A Very High Momentum Particle Identification Detector for the ALICE experiment

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Abstract. The main purpose of the ALICE experiment at CERN is to identify and study the quark-gluon plasma (QGP) in heavy ion collisions at the LHC. Among others, hadrochemistry allows for a detailed insight into the characteristics of the high temperature and density system created in these events. It is therefore important to be able to identify charged particles on a track by track basis. Moreover, results from high energy nucleus-nucleus collisions obtained by other experiments (e.g. at RHIC) indicate that it is imperative to extend the detection capability of ALICE to higher momenta. To meet these challenges, we propose the construction of the Very High Momentum Particle Identification Detector (**VHMPID**), which aims to identify charged pions, kaons, protons and antiprotons in the momentum range of 10 GeV/c < p_T < 30 GeV/c. In this contribution we will review the relevant physics arguments in proton-proton and heavy ion collisions as well as the detector proposal based on a RICH (Ring Imaging Cherenkov) detector with a C_4F_{10} radiator and a MWPC based CsI photon counter. In addition, we will present the advances in the development of an alternative multi-THGEM based CsI photon detector.

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PHYSICS MOTIVATION

The main purpose of the ALICE experiment is to identify and study the quark-gluon plasma (QGP) in heavy ion collisions at LHC energies [1]. The ALICE detectors [2] were designed in the mid-1990s with the aim to discover the properties of QCD matter at high temperatures in the soft regime. However, after the start of operation of RHIC at BNL in 2000, results from high energy nucleus-nucleus collisions have shown the importance of high momentum particles as hard probes and the need for particle identification in a very large momentum range. The ALICE detector has a unique capability to identify a wide variety of particles, however, by conception its momentum coverage for particle identification should be extended to meet new physics challenges at the LHC.

To significantly enhance ALICE's particle identification capabilities to a new regime of particle-by-particle measurements, we propose to construct a new detector for ALICE, the Very High Momentum Particle Identification Detector (VHMPID). The VHMPID aims to identify charged pions, kaons and (anti)protons in the momentum range 10 GeV/c < p_T < 30 GeV/c on a track-by-track basis. The detector is a state-of-the-art Ring Imaging Cherenkov detector (RICH), designed to meet the constraints of available space and structure inside ALICE, without compromising the prospect for new physics. The VHMPID covers 12% of the acceptance of the TPC and will be located on both sides of the PHOS detector.

In the present ALICE configuration the investigation of the high-p_T region is possible by the current sub-detectors in a limited way. The HMPID provides particle identification up to $p_T \sim 3$ and ~ 5 GeV/c for kaons and protons, respectively. The TPC can provide identification of charged hadrons at larger momenta on a statistical basis by using the energy loss measurements in the relativistic rise. However, results from RHIC have proven that high-p_T identified particles and high-p_T hadron-tagged jets carry more detailed information about the energy loss mechanism and correlations than charged particles alone. The proposed VHMPID detector will extend the track-by-track PID capability of ALICE in the high-p_T region and its combination with the existing calorimetry (EMCAL) settles new discovery potential for the collaboration.

At RHIC, a large enhancement of baryons and antibaryons has been observed relative to pions at intermediate p_T ($\approx$ 2 - 5 GeV/c), while the neutral pions and inclusive charged hadrons are strongly suppressed. This "baryon puzzle" is foreseen to be present at the LHC in a momentum range higher than at RHIC, p_T = 10 - 20 GeV/c [3]. Other authors using different arguments foresee also change in meson-baryon ratio for $p_T >$ 10 GeV/c, stating that jet quenching could leave signatures not only in the longitudinal and transverse jet energy and multiplicity distributions, but also in the hadrochemical composition of the jet fragments [4]. The key issue is to understand the mechanism of hadronization and its influence on the spectra of baryons and mesons. As hadrochemistry and PID triggered jet analysis allow for a detailed insight into the characteristics of the QGP, it is of crucial importance to be able to identify charged particles on a track-by-track basis.

Track-by-track PID has advantages over the statistical identification because it will allow to study aspects such as the conservation of baryonic number measuring the p-pbar correlations in the same side jet. Also one would expect the topology of events with high p_T protons to be distinct from the topology of a jet with a pion leading particle. Kaon identification may also be of interest in jet hadrochemistry as shown in [4]. And simply the track-by-track PID may be also usefull as a benchmark for the statistical identification.

THE DETECTOR LAYOUT

The construction of the VHMPID detector is based on earlier experience with the ALICE HMPID detector [5], thus much of the technology is in-hand. The physics requirements have driven the choice towards a RICH detector using a C_4F_{10} gaseous radiator in a focusing configuration. Figure 1 shows a schematic view of the detector layout. The Cherenkov photons emitted in the radiator are focused by a spherical mirror (of radius of curvature R) on the photodetector plane, located at R/2 from the mirror center.

The gaseous radiator. Perfluorocarbon gases C_nF_{2n+2} are characterized by refractive index and low chromaticity which best suit to particle identification (PID) above 10 GeV/c. The choice is restricted to C_4F_{10} ($\langle n \rangle \approx 1.0014$, $\gamma_{th} \approx 18.9$) [6], since, at room temperature, it is the only one suitable for the momentum range 10 - 30 GeV/c where PID is required. The radiator length, presently fixed at 80 cm, is limited by the maximum detector height compatible with the space available inside the ALICE experiment.

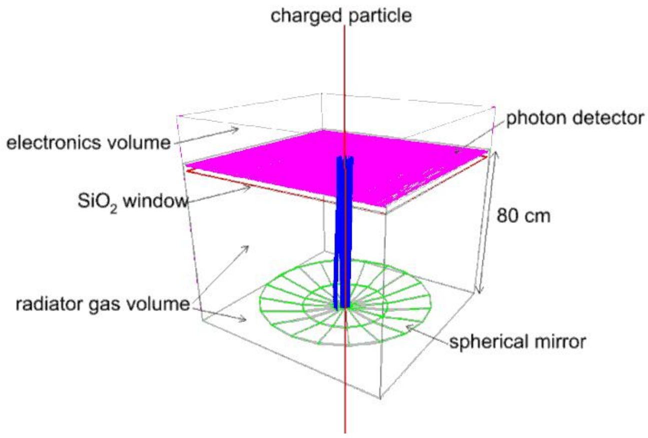

FIGURE 1. Principle scheme of the VHMPID with focusing RICH.

The photon detector. The photon detector is a Multi-Wire Proportional Chamber (MWPC) equipped with a CsI photocathode consisting of a pad-segmented cathode coated with a 300 nm thick CsI layer. The chamber has the same structure and characteristics as in the HMPID [7]. It is separated from the gaseous radiator volume by a 4 mm thick SiO_2 window. The gas used is CH_4, the pad size is 0.8 x 0.84 cm^2, the wire pitch is 4.2 mm and the anode-cathode gap is 2 mm. The Front-End electronics (FEE) is based on the Gassiplex chip, achieving 1000 e^- noise on detector; the single electron average pulse height at 2050 V is 35 ADC channels corresponding to about 40 000 e^-. In the actual HMPID design, the total space required by the photon detector in the radial direction is about 20 cm, largely determined by a vertical mounting of the FEE cards. We are considering a different layout with horizontal FEE cards to minimize the photon detector thickness and make available more space for the radiator or a possible dedicated trigger detector.

INTEGRATION IN ALICE

The detector design is strongly constrained by the limited space available inside the ALICE solenoid and the strength of the existing support structure (PHOS support beams) on which the VHMPID would be installed. The free volume under the space-frame sectors 11 and 12 next to the PHOS detector and D-CAL allows the installation of the VHMPID modules, as seen in figure 2. In order to maximize the acceptance, a design of 5 *super-modules* has been made, which would cover 12% of the acceptance with respect to the TPC in $|\eta| = 0.5$ for the leading particle.

The module size is limited in height to 1300 mm mainly by the space available between the frame and the false floor at the bottom of the solenoid. The other two dimensions, in the chosen spherical layout, i.e. with modules pointing to the interaction point, can reach a maximum of 1000 x 1400 mm to minimize the conflicts with the space-frame structure.

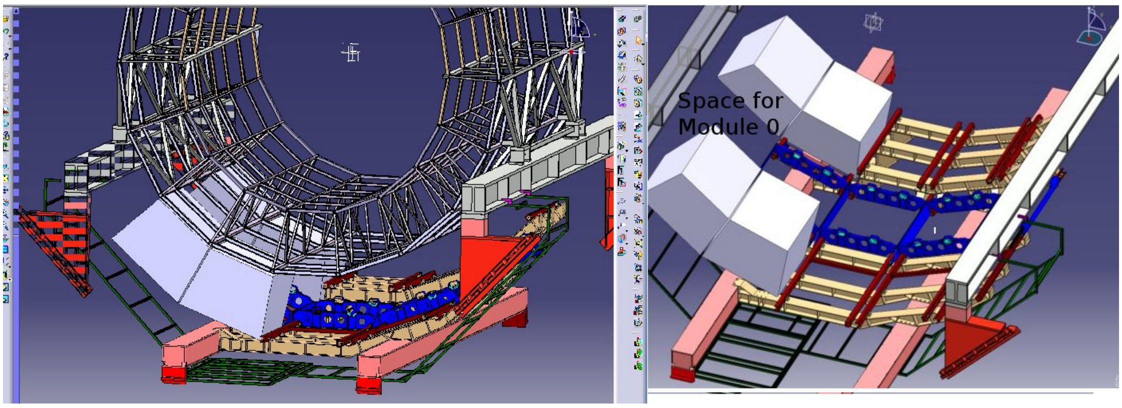

FIGURE 2. Model of the proposed VHMPID layout with two super-modules (white) on each side of the PHOS detector and space for a 1/2 supermodule prototype (Module 0).

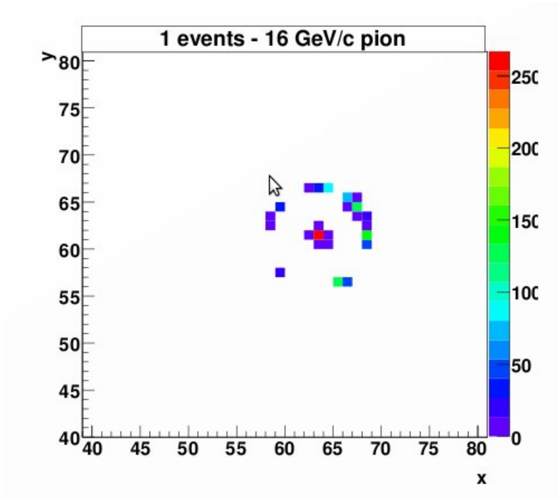

FIGURE 3. Cherenkov ring produced by simulation of a single 16 GeV/c pion.

DETECTOR PERFORMANCE

The performance and PID capabilities have been studied [8] by means of MonteCarlo simulations in AliRoot, the official simulation framework of the ALICE experiment. Figure 3 presents a single 16 GeV/c pion event for normal incidence in absence of background. A charged particle at saturation produces 20 photoelectrons and 12 photon clusters (the cluster can include two or more superimposed photons) on average.

Events obtained by overlapping Cherenkov rings from pions, kaons and protons, at different momenta, to background Pb+Pb HIJING events at LHC energies, have been analysed using the same pattern recognition procedure developed for the HMPID [9]. Starting from the impact point of charged particles and photons on the chamber, the Cherenkov angle is determined by means of a back-tracing algorithm. Then a Hough Transform is applied to filter out the background and improve the signal of identified

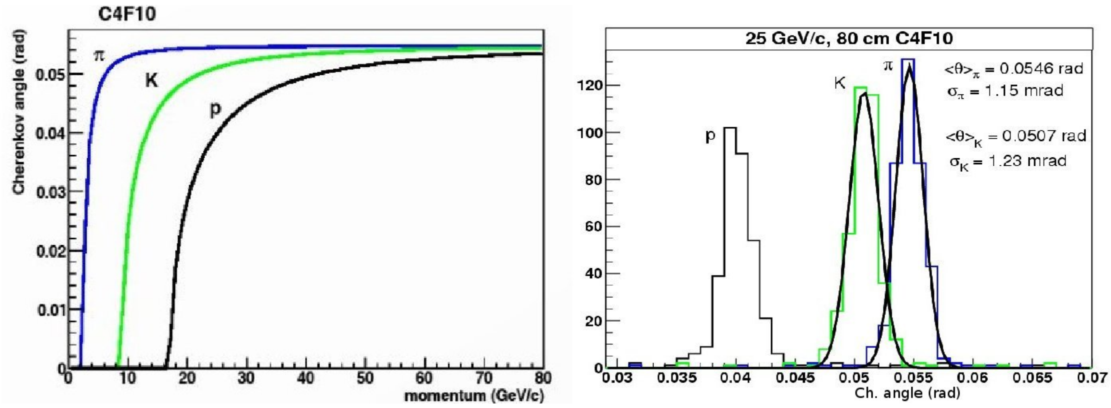

FIGURE 4. Left: Photon yield (eV^{-1} cm^{-1}) as a function of momentum for π, K and p in C_4F_{10}. Right: Distribution of ring-averaged Cherenkov angle for pions, kaons and protons of 25 GeV/c after the Hough Transform method.

particles. Figure 4 presents the ring-averaged Cherenkov angle distributions obtained for pions, kaons and protons of 25 GeV/c.

The summary of the PID performance obtained with the baseline VHMPID is given in Table 1, where absence and presence of signal refers to the detection of the Cherenkov ring. Positive identification lower limits are determined by Cherenkov emission thresholds and upper limits correspond to 3σ separation.

TABLE 1. Identification momentum range with C_4F_{10} radiator

Particle type	Absence of signal [GeV/c]	Presence of signal [GeV/c]
π	-	4-24
K	-	11-24
p	11-18	18-30

TRIGGER OPPORTUNITIES

Specialized triggering must be implemented to fully exploit the VHMPID detector, since the hadron yield drops rapidly in the momentum range of interest. Two trigger methods can be used to optimize the data collection with the VHMPID and to enhance the existing physics capabilities of ALICE.

Triggering by TRD. The current TRD design allows to determine the momenta of charged particles with a precision of 5% for particles with momentum 5 GeV/c, within 5 μs which is acceptable for L1 triggering [10]. The TRD provides a trigger for the HMPID in the momentum window 3-5 GeV/c. This method would need to be extended to higher transverse momenta ($p_T > 10\ GeV/c$) to meet the demand of data-taking with high-p_T particles in the VHMPID.

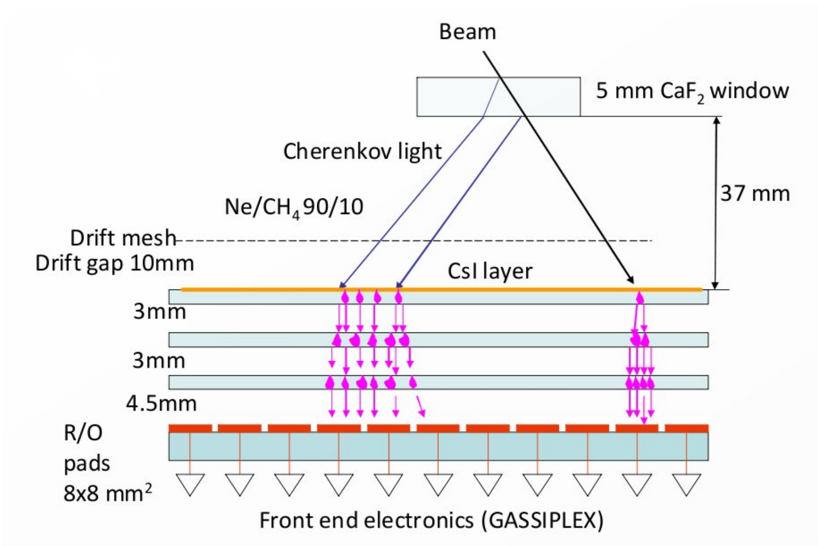

FIGURE 5. Layout of the RICH prototype with CaF_2 radiator and CsI-TTGEM photon counter.

Triggering by a dedicated high-p_T trigger detector. An effective alternative solution is to build a dedicated high-p_T Trigger Detector (HPTD) able to provide L1 triggering in the high momentum range [11]. It consists of four layers of tracking GEM-based detectors, occupying in total about 20 cm. By measuring the inclination of high-p_T particle trajectories at each detector plane and knowing the bending of the trajectories in the magnetic field, the particle momenta can be computed rapidly and used for triggering.

R&D ON ALTERNATIVE GEM BASED DETECTOR

An interesting alternative to the traditional MWPC-based photodetector is represented by a multi-GEM (Gas Electron Multiplication) detector combined with a CsI-coated photocathode. The main advantages of a GEM based detector would be a simpler and faster detector construction and the possibility to operate at higher gains due to the photon feedback suppression by the hole-type geometry.

Due to their robustness, both from the mechanical and operational point of view, we have focused our attention on TGEMs (Thick GEMs) [12], a device consisting of a printed circuit board (PCB) 0.5-1mm thick, metallized from both sides, with drilled holes of 0.5-1 mm diameter with a pitch of 0.8-1.2 mm. It is possible to obtain a gain close to 10^5 with a single TGEM and up to 10^7 with cascaded TGEMs [13].

Fig. 5 shows the layout of the RICH prototype tested at the CERN/PS [14]. It consists of a CaF_2 window, 4 mm thick, used as the Cherenkov radiator, coupled to a CsI-TTGEM (Triple TGEM), flushed with Ne+10%CH_4 or Ne+10%CF_4 at p = 1 atm. Each TGEM had a thickness of 0.45 mm, an active area of 10x10 cm^2, hole diameter of 0.4 mm (holes have 10 μm wide dielectric rims) and pitch of 0.8 mm. The readout was based on the standard ALICE HMPID electronics (GASSIPLEX and DILOGIC

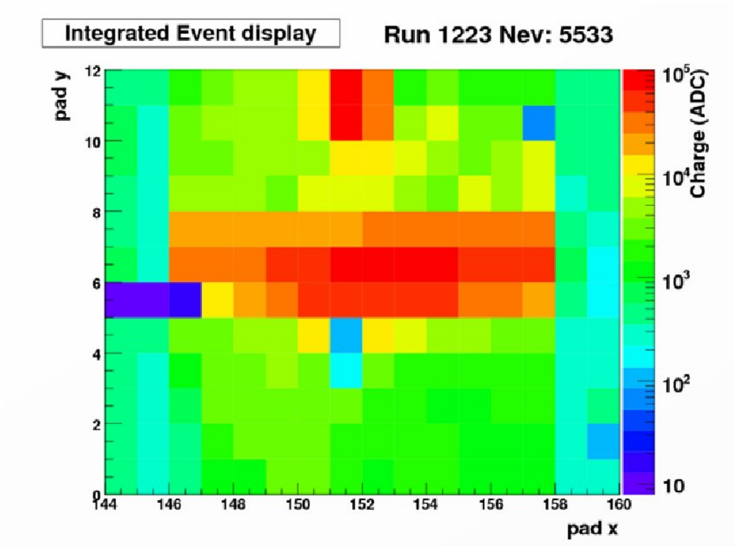

FIGURE 6. A typical image of the integrated events obtained during tests of the CsI-TTGEM RICH prototype oriented $\sim 32^\circ$ with respect to the beam. During this particular run the CsI-TTGEM was operated with an overall gain of $\sim 10^5$.The spot at the top is the image of the particle beam and the horizontal bands in the middle correspond to the detected Cherenkov photons.

chips developed within the HMPID project). Event monitoring and analysis have been carried out using the ALICE software package AMORE. The RICH prototype was then installed at the CERN PS/T10 beam test facility. Tilting the detector by an angle larger than 20° with respect to the particles direction, part of the Cherenkov cone escapes the CaF_2 radiator and falls in the acceptance of the top CsI-TGEM together with the MIP. Because of the detector configuration and the small photosensitive area, only a fraction of the produced Cherenkov radiation can be detected (Fig. 6).

CONLUSIONS

The RHIC results have proven the relevance of PID at high transverse momenta on a track-by-track basis. We propose to build a new detector which will enhance significantly the physics capabilities of ALICE exploring the new regime of hard processes at LHC energies, both in proton-proton and heavy-ion collisions. The proposed baseline VHMPID detector, using a C_4F_{10} Cherenkov radiator coupled to a MWPC-based CsI photo-detector, will allow charged hadron identification in the 10 - 25 GeV/c momentum range.

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