Assembly and performance study of a triple gas electron multiplier with a $^{55}$Fe source

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Abstract. In this work, a process for the assembly of a standard triple Gas Electron Multiplier detector and the study of the main variables was made at the Universidad Antonio Nariño, Colombia, detectors laboratory. The triple gas electron multiplier was tested with Ar/CO$_2$ mixtures in proportions of 70/30%, 80/20% and 90/10% using a $^{55}$Fe X-ray source (5.9 keV). The energy spectrum, energy resolution, effective gain and ionization rate were analyzed according to the applied voltage and the Ar/CO$_2$ gas mixture. The Universidad Antonio Nariño, Colombia, triple gas electron multiplier detector obtained an energy resolution of up to 19% and an effective gain close to $10^3$, where the detection efficiency is approximately 95%. These results were compared with other studies to check the triple gas electron multiplier performance.

1. Introduction

Gaseous radiation detectors have evolved to micro pattern gas detectors (MPGD) thanks to RD-51 collaborations, of which Universidad Antonio Nariño (UAN), Colombia. The RD-51 collaboration seeks to improve and disperse the current edge gaseous detectors, such as the micro-mesh gaseous structure (MICROMEGAS) and the gas electron multiplier (GEM) [1]. The UAN detectors laboratory has acquired different elements to the assembly, maintenance and start-up of a triple GEM since 2013. However, the assembly and performance study of the UAN triple GEM detector is necessary based on the materials, electronic and setup. The study conducted compares the main detector variables such as effective gain, energy resolution and detection efficiency with other GEM reported outcomes.

The triple GEM detector is a sealed chamber filled normally with a noble and quencher gas. Inside the chamber, the detector is composed of a drift electrode (cathode), three GEM-foils, and a readout board (anode). The GEM-foil is a conductor-isolator-conductor layer (5 µm – 50 µm – 5 µm of thickness respectively) with a triangular pattern of holes of 70 µm in diameter and 140 µm pitch. The connection of the upper and bottom electrodes of each GEM-foil with a differential voltage creates a very strong electric field into the holes. The primary ionization of the gas generated in the drift zone (space between the drift electrode and the first GEM-foil) creates pairs of ion-electron, where the electrons must pass through triple GEM holes to reach the read-out board, and ions go in the opposite direction toward the drift electrode. Avalanches (gain) are generated as a result of the primary electrons passing through the
GEM-foil holes and gaining kinetic energy to produce more gas ionization. The total detector gain is the convolution of each single GEM-foil gain [2-4].

The response of a single and triple GEM with the $^{55}$Fe radiation source of 5.9 keV has largely been demonstrated in different studies in terms of the energy spectrum, energy resolution, effective gain and detection efficiency [3,5,6]. The energy spectrum generated by the ionization of $^{55}$Fe photons produces two peaks: the main peak given by 5.9 keV photoelectric effect, and the 3.0keV peak (argon scape) generated by fluorescence (it is approximated 15% of the height of the main peak). Regarding the gain, the GEM detector increases exponentially the effective gain with the increment of the total voltage. The triple GEM with a gas mixture of Ar/CO$_2$ in proportion 70/30% at atmospheric pressure and at 4100 V total voltage gives an effective gain close to 10$^3$ [3]. In terms of detection efficiency, the rate detection increases rapidly with the growth of the total voltage until the stabilization zone (plateau zone), where the triple GEM reaches the maximum detection efficiency [6]. Based on previous information, we can determine when our detector performance comparing the previous GEM reports with respect to our outcomes.

2. Triple gas electron multiplier assembly and experimentation setup

The assembly process of the triple GEM was made with the different parts shown in Figure 1. Firstly, all the detector components were wiped and tested in a cleanroom (ISO 5) to guarantee an environment without dust. The standard 10x10 cm$^2$ GEM-foils were tested at 500 V to burn any possible microparticles inside the holes (with currents that were always below 3 nA) [7]. Secondly, three GEM-foils and a drift electrode were assembled to the readout board. The four gaps between the drift and each GEM-foil are also represented in Figure 1. The first ionization gap in the drift zone (Ed) was 3 mm, and 2 mm for the gaps called transfer zone 1 (Et1), 2 (Et2), and 3 (Et3). The final step in the assembly process was the detector sealing. The components in charge of that were the external frame with upper and lower O-rings, a mylar gas window of 18.2 mg/cm$^2$ (to make the radiation lose the minimum level of energy when passes through it) and the gas box cover. The detector tightness was assured when the gas cover box was screwed to the readout board through the external frame.

![Figure 1. Description of triple GEM components used in the detector assembly [8].](image)

The detector configuration depends on three main systems such as the voltage distribution, the flow gas control and the electronics for the signals lecture. The different components from the experimentation setup are described by blocks in Figure 2. For the voltage distribution system, we used a high voltage source CAEN NDT1470 (red block) and a voltage divisor (yellow block). The voltage divisor was designed with resistors to give a corresponding percentage of voltage for each component of the GEM-foil. The voltage distribution gave a percentage of 18.22% to the drift zone (Ed), and transfers zones 1, 2 and 3 (Et1, Et2, y Et3). The percentage voltage from GEM-foils 1, 2 and 3 was 10%, 9.12% and 8.0% respectively. This voltage configuration was given according to the Sauli report [3].

Subsequently, the mixture of gases used for the gas control system was Ar/CO$_2$ in proportions of 70/30%, 80/20%, and 90/10% at atmospheric pressure. A constant flow of the gas mixture was maintained with a couple of flowmeters at the detector gas input and output (green blocks) with a flux of 2.0+/−0.5l/h. The flowmeter installed at the detector gas output was in charge of checking if there was a gas leak inside the triple GEM. The renovation of the gas mixture into the detector ensured no fluctuation in terms of the detector effective gain, energy resolution and efficiency.
Finally, the lecture of the signals was made by the amplification system with a CSA (charge sensitive pre-amplifier) and a shaper with 1 µs of peak time (blue blocks). The amplification system transformed the tiny currents generated by the detector into a voltage with a ratio of 3 mV/10^{-15} C (standard deviation of 5.6 mV). The amplification system was connected to an oscilloscope Lecroy WaveRunner 62Xi of 600 MHz bandwidth (black block) to record all signal generated by the triple GEM detector.

3. Results
The detector performance was analyzed in terms of the main variables; energy spectrum, energy resolution, effective gain and detection efficiency. In terms of energy spectrum, the result of the triple GEM with Ar/CO₂ in a proportion of 70/30% and a total voltage of 4100V is shown in Figure 3 (blue line).

![Figure 3](image3.png)

**Figure 3.** Triple GEM energy spectrum from $^{55}$Fe source with Ar/CO₂ in a proportion of 70/30% at 4100 V of total voltage.

We can see three aspects in the picture; two fitted Gauss distribution (red line); the main distribution corresponds to the ionization of $^{55}$Fe photons of 5.9 keV; the second distribution at 3.0 keV of peak is

![Figure 4](image4.png)

**Figure 4.** Energy resolution from different Ar/CO₂ mixtures respect to the total triple GEM voltage.
argon escape being the 15% of the height of the main peak [9]; and the Landau distribution at low energies corresponds to the overall noise. The procedure to obtain the triple GEM energy resolution was performed by acquiring the energy spectrum from three Ar/CO$_2$ gas mixtures (70/30%, 80/20% and 90/10%) at different total voltages (from 3200 V and 4100 V). Additionally, we measured the FHWM of the fitted Gauss distributions with a mean of 5.9 keV to calculate the energy resolution. The energy resolution Re is given by $Re = \text{FWHM}/E$, where $E$ is the related energy of the peak (5.9 keV in this case). Figure 4 shows that for a higher proportion of argon, the best energy resolution (nearly 19%) is obtained with lower voltages.

We used the formula $G_{\text{eff}}=I/(f*mp*e)$ to calculate the effective gain of the triple GEM detector. Where $I$ is the current on the bottom electrode of the third GEM-foil, $f$ is the detection rate, $mp$ is the number of primary ionizations, and $e$ is the electron charge [10]. Figure 5 shows that the more proportion of argon, the less total voltage is needed to obtain high effective gains. The effective gain for all gas mixtures increases exponentially up to $10^4$ except to Ar/CO$_2$ in proportion 90/10% (sparks appeared at $5\times10^3$). This is the maximum effective gain before some sparks (related with discharge probability) begin to appear inside the detector leading to high risks towards damage the system - particularly of the GEM foils and the electronic amplifier.

Concerning terms detection efficiency, previous studies established that the efficiency and the rate detection increases rapidly until a stabilization called plateau zone [3-6]. Figure 6 shows the normalized rate detection evaluated with the three mixtures for Ar/CO$_2$. The plateau zone for the mixtures of 70/30%, 80/20% and 90/10% begins at 3800 V, 3600 V and 3300 V respectively. Therefore, the triple GEM can reach a high level of detection efficiency even with a low effective gain (greater than $10^3$).

4. Discussion
In terms of energy resolution, the best resolution the UAN detector obtained was 19%, improving the results compared to studies with a single and triple GEM. The best energy resolution for a single GEM was 21% [11] and 20% [12] for a triple GEM. However, based on Sauli [3] report the GEM is capable to reach energy resolution up to 15% with some changes in the setup configuration and the GEM-foils pattern of holes design. This parameter should be reviewed and improved for the UAN detector depending on the application this will operate.

The results we obtained according to effective gain were compared with two similar triple GEM configuration reports. Compared with Sauli results [3], we obtained the same effective gain ($10^3$) when the detector was operated with Ar/CO$_2$ in proportion 70/30% at atmospheric pressure and at 4100V of total voltage. The second study performed by Patra et al. [6] obtained similar results but they needed
300 V more of total voltage to attain the same effective gains we obtained. In this case, it could be related to some low-pass filters in the voltage distribution that they did not show in the experimentation setup.

The UAN triple GEM detector suffered from sparks when the proportion of Ar was at higher proportions (90/10%). According to other studies, in a triple GEM working with Ar/CO2 in a proportion of 70/30%, the discharge probability is constant with a value of 10^4 for effective gains up to 10^4. For effective gains greater than 10^4 the discharge probability increases rapidly up to 10^6 (when the effective gain reaches 3x10^4) [13,14]. Although a higher proportion of Ar gives greater effective gains with lower total voltages, the discharge probability is a very important point to take into account to avoid the damage of the triple GEM.

According to the detector efficiency, our results were evaluated taking into account the detector rate detection. The UAN triple GEM detector showed a similar behavior compared with other studies [3], [6]. This parameter indicates that the triple GEM is working well in terms of detection efficiency. However, for more accurate outcomes, it is necessary to add more detectors (such as scintillators) to check the coincidence in terms of detection and avoid possible false signals due to the overall noise.

5. Conclusions
The assembly and performance study of the UAN triple GEM with a 55Fe source demonstrates that the detector main variables we wanted to measure were working under competitive conditions compared with other studies. Based on the results we obtained, the recommended configuration of the UAN triple GEM is with a mixture of Ar/CO2 in proportion 70/30% and a total voltage of 4100 V. This configuration ensures an energy resolution of 19%, an effective gain of 10^4, a plateau zone reached in terms of detection efficiency and a discharge probability lower than 10^-6. Further changes in the GEM-foil design and experimentation should be done to still improving the performance of the triple GEM detector in terms of energy resolution and detection efficiency.

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