Chinese Physics C Vol. 38, No. 4 (2014) 046001

Investigation of GEM-Micromegas detector on X-ray beam of synchrotron radiation *

ZHANG Yu-Lian(张余炼)[1,2,3] QI Hui-Rong(祁辉荣)[2,3;1)] HU Bi-Tao(胡碧涛)[1]
FAN Sheng-Nan(范胜男)[2,3,4] WANG Bo(王波)[3] LIU Mei(刘梅)[2,3,4] ZHANG Jian(张建)[2,3]
LIU Rong-Guang(刘荣光)[2,3] CHANG Guang-Cai(常广才)[3] LIU Peng(刘鹏)[3]
OUYANG Qun(欧阳群)[2,3] CHEN Yuan-Bo(陈元柏)[2,3] YI Fu-Ting(伊福廷)[3]

[1] School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China
[2] State Key Laboratory of Particle Detection and Electronics, Beijing 100049, China
[3] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[4] University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: To reduce the discharge of the standard bulk Micromegas and GEM detectors, a GEM-Micromegas detector was developed at the Institute of High Energy Physics. Taking into account the advantages of the two detectors, one GEM foil was set as a preamplifier on the mesh of Micromegas in the structure and the GEM preamplification decreased the working voltage of Micromegas to significantly reduce the effect of the discharge. At the same gain, the spark probability of the GEM-Micromegas detector can be reduced to a factor 0.01 compared to the standard Micromegas detector, and an even higher gain could be obtained. This paper describes the performance of the X-ray beam detector that was studied at 1W2B Laboratory of Beijing Synchrotron Radiation Facility. Finally, the result of the energy resolution under various X-ray energies was given in different working gases. This indicates that the GEM-Micromegas detector has an energy response capability in an energy range from 6 keV to 20 keV and it could work better than the standard bulk-Micromegas.

Key words: gaseous detector, energy resolution, synchrotron radiation

PACS: 29.40.Cs **DOI:** 10.1088/1674-1137/38/4/046001

1 Introduction

Micromegas (micro-mesh-gaseous structure) [1] is a gaseous detector that is widely used in high energy physics, which profits from an excellent position resolution and the ability to work at high counting rates. However, one of the main problems with this detector is that it is particularly vulnerable to spark and discharge [2] at higher working voltages. GEM (gas electron multiplier) [3] is another kind of micro-pattern gaseous detector(MPGD) [4] that has also been extensively researched and implemented in several large-scale high-energy physics experiments, at CERN and elsewhere. GEM has many advantages, such as brilliant position resolution, good energy resolution, toleration of high counting rate and ease of assembly. Triple and quadruple GEM foils are usually cascaded to build higher gain detectors [5]. The problem which arises from the cascaded GEM detector is that the last GEM foil (the foil near the readout plan) is quite easily damaged to spark because of the large number of electrons passing through it.

To decrease the spark probability, the GEM-Micromegas detector was proposed and tested in several applications of high energy physics [6, 7]. This detector uses a GEM foil as a preamplifier element in the structure to reduce the amplification stress on Micromegas. Preamplification by the single GEM was ideal to obtain the higher gain that was needed, but with a lower working voltage than a Micromegas detector. The assembly of GEM-Micromegas detector and its performance have been described in a previous paper [8]. At the same gain, the spark probability of the GEM-Micromegas detector can be reduced to a factor 0.01 compared to the standard Micromegas detector, and an even higher gain could be obtained. We reported the experiment carried out at the X-ray absorption station (Beamline 1W2B) of the Beijing Synchrotron Radiation Facility (BSRF) in January. Compared with the position resolution of the Micromegas and GEM-Micromegas detectors, the energy resolution was less tested in different working gases and

---

Received 14 May 2013, Revised 19 June 2013

* Supported by National Natural Science Foundation of China (11275224)

1) E-mail: qihr@ihep.ac.cn

at different X-ray energies. Synchrotron radiation applications demand gaseous detectors with good position resolution as well as good energy resolution. In this experiment, the energy resolution property of a GEM-Micromegas detector was investigated in order to expand our preceding experiments and the results were compared with those of the Micromegas detector. The aim of the present activity was to explore the possibility of using a GEM-Micromegas detector in synchrotron radiation applications by analysing its energy resolution under different X-ray energies.

2 Experimental principle and setup

2.1 Principle of X-ray detection on synchronous radiation

In the laboratory, three types of X-ray sources can be provided, which are: an ^{55}Fe radioactive source, an X-ray machine, and a synchrotron radiation facility. Although an ^{55}Fe source could provide specific energy of X-ray, the intensity is low. To change the voltage and current of an X-tube, a higher energy and higher intensity of X-ray could be achieved by using an X-ray machine; however, the spectrum of the X-ray is continuous. a synchrotron radiation facility not only provides a single energy X-ray, but it also has a higher intensity in a small beam spot. A schematic diagram of the SR beam test is illustrated in Fig. 1.

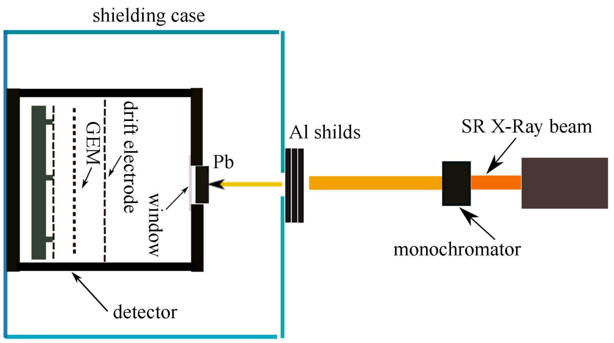

Fig. 1. A schematic diagram of testing on BSRF.

By adding a double crystal monochromator in the beam-line, the polychromatic light can be monochromatized and monochromatic light will be available. The intensity of Beamline 1W2B is 10^{12} photons/s and the spot size is 0.6 mm^2, using the Pb collimator. To guarantee the safe operation of the detector, the following steps are taken to protect the detector from too high an X-ray intensity:

1) The beam stop window of Pb is assembled in the exit of beam spot and the thickness is 2.0 mm; and,

2) Different numbers of layers of Al foils with thickness of 50 μm are stuck on the window of the detector to reduce the background electromagnetic noise and the intensity of the X-ray.

In the detector, the X-ray will interact with the working gas and produce primary ion-electron pairs in Region 1 or Region 2, which is shown in Fig. 2. Under the drive of an electric field, electrons emerging in Region 1 will drift toward the read-out pads and get avalanched when they pass through the GEM foil and Region 3. The gain in Region 1 is defined as $G_{\text{GEM}-\text{MM}}$ and the electron is avalanched by the GEM foil and the Micromegas detector.

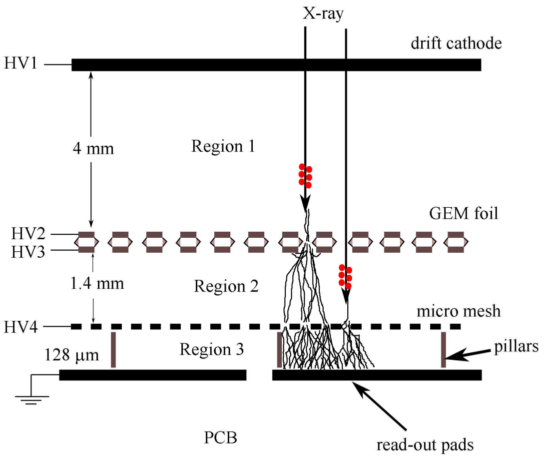

Fig. 2. A schematic diagram of the prototype GEM-Micromegas detector.

In Region 2, the electron is only avalanched by the Micromegas detector, the gain is defined as G_{MM}. Thus, the gain resulting from the GEM can be calculated as:

$$G_{\text{GEM}}=\frac{G_{\text{GEM}-\text{MM}}}{G_{\text{MM}}}. \tag{1}$$

Compared with the standard Micromegas detector, the GEM-Micromegas detector shows the same or even higher gain under the identical working voltage on Micromegas. Thus, the Micromegas could work under a relatively lower voltage, thereby reducing the spark and discharge rate, which would ensure the security of the detector. Meanwhile, the disadvantage of the cascaded GEMs, which is that the huge amount of electrons in the tiny hole of the last GEM foil make it the most vulnerable to sparking, can be avoided.

The energy calibration of the beamline has been done and the principle is shown in Fig. 3.

The attenuation of an X-ray beam traversing a medium could be written as:

$$\frac{I_1}{I_2}=\mathrm{e}^{-\mu D}, \tag{2}$$

where I_1 and I_2 denote the intensity of the beam traversing before and after the Cu target, recorded by Ionization 1 and Ionization 2, μ stands for the absorption coefficient, and D is the thickness. The absorption spectrum of Cu target could then be calculated, which is $\ln(I_1/I_2)$ as a function of X-ray energy. For example, the X-ray absorption spectra at the K-edge of copper is measured as 8977.766 eV, and the value from the standard library is 8978.876 eV. After calibration of the energy, a deviation of minus 1.1 eV is obtained with the actual energy and the setting energy. This indicates that the value of the X-ray's energy is very precise in the 1W2B experimental station.

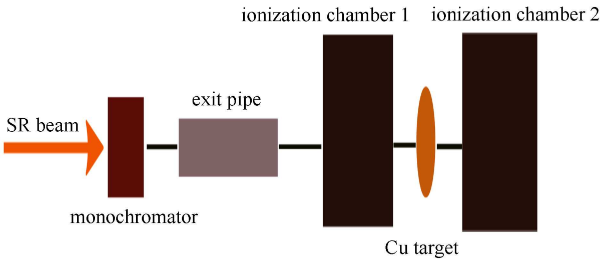

Fig. 3. The test diagram of the energy calibration of BSRF.

X-ray photons interact with matter in three different ways. The photoelectric conversion is the dominant physical process in the experiment. Take Argon for example, the binding energy of the electrons in the shell i is E_i and the energy of the ejected photoelectron is:

$$E_{\rm pe}=E_{X-{\rm ray}}-E_{\rm K}. \tag{3}$$

The excited atom could return to a lower state by emitting a characteristic X-ray with energy $E_{{\rm X'-ray}}$, or by transferring the energy to electrons within the atom and an auger electron escapes carrying the excess energy $E_{\rm Auger}$:

$$\begin{aligned} E_{\rm X'-ray}&=E_{\rm K}-E_{\rm L}, \\ E_{\rm Auger}&=E_{\rm X'-ray}-E_{\rm L}. \end{aligned} \tag{4}$$

In the energy spectrum, the values of full energy peak and escape peak could be calculated as [9]:

$$\begin{aligned} E_{\rm Full}&=E_{\rm pe}+E_{\rm Auger}, \\ E_{\rm Escape}&=E_{\rm pe}. \end{aligned} \tag{5}$$

In the experiment, the energy spectrum is obtained under different X-ray energies. When an X-ray with certain energy enters the detector, the values of the two energy peaks could be calculated by the theoretical functions. In the next section, the result of the comparison will be given with the experimental data.

2.2 Experimental schemes

The Micromegas detector is based on the bulk method and has an active area of 25 mm×25 mm. The cascaded structure of the GEM-Micromegas detector is composed of a drift electrode, standard GEM foil of 25 mm×25 mm from CERN, standard Micromegas of 25 mm×25 mm by IHEP, and a readout printed circuit board. The signal is collected by an avalanche electrode and amplified by the charge sensitive preamplifier of ORTEC 142IH and the amplifier of ORTEC 572 A. All of the information of the signal is acquired by the MCA of ORTEC ASPEC 927. The high voltage supply of the CAEN SY127 will provide the voltage independently for each electrode of the detector. In the four mixture gases, both the GEM-Micromegas and the standard Micromegas have been tested. These mixture gases are: 90%Argon+10%CO_2, 70%Argon+30%CO_2, 95%Argon+5%Isobutane and 90%Argon+10%CH_4. The energy resolution of GEM-Micromegas detector is measured in the synchrotron radiation X-ray source and compared with that of the Micromegas detector.

3 The experimental results and discussions

In every specific working gas, the gain curve and energy resolution are first tested with an ^{55}Fe X-ray source to determine the proper working voltage of the detectors. Then, the detectors are assembled in the X-ray beamline. To ensure that the detector works safely during the test, several steps are taken to protect the detectors from higher X-ray beam intensities. In the experimental process, the beam stop of the Pb layer is added in the center of the beam spot; at the same time, several layers

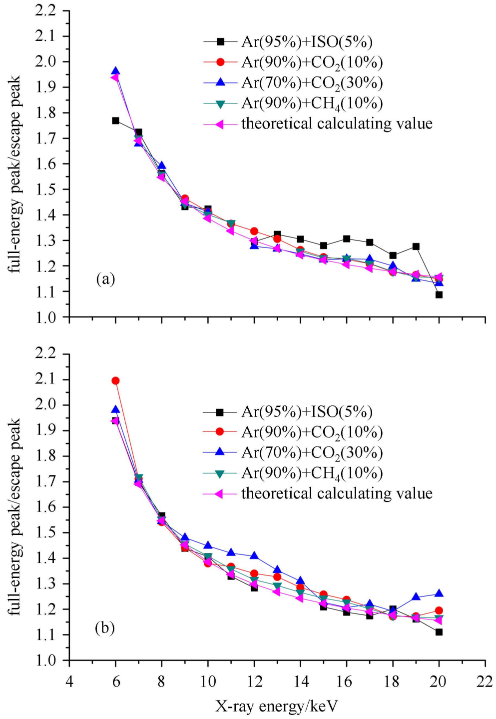

Fig. 4. The ratio of the full energy and escape peak in different energies and different working gases. (Micromegas detector(a) and the GEM-Micromegas detector(b)).

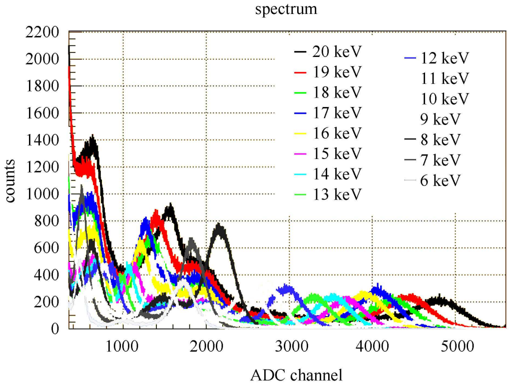

Fig. 5. Energy spectrum under various X-ray energies. (Working gas: 90% Argon, 10% CO_2).

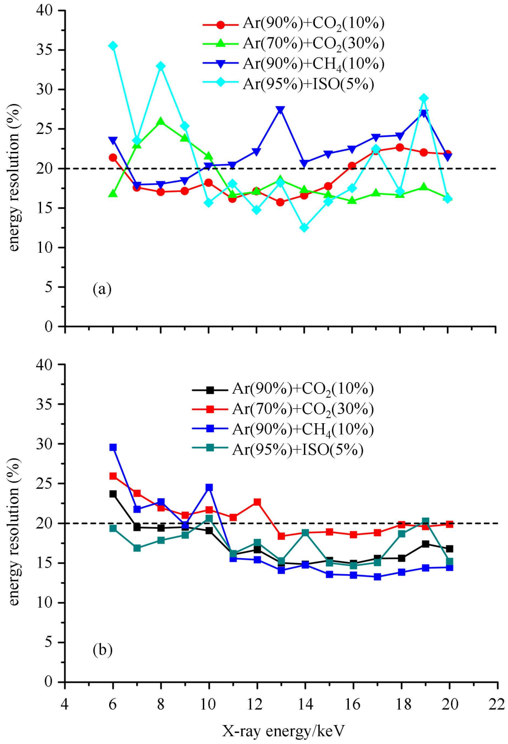

Fig. 6. Energy resolution of Micromegas(a) and GEM-Micromegas(b).

of aluminum foil are regarded as attenuating material to reduce the X-ray's intensity. By changing a single energy of the synchrotron radiation X-ray, all of the corresponding energy spectra will be obtained. The values of the full energy peak and escape peak are found by analyzing the energy spectrum and then compared with the value from the theoretical calculations. The results are given in Fig. 4. The value of the theoretical calculation is obtained according to Eqs. (3, 4 and 5). The range of values for $E_{\text{X-ray}}$ is from 6 keV to 20 keV, E_K is 3.2 keV, and E_L is 0.287 keV. In different working gases and different X-ray energies, the results of the two energy peaks show good agreement with the experimental data and the theoretical data. In the X-ray beam test, the energy spectrum under various X-ray energy is shown in Fig. 5.

The results of energy resolution by Gaussian fitting of the full energy peak are shown in Fig. 6. They indicate that both of the detectors have energy resolutions which are better than 30%. The GME-Micromegas detector could achieve a more stable energy resolution than the standard Micromegas detector at all energy ranges. At higher energies, the GEM preamplification in the detector decreases the working voltage of Micromegas to significantly reduce the affect of the discharge. Over 8 keV, the energy resolution of GEM-micrpmeagas detector is less than 20% and it is better than Micromegas detector under the same test condition.

4 Conclusion

In four different mixed working gases and at X-ray energies ranging from 6 keV to 20 keV, the GEM-Micromegas detector has been tested in beam X-ray on BSRF. The energy spectrum and energy resolution are obtained. The results indicate that the GEM-Micromegas detector has an energy response capability in all of the energy ranges and could work better than the standard bulk-Micromegas. Compared with standard Micromegas detector, the influence of discharge decreases and the GEM-Micromegas detector could maintain stable operation. Over 8 keV, the detector could obtain a better than 20% energy resolution. It can, therefore, meet part of the demand in synchrotron radiation research. In the next step, the size of the charge distribution requires further measurement.

We are grateful to all of our colleagues at 1W2B Laboratory of Beijing Synchrotron Radiation Source. We wish to thank Tian Lichao, Xiu Qinglei and Liu Yi for their help and discussion.

References

1 Giomataris Y et al. Nucl. Instrum. Methods A, 2006, **560**: 405
2 Alexopoulos T et al. Nucl. Instrum. Methods A, 2011, **640**: 110
3 Sauli F. Nucl. Instrum. Methods A, 1997, **386**: 531
4 Annu. Rev. Nucl. Part. Sci. 1999, **49**: 341
5 ZHENG X C, LI Y L, LAI Y F, LI J. Nuclear Electronics & Detection Technology, 2007, **27**: 89 (in Chinese)
6 Kane S, May J, Miyamoto J et al. A Study of Micromegas with Preamplification with a Single GEM. In: Proceeding for the International Conference on Advanced Technology and Particle Physics. Italy: 2001. 15
7 Kane S, May J, Miyamoto J et al. Nucl. Instrum. Methods A, 2003, **515**: 261
8 FAN Sheng-Nan et al. Acta Phys. Sin., 2013, **62**: 12
9 XIE Yi-Gang. Particle Detectors and Data Acquisition. Beijing: Science Press, 2003. 20 (in Chinese)