ALICE activity report 2021

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1 The ALICE experiment

The ALICE collaboration at CERN currently includes 40 countries, 174 institutions, and 1937 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 2019-22).

This report briefly summarizes the results obtained by the ALICE-LNF group for the upgrade of the ALICE experiment, the commissioning of the full apparatus and data taking, the commissioning 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).

The INFN-Frascati group has been very active also for physics analysis and in particular 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, an essential reference analysis for any light flavor physics.

Since fall 2019 the INFN-Frascati group covered different roles of responsibility, having a leading role to the ALICE Run Coordination, being in charge of the global ALICE commissioning and data taking operations until 2022, and being an elected member of the Management Board of the ALICE experiment, participating by defaults also to the Physics and Technical Boards.

2 ALICE commissioning

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.

The ALICE detector was fully upgraded during LS2. In the central barrel, the ITS (Inner Tracker System) was replaced with a new detector composed of 7 layer of MAPS sensors covering 10 m^2, an overall resolution of 12.5 GP and a spatial resolution of 5 μm (Fig. 1).

The TPC MWPC were replaced by 4-fold GEM chambers.

On the muon spectrometer, the Muon Chamber (MCH) and Muon Identifier (MID) front end were replaced and a new MAPS tracker was added in the forward region, in front of the MCH and MID to improve the overall tracking efficiency and resolution.

The rest of the ALICE detector was upgraded at the level for firmware to cope with the foreseen interaction rates of Run3: 50 kHz of MinBias PbPb and 1 MHz of pp.

In addition to the detector upgrades most of the readout electronics (except the one of the calorimeters) was upgraded to run in continuous readout (only the legacy detectors still needing to be triggered).

The whole data processing chain of Run 2 which was trigger based, was superseded by a new hardware and software setup which needed extensive commissioning. On the computing level all the detectors able to run in continuous mode have their front end readout via GBT links by the ALICE CRU (Common Readout Units) boards. The CRUs are hosted in the computing nodes of the First Level Processor (FLP) farm located into the shaft of the ALICE pit. Without trigger events all the data flow relies on time stamps. The FLP machines of each sub-detector (say ITS) assemble time based geographical sub-events called sub Time Frames (sTF). The FLP also run specific detector code (called local workflow) to perform either raw data QC (Quality Control) or some raw data processing (compressors). The sTF stream produced by the FLP farm is sent to the EPN (Event Processing Network) for complete Time Frame (TF) assembly. Here 1 TF contains 128 LHC orbits, equivalent to all collision events that happened during 11.7 ms. The FLP and EPN network are connected by a dedicated InfiniBand network passing of memory pages from

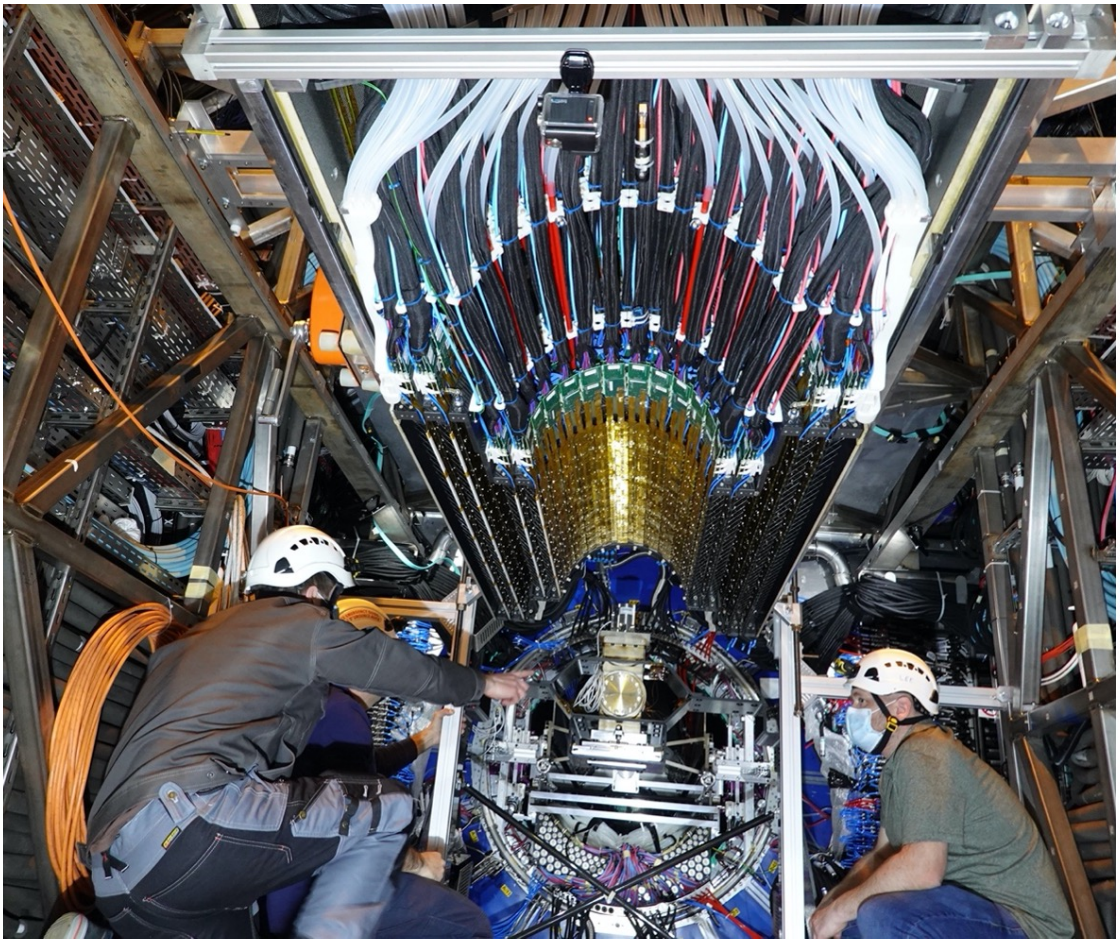

Figure 1: *Installation of the new Inner Tracking System in ALICE*

the FLP to the EPN farms over the network using a dedicated software (Data Distribution). The EPN farm consists of 250 server each equipped with 8 GPU used to perform the first pass of the data reconstruction online (Synchronous Reconstruction) and to compress the TF into packeted structures called CTF (compressed time frames) which can be transferred to the CERN EOS storage (Fig. 2).

The orchestration of the whole data acquisition relies on the ability to spawn the readout and QC processes on the FLP farm, engage the DD towards the EPN farm, allocate the required number of EPN nodes and generate the required workflow topology for the given run type: cosmics, pp, and PbPb.

During the first part of 2021, the activity on the main upgraded detectors focused on the finalisation of the commissioning of the TPC, ITS and MFT detectors with cosmic data tacking on the surface and development of the required workflows. At the same time commissioning and integration activity started for the legacy detectors such as the calorimeters (triggered) and the detectors using continuous readout (TOF, TRD) by means of electronics and firmware upgrades but were not uninstalled from the ALICE cavern.

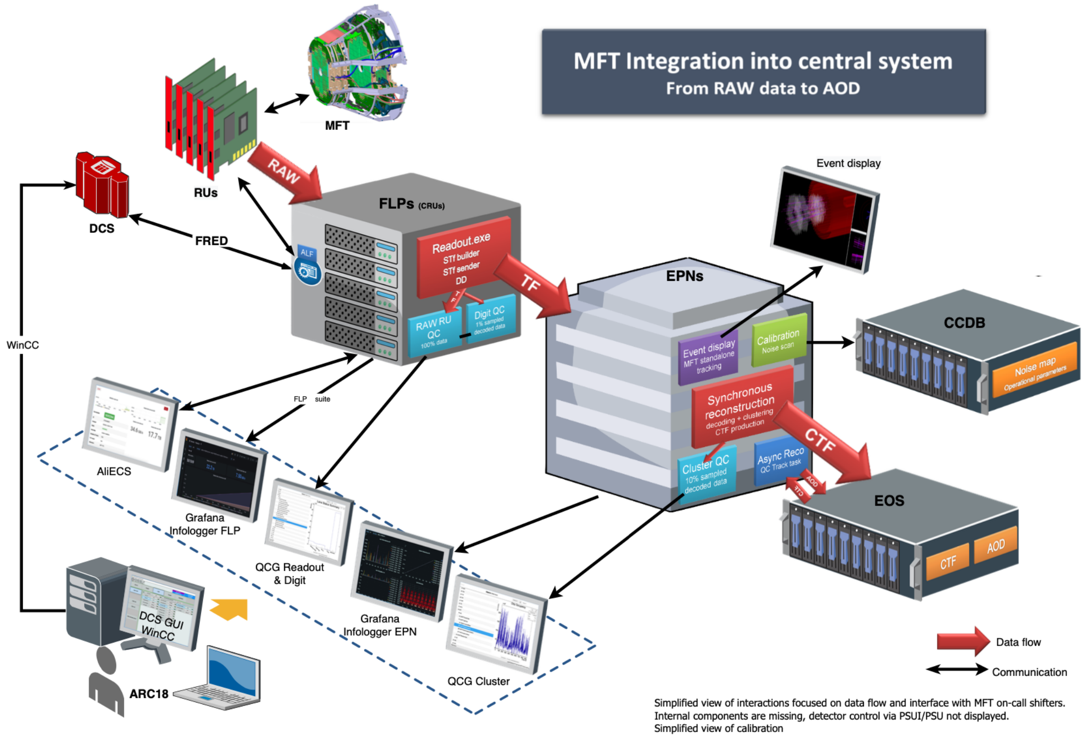

Figure 2: *MFT integration into central system*

From January to June 2021 the commissioning was performed in 5 Milestone Weeks where all the integration work was performed to develop a central control of the data taking moving from configuration and expert work on single detector nodes to orchestrated data taking. The global commissioning started in July and culminated with the successful operation of the upgraded ALICE detectors during the 2021 LHC pilot run when the accelerator delivered collisions at the injection energy at a rate of 1 kHz (Fig. 3).

3 Contribution to the ITS commissioning

It is worth to remind that the Frascati group provided 1/4 of the total Outer Barrel staves, building and assembling 29 staves between the end of 2018 and end of 2019. During this period, the INFN-Frascati group also developed a recovery procedure for damaged staves: since a stave is composed by 2 Half Stave (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 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. The assembly has been done at CERN in 2020 and the installation started in 2021. The Outer Barrel has been fully installed at the end of April and immediately after the Inner Barrel has been put in place.

The full ITS commissioning has been done in a standalone from mid May to mid July, with in total of 251 shifts organised with 2 persons in parallel (2 from remote n week days and 1 from remote + 1 on-site during nigths and weekends. The Frascati group fulfilled the assigned quota

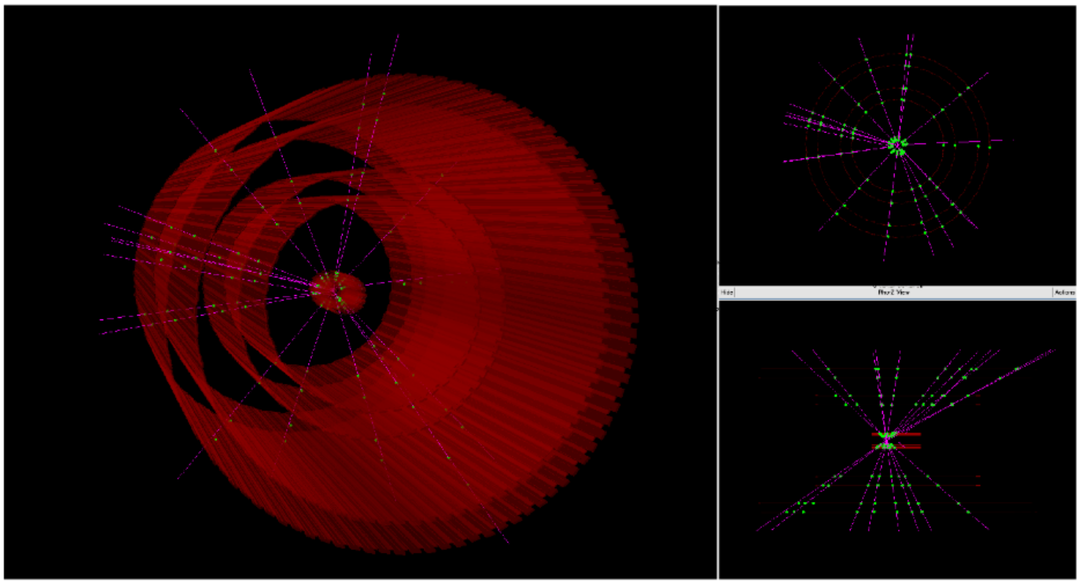

Figure 3: *First images of the ITS hits during the Pilot Beam Test in October.*

of 24/7 shifts, doing shifts at CERN by people on site and at LNF with remote shifters, due to COVID emergency (Fig. 4). From mid-July to mid-August, data taking with central services have been taken in order to validate the full readout chain with realistic rates and immediately after the global data taking started with all detectors in.

A pilot test beam occurred in October and the global commissioning continued till mid-November, when the Christmas break started.

4 Physics contribution

During 2021, the LNF activity has been focused on the analysis of small systems, based on the study of the collisions with at least one beam composed of protons, *i.e.* pp or pPb collisions. This kind of events, indeed, represents an essential reference for the understanding of the collision dynamics, and allow to disentangle the effects due to the emergence of a deconfined state (the Quark Gluon Plasma) - expected to occur only in PbPb collisions - from the so-called cold nuclear matter effects, that can mimic the former. The activity followed two different analysis, one performed on the pPb data collected at a center-of-mass energy of 8.16 TeV and one on the pp data collected at 5.02 TeV. As to the former, the low-p_T analysis previously performed at LNF, based on the Inner Tracking System (ITS), Time-Projection Chamber (TPC) and Time-of-Flight (TOF) - whose preliminary results have been approved in 2019 - has been combined to the high-p_t one performed trough the Cherenkov detector and the TPC relativistic-rise approach. The newly combined spectra, ranging from few hundreds MeV up to 20 GeV, have been used to extract the relevant observables. In particular, the ratio between the yields of different strange and non-strange hadrons to pions have been analyzed as a function of multiplicity, and the results on the pPb data at 8.16 TeV confirmed what has been previoulsy observed in ALICE, that is that the hadro-chemistry of the system seems to be mainly driven by the final state charged particle multiplicity and not by the system itself.

In addition to it, the extended spectra have been fitted through a global procedure, simul-

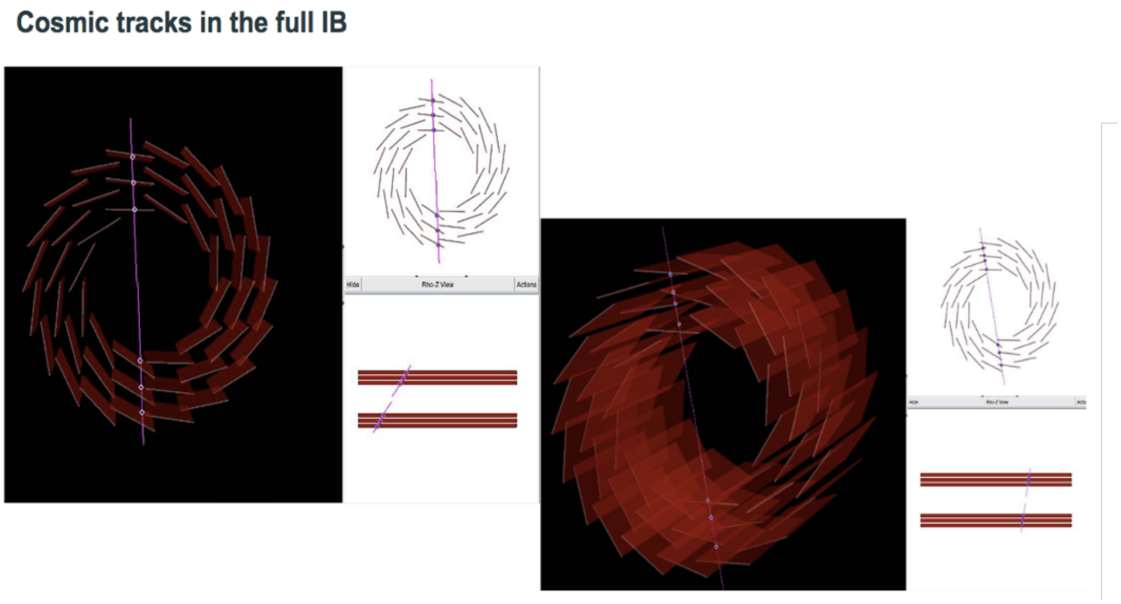

Figure 4: *Cosmic Tracks in the full Inner Barrel of the new ITS during commissioning.*

taneously including all the available flavors, to explore the dependence of the colliding system expanding velocity on the critical temperature. The new results confirmed what was observed in the former ALICE analysis performed on pPb collisions at 5.02 TeV. Thanks to the extension to high-p_T, the nuclear modification factor has been extracted from the spectra for pions, kaons and protons.

The updated results have been compared to the one already published in ALICE and based on the 5.02 TeV pPb data, and to the results obtained for the neutral pion on pPb collisions at 8.16 TeV (Fig. 5). The comparison triggered a series of checks that have been performed by the LNF groups. In particular, efforts have been devoted to the comparison of all the different elements entering into the definition of the nuclear modification factor, and an optimization procedure for identify the best ranges to be exploited when combining the analyses based on the 5 different particle-identification techniques has been carried on.

Based on the updated analysis, the LNF group prepared a paper proposal containing all the relevant results: the extended spectra for pions, kaons and protons (up to 20 GeV), the hadro-chemistry composition of the system, the analysis of the dependence of the expansion velocity on the critical temperature and the nuclear modification factor. The paper proposal has been presented at the ALICE Physics Forum and is now undergoing a second phase of review from the Physics Board. As to the extraction of the spectra on pp data collected at 5.02 TeV, the analysis performed on the Time-Projection Chamber has been completed, and it is now being extended to include also information from the Time-Of-Flight detector. Once done, the results will be combined to the ones obtained by A. Pournaghi in 2020 based on the Inner Tracking System.

5 Fellini Project

In 2021 LNF obtained a Fellini project "*Femto-Strong*" for Oton Vazquez Doce, who has been granted a Fellini MSCA-EU fellowship, entitled "Antikaon-deuteron femtoscopic correlations with

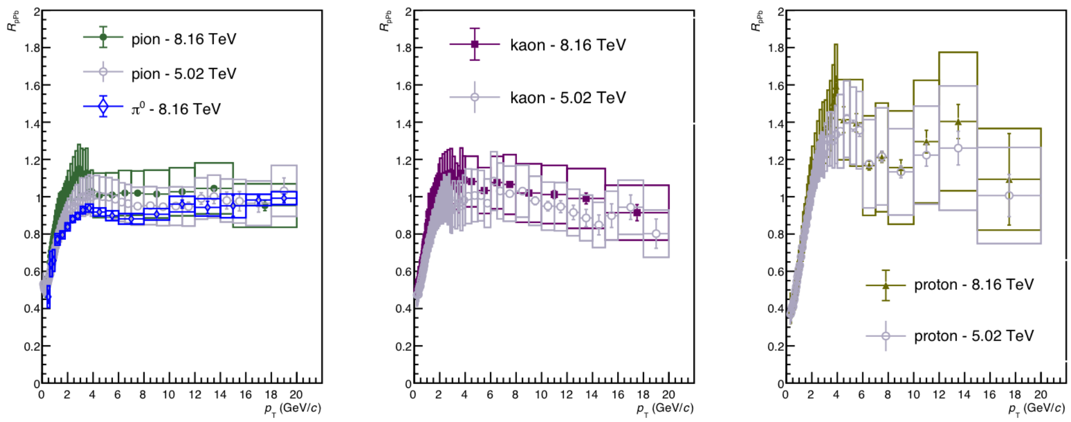

Figure 5: *Nuclear modification factor: comparison of pion data at 5.02 TeV and π^0 data at 8.16 TeV*

ALICE: A new era of hadron-hadron interaction measurements" is being developed. "*Femto-Strong* aims to perform a unique high precision measurement of the strong interaction between antikaons and deuterons by delivering the first study of the low momentum correlations of (anti)kaon-deuteron pairs via femtoscopy. The data sample used so far was collected by ALICE in proton-proton high multiplicity collisions at $\sqrt{s} = 13$ TeV from the LHC Run-2. The first Run-3 data will be used as well as soon as it is available. The project aims to extend the studies already performed by ALICE using (anti)kaon-proton pairs in different collision systems. Those studies have demonstrated that the femtoscopy data is a competitive experimental approach to study the (anti)kaon-nucleon interactions, delivering high precision data in the low momentum region. In the case of the interaction of (anti)kaons with deuterons, which constitute a key measurement in order to disentangle the isospin dependence of the (anti)kaon-nucleon interaction, there is currently no experimental information at all from traditional approaches like scattering experiments or kaonic atoms. The analysis is currently in an advanced stage, aiming to deliver the fist experimental data as preliminary figures for the upcoming Quark Matter conference. The correlation functions of kaon-deuteron and anti-kaon-deuteron pairs in function of the relative momentum k^* has been measured. The data is being compared with the expected correlation function from predictions from different theoretical approaches (chiral SU(3) potentials, Fadeev equations, etc) of the antikaon-deuteron interaction, using the available scattering parameters delivered by theoreticians. A key ingredient of the femtoscopy technique relies on the knowledge of the characteristics, in particular its size, of the source of hadrons produced in the hadronic collisions. So far, the analysis relies on the observed dependence of the bare size of such source with the transverse mass or the pair of detected particles, and considers as well the effects (enlargement of the source size) created by strong decaying resonances. Also, in order to compare with theoretical expectations, a good knowledge of the purity and fraction of secondary parrticles of the kaon and deuteron sample is mandatory and it has been determined experimentally, with purity higher than 95% in both cases and influence of secondary particles quantified and non-negligible only for the deuteron sample. In the framework of this project, it was finalized as well the femtoscopic studies of baryon-antibaryon pairs, submitted to PLB and under the review of the journal referees, and the first experimental study of the $-\Xi$ interaction, with a draft for an article currently in CR1 review within ALICE.

6 ALICE scientific output

The ALICE Collaboration has published 33 papers in 2021 and to date published 371 papers on international referred physics journals (Fig. 6).

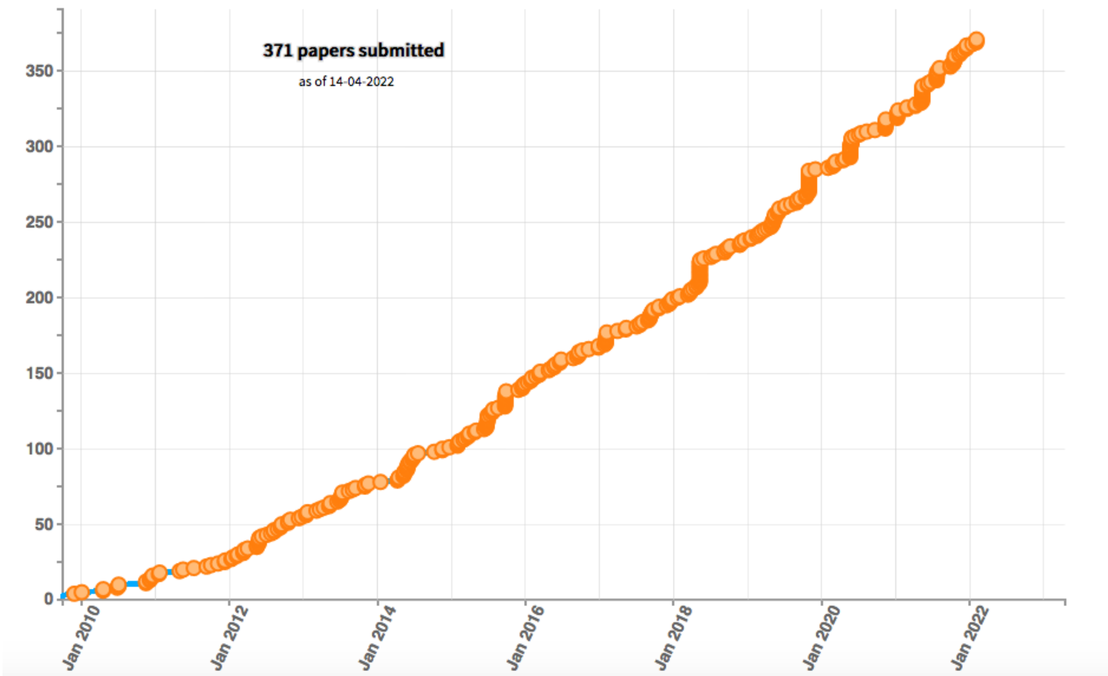

Figure 6: *Timeline of the total number of ALICE papers ("submitted" is to be intended as published+submitted) since the fist LHC beam at 900 GeV on November 23, 2009).*

The full list of ALICE publications can be found online at the link:
https://alice-publications.web.cern.ch/publications