Construction of Multi Wire Proportional Chambers for the CBM Transition Radiation Detector

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Abstract. The Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion Research (FAIR) will explore the QCD phase diagram in the region of high net-baryon densities. The Transition Radiation Detector (TRD) with its multi-layer design will provide electron identification for higher momenta and contribute to the fragment identification.

1. Introduction
The main aim of the Compressed Baryonic Matter experiment is the exploration of the QCD phase diagram in the region of high net-baryon densities by observing high energy nucleus-nucleus collisions. The high event rate of up to $10^7$ Hz grants access to rare probes like multi-strange hyperons, hypernuclei and vector mesons. To identify those rare observables an efficient background suppression is needed. Along with the high interaction rate this imposes high demands on the participating detectors in terms of precision, rate capability and radiation hardness. At CBM the task of a precise electron identification will be fulfilled by the Ring

Figure 1. Sketch of the phase diagram containing different predicted phase boundaries and states of matter. [2]
Imaging Cherenkov Detector (RICH) and the Transition Radiation Detector (TRD). While the RICH is effective for momenta below 6 GeV/c the TRD is the only detector capable of providing electron identification above 7 GeV/c. In addition the TRD can provide fragment identification by measuring the specific energy loss [2]. The overall design of the TRD at SIS100 consist of one station with four layers. Each layer is made of 20 large chambers measuring 99×99 cm$^2$ and 34 smaller chambers with outer dimensions of 57×57 cm$^2$.

2. Transition Radiation

Transition radiation occurs when a charged particle traverses the interface of two media with different dielectric constants [1]. The radiated spectrum depends on the Lorentz factor $\gamma$ and can be described for relativistic particles by the following expression:

$$\frac{d^2W}{d\omega d\Omega} = \frac{\alpha}{\pi^2} \left( \frac{\theta}{\gamma^{-2} + \theta^2 + \xi_1^2} - \frac{\theta}{\gamma^{-2} + \theta^2 + \xi_2^2} \right)^2$$

with $\xi_1^2 = \omega_{pi}/\omega$, where $\omega_{pi}$ is the plasma frequency of the foil and the medium in between, $\alpha$ the fine structure constant and $\theta$ the emission angle. As the yield of a single interface is far too low, radiators are constructed such that a passing particle crosses many interfaces. This can be implemented for example as a stack of foils. As shown in Fig.4 the radiated spectrum depends on the configuration of the radiator and the Lorentz factor of the passing particle. This enables the TRD to distinguish between electrons with a high Lorentz factor and particles with a low Lorentz factor such as pions. While the produced spectrum of regular foil radiators can be well described theoretically, making them a good reference, their construction is time-consuming and unpractical. Furthermore, the radiator needs an outer frame to hold the foils in place. Irregular radiators made from fiber or foam material have been proven to be a good self-sustaining alternative and have been tested at test beam campaigns. As a candidate for the final experiment a foam radiator was chosen which showed a performance close to a foil reference radiator.
3. Multi Wire Proportional Chamber
To detect the transition radiation a gas detector is used. Gas detectors are a cost-efficient solution to cover a large area while keeping the material budget low. As stated by their name, the active area of these kind of detectors consists of a gas filled volume. Inside an electrical field is created by several electrodes. Passing charged particles ionize the gas and the produced ion-electron pairs get separated by the electrical field. In a multi wire proportional chamber (MWPC) the electrical field is generated by a plane of anode wires and two cathode planes. The primary electrons drift towards the anode wires. The increasing field around the anode wires accelerates the primary electrons to the point where they can also ionize the gas. This effect is called the gas amplification and depends on the configuration of the electrical field. The produced electrical charge can be read out either directly through the anode wires or by the charge which is induced on the cathode planes. By separating the cathode plane into individually read out pads it is possible to get an additional position information. The distribution of the induced charge on the pads is described by the pad response function and depends on the pad width and the distance to the anode wires. Different designs of MWPCs have been tested. To minimize the absorption of the TR-photons before entering the gas volume, one of the cathode planes is implemented as a thin aluminized Mylar or Capton foil, which also serves as the entrance window. The signal collection time arises from the ion-movement. While a classical MWPC (Fig.5 left) is by far the fastest design, its gas amplification correlates strongly with the uniformity of the cathode planes. As the entrance window is made from a thin foil, even moderate pressure differences between the inside of the detector and the environment can cause a deformation which has a huge effect of the electrical field and therefore the gain. One possible
countermeasure is to place additional ground wires between the anode wires. These so-called field wires alter the electrical field and stabilize the gas gain. For the final design the entrance window is stabilized with a lattice grid and an additional drift region is added. This drift region is separated by the amplification through a cathode wire plane and decouples the electrical field from the entrance window. The thicker gas volume increases also the absorption probability of TR-photons. Even through this design is slower than the ones mentioned before, the signal collection time is within the design goal of 0.3 μs. To achieve the required position resolution in the order of 300 μm, the width of the pads and the distance to the anode wires is tuned in a way that the most central pads get 80% of the charge. This ensures a good position and energy resolution.

4. Front End Electronic
As the CBM experiment does not have a global trigger, a self-triggered front end electronic is used to read out the detector. The front-end boards (FEBs) are mounted directly on the back of each chamber (see Fig.3) and are equipped with special designed readout ASICs, the so-called SPADICs. Each SPADIC has 32 analog input channels [2]. The incoming signals are going first through a charge sensitive amplifier (CSA) before they are digitized by a continuously sampling 9-bit ADC. In the digital part a programmable digital filter can be used for tail cancelation and signal shaping. The hit detection logic can trigger on a configurable threshold or the slope of the signal. Furthermore the SPADIC is capable of triggering neighboring channels even if the signals on these pads do not meet the criteria to trigger the readout them self. This ensures that also the induced charge on neighboring pads is registered. Each triggered channel produces a hit message which includes among other information the digitized signal and a timestamp. This information is transferred via low-voltage differential signaling links (LVDS) to the Read Out Board (ROB) where the data transmitted via optical fibers to the entry nodes.

5. Electron identification
In order to identify particles, individual hit messages are getting combined by the cluster finder to individual hits and the information of the position and the total deposited energy gets extracted. The average energy loss for electrons is increased due to the additional energy deposition by the absorbed TR-photon, which causes a second maximum in the electron spectrum (See Fig.7). The separation of pions and electrons for tracks in the TRD will be done by a likelihood algorithm.
For the likelihood method a clean spectrum of electrons and pions is needed as an input. The likelihood for a given track to be an electron (or a pion) is defined as:

\[ L = \frac{P_e}{P_e + P_\pi}, \quad P_e = \prod_{i=1}^{N} P(E_i|e), \quad P_\pi = \prod_{i=1}^{N} P(E_i|\pi) \]  

with \( P(E_i|e) \) and \( P(E_i|\pi) \) as the probability that the energy deposit in layer \( i \) is caused by an electron or a pion, respectively. This likelihood for electrons and pions for a track with hits in at least three layers is shown in Figure 8. For a given electron efficiency, the fraction of misidentified pions can be directly derived by this method. The performance of a TRD can be determined by this pion efficiency. The design goal of this detector is to achieve a pion misidentification of less than 5% at an electron efficiency of 90%. Simulations based on data acquired at test beam campaigns have shown that this can be achieved with four layers.

**Figure 7.** The simulated average energy loss in a single chamber for electrons and pions.

**Figure 8.** Likelihood for a given track to be an electron (red) or pion (blue).

### 6. Conclusion

Even though many similar TRDs have been build, each new experiment provides new requirements and challenges. The CBM experiment with its unprecedented interaction rate places enormous demands on the rate capability of all detectors participating at the experiment. After smaller prototype chambers have been successfully tested, new full size detectors have been build and are already being tested.

### References

[1] A. Andronic and J. P. Wessels. Transition Radiation Detectors. Nucl. Instrum. Meth., A666:130-147, 2012.
[2] Technical Design Report of the TRD (to be published)