ALICE activity report 2018

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1 The ALICE experiment

The ALICE collaboration at CERN currently includes 41 countries, 176 institutes, and 1800 members: Italy and INFN have a prominent role participating with 12 groups and about 200 physicists. The Frascati group had a principal role in the construction and operation of the ALICE electromagnetic calorimeters (the EMCal and the DCal), in the operation of the ALICE detector, and in the upgrade foreseen for RUN3 (2021-22-23) with the construction of 1/4 of the new Inner Tracker System (ITS) Outer Layers (OL). In addition, the LNF group has contributed to the analysis of the jets from light flavors and on the extraction of observables related to fragmentation phenomena. From year 2017 the group took direct responsibility for the extraction of the π, K, and p spectra from the newest high-energy data set of p-Pb collisions at 8.16 TeV which is an essential reference analysis for any light flavor physics.

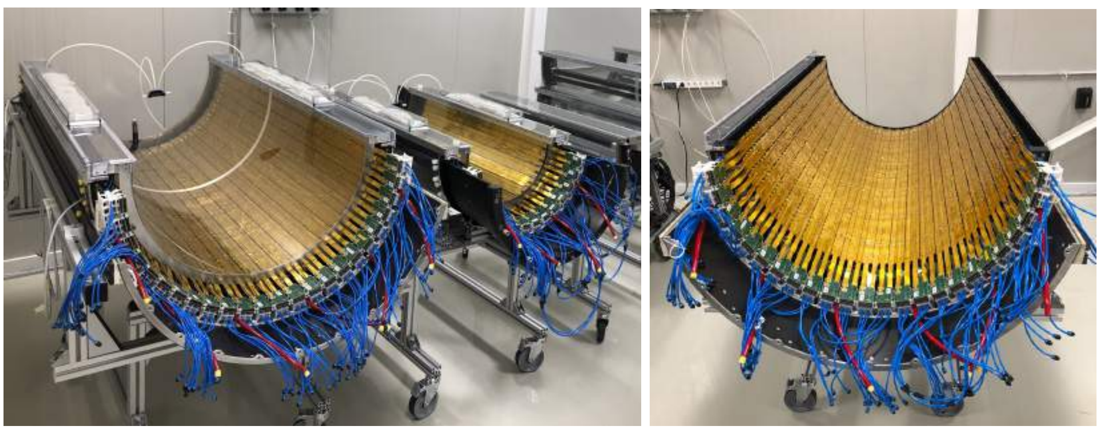

Figure 1: *Half layers construction progress at CERN. Top left: half layer 4 and 6. Top right: detail of half layer 6.*

The construction of the new ITS based on Monolithic Active Pixel Sensors (MAPS) technology is major a upgrade of the ALICE experimental apparatus: this new tracker will replace the existing one (which is based on hybrid pixel sensors, silicon strips, silicon drifts) and shall be installed during the second year of the LHC Long Shutdown 2 at the end of 2018.

At LNF, the infrastructure for the manipulation, processing and production of large area silicon detectors had to be designed and installed, and the know how was developed quickly and efficiently in order to fulfill the demand of an high yield and high efficiency production. The team was trained to work with realistic detector units and the silicon sensors electronic chain. The start of the mass production of functional staves was in March 2018 with a very short (basically 1 unit) pre-production phase.

The assembly-storage cycles are performed in two fully instrumented and optimized clean rooms of 42 m^2 (Cl 10 000, "white room" hosting a fast and flexible Mitutoyo Crysta Apex S 9206 Coordinate Measurement Machine (CMM) with a nominal resolution of 0.1 μm) and 25 m^2 (Cl 100 000, "gray room"), respectively.

The ITS upgrade schedule foresees the start of the commissioning of the already produced half-layers in May-June this year at CERN (Fig. 1) and the installation of the full ITS into the ALICE cavern in summer 2020. In this schema, the 4 OL production sites are producing 27 staves/site accounting for 1/4 of the Outer Layers, including spares.

Given the overall pixel density of the new ITS (12.5 billion pixels), even the fraction of the

OL staves produced at each site (hence at LNF) amounts to 2.7 gigapixels, out-pacing any existing pixel tracker available in HEP at the moment.

This highlights reveal the challenging and the uniqueness of the upgraded ITS detector: extremely small material budget (a factor 4 to 5 smaller than those of similar detectors installed at CERN), boost of tracking performance and spatial resolutions of the order of 5 μm to be able to perform frontier precision measurements requiring access to the rarest physics signals.

2 ALICE data taking

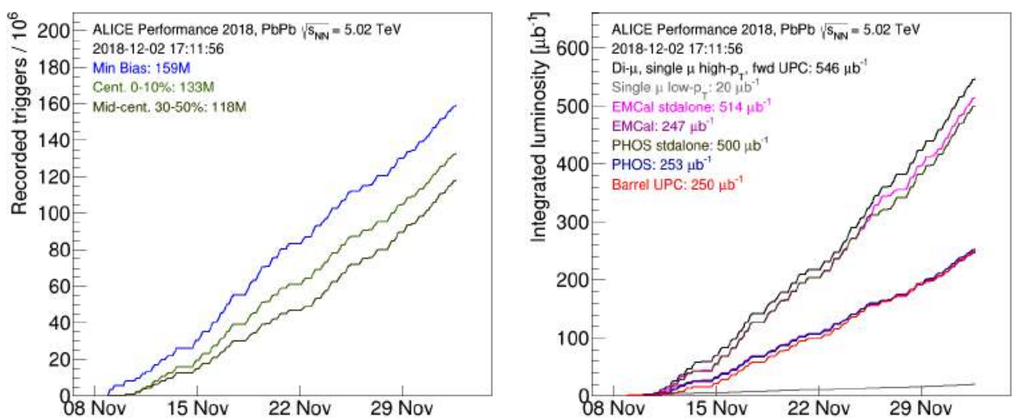

Figure 2: *Left: statistics collected in the ALICE central barrel for Minimum Bias triggers during 2018 Pb-Pb operation. Right: integrated luminosity collected for rare triggers during the same period.*

The ALICE 2018 data taking campaign saw the second Pb-Pb run for RUN2 (2015-18) and was very successful. ALICE which took data with 92% running efficiency and collected 908 μb^{-1} and 160 millions Minimum Bias events. In p-p ALICE has been running stably for the full year, integrating almost 17 pb^{-1} of luminosity, collecting 1 billion Minimum Bias events, and 650 millions of high multiplicity p-p events.

3 ITS upgrade Production Status

In 2021, the LHC will increase the luminosity of the heavy ion beams and deliver to ALICE an instantaneous luminosity of $L = 6 \times 10^{27} cm^{-2} s^{-1}$ corresponding to an interaction rate of 50 kHz in Pb-Pb collisions. The increased collision rate requires the replacement of the ALICE present silicon trackers and TPC readout chambers. The LNF ALICE group joined the Inner Tracker System Upgrade project in 2012, however the effort to match the challenges of the production goals increased dramatically starting from mid 2016. The already existing infrastructure hosted in Bl. 27 / ASTRA (which heat pump was replaced) was completely reorganized to cope with the requirements for the assembly and the manipulation of very fragile and low-thickness (100 μm) silicon sensors with open wire bonds. Two clean rooms have been refurbished during year 2016-18. The purpose of the clean rooms is to parallelize the module production to avoid bottleneck and/or bubbles in the operation pipeline. Each so-called ITS "stave" is composed by two Half-Staves (HS) where an HS is in turn composed by 7 Outer Barrel (OB) base modules (Hybrid Integrated Circuits) containing 2 rows of 7 ALPIDE sensors.

Figure 3: *Left: an OB HIC at the reception test. Center: the HIC is contained in a carrier plate which allows transport, storage, powering, testing, and vacuum gripper placement for handling. The left side of the HIC shows the so-called "tab" used to connect the sensors to the readout system. Once the HIC is qualified for alignment and gluing, the tab has to be cut. Right: the two HS assembled in a stave: the sensors are glued directly on the carbon fiber strips. The blue pipes are the embedded water cooling lines (input and output). The HS are read-out by soldering an extension tab which is the interface with the outside world of the 98 ALPIDE chips. It can be clearly seen that the two HS come in different flavors (upper and lower) which have a partial longitudinal overlap requiring a definite sequence of installation.*

The ALPIDE sensors are aligned and glued to the HIC printed circuit using a custom assembly machine in the HIC production centers (Bari, Strasbourg, Liverpool, Wuhan, and Pusan) and then are bonded with three Al wire per pad to ensure redundancy to wire breaking. The wire bonds are not protected: this avoids the introduction in the detector of materials that can degrade with time but on the other hand introduces a "zero tolerance" also in case of minor mishandlings. In total an HS features 98 ALPIDE sensors (7 HICs and 7×2 chips per HIC) for a total of 51 megapixels.

The two rows of sensors are readout independently using a Master-Slave scheme: the first sensor of the row acts as a master collecting the hits from the remaining 6 slaves in addition to its own. Such a setup is suitable for the ITS outer layers as the expected occupancies are much less

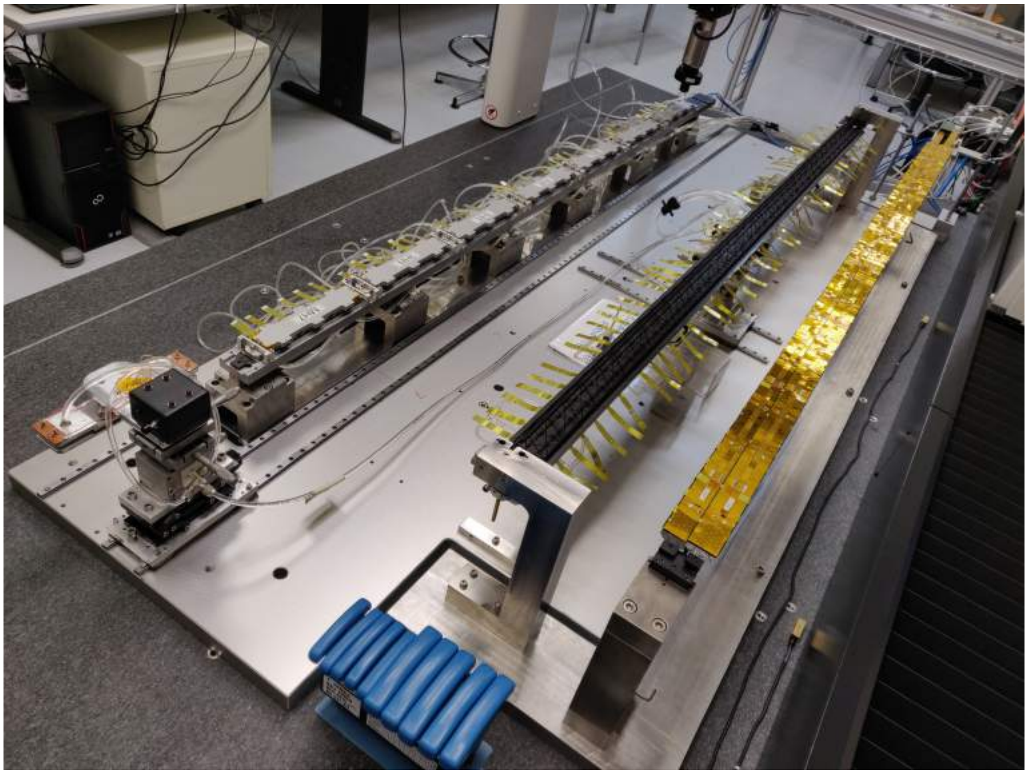

Figure 4: *Three tasks going on in parallel on the CMM jig. Station 1 (left) contains 7 HICs aligned and glued to make an HS. The vacuum grippers used to bring the HICs from the carrier plates to the gluing position can be seen as they are removed only when the Araldite 2011 glue has cured. Station 2 (center) contains an already finished stave ready to be moved in the "gray area" for the installation of the PB and BB, and their folding. Station 3 (right) contains a finished stave, with the PB and BB already folded, for the final metrology.*

then those of the inner barrel being as close as 22 mm to the interaction point. In this case the ALPIDE sensors which make up an Inner Layer (IL) stave are readout individually to cope with the rates.

Before usage, the HICs have to the electronically tested for integrity using the "tab" interface shown in the left and central photos of figure 3. The high density "firefly" connectors are soldered directly on the HIC printed circuit and once the HIC is tested must be cut at the level of the pad contacts in order to make the HIC alignable.

The cut is performed using a custom high-precision cutting system which rail can run the blades only 50 μm away from the silicon sensor edges as shown in the left part of figure 3. The cut HICs possess contact pads for the CLK, CTRL, and DATA lines at both ends. At this point 7 of them can be aligned and glued (chip side facing down) on water-cooled carbon fiber strips to make the HS. The HICs have reference markers which can be aligned (using the CMM) along the longitudinal and transverse directions with an accuracy of the order of 10 $\mu m/1.5m$. After the alignment the HICs making up an HS must have the module-to-module interconnections soldered and the termination resistors removed (except the HIC in position 7) to enable the readout lines

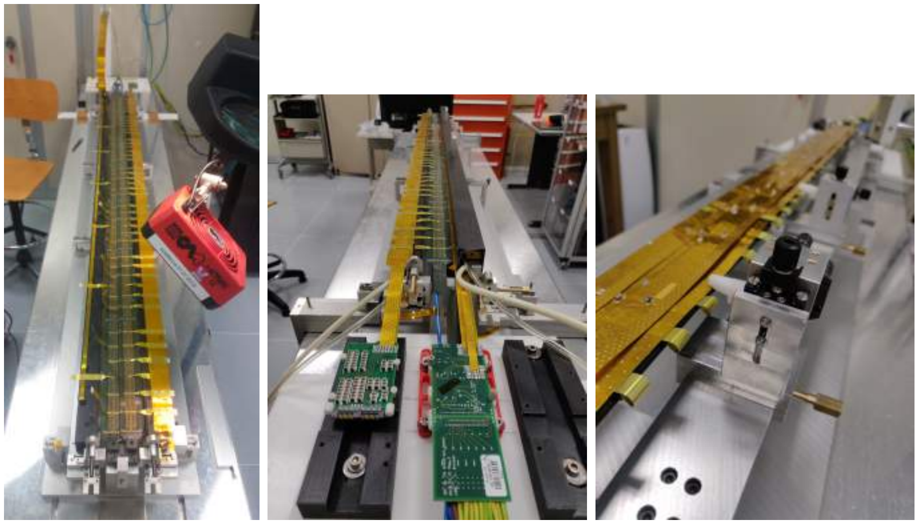

Figure 5: *The left picture shows a stave on the folding jig with the power and bias bus distributions ships ready for soldering on the handling bars. The upper PB is rolled out to allow the soldering of the BB to the corresponding HIC cross cables. Once the BB is soldered, the PB is lowered to be soldered to the remaining cross cables. The center figure shows a PB+BB assembly rotated and inserted into the U-arms of the upper half stave (keep in mind that the HS is upside-down in this position) with the filter board connected to the break-out board from the power board. In this position the HS is tested to make sure no bonds were damaged by the folding procedure. The carbon fiber handing bar is removed if the test is successful. The right photo shows the two PB+BB systems folded and the insertion of the remaining (smaller) U-arms to lock the busses into position.*

along the HS. Each HIC position along the HS is bit encoded by 3 resistors which are removed using soldering tweezers to program the module address.

As mentioned above, two HS are needed to make a stave. The HS come also in two flavors: upper and lower and they must be glued to the carbon fiber support frame (Space Frame, SF) in the sequence (upper, lower) as there is an overlap of 2 mm between them as shown in the right part of figure 3. The produced stave is then moved out from the CMM jig to the “Gray Area” for the soldering of the power distribution lines (Power Bus - PB - and Bias Bus - BB) and for additional electronic testing. The “Grey Area” also hosts the incoming and outgoing storage facilities.

The CMM jig has three stations: station 1 is used to perform the HIC alignment and gluing for an HS of given flavor, while the second station is used to align and glue an already soldered HS to the support structure (SF). The third station is used to validate the finished stave metrologically before and after the installation and folding of the power and bias distribution lines (Power Bus, PB and Bias Bus, BB) as shown in figure 4.

Once the Stave is assembled it is moved into the “Gray Area” for the installation of the power distribution system and the final tests. The two HS have separate powering called PB(BB)-U and PB(BB)-L and their relative filter boards, where L stands for lower and U stands for upper. The assembly of PB, BB, and filter board is soldered on a custom jig were the required ceramic capacitors (Murata GRM 220 μF) are first soldered to the PB. The position of soldering defines if the PB is of U or L type. The amount of tin that has to be used to solder the capacitors must be carefully controlled in order to avoid the introduction of extra thickness which can cause mechanical interferences once the stave is inserted into the half barrel. The folding jig has two handling bars which can hold the PB and BB stripes in place using suction cups. These bars are fixed to the jig by means of special pivots screws which can first rotate, then step down and slide. The upper PB+BB assembly has to be inserted between the HS-U and HS-L inside special holders glued on the HS called U-arms. More U-arms are put after the folding to ensure the PB+BB system cannot move and is kept at an appropriate distance from the bonds underneath.

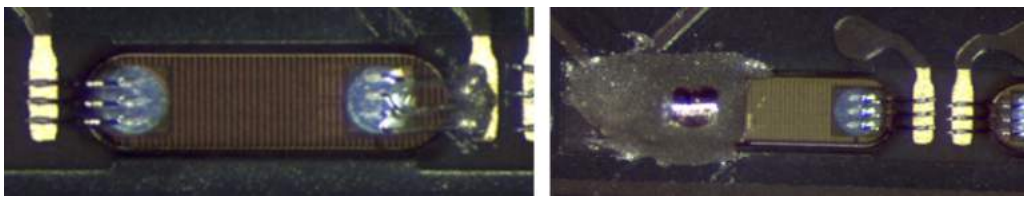

Figure 6: *Left: wire bond repair with metal insertion embedded in conductive glue. Right: wire bond repair with conductive glue only.*

The stave is finally inserted in an aluminum box which is in turn closed with an envelope to keep the relative humidity under control. The Al box is inserted in a wooden box which has a suspension system to minimize mechanical shocks during the transport. The temperature must be also controlled and it shall never drop below 15° during the transport. At the time of this publication 13 staves have been already sent to CERN and the production of stave 20 is about to start (representing 70% of the planned LNF quota).

The production rate for the LNF started in spring 2018 and reached a sustained rate of 1 stave/week at the end of 2018 (see figure 7). The present production yield is 91% (fraction of detector grade HS). The gap during the month of August-September 2018 was due to the holiday break and to the effort made by the LNF team to develop a technique of wire bond repairs using different techniques (metal insertions) and different conductive glues. A series of wire bonds mass repairs were conducted on a test HIC which was then sent to the Pavia climatic chambers for aging tests. The conductive glue (Ablestik 57C) was finally used to successfully repair one bonding on a production stave and it's being considered as a standard tool to recover lost sensors (figure 6).

In conclusion, the ITS production in Frascati has successfully ramped up in 2018 and is proceeding at a very good rate and high yield. As the LNF production capability is comparable or higher then other production sites, load balancing to help the sites lagging behind may be foreseen in 2019 to make sure that all the OL staves will be at CERN on time for the ITS surface commissioning (the Inner Barrel construction is already completed).

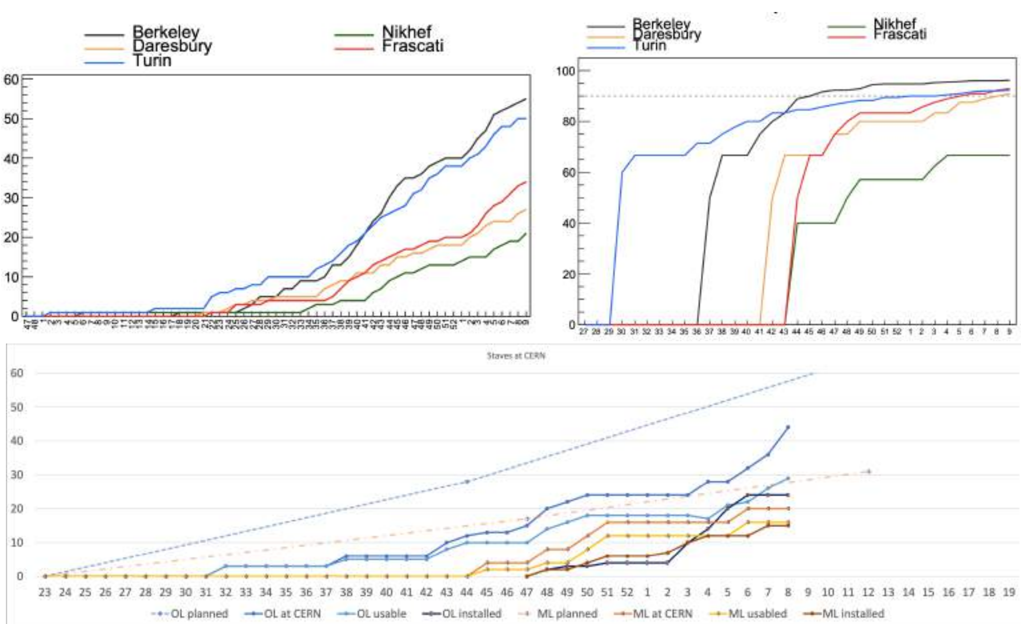

Figure 7: *Top left: integrated HS output from the Outer Layers production centers. The red line is the LNF production for detector grade HS. Note that the Middle Layers production is only apparently faster since the ML HS are shorter (4/7 of an OL HS). The August-September gap for the LNF production is due to the time devoted to develop a wire bond repair technique using conductive glues, and the derivative for 2018 is excellent. Top Right: stave yield for the different production centers. Also in this case the LNF performance is excellent. Bottom: overall all production rate and expected input of staves at CERN. The trend is converging to the required rate.*

4 Physics contribution

The LNF group is responsible for the analysis aiming at the extraction of spectra for pions, kaons and protons in p-Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV with ALICE. The data set collected at the end of 2016 represents an important chance to test the emergence of possible initial state effects, by comparing the spectra of identified light hadrons extracted in this dataset to the ones measured in previous pp and Pb-Pb data in a wide transverse momentum range. LNF group performed the

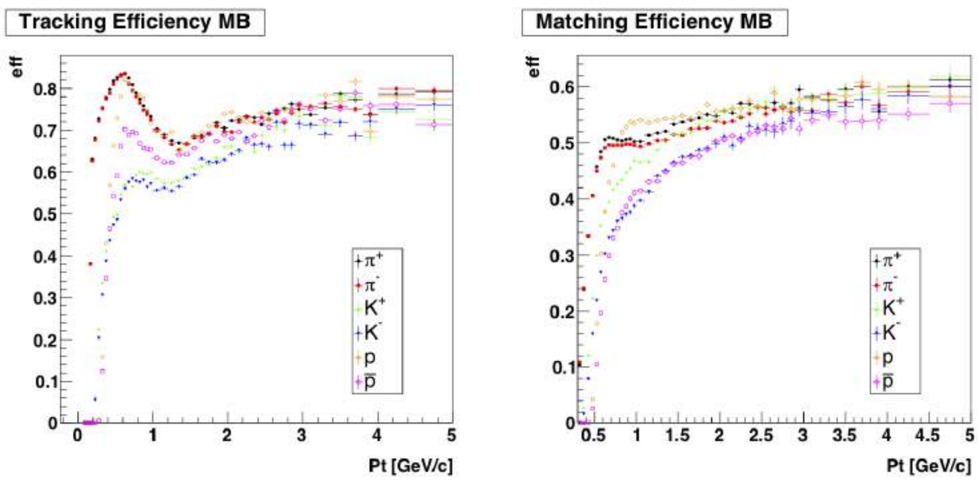

Figure 8: *Left panel: Anti-p and K^- tracking efficiency include Geant3/Geant4 and Geant3/FLUKA corrections respectively. Right panel: Matching efficiency. Very slight dependence on multiplicity, but big statistical fluctuation: the MB is used to correct the spectra*

analysis at midrapidity over a wide transverse-momentum range (100 MeV/$c < p_{\mathrm{T}} <$ 20 GeV/c) for different multiplicity classes ranging from central to peripheral ones. For the low-p_{T} part, the excellent tracking PID capabilities have been employed and matched to the low-to-medium momentum tracks reconstructed and identified through the Time-Projection Chamber (TPC), that represents the main tracking system of the ALICE detector. For both the ITS and the TPC, particle identification is based on the measurement of the particle energy loss.

During last year, LNF group finalized the spectra extraction with the three subsystems, and proceeded with the spectra combination in order to extract the light-flavor yields in the whole p_T range. In particular, raw spectra from ITS, TPC and TOF (Time Of Flight) were corrected for efficiency 8 and contamination from secondary particles (*e.g.*, the ones from materials or from weak decays) to produce the final, corrected spectra. Systematics were evaluated individually for the three analyses in the different multiplicity classes. Parallel to the multiplicity dependent analysis, a Minimum Bias analysis has also been performed, integrating the results on the full multiplicity range.

Once the systematics evaluation has been completed, ITS, TPC and TOF spectra were compared on the overlapping regions, proving full consistency of the three analyses. Spectra have been then combined through a suitable algorithm, that takes into account the systematic uncertainties through an appropriate weighting procedure. The final spectra are now being fitted through phenomenological descriptions, as the *Blast-Wave* fit, aiming at the final extraction of the relevant parameters for constraining the underlying mechanism responsible of the light-hadron production.

As the final step, the present measurement on p-Pb data will be combined with parallel measurements on pp data to extract the so-called *nuclear modification factor*, that will eventually shed light on the emergence of possible cold-matter and/or initial state effects in the p-Pb system.

4.1 ALICE scientific output

The ALICE Collaboration has submitted roughly 100 papers in the last year and to date published 240 papers on international referred physics journals (Fig. 9).

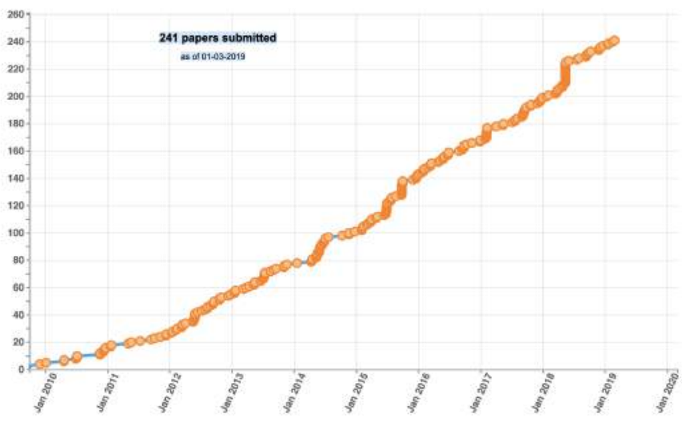

Figure 9: *Timeline of the total number of ALICE papers ("submitted" is to be intended as published+submitted) since the fist LHC beam at 900 GeV on November 23, 2009).*

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