The ALICE Transition Radiation Detector

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The ALICE Transition Radiation Detector (TRD) is equipped with 750 m^2 total area of gas chambers with radiators for particle tracking and electron identification above 1 GeV/c, divided in 540 modules organized in 18 sectors and 6 layers, in a barrel geometry between 2.9 and 3.7 m from the beam axis. The TRD will also serve as a trigger on high-p_t e^+e^- pairs in order to reduce the collision rate to the readout event rate, by increasing the statistics on rare signals such J/Ψ and Υ. In this paper the ALICE TRD will be briefly introduced.

1. Introduction

At LHC the so-called Quark Gluon Plasma (QGP) is expected to be produced in Pb-Pb collisions at center-of-mass energy of 5.4 ATeV. ALICE is a dedicated experiment to study the properties of this new state of matter. As one of the ALICE sub-detectors the TRD[1,2] enhances its physics program. It provides electron identification capability. Via the di-electron channel the production of light and heavy vector-mesons as well as the continuum will be measured. The single-electron channel will measure the semi-leptonic decays of hadrons with open charm and open beauty. As a fast trigger the TRD improves the rate of accepted events with an Υ or high-p_t J/ψ. At the trigger level jets with high E_t can be selected by requiring several (3 or more) high-p_t tracks in a TRD module.

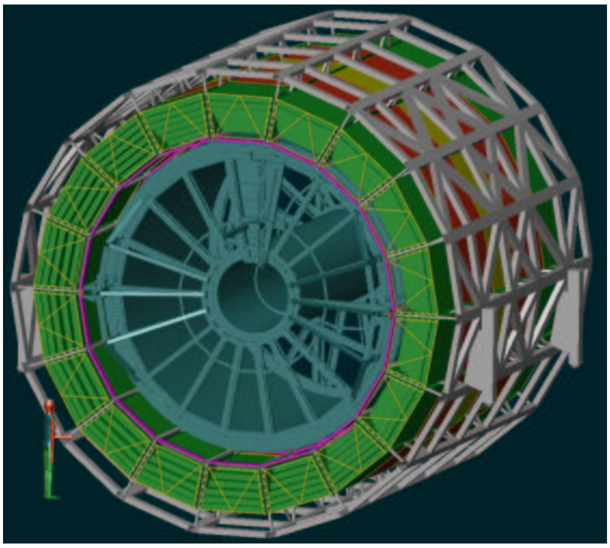

Figure 1. View of the ALICE space frame with the TPC and TRD installed.

2. The TRD in Numbers

Figure 1 shows the space frame to which the ALICE central detectors are attached, with the TRD starting at 2.9 m (outer limit of the Time Projection Chamber (TPC) of ALICE) and extending to 3.7 m. With an overall length of 7 m along the beam axis, it covers the central rapidity region of $|\eta| < 0.9$. The total thickness in the radial direction is 15% radiation lengths. The TRD is segmented into 18 sectors in azimuth, each subdivided into 5 sections along the beam axis with 6 layers of chambers in the radial direction. This adds up to 540 individual detector modules with a total active area of roughly 750 m^2 and a total gas volume of 27.2 m^3. The largest module is 159 cm long, 120 cm wide and 13 cm high including electronics and cooling. One prototype of this largest detector module has already been built, five more will be finished in September.

Figure 2 presents a cross section of a TRD individual detector element (not to scale). It consists of a 4.8 cm thick radiator (see 3.1), a 3.7 cm thick gas chamber filled with Xe/CO_2 (85:15) and a cathode pad readout plane. The readout electronics of the approximately 1.2 million pads is located directly on the backside of the pad plane.

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*A list of the members of the ALICE TRD collaboration is given at the end of this paper

3. Principle of Operation

After a particle passes the radiator where the Transition Radiation (TR) photons are produced, it propagates through the gas chamber and ionizes the gas along its track. Both these ionization electrons and those from the absorption of the TR photons drift towards the amplification region in the chamber and produce avalanches around the anode wires. Each avalanche induces a signal on the cathode pads. This induced signal is sampled in 15 time bins corresponding to the 3 cm deep drift region.

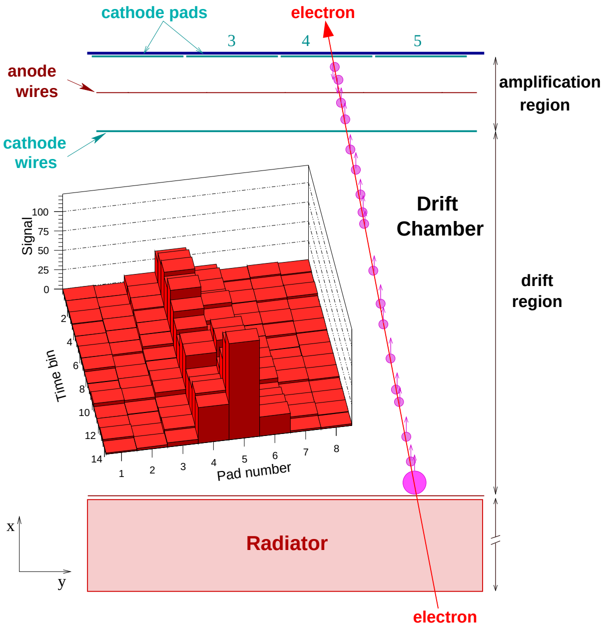

Figure 2. Schematic illustration of the ALICE TRD principle (for actual dimensions refer to the text). A projection of the chamber in the x-y plane, the bending plane of the particles, is shown. In the inset the pulse height for adjacent pads as a function of drift time is plotted for the depicted electron track with a large energy deposition from the conversion of the TR photon at the entrance of the chamber[4].

3.1. Radiator

The components of the radiator were chosen as a compromise between TR yield, radiation thickness and mechanical stability. The radiator consists of polypropylene fibre mats with a thickness of 3.2 cm (fibre diameter 17 μm), sandwiched between two Rohacell HF71 sheets with 8 mm thickness each. This combination was tested for its performance. A pion rejection factor of 100 was found, as desired [2], at an electron efficiency of 90% [5](see also section 5.1).

3.2. Gas Chamber

The gas chamber is subdivided via a cathode wire plane in two volumes, the drift region (3.0 cm) and the Multi Wire Proportional Chamber (MWPC) (0.7 cm). An electric drift field is set to 700 V/cm between the drift electrode glued to the inner side of the radiator and the cathode wires. For the chosen gas mixture, this corresponds to a drift velocity of 1.5 cm/μs. In the MWPC the secondary electrons are amplified with a gain of about 5000. The wires run in the ϕ direction (bending plane), where the best position resolution is required for an accurate transverse momentum determination.

3.3. Readout

The cathode readout pads are rectangular with an average area of 6 cm^2. The signals induced on the pads are sampled 15 times during of the drift time. The ratio of the charge shared between adjacent pads for each time sample allows local position determination along the track.

4. Electronics and Trigger

4.1. Electronics overview

Figure 3 illustrates schematically the TRD electronics chain. The Front End Electronics (FEE), distributed on the back of the pad plane, is accommodated on Multi Chip Modules (MCM), each serving 18 readout pads. One MCM assembles two ASICs (Application Specific Integrated Circuit): one analog ASIC with 18 PreAmplifier/Shaping Amplifier channels (PASA) and one analog/digital ASIC, containing ADC, digital filter, Tracklet PreProcessor (TPP), event buffer and Tracklet Processor (TP). The last three layers are referred to as the Local Tracking Unit (LTU). The Global Tracking Unit (GTU) is the common processor for the LTU data coming from the 540 TRD modules.

4.2. Trigger Concept

The TRD trigger system is integrated in order to select high-p_t electron pairs by taking advantage of tracking and TR signature on a 6 μs time scale (see Figure 4 and [6]).

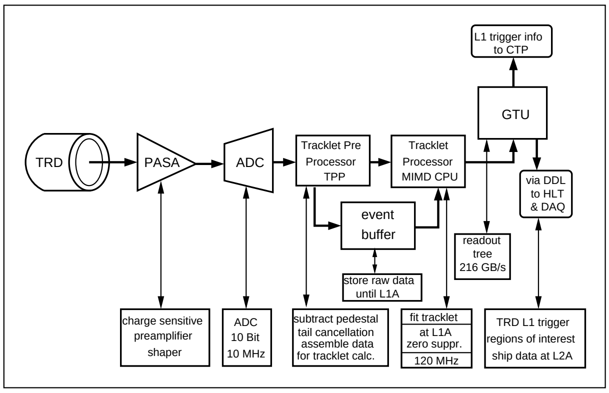

Figure 3. Basic components of the TRD front-end electronics. Everything except the GTU is mounted on the detector itself. The ADC, digital filter, TPP, TP and the event buffer are incorporated in a single chip. L1A, L2A refer to the different trigger levels of the Central Trigger Processor of ALICE

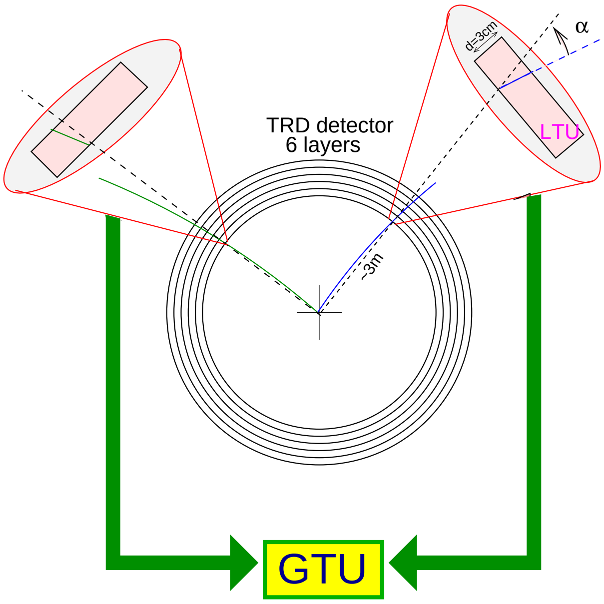

Figure 4. Schematic illustration of the trigger concept.

In the trigger mode, the TRD performs a fast tracking and selection of high-p_t particles, based on the short drift time of 2 μs and on the TR signature. The recording of the ADC data into the event buffers starts with each pretrigger, and during the drift time the TPP accumulates the sums for the linear fit of the tracklets (local track segments in a chamber) and combines the digits information into a local Particle Identification (PID) measurement. If the Level 0 Accept was issued, at the end of the drift time the TP can already search, fit and select the tracklets. The p_t is estimated by the tracklet deflection from the direction of a primary vertex particle with infinite momentum. With a p_t cut at 2 GeV/c, about 40 tracklets per chamber are shipped after 4.5 μs to the GTU. The GTU selects track candidates from matching at least 3 tracklets from different TRD layers, updates and applies a second cut in the transverse momentum at 2.7 GeV/c, and computes global PID information. If the TRD triggers on e^+e^- pairs, a further cut in the invariant mass can be applied. After 6 μs the TRD can contribute to the Level 1 of the Central Trigger Processor (CTP) with a trigger signal, and to the more elaborate High Level Trigger (HLT) with regions of interest over a larger band width. The Level 1 Accept (L1A) starts the reading of the FEE event buffers into the event buffer of the GTU, completed by putting the TRD electronics back into the stand-by mode. With a Level 2 Accept (L2A) the event is shipped to the HLT and to the Data Acquisition (DAQ).

5. Detector Performance

5.1. Pion Rejection

As outlined in the ALICE proposal[3] a pion rejection factor of 100 is the goal. Figure 5 shows the pion efficiency (=1/rejection factor) as a function of the particle momentum at an electron efficiency of 90%. The points shown are computed[2] for 6 layers based on measurements at GSI in Darmstadt performed with a single chamber[3]. The radiator used consisted of pure polypropylene fibres.

Due to the onset of the TR production we observe strong pion suppression around 1 GeV/c. Around 2 GeV/c a saturation in the pion suppression is reached. Saturation in the TR yield and the pion relativistic rise are responsible for this behavior. The pion rejection is expected to worsen for momenta above 3 GeV/c.

To evaluate the detector and physics performance, the test beams results were used to adjust the parameters of the simulations. These

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[2] The used extraction methods are: TMQ: Truncated mean on energy deposit, L-Q: Likelihood on total energy deposit and L-QX: two-dimension likelihood on charge deposit and drift chamber depth.

simulations were carried out within the object oriented framework AliRoot which was developed for ALICE.

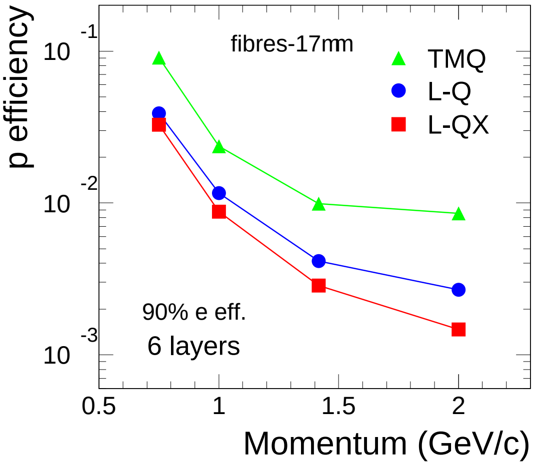

Figure 5. Pion efficiency at 90% electron efficiency as a function of the momentum for a 17 μm fibres radiator.

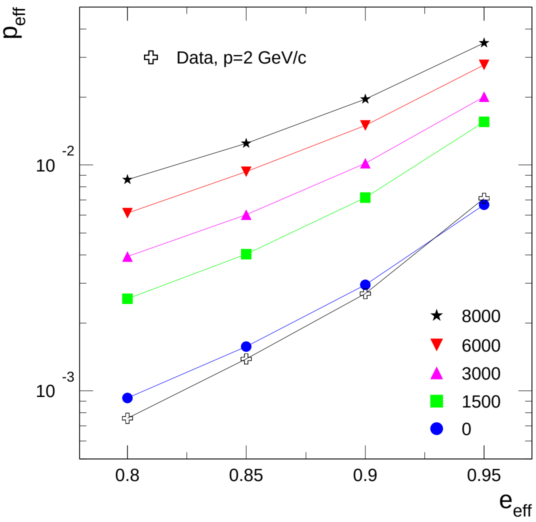

Figure 6. Pion efficiency as a function of electron efficiency and multiplicity at a track momentum of 2 GeV/c.

With regard to the pion rejection one important issue is the behavior at the expected high multiplicity for Pb-Pb collisions in ALICE. The experiment is designed for a maximum charged particle density at midrapidity of dN_{ch}/dy=8000. Figure 6 shows that going from well isolated tracks to full multiplicity the pion rejection for 90% electron efficiency deteriorates by a factor 6 – 7. Even for this worst case assumption the pion rejection factor is still close to the desired value of 100.

5.2. Momentum Resolution

Simulations show that the position resolution in the bending direction ($r-\phi$) is 400 (600) μm for low (high) multiplicity. With this position resolution a momentum resolution $\delta p/p = 2.5 \oplus 0.5\%$ (0.8%) p (in GeV/c) results for low (high) multiplicity.
Along the pads, in beam direction, the position resolution is 1.7 cm independent of the multiplicity. This value can be improved by slightly tilting the pads. By tilting the pads by 2 ° in alternating direction between successive layers the resolution improves to 4 mm.

6. Physics Performance

6.1. Υ Invariant Mass Resolution

The Υ reconstruction with the TRD was studied on simulations of Pb-Pb collisions at varied multiplicity, using a parametrisation of the HIJING generator plus few hundred electron pairs added in the range of the $\Upsilon \rightarrow e^+ e^-$ decay channel [6]. The efficiency on this signal and the associated background were also evaluated in the TRD trigger mode. Figure 7 shows the reconstructed invariant mass with the TRD resolution of the L1 trigger. A resolution of 245 MeV/c^2 is achieved at the nominal magnetic field of 0.4 T, pointing out that the distribution has a tail towards lower masses due to the bremsstrahlung losses in materials in front of the TRD. With the off-line TRD full tracking and by including information from the other barrel detectors (ITS, TPC), this result is significantly improved, allowing an Upsilon invariant mass resolution of 100 MeV/c^2.

6.2. Trigger Capability

The importance of the TRD as a trigger is underlined by looking at the yield in high-p_t J/Ψ and Υ within the limited band width of the DAQ and storage. The estimated ALICE running year is 10^6 s at an average luminosity of $L = 5 \times 10^{26}$cm^{-2}s^{-1}, with an observed collision rate of 2 kHz. Without TRD trigger, about 2500 J/Ψ with $p_t > 5.5$ GeV/c and about 160 Υ

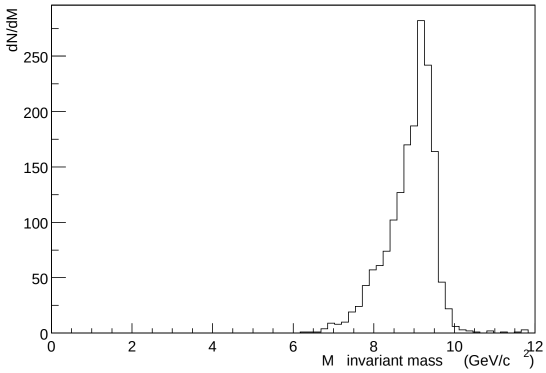

Figure 7. Di-electron invariant mass distribution from Υ decays as reconstructed in the TRD.

would be recorded for minimum bias collisions at an event rate of 20 Hz in the DAQ. The trigger enhances significantly these numbers, to 10000 high-p_t J/Ψ and about 2300 Υ.

7. Conclusion

The TRD considerably expands the physics program of the ALICE experiment. It is well suited to study heavy meson production in the high multiplicity environment of Pb-Pb collisions at LHC. At the trigger level rare heavy mesons like the Υ can be selected. In conjunction with the other tracking detectors of the ALICE central barrel, the mass of the Υ can be determined with a resolution of 1%. With an active area of 750 m^2 and 1.2 million readout channels the ALICE TRD will be one of the largest TRDs ever built.

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