THE ALICE TRANSITION RADIATION DETECTOR

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ABSTRACT

In this talk an overview of the ALICE TRD[1]is presented. The ALICE TRD consists of 540 individual detector modules with a total of 1.2 million readout channels. It allows electron identification above a momentum of 1 GeV/c and is capable of providing a very fast and efficient trigger on electrons with large transverse momentum p_t. It will operate in a very high multiplicity environment. The rapidity density of charged particles in collisions of Pb nuclei at $\sqrt{s} = 5.5$ ATeV is expected to be as high as $dN/dy = 8000$.

1 Introduction

The main goal of ultra-relativistic heavy ion physics is the investigation of the properties of the so-called quark gluon plasma (QGP). At the Large Hadron

[1] a list of the members 1) of the ALICE TRD 2) working group can be found at the end of the manuscript

Collider (LHC) this plasma of deconfined quarks and gluons is produced in collisions of Pb nuclei at 5.5 ATeV. This is an unprecedented energy regime for the study of heavy ion collisions. ALICE [3] is the dedicated heavy ion experiment at LHC to study theses collisions. The anticipated initial energy density reached there is as high as $\epsilon \simeq 1000$ GeV/fm^3 (about 6000 times the energy density of a Pb nucleus in its ground state). The lifetime of such a plasma until freeze-out may be as long as $\tau_f \simeq 70$ fm/c and the volume at freeze-out may reach $V \simeq 10^5$ fm^3 (about 65 times the volume of a Pb nucleus). These collisions may produce a charged particle density of up to $dN/dy = 8000$. Most of these particles are pions and are subject to strong final state interaction. They will be detected in the central barrel of the ALICE experiment in a rapidity interval $|\eta| < 0.9$. Leptons are an excellent tool to study the early stage of the collision, i.e., the QGP, since they do not interact strongly. The investigation of electron-positron pairs from the decay of Quarkonia (J/ψ,ψ',Υ), from semi-leptonic decays of B- and D-mesons, from the decay of low-mass vector mesons, and from continuum radiation in the central barrel of ALICE are accessible with the TRD. It will have to identify electrons with momenta above 1 GeV/c in a large background of pions. Also, because of the small production cross sections of Υ that decay into electron-positron pairs, it will in addition serve as a fast trigger detector for electrons with transverse momenta $p_t > 3$ GeV/c.

In the following an overview of this detector will be presented. Specific issues of the trigger capabilities [4], the custom front-end electronics [5], and results from test beam measurements [6] are presented in separate contributions to this conference.

2 The ALICE TRD in Numbers

The individual detector elements (a cross section - not to scale - is shown in Figure 2) of the ALICE TRD consist of a radiator, a drift and conversion region with Xe/CO_2 (85:15), and a multi-wire proportional section with pad readout. The largest chamber is 120 cm wide, 159 cm long, and 13 cm high including electronics and cooling. The readout and trigger electronics of the approximately 1.2 million pads is directly connected to the backside of the pad plane. The signals induced on the pads are sampled 15 times for the duration of the drift time leading to a total of roughly 17 million readout pixels.

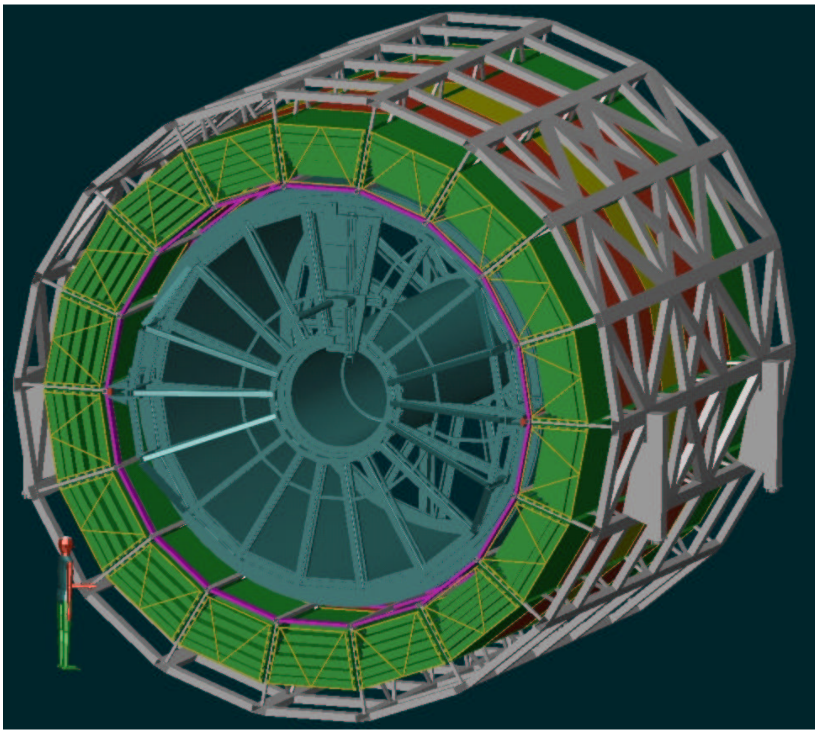

Figure 1: *View of the ALICE space frame with the TPC and TRD installed.*

The central detectors of ALICE are attached to the so-called space frame shown in Figure 1. The TRD is located just outside the TPC starting at a radius of 2.9 m and extending to 3.7 m. The overall length of the detector is 7 m. It covers the central rapidity region $|\eta| < 0.9$. The 540 individual detector modules of the TRD are grouped into 18 supermodules in azimuthal direction which are subdivided into 5 sections along the barrel and consist of 6 layers with a total active area of 736 m^2 and a total gas volume of about 27 m^3.

For the successful measurement of electrons in this environment the design of the detectors has to minimize any material in its active region. The total anticipated thickness of the 6 detector layers is $X/X_0 = 14.3\%$.

In the nominal magnetic field of the ALICE magnet (B=0.4 T) the position resolution in $r\phi$-direction of 400(600) μm respectively for low(high) multi-

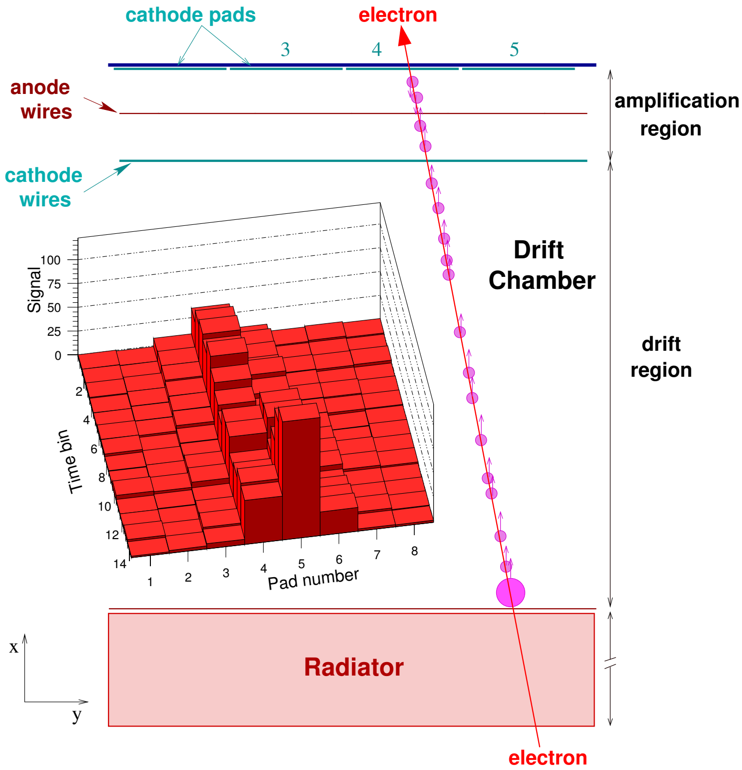

Figure 2: *Schematic illustration of the ALICE TRD principle (for actual dimensions refer to the text). A projection of the chamber in the $x-y$ plane, the bending plane of the particles, is shown. In the inset the pulse height for adjacent pads as a function of drift time is plotted for the depicted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

plicity will yield a momentum resolution of $\delta p/p = 2.5\% \bigoplus 0.5\%(0.8\%)/GeV/c$. The pion suppression at 90% electron efficiency for $p_t > 3$ GeV/c will be better than 100.

3 Principle of Operation

Figure 2 shows a cross section through one of the six layers of the detector. Before entering the drift and conversion section of the readout chambers particles pass through the radiator. The radiator has been optimized to provide a good compromise between TR yield, radiation thickness, and mechanical stability.

Therefore, a large variety of radiators has been tested. The current design foresees a sandwich of 48 mm thickness consisting of carbon fiber reinforced ROHACELL HF71 (polymethacrylimide) and 40 mm of polypropylene fiber mats (17 μm fiber diameter). The drift electrode will be directly glued to the radiator. The radiator is followed by a drift and conversion region of 30 mm with a drift field of 700 V/cm. For the chosen gas mixture this corresponds to a drift velocity of 2 cm/μs. The secondary electrons are amplified in the multi-wire proportional counter with a gas gain of around 6000.

The wires run in $r\phi$-direction where the best position resolution has to be achieved for an accurate momentum determination. The readout pads are rectangular with an average area of about 6 cm^2. The induced signal on the pads is recorded in 15 time samples. The inset in the drawing shows the time sequence of pulse heights for the depicted electron track. The ratios of charges recorded on adjacent pads for each time sample allows local position determination along the track. From the inclination of the track the momentum can be inferred.

4 Electronics Overview

A block diagram of the main components of the readout electronics of the TRD is shown in Figure 3. All components apart from the Global Tracking Unit (GTU) are implemented in two custom ASICs and are directly mounted on the detector in order to optimize latency for the trigger decision. The analog ASIC contains the pre-amplifier, shaper, and output driver. The other ASIC is a mixed analog/digital design containing the ADC, tracklet pre-processor, event buffer, and tracklet processor. Both chips are mounted on a so-called multi-chip module (MCM) serving 18 pads. The pre-amplifier and shaper circuit has a conversion gain of 6.1 mV/fC, a shaping time of 120 ns, an input dynamic range of 164 fC, and provides a maximum differential output of 1 V. The anticipated maximum equivalent input noise is 1000 e in system. The power consumption per channel is 10 mW.

The baseline for the ADC relies on a 0.25 μm design of a 10 bit 10 MHz differential ADC with a maximum power consumption of 20 mW. It is followed by a digital filter. This is necessary in order to compensate the long tails of the pulses due to slow ion drift and tails from the electronics, i.e., the time response function. Without such a filter significant distortions in the position

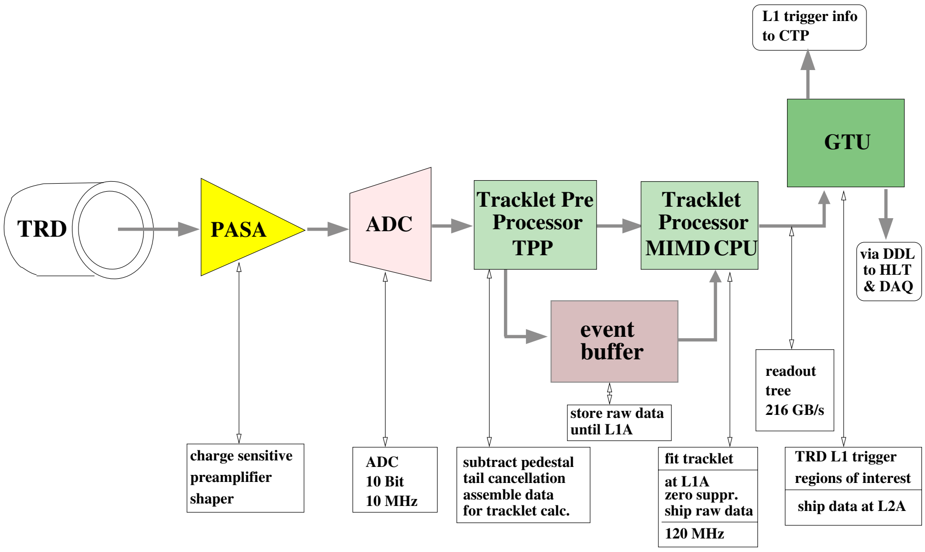

Figure 3: *Basic components of the TRD front-end electronics. Everything but the Global Tracking Unit (GTU) is mounted on the detector itself. The ADC, digital filter, tracklet pre-processor, tracklet processor, and event buffer are incorporated in a single chip. (L1A, L2A refer to the different trigger levels of the Central Trigger Processor (CTP) of ALICE.)*

measurement would be incurred depending on the history of pulse heights. These position measurements are used to reconstruct the short track pieces (tracklets) inside the drift region.

The output of the ADC is directly fed into the tracklet pre-processor. Here, all relevant sums are calculated which are subsequently used by the tracklet processor in order to calculate the position and inclination of tracklets, i.e., the track pieces contained in the drift region. All tracklets are shipped to the GTU, where tracklets from the individual layers are combined and matching cuts as well as momentum cuts and more complicated cuts (such as cuts on the invariant mass of pairs) are applied.

In Figure 4 the timing diagram for the individual steps in the processing of the tracklets are shown. All computations are finished and the trigger decision of the TRD is sent to the Central Trigger Processor (CTP) 6.1 μs after the interaction. Also shown at the bottom of the Figure is the frequency at which the digital circuitry needs to run at the various stages of processing after an

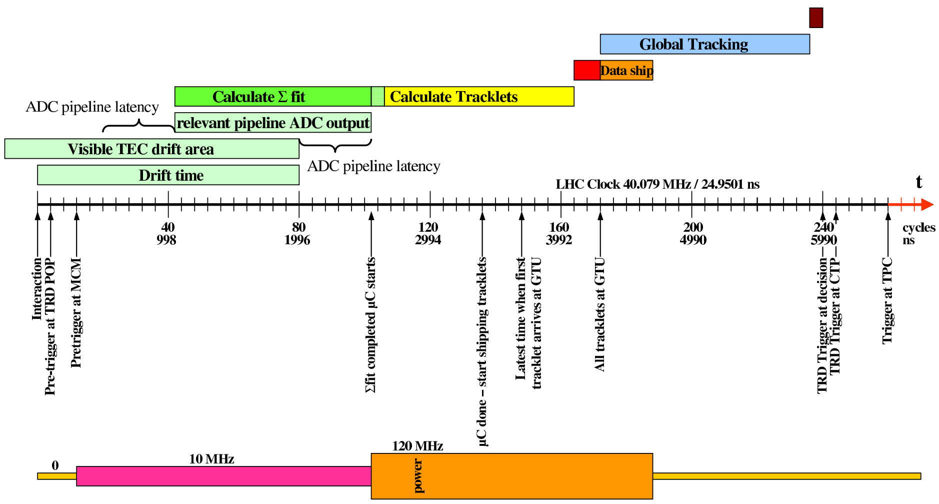

Figure 4: *Timing of the TRD trigger. The time axis is calibrated in units of the LHC clock period. Each tick corresponds to four clock cycles or about 100 ns.*

initial pre-trigger signal that wakes up the TRD electronics has been received. The width of the boxes indicates the power consumption. It is worthwhile noting that the integral bandwidth to the GTU that is handled by the readout tree on the detector is 216 GB/s. The bandwidth for data to the DAQ or the High Level Trigger via the DDL is 1.8 GB/s.

5 Physics Performance

Results from our test beam measurements [6] have been used to adjust parameters in the simulation of the detector. In particular data from measurements of the TR performance of the sandwich radiator have been parameterized. A correct description of the energy deposition, Lorentz angle, TR absorption cross section, pad response function, and the response of the electronics were also included in the simulations. They were carried out within the object-oriented framework AliRoot [7] developed for ALICE.

The response of the detector has been tested with events of varying multiplicity up to the highest anticipated multiplicity density of primary charged particles of $dN/dy = 8000$. To enhance statistics additional electron tracks

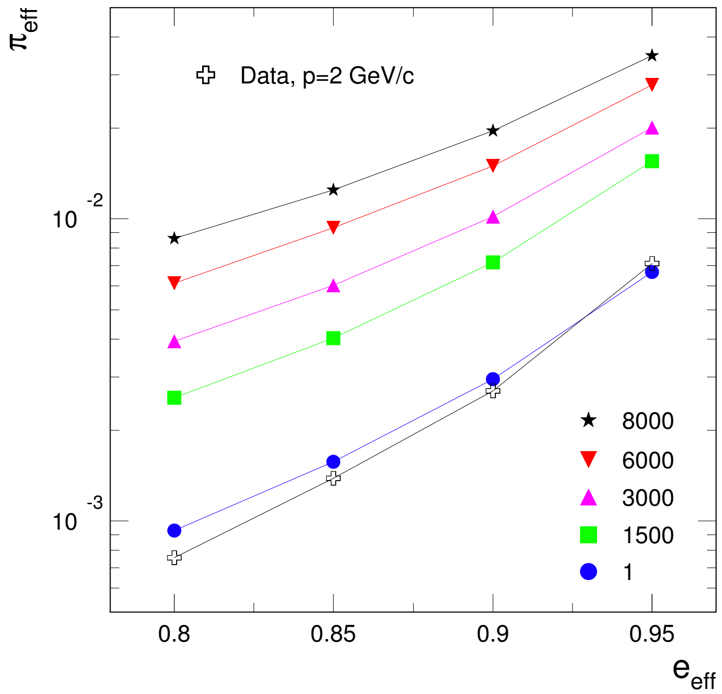

Figure 5: *Pion efficiency as a function of the electron efficiency for different event multiplicities (1-8000) and tracks of* $p = 2\,GeV/c$ *total momentum.*

have been embedded into these events in order to evaluate the pion detection efficiency as a function of electron detection efficiency for various event multiplicities as shown in Figure 5. At 2 GeV/c electron momentum and for the highest multiplicity, a pion rejection of a factor of 50 can still be achieved, while for lower multiplicities rejection factors well above 100 are possible.

The mass resolution for the Υ ($m = 9.46$ GeV/c^2) that can be achieved by combining electrons and positrons with $p_t > 3$ GeV/c as provided by the Level 1 trigger is 245 MeV/c^2. It has a tail towards lower masses due to radiative losses of the electrons in material in front of the TRD. A global track fit including measurements from the Inner Tracking System (ITS) and the Time Projection Chamber (TPC) improves the resolution to around 100 MeV/c^2 at the nominal magnetic field of B=0.4 T.

The importance of the dedicated trigger becomes obvious when looking at the yield of high p_t J/ψ and Υ. ALICE runs for about one month per year. Hence all estimates are based on a total of 10^6 s running at a luminosity of

$L = 5 \cdot 10^{26}$ cm^{-2}s^{-1}. Without a trigger on high p_t electrons and positrons about 2500 J/ψ ($p_t > 5.5$ GeV/c) and about 160 Υ can be recorded independent of centrality. With the trigger ($p_t > 3$ GeV/c) the number of high p_t J/ψ is quadrupled and about 2300 Υ will be collected.

6 Conclusions

The ALICE TRD is amongst other things well suited to study quarkonia production in the high multiplicity environment of ultra-relativistic Pb collisions at the LHC. In conjunction with the other tracking detectors of the ALICE central barrel it will be possible to measure the Υ mesons with a mass resolution of 1%. With an active area of 736 m^2 and 1.2 million readout channels it will be one of the largest TRDs. The integration of all readout and trigger electronics directly on the detector will greatly reduce electronics costs compared to conventional readout schemes.

Currently, it is foreseen to install 50% of the detector in time for the first LHC beam at the end of 2005. Provided additional funds can be made available, the second half of the detector can be installed during the winter shutdown at the beginning of 2007.

7 References

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