The Seasonal Dependence of the Prototype Gas Electron Multiplier and the Long-Term Analysis of the Electronics

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ABSTRACT

High energy physics experiments require detectors and electronics that are capable of high precision stable energy read out. KPiX is a multi-channel electronic chip designed for the time synchronous requirements of the Silicon Detector in the International Linear Collider (ILC). The KPiX v.9 has overcame the timing adjustment and is expanded to 1024 channels from 512 when compared with previous versions of the electronics. The study focus on investigating the aging effect of the KPiX V.9 electronics using the prototype 30cmx30cm gas electron multiplier developed by the UTA team. The self-trigger mode of KPiX enable the study of the electronics though the chip's gain variation over the 2.5 year period. The study provides invaluable information of the chip on its future performance on the calorimeters in SID. The presentation will also show the longterm behavior of the gas electron multiplier detector.

INTRODUCTION

With the recent break through in high energy physics where the Higg's boson is discovered, the study of particle physics using advance detector is at all high time. Questions such as the existence of super-symmetry, properties of the Higg's boson and the nature of dark matter and energy all encourages further developments on more advance detectors. The International Linear Collider project is the biggest linear collider since the Stanford Linear Accelerator Center (SLAC) Collider. While the project is still in development phase, it is inspired to be the highest energy collider of its kind. As High energy physics experiment requires high precision read out, the UTA advance detector team has worked on a possible candidate technology for the digital hadron calorimeter called the Gas Electron Multiplier (GEM). Coupled with the KPiX read out chip developed by SLAC, a 30cmx 30cm prototype, double layers, single etched GEM went through a characterization test and has been closely monitored for its long-term behavior. In this paper, the seasonal dependence of the prototype Gas Electron Multiplier is studied and the long-term aging effects of the electronics read out system are studied. This note is also an update on the long-term behavior of the GEM chamber itself.

GEM as the Active Element in the Silicon Detector (SID) of ILC

In the proposed Digital hadron calorimeter (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 encourages 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.

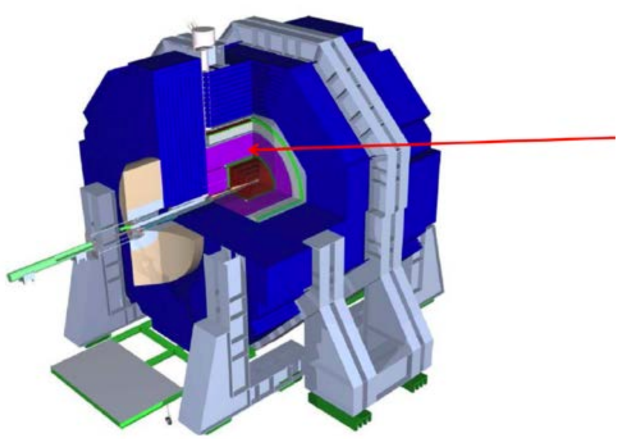

FIGURE 1. The SID detector of the ILC. The violet part is where the DHCAL system is intended to be installed.

EXPERIMENTAL SETUP

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 single side 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.

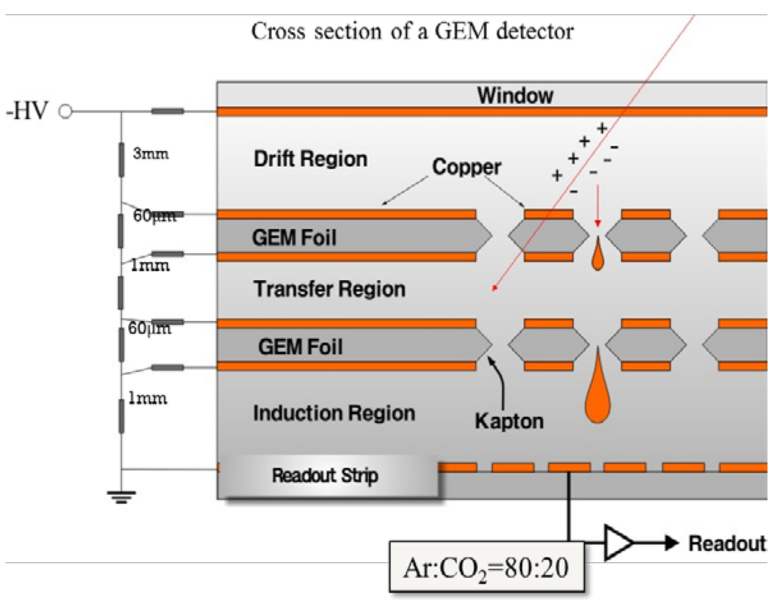

FIGURE 2. GEM detector cross section

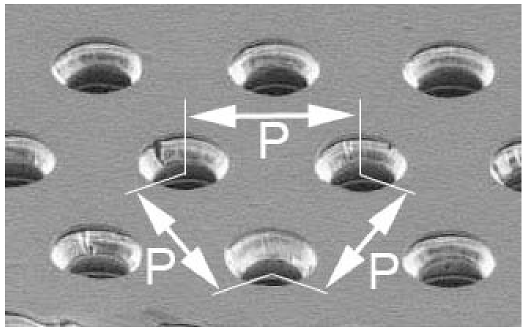

FIGURE 3. prototype 28cm x28cm GEM foil with a pitch of 180 micrometer.

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-channels 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 4: 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.

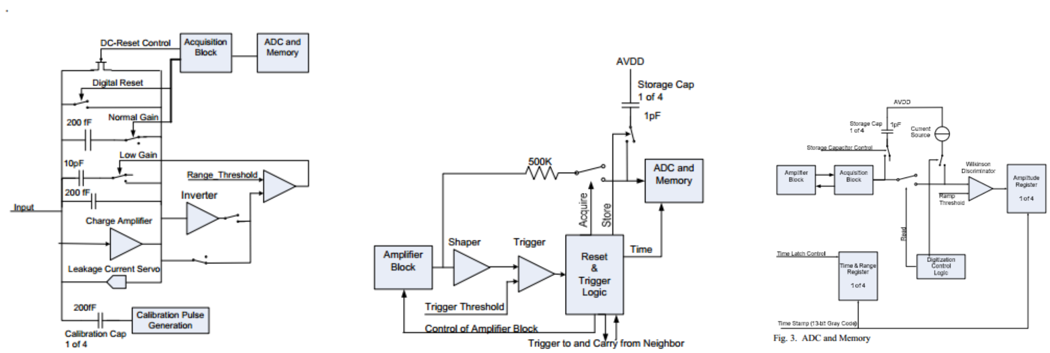

FIGURE 5. The Functional Blocks of KPiX

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.

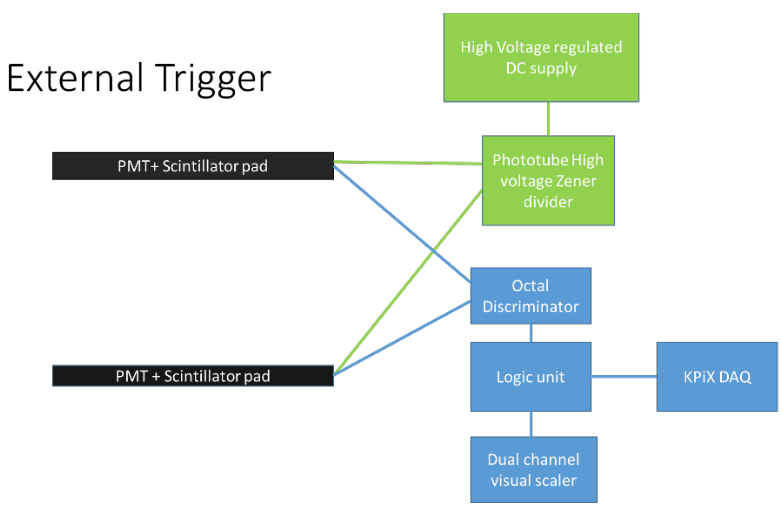

FIGURE 6. The external trigger layout. The Green block is the power supply block, while the blue blocks are the signal discriminator block.

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.

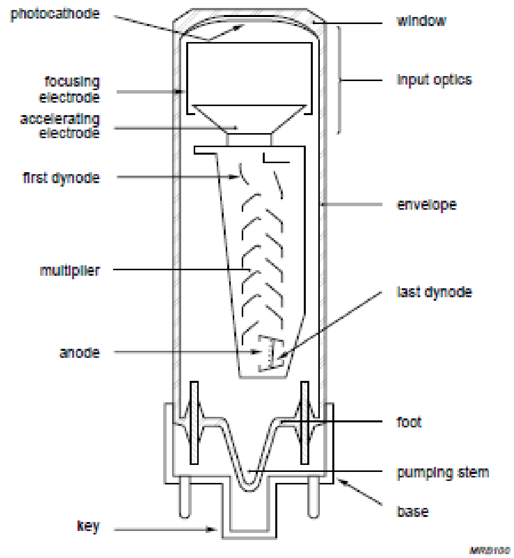

FIGURE 7. A Sample photomultiplier tube

ANALYSIS

Update on the Long term Behavior of the prototype GEM detector

Since the last note (LC-37)on the long term behavior of the prototype detector, the more data point has been taken. The following is a short review on the methodology and the new data. Refer to LC-37 for more details on the methods of the analysis.

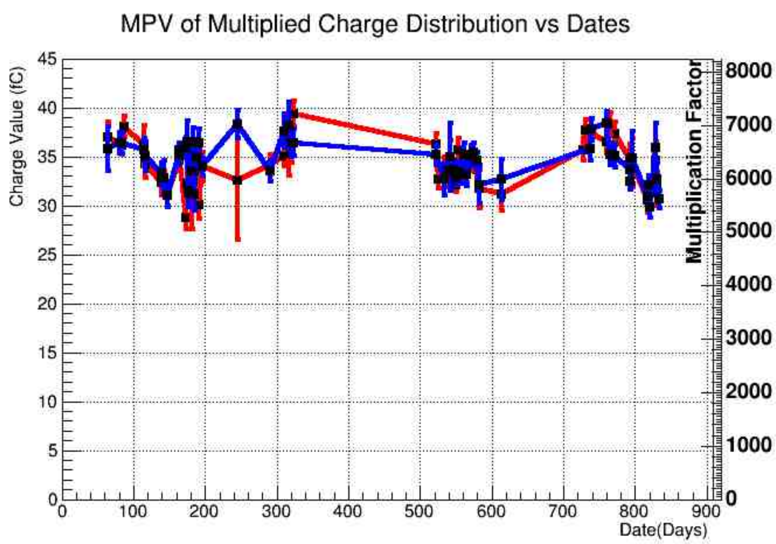

FIGURE 8 :MPV of multiplied charge distribution vs days (Red: Before pressure correction; Blue: After pressure correction

The Yearly behavior and seasonal dependence of the GEM detector

Experiments are conducted to find the yearly behavior of the detector and to find if there is a seasonal dependence on the performance of the detector.

Using data from the long-term behavior a lines are produced to describe the seasonal dependence of the detector.

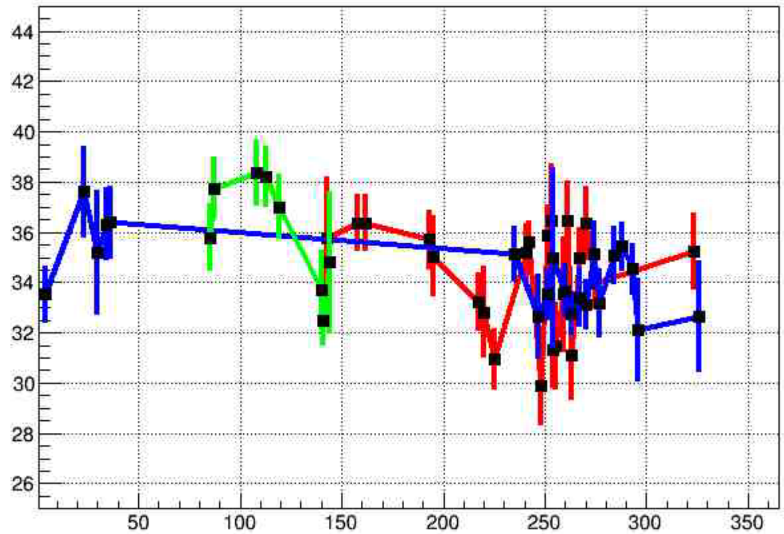

FIGURE 9: MPV of multiplied charge value distribution vs days of the year(Red: 2012, Blue: 2013, Green: 2014)

The following 3 graphs shows the charge distribution read out from the KPiX system after the magnification by the GEM detector fitted by a Gassian fit. The mean value averages at . Note that the chi-square/ndf values are close to 2 for all the distributions produced. Therefore the fit is not a good representation of the data.

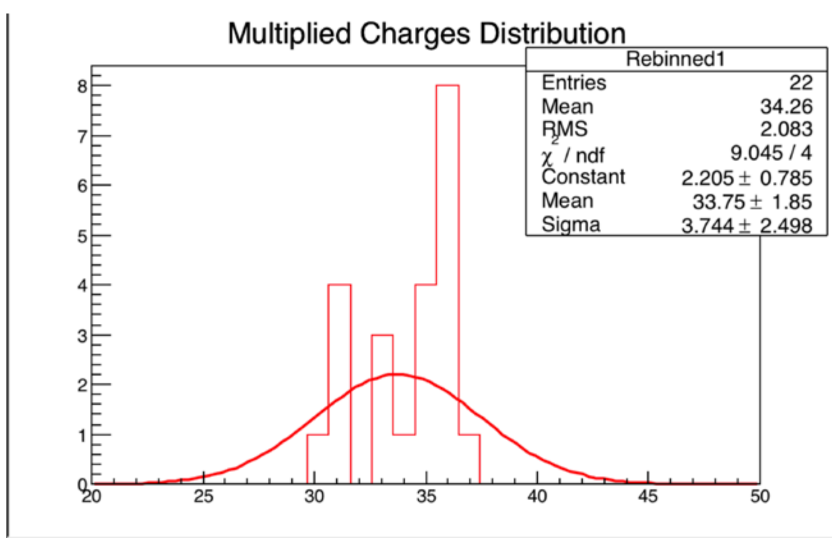

FIGURE 10: The charge distribution of the MPV value of charge distribution in year 2012

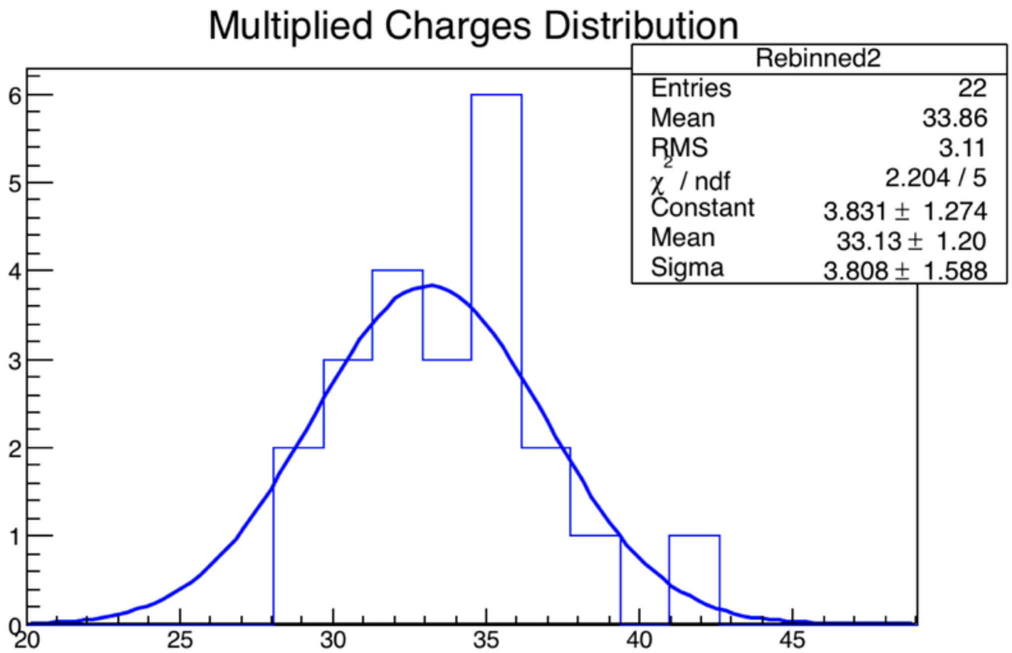

FIGURE 11: The charge distribution of the MPV value of charge distribution in year 2013

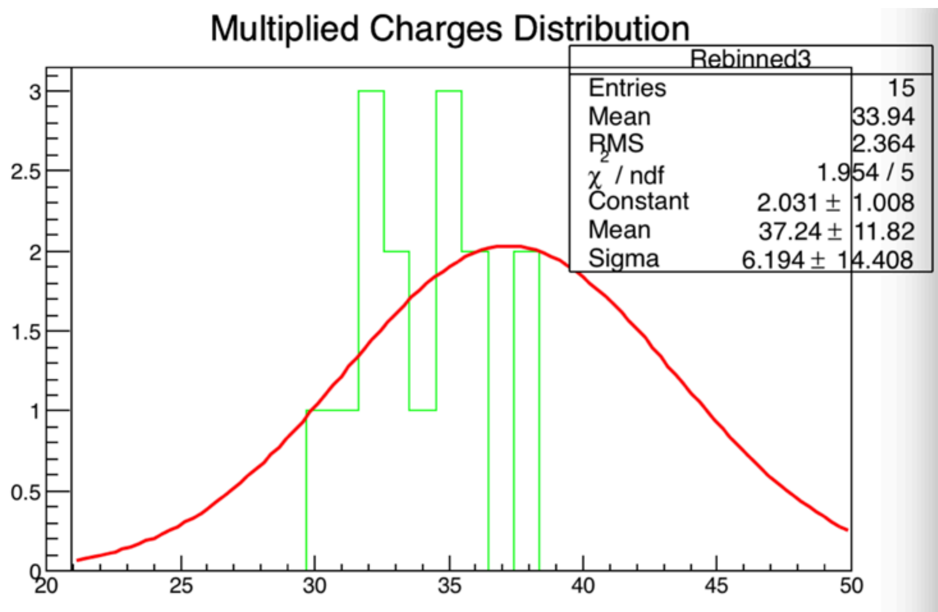

FIGURE 12: The charge distribution of the MPV value of charge distribution in year 2013

Seasonal dependence of the detector

Two different methods are devised to study the seasonal dependence of the gain (proportional to the MPV of the multiplied charge distribution, see LC-37) of the detectors.

First, the correlation ratio η, given by the following formula:

$$\eta^2 = \frac{{\sigma_{\overline{y}}}^2}{{\sigma_y}^2}, \text{ where } {\sigma_{\overline{y}}}^2 = \frac{\sum_x n_x(\overline{y}_x - \overline{y})^2}{\sum_x n_x} \text{ and } {\sigma_y}^2 = \frac{\sum_{x,i}(y_{xi} - \overline{y})^2}{n},$$

-(1)

The closer the correlation factor is to 1, the better the seasonal dependence.

Second, we can study the correlation between the lines by mutual information given by

$$I(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log\left(\frac{p(x,y)}{p(x)\,p(y)}\right),$$

-(2)

The factor between the joint probability normalized by each line's individual marginal probability could provide us with the information that is needed to correlate the lines. the mutual information factor I could take any value from 1 to 0. The higher the value, the higher the correlation between the 2 lines.

As time ran out before the ending of this semester, the seasonal dependence study has to carry on during winter break.

The aging effect of the electronics

The GEM read out signal is read by the KPiX electronic system. Therefore in order to ensure accurate and precise read out values, the performance of the electronics needs to be examined. To ensure consistent and precise signal output, the aging effect of the electronics needs to be studied.

The KPiX is a self-calibrating electronics system where the electronics gain of the chip is found by the self-signal generation block. The self-generated signal block in KPiX generates signal of known charge value and sends the signals through all three electronics blocks in KPiX. (Refer to the experimental setup session for details) Signals of certain values will be produce corresponding to the certain known charge value of the signals.

As the relationship between the charge value and the signal value is linear before saturation (under 140fC), a correlation factor called the electronic gain can easily be found.

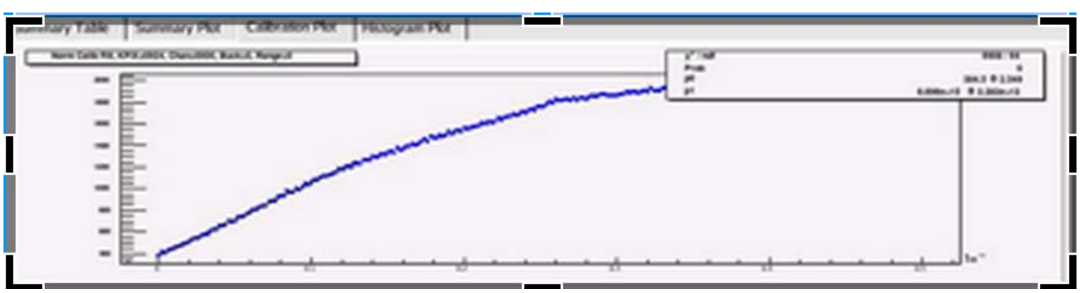

FIGURE 13: ADC value VS charge value (Graph generated by the KPiX 9 GUI)

The stability of the electronics gain value of each of the 64 read out channels being studied could telltale the aging effect of the system. The variation across channels revel information about the inter-channel variation in behavior of the chip.

Using monthly data over the period of 2 years, we found the electronics gain vs time graph of all 64 channels and the electronics gain distribution histogram, the result is shown as below. The intra-channel variation average at 5.00 E14 ADC/fC and the interchannel range is about 5.5E15 ADC/fC. The result shows that the read out electronics is very stable over the period of 2 years.

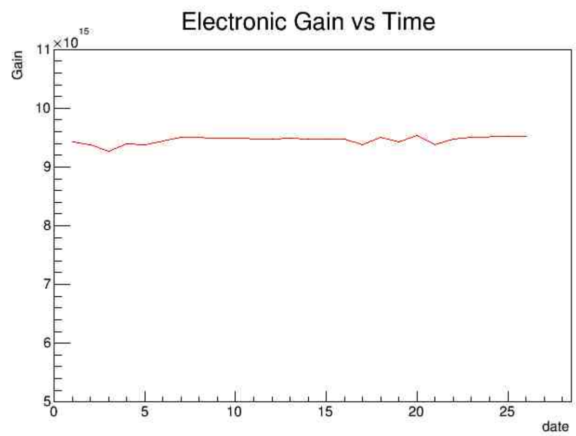

FIGURE 14: Electronic gain (ADC/fC) vs months (channel 0)

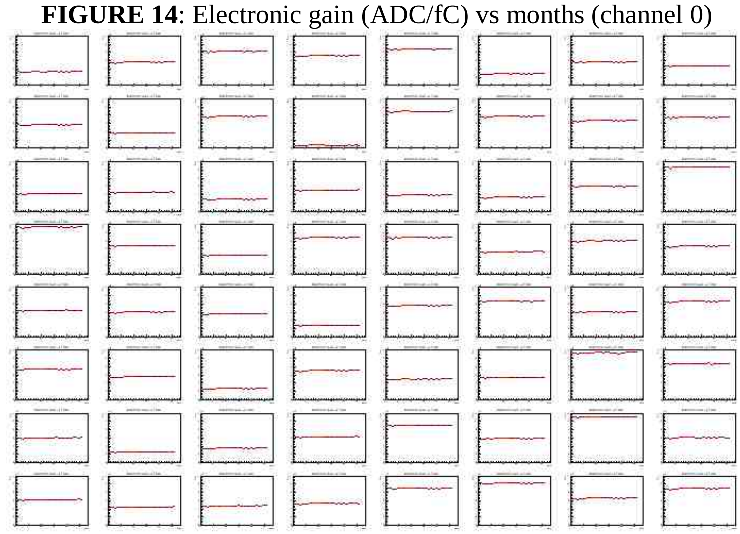

FIGURE 15: Electronic gain (ADC/fC) vs months (All 64 channels)

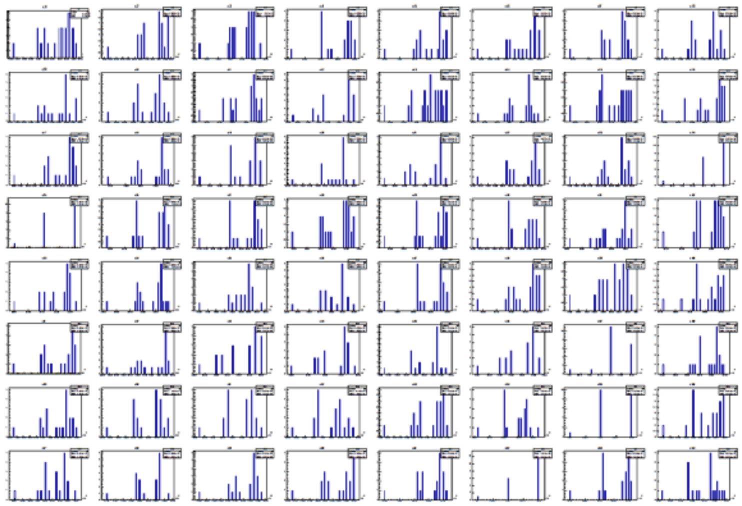

FIGURE 16: Electronics gain distribution (all 64 channels)

CONCLUSION AND FUTURE WORK

The study of the GEM multiplier shows that the detector is capable of long-term stable multiplication with little variation over time, which is consistent with the result found in LC-37. Building upon the previous study, the aging effect of the electronics is found and the result further ensures that the GEM system is a reliable candidate for the active element for the DHCAL system in the SiD in ILC. Futher study needs to be done on the seasonal dependence of the behavior of the detector, and individual channels could be analysis for further information on the behavior of the detector.

ACKNOWLEDGMENTS

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