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Position resolution and electron identification with prototypes of the ALICE TRD

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Abstract

A Transition Radiation Detector (TRD) has been designed to improve the electron identification and trigger capability of the ALICE experiment at the CERN Large Hadron Collider. Especially at the trigger level, excellent performance is required in terms of pion rejection and tracking. Four identical TRD prototypes were tested at the secondary mixed electron/pion beam facility at the CERN PS over a momentum range from 1 to 6 GeV/c. We present measurements of position and angular resolution, the measured momentum dependence of the pion efficiency, and comparisons to simulations.

1. Introduction

ALICE is the dedicated heavy ion experiment at the CERN Large Hadron Collider (LHC). Particle separation and tracking are important design features and challenging tasks, in particular for the high particle multiplicities of central Pb–Pb collisions at the LHC. In ALICE a Transition Radiation Detector (TRD) is added to increase the electron identification and online tracking performance of the experiment [1]. Thus the TRD requires excellent pion rejection and position resolution.

In conjunction with other ALICE detectors, the TRD will allow to explore the production of quarkonia (J/ψ, ψ' and the members of the Υ family) as well as open charm and open beauty.

The TRD surrounds the ALICE Time Projection Chamber (TPC), starting at a radius of 2.9 m and extending to 3.7 m. It has an overall length of 7 m and covers the rapidity range from −0.9 to 0.9. The total anticipated radiation thickness is $X/X_0 = 15\%$. The TRD is segmented into 18 sectors in the azimuthal direction. Each sector consists of 6 layers in the radial direction and is composed of 5 stacks in the longitudinal direction. This amounts to 540 individual detector modules with a total active area of roughly 750 m^2 and 1.2 million read-out channels. The largest module is 159 cm long and 120 cm wide. Each module is

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13 cm thick, including radiator, electronics and cooling.

Each TRD drift chamber is composed of a 3 cm drift region, a 0.7 cm amplification region and a 4.8 cm thick radiator, which is a sandwich of polypropylene fibers and Rohacell foam. As signatures to discriminate incident electrons from pions, the different energy loss at given momentum [2] and the emission of Transition Radiation (TR, X-ray photons with an energy up to about 30 keV) are used. A high-Z gas mixture (Xe, CO_2 15%) is used to provide an efficient X-ray photon absorption. The drift chambers are equipped with cathode pads of approximate size $0.7 \times 8\,\mathrm{cm}^2$ and read out via charge sensitive preamplifiers/shapers (PASA). Charge sharing between adjacent pads allows to reconstruct the position of the clusters along a pad row. The drift time for the whole drift region is about 2 μs and the induced signal is sampled at 10 MHz to record the time evolution of the signal [3,4]. Since the massive ions move slowly compared with the sampling time, the signals exhibit long tails. Convoluted with the response of the PASA, the ion tails give rise to a strong correlation between subsequent time bins. The tails can be approximated by an exponential function, and in order to remove/reduce the correlation effect, they are subtracted in the data as a function of time (tail cancellation).

To improve the position resolution in the second direction along the pad columns (the z-direction in the ALICE layout), the pads are tilted by an angle of 2°. However, in this publication we only discuss resolutions along the pad rows, since in that direction the resolution matters for momentum measurements.

2. Simulations of the TRD performance

For simulations of the TRD performance we use AliRoot [5], the ALICE software package. AliRoot provides an object oriented framework for event simulations and reconstruction in the ALICE detector. The interaction of the charged particles with the detector materials is implemented using Geant 3.21. For the study of electron identification capabilities the production of TR has to be part of the simulation. Since this is not included in Geant 3, it was explicitly added to AliRoot, using an approximate formula for the TR yield of a regular stack of foils with fixed thickness, including absorption [1].

3. Measurements with prototypes

The measurements were carried out at momenta of 1–6 GeV/c at the T10 secondary beam line at the CERN PS. The momentum spread was about 1%. The beam was a mixture of electrons and negative pions and clean samples of each particle type were selected using coincident thresholds on two Cherenkov detectors and a lead-glass calorimeter.

We tested four identical prototype drift chambers, with a construction similar to that anticipated for the final TRD, but with smaller active area ($25 \times 32\,\mathrm{cm}^2$). We used a prototype of the PASA with a noise on-detector of about 1200 electrons (r.m.s.). The FWHM of the output pulse is about 100 ns for an input step function. The nominal gain of the PASA is 12 mV/fC but during the present measurements we used a gain of 6 mV/fC to better match to the range of the employed Flash ADC system with 0.6 V voltage swing. The high voltage at the anode wires was adjusted to four values corresponding to gas gains of 2400, 3900 (nominal value), 6200 and 9600.

Fig. 1 shows a typical event in a TRD module. The pulse height is sampled at 10 MHz on eight pads. For each time bin the position along the pad rows is reconstructed using the measured pad response function [1]. A straight line fit is then applied to the reconstructed positions, which leads to the incident particles track.

Fig. 2 shows the position resolution as a function of the signal-to-noise (S/N) ratio for electrons and pions. The particle tracks lie on a plane parallel to the anode wires and perpendicular to the pad rows. Their angle with respect to the normal to the anode wires is 15°. As position resolution we define here the width of a Gaussian fit (within 3σ) to the distribution of the residuals of the reconstructed points with respect to the straight line fit. This number is averaged over the four chambers. At the nominal gas gain it is

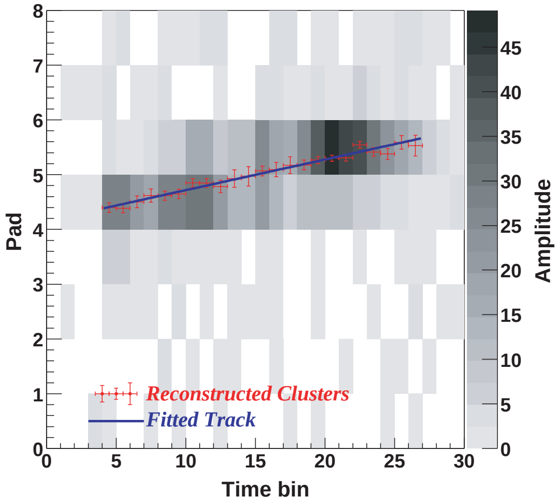

Fig. 1. Example of an event. We show the pulse height versus time bin number on eight pads. For each time bin the position is reconstructed using the measured pad response function. A straight line fit leads to the reconstructed track of the incident particle.

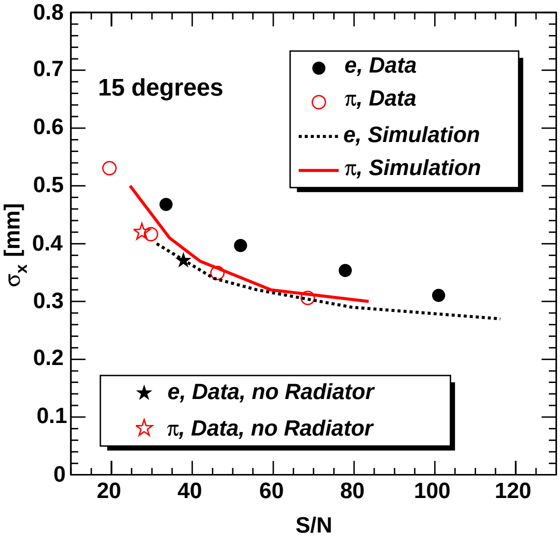

Fig. 2. The position resolution of the TRD as a function of the S/N for electrons and pions at 3 GeV/c. We show measured data (squares and circles) and simulation results (lines). The incident angle is 15°.

0.4 mm for both particle types. We observe a deterioration in position resolution for electrons as compared with pions, if a radiator is used in front of the drift region. This might be explained by the TR and/or bremsstrahlung generated in the foam/fiber radiator material. Further investigations will clarify this point.

The position resolution as a function of the angle is shown in Fig. 3. We find values between 0.2 and 0.4 mm. The agreement between simulation and measurement is good. The gain in the simulation was adjusted such to reproduce the measured S/N value for pions ($S/N \approx 30$).

Fig. 4 shows the angular resolution as a function of the angle. This resolution is defined here as the width of a Gaussian fit within 3σ to the distribution of reconstructed angles. For electrons and pions it is between 0.4° and 0.7°. In contrast to the results concerning position resolution, the measured angular resolution is similar for electrons and pions. This effect is not reproduced by the simulations and might again be connected to the generation of TR and/or bremsstrahlung photons in the radiator material. This point is currently under investigation.

Fig. 5 shows the measured momentum dependence of the pion efficiency (the pion rejection is the inverse of this value) for various radiator types. The measurements were carried out at 15° incident angle to minimize any influence of space charge on the gas gain [6]. A bi-dimensional likelihood on the measured integrated energy deposit and on the

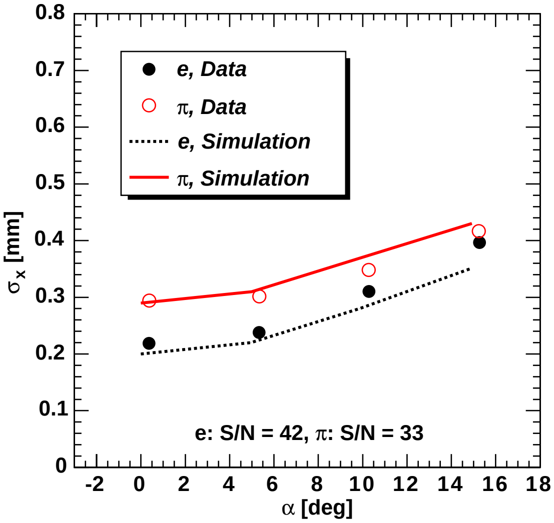

Fig. 3. Position resolution as a function of the angle at 3 GeV/c momentum.

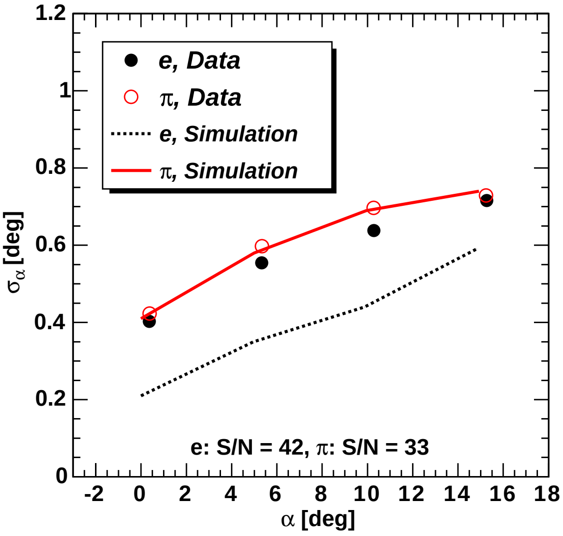

Fig. 4. Angular resolution as a function of the angle at 3 GeV/c.

position of the largest cluster found in the drift region is employed. For six layers (the final ALICE configuration) a pion rejection factor better than 100 at 90% electron efficiency can be achieved.

4. Summary

We tested four similar small prototypes of ALICE TRD chambers at the secondary mixed electron/pion beam facility at the CERN PS. Position resolution and pion rejection meet the required performance of the ALICE TRD. For the nominal signal-to-noise (S/N) value a point resolution down to 0.2 mm and an angle resolution down to 0.4° (both at 0° incidence) were measured. The measured position resolution at given gas gain is always better for electrons than for pions, which is reproduced by our simulations. Accordingly, one expects a better angular resolution for electrons. This behavior is also shown by the simulations. However, in the data the performance is similar for electrons and pions. This point is under further investigations.

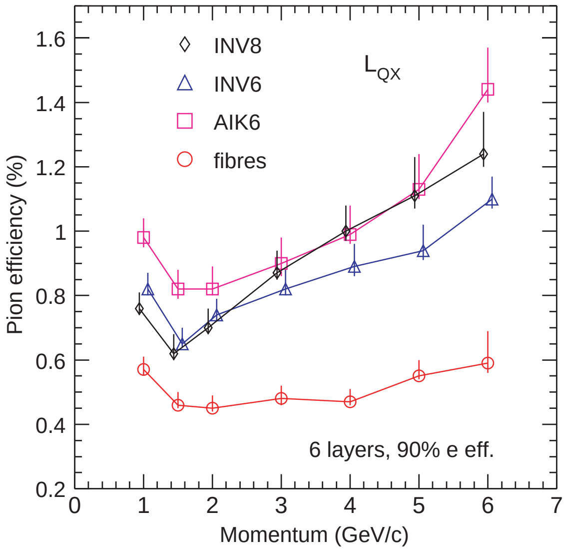

Fig. 5. Pion efficiency as a function of momentum for various radiator types. A bi-dimensional-likelihood method (L_{QX}) is employed. INV6, AIK6 and INV8 denote different radiator sandwiches composed of polypropylene fiber mats and two sheets of Rohacell in different configurations, but with thickness 4.8 cm each. The thickness of the pure fiber radiator was 4 cm.

A bi-dimensional likelihood method making use of the time-structure of the TR leads to a pion rejection factor better than 100.

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