HMPID contribution to the ALICE physics program in Run-3

The HMPID can identify with 3 sigma separation pions and kaons in the momentum range 1-3 GeV/c and (anti-)protons in the range 1.5-5 GeV/c (Fig. 1). It covers the 5% of the TPC acceptance with 98% of matching efficiency for tracks reconstructed in the TPC and passing in the HMPID acceptance. In Run-3 thanks to the upgrading of the RO firmware the HMPID will increase the event read out rate at ~10 KHz for pp, p-Pb and to ~6 KHz in Pb-Pb events, 10 times higher than Run-1 and Run-2 when limited by the TPC rate. Therefore, it can contribute to the physics analysis with ten times the vent statistics collected during Run-1and 2.

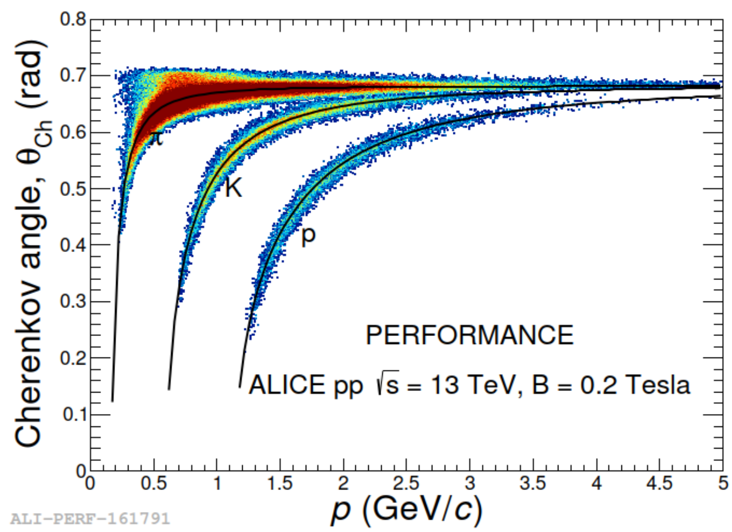


Figure 1: HMPID Cherenkov angle vs track momentum for pp @ 13 TeV data, with B = 0.2 Tesla Continuous lines represent theoretical Cherenkov angle values vs track momentum.

The physics subjects can be summarized as follow:

- Light nuclei identification
  - Deuteron in pp collisions in the momentum bin 10 GeV/c
  - Deuteron in Pb-Pb collision in the momentum bin 10-12 GeV/c, not only in central collision, and identification of triton and helium till 7 GeV/c;
  - Measurement of (anti-)nuclei absorption cross section;
- PID cross-calibration of HMPID-TOF-TPC
- Identified particle correlation study :
  - p/π ratio in the bulk and in the jets;
- reduction of combinatorial background in topological identification:
  ($e.g.$: $\Lambda_c^+ \rightarrow p + K^- + \pi^+$ and/or $\rho \rightarrow e^+e^-$);
- Pions, kaons and protons PID in lighter nuclei collisions (O or Ar);
- Experiment alignment.

Light nuclei identification

The HMPID can identify light nuclei such as: deuteron, triton, helium (^{3}He).
Let's distinguish two cases:
pp collisions: Considering the production rate of light nuclei, the transverse momentum range of interest and the HMPID acceptance, only the contribution to the deuteron identification could be possible. Scaling by the proper factor the (anti-)proton yield shown in Fig. 2, the required statistics in the HMPID to extend the deuteron spectrum up to 10 GeV/c with 3 sigma d/p separation would be of the order of 10^{11} MB pp events. According to the tables circulated in the HL-LHC_Phys_WG5 meeting (A. Dainese), in Run-3 ALICE planned to register ~4.8 10^{11} events. Considering the HMPID event rate in pp of 10 KHz and the TPC ones of 200 KHz, the available statistic for HMPID would be of the order of 2.4 10^{10} , that we consider at the limit but still suitable for the proposed analysis.
For comparison. Using TOF, the deuteron spectrum, could be extended up to 7 GeV/c with 3 sigma d/p separation, and up to 9 GeV/c with 2 sigma d/p separation profiting of the Run-3 statistics.
This measurement can be useful for deuteron spectrum extrapolation at higher p_T, needed for theoretical study, for example to have a better insight in the quest of establishing the composition of the X(3872) particle.

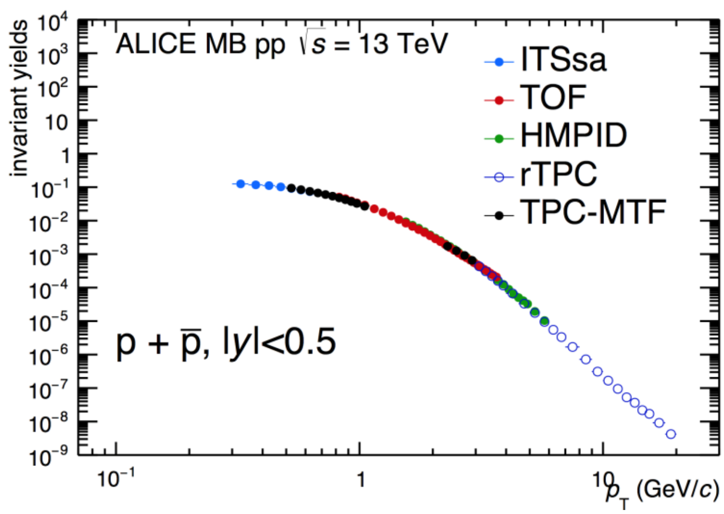


Figure 2: Transverse momentum spectrum of (anti-)protons measured by the different ALICE PID detectors in the relevant p_T intervals, in minimum bias pp collisions at 13 TeV.

Pb-Pb collisions: the HMPID measurements performed by analysing 10M events of the Run-1 Pb-Pb collisions allowed extending the deuteron spectrum up to 8 GeV/c in the centrality bin 0-10% as shown in Fig. 3. These results have been published. The same analysis performed in Run-2 is not yet published.

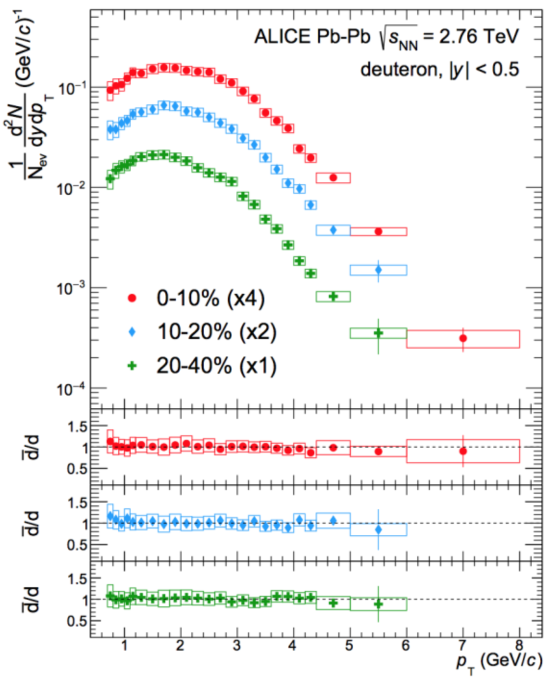


Figure 3: In the upper panel the deuteron p_T spectra are shown for the three centrality intervals extended to high p_T with the TOF and HMPID analyses. In the lower panels the ratios of anti-deuterons and deuterons are shown for the 0–10%, 10–20% and 20–40% centrality intervals, from top to bottom. The ratios are consistent with unity over the whole p_T range covered by the presented analyses.

In Fig. 4 (left panel) the scatter plot of Cherenkov angle and the squared mass distribution (right panel), for events in the central region 0-10%, are shown.

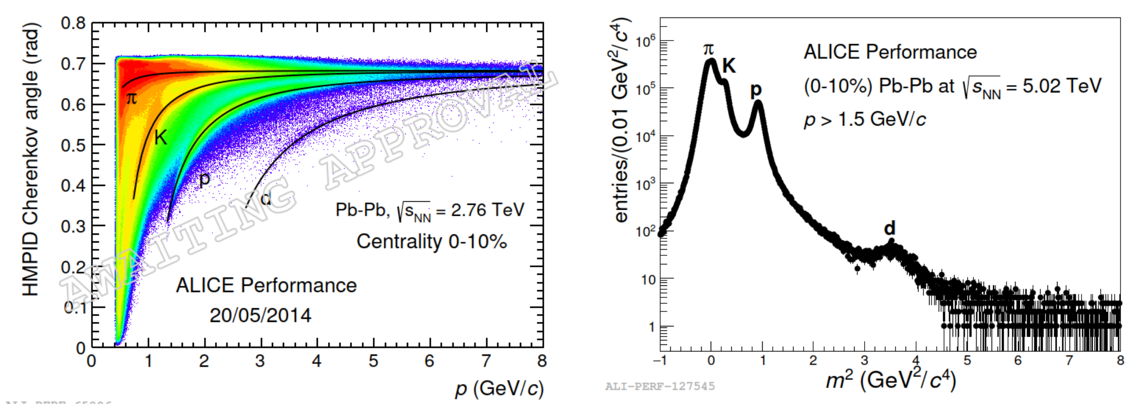


Figure 4. (left panel) HMPID Cherenkov angle vs track momentum for Pb-Pb @ 2.76 TeV data (centrality 0-10%). Bands: Pions, Kaons, Protons and Deuterons. Solid lines are theoretical Cherenkov angle values vs track momentum. (Right panel) Particle squared mass distribution obtained from the Cheenkov angle measured in the HMPID combined with the momentum

information provided by the ALICE tracking devices, in central (0-10%) Pb-Pb collsions at #sqrt{s} = 5.02 TeV

In the left panel the deuteron events are easily distinguishable up to 8 GeV/c. Based on the upcoming 2018 Pb-Pb sample of 0.25 nb^{-1}, where 150M central events (0-10%) are expected, and about 130M in 30-50%, the HMPID can extend the deuteron spectrum up to 10 GeV/c.

During Run-3, in 2022 it is planned to collect 2.85 nb^{-1} data (2.3 10^{10} MB events) in Pb-Pb collisions with B = 0.2 T. The HMPID performances at lower magnetic field are better, i.e. the background contamination of the Cherenkov patterns is much lower because of particles impinge on the detector more vertically. In Fig. 6 and Fig. 7 the Cherenkov angle measured by the HMPID in two p_T bins, in the most central Pb-Pb and Xe-Xe collisions, are shown respectively. Despite the quite close value of the primary tracks multiplicity in the HMPID acceptance in the two cases, as shown in Fig. 5, the background (area below the yellow curve) at B = 0.2 T (Xe-Xe collisions) is clearly smaller.
Profiting of this, using 0.2 T data, the HMPID could provide deuteron spectrum up to 12 GeV/c and not only in the most central collisions.

For triton and helium, by a first estimate, with about 500M central events (0-10%), the HMPID can fill the 7GeV/c spectrum bin with ~100 entries. Considering that the HMPID read out rate is a factor 7 smaller the average TPC ones of ~ 35-40 KHz, a statistics of ~ 300M central events will be available, so even if with a bit less of entries, the epectrum extension up to 7 GeV/c is still possible.

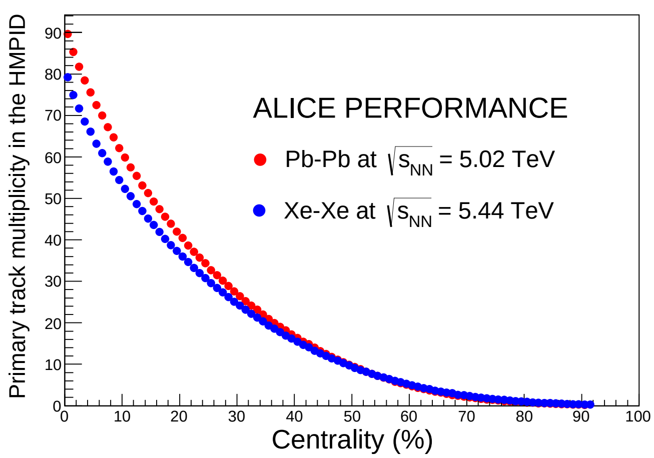


Figure 5: Primary tracks multiplicity in the HMPID acceptance as a function of centrality in Pb-Pb collisions (red) at $\sqrt{s_{NN}}$ = 5.02 TeV with B = 0.5 T and Xe-Xe collisions (blue) at $\sqrt{s_{NN}}$ = 5.44 TeV with B = 0.2 T.

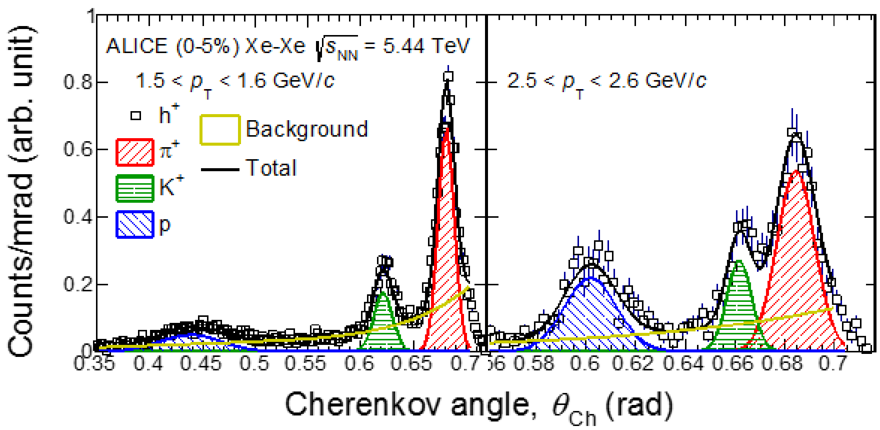


Figure 6: Distributions of the Cherenkov angle measured in the HMPID with B=0.2 T, for positive tracks having p_T in two ranges, 1.5-1.6 GeV/c (left) and 2.5-2.6 GeV/c (right), in central (0-5%) Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV. The histograms have been scaled to have a similar maximum value.

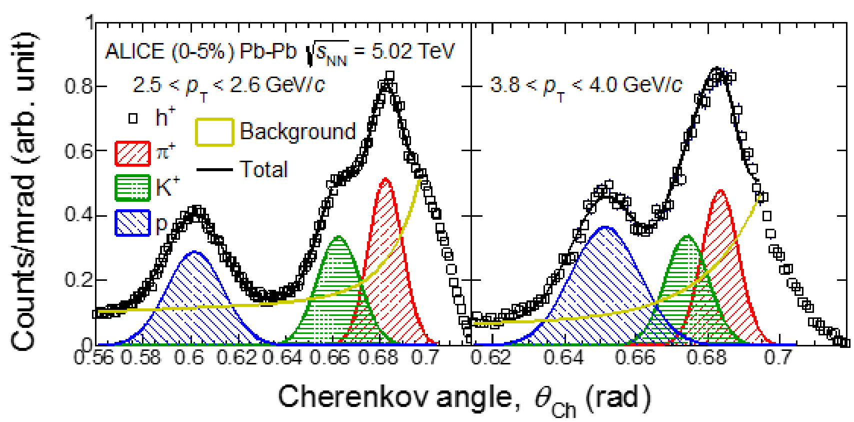


Figure 7: Distributions of the Cherenkov angle measured in the HMPID with B=0.5 T, for positive tracks having p_T in two ranges, 2.5-2.6 GeV/c (left) and 3.8-4.0 GeV/c (right), in central (0-5%) Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The histograms have been scaled to have a similar maximum value.

Measurement of (anti-)nuclei absorption cross section

The measurements of light (anti-)nuclei production is important to understand the production mechanism of multi-baryon states. These objects have a large sensitivity to the chemical freezeout temperature due to their large mass and the exponential dependence of their production yield ~ exp $(-m/T_{chem})$. The largest source of systematic uncertainties in the measurement of light antinuclei production is the limited knowledge of their absorption cross section due to hadronic interactions with the detector material. Measurements of the anti-deuteron absorption exist for

momenta p > 13.3 GeV/c [2] and for p > 25 GeV/c [3]. Current estimates rely on parametrizations of these measurements used to extrapolate the absorption to lower energy. Reducing the systematic uncertainties in the (anti-)deuteron yield measurement is crucial to understand the trend of the d/p ratio as a function of the charged particle multiplicity. This ratio shows a hint of a decrease for the highest multiplicities which might be interpreted as a rescattering effect in the hadronic phase. The statistical hadronization model, instead, predicts a constant ratio in the same multiplicity range. The deviation from a constant trend is currently not significant due to the large systematic uncertainties, thus limiting the sensitivity to possible rescattering effects.
Finally the knowledge of the absorption cross section of light anti-nuclei could also be of interest for astrophysics in modelling the propagation of anti-deuteron in the interstellar medium.

The absorption cross section of antinuclei can be measured in ALICE by placing an absorber of thickness Δx and density ρ in front of the HMPID and measuring the number of antinuclei before and after the absorber:

$$N = N_0 \times e^{-\frac{\Delta x}{\lambda_i}} \quad with \ \lambda_i = \frac{A}{\rho N_A \sigma_h} \tag{1}$$

A schematic sketch of the proposed setup is illustrated in Fig. 8.

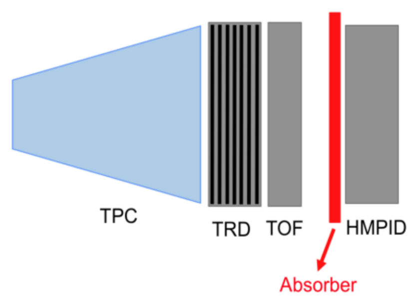


Figure 8. : Sketch of the experimental setup used to measure the antinuclei absorption cross section.

The optimal material is being investigated among those with a small hadronic interaction length λ_i and large electromagnetic radiation length X_0. A polyethylene slab is an option. As an example: in a slab with a thickness of $\lambda_i/3$ (about 25 cm), the 30% of anti-deuteron will be absorbed. The MWPC's of the HMPID can be used to detect tracks already identified in the TPC, TRD and TOF that passed through the absorber. No identification in the HMPID is requested. The modules without the absorber could be used to study how the background from mismatched tracks in the TOF propagates to HMPID. Moreover, in Run-3 the TRD will be used for tracking, significantly reducing this background component in the TOF response.
After a first check, the insertion of absorbers with thickness of the order of 20 cm should be possible without the temoval of the detector.
The readout rate of the HMPID in Pb–Pb collisions can reach a factor ∼ 10 of the

current rate. Considering that the HMPID covers 5% of the TPC acceptance, the expected number of antinuclei candidates of mass number A in the HMPID, assuming a fraction f of the 7 available modules equipped with the absorber, is:

$$N_A^{HMPID} = (N_{A,present}^{TPC} \times\ 0.05\ \times f)\ \times \epsilon\ \times 10 \qquad (2)$$

where N_A^{TPC} is the total number of antinuclei with mass number A in the full TPC acceptance of Run-2 (integrated over all centralities), and ε is the fraction of antinuclei that will be absorbed in the material. With the deuteron statistics of 2.5 10^5 events registered during the 2016 Pb-Pb run, f=2/7 and ε=0.3, then 10^4 deuterons will interact in the absorbers.

We expect a measurement of the absorption cross section of antideuterons in 0.5 < pT < 4 GeV with a statistical precision in the range 2-40% as shown in Fig. 9, left panel. The measurement for $\overline{^3_2He}$ can also be done in the momentum interval 1-3 GeV/c with a statistical precision in the range 20-40% as shown in Fig. 9, right panel.

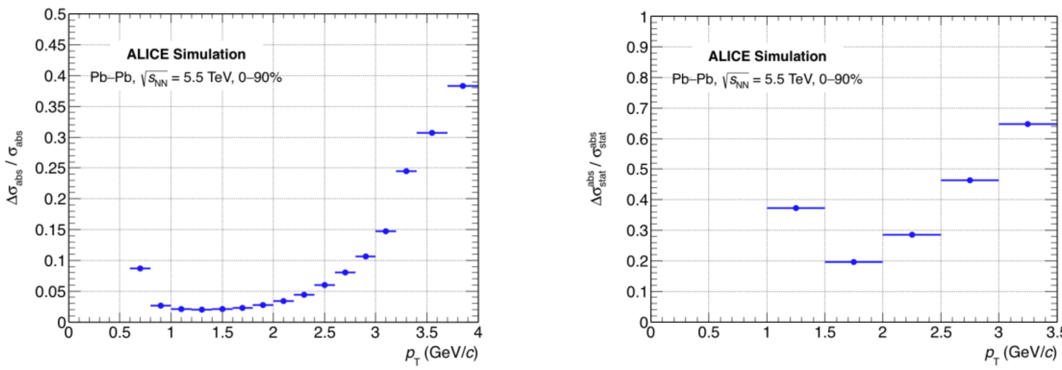
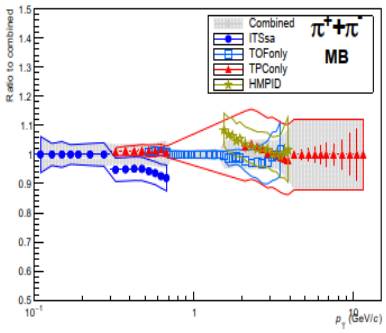


Figure 9. Expected statistical precision in the measurement of the absorption cross section for anti-deuterons (left panel) and anti-^{3}He (right panel).

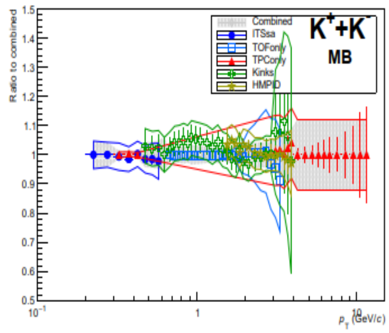
PID cross-calibration of HMPID-TOF-TPC

The TPC and TOF will undergo an upgrading program, especially TPC that will replace the MWPC's with new GEM modules. At the beginning of Run-3 HMPID will undergo only to the upgrading of the RO firmware. Therefore, it can select with 3 sigma separation samples of π, K and p in the range 1-5 GeV/c to be used for cross-calibration of TOF and TPC to probe the preliminary PID performance.

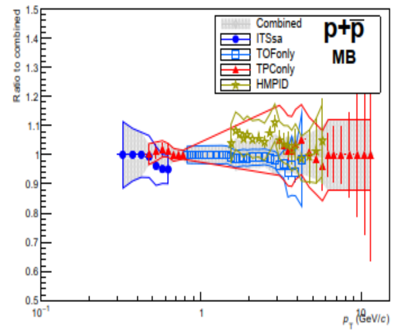
In Fig. 10, in pp collisions the HMPID overlaps well with both TPC and TOF, with uncertainties smaller than the TPC and also of the highest-pT TOF points.



(a) $\pi^{+}+\pi^{-}$: Ratio to combined



(b) $\pi^{+}+\pi^{-}$: Ratio to combined



(c) $\pi^{+}+\pi^{-}$: Ratio to combined

Figure 10. Ratio to combined spectra for all the analyses in pp collisions at 5.02 TeV.

Considering that the collision energies in Run-3 will all be different from the Run-2, therefore there is no published spectrum that can be used for precise benchmarking.

Identified particles correlation study

Thanks to the application of proper acceptance corrections, the HMPID measurements could be used for identified particle correlation study. In the past, in pp collisions at 7 TeV, this analysis has been performed, correlating one trigger particle in the full TPC acceptance with one identified in the HMPID acceptance. In this way the p/π ratio in the bulk and in the jets has been evaluated (Fig. 11). This result has been used to cross check the same measurement (not published) obtained using TPC/TOF PID. The two measurements are in agreement within statistical and systematic errors. In Run-3 this study can be completed crosschecking with an event statistics in the HMPID ten times higher.

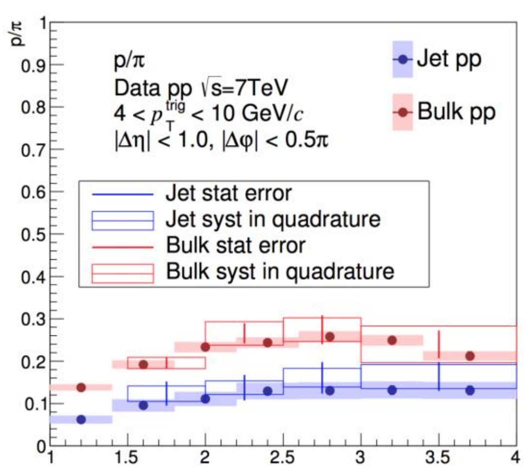


Figure 11: Proton-over-pion p/π ratio as measured with the HMPID detector. Empty rectangles (combined sys. and stat. errors) represent the points measured with the HMPID. The ratio is measured in jet and bulk and in the figure, it is compared with correlation analysis using TOF templates [1]. The results agree within statistical and systematic errors.

Combinatorial background reduction for the topological identification

The HMPID can be used to reduce the combinatorial background in the invariant mass distribution for topological identification. A physics channel where to use this technique could be $\Lambda_c^+ \to p + K^- + \pi^+$. Selected events with a proton identified by TPC-TOF and passing through the HMPID can benefit of an additional proton identification producing a separate sample (with a reduced statistic) where possible improvements in terms of signal/background ratio can be checked.

The HMPID can also identify electron in the momentum range 200 – 600 MeV/c and it could be used in events where one or more decay products are electrons (e.g.: $\rho \to e^+e^-$). If we consider to operate with a magnetic field B=0.2T, for an electron of 200 MeV/c the curvature radius is of the order of 3.2 m and this means that it can impinge on the HMPID (Fig. 1).

Anyway, in the study of the physics channel $\rho \to e^+ + e^-$, the TPC electron identification via dE/dx is already effective, except around 500 MeV/c and ~1GeV/c where the K and p dE/dx bands cross the electron band (Fig. 12). There the TOF identification can help but it reduces the efficiency. Therefore, the study on how the HMPID with the proper cuts, could alternatively improve the K and p rejection, might deserve to be done.

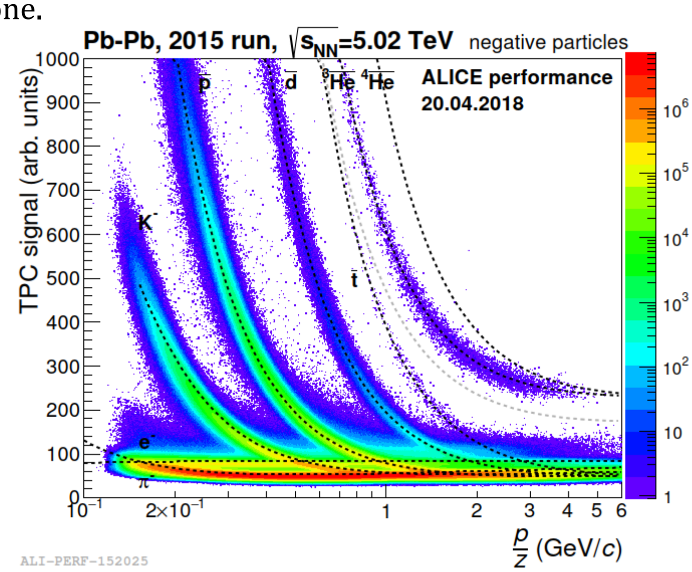


Figure 12: TPC dE/dx vs Rigidity distribution for all events passing the offline trigger selection of events with at least one Z>1 track candidate. ONLY NEGATIVELY CHARGED PARTICLES ARE SHOWN

Pions, kaons and protons PID in lighter nuclei collisions

If in Run-3 ALICE will collect data from lighter nuclei collisions (Oxigen or Argon), the HMPID can measure pion, kaon and proton yields as done during Run-1 and Run-2 data taking periods. In Fig. 13 the transverse momentum spectra of pions, kaons and (anti-)protons measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, collected in 2015, for different centrality classes are shown. About 100 millions of events in HMPID are needed that can be taken in few hours of TPC data taking.

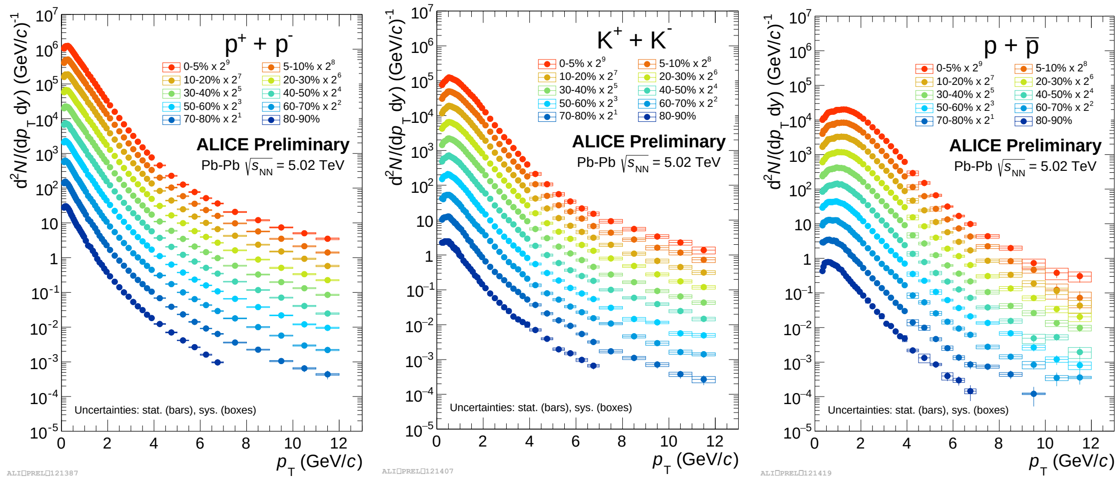


Figure 13: Transverse momentum spectra of pions (left), kaons (middle) and (anti-)protons (right) measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV for different centrality classes. Scale factors are applied for better visibility. Statistical and systematic uncertainties are displayed as error bars and boxes around the data points, respectively.

Experiment alignment

The HMPID can provide the impact points of tracks in the MWPC's (MIP clusters) at a distance of about 5 m from the collision point. They can be used as a good constraint in the global alignment especially to monitor the radial expansion or squeeze of the whole ALICE setup. An effective temperature monitoring systems based on 4 sensor/MWPC ensures an accurate mesurement with possibility to correct for the detector itself expansion/squeese.

During 2006 a survey of the seven MWPC's on the cradle, and of the cradle in ALICE was carried out. Permanent reference points were fixed on the MWPC's and on the cradle supporting the modules so, the HMPID position was precisely determined in the ALICE reference system. The precisions of the location of the MIP clusters is of the order of ±2 mm in the local HMPID X-Y pad plane (perpendicular to the radial direction) and ~ ±3 mm (more precise cross-check required) in the radial direction, respectively.

Conclusion

For the HMPID the most relevant physics cases for continued running in Run-3 can be summarised as follow:

- **light nuclei detection(deuteron, triton and 3He).**
  - **In pp,** with 2.4 10^{10} events, the 10 GeV/c momentum bin for the deuteron can be filled in. This extension of the spectrum measurement is of interest t in the quest of establishing the composition of the X(3872) particle.

- **In Pb-Pb,** already in 2018 , with 150 M events (0-10% centrality), the deuteron momentum bin at 10 GeV/c can be filled in. In 2022, with B=0.2 T and a statistics of 2.3 10^{10} M MB events (~300 M central in HMPID), also the 12 GeV/c bin can be filled in, and not only in the most central collisions (0-10%). The triton and the ^{3}He spectra up to 7 GeV/c using central collisions can also be measured. Cross-check with TPC-TOF mesurement to be done.

- **Measurement of absorption cross section for antiprotons and light anti-nuclei** (anti-deuterons and $\overline{{}^{3}_{2}He}$). For anti-deuteron in the range 1-4 GeV/c the expected statistical precision is 2-40% and for the anti-^{3}He in the momentum range 1-3 GeV/c, the statistical precision is in the range 20-40%. This is based on the installation of two absorbers, 1/3 λ_i , in front of the HMPID modules, and using only the MWPC's response to the MIP (no PID). In this case a reduction factor of the HMPID acceptance < 2/7, has to be considered when in this document other event statistics are computed.

- **PID cross-calibration of HMPID-TOF-TPC.** Considering that in Run-3 the collision energies at will all be different from the Run-2, therefore there is no published spectrum that can be used for precise benchmarking. As done in Run-2, HMPID in the range 3-5 GeV/c can reduce the systematic error in the hadron spectra measured by TOF and TPC, where their PID performance are poor.

- The **Identified particles correlation study.** The p/π ratio in the bulk and in the jets has been measured with HMPID and used to cross check the ones (not yet published) done with TPC/TOF PID. The two measurements are in agreement within statistical and systematic errors. In Run-3 this study can be completed crosschecking with an event statistics in the HMPID ten times higher.

- Finally the reduction of the combinatorial background and the experiment alignment can also be cited as further usage of HMPID during Run-3.

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[1] https://alice-notes.web.cern.ch/system/files/notes/analysis/355/2016-Feb-05-analysis_note-ParticleRatiosJetAndBulkHMPID.pdf.

[2] F. G. Binonetal., "Absorption cross-sections of 25 Gev/c antideuterons in Li,C,Al,Cu and Pb", Phys. Lett., vol. 31B, pp. 230-232, 1970.

[3] S. P. Denisov, S. V. Donskov, Yu. P. Gorin, V. A. Kachanov, V. M. Kutjin, A. I. Petrukhin, Yu. D. Prokoshkin, E. A. Razuvaev, R. S. Shuvalov, and D. A. Stojanova, "Measurements of anti-deuteron ab-sorption and stripping cross sections at the momentum 13.3 Gev/c", Nucl. Phys., vol. B31, pp. 253-260, 1971.