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The VHMPID detector in the ALICE experiment at LHC

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The ALICE experiment is devoted to measure the properties of the strongly interacting matter created in heavy-ion collisions at LHC at $\sqrt{S_{NN}}$ = 5.5 TeV. Heavy ion collisions at RHIC have shown an anomalously high baryon to meson ratio in the so called intermediate momentum range of 2 to 6 GeV/c. Theoretical predictions, using different arguments, foreseen that the baryon enhancement at LHC will be present in a momentum range higher than at RHIC, namely p_T = 10 - 30 GeV/c. To be able to study this phenomenon in details, upgrades of the ALICE detector systems to extend track-by-track identification capability of protons up to 10 GeV/c and more, are necessary. A possible upgrade is under study. Different solutions have been taken into account, but the more interesting consists of a ring imaging Cherenkov detector, that exploits the focusing properties of a spherical mirror and gas C_4F_{10} as Cherenkov radiator. The photons detection is provided by a multiwire chamber or a GEM-like detector coupled with pad-segmented CsI photocathodes. The new device has been named VHMPID (Very High Momentum Particle Identification Detector). Description of VHMPID and performance results from simulation are reported.

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[†] A footnote may follow.

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1. Introduction

At Relativistic Heavy Ion Collider (RHIC) has been observed a large enhancement of baryons and antibaryons relative to pions at intermediate $p_T \approx 2$ - 5 GeV/c [1, 2] (Fig. 1), while the neutral pions and inclusive charged hadrons are strongly suppressed at those p_T. The baryon puzzle observed at RICH can be interpreted with the "partons recombination" or "coalescence" mechanism. In the recombination scenario quark-antiquark pair close in the phase space can form a meson at hadronization, while three (anti)quark can form an (anti)baryon. At LHC where the density of jets is very high, a new phenomenon originates where the recombination of shower partons in neighboring jets can make a significant contribution. It is foreseen that the baryon enhancement will be present in a momentum range higher than at RHIC, $p_T \approx 10$ - 20 GeV/c [5]. Other authors using different arguments foresee also change in meson-baryon ratio for $p_T > 10$ GeV/c; jet quenching can leave signatures not only in the longitudinal and transverse jet energy and multiplicity distributions, but also in the hadrochemical composition of the jet fragments [6]. On the experimental side, today in ALICE, the reach of proton identification on track-by-track basis is up to 5 GeV/c using the HMPID [7, 8] and statistical identification is possible up to 30 GeV/c, using the relativistic rise in the TPC [9]. According to these arguments, it seems important to have the possibility to identify hadrons up to momenta well above the current limits of ALICE for track-by-track identification, to understand the mechanisms of the hadronization and the influence of these mechanisms on the spectra of baryons and mesons. Furthermore, the combination of a small size particles identification detector, located opposite to the electromagnetic calorimeter (EMCal) in ALICE, opens interesting possibility to distinguish quark and gluon jets in gamma - jet events and subsequently the study of the probability of fragmentation in pions, kaons or protons.

The possibility to extend track-by-track identification capability of the ALICE apparatus, by means of a new detector, has been taken into account. The new detector, named Very High Momentum Particle Identification Detector (VHMPID), is based on Cherenkov imaging, using low refractive index gas as Cherenkov radiator. In the following VHMPID description is reported

2. Detector description

Due to the existing space in the ALICE apparatus and to the physics requirements the only possibility is to use gas Cherenkov counters as the choice detector. Since the values of momentum where the identification is required, a Cherenkov radiator with low refractive index is needed. Gas with low refractive index that qualify as radiators are fluorocarbons gas like CF_4 ($< n > \approx 1.0005$, $\gamma_{th} \approx 31.6$), C_4F_{10} ($< n > \approx 1.0014$, $\gamma_{th} \approx 18.9$) and C_5F_{12} ($< n > \approx 1.002$, $\gamma_{th} \approx 15.84$) [10]. These gases contrary to hydrocarbons, are not flammable. CF_4 has a drawback consisting in a consistent emission of scintillation photons, when it is crossed by a charged particle. The scintillation in CF_4 produces a number of photons N_{ph} = 1200/MeV [11], that represent an important source of background. The disadvantage of C_5F_{12} is its boiling point at 28 °C which requires heating of the detector to keep the radiator in a gaseous state. C_4F_{10} on the other hand does not produces scintillation, and has good transmittance properties; its boiling point is T_b = -2 °C, so that it is in the gaseous state at ambient temperatures. We therefore restrict our considerations to the latter gas. Refractive index and Cherenkov emission angle of C_4F_{10} are shown in Fig. 3

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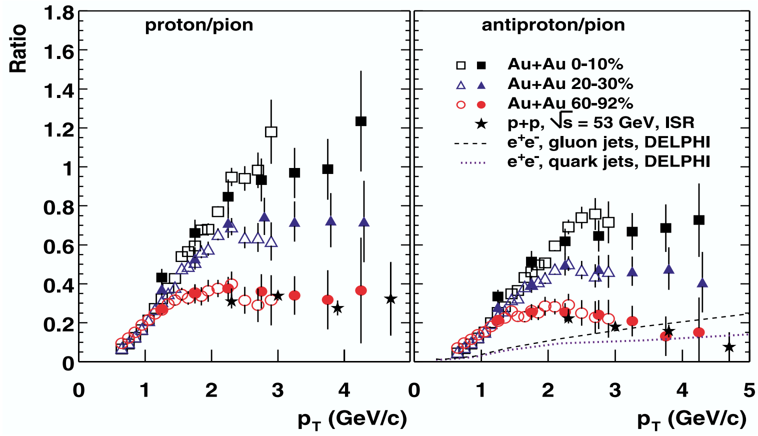


Figure 1: *[2] p/π (left) and $\overline{p}/\pi$ ratios for central ($0 \div 10\%$), midcentral ($20 \div 30\%$), and peripheral ($60 \div 92\%$) Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Open (filled) points are for $\pi^{\pm}(\pi^0)$, respectively. Data from $\sqrt{s} = 53$GeV p + p collisions [3] are shown with stars. The dashed and dotted lines are $(\overline{p}+p)/(\pi^+ + \pi^-)$ ratios in gluon and in quark jets [4].*

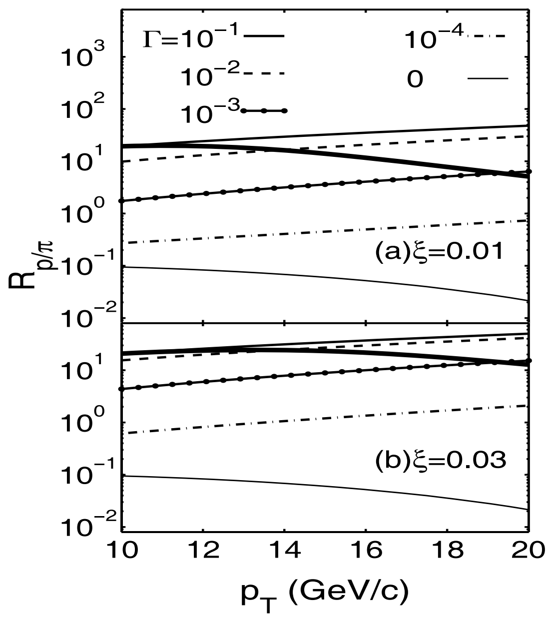


Figure 2: *The proton-to-pion ratio of the p_T distribution at LHC. The heavy solid lines show the ratio when $\Gamma(p_T)$ is taken to decrease as p_T^{-7}. The light solid lines present the ratio when only a single jet contributes. (Figure taken from [5]).*

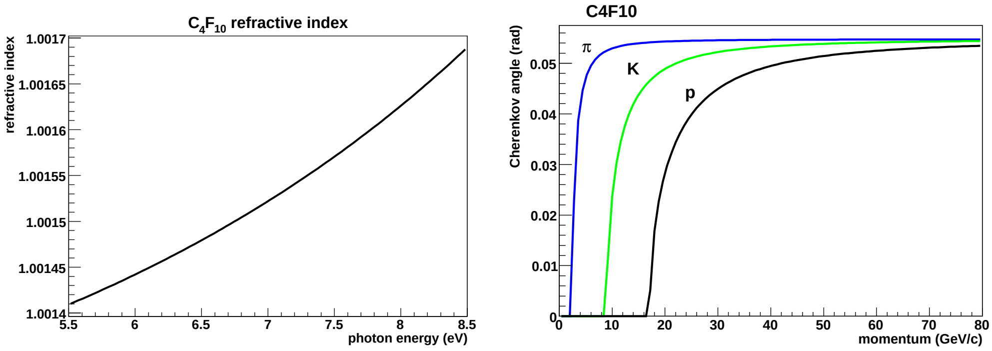


Figure 3: Left: C_4F_{10} refractive index as a function of photon energy. Right: Cherenkov emission angle for pion, kaon and proton as a function of momentum.

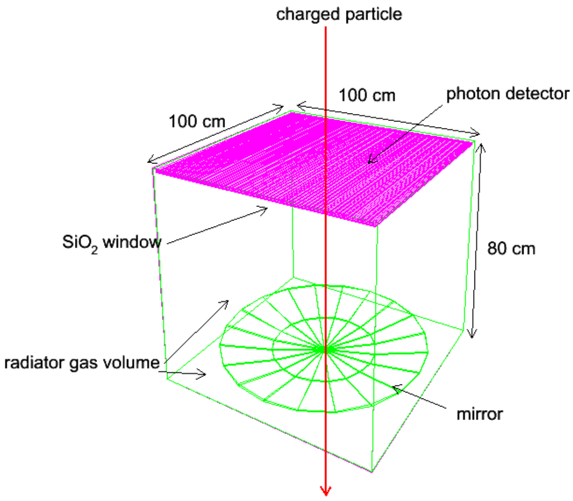
The photon detector consists of pad-segmented CsI photocathodes in a multiwire chamber. The chamber has the same structure and characteristics of that used in the High Momentum Particle Identification (HMPID) detector [8]. The amplification gas is CH_4, the pads size is 0.8x0.84 cm^2 (wire pitch 4.2 mm), and the single electron pulse height is of 34 ADC channels (1 ADC = 0.17 fC), corresponding to a gain of $4{\cdot}10^4$, at 2050 V. An interesting option for the photon detector could be a GEM-like detector combined with a reflective CsI photocathode [12]. Preliminary measurements have shown that with the GEM-like detectors one can achieve quantum efficiencies for CsI similar to the ones achieved with pad photocathodes in conjunction with the MWPC. The advantage of the GEM-like detector is the possibility to operate at higher gains due to the photon feedback suppression by the hole-type geometry. An interesting possibility would arise if it would be possible to operate the GEM-like structure in the radiator gas. Such possibility would considerably simplify the detector eliminating the quartz window.

The detector setup presented here combines the C_4F_{10} and the photon detector with the focusing properties of a spherical mirror of radius R, successfully used in many RICH detectors. The photons emitted in the radiator are focused in a plane that is located at R/2 from the mirror center. In Fig. 4 a schematic view of the detector is shown. The detector dimensions are 80x100x100 cm^3, the mirror radius of curvature is R = 160 cm. The radiator is separated from the chamber by a SiO_2 window of 4 mm of thickness. In Fig. 4 the material optical properties and CsI quantum effciency are shown.

3. Detector performance

The simulation has been executed in AliRoot [13], the official off-line framework of the ALICE experiment. Only the setup that uses MWPC as photon detector has been simulated. To simulate the particle interaction with matter the program GEANT3, interfaced with AliRoot, is used. From energy loss values coming from mip or photoelectron hits, the total charge generated by electron-ion pairs avalanche is calculated. According to the Mathieson distribution [14] the value in ADC channels of the charge induced on photocathode pads is retrieved.

The interception points of the photons with the focal plane, for one event, looks like those shown in Fig. 5. Even in extreme conditions of displacement from the center and angle (Fig. 6) the



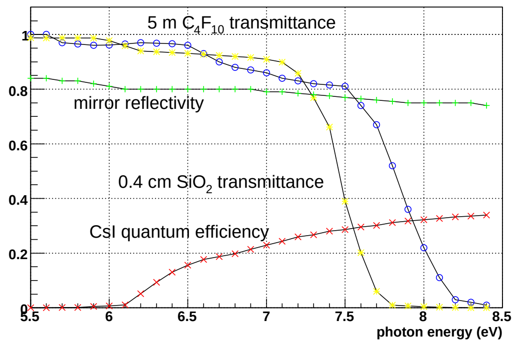


Figure 4: Left: Schematic picture of VHMPID design. Right: Detector material optical properties and CsI Q.E..

Table 1. Momentum range of identification for π, K and p using pattern recognition method (assuming 3σ separation) in presence of Pb-Pb background and for p in threshold mode.

Particle	Pattern recognition	Threshold mode
π	3–14 GeV/c	
K	9–14 GeV/c	
p	17–26 GeV/c	8–15 GeV/c

basic pattern is conserved, even if the charged particle impact point is outside the ring. In Fig. 7 is shown the distribution of the number of detected photons and of photon clusters per event for a $\beta \approx 1$ charged particle, respectively. It produces 14 photoelectrons and 9 photon clusters (the cluster may include two or more superimposed photons) on average. The focusing properties of this setup enable measuring the emission Cherenkov angles. A pattern recognition algorithm has been implemented. Starting from the impact point of charged particles and of photons on the chamber, by means of a back-tracing algorithm the photon emission angle has been retrieved. Pattern recognition has been implemented in the presence of background given by Pb-Pb collision at LHC energies. In this case, to identify the signal from the background the Hough Transform procedure has been applied [15, 16]. In Fig. 8 the angle distribution for single cluster is shown, it is possible to see the photon signal and the background. In Fig. 9 are shown the results for pions, kaons and protons of 14 GeV/c and 26 GeV/c respectively, embedded in a HIJING event using the Hough Transform method. The overall performance of the detector is shown in Table 1. Threshold mode identification for protons is also considered. The identification range can be extended increasing the detector length, but one has to match with the available space in ALICE. The free space under the space-frame sectors 13 and 14 allows integrating maximum six modules, no more than 80 cm in length, on each side of the PHOS cradle. In Fig. 10 a possible VHMPID layout is shown.

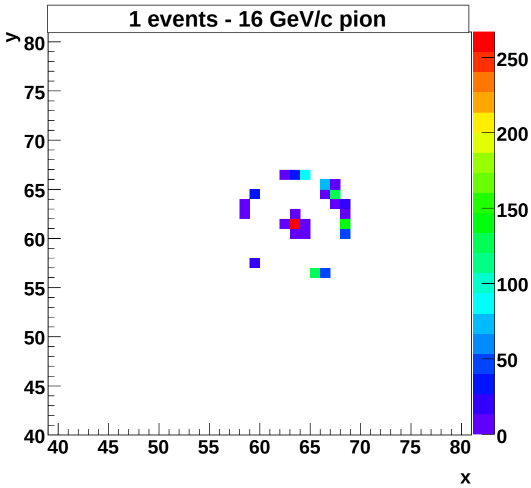


Figure 5: *Pattern for single 16 GeV/c pion.*

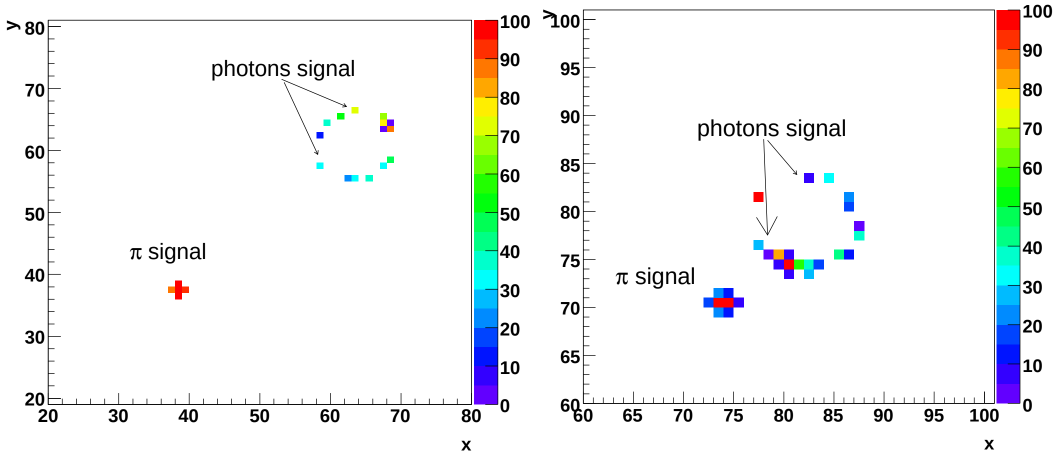


Figure 6: Left: Patterns for single orthogonal pion at saturation, hitting the detector 30 cm from the center. Right: Patterns for single pion at saturation with an incidence angle of 10 degrees.

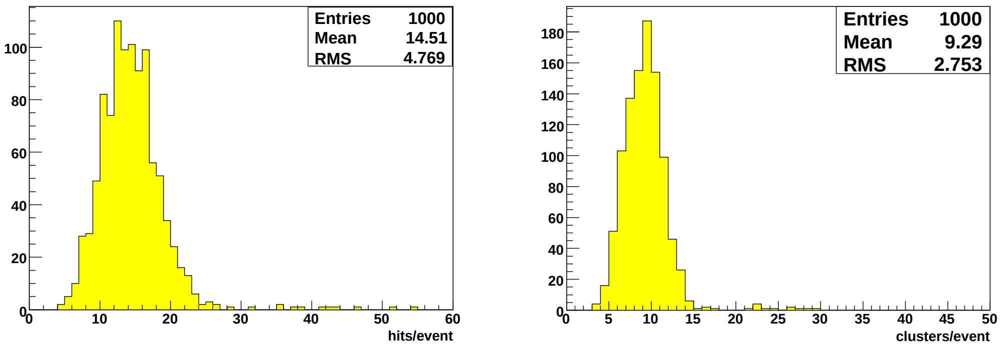


Figure 7: Left: Distribution of the number of photoelectrons per event, for a $\beta \approx 1$ charged particle. Right: Distribution of the number of photon cluster per event, for a $\beta \approx 1$ charged particle.

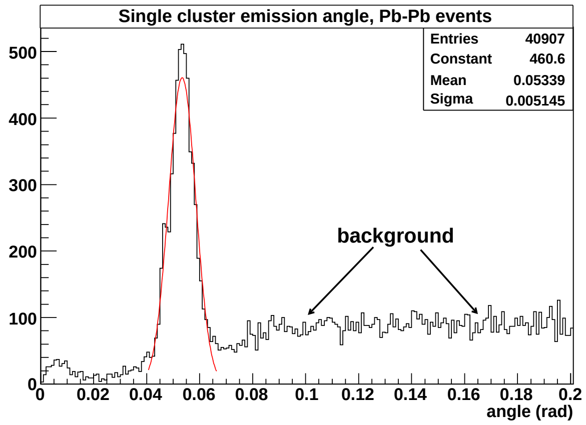


Figure 8: *Distribution of single cluster angle in presence of Pb-Pb background.*

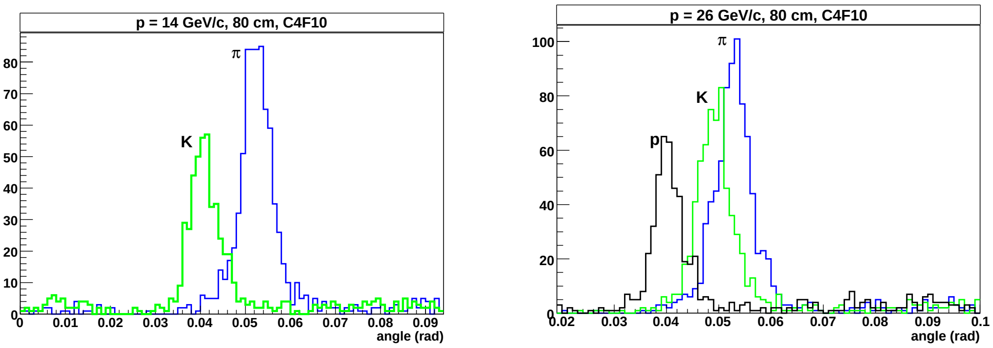


Figure 9: Left: Distribution of ring angle, for pions and kaons of 14 GeV/c in presence of Pb-Pb background. Right: Distribution of ring angle, for pions, kaons and protons of 26 GeV/c in presence of Pb-Pb background.

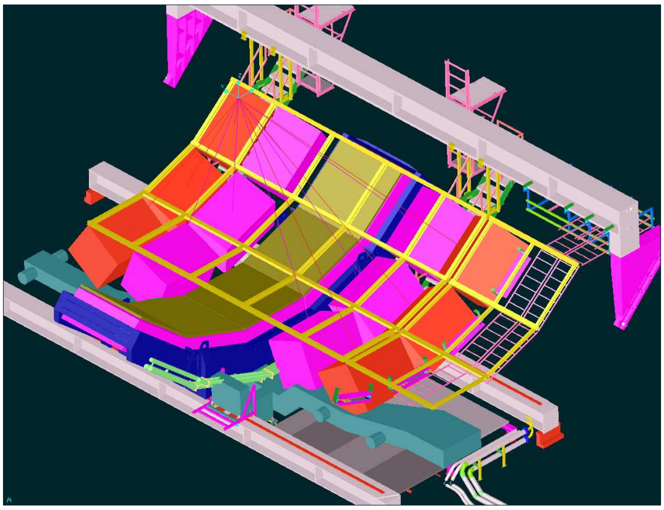


Figure 10: *1 3-D model of the proposed VHMPID layout with six modules on each side of the PHOS detector.*

4. Conclusion

In the present work full simulations for the VHMPID detector performed in the framework of the ALICE reconstruction system have been presented. According to these results it seems possible to improve the PID capability of ALICE, complementing the existing particle identification at high momenta, which relies on the performance of the TPC in the relativistic rise region. Test beam on the first prototype of VHMPID are foreseen already for November of 2008 at CERN. To enrich the sample with interesting event, triggering option for VHMPID has been also considered, using a dedicated trigger [17, 18] and/or photons in the EMCal.

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