Department of Nuclear Engineering and Management
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Position Sensitive Radiation Detector Based on G-GEM with Pulse Counting System for Beta Ray Imaging

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Outline

1. **Introduction**

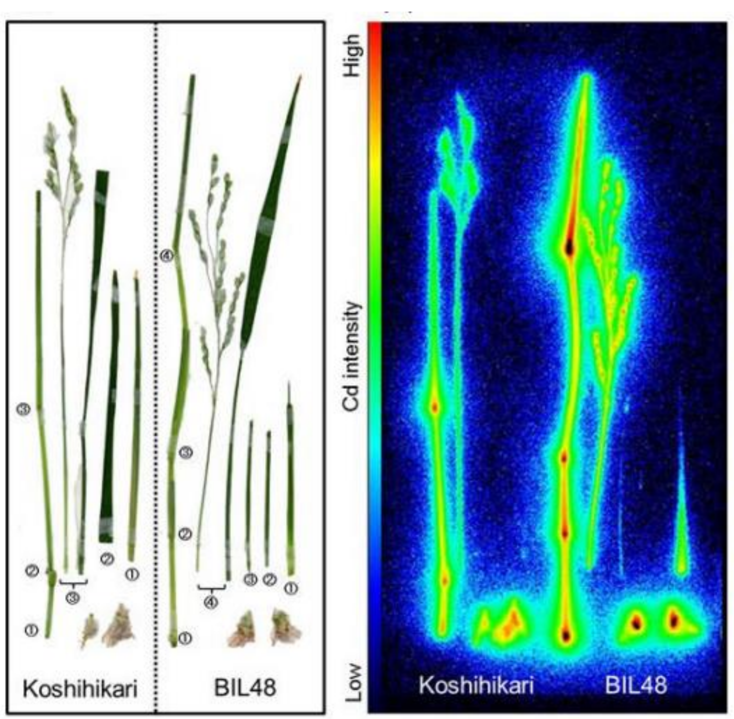
2. **Materials and Methods**
    - **Glass Gas Electron Multipliers (G-GEMs)**
    - **Charge Readout and Readout Electronics**

3. **Results and Discussion**

4. **Conclusion**

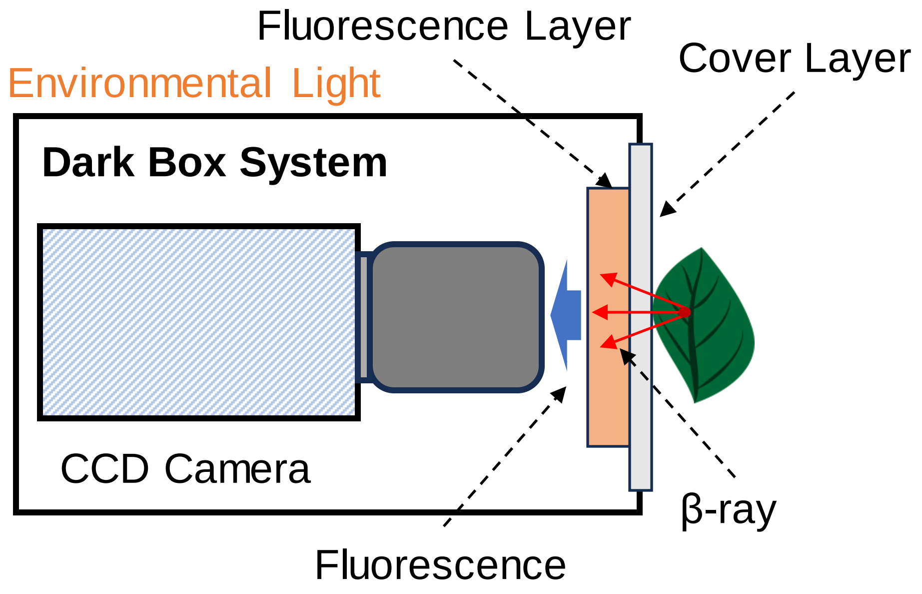
Beta Ray Imaging

Living Plant Autoradiography



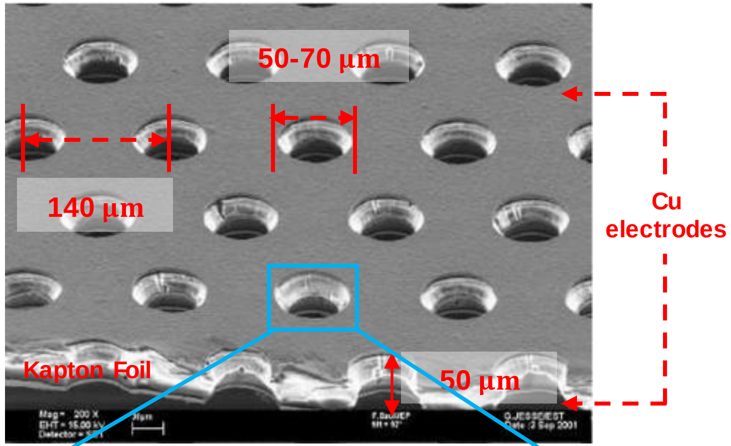
[1] Ishikawa et al. BMC Plant Biology 2011, 11:172

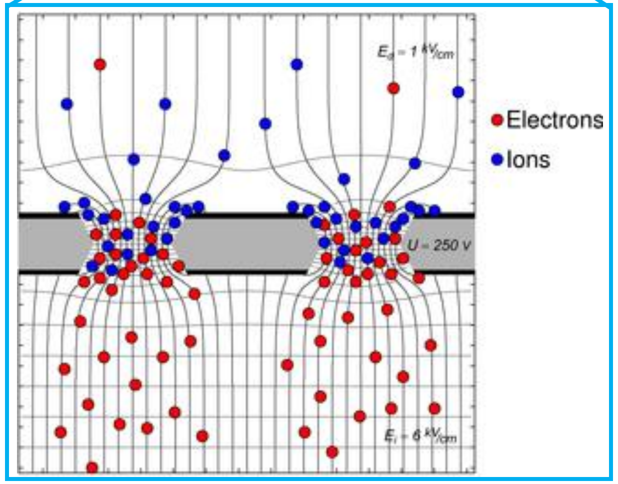
- To observe transport and distribution of chemical substances.
- To observe radioactive contamination of plants after nuclear accident.

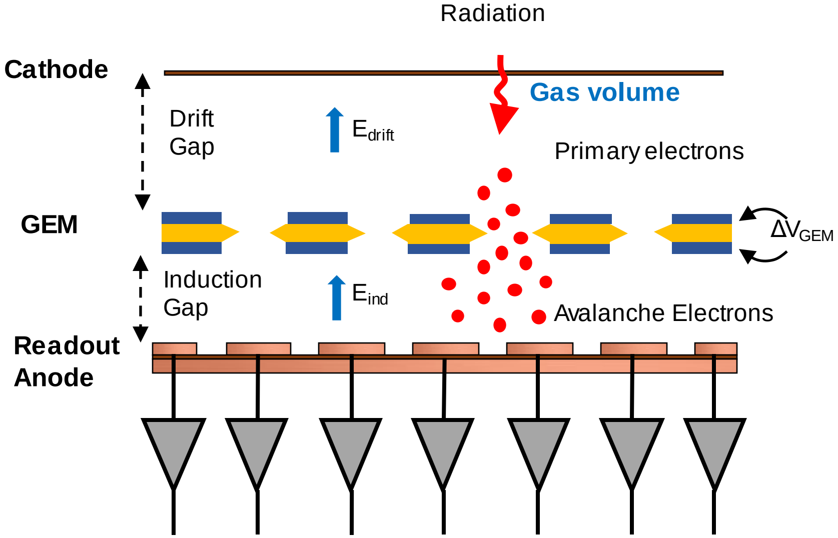


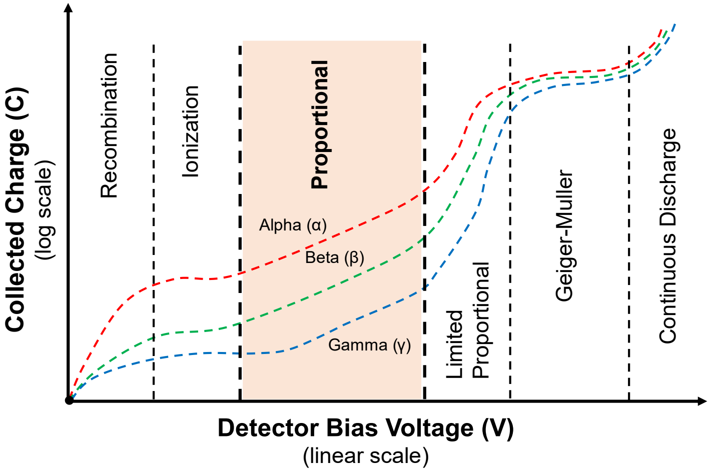
The needs for imaging detectors:
- Low energy detection
- Energy resolving capability
- Real time imaging
- Large area imaging
- Insensitivity to visible light

MPGD and Gas Electron Multipliers (GEMs)









- It is fabricated using photolithography process incorporating Kapton foil substrate and Cu electrodes.
- Holes act as proportional counter.

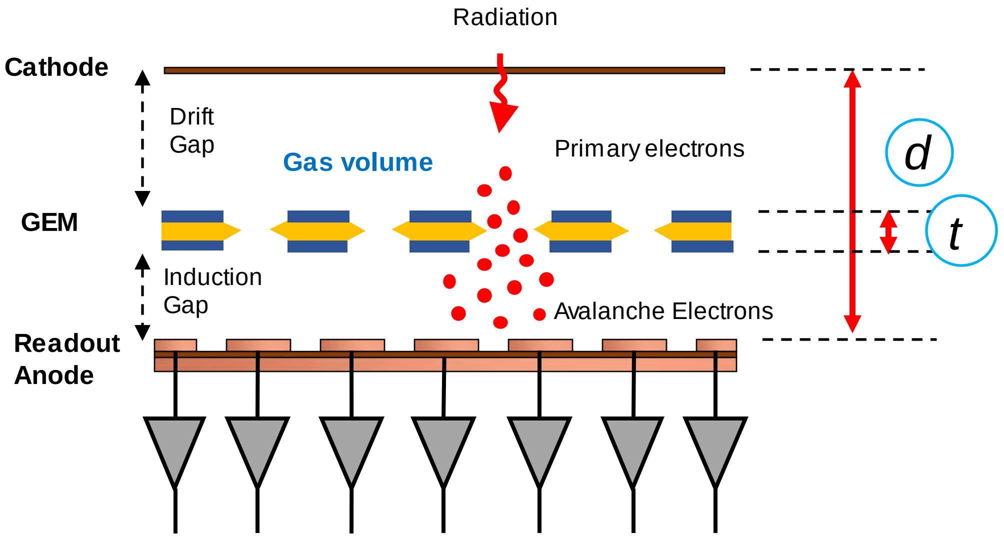
Advantages:

- High charge gain
- Real time imaging
- Large area imaging
- Insensitive to the visible light

[1] F. Sauli, Nucl. Instrum. Methods Phys. Res. A, 805, 2 (2016)
[2] https://flc.desy.de/tpc/basics/gem.

Glass Gas Electron Multipliers (G-GEMs)

GEMs based Detectors



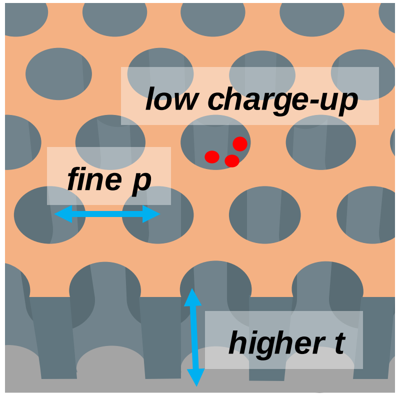
- There are Trade-off between charge gain (t) and spatial resolution (d).

- **G-GEMs** are made using photosensitive etchable glass substrates through photolithography techniques (*t in hundreds*).

Some Substrate Properties

"HOYA Corporation"

	Kapton (Polyimide)	PEG3	PEG3C
Volume Resistivity (Ω.cm)	10^{18}	8.5×10^{12}	4.5×10^{14}
Bending Stress (MPa)	69	65	150
Young's Modulus (GPa)	18.6	79.7	90.3



G-GEM Substrate:
- High gain in single stage (thick substrate)
- Electrical stability (low volume resistivity)
- Mechanical stability (high bending stress)
- Low outgassing (inorganic substrate)

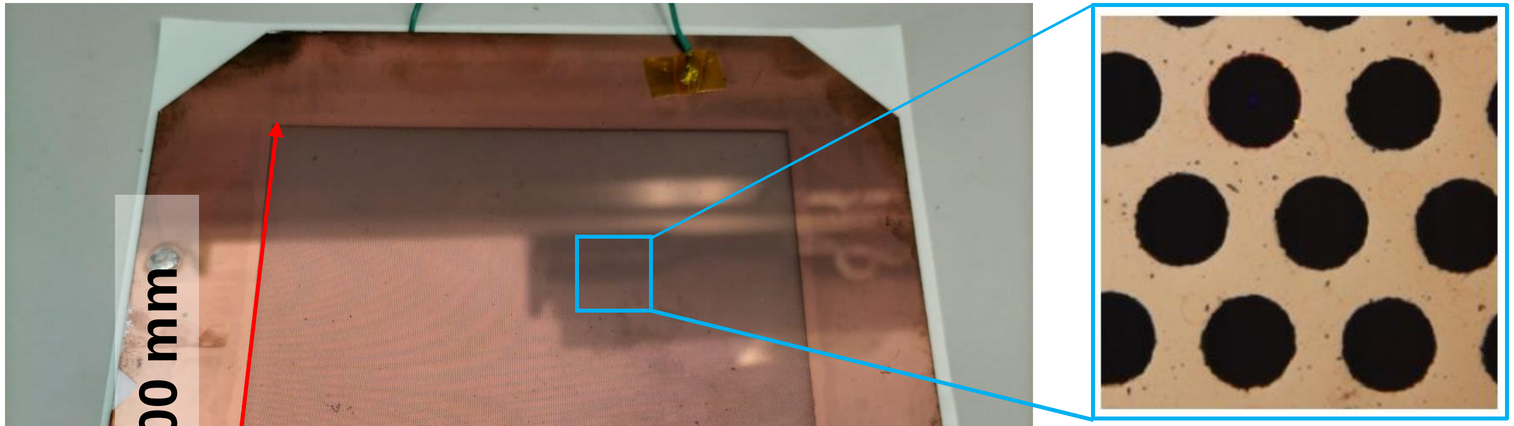
\+ G-GEMs based detectors: Low complexity, power consumption, and cost

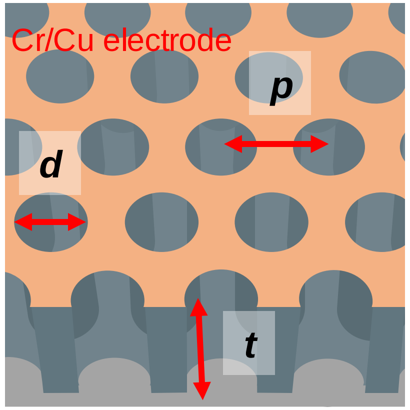
Readout System for G-GEMs

Objectives:

- Developing G-GEM based detector for imaging detector, especially for beta ray imaging using pulse counting system.
  - G-GEM characterization
  - Imaging Detector Evaluation
  - Beta Ray Imaging Demonstration

Glass Gas Electron Multipliers (G-GEMs)

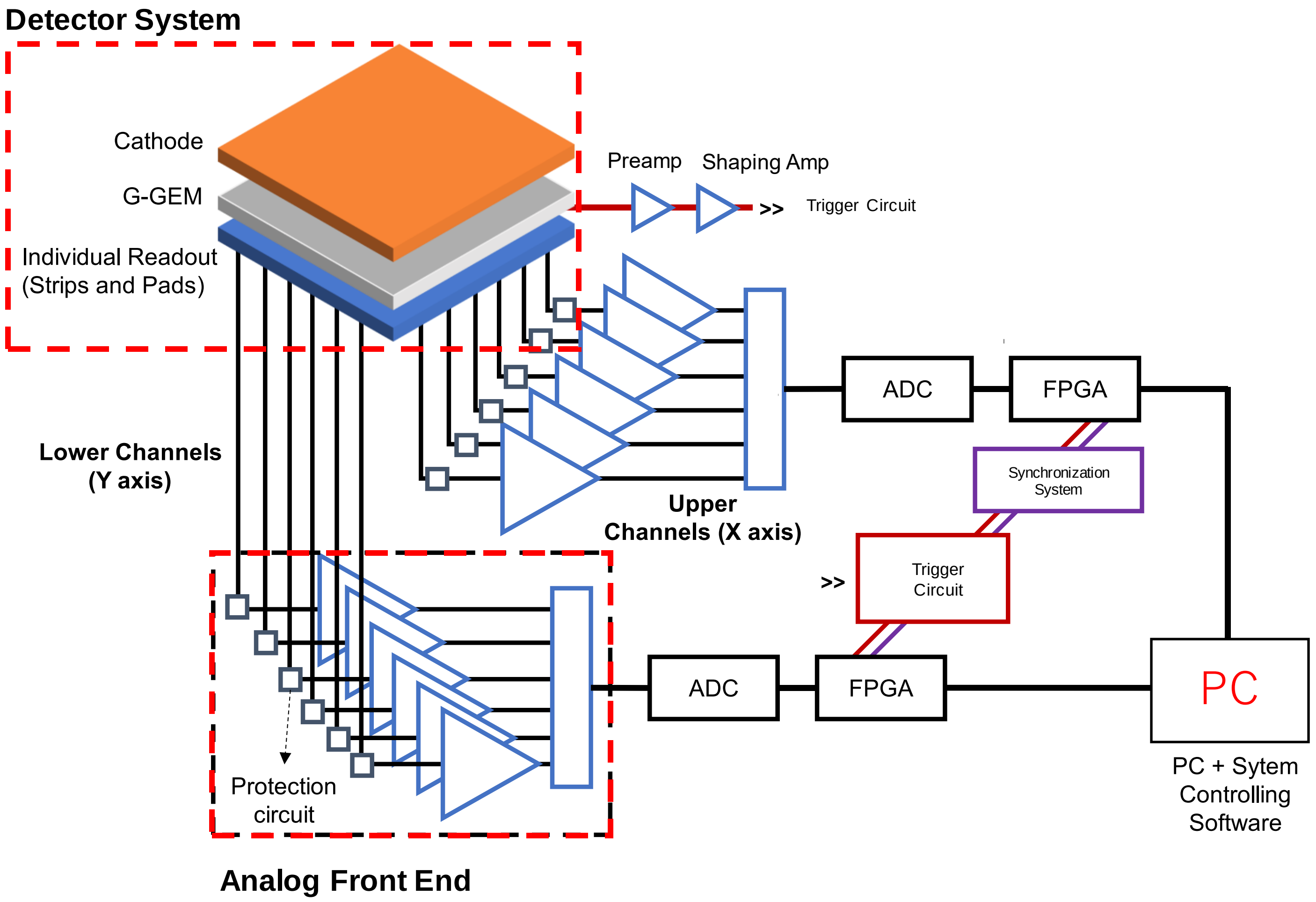




	Kapton (Polyimide)	PEG3
Substrate Thickness *t* (µm)	50	680
Hole Diameter *d* (µm)	55-70	170
Hole Pitch *p* (µm)	140	280
Hole Shape	Biconical	Cylindrical
Electrodes	Cu (5 µm)	Cr (Few hundred Å) / Cu (2 µm)
Sensitive Area (mm^2)	100 × 100 (Typically)	100 × 100

- The G-GEM was fabricated in the thick substrate of *PEG3* from Hoya Corporation to achieve high gain with single stage through *photolithography* (wet etching) and UV irradiation methods.

Imaging System



Detector System

- Cathode, single stage G-GEM, strip and pad readout inside chamber system.

Analog Front End

- Charge sensitive preamplifier and Shaping amplifier

Signal Conversion

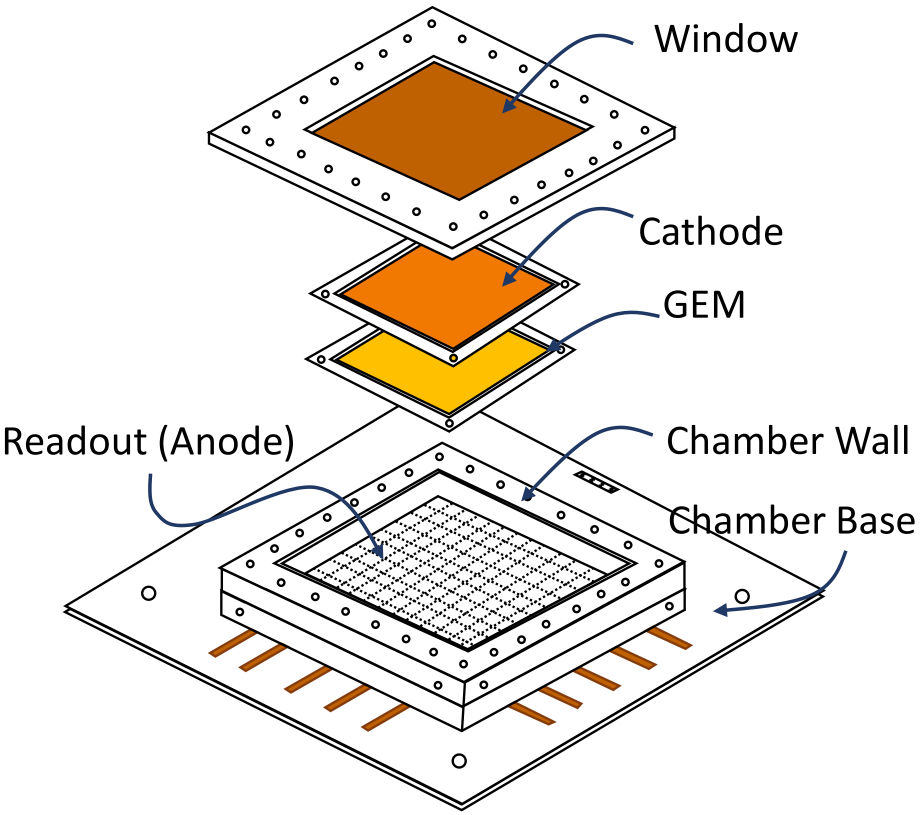
- ADC

Data Acquisition System

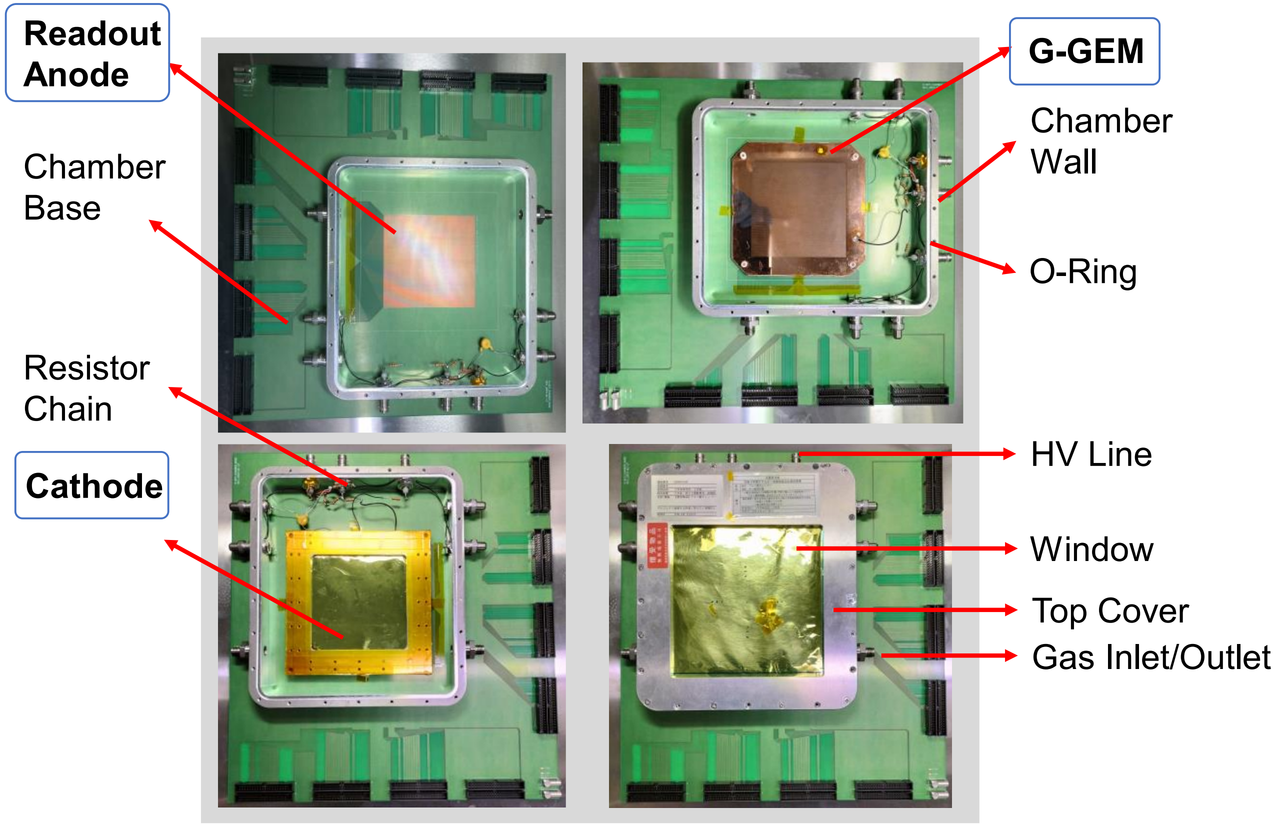
- FPGA and PC

Detector System

Detector Structure

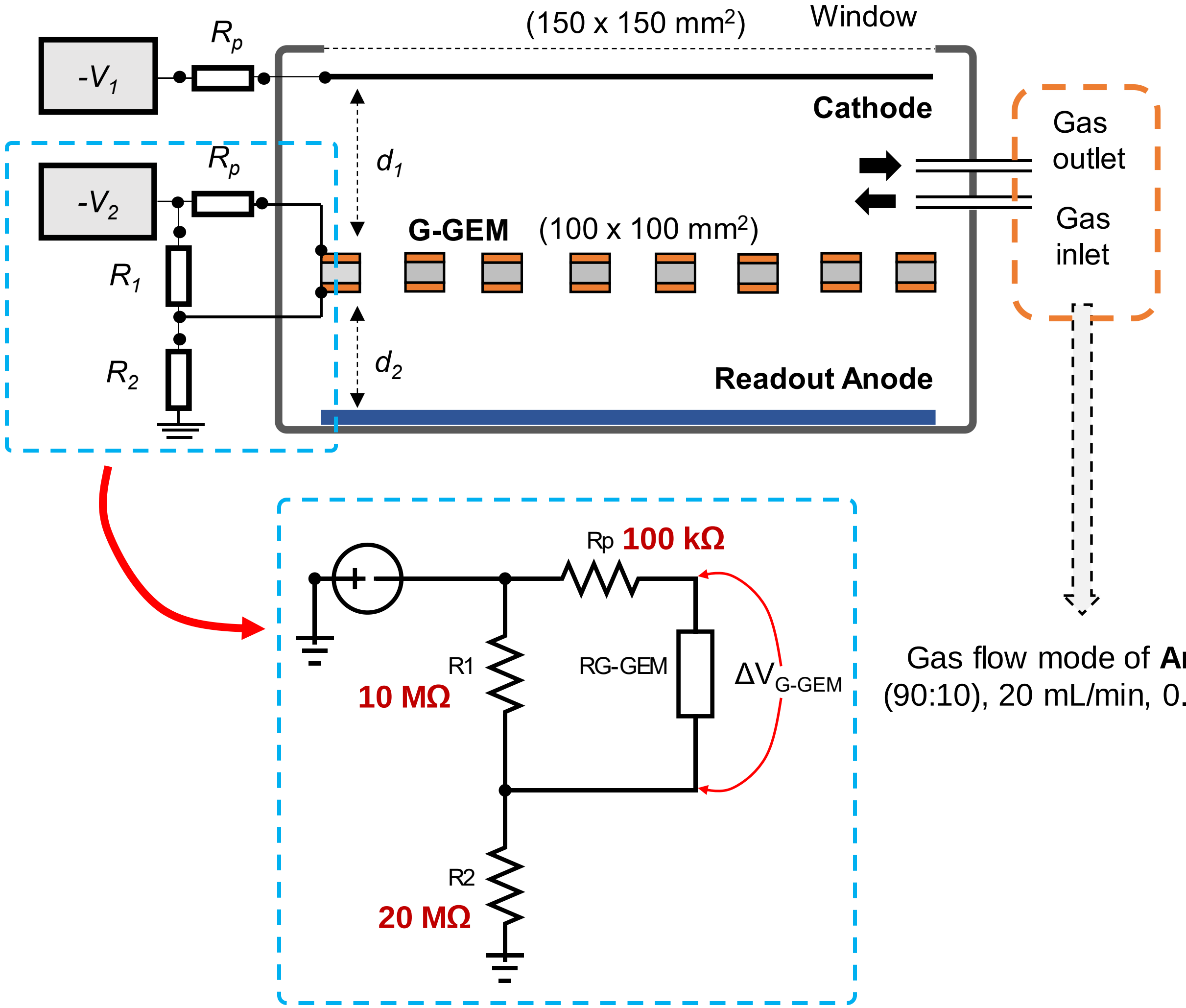


Implemented System



- Window and cathode : aluminized Kapton foil (150 × 150 mm^2).
- G-GEM : single stage PEG3 G-GEM

Detector System



Gas flow mode of **Ar/CH_4** (90:10), 20 mL/min, 0.1 MPa

- Voltage Difference between G-GEM electrodes:

$$\Delta V_{G-GEM} = V_2 \frac{R_{parallel}}{R_{parallel} + R_2}$$

$$R_{parallel} = R_1 // \left(R_p + R_{G-GEM}\right)$$

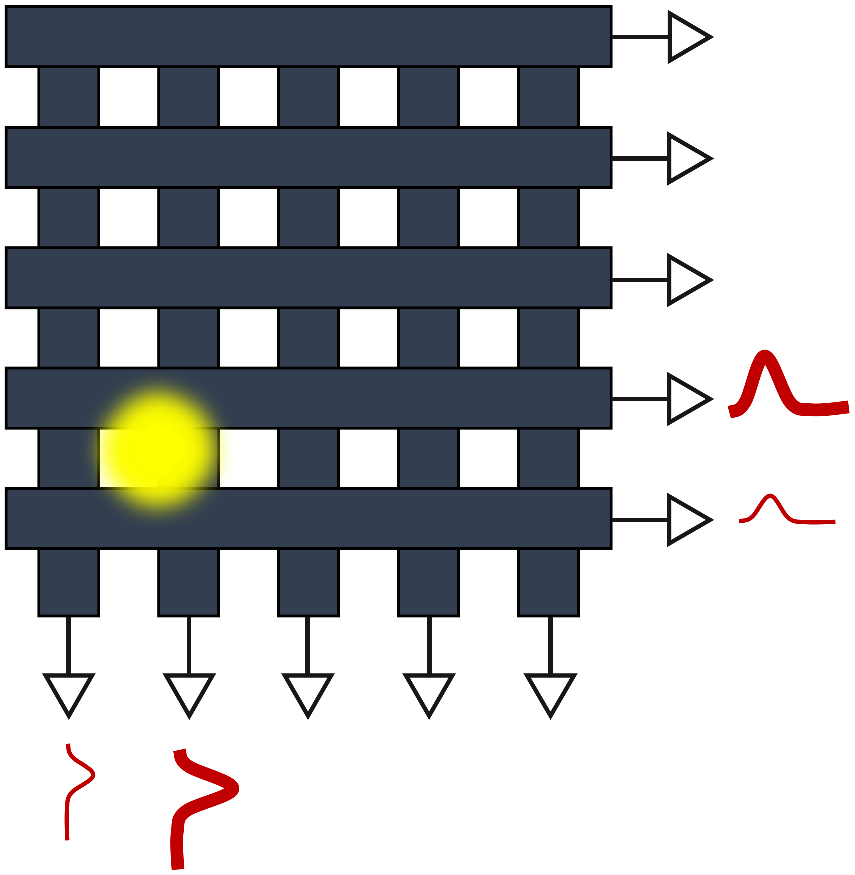
- Electric field in the drift and induction region:

$$E_{drift} = \frac{V_2 - V_1}{d_1}$$

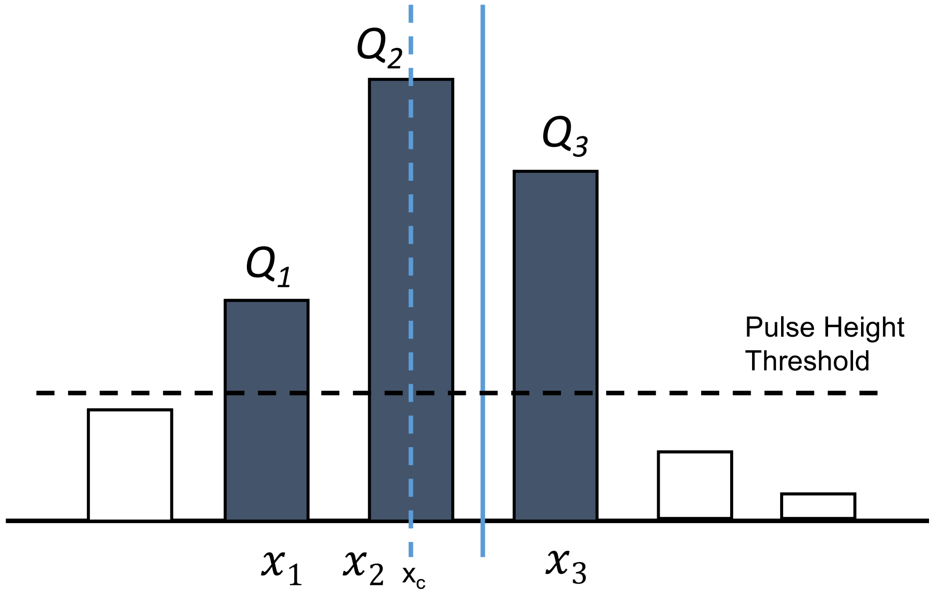
$$E_{ind} = \frac{V_2 - \Delta V_{G-GEM} - V_{anode}}{d_2}$$

Image Reconstruction

Event illustration in strip readout



Central of Gravity:

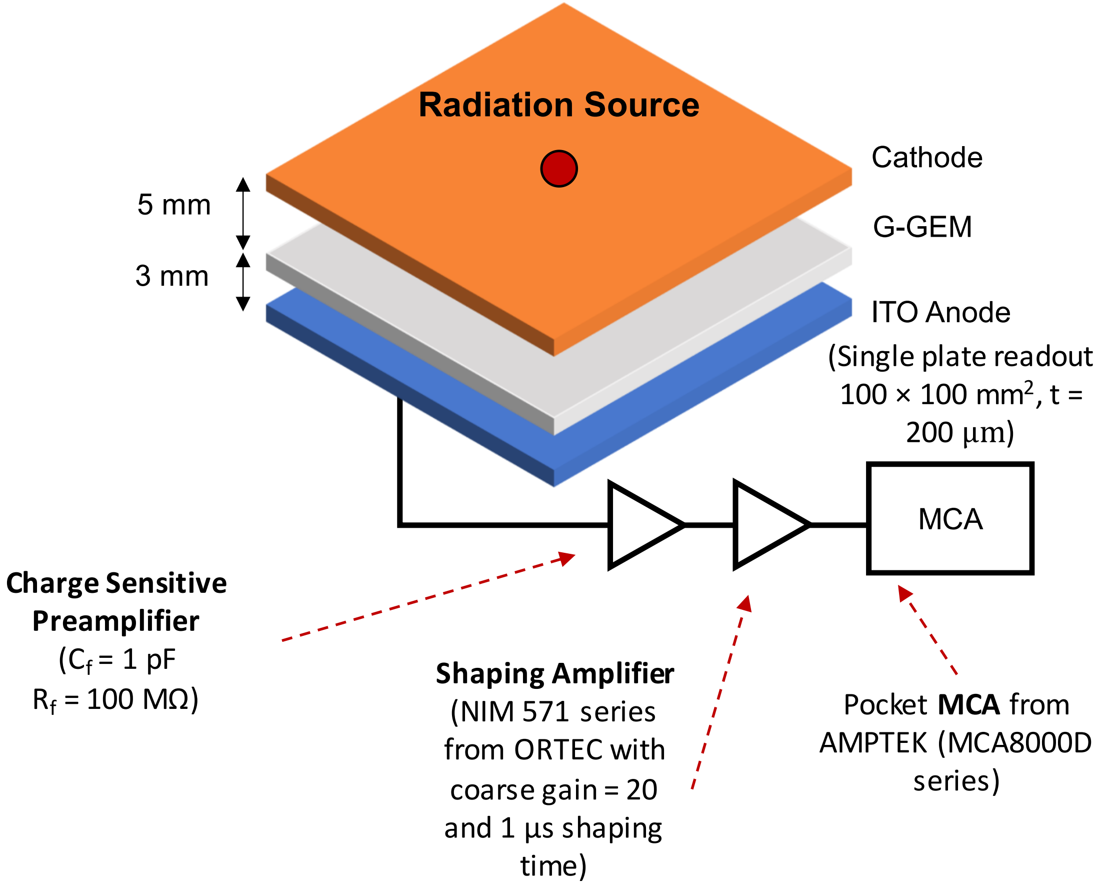


Interaction position in x: $x_c = \frac{\sum_{i=0}^{N} Q_i x_i}{\sum_{i=0}^{N} Q_i}$

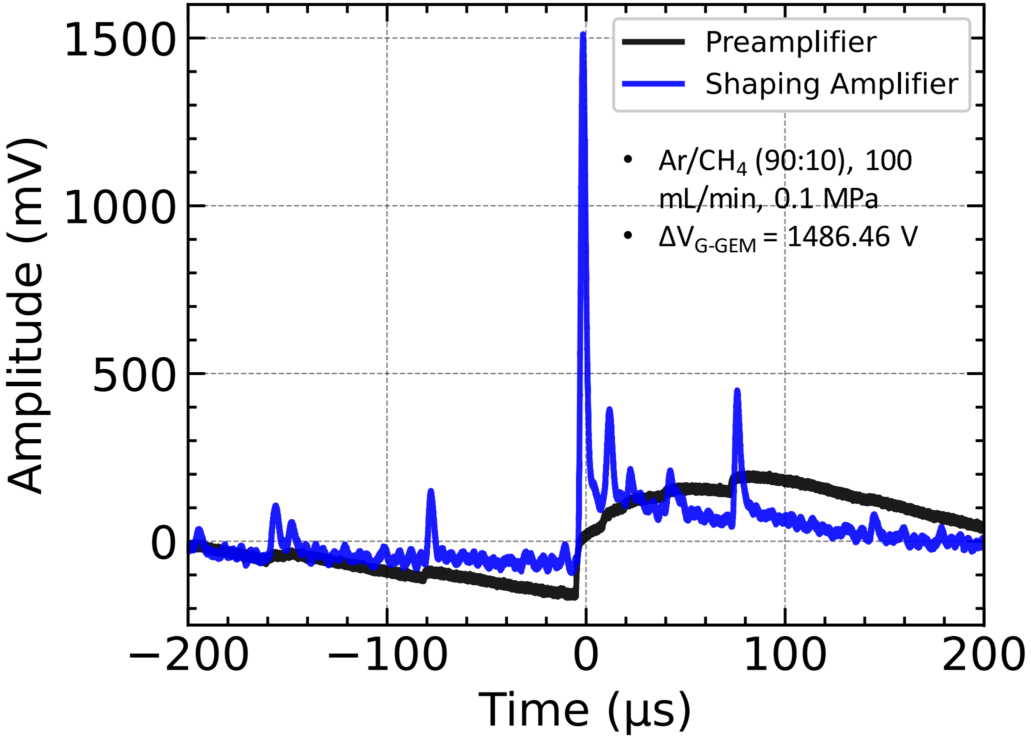
Interaction position in y: $y_c = \frac{\sum_{i=0}^{N} Q_i y_i}{\sum_{i=0}^{N} Q_i}$

1. G-GEM Characterization

Characterization Setup



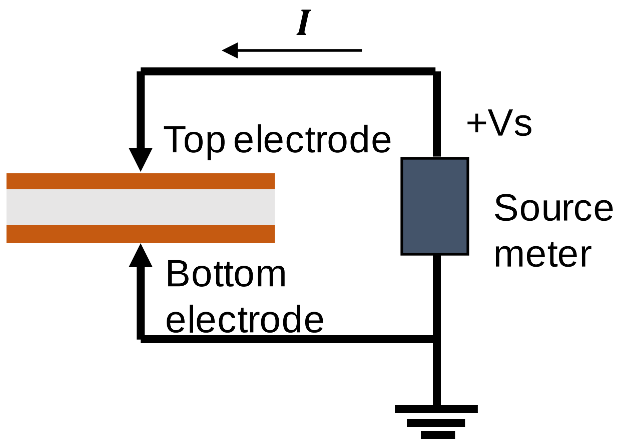
Typical Waveform of G-GEM

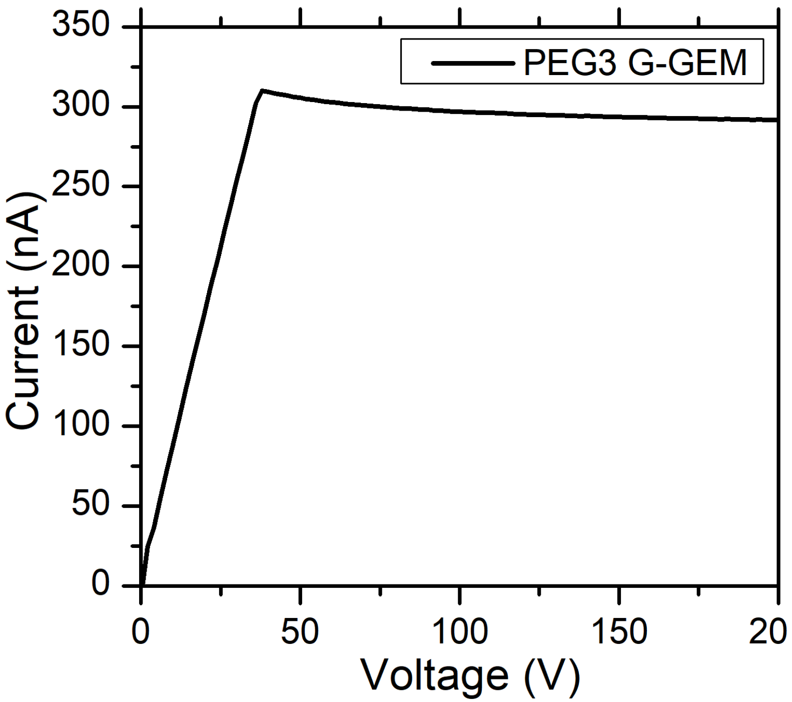


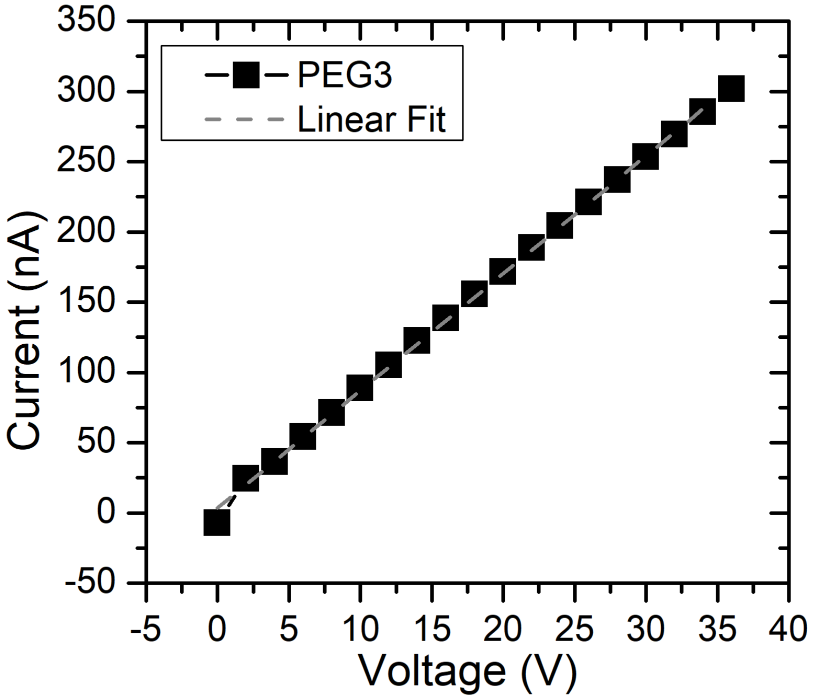
The pulse was based on ^{90}Sr radiation with activity less than 1 M Bq.

1. G-GEM Characterization

Resistance Between G-GEM Electrodes



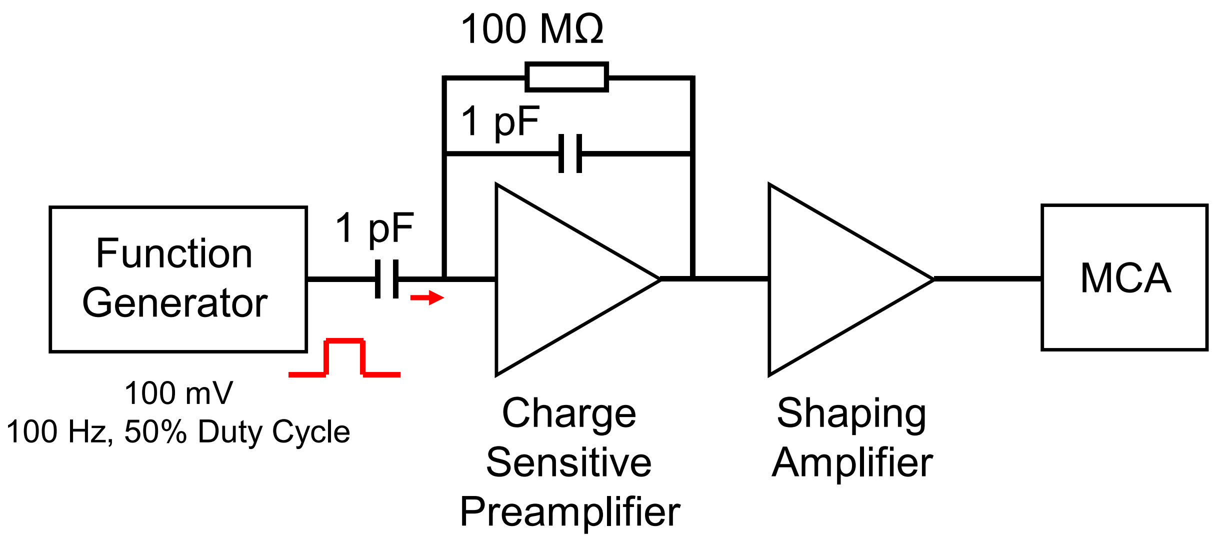




- The surface resistance of G-GEM is calculated based on the V-I profile in the ohmic region.
- The resistance between two electrode was $1.23 \times 10^{8}\ \Omega$.

1. G-GEM Characterization

Calibration (reference charge) for Effective Gain Estimation:

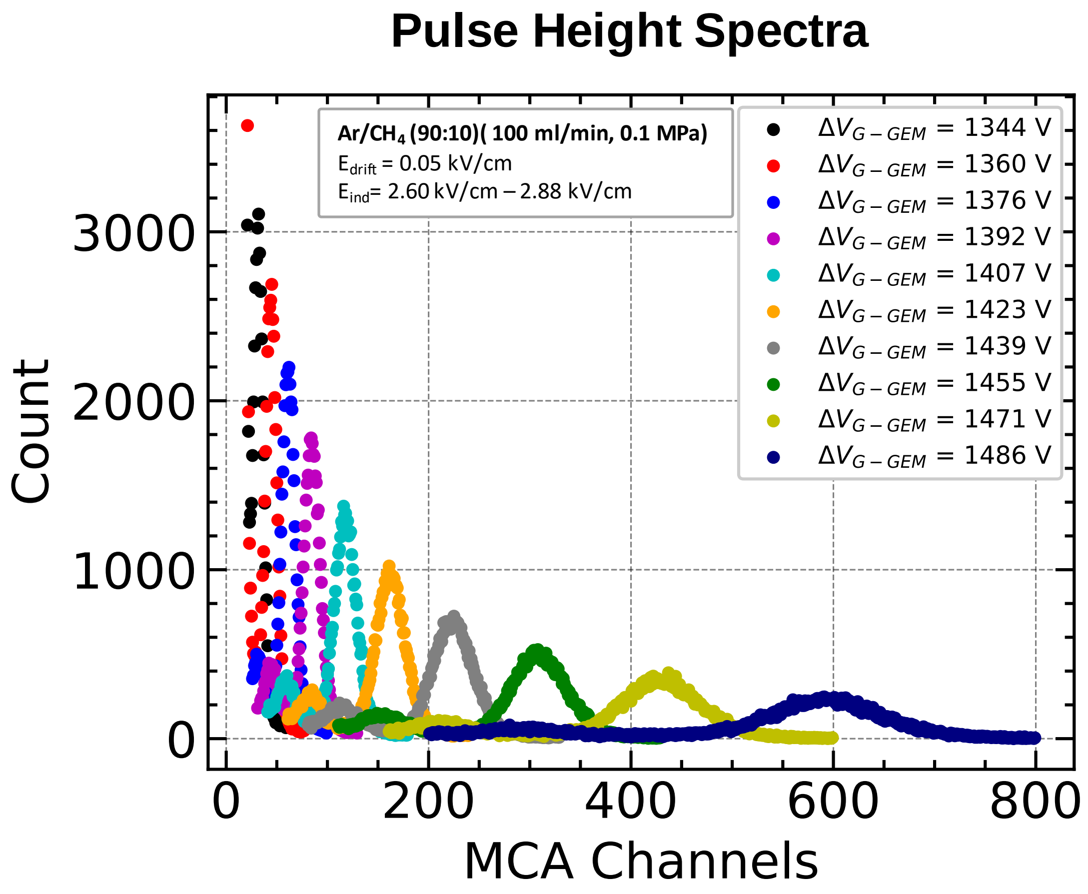


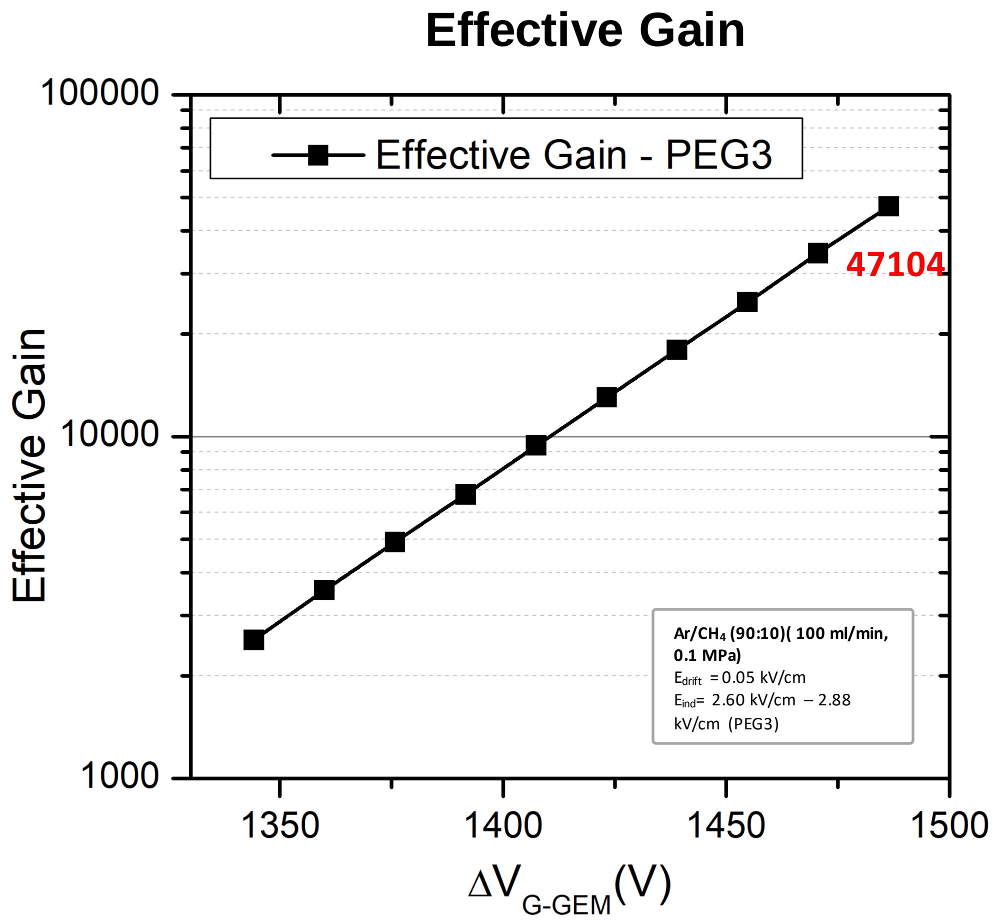
$$G_{eff} = \frac{CV_iW}{eE}\left(\frac{cent_{rad}}{cent_{ref}}\right)$$

W = 0.026 keV for Ar Gas
E = 5.9 keV for ^{55}Fe
e = 1.6×10^{-19} C

- The effective gain was estimated based on comparison main peak centroid of ^{55}Fe (5.9 keV) and centroid from reference pulses.

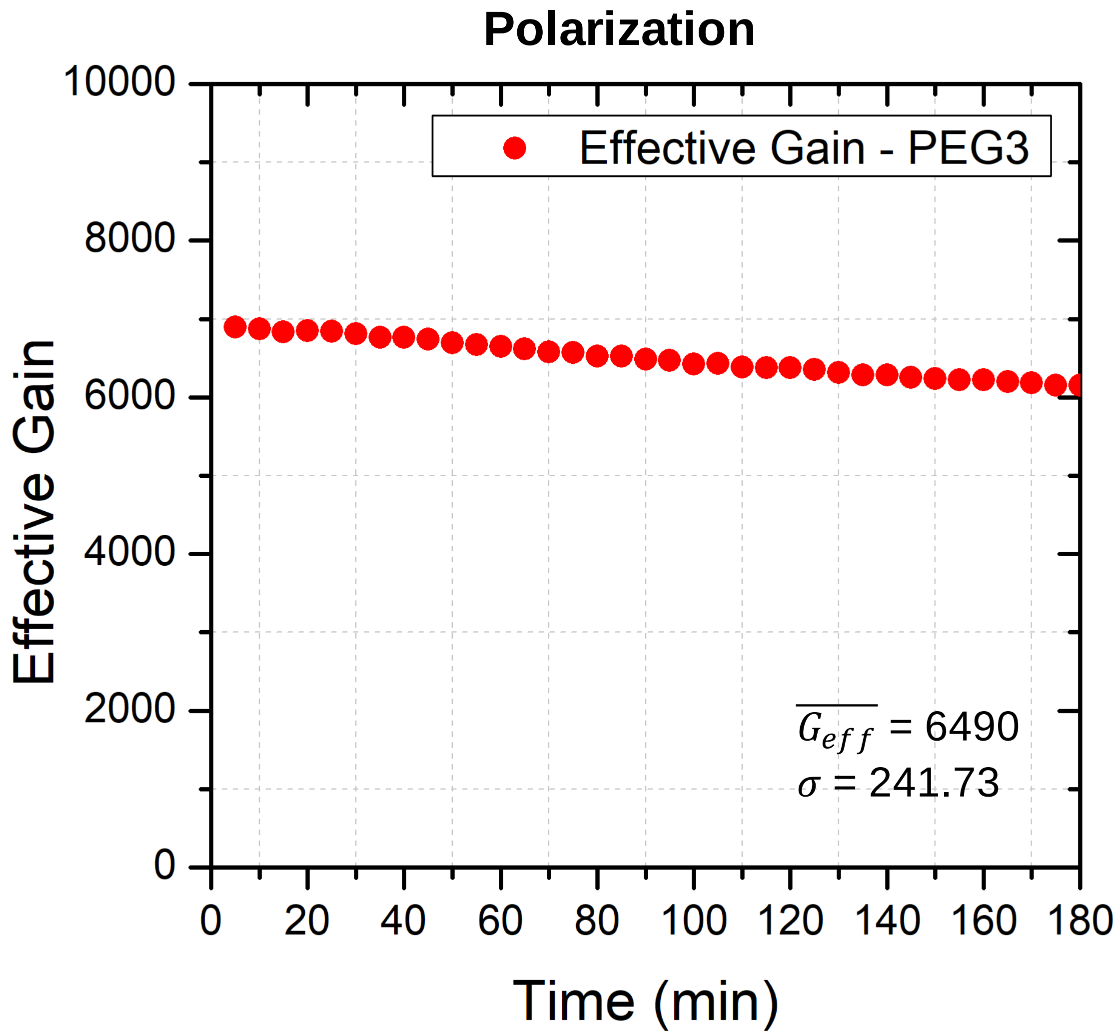
1. G-GEM Characterization





The effective gain of PEG3 G-GEM achieved an order of 10^4 with single stage.

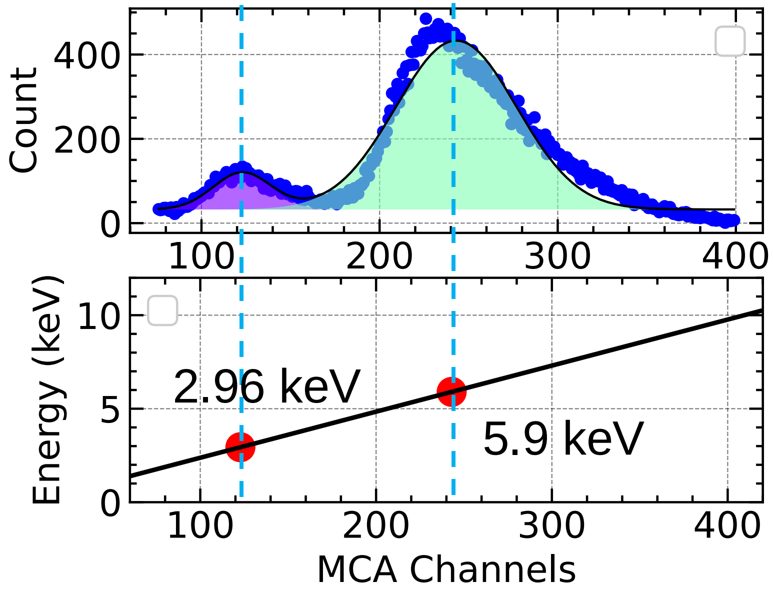
1. G-GEM Characterization

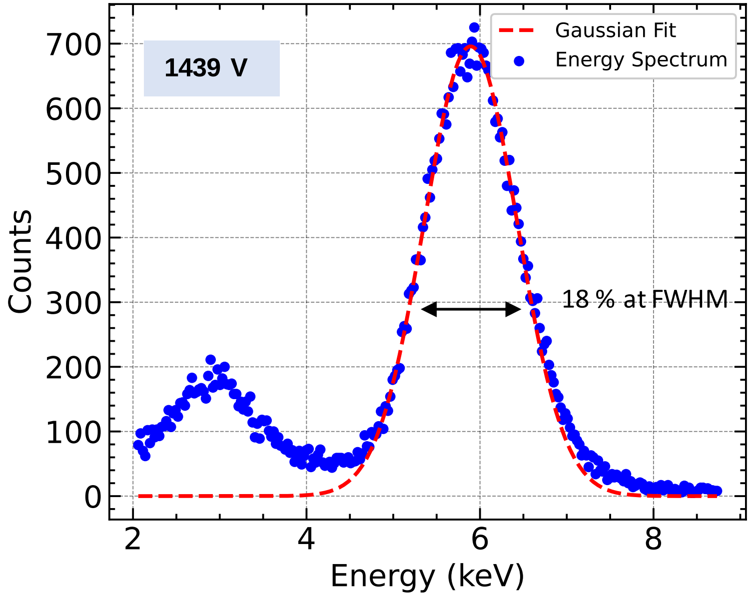


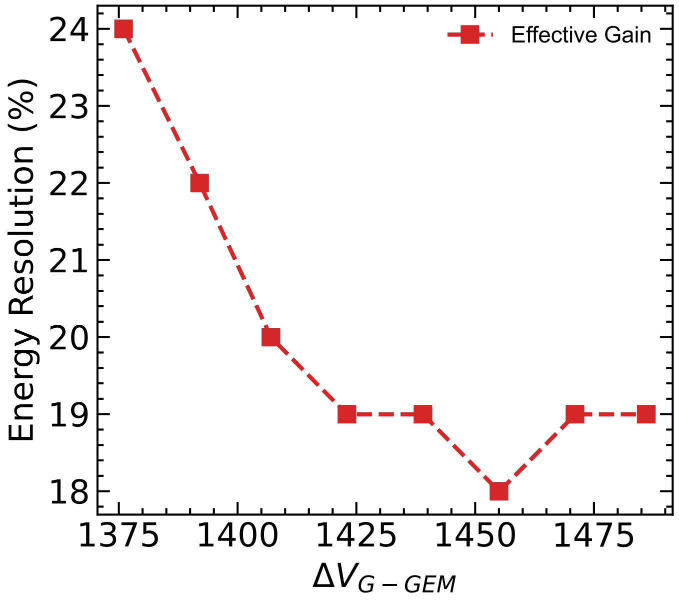
- The ^{55}Fe source was weak (global count of about 2 kHz) so that the charge-up effect was considered to be very small.
- Gain decrease was considered coming from high voltage (polarization) causing ion migration (it has not been studied yet)
- The total gain in 180 minutes was considered small enough (around 5%).

1. G-GEM Characterization

Energy Resolution



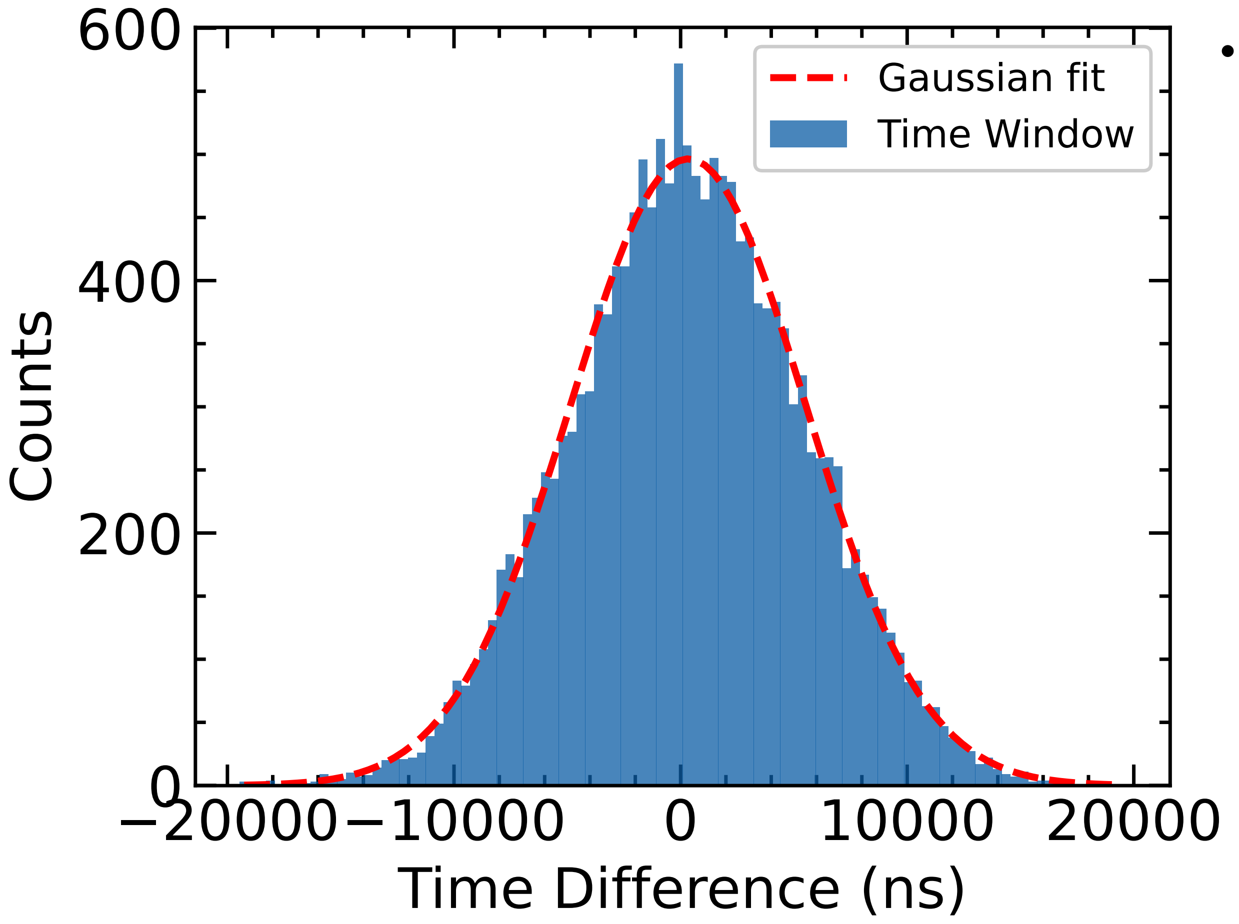




- The achieved energy resolution increased with increasing gain due to higher signal to noise ratio.
- Variation of avalanche process decreased the energy resolution after ΔV_{G-GEM} of 1439 V.
- PEG3 G-GEM achieved an optimum energy resolution of 18 % at FWHM.

2. Imaging System Evaluation

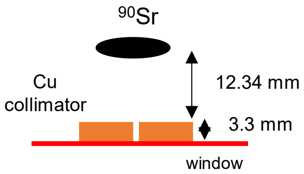
Time Window

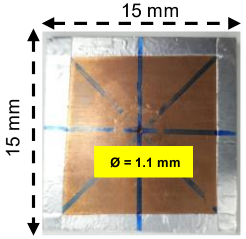


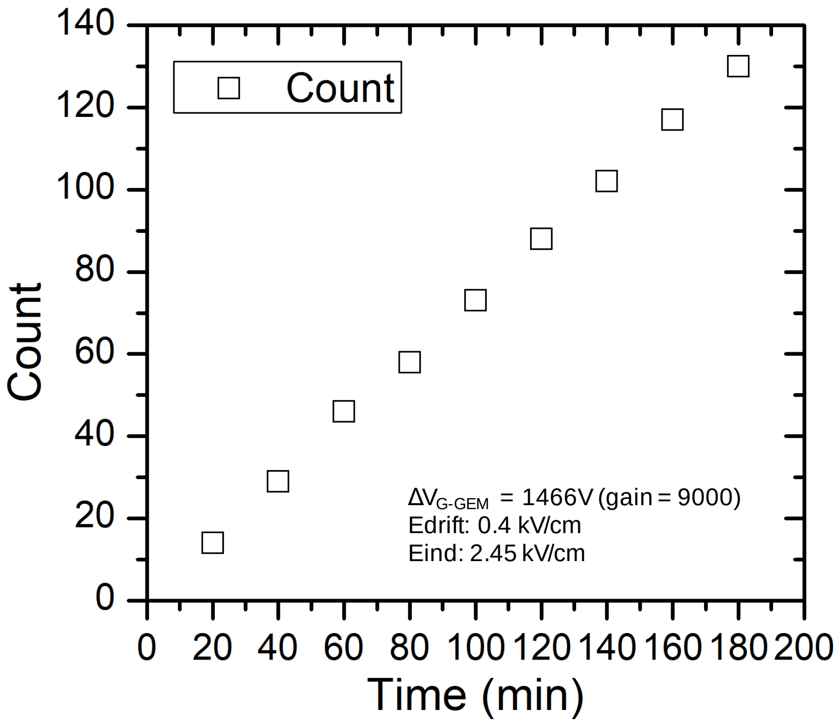
- Fitting the distribution with a Gaussian function yielded an FWHM of 12407 ns.

2. Imaging System Evaluation

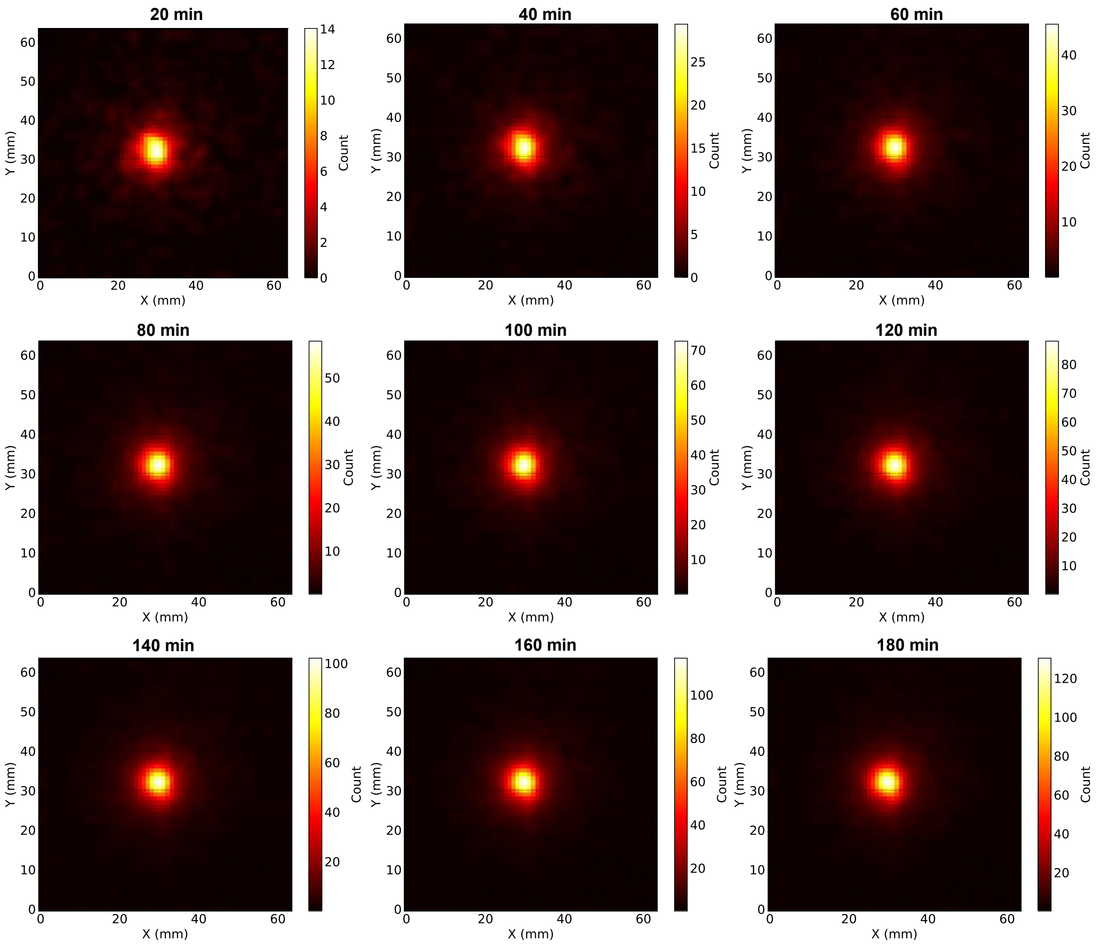
Sampling Stability







$$g(x,y) = \frac{1}{2\pi\sigma^2} e^{-(x^2+y^2)/(2\sigma^2)}$$



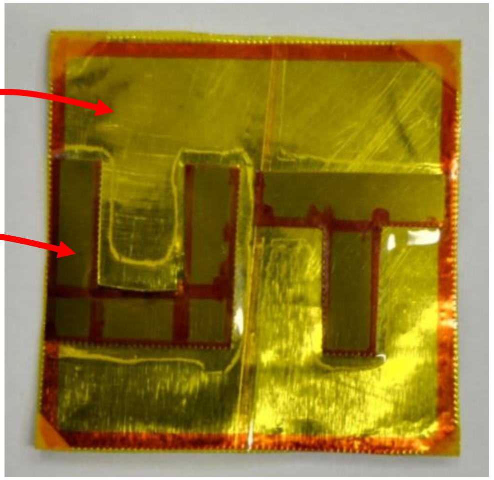
- The gaussian filter function was employed.
- The linearity of count over time showed the stability of counting.

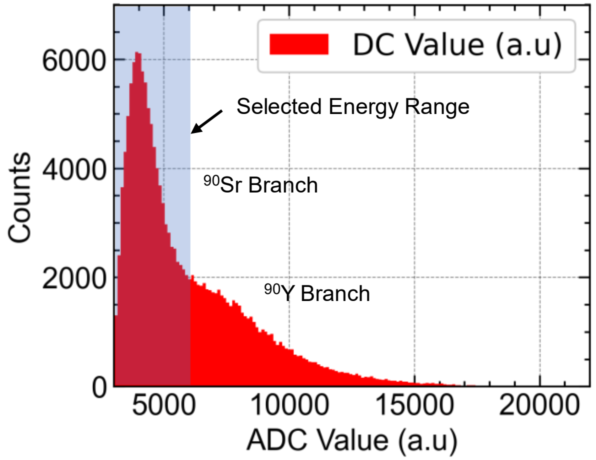
3. Beta Ray Imaging Demonstration

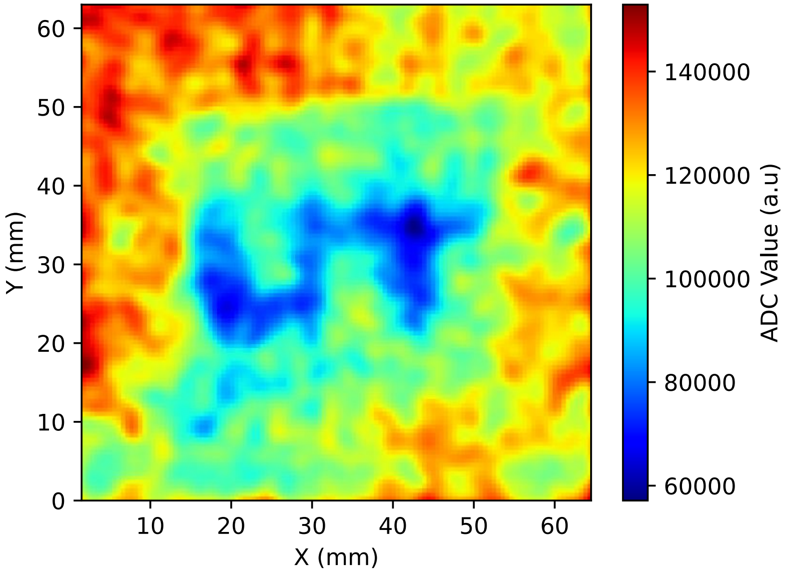
Energy Resolving Capability (Potential)

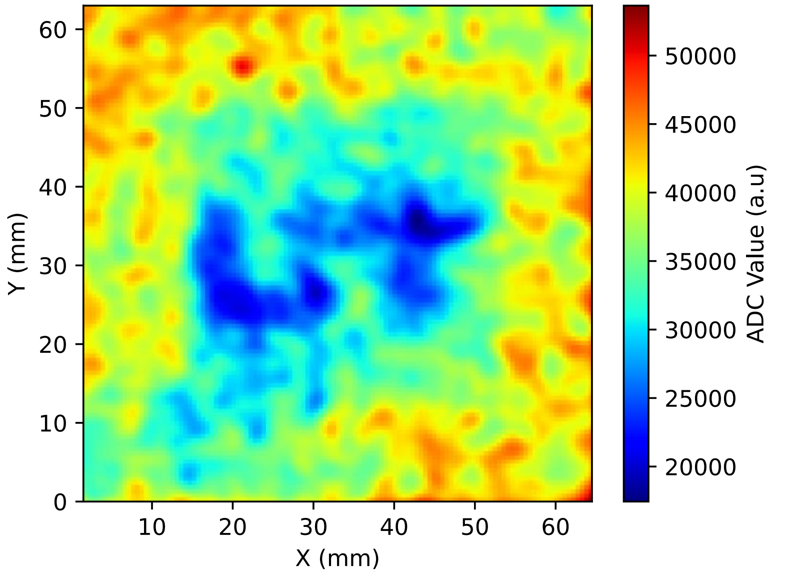
Thin Al Foil

40Zr (t = 0.127 mm)









- The parameters was set at gain of 10000, drift field of 0.2 kV/cm, and induction field of 2.56 kV/cm.
- The image was weighted by the ADC value and enhanced by gaussian filter function ($\sigma = 1$).
- The different profile with selected energy range showed a potential for conducting imaging with resolving energy.

Conclusion

- The study developed Gas Electron Multiplier (G-GEM) detector with a strip readout integrated with the pulse counting readout electronics for beta ray imaging.
- The PEG3 G-GEM exhibited promising characteristics, achieving a high effective gain of 10^4 with single stage.
- Successful detection of low-energy X-rays from a ^{55}Fe source was demonstrated, showing an energy resolution of 18% at FWHM.
- The imaging reconstruction effectively captured the energy distribution from beta rays limited by factors such as the spread of high-energy beta rays and the system's drift gap.

Thank You For Listening