PHYSICS WITH ALICE TRANSITION RADIATION DETECTOR*

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Measurements of heavy quarkonia states, such as J/Ψ, Ψ', Υ, Υ', and high p_{T} charged particles carry important information to characterize the quark gluon plasma produced in high energy heavy ion collisions at LHC. The ALICE Transition Radiation Detector (TRD) provides clear separation of electrons from the large background of pions and improves the tracking performance of ALICE central barrel detectors. The TRD also provides a fast trigger signal on high transverse momentum charged particles. In this paper we present the capabilities of heavy quarkonia reconstruction and jet trigger of TRD.

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1. Introduction

ALICE is dedicated to measure variety of particles produced in heavy ion collisions and $p{+}p$ collisions at LHC [1]. It explores the characteristics of quark gluon plasma (QGP) phase at high energy density and temperature. Production yield of $c\bar{c}$, $b\bar{b}$ states, and high-p_{T} jets are important aspects will be studied in ALICE. Both probes interact with the QCD medium and might carry characteristic information of it.

At LHC, Pb+Pb collisions at unprecedented high energy of $\sqrt{s_{NN}} = 5.5$ TeV will be achieved. The design luminosity for Pb+Pb collision is 10^{27} cm^{-2}s^{-1}. Theory predicts that primordial heavy quarkonia are suppressed at high temperature conditions [2]. According to Satz, a melting pattern of the charmonium can be seen [3]. As the temperature of the QGP medium increases, Ψ' and χ_c will be dissociated at lower temperature than

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J/Ψ. The sequence of the melting will give the precise information about the system temperature and QCD interaction mechanism. However, initial charm production is a factor ten higher than at RHIC energies. In such high temperature, statistical recombination of $c\bar{c}$ states will be enhanced and the overall J/Ψ production rate will be increased at LHC. The statistical model calculation predicts that the J/Ψ production rate will be enhanced due to such statistical recombination by factor 20 larger than RHIC [4].

Jet production at LHC energy is also enhanced compared to RHIC. The fraction of the hard scattering cross section relative to the total cross section will reach 98% at LHC compared 50% at RHIC [5]. Jet yield at 20 GeV will be 1000 times larger than the yield at RHIC, and jet with leading particle energy of 100 GeV or more can be observed. Since jet partons are created in the initial scattering of the partons at the early stage, it traverse inside the QGP medium and have strong energy loss due to the strong coupling inside the medium. Due to parton energy loss, the energy of the fragmentation particles are reduced and high-p_{T} particle yield is suppressed.

Measurements of the quarkonia production were performed at SPS and RHIC, and J/Ψ were found to be suppressed [6]. Suppression of high p_{T} particles are also clearly observed at RHIC. The strong N_{coll} scaling violation in the jet production cross section was seen [7]. At LHC, not only the same measurements as RHIC but also precise measurements of the jet structure modification, distribution of momentum of the jet fragments perpendicular to the jet axis (j_{T}), and fragmentation patterns will become accessible.

The Transition Radiation Detector (TRD) is one of the important detectors in ALICE to perform these measurements. The ALICE TRD is designed to identify electrons decayed from quarkonia, in a large particle background mainly consisting of charged pions and to improve the particle tracking performance in the high multiplicity environment expected in heavy ion collisions at the LHC [8]. The expected multiplicity ($dN/d\eta$) at mid-rapidity in Pb+Pb collision at LHC is anticipated to be between about 1500 and 3000.

2. The Transition Radiation Detector

As shown in Fig. 1 (left), the TRD consists of pad read-out drift chamber operated with Xe, CO_2 (15%) gas mixture, transition radiators for the electron identification made from a sandwich of foam and fiber materials, and readout electronics. Accurate pulse height measurement in drift chamber for the duration of the drift time ($\sim 2\mu$s) is necessary. The transition radiation (TR) photons produced in the radiator absorbed in the gas volume and ionizes the atom. The electrons produced by TR photons are superimposed on the electrons produced by ionization energy loss.

Fig. 1 (right) shows the average pulse height according to the drift time for electrons and pions obtained by the test beam experiment at PS, CERN. For electrons, the pulse height with and without transition radiator are shown. A stack of six TRD chambers was irradiated with charged particles beam at momentum range of 1 to 10 GeV/c to study performance of the TRD chambers [9]. The beam was identified to be pions or electrons by a Cherenkov detector and an electromagnetic calorimeter, and results were obtained for electrons and pions. The characteristic peak at larger drift times in case of electrons with radiator is due to absorbed TR in the gas.

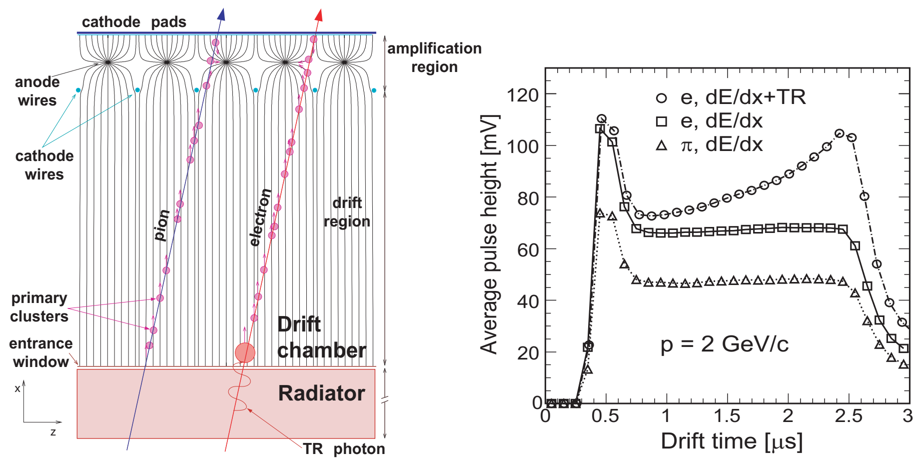

Fig. 1. Left: Schematic illustration explains the TRD principle. Electrons produced by ionization energy loss and by TR absorption drift along the field lines towards the anode wires, and are amplified in the amplification region. The induced charge on the cathode pads is read out by the electronics at 10 MHz sampling rate. Right: Average pulse height as a function of the drift time for 2 GeV/c electrons with TR, electrons without TR, and for charged pions obtained by test beam experiment.

TRD surrounds the Time Projection Chamber (TPC) in the central barrel of ALICE. Inside the TPC, the silicon inner tracking system (ITS) is located. Particle tracking is mainly performed using those three detectors.

540 large area ($\sim 1.2 \times 1.4$ m^2) TRD chambers with drift direction perpendicular to the wire planes are arranged into 18 super-modules. One super-module contains 30 TRD chambers. The total number of readout channels is 1.18 million.

For the track-by-track electron identification, the likelihood method is used [8]. The probability distributions of deposited energy by dE/dx and TR were obtained for identified electrons and pions in the test beam experiment. The probability distributions were then used to calculate the likelihood of the particle to be identified. A factor of 100 pion rejection for 90% electron identification efficiency is the design goal of the ALICE TRD consisting of 6 planes of the detector. This has been achieved in measurements in the test beam experiment. Fig. 2 (left) shows the measured pion efficiency at electron efficiency of 90% obtained in the test beam experiment [9]. Pion efficiency of 1.5% at low momentum is achieved. The pion efficiency increases with momentum since dE/dx increases in this momentum region. The TRD is required to be able to find stiff particle tracks. A momentum resolution of $\Delta p_{\mathrm{T}}/p_{\mathrm{T}} \sim 5\%$ at $1 < p_{\mathrm{T}} < 10$ GeV/c is necessary. Fig. 2 (right) shows the p_{T} resolution of the tracks reconstructed by only with TPC, TPC with ITS, and with all detectors including TRD. With TRD, $\sim$2% momentum resolution is achieved.

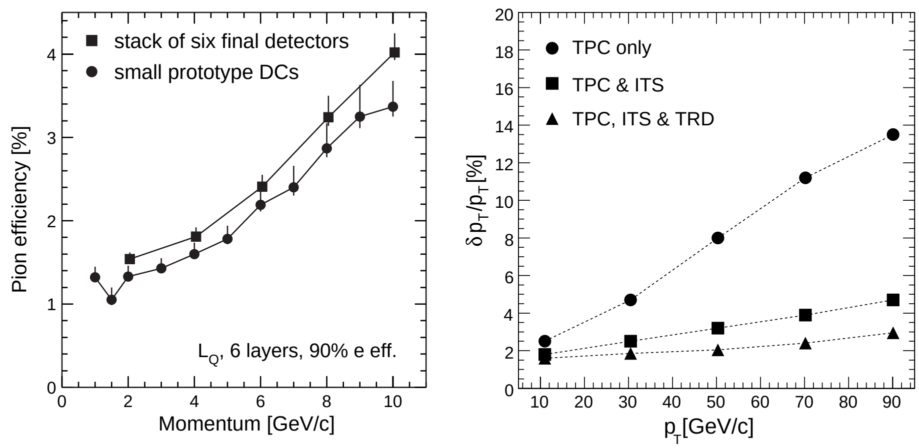

Fig. 2. Performance of the TRD. Left: pion efficiency at electron efficiency of 90% for two different TRD stacks (final detector and smaller prototype detector) and for different particle momentum. Right: tracking momentum resolution.

3. Quarkonia reconstruction in ALICE

The reconstruction capability of quarkonia states was studied by Monte Carlo simulation. The parameterized HIJING event generator was used to simulate background particles. J/Ψ, Ψ', Υ, Υ', and Υ'' resonances were embedded into the background event. Cross section of the quarkonia was determined from Color Evaporation Model calculations [10] for nucleon+nucleon collision at $\sqrt{s} = 5.5$ TeV and scaled by number of binary collisions in Pb+Pb collisions obtained by Glauber model calculations. Nuclear shadowing effect was also considered here.

Fig. 3 shows the simulated invariant mass spectra of electron pairs for 7.5×10^7 Pb+Pb 10% most central collisions [11]. The number of events corresponds to estimated number of collisions ALICE will record in one year of running (10^6s) with 200 Hz data recording rate. The average charged particle density of the simulated underlying event is $dN/d\eta \sim 3000$.

Clear signals for the J/Ψ and Υ can be observed on top of the uncorrelated combinatorial background. As source for the background, semi-leptonic decays of open charm and beauty contribute up to high mass regions (dashed and dashed-dotted lines). In the Υ mass region, the background from charged pions is still of the same order of magnitude as the signal.

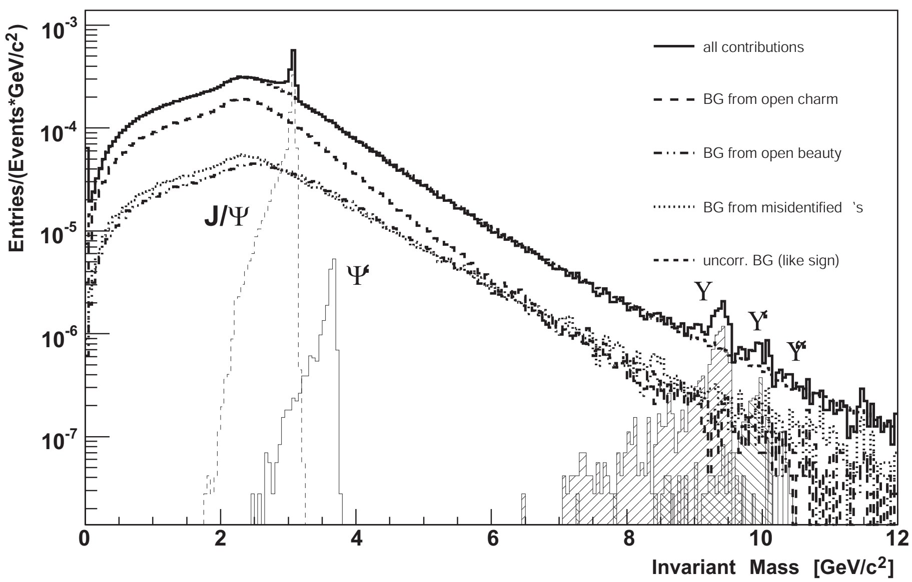

Fig. 3. The invariant mass distribution of electron pairs for 7.5×10^7 central Pb+Pb collisions. The sum of all contribution (solid line) is shown as well as the background contributions from open charm and open beauty and misidentified pions. The total uncorrelated background was constructed with the like-sign technique.

To demonstrate the analysis to be done for the real data, the background shape was estimated by combining two particles with the same sign charges. Fig. 4 shows the invariant mass distributions of electron pairs after background subtraction for different mass region of Ψ states and Υ states. J/Ψ can be reconstructed in this high multiplicity environment. Υ is more difficult than J/Ψ but still can be reconstructed.

For J/Ψ, $S = 110 \times 10^3$ signals were detected with signal to noise ratio $S/N = 1.2$. For Υ, $S = 900$ and $S/N = 1.1$. For Υ', $S = 250$ and $S/N = 0.4$. The significance $(S/\sqrt{S+N})$ is 245, 21, and 8 for J/Ψ, Υ, and Υ', respectively. The significance of the J/Ψ signal goes down below 30 for p_{T}=10 GeV/c^2 at $dN_{\mathrm{ch}}/d\eta$=3000. The reconstructed peaks were fitted by a Gaussian function. The mass resolution is 33 MeV/c^2 for J/Ψ, and 80 MeV/c^2 for Υ.

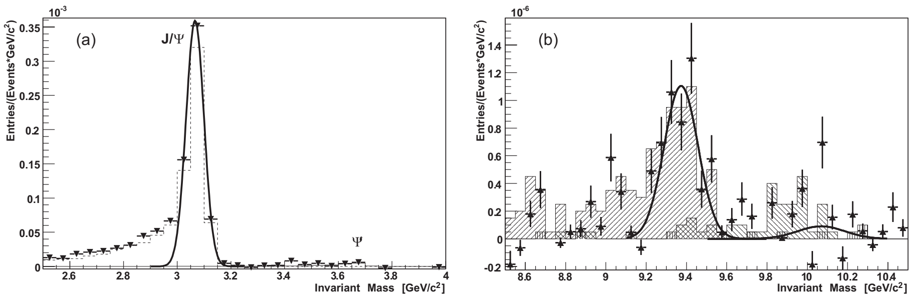

Fig. 4. Invariant mass distribution of electron pairs for 7.5×10^7 central Pb+Pb collisions in the (a) J/Ψ mass region and (b) Υ mass region, after background subtraction (symbols). The asymmetric deviation of the peak shape from the Gaussian function is due to the bremsstrahlung of the electrons in the material. The dashed line in (a) and shaded area in (b) are the expected signal shape without combinatorial background.

4. Jet trigger with TRD

The jet triggering capability using the TRD was studied by Monte Carlo simulation [12]. The rate of jets expected in ALICE was determined using PYTHIA [13]. PYTHIA was used to calculate the jet cross section for $p+p$ collisions at $\sqrt{s} = 5.5$ TeV, and result was multiplied by K-factor of 1.5.

The jet multiplicity in central 15% Pb+Pb collision was then calculated by multiplying the obtained cross sections by the nuclear overlap function T_{AB} averaged over impact parameter in the considered centrality range. Assuming a rate of clean minimum bias collisions of 1 kHz at LHC, and with the acceptance of the ALICE TPC of $|\eta|$=1.8, the expected jet rate is obtained as 1 and 0.01 for jet total energy of $E_{\mathrm{T}} > 100$ GeV and $E_{\mathrm{T}} > 250$ GeV as shown in Fig. 5.

In ALICE, TPC and TRD provide jet reconstruction capability via charged particles. The fraction of the jet energy carried by charged particles was estimated to be approximately 65 ± 20%. It is almost independent of the jet total energy.

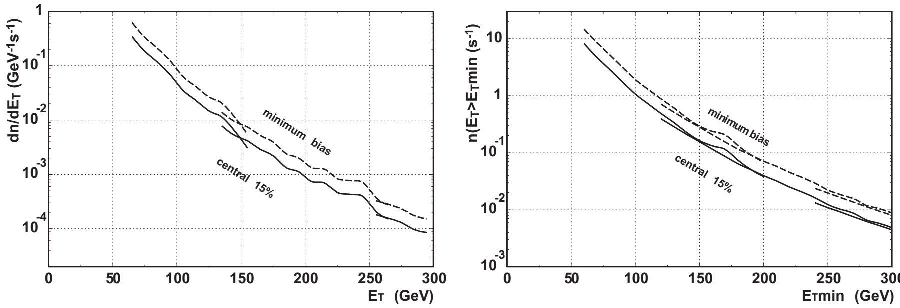

Fig. 5. Rate of jets into TPC acceptance in Pb+Pb collisions at LHC for minimum bias collisions (dashed lines) and 15% central collisions (solid lines). The left plot shows the jets rate per unit pseudorapidity, and right plot shows the inclusive jets rate above the threshold energy E_{Tmin}.

TRD can provide a trigger, needed for jets with $E_{\mathrm{T}} > 150$ GeV. The trigger can be constructed by requiring a number of high p_{T} charged particles within a solid angle cone. The p_{T} is determined from the curvature of the track crossing the six planes of the TRD within 6 μs data processing delay from the collision time. The optimum jet cone size is roughly the same as the solid angle of a single TRD chamber ($\Delta\eta = 0.36$ and $\Delta\phi = 0.35$). The efficiency of such a trigger, simulated using jets from PYTHIA calculation is shown in Fig. 6. The efficiency of a TRD standalone jet trigger can reach more than 90% at 150 GeV jet energy. The bias and contamination on the jet trigger are under investigation.

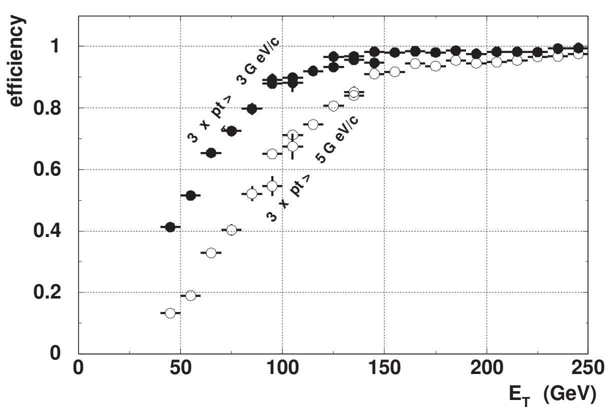

Fig. 6. Efficiency of a jet trigger based on requiring three high p_{T} charged particles in any of the 90 TRD chambers.

5. Conclusions

The ALICE TRD provides a suitable pion rejection and tracking performance to identify electrons and electron pair produced in $p+p$ or Pb+Pb collisions at LHC together with ALICE central barrel detectors. The reconstruction performance of the J/Ψ, Υ, and higher states were studied by Monte Carlo simulation and found to be feasible with real data. As a result from these simulation studies, the reconstruction of J/Ψ is feasible up to p_{T}=10 GeV/c^2 in the high multiplicity environment. TRD has also suitable capabilities to provide trigger for jet. The trigger efficiency is larger than 90% for jet with total energy above 150 GeV.

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