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Discriminating cosmic muons and X-rays based on rise time using a GEM detector *

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Abstract: Gas electron multiplier (GEM) detectors have been used in cosmic muon scattering tomography and neutron imaging over the last decade. In this work, a triple GEM device with an effective readout area of 10 cm × 10 cm is developed, and a method of discriminating between cosmic muons and X-rays based on rise time is tested. The energy resolution of the GEM detector is tested by ^{55}Fe ray source to prove the GEM detector has a good performance. Analysis of the complete signal-cycles allows us to get the rise time and pulse heights. The experiment result indicates that cosmic muons and X-rays can be discriminated with an appropriate rise time threshold.

Keywords: gas electron multiplier, cosmic muon, X-ray, rising time, discrimination

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1 Introduction

GEM detectors are designed to detect charged particles with good performance, including high effective gain, good position resolution, high counting rate and so on [1, 2]. GEM detectors can also detect radiation with a gain as high as 10^6 for triple GEM foils. Due to the good position resolution and high efficiency of detection, GEM detectors are widely used in cosmic muon scattering tomography (MT) [3]. In most cases, the bottleneck for cosmic tomography is the flux. Usually the flux of cosmic muons is about 1 cm^{-2} min^{-1}, so the exposure time is crucial in practical applications. Background has a great impact on the minimum exposure time and track reconstruction, so reducing the background is particularly important. Taking into account the tomography environment and GEM detection efficiency of different types of radiation, the largest contribution to the background is from X-rays. GEM detectors have also been extensively applied to neutron imaging due to their plasticity. A GEM detector can easily become a neutron detector by coupling with high-density polyethylene (HDPE) as a neutron-proton converter [4, 5]. The X-rays generated by neutrons interfere greatly with the measurement of the effective neutron response [6] and proton track reconstruction. Neutron response signals and X-rays are discriminated by the pulse heights in Ref. [6], with a big deviation. As the same time, GEM detectors are widely used in high energy physics experiments as track detectors. X-rays influence the track reconstruction of high energy particles which pass through the GEM detector.

Therefore, discriminating X-rays and cosmic muons is meaningful for muon tomography and neutron imaging. The traditional method of reducing X-rays is anti-coincidence with two plastic scintillators, which complicates the experimental setup. Discriminating X-rays and charged particles is also meaningful work.

In gas, different particles deposit energy in different ways. Charged particles, such as protons, deposit energy along their track and produce ion-electron pairs over the whole track. In contrast, X-rays lose their energy in a small region. These different ways of depositing energy present differently in the time characteristics of the signals. In this paper, we discriminate cosmic muons, which deposit energy along their track like proton, and X-rays, based on the rise time. The conclusion can also be generalized to discriminate between charged particles and photons in micro-pattern gas detectors (MPGDs).

2 Experimental setup

A triple GEM detector was used, which works in a proportional mode as shown in Fig. 1. It consists of

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three GEM foils, a cathode plane and a read-out anode with 496 one-dimensional strips. The sensitive area is 10 cm×10 cm and the width of the strips is 100 μm. Three GEM foils separate the chamber into four gaps. The thickness of the drift gap is 3 mm, while the thickness of the induction gap is 4 mm. The distance between the two GEM foils is 2 mm. The detector was operated based on a continuously flushed Ar/CO_2 gas mixture (80/20 percentage in volume). A voltage divider was employed to supply the bias voltage to the detector, which avoids electric fields becoming too high in the case of a discharge. For further protection, an additional 10 MΩ protection resistor was connected with the electrode. The work bias voltage was −2825 V, while the bias voltage of GEM foil was 353 V, and the electric field of drift gap and induction gap were 1177 V/cm and 1324 V/cm respectively.

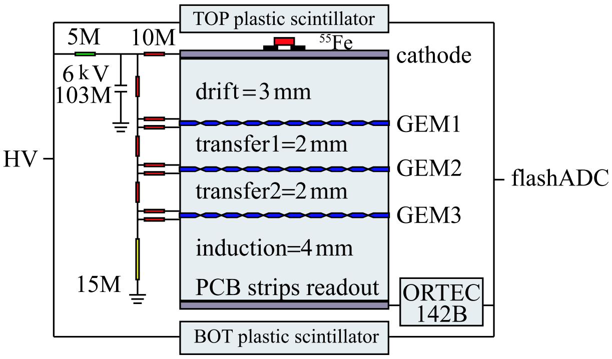

Fig. 1. Experimental setup of triple GEM detector.

The energy spectrum of the triple GEM detector was measured with a ^{55}Fe 5.9 keV X-ray source, as shown in Fig. 2. The energy resolution is about 20.4%, and the escape peak of argon and full photo-electron peak of the ^{55}Fe X-rays are distinguished completely, which demonstrates the GEM detector has good performance. The detection system has a good energy linearity relationship, for the ratio of the two peaks is 1.96.

The GEM detector was placed between two plastic scintillators with 10 cm×15 cm effective area. In order to conduct signal studies, the plastic scintillators signal and the GEM detector signals pre-amplified by a charge sensitive preamplifier (ORTEC 142B) were recorded, using a 1.8 GHz sample frequency FlashADC with four channels. The working voltage of the scintillator was set to a suitable value so that the height of the cosmic muon signal could be recorded and easily compared with a threshold. The work bias voltages of the plastic scintillators were −1483 V and −1273 V, respectively. The bias voltages were delivered to each detector by a CAEN module N472.

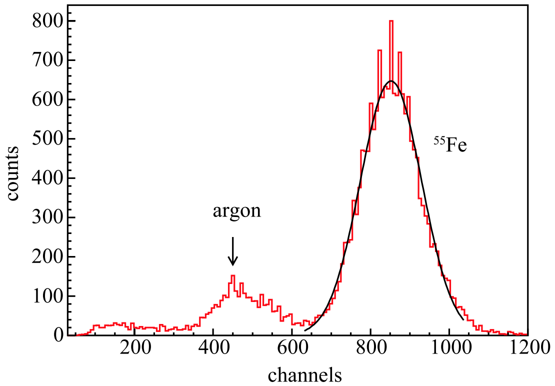

Fig. 2. ^{55}Fe 5.9 keV X-ray source spectrum measured by triple GEM detector.

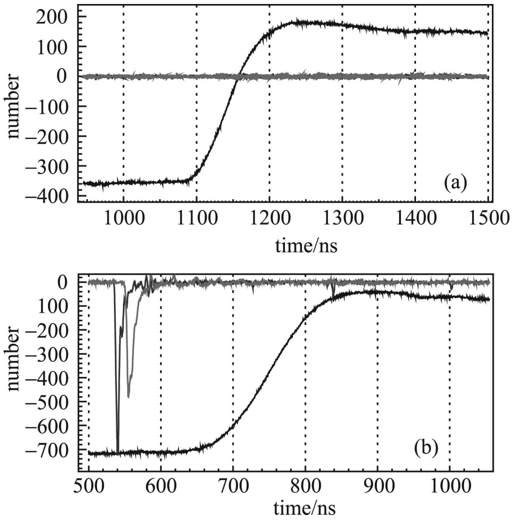

Fig. 3. (color online) Typical signals of three detectors. The blue curve sample and red curve sample represent the signals of the top plastic scintillator and bottom plastic scintillator, respectively. The black curve sample is the signal of the GEM detector from X-rays (a) or cosmic muons (b).

Two typical signals are shown in Fig. 3. The black curve is the GEM detector signal waveform of the ^{55}Fe X-rays (a) or cosmic muons (b), the blue curve sample is the signal waveform of the top plastic scintillator, and the red curve sample represents the signal waveform of the bottom plastic scintillator. ^{55}Fe X-ray signals were triggered by internal trigger using the GEM detector signal, while the cosmic muon signals were triggered by internal trigger using signals from the plastic scintillator. The signals are easily discriminated by analyzing signals from the three detectors with coincidence and anti-coincidence method. If the magnitudes of the two plastic scintillator signals are both larger than a given threshold in one event, the corresponding signal of the GEM detector is identified as a cosmic muon signal. In contrast, the GEM signal is identified as induced by X-rays if the magnitudes of the two plastic scintillators are both smaller than a given threshold.

3 Results and discussion

Figure 4 shows the energy deposition of cosmic muons (blue histogram) and the energy spectrum of ^{55}Fe 5.9 keV X-rays (red histogram). The cosmic muon spectrum fits well to a typical Landau distribution (black curve) as expected from minimum ionizing particles. This implies that the events discriminated by coincidence are indeed the cosmic muon events. With the detector's rise time defined by the time required for the output signal to rise from 10% to 90% of the maximum value, the result of the rise time for ^{55}Fe X-rays and cosmic muons is shown in Fig. 5. The total number of cosmic muons is equal to the total number of ^{55}Fe X-rays. This was determined by fitting a Gaussian function to the ^{55}Fe X-ray rise time spectrum and cosmic muon rise time spectrum. The FWHM of rise time for 5.9 keV X-rays is 4.11 ns and for cosmic muons is 53.69 ns. The mean rise time for 5.9 keV X-rays is 89.4 ns, while the mean rise time for the cosmic muons is 135.7 ns.

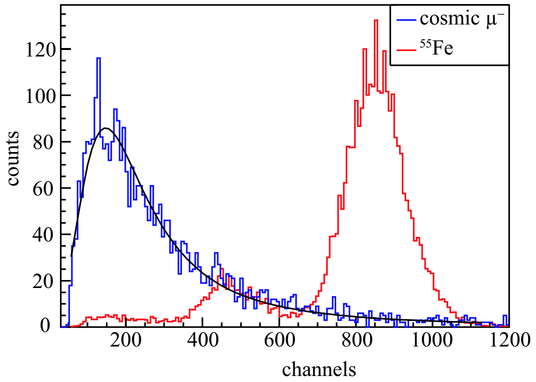

Fig. 4. (color online) Energy deposition of cosmic muons (blue histogram) and of ^{55}Fe X-rays (red histogram). The black line is a typical Landau distribution fitted to the cosmic muon spectrum.

There are two reasons for the rise time of 5.9 keV X-rays. First, electron drift time in the induction gap (4 mm) gives the main contribution to the rise time of the 5.9 keV X-rays. Fig. 6 shows a simulation of charge induction in the readout PCB with 4 mm induction gap based on GARFIELD++ [7]. The induction gap contributes about 74 ns, according to our simulation. Second, the rise time of the preamplifier (ORTEC 142B) has a great influence on the rise time of the signal. However, with the increase of the detector output capacitance, the rise time increases.

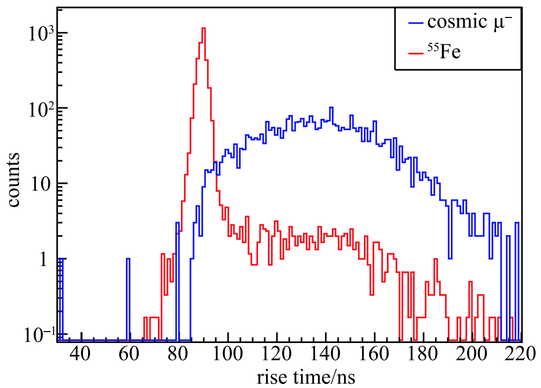

Fig. 5. (color online) The rise time spectrum for ^{55}Fe 5.9 keV X-rays and cosmic muons. The blue histogram and red histogram represent the rise time of cosmic muons and X-rays respectively. The y-axis is logarithmic.

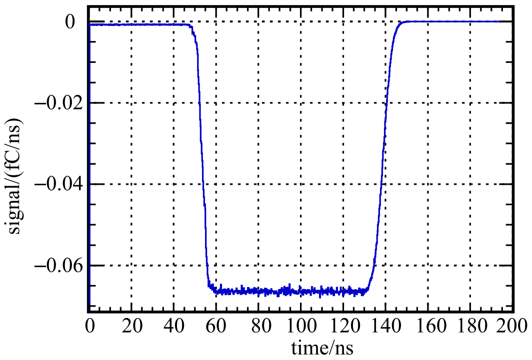

Fig. 6. Result of the simulation of charge induction in the readout PCB with 4 mm induction gap based on GARFIELD++.

The FWHM of the X-rays is smaller than the FWHM of the cosmic muons because the ion-electron pairs produced by the X-rays are in a small region, so the electron density is larger than that produced by cosmic muons which deposit their energy over their track. All electrons from X-rays drift into the induction gap in a short time, with large electron density, which can immediately trigger the preamplifier. Electrons from cosmic muons drift into the induction gap over a longer time, depending on the thickness of the drift gap, with small electron density, which leads to discreteness of the preamplifier response time. The large FWHM of cosmic muon rise time decreases the effectiveness of discriminating X-rays and cosmic muons, especially when the rise time of the X-rays is close to that of the cosmic muons.

There are some X-ray events with rise time longer than 100 ns in the ^{55}Fe X-ray rise time spectrum shown in Fig. 5. These events do not fit a Gaussian statistical distribution. Taking into account the experimental setup, the effective area of both plastic scintillators are 10 cm×15 cm, close to the effective area of the GEM detector, so the scintillator cannot completely cover the GEM detector. These events are suspected to be cosmic muons which do not pass through the top scintillator or bottom scintillator. In Fig. 7, the red solid circles represent the percentage of ^{55}Fe X-ray events whose rise times are longer than the threshold, and the blue solid triangles represent the percentage of cosmic muon events whose rise times are shorter than the threshold. 97% of cosmic muons can be discriminated from X-rays, and 97% of X-rays can be discriminated from cosmic muons when the threshold is 97 ns.

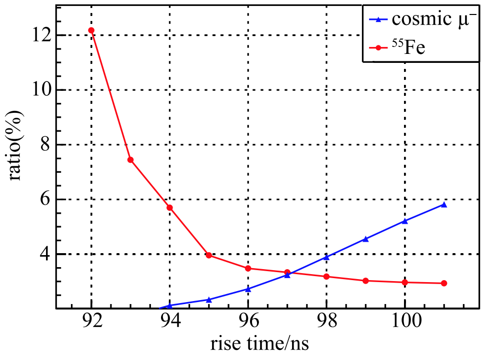

Fig. 7. (color online) Discriminated result of ^{55}Fe X-rays (red solid circles) and cosmic muons (blue solid triangles) with different thresholds.

4 Conclusions

Energy resolution of the triple GEM detector has been measured with a ^{55}Fe 5.9 keV X-ray source. The results confirm that the triple GEM detector has a good energy resolution of around 20.6% and a good energy linearity relationship. A discriminating experiment based on rise time was studied, and experimental results confirm that 97% of cosmic muons and X-rays can be discriminated through rise time for GEM detectors. We can infer that the rise time of signals can also be used to discriminate charged particles and photons. This method can improve neutron detection data and improve the tracking accuracy of charged particles in high energy physics experiments. For further optimization, three measures can be taken to reduce the intrinsic rise time. First, using a fast time preamplifier such as APV25, instead of 142B [8]. Second, as mentioned before, reducing the capacitance can reduce the rise time. Interconnecting fewer readout strips and grounding the other strips can therefore reduce the capacitance of the GEM detector with the sacrifice of effective area. Finally, reducing the thickness of induction region with a 100 μm-thick metallic mesh. However, it is easy to increase cosmic muon rise time by increasing the thickness of the drift region and decrease the FHMW of cosmic muons by increasing the voltage of the GEM foil.

As discussed above, there are two important things which should be done in future. The construction of the GEM detector should be improved with the methods mentioned before to discriminate X-rays and cosmic muons better, and a neutron source should be detected to discriminate X-rays and recoil protons based on rise time.

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