ALICE activity report 2016

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1 The ALICE Experiment

The ALICE collaboration has grown to include 42 countries, 174 institutes, and 1800 members. Italy has a prominent role participating with 12 groups and about 200 physicists. The Frascati group participated in the construction and operation of the main electromagnetic calorimeters, the EMCal/DCal. On the data analysis side, the group is focused on the physics of jets from light flavors, and on the extraction of observables related to fragmentation phenomena. This choice comes from the fact that the calorimeters enables ALICE to explore the physics of jet quenching, *i.e.* the interaction of energetic partons with the QCD hot and dense medium, over the large kinematic range provided by the LHC.
Starting from year 2012, ALICE decided to undergo a major upgrade of the experimental apparatus by constructing a new generation of Inner Tracking System (ITS) based on Monolithic Active Pixel Sensors (MAPS). The new silicon tracker will replace the existing ITS and will be installed during the LHC Long Shutdown 2. The ITS Upgrade project sees the participation of most of the Italian INFN groups. The LNF team actively contributed to the the R&D for the detector assembly, to the silicon chip electronic testing and in the beam tests for the characterization of the silicon chip prototype. The start of the production phase is planned for September 2017. The LNF team will produce 1/4 of the total number of modules (staves) composing the Outer Layers (OL) of the new ITS exploiting a ISO class 7 clean room hosting a fast, flexible Mitutoyo Crysta Apex S 9206 Coordinate Measurement Machine (CMM) with a nominal resolution of 0.1 μm. The overall ITS-U project is well on track for the installation at the ALICE pit starting in 2020 (Fig. 1)

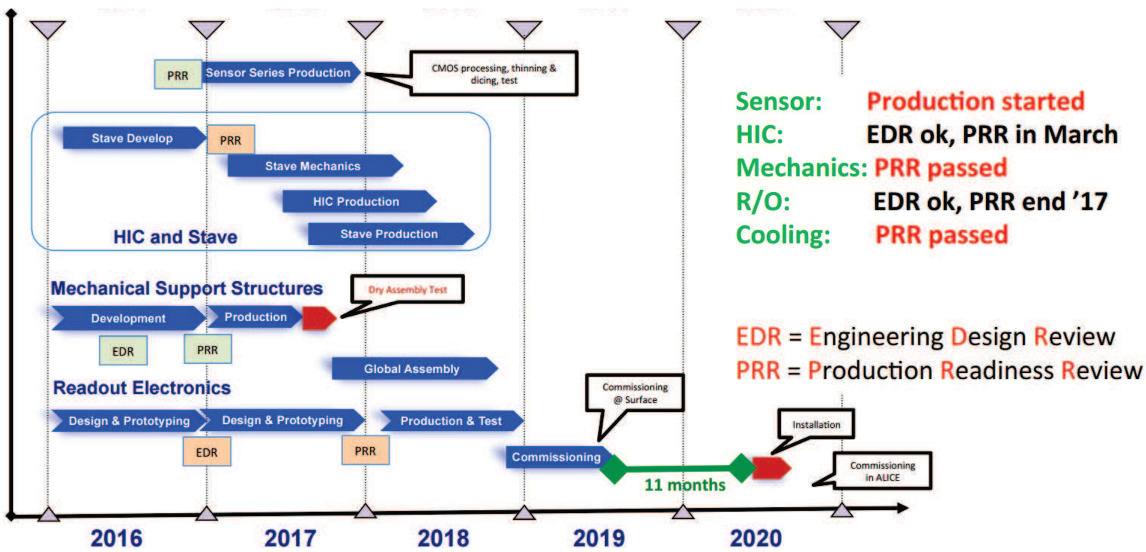

Figure 1: *The R&D phase for the ITS-U is successfully completed, and the production of the ALPIDE sensor started. The large scale detector production will go to full capacity during 2017.*

The challenging and the uniqueness of the ALICE ITS-U project are the extremely small material budget - a factor 4 to 5 smaller than those of similar detectors installed at CERN - and the very high granularity in terms of number of active elements needed to provide enough vertexing and tracking capabilities for frontier precision measurements which require access to the rarest physics signals.

2 ALICE data taking

The 2016 data taking campaign was successful for ALICE, both for p-p and p-Pb collision periods, thanks to the good combined efficiency of the experiment and of the accelerator. The machine has been in Stable Beam operation for ∼70% of the running time, accumulating only 4% of dead time due to failures.

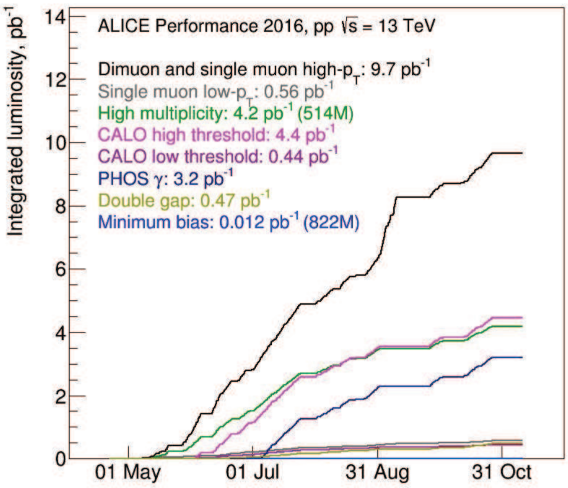

Figure 2: *Integrated luminosity collected for the different kind of triggers during p-p operation.*

The rest of the time has been used for the needed operational changes. The good overall operational efficiency, came from the introduction of the combined Ramp & Squeeze mode, the shorten pre-cycle time, a minimum turn around of less than 3 h, and the reduction of the slots for Machine Development. The collision energy for p-p remained 13 TeV (same as 2015) using a 25 ns filling with 2220 bunches per ring. A remarkable fact to be reported concerns the LHC heavy ion operation where the machine was able to deliver collisions at both 8.16 and 5.1 TeV c.m.s. energies for the p-Pb period. In p-p mode, ALICE run with luminosity leveling and collected 822 M

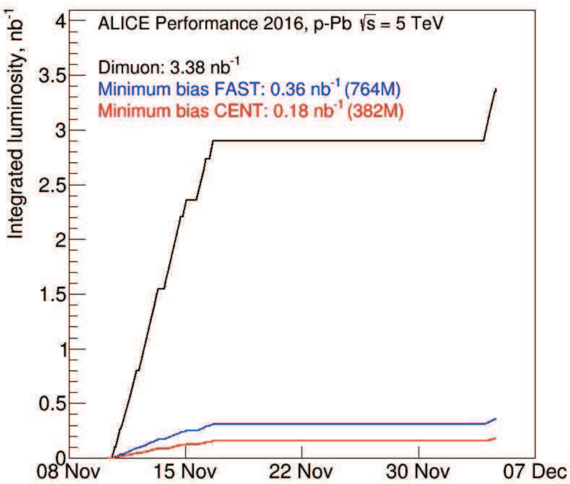

Figure 3: *Integrated luminosity collected during the p-Pb run at 5.1 TeV energy. This running period has been devoted to Minimum Bias physics.*

Minimum Bias (MB) and 514 M High Multiplicity events with the central barrel detectors. Single and di-muon rare triggers were also collected with the Muon Spectrometer for an integrated lumi of 9.7 pb^{-1} while roughly 8 pb^{-1} of γ triggers were collected with the electramagnetic calorimeter at different thresholds, see Fig. 2.

The average running efficiency for the experiment was around 90% for the whole running period with a peak of 95% during the p-Pb 5.1 TeV running period when the machine delivered 389 bunches colliding in ALICE at a β^* of 2 m and very long fills (>30 h). The nominal filling was made of trains with alternating bunches spacing at 100/200 ns to deliver some luminosity also to LHCb (originally not participating in heavy ion runs). As usual, ALICE run leveled at the target lumi 0.008 Hz/μb corresponding to an hadronic interaction rate of ~17 kHz with small pile-up ($\mu < 1\%$). During this period, devoted to Minimum Bias (MB) physics, more then 1 100 M MB events have been collected with different trigger clusters, as shown in Fig. 3.

The data taking conditions in p-Pb at 8.16 TeV were modified to deliver more collisions to the high-luminosity experiments, so the beams underwent to a larger burn off, hence shorter fills (~9 h) were available. ALICE took data focusing on rare triggers with 200/300/400 bunches colliding and rates up to 300 kHz and high pile-up (μ up to 8%). This second part of the run was split in two periods, by reversing the beam species. The first period is identified as p-Pb, where the protons travel in the direction of the Muon Spectrometer which allows to measure at low-x in the Pb. The other period is Pb-p which provided additional statistics to investigate the signs of medium effects in the Pb hemisphere ($\psi\prime/\psi$), already observed in the LHC Run 1. In addition, with this configuration, a powerful photon beam is sent towards the proton, providing an interesting dataset for Ultra Peripheral Collisions. The integrated luminosity statistics are shown in Fig. 3.

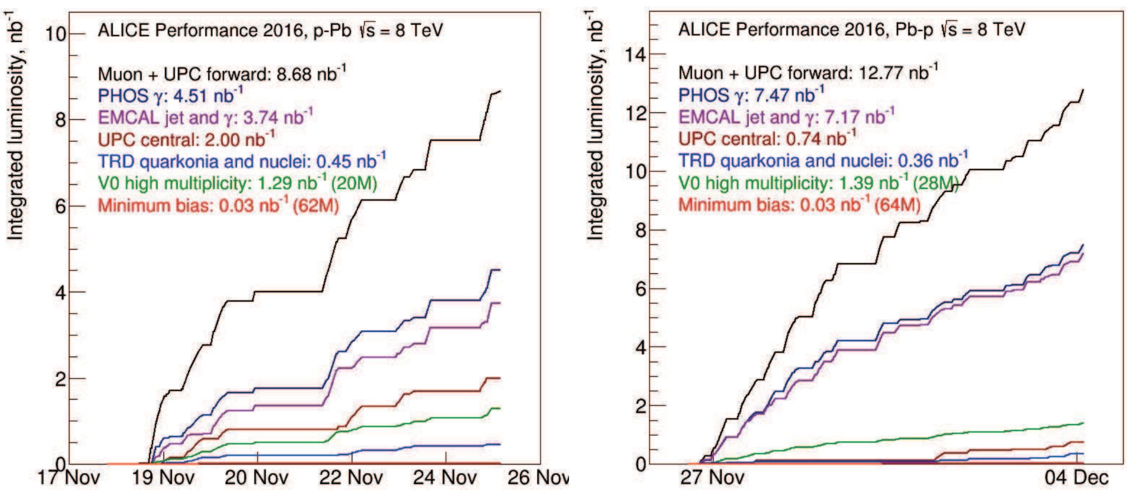

Figure 4: *Integrated luminosity collected by the ALICE detector during the 2016 p-Pb and Pb-p running periods at 8.16 TeV. The main rare triggers contributions are shown in both cases, together with the Central Barrel data for MB and High Multiplicity events.)*

3 ITS-U Status

The LNF ALICE team is fully engaged in the Inner Tracker System Upgrade (ITS-U) project. In particular, the LHC, after the second Long Shutdown in 2019-20, will progressively increase the luminosity of the heavy ion beams and will be able to deliver in ALICE an interaction rate of 50 kHz in Pb-Pb collisions, *i.e.* an instantaneous luminosity of $L = 6 \times 10^{27} cm^{-2} s^{-1}$. The increased collision rate requires the replacement of the main ALICE tracking devices. Among those, the current silicon detectors (which are based on different hybrid technologies as pixel, drift, and strip) will also be fully replaced with a new, super-thin, high-resolution, multi-layered, low-material-budget, 13 000 Megapixel system able to cope with the foreseen particle rates and enhancing the vertexing and tracking capabilities at low (p_T).

This innovative pixel detector is based on a TowerJazz 0.18 μm CMOS MAPS technology allowing for a maximum chip length of 30 mm in z-direction.

In order to withstand interaction rates of up to 50 kHz for Pb-Pb collisions and 1 MHz for p-p collisions, the maximum acceptable sensor integration time is about 30 μs to limit pile-up and loss of tracking efficiency. The maximum dead time is 10% at 50 kHz Pb-Pb (equivalent to 4 MHz of p-p) interaction rate.

Ensuring full functionality, especially for the ITS inner layers (radius of 22 mm), the sensors tolerate radiation levels of 2 700 krad, including a safety factor of 4 for a collected data set corresponding to 10 nb^{-1} Pb-Pb and 6 pb^{-1} p-p collisions.

One of the highest criticalities in the ITS-U project concerns the assembly procedure for the manipulation of very fragile low thickness (50-100 μm) silicon detectors. Also, the tracking target resolution puts stringent limits on the accuracy of the positioning of each single detecting element. The goal is to reach a geometrical alignment of the individual modules in the horizontal plane of 20 μm or better and a planarity along the stave of less then 200 μm.

The LNF team, together with other sites as Daresbury, Nikhef, and Torino, is committed to the production of a total of 108 staves (a stave refers to a mechanical detector unit) for the OL of the new ITS: each stave contains two readout units, referred as Half Staves (HS), while for the Middle and Inner Layers a stave is also a readout unit.

Each HS contains 7 Hybrid Integrated Circuits (HIC) which in turn allocate 14 wire-bonded pALPIDE4 silicon chips glued on a carbon fiber plate containing the cold water cooling loop (Cold Plate). The pALPIDE4 (the production version of the silicon chip) has passed the readiness review on November 2016. The final chip production started afterwards and the first two lots of 25 wafers (each wafer yields ∼45 chips) are expected to arrive at CERN by the end of March. The total quantity of wafers to be produced is between 1 000 and 1 400 depending on the yield.

3.0.1 Mechanical stave assembly

The detector development activity is focused on the assembly tooling development for the production of the OL staves, and on the definition of strict procedures for the assembly, alignment, soldering and testing of the staves. In particular the LNF team has been very active in pioneering the assembly and alignment of staves using the so called dummy HICs (electronically inert parts reproducing the required mechanical characteristics).

The first test to align and construct a stave was carried on in July 2016 with the help of the Torino team. The work, performed at LNF with our CMM, consisted in the alignment of two empty Half Staves, *i.e.* made only of carbon fiber plates (CP) with no HICs modules glued on them. Once aligned, the two empty HS have been glued to the support structure (Space Frame). The planarity obtained for this first stave was of the order of 400 μm over a length of 1 500 mm: this figure is larger then the nominal specifications (100-200 μm) and can be explained with the fact that the setup used in the exercise was not the final one, hence not fully optimized. The resulting stave was sent to Padova were it could be used to carry on an insertion test.

Following this preliminary work, the LNF team started planning for a more realistic test to be carried on autonomously, and for this reason it was decided to produce a first generation of dummy HIC modules in order to perform the full procedure of alignment and module gluing to obtain a complete mechanical stave. A number of fiber glass modules with semi-realistic reference marks have been produced to this purpose, and the necessary parts to construct two new staves have been requested from CERN. After few preliminary exercises, carried on during the summer, the LNF team reached the needed confidence and autonomy to perform the assembly of the first full mechanical stave which was produced in October 2016 using fiber glass dummy HICs and allowed the validation of the full alignment, assembly and the critical gluing procedure under the CMM control. The execution of the full steps of the procedure was also useful to tune the CMM software to the LNF construction jig. The LNF team proposed the use of fiber glass semi-realistic HIC modules to the ITS collaboration as a standard training method and our proposal was approved to be exported to all production sites.

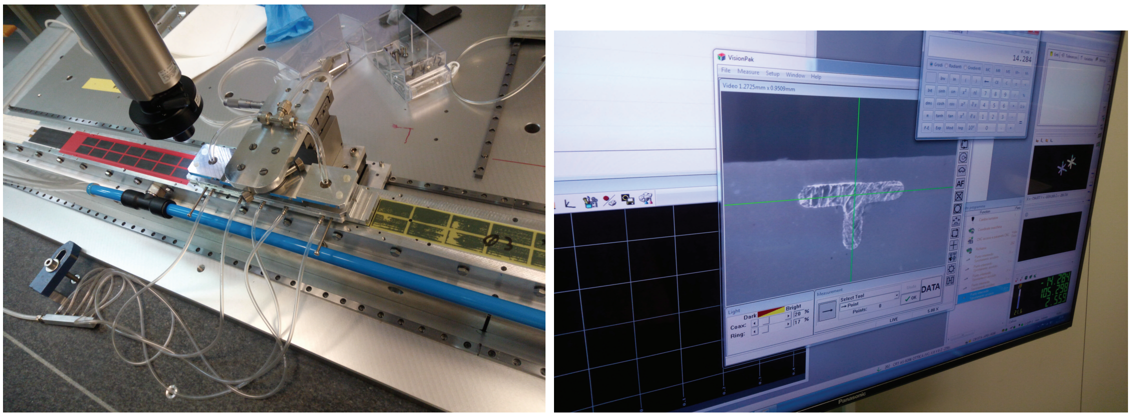

Figure 5: *The left panel shows one carbon fiber Cold Plate on the vacuum base with one glued module and a second one being placed: the carriage holds via vacuum another fiber glass module to be glued on the Cold Plate. A gulung mask (to be removed once the glue is dispensed) is also visible. The right panel show a detail for the marker of the fiber glass dummies as seen from the CMM camera. The dimensions of the marker are ∼100 μm.*

In order to move one step forward, the LNF team planned the production of dummy HICs with fully realistic markers and 16 modules (14 + 2 spares) were produced in Bari by a collaboration of the BA-LNF teams using a Mylar foil (placeholder for the printed circuit) with 4 pad chips at the corners, shown in Figs. 6 and 7. The pad chips are silicon pads of 100 μm thickness which possess the reference markers but no CMOS layer, so they are suitable for realistic manipulation, and alignment tests.

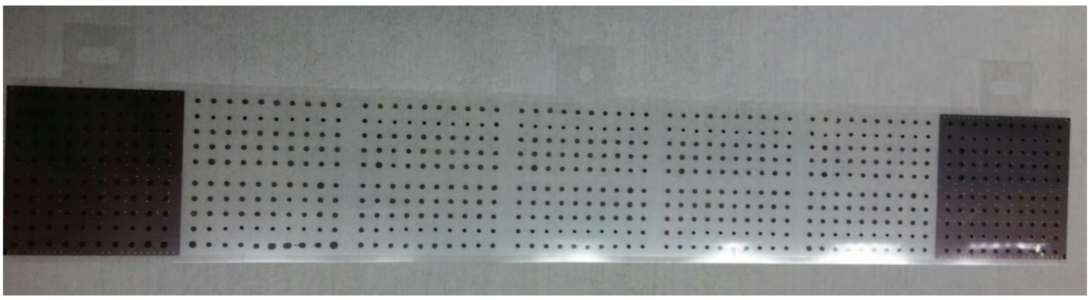

Figure 6: *The picture shows the Mylar dummy HIC. The four pad chips are visible at the corners.*

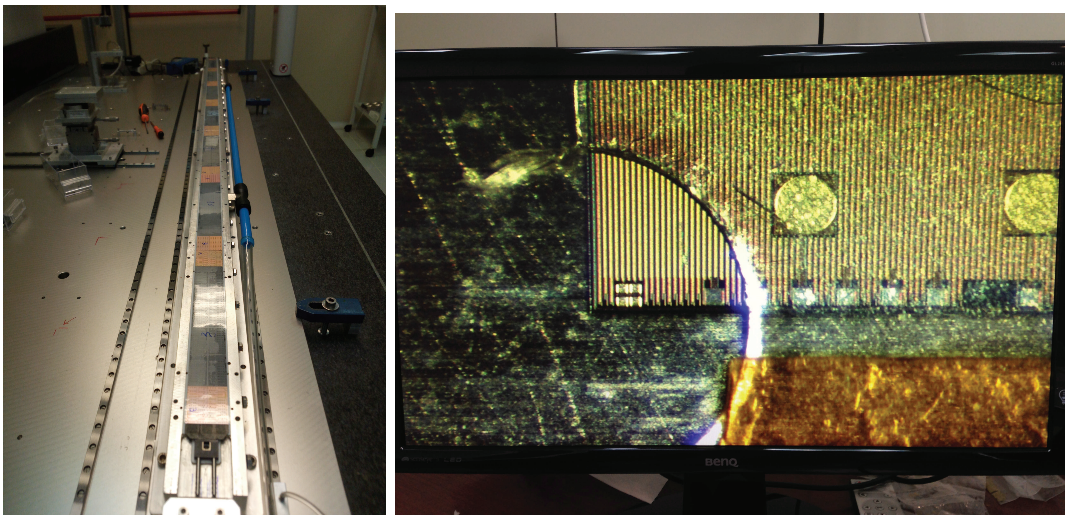

Figure 7: *The left picture shows an aligned HS locked by vacuum on the assembly base. The glued Mylar dummy modules are visible. The right picture shows a magnification of one dummy HIC pad chip at corner, where the reference marker of 5 μm size is clearly visible.*

A first HS with Mylar dummy HICs was produced at LNF before the Christmas break and a second one after the holidays. The full mechanical stave was produced and metrologically tested in January 2017. The result of the module alignment along the stave is very good and in line with the project specifications of $< 20\mu$m (Fig. 8) confirming the high level of expertise gained by the LNF team.

3.0.2 Soldering tests

Each produced HS has 6 electrical interconnections to be soldered in order to be readout. The soldering has to be performed under microscope with a precise timing and temperature of the welding tip. Soldering tests on prototypes of the interconnection structure have been performed at LNF and Torino to select the most appropriate tip, welding material and technique. It turned out that the best results in terms of electrical and mechanical contact are obtained with a welding tip "type 2" delivering a temperature of 183 °C and with a EDSYN Sn62% Pb36% Ag2% soldering wire of cross section of 0.35 mm. The HS soldering is performed on the tool were the HS is produced (HS base) which can be moved from the CMM table to the soldering table. A jig is being designed and will be produced at LNF to precisely place the soldering point under a microscope. The HS base can slide along the jig rails from right to left so that each HIC-HIC interconnection point is soldered. Once the stave interconnections are fully soldiered, a service Power Bus is placed on the jig to perform an electrical connectivity and readout test.

3.0.3 ALPIDE chip readout station

The stave production foresees a wide range of electrical and readout tests both on the incoming HICs and on the outgoing HS and final staves and for this purpose an extensive knowledge of the chip readout electronics and protocols is needed to setup the proper test chain. The LNF team received a chip carrier board equipped with a single pALPIDE4 which was interfaced to a VME based data acquisition system (MOSAIC). The MOSAIC card is controlled by custom software running on a standalone Linux PC (Fig. 9).

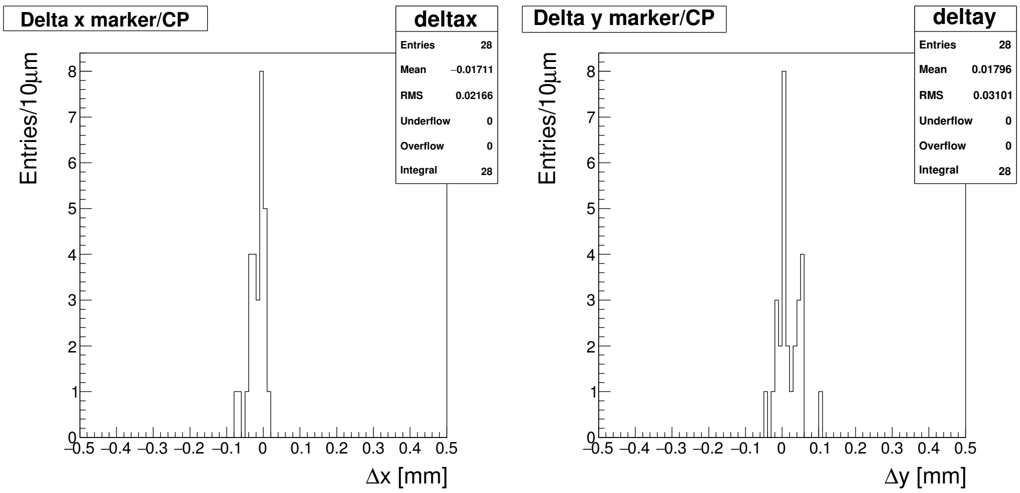

Figure 8: *Left panel: distribution of the differences between the nominal and the measured marker positions along the x (short) direction (dimension) of the Half Stave. The right panel shows the same for the y (long) direction (dimension).*

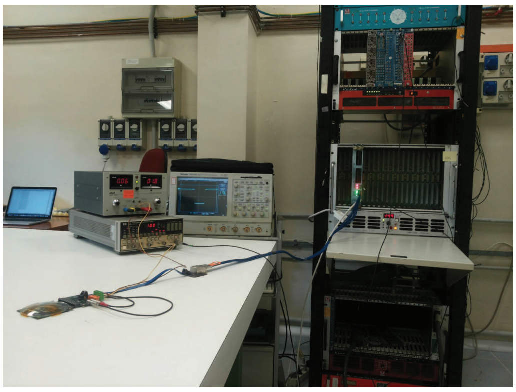

Figure 9: *Test setup for the read-out of the pALPIDE4 chip at the LNF. The single chip carrier board is interfaced to the MOSAIC VME system which is in turn controlled by a Linux computer.*

The test system has been debugged and brought to establish a proper connection between the chip, the MOSAIC and the PC. Afterwards, the MOSAIC board could be configured to test the chip in pulsed mode with different triggers: internal and external. Once the standalone setup and all the tests to assess the basic functionalities are completed, the chip will be exposed to a test beam foreseen for April 2017 at the LNF Beam Test Facility. The single carrier board does not provide a back bias to the pALPIDE4, so we do not expect a signal to noise ratio comparable with the sensors that will operate in production conditions. The final MOSAIC based test setup foresees 2 test stations: one station, equipped with one card will be kept into the clean room and used to test the incoming HICs and the outgoing HS. The other station, equipped with 2 MOSAIC card will be kept in the "gray" room, where it will be used to test the complete stave once the power bus will be soldered. This step is the last validation for the stave to be sent out for the final assembly.

4 EMCal/DCal Status

The LNF team was one of the main actors in the 12 EMCal and 8 DCal super-modules construction and sponsored the readout and trigger unification with the already installed 4 PHOS modules, with the implementation of a common electronic technology (SRU/TRU: Scalable Readout Unit / Trigger Region Unit). This upgrade was carried on during the LHC Long Shutdown 1 in order to cope with the high luminosity data taking at 50 kHz Pb-Pb foreseen for Run 3 and to have a large-area calorimeter coverage. The three systems are sometimes collectively refereed to as "CALO".

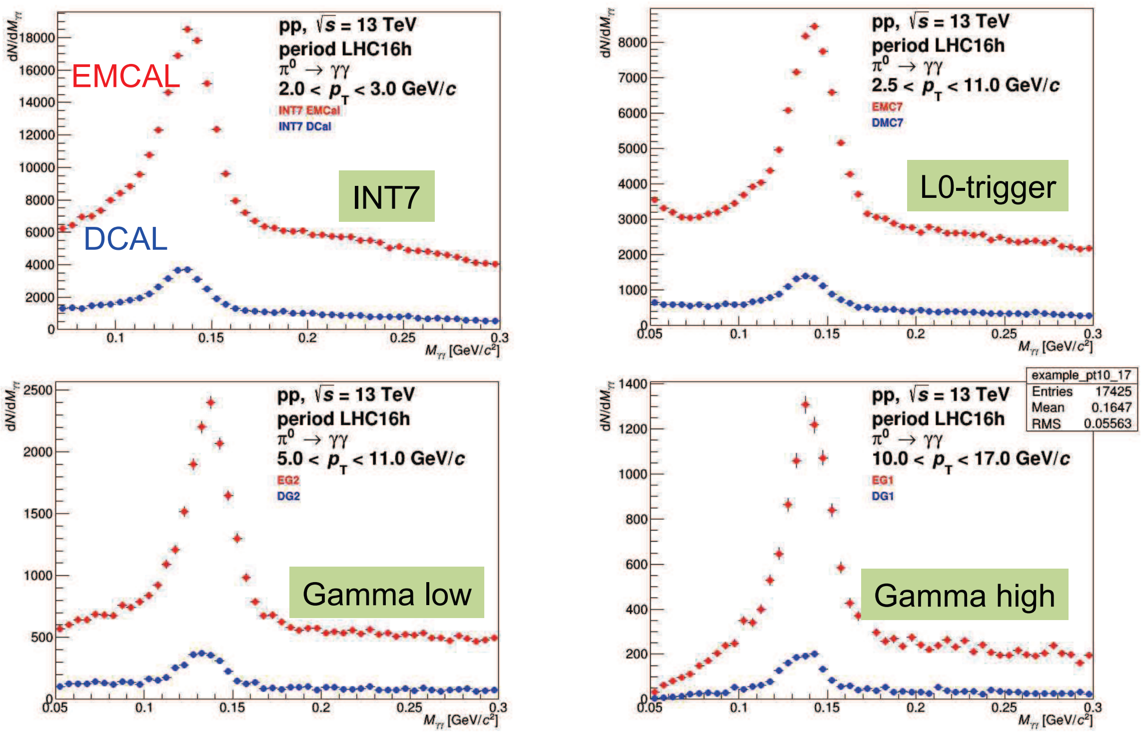

Figure 10: π^0 *reconstruction for the EMCal and DCal calorimeters from different data sets (triggers): Minimum Bias (INT1), Level 0 (L0), L1-γ at low threshold and L1-γ at high threshold.*

The EMCal and the DCal provide fast triggers signals (Level-0 and 1) for photons, electrons, and jets. EMCal/DCal data can be post processed on the ALICE High Level Trigger (HLT) as well. These calorimeter measure the neutral energy component of jets, enabling full jet reconstruction in all collision systems, from proton-proton to PbPb, passing through the pPb collisions. The combination of the EMCal+DCal calorimeters, the excellent ALICE charged tracking capabilities, and the modest ALICE magnetic field strength, is a preferred configuration for jet reconstruction in the high background environment of heavy-ion collisions. The combination of the information coming from the two calorimeter back-to-back arms allows a detailed optimization of background rejection while preserving the crucial jet quenching signals down to very low transverse momenta.

The EMCal/DCal and PHOS participated in physics runs with p-p collisions at 13 TeV, p-Pb at 5.02 TeV, p-Pb and Pb-p at 8.16 TeV taking both MB p-p and p-Pb data along with the whole ALICE. The EMCal/DCal and PHOS L0 and L1 triggers were approved by the Physics Board for the data taking in June and July respectively, and the high integrated luminosity recorded with all CALO triggers is shown in Figures 2,3, and 4. In p-p collisions the thresholds for the L0 single shower trigger was 2.5 GeV, while for the L1 γ-low andγ-high a value of 4 GeV and 9 GeV were used. The thresholds for the jet triggered were jet-low 16 GeV and jet-high 20 GeV, respectively. The EMCal/DCal (PHOS) participation to the physics running was $\sim$88% ($\sim$94%) for MB physics and $\sim$93% ($\sim$98%) for rare triggers. The EMCal/DCal calibration and performance for the different trigger modes is shown in Fig. 10 where an outstanding π^0 invariant mass peak is clearly seen for each trigger mode separately.

The EMCal/DCal system was also used for the J/ψ identification in the central barrel: as shown from Fig. 11 the invariant mass peak can be clearly seen in L1-γ triggered events both at high (EGA2) and low (EGA2) threshold for p_T ranges going from $5 < p_T < 7$, $7 < p_T < 11$, and $11 < p_T < 20$ GeV/c.

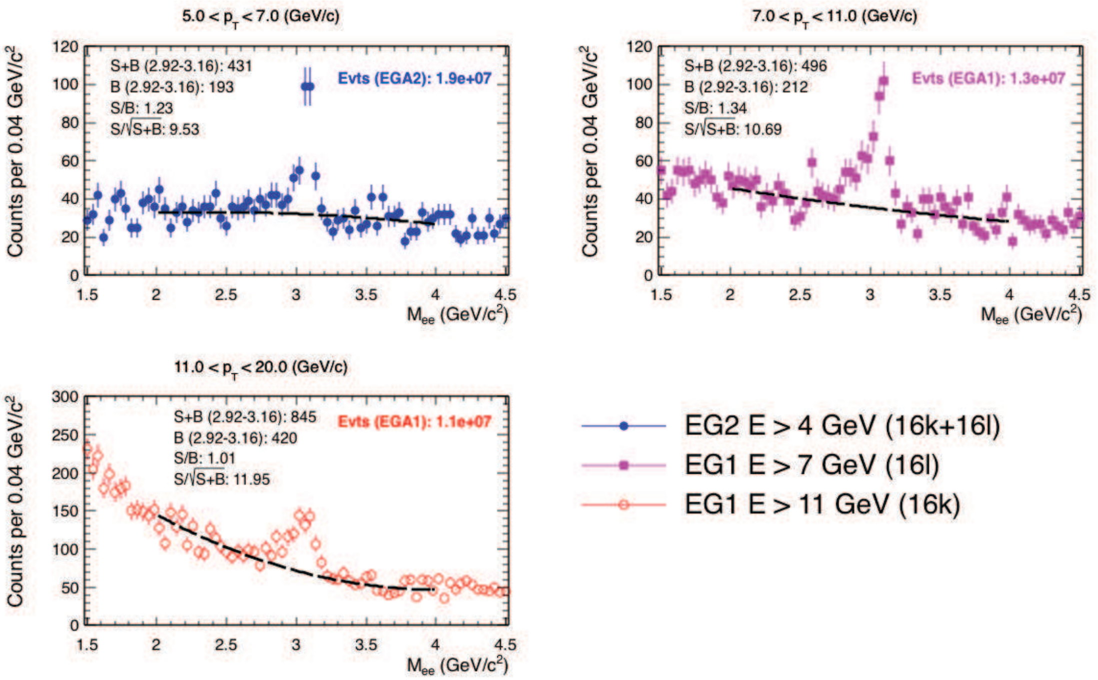

Figure 11: *EMCal/DCal based Jψ identification in the central barrel using L1-γ triggered events both at high (EGA2) and low (EGA1) threshold for different p_T ranges*

The EMCal/DCal also took part to the p-Pb run both at 5.1 and 8.16 TeV. The trigger thresholds have been validated according to the different collision energies and running modes as 5.1 TeV period was devoted mainly to MB physics while the top energy period to rare triggers. In particular, the trigger thresholds were fixed as follows:

5.1 TeV, MB triggers:
L0-γ = 2.5 GeV, L1-γ low = 6.5 GeV, L1-γ high = 11 GeV,
jet-low = 20 GeV, jet-high = 25 GeV

p-Pb and Pb-p at 8.16 TeV, rare triggers:
L0-γ = 2.5 GeV, L1-γ low = 5.5 GeV, L1-γ high = 8 GeV,

jet-low = 18 GeV, jet-high = 23 GeV

An example of the EMCal/DCal performance is shown in Fig. 12 where the η^0 and π^0 peaks are reconstructed from L1-γ data in the range $6 < p_T < 13$ GeV.

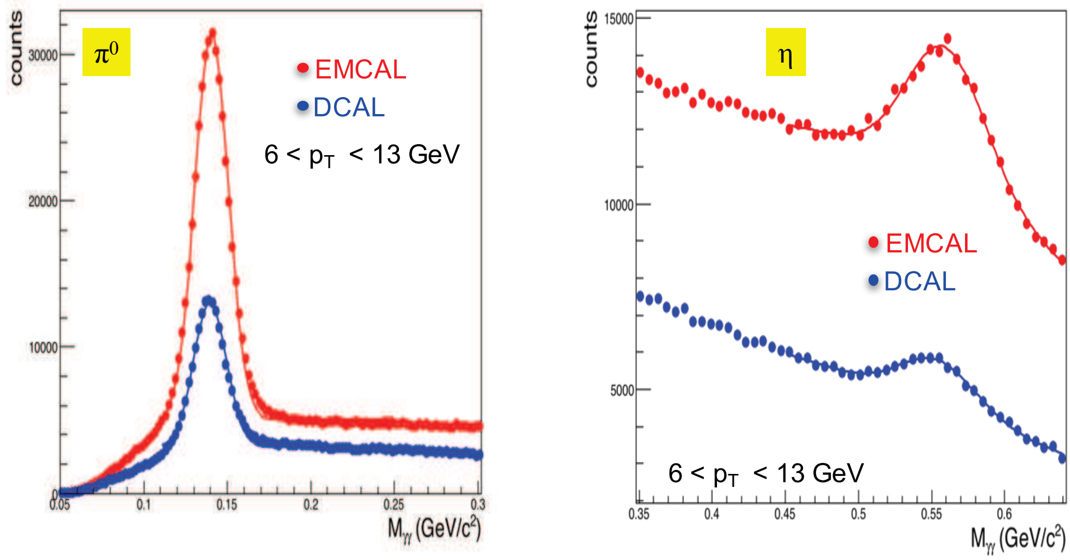

Figure 12: *η and π^0 mesons invariant mass peaks as reconstructed from L1-γ data in the range $6 < p_T < 13$ GeV for p-Pb collisions at 8.16 TeV. The contribution of the two arms of the EMCal/DCal calorimeter system are shown separately.*

4.0.1 Hardware inteventions

The EMCal/DCal calorimeter system is currently being maintained for the EYETS (Extended End of Year Technical Stop) of the LHC. The intervention are driven by issues seen during the 2016 run. In particular a number of in-run recovery action failed because of front end cards not responding. In addition there a firmware update is being done on the readout electronics (SRU). New CAT6/7 Ethernet cables will be used to to connect the front end cards to the FECs SRU to reduce the error rates in the data transmission. A number of SRU units will also be relocated to reduce the mechanical interference with the ALICE TOF services. One LED control unit is being repaired (was affected by the power cut on 20/11/2016) and will be put back in place. One trigger unit (TRU) is being replaced also affected by the power cut and 21 front end card have been removed and are being repaired.

4.0.2 EMCal related papers

The invariant differential cross sections for inclusive π^0 and η mesons at midrapidity were measured using data collected p-p collisions at 2.76 TeV for transverse momenta up to 20 GeV/c. The large p_T was achieved by combining various analysis techniques and different triggers, in particular those provided by the EMCal system. The paper was submitted to Physical Review D with the title "Production of π^0 and η mesons up to high transverse momentum in p-p collisions at 2.76 TeV" (arXiv:1702.00917).

4.1 ALICE scientific output

The ALICE Collaboration has submitted 20 papers in the last year and published 157 papers on international referred physics journals (Fig. 13).

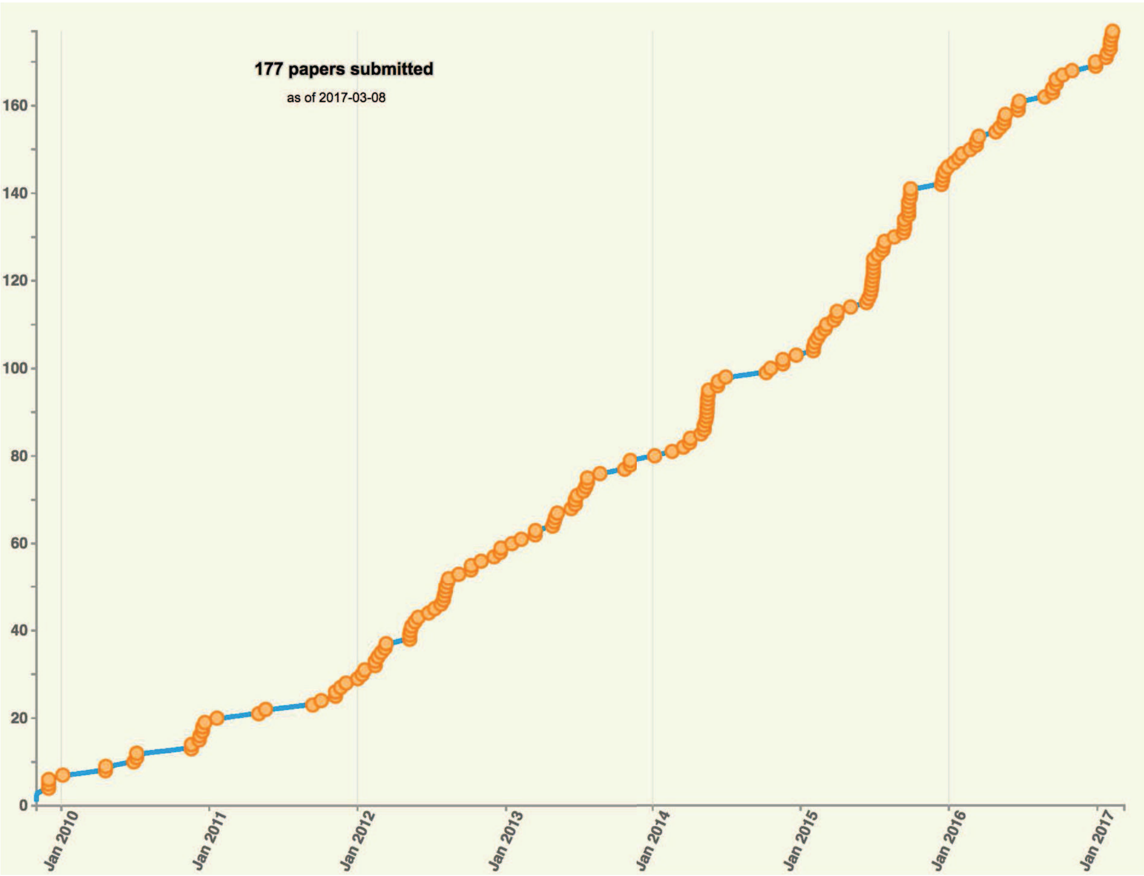

Figure 13: *Timeline of the total number of ALICE papers ("submitted" is to be intended as published+submitted) since the fist LHC beam at 900 GeV on November 23, 2009).*

The full list of ALICE publications can be found online at the link:
http://aliceinfo.cern.ch/ArtSubmission/publications