Status and first Results of the CBM TRD Prototype Development

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Abstract.   The measurement of decay products from rare particles in the CBM experiment defines the requirements for the used detector systems. This report describes the approaches for the Transition Radiation Detector to fulfil these requirements and presents the current status of the prototype development. First results from beam tests with these prototypes are discussed.

1. Introduction

The Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion Research (FAIR) is aimed to measure rare observables in an environment of unprecedented high particle flux. The measurement of the D-mesons and the J/ψ as well as its excited states defines the experimental requirements of this experiment. Almost all listed particles in the left panel of Figure 1 decay into electrons and positrons or pions. The precise and fast discrimination between these decay products is an essential key feature of CBM. The purpose of the Transition Radiation Detector (TRD) is to provide this capability. The employed Multi-Wire Proportional Chambers (MWPC) additionally provide sufficient position resolution for the experiment-wide particle tracking and can be designed to be fast enough for the extreme high event rates at FAIR. The future CBM experiment is planed to be modular so that two different setups can be realized: an electron identification setup with very efficient electron/pion separation, and tracking capabilities and a muon detection setup where the TRD only contributes to tracking between the muon chambers (MUCH) and the time-of-flight detector (TOF). The SIS100 StartUp-Version of CBM also includes one TRD station for track matching to TOF. Both setups are depicted in the right part of Figure 1. In the current design of the TRD for SIS300, the active area covered by the detector is $585\,\mathrm{m}^2$ where 800.000 channels are read out. The TRD is divided in 3 stations with 10 layers in total. The first two stations consist of 4 layers each. The TRD is designed for a track density of 600 charged particles in an angular range of 2.5° to 25°at an event rate of 10 MHz. The misidentification of a pion as an electron has to be smaller than 1% at 90% electron efficiency for electrons with a momentum larger than $p =$1.5 GeV/c. The typical position resolution of the used MWPC design, in the order of $250\,\mu$m, is sufficiently precise for track reconstruction and matching to other detector systems.

2. Detector concepts with and without dedicated drift region

The TRD consists of two main detector parts: the radiator which generates the transition radiation (TR) photon depending on the γ-factor of the charged particle passing through, and
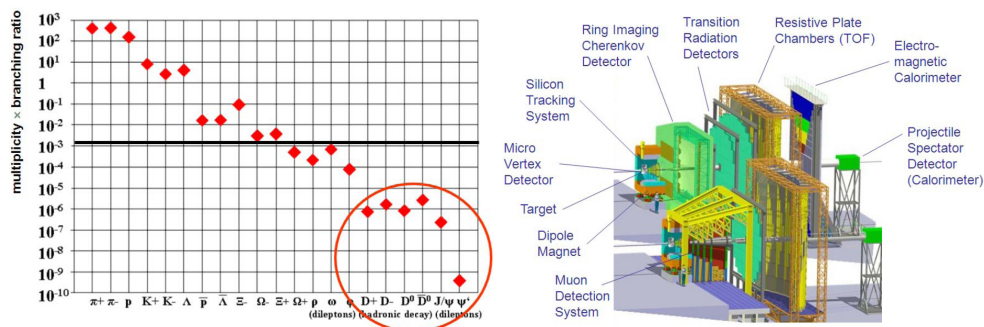
Figure 1. Left: Expected production rate of observables in Au+Au-collisions ($E_{beam} = 25\,\text{GeV}$). Right: Schematic view of the planned CBM experiment at SIS300: muon detection setup in front, electron identification setup in the back. [1]

the MWPC which absorbs the TR photon, in addition to the ionization signal of the charged particle. The symmetric detector design without a dedicated drift region only provides an amplification region and therefore only requires one wire plane which results in an easy-to-construct detector. The signal generation is, compared to a MWPC with dedicated drift, faster. This conceptual design is followed by the CBM TRD group at Institut für Kernphysik Frankfurt. The detector design with drift region consists of a MWPC with two separate regions in the detector: a dedicated drift and an amplification region. It requires two wire planes, the intrinsic signal generation is slower due to the additional drift region compared to the design without drift zone. The advantage of this concept is that the MWPC and the readout pad geometry are decoupled from the overall thickness of the detector which allows a more flexible design. This type of TRD has been build for the ALICE TRD[3] and it is followed by the CBM TRD group at Institut für Kernphysik Münster.

3. Prototype Construction
Based on results from previous test beam campaigns [4] and simulations [5] prototypes without drift region are built with dimensions of the active gas volume of $150 \times 150 \times [4+4; 5+5; 6+6]\,\text{mm}^3$. The aluminium frame was covered with $20\,\mu m$ aluminized mylar foil as entrance window. The anode wires are $20\,\mu m$ gold plated tungsten wires with $2.5\,\text{mm}$ spacing. The pad geometry is $5 \times 50\,\text{mm}^2$. With these MWPCs different radiator types have been tested. The sandwich-type radiator as used in the ALICE TRD made of $8\,\text{mm}$ *ROHACELL* foam sheets coated with $25\,\mu m$ aluminized mylar foil on carbon fibre sheets, and $40\,\text{mm}$ polypropylene fibres was used as reference. A foam radiator made of polyethylene foam (which is used as commercial packing material) with a bubble size of $0.7\,\text{mm}$ was chosen to provide around 350 transitions. Also regular foil radiators made of $20\,\mu m$ polypropylene foil glued to an $0.5\,\text{mm}$ aluminium frame as spacing between foils has been built in combinable stacks of 50 transitions each, so that up to 350 foil layers can be used. The detectors are read out by *Self-triggered Pulse Amplification and Digitization asIC* (SPADIC) in version 0.3 combined with the *SUSIBO*[6] readout board. The 8 bit current-sensitive ADC reads out 8 channels with 45 time bins each, at a sampling frequency of $25\,\text{MHz}$.

4. Results from in beam Test Measurements
The constructed prototypes with amplification region only and the prototypes with an additional dedicated drift region were tested in October 2011 at the CERN PS[7] providing a mixed electron and pion beam with particle momenta of 2 - 10 GeV/c. The raw signal read out by the SPADIC is corrected for baseline variations using empty events. Correlated noise is calculated using

a covariance matrix method and subtracted from the raw signals. The integral of the noise-corrected signal in the hit region (time bins 10 to 44 of the SPADIC signals) is clustered in the pad direction. The sum of the three largest pad signals in the cluster is defined as the total deposited charge q_{tot}. Figure 2 shows the total deposited charge for the Frankfurt 4+4 mm-prototype (only amplification region) and the Münster prototype with 3 mm distance from readout pads to anode wires, 3 mm distance of the anode wires to the cathode wires and 6 mm distance of the cathode to the entrance window (MS336). Both prototypes have been equipped with the same ALICE-type sandwich radiator. It has to be emphasized that independent analyses using different signal cuts are applied. The normalized spectra of the total
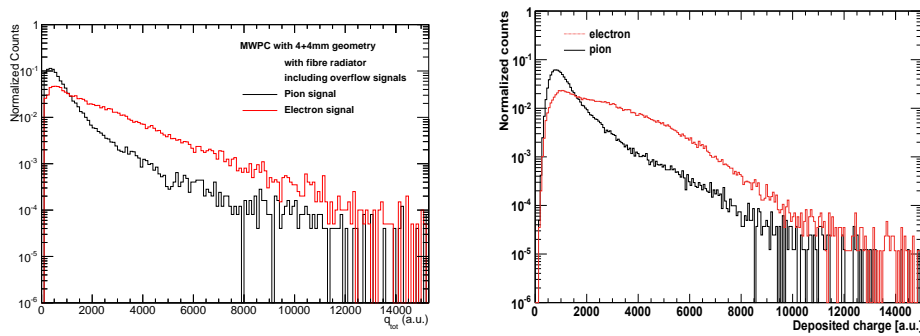

Figure 2. Total deposited charge in the FFM 4+4 mm (left) and MS336 (right) prototypes. Electrons are shown as red line, pions in black.

deposited charge serve as the input to a likelihood method to determine the electron and pion discrimination capability of the respective radiator and MWPC prototype combination. The normalized counts are interpreted as the probability P_e and P_π of electrons/pions depositing the measured charge. Using this measurement for one single detector layer one can extrapolate the electron likelihood L for multiple layers from

$$L = \frac{P_e}{P_e + P_\pi} \quad with \quad P_e = \prod_{i=1}^{N} P\left(q_{tot,i}|e\right) \ , \quad P_\pi = \prod_{i=1}^{N} P\left(q_{tot,i}|\pi\right) \tag{1}$$

where N is the number of extrapolated layers. For an electron efficiency of 90%, the corresponding integrated percentage of pions misidentified as electrons is shown in Figure 3 for different radiators as function of the number of extrapolated layers. One can achieve a pion misidentification of less than 1% for more than 6 detector layers with regular radiators (foil radiators) or more than 8 detector layers with foam-based radiators. The pad response function has been measured for all detector prototypes. Figure 4 shows the result for the FFM 4+4 mm and FFM 5+5 mm prototypes. It can be clearly seen that the pad geometry was not optimized for the given wire geometry. The central pad carries only a fraction of roughly 60%, the remaining charge is distributed on the neighbouring pads. When applying a simple straight line tracking algorithm, which only interpolates between three identical MWPC layers and calculates the distance between the reconstructed (center of gravity) an the measured position without any alignment and without any external reference, a position resolution of $291\pm10\,\mu$m can be achieved for the FFM 5+5 mm prototype. Using an iterative approach to correct also for spatial uncertainties a position resolution of $200\pm50\,\mu$m for the MS336 prototype was reached.
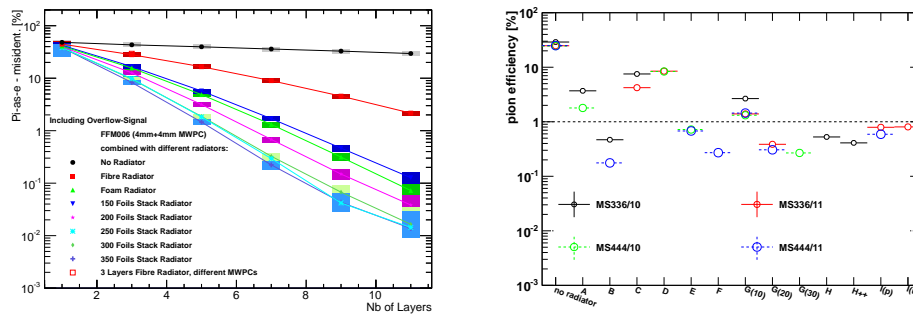
Figure 3. Fraction of misidentified pions for the FFM 4+4mm, as a function of the number of layers (left), and in MS336 (right) for 10 extrapolated layers and different radiator types (A is ALICE Type Radiator, B is a regular foil radiator with 250 layers, C to F are different regular foil radiators, G are fibre mats of variable thickness, I is mixed foam and foil-based radiator and H is a foam radiator)[8].
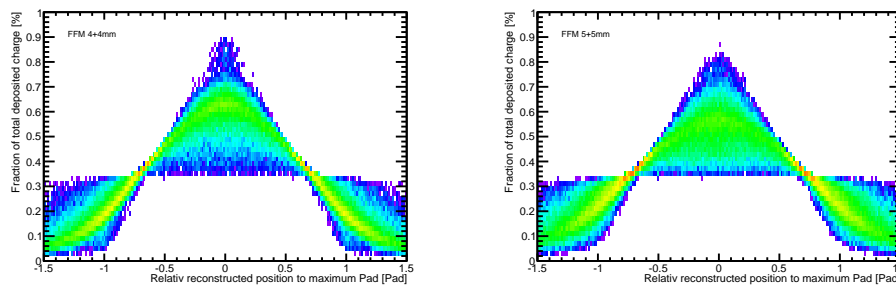

Figure 4. Pad response function for the FFM $4+4\,\mathrm{mm}$ (left) and FFM $5+5\,\mathrm{mm}$ (right) prototypes. The reconstructed position in the MWPC relative to the maximal pad is shown on the x-axis, the y-axis shows the fraction of the total charge in the corresponding pad.

5. Future Developments

Based on the results of the test beam time in 2011, the development of full-size prototypes ($600 \times 600\,\mathrm{mm}^2$) for the inner part of the TRD in the first two stations has started. Detector layout with and without dedicated drift region are considered. A common pad plane was designed which provides different sizes of readout pads to accommodate all considered prototype geometries. The prototype with amplification region only is designed in a modular way. The detector body consists of an aluminium frame and a honeycomb support structure holding the pad plane and the read out electronics. Distance ledges and the anode wires are attached to this main part. The detector is closed by a cover which holds a thin aluminized mylar foil as entrance window, as well as an optional support structure. A technical drawing of the prototype is shown in the left part of figure 5. The procedure for stretching the entrance foil is based on a thermal expansion[10]. The foil is fixed to a plexiglass frame, which is heated, the resulting expansion causes a mechanical stretching of the foil. Simulations of the deformation of a $600 \times 600\,\mathrm{mm}^2$ large entrance window and the mechanical stress of MWPC body were performed using the ABAQUS software framework [11]. A mylar foil stretched at a plexiglass temperature of $60\,^\circ\mathrm{C}$ gets bulged by $0.076\,\mathrm{mm}$ at an overpressure of $0.01\,\mathrm{mbar}$. These simulations were verified by measurements on a full-size prototype window. The deformation of the entrance window modifies the gas gain of the MWPC. These variations were simulated with the GARFIELD

software package [12]. The right pad of figure 5 shows the relative gain change as a function of the distance of the entrance window to the anode wires for three detector geometries with amplification region only. According to these simulations, a gas gain variation of less than 10% can be achieved if the gas system limits differential pressure variations to less than $0.01 mbar$.
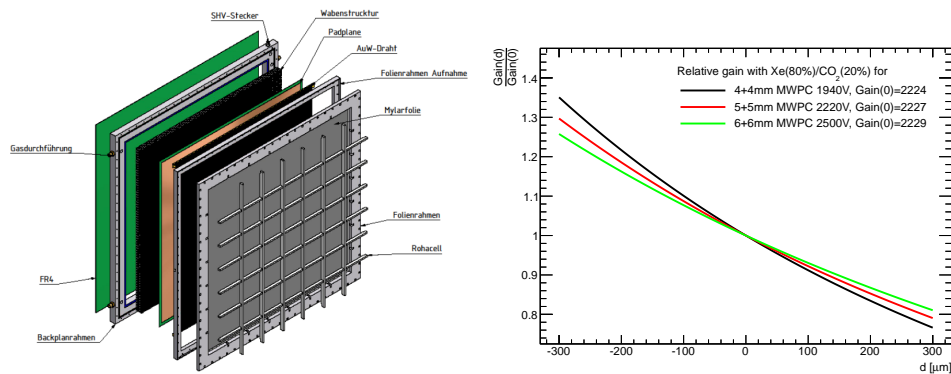

Figure 5. Left: Technical drawing of a full-size prototype. Right: Relative gain change depending on the displacement of the entrance window for three detector types with amplification region only.

6. Summary and Outlook

Results from beam test show that small prototypes with and without additional drift region fullfill the requirements of the CBM TRD for electron / pion separation and position resolution. Based on the results, no obvious preferences for final detector concept could be given. Large scale prototypes will be studied in upcoming beam tests. The final detector setup, including the number of stations and layers, the choice of the radiator, and the requirements for infrastructure and supply have to be evaluated. A Technical Design Report is scheduled for submission in 2014.

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