The Long Term Behavior of 30cmx30cm GEM Detector

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Abstract. The Gas Electron Multiplier (GEM) technology is one of the next generation radiation detector technologies that utilized the ionization in gaseous medium and the electron avalanche to detect a magnified charge value from various radiation and charge particles. With its low building cost, low discharge rate and high resolution, GEM is currently being considered to be one of the candidate gap detectors for the International Linear Collider (ILC) in Japan. It is therefore of crucial for us to study the long term stability of amplification power of the detector. Using cosmic radiation as our radiation source, data has been taken continuously in the past 2 years by the high energy physics group in University of Texas at Arlington to characterize the stability of the 30cmx30cm detector. Effect of atmospheric pressure to the detector amplification is eliminated by a correction algorithm. Noise study has been done to eliminate excessive noise produced by the detector as well as its readout chip.
Result shows that the detector gives us a stable 35.05fC average MPV for the cosmic MIPs with few fC of chamber noise and about 0.5 of chip noise. GEM should work well as a digital calorimeter for uses in the ILC project.

Keywords: SID DCAL GEM .

INTRODUCTION

Future high energy physics experiments will cover a lot of ambitious physics topics. Topic such as electroweak symmetry breaking, supersymmetry and dark matter searches all require a high precision jet energy measurement.

In the International Linear Collider (ILC) project, a 40 layers Digital Hadron calorimeter (DHAL) is proposed to be utilized as the hadron calorimeter for Silicon Detector (SiD) which would serve to track and identify charged hadron from the collision. It is one of the many trackers and calorimeters employed in the SID to study the particles and radiation produced using the particle flow algorithm. [1]

In the proposed DHAL, each of the 40 layers will consist of a steel absorber, an active element layer and a read-out layer. The active element will be used to track particle energy and position. Different technologies are studied to find the best candidate for the active element of DHAL. Resistive plate Chamber (RPC) and MicroMegas are two of the competing candidates.

In 2003, in the ILC-DHAL group begin its study the possibility of using the Gas Electron Multiplier (GEM) technology as an active element for the calorimeter over Resistive Plate Chamber. GEM have shown promising performance in previous high energy experiments in DESY and CERN. This encourage the further research and development of the GEM technology.

A research group led by the University of Texas at Arlington began the construction of prototype GEM has a shorter pulse width (3ns) and a lower smallest readable signal (5fc) than RPC. A characterization test also show that GEM is robust a robust detector. The pion hit rate per unit area saturates at 10^9hit per mm^2. And It is able to withstand 10^{12} hit per mm^2 particle shower with no damage observed. [3]

To investigate the aging effect of the GEM detector to determine its long term stability, a study is done to study the long term behavior of the GEM detector. Results are shown in the following.

INSTRUMENTATION AND METHODS

Specifications of the prototype 30cmx30cm GEM detector

In this 30cmx30cm prototype detector, 2 layers GEM foils are used. Each layer of GEM foil consists of a 50μm of kapton, which is sandwiched by two 5 μm of copper. Each GEM foil has a 31cmx 31cm dimension, with an active area of 28cmx28 cm. The foils are produced by the double masked chemical etching technology in CERN. Holes 85μm in diameter are densely etched over the active area of the foil with an average pitch 140µm in a triangular geometry.

The prototype 30cm x30cm GEM detector has a 3mm drift region, 1mm transfer region and a 1 mm induction region. This is known as a 3-1-1 configuration.

The prototype is filled with argon and carbon dioxide mixture at an 80:20 ratio. The mixture is chosen over the conventional 70:30 ratio to generate a 3 factor increase in gain.

The readout of the system consists of 64 1cmx1cm pixel pads made of copper at the anode board.

The working mechanism of GEM

When charged particles passes through a gas medium, electromagnetic events happen at a probability orders higher than strong or weak force interaction when charge particles passes through a medium and it is much easier to measure than the weak interactions as electromagnetic interaction happen deposit energy at a magnitude order of 10 higher than those of weak interactions. Due to this fact, many high energy calorimeter make used of the electromagnetic interaction of particles to study the precise energy of particles

There are different kinds of electromagnetic interactions. When charged particles pass through a gas medium, gas atom ionization and excitation are the major mechanism of energy deposition. While they could affect the mean free path of the charged particle passing through, other electromagnetic processes such as bremsstrahlung, Cerenkov and transition radiation does not deposit enough energy in the detector and therefore can be ignored. [1]

As high speed charge particles enter the drift region of the GEM detector, argon and carbon dioxide gas molecules are ionized in the chamber to form positive ions and electrons. The electrons formed are directed down the electric field of -1.3$\times 10^4\ V/m$ to swim towards the anode to be read out. Between the initial ionization and the final read-out, the electrons passes through holes in both layers of the GEM foils. In each foil, the electrons are accelerated by an electric field of 7$\times 10^6\ V/m$, an avalanche effect would occur at this level of electric field, more argon gas atom will be ionized. The original electron and the electron formed from the avalanche effect will pass through a second foil and more electons will be created. Finally, electrons will reach the anode board for an electronic read out.

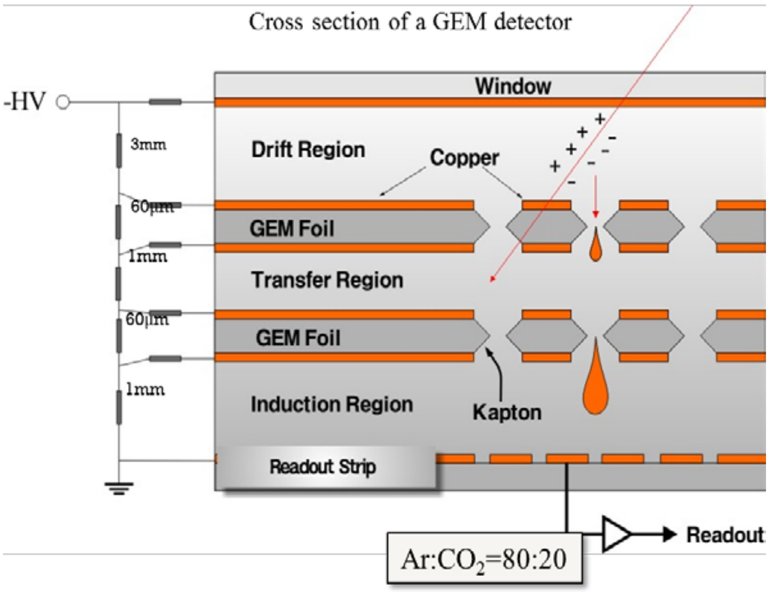

FIGURE 1. GEM detector cross section

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KPiX DAQ system

Developed by the standford linear KPiX DAQ system is a 1024 channels chip that is designed for the silicon-tungsten tracker or electromagnetic calorimeter for the SID in ILC. [4] The 512 channel prototype chip used is capable of a 13 bit amplitude of readout. The multichannel chip designed to avoid expensive extensive wiring. In this experimental setup, the kpix chip is coupled with the GEM detector for an accurate measurement of the energy value of the incoming charge.

SPECIFICATIONS

Noise Floor	0.15 fC, (1000 el.)
Peak Signal (Dual Range)	10 pC
Range Switching	Selectable, ~400 fC
Trigger Threshold (normal)	Selectable, 0.1 to 10 fC
Calibrator	Full Scale, two Ranges
Buffer Depth	Four each Pixel

Figure 2: KPiX specification[4]

As the KPiX chip is designed for uses in the LHC, where particle collision are synchronized, it therefore has a duty cycle of 50hz and a train time of 1ms like the beam period of ILC. KPiX only runs on full power during the train time to lower power consumption to <20 μW/channel.[4]

The prototype KPiX chip KPIX9 that is utilized in for the 30cmx30cm prototype GEM detector only use 64 channels of the 512 channels in KPiX has 2 mode of triggering, namely self-trigger and external-trigger. In the long term behavior study of the GEM detector, external trigger mode is used as cosmic ray is being used as a source for the study. In the next section there will be more detailed discussion on the external trigger set up.

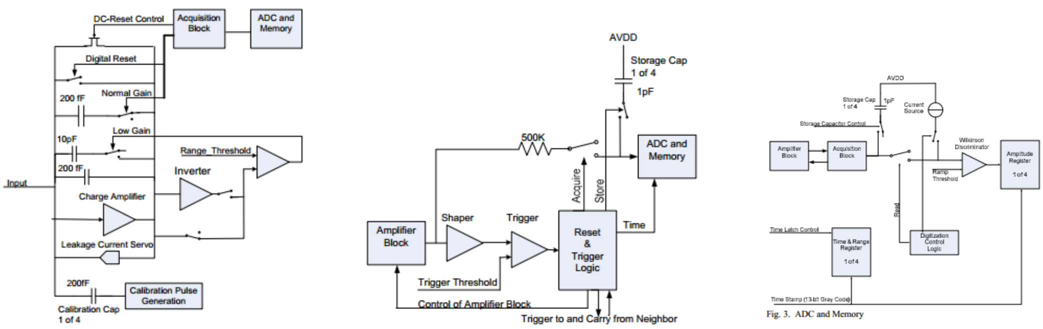

FIGURE 4. The Functional Blocks of KPiX

The data acquisition and electronic circuit of KPiX can be divided into 3 blocks, the amplifier block, the acquisition block, and the ADC and memory block. The above diagram shows the electronic layout of each functional block within KPiX.

External Trigger System

In this experimental set up, 2 10cmx10cm trigger pads, each connected to a photomultiplier tube, sandwich the GEM prototype detector at a distance of about 28 cm apart. The trigger pads are slightly larger than the anode read out board, which is 8cm x8cm in size.

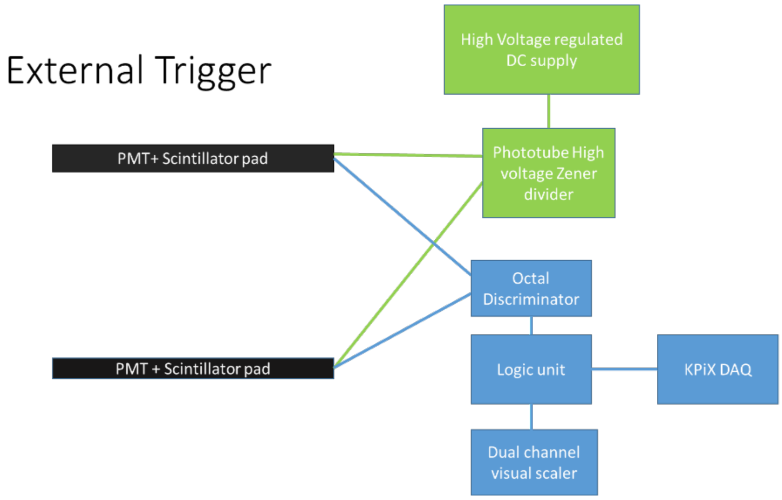

FIGURE 4. The external trigger layout. The Green block is the power supply block, while the blue blocks are the signal discriminator block.

Scintillator and Photomultiplier

When charge particle passes through both scintillator pads, photons are formed in the scintillator pads. The photons formed are directed to the PMT tube. In the PMT tube, the incident photon ionize electron at the photocathode and the electron proceed to move through a zig-zag of dynodes through an electric field. The electrons collide and ionize more electrons in the each dynodes to be read out in the end. A multiplied number of electrons will be read-out at the anode.

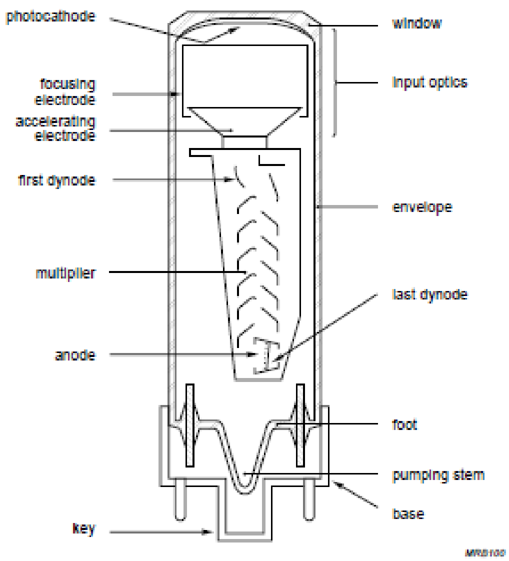

FIGURE 5. A Sample photomultiplier tube

Discriminator and Logic Unit

In this experimental setup, charge signal from the both PMT are each connected to a discriminator which turn analogue signals to digital signals if when the incoming signal is above the set threshold. In our experiment the threshold is set at -100mV. Both discriminators are connected to a logic unit operating under an “And” mode with a time width of 5ns. When 2 independent digitalized signal below -100mV is detected on both scintillator with a time difference of less than 5ns, the logic unit will give out a “1” digital signal, signaling that a cosmic particle has pass through. This signal is send to the KPiX DAQ system to signal the electronics to read out the charge value of the signal that passes through it. For spares and low energy sources like the cosmic ray, the external trigger is an effective way to distinguish actual signal from noise.
3. Characterization of the external trigger system.
As the GEM detector system relies on an efficient external trigger system to maximize the cosmic ray read out it is essential to optimize the external trigger system.

CHARACTERIZATION OF THE EXTERNAL TRIGGER SYSTEM

Efficiency of the External Trigger System

Due to the fact that collection efficiency of the scintillator and the quantum efficiency of the photomultiplier tube are often at a factor less than one, the number of signals send to the discriminator is often lower than the number of particle that actually pass through the detector. Understanding the efficiency of the external trigger system help make sense of the data.

Efficiency of the photomultiplier is given by the following formula:

$$\text{Efficiency} = \frac{\text{\# of hits readout at the anode of the PMT every 10 minutes}}{\text{Theoretical \# of hits passing through the scintilator pad every 10 minutes}} \quad (1)$$

With the number of cosmic minimum ionizing particle passing through a 10cm x10cm scintillator to be approximated to be 100. With the threshold of the discriminator set to be -100mV. The efficiency of the top scintillator pad and PMT is found to be 22% while the lower scintillator pad and PMT is found to have a 50% efficiency. The difference could be caused by different level quantum efficiency, collection efficiency and dark current level for each device pairs.

Minimum Threshold of the Discriminator

The threshold of the discriminator is set by connecting the PMT to an oscilloscope. There is a distinct peak of about -100mV of noise on the screen of the oscilloscope, where as a cosmic signal is at a level much higher than that.

Optimum Operating Voltage of the Photomultiplier Tube

When the operating voltage of the PMT increases, the number of the electrons multiplied increases. The increase in multiplication is not linear, but rather a plateau curve where it the gain of the PMT would saturate after a certain high voltage level. If voltage is increased pass the plateau region breaking down of dynode and discharge happens, the gain would further increase but the dynodes in the PMT would be at risk of breaking from large number of electron hits. Therefore, in order to operate the PMT at an optimum voltage with maximum hits, a hit vs voltage study was done to investigate the optimum operating voltage of the PMT in the middle of the plateau region.

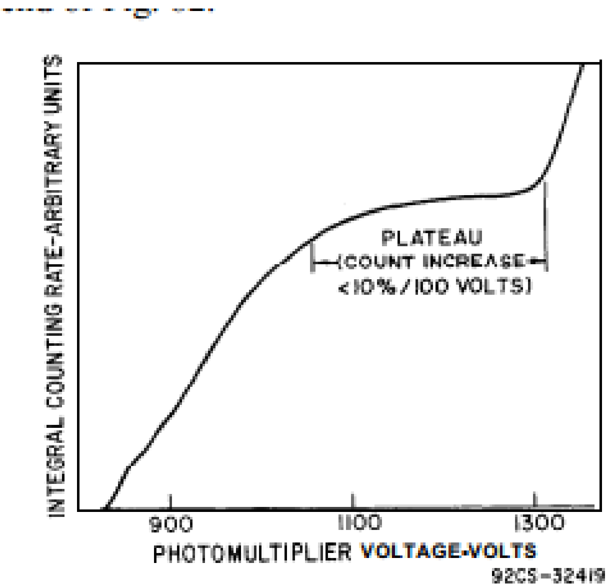

FIGURE 6. The Plateau curve of Photomultiplier [5]

An example of a hit plateau curve with varied voltage of a photomultiplier tube By varying the voltage supply of the PMT and measuring the hit count on each PMT using a discriminator.

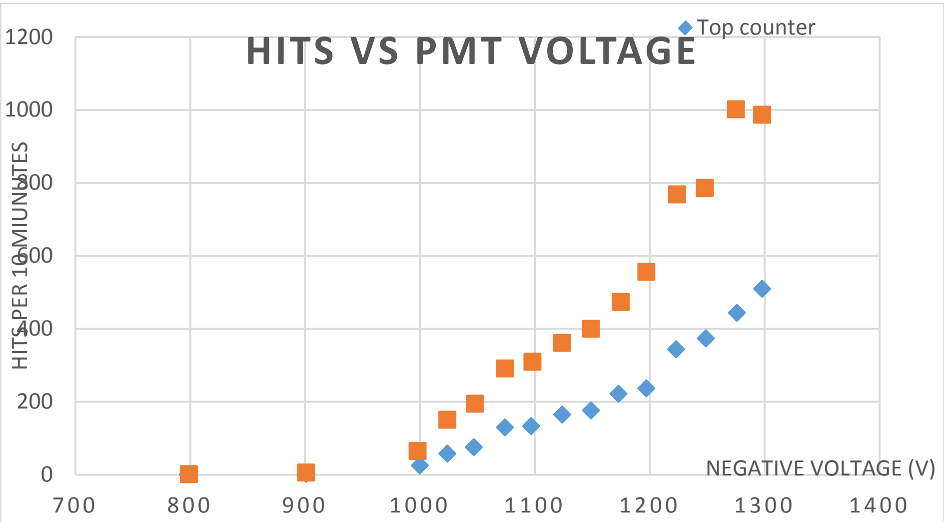

FIGURE 7. Number of hit count vs PMT operating voltage

In the figure above, we can see that there is a plateau between the range of [(-1080V)-(-1150V)] for the bottom PMT and a plateau between the range of [(-1120)-(-1200V)] for the top PMT. Using this information, we set the operating voltage of the top PMT at 1154V and the operating voltage of the bottom PMT at 1112V.

4. Long term behavior study of the GEM detector

Previous studies have discussed the characterization and the general performance of the detector [5]. To investigate the stability and robustness of the detector over a long period of time, a continuous study is done to study the long term gain variation of the detector.

LONG TERM BEHAVIOR STUDY OF THE GEM DETECTOR

Previous studies have discussed the characterization and the general performance of the detector [5]. To investigate the stability and robustness of the detector over a long period of time, a continuous study is done to study the long term gain variation of the detector.

Pressure correction

As a rough approximation, the perfect gas law $P=NKT$ predicts that there is a dependence between pressure and gas concentration in an open gas system. Gas concentration of a GEM detector can affect the gain of the detector in two ways: first, an increase in gas concentration increase the gas molecule to be ionized along the way. If this effect is dominate, we would expect an increase in the gain of the detector when pressure increase, as more electrons will be produced in the avalanche process; second, an increase in gas pressure can lower the drift velocity of the charged particle, as the drift velocity.

Using the self-trigger mode of KPiX and Fe55 as the source, the pressure dependence of the gain of the detector isfound

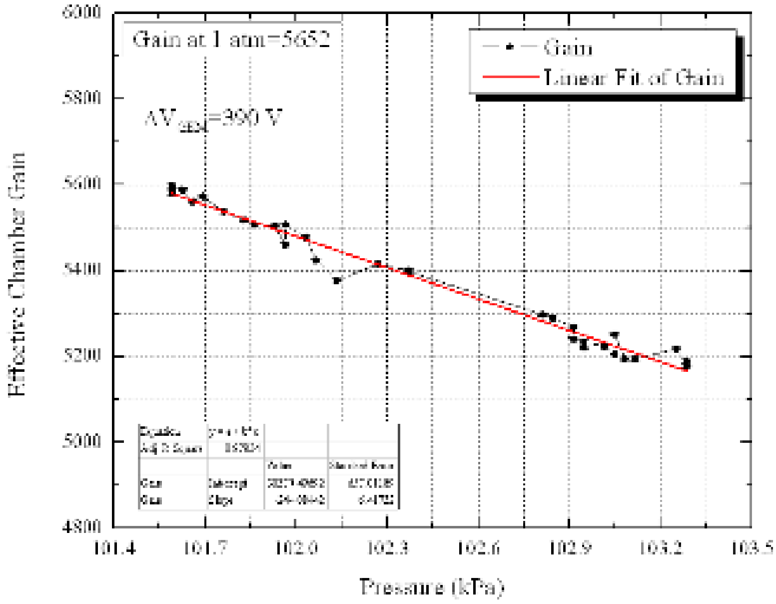

FIGURE 8. The Gain versus pressure dependence graph

From the graph above, the gain of the detector and the atmospheric pressure is found to be related by the formula:

$$Gain = -303.9P + 33509 \quad (2)$$

Where P is pressure in Kpcal.

The pressure correction factor A is:

$$\mathrm{A} = \frac{Gain(1atm)}{Gain(atmospheric\ pressure\ at\ the\ time\ the\ hit\ was\ read\ out)} \quad (3)$$

Long Term Behavior of GEM

Using external trigger mode of KPiX, we take data every week over the past 2 year period using cosmic radiation. A charge distribution plot is created for each run using the prototype 30cmx30cm GEM detector.

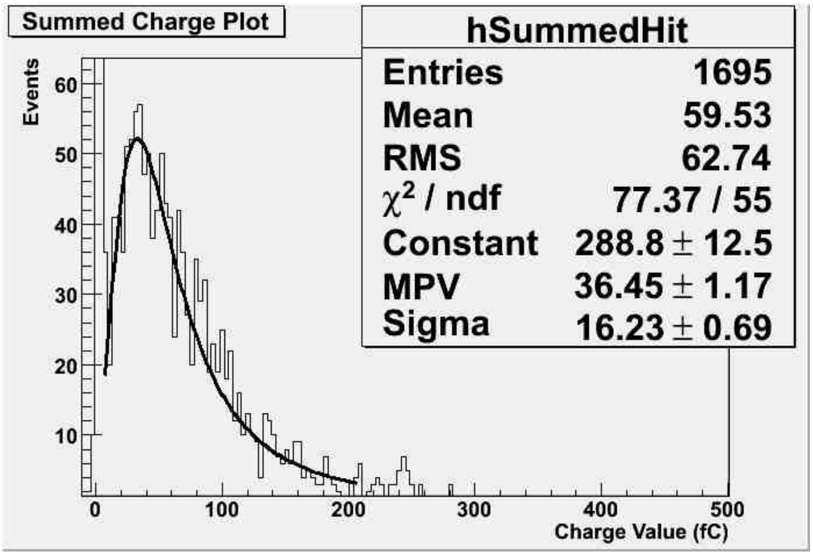

FIGURE 9. A charge distribution of cosmic radiation created by the GEM detector coupled with the KPiX chip with a distinct landau fit.

Using the MPV value of each plot, a multiplied charge value vs date plot is create. The blue line on the graph shows the MPV value of the multiplied charge distribution. The orange line show the MPV value of the distribution after multiplying it with the pressure correction factor A in (3).

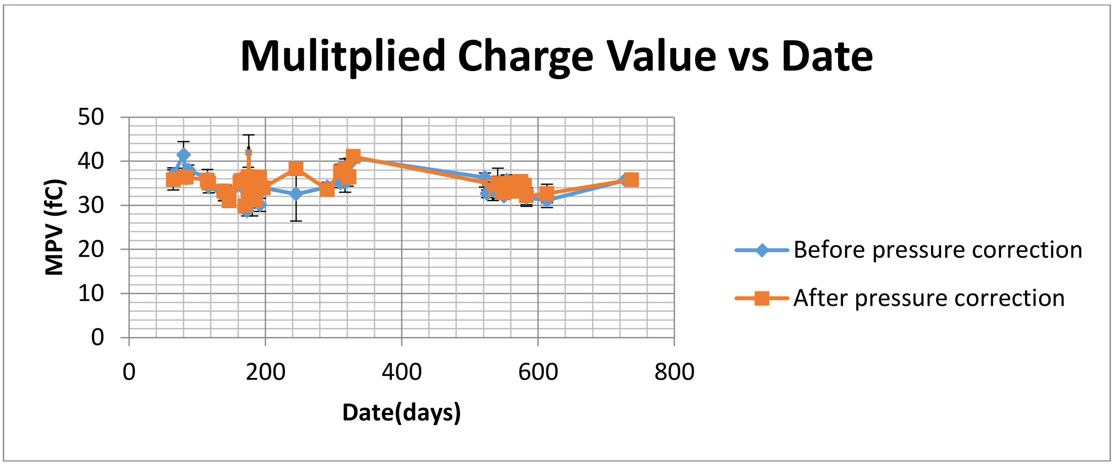

FIGURE 10. The multiplied charge value vs date

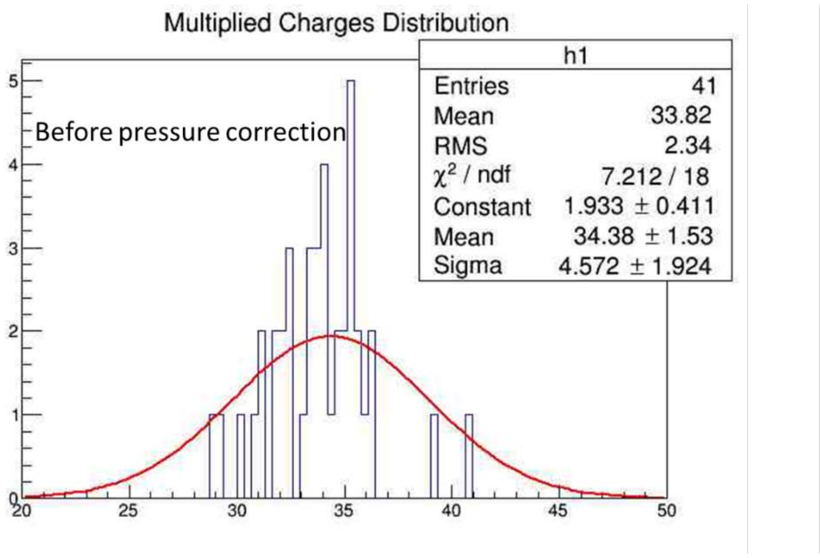

FIGURE 11. Multiplied charge distribution before pressure correction (Fit: Normal)

The Mean charge value read out before atmospheric pressure correction: 34.38+-1.53 fC. The standard deviation of the distribution 4.572+-1.924fC.

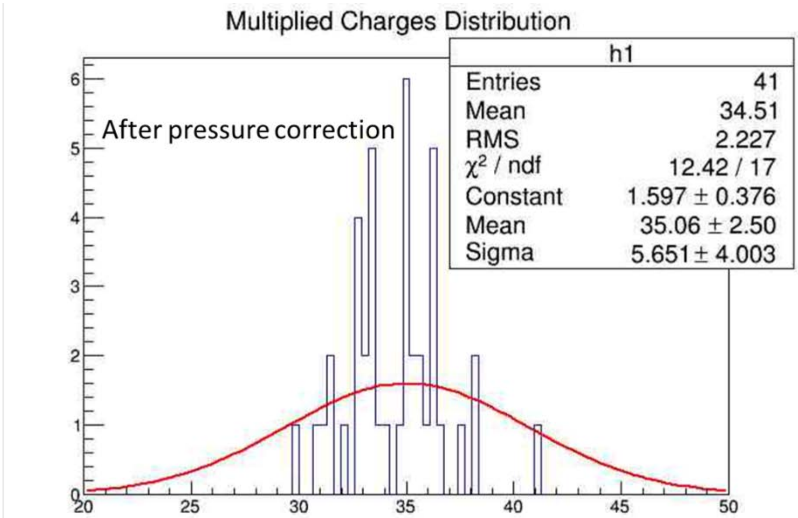

FIGURE 12. Multiplied charge distribution after pressure correction (Fit:Normal)

The Mean charge value read out after atmospheric pressure correction: 35.06+-2.50fC. Standard Deviation: 5.651+-4.003fC.

Gain of Prototype GEM

The gain of a detector is defined as the following

$$Gain = \frac{Charge\ formed\ from\ ionization\ of\ gas\ in\ the\ drift\ region}{Charge\ read\ out\ in\ the\ anode\ board} \quad (4)$$

The Bethe-Bloch-formula shows that the energy loss due to ionization pathway is a direct function of the energy of the particle, therefore energy of the particle can be inferred if we can accurately measure the energy loss of particle when it passes through the detector. [2] The Bethe-Bloch formula is shown in the following:

$$\frac{\mathrm{dE}}{\mathrm{dx}} = -K\frac{Z}{A}\frac{\rho}{\beta^2}\left\{ln\frac{2mc^2\beta^2E_M}{I^2(1-\beta^2)} - 2\beta^2\right\}, \qquad K = \frac{2\pi N z^2 e^4}{mc^2} \quad (5)$$

"N is the Avogadro number, m and e are the electron mass and charge, Z and A are the atomic number and mass respectively, and ρis the density of the medium; I is its effective ionization potential; z is the charge and β the velocity in unit of the speed of light of the projectile. In the electrostatic unit system and expressing energies in MeV, K=0.154 MeV $g^{-1}cm^{-2}$ for unit charge projectiles. In the system used, the rest energy of the electron, equals 0.511mc^2MeV. [2]

The energy lost per unit length $\frac{\mathrm{dE}}{\mathrm{dx}}$ and he energy it takes to ionize an electron/positive ion pair W is given in the following:

TABLE 1. Energy loss per unit length and energy required to form an ionization pair in different material.

	$\frac{\mathrm{dE}}{\mathrm{dx}}$	**W**	**Charge ionized at the drift region=** ($\frac{\mathrm{dE}}{\mathrm{dx}} \div W$) ***h*e**	**% volume in GEM detector**
Argon	2.44keV/cm	26eV	4.38$\times 10^{-18}C$.	80%
Carbon dioxide	3.01keV/cm	33eV	1.64$\times 10^{-18}C$	20%

[2]

The used $\frac{\mathrm{dE}}{\mathrm{dx}}$ and W values are given in the report by F. Sauli in "Principles of the Operation of Multiwire Proportional and Drift Chamber"

Where h is the height of the drift region (0.3cm) and e is the electron charge 1.602$\times 10^{-19}C$. Summing the volume factored charge ionized in the drift region of argon and carbon dioxide, charge ionized by the drift region is found to be 6.80$10^{-18}C$.

The gain is calculated in accord with formula (4). Its average value is found to be 7747.5.

CONCLUSION

The prototype GEM detector is found to be able to show a steady long term behavior. The read out charge value after pressure correction averages at 35.06+-2.50fC with a standard deviation of 5.651+-4.003 fC. The gain of the detector averages at 7747.5, a promising number considering the low operating voltage of GEM. With electronic noise at 0.5fC and chamber noise at 3-4fC, the prototype GEM detector show promising long term stability as a sensitive layer for DHCAL.

ACKNOWLEDGMENTS

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