Fine Pitch GEMs in Triple GEM Detectors

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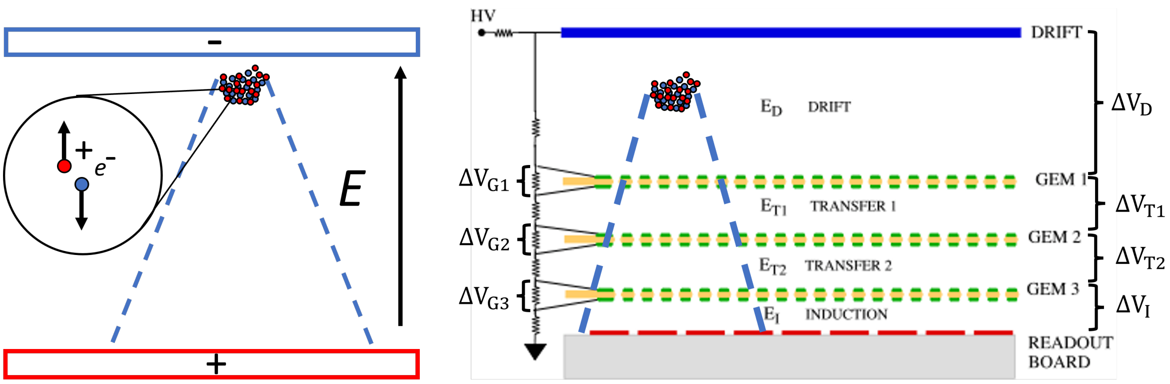
Introduction

During my stay as a Summer Student at CERN I have worked with triple Gas Electron Multiplier detectors (triple GEM detectors) in the Gaseous Detector Development (GDD) group. The project has been research into whether certain properties of the standard triple GEM detector can be improved by using a GEM foil with a smaller pitch. The investigation focused on three properties: Spatial resolution of the detector, high gain/saturation effects at high gain of the detector, and stability towards discharges in the detector. In this report, the work that has been done will be outlined, and the outlook of the investigation is presented.

Gaseous detectors

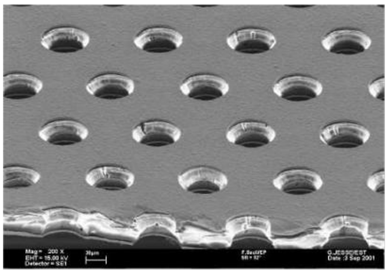
A sketch of a gaseous detector can be seen in Figure 1. It consists of a sensitive volume filled with gas that can be ionized by high energy particles entering the detector surrounded by an anode and a cathode setting up an electric field. The ionization results in electron-ion pairs being created, and the electrons drift to the anode while the ions drift to the cathode. This induces a charge on the anode which can be measured as a current constituting the read out of the detector. The amount of primary charge is however too small to detect, so it needs to be multiplied to produce a signal. The number of times a single electron is multiplied is the gain of the detector.



a) b)

Figure 1: a) Illustration of sensitive volume of gas detector with an electron cloud. b) A triple GEM detector. The diffusion of the electron cloud is illustrated with the blue dashed lines. Parts of the figure taken from [4].

One way to amplify the initial charge is with a Gas Electron Multiplier (GEM)



a)

	Standard GEM	Fine Pitch GEM	Thin Fine Pitch GEM
Pitch	140 µm	90 µm	60µm
Thickness	50 µm	50 µm	25µm
Inner Ø	50 µm	50 µm	25µm
Outer Ø	70 µm	60µm	30µm

b)

Figure 2: a) A picture of a GEM foil [4]. b) Table of dimensions of the different tested GEM foils.

(Figure 1). The standard GEM foil consists of 50µm kapton layer sandwiched by two 5µm of copper in which holes have been etched in a hexagonal pattern (Figure 2). The distance between the holes is known as the pitch of the detector, and is 140µm for the standard GEM foil. By applying a large voltage difference between the top and bottom layer, a strong electric field is set up within the holes of the foil. When electrons pass through, they gain energy leading to secondary ionization of gas atoms thus multiplying the initial electron. This process is known as an avalanche [4].

It is common to use three GEMs spaced slightly from each other to amplify the primary charge. This configuration is known as a triple GEM and exploits the fact that a single ionizing particle can produce a cloud of primary charge, which will spread out in the detector volume as it drifts towards the anode. This spreading out is called diffusion [4]. At the first GEM a few holes of the foil may provide the amplification, but due to the diffusion in between GEM1 and GEM2, more holes will participate in the second layer and so on for the 3rd layer. In this way the charge is multiplied a lot without increasing the number of electrons needing to go through a single hole as drastically. High electron density per hole can lead to saturation effects where the positively charged ions generated in the GEM holes modify the electric field thus changing the amplification. This is said to be an effect of space charge [4]. At even higher electron densities a spark between the layers of the GEM can damage the detector [1].

Because of this, it is interesting to look into the properties of a triple GEM detector with small pitch GEMs, and thus higher hole density. One can set up the following hypotheses about what would be observed

- Higher gain before saturation.
- Higher achievable gain before discharging.

- Better spatial resolution.

The reasoning is as follows: Higher amount of holes will mean lower electron density per hole thus meaning higher gains before saturation effects. The same reasoning means higher gains should be achievable before discharging ensues. Improvements in spatial resolution would be expected because of the higher hole density of the GEM foil thus entailing a more fine grain sampling of the charge cloud.

In all measurements the same triple GEM detector was used and continuously flushed with a mixture of 70% Ar and 30% CO_2. The interaction of high energy particles with the argon can release either one electron and a photon or two electrons within the gas volume [5]. Carbon dioxide acts as a quencher limiting the avalanche process [3].

Spatial resolution measurements

Methodology

The spatial resolution of triple GEM detectors with different configurations of GEM foils were measured in the RD51 Test Beam of July 2023 where I participated. The detector under test (DUT) was placed in a telescope with three other triple GEM detectors that were used as position reference. When a muon beam was sent through the telescope, the track could be reconstructed from the tracking detectors, and the position reading of the DUT could be compared to this track in order to calculate spatial resolution. Data taking consisted of changing the fields in the different parts of the detector and tracking the spatial resolution and efficiency of the DUT.

In order to compare different configurations, a gain curve with the effective detector gain as a function of the tuned voltage difference was produced using an 55Fe x-ray source. An equivalent source was used to measure the absolute gain in the lab. Thus configurations could be compared in terms of absolute effective detector gain. The process of transforming the raw data is illustrated in Figure 3.

Preliminary results

Two of the configurations tested was a triple GEM detector with three standard GEM foils and one with three fine pitch GEM foils. The dimensions of these foils are given in Figure 2. Two of the measurements consisted of varying the voltage across GEM1, and the drift field, which is the field that collects charge in the sensitive region of the detector, (ΔV_{G1} and ΔV_{D} in Figure 1) respectively.The preliminary result is displayed in Figure 4. The fine pitch triple GEM achieves a better spatial resolution in both the GEM1 and drift field scan.

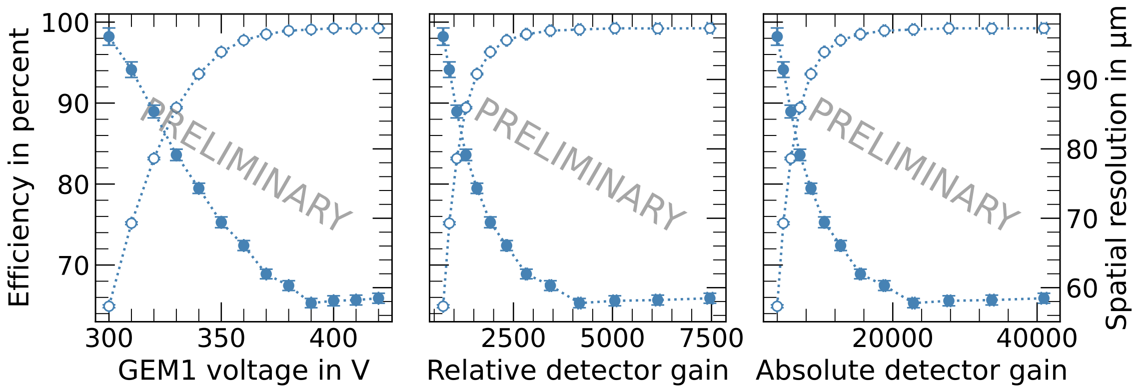


Figure 3: Left: Spatial resolution and efficiency of 3x standard GEM triple GEM detector in terms of GEM1 voltage. Middle: Same data but with GEM1 voltage converted to relative detector gain using 55Fe gain curve. Right: Same data but with absolute effective gain. Filled in points are spatial resolution and outlined points are efficiency.

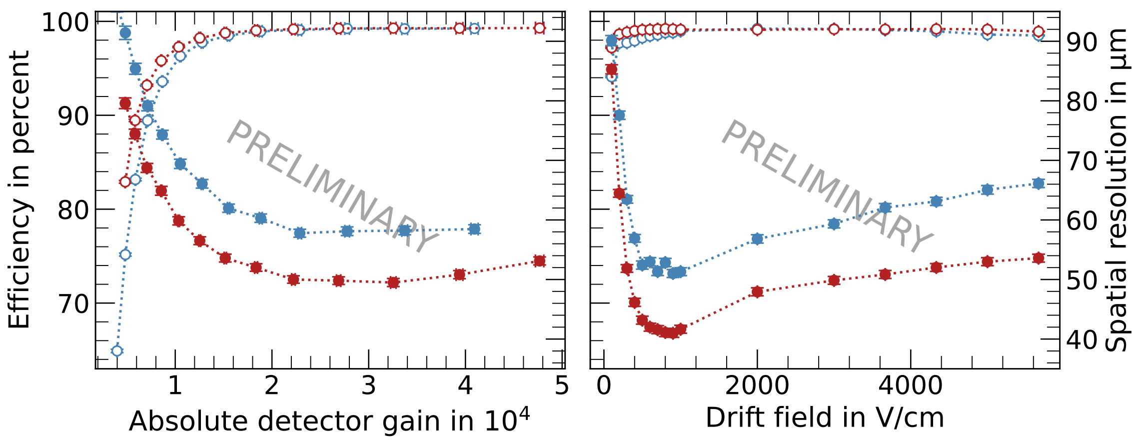


Figure 4: The spatial resolution and efficiency of triple GEM detectors with 3 of the same GEM. Blue: 3x standard GEM. Red: 3x Fine pitch GEM. Left: The efficiency and spatial resolution while ΔV_{G1} was changed. Right: The same parameters while ΔV_{D} and thus the drift field was changed. Filled in markers indicate spatial resolution while hollow markers indicate efficiency.

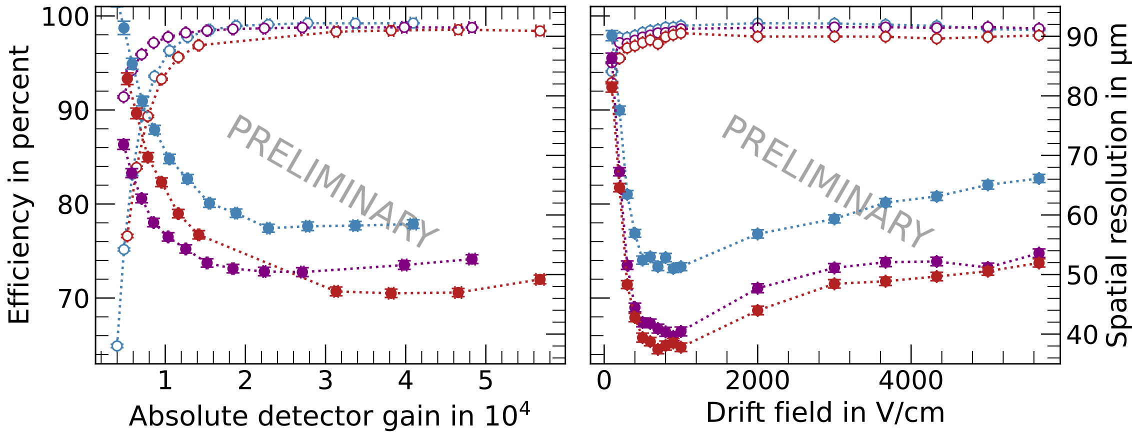


Figure 5: The spatial resolution and efficiency of triple GEM detectors with standard GEM in position 2 and 3 and varying GEM in position 1. Blue: Standard GEM. Red: Fine pitch GEM. Purple: Thin fine pitch GEM. Left: The efficiency and spatial resolution while ΔV_{G1} was changed. Right: The same parameters while ΔV_{D} and thus the drift field was changed. Filled in markers indicate spatial resolution while hollow markers indicate efficiency.

Detector configurations where the last two GEMs were left as standard ones while the first GEM was varied was also conducted. This is especially interesting since the spatial resolution of the detector could be hypothesized to benefit the most from the finer granularity of the first GEM since the amount of primary charge is much lower than the amplified number of electrons in the later stages. Again, the voltage across GEM1 and the drift field was scanned and the results are plotted in Figure 5.

An improvement of the spatial resolution when going from the standard to the fine pitch GEM is seen, but when going to an even finer pitch GEM, the spatial resolution does not improve. At first glance this contradicts the hypothesis that the spatial resolution should increase with higher hole density. However, the different thickness of the thin fine pitch GEM could explain this. The drift and transfer fields in this measurement were used at the optimized values for a triple GEM detector with only standard pitch GEMs. Thus a better spatial resolution might be possible with tweaked transfer fields.

Another important observation is that the configuration with a fine pitch GEM in the first position and 2 standard GEMs achieves a better spatial the resolution than the 3x fine pitch GEM in the drift scan. This could be due to optimized transfer fields for the standard GEM plus the finer sampling at GEM1, but also at a glance indicates that the greatest benefit in terms of spatial resolution is gained when varying the pitch of the first GEM foil.

Saturation measurements

Methodology

Saturation measurements were performed in the GDD lab using a 55Fe x-ray source. The source was placed above the detector which had its electric fields scanned while the gain and energy spectrum as measured. The gain was calculated by the induced current on the anode and the spectrum was recorded by electronically amplifying and shaping the current induced on the bottom of the 3rd GEM and putting the amplitudes of these waveforms into a histogram. The release of either 1 or 2 electrons from the argon at interaction with the x-rays results in two peaks in the spectrum: The highest is the photo, or full energy, peak corresponding to all energy deposited in the detector while the smaller is the escape peak corresponding to the photon escaping the detector volume [5]. Due to the release of primary charge, these two peaks should have their mean in a ratio 2:1. If saturation sets in, this ratio would tend away from two as the higher amount of primary charge in the events recorded in the photo peak saturate the detector earlier than the events due to the escape peak [2].

The greatest amount of charge is at the 3rd GEM so the benefit of more holes could also be hypothesized to be most pronounced when the fine pitch foil is placed in this position. Therefore scans were conducted recording the spectrum and effective detector gain with varying injected charge (charge entering the 2nd transfer field), the electric field within transfer 2, and ΔV_{G3}.

Preliminary results

By the end of my summer studentship I had completed various measurements of the saturation of a configuration of standard GEM in position 1 and 2 and fine pitch GEM in position 3. Some selected ones are displayed in Figure 6.

It is seen that higher gain at the 3rd GEM leads to earlier onset of saturation effects. This can be interpreted as greater amplification within a single hole producing more ions leading to space charge effects. To delay the onset of saturation, it is seen that it is beneficial to go to a smaller transfer 2 field by reducing ΔV_{T2}. This can be interpreted as giving the electron cloud more time to diffuse before reaching GEM3 meaning that more holes will be included in the amplification process and saturation therefore sets in later.

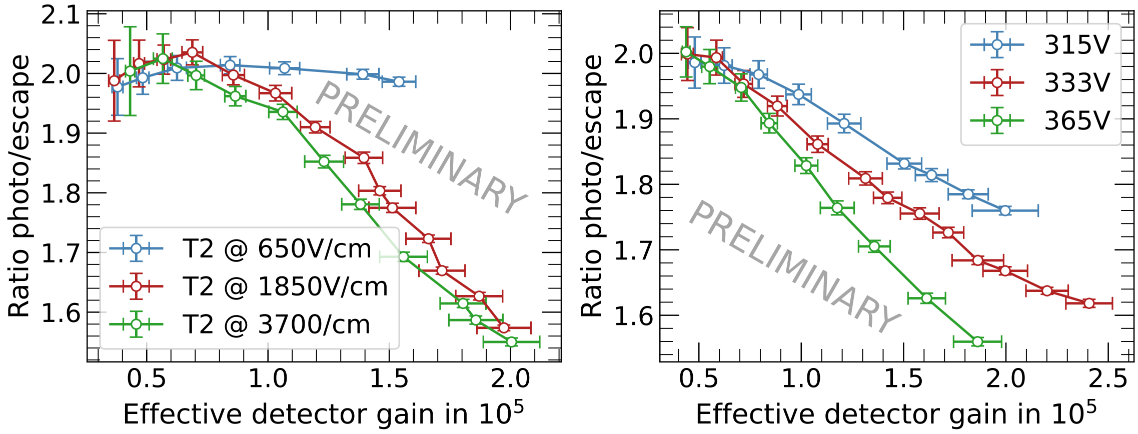


Figure 6: Measurements of saturation setting while varying different parameters of the detector. Left: The ratio of the mean of the photo peak and escape peak for fixed transfer 2 field as given in the legend. To change the detector gain, ΔV_{G3} was varied. Right: The ratio of the mean of the photo peak and escape peak for fixed ΔV_{G3} as given in the legend. To vary the gain, the injected charge was changed by varying ΔV_{G1} and ΔV_{G2} together in equal steps.

Stability measurements

During my stay at CERN I took steps towards starting stability measurements but in the end I was not able to begin the measurements themselves. Maybe this preparation can be of use in future measurements of the stability of the different GEM foils.

Conclusion and outlook

In conclusion, the preliminary results indicate that an improvement of the spatial resolution when using the finer pitch GEM is achievable. The saturation measurements were done for the fine pitch GEM hinting at the great importance of diffusion of the charge cloud and thus the number of holes included in the amplification process, but unfortunately I was unable to complete corresponding measurements using the standard GEM. These measurements could be done to establish whether there is anything to be gained in using a finer pitch GEM in place of the standard one. In terms of stability against discharges, some steps were taken towards starting this investigation but no measurements were taken during my stay at CERN.

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