Development of high efficiency and high resolution thick-GEM detectors for muography application

PSD14: International Conference on Position Sensitive Detectors, 2026
03/09/2026

Saikat Ghosh, Shubhabrata Dutta, Promita Roy, Subhendu Das, Supratik Mukhopadhyay, Nayana Majumdar

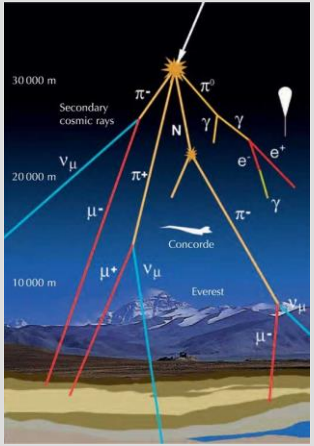
Saha Institute of Nuclear Physics
A CI of Homi Bhabha National Institute

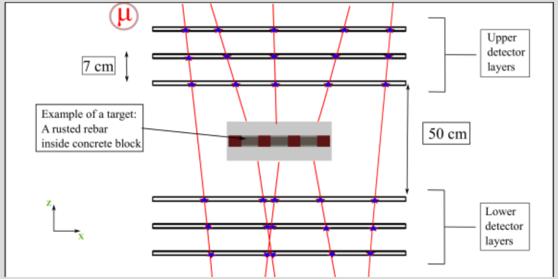
Outline of the talk

- Motivation.
- Detector requirement.
- Manufacturing.
- Conditioning.
- Characterization.
- Detection efficiency measurement.
- Measurement of position resolution.
- Effect of detector properties on imaging .
- Conclusion.

Motivation

- Cosmic muons passing through the matter causes EM interaction such as mcs, ionisation, atomic excitation, Bremsstrahlung.
- Minimum ionizing particle (1-10 GeV) $\Rightarrow$ can travel long distance within matter without losing much of its energy.
- Tracks before and after interaction can be interrogated using particle detectors.

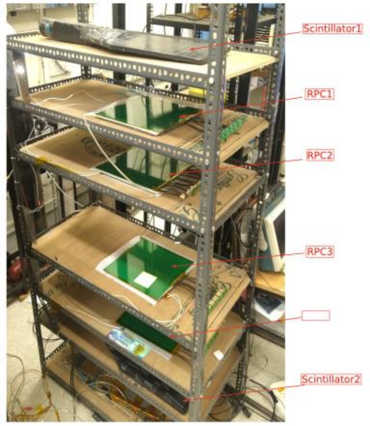


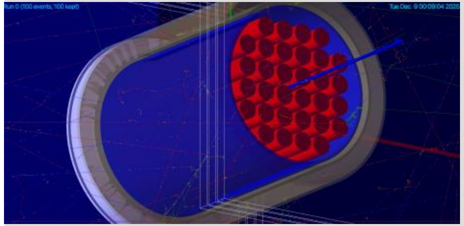


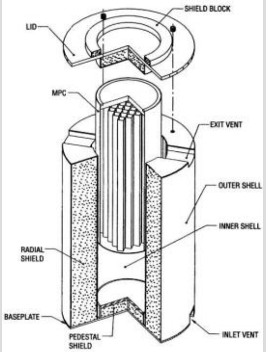
$$\sigma = \frac{13.6MeV}{\beta cp}\sqrt{\frac{L}{X_0}}(1+0.038ln\frac{L}{X_0})$$

$$X_0 = \frac{716.4(gm/cm^2)}{\rho}\frac{A}{Z(Z+1)ln(\frac{287}{\sqrt{Z}})}$$

- Muon absorption tomography.
  - Depends on matter density
  - Path travelled inside the material
- Muon scattering tomography.
  - Mainly multiple coulomb scattering.
  - Scattering angle follows Gaussian distribution.
  - σ depends on thickness of the material and radiation length.
  - Depends on Z and ρ of the material.







Detector requirements

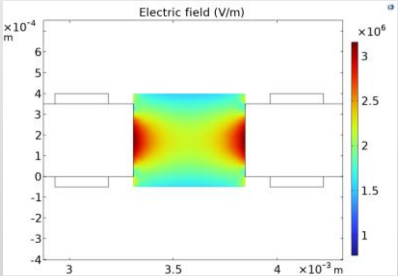
Robust large area detector with good position resolution and low manufacturing cost is required.

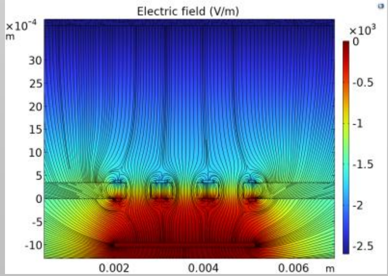
Thick-GEM detectors

- A **robust gaseous detector** derived from GEM technology. 5-10 fold enlarged version.
- Uses a **thick insulating plate** with mechanically drilled holes and copper electrodes on both sides.

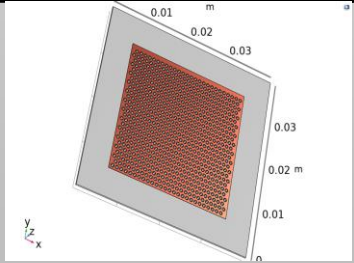
Why THGEM

- High gain (10^4–10^5) with good stability.
- Mechanically strong and **cost-effective for large areas**.
- Good spatial resolution and muon detection efficiency.
- Suitable for harsh High and long-term experimental conditions.

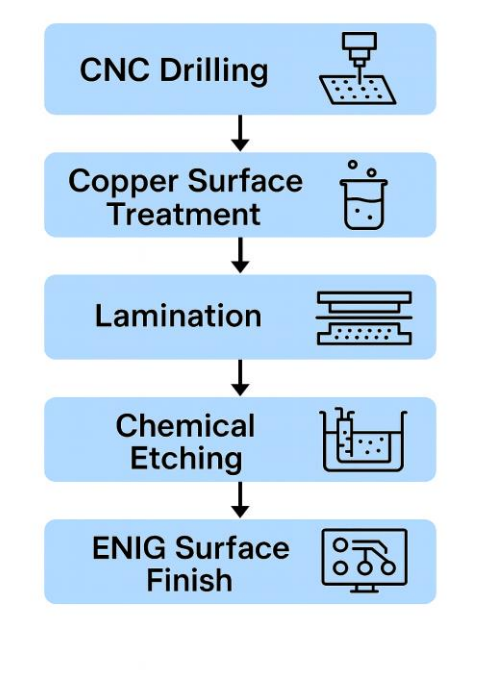


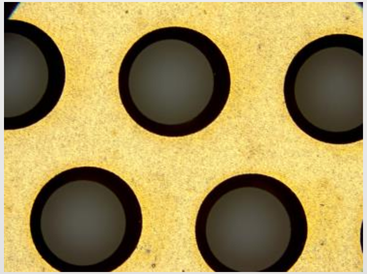


Detector	Spatial Resolution	Production cost	Electronics cost	Operation
Scintillator Bars	1–10 mm	Low	High	Robust, easy
Scintillator Fibres	10–100 μm	High	High	Industrial; avoid bending
MWPC	0.1–1 mm	Medium	Medium	Complex; T/P dependent
MPGD	10–100 μm	High	Medium	Complex; T/P dependent
RPC/MRPC	0.1–1 mm	Low	Low	Easy; T/P dependent
Silicon Microstrips	1–100 μm	High	High	Robust, radiation hard

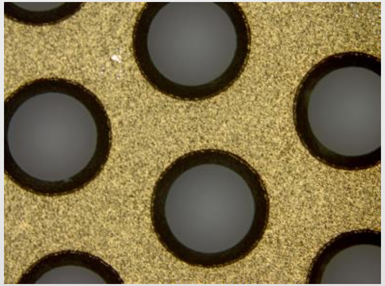


Manufacturing





Manual etching process

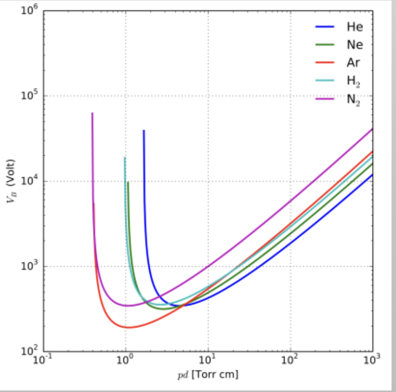


Chemical spray etching

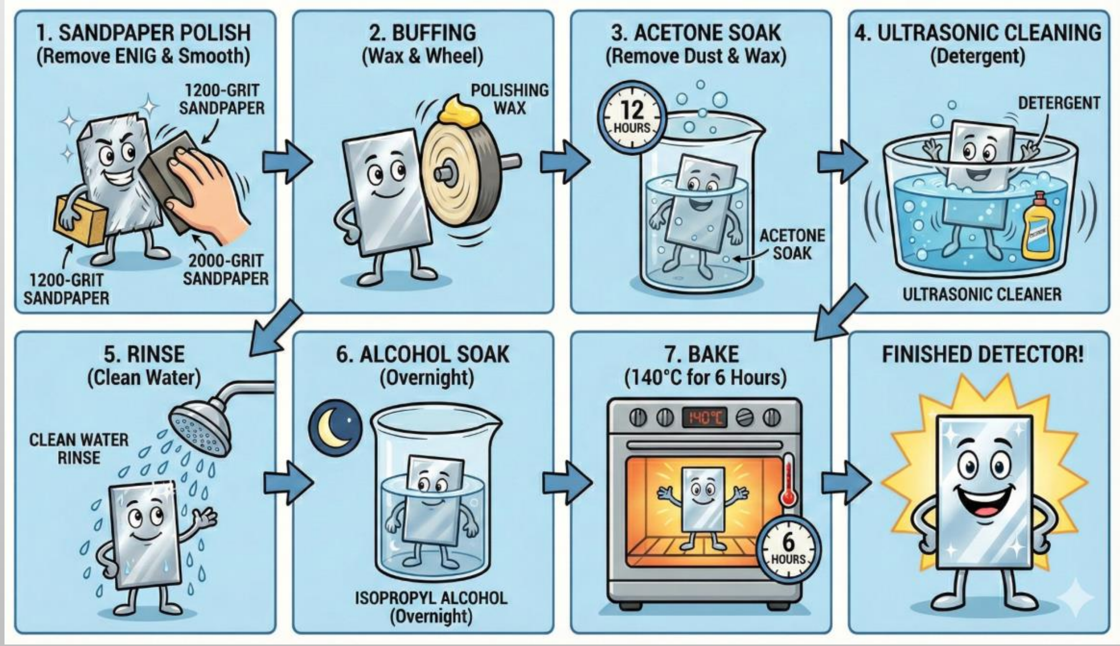
Copper surface treatment with sulphuric acid creates rough edges on the copper rim.

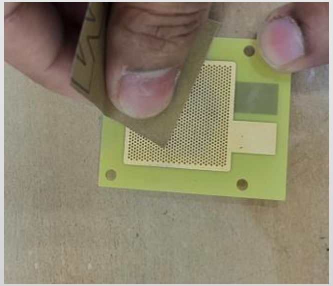
This makes the detectors to generate spark at very low voltage.

Thickness	Maximum High voltage reached in N_2	Paschen limit for 50 micron Rim
270μm	1800 V	2200 V
400μm	1950 V	2600 V



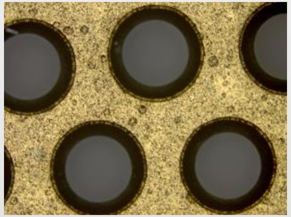
Surface treatments

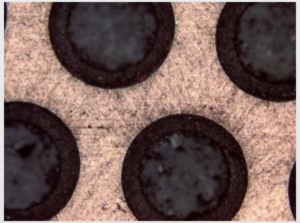




Results

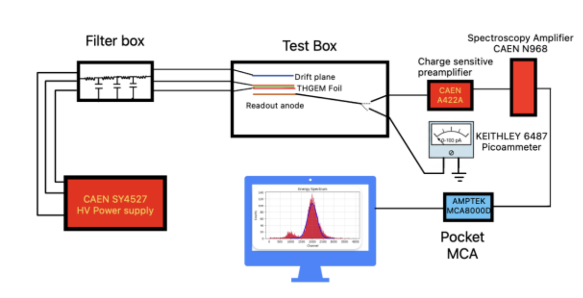
	Before surface treatment	After surface treatment
High voltage limit in N_2	(i) 1600 V (ii) 1900 V	(i) 2700 V (ii) 2500 V
Working voltage range in Ar-CO_2 (90:10)	(i) No working region observed. (ii) 1100-1220V	(i) 1400-1550 V (ii) 1100-1350 V
Maximum gain achieved	(i) — (ii) 2000	(i) 5500 (ii) 7500

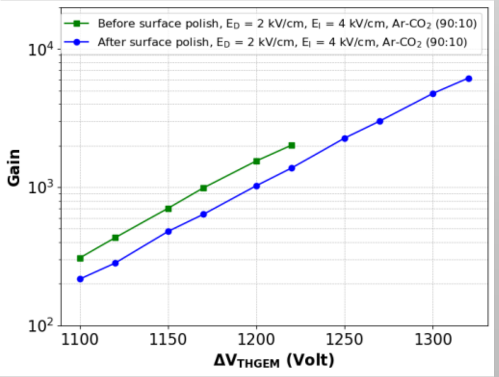




After sandpaper polishing

After buffing

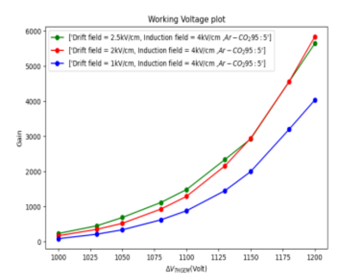




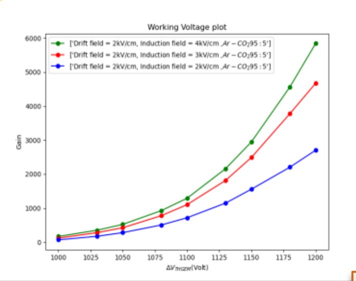
Manufacturer	Hole diameter	Pitch	Rim width	Thickness	Material
electronkolkata.in	500 μm	1000 μm	100 μm	355μm	FR4, IS410
micropack.in	400μm	800μm	50μm	269μm	FR4 ITEQ IT-180A

Characterization

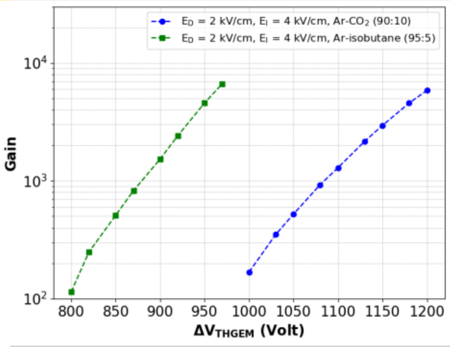
Variation of gain with working voltage for different drift fields.



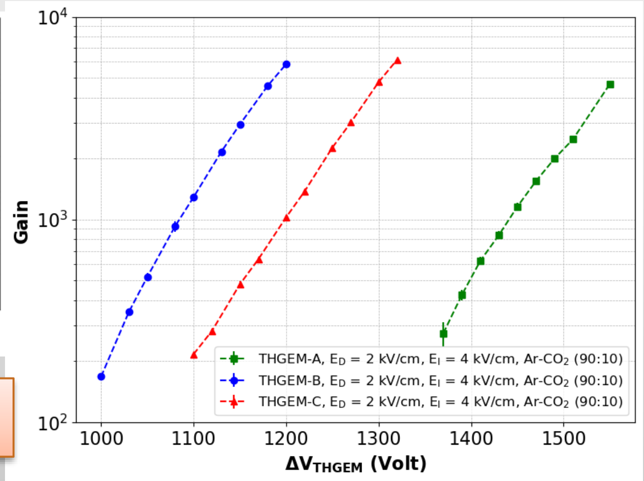
Variation of gain with working voltage for different induction fields.



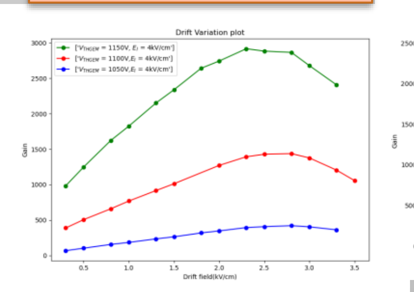
Variation of gain with two different gas mixtures



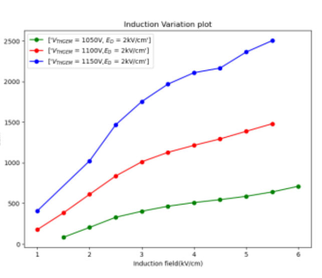
Variation of gain with working voltage in three different THGEMs



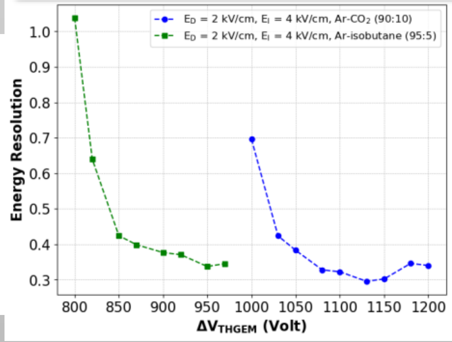
Variation of gain with changing the drift field at different THGEM voltages

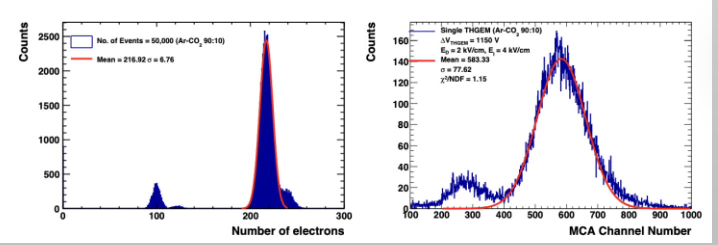


Variation of gain with changing the induction field at different THGEM voltages



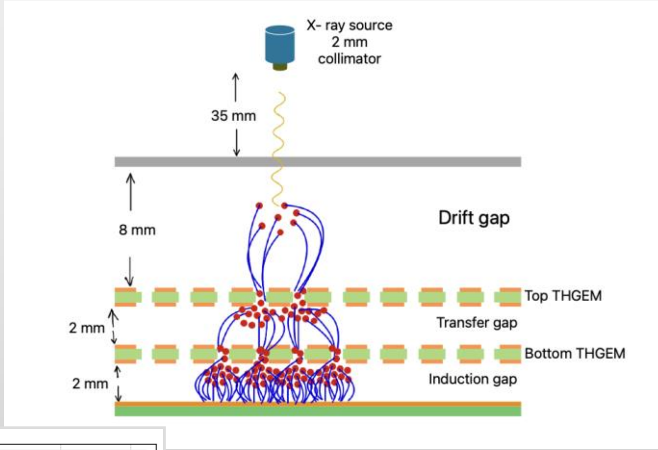
Variation of energy resolution with THGEM voltages

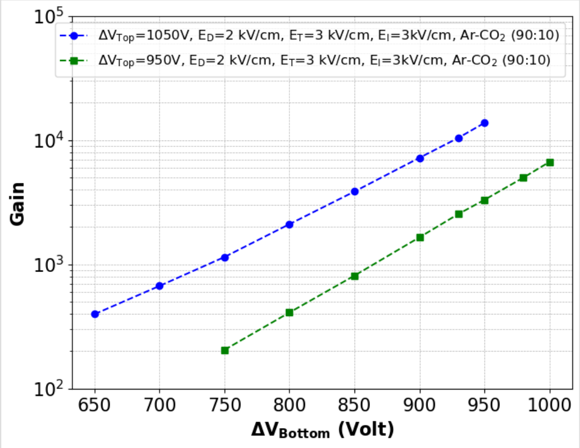


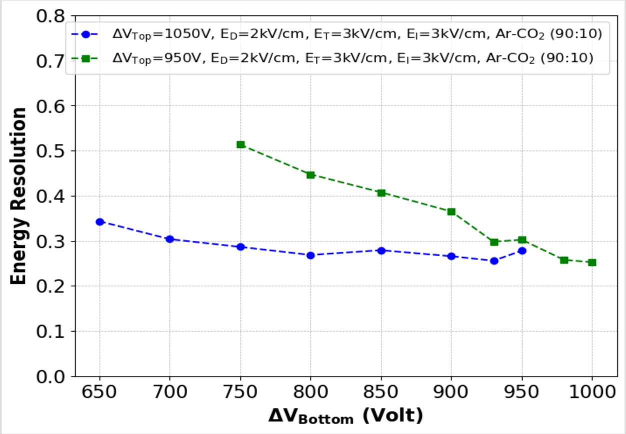


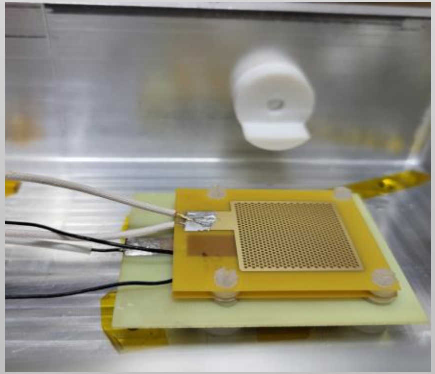
Double stage gain

- Sufficient gain without any discharge is the ideal operating condition.
- Large voltage difference for single THGEM configuration causes breakdown.
- Signal distribution in neighbouring strips may improve position resolution.



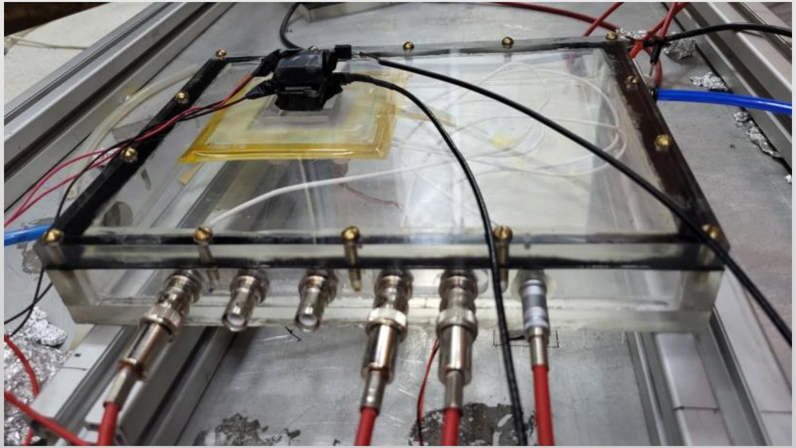


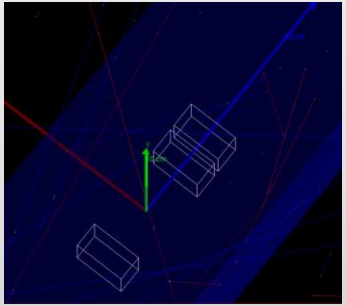


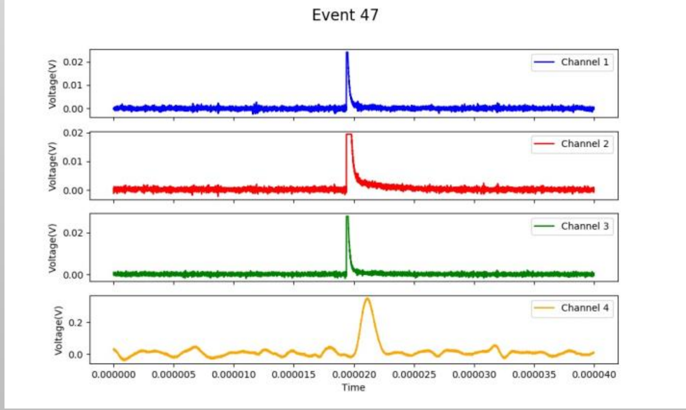


Variation of gain with Bottom THGEM voltage for to fixed Top THGEM voltages

Muon detection efficiency measurement



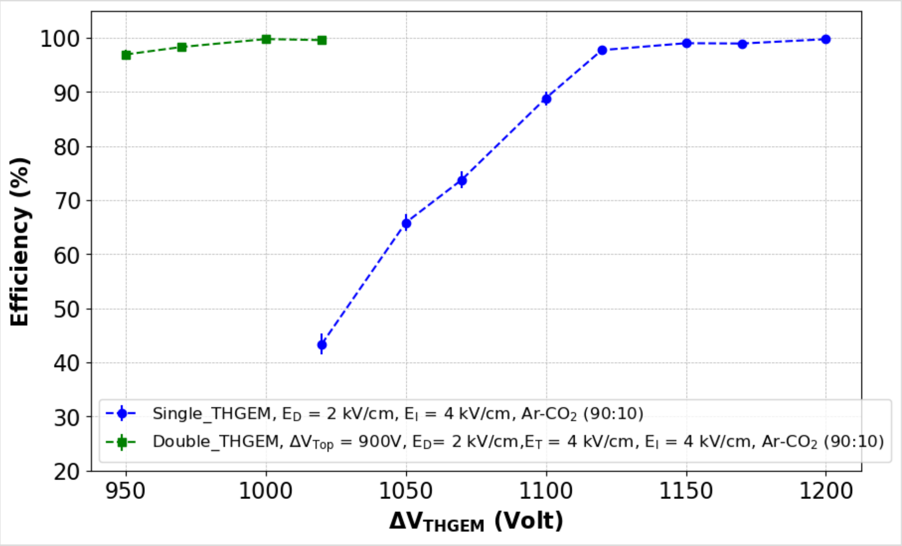




- Scintillator-SiPM based muon coincidence setup has been built.
- Oscilloscope logic trigger has been used to find the actual muon events.
- Each of these spectrum has been saved and further analysed to find the occurrence of detector hits.
- The test detector signal arises on the spectrum with a delay of 0.8 μs.

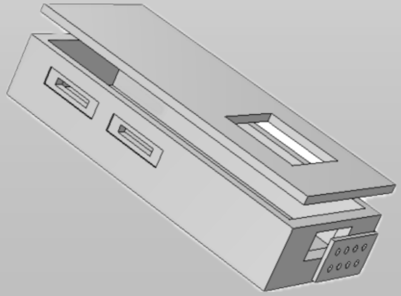
Efficiency

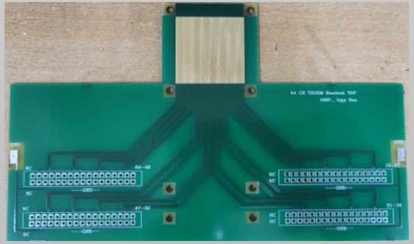
- There are electrical noises and spark on the Thick-GEM detector which generates oscilloscope triggers.
- Have to be extremely careful while choosing the true events.
- A threshold cut of 50 mV in THGEM signal has been used to select an event as detected muon event.
- Each data point does not comprises of same number of total events.
- 600-1200 events has been taken for efficiency calculation.
- 1 µs trigger window has been selected.

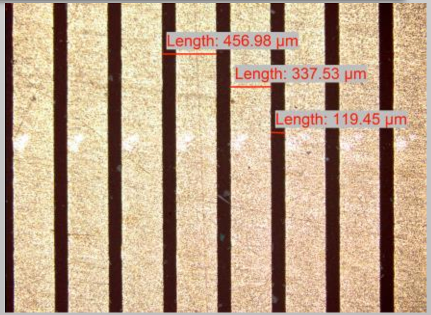


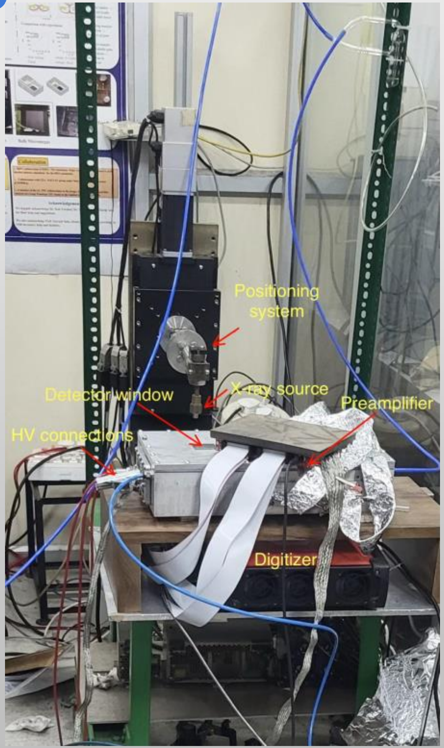
Position Resolution Measurement study

- Imaging of different structures with muons require precise reconstruction of its track, thus hit position should be determined accurately.
- Knowledge of the position resolution of the detector is important as how much we can trust the detector hits.
- The method involves moving an x-ray source precisely and how much the detector hits moves accordingly.
- A multi-strip readout board with multi-channel data acquisition system is required for this purpose.
- Strip pitch is 450 µm and strip width is 350 µm.

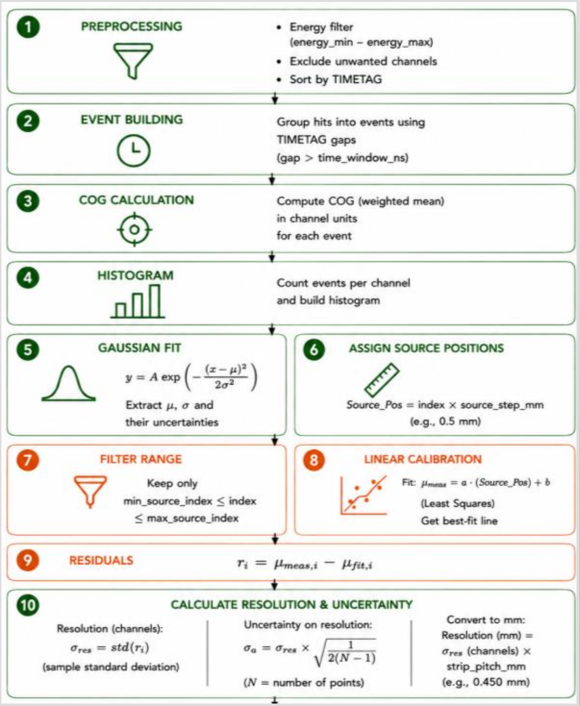


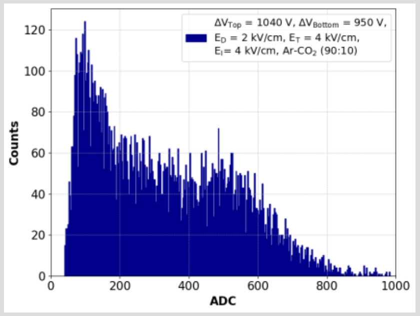


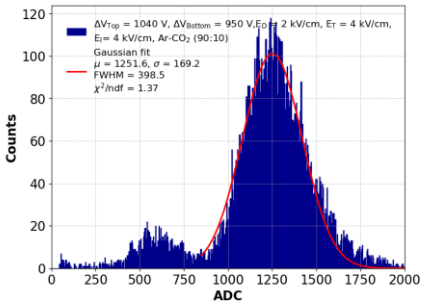


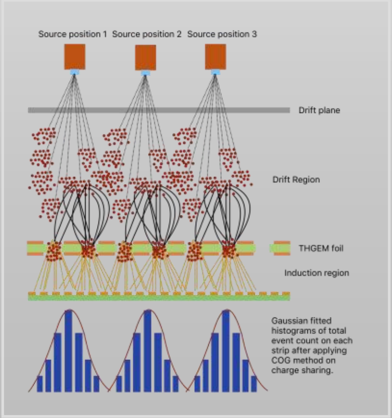


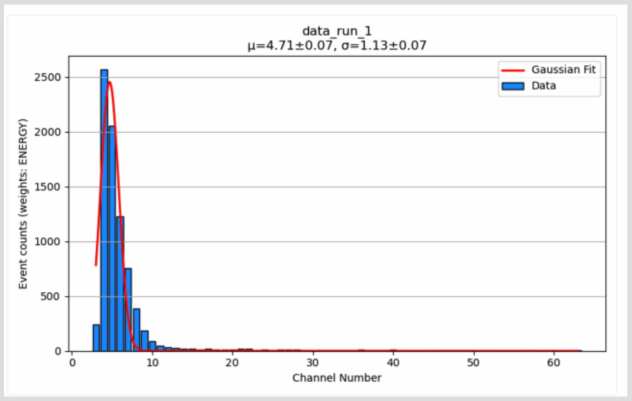
Data acquisition and event reconstruction





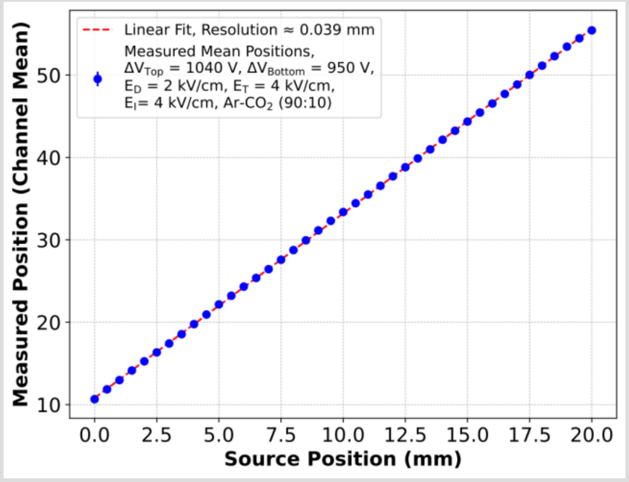


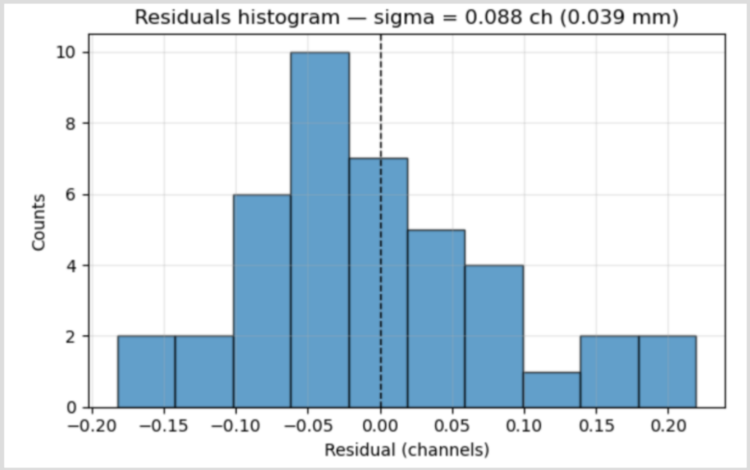




Position resolution calculation

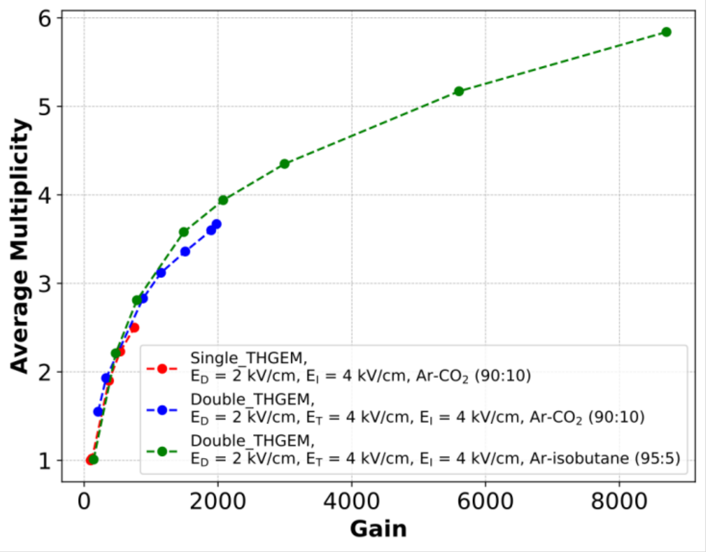
- The source with 2 mm collimator has been moved 0.5 mm at each step with accuracy 0.5 µm.
- Position of the source has been determined from the fitted gaussian.
- Residual is the difference between the actual movement of the source and the reconstruced source movement.
- σ of the residual distribution is the position resolution.

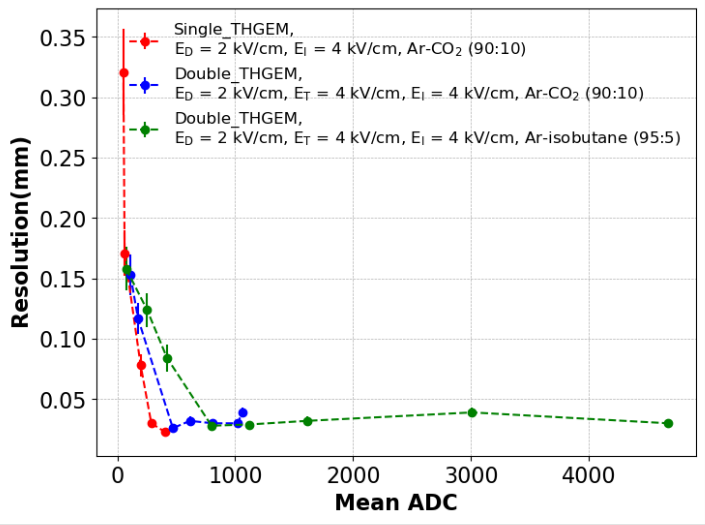




Variation of position resolution

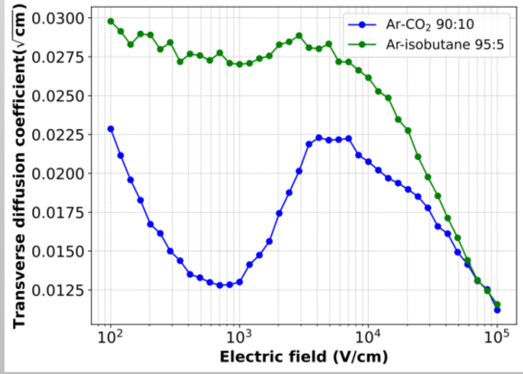
- Multiplicity increses with increasing gain.
- At the same gain multiplicity is high for double stage configuration than single stage.
- Also at the same gain the multiplicity is higher for Ar-isobutane mixture than Ar-CO_2 mixture.
- Same also applies for the Position resolution.

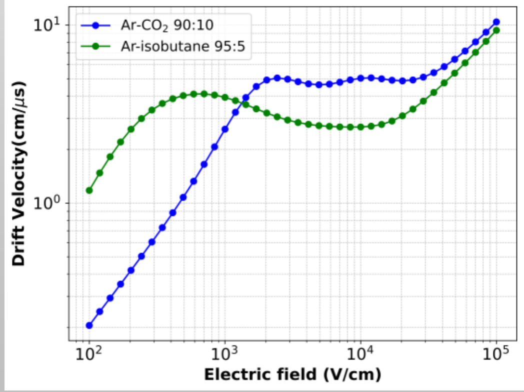


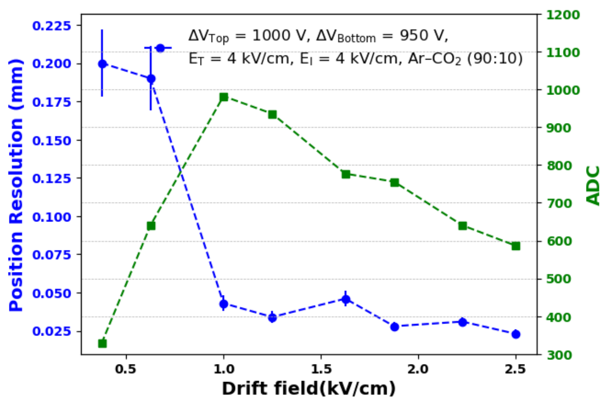


Resolution variation

- Less multiplicity in Ar-CO_2 mixture can be explained from the Magboltz calculations.
- The transverse diffusion coefficient is less and Drift velocity is high for Ar-CO_2 mixture.
- At lower drift-field values, the position resolution is relatively poor because of
- Lower effective detector gain
- Lower electron drift velocity, and
- Larger transverse diffusion in the drift region.

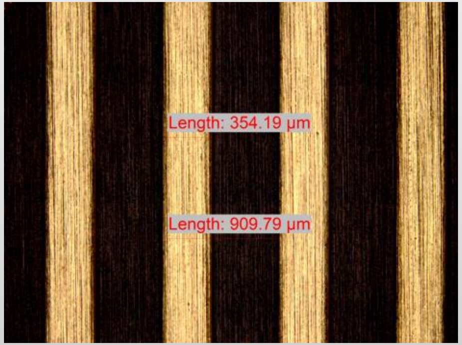


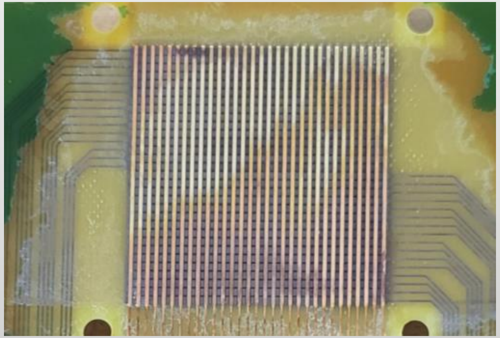


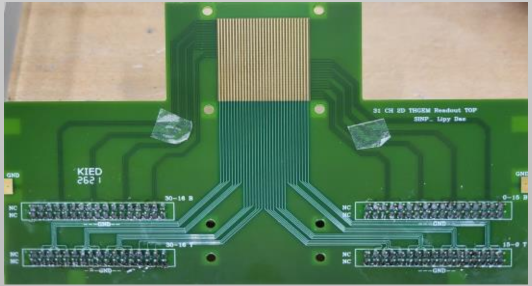


2-D Readout

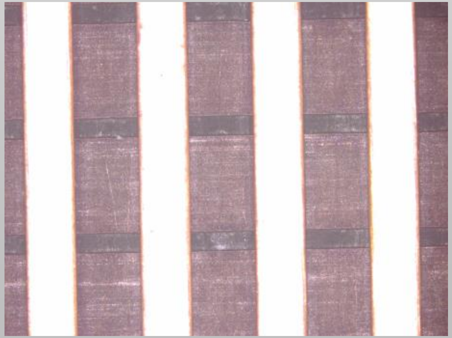
- A 2-D readout has been designed and fabricated with local PCB manufacturing industries.
- Strip pitch is 0.9 mm and width is 0.35 mm in X-plane and 0.75 mm in Y-plane.
- The middle Polymide layer has been ethched chemically with Ethylene diamine and KOH solution to expose the bottom copper layer for electrons to become transperent.





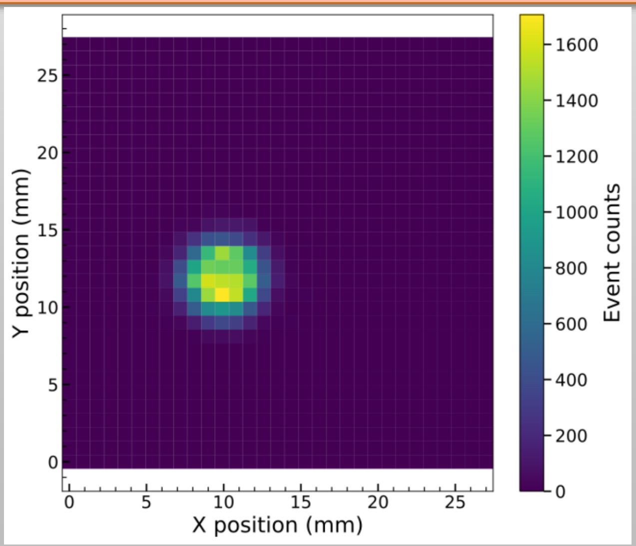


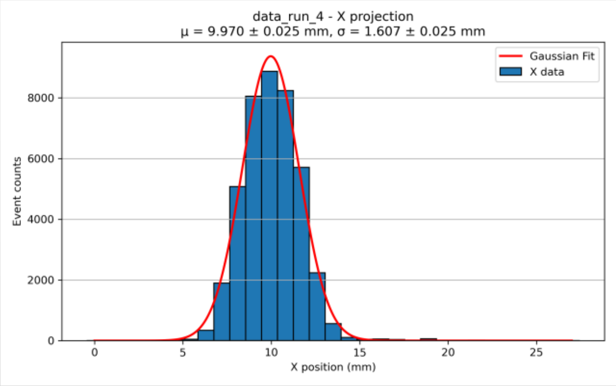
	0.02	SM
	0.035	PLATED COPPER
LAYER-1	0.018	TOP LAYER
	0.05	Polymide
LAYER-2	0.018	MIDDLE LAYER
	0.035	PLATED COPPER
	0.162	PREPREGS
	0.6	0.6 MM CORE
LAYER-3	0.018	BOTTOM LAYER
	0.035	PLATED COPPER
	0.02	SM
	1.011	**mm±10%**

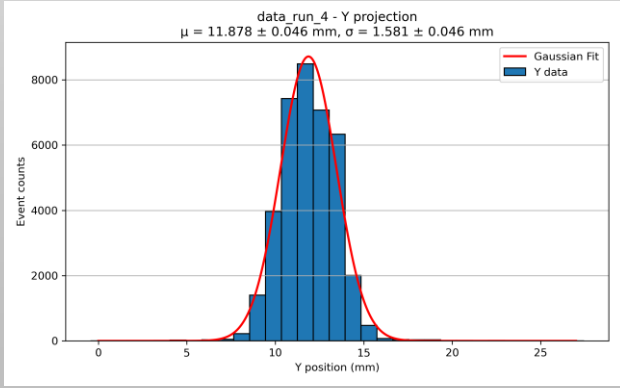


2-D image

- Fe^{55} source with 2 mm collimator has been placed.
- Event reconstruction has been done within a specific time window applied.
- COG applied to find the actual event location in both X and Y plane.







Effect of detector properties on Muon imaging

Spatial Resolution (um)	AUC	t-score	p-value
50	0.9250578704	17.18754771	2.17E-45
200	0.9072145062	15.51356976	1.33E-39
500	0.831404321	10.60061004	2.31E-22

Resolution (um)	AUC Separation	t-score	p-value
50	0.9819018454	30.98462577	5.11E-66
200	0.9696518133	28.9706047	1.73E-62
500	0.9195191937	21.49349624	3.86E-47

iron - class A
rust - class B

$AUC = P(x_A > x_B) + 0.5 * P(x_A = x_A)$

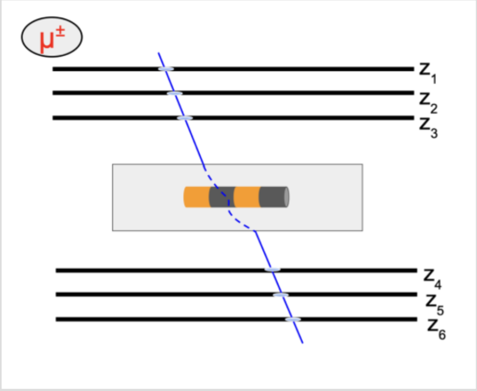
Rust-Iron discrimination

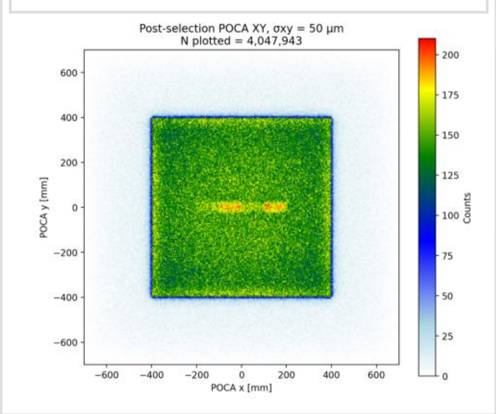
$$H_0 : \mu_A = \mu_B$$
$$H_1 : \mu_A \neq \mu_B$$

$$t_{\mathrm{Welch}} = \frac{x_A - x_B}{\sqrt{\frac{s_A^2}{n_A} + \frac{s_B^2}{n_B}}}.$$

μ_A, s_A, n_A denote the mean, standard deviation, and pixel count of the reference distribution (iron)
μ_B, s_B, n_B represent those of the test distribution (rust)

Iron-Concrete discrimination





Conclusion and future outlook

- **Locally fabricated THGEMs** demonstrated stable operation and high gain, reaching **$>6 \times 10^3$ (single)** and **$\sim 3.3 \times 10^4$ (double)** in Ar-based gas mixtures.
- Achieved **>95% muon detection efficiency**, with a peak efficiency of **99.5%**, confirming suitability for charged-particle tracking.
- Excellent position resolution was achieved using COG reconstruction.
- Detector performance showed dependence on **gas composition and drift field**, with Ar–CO_2 providing superior resolution in the low-gain regime.
- Muography simulations demonstrate that improved spatial resolution enhances **material discrimination** and increases the fraction of image-suitable muon events.
- **Future:** Scale up THGEM fabrication, develop **larger readouts**, and integrate **multiple tracking planes** toward a full-scale muography system.

Acknowledgement

- Prof. Nayana Majumdar, Prof. Suprartik Mukhopadhyay.
- Dr. Sridhar Tripathy, Dr. Promita Roy, Dr. Subhendu Das, Dr. Pralay Kumar Das, Mr. Shubhbarata Dutta.
- Nilanjan Biswas , Lipy Das, Sudipta Barman for their tireless effort in helping designing the experiment.
- I like to express my gratitude towards SINP, HBNI and DAE for providing necessary funding and equipment throughout the work.

Thank you!