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Pattern recognition and PID procedure with the ALICE-HMPID

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ABSTRACT

The ALICE apparatus is dedicated to the study of pp, p–Pb and Pb–Pb collisions provided by LHC. ALICE has unique particle identification (PID) capabilities among the LHC experiments exploiting different PID techniques, i.e., energy loss, time-of-flight measurements, Cherenkov and transition radiation detection, calorimetry and topological ID. The ALICE-HMPID is devoted to the identification of charged hadrons. It consists of seven identical RICH counters, with liquid C_6F_{14} as Cherenkov radiator ($n \approx 1.299$ at $\lambda_{ph} = 175$ nm). Photons and charged particles detection is performed by a proportional chamber, coupled with a pad segmented CsI coated photo-cathode. In pp and p–Pb events HMPID provides 3 sigmas separation for pions and kaons up to $p_T = 3$ GeV/c and for protons up to $p_T = 5$ GeV/c. PID is performed by means of photon emission angle measurement, a challenging task in the high multiplicity environment of the most central Pb–Pb collisions. A dedicated algorithm has been implemented to evaluate the Cherenkov angle starting from the bi-dimensional ring pattern on the photons detector, it is based on the Hough Transform Method (HTM) to separate signal from background. In this way HMPID is able to contribute to inclusive hadrons spectra measurement as well as to measurements where high purity PID is required, by means of statistical or track-by-track PID. The pattern recognition, the results from angular resolution studies and the PID strategy with HMPID are presented.

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1. The ALICE-HMPID detector and the pattern recognition algorithm

The High Momentum Particle Identification Detector (HMPID) [1] performs charged hadrons identification by means of the measurement of the emission angle of Cherenkov radiation and of the momentum information provided by the ALICE tracking devices. The measurement of the photon angle in the HMPID requires the tracks to be extrapolated from the central tracking devices of ALICE, the Inner Tracking System (ITS) and the Time Projection Chamber (TPC), and associated with the corresponding cluster of the minimum ionizing particle in the HMPID cathode plane. Starting from the cluster centroid one has to reconstruct the angle under which the photon causing it could have been emitted if belonging to the given track. The procedure implemented to achieve such a result is called "backtracing" [1]. Background discrimination is performed exploiting the Hough Transform Method (HTM) [2]. HTM is an efficient implementation of a generalized template matching strategy for detecting complex patterns in binary images. The starting point of the analysis is a bi-dimensional map with the impact point (x_p, y_p) of the charged particles, hitting the detector plane with known incidence angles (θ_p, ϕ_p), and the coordinates (x, y) of the impact points of both Cherenkov photons and background sources. A "Hough counting space" is constructed for each charged particle, according to the following transform: $(x, y) \rightarrow ((x_p, y_p, \theta_p, \phi_p), \eta_c)$, where η_c is the angle obtained from the backtracing procedure. (x_p, y_p, θ_p, ϕ_p) is provided by the tracking of the charged particle, so the transform will reduce the problem to a solution in a one-dimensional mapping space. An η_c interval with a certain width is defined. Moving with a step of 1 mrad such window along the η_c distribution, the number of η_c values at each step is counted. The Cherenkov angle θ_c of the particle is provided by the average of the η_c values that fall in the interval with the largest number of entries.

The result of such procedure is shown in Fig. 1, where the reconstructed Cherenkov angle θ_c is shown as a function of the track momentum, in case of p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV data. Three bands are present, they correspond to pion, kaon and proton signals. The experimental values are in good agreement with the theoretical curves.

2. Angular resolution study

The HMPID angular resolution depends on four main contributions [1]: the chromatic error due to the wavelength spread of the

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produced photons; the geometrical error due to the photons emission points spread; the localization error related to the discrete size of the cathode pads; the tracking error related to the not perfect knowledge of the tracks parameters, mainly due to the multiple scattering in the material budget in front of the detector. The first three contributions have been evaluated by means of both analytical calculations and Monte Carlo simulations, and they have been parametrized as a function of track momentum, track incidence angle and photons emission angles (polar and azimuthal). In this way for each track it is possible to evaluate the expected theoretical resolution as the average on the produced photons for the given track. This evaluation does not take into account the tracking error, so it has been necessary to compare the theoretical resolutions with the real data distributions. To extract a correction factor the pull technique has been used. The pull is defined as the following:

$$pull^i = \frac{\theta^i_{exp} - \theta^i_{theor}}{\sigma^i}, \quad i = \pi, \mathrm{K}, \mathrm{p} \tag{1}$$

where θ^i_{exp} is the experimental angle for the given particle specie (selected using another PID technique available in ALICE), θ^i_{theor} is the theoretical angle and σ^i is the expected resolution at the given momentum value and particle specie. If the expected resolution is compatible with the actual one, the pull distribution follows a Gaussian one with mean 0 and standard deviation 1, each deviation of the σ value from the unity is due to a wrong estimate of the resolution. A correction factor as a function of the chamber occupancy for pions, kaons and protons has been evaluated in this way. The maximum deviation between the expected resolution and the experimental one is of the order of 25%.

3. Tracking procedure

The HMPID is located ≈ 5 m away from the primary vertex, hence tracks have to be propagated through significant material budget after the TPC, with a radiation length of $\approx 0.36\ X_0$ and $\approx 0.46\ X_0$ from the beam pipe. Reconstructed tracks are propagated up to the HMPID cathode planes by means of a dedicated algorithm. Below 2 GeV/c the residuals between the extrapolated track point and the MIP impact point are > 2 cm (Fig . 2). In the tracking procedure, the running track is picked up at the last TPC point and propagated up to the HMPID through the Transition Radiation Detector (TRD) and the Time Of Flight (TOF) detector. The extrapolation algorithm takes into account the energy loss and the dependence of the magnetic field value on the distance from

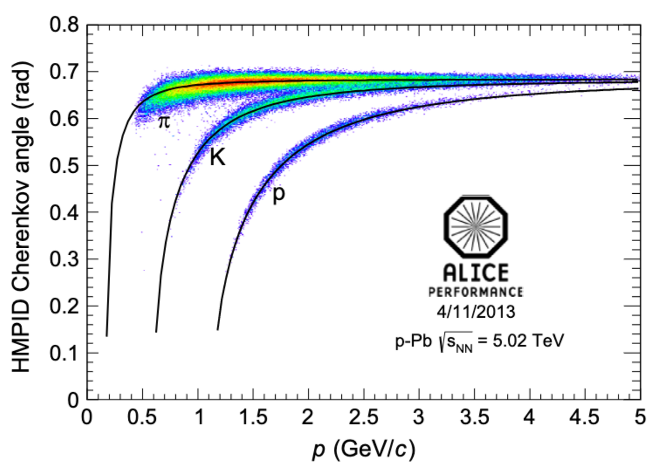

Fig. 1. Cherenkov angle from HMPID vs track momentum in p–Pb data.

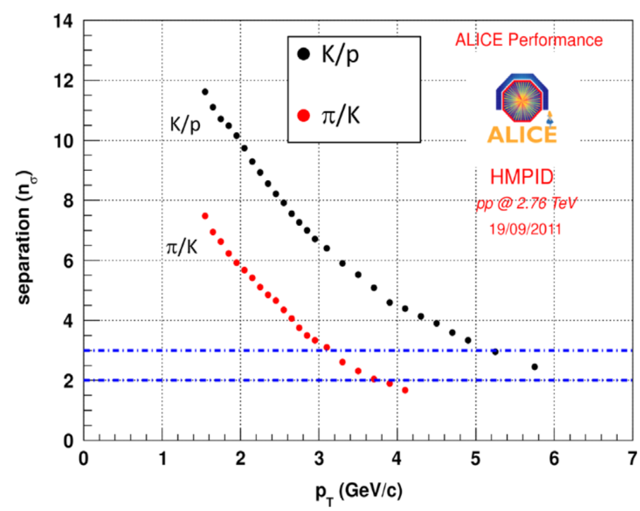

Fig. 3. The separation in σ units for π/K and K/p as a function of transverse momentum in HMPID, in case of pp collisions at $\sqrt{s} = 2.76$ TeV data. The two blue lines represent 2σ and 3σ limits. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

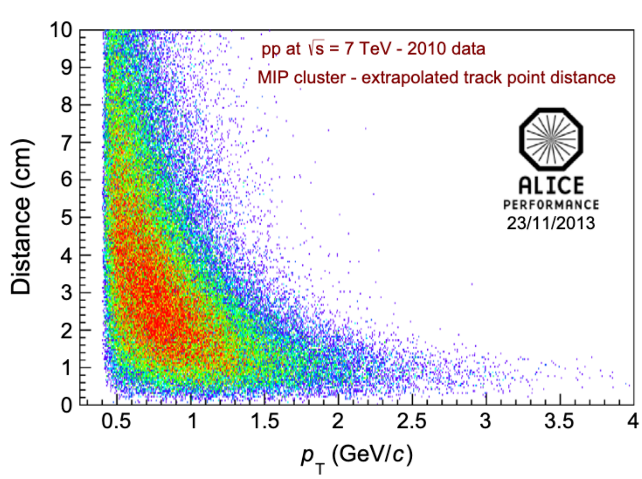

Fig. 2. Distribution of the distance between the MIP cluster point and the closest extrapolated track point at HMPID chamber plane (HMPID module 2) vs transverse momentum, in case of pp collisions at $\sqrt{s} = 7$ TeV data.

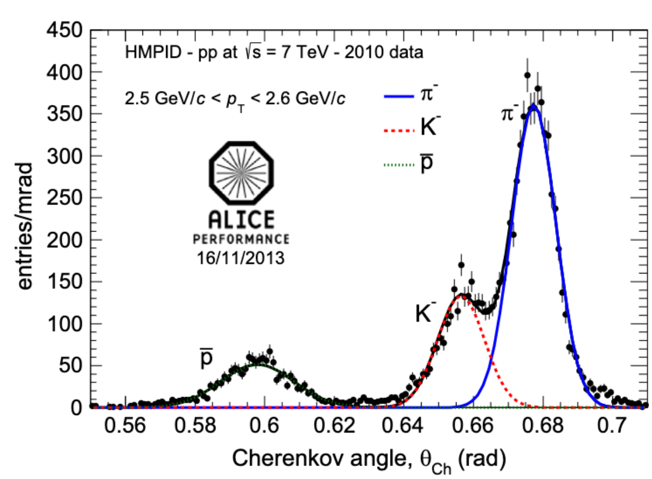

Fig. 4. Distribution of the Cherenkov angle measured in the HMPID for negative tracks in a narrow transverse momentum bin, in pp data. A three-Gaussian fit is applied to evaluate the raw yields.

the interaction point. In particular it is possible to exploit the precise knowledge (1 mm precision) of the HMPID MIP cluster information in the track fitting to reduce the error related to the tracking. The usage of HMPID MIP clusters information in the tracking procedure improves the track angular resolution, bringing the resolution of the Cherenkov angle close to the design values of ≈ 4 mrad [1] for orthogonal tracks at $\beta \approx 1$ and with fully accepted rings (maximum number of detected photons). In Fig. 3 the derived π/K and K/p separations in sigma units are shown.

4. Particle identification procedure

Particle identification with HMPID can be performed using two different approaches: on statistical basis and on track-by-track basis. A statistical approach to extract the particle yields can be used in the case of inclusive hadrons production studies. A track-by-track approach can be used in the case of jets physics studies, where the jet leading particle identification is needed, or in the case of hadrons correlation studies.

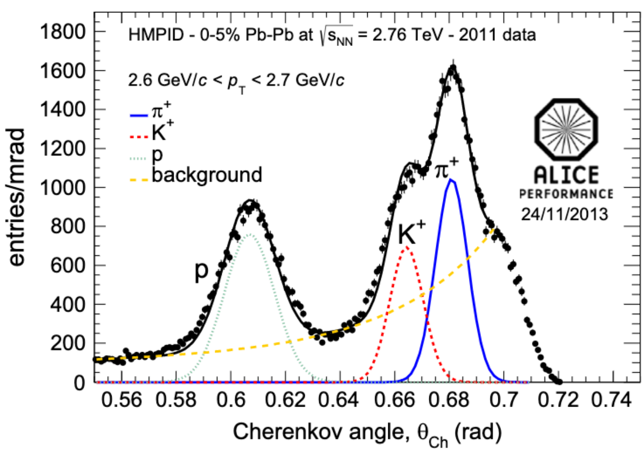

Fig. 5. Distribution of the Cherenkov angle measured in the HMPID for positive tracks in a narrow transverse momentum bin, in Pb–Pb data (0–5% centrality). The shoulder in the distribution starting at 0.7 rad is a boundary effect due to the finite chamber geometrical acceptance.

Identification on statistical basis: in pp and p–Pb collision events, due to the low event multiplicity, the background is negligible, so it is possible to extract the particle raw yields from a three-Gaussian fit to the Cherenkov angle distributions in a narrow transverse momentum range (Fig. 4). The function used is the following:

$$f(\theta) = \frac{Y_\pi}{\sigma_\pi\sqrt{2\pi}} e^{-(\theta-\langle\theta_\pi\rangle)^2/2\sigma_\pi^2} + \frac{Y_K}{\sigma_K\sqrt{2\pi}} e^{-(\theta-\langle\theta_K\rangle)^2/2\sigma_K^2} + \frac{Y_p}{\sigma_p\sqrt{2\pi}} e^{-(\theta-\langle\theta_p\rangle)^2/2\sigma_p^2} \tag{2}$$

The fitting function has nine parameters to be calculated, the three mean values, the three sigma values and the three yields. To obtain the best evaluation of the particle yields it is needed to know the other two parameters and fix them in the fitting. In case of the most central Pb–Pb collisions (0–10% of centrality) due to the high particles multiplicity, the three Gaussian distributions for pions, kaons and protons in a narrow transverse momentum bin are convoluted with a distribution that strongly increases with the Cherenkov angle (Fig. 5). It is due to wrong identification in the high occupancy events: the larger is the angle, the larger is the probability to find background clusters; the background is uniformly distributed on the chamber plane and it consists of signals from other tracks or photons in the same event. The chamber occupancy in the most central collisions has an average value of $\approx 3\%$. A polynomial function of 6° order is used to fit the distribution of the misidentified tracks.

Identification on track-by-track basis: from the knowledge of the expected Cherenkov angle and the expected theoretical standard deviation, it is possible, for each track, to calculate the values of two PID estimators: the first is the probability to be one of the charged hadron species and the second one is the difference between the value of the measured angle and the expected theoretical one in sigma units. The latter estimator, commonly used within the ALICE collaboration, is defined as the following:

$$N_\sigma^i = \frac{|\theta_{exp} - \theta_{theor}^i|}{\sigma_i} \tag{3}$$

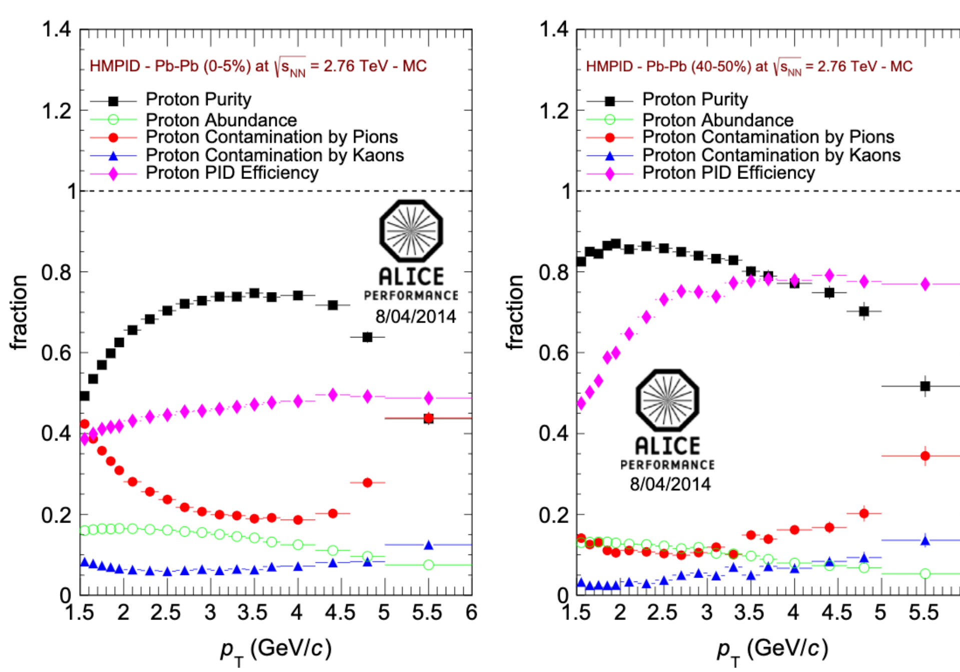

Fig. 6. Efficiency, purity and contamination for protons extracted from Hijing Monte Carlo simulation of Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, in two different centrality bins, 0–5% (left), 40–50% (right).

where θ_{exp} is the measured angle, θ^{i}_{theor} is the theoretical Cherenkov angle, calculated in each mass hypothesis, and σ_i is the expected resolution. Applying a cut on N^{i}_{σ} values it is possible to select a sample of identified hadrons with a given efficiency, purity and contamination, defined as the following:

$$\epsilon_i = \frac{N^{t}_{id}(i)}{N_{tot}(i)}, \quad p_i = \frac{N^{t}_{id}(i)}{N_{id}(i)}, \quad c_i = \frac{N^{w}_{id}(i)}{N_{id}(i)} \tag{4}$$

where $N_{tot}(i)$ is the number of particles of type i, $N_{id}(i)$ is the number of particles identified as type i, $N^{t}_{id}(i)$ is the number of true particles of type i identified as type i and $N^{w}_{id}(i)$ the number of non-type i particles identified as particles of type i, with $i = \pi$, K, p. In Fig. 6 the efficiencies, the purities and the contaminations for protons in Pb–Pb collision in two different centrality bins, extracted from Hijing [4] Monte Carlo simulation, imposing $N^{p}_{\sigma} < 2$ are shown. The simulation has been performed in the official simulation framework of ALICE, AliRoot [3]. In the most central collisions due to the presence of a large background, the protons efficiency and purity is lower than that obtained in the more peripheral ones. An improved PID algorithm giving a smaller weight to large angle clusters is being developed, it will reduce the background contribution in the angle reconstruction.

5. Conclusion

The pattern recognition algorithm and the PID procedure and performance have been presented. The HMPID detector successfully provided particle identification during LHC RUN1 data taking period, in pp, p–Pb and Pb–Pb collision data. Improvement of the pattern recognition algorithm is in progress, it is foreseen to introduce a weight for each cluster to increase the angle reconstruction efficiency in high multiplicity environments.

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