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Physics with the ALICE Transition Radiation Detector

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ABSTRACT

The ALICE Transition Radiation Detector (TRD) significantly enlarges the scope of physics observables studied in ALICE, because it allows, thanks to its electron identification capability, to measure open heavy-flavour production and quarkonium states, which are essential probes to characterize the Quark-Gluon-Plasma created in nucleus–nucleus collisions at LHC. In addition the TRD enables to enhance rare probes due to its trigger contributions.

We report on the first results of the electron identification capability of the ALICE Transition Radiation Detector (TRD) in pp collisions at $\sqrt{s}=7$ TeV using a one-dimensional likelihood method on integrated charge measured in each TRD chamber. The analysis of heavy flavour production in pp collisions at $\sqrt{s}=7$ TeV with this particle identification method, which extends the p_t range of the existing measurement from $p_t=4$ GeV/c to 10 GeV/c and reduces the systematic uncertainty due to particle identification, is presented. The performance of the application of the TRD electron identification in the context of J/ψ measurements in Pb–Pb collisions is also shown.

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1. Introduction

A Large Ion Collider Experiment (ALICE) [1] is the dedicated detector to study all aspects of heavy ion collisions at the LHC at CERN. It is assumed that, in nucleus–nucleus collisions at high energies, a high density de-confined state of strongly interacting matter, known as Quark-Gluon-Plasma (QGP), is created. ALICE is designed to measure a large set of observables in order to study the properties of this QGP. The Transition Radiation Detector (TRD) [2] provides electron identification in the ALICE central barrel ($|\eta|<0.9$) at momenta $p>1$ GeV/c, where pions cannot be efficiently rejected via energy loss measurements in the Time Projection Chamber (TPC). In addition, the TRD can be used to trigger on identified particles with high transverse momenta, thus providing enriched samples of single electrons or electron–positron pairs, and to select jets. Therefore the TRD significantly enlarges the scope of physics observables.

The following probes are regarded as essential probes of the conditions of the Quark-Gluon-Plasma and can be accessed with the help of the TRD:

- Open heavy-flavour production
  Open charm and beauty can be detected with the ALICE central barrel in the semi-electronic decay channel: D, $B \rightarrow e^{\pm}+X$. Because of their high mass, charm and beauty quarks are mainly produced on a very short time scale ($\tau \approx 1/(2m_q) \lesssim 0.1$ fm/c) in hard scattering processes during the initial stage of the collision. Thus heavy quarks witness the entire evolution of the dense matter and are sensitive to the properties (gluon densities, temperature, volume) of the de-confined medium through in-medium energy loss. Open charm and beauty production cross-sections are also needed as a reference for quarkonia studies, because at LHC energies heavy quarks are mainly produced through gluon–gluon fusion processes ($gg \rightarrow Q\overline{Q}$). In addition the B meson production measurement allows to estimate the contribution of secondary J/ψ($B \rightarrow J/\psi + X$) to the total J/ψ yield.
- Quarkonium states ($c\overline{c}$ and $b\overline{b}$)
  J/ψ,ψ' and Υ can be measured with the ALICE central barrel in the di-electron channel. According to one prediction, the $c\overline{c}$ and $b\overline{b}$ states should be sensitive to the temperature of the QGP, because of their dissociation due to colour-screening [3]. Charmonium regeneration models [4,5] on the other hand predict that $c\overline{c}$ bound states can be abundantly produced by recombination of c and $\overline{c}$ quarks during hadronization. This recombination mechanism would lead to a quarkonium enhancement at high energies.
- Jets and γ-jet production
  These probes allow to study parton energy loss and medium-modified fragmentation functions to unravel the detailed spatial and temporal structure of the QGP. The TRD provides the necessary trigger to enhance the statistics of these data samples.

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- Virtual photons $\rightarrow e^+e^-$ and Drell–Yan production
  These processes are very challenging to detect. However they allow to investigate thermal radiation in the mass window between J/ψ and Υ. Thermal radiation not only serves as a proof of de-confinement but also provides a direct measurement of the temperature of the QGP.

As a reference, the corresponding studies have to be performed in proton–proton collisions. In addition, the measurements of heavy-flavour production in pp collisions allow to test perturbative Quantum Chromodynamics in a new energy domain. In the case of hadroproduction of quarkonium states non-perturbative aspects are also involved. The ALICE physics program further covers studies of p-Pb collisions in order to disentangle initial and final state effects.

2. The transition radiation detector

To achieve the physics goals listed above, the ALICE TRD was designed to reject pions by a factor 100, to work in the high multiplicity environment of heavy ion collisions as well as to provide in the bending plane a space point resolution better than 400 μm and an angular resolution better than 1°.

The TRD consists of 522 chambers arranged in six layers surrounding the TPC at a radial distance $r (2.9 \leq r \leq 3.7$ m) from the beam axis, with a maximum length of 7 m along the beam axis (corresponding to a pseudo-rapidity coverage of $|\eta| < 0.9$). It has an active area of roughly 675 m^2 and the total radiation length for the six layers is about 25% of X_0. Fig. 1 shows the cross-section of a TRD chamber, which has an average size[2] of 135 cm × 103 cm and is about 12 cm thick, including radiator, electronics and cooling. The gas volume, filled with a Xe CO_2 mixture (85:15), is subdivided by a cathode wire grid into a 3 cm drift region and 0.7 cm amplification region equipped with anode wires. The signal induced on the segmented cathode plane is typically spread over two to three pads. Each pad has an average size[1] of 0.7 cm × 8.7 cm. The front-end electronics is directly mounted on the back of the TRD chamber. The pad signals are read out and processed in a custom built charge sensitive preamplifier-shaper circuit and digitized by a 10 MHz ADC to record the time evolution of the signal. The drift time of about 2 μs is sampled in 20 time bins.

Fig. 2 shows the average pulse height as a function of drift time for pions and electrons with a momentum of 2 GeV/c passing through the TRD chamber. The peak at early drift times is due to the charge deposit in the amplification region, where the charge drifts from both sides to the anode wire. The plateau at intermediate drift times originates from the drift region. Comparing pions with electrons, one sees that the latter deposit on average more charge, because of the higher specific energy loss at this momentum.

A 4.8 cm thick radiator, a sandwich of polypropylene fibers and Rohacell foam, which provides many boundaries between media with different dielectric constants, is placed in front of each drift region.

Transition Radiation (TR) is emitted if a relativistic particle ($\gamma \gtrsim 1000$) traverses the radiator [7]. At LHC energies TR is only generated by electrons. The produced TR photons (1–30 keV) are absorbed in the drift volume preferentially close to the radiator by the high Z-gas mixture (Xe-based), which corresponds to long drift times to the anode wire. This contribution is visible in Fig. 2 as the characteristic peak at large drift times and enables an even better separation of electrons and pions.

[2] The dimensions change with distance from the interaction point to achieve a constant granularity.

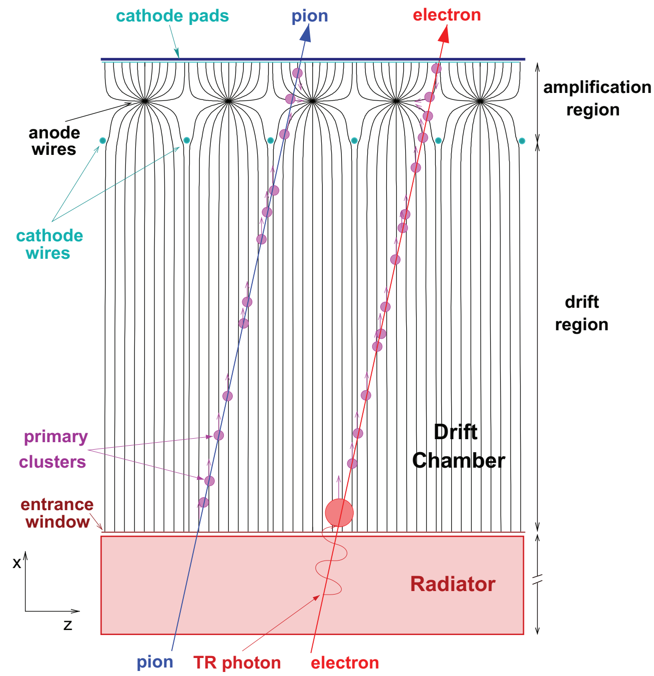

Fig. 1. Schematic cross-section of a TRD chamber including radiator.

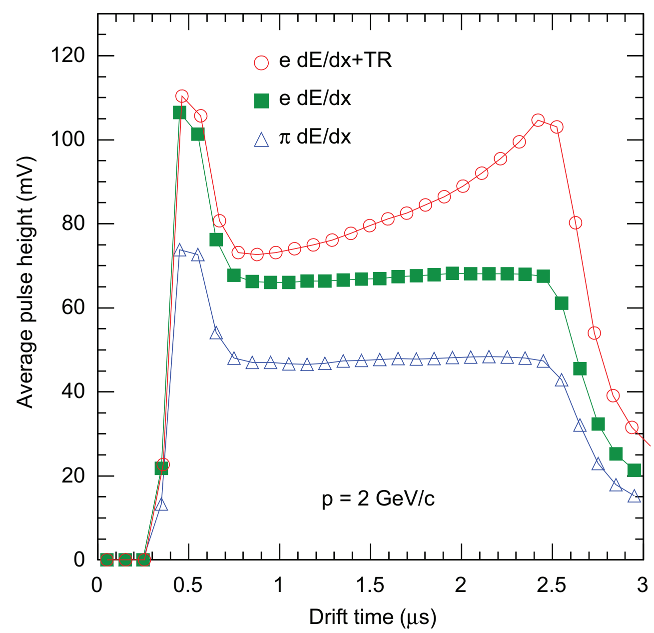

Fig. 2. Average pulse height as a function of drift time for pions and electrons with and without radiator (testbeam measurements) [6].

3. Electron identification

The track-by-track electron identification is at the moment based on the simplest method of TRD particle identification—one-dimensional likelihood on the total integrated charge measured in a single TRD chamber (tracklet).

Fig. 3 shows the charge deposit per TRD chamber for pions and electrons at a momentum of 2 GeV/c from pp collisions at

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