lacks an explanation.

The discrepancy could be due to the presence of new physics, or to a lack of precision in the determination of the expected SM value or perhaps to a lack of precision in experimental measurements. During 2020, a new experimental result is expected from the new generation of (g-2) experiments at Fermilab (USA).

Since June 2019, the MUonE project made progress : the Letter of Intent [1] was submitted to the concerned committee (the SPSC), which, at their January 2020 meeting, took into consideration the request of a test run in 2021 with the muon beam M2. The aim of of the test is demonstrating that the proposed measurement is feasible with the planned precision. The challenge is all in the systematic uncertainty. The requested test run was approved by the CERN Research Board.

The MUonE international collaboration is still forming, and at present there are groups from China, Italy, Poland, Russia, UK, and USA. All the efforts of the collaboration are now addressed to prepare this test run, foreseen at the end of 2021 and expected to last for 3 weeks.

The test must provide answers to several crucial questions, some of the most important are: i) is it possible to operate in an efficient way the setup in order to collect efficiently elastic scattering data $\mu+e \rightarrow \mu+e$ at a very high rate (the beam will have ~ 50 MHz); ii) which systematic uncertainty is achievable with the planned detector; iii) which trigger, acquisition and volume of data will need to be managed.

In figure 1 the scheme of the layout of the test is shown. It consists of two of the 40 stations foreseen for the final apparatus: each station is composed of a target (T1,T2) and 3 planes of Si trackers. The 3 planes before T1 are dedicated to precisely measure the direction of the incoming muon track.

A calorimeter at the end will be used to distinguish muons from electrons when they are emitted at a very close angle, i.e. both at about 2.5 mrad. In this kinematic region, the two particles have about the same energy of around 75 GeV each.

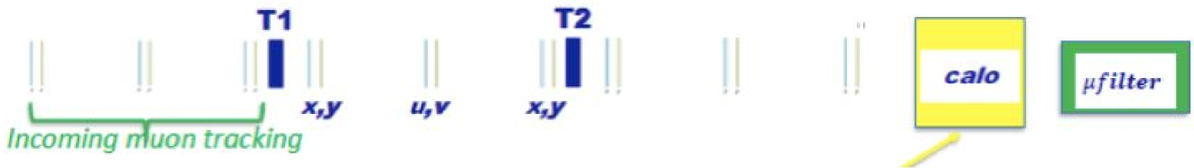

Figure 1: The two foreseen stations followed by a calorimeter and a muon filter (not to scale).

In three weeks of running we expect to collect statistics of the order of 10^8 elastic events. Such statistics will not allow to extract the quantity aμHLO, but we plan to measure the αlep corrections to the running of αem, and that quantity will be taken as a test bench for the feasibility of the final measurement.

Moreover, the collaboration has a strong component of theorists, who are deeply committed to bring the precision of the theoretical calculations to the necessary precision, at NNLO. Beyond NNLO, the contribution to the systematics of the theoretical calculation will be of the order of 10^{-6}, adequate for the final precision of the MUonE measurement.

Within the theory community involved in the project there is sufficient expertise which has already provided a well definite and necessary solid ground of support for the MUonE experiment. Nevertheless new goals have still to be achieved to further assess the theoretical basis to the experiment and to reach the aimed accuracy.

A first step will be to obtain a fully differential Monte Carlo program containing fully massive NLO electroweak contributions, fully massive at NNLO as well as the NNLO for hadronic contributions. In addition, the cross-section evaluation with a fixed-order calculation will be matched to a parton shower result by taking into account multiple photon emissions which will be, initially, at leading logarithmic accuracy [3].

Two different implementations of such a code are planned to be developed in order to appropriately check their compatibility. Furthermore a phenomenological analysis, in close collaboration between experimentalists and theorists will investigate if the theory approach to the measurements could be considered adequate. In this respect a careful error estimate of the missing terms will be crucial [1].

The MUonE project [2] has entered in a phase where the important demonstration of the feasibility of a such a precise measurement must be provided, in the conditions we plan to run the final experiment (same beam, same location, same tracking elements).

New collaborators are welcome, and the challenge should be very interesting for young people interested to participate in an experiment through all its different stages, from the planning to the final measurement.

Further Reading

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Deep Neural Networks for particle reconstruction in high-granularity calorimeters

by ***Jan Kieseler (CERN)***

PDF version

Precision measurements in high energy physics as well as an increasing amount of searches for new phenomena rely on a precise reconstruction of the event that caused a particular signature in the detector. Particle flow algorithms [1, 2, 3, 4] aim to identify individual particles before they are merged to compound objects such as jets or missing (transverse) momentum. These approaches exploit all subdetector systems to resolve ambiguities and allow to apply calibrations on the level of individual reconstructed particle candidates. In consequence, particle flow algorithms typically lead to gains in physics performance. For existing detectors, they rely heavily on track information to resolve ambiguities [1, 2], since the calorimeter granularity is often insufficient to disentangle close-by particles or identify the particle type with high accuracy. These shortcomings can be addressed by high-granular calorimeters (HGCs) with high lateral, but also high longitudinal segmentation, where even close-by showers can be disentangled. Moreover, the identification and the energy measurement of individual particles can be enhanced by resolving the fine structure of the shower.

Therefore, high granular calorimeters are investigated for future lepton and hadron collider experiments. The focus of the lepton collider experiments is more on a precise measurement of the particle properties and because the overall radiation is lower, scintillator-based solutions can be employed, as proposed by the CALICE collaboration [5, 6]. For hadron colliders, also radiation considerations play a crucial role, leading to choosing more radiation hard detectors, such as a highly granular liquid Argon sampling calorimeter proposed for the hadronic phase of the future circular collider (FCChh) [7] to cope with up to 1000 simultaneous interactions per bunch crossing (pileup). For the high luminosity LHC phase, the endcap calorimeters of the CMS experiment will be replaced by the CMS high granularity calorimeter (HGCal), each endcap being a sampling calorimeter with 50 layers and in total 3 Million sensors. The sensors are made of silicon with sizes as low as 0.5 cm 2 at high pseudorapidities and in the first layers and scintillator material combined with silicon photomultipliers in areas with less radiation [8]. Also the other proposals for future calorimeters in Ref. [5, 6, 7] have similar granularities, far below the size of individual showers. Therefore the challenges for reconstructing individual particles from the energy deposits in each cell are very similar, despite different choices for the detector hardware.

To reconstruct particles in these calorimeters, the challenges are two-fold: the large number of readout channels requires fast algorithms, in particular at trigger level. However, at the same time, the algorithms should exploit the possibilties the detectors offer to the fullest, which requires sophisticated techniques that can not only reconstruct electromagnetic- but also hadronic showers, which have strongly irregular shapes with electromagnetic components, hadronic components and minimal ionizing particle (MIP) tracks connecting different parts of the shower. If possible, the algorithms should also include information from other tracking subdetectors to facilitate a fully consistent particle flow approach, including timing information for each particle to further control the effect of pileup. Even though high granularity calorimeters can be seen as dense trackers, approaches from tracking cannot be adapted easily. One of the main complications here is that tracks are objects with a well defined and very consistent helix shape in comparison to calorimeter showers, where shower shapes vary widely and inconsistently, particularly for hadronic showers. This can easily lead to problems in particular for strictly sequential algorithms, e.g., when electromagnetic showers are reconstructed first, and then the remaining deposits are reconstructed as hadronic energy. In this case, an early showering hadron would be reconstructed as an electromagnetic shower, with parameters optimised for such a shower, and the remnant would be mis-reconstructed as either a low energy hadron or the hadron reconstruction would fail due to the unexpected shower shape of the hadronic remnant, leading to worse a energy resolution and misidentification of individual particles.

Deep neural networks (DNNs) can in principle help to address both requirements on the reconstruction (good computing and physics performance) simultaneously. Even though they usually incorporate many more operations than standard algorithms, almost all operations are large matrix multiplications that are inherently parallelisable. In particular on dedicated hardware such as graphics processor units or field programmable gate arrays, that support up to thousands of parallel operations per clock cycle, the computation time can reduce almost linearly for large networks. This fact can provide benefits at trigger level as well as for offline reconstruction. As far as the physics performance is concerned, DNN based approaches have proven to be superior to standard approaches, in particular for complex problems that cannot easily be expressed in a simple physics model; or where the simple physics model does not fully apply due to detector effects. One example is the identification of the jet origin (jet tagging), where DNN based approaches have already become the default algorithms [9, 10, 11, 12, 13]. One strength of DNNs is that instead of a sequence of steps, where each step potentially removes information, they in principle allow to retain the full information up to the final reconstructed quantity, which is even often expressed as a probability. Therefore complications such as the example of the early showering hadron above can be avoided.

The key to reconstruction with DNNs is to adapt the neural network architecture to the structure of the problem. For example, many advances in computer vision only became possible through convolutional neural networks (CNNs) [14] which exploit the translation invariance of the image through moving kernels that find certain features (edges or complete objects) independent of their position. The CNN architectures require a strict equidistant grid, and are therefore only applicable to particular detector geometries. One example of a calorimeter with such geometry is the proposed barrel calorimeter for the FCChh detector. There, the application of a customised CNN architecture shows excellent performance for charged pion energy reconstruction as shown in Figure 1. The CNN is extended to three dimensions and adapted to perform optimal identification of hadronic and electromagnetic shower components: each kernel provides the local energy sum in addition to almost linear local corrections together with more non-linear corrections that take into account a larger area.

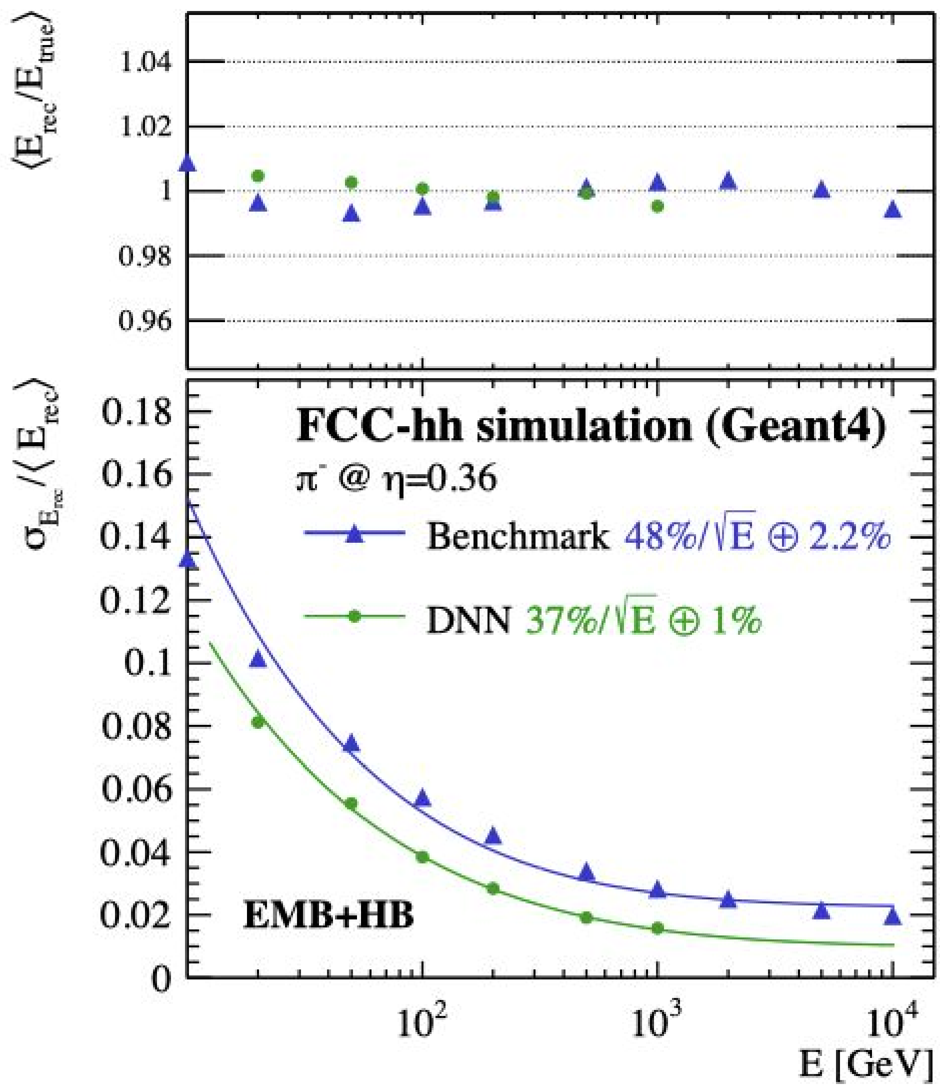

Figure 1: Energy response and resolution of charged pions in the FCChh barrel calorimeter using a DNN based approach and a globally calibrated topological clustering approach as benchmark.

Despite the promising results, this approach does not generalise to the irregular geometries of typical calorimeters at colliders and furthermore does not allow to incorporate track information in a natural way, needed for a consistent particle flow algorithm. A better representation of the calorimeter data is given by point clouds. In a point cloud, each sensor is represented by a point with position and other features, e.g. energy, sensor size, and timing information. This representation does not require a regular grid and can be sparse, such that only sensors with significant energy over threshold need to be processed.

To reconstruct individual quantities like particles from a point cloud or for segmentation (clustering) of objects in a point cloud, graph neural networks (GNNs) [15] have received increasing attention in the last years. These rely on vertices and edges connecting the vertices. Typically, information is exchanged along the edges, which might carry properties of their own that contribute to this information exchange. This approach has proven to be very powerful for jet tagging [16, 17], but also for segmentation of three dimensional objects in computer vision applications, e.g. in Refs. [18, 19, 20]. In addition, the representation as point clouds makes it possible to integrate track information and calorimeter hits in a natural way into the network, since both can be represented by vertices in the graph. For the application to particle reconstruction in calorimeters dedicated GNN architectures have been developed, addressing physics performance and also computing resource requirements [21]. The proposed GravNet performs the information exchange between neighbouring vertices, weighted by their distance. The vertex properties are transformed into a low dimensional space, where distances and neighbour relations are evaluated, and to higher dimensional features, which are exchanged between neighbour vertices. This distinction reduces the resource requirements as compared to proposals from the computer science literature, e.g. in Ref. [19] while having the same reconstruction performance. In addition, it removes the need to define the edges by hand in a preprocessing step. The qualitative performance is illustrated in Figure 2, showing two charged pions with an energy of approximately 50entering the calorimeter. Their showers develop very differently, however the GNN model is able to predict the energy fractions accurately.

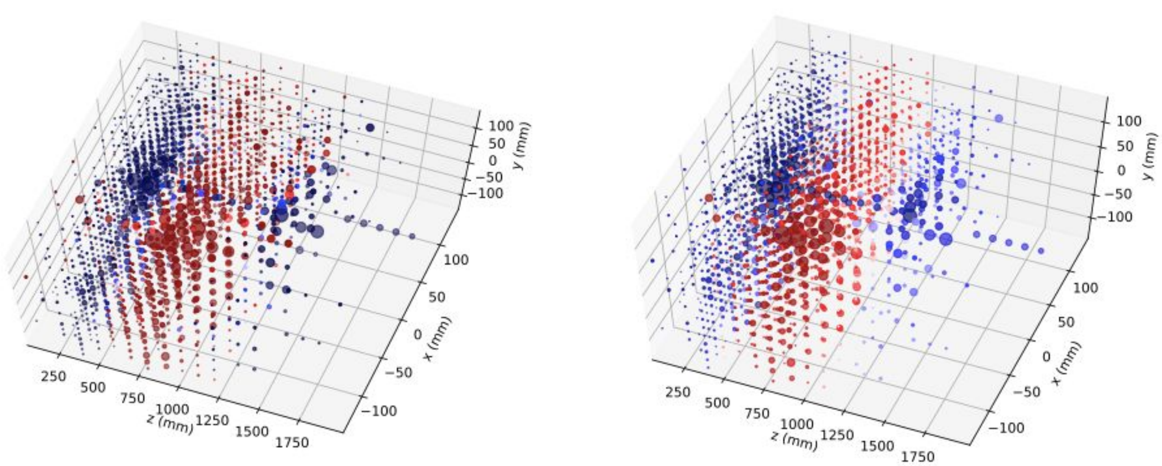

Figure 2: Comparison of true energy fractions (left) and energy fractions reconstructed by the GravNet model (right) for two charged pions with an energy of approximately 50. Colours indicate the fraction belonging to each of the showers. The size of the markers scales with the square root of the energy deposit in each sensor [21].

This architecture has been adapted for the CMS HGCal for up to 5 showers and shows similar excellent reconstruction performance here, as shown in Figure 3. Particles of different types are separated accurately and simultaneously by the same algorithm.

Despite the excellent performance, these studies have the disadvantage that they do not generalise directly to an unknown number of particles in the detector. These models predict energy fractions per sensor, so the number of expected showers determines the number of fractions to be predicted and and upper bound needs to be defined a priori. Setting this bound to a very large number is not feasible, since it introduces problems with combinatorics in the training when matching and comparing true and reconstructed fractions. One solution would be to use a seed driven algorithm, where first seeds are identified and then particle properties are reconstructed around those seeds. However, this comes with some of the disadvantages of sequential algorithms as far as information loss is concerned and leads to computational overhead since the pattern recognition needed for seeding and final reconstruction is almost identical.

Another solution to the problem is to reconstruct edge features rather than vertex features. Instead of reconstructing a fraction per sensor, the connecting edge between two sensors is classified as either belonging to the same shower or to a different shower. This approach has been successfully studied for tracking applications [23, 24] and also for calorimeter clustering [25]. While this method in principle resolves the issues mentioned above and allows to predict an unknown number of showers, it comes with strict requirements: before the GNN is applied, all possibly true connections between sensors need to be inserted in the graph, such that they can be classified by the network, and the same connections need to be evaluated once classified to built the shower under question. Moreover, the binary nature of an edge classification makes this approach less applicable to situations with large overlaps and fractional assignments, however additional particle properties such as particle type or energy can also be attached to the edges and reconstructed. The final object properties can then be determined through the mean of all connected edges, requiring an additional step.

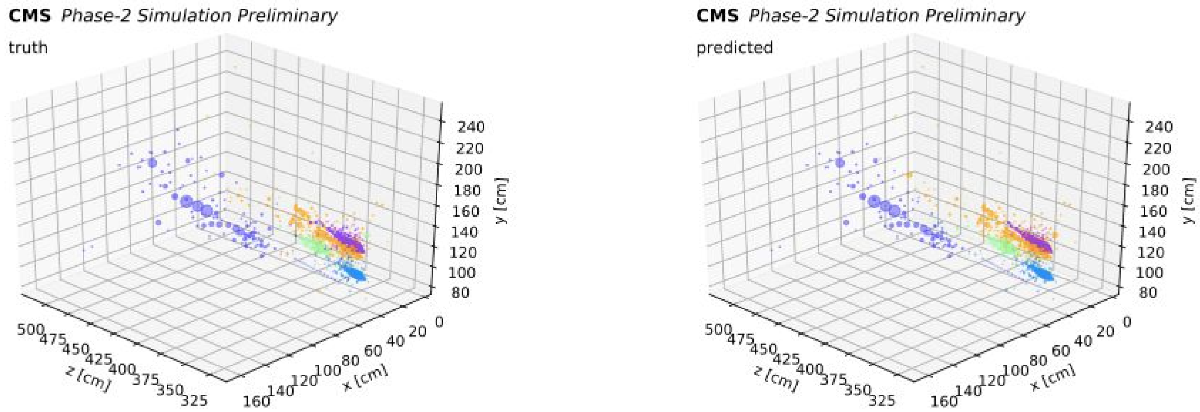

Figure 3: Comparison of true energy fractions (left) and energy fractions reconstructed by the GravNet model (right) for different particles entering the CMS HGCal. Colours indicate the fraction belonging to each of the showers. The size of the markers scales logarithmically with the energy deposit in each sensor. The particles enter the calorimeter from the bottom right. [22].

There are multiple other approaches from computer vision to solve the problem that comes with predicting an unknown number of objects in a point cloud or an image. Most use a grid to create anchor boxes [26, 27, 28, 29, 30, 31, 32], which are sensitive to the anchor box sizes, aspect ratios and their density [30, 28] and do not generalise easily to sparse point clouds. Recent anchor free approaches identify key points instead of using anchor boxes, which are tightly coupled to the physical centre of the object [33, 34]. While these techniques are well established in computer vision, they do not apply directly to detector data. The object condensation method [35] overcomes the problem by clustering the vertices in a learnable space that is fully detached from the physical input dimensions. All particle properties are accumulated by the neural network in one representative point for each cluster. These representative points have a well defined minimal distance in the clustering space and can therefore be collected with a simple algorithm. Moreover, they are not seeds around which the object properties are determined, but they form through the object being identified directly, omitting a sequential approach. This training method can be applied to existing neural network architectures such as e.g. GravNet, to extend the promising results on a limited number of particles to an unlimited number of particles without combinatorics issues.

The next step will be to combine neural network architectures that have shown excellent performance for a limited number of showers and methods to extend them to reconstruct an unknown number of particles. In this process it is only natural to also include information from other subsystems facilitate a fully consistent particle flow approach. Once the performance of these algorithms is proven in simulation, techniques to mitigate differences between simulation and data can be directly incorporated in the reconstruction algorithms, e.g. through domain adaptation techniques [36, 37] or other adversarial approaches which allow to include data directly in the training. The lessons learnt from developing GNN techniques used for reconstruction will also be pivotal for generative adversarial based simulation techniques that could provide the speedup needed for simulating events at the high luminosity LHC, and that could also benefit from incorporating data to improve the simulation directly (see e.g. Ref. [38] and therein).

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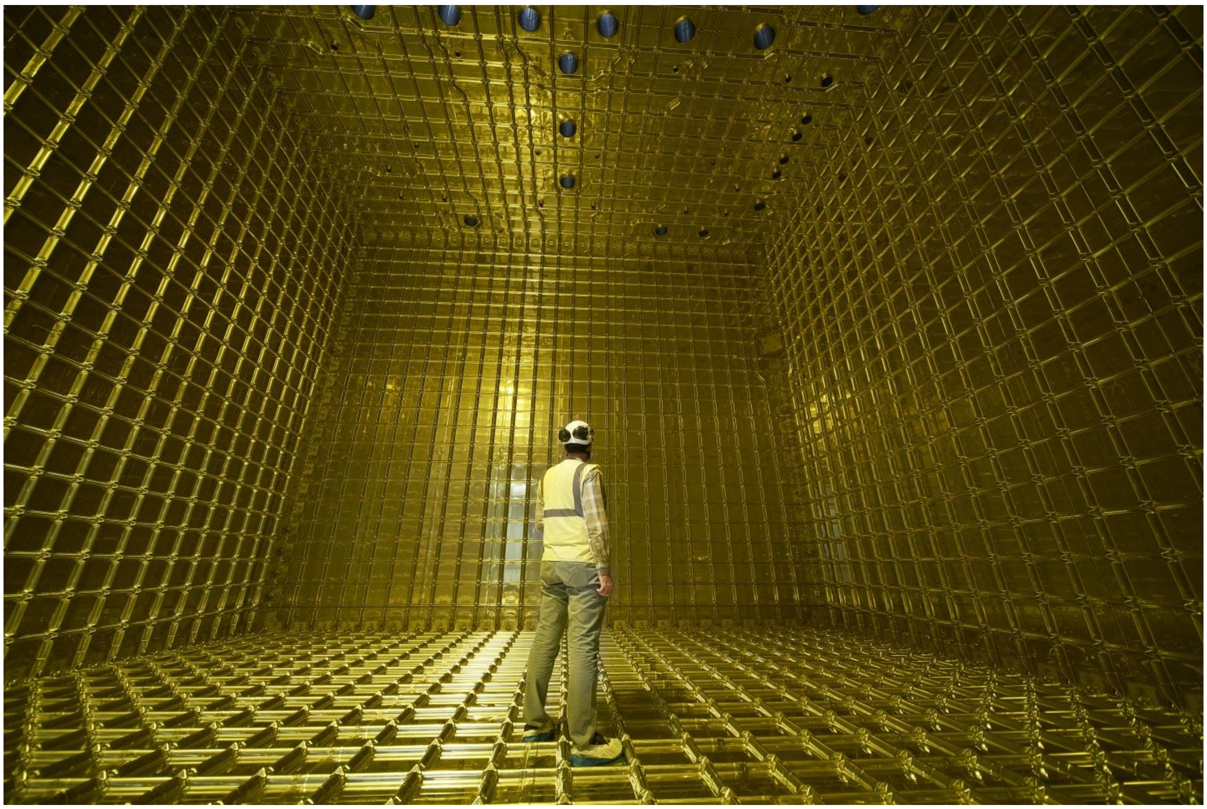
Proto-DUNE at CERN: New technologies for new discoveries

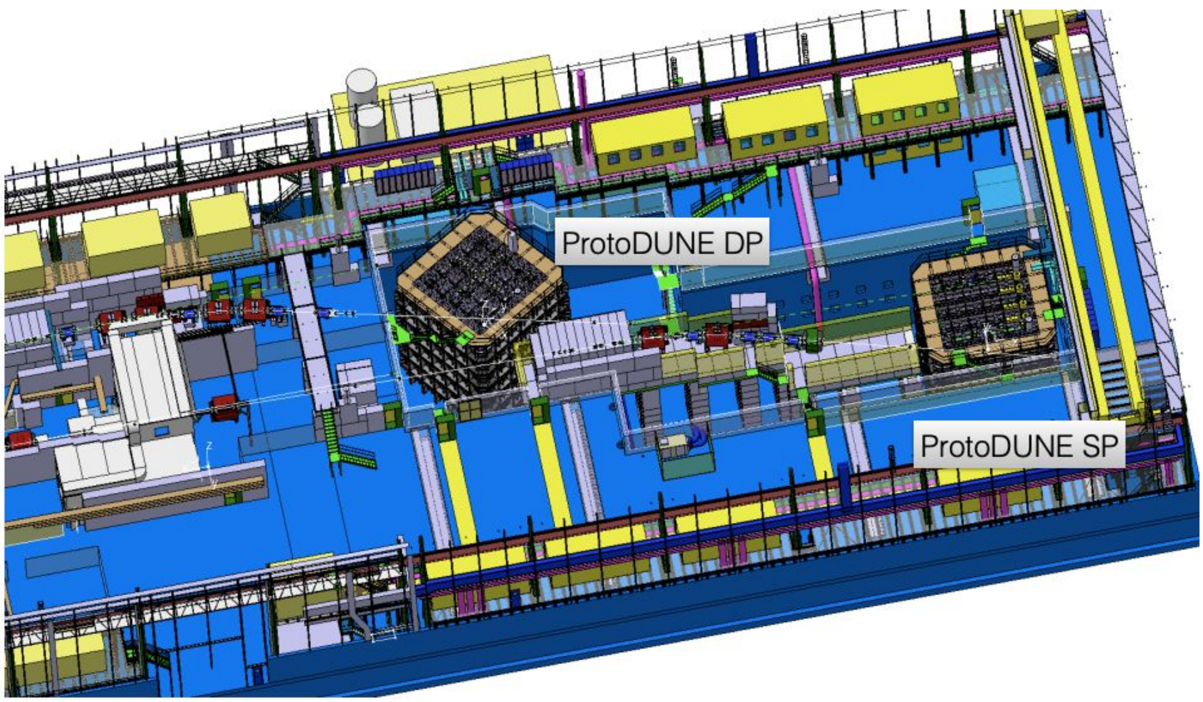
Following many years of R&D work, recent results from ProtoDUNE-SP, the single-phase DUNE Far Detector prototype at the CERN Neutrino Platform, now validate the Liquid Argon Time Projection Chamber (LArTPC) technology choice for DUNE providing the necessary information for the DUNE Technical Design Report (TDR) [https://arxiv.org/abs/2002.03010] recently published by the collaboration.



The ProtoDUNE experimental program is designed to test and validate the technologies and design that will be applied to the construction of the DUNE Far Detector at the Sanford Underground Research Facility. (Image: CERN).

ProtoDUNE-SP (NP04) represents a crucial part of the effort towards the construction of the first DUNE far detector module (17 kt total LAr mass) but with its ~1 kt of mass is also a significant experiment in its own right. It may well be the biggest prototype ever built. Impressively following the official approval of proto-DUNE in December 2015, from the fabrication of the detector components in the US and around the world, tests and assembly inside the cryostat built at CERN and up to the commissioning and start of operation, all took less than three years.

Previous expertise and a well-coordinated global effort allowed to build and operate the new detector prototype in record time as shown in the above photos (Credits: DUNE Collaboration).



Location of the ProtoDUNE-SP and ProtoDUNE-DP in the EHN1 experimental area at CERN's Prévessin site (Credits: DUNE Collaboration).

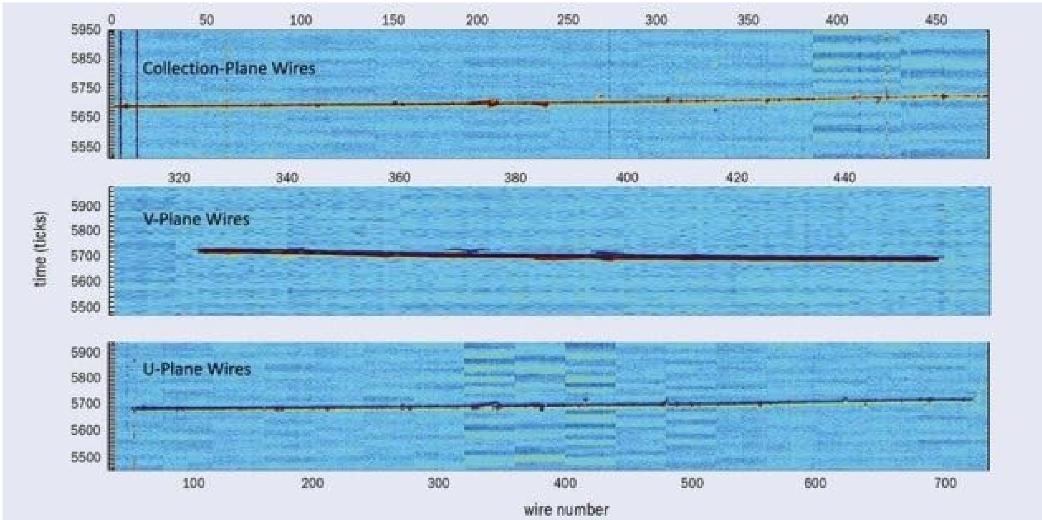
Building and operating a new detector of this volume and complexity in such a short lapse of time was an amazing achievement. It was the result of a global collaborative effort of many DUNE groups mixed with CERN's know-how and existing infrastructure. "If one makes a prototype that is twice bigger than the biggest LArTPC experiment for physics built so far, this tells you how incredible the size of DUNE will eventually be and also how fundamental is considered this step" says Fermilab's Flavio Cavanna, co-coordinator of the ProtoDUNE effort at CERN and continues "The liquid Argon TPC was always considered as a promising break-through in particle detection technology, but it is only now thanks to the endorsement of the HEP community at large – from Fermilab to CERN, from the US to Europe and the International - that successfully build ProtoDUNE and demonstrated through its great performance that the way to DUNE is open".

Major underground neutrino experiments currently employ the Water Cherenkov technology. For example, Super-Kamiokande in Japan uses a great number of phototubes surrounding a very large volume of water and looks for Cherenkov light rings emitted when an incoming neutrino creates an electron or a muon in the water. This is a relatively simple technology that in the course of decades of continued use and refinements has proven to be extremely robust and reliable. According to Cavanna, "The greatest discoveries in neutrino oscillations came from Cherenkov detectors. Looking now for new discoveries, a new technology - capable of providing data of unprecedented quality, with fine detailed images of the neutrino interaction, individual identification of the emitted particles and a precise measurement of their energy - is deemed as a key element of the endeavour".

LArTPCs promise exquisite neutrino detection capability and efficient background rejection. The long and in the end very successful development of the technology was pursued by the ICARUS Collaboration, starting back in the early '90s and up to the realisation of the first large-scale LAr detector, featuring 2 x 370 t LAr modules, built at the INFN Gran Sasso National Laboratory in Italy and operated from 2010 to 2013 on the CNGS high energy long baseline neutrino beam. In the meantime, at Fermilab ArgoNeuT a very small LArTPC first operated in 2009 on the NuMI beam – a lower, few GeV energy neutrino beam – producing a lot of physics results and insight on neutrino interaction mechanisms. More recently, in 2015 a mid-large size, about 100 t liquid-argon detector called MicroBooNE started operating (and still is) on the Booster neutrino beam, the other Fermilab beam at even lower energy. MicroBooNE is exploring some controversial observations from previous short baseline experiments, that if interpreted as due to neutrino oscillation may point to a possible new type of non-interacting neutrinos, therefore called "sterile". Nowadays, on the same beam line, Fermilab is preparing to start operating the refurbished ICARUS detector, now in its new home in Illinois, and another large LArTPC – SBND - is advanced in construction. These two will be acting as far and near detectors respectively to fully resolve the quest for sterile neutrinos.

A big leap in detector size is now ahead of us with DUNE, also considering the correlated incremental complexity for operating deep underground. Unlocking the mystery of the matter's abundance unbalance in the Universe by detecting the difference in oscillation patterns between GeV neutrinos and antineutrinos generated at far distance is one of the the primary goals of the DUNE long-baseline experiment. However, the LArTPC for this experiment must stretch its sensitivity for searches of those rare signals at much lower energies, that could possibly come from SuperNova neutrinos, from solar neutrinos and possibly from other sources of phenomena beyond the Standard Model, thus offering a diverse physics programme. According to Cavanna, “LArTPC is a finer and articulated technology that inaugurates a new era in neutrino physics and may expand our understanding of fundamental, though yet uncovered, phenomena in our Universe. In this scenario, ProtoDUNE serves as a bridge toward DUNE, allowing not only to understand how it can be scaled up to the much larger size needed for DUNE, but also to test and further perfect the technology toward its ultimate limits. We really want to see how far we can go, and test beam data is a perfect playground for this”.

A great feature of the LArTPC technology is that when you build a new detector – and is done right, filled with pure liquid Argon, you can immediately have a fully responsive detector. “You push the HV button of the power supply and as soon as the electric field inside the TPC reaches its nominal value, a second later you get the first event on your screen, crisp and clean, no need of complicated software manipulation of data, no signal filtering or noise suppression algorithms. You can just stay there staring at the beautiful events appearing on your laptop’s screen – Cavanna says - or even better on the large screens in the control room”. This is what happened on September 21, 2018 around 9:30 in the morning at the CERN Neutrino Platform. The ProtoDUNE detector, after an incredible one-year long rush to assemble the detector in time to meet the beam, smooth and flawless reached its nominal HV and immediately started collecting data from the CERN’s beam in the North Area and continued until the beams went off for LS2. ProtoDUNE-SP collected more than 4 million triggers of particle interactions in the LArTPC. To better visualize the spectacular high-energy electromagnetic and hadronic showers developing in the hundreds of cubic meters fully active LAr volume of ProtoDUNE a live, 3-D event display of the liquid-argon detector was made available showing the revolving and zoomable image of the events just captured in all details as never seen before [a gallery of ProtoDune-SP events is available HERE].

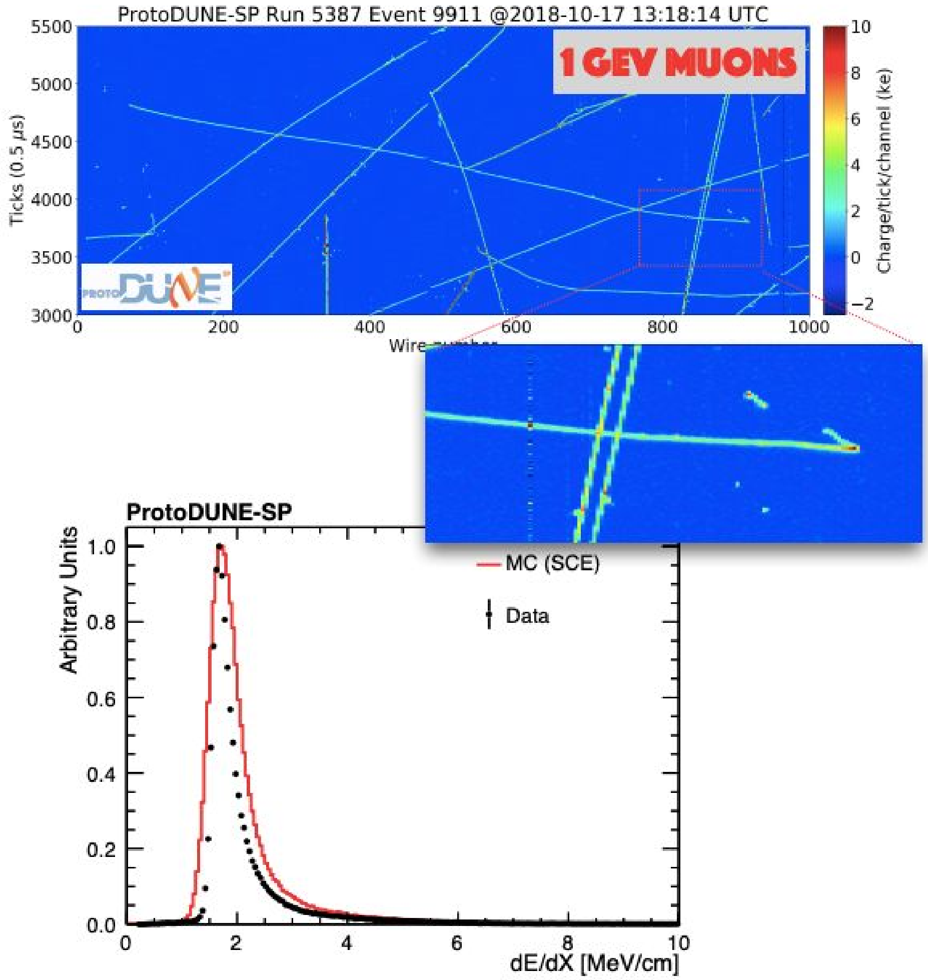


One of the first cosmic-muon tracks recorded by the ProtoDUNE detector at CERN during September. Three wire planes, each made up of thousands of individual wires, recorded the signal of a muon as it traveled approximately 3.8 m through the detector's liquid-argon volume. Image credit: DUNE collaboration (Credits: DUNE Collaboration).

"ProtoDUNE-SP collected more than 4 million beam triggers of particle interactions in the TPC in a few weeks of beam time. The collected data - with huge data volume per event - were transmitted, the events reconstructed and shared immediately with collaborators around the globe demonstrating how future DUNE datasets will be collected and distributed for analysis with the collaboration", Cavanna says. The work of the ProtoDUNE analysis team was first to fully characterize the performance of the detector and calibrate it, and then as the next step to perform physics measurements of hadron interactions on argon nuclei relevant for the future neutrino oscillation studies in DUNE. For example, the inclusive and exclusive interaction cross sections of charged pion on Ar nuclei have never been measured before. In the GeV neutrino interactions expected in DUNE, pions are produced and these may re-interact inside the target Ar nucleus with these same mechanisms observed with test-beam pions. The collaboration has just announced that a first paper is ready for publication, quite remarkably only one year after the beam run was completed and while data taking with cosmics is still going on. It contains details of the detector characterization with beam particles and a thorough analysis of the detector performance. Under several aspects the results are found better than expected from MC simulations or from previous bench tests of detector components.

The photo-detector, for example, by detecting the abundant scintillation light from ionizing events in LAr, is meant to provide prompt information about the interaction time (t_0 time) necessary for the reconstruction of the event in the TPC. The excellent response of the ARAPUCA photo-detectors in ProtoDUNE-SP demonstrated during the beam test, led the team thinking that it can be more than an auxiliary detector for the TPC. As Cavanna notes: “The performance of this element, somehow exceeding our expectations, made us think that the photo-detector can act as an additional detector on its own, just like to have two detectors in one, offering valuable information for the physics of the events that we observe”. Combined with the TPC, while paving the way for a more precise calorimetric energy reconstruction, it should allow to more accurately identify the nature of the recorded events, in particular in the low energy range of the astrophysical neutrinos. How these developments could enhance the physics reach of DUNE is currently under study.

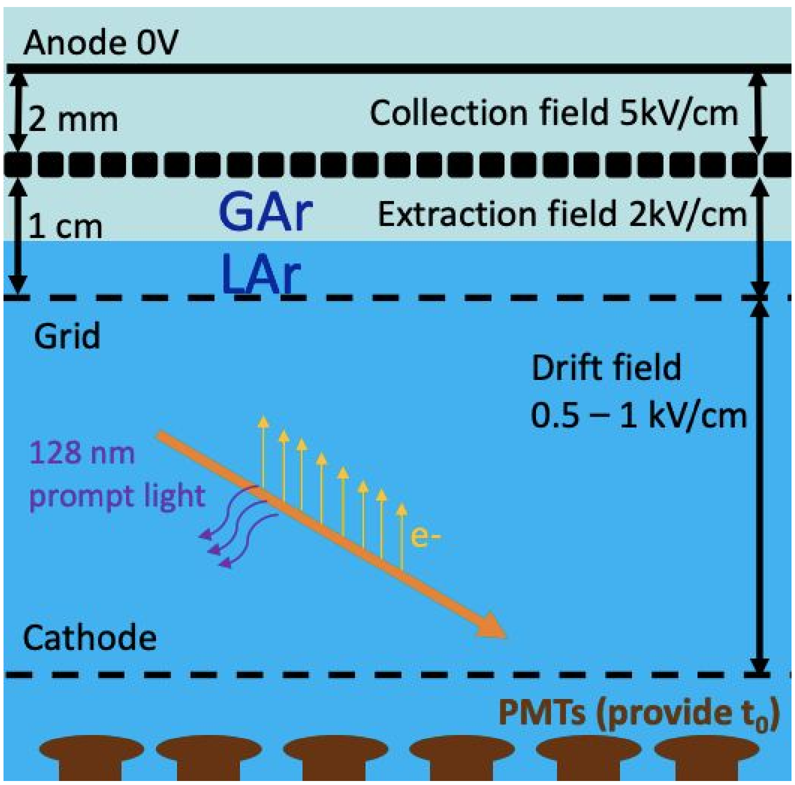
From the cold electronics readout of the TPC, a remarkable signal-to-noise (S/N) ratio of 40 was measured from raw data, largely exceeding the predicted figure. And when noise suppression through offline software was applied to data, S/N further improved to ~50, pushing down the energy threshold for signal detection. In addition to the excellent behaviour of the detector, the extraordinary purity level of the liquid Argon, achieved by close-loop recirculation through a system of Oxygen adsorbers and molecular sieves, and the very careful grounding and shielding adopted to protect the readout electronics against ambient EM noise and interferences made the data recorded by the ProtoDUNE-SP LArTPC of unprecedented quality.



Proto-DUNE-SP demonstrates excellent capabilities for calorimetry. Thanks to the TPC, the readout electronics and the analysis software the analysis resolution is better with the detector than in the MonteCarlo simulations. Several examples including protons, pions and muons were presented by F. Cavana during a recent CERN Colloquium (Credits: DUNE Collaboration).

One of the major challenges in the data analysis was the large number of cosmic rays – 70 on average – overlaid to the beam event in the same recorded time frame. "Operating on surface in the North Area hall at CERN, we had to deal with a cosmic rate million times higher than what the DUNE detector will see once installed in the kilometer-deep cavern at the Sanford Underground Research Facility in South Dakota" explains Cavanna, "the beam event must be extracted from the crowd of cosmic tracks nearby, and the electric field distortion created inside the TPC must be corrected… not at all an easy job!". To deal with this challenge, starting from the experience of MicroBooNE, also running on surface, the collaboration developed an offline analysis framework that allowed decouple from the cosmic background and the correlated space charge effects. "Developing this complicated analysis framework enabled us to run an underground neutrino experiment on a hadron (and electron) beam line on the Earth's surface!" concludes Cavanna.

Those who recently visited the North Area may have seen that indeed there are two almost identical ProtoDUNEs operating nearby one another. So far, we discussed ProtoDUNE-SP, the first that came online. The other one – dubbed ProtoDUNE-DP - activated one year later in August 2019, implements a novel version of the LArTPC technology, coined "Dual Phase" as both liquid and gas forms of argon are employed to record the tracks. The gaseous phase is used to amplify faint ionization signals generated in the liquid phase. The sensors are located at the top of the detector inside the gaseous argon. Compared to the single-phase technology, this setup could yield stronger signals and thus search for rare processes at lower energy that could be discerned from large backgrounds. When fully tested and validated, this new technology is expected to be adopted in one of the successive modules of the DUNE experiment.

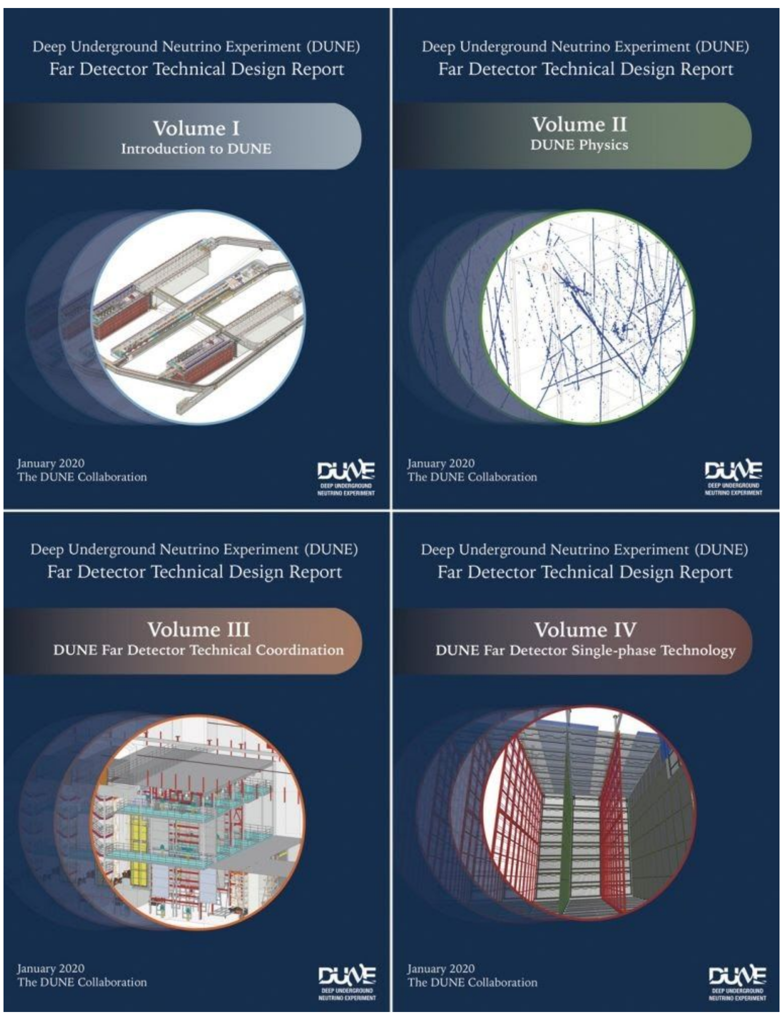


Schematic of the Proto-DUNE double-phase LAr TPC concept currently tested at CERN (not to scale). Credits: DUNE Collaboration

Dual-phase technology presents a second advantage; as all the electronics boards are located on top of the gas layer they can be accessed via special chimneys without disrupting the liquid phase of the detector where LAr is kept at a temperature of -184 °C. Since last summer, the dual-phase prototype (ProtoDUNE-DP, NP02) is recording cosmic data and the collaboration is analyzing them.

Testing a new technology often brings new challenges! During the tests, the team observed the formation of bubbles and waves on the liquid argon surface. This is critical because the signal in the gas comes from the extraction of the ionization charge through the liquid Argon surface, and any perturbation can compromise the extraction. The origin of the formation of these bubbles= and waves is not clear, but the team discovered that the phenomenon is mitigated by increasing the pressure of the gas above the liquid. Solving this issue and studying the performance of the dual phase detector will open the way for large-scale application of the dual phase technology in DUNE.

The successful operation of the ProtoDUNE-SP detector at the CERN Neutrino Platform was a crucial step towards proving the capability of doing physics with the new LArTPC technology in the DUNE experiment. The ProtoDUNE-SP first paper reporting on the detector performance will soon be publicly available. The outcomes of the ongoing tests of ProtoDUNE-DP with the dual phase detector technology will help decide the number of modules using the single-phase and dual phase technologies in the final DUNE experiment.



The four volumes of the DUNE Far Detector Technical Design Report published in February are available here:

Vol.I: **https://arxiv.org/abs/2002.02967**

Vol.II: **https://arxiv.org/abs/2002.03005,**

Vol.III: **https://arxiv.org/abs/2002.03008,**

Vol.IV: **https://arxiv.org/abs/2002.03010**

FCC software workshops and hands-on tutorials

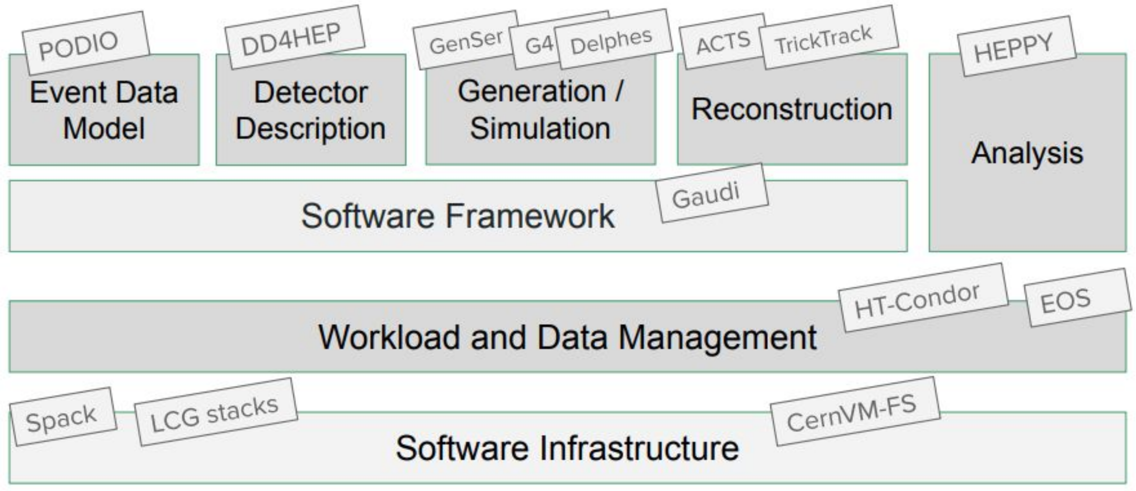
*by **Gerardo Ganis & Clement Helsens (CERN)***

PDF version

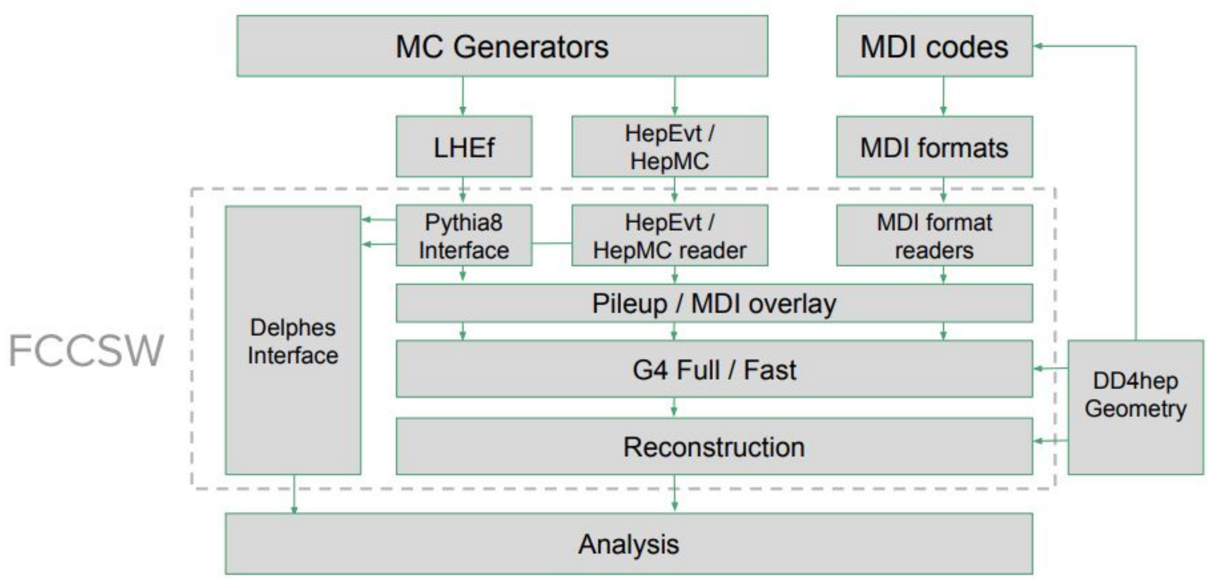
In October 2019, the first FCC Software Workshop and Hands-on Tutorial was held at CERN by the EP-SFT group in collaboration with the FCC study coordination group. Following its success a second edition was held during the last FCC physics workshop (January 2020). The purpose of these events is to introduce to the participants the status and plans of the FCC Software and the current use of it. The workshops offered a complete overview of the FCC software and the status of the major components.

The first FCC Software Workshop in October was structured with half a day of technical overview and talks on specific components on the afternoon of the first day, and hands-on exercises during the entire second day. It included talks on specific components such as the well known Gaudi framework, developed and used by LHCb and ATLAS and on which FCCSW is based, and DD4hep, a tool for geometry description developed in the context of the AIDA 2020 programme and use of which is continuously expanding. A session on Monte Carlo generators followed, focusing in particular on those more relevant for the FCC-ee studies.

Moreover, Staszek Jadach accepted the invitation to overview the KKMC and TAUOLA generator tools; these programs originated from the LEP studies and, despite the fact that they will need to be significantly improved for FCC-ee, are still today the best options for precision studies at future lepton colliders. An overview of the end-user analysis tools closed the first day.

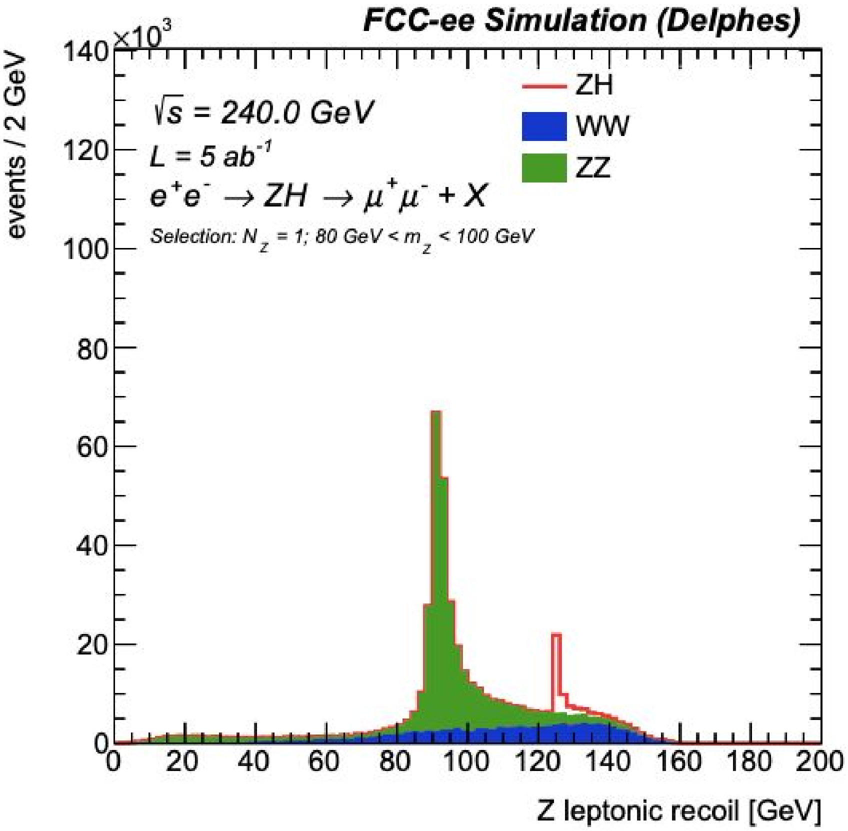


Tentative schematic of the different components entering the design of the FCC Software.



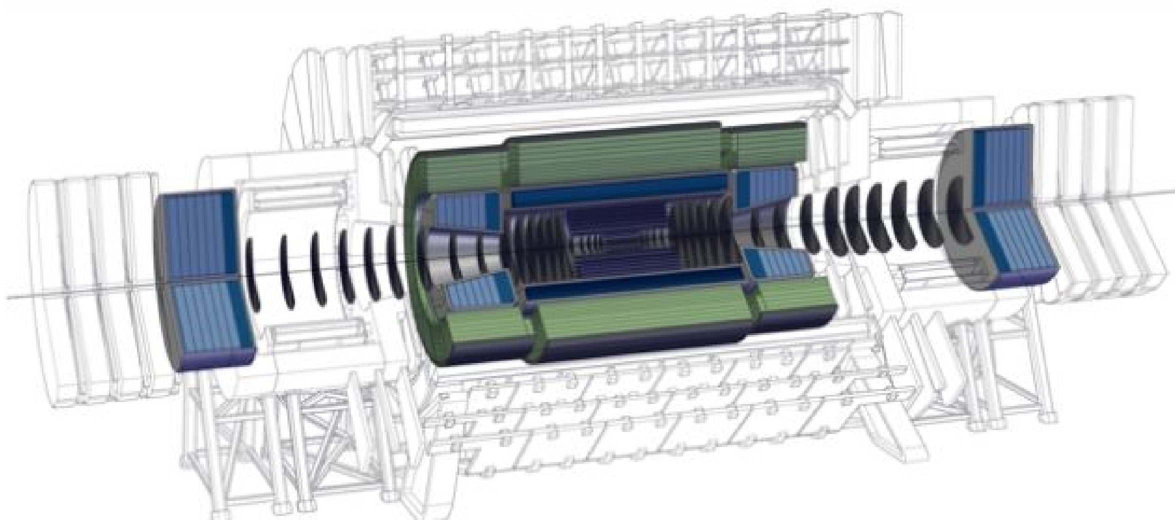
Schematic overview of a typical workflow of the FCC Software.

The second day was dedicated to hands-on exercises. A set of tutorials was prepared to drive the participants through a full example of the analysis workflow, the usage of fast simulation, the evaluation of the performance of a given calorimetric solution and the full simulation of the IDEA drift chamber. The tutorial exercises were initially run on the CERN SWAN facility and then on LXPLUS. A CernVM-based virtual machine, specialised for the FCC software was also made available and could be used for the exercises.



At leptonic colliders the Higgs-boson will be dominantly produced by Higgs stralhung from a Z-boson, the so called ZH production mode. As the of center of mass energy is known, it is thus possible to calculate the HIggs-boson mass from the recoiling reconstructed objects of the Z-boson candidate. This plot shows the recoiling mass after having selected a Z-boson decaying to a pair of muons (Credis: FCC collaboration).

Following this workshop, a one-day hands on tutorial was organized during the 3rd FCC physics meeting (January 2020) as it was a perfect occasion to discuss how to prioritize the needs in terms of software development. Discussions focussed on the FCC-ee software as the needs for a future hadron collider (FCC-hh) may be delayed to profit from lessons and synergies with the HL-LHC software development community.



Schematic of the overall proposed FCC-hh detector. (Credits: FCC collaboration)

Both events were well attended, bringing together more than 30 participants thus reflecting the community's interest in these developments. A feedback form, circulated among the participants, indicated a high level of appreciation for these initiatives while precious suggestions for improvements have been received, in particular for the hands-on tutorials.

To respond to a popular request of the FCC community, more editions of hands-on exercise sessions are planned this year.

Towards high-precision luminosity for CMS in Run 3 and beyond

by ***Georg Auzinger & Anne Dabrowski (CERN)***

PDF version

Luminosity is a key parameter for any collider-based high energy physics experiment as it links the interaction rates observed in an experiment to the cross sections of physics processes. Therefore, it is a key ingredient to most major analyses performed at an experiment and the uncertainty on the luminosity measurement is often a major contribution to the total uncertainty. Luminosity is also used by the LHC operators to optimise the beam conditions for data taking in all LHC experiments and by the experiments to set for example the prescales in the trigger menu. This measurement is commonly referred to as “online luminosity”, as it has to be provided to the LHC in almost real-time whereas the luminosity measurement used for physics analyses is the result of tedious calibration work performed by luminosity experts, containing a number of corrections to the online measurement. These corrections include improvement in the absolute luminosity calibration, by careful inclusion of all corrections needed in the van der Meer scan measurement technique, used to extract the luminosity calibration, and also corrections for detector effects of non-linearity as a function of single bunch instantaneous luminosity (proportional to pileup), corrections to out-of-time effects and corrections to any inefficiencies measured during the full data taking period.

In CMS, measuring the luminosity falls under the responsibility of the Beam Radiation Instrumentation and Luminosity project (BRIL), which operates a set of dedicated detector systems for this purpose. These detectors are optimised to measure luminosity and monitor beam conditions. Having multiple of these systems not only provides redundancy (the LHC control room requires to have a good number at all times) but also allows to track system stability and flag sudden changes in detector efficiency. As the luminosity measurement boils down to “counting” an observable that is proportional to luminosity, only multiple, redundant measurements allow to judge if a sudden change in count rate is due to a detector effect or an actual change in beam conditions.

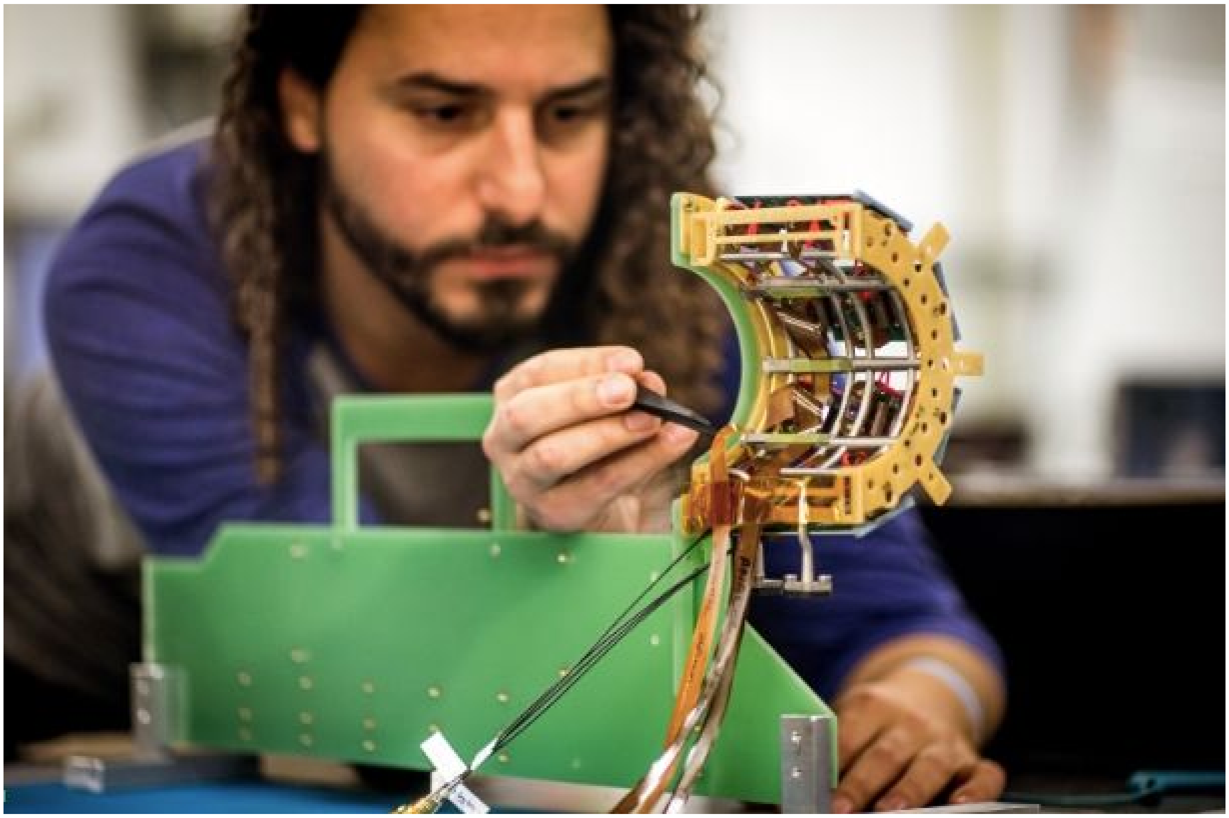


Figure 1: Andres Delannoy is shown working on one of the four cassettes of the Pixel Luminosity Telescope (PLT), one of the luminometers that the BRIL project is rebuilding in preparation for Run 3 (Credits: CMS Collaboration).

In the presently ongoing Long Shutdown 2 of the LHC, the BRIL project is working to replace and upgrade two of the backbones of the luminosity system in CMS, namely the Pixel Luminosity Telescope (PLT) and the Fast Beam Conditions Monitor (BCM1F) with the goal of improving performance for Run 3 which is scheduled to start in May 2021. These two systems are mounted on a common support structure and installed behind the Forward Pixel Detector in the very heart of CMS where the radiation environment is particularly unforgiving and thus components can suffer from radiation degradation.

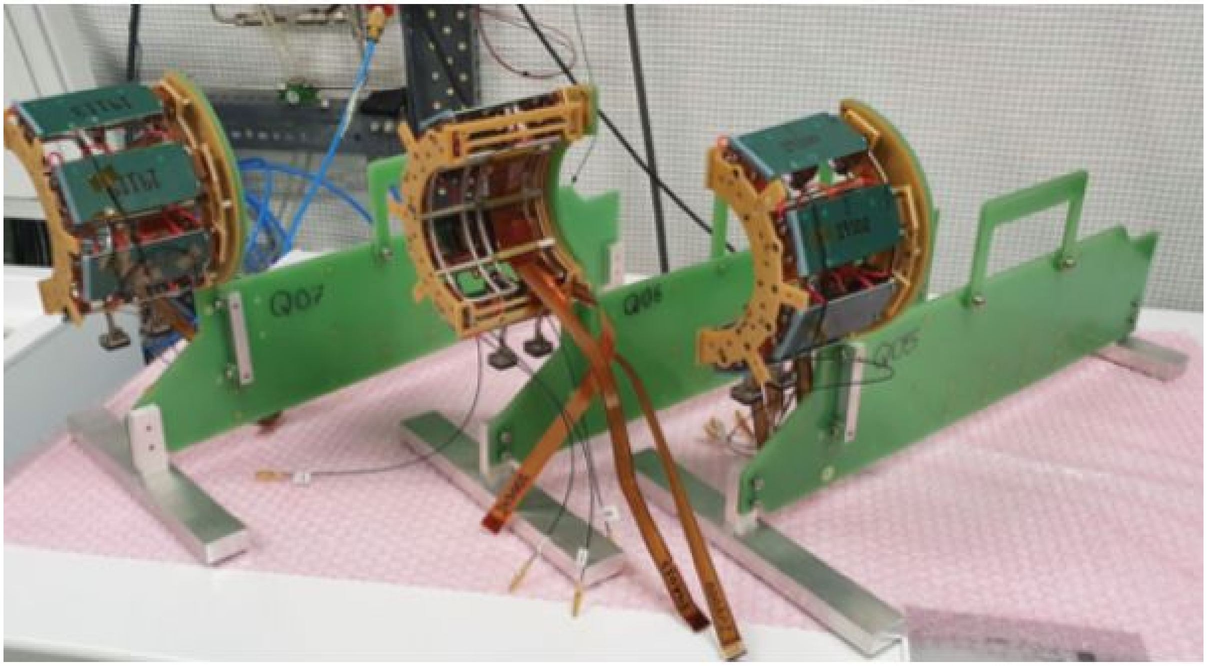


Figure 2: Photo of the PLT rebuild, ongoing in the BRIL lab in building 186 during LS2. Three of the four quadrants have been assembled so far. It is foreseen to build in total eight such quadrants, so that two complete PLT detectors are available for installation during Run 3. (Credits: A. Delannoy, CMS Collaboration).

In order to maintain top performance throughout Run 3, two new, exact copies of the Run 2 PLT are currently being built from spare parts at CERN, steered by the leadership of two BRIL institutes; the University of Tennessee and Rutgers University. “If the new PLT deteriorates faster than we anticipated, or the Run 3 program is extended to accumulate a larger than expected integrated luminosity, we can replace it very easily since we have a second copy” says Andrés Delannoy, who is overseeing the PLT replacement. Three of a total of eight quadrants have already been constructed, with the rest anticipated in the upcoming months.

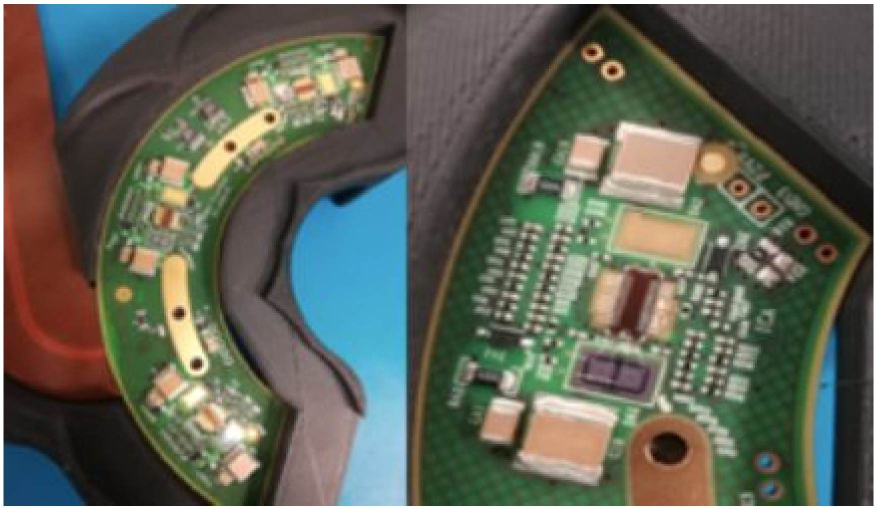


Figure 3: The CMS prototype LS2 BCM1F-silicon detector at CERN. The production of final boards is ongoing in the CERN Micro-Pattern-Technology (MTP)-workshop (Credit: CMS Collaboration).

On the other hand, the BCM1F detector is undergoing an evolution and some design improvements. The Run 2 version of this detector was based on a mix of primarily polycrystalline diamond- and some silicon sensors. Operations over the last few years indicated that the silicon-equipped channels showed overall better performance and stability. Therefore the new detector will be based entirely on novel, AC-coupled silicon-pad detectors made from very radiation-tolerant material that was chosen for the upgrade of the CMS Tracker in the High Luminosity LHC - it is the first time that these materials will be installed in CMS. The new Fast Beam Conditions Monitor will also be equipped with active cooling to ensure longevity and performance throughout the entire Run 3. The necessary R&D and engineering work for this evolutionary design improvement is shared mainly among DESY and the BRIL group in the EP-CMX group at CERN, with engineering support from CERN's EP-DT group and the CERN Micro-Pattern-Technology (MTP)-workshop. While the first prototype boards have been produced and tested at CERN with very promising results, the final production is currently underway and will be equipped with components and sensors later in spring for a final checkout and integration with the PLT on a common mechanical structure in the Fall of 2020.

Other activities to improve the luminosity measurement in Run 3 and beyond are ongoing in parallel. The first is implementing the so-called 'Pixel Cluster Counting' (PCC) workflow - so far an offline analysis - to the high level trigger of CMS, for a quasi-online availability of the data at a potentially higher trigger rate. The second is an exploitation of the CMS Trigger Scouting demonstrator system to provide a count of the muons reconstructed by the Level 1 trigger as an additional real-time measurement with bunch-by-bunch data.

These two LS2 developments are considered important stepping stones towards the Phase 2 Upgrade of CMS for the High Luminosity LHC era where a variety of CMS subsystems will provide data for luminosity measurement via dedicated data paths to ensure availability and redundancy. Most notably, a real-time implementation of Pixel Cluster Counting in the forward extension of the Inner Tracker with a dedicated luminosity processing back-end will form the backbone of the BRIL strategy and thus gaining experience with PCC in the HLT is extremely valuable to develop algorithms and correction strategies. “The target precision for luminosity in Phase 2 will be 1 per-cent which is extremely difficult to achieve and requires input from many systems with ideally orthogonal systematics and excellent statistical precision” says Anne Dabrowski, co-manager of the BRIL project. To meet these very demanding requirements, BRIL is also studying concepts for a dedicated, purpose-built luminometer. The project has recently published a CMS note titled “**The Phase-2 Upgrade of the CMS Beam Radiation, Instrumentation, and Luminosity Detectors: Conceptual Design**”**[1]**, outlining the luminosity strategy and instrumentation options fo HL-LHC that will be further developed for the BRIL Technical Design Report to be submitted in the second quarter of 2021.

Further Reading

[1] https://cds.cern.ch/record/002706512?ln=en

FASERν: looking for high-energy collider neutrinos

by ***Jamie Boyd (CERN)***

PDF version

In December 2019 a proposed upgrade of the FASER detector designed to study neutrinos at the LHC was approved by CERN. The new detector called FASERν will be placed in front of the main FASER detector, 480-m in front of the ATLAS collision point, and exactly aligned with the collision axis.

Although FASERν will be the first experiment to detect neutrinos produced by a collider, this is not a new idea. CERN theorist Alvaro De Rujula proposed to study such neutrinos in the 1980's and there were even discussions to have a dedicated neutrino experiment at the LHC. This did not happen, thus leaving the way for FASERnv to be the first such experiment.

FASER is designed to search for neutral, weakly interacting, light new-particles, produced in the decay of mesons that are produced in the LHC collisions. Neutrinos are very similar to the hypothetical signal that FASER is searching for, with one main difference being that we know that neutrinos exist. With this in mind, the FASER collaboration studied the possibility of detecting and studying neutrinos with FASER. Since neutrinos do not decay (unlike the new physics particles that FASER will search for) and are weakly-interacting, a heavy target is needed for the neutrino to interact with and therefore a new detector and target (FASERν) had to be added to FASER. Figure 1 shows a schematic of the LHC neutrino "beam-line" that FASERν will use.

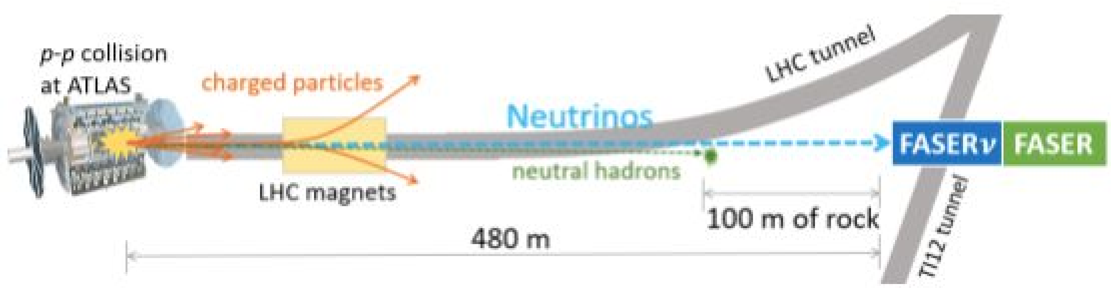


Figure 1: High-energy mesons are produced at the interaction point of the ATLAS experiment in the far-forward direction, of which a fraction decay into neutrinos. The remaining charged particles are deflected by the LHC magnets. The neutrinos then travel to the FASERν detector 480m downstream of ATLAS, passing through 100 m of rock, which stops any other neutral particles produced in the collisions from reaching FASER.

The FASERν detector [1] is made up of interleaved films of emulsion and 1mm-thick tungsten plates. The very dense tungsten acts as the target where the neutrino may interact and the emulsion films can be used to track charged particles produced in the neutrino interaction. The space in front of FASER is limited and so the FASERν detector is only 1.3 m-long and 25 cm x 25 cm in the transverse direction, but despite this, due to the density of tungsten the detector weighs 1.3 tonnes. This is massive enough for more than 20000 neutrino interactions to occur in the detector during Run 3 of the LHC. Figure 2 shows the proposed location of FASERν directly in front of the FASER spectrometer in the TI12.

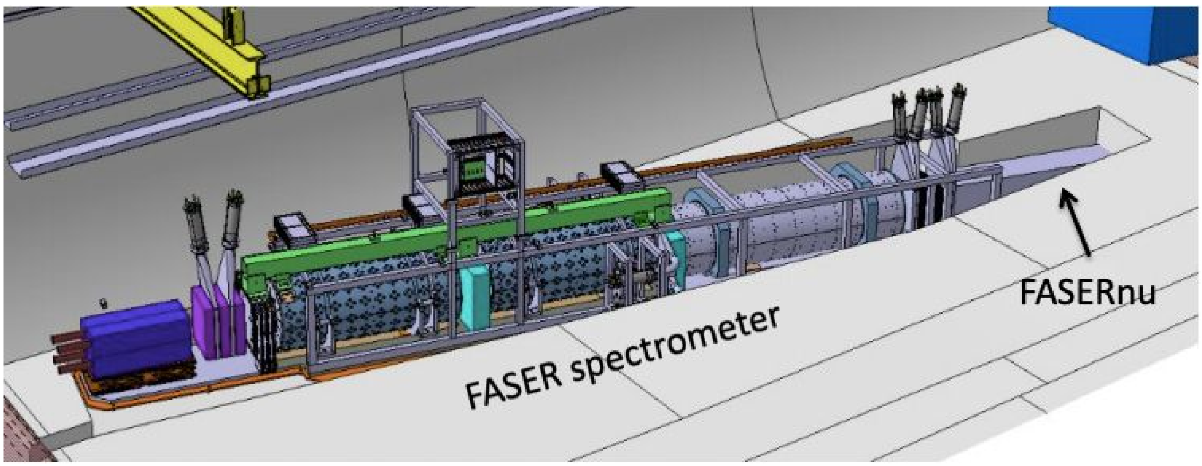


Figure 2 – Integration model of the FASER spectrometer and the FASERν detector installed in the TI12 tunnel in the LHC complex.

Emulsion detectors are based on silver bromide crystals (with diameter 0.2 μm) dispersed in a gelatine substrate. When a charged particle passes through the emulsion, the ionization is recorded quasi-permanently, and it can then be amplified and fixed by chemical development. Such detectors can make extremely precise position measurements of the trajectories of charged particles, which makes them ideal for observing short-lived particles like tau-leptons that could be produced in a neutrino interaction. However, they do not have any time resolution, and all charged particle tracks are recorded while the detector is in place. With a too high density of particle tracks the analysis becomes impossible, so the detector will have to be replaced during every Technical Stop of the LHC (about every 2-3 months), which should limit the track density to less than 10^6 tracks/cm^2. This poses a logistical challenge as the detector needs to transported 500 m along the LHC and then lifted over the accelerator to be installed. A crane and protective cover have already been put in place to allow the installation of the main FASER detector components, while they can also be used to carry in and out the FASERν detector.

In order to understand the backgrounds for FASER a small emulsion detector was installed in the TI12 tunnel (the FASER location) during part of the 2018 LHC run. This detector was exposed to

12.5/fb of 13 TeV collision data. The results were used to measure the charged particle background rate in FASER, and to validate the background simulations. The results have also been used to validate the FASERv concept, and a number of neutral multi-track vertices have been seen in the analyzed data (as shown in Figure 3), which could be from neutrino or neutral hadron interactions. Analysis is ongoing to select a high purity set of neutrino interactions.

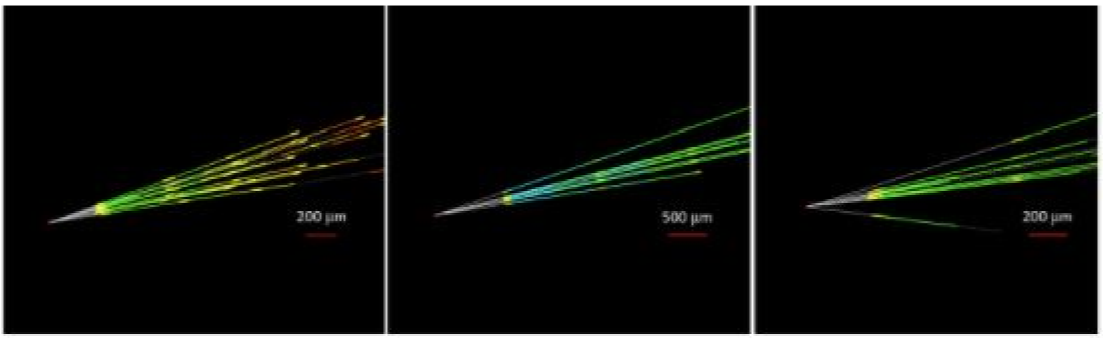


Figure 3: Three selected reconstructed neutral vertices from the test emulsion detector installed in TI12 in 2018 and exposed to 12.5/fb of 13 TeV pp collision data.

Due to the large luminosity of the LHC a huge number of neutrinos are produced and most in the very forward direction covered by FASER(v). For example in Run 3 of the LHC (2021-2024 running, and assumed to be 150/fb of 14 TeV collisions) we expect 10^{12}, 10^{11}, and 10^{9} muon neutrinos, electron neutrinos and tau neutrinos, respectively, to traverse FASER(v). Due to the very low interaction cross-section only a tiny fraction of these will interact in the detector, but we still expect to have ~20000, 1300, and 20 interactions of the three types of neutrino in FASERv. Interestingly, the neutrinos interacting in FASERv will be in an energy regime never probed before, thanks to the high-energy of the LHC collisions. Figure 4 shows the projected cross-section measurements of the three neutrino flavours that FASERv could make during Run-3, as a function of the neutrino energy. It can be seen that for electron and tau neutrinos these will be the highest energy neutrino measurements ever made, whereas for muon neutrinos the FASERv results will fill the gap between lower energy fixed-target measurements, and those from the IceCube experiment. As well as these cross-section measurements FASERv results will provide insight on forward physics production in proton collisions, and may also help to constrain potential new-physics effects in the neutrino sector. The physics prospects of FASERv are discussed in detail in Ref. [2].

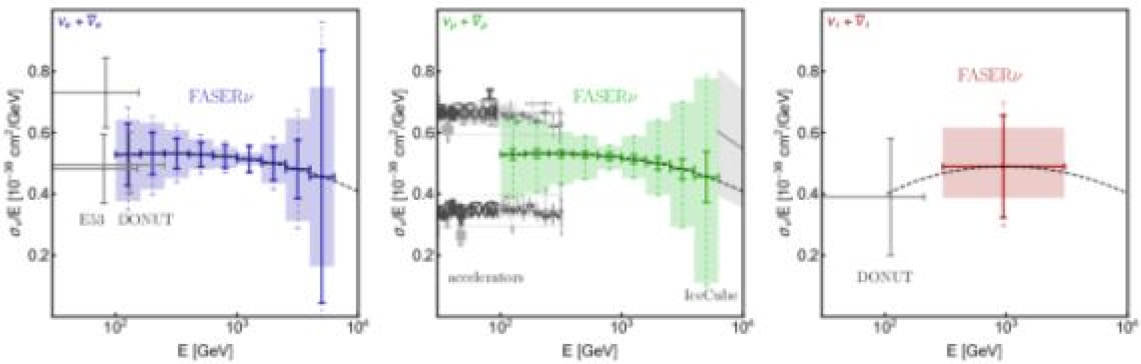


Figure 4: Projected FASERv sensitivity for neutrino cross-section measurements for electron (left), muon (middle) and tau (right) neutrinos as a function of the neutrino energy. The projections correspond 150/fb at 14 TeV (the expectation for LHC Run 3). Existing measurements are shown in grey.

Initially FASERv data will not be combined with information from the main FASER spectrometer. However, a possible future upgrade will include the installation of an interface tracking-detector, that would allow matching the tracks from vertices reconstructed in FASERv with events triggered in the FASER spectrometer. This would allow the charge of an outgoing muon to be measured by its bending in the spectrometer, so as to distinguish neutrino and anti-neutrino interactions. In addition the spectrometer information would improve the energy estimate of the reconstructed neutrino, and aid the background rejection.

Work is ongoing to finalize the design of the FASERv detector structure and to purchase and test the components along with progress on the civil engineering discussed by Jonathan Gall and Eliseo Perez-Duenas in their article in the same issue. FASERv will be installed into position shortly before the start of LHC collisions in Run 3 (scheduled in summer 2021). The collaboration is eager to analyze the first data and study the highest ever man made neutrinos, broadening the physics output from the LHC complex.

Further Reading:

[1] – FASER Collaboration, “FASERv: Technical Proposal”, arXiv:2001.03073

[2] - FASER Collaboration, “Detecting and Studying High-Energy Collider

Neutrinos with FASER at the LHC”, Eur. Phys. J. C 80 (2020) 61, arXiv:1908.02310

Civil Engineering for FASER

by ***Jonathan Gall & Eliseo Perez-Duenas (CERN)***

Civil engineering work to enable the installation of the FASER experiment in TI12 - the former LEP injection tunnel from the SPS - has successfully completed. The FASER experiment is designed to detect new physics particles produced by the LHC at Point 1. To detect any long-lived weakly interacting particles produced, the FASER experiment must be located exactly on the line of sight of the point 1 ATLAS experiment collision axis. Civil engineering work allowed to create the 6.6 by 1.4m space reservation in the tunnel floor.

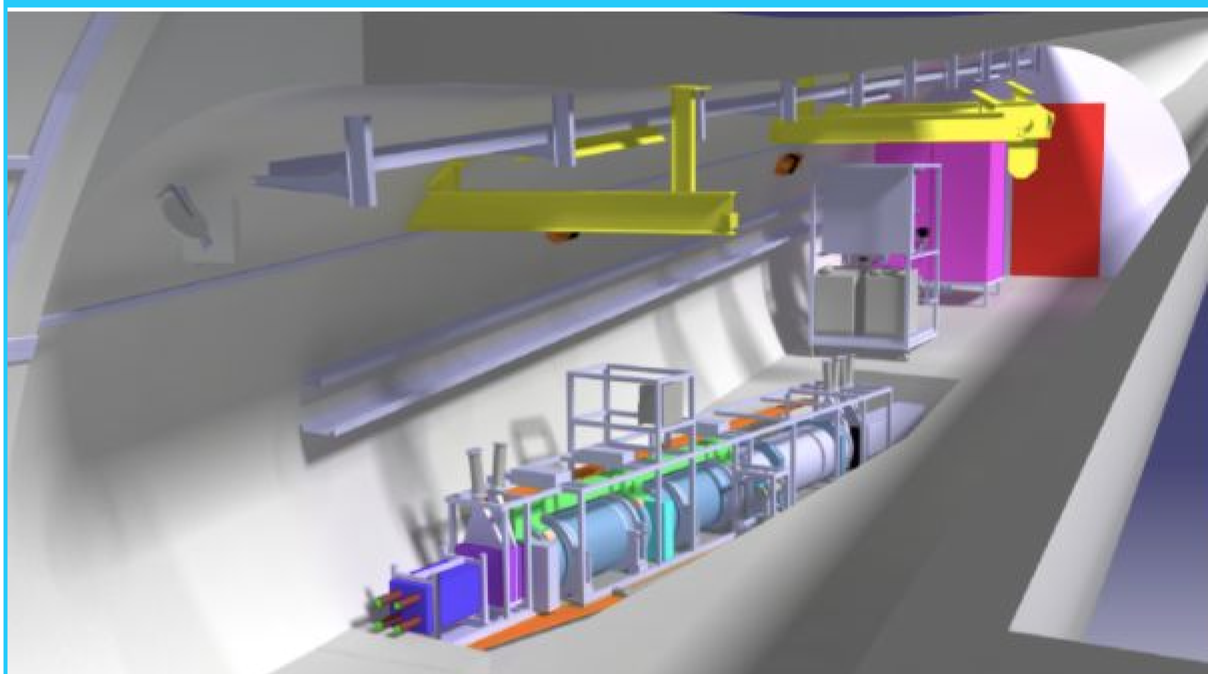


Figure 1: A 3D model showing the experiment in place along the beam axis following CE enabling works.

Civil engineering works are not easily carried out in laboratories and CERN is no exception. To allow works to be undertaken without disrupting the LHC, a large airlock to contain any dust and moisture effects has been installed. The works site is put under negative pressure to ensure any air currents flow into the area, not out. During the CE work, we also minimised the dust and vibration produced using water suppression techniques when carrying out diamond tip saw cutting or coring to create the required experimental space.

Figure 2: View of TI12 during the CE works looking down the slope towards the LHC (top) and the final trench for the installation of FASER following the successful completion of the project (bottom).

Works were carefully planned to avoid any instability, despite excavation up to around 1m deep in the tunnel floor. In order to manage the possible ground constraints during and after the excavation, a 3D Model was created to understand the geotechnical behaviour of the surrounding rock and tunnel.

During works, we nevertheless had to monitor for any movement. A total of 28 targets are automatically scanned every 2 hours so we know TI12 is still where it should be. We ensured that the existing drainage systems operate during works, despite the fact they will be severed during works. To do this, a dam to catch water has been installed at the upstream end. A float in the dammed section operates like a "toilet" so when water reaches a certain level, a pump is activated to ‘flush’ the water around the works site and back into existing drains.

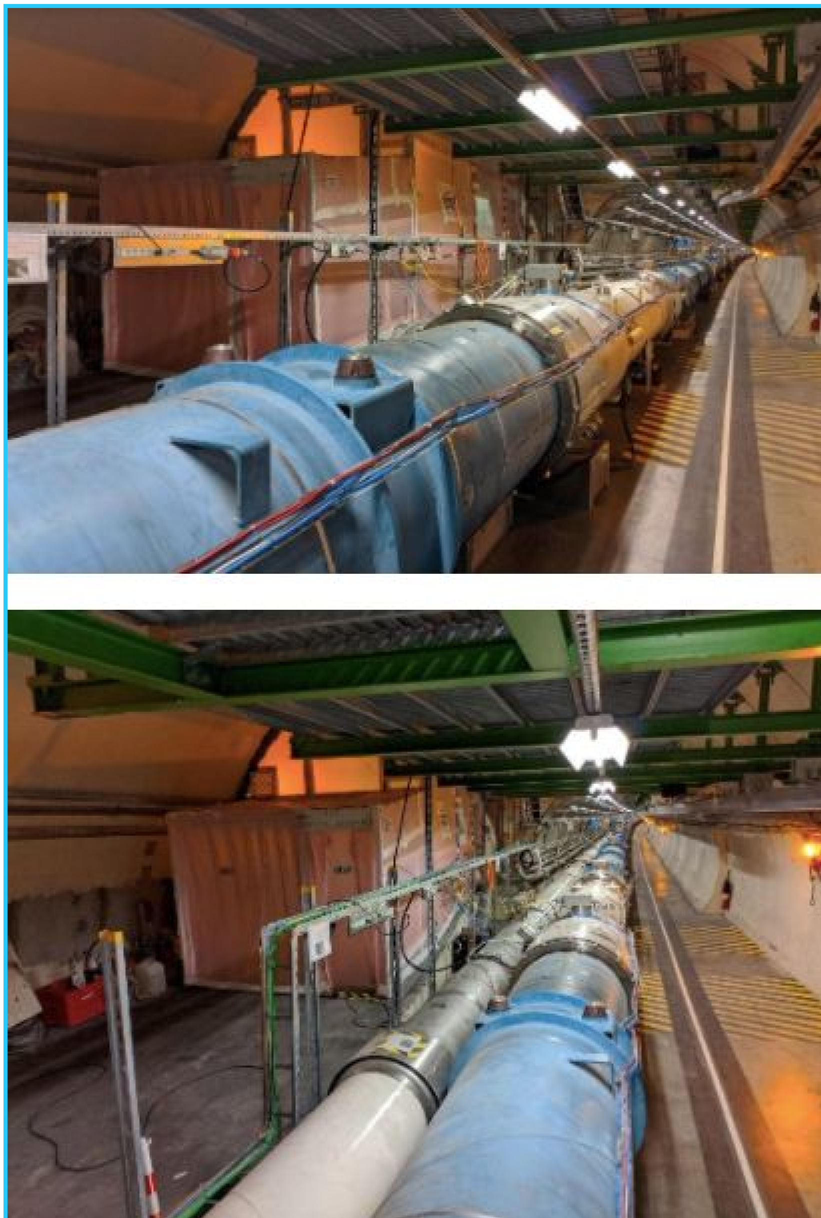


Figure 3: Views showing the airlock looking from LHC towards TI12.

Civil Engineering work for FASER has been planned and managed by the SMB-SE Future Accelerators Section. The contractor, Dimensione, completed the work on schedule this month. Following completion, the site will be handed over for the integration and detector installation work packages.

ISOLDE dives deeper in the mystery of the odd-even staggering effect

by Panos Charitos

PDF version

In a recent paper, to appear in Nature Physics in the next weeks (arXiv:1911.08765v3), the CRIS collaboration, located at the ISOLDE facility in CERN, presents measurements of charge radii of exotic copper isotopes that shed further light on one of the most pertinent open problems in nuclear theory; namely the accurate reproduction of the nuclear size and binding energy, and the odd-even staggering effect (OES) of these observables.

It has long been known that nuclear charge radii globally scale with $A^{1/3}$ (where A is the number of nucleons in the nucleus). Careful measurements using high-resolution laser spectroscopy methods, reveal that on top of this global trend, there are small, yet measurable, changes in the radius as we move from a nucleus with an even number of neutrons (or protons) to its neighbor with an odd number of nucleons. These odd-even variations can be found throughout the nuclear landscape and many of them have been studied in the past 40 years at ISOLDE using the Collinear Laser Spectroscopy (COLLAPS) experimental beam line [1]. The development of nuclear theories which can model this OES accurately is an ongoing challenge. Furthermore, the OES phenomenon varies with the number of protons and neutrons, which amplifies the challenges for nuclear theory.

These puzzles continue to motivate a rich experimental programme to explore the exact mechanism at play and consequently deepen our understanding of the nuclear forces inside the nuclear medium. A pivotal role in this exploration is played by measurements of the properties of doubly-magic nuclei, or nuclei in their vicinity. Nuclei are said to have a magic number of protons or neutrons, when these nucleons fill complete shells (similar like the noble gas electron configurations in atoms). If the number of protons and the number of neutrons are both magic, the nucleus is said to be “doubly magic”. The nuclear chart shows that several doubly magic isotopes exist far from the so-called “valley of stability,” the region that comprises all stable and long-lived nuclei. Their study of these "exotic" doubly-magic isotopes and their immediate neighbors with a very unbalanced ratio of protons-to-neutrons, has been proven pivotal in deepening our understanding of nuclear forces and many-body dynamics.

The recent results reported by the ISOLDE team extend measurements of the charge radii of short-lived copper isotopes up to the very exotic ^{78}Cu (Z = 29, N = 49) using the new Collinear Resonance Ionisation Spectroscopy (CRIS) method at ISOLDE-CERN. This nucleus is of particular importance, since it has only one additional valence proton and one valence neutron hole outside of a doubly magic ^{78}Ni core; read more about how ^{78}Cu provides insight into the structure of nickel in [2]. The presence of the odd proton provides crucial insights into the single-particle proton structure and how this affects the charge radii. Previously, the charge radii of copper isotopes could only be extracted experimentally up to ^{75}Cu (N = 46) using the optical detection method in the COLLAPS experiment [3]. This isotope was produced at a rate of 30.000 ions per second. In order to study ^{78}Cu which is produced at a rate of only 20 ions per second, the experimental sensitivity of the laser spectroscopy technique had to be improved with a factor of more than 1000. This is a reflection of a general trend in experimental nuclear physics: the study of the properties of isotopes close to exotic doubly closed shells (e.g. ^{78}Ni and ^{100}Sn) has so far been prohibitively difficult due to their very low production rates. Thus innovative methods have to be developed, that are much more sensitive than existing ones. The new paper by the CRIS group provides an answer to this key experimental challenge, by describing a more efficient method for measuring nuclear charge radii.

Experimental challenges and setup

To produce a sample of these short-living isotopes of interest, that does not contain too many other unwanted species, various steps at CERN’s ISOLDE facility have been employed. A beam of 1.4-GeV protons, produced by the CERN PS-Booster, was sent onto a neutron converter, producing neutrons which in turn induced fission of 238U atoms. Hundreds of radioactive isotopes were produced which diffused out of the very hot target into an ion source. The element-selective resonance ionization laser ion source (RILIS) produced ions of all the Cu isotopes, which were accelerated to 30 keV in preparation for mass separation. Using ISOLDE’s

High Resolution Separator, ions with different mass-to-charge ratios are separated and guided to ISCOOL, a linear gas-filled RF trap where they are accumulated for up to 10 ms. The selected ions are then released in a short bunch (few microseconds long) and guided into ISOLDE's Collinear Resonance Ionisation Spectroscopy (CRIS) experiment [4]. There the ions were neutralized through a charge-exchange reaction with a potassium vapor, and entered into an ultra-high vacuum region. In that UHV region, the atom beam is overlapped with two laser beams. The first laser beam excites the atoms of Cu using a 249 nm wavelength, with a laser frequency that is fine tuned to excite a specific isotope of Cu. These excited atoms are further excited into an auto-ionising state, chosen for optimal ionization efficiency so that at the end of the beam line, these resonantly-excited ions can be deflected from the other species that are present in the beam. This allows to count in a quasi background free environment the number of ions that were created, as a function of the wavelength of the first laser beam.

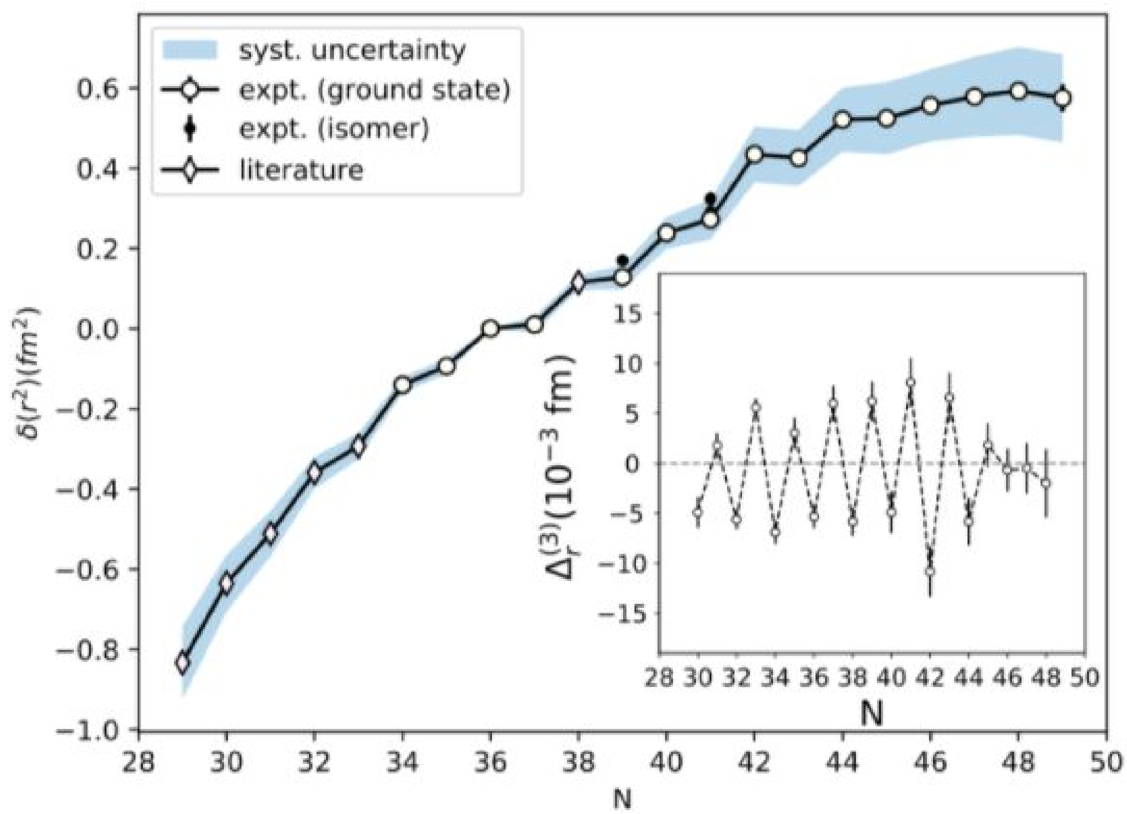


Figure 1: Values of the mean square radius for $^{63-66,68-78}$ Cu (relative to ^{65}Cu) from this work as a function of neutron number N, alongside the literature values for $^{58-62,67}$Cu. The inset shows the OES of the radii. Error bars are statistical (one standard deviation). In the main plot, these errors

are too small to be seen except for ^{78}Cu. The blue shaded area represents the systematic uncertainty due to the atomic parameters (Credits: ISOLDE Collaboration).

Results

Using ISOLDE's unique capabilities to produce and manipulate radioactive ions, and the inherently high efficiency and selectivity of the CRIS method, the team obtained for the first time new measurements of the hyperfine structure of the copper atoms up to N=49. The high efficiency and selectivity of the CRIS technique allows the observation of signals with detection rates of less than 0.05 ions/s on resonance. These detection rates were sufficient for a successful measurement of the charge radius of ^{78}Cu in less than one day, while in the case of other isotopes only a few hours of beam time were required.

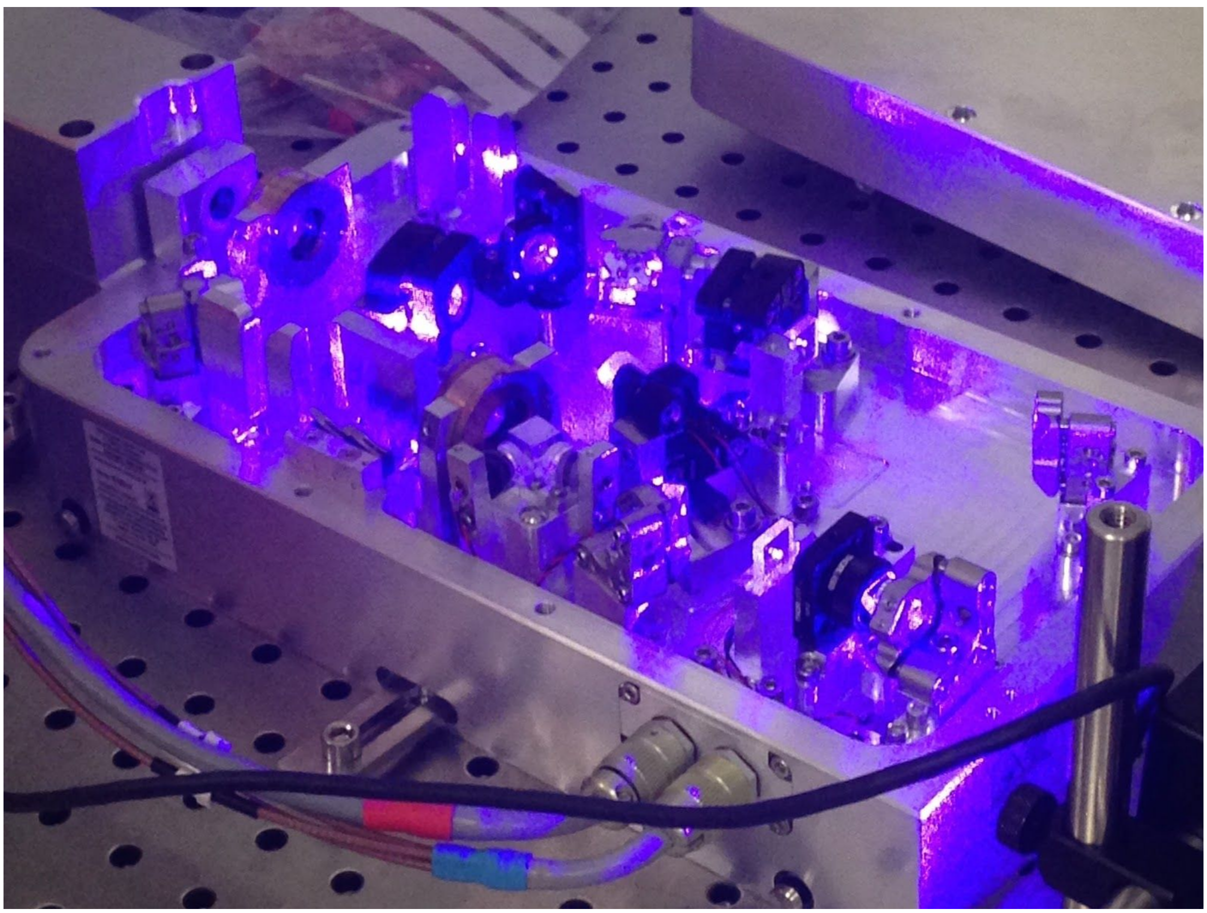


Figure 2: CRIS experiment uses lasers to probe the hyperfine structure of the atom of interest. When the lasers are on the correct frequency, they step-wise excite and ionize an electron from the atom (Credits: CRIS/iSOLDE Collaboration).

From this dataset, the changes in the mean-squared charge radius of these isotopes could be derived. The results extend the knowledge of the charge radii of the copper isotopes by another three neutron numbers, up to ^{78}Cu (N = 49). The new data thus represent an important step towards understanding of the nuclear sizes in close proximity to the very neutron-rich doubly magic system of ^{78}Ni. The new results enable a detailed study of the state-of-the-art in nuclear theory, in an area of the nuclear chart where radius predictions of these theories have so far not been evaluated in detail. Analysis of data show how modern Density Functional Theory (DFT) and the Valence-Space In-Medium Similarity Renormalization Group (VS-IMSRG) frameworks can both be used to explore the OES for the copper isotopic chain between neutron numbers N=29 and N=49.

Both theoretical methods show exceptional capabilities in reproducing the radii and the OES effect. Given the complexity of the medium-mass copper nuclei, and the presence of the unpaired valence proton, this work also represents a milestone for nuclear theory. From the comparison of the theoretical calculations, the relation between the global behaviour of charge radii and the saturation density of nuclear matter is demonstrated. Furthermore, the local charge radii variations, which reflect the many-body polarization effects, naturally emerge from A-body calculations fitted to properties of A ≤ 4 nuclei. These observations provide an important step in the understanding of the nuclear binding energy and charge radii, and thus a major milestone on the path towards a predictive nuclear theory.

Comparison with heavier odd-Z systems near the heaviest self-conjugate isotope ^{100}Sn are expected to provide the next challenge. Using the experimental developments that were made for the study of the copper isotopes, these nuclei near ^{100}Sn can now be studied experimentally over a range or more than 30 isotopes.

Note: The author would like to thank Ruben de Groote and Gerda Neyens for their useful comments and feedback.

Further Reading:

[1] J. Phys. G: Nucl. Part. Phys. 44 (2017) 064002 (21pp) https://doi.org/10.1088/1361-6471/aa6642

[2] R. P. de Groote et al, Phys. Rev. C 96, 041302(R) (2017)

[3] M. L. Bissell et al, Phys. Rev. C 93, 064318 (2016)

[4] K.T. Flanagan et al., Phys. Rev. Lett. 111, 212501 (2013)

You have to love the penguins

by ***Patrick Koppenburg (NIKHEF), Panos Charitos (CERN)***

PDF version

In 1977 John Ellis made a bet with a student, Melissa Franklin, “If you lose this game of darts,” Franklin said, “you have to use the word ‘penguin’ in your next paper.” John Ellis lost and as a result he coined the term Penguin decays while investigating charge-parity violation the Feynman diagrams of which “look like penguins” [1].

These diagrams describe particle processes that happen through more complicated processes compared to what we observe in most particle decays happening in the Standard Model due to the weak interaction. Most of the processes proceed through what is called tree-level decays described by Feynman diagrams that look like the junctures of tree branches. For example a neutron, consisting of three quarks, decays to a proton (three quarks), an electron and a neutrino. The interaction, mediated by the W boson, is represented in the Feynman diagram below (Fig.1).

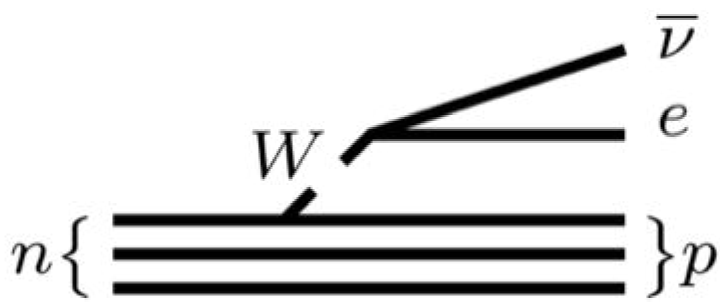


Figure 1: Example of a tree-level Feynman diagram showing the decay of a neutron to a proton via W boson.

However, this is not the case for all decays as some of them include the brief exchange of virtual particles - through so-called loop processes - that can recombine into new components and allow for a change in the flavor of quarks.

The first discovered penguin decay was b→sγ in which a bottom quark decays to a strange quark and a photon involving a W boson but also a top quark. The Feynman diagram is shown in Figure 2.

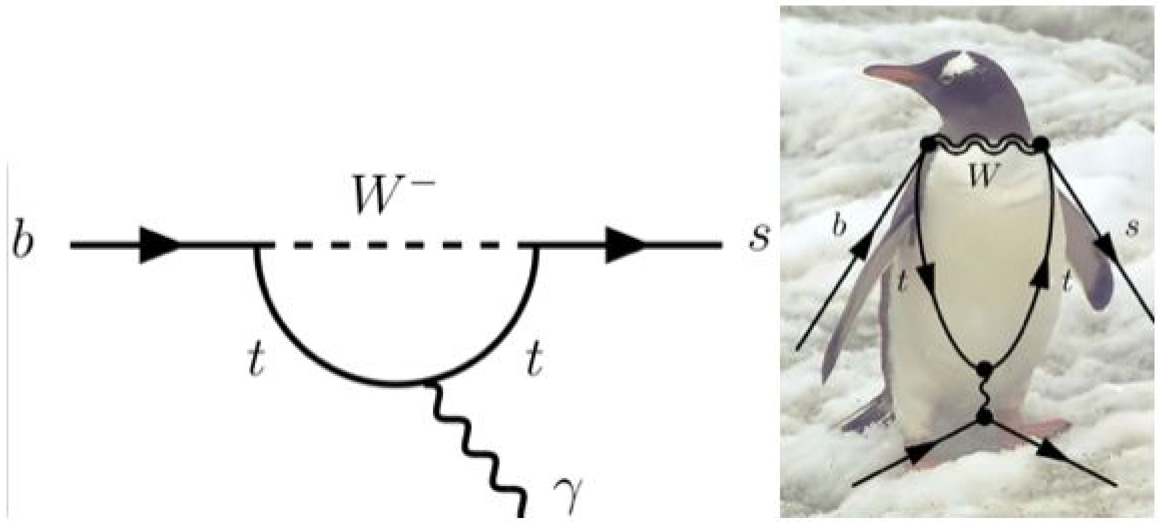


Figure 2: Showing one of the first proposed penguin diagrams proposed to describe electroweak Feynman process forbidden by tree-diagrams. The right image showsu how this processes resembles the shape of a penguin with the loop standing for the wide white stripe extending like a bonnet across the top of its head and its bright orange-red bill.

This decay was observed about 30 years earlier, in 1993 by the CLEO experiment in the US [2]. As you can see in Figure 3, a clear peak in their results corresponds to the mass of the B meson (the lightest particle to contain a bottom quark).

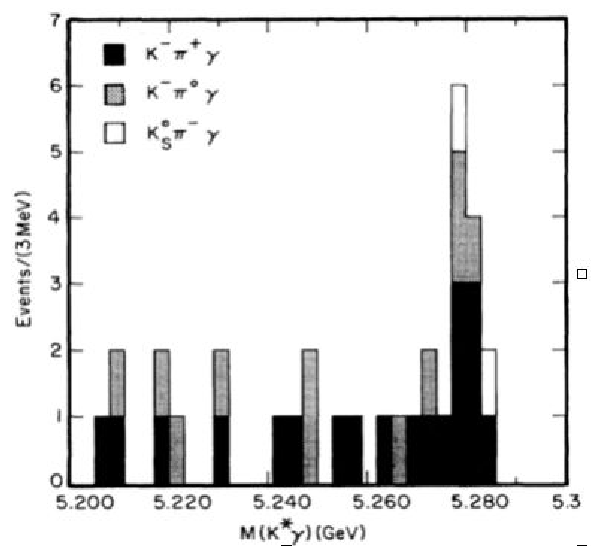


Figure 3: The mass distribution for the B candidates is clearly shown in this plot. There are 8 events in the signal region corresponding to the mass interval 5.274— 5.286 GeV (taken from [2]).

A penguin diagram represents a process where one quark flavor of matter particle changes into another flavor while emitting a photon or gluon: for example, a bottom (b) quark converting into a strange (s) quark and a photon. These processes are rare in the Standard Model and are interesting because they can get large enhancements from new physics and this is what we will discuss.

Previously we referred to perhaps the simplest case of a Penguin diagram of a b -> sγ decay. In fact, one could consider more complicated processes taking place. For example one could add two leptons in the diagram as shown below (Fig. 4) or even think the possibility of having a Z boson instead of a photon (γ) and making one more step to replace the Z boson with a loop that will involve a W boson and a neutrino (see Fig.5).

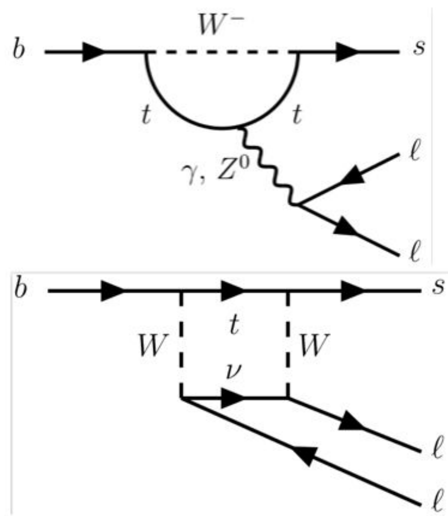


Figure 4: Penguin diagram showing the decay of a b to s quark (top) and with a box process involving a W boson as well as a top quark (bottom).

So far we have introduced three different processes describing the beauty decay to strange shown in Figures 2 and 4. They represent possible decays of particles containing a bottom quark to particles containing strange quarks and in the framework of the Standard Model. $B \to K^*\mu^+\mu^-$ decays. Such flavour-changing neutral processes are forbidden at the lowest perturbative order in the Standard Model, and can only be realized when including higher-order loop processes involving virtual W bosons as we discussed. In the SM they are very suppressed at the level of one in a million or so.

For example, we can choose $B \to K^*\mu^+\mu^-$ where a B meson decays to a kaon (with a strange quark), a light pion and two muons. The decay of a B meson (containing a b quark and a d quark) into a K^{*0}

meson (s and d) and a pair of muons is quite a rare process, occurring around once for every million B meson decays. It involves a change of the quark flavour, $b \rightarrow s$, while preserving the total charge) and it is possible only via electroweak penguin and box processes while it is forbidden at tree level.

This decay can be described using three angles and two masses as shown in Figure 5 where one can see the angles θ_l, θ_K and a third angle φ between the plane defined by the dimuon pair and the plane defined by the kaon and pion in the B0 rest frame.

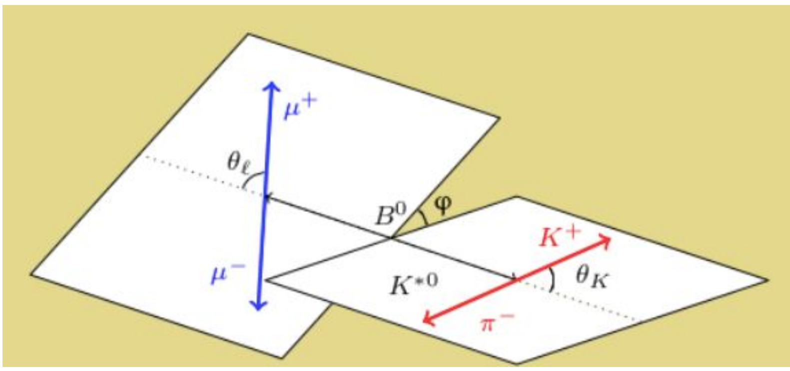


Figure 5: The final state of the decay $B^0 \rightarrow K^{*0}\mu^+\mu^-$ can be described by q^2, the invariant mass squared of the dimuon system, and three decay angles Ω~ = (cos θ_l , cos θ_K, φ).

It should be noted that this decay is quite susceptible to the presence of new particles that could decay through competing processes and thus significantly alter the branching fraction of the decay and the angular distribution of the final-state particles described above. Our theoretical predictions of angular observables are less affected by uncertainties in the B^0 --> K^{*0} decay, which makes it an interesting channel for experimental observation.

The two masses are the masses of Kπ systems and μμ systems. The reason for choosing Kπ systems in the K* region is because that's where most of the data lie and we are able to study a very clean spin-1 Kπ system. The angular observables and their correlations are reported in bins of q^2; a free variable that stands for the invariant-mass squared of the dimuon system. How often a decay picks a particular combination of angles can give us information about the underlying physics mechanism and the possible presence of new physics in the form of small deviations compared to the SM predicted value.

The following LHCb plot [3] using data from the second LHC run shows the distribution of the cosine of angle θ_ℓ over a given range of the q^2 parameter. Looking carefully, the distribution appears to be asymmetric towards larger values of the cosine of this angle. This is an intriguing result, waiting for higher statistics as it could point to new hypothetical particles like those predicted by supersymmetric theories, the existence of new bosons or leptoquarks all of which could enter in the penguin diagrams described before.

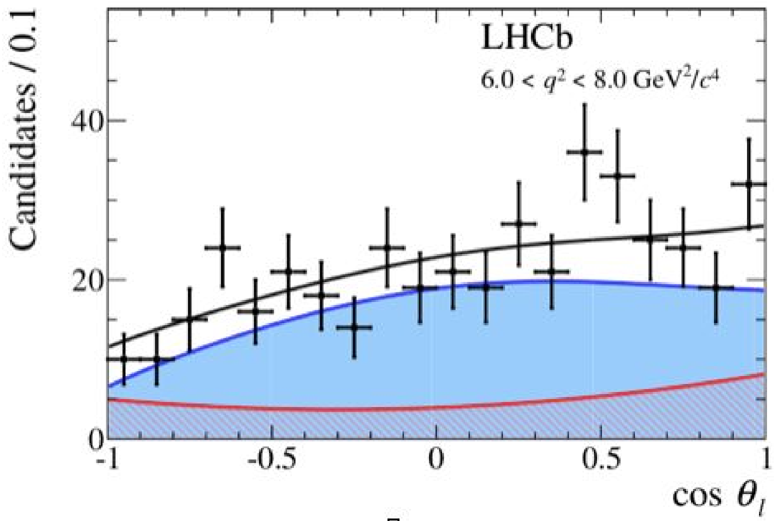


Figure 6: Projections of the fitted probability density function on the decay angles for the bin 6.0<q^2<8.0 GeV^2/c^4. The blue shaded region indicates background.

The observed asymmetry in the distribution of angles can also be plotted versus q^2; a variable named AFB and representing forward-backward asymmetry of the dimuon system. In the region of 6<q^2<8 the asymmetry is found to be positive as shown in Figure 7, where one can see the uncertainties (vertical bars) and the theoretical predictions (magenta). Along with better experimental/statistical accuracy we also need new theoretical calculations to understand the SM predictions and the respective theoretical errors.

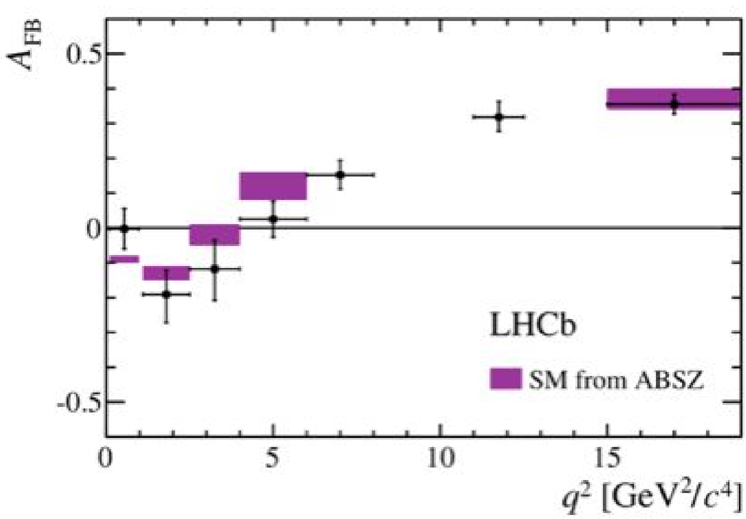


Figure 7: Results for the CP-averaged angular observables AFB in bins of q^2 compared to the SM predictions.

Eluned Smith of RWTH Aachen University presented this result at a CERN seminar on 10 March, on behalf of the LHCb collaboration [4]. For the analysis, the team combined data collected during Run 2 with those of the previous LHC run, actually doubling the data compared to the previous measurement in 2015 based only on Run 1 data.

The plot below shows the angular distributions (a variable named P5′) of the $B^0 \to K^{*0}\mu^+\mu^-$ decay in the $4.0<q^2<6.0$ and $6.0<q^2<8.0 GeV^2/c^4$ bins. The local tension in the measurement of P5′ is reduced from 2.8 and 3.0σ measured in the Run1 data analysis down to 2.5 and 2.9σ. However, a global fit to several angular observables shows that the overall tension with the SM increases from 2.9 to 3.3σ which is still too low before claiming evidence for new physics.

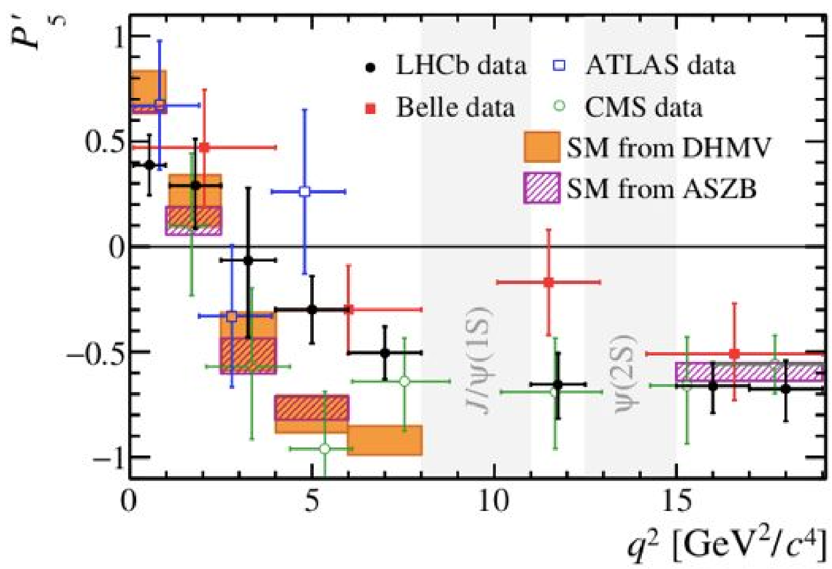


Figure 8: Angular distributions of P5′ for the $B^0 \to K^{*0}\mu^+\mu^-$ decay.

Data from BaBar and Belle add further intrigue, though with lower statistical significance. In 2016, the Belle experiment at KEK in Japan performed its own angular analysis of $B^0 \to K^*0\mu+\mu-$ using data from electron—positron collisions and found a 2.1σ deviation in the same direction and in the same q^2 region as the LHCb anomaly.

This result is more intriguing as it is linked with another anomaly observed by the LHCb experiment. In 2014, using data collected during LHC Run 1, the LHCb collaboration compared the rates of the reactions $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$ to test lepton universality. If all leptons have the same couplings to gauge bosons, as the SM assumes, the ratio of these two reaction rates should be equal to unity, apart from well-understood effects related to the different lepton masses. But LHCb's measurement of this ratio, R(K*), for the same decay ($B^0 \to K^{*0}\mu^+\mu^-$) differed from the SM prediction with a statistical significance of 2.4 standard deviations, and that for the similar decay $B+ \to K^+\mu^+\mu^-$ by 2.5 standard deviations, These deviations, if confirmed, suggest a violation of lepton-flavour universality, one of the key properties of the SM. The two results made physicists speculate that they can be caused by the same type of new physics, with models involving leptoquarks or new gauge bosons in principle able to accommodate both sets of anomalies. Further data analysis from the data collected during Run 2 and those from future runs of the LHC will shed more light on the nature of this anomaly.

Further Reading

[1] The story is beauiifully told in a Symmetry article: HERE

[2] R. Ammar et al., "Evidence for penguin-diagram decays: First observation of B→ K* (892)γ", Phys. Rev. Lett. 71, 674 (1993)

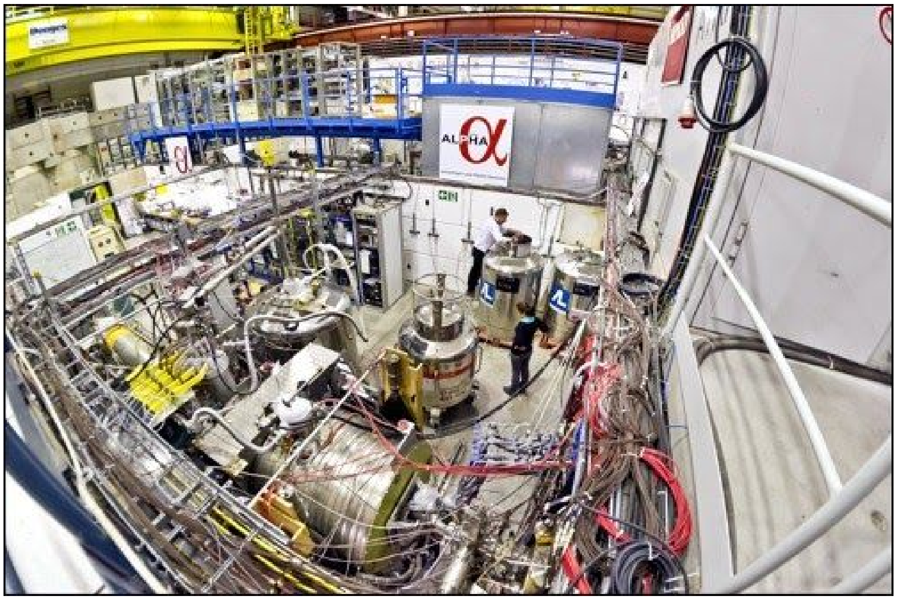
[3] LHCb Collaboration 2016 arXiv :1512.0442 (published in JHEP 1602 (2016) 104).

[4] LHCb Collaboration 2020 arXiv:2003.04831

ALPHA publishes first measurements of quantum effects in antimatter

by ***Panos Charitos***

PDF version



The ALPHA collaboration at CERN has reported the first measurements of fine structure effects and Lamb shift in the energy structure of antihydrogen that provide another test of comparison between antimatter and ordinary matter. The results, described in a paper published in Nature, show that these first measurements are consistent with theoretical predictions of the effects in "normal" hydrogen, and pave the way for more precise measurements of these and other fundamental quantities.

In 1947, American physicist Willis Lamb and his colleagues observed an incredibly small shift in the energy levels of the hydrogen atom as the atom's electron and proton interacted with vacuum. Under traditional physics theories of the day, the Lamb shift shouldn't have occurred. The 'nothing' of vacuum shouldn't influence the atomic behavior of hydrogen. The discovery spurred the development of a new quantum electrodynamics theory to explain the discrepancy, and won Lamb the Nobel Prize in Physics in 1955. Now, physicists with the ALPHA Collaboration at CERN have detected and measured the Lamb shift in antihydrogen, the antimatter counterpart of hydrogen.

The ALPHA team creates antihydrogen atoms by binding antiprotons delivered by CERN's Antiproton Decelerator with antielectrons. It then confines them in a magnetic trap in an ultra-high vacuum, Laser light is then shone onto the trapped atoms to measure their spectral response. This technique helps measure known quantum effects like the so-called fine structure and the Lamb shift, which correspond to tiny splittings in certain energy levels of the atom, and were measured in this study in the antihydrogen atom for the first time. The team previously used this approach to measure other quantum effects in antihydrogen, the latest being a measurement of the Lyman-alpha transition.

The fine-structure splitting of the second energy level of hydrogen is a separation between the so-called 2P3/2 and 2P1/2 levels in the absence of a magnetic field. The splitting is caused by the interaction between the velocity of the atom's electron and its intrinsic (quantum) rotation. The "classic" Lamb shift is the splitting between the 2S1/2 and 2P1/2 levels, also in the absence of a magnetic field. It is the result of the effect on the electron of quantum fluctuations associated with virtual photons popping in and out of existence in a vacuum.

In their new study, the ALPHA team determined the fine-structure splitting and the Lamb shift by inducing and studying transitions between the lowest energy level of antihydrogen and the 2P3/2 and 2P1/2 levels in the presence of a magnetic field of 1 Tesla. Using the value of the frequency of a transition that they had previously measured, the 1S–2S transition, and assuming that certain quantum interactions were valid for antihydrogen, the researchers inferred from their results the values of the fine-structure splitting and the Lamb shift. They found that the inferred values are consistent with theoretical predictions of the splittings in "normal" hydrogen, within the experimental uncertainty of 2% for the fine-structure splitting and of 11% for the Lamb shift.

"The work confirms that a key portion of quantum electrodynamics theory holds up in both matter and antimatter. It takes us a step closer to understanding the differences between matter and antimatter, and why so much antimatter vanished after the Big Bang" said Dr. Jeffrey Hangst, spokesperson for the ALPHA experiment adding that "Finding any difference between these two forms of matter would shake the foundations of the Standard Model of particle physics, and these new measurements probe aspects of antimatter interaction — such as the Lamb shift — that we have long looked forward to addressing,"

Next for the ALPHA collaboration is chilling large samples of antihydrogen using state-of-the-art laser cooling techniques. "These techniques will transform antimatter studies and will allow unprecedentedly high-precision comparisons between matter and antimatter."

Further reading:

M. Ahmadi et al. Investigation of the fine structure of antihydrogen. Nature 578, 375-380; doi: 10.1038/s41586-020-2006-5

Heterogeneous computing efforts for high-energy physics

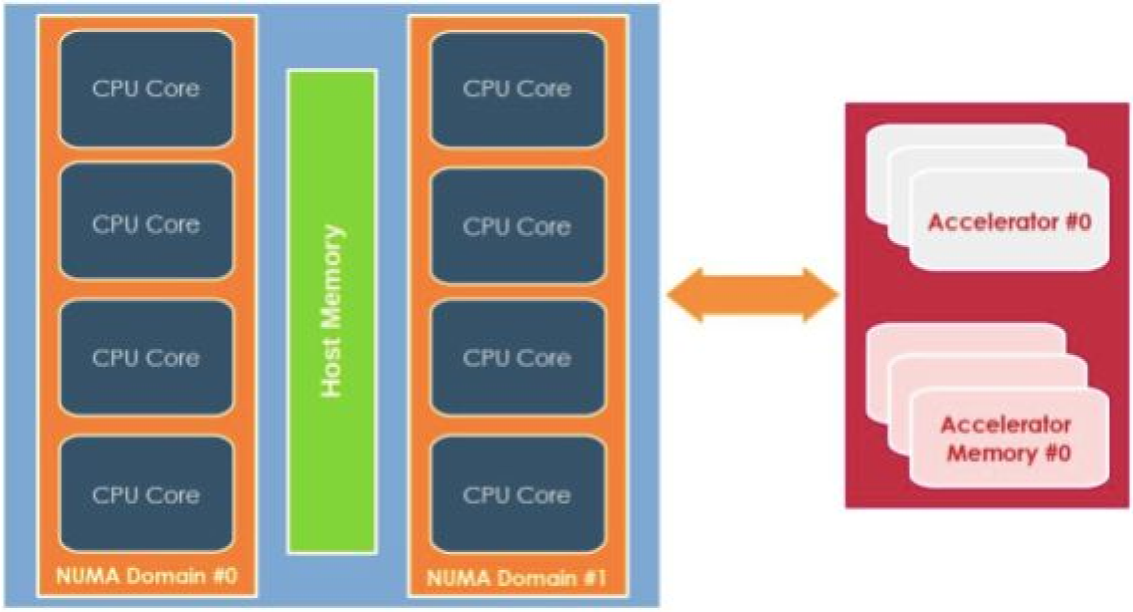
*by **Felice Pantaleo (CERN)***

PDF version

Substantial improvements to the current experiments at the LHC are underway, and new experiments are being proposed or discussed at future energy-frontier accelerators to answer fundamental questions in particle physics. At future hadron colliders, complex silicon vertex trackers (3D and 4D) and highly granular calorimeters must operate in an unprecedentedly challenging experimental environment; moreover, the real-time event selection will pose even greater challenges.

Experimental computing infrastructure used to rely on the industry to deliver an exponential increase in processor performance per unit cost over time. The main contribution to the gain in microprocessor performance at this stage came mainly from the increasing clock frequency along other improvements in computer architecture.

Applications' performance doubled every 18 months without having to redesign the software or changing the source code. To keep on this trend, the size of transistors had to be halved every 18 months. However, in the early 2000s, the layer of silicon dioxide insulating the transistor's gate from the channels through which current flows was just five atoms thick and could not be shrunk anymore. The evolution of processors hence changed towards a trend of an increasingly higher number of independent and parallel processing units. Today, scaling performance with processors' generations can be achieved only via application-level parallelism and by exploiting dedicated architectures specifically designed for particular tasks.



Heterogeneous Computing System: a host, usually coming with multiple CPU cores and its memory is connected through a bus to one or more accelerator devices, each with its own memory.

As an example, in 2008, the CERN EP department started a dedicated R&D programme because failing to adapt would have implied severe consequences for the long-term evolution of the LHC programme and future initiatives determined by unsustainable costs for software and computing [R&DMulticore].

Heterogeneous computing is the strategy of deploying multiple types of processing elements within a single workflow and allowing each to perform the tasks to which it is best suited. This approach extends the scope of conventional microprocessor architectures, taking advantage of their flexibility to run serial algorithms and control flow structures, while leveraging specialized processors to accelerate the most complex operations hundreds of times faster than what general-purpose processors can achieve.

There exist accelerators dedicated to random number generation, compression and decompression, encryption and decryption, matching of regular expressions, decoding of video and audio streams. The accelerator that, more than any other has become ubiquitous in the panorama of High-Performance Computing and Industry is the Graphics Processing Unit (GPU).

Traditional CPU and GPU architectures are based on very different design philosophies. CPUs have a latency-oriented design, with a small number of very flexible arithmetic logic units can provide the user with a result of a flow of execution in a small amount of time.

On the other hand, the design of GPUs has been shaped in the years by the video game industry. GPUs have vector processing capabilities that enable them to perform parallel operations on very large sets of data and to do it with much lower power consumption relative to the serial processing of similar data sets on CPUs. For this reason, GPU design is referred to as throughput-oriented.

Heterogeneous Computing at CERN

Today the experiments' online and offline computing infrastructures are facing the following challenges:

- reducing power consumption and cooling costs;
- improving performance;
- reconstructing, simulating and managing ever-expanding volumes of data;
- being able to exploit efficiently national Supercomputing resources, in which up to 95% of the processing power is coming from GPUs

Heterogeneous computing could help in addressing these challenges, but before adopting this paradigm shift some preparations are required.

Today, reconstruction and simulation core algorithms are typically written using C++, for improved performance, and configured using Python, for flexibility. All the core algorithms are plugged together in large frameworks that schedule their execution based on satisfied data dependencies. Some of these frameworks are able to schedule algorithms in parallel, in order to maximize hardware resources utilization and event throughput.

Since many applications include both algorithms that could benefit from acceleration and code that is better suited for conventional processing, no one type of processor is best for all computations: heterogeneous processing allows exploiting the best processor type for each operation within a given application, provided that the underlying software framework is able to support and schedule them.

In order to program GPUs in C++, a variety of libraries has been developed in the last decade: e.g. CUDA, HIP, OpenCL, SYCL. In order to harness the maximum throughput that such a device has to offer, often algorithms and data structures have to be redesigned by e.g. reducing the number of branches in algorithms or moving from Array-of-Structures to Structures-of-Arrays data formats. On the other hand, once a program has been implemented to execute on massively parallel architectures, reusing the newly designed data structures and algorithms on traditional CPUs could potentially give performance benefits. Making software able to execute on GPUs and CPUs with reasonable performance is many times a requirement, especially if this software runs on the WLCG, in which some machines might have a GPU installed while others might not. For this reason, R&Ds are ongoing for using performance portability libraries such as Alpaka [Alpaka], Kokkos [Kokkos] and OneAPI [OneAPI]. Provided that the starting code exposes parallelism, these libraries provide an interface that hides the back-end implementation allowing the same source code to be compiled for multiple architectures and execute with good performance.

Heterogeneous computing in LHC and SPS Experiments at CERN

Experiments' trigger farms are isolated and controlled environments. This feature makes them a fertile ground for software optimization and adoption of new technologies in order to retain better physics selection in an environment with latency and throughput constraints.

ALICE was operating a prototype for GPU tracking in the High Level Trigger during LHC Run 1.In LHC Run 2 it was performing the full tracking of the Time Projection Chamber (TPC) on GPUs in the High Level Trigger Farm at around 1000 Hz of Pb-Pb collisions. For LHC Run 3, the increased collision rate (50 kHz) requires a novel approach: instead of selecting data with triggering techinquesthe full raw data are processed in the online computing farm in software.

ALICE will record minimum bias Pb-Pb collisions in continuous read out, corresponding to 3.5 TByte/s of raw data entering the computing farm. This increase in event rate cannot be handled by simple scaling of the online computing farm using traditional approaches.

Because of its GPU experience from Run 1 and 2, ALICE considered GPUs for the backbone of online data processing in Run 3. The dominant part of the real time processing will be tracking and data compression of the TPC, which will fully run on GPUs, leveraging the experience from their experience. On top of this baseline scenario, ALICE plans to employ the GPUs of the computing farm also for the asynchronous reconstruction when there is no beam in the LHC. The asynchronous reconstruction produces the final, calibrated reconstruction output and runs many more algorithms. ALICE is working to identify the computational hot spots and port promising candidates onto GPUs to use their farm in the optimal way across the different modes of operations and workflows. The ALICE GPU code is written in a generic way: a common source code targets traditional processors as well as GPUs of different vendors using different APIs such as OpenCL, CUDA, and HIP.

ATLAS collaboration is actively investigating ways of making maximal use of new/heterogeneous resources in computing. In the past year much of the work went into evaluating all existing and upcoming possibilities for writing experimental software that could run on non-CPU back-ends. Many significant developments happened in this area since the last of the big tests that ATLAS made in its trigger project with GPUs back during LHC's Long Shutdown 1. With investigations continuing with looking at various ways of writing accelerated software, in a collaboration between trigger and offline software developers, ATLAS will revive the codes written during LS1, now using the latest programming techniques, to test how the latest/greatest hardware handles the calculations that needed for quickly reconstructing ATLAS data.

CMS CERN Team, set up in 2016 the Patatrack software R&D incubator, in order to create a fertile ground for disruptive ideas and maximize the impact that young scientists can have on the experiment physics reach. Since the day-0, the Patatrack incubator has worked in tight collaboration with CERN openlab, CERN Idea Square, industrial partners and universities.

Patatrack tries to help new ideas to go beyond the proof of concept stage and enter in production. Most of the ideas are explored during hackathons, which are held three times per year. This creates unique opportunities for scientists with different backgrounds and domain knowledge to work together, understand each other's problems and converge quickly to the best possible solution.

Group photo of the 7th Patatrack Hackathon held at CERN in September 2019.

The main R&D line that the Patatrack team has pursued is the heterogeneous online reconstruction of charged particle trajectories in the Pixel Detector starting from the LHC Run-3. In 2018, the Patatrack team demonstrated that it is possible to exploit efficiently GPUs from within the CMSSW, the offline and online CMS reconstruction software. New algorithms were developed making it possible to show that a small GPU like an NVIDIA T4 can produce almost the same event throughput as two full HLT nodes (dual socket Intel Xeon Gold 6130), at a fraction of the cost of a single node, while producing equal or better physics performance. The choice of this kind of low power and low profile GPUs makes it possible to deploy them on existing nodes as well as on newly acquired machines. Through collaborations with the CERN IT department and CERN openlab, the Patatrack team is investigating the exploitation of High-Performance Computing resources and participating in the definition of benchmarks for easing the procurement of heterogeneous hardware.

During 2020, the CMS experiment will continue its investigation on performance portability strategies, for avoiding code duplication and making the code easier to maintain, test and validate.

LHCb activities in heterogeneous computing have been concentrating on the developments of the all-software software trigger for data-taking in Run3 and beyond. The upgraded LHCb experiment will use a triggerless readout system collecting data at an event rate of 30 MHz. A software-only High Level Trigger will enable unprecedented flexibility for trigger selections. During the first stage (HLT1), a subset of the full offline track reconstruction for charged particles is run to select particles of interest based on single or two-track selections. Track reconstruction at 30 MHz represents a significant computing challenge, requiring an evaluation of the most suitable hardware to be used as well as algorithms optimized for this hardware.

In this context, the Allen R&D project [1] started in 2018 to explore the approach of executing the full HLT1 on GPUs. This includes decoding the raw data, clustering of hits, pattern recognition, as well as track fitting, ghost track rejection with machine learning techniques and finally event selections. Algorithms optimized for many-core architectures were developed and integrated in a compact, modular and scalable framework. Both the physics performance and event throughput of the entire HTL1 application running on GPUs are adequate such that this architecture is being considered as an option alternative to the baseline architecture for Run3, running on x86 processors. Integration tests are currently ongoing [2] to further validate this approach.

In the same context of software trigger for the LHCb upgrade, R&D studies are being performed towards fast pre-processing of data on dedicated FPGAs, namely in producing in real-time sorted collections of hits in the VELO detector [3]. These pre-processed data can then be used as seeds by the High-Level Trigger (HLT) farm to find tracks for the Level 1 trigger with much lower computational effort than possible by starting from the raw detector data, thus freeing an important fraction of the power of the CPU farm for higher-level processing tasks. While the full VELO tracking on FPGA systems, based on the extremely parallelized Retina algorithm, is considered not to be ready yet for Run3, the clustering of VELO hits on FPGAs is close to being adopted as a baseline for data taking in Run3.

At experiments looking for ultra-rare events, like NA62, event selection at trigger level is of paramount importance. A project to employ GPUs at the first level of the event selection started to study the feasibility of an approach based on high-level programming in places where usually embedded software and hardware is employed for latency reasons.

The NA62 RICH detector is important to define the Time of Arrival of particles. The real-time reconstruction of Cherenkov rings with GPUs has been the first demonstrator of this heterogeneous pipeline. The event rate is about 10MHz and the maximum allowed latency at this level of the trigger is 1ms. The demonstrator was successful thanks to the development of a Network Interface Card, NaNet-10, that enables direct data transfer (RDMA) from the acquisition buffers to the GPU memory, hence decreasing the latency for data transmission. NaNet-10 uses a 10Gbit link together with a PCI Express 3 connection to the host machine. During the 2018 data taking the heterogeneous system featuring an NVIDIA P100 has processed event data coming from four RICH readout boards (TEL62). It has achieved a maximum latency of 260 us, with an average latency per event of 130ns. NA62 will employ this heterogeneous system in production for leptonic triggers during the data taking after this long shutdown.

All these efforts demonstrate the recognition of heterogeneous computing paradigm allowing to increase the physics reach of experiments by improving the trigger efficiency and to harness computing facilities of High-Performance Computing centers and industry across the world. Heterogeneous computing calls for a paradigm shift driven by the challenges of the High-Luminosity LHC and future experiments to help maximize scientific returns.

Futher Reading

[1] https://indico.cern.ch/event/773049/contributions/3474298/

[2] https://indico.cern.ch/event/773049/contributions/3473255/

[3] https://indico.cern.ch/event/773049/contributions/3474316/

References

[TEL62 and NA62 Trigger] Nucl.Instrum.Meth. A929 (2019) 1-22

[Nanet] J.Phys.Conf.Ser. 1085 (2018) TWEPP2018 (2019) 118 10

[RDMulticore] https://twiki.cern.ch/twiki/bin/view/LCG/MultiCoreRD

[Alpaka] https://github.com/ComputationalRadiationPhysics/alpaka

[Kokkos] https://github.com/kokkos/kokkos

[OneAPI] https://software.intel.com/en-us/oneapi

CHIPS: A new EP-ESE service for the HEP community

by ***Xavi Llopart Cudie***

PDF version

ASIC technology and designs are becoming increasingly complex but bring potentially huge benefits to HEP experiments (see also previous EP article "A bright future for microelectronics"). Figure 1 summarises the evolution of CMOS technologies in the last decades, and their increasingly delayed adoption in HEP. Each CMOS generation is identified by the minimum physical feature that can be produced in silicon, that is the minimum length of each MOS transistor. In our community, we are using today the 65nm generation, while industry is producing chips in the 7nm one, 6 generations ahead. With the decrease in the size, accompanied by a proportional saving in power consumption, the number of transistors that can be integrated on a single chip largely increases (see the dark blue line). In addition, reliably manufacturing multi-billion fully-functional transistors per chip requires many more processing steps, some of which beyond what could be imagined only a decade ago. This increased complexity in technology also affects circuit design, and as a consequence some HEP designs might be confronted with the tangible risk of failure or delay with potentially severe consequences on the physics programme.

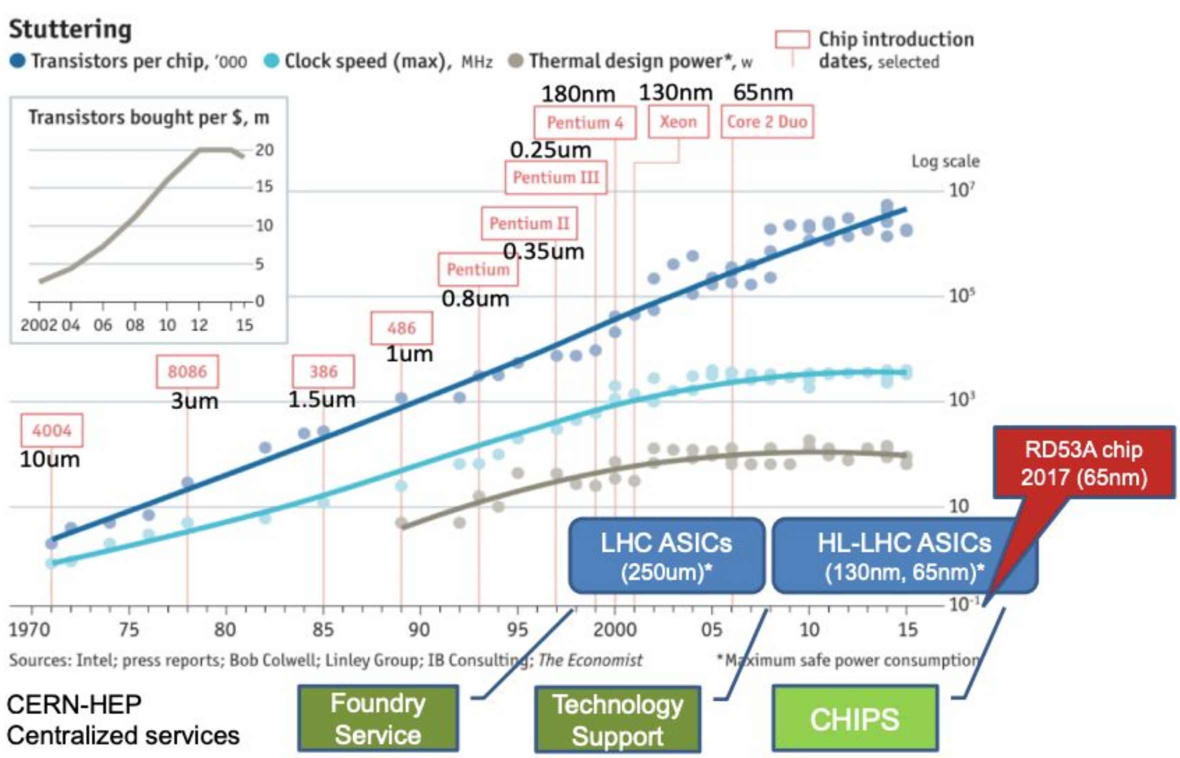


Figure 1: The evolution of microelectronics technology in the last decades is characterised by a steady decrease in MOS transistor size, that made it possible to increase the number and speed of transistors per chip and to lower their power consumption (taken from K. Kloukinas, 2019). HEP adopted the 250nm node in 1997-98 for the design of most of the ASICs now participating in the LHC data taking. CERN created a Foundry Service to assist the HEP community in the production of ASICs, which evolved into a more comprehensive Technology Support when our community moved to 130 and 65nm for circuits targeting the LHC and HL-LHC upgrades. Meanwhile, industry is now manufacturing the most advanced chips 6 generations ahead, in the 7nm node.

The new and more sophisticated design tools and design flows that are now available to ASIC designers must be used in these technologies. As a community, we have to face the challenges associated with the new level of design and verification complexity. This means developing and following scrupulously the Digital-on-Top design methodology. In this methodology, a fully scripted automated flow is used to drive the digital tools to design and implement the digital circuitry around the analog blocks. This flow facilitates the top-level architectural design, which can be emulated and verified using Universal Verification Methodology (UVM), simulation and functional verification, floor planning and power planning, logic synthesis, cell placement and signal routing, timing analysis, physical verification and power analysis. This flow is particularly adapted for large and complex designs implemented in advanced very deep submicron technologies. It requires perhaps an order of magnitude more effort than the Analog-on-Top approach but, where carefully followed, it strongly mitigates the risk of a failed design.

As a community we are already benefiting from the careful and thorough adoption of such techniques in the preparation of designs for the HL-LHC upgrades. Examples include developments for several experiment-dedicated and common chips. However, these techniques are still not applied systematically to all large scale ASIC designs for HEP experiments. In an attempt to facilitate the adoption of these modern design techniques, a new CERN-HEP IC design Platform and Services (CHIPS) activity has been started in the Microelectronics Section of the ESE group at CERN in January 2020, for an initial duration of 5 years.

The EP-ESE-ME already supports the HEP community with common design platforms and standardized design techniques since 2008 through the ASIC Technology Support and Foundry Services platform (https://espace.cern.ch/asics-support) led by Kostas Kloukinas. However, the amount of support provided is strongly constrained by an organizational structure where the support depends on a very small group of individuals. The CHIPS project is a new activity within EP-ESE-ME to further extend the support and encompass ASIC design and verification. The action plan has three main points:

1. To involve design and verification experts in the support. While at present only a small core team in the EP-ESE-ME section provides support, the new initiative foresees to redistribute the technical support tasks that can only be provided by experienced practitioners more uniformly across the designers in the section. For each step in the design flow one or two specialists will be identified and these will be tasked with supporting outside groups.
2. To extend the subcontract of specialized tasks outside CERN, reinforcing contracts with companies able to give punctual help with particular issues related to the tools and design flow. These facilities should be available both to CERN engineers and to members of the community. As with all such external contracts there should be one person responsible (of course with a back-up) to act as intermediary between the company and the designers.
3. To train and coach. Continue to organize formal training sessions to expose designers to the latest tools and, in particular, to educate them in the use of the common design platform. Furthermore, the initiative foresees the creation of 'hot desks' at CERN that could be allocated to host designers from the HEP community for several months. This would considerably favor exchanges and contribute to increase the shared expertise in the community.

A diagram of the CHIPS activity organization is shown below. Xavier Llopart is the appointed CHIPS Project Manager. With the help of the ME Section Leader, the CHIPS Project Manager will receive the support requests (chips.support@cern.ch), propose the most suitable solution (direct support, on-the-job training, specialised contract), and coordinate its implementation. The CHIPS service framework has now been launched. First requests are being received, and support solutions are being analysed. In time, this initiative should help design teams in the HEP community to achieve first-silicon success using modern high performance but expensive technologies. This goal will be reached by providing design support and diffusing expertise across the HEP community, where design teams are scattered and often composed of a very small number of practitioners that can not specialise in all the steps and tools necessary for the design of complex chips.

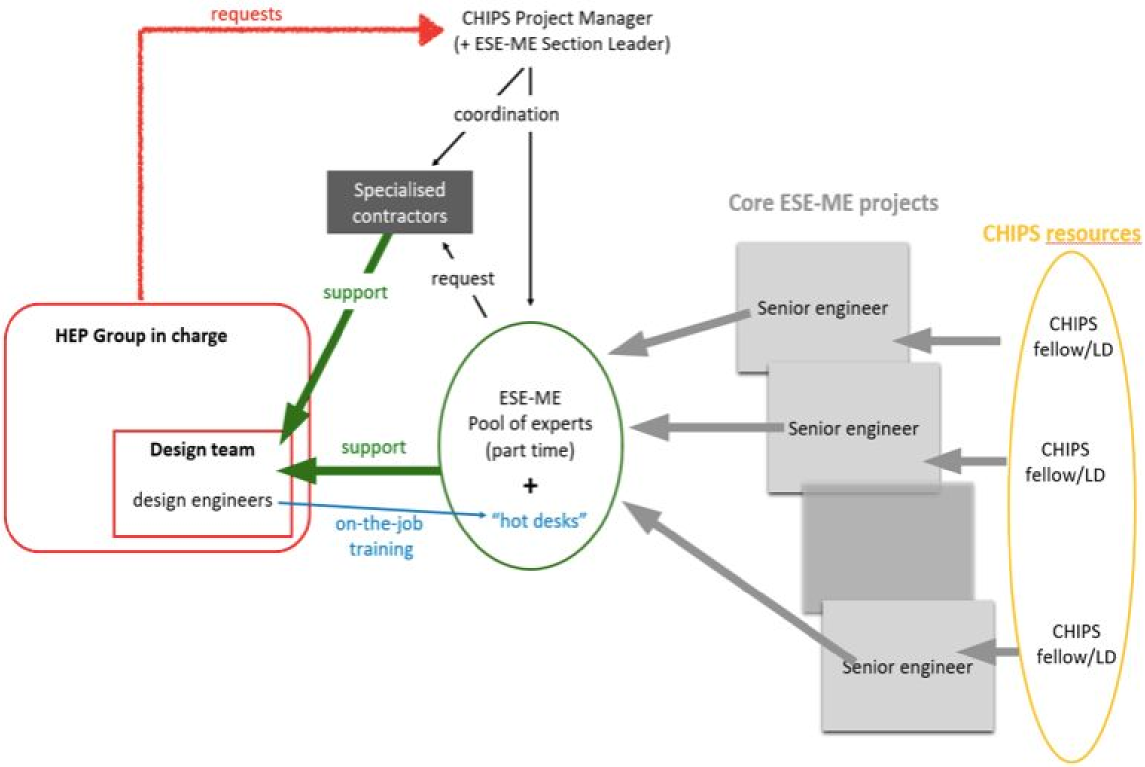


Figure 2: The organization of the CHIPS initiative foresees a central pool of expert practitioners from the core EP-ESE-ME projects. Under the coordination of a Project Manager, support to the HEP groups in charge for the ASIC design can be provided in different forms.

Upgrade of the EP Irradiation Facilities: The Gamma Irradiation Facility GIF++

*by **Martin R. Jäkel and Federico Ravotti (EP-DT-DD)***

PDF version

In the spirit of the ongoing LS2, the time without particle beams is currently used to significantly upgrade the two CERN Irradiation facilities run by EP-DT : IRRAD & GIF++. Both facilities deliver essential services to the HEP community, with the focus on validating and optimising detector technologies for the High-Luminosity upgrade of the LHC in 2025 and CERN projects beyond. In this series of articles, we will describe the different upgrade projects based on very different requirements. While the IRRAD upgrades need to fit within the overall East Area renovation project, the Gamma Irradiation Facility GIF++ needs to be maintained in operation throughout the whole LS2 to support the ongoing mass-production and ageing tests for muon detectors of the LHC Experiments.

Located on the H4 beam-line in EHN1 North Area, the GIF++ is a unique place where a high-energy muon beam (150 GeV/c) is combined with a strong 137Cs gamma source. The facility has been built in 2014 in a shared effort by the EN and EP department and was specifically designed to test real size detectors of several square meters, as well as to host a variety of smaller prototype chambers. Equipped with a comprehensive gas distribution system, a wide range of available gases, mixer units as well as the possibility to use premixed gas bottles, the facility regularly hosts muon detectors from all four LHC experiments as well as from outside collaborations.

CERN's Irradiator (137Cs, 14 TBq as of 2014) is operated throughout the year, independently of the SPS beams, and provides two independent gamma irradiation zones with a total floor space of more than 100 m^2. Two attenuator filter systems allow the gamma field in each zone to be tailored to the needs of the setups under test. It can provide high fields (≤ 2 Gy) for ageing studies or can be used to simulate the expected background conditions for which each detector has been designed. The muon beam available during specific runs (6-8 weeks per year) can then be used to show the tracking performance under these expected conditions. The GIF++ is therefore a vital test facility to prepare the LHC experiments for the upcoming HL-LHC.

Replacement of the original GIF (West Area) in 2014, the introduction of two independent irradiation zones, and more than doubling the existing area, allowed the GIF++ to host many more setups throughout the year and increase its user base. However, in 2018 it became clear that the success of this facility was pushing it to its operational limits. With more than 20 large scale setups hosted throughout the year and up to 11 setups tested simultaneously in the muon beam (Fig.1), the situation became critical and called for major upgrade plan.

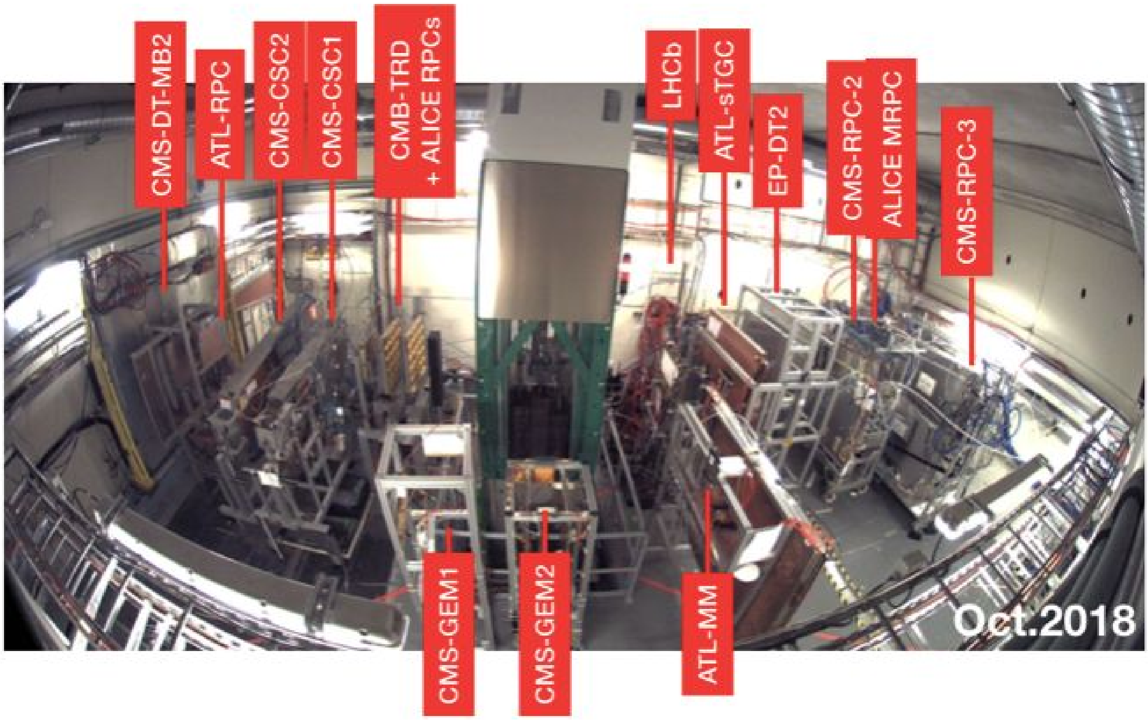


Figure 1: The Irradiation bunker during the muon beam time in October 2018.

To overcome the impelling space problems, an extension of the irradiation bunker was proposed. With the help of EN-EA, part of the upstream area on the H4 beam-line could be freed, allowing an extension of the irradiation bunker by 9.6 meters, adding nearly 60 m^2 of radiation field. This one-sided extension would also create a dedicated low-radiation zone (by up to 14 m distance from the source), making the test of multiple chambers with different gamma field requirements possible at the same time. This project was supported by all four LHC experiments as well as the EN and EP department. In a combined effort, the required funding was allocated, and the preparation work could start in late 2018.

One of the main challenges of the extension project was that the mass-production tests for the ATLAS New Small Wheel (NSW) chambers could not be delayed, and several long-term ageing studies (ATLAS, CMS) needed to be continued. In addition to the scheduled tests, ALICE made an urgent request to test TPC upgrade chambers in the GIF++ following the discovery of a hardware fault. All chambers needed to be tested, and in case necessary be repaired and re-tested in time for the installation in Point 2. Therefore, the GIF++ facility needed to be kept operational for a maximum of days during 2019. On the other hand, the parallel mass production test required by ATLAS for the sTGC and MicroMegas chambers could greatly benefit from the additional space of the extended bunker.

By carefully rearranging the corner blocks of the existing bunker shielding, it became feasible to prepare the extended bunker area independently from the facility operation. Over several weeks, the bunker walls, cable trays, false floor etc. could be installed (Fig.2). Finally, in July 2019, the facility was stopped during only 2 additional weeks to finalize the extension followed by one week to perform the compulsory annual maintenance of the 137Cs Irradiation system.

Figure 2: Preparation of the shielding wall for the bunker extension (top left). Installation of the false floor (top right). Combining the bunker parts by removing the separation wall (bottom left). The extended irradiation bunker during commissioning (bottom right).

To optimise the available space in both irradiation fields, the Irradiator was also displaced by 90 cm towards the upstream wall (Fig.3). This freed the necessary space in the downstream area for the mass-production chamber tests, while still preserving the low-irradiation field in the far upstream. On 19th of July, the DSO test of the extended facility was successfully past, and the facility could restart is full operation on time providing now more than 100 m^2 of irradiation floor space.

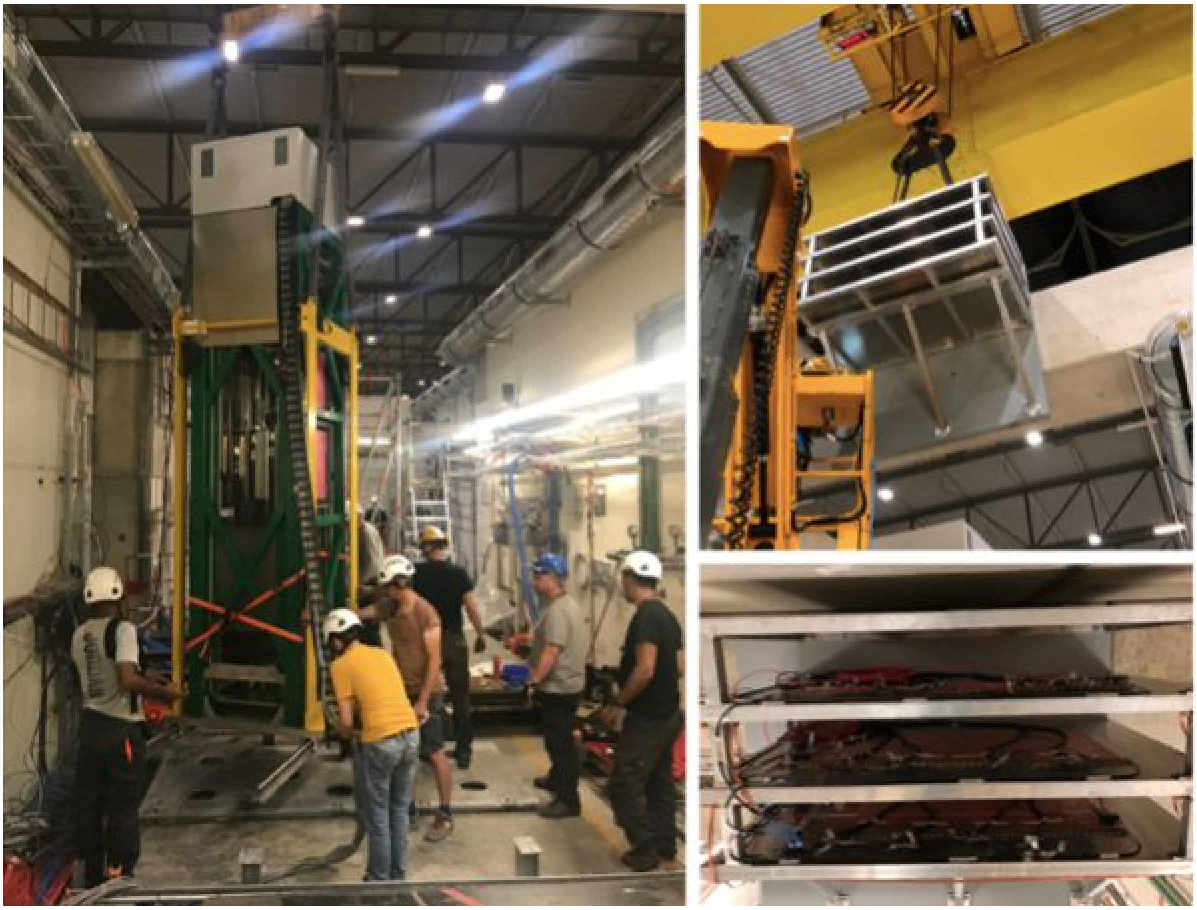


Figure 3: To optimise the usage of both irradiation fields, the Irradiator has been relocated to 90 cm upstream (left). Installation of the cosmic tracker support (right top) and the first 3 muon chambers of the roof tracker based on ATLAS RPC technology (right bottom).

In the shadow of the main extension project, multiple improvements could be accomplished in 2019, including a doubling of the primary gas distribution panels. Thanks to the work from a summer student, the operation web page of the facility (https://gif-irrad.web.cern.ch) has been completely redesigned, and it is now possible to retrieve all centrally stored operation values (e.g. Irradiator status, applied filter, environmental and gas parameters, etc.) via a simple web interface. Several days were spent for removing no longer used cables to guarantee enough free space in the cable pass-throughs for future installations.

Since the muon beam, produced by the SPS, will not be available until the second quarter of 2021, we took an extra effort to improve the facility capabilities to trigger on cosmic muons. Built from ATLAS RPC muon chambers, the first 3 (out of 4) roof chambers have now been installed and – with the previous installed ground confirmation chambers - complete the cosmic muon tracker in the downstream area. To provide additional trigger capabilities also in other spaces inside the bunker, a prototype of a mobile cosmic trigger has been developed (Fig.4). Build from 4 recuperated muon chambers (M1R3, double layer) that became available from LHCb during LS2, the frame is designed to fit around installed setups and can be tilted as needed to get the best compromise of cosmic muons and gamma irradiation. The first results of the cosmic trigger being able to work in the variable gamma background are very promising. If the need arises, the system can easily be extended or duplicated.

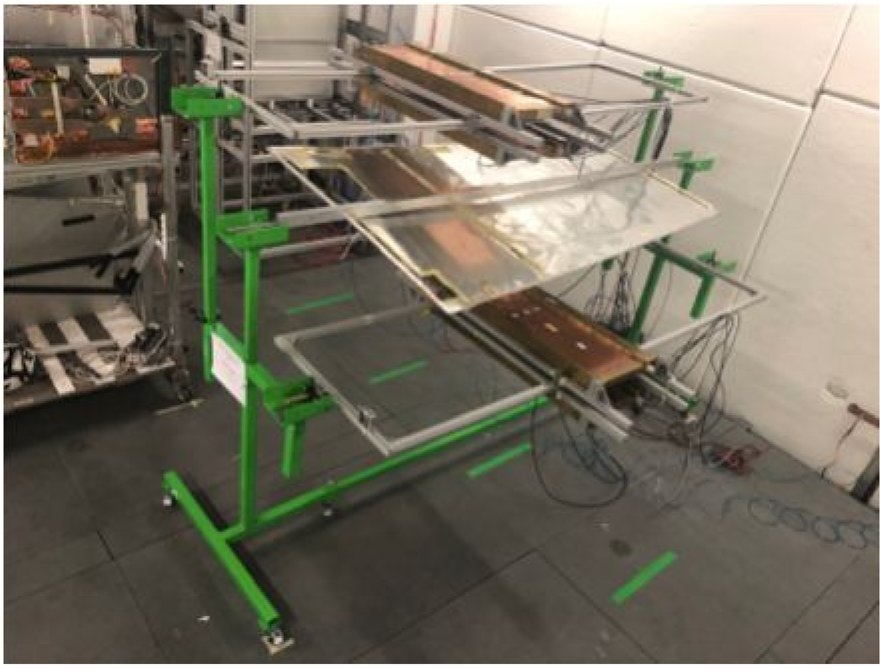


Figure 4: Prototype of a mobile cosmic trigger build from recuperated LHCb muon chambers. The frame is designed to fit around a typical muon chamber under test inside the irradiation bunker.

With the majority of the upgrade work completed in the GIF++, the focus in 2020 will now shift to the upgrade of the CERN proton IRRADiation facility (IRRAD) in the East Area (www.cern.ch/ps-irrad). The main LS2 projects for IRRAD concern the extension of the storage and sample-handling area and the renewal of the beam instrumentation of the T8 beam line in order to cope with the increasing demand for running the East Area facility with Heavy Ion beams.

Using 3D printing technique for future neutrino detectors

by ***Davide Sgalaberna, Umut Kose & Albert De Roeck (CERN)***

PDF version

Plastic scintillator is one of the most used active materials in high-energy physics. A charged particle crossing a plastic scintillator loses part of its initial energy and produces a quantity of scintillation light that depends on its energy and type. This property allows using this technology for distinguishing between protons, electrons, pions or muons. These detectors can be used to track particles [1] and reconstruct the momentum of stopping charged particles. Performant sampling calorimeters can be made by alternating thin plastic scintillator tiles or fibers with thin layers of lead/iron [2, 3].

Plastic scintillator detectors are widely used in neutrino long-baseline oscillation experiments, whose goal is to observe the violation of the Charge-Parity symmetry in the leptonic sector, providing a plausible explanation to the clearly-observed matter-antimatter imbalance in the universe. These experiments use an intense (anti-)neutrino beam, with energies of a few hundred MeV to a few GeV, generated by accelerated protons impinging on a target. The rate and the energy spectrum of neutrinos are measured close to the target by a 'near detector', before oscillations occur, and at a distance of several hundred kilometers by a 'far detector', where the oscillation probability is near maximal/reaches its maximum. Measurements of oscillation phenomena are carried out through comparison of the observations in both detectors, to cancel out key systematic errors [4]. Past neutrino experiments, like MINOS [5] and Minerva [6], instrumented their near or far detectors with plastic scintillators.

T2K, the current world-leading neutrino oscillation experiment, in Japan, is upgrading its near detector, ND280. Although results from previous runs have provided first indications of substantial leptonic CP-violation [7], it is upgrading the near detector (ND280) to reduce the systematic uncertainties, dominated by the poor knowledge of the neutrino interaction cross section. Hence, T2K is planning for a second phase to be started in 2022 and completed around 2025 [8].

ND280 will adopt a plastic scintillator detector as active neutrino target, surrounded by Time Projection Chambers and Time-of-Flight detectors [9].A novel detector technology, the Super Fine Grain Detector (sFGD) has been adopted as the plastic scintillator (PS) active target [10]. It comprises a two-ton polystyrene-based PS detector segmented into 1x1x1 cm3 cubes, leading to a total of around two million sensitive elements. Each cube is surrounded by a reflector that traps the light. Wavelength-shifting (WLS) optical fibers inserted along three axes are used to convey the light to photodetectors that precisely measure the energy deposited. This detector geometry, shown in Fig. 1, provides isotropic 3D tracking and identification of charged particles, vastly improving on the state of the art. The fine granularity will allow to detect the low-energy protons and pions produced by neutrino interactions.

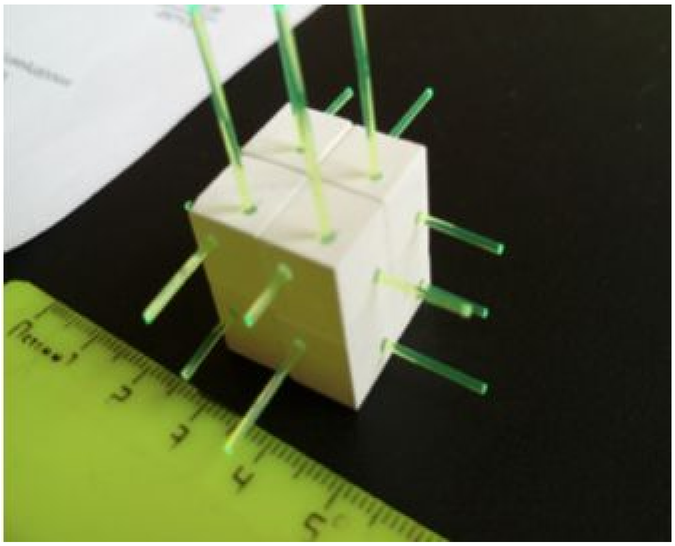


Figure 1: Example of sFGD [10].

A detector technology analogous to sFGD is part of the conceptual baseline of the DUNE [11] ND. Made of 12M cubes, it will collect a high-statistic data sample and will precisely detect neutrons produced by neutrino interactions and precisely reconstruct their energy by measuring the time-of-flight. A 3D granularity finer than 1x1x1 cm^3 would allow a more precise particle tracking and reduce the detection threshold for low-energy hadrons, particularly important for improving the modeling of neutrino interactions. However, the detector assembly would become much more difficult since the number of cubes would drastically increase. This will be a major step forward towards the world's first statistically significant observation of neutrino CP-violation.

Future constructions of sFGD-like detectors will therefore require a step change in technology. The ideal solution would be to produce a 'super-cube', a single massive block of scintillator containing many optically independent cubes. A non-scintillator mockup example is shown in Fig. 2. Traditional technologies (e.g. extrusion and injection moulding) cannot achieve this goal with sufficient precision, but it is possible that a super-cube could be produced using 3D-printing technology.

In the last decade, the field of additive manufacturing (AM) has revolutionized production methods for many objects; almost any shape can be quickly obtained, using many different materials, and with precision of 0.1 mm or better. First tests of 3D-printing of PS have been performed by some research groups, with promising results, but not yet at the level of optimization needed for physics experiments [12]. However, the field of AM is rapidly maturing, and new techniques are continuously being developed and improved. The excellent precision of 3D printers will allow the construction of a plastic scintillator detector with very fine spatial granularity, further improving the tracking performance. Most of the current 3D printers are capable of producing objects of sizes up to 40x40x40 cm3 or bigger and are relatively fast (about one day).

Applying AM to PS will have a large number of applications across many other branches of high-energy physics, like reactor neutrinos (e.g. SoLid [13]) or fast detector prototyping. AM will also boost the performance of detectors used in astroparticle physics experiments, that need full solid angle acceptance combined with high granularity.

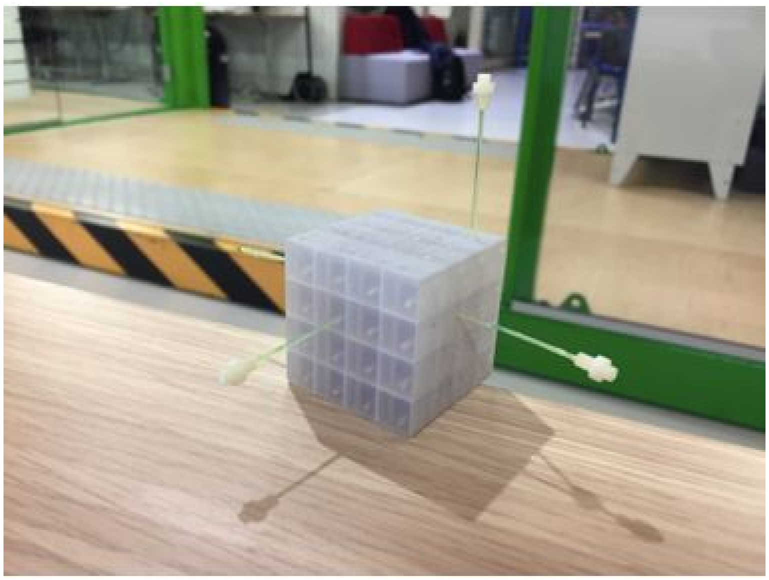


Figure 2: Mockup of SuperCube for illustration purpose.

A collaboration that comprises CERN EP, the Haute Ecole d'Ingenierie et Gestion du Canton Vaud (HEIG-VD), the Institute for Scintillation Materials of the National Academy of Science of Ukraine (ISMA) aims to apply AM techniques to plastic scintillator with good detection performances to build the first 3D-printed plastic scintillator detector ever. A R&D agreement that describes the role of each partner has been defined: ISMA, leader in the scintillator development and production, will optimize the plastic scintillator composition, the Addipole laboratory at HEIG-VD, with strong expertise in additive manufacturing, will take care of the 3D-printing process of plastic scintillator, while CERN will test the scintillation light output and guide the collaboration toward the achievement of the required performance. If the R&D project is successful, it will represent a paradigm shift in the field and will certainly have a large number of applications across many branches of high-energy physics and outside the field.

A production chain aiming for R&D has been set for Fused Deposition Model (FDM) technique using polystyrene-based scintillators. The strategy is 3D-printing of plastic scintillator material widely used in particle physics, whose scintillation light and timing performances are good and very well known. A new scintillator composition would introduce more uncertainty in the understanding of the real performance. Moreover, for neutrino experiments it is very important to have carbon-based active material with very low contamination from other nuclei, to avoid introducing additional systematic uncertainties in the neutrino interaction modeling, and the presence of a large quantity of hydrogen that enhances the neutron detection capabilities. As shown in Fig. 3, a polystyrene-based scintillator filament has been produced, optimized for usage in FDM printers. Several plastic scintillator cubes of about 1x1x1 cm3 have been 3D-printed.

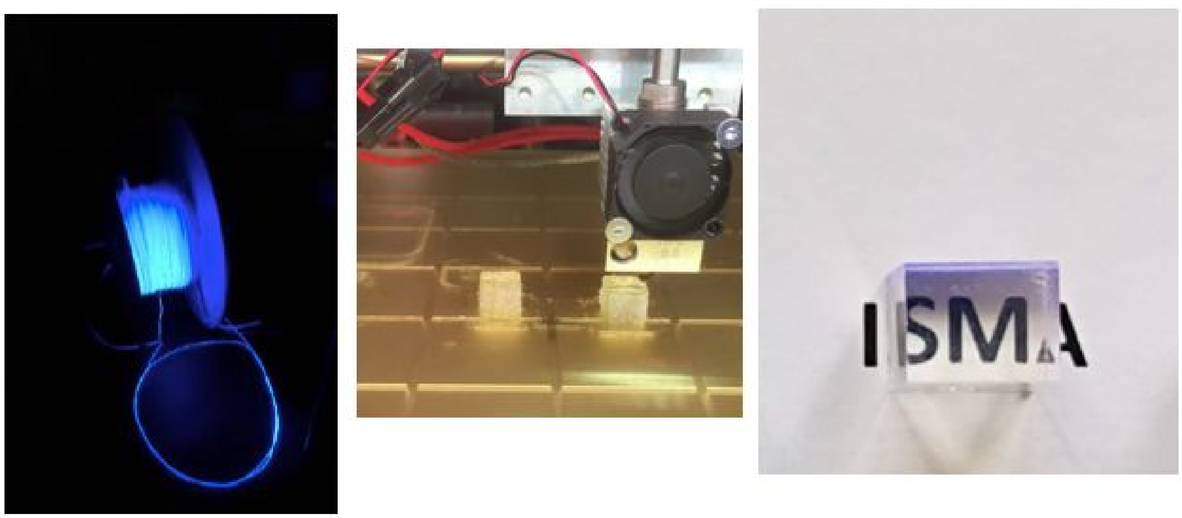


Figure 3: Different steps of the FDM 3D-printing process of a polystyrene-based scintillator cubes is shown: filament (left), 3D-printing (middle), final scintillator cube (right).

Light output tests show good transparency and light yield, comparable with the more standard production techniques such as extrusion, injection moulding. A strontium-90 source was used. Electrons of about 1-2 MeV were detected by a 3D-printed cube. An optical connector maximized the coupling between the cube and the silicon photomultiplier (Hamamatsu MultiPixel PhotoCounter). This preliminary test gives the first proof of principle of 3D-printing polystyrene-based plastic scintillators.

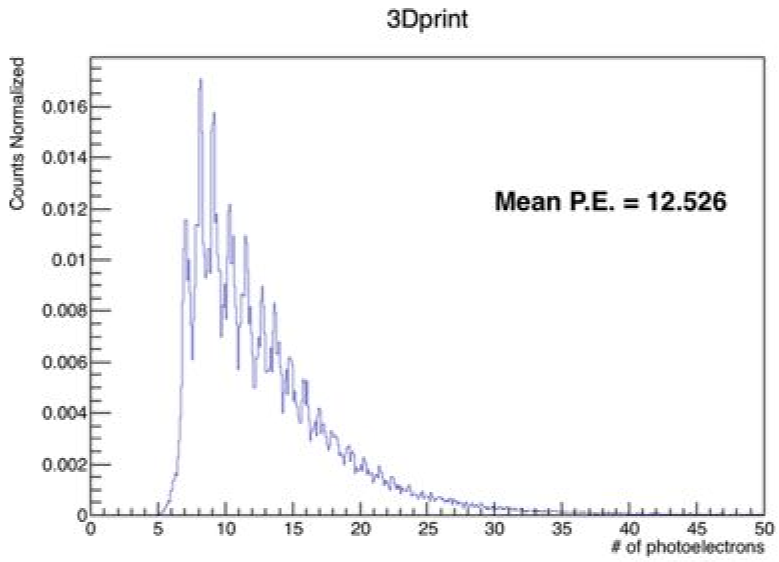


Figure 4: ^{90}Sr spectrum (photodetector photoelectron) of FDM-printed cube

The next steps will try to confirm the obtained results by collecting a relatively large cosmic data sample. In the future the R&D will move toward the first SuperCube production, i.e. 3D-printing the three holes and the optical reflector. Moreover, other additive manufacturing techniques will be tested and compared to FDM. If the R&D will be successful, the technology will be ready for the future neutrino oscillation experiments as well as applications outside high-energy physics.

The EP-Neutrino group is playing a leading role both in the T2K near detector upgrade as well as in the DUNE near detector design and has now started an R&D to demonstrate the possibility to apply additive manufacturing to plastic scintillator. If successful, it will provide the possibility of building the first 3D-printed particle detector used in a real experiment.

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ATLAS and CMS joint bootcamp for analysis preservation

*by **Clemens Lange (CERN)***

PDF version

Last month, 30 young graduate students and postdocs gathered at CERN to attend the first joint ATLAS an CMS analysis preservation bootcamp, organised by Sam Meehan, Clemens Lange, Lukas Heinrich (CERN), and Savannah Thais (Princeton). Over the course of three days, workshop participants learnt through hands-on tutorials and a great team of volunteer mentors how they could make their analyses reproducible using state-of-the-art software tools.

Figure 1: Thumbs up from the participants of the first joint bootcamp on analysis preservation (Credits: Samuel Meehan).

Starting from an example analysis distributed as a zip archive, the highly motivated crowd familiarised itself with the concept of continuous integration using CERN's GitLab installation. This platform allows everyone to run automated tests on their analysis code, from simply making sure the code compiles to performing sophisticated tests such as running the full analysis on actual data and simulation files to validate that the code changes did not break the analysis logic.

The focus of the second day were software containers: as soon as the analysis code is under version control on GitLab, the tested and compiled code can be packaged into a so-called software container image, which includes everything needed to run the analysis: code, runtime, system tools, system libraries and settings. Due to the huge amounts of data processed in high-energy physics, the actual data sets themselves are, however, usually not included. These software containers can be versioned so that one knows exactly which code was run at which time, and can be executed using high-throughput batch processing systems such as CERN's HTCondor-based batch service. In addition, this enables the leverage of on-demand remote compute clouds with effectively unlimited computing power.

However, one does not have to stride far to be able to make use of cloud computing. REANA, a data analysis platform for reproducible research with focus on high-energy physics workloads, is primarily developed at CERN. The third day of the bootcamp therefore culminated in a tutorial on using REANA, demonstrating how cloud computing and workflow technologies can work together, effectively allowing full-scale analyses to be executed and therefore also be reproduced on the push of a button.

Figure 2: The third day of the workshop was dedicated to the REANA platform; one of the key tools for reproducible research in high-energy physics. (Credits: Samuel Meehan)

In the afternoons, the participants split into two groups to focus on the details of ATLAS- and CMS-specific analysis software and authentication methods. In addition, the ATLAS group learnt about the RECAST project whereas CMS participants were able to get in touch with the CERN Analysis Preservation platform. Thanks to the HEP Software Foundation and the IRIS-HEP project, instructors, mentors, and participants could also exchange their experiences across LHC collaborations over a dinner.

CERN has embarked on the initiative to share collected data from LHC experiments as open data to the public. The analysis preservation bootcamp made direct use of that by using CMS Open Data including a published example analysis for the morning tutorials. However, there is no explicit guarantee that any analysis code published online is actually working several years after it was originally published. Furthermore, as the amount of data collected and analysed by the LHC increases, the real "logic" of the analyses is often encoded in software – from the precise way in which collisions are selected to the statistical treatment leading to the final measurement. This points to the need of preserving and ensuring the reproducibility of any analysis.

It is important to be able to easily re-run previous analyses while even reducing the required resources (i.e. time and computing power). Moreover, ensuring the reproducibility of an analysis will allow theorists to reinterpret results of previous searches and relatively quick test new theories of a large part of parameter space; a particularly important feature as we are entering in a data-driven exploratory era in particle physics.

This workshop comes in a long series of previous initiatives both by the ATLAS and CMS Collaborations (in collaboration with CERN's IT Department and Research and Computing Sector) to train physicists on the available tools and resources. It should be noted that these efforts complement open data initiatives like CERN's Open Data portal in a vital way, as also covered last year in a focus issue of the CERN Courier.

The bootcamp also offered the opportunity to the organisers to get feedback from the community and discuss possible improvements that could make the tools/methodology easily widespread-adopted in future analysis. With the second run of the LHC finished and the upgrade for Run-3 underway, some time will pass until the four LHC experiments have collected enough new data to significantly increase the sensitivity to Beyond Standard Model phenomena or the precision of Standard Model measurements. In turn, this implies that the current analyses being finalized on the full Run-2 dataset will be the most precise studies at LHC-scale physics for a long time. It is thus crucial that the details of those analyses are fully preserved, and the bootcamp was one further step into this direction.

Artificial neural networks shed light on rare SM processes.

PDF version

In a new paper released last month, the ATLAS Collaboration reported the observation of a single top quark produced in association with a Z boson (tZq) using the full Run-2 dataset, thereby confirming earlier results by ATLAS and CMS using smaller datasets.

As reported in an ATLAS Physics Briefing, physicists studied over 20 billion collision events recorded by the ATLAS detector, looking for events with three isolated leptons (electrons or muons), a momentum imbalance in the plane perpendicular (transverse) to the proton beam, and two or three jets of hadrons originating from the fragmentation of quarks (with one jet originating from a b-quark).They were able to identify about 600 candidate events with such a signature and after applying strict selection criteria still about 120 of those were expected to come from the tZq production process.

Therefore, ATLAS physicists employed machine learning techniques to best separate their signal from background processes. They trained an artificial neural network to identify tZq events using precisely simulated data. As explained in the Physics Briefing: "The neural network provided each event with a score (ONN) that represented how much it looked like the signal process. To check that the simulation fed to the neural network gave a good description of the real data, physicists looked at events with similar signatures (control regions) that are dominated by background processes. Various kinematic distributions of the 600 selected signal-region events were also checked."

The neural network score was evaluated in both signal (Figure 1) and control regions to allow better constraining of the background levels with real data. The tZq signal was extracted and the cross-section for such event was computed with an uncertainty of 14%. This is over a factor of two more precise than the previous ATLAS result, which was based on almost four times less data (from 2015 and 2016). The cross-section was found to be in agreement with the prediction from Standard Model, confirming that even the heaviest particles in the Standard Model still behave as point-like elementary particles.

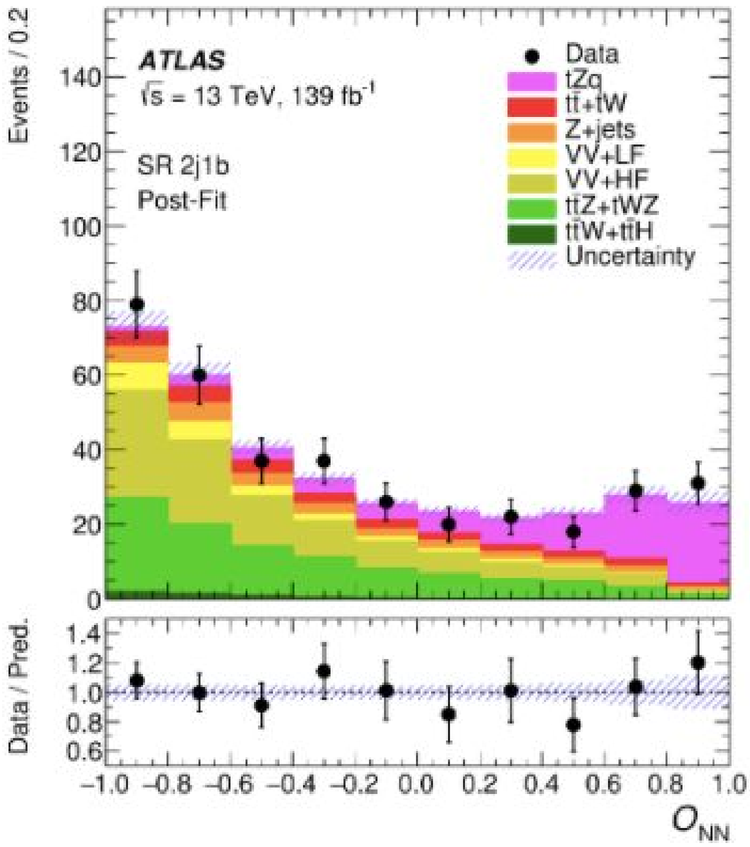


Figure 1: The neural network output (ONN) distribution for one of the signal regions. Data is shown in black. The simulated signal is shown in magenta. Backgrounds are shown in other colours. The high part of the ONN spectrum is dominated by signal events. (Image: ATLAS Collaboration/CERN).

Further, by selecting for events identified by the neural network as very likely to be tZq events (O_{NN} > 0.4), ATLAS examine whether the kinematic distributions are well described by the Standard Model calculations as shown in Figure 2.

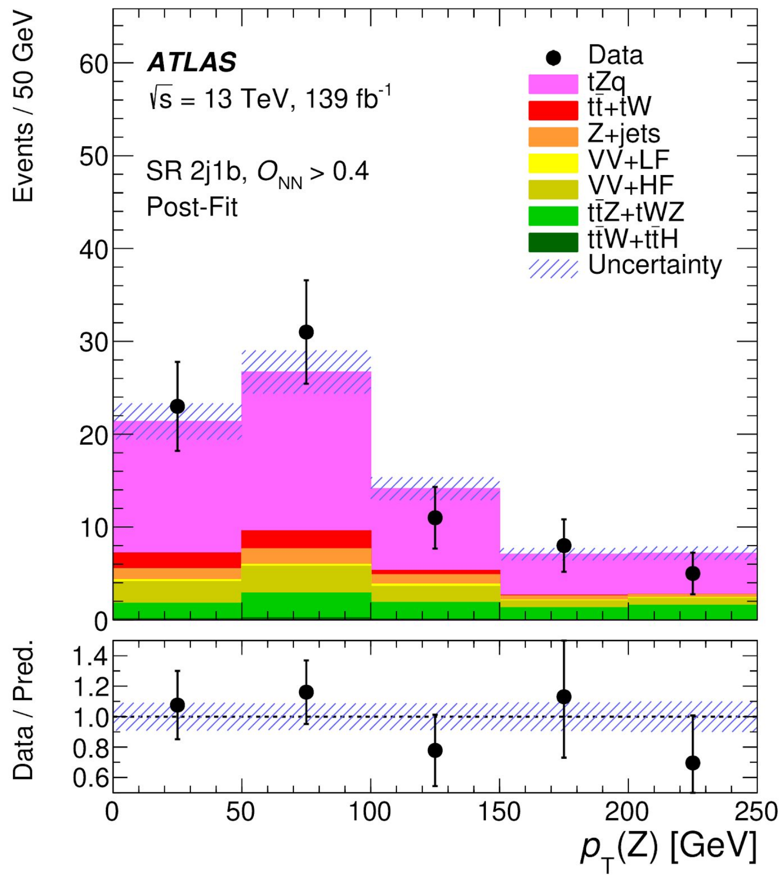


Figure 2: Distribution of the reconstructed Z boson transverse momentum for events with a neural network output (ONN) > 0.4. The simulated signal is shown in magenta. Backgrounds are shown in other colours. (Image: ATLAS Collaboration/CERN).

With the observation of the tZq production process now confirmed, ATLAS researchers can anticipate its study in even greater detail. Measurements of the cross-section as a function of kinematic variables will allow physicists to carefully probe the top quark's interactions with other particles. Will more data unveil some unexpected features? Look forward to seeing what Nature is hiding in the top world.

Another interesting option explored by the LHC experiments is the search for new particles that exist for more than a fleeting moment in time before decaying to ordinary particles (see previous EP article "Exploring the LifeTime frontier"). The so-called "long-lived" particles can travel measurable distances (fractions of millimetres or more) from the proton-proton collision point in each LHC experiment before decaying. Often, theoretical predictions assume that the long-lived particle is undetectable. In that case, only the particles from the decay of the undiscovered particle will leave traces in the detector systems, leading to the rather atypical experimental signature of particles apparently appearing from out of nowhere and displaced from the collision point.

Standard algorithms used to interpret the data from proton-proton collisions are not designed to seek out such odd-looking events. Therefore, the CMS Collaboration has developed an artificial neural network to identify these unusual signatures as explained in a recent CMS update. The neural network has been trained (with supervision) to distinguish sprays of particles known as “jets” produced by the decays of long-lived particles from jets produced by far more common physical processes. A schematic of the network architecture is shown in Fig. 3 and its performance is illustrated in Fig. 4. The network learns from events that are obtained from a simulation of proton-proton collisions in the CMS detector.

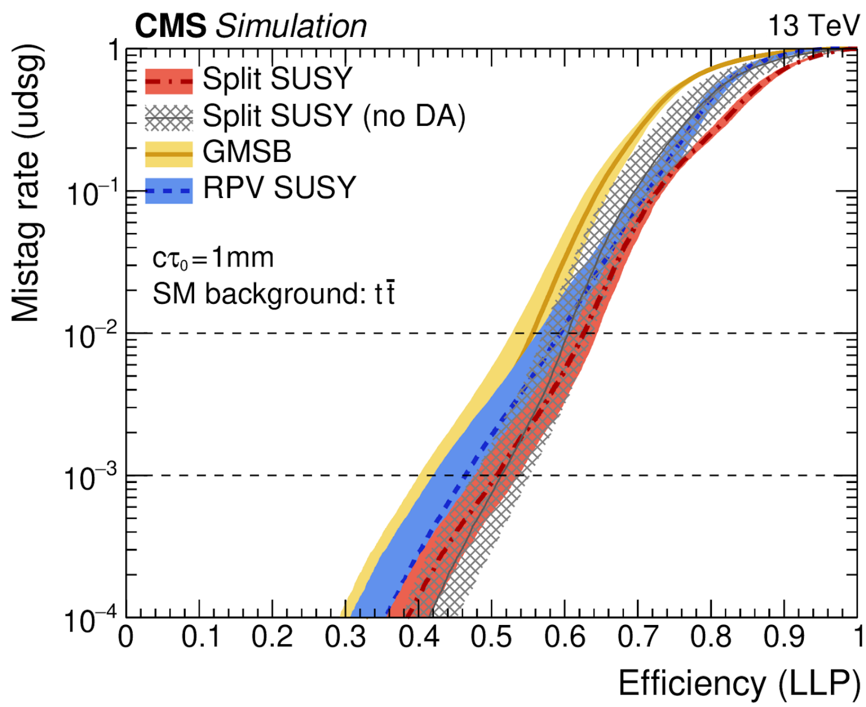


Figure 3: An illustration of the performance of the network. The coloured curves represent the performance of different theoretical supersymmetric models. The horizontal axis gives the efficiency for correctly identifying a long-lived particle decay (i.e. the true-positive rate). The vertical axis shows the corresponding false-positive rate, which is the fraction of standard jets mistakenly identified as originating from the decay of a long-lived particle.

The study used both real collisions data and simulated events to train the network (see Fig.4). As explained: "This approach is used because the simulation - although very sophisticated - does not exhaustively reproduce all the details of the real collision data. In particular, the jets arising from long-lived particle decays are challenging to simulate accurately. The effect of applying this technique is that the information provided by the neural network agrees to a high level of accuracy for both real and simulated collision data. This behaviour is a crucial trait for algorithms that will be used by searches for rare new-physics processes, as the algorithms must demonstrate robustness and reliability when applied to data."

In the next monhts, the CMS Collaboration will deploy this new tool as part of its ongoing search for exotic, long-lived particles. This study is part of a larger, coordinated effort across all the LHC experiments to use modern machine techniques to improve how the large data samples are recorded by the detectors and the subsequent data analysis. The experience gained from these studies will increase the physics potential during Run 3, from 2021, and beyond with the High Luminosity LHC.

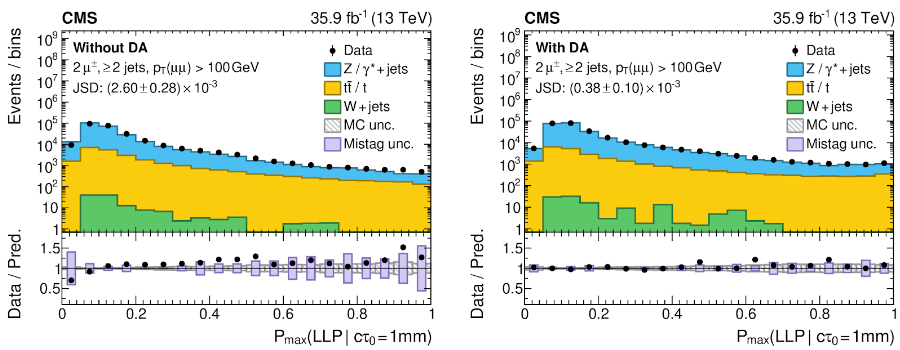


Figure 3: Histograms of the output values from the neural network for real (black circular markers) and simulated (coloured filled histograms) proton-proton collision data without (left panel) and with (right panel) the application of domain adaptation. The lower panels display the ratios between the numbers of real data and simulated events obtained from each histogram bin. The ratios are significantly closer to unity for the right panel, which indicates an improved understanding of the neural network performance for real collision data, which is crucial to reduce false positive (and false negative!) scientific results when searching for exotic new particles.

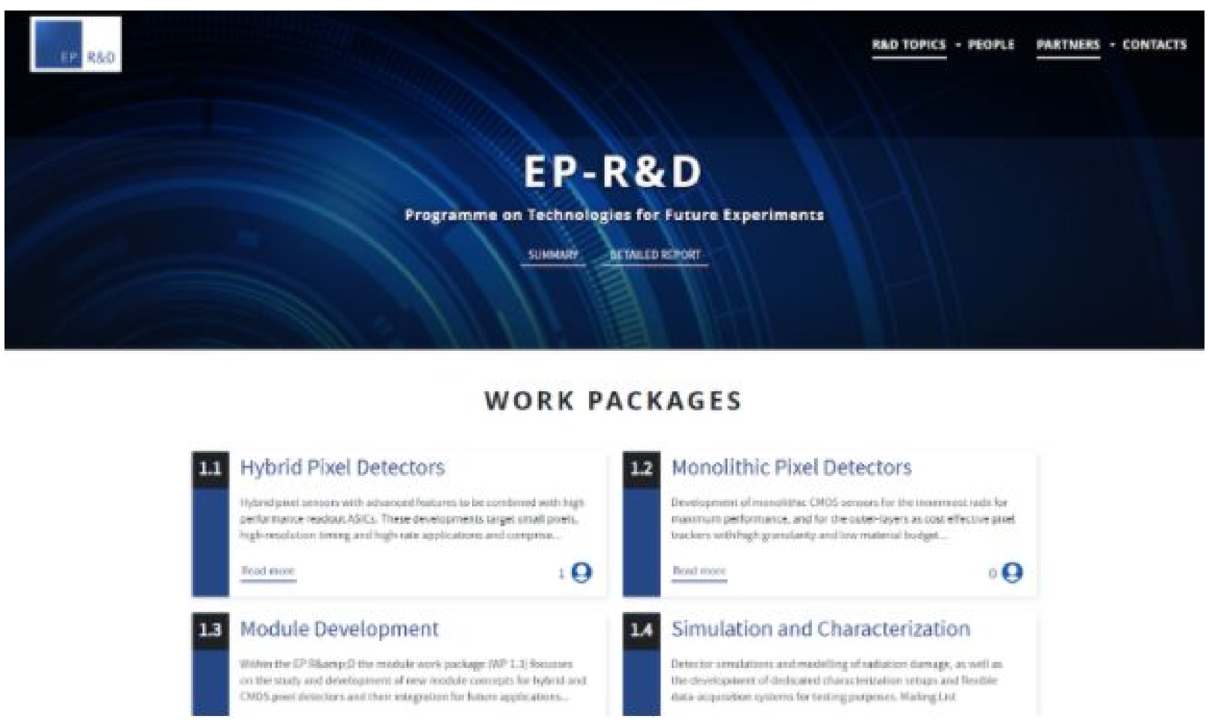
Note: The story is based on information from the ATLAS and CMS public websites as mentioned in the text.

EP launches new R&D programme for detector technologies

PDF version

Progress in fundamental physics calls for pushing the current state-of-the-art for detectors, and developing new technologies that would boost the efficiency while reducing the cost and the environmental impact of future experiments. For future experiments to continue playing their important role in scientific inquiry a solid programme on developing detector technologies is needed.

This spirit lies at the core of CERN’s EP department R&D programme on Technologies for Future Experiments that was officially launched last autumn during a one-day workshop at CERN’s Council Chamber. A dedicated website for this programme is under development, offering a space for the members of the programme to present their progress and discuss new ideas. Following a training session earlier this year in February, project participants (CERN Staff member, fellows, PhD and technical students) will be invited to share their work over the next couple of months until the final release of the website in May.



The EP R&D programme is the outcome of a two-year consultation process with the different stakeholders both from CERN and from other laboratories, launched in November 2017. During two subsequent R&D workshops in March and September 2018, working groups presented R&D lines and the key challenges for the experiments during the HL-LHC phase of the LHC and at future colliders. Following a bottom-up approach an overall strategic plan and a list of key topics has been identified, culminating in a document submitted to CERN's Enlarged Directorate.

Currently, the programme comprises 11 Working Packages in the areas of Gas and Silicon Detectors (exploring monolithic and novel hybrid-pixel technologies) and Calorimetry while separate working groups will explore the mechanical requirements (including low-mass structures and cooling), Integrated Circuit technologies and High-Speed links needed for the fast transmission of data, as well as the software requirements to ensure efficient analysis and fast simulations. Finally, a separate topic of key importance is the design of experimental magnets that are used to deflect the charged particles coming from the interaction region. Furthermore, each work package covers a number of tasks and specific deliverables exploiting synergies and ensuring a smooth collaboration given the overlap between certain aspects of detector design.

The programme is supervised by a Steering Committee chaired by the Head of the Physics Department while Christian Joram acts as Programme Coordinator and is in charge of the implementation of this ambitious R&D programme. Today, particle detectors merge different possible techniques to create “digital images” of particles and the defined tasks will push the limits of these technologies, giving the opportunity to get more refined images at higher speed and with lower energy consumption and at decreased costs.

The new R&D programme builds on CERN’s long-standing tradition in the development of new detectors. The work of the RD18, RD50 and RD51 collaborations was discussed in detail while possible new collaborations were presented by Burkhard Schmidt, leader of EP’s Detector Technologies group. In his talk he stressed the positive aspects of collaborative R&D, including the boost in creativity through the exchange of fresh ideas as well as the profits from establishing economies of scales between the participating institutes. However, collaborative R&D also requires certain investments and to build a critical mass of institutes and industrial partners who can bring their expertise and show their strong commitment to the R&D effort. The newly launched EP R&D can profit from previous experience and the upsurge in interest in many areas of the world that developed expertise – along with a dedicated community of experts in detector technologies - through previous collaborations with CERN.

The programme also attracts international interest while seeking global coordination on development of novel technologies. During the EP R&D programme launch event, guests Maria Chamizo Llatas from Brookhaven National Laboratory and Petra Merkel from Fermi National Laboratory gave an overview of the US plans for future detector R&D while CERN’s Lucie Linssen offered an update from the AIDA++ open meeting and plans for a new EU proposal focusing on “Innovation for Detector Technologies for Accelerators'' with an eye to the LHC experiments upgrades, detectors for neutrino experiments as well as for future Higgs factories and other planned detectors. The meeting closed with a presentation from the recent activities of the ECFA detector panel in light also of the ongoing update of the European Strategy for Particle Physics (see: //ep-news.web.cern.ch/content/investing-detector-technologies).

To quote the late Freeman Dyson “New directions in science are launched by new tools much more often than by new concepts”, and the launched EP R&D programme promises the development of new tools and technologies that will allow us to continue exploring the tiniest scales of nature during the HL-LHC upgrade, and go further than the LHC in exploring the intensity and energy frontier beyond our current reach.

COVID 19: The crisis and high-energy physics

by ***Markus Elsing & Panos Charitos (CERN)***

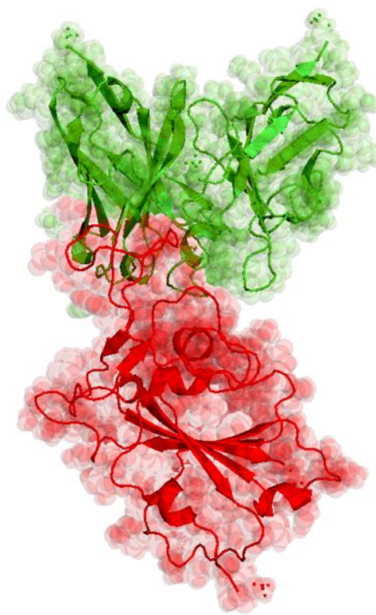
PDF version

As the new coronavirus has infected hundreds of thousands of people around the world and continues to spread, leading the WHO to declare a pandemic, scientists and public health officials are racing to understand the virus and tackle the growing public health crisis. In this rapidly evolving situation, many unknowns remain about the new properties of the virus.

Perhaps two of the most crucial questions occupying virologists and drug developers in the fight against COVID-19 are: what makes the new virus so good at infecting people? and how does it reproduce so quickly? Understanding its biochemical and structural makeup is crucial for diagnosing infections, for developing and testing drugs and tremendously helpful for designing efficient vaccines.

These questions and the scale of the challenge has mobilized the high-energy physics community to spring into action. This is not surprising for a dynamic fast-moving field like particle physics with a long record of successes based on the interaction of calculation, inspiration, engineering, and tinkering. As Tedros Adhanom Ghebreyesus, the president of the WHO commented: “This is not just a public health crisis, it is a crisis that will touch every sector — so every sector and every individual must be involved in the fight” **[1]**.

Researchers have been working around the clock since the COVID-19 outbreak came to light to characterize the virus, and understand why it is so infectious. First reports of an unknown pneumonia were reported on the 31st December 2019 and by 11th January six virus sequences were made available to researchers. A few weeks later, on the 5th of February, a research team at ShanghaiTech University in China uploaded the structure of the virus’s main protease to the Protein Data Bank (DOI:10.2210/pdb6lu7/pdb), having obtained the dataset using X-ray crystallography at the Shanghai Synchrotron Radiation Facility. The above timescale is impressive given that just a decade ago we would need more than three months would have been required as was the case for the SARS coronavirus in 2003, and perhaps even a year for previous viruses like HIV.



A model of the SARS-COV-2 RBD (Receptor-Binding Domain) bound to a human antibody simulated thanks to the Folding@home project. Ongoing projects aim to deepen our understanding of how the virus interacts with the human ACE2 receptor, and in the development of medical treatment to disrupt viral interactions with human receptors. (Image: Folding@home, CC BY-SA 4.0)

Acquiring such high-quality data within a short timescale was made possible thanks to advances in accelerator techniques and the development of new-generation synchrotron facilities and free-electron laser facilities around the globe. The combination of intensity and tunability makes synchrotron facilities a powerful all-purpose tool to get detailed information on the structure of the virus, providing unprecedented precision. Fundamental research for high performance future colliders have significantly reduced the costs for building and operating such facilities and boosted their performance, offering higher resolution and in parallel reducing the required running times. The role of experienced accelerator operators and experts in control systems should not be neglected, that maximize the reliability and availability of these infrastructures.

The role of accelerator physics in current efforts to tackle the COVID-19 outbreak are discussed in two recent articles in Physics World **[2]** and in the CERN Courier **[3]** by Tessa Charles, an accelerator physicist at the University of Melbourne. The latter tells in some detail the story of the UK's DIAMOND synchrotron facility, one of the first to set up experimental trials for generating protein crystals and determine the atomic structure of the new virus. “With the huge numbers of data sets, they could pin down the parameters of the viral protease with a high degree of confidence. And with the synchrotron light source they were able to create and analyse the diffraction patterns rapidly. The same amount of data collected with a lab-based X-ray source would have taken approximately 10 years. At Diamond, they were able to collect the data in a few days of accumulated beamtime."

As of today, several synchrotron facilities contribute in mapping molecules that could work against the virus, and the community has published calls enabling researchers working on these studies to gain rapid access to beamtime. The website www.lightsources.org offers a rich repository of access policies and open calls for proposals. Structures of the CoV-2 spike protein, the primary target of most medical approaches, have already been solved by crystallography or electron cryo-microscopy (cryo-EM) techniques by groups at facilities in Europe, United States and China.

Researchers are sequencing both the novel coronavirus, by focusing on several tell-tale features of the virus, and the genomes of people with COVID-19 to understand, among other things, the spread of the disease and who is most vulnerable. Efforts are ongoing to analyse the genetic template for spike proteins, armatures on the outside of the virus that it uses to penetrate the outer walls of human cells and reproduce in our body.

Protein structure simulations are a computationally intensive effort that requires large computing resources. Citizen science projects like Folding@Home and Rosetta@Home use numerical calculations to resolve the 3D structure of such proteins. Folding@home **[4]** provides a distributed computing network that allows people to donate their idle PCs running at homes and offices for globally distributed processing. There has been a roughly 1200% increase in contributors according to Folding@Home with 400,000 new members since the middle of March. The distributed computing project is now working with about 470 petaflops in its quest to fold proteins, enough to eclipse the world's top seven supercomputers combined. HEP people are collaborating with them and other initiatives, bringing in their expertise in tackling large scale high performance computing problems and computing centres, including CERN, are offering specific resources where needed.

Fast data sharing and analysis are key for tackling the current COVID-19 outbreak. Scientists around the world are using platforms like ZENODO at CERN to effectively share open data and information. Initiatives like Science-Responds.org take advantage of the internationally linked high-energy physics community to exchange information about ideas and projects, to establish contacts with experts, in an effort to help fight the disease. People are engaging themselves in public hackathons like the upcoming versusvirus.ch to develop community solutions for a broad spectrum of questions, from strategies and tools to prevent spreading the virus, to using data to fight fake news.

Data scientists from within our community work are reaching out to epidemiologists and medical experts, to help them in their data analysis and modelling efforts. However, when turning our attention to healthcare data we need to remember how crucial it is to ensure that information is interpreted and visualised appropriately. Amanda Makulec **[5]**, an expert in healthcare visualisation reminds us that “the stakes are high around how we communicate about this epidemic to the wider public” and stresses the necessity of “always understand the context of the data you’re working with, but is essential when creating and sharing visualizations during an epidemic where those visualizations have the potential to incite panic just as much as they have the potential to inform."

In the face of this global crisis, the global high-energy physics community - a community with a long-standing tradition of international collaboration - is offering resources, technologies and useful expertise to fight the pandemic. CERN as a global centre of excellence in scientific research has established a dedicated task force "CERN against COVID-19" to draw from the numerous proposals of the community and to help turning them into well-coordinated projects to maximise their impact profiting of the large network of CERN collaborations with laboratories, universities and industries. Among the many proposals received the ones concerning rapidly manufactured ventilator systems, availability of CERN computing resources for protein search for fighting the virus and manufacturing of full or parts of 3D printed masks are the ones that have been already addressed, while educational proposals and many others are being worked on very actively in this moment.

Further reading:

[1] WHO DG’s Opening Remarks at a Media Briefing on COVID-19 on the 11th of March 2020: https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020

[2] "How Physics is helping fight the pandemics" by Jon Cartwright (Physics World, April 2020 issue): https://physicsworld.com/a/covid-19-how-physics-is-helping-the-fight-against-the-pandemic/

[3] "Synchrotrons on the coronavirus frontline" by Tessa Charles (CERN Courier, April-May 2020 issue): https://cerncourier.com/a/synchrotrons-on-the-coronavirus-frontline/

[4] "Coronavirus - What we're doing and how you can help in simple terms) by Greg Bowman: https://foldingathome.org/2020/03/15/coronavirus-what-were-doing-and-how-you-can-help-in-simple-terms/

[5] "Ten Considerations Before You Create Another Chart About COVID-19" by Amanda Makulec (The Medium, 11 March 2020):

https://medium.com/nightingale/ten-considerations-before-you-create-another-chart-about-covid-19-27d3bd691be8