Nuclear Instruments and Methods in Physics Research A 598 (2009) 152–155

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Particle identification with the ALICE detector

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ARTICLE INFO

Available online 23 August 2008

Keywords:
Heavy ion
Particle identification

ABSTRACT

This paper describes the particle identification (PID) capability of the ALICE detector. ALICE makes use of several particle discrimination techniques to address successfully the challenge of identifying particles in high-density events produced in Pb–Pb interactions at LHC energies. The combination of several sub-detectors makes the measurement more robust and wider in momentum, allowing the detector to use the PID as a key tool for the complete understanding of heavy-ion collisions at LHC.

1. Introduction

Particle identification (PID) is one of the most challenging tasks of the ALICE [1] detector: particles with momentum from about 0.1 GeV/c to several GeV/c have to be identified in high-density events, with an expected charged particle multiplicity of thousands of particles per unit of rapidity. To reach this goal the detector makes use of several techniques: each detector attempts to cover a different range of energy, so that their combination can address the large momentum range required by physics. This paper describes the features and the expected performances of the detectors contributing to the PID.

2. The Inner Tracking System (ITS)

The goal of the ITS [2] is the determination of the primary vertex and the secondary decay vertices, and PID/tracking at low momentum. It includes three different detectors, based on the silicon technology. Starting from the beam pipe, we find the Silicon Pixel Detector (SPD), then the Silicon Drift Detector (SDD) and finally the Silicon Strip Detector (SSD). The SDD and the SSD contribute to the charged PID by measuring the charge deposited by ionizing particles. The identification relies on the classical simultaneous measurement of the particle momentum and of the particle-truncated dE/dx (Fig. 1).

When speaking of PID capability of a given detector, the efficiency/contamination is usually given for a pair of particles to be discriminated. In a heavy-ion experiment it is more appropriate to study the detector separation power in a simulated event, where the proper particle ratio of the thousands of particles crossing the sub-detectors is generated. The results reported in this paper refer to events simulated using the HIJING code. The ITS can separate pions and protons up to 0.8 GeV/c with more than 90% efficiency, while having a contamination $<10\%$. In the same momentum range, pion (π) and kaon (K) separation is of course more difficult: anyway an efficiency larger than 80% can be obtained, while keeping the contamination to 20% level.

3. The Time Projection Chamber (TPC)

The ALICE TPC [3] is a large-volume detector ($\sim$88 m^3), filled with a 90% Ne–10% CO_2 mixture. The TPC has an inner radius of 85 cm, given by the maximum acceptable hit density (0.1 cm^{-2}), and an outer radius of 250 cm, given by the length required for a dE/dx resolution. The readout chain includes, for each channel, a preamp shaper, a 10-bit ADC and a fairly complex digital circuit that performs tail cancellation, digital baseline restoration and data compression.

The TPC end plates are each segmented into 18 trapezoidal sectors and equipped with multi-wire proportional chambers (MWPCs) with $\sim$560,000 cathode pad readouts. The dE/dx resolution is about 6.5% in the case of central Pb–Pb events, improving to 5% for peripheral interactions. A 2σ separation between π and protons can be obtained for momentum $p<1.2$ GeV/c or $p>2.4$ GeV/c, while a 2σ separation for π/K can be obtained for $p<0.6$ GeV and $p>2.5$ GeV. The TPC detector was installed in the ALICE frame on early 2007 and is now being commissioned.

4. The Transition Radiation Detector (TRD)

The TRD [5] is equipped with 750 m^2 total area of gas detectors for particle tracking and electron identification above 1 GeV/c. The detector is made of 540 modules, containing a gas chamber with radiators. The 18 sectors are arranged in a barrel geometry

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doi:10.1016/j.nima.2008.08.074

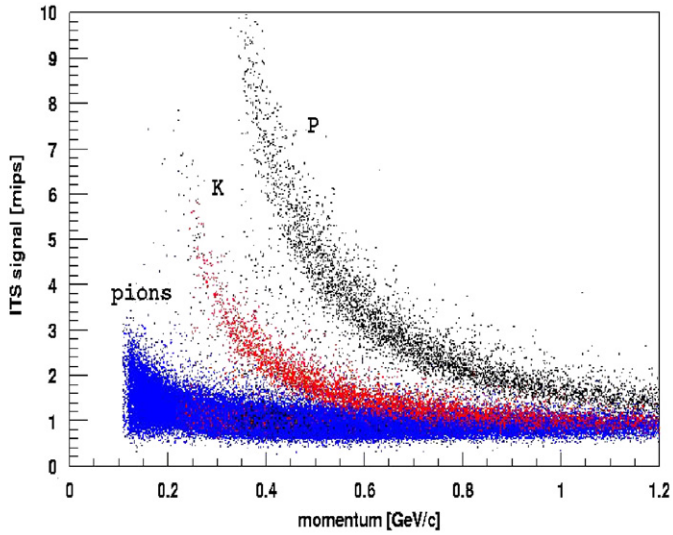

Fig. 1. Simulation of the truncated dE/dx measured by the ITS system as a function of particle momentum.

between 2.9 and 3.7 m from the beam axis. It makes use of a Xe(85%)–Co_2(15%) gas mixture and provides about 1.2 million readout channels. The TRD can separate electrons with an efficiency larger than 90%, while keeping the pion contamination at the level of 10^{-2}. Due to the relativistic rise the separation between pions and electrons based only on dE/dx would be reduced as a function of momentum. Since electrons produce transition radiation in this momentum range, the resulting pion efficiencies can be calculated using a likelihood on the total integrated energy loss (LQ). In addition, the exponential probability for absorption of TR photons in the gas mixture can be exploited in a bidimensional likelihood (LQX). Here, the distribution of the time bin with the maximum measured amplitude is used together with the total integrated charge. Moreover this effect can be exploited by using a neural network approach. Fig. 2 shows the pion efficiency as a function of electron efficiency for different particle multiplicities per unit of rapidity. Presently two TRD modules have been already installed and other two will be installed shortly.

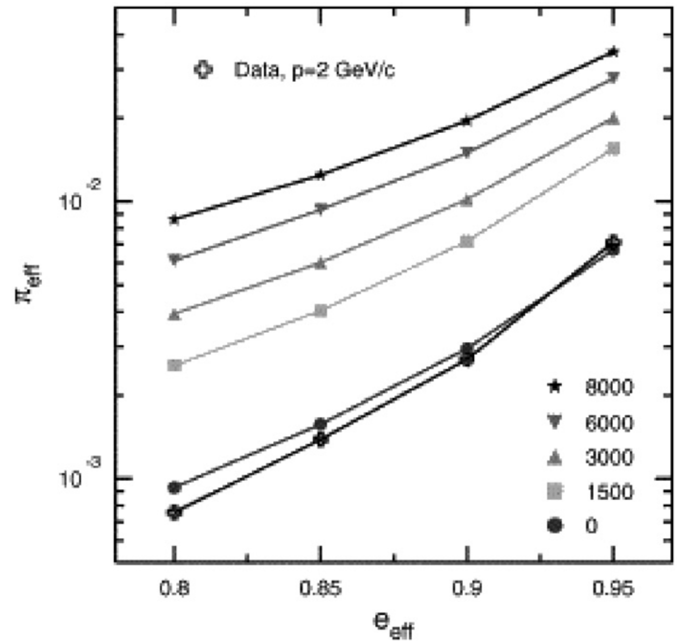

Fig. 2. TRD pion efficiency as a function of electron efficiency, for different charged particle multiplicities per unit of rapidity. Test beam data are shown as crosses.

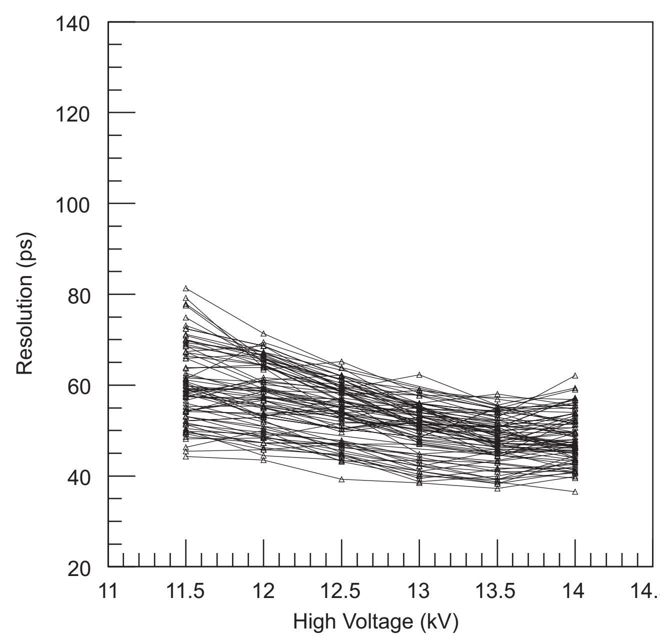

Fig. 3. TOF time resolution as a function of applied voltage. Each line shows the performance of a channel, measured during a test beam.

5. The Time of Flight (TOF)

The TOF [4] is arranged in 18 supermodules, covering 3600 in azimuth and $|\eta|<0.9$, for a total area of $\sim 150\,m^2$.

It makes use of the Multi-gap Resistive Plate Chamber (MRPC), offering an excellent time resolution combined with a high efficiency. Each supermodule is made of five modules, containing a number of MRPC strips ranging from 15 to 19.

Each MRPC strip contains two stacks of resistive glass plates, spaced one from the other with equal-sized spacers, creating a series of uniform gas gaps with voltage applied to the external surfaces. Electrodes are connected to the outer surfaces of the stack of resistive plates while all the internal plates are left electrically floating.

The MRPC stack is made of six glasses, forming five gaps. Each gap has a width of 250 μm and is filled with the gas mixture $C_2F_4H_2$(90%)–C_4H_{10}(5%)–SF_6(5%).

Approximately 157,000 channels are connected with a Front End card equipped with the NINO ASIC. The signal produced by the ASIC is read out by HPTDC chips. Several beam tests have been performed, giving a total time resolution better than 60 ps. Fig. 3 shows a TOF prototype time resolution as a function of the applied voltage. Each line indicates the performance of a single channel in the module. When computing the TOF PID capability, as a safety margin, the TOF time resolution was considered at $\sigma_t = 80$ ps. With such resolution, the TOF is expected to provide a π/K and K/p separation better than 3σ up to a track momentum $p\sim 2.5$ GeV/c and $p\sim 4$ GeV/c, respectively. At present 15 of the 18 TOF supermodules have been mounted and are being commissioned.

6. The High-Momentum Particle Identification Detector (HMPID)

The High-Momentum Particle Identification (HMPID) [6] system enhances the PID capability of ALICE beyond the

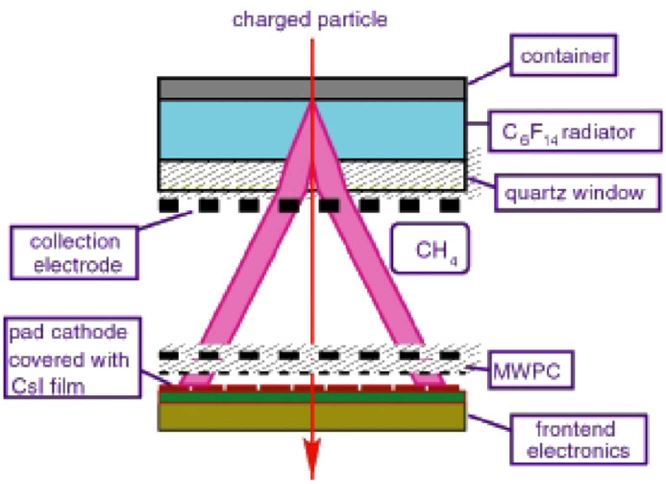

Fig. 4. Overview of the HMPID.

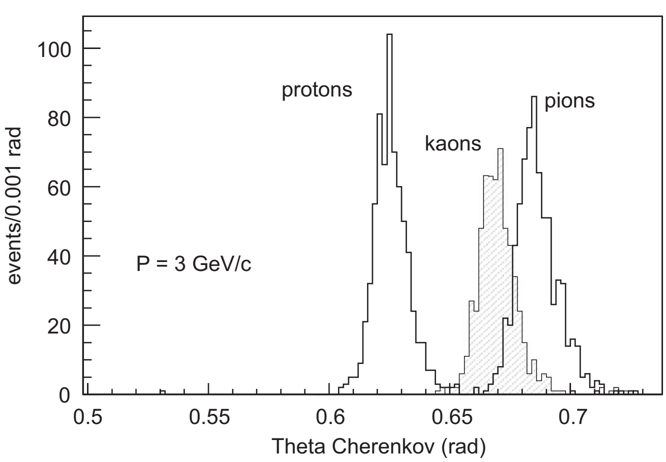

Fig. 5. HMPID-reconstructed Cherenkov angle theta for protons, kaons and pions with momentum 3 GeV/c in a simulated event with $dN/d\eta = 6000$.

momentum range allowed by energy loss measurements (ITS and TPC) and by the TOF. It consists of seven modules (Fig. 4), each of area $(1.5 \times 1.5)\,m^2$. Cherenkov photons are emitted while charged particles cross the 15 mm-thick layer of C_6F_{14}, thus acting as radiator. They impinge on the photodetector, separated from the radiator by a proximity gap of 80 mm such that Cherenkov rings of convenient size are obtained without a focusing device. The photodetector is a MWPC having a cathode covered with a CsI layer 300 nm thick, thus acting as photoconverter. The same cathode is segmented into pads of localization of photoelectrons, mandatory in the ALICE high-density particle environment. The second cathode is made of 100 μm-diameter gold-plated copper beryllium wires, spaced by 2.1 mm and located at 2.2 mm from the anode plane. The anode plane, which is made of 20 μm gold-plated tungsten rhenium wires, is located at 2 mm from the pad plane. The HMPID detector has been designed to extend the useful range for the identification of π/K and K/p, on a track-by-track basis, up to 3 and 5 GeV/c respectively. Fig. 5 shows the HMPID capability to discriminate 3 GeV/c π/K/p.

7. The muon spectrometer

The muon spectrometer [7] is designed to measure the production of complete spectrum of heavy quark resonances, namely J/Ψ and Ψ″, Υ,Υ′, and Υ″. The spectrometer consists of a 3 Tm magnet, a hadron absorber, ten planes of thin MWPC equipped with highly segmented cathode planes for tracking and four planes of Resistive Plate Chambers (RPCs) for muon identification and triggering. A high-density small-angle absorber with a central hole shields the spectrometer from the particles emitted at angles below 2°, allowing the beam particles to traverse the spectrometer.

The construction of gas-filled chambers with pad readout is based on a well-known technology. However, the large total surface of the muon chambers, over $100\,m^2$, and the huge number of electronic channels employed, almost one million, required an intensive R&D activity to optimize cost and performance. Both in proton–proton and in heavy-ion collisions, the detector has a mass resolution $\sim$100 MeV/c^2 at quarkonia masses of 10 GeV and better than 70 MeV/c^2 in the J/Ψ region, and momentum precision (about 1%) sufficient to separate all states on a continuum due to B and D meson decays and Drell–Yan processes.

8. The Photon Spectrometer (PHOS)

The goal of the PHOS [8] detector in ALICE is to detect and identify real photons and to measure with high resolution their four-momentum, to perform a physics program exploiting direct photons and neutral mesons as privileged probes. Located at 4.6 m from the vertex, it is a highly segmented $PbWO_4$ calorimeter. The five modules, made of a 56×64 crystal matrix, cover a η range $-0.12 < \eta < 0.12$ and azimuth angles $40^\circ < \phi < 140^\circ$. Each of the 17,920 crystals is equipped with an APD diode and a low-noise, charge-sensitive preamplifier. Measurements of neutral pions and direct photons will be performed over a broad range in momentum from 1 to 80 GeV/c. The prototypes were tested during dedicated test beam, showing a time resolution $\sigma \sim 0.5$ ns for $E > 1.5$ GeV and an average energy resolution of about 3%.

9. The electromagnetic calorimeter (EMCal)

The goal of the ALICE EMCal [9] is to enhance the ALICE capabilities for jet quenching measurements. In addition the EMCal enables triggering on high-energy jets, reduces significantly the measurement bias for jet quenching studies, improves jet energy resolution and increases the existing ALICE capabilities to measure high-momentum photons and electrons. Combined with the ALICE's excellent capabilities to track and to identify particles from very low p_t to high p_t, the EMCal enables an extensive study of jet quenching at the LHC. The chosen technology is a layered Pb-scintillator sampling calorimeter with a longitudinal pitch of 1.44 mm Pb and 1.76 mm scintillator with longitudinal wavelength shifting fibre light collection (Shashlik).

The full detector spans from $\eta = -0.7$ to $\eta = 0.7$ with an azimuthal acceptance of $\Delta\phi = 110^\circ$. The detector is segmented into 12,672 towers, each of which is approximately projective in η and ϕ to the interaction vertex.

10. Combining sub-detector PIDs

The sub-detectors described above can discriminate the large amount of particles produced in the heavy-ion interaction [10]. Each of them provides the best PID efficiency in a given momentum range, so that combining their response improves the global ALICE PID capability. As an example we show in Fig. 6 the K identification efficiency (continuous line) and contamination (crosses), as a function of the particle momentum, obtained

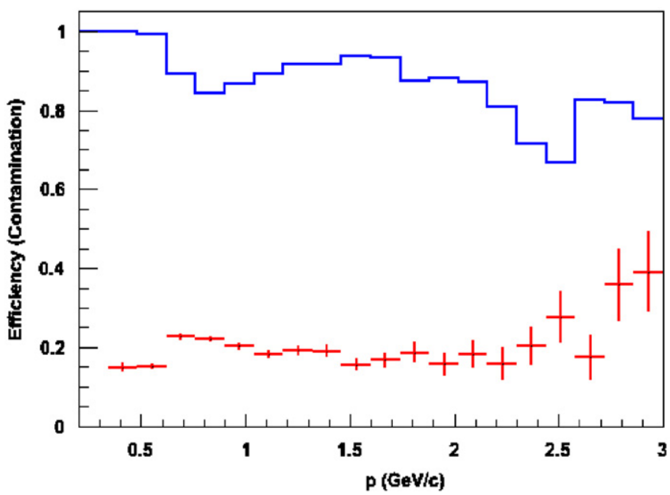

Fig. 6. Kaon efficiency (continuous line) and contamination (crosses) obtained by combining the simulated ITS, the TPC and the TOF PIDs.

by combining the ITS, the TPC and the TOF. The ratio of the different particle types produced in the event is taken into account using Pb–Pb events generated by the HIJING code. Independently of the momentum considered, the combined probability is higher (or equal) than in the case of any of the detectors working in stand-alone mode, while the contamination is always lower (or equal) than the contamination obtained with the single-detector PID procedure. It is worth nothing that the combined PID efficiency/contamination is a weaker function of momentum than that of single detectors. Further improvements can be achieved at higher momentum too. For instance combining the dE/dx measured for each track by the TRD and by the TPC. Recently other sub-detectors have been combining the simulated ITS, the TPC and the TOF PIDs proposed, aiming to extend the identification of π/k/p in ALICE up to 10 GeV/c, such as the Focusing Aerogel RICH (FARICH) [11].

11. Conclusions

The ALICE detector makes use of several techniques to identify charged hadrons: spanning from dE/dx at low energy, TOF at intermediate energies and Cherenkov imaging at the highest energies. Electron identification takes advantage of the TRD and of the EMCAL sampling calorimeter, while photon tagging relies on the $PbWO_4$ crystal used by the PHOS. Muons are triggered and analyzed by the forward muon spectrometer, making use of gas detectors and of a dipole magnet. The sub-detector PID combination provides a robust, momentum-wide PID, allowing a comprehensive study of heavy-ion collisions at LHC energies in the next years.

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