ALICE activity report 2019

N. Bianchi, E. Dané, A. Fantoni, P. Gianotti, M. Matteo (Tec.), P. F. Toledo Matuoka (Ass.),
V. Muccifora, P. Larionov, R. Lenci† (Tec.), A. Orlandi (Tec.), E. Paoletti (Tec.), G. Papalino† (Tec.),
S. Pisano (Ass.), L. Passamonti (Tec.), D. Pierluigi (Tec.), A. Pournaghi (Ass.)
F. Ronchetti (Resp.), A. Russo (Tec.), E. Spiriti, M. Toppi, A. Viticchié (Tec. Ass.)
† *LNF Electronic Service*

1 The ALICE experiment

The ALICE collaboration at CERN currently includes 39 countries, 175 institutions, and 1917 members. In turn, INFN participates with 12 groups for a total of about 200 physicists. The INFN-Frascati group is a very active contributor to the scientific output of the collaboration in terms of detector construction, operation, and physics analysis. In fact, the INFN-Frascati group played a key role in the construction and operation of the ALICE electromagnetic calorimeters (the EMCAL and the DCAL), in the upgrade foreseen for RUN3 (2021-24) with the construction of 1/4 of the new Inner Tracker System (ITS) Outer Layers (OL), and in the operation of the entire ALICE detector (Run and Commissioning Coordination, 2013-15 and 2019-21).

This report will summarize the results obtained in Frascati for the construction of the new ALICE Monolithic Active Pixel Sensors (MAPS) ITS which has replaced the old Run 1-2 device (based on hybrid pixel sensors, silicon strips, silicon drifts).

A production infrastructure for large area silicon sensors was designed and installed at LNF and the group quickly developed the know-how needed fulfill the demand of an high yield and high efficiency production rates. The mass production of functional staves (started in March 2018) ended in June 2019 with a short tail of spares production at the end of 2019.

The assembly-storage cycles were performed in two fully instrumented and optimized clean rooms of 42 m^2 (Class-10000, 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 (Class-100000), respectively.

The produced staves have been assembled on the surface at CERN and the commissioning of the inner and outer barrels started in June 2019. The INFN-Frascati group is taking part in the commissioning campaign by covering its quota of the 24/7 detector shifts (the installation of the new ITS into the ALICE cavern is scheduled for the end of July 2020).

The results obtained by the INFN-Frascati group in the extraction of the π, K, and p spectra from the newest high-energy data set of p-Pb collisions at 8.16 TeV (an essential reference analysis for any light flavor physics) will be also discussed.

Finally, since fall 2019 the INFN-Frascati group participates to the ALICE Run Coordination (in charge of the global ALICE commissioning and data taking operations until 2021), to the Physics Board, and to the Management Board.

2 ALICE commissioning

In 2018, the ALICE data taking campaign was successfully closed by the second Pb-Pb run for Run 2 (2015-18): overall, the running efficiency has been around 92% and ALICE collected 1.34 nb^{-1} in Pb-Pb, 43.3 nb^{-1} in p-Pb, and 66.3 pb^{-1} p-p.

Once the LHC entered Long Shutdown 2 (LS2), the ALICE activities focused on the upgrades: the old ITS and the TPC were extracted from the cavern in the first part of the year. The old ITS was decommissioned and is now part of the permanent exhibition at the ALICE site (P2). The TPC was parked in the large clean room at P2 for the replacement of the MWPC end-caps with the new 4-foil GEM chambers. The replacement of the chambers and their services started in March and ended in June 2019. The new front-end electronics was installed in October 2019 and the new chambers have been tested with X-ray irradiation in November. The pre-commissioning phase started in December 2019 with sector-by-sector laser and cosmic runs. The installation of the TPC in the cavern is scheduled for the end of March 2020.

The two half-barrels of the other ALICE main tracking device - the new ITS - were fully assembled by the end of 2019 on the surface at CERN as shown in Fig. 1. The Inner Barrels were included in the readout and were routinely participating in threshold scans, fake-hit rates and cosmic runs. On the other hand, the Outer Barrels underwent a complete powering campaign and will be included in the running in March 2020. The installation of the ITS in the cavern is scheduled for the end of July 2020, while the start of the global ALICE commissioning is foreseen for November 2020.

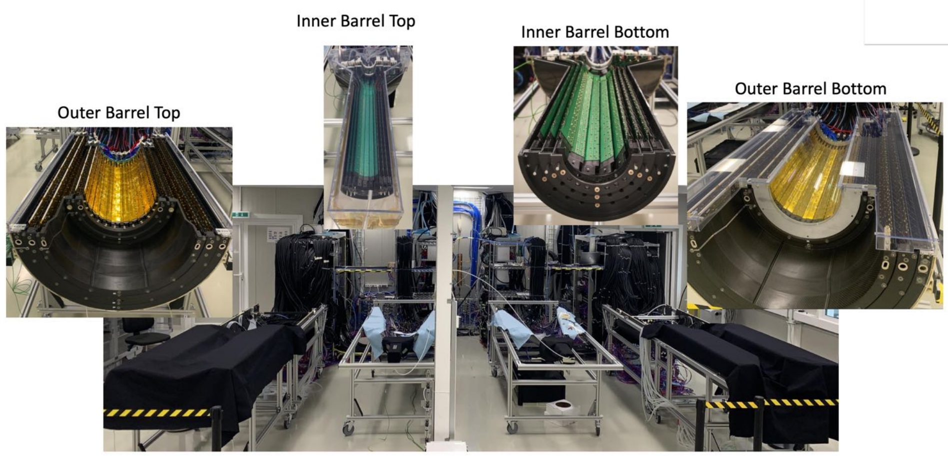

Figure 1: *The full ITS constructed in the clean room at the CERN Meyrin site. The Inner and Outer Barres can be seen in the center of the photo covered with a black tissue during commissioning data taking to avoid light induced noise. Details of the fully assembled inner and outer layers can be seen on the top photos.*

The construction and upgrade of the remaining ALICE detectors during 2019 did match the milestones of the master schedule and is compatible with the LHC plans and will not be discussed in detail here. In 2021 the LHC will increase the luminosity of the heavy ion beams and deliver an instantaneous luminosity $L = 6 \times 10^{27} cm^{-2} s^{-1}$ or higher. The upgraded ALICE detector is able to cope with the increased collision rates using the new GEM TPC and the MAPS ITS and will run at an interaction rate of 1 MHz during p-p operations and 50 kHz in Pb-Pb collisions.

As mentioned in the introduction, the INFN-Frascati group is in charge of the global ALICE commissioning and operation for the critical phase of the restart of the LHC after LS2.

3 Contribution to the ITS upgrade

The LNF ALICE group joined the ITS Upgrade project in back in 2012 and entered the development and pre-production phase in 2016. The ITS mass production started in February 2018 and was fully completed by the end of 2019. The existing infrastructure hosted in Bldg. 27 (ASTRA) was completely reorganized to cope with the assembly and the manipulation of a large quantity of fragile and low-thickness (100 μm) silicon sensors with unprotected wire bonds.

The assembly workflow was carried out in two clean rooms to parallelize the stave production to avoid bottleneck and 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 Layers (OL) modules (Hybrid Integrated Circuits or HIC, containing 2 rows of 7 ALPIDE sensors each). An OL-HS is 1500 mm long while a Middle Layer HS (which is using the same HICs) is 800 mm long and contains only 4 HICs. The Frascati site, together with the other EU sites, has been assembling only OL-HS (composed by 7 HICs). ML-HS (composed by 4 HICs) were assembled in Berkeley (see Fig. 2 for details).

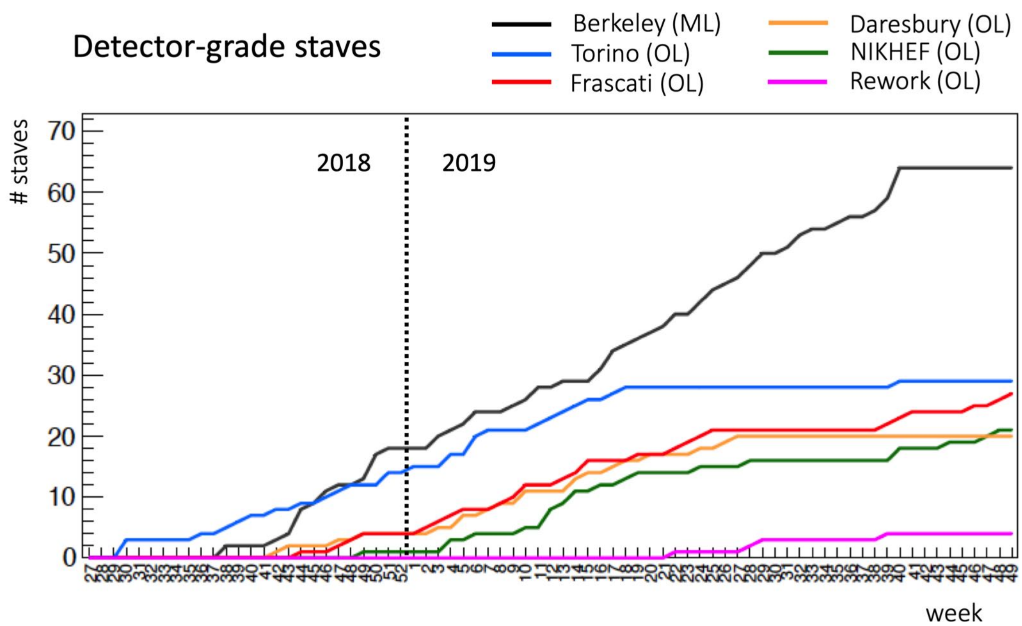

Figure 2: *Detector grade stave production rates for the different sites: OL staves (1500 mm long) were produced in Frascati, Torino, Nikhef, and Daresbury. ML staves (800 mm long) in Berkeley where the production rate was intrinsically higher due to the smaller dimensions (the black ML curve has to be scaled down by 4/7 to compare with the other OL curves). The Frascati performance is quite remarkable: comparable to Torino (where the development started more the one year before) and significantly higher then Nikhef and Daresbury. Frascati also contributed to the "rework" curve since the technique for recovering broken staves was developed at LNF.*

To construct an OL-HS, ALPIDE sensors are positioned and glued to a flexible printed circuit using a custom assembly machine in the HIC production centers (INFN-Bari, Strasbourg, Liverpool, Wuhan, and Pusan). The sensor pads are then bonded with three Al wire to ensure some degree of redundancy against breaking. However, the wire bonds are not protected to avoid the introduction of materials that can degrade with time and working with exposed bonds implies a very reduced tolerance also in case of minor mishandling. In total an OL-HS features 98 ALPIDE sensors (7 HICs and 7×2 chips per HIC) so that a full Stave brings 102 Megapixels: i.e. the Frascati site alone has assembled a "detector" of roughly 2.8 Gigapixels resolution.

The HICs used to assemble an HS carry reference markers which can be aligned using the CMM along the longitudinal and transverse directions with an accuracy of the order of 10 $\mu m/1.5\ m$. After the alignment the HICs must have the module-to-module interconnections soldered and the termination resistors removed to enable the addressing. By design, the resulting HS come in two flavors: upper and lower and they must be glued to the carbon fiber support frame in the proper sequence. The produced stave is then moved out from the CMM jig for the soldering of the power and bias lines and for additional electronic testing.

The folding of the power lines (power and bias bus) is carried out on a custom jig which has two handling bars holding the flat cables in place using suction cups.

Once the power bus is folded and fixed using custom designed spacers, the stave is inserted

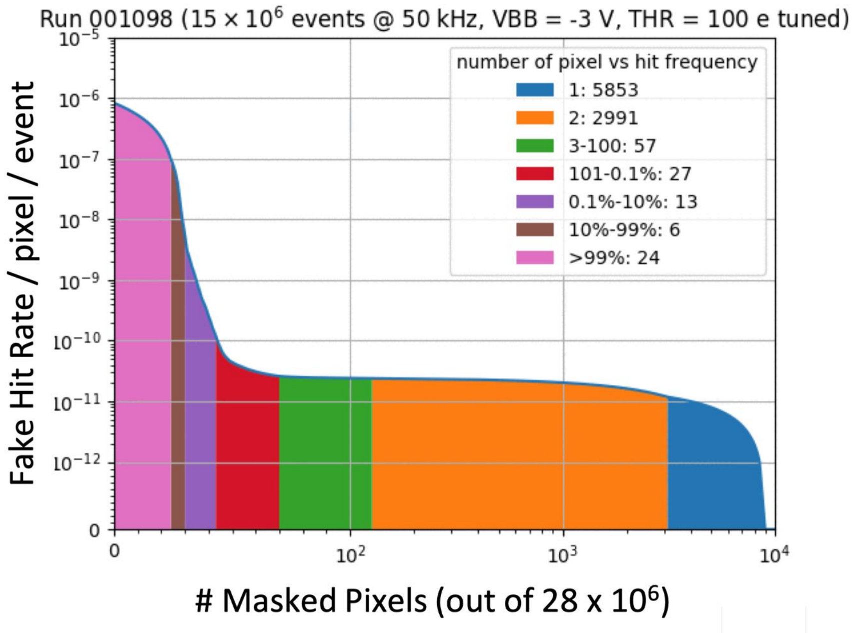

Figure 3: *Fake hit rate as a function of the number of masked pixels. Masking just 30 pixels eliminates 99% of the fake hits.*

in an aluminum box which is closed with an envelope to keep the relative humidity under control. The Al box is in turn fixed on a suspended tray placed into a wooden box to minimize mechanical shocks during transport. The temperature must be also controlled and the procedure foresees that it shall never drop below $15°C$ during the shipment.

The production rate at LNF reached a sustained rate of 1 stave/week between the end of 2018 and June 2019 while the final production yield reached 97% (fraction of detector grade modules) for 29 produced staves (27 nominal staves + 2 spares). The INFN-Frascati group also developed a recovery procedure for damaged staves: since a stave is composed by 2 HS a tool was engineered at LNF to detach the already glued HS from the support to reuse the detector grade parts in a new stave.

The OL staves produced at LNF, together with the one produced in INFN-Torino, Nikhef, Daresbury and the ML staves produced in Berkeley have been assembled at CERN into the so called Half-Barrels (top and bottom). The two half-barrels have been connected to the cooling and readout electronics services on the surface (clean room of Bldg. 167 in Meyrin) where the commissioning started in mid 2019. The surface commissioning of the ITS includes a powering campaign to assess the detector stability and continuous running of thresholds scans and noise (fake hit rate, see Fig. 3) runs to validate the number of bad or noisy pixels. Cosmic runs are routinely taken to validate the intrinsic alignment of the detector, Fig. 4. The Frascati group has fulfilled its quota of the commissioning shifts at CERN for 2019 and has started to gain expertise in the detector operation.

In conclusion, in only three years (2016-19) the INFN-Frascati group has successfully acquired and mastered the technological know-how for processing and producing large-area, small material budget, MAPS-based silicon tracking detectors. The LNF site exceeded the production

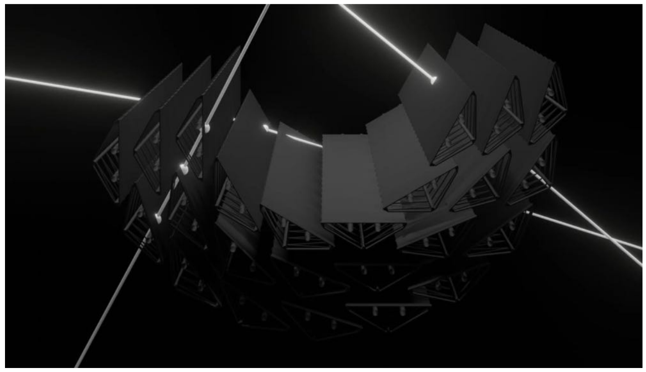

Figure 4: *Rendering of real cosmic ray events in the Inner Half Barrel (1 event/s).*

of the assigned nominal quota of detector grade staves and fulfilled the goals within the allocated time and with a high yield. In addition, spares have been produced and a technique to recover broken staves developed and applied. The group is now focused on the ITS surface commissioning (assigned quota of commissioning shifts was fulfilled for 2019) and preparing for the installation of the detector in the ALICE cavern.

Figure 5: *The INFN-Frascati team celebrates the end of the ITS upgrade production in the ASTRA clean room. The 29 ITS staves assembled at LNF add up to total of 2.8 Gigapixels and can be considered one of the largest silicon pixel detectors currently existing in the world.*

4 Physics contribution

During 2019, the INFN-Frascati group analysis activity has been devoted to the finalization of the measurement of light hadron spectra on ALICE data collected through p-Pb collisions at a center-of-mass energy $\sqrt{s_{NN}} = 8.16$ TeV. Light-flavor spectra represent indeed an essential tool in understanding the underlying mechanisms in Pb-Pb collisions. In fact, they allow to test the emergence of a deconfined phase - the so-called **Quark-Gluon Plasma** (QGP) - through the analysis of the spectral shape of hadron p_{T} distributions. From the latter, it is possible to extract the thermodynamic properties of the system created during the collision, as the kinetic freeze-out temperature and the fireball expansion velocity. However, some phenomena typically attributed to the emergence of a deconfined phase can be mimicked by alternative processes, as the ones known as *Cold Nuclear Matter effects*, as the modification of the parton distribution functions in the nuclear environment or shadowing effects. These effects can be studied by analyzing p-Pb collisions, where no deconfined phase should appear, given the smaller energy density produced in the collision..
The INFN-Frascati group is responsible of the analysis aimed at measuring light-flavor spectra in p-Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV, by using information from the relevant ALICE sub-detectors, namely the *Inner Tracking System* (ITS), the *Time-Projection Chamber* (TPC) and the *Time-Of-Flight* (TOF). By combining the information from the three detectors, the final spectra for pions, kaons and protons have been extracted. They are shown in Fig. 6 as a function of the different multiplicity classes and for Minimum Bias events. The hardening of the spectral shape for increasing multiplicity is normally understood, in Pb-Pb collisions, in terms of radial flow. However, the same shape is observed in p-Pb data. Another interesting observable that can be extracted from transverse momentum distributions is the ratio to pions of the different species. It is shown in Fig. 7, and it describes the chemical compositions of the system.

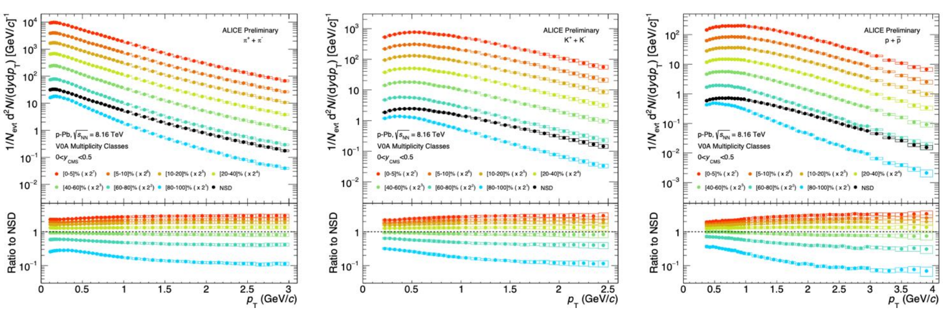

Figure 6: *Transverse momentum spectra for pions, kaons and protons for different multiplicity classes and for Minimum Bias.*

It can be noticed that there is a continuous evolution of the ratios when moving from the low multiplicity event collected in pp collisions to the high multiplicity ones from Pb-Pb collisions. As to the thermodynamic properties of the system, they can be extracted by simultaneously fitting the spectra of different hadrons through a proper functional form, namely the Blast-Wave model. In Fig. 8 the results of the fit are shown, *i.e.* the kinetic freeze-out temperature as a function of the expansion velocity for different multiplicity classes, together with the results for different systems and energies. The new p-Pb results confirm the trend already observed on p-Pb data at $\sqrt{s_{NN}} = 5.02$ TeV, with a T_{kin} a little bit higher.

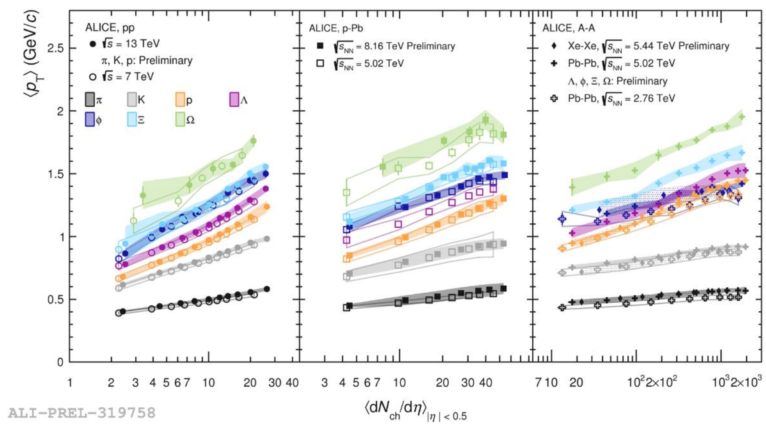

Figure 7: *Ratio to pions of different particles for several colliding systems and energies, as a function of the final state multiplicity.*

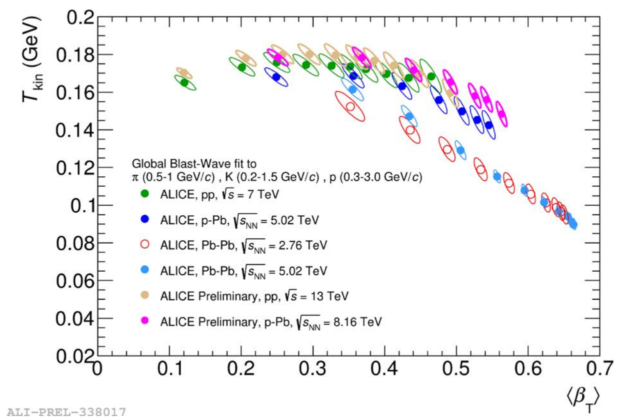

Figure 8: *Kinetic freeze-out temperature and expansion velocity of the system created in the collision for different colliding systems and energies.*

On May 2019 the analysis was approved by the collaboration, and preliminary results have been presented on June 2019 at the conference *Strangeness in Quark Matter* (SQM2019) in Bari and on November 2019 at the *XXVIIIth International Conference on Ultra-relativistic Nucleus-Nucleus Collisions* (QM2019) in Wuhan (China).

The paper is in preparation.

4.1 ALICE scientific output

The ALICE Collaboration has submitted roughly 90 papers in the last year and to date published 287 papers on international referred physics journals (Fig. 9).

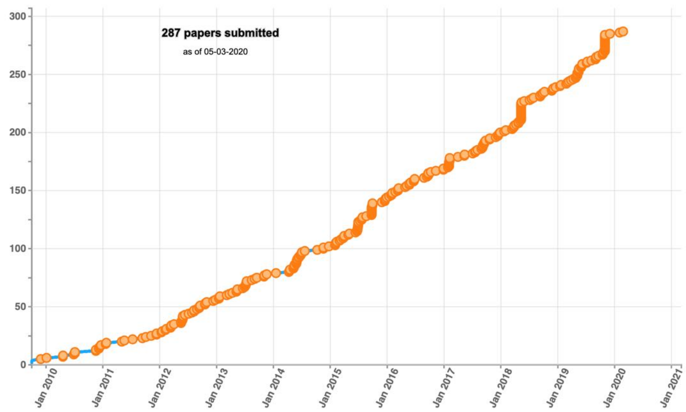

Figure 9: *Timeline of the total number of ALICE papers ("submitted" is to be intended as published+submitted) since the fist LHC beam at 900 GeV on November 23, 2009).*

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