Comparing different methods of position reconstruction considering 1D readout of GEM detectors

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Abstract. Gas Electron Multiplier (GEM) based detectors contain microstructures that provide amplification, via avalanche multiplication, for the charges generated due to ionizing radiation. The readout of the detector is responsible for collecting electrons multiplied by the GEM structure and it may be position sensitive. In this preliminary study, we created algorithms to compare the error of three different methods for position reconstruction. All these methods are based on weighted averages. In the algorithm we modeled an electron cloud as a normalized Gaussian function that is collected by a 1D readout of strips affected by white noise, then we made a clustering algorithm to identify the strips that collected the electron cloud. The method that uses the weight equal to squared charges shows the highest errors for narrow clouds, when the σ value (standard deviation of a Gaussian function) is closer to the strip width. Nonetheless, the errors of the three methods get similar results for a σ approximately equal to the width of one and a half strips.

1. Introduction

Gas Electron Multiplier [1] (GEM) detectors are a type of Micro Pattern Gaseous Detectors (MPGD) with microstructures capable of multiplying and amplifying charges generated due to ionizing radiation. A GEM structure consists of a thin foil of polymer, coated on both sides with a metallic layer, having a regular hexagonal pattern of micro-holes etched on it. A typical geometry for a GEM consists of 50 µm thick foil with 50 µm diameter holes with 140 µm pitch, as shown in figure 1.

The free electrons generated by radiation depositing energy in the drift region, see figure 2, reach the GEM micro holes. Due to the small distance between GEM's metallic layers, a few hundred volts applied in these electrodes are intense enough to give electrons sufficient energy for an avalanche multiplication, figure 3. In order to increase the gain of the electrons, successive GEMs can be stacked, just as shown in figure 2. While the electrons drift through the detector a diffusion process occurs due to elastic collision between electrons and gas molecules, which influences the electron cloud distribution.

The cloud of electrons multiplied by the GEM is eventually collected using a readout that makes the detector sensitive to position, being possible to reconstruct images. For example, we can reconstruct 2D images using a 2D readout of strips or pads, as shown in figure 4. In the case of this study, we considered a 1D readout, since its simple geometry is a good model for

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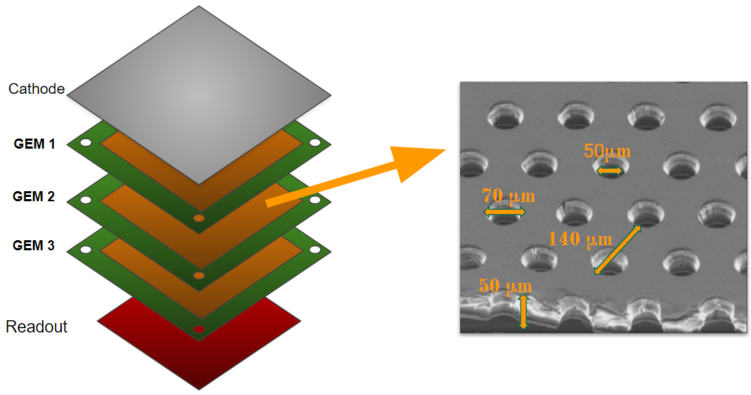

Figure 1. On the left side we have schematic GEM detector. On the right side we have a electron microscope image of a GEM structure (from [1], edited).

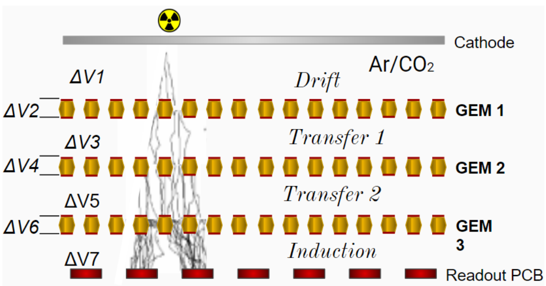

Figure 2. Electrons through the detector being multiplied and suffering diffusion.

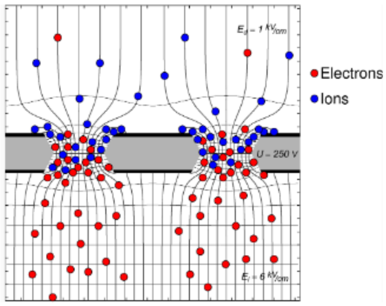

Figure 3. Electron avalanche by a GEM foil [2].

initial tests in the laboratory. The 1D readout of strips considered consists of a printed circuit

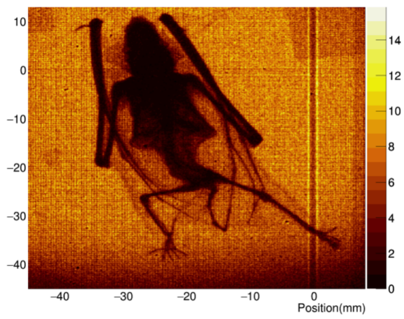

Figure 4. 2D X-ray image of a small animal made using GEM detectors and a 2D readout [3].

board, which we developed using the software gEDA [4], figure 5. The 10 cm x 10 cm area for the collection of the charge consists of a pattern of 256 parallel strips with 0.2 mm strip width and 0.39 mm pitch. For further experimental work, the strips are going to be connected to a system that reads the signal of each strip individually, then the measurements can be compared to the model studied.

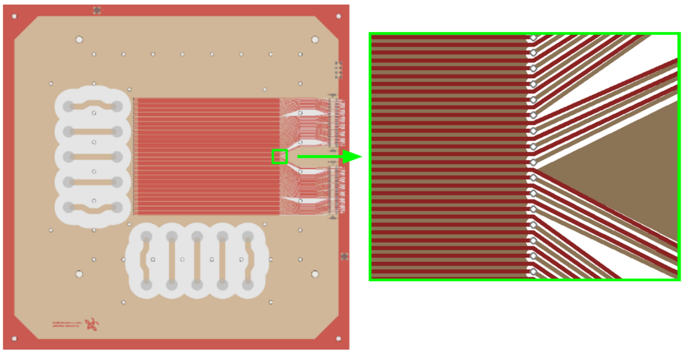

Figure 5. PCB design of 1D readout of strips (right) and detail of the conductive strips with the trace toward the connector (left).

2. Clustering algorithm

The algorithms were made using Python [5] programming language, considering a 1D readout of strips. From previous work [3] is known that the cloud widths of the order of 0.2 mm are expected in a typical detector used in our laboratory: gas mixture of Ar/CO2 (70/30) and an electrical field of 400 V/cm in a drift region of around 1 cm. Therefore for this study we have modeled a 1 cm readout, from -0.5 cm to 0.5 cm, where the coordinate 0 is in the middle of the strips pattern. The clouds were generated in the range $-0.8\,\text{mm}$ to $0.8\,\text{mm}$, so the cloud didn't suffer edge effect. The charge clouds were modeled as normalized Gaussian functions centered in μ with standard deviation σ.

$$Gauss(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \tag{1}$$

The charge collected by a strip centered on x_j, is given by the equation 2, with L being the strip width. The model takes into account that the charge signal collected by the strip is affected by white noise. Then we considered a gaussian noise with $\sigma_r = 0.01$ AU for each strip j, aiming to bring the model closer to reality, as shown in the equation 3.

$$q_j = \int_{x_j - L/2}^{x_j + L/2} Gauss(x)dx \tag{2}$$

$$Q_j = q_j + Random.Gauss(\sigma_r) \tag{3}$$

A clustering algorithm is used to identify the strips corresponding to charges that came from the electron cloud. The algorithm first looks for a strip whose signal is above a defined threshold, 0.08 AU in this work, to find a strip that definitely contains a signal. Then, starting from this seed strip, the algorithm scans in both direction to construct a cluster. The scan stops when it finds a strip that collected a negative charge, which means just noise. So we are going to find the positions n_1 and n_2. Which n_1 represents the first strip of the cluster and n_2 the last one, as shown in figure 6.

3. Charge reconstruction and position reconstruction methods

After using the clustering algorithm, to estimate the total charge collected by the readout, we calculated the sum of the charge collected by all strips in the cluster.

$$Q_{Total}\left(\mu\right) = \sum_{j=n_1}^{n_2} Q_j \tag{4}$$

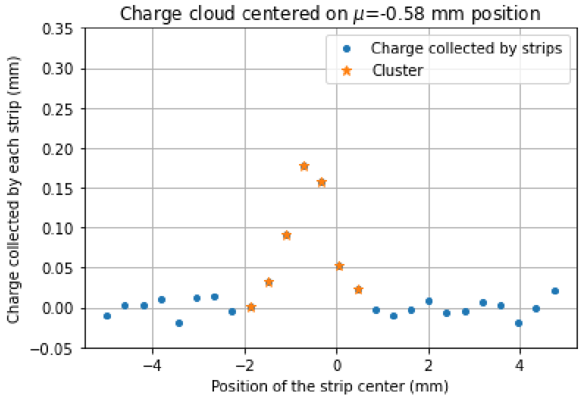

Figure 6. An example of clustering made by the algorithm.

The position reconstruction is important because it is an approach to the ionization event localization. In this work, the center of the electron cloud μ was reconstructed by weighted averages, equations 5, 6 and 7, similar to the center of mass equation. These weights were chosen in order to evaluate the impact of lower and higher charges in the charge and position reconstructions. The logarithmic weight gives more importance to lower charge values, the squared weight to the higher values, and the linear weight is between them.

$$P_{lin} = \frac{\sum_{j=n_1}^{n_2} Q_j x_j}{\sum_{j=n_1}^{n_2} Q_j} \tag{5}$$

$$P_{sq} = \frac{\sum_{j=n_1}^{n_2} (Q_j)^2 x_j}{\sum_{j=n_1}^{n_2} (Q_j)^2} \tag{6}$$

$$P_{log} = \frac{\sum_{j=n_1}^{n_2} ln\,(Q_j + 1)\, x_j}{\sum_{j=n_1}^{n_2} ln\,(Q_j + 1)} \tag{7}$$

Then we can calculate the error of the reconstructed position, defined as the equation 8, for the three different methods.

$$Error(\mu) = P - \mu \tag{8}$$

4. Results

In order to estimate systematic uncertainties on position and charge reconstructions, a Monte Carlo (MC) method was used. The MC method consists of a class of algorithms that repeatedly draw random samples to estimate numerical results. For each position μ and width σ of the cloud, the charge and position were calculated N times, making each time a new random draw for the noise (equation 3).

We estimated a value for the total charge using MC with N = 1000 draws for the noise using equations 3 and 9.

$$\bar{Q}_{Total}\,(\mu) = \frac{1}{N} \sum_{i}^{N} Q_{Total_i}\,(\mu) \tag{9}$$

For each μ and σ the error (equation 8) of the reconstructed position was calculated for N=1000 draws of charge noise, then the systematic error was calculated as a mean value of the errors (equation 10).

$$\overline{Error}(\mu) = \frac{1}{N}\sum_{i}^{N} Error_i(\mu) \tag{10}$$

The total charge and total error were calculated on different positions of the electron cloud relative to the strips pattern, for M = 41 positions.

The total charge, figure 7, oscillates around approximately 0.5 AU because the pitch length is two times the strip width. Note that this value is slightly higher than 0.5 AU due to the noise contribution.

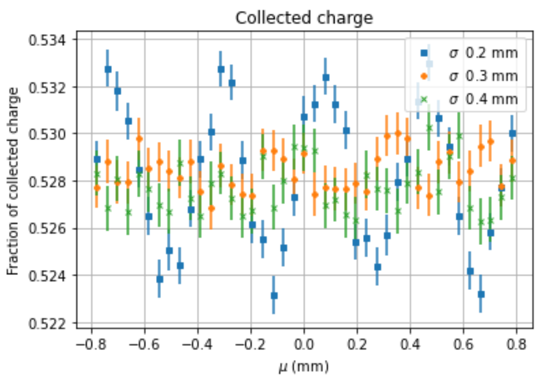

Figure 7. Fraction of collected charge for clouds in different positions μ relative to the readout.

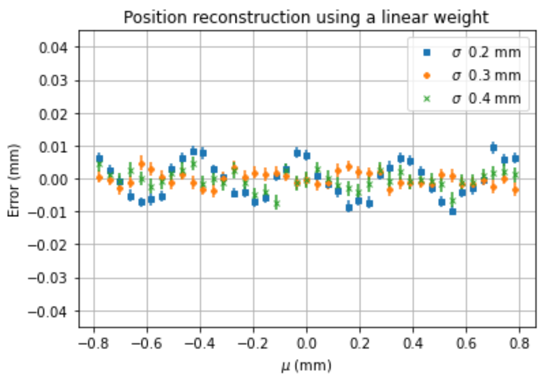

Figure 8. Position reconstruction calculated as a weighted average, considering the charge collected by each strip as the weight.

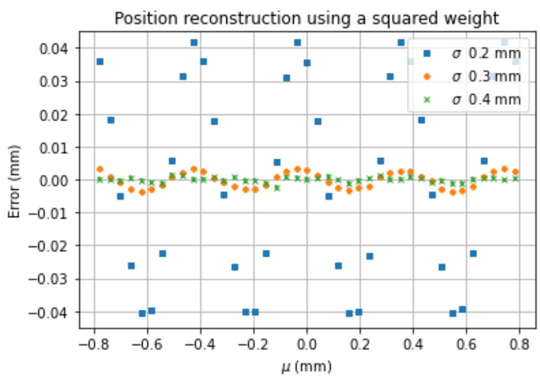

Figure 9. Position reconstruction calculated as a weighted average, considering the charge squared collected by the strip as the weight.

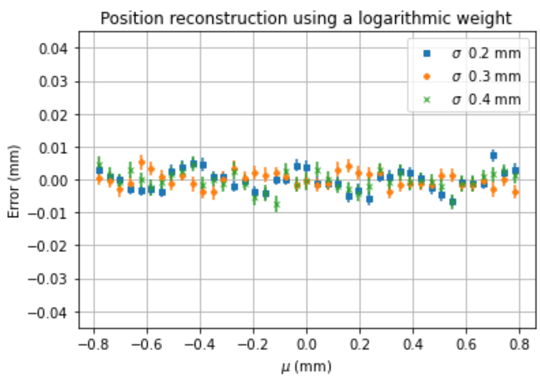

Figure 10. Position reconstruction calculated as a weighted average, considering the logarithm of the charge collected by each strip as a weight

Since the errors of position reconstruction oscillate with different amplitudes depending on the method and on the electron cloud width σ, as you can see in figures 8, 9 and 10, we calculated a RMS value for each method, equation 11. So with the RMS values, we were able to compare the three different methods for different values of σ. The graphs in figure 11 show that the errors depend on the method applied and the electron cloud width. For small cloud widths the method of sum of squared charges has the highest RMS values compared to the other methods. Nevertheless, when σ is higher than approximately 0.3 mm, which is the width of one and a

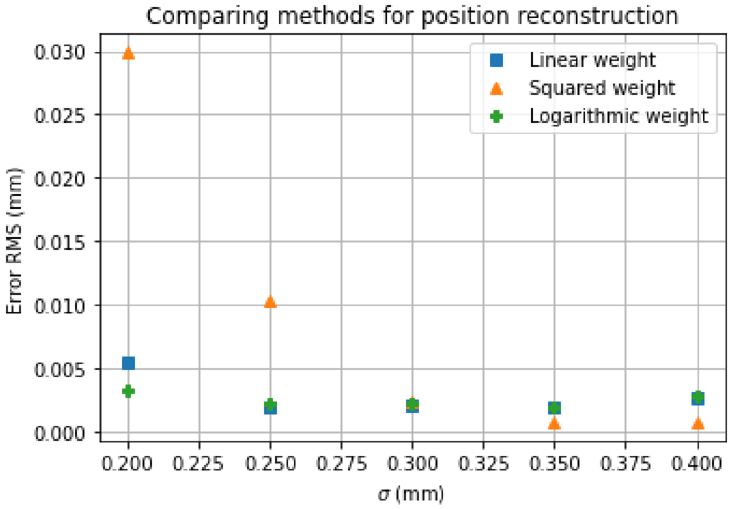

Figure 11. Comparing the errors of three different methods for position reconstruction using the RMS value, for different charge clouds σ.

half strips, the three methods have similar RMS values, with the method of the squared charges being slightly lower than the others.

$$RMS = \sqrt{\frac{1}{M}\sum_{k}^{M}\overline{Error}\left(\mu_k\right)^2} \tag{11}$$

5. Conclusion

In this work we have modeled the electron clouds collected by a 1D readout of strips as Gaussian functions, considering a white noise affecting the collected charge. A clustering algorithm was used to identify which strips collected the electron cloud, then the position of each given event of ionization was estimated using three different methods. For the total collected charge and the errors of position reconstruction of events, the values and their uncertainties were estimated using MC. Then the errors of the three different methods were compared by the RMS values considering different cloud widths.

The graphs comparing the methods give that the squared charge method has the highest errors for the smallest cloud widths. However, all three methods get similar residuals when the cloud gets larger, as shown in figure 11. That is the case for electron clouds that have σ larger than approximately one and a half strip width.

The code developed accepts different inputs such as discrete electron clouds. Then, for further works, we will use the distribution simulated using Garfield++ [6] software.

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