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Physics topics in the International Linear Collider (ILC) requires detectors for high precision jet energy measurements.

The Gas Electron Multiplier (GEM) is a good candidate as an active gap detector for the calorimeter by the particle flow approach (PFA). (Yu)
Stands for Gas Electron Multiplier

Next Generation Micro-strip Detector Technology

Merit:

- Lower voltage is needed
- Lower chance of discharge/sparks that may damage the electronics
- Excellent Resolution.

Possible application:

- Particle and radiation detector in ILC and LHC, medical Diagnostics and Portal Imaging.
- Intensifier for CCD camera
- X-ray Polarimeter to study polarization of supernovas and pulsars

8 keV absorption radiography of a small mammal. The horizontal image is 6 cm.

A cosmic ray passes through chamber it ionizes ArCO2 mixture in the chamber. Ionized electrons travel down by the electric field (drift region: 1.3e+4 V/m), they pass through holes in the 2 layers of GEM foils with a much higher electric field (7e+6 V/m). The high electric field cause a cascade of electron to be ionized (Multiplication). The multiplied electrons is read out at the anode board.

Gain = \# of electrons read out on the anode / \# of electrons ionized in the drift region

The cross section of a GEM detector shows the structure: Window, Drift Region, Transfer Region, Induction Region, GEM Foils, and Readout Strip. The Ar:CO2 mixture ratio is 80:20.

The image of a standard GEM foil shows regular pierced bi-conical holes: Diameter of the holes: D(cu):85µm; D(polyimide):55µm
Dr. Andy White proposed to have GEM as an active element of DHCAL in 2002. The group has been working on the GEM project since then.

**ArCO2 gas Supply**
- Ar: CO2 -> 80:20

**High Voltage Supply**
- Across each GEM chamber (1900V)

**Low Voltage supply**
- For the readout electronics (5-6V)

**2 scintillator**
- Sandwiching the GEM chambers
- Work as a Hodoscope
- The Kpix system only read out when both scintillators detect a signal -> Less stress on the electronics

**Kpix Readout system**
- System that reads out the signal from GEM to the computer
- System is able to read a magnitude of signal -> can measure effective gain and efficiency of the GEM chamber

**4 GEM chambers**
- Specifications:
  - Active area: 280x280 mm^2
  - Active gas room: 350x350x6 mm^3
  - 64 readout channels (1x1 cm^2)

**Dimensions and Specifications**
- GEM foil: 310x310 mm
- Active area: 280x280 mm^2
- Active gas room: 350x350x6 mm^3
- 64 readout channels (1x1 cm^2)
- **Effective Gain** -> An Important index of how efficient GEM is.
- **Stability** of GEM chamber over a long period of time
  - The more stable it is the more reliable of an candidate GEM is as a gap detector
  - Investigation of the long term behavior of GEM is therefore important
Gain = \# of Electrons read out on the anode board/\# of electrons ionized in the drift region

\# of Electrons read out on the anode board = MPV/Charge of an electron

If the \# of electron ionized at the drift region is constant, then the MPV value of the charge distribution plot is a good analogy to the effective gain of the GEM device!
Gain = $-303.9 \times \text{Pressure (in Pascal)} + 35509$ 

Motivation:
The gain process $\rightarrow$ pressure dependent
(GEM is a open air system)

$k$:
Pressure correct the cosmic run data to get cosmic ray amplification data that reflects the performance of the detector under 1 atm.

Effective Gain = $\#$ of Electrons read out at the anode board/$\#$ of Electrons ionized at the drift region

Gain data of a cosmic run

[*1] Park, Seongtae PhD. “Hadron Calorimeter with GEMs“, Powerpoint, CALICE Workshop, March 2010

[*2]: Baldelomar, Edward (Unpublished).
- Long term behavior of the **MPV of the charge value** at the anode read-out pads

![MPV vs Date](image_url)
Before pressure correction

\[ \langle Q \rangle = 33.12 \pm 0.40 \text{ fC} \]

After pressure correction

\[ \langle Q \rangle = 34.75 \pm 0.37 \text{ fC} \]
Challenge:
Aging readout KPiX chip.
Some channels are performing worse than the rest.

Study:
Isolating the bad channels

Possible solution:
Raising the threshold
Masking the channel

Cluster of hits in some channels
High RMS value for some channels in pedestal data
Creating bad Channels: By normalized hit count in cosmic ray runs

- **X9 cosmic ray runs done over 2 months**

**Normalization** of the hit count of each channel

Creating a Normalized hits of each channel vs runs graph

Finding a list of channels with the highest average normalized hit value
Locating bad channels: by the **RMS value** of the pedestal data

The RMS value of the pedestal data is a reflection to the condition of the electronics.

Lower RMS -> Better electronics condition

**Finding the RMS value of the pedestal data**

**Creating RMS value over time graph of every channels**

**Finding a list of channels** with a the highest average RMS value
### Noise run top 10 highest RMS

<table>
<thead>
<tr>
<th>Channel#</th>
<th>Average RMS value (femtoCoulomb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>126</td>
<td>1.357756</td>
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<tr>
<td>192</td>
<td>1.219496</td>
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<tr>
<td>0</td>
<td>1.15875</td>
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<tr>
<td>159</td>
<td>1.071566</td>
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<tr>
<td>254</td>
<td>1.04514</td>
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<tr>
<td>161</td>
<td>0.963316</td>
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<tr>
<td>510</td>
<td>0.879144</td>
</tr>
<tr>
<td>490</td>
<td>0.867683</td>
</tr>
<tr>
<td>128</td>
<td>0.774578</td>
</tr>
<tr>
<td>158</td>
<td>0.770403</td>
</tr>
</tbody>
</table>

### Cosmic Run top 10 Normalized Hits

<table>
<thead>
<tr>
<th>Channel#</th>
<th>Normalized Hits</th>
</tr>
</thead>
<tbody>
<tr>
<td>126</td>
<td>0.039742</td>
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<tr>
<td>0</td>
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<tr>
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<tr>
<td>127</td>
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<tr>
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<tr>
<td>490</td>
<td>0.017771</td>
</tr>
</tbody>
</table>
✓ **Pressure Correction:**
  ➢ Found the gain of the chamber at 1 atm.

✓ **The Noise Channels Studies:**
  ➢ Some channels need to be **masked** or the **threshold need to be raised**.

✓ **The Long Term Behavior:**
  ➢ GEM is capable of giving us a **stable long term behavior**
  ➢ Chamber is Characterized by:
    ~35 fC MPV for cosmic ray MIPs
    ~0.5 fC of KPiX noise,
    **A few fC of Chamber noise**

We conclude that GEM-based active layer should work well for a digital calorimeter.
UTA has worked on the GEM system for over 10 years:

- Different chambers have been used: 10cm x 10cm, 1 inch x 1 inch, 30cm x 30 cm.

The 30x30 prototype chamber has shown a stable behavior over the past 2 years. A new prototype chamber 1m x 1m LGEM is under construction right now for us to understand the technology better as a potential gap detector for the project in ILC.

[*] Park, Seongtae PhD. “Hadron Calorimeter with GEMs“, Powerpoint, CALICE Workshop, March 2010
(Above): Kpix read-out pad, made out of 64 small individual pads, stimulation of a hit

Adding the highest and second highest value together for a summed charge value
-> Enable detecting of charge signal that fall between 2 readout pads