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Images of triple gas electron multiplier with pixel-pads*

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Testing of a triple gas electron multiplier (GEM) with pixel-pads is described. Images by scanning and suspending radioactive sources were obtained by using 96 channels digital data acquisition (DAQ) system which was composed of 96 8×8 mm^2 pads and associated electronics channels.

Keywords: gas electron multiplier, images, digital data acquisition system
PACC: 2940T, 2940H

1. Introduction

Gas electron multiplier (GEM)[1] is one of position sensitive gas detectors developed by European Organization for Nuclear Research (CERN) in the past few years. Its basic component is the kapton foil coated with copper on double sides, and etched with high density of micro holes. In working condition, with high voltage applied between the two copper sides, the electrons can be avalanched inside the holes, leading to the amplification of primary ionization in the drift region. The amplification structure and readout boards are completely separated so as to allow of full flexibility in the choice of the geometry of the readout pattern. So GEM has a lot of excellent performance: high counting rate, small amount of material, high spatial and time resolution and convenient readout. It has good applications in many fields.

To meet the requirement of two-dimensional detectors used for Beijing Synchrotron Radiation Facility (BSRF), a triple-GEM with pixel-pads was studied. The feasible conditions for various images are selected in the following three respects: 1) The appropriate gain of the triple-GEM; 2) Dependence of the energy resolution on different pad dimension. 3) Temperature influence on effective gain. Images were obtained by two methods with multi-channel DAQ system.

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2. Structure and experimental setup of a triple-GEM

A triple-GEM prototype with sensitive area of 100×100 mm^2 is constructed with standard foils from CERN, which consists of three GEM foils sandwiched between two conductive planes. As the cathode, a copper mesh and thick GEM with same voltages on both copper sides have been tried, and a standard GEM foil also with the same voltages was finally used to avoid discharge and obtain a better particle penetrating rate. The signal collection plane is a printed circuit board with 96 square pads. Each pad is 8×8 mm^2 with 0.2 mm insulating gap. A cross-section of this detector, together with the labeling of the different detector parameters used in this paper, is shown in Fig.1. The

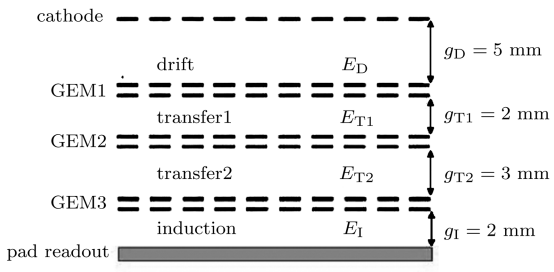


Fig.1. Cross-section of the triple-GEM. E_D, E_{T1}, E_{T2}, E_I are the fields of drift, transfer1, transfer2, and induction, respectively; g_D, g_{T1}, g_{T2} and g_I are the drift, transfer1, transfer2 and induction gaps, respectively.

high voltage is provided by CAEN SY−127 multi-channel power supply, and the measurements have been performed in a Ar/CO_2 gas mixture (70/30).

For imaging, each pixel is connected to a current preamplifier (FBPANIK[1)]), which current amplification for various channels is about 30 (with the impedance 390 Ω). Through SGS cards of ALEPH muon detector electronics with serial readout, the splitter board, a converter board, CAMAC module C187 (CAEN) and by using ROOT package, the DAQ system has successfully carried out the data acquisition, online display and data analysis.[2] Inside the SGS card, there are 32 channels of discriminators, for shaping as well as shift-registering for serial readout. In addition, it can give a fast-OR signal to trigger the system. Once there is a fast-OR signal, SGS card will transfer the data of fired signals to splitter board and C187 via differential signal cable. The control signals, such as Test, Clock and Load are sent from C187 to SGS card via the converter board and splitter board. The load signal is 1.2 μs and the clock signal is 200 ns. Setting threshold of the discriminators at 100 mV is enough to reject the noise (about 40 mV) of the DAQ system.

3. Performance of the triple-GEM for image experiment

It is necessary to study some basic performances, especially to select the appropriate effective-gain of the triple-GEM prototype with the specific small pads of 8×8 mm^2 in order to either meet the requirement of the DAQ system with respect of the signal level, or to avoid any discharges caused by the over gain.

3.1. The appropriate voltage for each GEM foil

The effective gain as a function of the sum of the voltages applied on the three GEM foils with $E_D = E_{T1} = E_{T2} = E_I = 2\ kV \cdot cm^{-1}$ is shown in Fig.2. One may see that in the region from 1050 V to 1170 V the effective gain of single pad increases linearly. In addition, someone prefers that three GEM foils are set to the same voltage,[3,4] but reference [5] points out that it is better if selecting the decreasing voltage configuration: $\Delta V_{G1} \geq \Delta V_{G2} > \Delta V_{G3}$ to keep low the voltage of the last stage in order to avoid discharges closing to the readout region which may destroy the electronics and GEM foil itself. Seeing that, in our measurement of images, we have also followed this decreasing voltage configuration and avoided to use the maximum values.

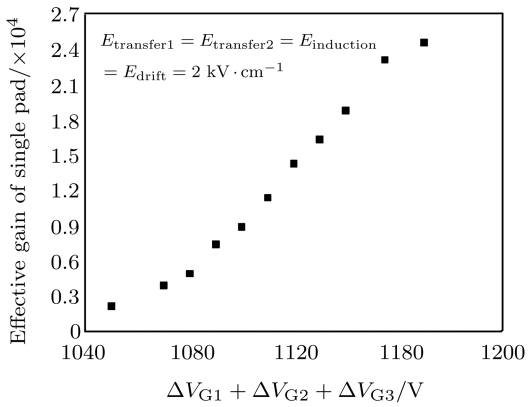
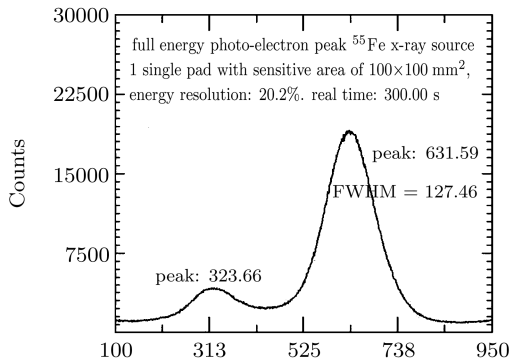


Fig.2. The effective gain of single pad versus the sum of the voltages applied on the three GEM foils ΔV_G^{sum}, with $E_D = E_{T1} = E_{T2} = E_I = 2\ kV \cdot cm^{-1}$.

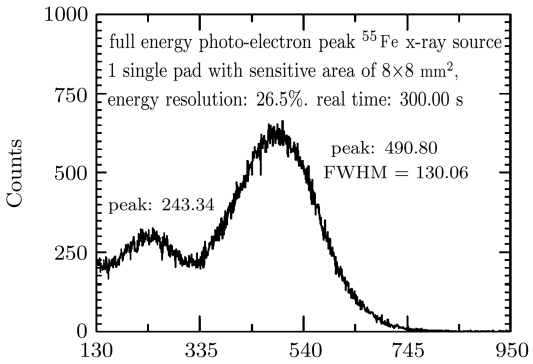
3.2. Energy spectrum of ^{55}Fe

The energy resolution was measured and compared with a 8×8 mm^2 single pad for image purpose and a large single pad (100×100 mm^2) by using ^{55}Fe(2.3×10^7 Bq) x-ray source, home-made charge sensitive preamplifier (86-01), home-made main amplifier (FH1003A) and a multi-channel analyzer (ORTEC918A). For the large single pad, a best energy resolution (20.2%), good linearity (full energy peak/escape peak ratio 1.95) and a better peak/valley ratio (5:1) have been obtained (Fig.3.(a)). For the smaller pad (8×8 mm^2), the best energy resolution (26.5%) and peak/valley ratio are worse than those for large one (Fig.3.(b)). The reason comes mainly from two points: one is that the inductive signals caused by the movement of multiplied electrons towards the anode could not be collected on a smaller pad. Another is that signal/noise ratio of small pad is worse than the one of large pad.

[1)] ETH–ZUERICH Institut fuer Hochenergiephysik Switzerland Note (1997.09.03)



(a) The fields and voltages are $\Delta V_{\rm G}^{\rm total} = 1200$ V, $E_{\rm drift} = 2\ {\rm kV\cdot cm^{-1}}$, $E_{\rm transfer1} = 2.5\ {\rm kV\cdot cm^{-1}}$, $E_{\rm transfer2} = 2.3\ {\rm kV\cdot cm^{-1}}$, $E_{\rm induction} = 2\ {\rm kV\cdot cm^{-1}}$.



(b) The fields and voltages are $\Delta V_{\rm G}^{\rm total} = 1200$ V, $E_{\rm drift} = E_{\rm transfer1} = E_{\rm transfer2} = E_{\rm induction} = 2\ {\rm kV\cdot cm^{-1}}$.

Fig.3. ^{55}Fe full energy photo-electron peak (5.9 keV) of GEM coupled to pads with different dimensions.

3.3. Temperature influence on effective gain

The effective gain is influenced by the environmental temperature, which has been found in our image measurements during different seasons. By changing the temperature of environment, one may obtain the temperature effect on the triple-GEM prototype similarly. It is shown in Fig.4 that the effective gain changes from 0.56×10^4 to 1.20×10^4 with the environmental temperature varying from 16.5 °C to 22 °C. In the lower temperature environment, good signal/noise ratio of image data acquisition could be reached by changing the radioactive source (from soft x-ray of ^{55}Fe to hard x-ray of ^{241}Am) and reducing the threshold of the discriminators.

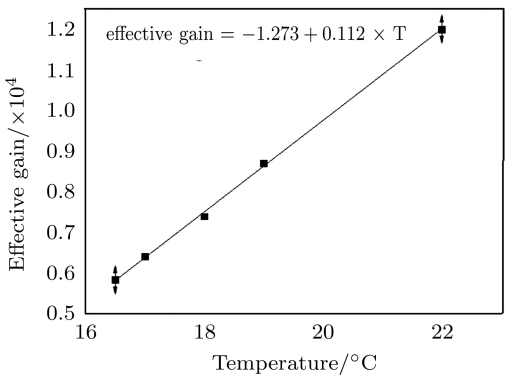


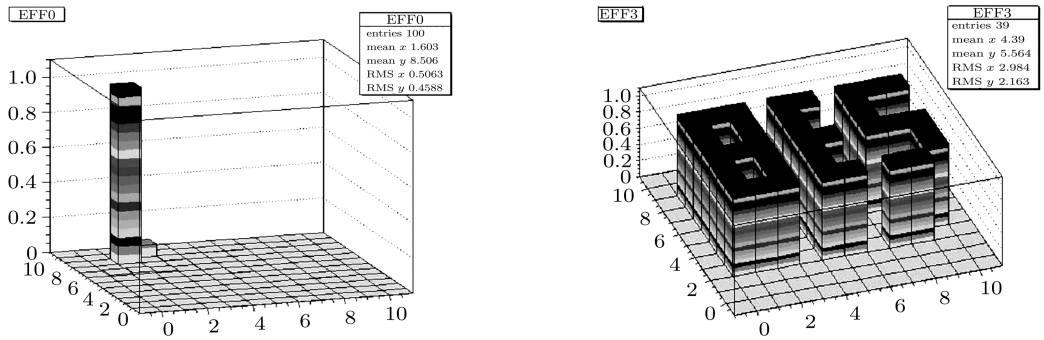
Fig.4. The effective gain versus the environmental temperature. All high voltage values keep constant. $\Delta V_{\rm G1} = 400$ V, $\Delta V_{\rm G2} = 390$ V, $\Delta V_{\rm G3} = 380$ V, $E_{\rm drift} = E_{\rm transfer1} = E_{\rm transfer2} = E_{\rm induction} = 2\ {\rm kV\cdot cm^{-1}}$.

4. Results of images

Two methods have been considered. One is by scanning or moving radioactive source on the upper layer of the window. The other is by suspending the source far away from the input window near the cathode for different distances. The images of the objects are obtained by the counting rate on different pads, similar to Ref.[6]. Several sources have been tried.

4.1. Image by scanning source

In order to obtain a meaningful 'BES' profile (See Fig.5(b)) with too large dimensions of 80×80 mm^2, the method of scanning radioactive source was used. For the future purpose, to be used with synchrotron radiation beams and more concentrated fired locations under collimated condition, ^{55}Fe x-ray source is preferable. In addition, for this source, a thick foil (1 mm) with a 'BES' size slot glued by a fairly thin mylar film (20 μm) is used as the window of the detector. By moving ^{55}Fe x-ray source (2.3×10^7 Bq) above the associated pads location one by one (60 sec/pad) with some detailed software treatment, the good 'BES' image was obtained as shown in Fig.5(b). The measurement is done at 22 °C, the drift field is put down to 1 ${\rm kV\cdot cm^{-1}}$ to avoid discharges and the sum of the voltages applied on the three GEM foils $\Delta V_{\rm G}^{\rm sum}$ is relatively low.



(a) (b)

Fig.5. BES image. The fields and voltages are $\Delta V_{\rm G1} = 370$ V, $\Delta V_{\rm G2} = 350$ V, $\Delta V_{\rm G3} = 340$ V, $E_{\rm drift} = 1\ {\rm kV \cdot cm^{-1}}$, $E_{\rm transfer1} = E_{\rm transfer2} = E_{\rm induction} = 2\ {\rm kV \cdot cm^{-1}}$.

Some treatment procedures are as follows: The result of one typical location is shown in Fig.5(a). Less counting rates on the neighborhood pads (1 to 3 pads) are mostly caused by optimum setting threshold of DAQ system. The centre pad, defined as the fire position, is rejected the neighborhood contributions. Compared with this procedure, the treatment by using 2-dimentional (X, Y) Gauss fitting is more convenient. Summing up the Gauss fitting peak points within the domain of associated $i^{\rm th}$-pad locations $(\Delta X_i,\ \Delta Y_i)$, after aggregating all the location columns, the 'BES' image (Fig.5.(b)) is obtained. In the figure, Z coordinate axis represents the ratio of counting rate of each pad to the overall rate of the whole.

4.2. Images by suspending radioactive sources

The image of a copper ring is obtained by suspending ^{241}Am 59 keV x-ray source (3.7×10^{10} Bq) 20 cm far away from the window, as shown in Fig.6. The dimensions of various black squares are associated with the counting rates on the various pads. The images are clear, but still not satisfactory enough due to the pad dimensions, the limited number of pads and the lack of strong radioactive source or particle beams.

The images have been tested from three different suspending distances. Using ^{241}Am, the distances 5 cm, 20 cm and 50 cm have been tested. The image is better for 20 cm (Fig.6), and both the images of 5 cm and 50 cm are worse due to too large unirradiation angle with bad edge effect caused by inclined particles and too low source intensity respectively.

In addition, three different radioactive sources (^{55}Fe 5.9 keV x-ray source (2.3×10^7 Bq), ^{90}Sr 2.283 MeV β-ray source (1.85×10^9 Bq), ^{239}Pu 5.155 MeV α-ray source (1.0×10^6 Bq)) have been tried. Due to the characteristics of the three different radioactive sources: short range of ^{239}Pu source,

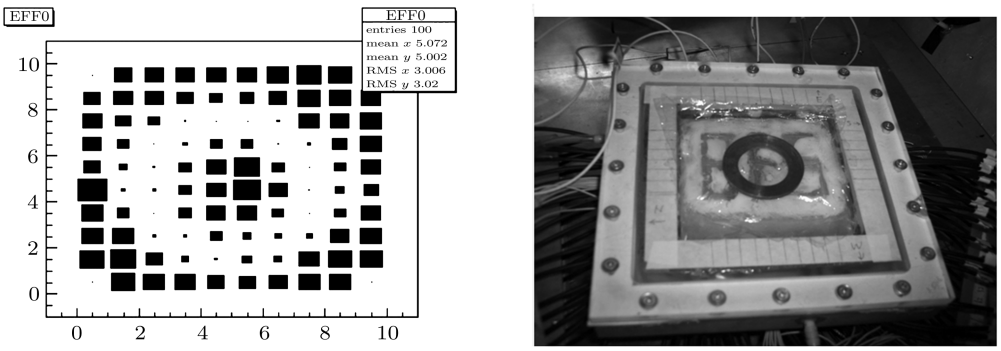


Fig.6. Images of a copper ring obtained by suspending ^{241}Am source. The fields and voltages are $\Delta V_{\rm G1} = 400$ V, $\Delta V_{\rm G2} = 390$ V, $\Delta V_{\rm G3} = 380$ V, $E_{\rm drift} = E_{\rm transfer1} = E_{\rm transfer2} = E_{\rm induction} = 2\ {\rm kV \cdot cm^{-1}}$.

as well as lower signal and serious attenuation of ^{55}Fe source, these two sources were rejected. The results of images with ^{241}Am and ^{90}Sr source show that it had better using ^{241}Am source and worse for ^{90}Sr due to its too much secondary effects.

5. Conclusions

(i) By study of some operation properties of the triple-GEM, the appropriate and satisfactory conditions have used for obtaining the images in the laboratory.

(ii) Several images were obtained with triple-GEM and the data acquisition system by two different methods successfully.

(iii) The dimension of pad of this work is a little large. In order to get better results, small pads (1×1 mm^2) with ASIC pre-electronics are prepared to test, and both resistive film and resistive pads are considered and planned. Two-dimensional strip readout with multi-channel analog DAQ system is being tested to obtain better images.

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