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High counting rate transition radiation detector

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Abstract

A new Transition Radiation Detector (TRD) prototype with high granularity for a high counting rate environment, required by the CBM experiment at the future experimental facility FAIR, GSI-Darmstadt, was designed and built. A solution for such a detector is a multiwire proportional chamber with a minimized drift region, reduced to a cathode – readout pad plane distance of 6 mm and a multiwire anode plane in the middle. Results of the ^{55}Fe source tests and of the in-beam investigations of the rate capability in terms of signal deterioration and position resolution degradation with the increase of the counting rate are presented. Based on the measured deposited energy spectra, the discrimination between electrons and pions as a function of number of layers was estimated by Monte Carlo simulations.

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Keywords: Gaseous detectors; Transition radiation detectors; High counting rate; Electron/pion discrimination

1. Introduction

The next generation of experiments in hadron physics, as is the CBM experiment [1] at the future experimental facility FAIR, GSI-Darmstadt, has to be able to measure extremely rare signals.

This requires high interaction rates that impose to the detectors unprecedented performances in terms of speed, granularity and radiation hardness.

The main challenge for the R&D activity of gaseous detectors for such experiments is to develop fast detectors which keep their performance in a high counting rate environment.

The expected particle rates for the CBM-TRD subdetector, in particular at small polar angles, are up to 10^5 particles/cm^2 s for 10^7 interactions/s of minimum bias Au + Au collisions at 25 A GeV [1].

Two concepts of TRD are well known by now: the ALICE-TRD [2] using a high granularity readout electrode gives very good performance in a high multiplicity environment and at low counting rate, and the ATLAS-TRT [3] based on straw tubes, with lower granularity but a good performance up to a counting rate of 10^6 particles/cm^2 s.

Based on these considerations, a natural solution for a fast TRD detector with a high granularity which could fulfill the requirements of the CBM experiment would be a Multiwire Proportional Chamber (MWPC) with a minimized drift region of 3 mm, in order to reach the required speed of the readout of the signals and to reduce the possible space charge effects. A pad readout electrode with a corresponding granularity has to be used in order to reach the desired occupancy per event [1].

This paper presents the results of the tests performed with such a prototype. Section 2 describes the basic principle of the design and the construction of the prototype. The results of the measurements with an ^{55}Fe source and in-beam, performed at the SIS accelerator of GSI-Darmstadt, are described in Section 3. Section 4 is dedicated to the conclusions.

2. Detector description

The new TRD prototype is composed of a radiator and a MWPC, a sketch of the counter structure is shown in Fig. 1.

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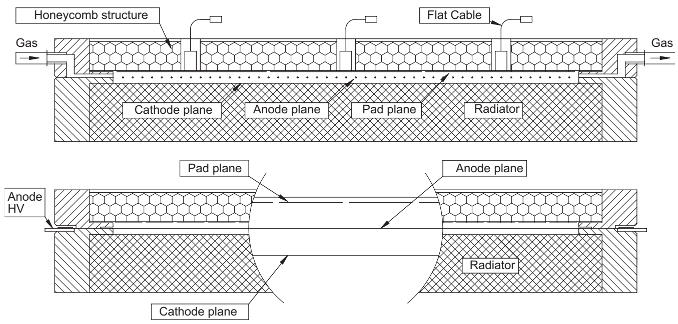

Fig. 1. Cross-sections through the detector: perpendicular (upper part) and parallel (lower part) to the direction of the anode wires.

The chamber has a symmetric structure with the anode wire plane situated in the middle, at 3 mm distance, between the cathode plane and, respectively, the readout pad plane electrode. In order to reduce the possible space charge effects by reducing the amount of charge amplified at each anode wire (W–Au, 20 μm), a small pitch of 2.5 mm between anode wires was used. The pads are grouped in three rows along the anode wires with 30 pads per row. Each pad has a rectangular shape and an area of about $7.5 \times 80\,\mathrm{mm}^2$ (the pad width is along the anode wire direction). The readout pad plane is reinforced by a honeycomb structure. The radiator (Rohacell foam HF71) is in contact with the cathode plane made of an aluminized mylar foil (25 μm). The counter has an active area of $240 \times 240\,\mathrm{mm}^2$.

3. ^{55}Fe source and in-beam tests

3.1. Source measurements

The prototype was tested at different anode voltages using an ^{55}Fe source and an Ar/CO_2(85%/15%) gas mixture.

The pad signals were amplified by a custom built charge sensitive preamplifier/shaper (PASA) based on discrete components. It has a gain of 2 mV/fC and a noise of 1800 electrons r.m.s. The charge or pulse height information was obtained as the sum of the sampled charge information, delivered by a FADC converter of 33 MHz sampling frequency, on the three consecutive pads in a row fired in an event (the pad with maximum charge (p_i) and its left (p_{i-1})–right (p_{i+1}) neighbours), in order to obtain the total deposited charge. The obtained energy resolution from the Gaussian fit of the main peak of the ^{55}Fe X-ray source was 8.6% (σ) (Fig. 2).

3.2. Experimental setup for in-beam measurements

The in-beam tests have been performed at the SIS accelerator of GSI, Darmstadt in a joint measurement campaign of the JRA4-I3HP Collaboration.

The prototype (Buch-TRD) has been placed between two plastic scintillators (Pl1 and Pl2, each with an area of $5 \times 5\,\mathrm{cm}^2$), used for time of flight (TOF) information and as a beam trigger, and between two double sided silicon strip detectors (Si1 and Si2, each with an active area of $32 \times 32\,\mathrm{mm}^2$, 50 μm strip pitch) for the beam profile definition. Electrons and pions are tagged using the information provided by a lead glass calorimeter (Pb) placed along the beam line (Fig. 3).

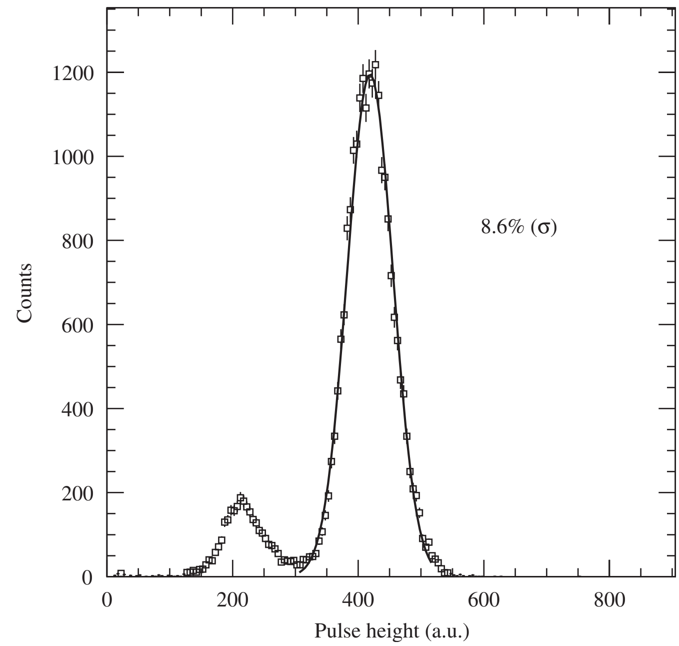

Fig. 2. The energy spectrum of the ^{55}Fe source with an Ar/CO_2(85%/15%) gas mixture, at 1700 V anode voltage.

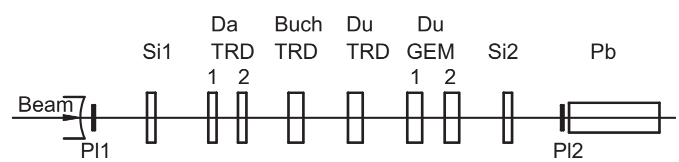

Fig. 3. Experimental setup used for the beam tests. The prototype discussed here is marked as Buch-TRD.

The amplification of the signals was made by the same PASA used for the source tests. The digital conversion of the signals was made by a FADC converter with 33 MHz sampling frequency (0.6 V swing and an adjustable base-line). The MBS – DAQ system [4] was used for data acquisition.

3.3. In-beam test results

The effect of the high counting rate environment on the detector performance was studied using a mixture of positive particles of 2 GeV/c momentum, in which the protons have been the dominant component. The counting rate per area of detector was changed by varying the extraction time of the beam at a given beam intensity. The protons were selected using TOF information. The charge

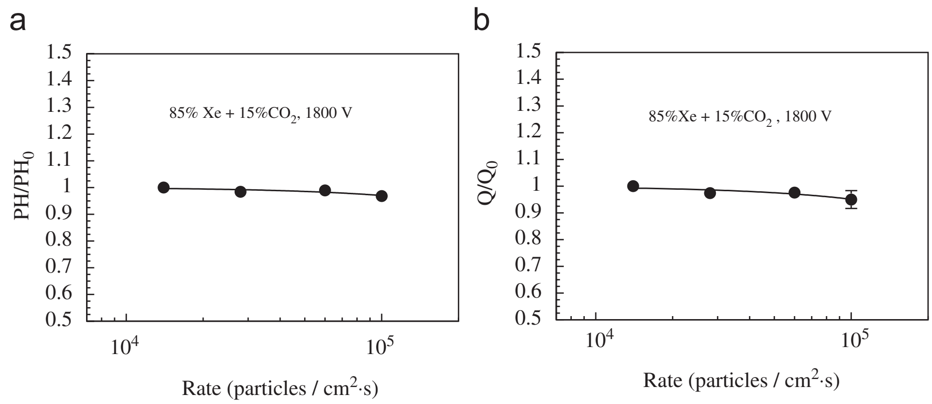

Fig. 4. The rate dependence of the mpv values normalized to the mpv value at the lowest rate of (a) the maximum pulse height distribution, and (b) the charge distribution, for a $Xe/CO_2(15\%)$ gas mixture at 1800 V applied voltage.

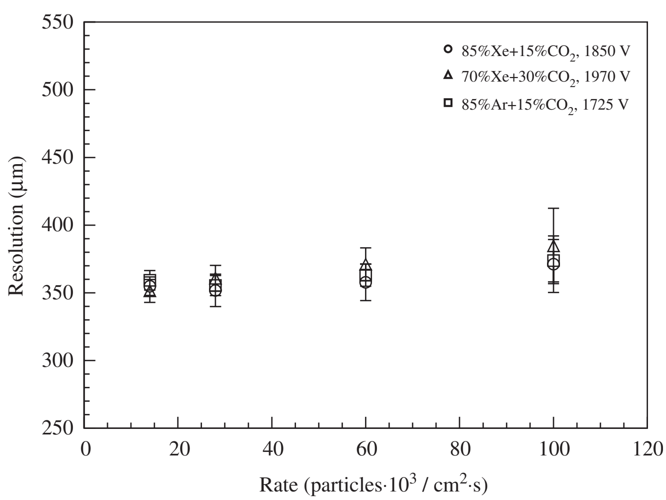

Fig. 5. The position resolution as a function of the counting rate for different gas mixtures and applied voltages.

or pulse height information was obtained as it was described in Section 3.1. From Landau fits to the proton maximum pulse height (PH) and to the integrated charge (Q) distributions the most probable values (mpv) were obtained for each counting rate.

The effect of the space charge on the gas gain [5] can be seen in Figs. 4(a) and (b). The relative degradation of the pulse height and of the integrated charge was $3.2 \pm 2.1\%$ (Fig. 4(a)) and $5.0 \pm 3.4\%$ (Fig. 4(b)), respectively, at the highest rate (10^5 particles/cm^2 s), for a $Xe/CO_2(85\%/15\%)$ gas mixture and 1800 V applied anode voltage.

The position was reconstructed from the charge sharing among three neighbouring pads (p_{i-1}, p_i, p_{i+1}) along the wire direction. The position resolution is then obtained as the standard deviation of a Gaussian fit to the distribution of residuals between the Buch-TRD prototype and the Da-TRD2 prototype [6] (see Fig. 3), from which the contribution of the Da-TRD2 prototype is quadratically subtracted. The position resolution of the Da-TRD2 is given by the square root of the variance of a Gaussian fitted to the distribution of the residuals of the two identical prototypes (Da-TRD1 and Da-TRD2), considering equal contribution of both chambers.

At the lowest rate the obtained position resolution is ~350 μm and its degradation as a function of rate is less than 40 μm (Fig. 5). One should mention that for this prototype the pad sizes were not optimized to reach the position resolution required by the CBM experiment.

From a short run with negative particles (electrons and pions) of 1 GeV/c momentum, the pulse height distributions for electrons and pions (Fig. 6(a)) were obtained summing the signals on the central pad (p_i) and the adjacent pads (p_{i-1}, p_{i+1}).

Superpositions of Landau and Gaussian functions fitted to the spectra presented in Fig. 6(a) have been used as probability distributions in the Monte Carlo simulations, in order to estimate the electron/pion discrimination as a function of number of layers. One TRD layer, as represented by the measured prototype, is composed of a radiator and a MWPC.

The pion efficiency denotes the fraction of pions falsely identified as electrons by a cut defined as resulting in a 90% efficiency to identify electrons when applied to the electron signal distribution. According to this definition, the pion efficiency was extracted using a likelihood analysis technique [7].

For the Rohacell HF71 radiator of the prototype, an anode voltage of 1900 V and a $Xe/CO_2(85\%/15\%)$ gas mixture, the pion efficiency at 90% electron efficiency can be followed in Fig. 6(b) as a function of number of layers. The obtained pion efficiency for a configuration with ten layers is ~3%. This result could be improved using a radiator with better performances concerning the transition radiation yield [2] as is a regular periodic stack foil radiator [8].

4. Summary and outlook

The signal deterioration and the position resolution degradation as a function of the counting rate up to 10^5 particles/cm^2 s are minor for the TRD prototype

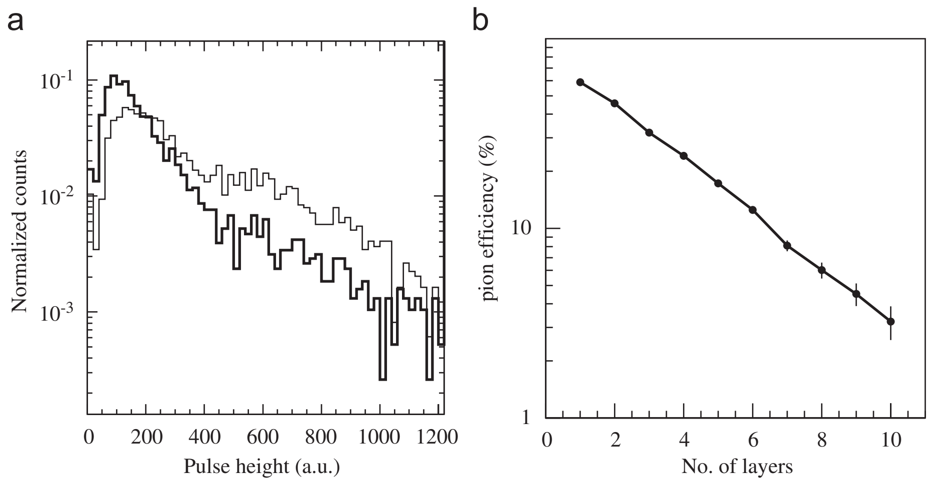

Fig. 6. (a) Experimental pulse height distributions for electrons (thin line) and pions (thick line) used as input for the Monte Carlo simulations. (b) Pion efficiency at 90% electron efficiency at 1 GeV/c momentum as a function of number of TRD layers for a Rohacell HF71 radiator and 1900 V anode voltage.

presented in this paper. In order to increase the conversion efficiency of the transition radiation in a single TRD layer, conserving the counting rate performance, a new prototype, based on a double MWPC relative to a double sided pad readout electrode, is under investigation.

Acknowledgements

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