RATE CAPABILITY OF A HIGH EFFICIENCY TRANSITION RADIATION DETECTOR

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In this paper we present details on the counting rate capability of a new *Transition Radiation Detector* (TRD) prototype based on a symmetric geometry of two MWPCs relative to a common, central pad structure readout electrode. Results 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 for different Xe based gas mixtures and applied anode voltages show negligible deterioration of these parameters up to 2×10^5 particles·cm^{-2}·s^{-1} counting rate.

1. INTRODUCTION

A new *Transition Radiation Detector* (TRD) prototype for electron – pion discrimination in high counting rate environment with a pion efficiency (the fraction of misidentified pions as electrons at a given electron efficiency) better than 1% for a six layer configuration and a position resolution better than 200 μm has been recently developed [1, 2]. This type of detector fulfills the requirements of the CBM (*Compressed Baryonic Matter*) experiment [3] at the future FAIR (*Facility for Antiproton and Ion Research*) [4] in terms of e/π discrimination capability with a reduced number of channels and material budget in a high counting rate and multiplicity environment.

The performance of the CBM-TRD subdetector, (a pion efficiency better than 1% for an electron efficiency better than 90% and a position resolution of the order of 200–300 μm), has to be preserved up to more than 1×10^5 particles·cm^{-2}·s^{-1} counting rate [3].

It is well known that the space charge built up in a gas detector operated in high counting rate environments reduces the electric field in the active region. Therefore the performance of such detectors deteriorates at high counting rates. High counting rate performance may be restored by appropriate choice of geometry, gas mixture and signal processing electronics.

The performance of a new TRD prototype as a function of counting rate in terms of stability of the gas gain and position resolution for different Xe based gas mixtures and applied anode voltages is presented in the paper.

2. DETECTOR GEOMETRY

Detailed description of the detector geometry has been presented in a previous paper [1]. The main idea for the design and construction of a new TRD configuration which fulfills the counting rate requirement of the CBM experiment was to build a MWPC with a gas gap thickness of 6 mm [5] in order to shorten the charge carrier drift time and consequently reduce the space charge effects. Up to intensities of 10^5 particles·cm^{-2}·s^{-1} no major deterioration of its performance has been observed [5], [6]. The conversion efficiency of the *transition radiation* (TR) in a single TRD layer of such a geometry is reduced. The absorbtion length in Xenon of a typical TR photon energy of 10 keV [7] is 1 cm [8].

In order to improve the conversion efficiency of TR in a single TRD layer, a new detector architecture, based on two symmetric such MWPCs relative to a common, central readout electrode, was designed, built and tested [1]. The readout electrode has a pad structure (5×10 mm^2 pad area) on both sides, two rows of nine pads on either side, along the anode wires. The corresponding pads on the upper and lower surface are connected. The two multiwire anode electrodes (2.5 mm pitch), up and down relative to the central electrode were made from gold plated tungsten wires of 20 μm diameter. Aluminized mylar (25 μm) was used to close the gas volume providing at the same the cathode of the respective MWPC.

3. EXPERIMENTAL SETUP

The in-beam tests were performed in a joint measurement campaign of the JRA4-I3HP(FP6) Collaboration. The experimental setup, presented in Fig. 1, comprises two silicon strip detectors for beam profile definition, two arrays of plastic scintillators for time of flight information, a Pb-glass calorimeter and a gas-filled Cherenkov detector for e/π discrimination.

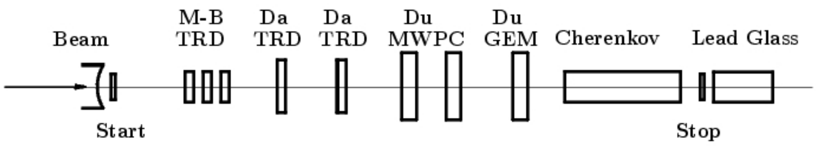


Fig. 1 – In-beam test setup. Results from the TRDs labeled M-B TRD are discussed in this paper. Start and Stop signals were generated by scintillator arrays of 4 NE102 strips each. A gas Cherenkov counter and a lead glass calorimeter were used for particle identification.

The signals delivered by 16 cathode readout pads (8 consecutive pads of each row) were processed using a new generation of PASA front-end electronics [10]. They were digitized by an 8-bit non-linear Flash ADC (FADC) system with 25 MHz sampling frequency (0.6 V swing and an adjustable baseline). The MBS-DAQ system [11] was used for data aquisition.

Gas mixtures of Xe/CO_2: (90%/10%), (85%/15%), (80%/20%), were circulated through the counter at atmospheric pressure. Xe based gas mixture was chosen in order to assure effcient absorbtion of the transition radiation X-ray produced only by particles with a Lorentz factor larger than 1000 [7]. The resulting signal, in this case, is the sum of the charge associated to the ionization of the charged particle in the chamber and to the transition radiation conversion.

4. PION REJECTION

The pion rejection factor was extracted using the likelihood on integrated energy deposit [12]. The pion efficiency at 90% electron efficiency for 1.5 GeV/c momentum as a function of the number of layers for a Rohacell radiator, a Xe/CO_2 (85%/15%) gas mixture and an anode voltage of 1800 V was estimated by Monte Carlo simulations, using as input the experimental data. For a six layers configuration a pion efficiency of 3.3% is reached (Fig. 2). The estimated pion efficiency for a 6 layers configuration of a TRD detector based on the developed prototype and a polypropylene foil stack radiator is 0.7% [1].

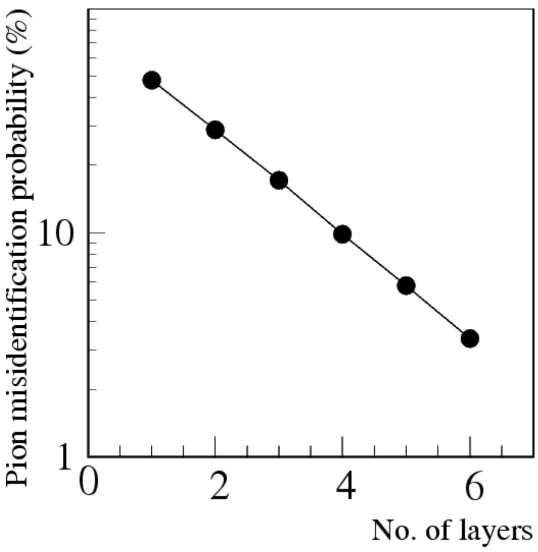
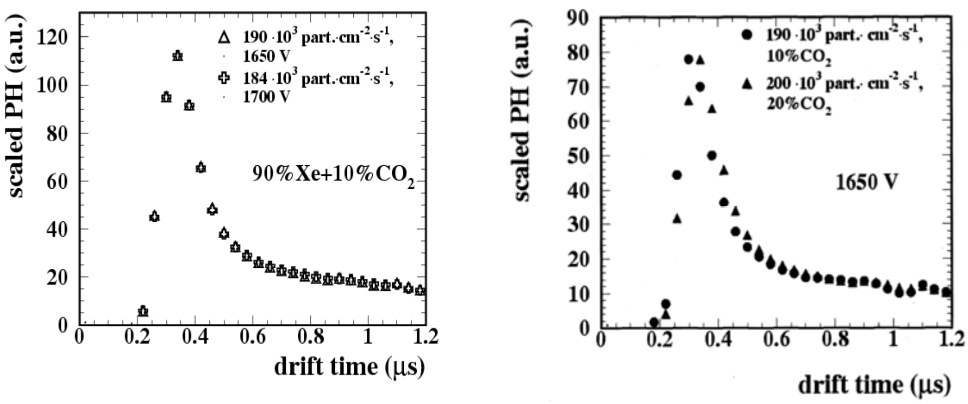


Fig. 2 – Pion efficiency at 90% electron efficiency for 1.5 GeV/c momentum as a function of the number of layers using a Rohacell radiator and an anode voltage of 1800 V [1].

5. RATE DEPENDENCE

5.1. GAIN

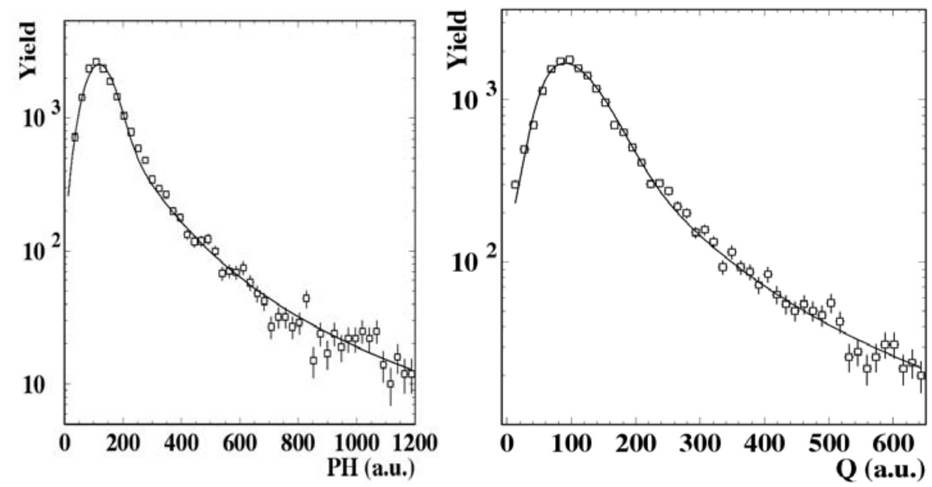
The measurements have been performed using a mixture of positive particles of 2 GeV/c momentum in which the protons have been the dominant component. The counting rate per unit area of detector was changed by varying the extraction time of the beam at a given beam intensity. Time distribution of the pulse height averaged over many events and scaled to the maximum value, at the highest measured rates for these runs (1.90×10^5 and 1.84×10^5 particles$\cdot$cm$^{-2}\cdot$s^{-1}), are shown in Fig. 3 a) for the same gas mixture (Xe/CO_2 (90%/10%)) at two different applied anode voltage: 1650 V and 1700 V. The same type of distributions are shown in Fig. 3 b) for the same anode voltage, 1650 V, and two different gas mixture: Xe/CO_2 (90%/10%) and Xe/CO_2 (80%/20%) at the highest measured rates for these runs (1.90×10^5 and 2×10^5 particles$\cdot$cm$^{-2}\cdot$s^{-1}). The signal is obtained from the sum of the sampled charge information delivered by a FADC converter of 25 MHz sampling frequency on six pads fired in an event in order to obtain the total deposited charge: the three consecutive pads (the pad with maximum charge (p_i) and its left (p_{i-1}) – right (p_{i+1}) neighbours) in one row and their three corresponding neighbours (p_{i+8}, p_{i-1+8}), p_{i+1+8}) in the other row. One cannot observe any difference between the tails of the signals with the high voltage or gas composition. The good behaviour of the average pulse height as a function of time for different particle rates have been presented in [2].



a) b)

Fig. 3 – Time distribution of the average pulse height, scaled to the maximum value, for: a) a Xe/CO_2 (90%/10%) gas mixture and two different applied anode voltages, 1650 V and 1700 V at the highest rates (1.90×10^5 and 1.84×10^5 particles cm$^{-2}\cdot$s^{-1}); b) the same applied anode voltage, 1650 V, and two different gas mixtures: Xe/CO_2 (90%/10%) and Xe/CO_2 (80%/20%) at the highest rates (1.90×10^5 and 2×10^5 particles$\cdot$cm$^{-2}\cdot$s^{-1}).

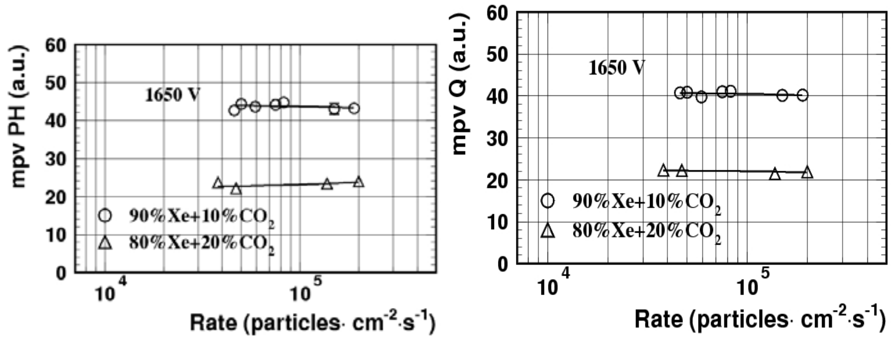
The amplitude and integrated charge behaviour as a function of counting rate was analysed for different gas mixtures and applied anode voltages in order to obtain the space charge effect on the measured gain. Because the development of the charge avalanche is located in the time interval 0.2–0.6 μs (Fig. 3), the integrated charge (Q), respectively, maximum pulse height information (PH) were obtained from the signal located in this time region. The deposited energy spectra (in terms of PH or Q) were fitted by a superposition of Landau and Gauss functions (Fig. 4 a) and b)). The most probable values (mpv) were extracted for each counting rate.



a) b)

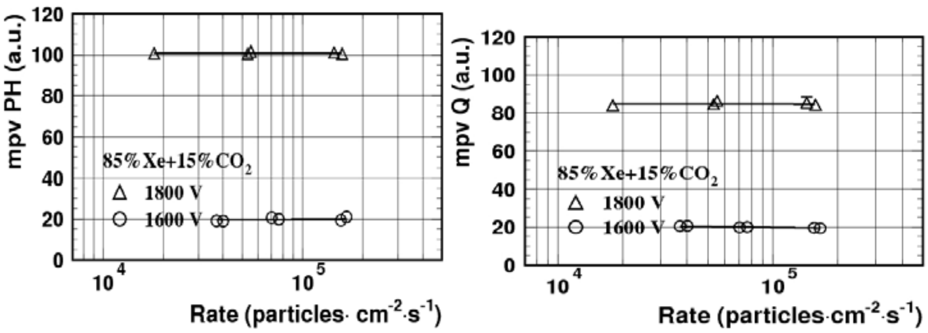
Fig. 4 – Experimental pulse height (a) and charge distributions (b) fitted with a superposition of Landau and Gauss functions, for a Xe/CO_2 (80%/20%) gas mixture and 1850 V applied anode voltage at 4.5×10^4 particles·cm^{-2}·s^{-1}.

In Fig. 5 are presented the rate dependence of the mpv values of PH (Fig. 5 a)) and Q (Fig. 5 b)) distributions for two different gas mixture (Xe/CO_2 (90%/10%) and Xe/CO_2 (80%/20%)), at the same anode voltage, 1650 V. The signal deterioration is negligible up to about 2×10^5 particles·cm^{-2}·s^{-1} for both quencher contents. The signal amplitude and charge as a function of the counting rate for a Xe/CO_2(85%/15%) gas mixture at two applied anode voltages, 1600 V and 1800 V are shown in Fig. 6 a) and Fig. 6 b), respectively. As one could be seen the signal remains almost unchanged up to more than 1.5×10^5 particles·cm^{-2}·s^{-1}. The effect of the space charge built-up at high rate on the signal amplitude and charge for a Xe/CO_2 (80%/20%) gas mixture, for two different applied anode voltages, 1650 V and 1850 V, is shown in Fig. 7 a) and Fig. 7 b), respectively.



a) b)

Fig. 5 – The rate dependence of the mpv value of a) the maximum pulse height distribution, and b) the charge distribution, for Xe/CO_2 (90%/10%) and Xe/CO_2 (80%/20%) gas mixtures at 1650 V applied anode voltage.

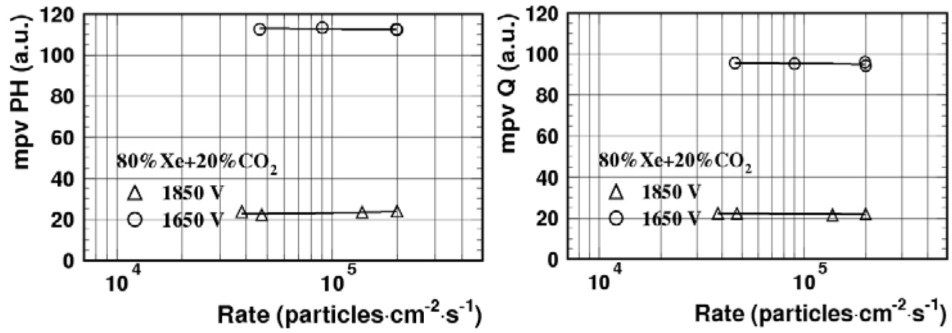


a) b)

Fig. 6 – The rate dependence of the mpv value of a) the maximum pulse height distribution, and b) the charge distribution, for Xe/CO_2 (85%/15%) at 1600 V and 1800 V applied anode voltages.

The high counting rates require low gas gain in order to avoid space-charge and ageing effects. The high counting rate could cause the multiple event pile-up at lower applied voltage due to the lower drift velocity of the charge carriers. For a given gas mixture the pile-up depends on the applied anode voltage, shaping time of the front-end electronics and increases with the counting rate. At high rates, signals from subsequent events can overlap increasing the signal amplitude/charge and deteriorating the pion rejection performance of the detector. The results presented above for the two gas mixtures at the lower applied voltages (Fig. 5) show that the signal pile-up is not significant for this detector prototype.

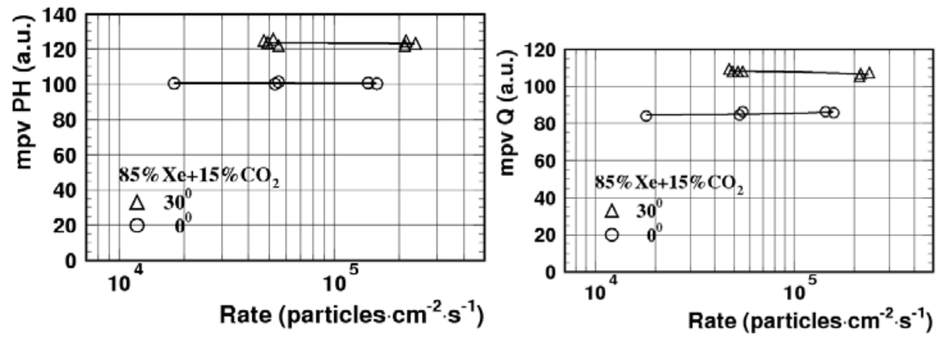
The amount of the positive space charge within the gas gap depends on the value of the gas gain at a given detector geometry, anode voltage, gas composition and pressure. As far as the electric field due to space charge of positive ions is lower than a critical value, its influence on the external electric field is not important. When the space charge becomes sufficient to disturb the external electric field, the reduction of the gas gain due to the screening effect of the cloud of positive ions starts to take place. In Fig. 6 and Fig. 7 we can see that no significant gain deterioration arising from the space charge effect, at the highest applied voltage in each case, is observed.



a) b)

Fig. 7 – The rate dependence of the mpv value of a) the maximum pulse height distribution, and b) the charge distribution, for Xe/CO_2(80%/20%) at 1650 V and 1850 V applied anode voltages.

The effect of the space charge on the signal is most pronounced for tracks at normal incidence to the anode wires for which the charge collection takes place in a very confined region on the anode wire [13]. The effect is the screening of the anode potential by the high density positive ions and the reduction of the gas gain. At normal incidence the gas gain saturation could appear for high rate and large applied voltages affecting the pion rejection performance of the detector. For tilted tracks, this effect is less pronounced because the positive space charge is spread over a larger region of the anode wire.



a) b)

Fig. 8 – The rate dependence of the mpv value of a) the maximum pulse height distribution, and b) the charge distribution, for Xe/CO_2(85%/15%) at 1800 V applied anode voltage at normal incidence and at 30 degree incident angle.

The results presented in Fig. 8a) and b) show a negligible deterioration of the signal for the Xe/CO_2 (85%/15%) gas mixture and 1800 V applied anode voltage at normal incidence, comparative to the incidence at 30º angle. We can therefore conclude that the gas gain saturation at normal incidence as a function of counting rate, for these gas mixture and applied anode voltage is negligeable.

5.2. POSITION RESOLUTION

The dependence of the position resolution on the counting rate is another important issue investigated in this work. In the geometry of the readout electrode of the presented prototyope the fraction of the induced charge on adjacent pads depends on the arrival position of the incident particle. The charge sharing between adjacent pads in a row provides the measure of the position of the avalanche along the anode direction. For each event, the central pad is determined as the pad with the maximum charge. The position was determined using a Gaussian fit of the pulse height distribution on three consecutive pads. The position resolution is given by the square root of the variance of a Gaussian fit to the distribution of residuals between two identical detectors, considering equal contribution of both chambers. The obtained position resolutions as a function of counting rate for three different Xe based gas mixtures and applied anode voltages are presented in Fig. 9. The signal to noise ratio was varied via the anode voltage. The position resolution improves with the increase of the signal-to-noise ratio [2]. The position resolution was 150 μm at the lowest rate for the Xe/CO_2 (80%/20%) gas mixture and 1850 V working voltage and its degradation with the increase of the counting rate is not significant up to 2×10^5 particles $cm^{-2}s^{-1}$.

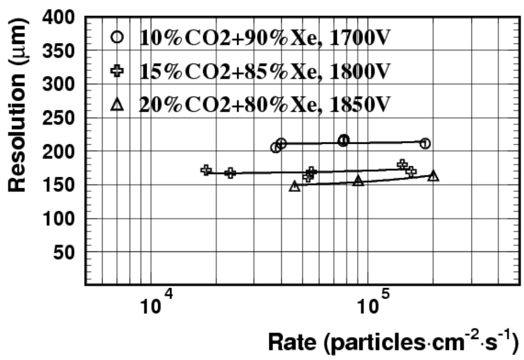


Fig. 9 – The position resolution as a function of the counting rate for different gas mixtures and applied voltages.

6. CONCLUSIONS

The electron – pion discrimination performance of the new TRD prototype has been demonstrated in a previous paper [1]. The presented results show that the detector has reliable and stable operation in high counting rate environment (no significant signal deterioration and position resolution degradation) up to about 2×10^5 particles $cm^{-2}s^{-1}$, for all used gas mixtures and applied voltages. Based on the obtained results a real size prototype with an optimized geometry of the readout electrode in order to provide two dimensional position information is under investigation. Last but not least we should mention that in the present measurements only a small active area of the detector, of about 4 cm^2, was exposed to the counting rate. Therefore, measurements with the whole active area of the counter exposed at similar counting rates are mandatory.

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