Performance studies of GEM detector for future Heavy-Ion experiments

Sayak Chatterjee, Arindam Sen, Supriya Das, **Saikat Biswas**
Department of Physics
Bose Institute

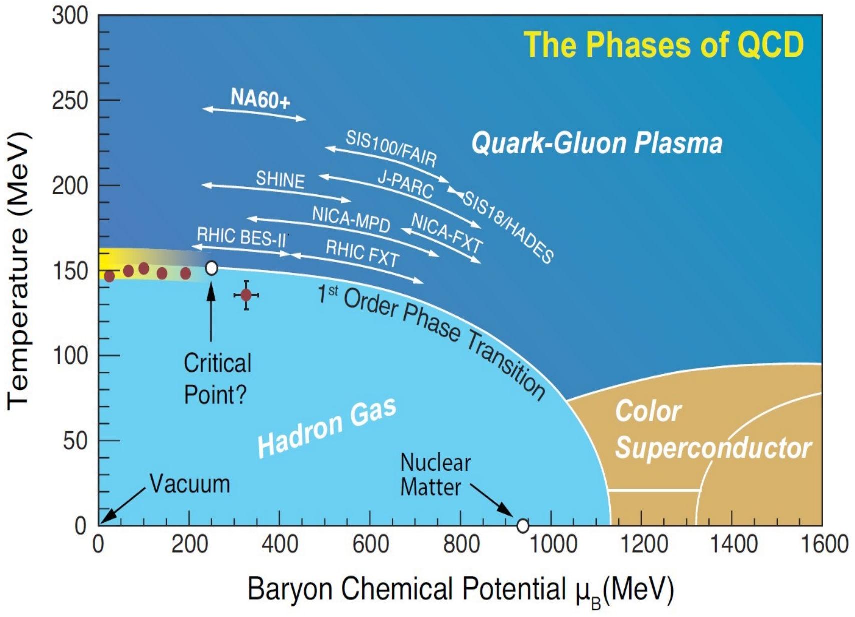
XXV DAE-BRNS HEP SYMPOSIUM, IISER Mohali, December 12-16, 2022

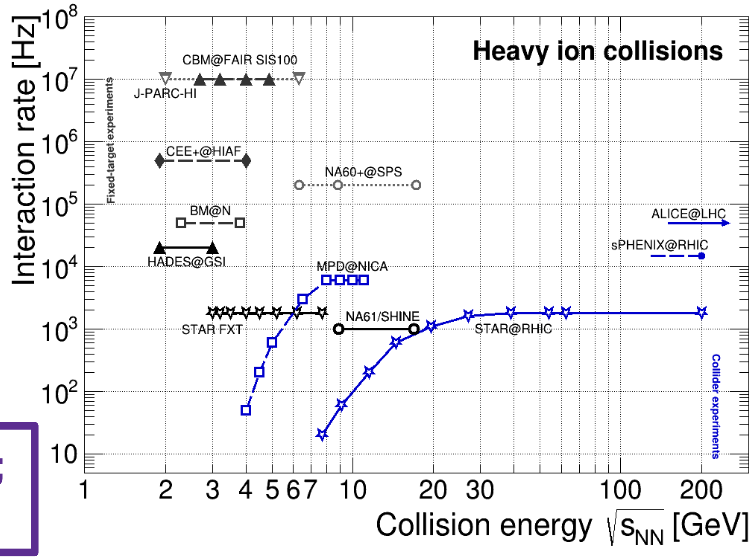
Outline

- **Introduction**
- **Gas Electron Multiplier (GEM) detector**
- **Characterisation of GEM detector**
  - Efficiency
  - Uniformity in performance
  - Long-term stability study
- **Effect of radiation on the performance of the chamber**
  - Charging-up effect
- **Summary**

Introduction

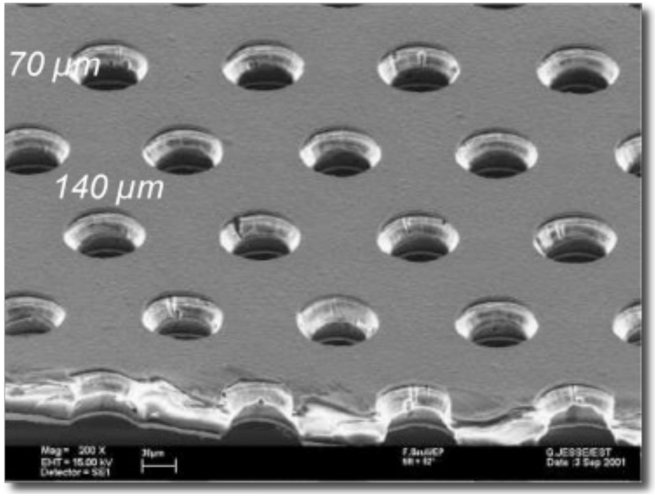
- **Systematic exploration of the QCD phase diagram**
  - Low baryon density regime (LHC, RHIC ...)
  - High baryon density regime (RHIC BES, SPS, CBM ...)
- **Precise measurement of the physics observables of interest**
  - High luminosity
- **Detectors with high rate handling capabilities**
  - Micro Pattern Gas Detectors (MPGD)
- **Innovative technologies for data acquisition**





Eur. Phys. J A53 (2017) 60; CBM Collaboration, EPJA 53 3 (2017) 60; T.Galatyuk, NPA982 (2019), update (2021)

Gas Electron Multiplier (GEM)



- GEM foil is made of Copper cladded Kapton foil of thickness 60 μm
- Good rate handling capability (~ 1 MHz/mm^2)
- High efficiency (>95%)
- Can be operated in cascaded mode
- Good spatial resolution (~ 70 μm)
- Operated with non-flammable gas mixtures (conventionally Ar-CO_2)
- Depending on the photolithographic techniques used, the GEM foils are classified as Double Mask (DM) or Single Mask (SM) GEM foils

Reference : F. Sauli, Nucl. Instr. and Meth. A386 (1997) 531, S. Bachmann *et al.*, Nucl. Instr. and Meth. A479 (2002) 294

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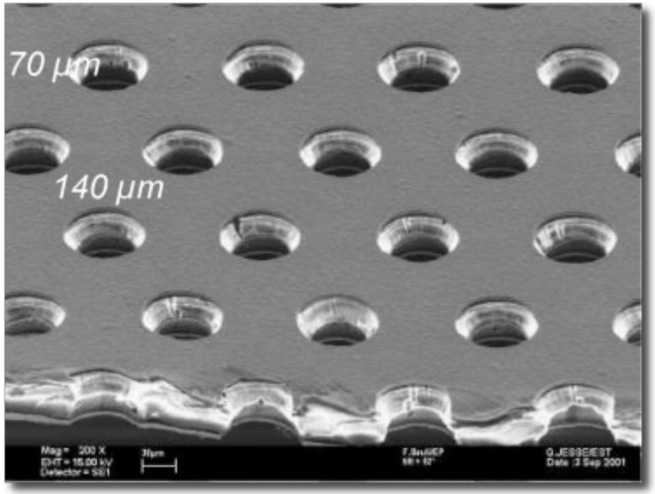

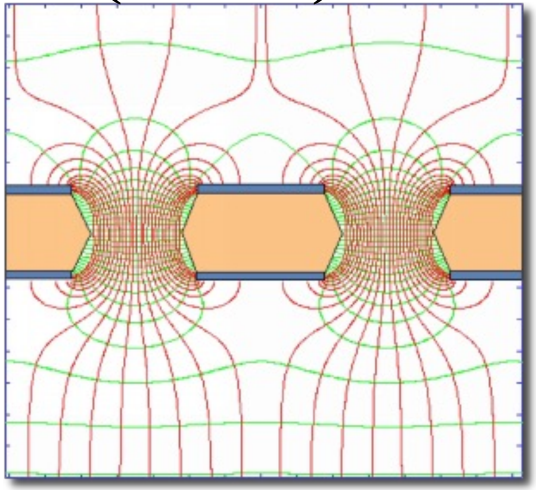

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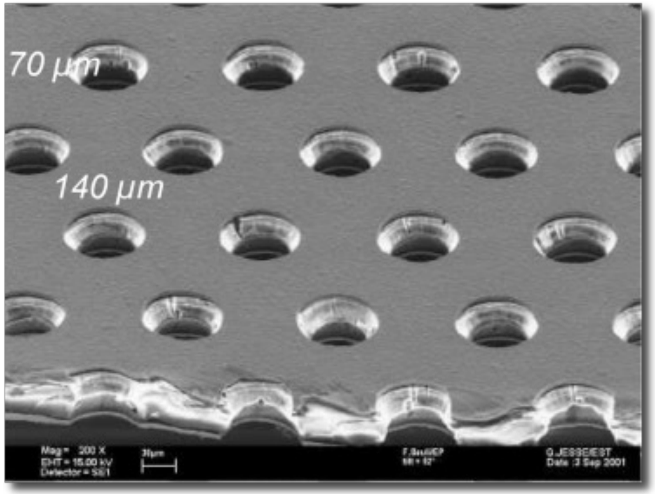

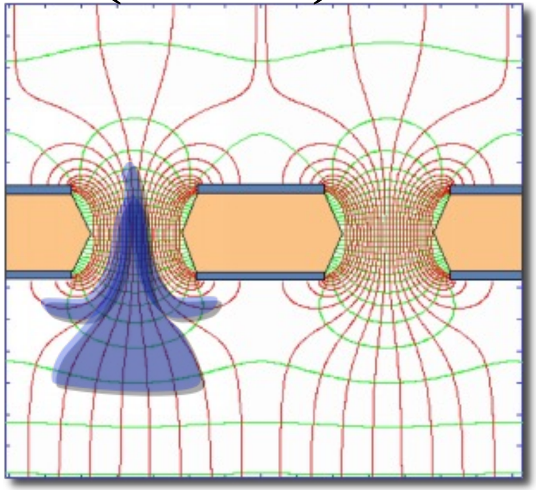

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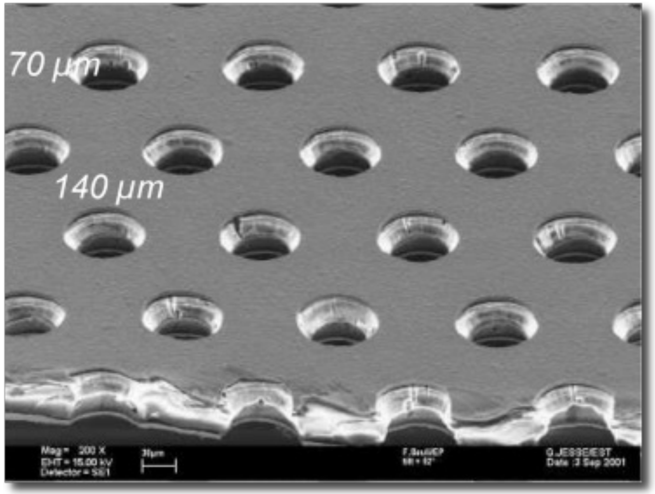

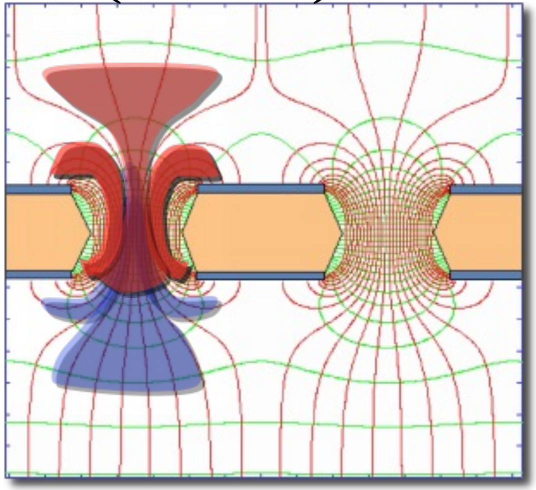

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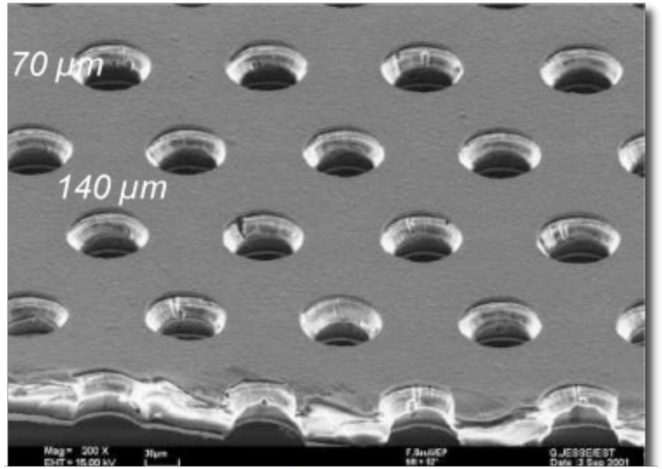

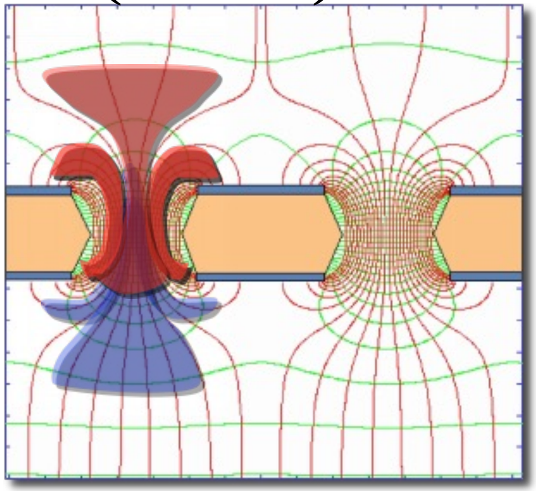

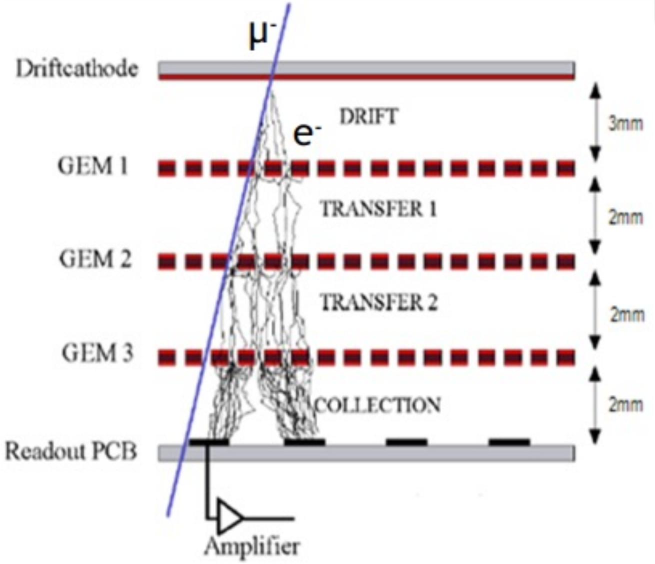

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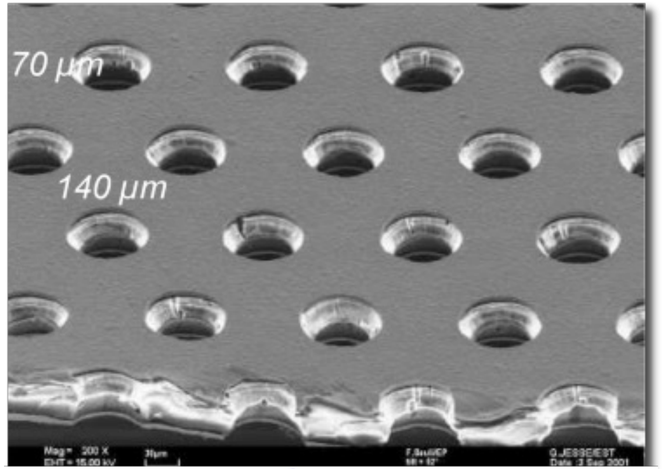

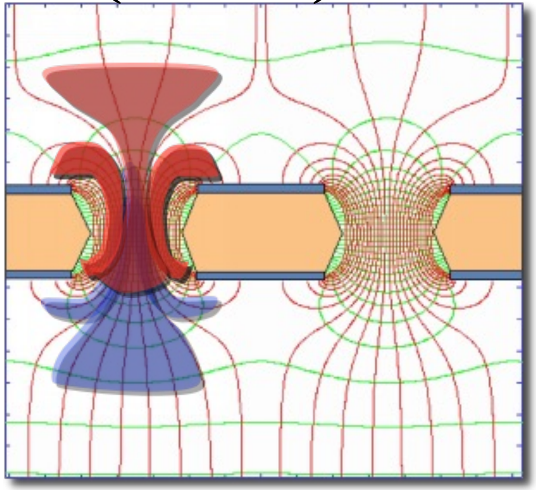

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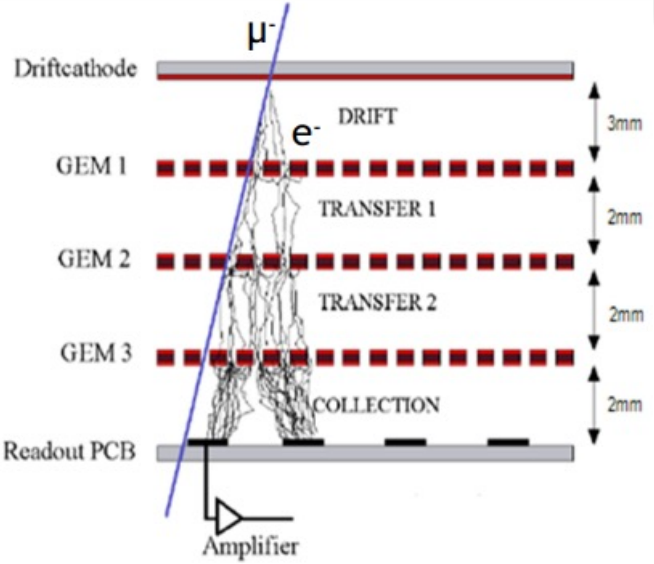

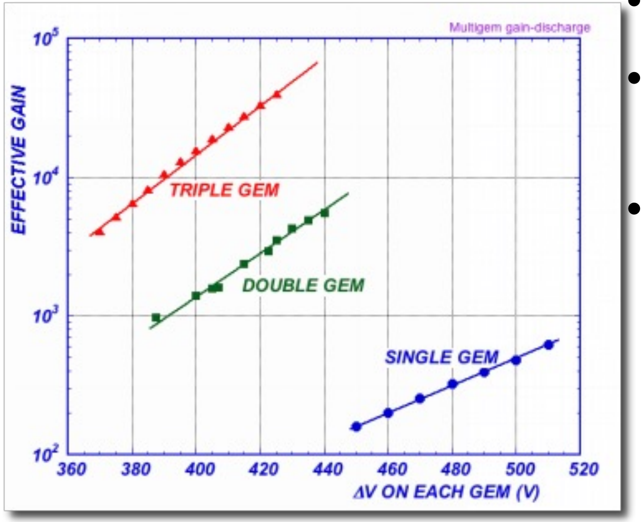

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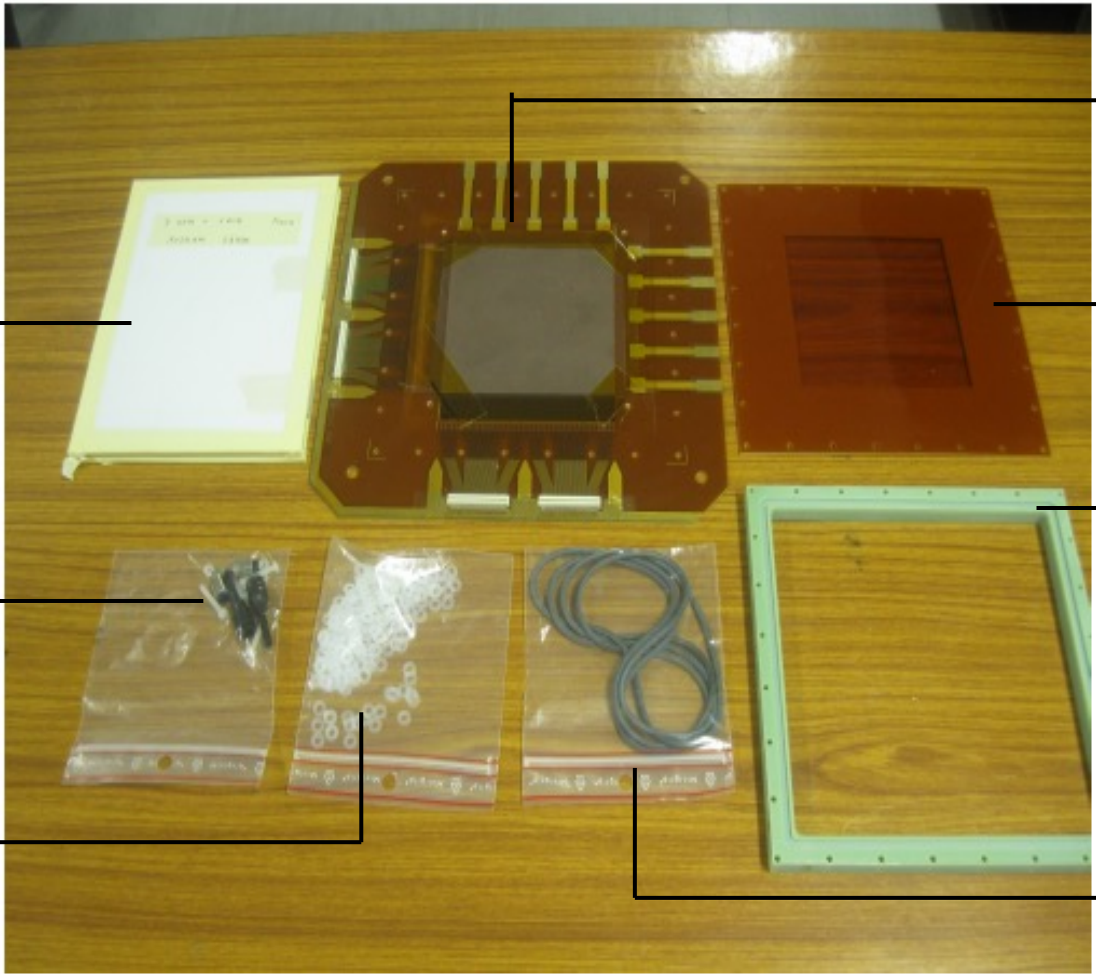
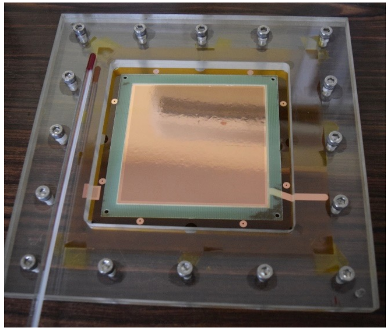
Triple GEM chamber: Fabrication and prototypes

Components used in the fabrication of triple GEM chamber

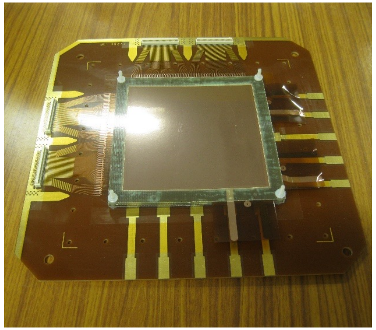


Building of a GEM detector

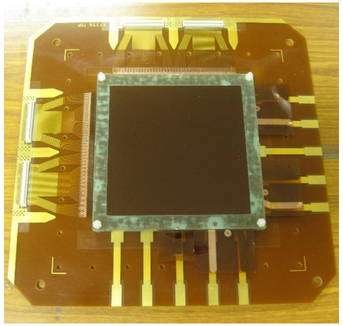
GEM foil



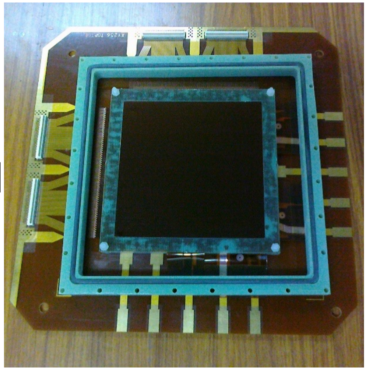
Stretching of the GEM foil



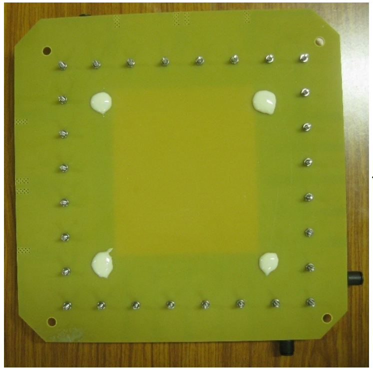
GEM foil on read-out plane



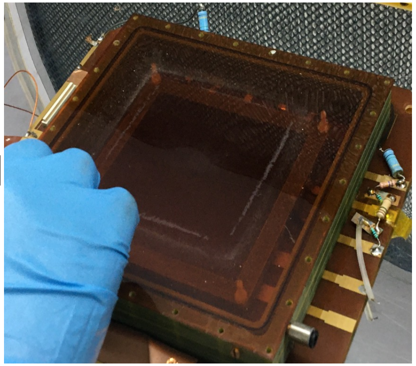
Drift plane is placed



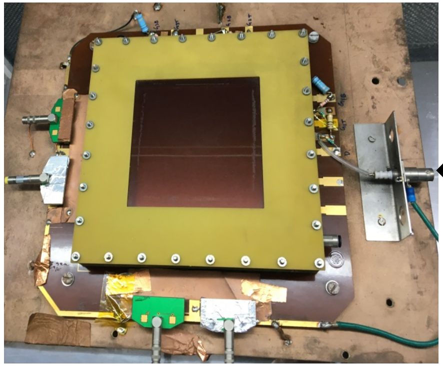
Frame is placed with O-ring



Gluing at the bottom

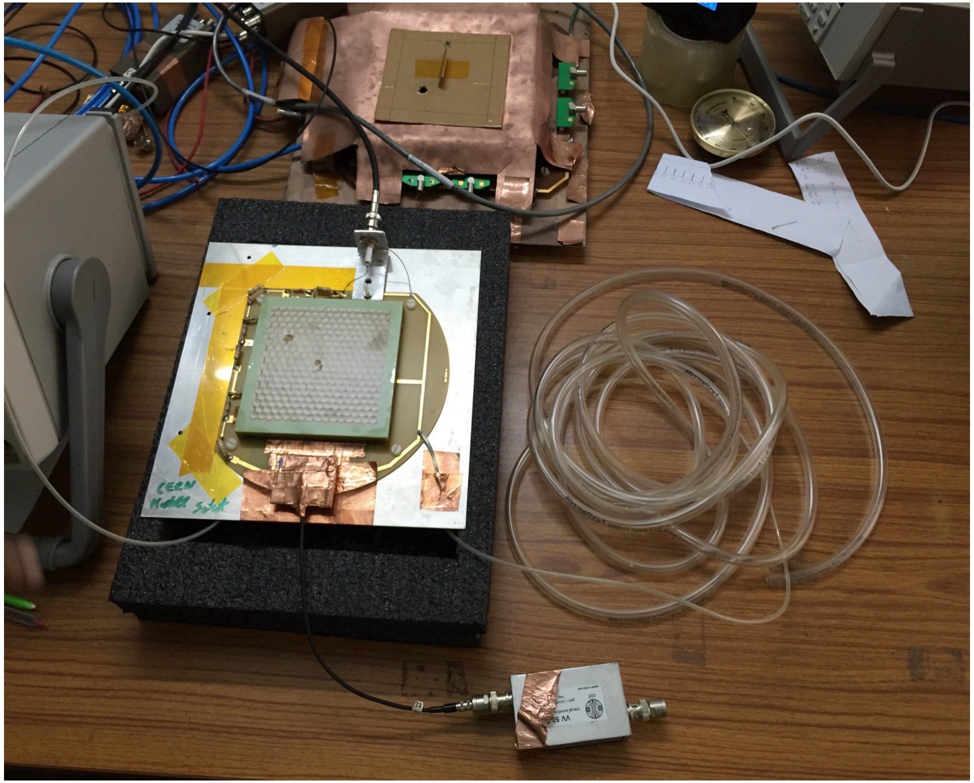


Kapton window is placed

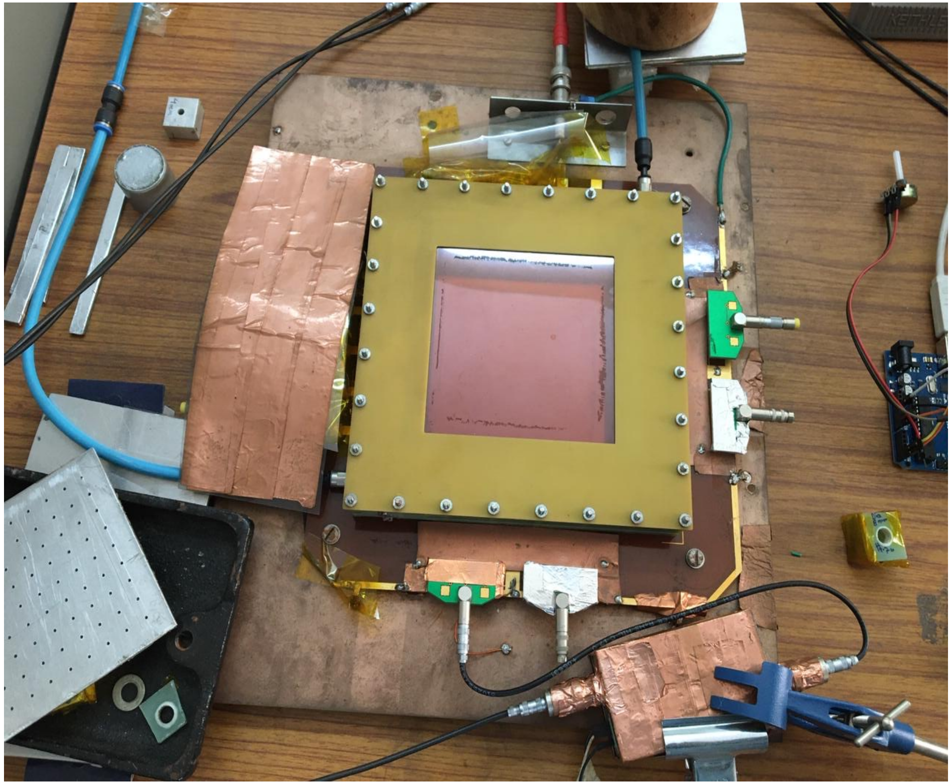


Assembled GEM

Triple GEM chambers prototype under testing at Bose Institute

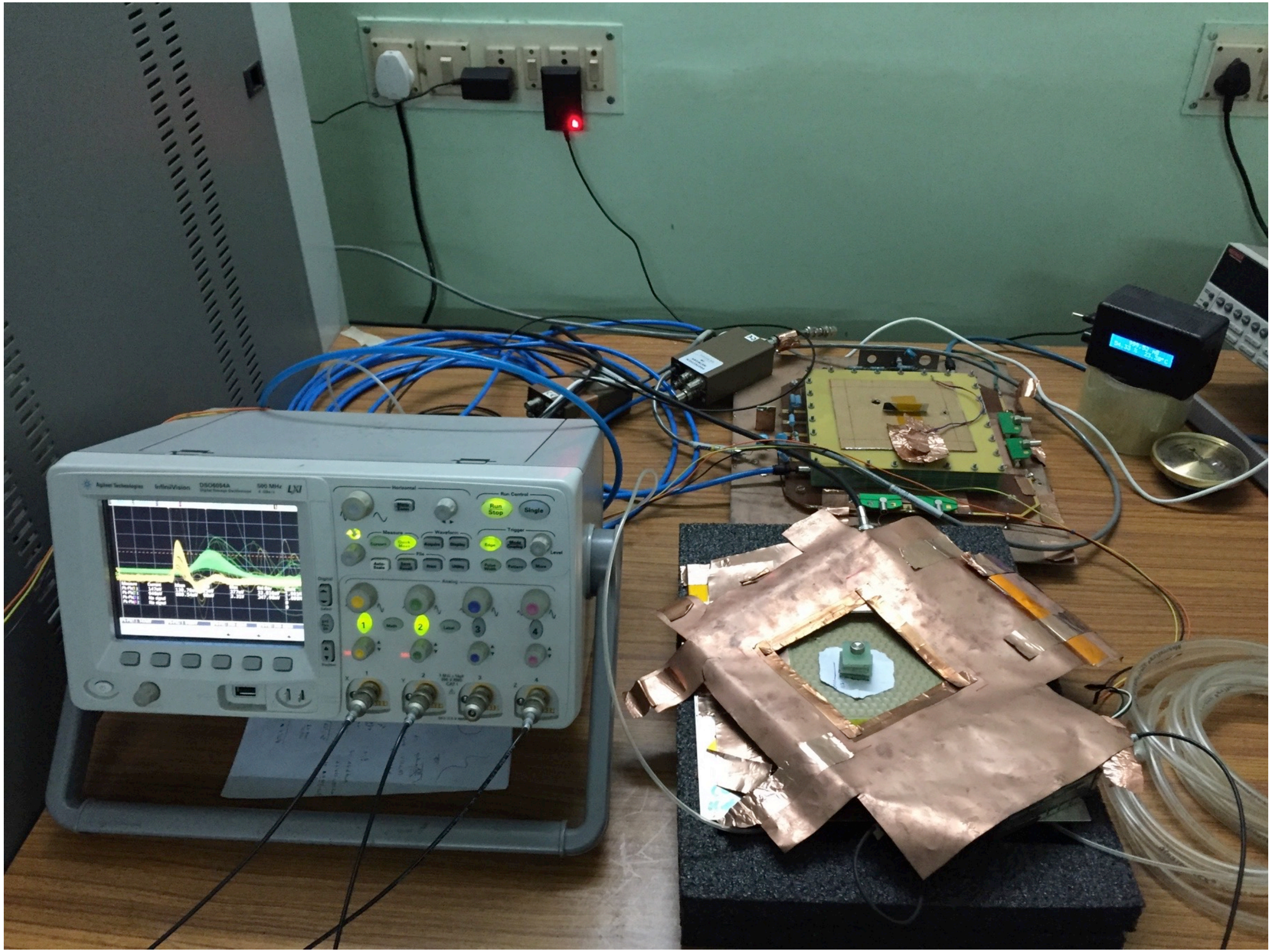


Double Mask (DM) triple GEM chamber



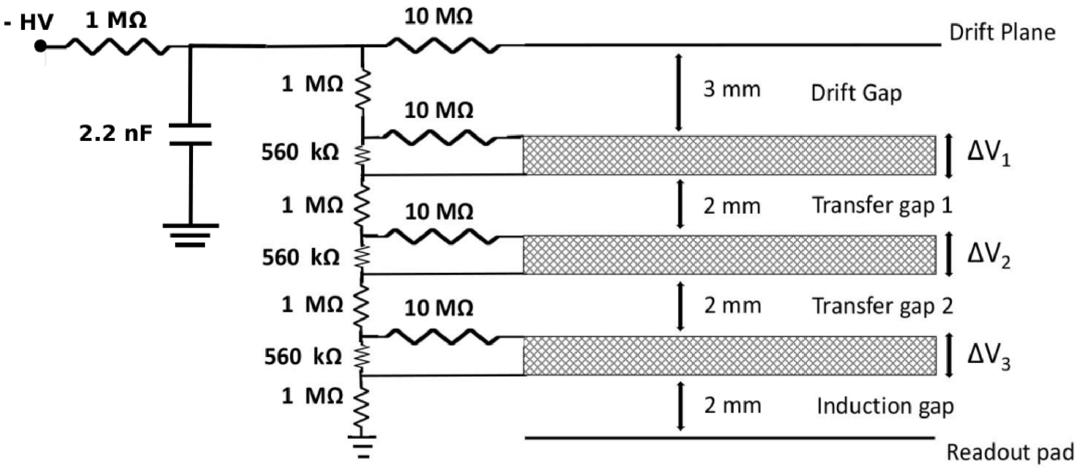
Single Mask (SM) triple GEM chamber

Triple GEM chamber prototype under testing at Bose Institute



Characteristics studies of triple GEM prototypes at Bose Institute

Characteristics studies



Schematic of the High Voltage distribution of the SM mask triple GEM chamber of dimension 10×10 cm^2

Dimension of the chamber: 10×10 cm^2

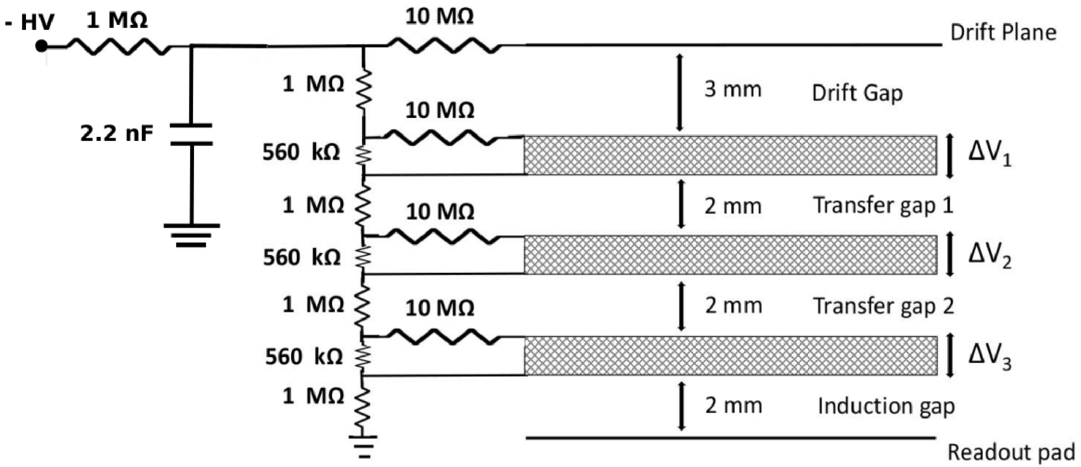
GEM: SM & DM triple GEM chamber

Source: Same Fe^{55} X-ray (5.9 keV) source is used for irradiation and monitoring the spectrum

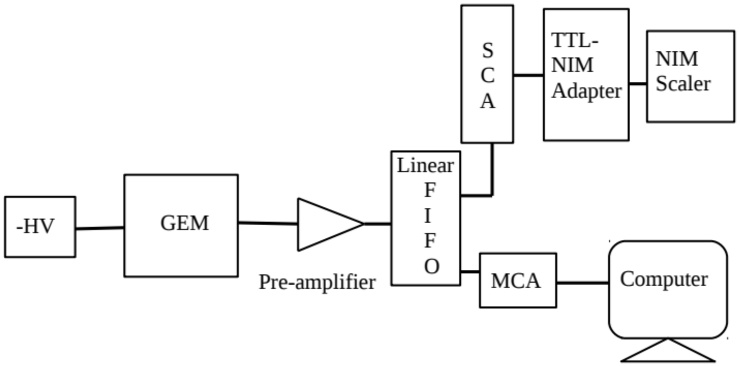
Gas mixture: Ar/CO_2 (Continuous flow mode)

Preamplifier gain: 2 mV/fC (charge sensitive)

Characteristics studies



Schematic of the High Voltage distribution of the SM mask triple GEM chamber of dimension 10×10 cm²



Schematic representation of the electronics setup

Dimension of the chamber: 10×10 cm^2

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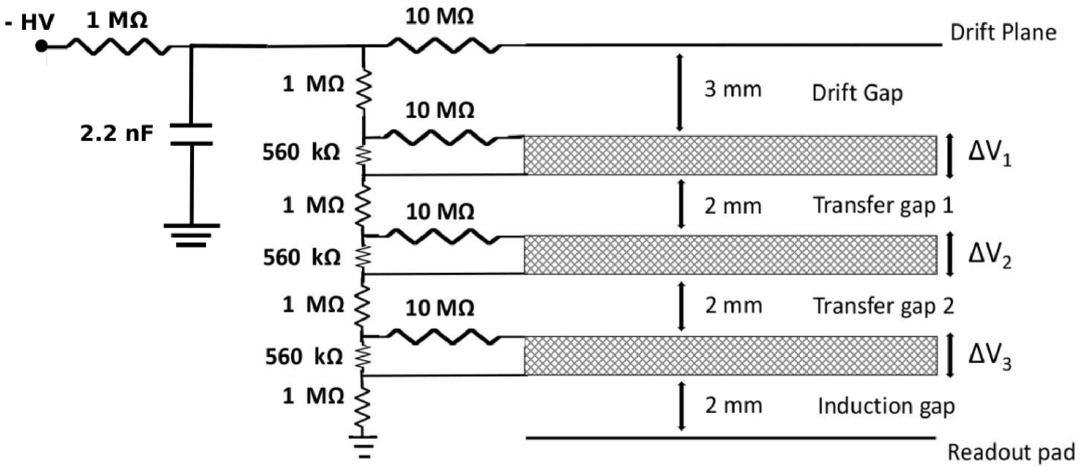

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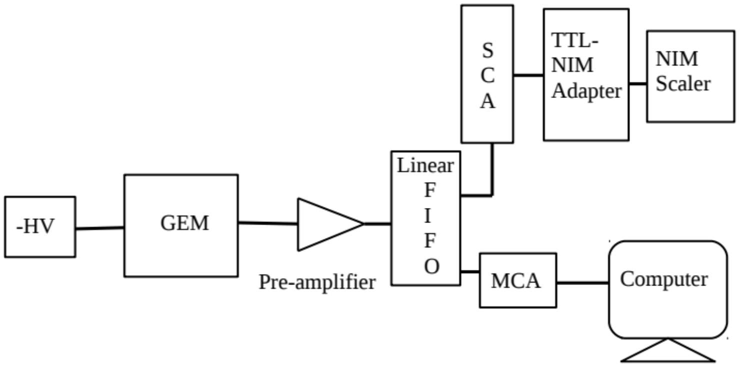

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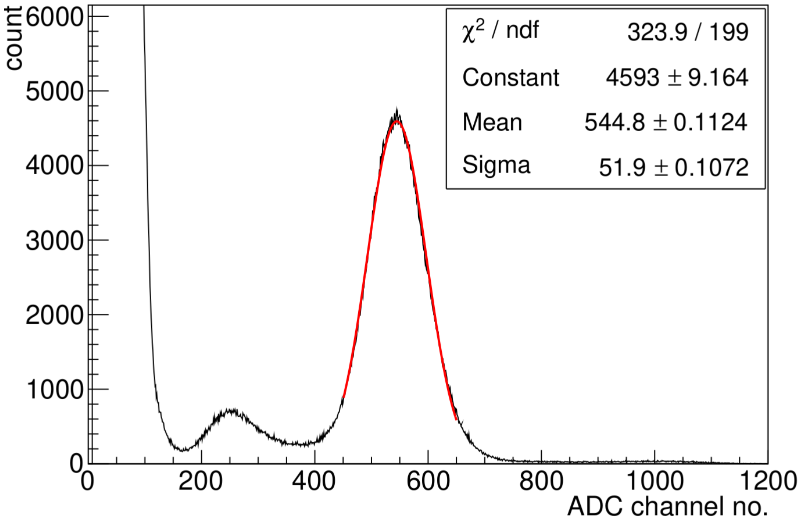

Fe^{55} spectra at ΔV ~ 410 V and with Ar/CO_2 gas mixture at 70/30 volume ratio

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Gas mixture: Ar/CO_2 (Continuous flow mode)

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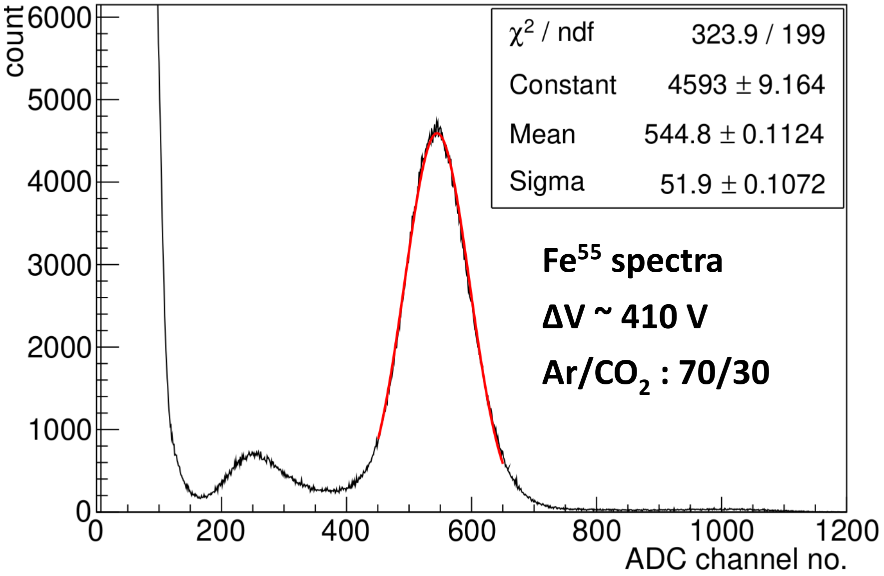
Gain, energy resolution & count rate



$$\textbf{Gain} = \frac{\text{Output charge}}{\text{Input charge}} = \frac{\text{(Mean pulse height/ 2 mV) fC}}{\text{No of primary electrons} \times \text{e C}}$$

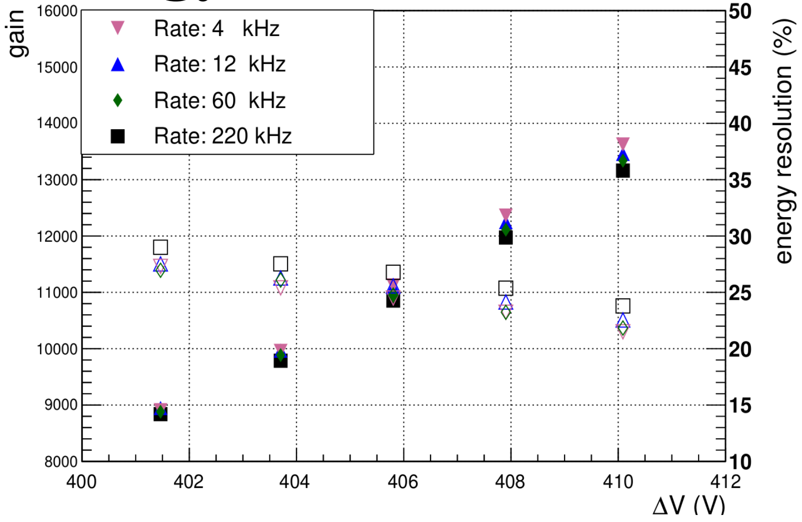
$$\textbf{Energy resolution} = \frac{\text{Sigma} \times 2.355}{\text{Mean}} \times 100\ \%$$

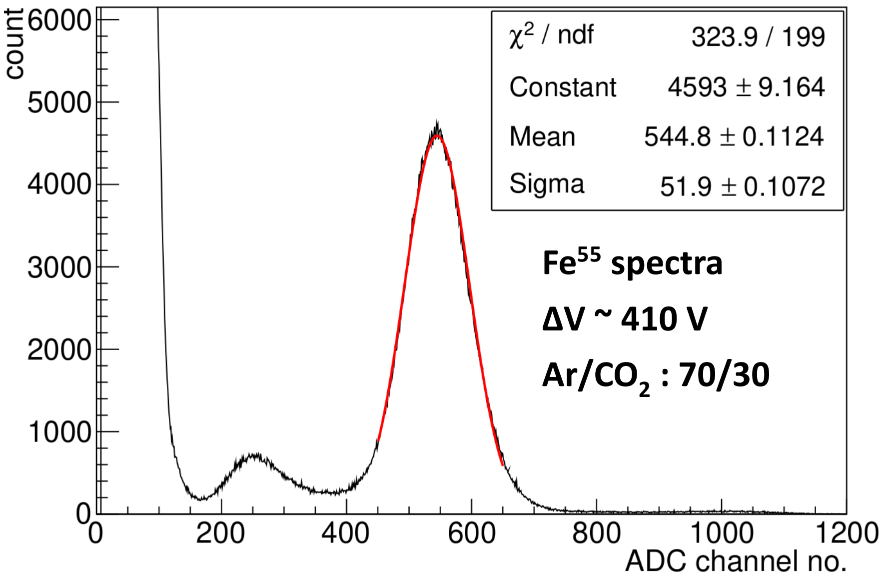
Number of primary electrons (n)

$$\mathbf{n} = E_{gamma}\left(\frac{\%\text{ of Ar}}{W_{Ar}} + \frac{\%\text{ of }CO_2}{W_{CO2}}\right)$$

For Ar/CO_2 in 70/30 volume ratio, the average number of the primary electrons is 212 with the 5.9 keV X-ray source

Gain, energy resolution & count rate





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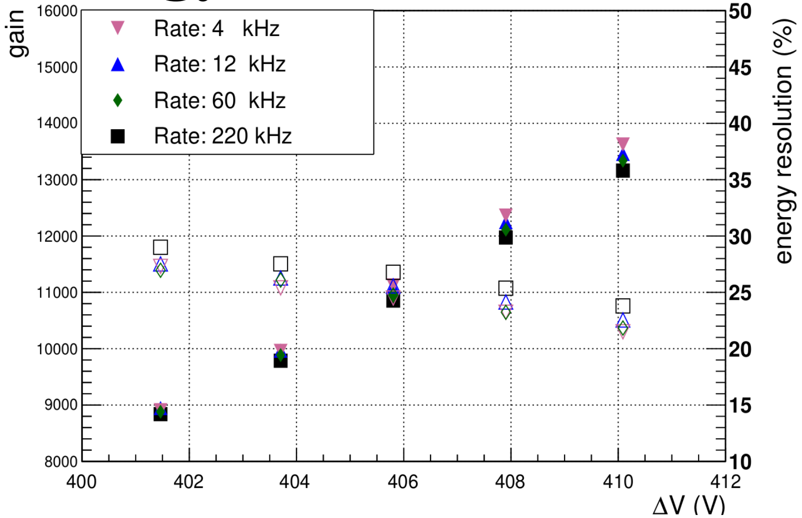

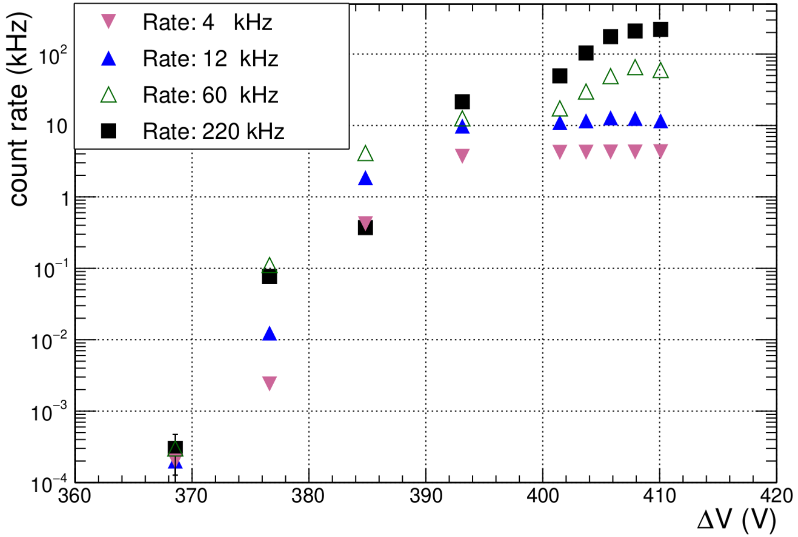

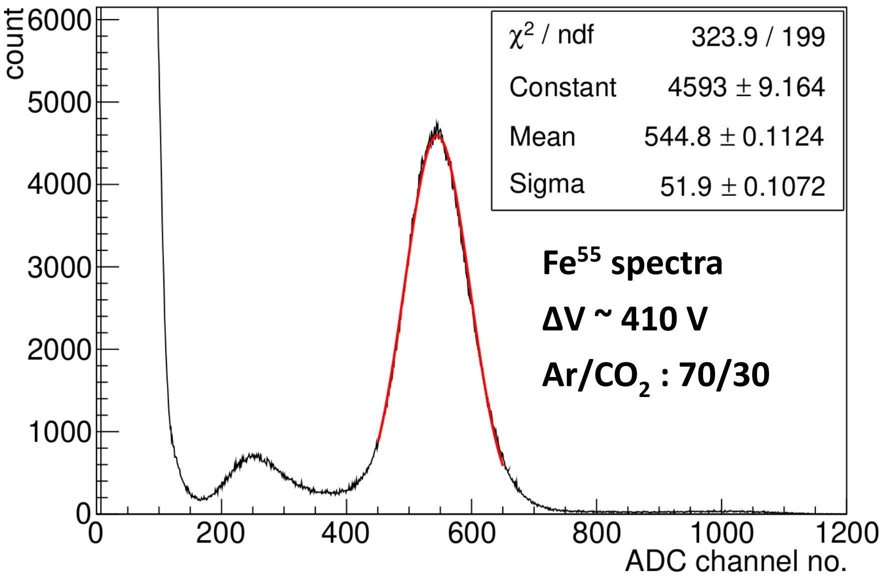

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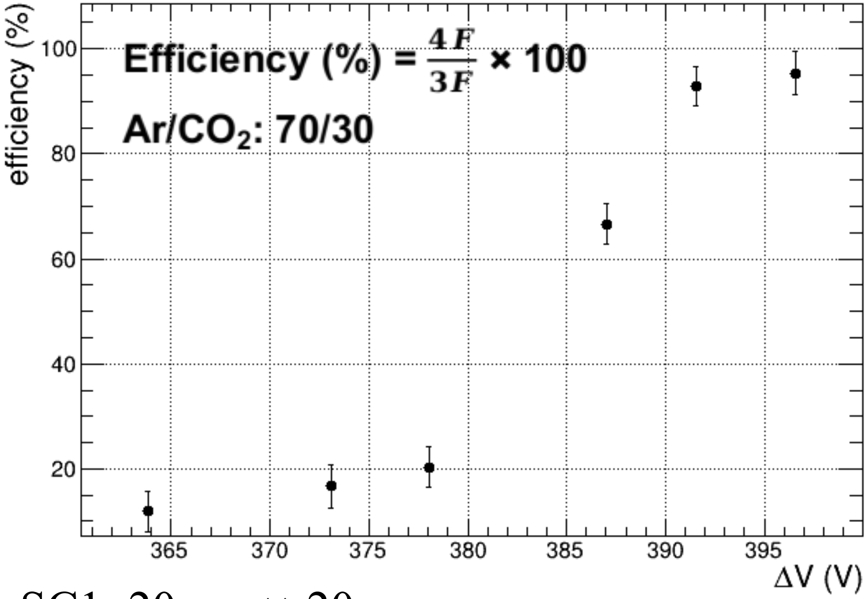
Measurement of efficiency

Efficiency measurement



SC1: 20 cm × 20 cm

SC2: 2 cm × 10 cm

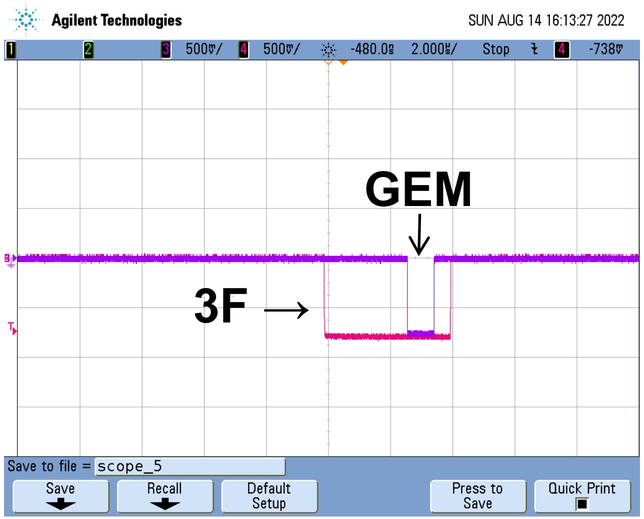
SC3: 10 cm × 10 cm

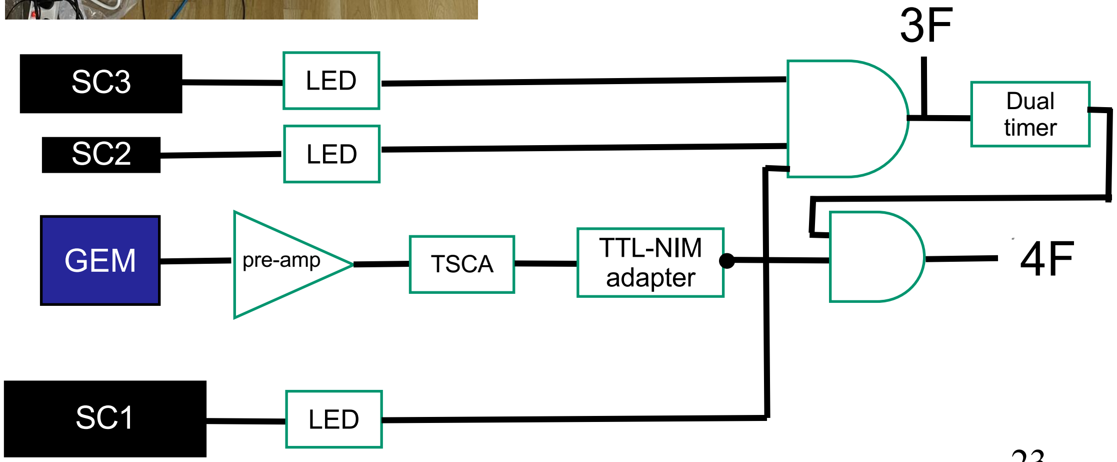
Threshold to scintillators: - 10 mV

Threshold to GEM: 0.15 V

Gain of TSCA: 20 × 0.5 = 10

Width of 3F signal: 3 μs

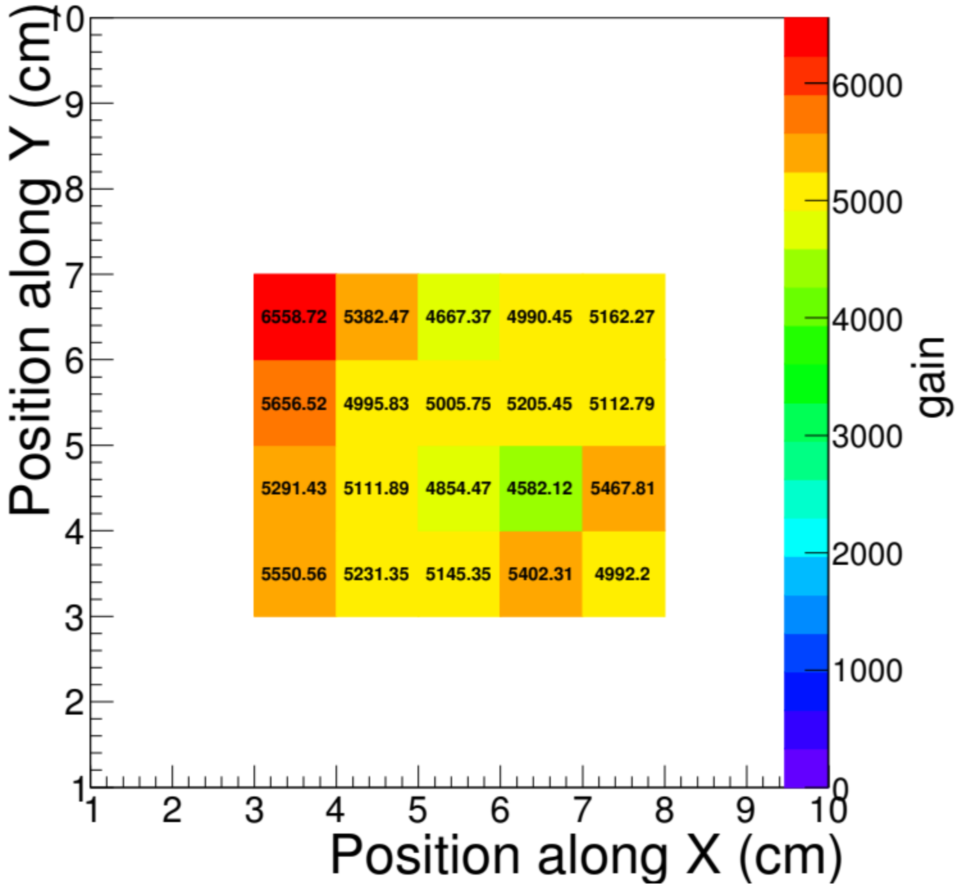




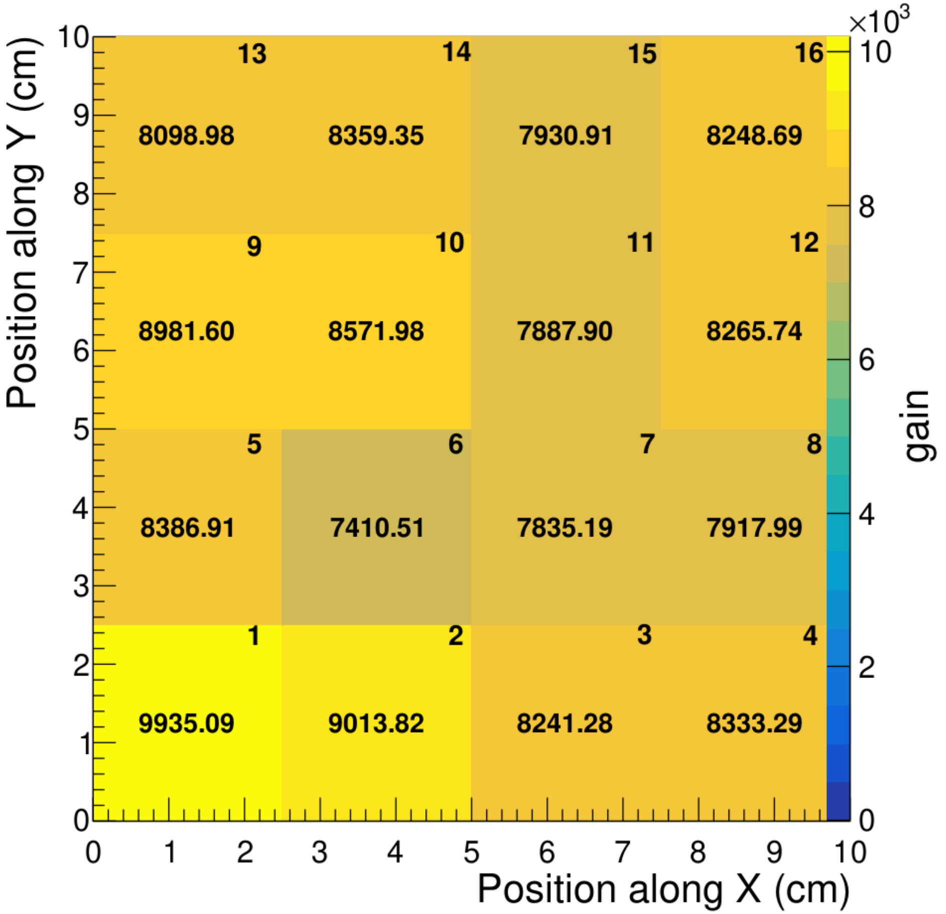
Efficiency measurement setup; top left: lab setup, bottom: electronic setup

Measurement of uniformity in the characteristics of triple GEM chamber prototypes

Uniformity in gain of a triple GEM chamber



DM GEM; ΔV ~ 386 V; Ar/CO_2 : 70/30
Fluctuation < 10%



SM GEM; ΔV ~ 403 V; Ar/CO_2 : 70/30
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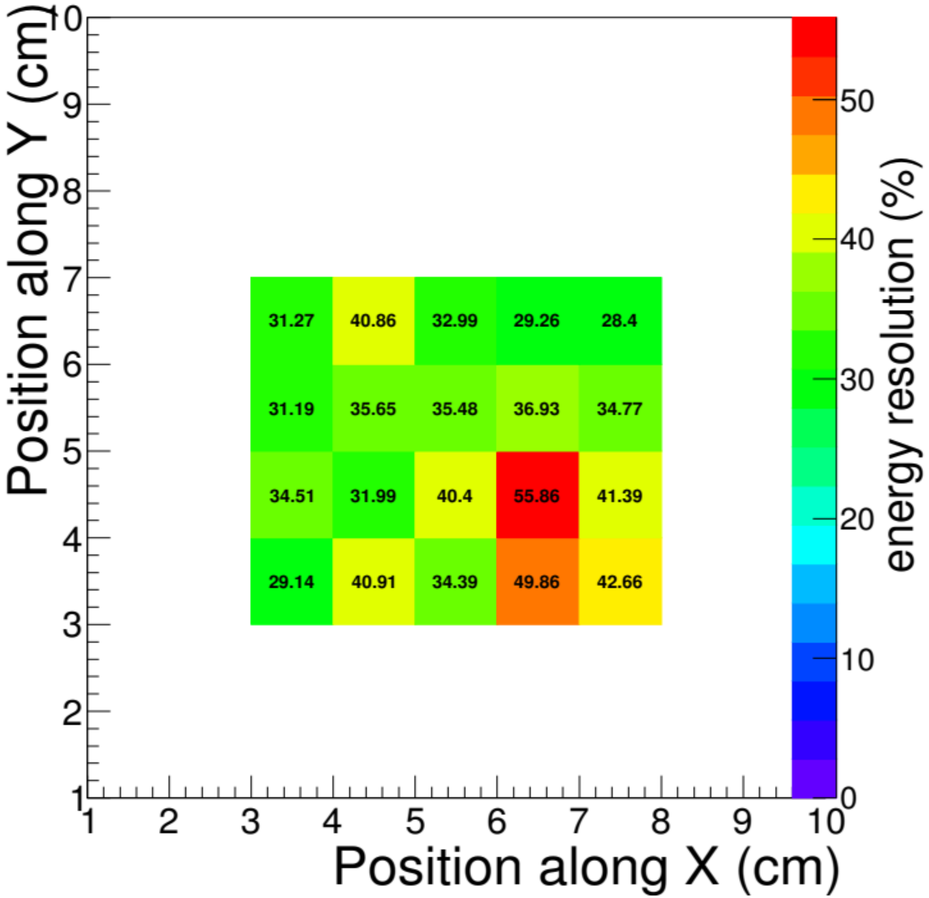
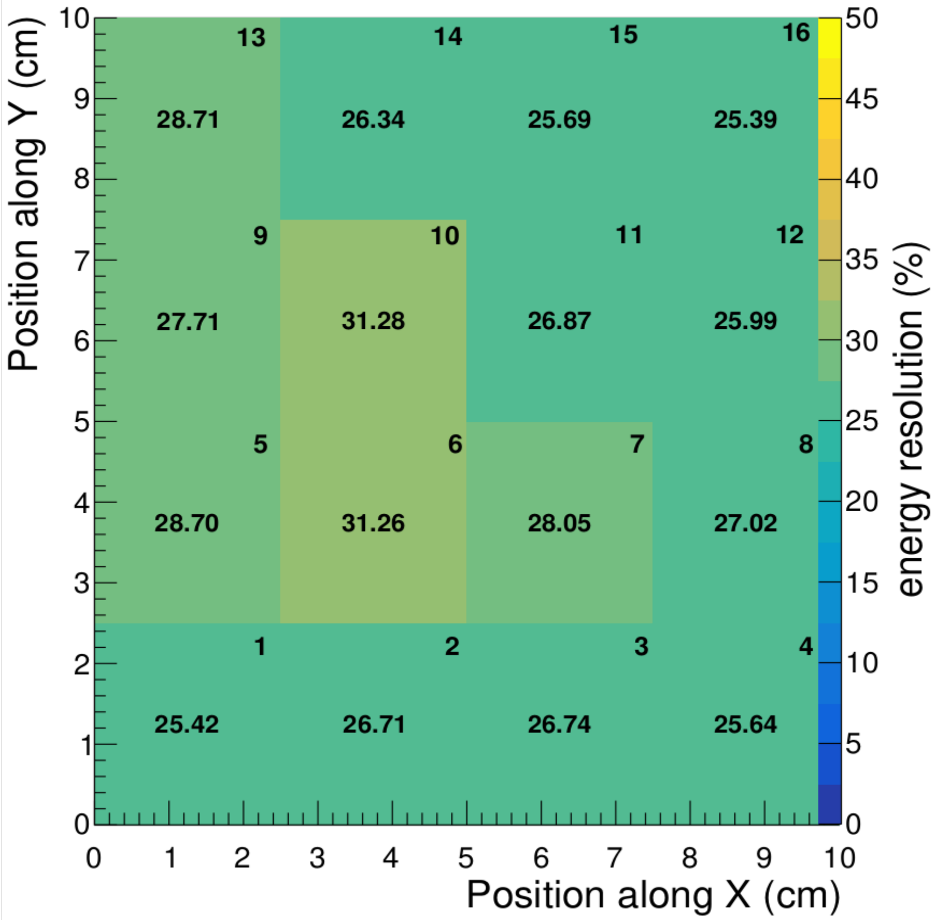
Reference : S. Chatterjee *et al.*, Nucl. Instr. and Meth. A936 (2019) 491, arXiv:2206.10876v1

Uniformity in energy resolution of a triple GEM chamber



DM GEM; ΔV ~ 386 V; Ar/CO_2 : 70/30
Fluctuation < 20%



SM GEM; ΔV ~ 403 V; Ar/CO_2 : 70/30
Fluctuation < 10%

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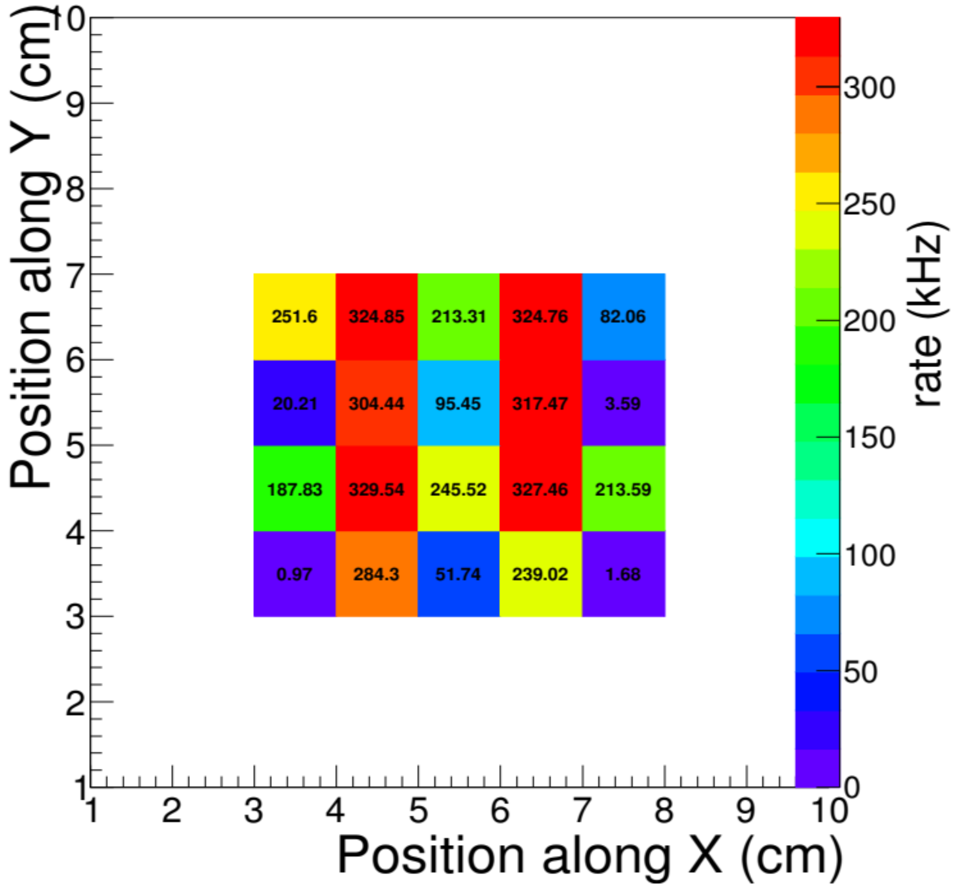
Uniformity in count rate of a triple GEM chamber



DM GEM; ΔV ~ 386 V; Ar/CO_2 : 70/30
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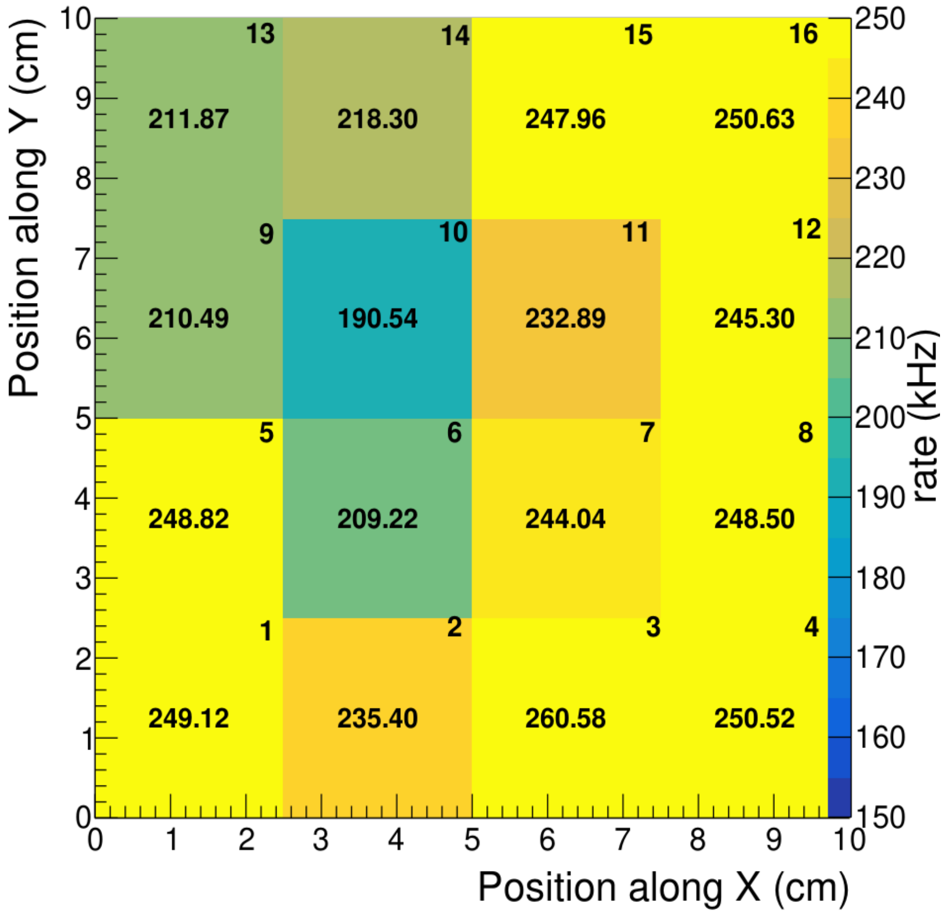

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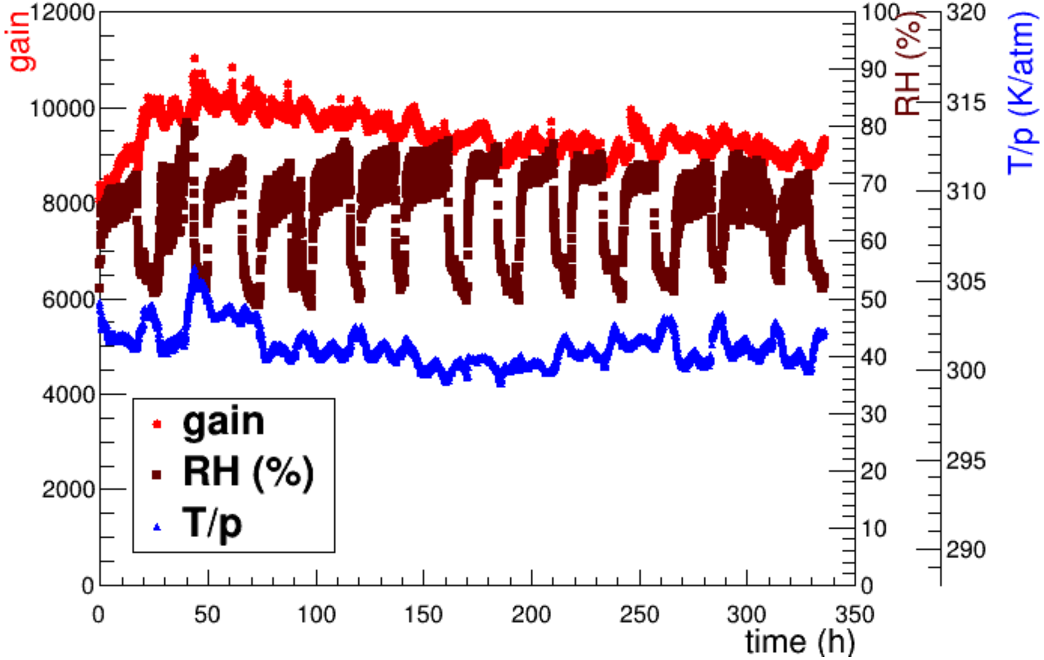
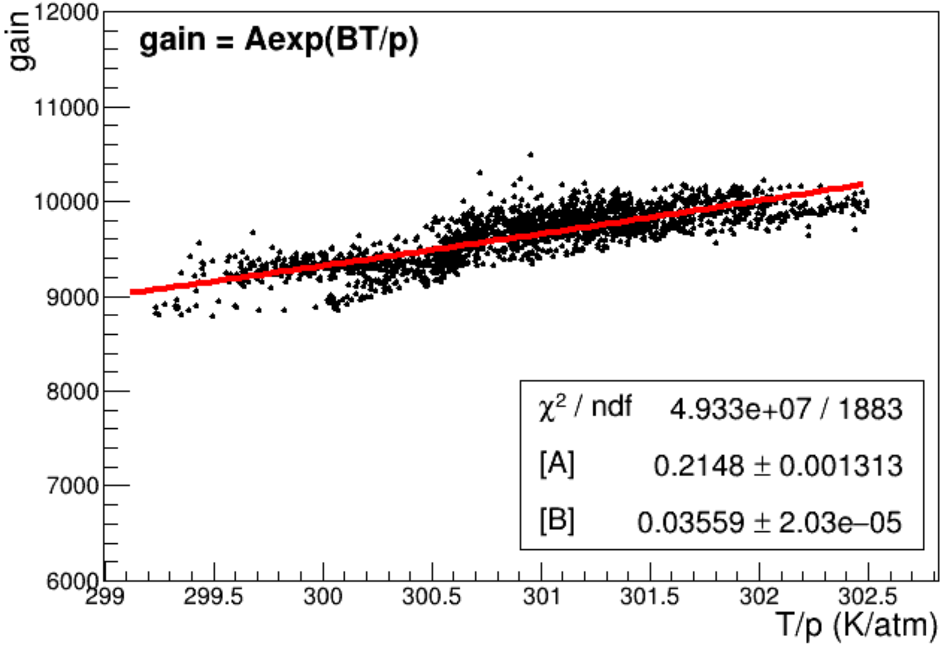
Long-term stability study of triple GEM prototypes

Variation of gain with T/p

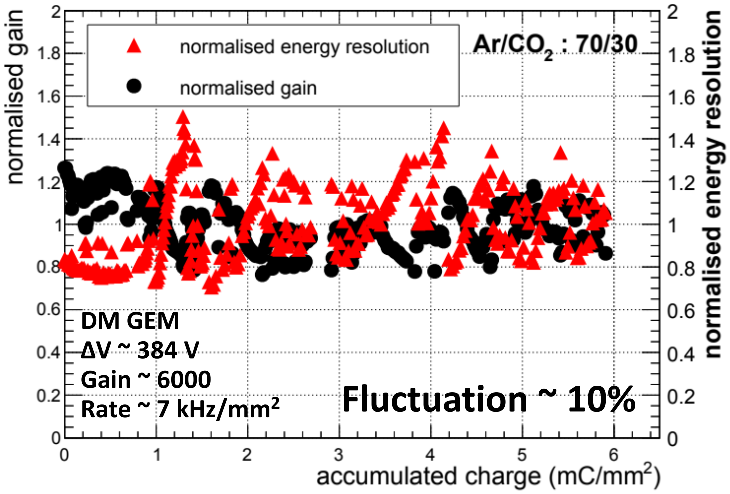


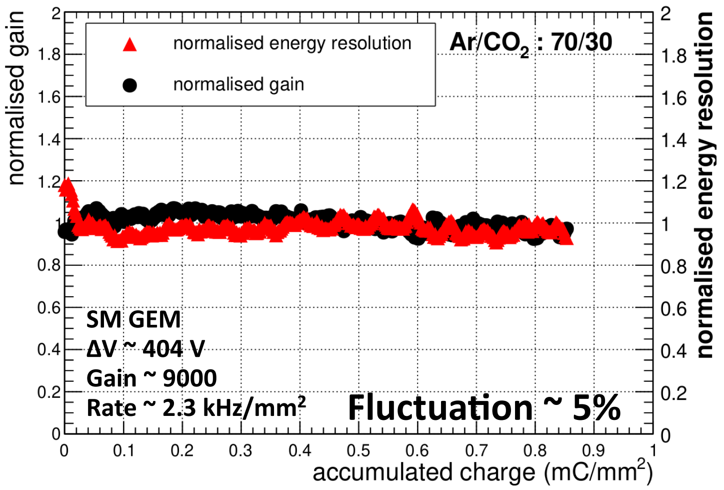


- **Gain of the chamber can be expressed as e^α, where α is the first Townsend coefficient**
- **Townsend coefficient $\alpha \propto 1/\rho \propto T/p$; ρ =** mass density**, T =** temperature**, p =** pressure
- **Gain of the chamber depends on the variation of T/p**
- **Gain is normalised using a parameterisation of the form $Ae^{(BT/p)}$**

S. Chatterjee et al., NIMA 1046, 167747 (2023)

Normalised gain & energy resolution vs accumulated charge





$$\frac{dq}{dA} = \frac{r \times n \times e \times G \times dt}{dA}$$

r = rate, ***n*** = no of primary electrons, ***dt*** = time, ***e*** = electronic charge
G = gain, ***dA*** = irradiated are

Gain and energy resolution is normalised by T/p ratio to nullify the effects of temperature and pressure variations

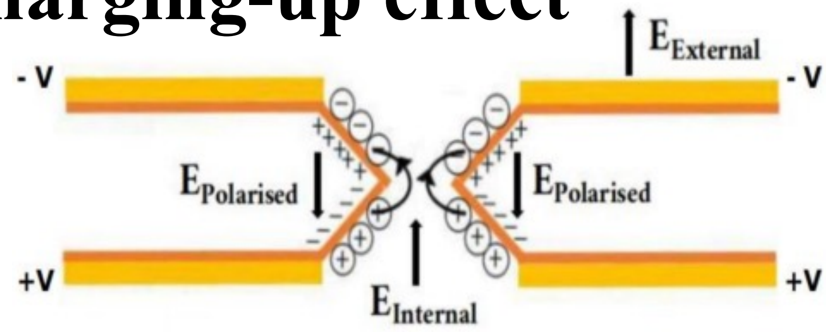
No significant degradation in normalised gain and energy resolution is observed

Typical accumulated charge for 10 CBM years is ~ 0.8 mC/mm^2 at the gain of 10^3

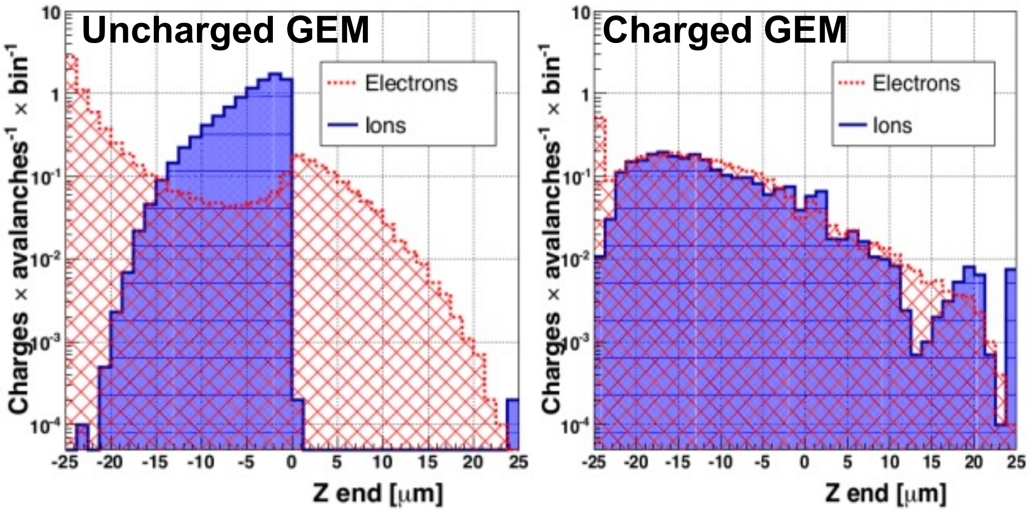
Reference : S. Chatterjee *et al.*, Journal of Physics: Conference Series, 1498 (2020) 012037

Charging-up effect in triple GEM chamber prototypes

Charging-up effect



Schematic representation of the charging-up effect inside the GEM hole

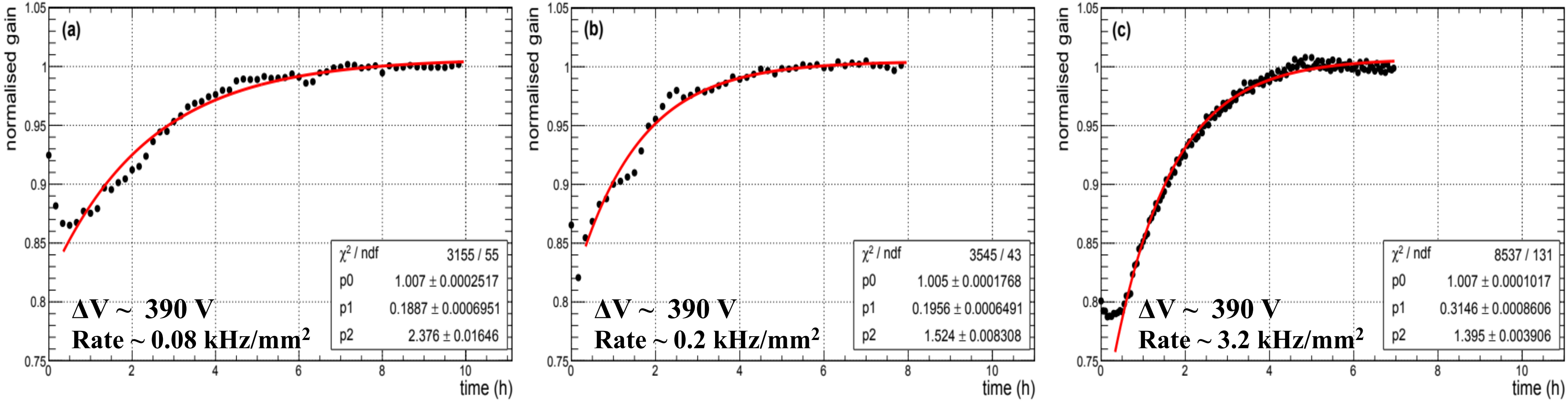


Simulated spatial distribution of deposited on the insulator surface of the uncharged and charged GEM foil

- During the multiplication process inside the GEM hole, electrons and ions diffuse to the polyimide part of the GEM and adsorbed there.
- These new charges accumulate over time and dynamically change the electric field inside the hole. This is known as the charging-up effect.
- Those accumulated charges create a lensing effect and as a result, the gain increases for the first few hours of operation.
- After some time when the dynamical equilibrium is reached, the gain reaches asymptotically a constant value.

Reference : P.M.M. Correia *et al.*, 2014 JINST 9 P07025

Charging-up effect in DM GEM

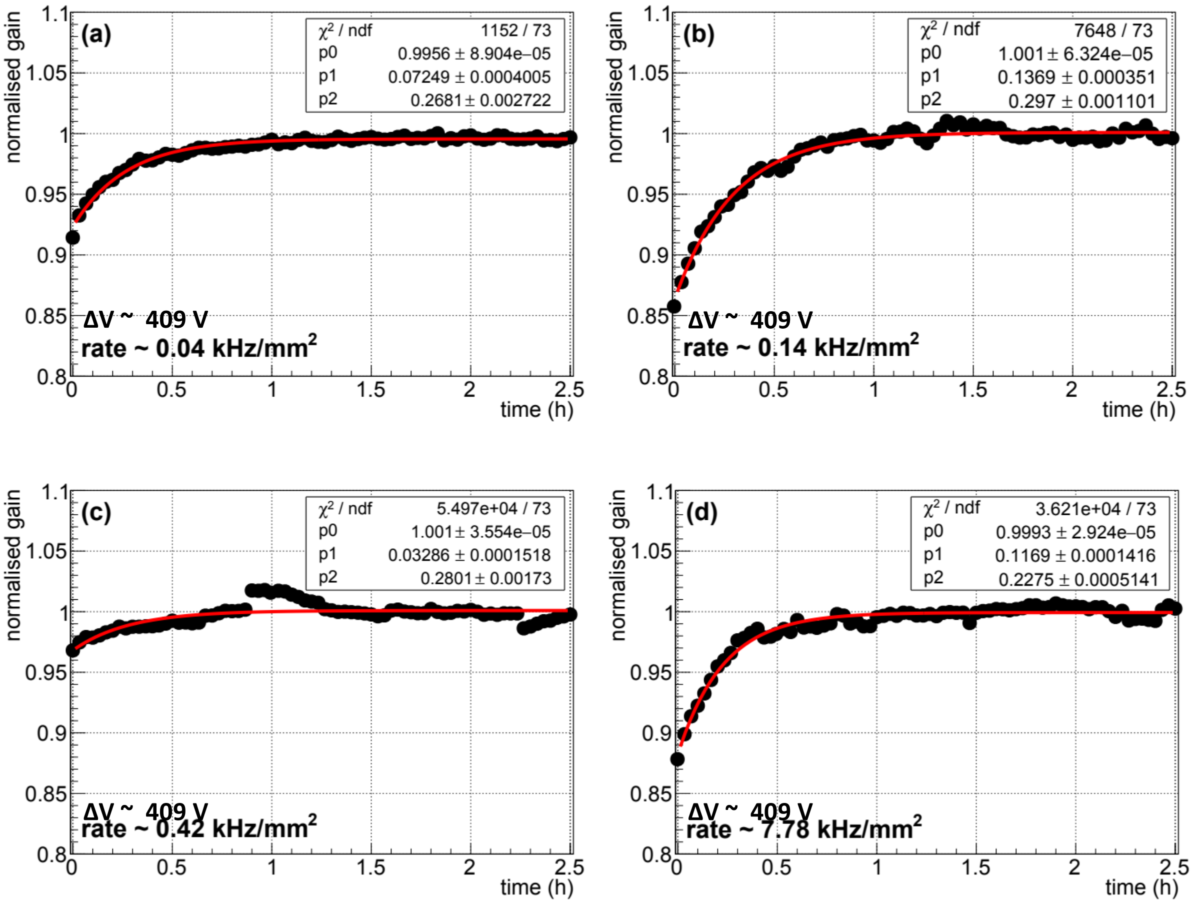


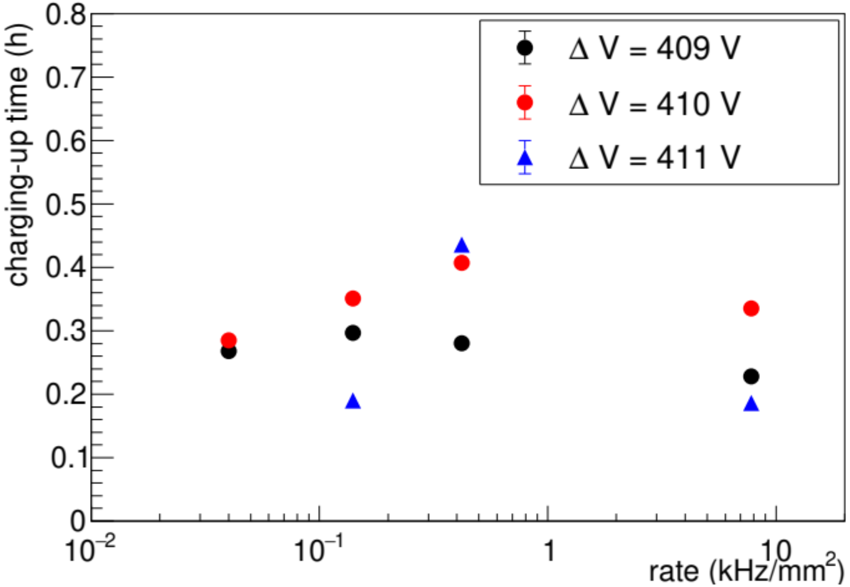
ΔV (V)	Rate (kHz/mm²)	Charging-up time (hour)	Saturated gain
~ 390	~0.08 ~0.2 ~3.2	2.376(±0.0165) 1.524(±0.0083) 1.395(±0.0039)	~4900 ~5100 ~5500

- **Gain is normalised to eliminate the effects of temperature and pressure**
- **Normalised gain is fitted with $p0\,(1 - p1\,e^{-t/p2})$, taking analogy from the charging-up of RC network**

Reference : S. Chatterjee *et al.*, 2020 JINST 15 T09011

Charging-up effect in SM GEM

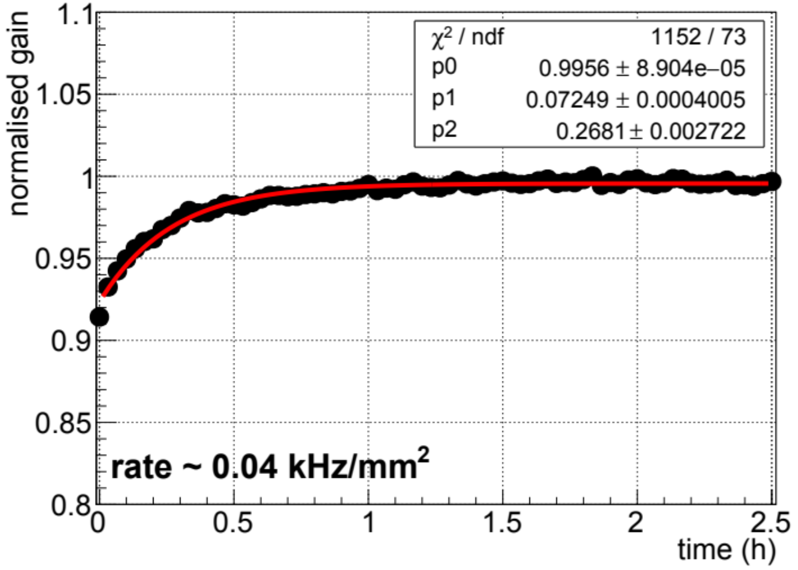


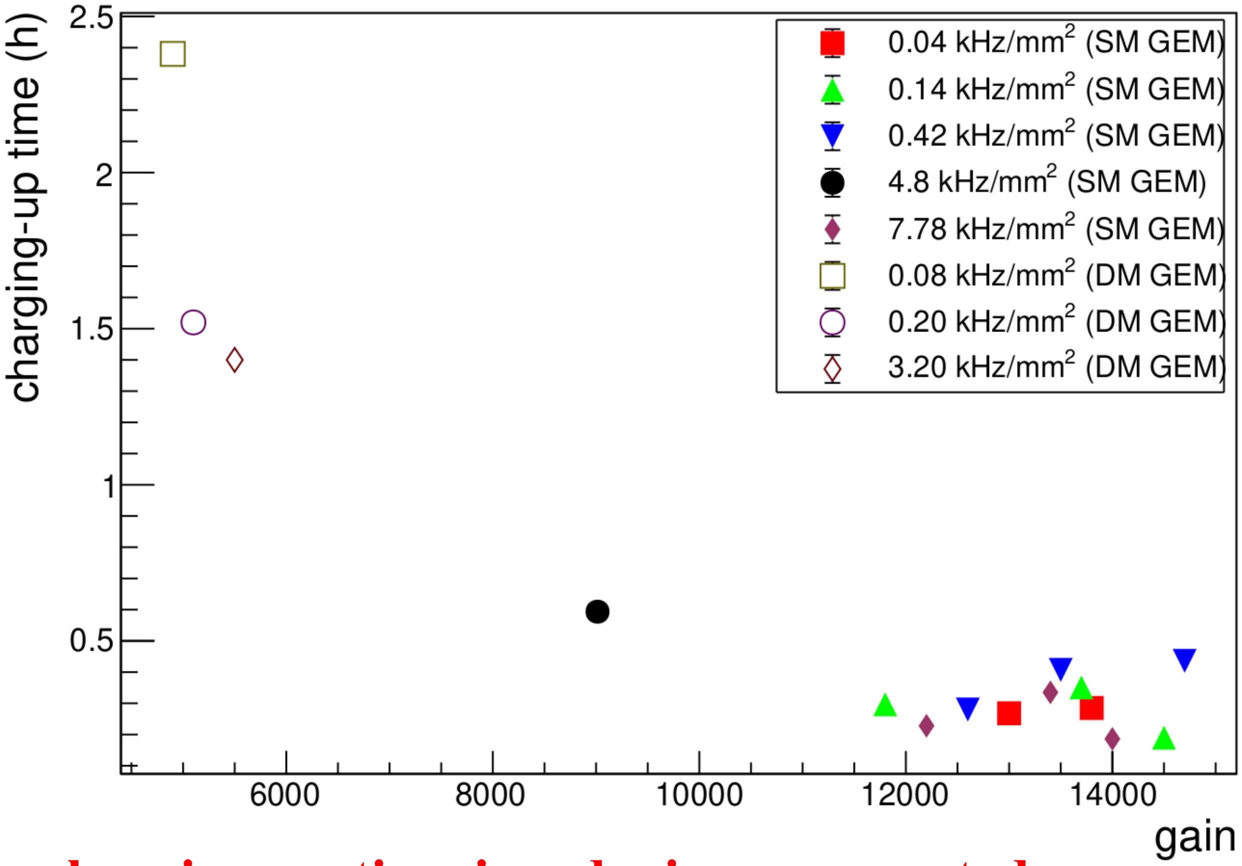


- **Charging-up time is found to be between 0.2 – 0.4 hours for the saturation gain ~ 10^4**

Reference : S. Chatterjee *et al.*, NIMA 1014 (2021) 165749

Variation in charging-up time with gain



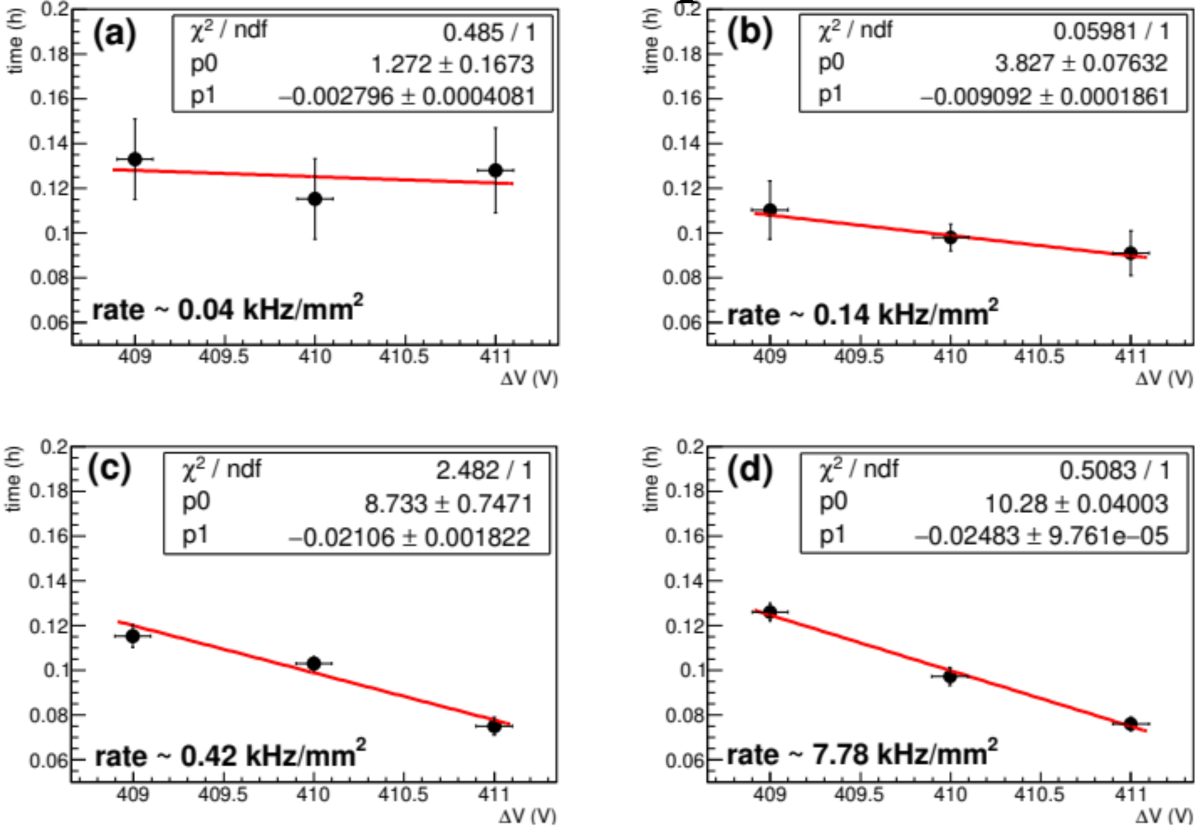


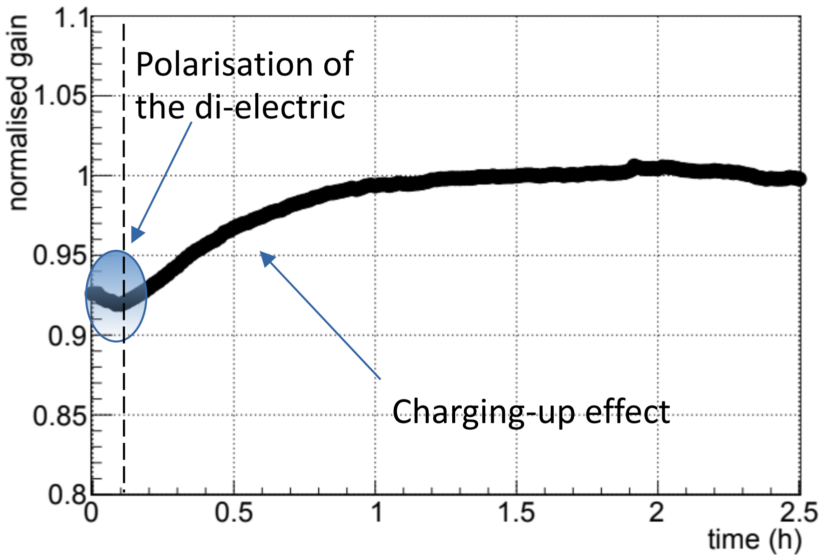
normalised gain = p0 (1 - p1e$^{-t/p2}$)

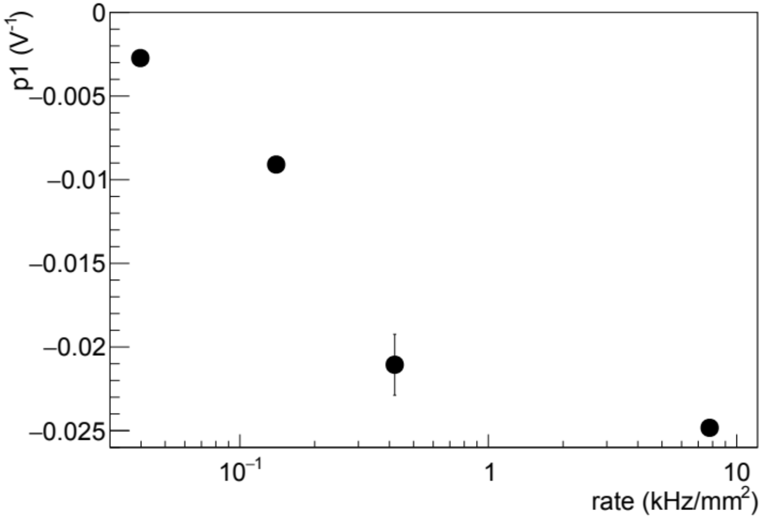
p2 ➔ Charging-up time

With increasing gain, the charging-up time is reducing as expected

Effect of di-electric polarisation







- **The time up to which the gain decreases initially due to the polarisation effect is anti-correlated with the voltage across the GEM foil.**
- **The rate of decrease of time with ΔV increases with the increasing rate of irradiation.**

Reference : S. Chatterjee *et al.*, NIMA 1014 (2021) 165749

Summary

- **Characteristics studies of triple GEM chambers**
  - Efficiency of the chamber is measured using cosmic rays
  - Uniformity in performance is investigated in terms of gain, energy resolution and count rate of the chamber using Fe^{55} X-ray source
  - Long-term stability in performance is investigated with different Ar/CO_2 based gas mixtures
- **Effect of irradiation on the performance of the chamber**
  - The charging-up phenomena is investigated for different irradiation rates and at different gain of the chamber

Thank you for your attention!!!