GEMs Semester Report and Background for new Research Students

Nicholas Leioatts, *Florida Institute of Technology* E-mail: nleioatt@fit.edu

Abstract—GEM detectors (Gaseous Electron Multiplier) are a type of MPD (micro pattern detector) that introduce a new standard in spatial resolution. They offer fast tracking because of the absence of an ion-tail, and the flexibility of a wide range readouts since the detection stage and amplification stages are completely separate. This makes GEM detectors suitable for many different types of experiments. We are constructing a triple GEM for Muon Tomography. Simulations in GEANT have shown that we can reconstruct the tracks of cosmic ray muons and distingush between scattering by dense nuclei versus light nuclei. Here we present the current progress of building a proof of concept detector.

Index Terms—GEM, Muon Tomography

1 Introduction

GEM detectors are a simple and elegant way to amplify signal in a particle physics experiment. Amplification takes place in a high electric field created by 'foils.' The foils are constructed from two thin copper sheets which are joined with a kapton layer in between. Then small holes on the order of 50-70 microns are then photo-etched through the foil in a close pattern [4]. When a potential difference is applied to the separate copper layers these holes form regions of high electric field on the order of 40-60 kV/cm (see fig. 1) [9]. The gain is achieved when ionized electrons cascade through this field. Higher gain can be achieved by stacking foils, which causes an avalanche through the foils [3]. The gain is on the order of 8000 for a triple stacked GEM [4].

The GEM is a gaseous detector held in a constant mixture usually of some ratio of Argon and Carbon Dioxide. The Carbon Dioxide acts as a quencher that keeps the ionization from creating a self-sustaining breakdown and the Argon gas provides a donor electron that is ionized by an energetic particle [5]. Argon and Carbon Dioxide behave similarly for a minimum ionizing particle [7]:

	Primary Electrons/cm	Total Electrons/cm
Ar	25	103
CO_2	35	107

However, the number of secondary electrons is not linear as ionized electrons are accelerated and ionize other atoms. Another process for creating secondary electrons is ionization from photons released from deionized electrons. Carbon dioxide is a good quencher because of its high cross section for these photons. A good quencher is vital to the spatial resolution other detector because it keeps the avalanche centralized. The electrons drift with a velocity:

$$V = \mu|\hat{E}|1/(1+\omega 2\tau 2)(\hat{E} + \omega\tau(\hat{E}\times\hat{B}) + \omega 2\tau 2(\hat{E}\cdot\hat{B})\hat{B}$$

where ω = cyclotron frequency, $\frac{eB}{mc}$, μ is the electron permeability, $\tau = \frac{\mu m}{e}$ is the time between collisions and $\hat{E}$ and $\hat{B}$ are the directions of the $\vec{E}$ field and $\vec{B}$ field.

The ionized electrons are then accelerated through the holes in the foils, where they encounter the high electric field which causes the ionization of more electrons [2] & [3]. This detector is fast, relatively inexpensive to build, and provides high spatial precision [3]. Spatial precision is dependent on the gas and depicts the size of the incoming packet of electrons. Typically electrons drifting through 1 cm of material will have a resolution on impact of about 30-50 microns [7].

Acceleration is due to the geometry of the electric field around the holes of the foil. The ionized gas is pushed back in the opposite direction of the electrons, so the pulse that reaches the readout plane is quick. Signal pulses have an edge of a few nanoseconds, with a full pulse being 20-100 nanoseconds. This allows the GEM detector to track single events. Industrially produced foils are also being commissioned which drives the cost of this detector even lower [2]. The market for these foils is due to the many applications where GEMs are well suited. Many separate, unique readout geometries can be used. The readout for GEM detectors is completely separate from the amplification and since the ions are driven in the opposite direction it can be very simple [4]. Among these are CMOS pixel chips and various multichannel amplifiers.

2 Background and Previous Work

The GEM detector was first thought up by Fabio Sauli of the CERN gas detector development group and

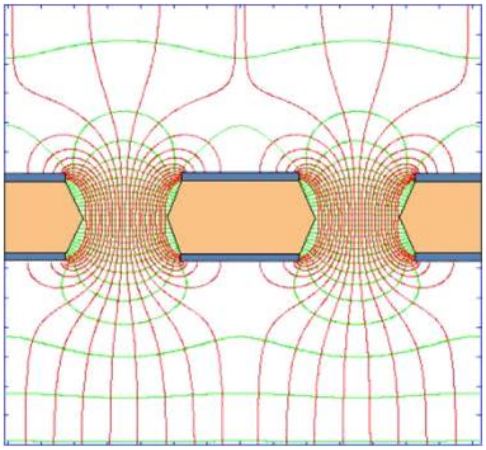

Fig. 1. Electric Field in Foil

used in the COMPASS experiment for particle tracking [3]. These detectors have proven their longevity at COMPASS where they have been working for several years. Medical and radiography are other useful projects that utilize GEM detectors [5]. The capability of a 2-D readout with 50μm precision makes it useful for tracking and aiming radiation therapy devices. This also makes it a favorable detector for muon tomography.

We plan to utilize GEM detectors for muon tomography. Cosmic rays bombarding the atmosphere decay into muons, pions, and neutrinos. At sea level there is a constant muon flux of about 1 per minute per square centimeter. These heavy electrons are relatively stable traveling through buildings and steel with ease. Muons travel nearly the speed of light, so it would take some large force to deflect their path; and that is exactly what we are looking for. Dense nuclei, or high Z material, can cause a cosmic ray muon to scatter by several mrad, and our detector is just sensitive enough to pick up on these lensing effects. Specifically, we are looking for dense, fissable material such as Uranium. Since the muons are slow to decay nuclear material cannot be shielded as it could be from direct detection.

Using GEM detectors the back azimuth of a particle is compared before and after traversing a set distance. If these vectors have been scattered we can determine their intersection and point of closest approach (POCA). This has been modeled in GEANT [8]. From this information a scattering angle and point of scattering is measured. We can then see if the tracks are signature of high Z material or a larger amount of Medium Z material, like lead or iron. One flaw to this method is the identification of false positives, like Tungsten. This dense material shows a very similar signature to Uranium and work being done to distinguish between the two materials is being tackled through modeling [8].

Our configuration is a triple GEM (see fig. 2) in a 70:30 mixture of Ar:CO2, shielding gas, tailored to a signal of cosmic ray muons and is being constructed here at Florida Tech. We have been commissioning the detector with a constant Fe55 source (5.9 KeV x-ray emission). Our goal is to provide a proof of concept using a smaller detector before building the 30 cm x 30 cm version [10].

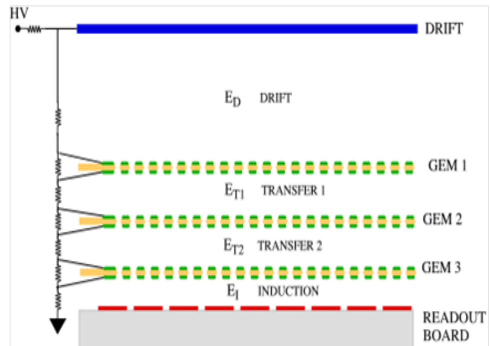

Fig. 2. Triple GEM Geometry

3 Hardware Issues

The detector was not without its problems, which would ultimately spell the end of the current implementation of the detector. Currently three lids have been made, only one of which is air tight. This is a vital concern since the characteristics of our AR:CO2 mixture are very well known, but trace amounts or oxygen and moisture can cause discrepancies in the overall gain of the detector [6].

Another issue is with the HV supply. We made independent resistor chains for each of the foils. This allows for better charge dissipation, but it is not as fine a solution to sparking as capacitively coupling these chains to ground. The problem is that this capacitance shows up as a significant contribution to our background noise.

Oscillations in the readout were another concern separate to noise caused by the insufficient shielding to the HV circuits. This problem was caused by a capacitance build up in the readout. The starting size was .7 x 11.4 cm, an area of about 8 cm2. This final size of the readout is .3 x .5 cm, or about .15 cm2. Which brings the capacitance down by a factor of 50. Along with bypassing the connector and soldering the pin directly to the readout we eliminated these oscillations.

The last problem to tackle is sparking between foils. The initial motivation for a triple stacked GEM detector over a single foil was to allow high gain in several lower amplification fields. Discharges are responsible for aging the detector by carbonizing the Kapton dielectric between the two copper faces of the foil. Sparking can be seen on the foils themselves (see fig. 3) and is characterized by a large leakage current (5 nA) between the foils. We measure for this on the more positive two foils during runs.

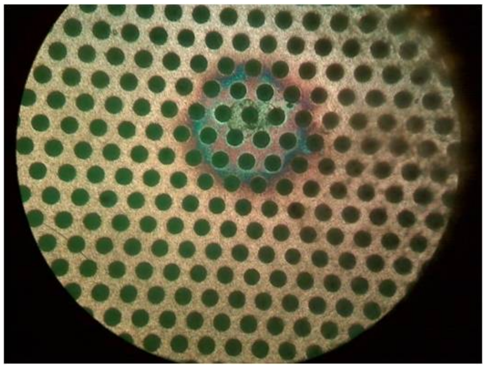

Fig. 3. Close Up of Sparking on Foil

Sparking has occurred in our setup several times and its causes are numerous, stemming from both the supply voltage and the geometry and construction of the foils. First, our mounting process is not as rigorous as that of CERN's group, which allows the weight of our foils to pull significantly. At the midpoint our foils can fluctuate as much as 0.8 mm. This can change the distance between adjacent foils, lowering the breakdown voltage needed to spark across the gap. We have prepared several stretching jigs, but need to refine our procedure to ensure the necessary tension before mounting. The other major problem lies in the power scheme. We use a linear DC-DC converter to attain high voltage and then resistor chains to supply the necessary voltage. Measurements show proper voltage differences between adjacent foils, but the circuit allows charge to build up on the foils. Along with the coarse power supply, which drives the voltage high very quickly, charges build up on the foils and cause sparking. Voltage should be ramped up slowly to condition the detector [6], and our current design does not allow this. Sparking is currently our biggest obstacle; power supply options are being reviewed and premounted foils are on order to test with our set up.

4 Future

In future implementations we will utilize a standardized box for construction of 10 x 10 cm foils. This system contains its own gas ports and integrated electrical connections. This will virtually eliminate gas leakage problems giving a constant gas flow, a necessity for uniform gaini. This will also allow us to utilize a standard size foil and readout available through CERN's gaseous detector group. For these tests a 50 micron precision readout was purchased, but no amplifier or filtering options have been discussed yet.

Next will be the construction of a 30 x 30 cm foil to test the limits of the stretching procedure. This will be closer to the proposed foil size and allow us to troubleshoot problems caused by the increased area.

We will also be working on a multichannel, quick readout to provide our muon tracking. The readout will need to have high spatial precision in order to interpolate the small scattering angle, but with an overall detector size on the order of 3 x 5 meters will need to be efficient to keep cost and computing power down.

5 Conclusions

GEM detectors are a powerful means of amplification, but are not quite as robust as previously thought. Aging of the foils due to sparking remains a primary concern. The foil conditioning process used was too short and needs to take place on the order of months [6].

The use of a new amplification system will yield high spatial precision and simulations show promising results for the detection of high Z material [8]. We have shown that the point of closest approach can be reconstructed and high and low Z materials show different signals, however there are still instances of false positives. A proof of concept detector remains to be built in the following months.

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