Avalanche simulations on single GEMs

Mythra Varun Nemallapudi[1]

[1] Department of Physics, University of Arkansas
Mentors - Rob Veenhof, Leszek Ropelewski
Thesis external advisor - Archana Sharma
Thesis internal advisor - Reeta Vyas
Working group - GEMs for CMS

23-11-2011, RD51 mini week

Outline

- Experiments on Gasmixtures (Oct 2011)
  - Method
  - Observation
  - Analysis
- Experiments on Gasmixtures (Nov 2011)
  - Method
  - Observation
  - Analysis
- Charge-up effects
- Models proposed
- Penning parameter
  - Description and method
  - Comparison with experimental data
  - Goodness of fit
- Further analysis and Future work

Gain measurement with different gas mixtures (Oct)

(in collaboration with) Laura Franconi and Dr.Renju Thomas

Experimental setup

- $E_{\mathrm{D}} = 2\ \mathrm{kV/cm},\ E_{\mathrm{I}} = 3\ \mathrm{kV/cm}$
- $V_{\mathrm{GEM}} = 200V\ to\ 560V$
- $\mathrm{Argon} - \mathrm{CO_2}$
- $\mathrm{c(Ar)} =\ 50\%, 70\%, 80\%, 90\%$

Experimental method

- Voltages applied
- X-ray irradiated with 2mm collimator
- Anode current measured with pico-ammeter
- Higher gains measured first($V > V_{start}$)
- Lower gains measured next ($V < V_{start}$)
- V_{start} value chosen slightly below the plateau
- Same spatial point on the GEM for all measurements

Gain Measurements (Oct)

Observation

Gain

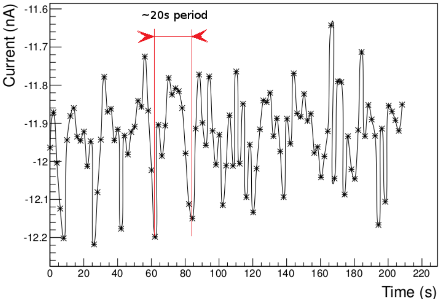


Figure: Plot of current vs time for the mixture Ar-CO_2 $80 - 20\%$ at $480V$

Fourier transform

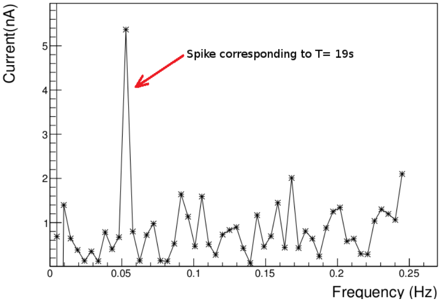


Figure: Plot of current vs frequency for the mixture Ar-CO_2 $80 - 20\%$ at $480V$

Gain Measurements (Oct)

Observation

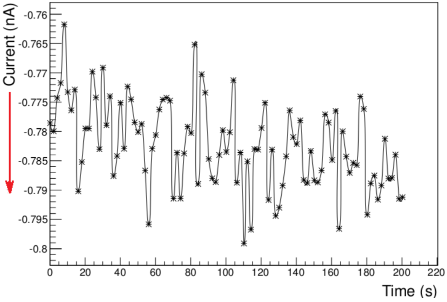


Figure: An increase in current observed for the mixture Ar-CO_2 $80-20\%$ at $360V(V_{start})$

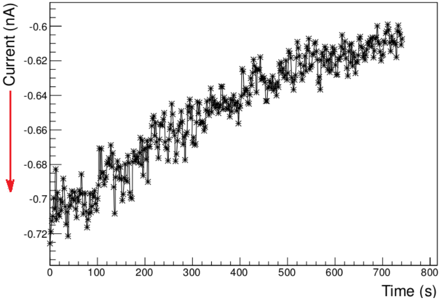


Figure: A decrease in current observed for the mixture Ar-CO_2 $80-20\%$ at $340V$

Note: Values of current are negative owing to the measured electron current

Gain Measurements (Oct)

Observations

- Fourier analysis reveals 19s oscillations in current
- Gain decreases by $15 - 30\%$ for lower gains
- Gain is stable for higher gains
- Gain offset upto 30% between lower and higher gains
- Marked difference in the gain trend above and below V_{start}

Analysis

- Oscillations not due to filter settings in current device
- Shift in gain can be due to Charge up effects
- Source of oscillation unknown

Gain measurement with different gas mixtures (Nov)

(in collaboration with) Laura Franconi, Özkan Şahin and Yalçın Kalkan

Experimental setup

- $E_{\mathrm{D}} = 2\ \mathrm{kV/cm}$, $E_{\mathrm{I}} = 3\ \mathrm{kV/cm}$
- $V_{\mathrm{GEM}} = 50V\ to\ 520V$
- $\mathrm{Argon} - \mathrm{CO_2}$
- $\mathrm{c(Ar)} =\ 70\%, 90\%$

Experimental method

- Different, clean spatial points on GEM for every voltage setting
- Points spaced $0.5\mathrm{cm}$ apart to avoid irradiation on other regions
- Pulse height measured for low rates at plateau voltage
- X-ray irradiated with 1mm (dia) collimator
- Gain measured upwards in voltages starting $50\mathrm{V}$
- Current measured for $\sim 15 - 30$mins every point

Gain Measurements (Nov)

Observation

Low gain

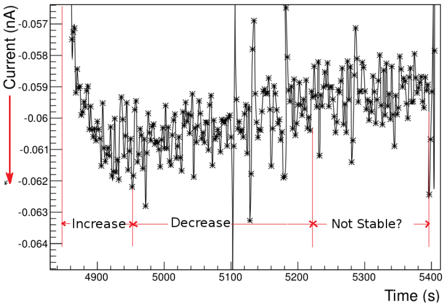


Figure: Plot of current vs time for the mixture Ar-CO_2 $70 - 30\%$ at $320V$

High gain

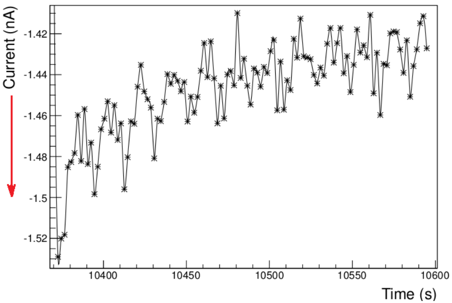


Figure: Plot of current vs time for the mixture Ar-CO_2 $70 - 30\%$ at $480V$

Note: Values of current are negative owing to the measured electron current

Gain Measurements (Nov)

Observation

1. Region A- Initial increase in current to reach a maximum value
2. Region B- Decay of the current
3. 'Region A' was not observed for higher gains
4. Time taken to reach maximum decreases with increasing gain
5. Relative variation in gain decreases with increasing gain
    - $\sim 30\%$ for lower gains
    - $\sim 5\%$ for higher gains

Charge-up
Previous observations(Gabriele Croci)

Gain Stability

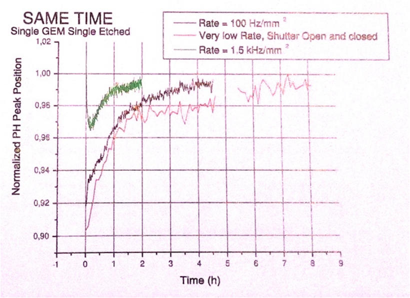


Figure: Plot of GEM stability over time extracted from diploma of Gabriele Croci - Study of relevant parameters of GEM-based detectors

Interpretation Two phenomenon occuring:

1. Charge-up: Responsible for focussing of E-field thereby increasing gain
2. polyimide polarization: Causes an opposing E-field thereby decreasing gain

Note: Values of current are negative owing to the measured electron current

Charge-up
Rate of loss

- $\mathrm{I_{anode}} = 2\mathrm{nA}$
- Number of $e^{-} = 1.25 \times 10^{10} s^{-1}$
- Xray collimated area - Circle of $1\mathrm{mm}$ diameter
- Number of gem holes in the given area $= 45$
- Expected loss at 20% of effective gain$= 2.5 \times 10^{9} s^{-1}$
- Rate of e^{-} deposition per hole $=5.5 \times 10^{7}\mathrm{Hz}$

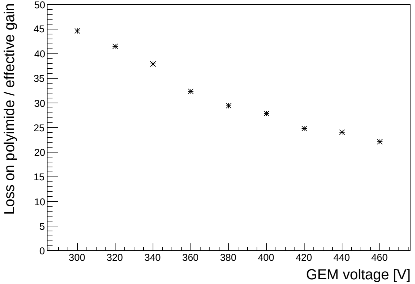


Figure: Plot of % fraction of loss on polyimide/effective gain vs $\mathrm{V_{GEM}}$

Charge-up
Model

Gain increase

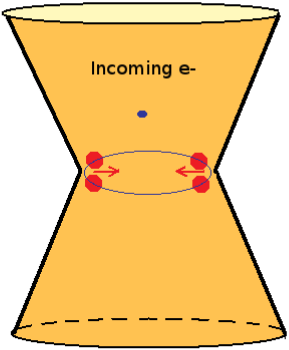


Figure: E-field due to $e^{-}s$ on polyimide that reduce further losses

Gain increase

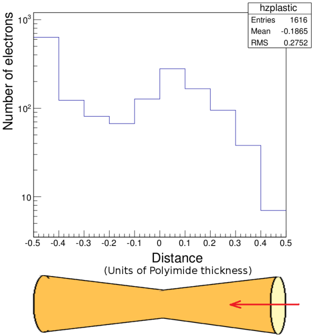


Figure: Histogram of loss distribution on polyimide at low gains

Charge-up

Model

Gain decrease

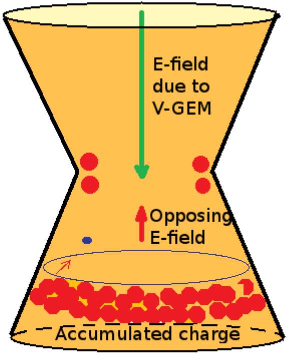


Figure: Large accumulation of charge causing an opposing E-field

Gain decrease

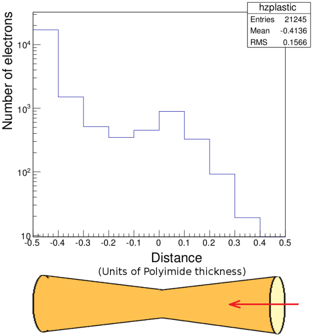


Figure: Histogram of loss distribution on polyimide at high gains

Gain Measurements (Nov)

Analysis

- A clear case of charge-up influencing the gain
- Increase of gain
  - Initially accumulated $e^- s$ distort the E-field pushing away the incoming $e^- s$ from polyimide which would otherwise be lost
  - polyimide loss $\%$ decreases drastically, reaching zero (arguably)
  - Effectively increases the gain
- Reduction of gain
  - As more charges accumulate, a vertical component of E-field is produced
  - This reduces the net E-field inside GEM hole
  - Situation is equivalent to a reduced GEM voltage

Gain Measurements (Nov)
Further Analysis

- Calculation of the two predominant phenomena:
  1. Polyimide loss function (essentially a rapidly decreasing function)

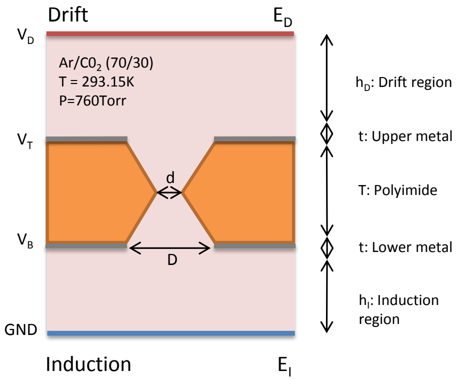
$$Loss\% = L_0 \times f \downarrow (t_0)$$

  2. Net charge deposited and the opposing E-field developed
- Polyimide conductivity influences the recombination of e^- deposited on polyimide
- Scaling of time and gain doesn't agree with the expected values
- Space charge influence should be considered
- Role of ion deposition in reducing the gain
- X-ray stability to be checked

Simulation Setup

Standard GEM

- $V_\mathrm{D} = -V_\mathrm{T} - E_\mathrm{D} \times h_\mathrm{D}$
- $V_\mathrm{I} = V_\mathrm{B} + E_\mathrm{I} \times h_\mathrm{I}$
- $V_\mathrm{T} = -V_\mathrm{B} = -\frac{1}{2} V_\mathrm{GEM}$
- $\varepsilon_{r,\mathrm{polyimide}} = 3.5$
- $\rho_{r,\mathrm{metal}} = 0$
- $h_\mathrm{D} = 3\mathrm{mm},\ h_\mathrm{I} = 2\mathrm{mm}$
- $D = 70\mu\mathrm{m},\ d = 50\mu\mathrm{m}$
- $T = 50\mu\mathrm{m},\ t = 5\mu\mathrm{m}$
- $P = 140\mu\mathrm{m}$



Finding the Penning parameter

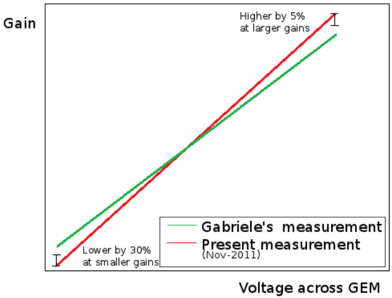


Figure: Hypothetical plot showing the gain behaviour for different measurement sets and its effect on χ^2

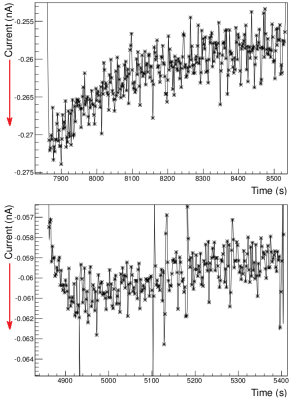


Figure: Gain behavior at lower(fig.below) and higher(fig.above) gains influencing the initial value

Finding the Penning parameter

Simulation setup

- $E_{\mathrm{D}} = 2\ \mathrm{kV/cm}$
- $E_{\mathrm{I}} = 3\ \mathrm{kV/cm}$
- $V_{\mathrm{GEM}} = 200\ \mathrm{V\ to\ 500\ V\ in\ steps\ of\ 20V}$
- $\mathrm{Argon - CO_2}$
- $\mathrm{c(Ar)} = 70, 90$
- Number of avalanches for $\mathrm{V_{GEM} = 200V\ to\ 440V\ is\ 10,000}$
- Number of avalanches for $\mathrm{V_{GEM} = 460V,\ 480V\ and\ 500V\ is\ 3,000}$

Experimental data

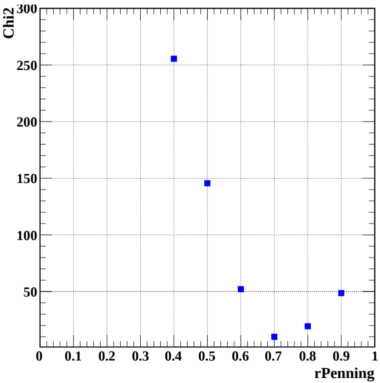
Measurements on gas mixtures Nov(2011)

The equation

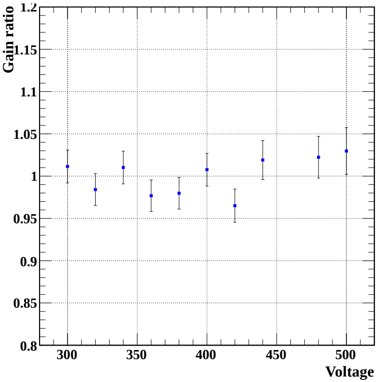
$$\chi^2 = \Sigma \left(\frac{G_{measured} - g_{scaling} G_{simulated} - g_{offset}}{\sqrt{\sigma^2_{measured} + \sigma^2_{calculated}}} \right)^2$$

Finding the Penning parameter

χ^2 plot for Ar/CO_2 (70/30)

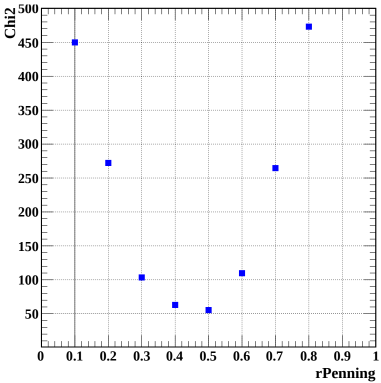


Gain ratio at rP = 0.70

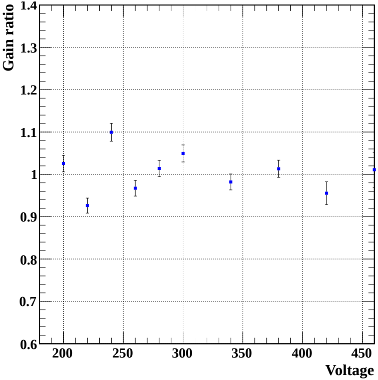


Finding the Penning parameter

χ^2 plot for Ar/CO_2 (90/10)



Gain ratio at rP = 0.50



Future work
Overview

1. Gain measurements at low X-ray rates
2. Measurements for gain dependence on diameter and pitch
3. X-ray machine stability measurements
4. Achieve a complete understanding of charge-up through simulations and comparison with measurements

Future work

Low rate measurements

Set up

- X-ray collimator 1cm diameter
- Reduced photon rate by absorbers
- Nickel absorber to filter K_β line of X-ray
- Previously unused GEM for measurements
- $\text{I}_{\text{sampling}}$ reduced from 2s to 20ms

Initial-rate of charge up per GEM hole

- Greater number of GEM holes (4500)
- Charge up rate per hole reduces by 100 times
- Sampling zoomed 100 times
- $\sim 10^4$ factor slowing down of charge up

Future work

Influence of GEM hole diameter

- Need for the measurement
  - Difference in the behavior of GEM gains at lower diameters between experimental data (S Bachmann et al. -1999) and simulated data
  - Inconsistencies in GEM fabrication affect gain
- GEMs being fabricated for the following hole diameters: $30 - 120\mu\text{m}$,
- Charge up effects crucial at low gem diameter

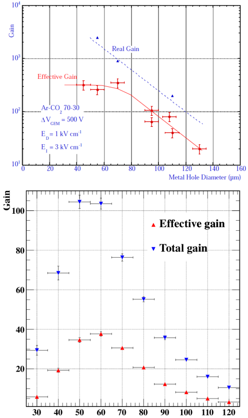


Figure: Comparison between measured(top) and simulated(bottom) gains

Acknowledgements

Rob Veenof, Leszek Ropelewski - RD51, Archana Sharma - CMS
Sven Dildick, Laura Franconi, Renju Thomas, Andrey Marinov, Stefano Colafranceschi, Marco Villa, Miranda van Stenis,Özkan Şahin, Yalçın Kalkan, Ankit Mohapatra and Tania Moulik