Characteristic study of 4GEM detector for future experiments

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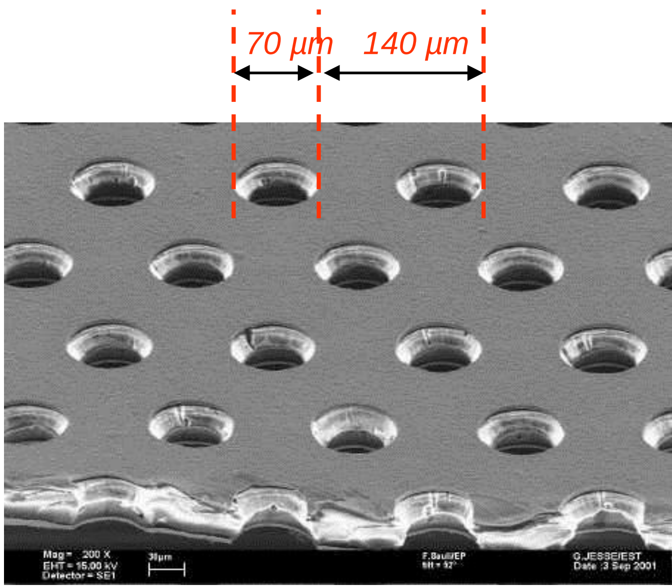
Outline of the talk

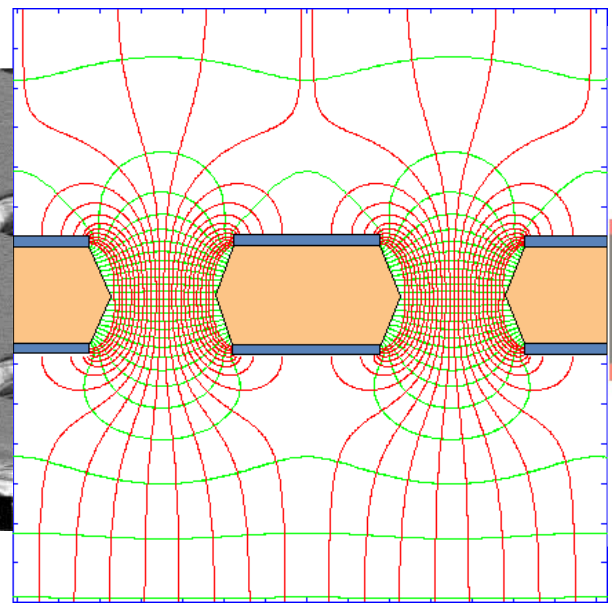
- Principle of GEM
- Motivation
- Detector details
- Test and results
- Summary

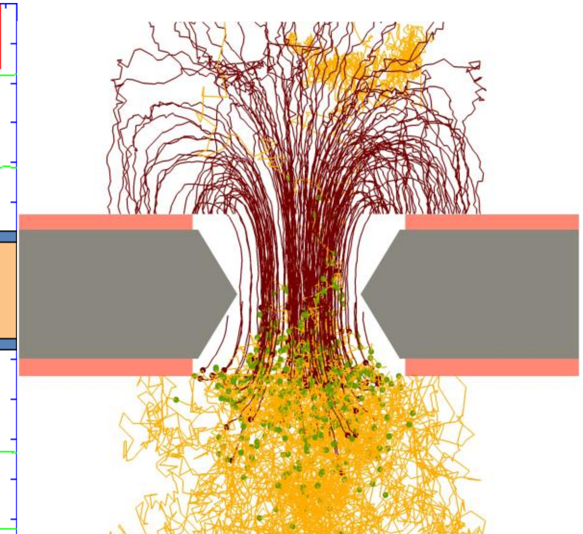
Gas Electron Multiplier (GEM)

Thin, metal-coated polymer foil with high density regular array of holes

Standard GEM geometry:5 µm Cu on 50 µm Kapton with 70 µm hole diameter and 140 mm pitch





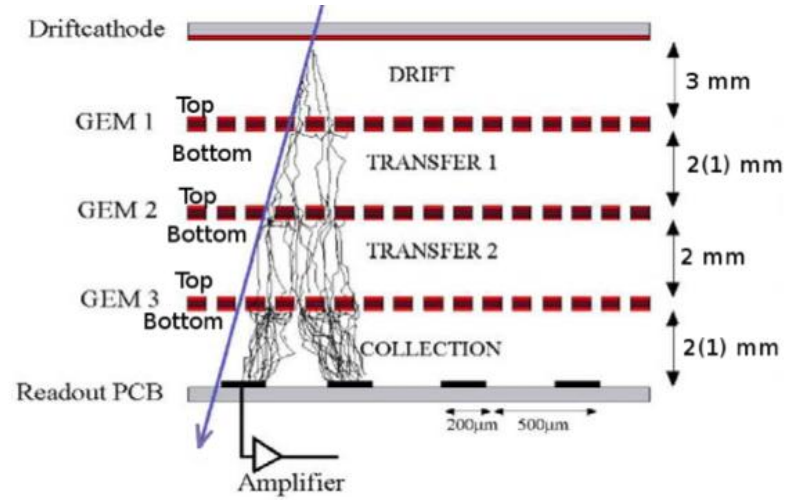


F. Sauli,
Nucl. Instrum. Methods A386(1997)531

Operating principle of GEM and its advantage

Detector properties:

- The regions of conversion, multiplication and signal induction are physically distinct → freedom in readout design choice;
- Signal is purely due to the motion of electrons in the induction region → no ion tail, fast signal;
- Ions are quickly removed from multiplication region → high rate capability
- Multiplication is divided in several steps → robustness to discharges;
- Light detector (3% X_0 /GEM foil)



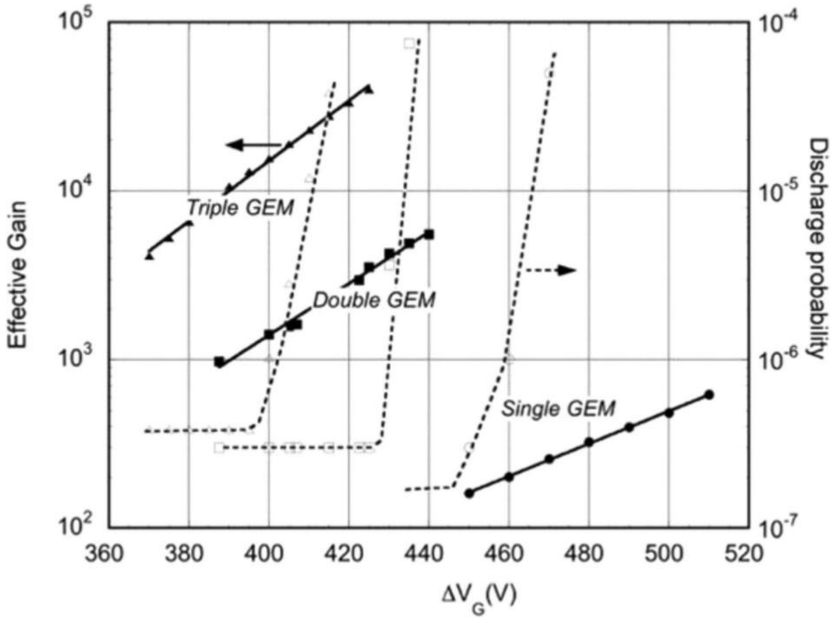
Typical electric field values

- E_{drift} ~ 1 kV/cm
- $E_{transfe}$ ~ 2 kV/cm
- $E_{induction}$ ~ 3 kV/cm
- E_{GEM} ~ 70 kV/cm

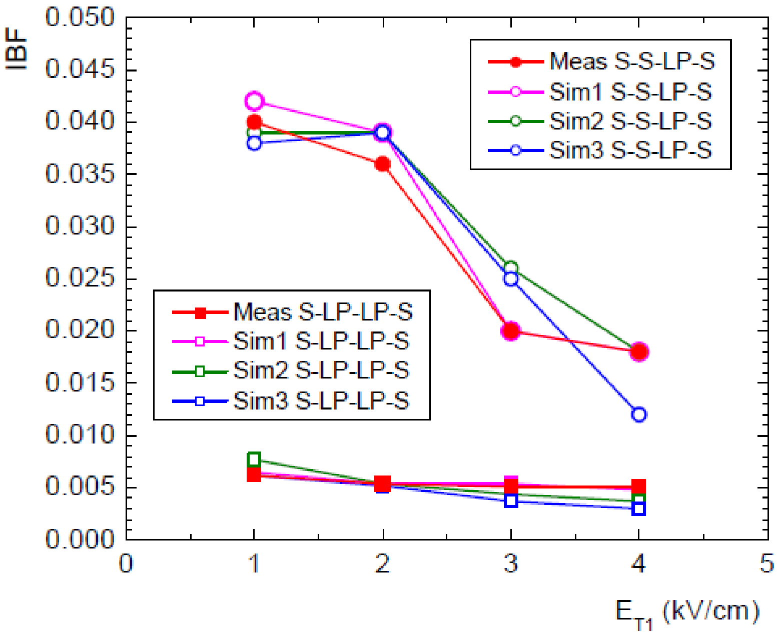
Advantage of 4GEM detector

The main advantage of using multiple GEM detector:

- Overall gain of the detector is attained with much lower operating voltage of the individual GEM. So very less prone of the discharge.
- Ion Back Flow (IBF) depends on gain, gas and geometry of the GEM detector. With multi GEM structure IBF improves a lot. Though the energy resolution decreases with reduction of IBF.



Effective gain and discharge rates as a function of voltage across GEM



Ref: ALICE TPC Upgrade TDR

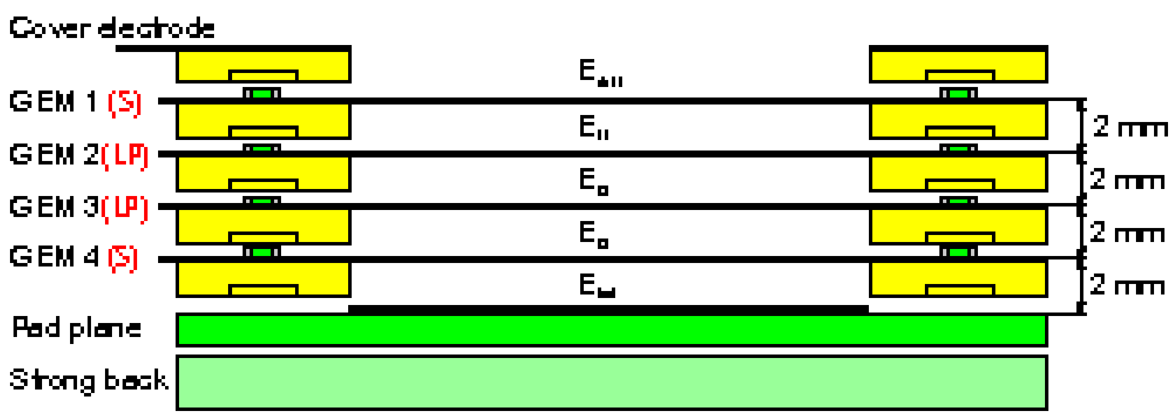
Motivation of the present work

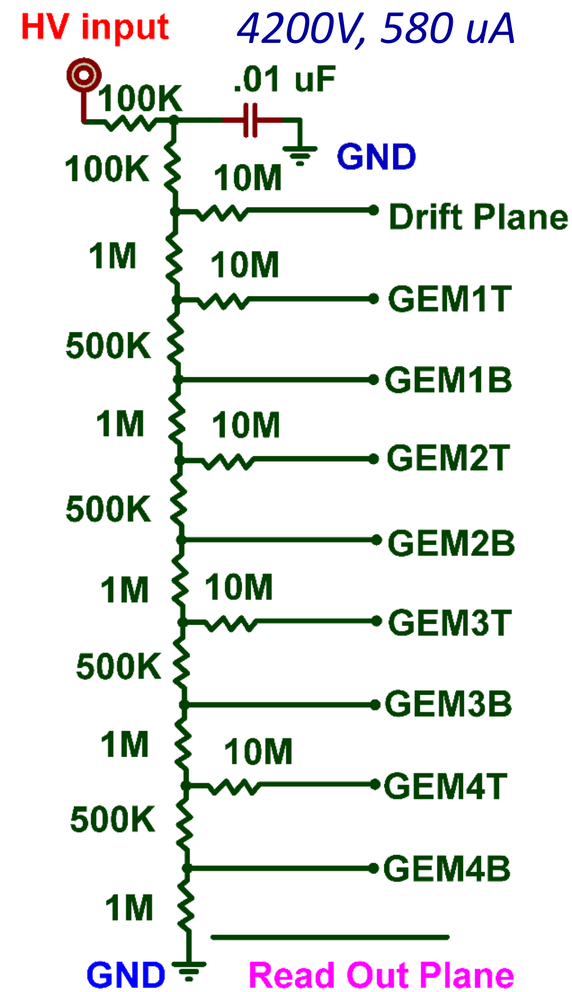
4 GEM detector is found to be very useful for the reducing of IBF, low discharge probability and high rate handling capability. It is useful for experiment like ALICE to cope up with large particle production rate. So it is important to study the 4GEM detector which is helpful for ALICE TPC.

- In this presentation characteristic studied of a 4GEM detector will be presented.

Detector details

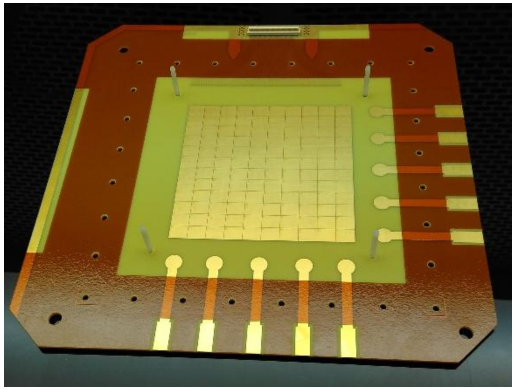
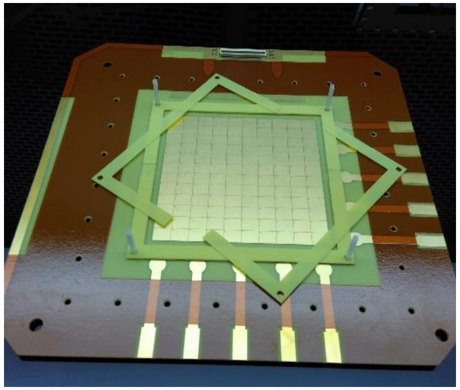
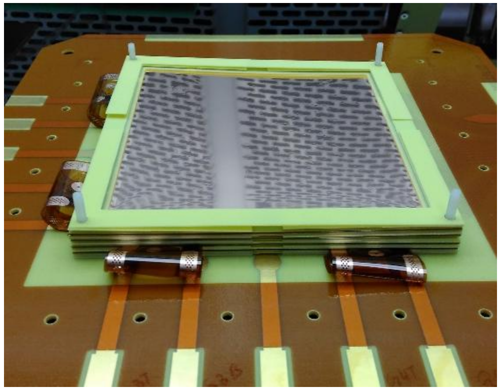
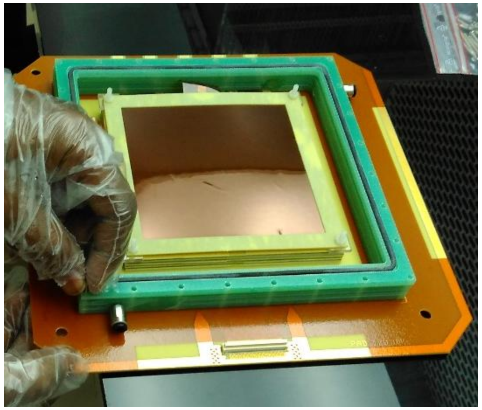
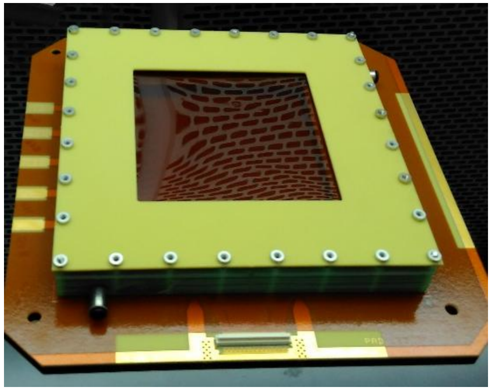
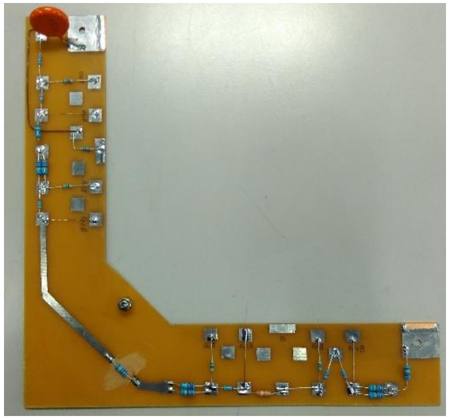
- The prototype 4GEM detector area of 10x10 cm^2 is assembled and tested in VECC lab.
- GEM foils are single conical with standard hole diameter and pitch, procured from CERN.
- The read-out plane is divided into 120 equal area pad.
- The drift gap, transfer gap and the induction gap are 4.8-2-2-2-2 mm respectively.
- High Voltage (HV) is applied using a resistor chain.
- The detector is operated using Ar/CO_2 90:10 gas.





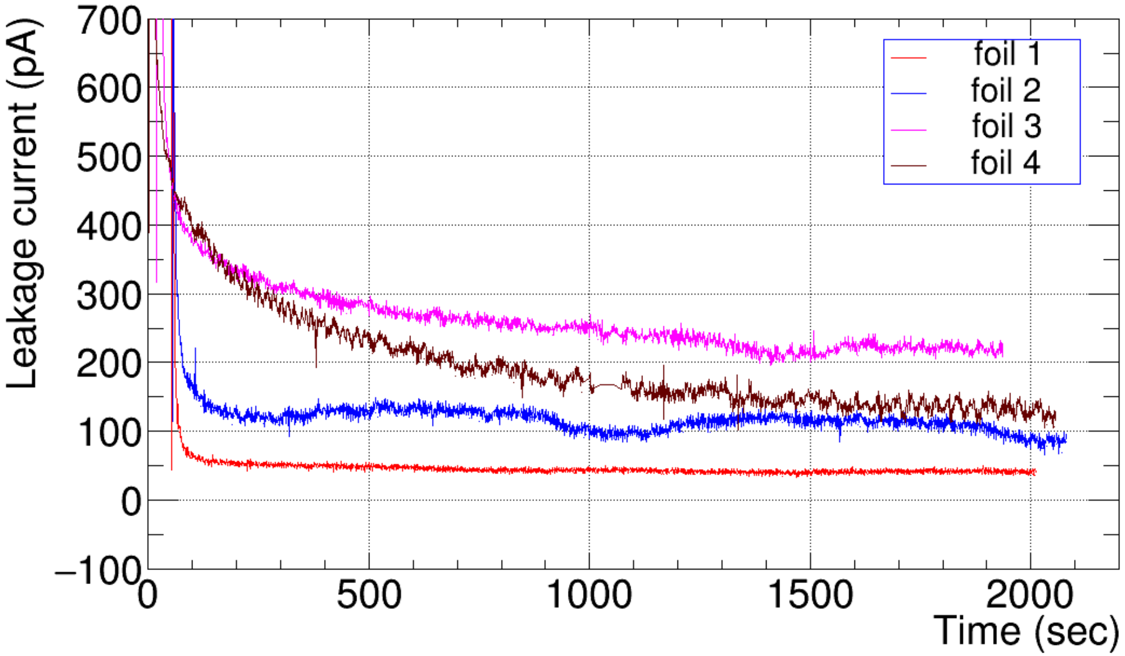
- E_d ~ 1.2 kV/cm
- $E_{t,i}$ ~ 3 kV/cm
- E_{GEM} ~ 60 kV/cm

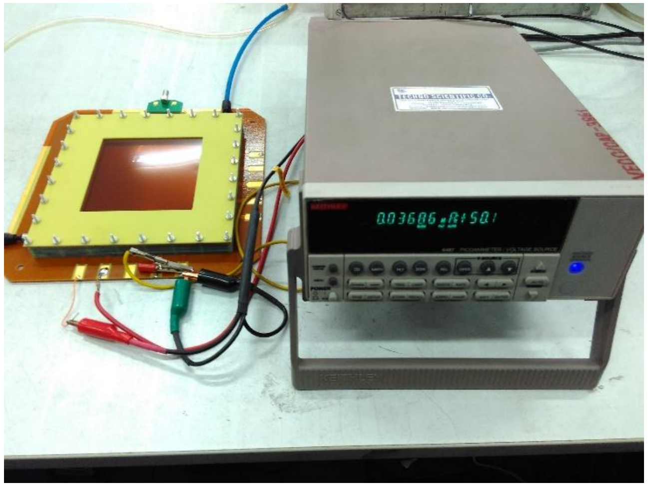
Pictorial view: assembly of 4GEM detector

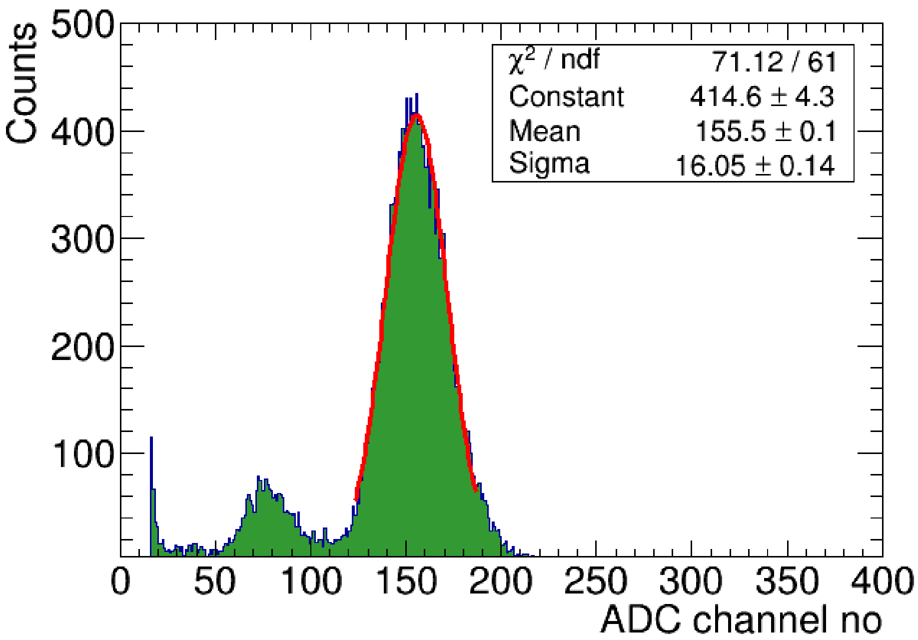
Leakage current measurement of individual GEM foils

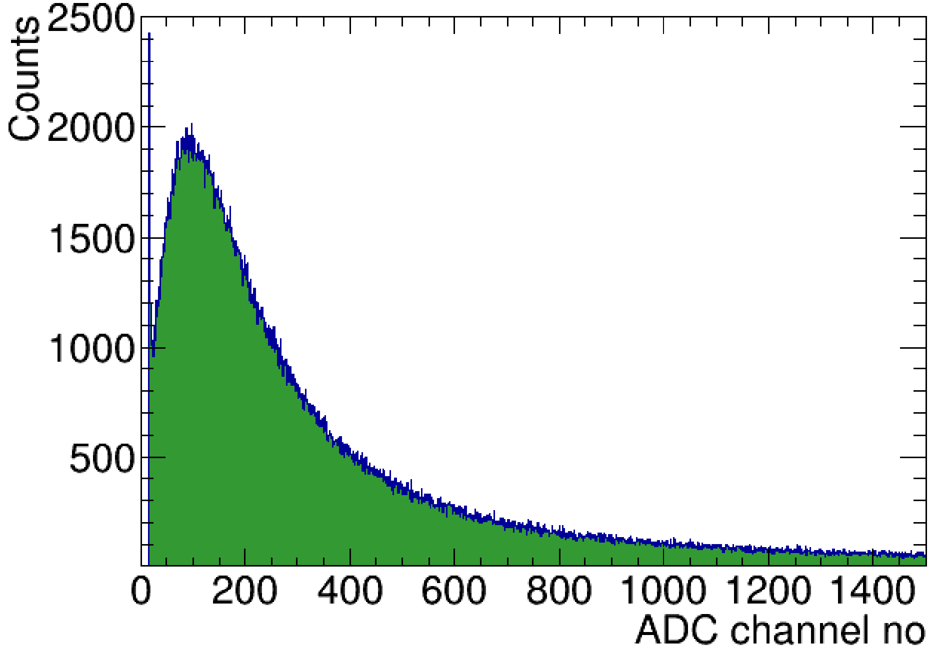
Quality testing of the individual GEM foils are done in N_2 environment. Leakage current < 500 pA at 500V is considered as good foil.





Spectrum of ^{55}Fe and ^{90}Sr

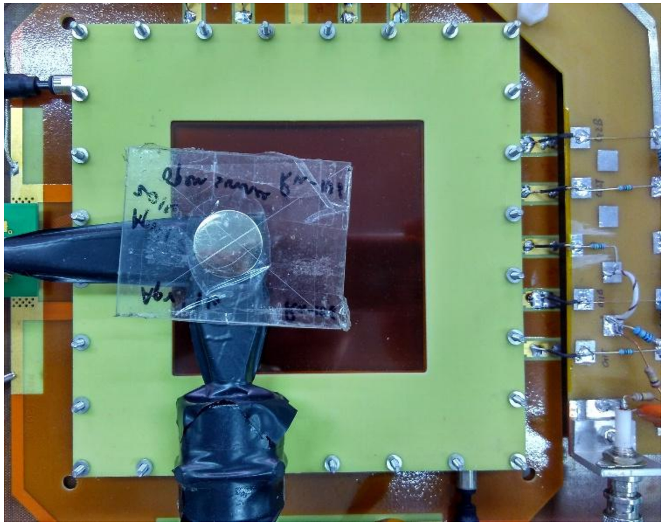




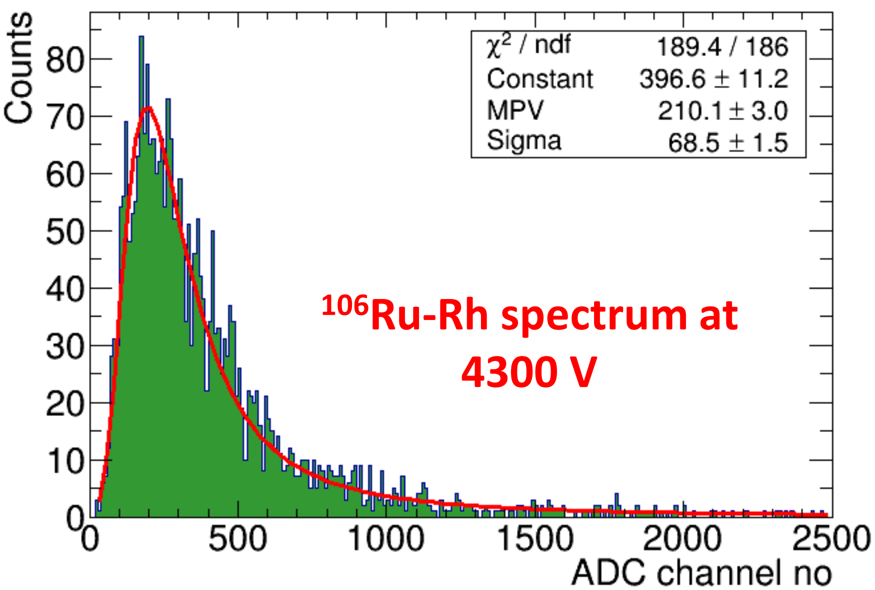
Fe^{55} spectrum @ 3900 V

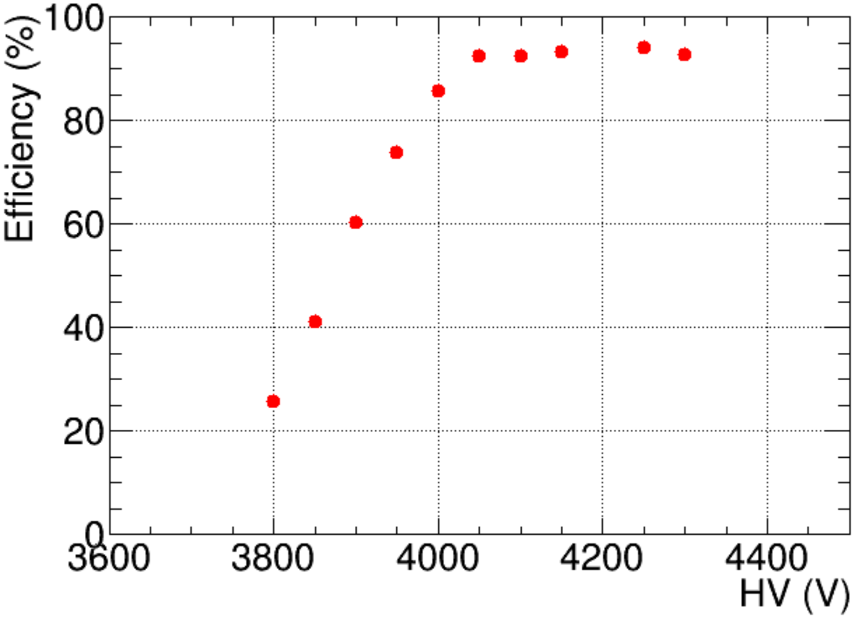
^{90}Sr spectrum @4250 V

^{106}Ru-Rh spectrum and efficiency measurement



- Efficiency measurement was performed using ^{106}Ru-Rh β-sources.
- Efficiency ~93% was obtained at the platue region.





Gain and energy resolution (FWHM)

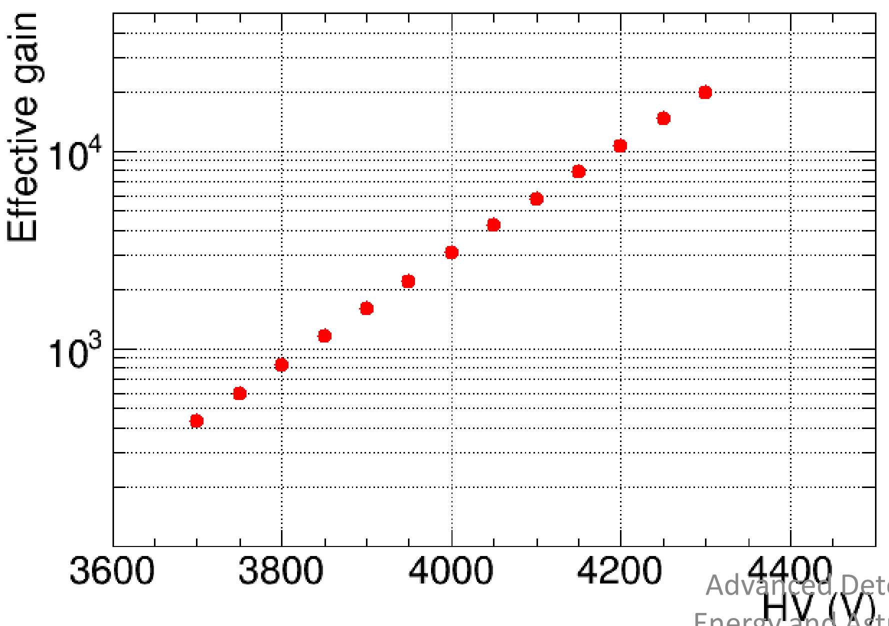
- Gain and energy resolution of the detector is calculated from the ^{55}Fe energy spectrums with different HV setting for Ar/CO_2 90:10 gas
- Resolution is corresponding to 5.9 keV X-ray and the optimum value is ~24%

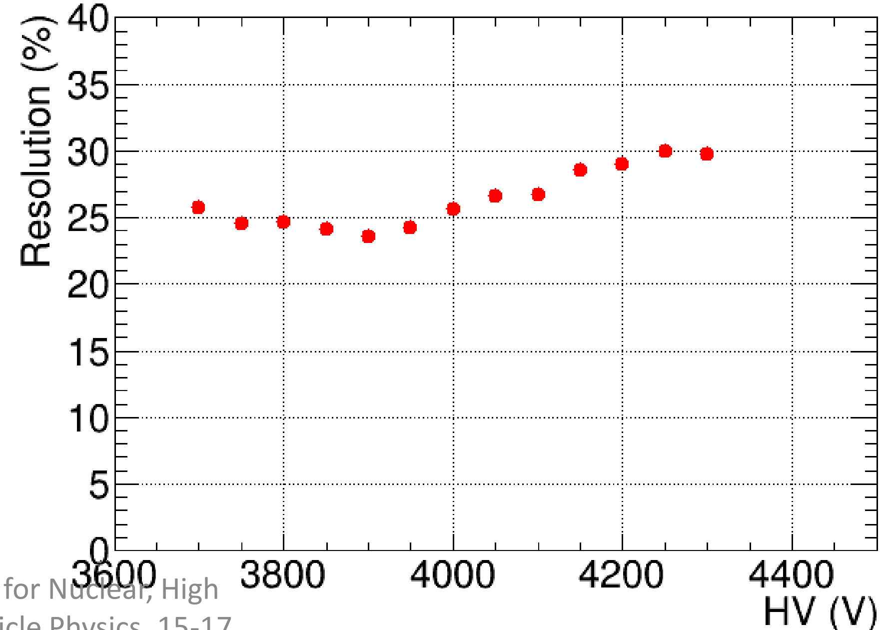
$$G_{eff} = \frac{Q}{N_p q_e}$$

Where,

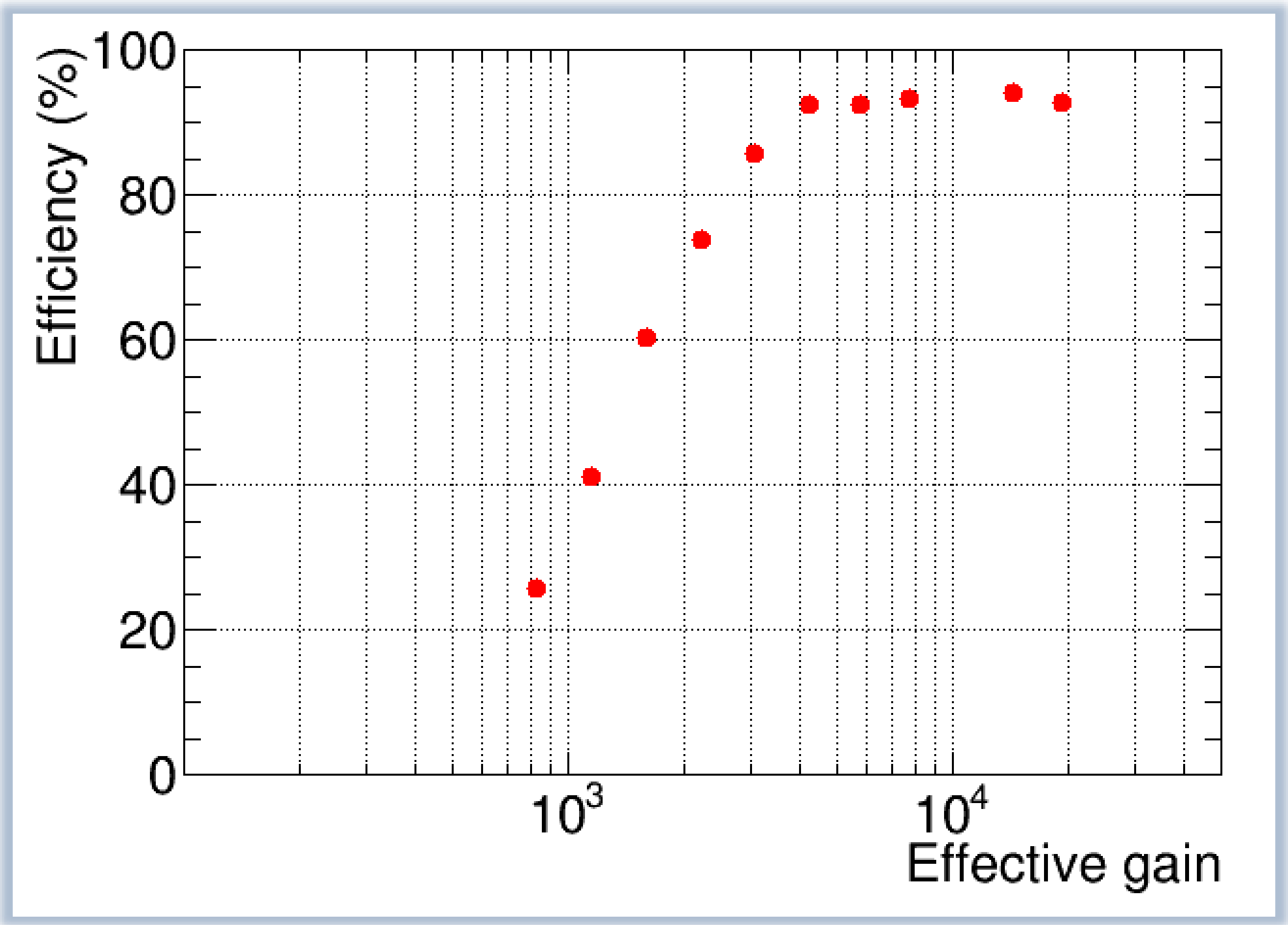
$$Q = \frac{V_{amp}}{G_{pre-amp} G_{amp}}$$

- Q – measured charge
- N_p – no. of primary ionization
- [N_p = 220, for Ar/CO2 (90:10)]
- q_e – electron charge





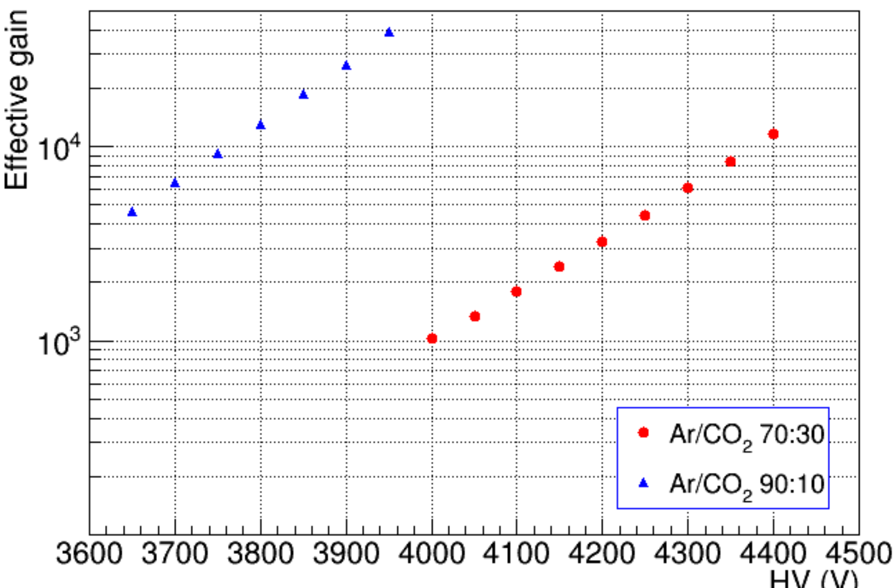
Efficiency *vs.* Effective gain



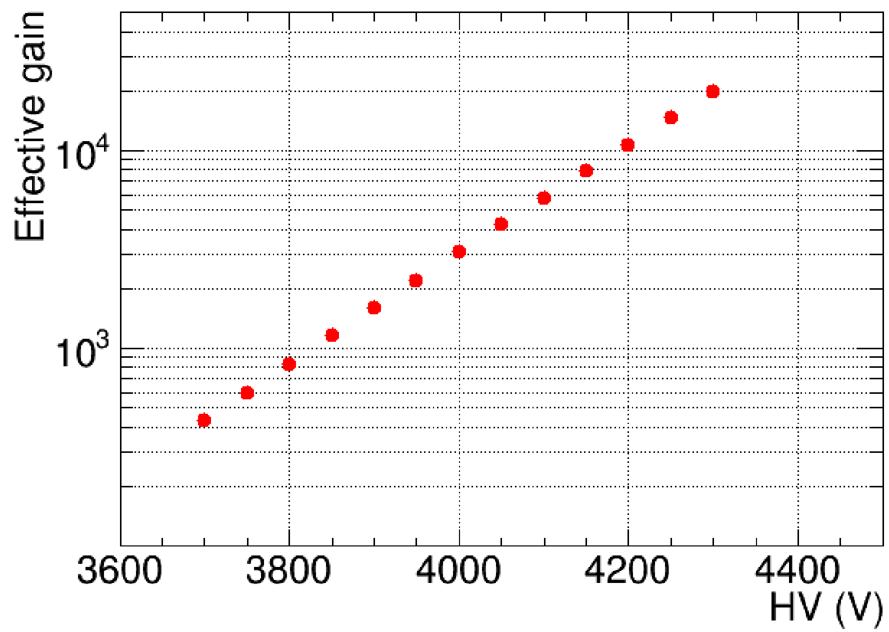
Comparison of gain with 3GEM detector

- The 3GEM detector (3-2-2-2 mm gap) is also tested with Ar/CO2 70:30 and 90:10 gas mixtures in VECC lab.
- The gain value of 4GEM using Ar/CO2 90:10 gas mixture is reached at lower ΔV_{GEM} voltage compared to 3GEM detector.

3 GEM

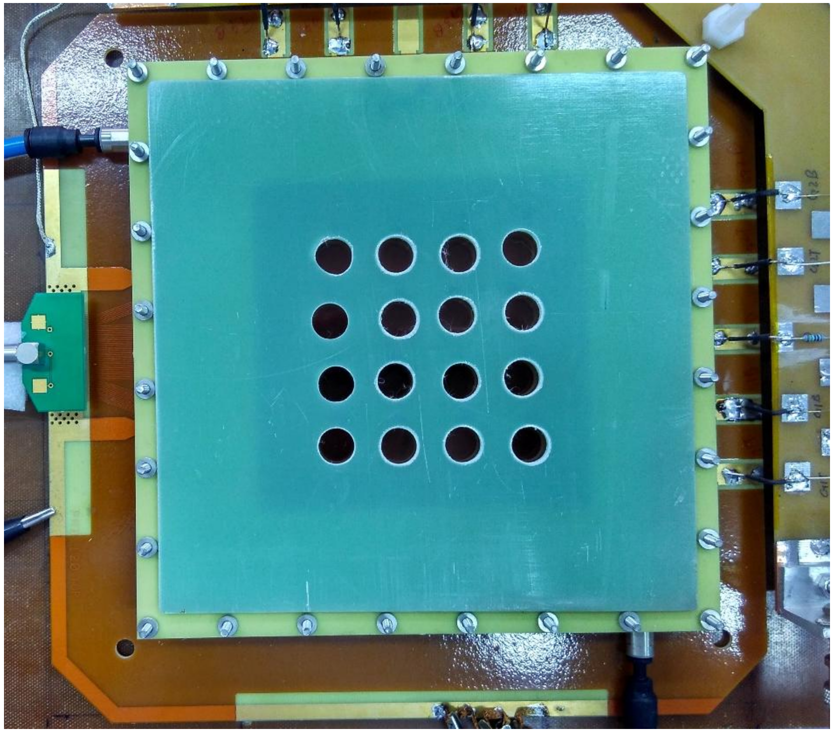


4 GEM



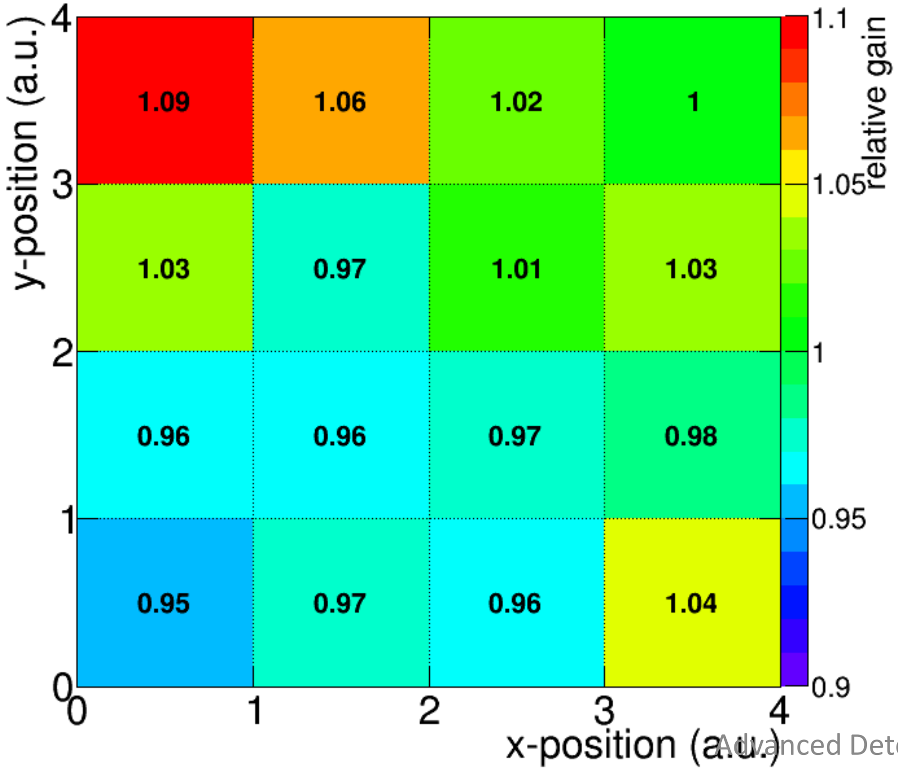
Spatial uniformity of gain

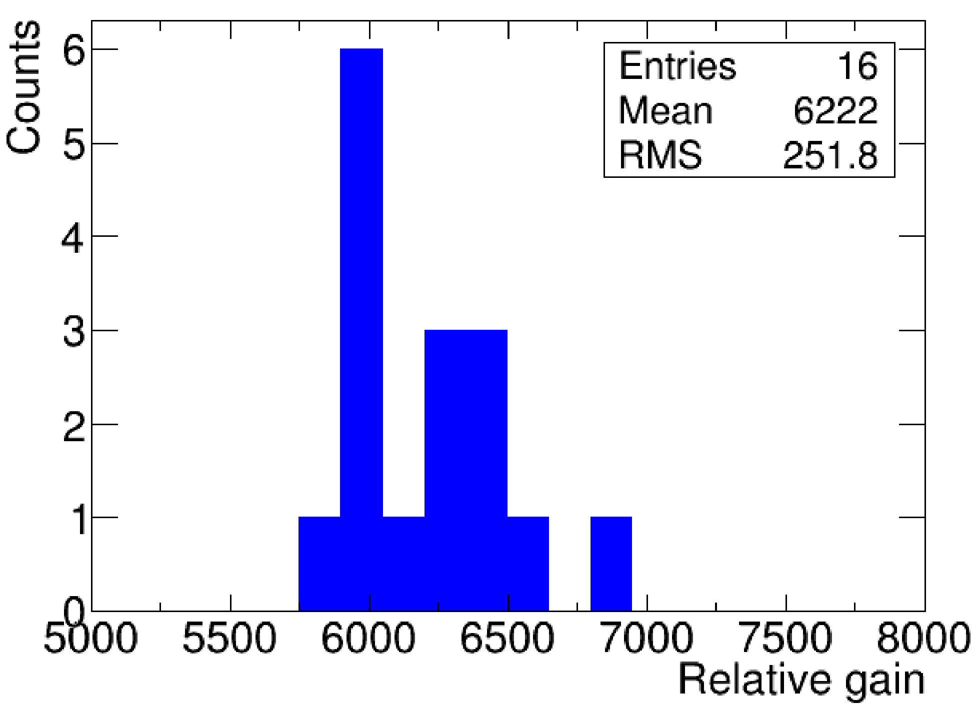
- For large area detectors used in the high energy physics experiments it is necessary to have uniform gain over the entire area.
- The uniformity of the GEM detector gain depends on factors like hole diameter variations, variations in gas gap due to defective stretching and electron transparency.
- A procedure for uniformity measurements has been developed.



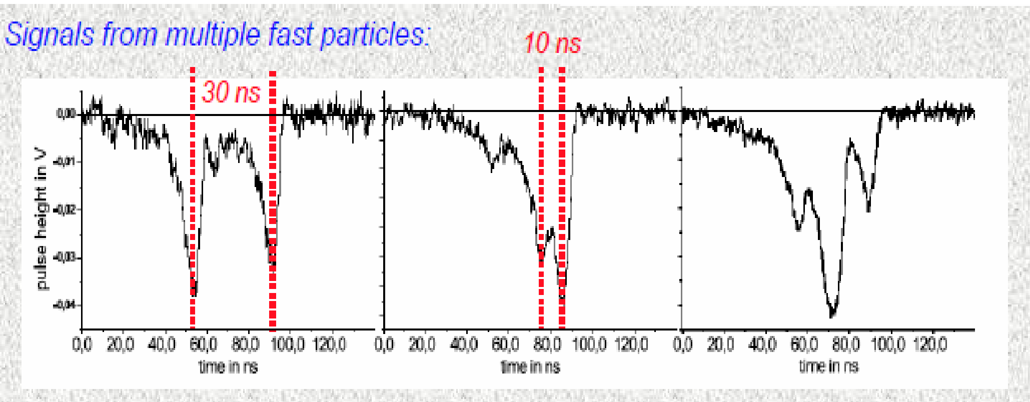
Spatial uniformity of gain

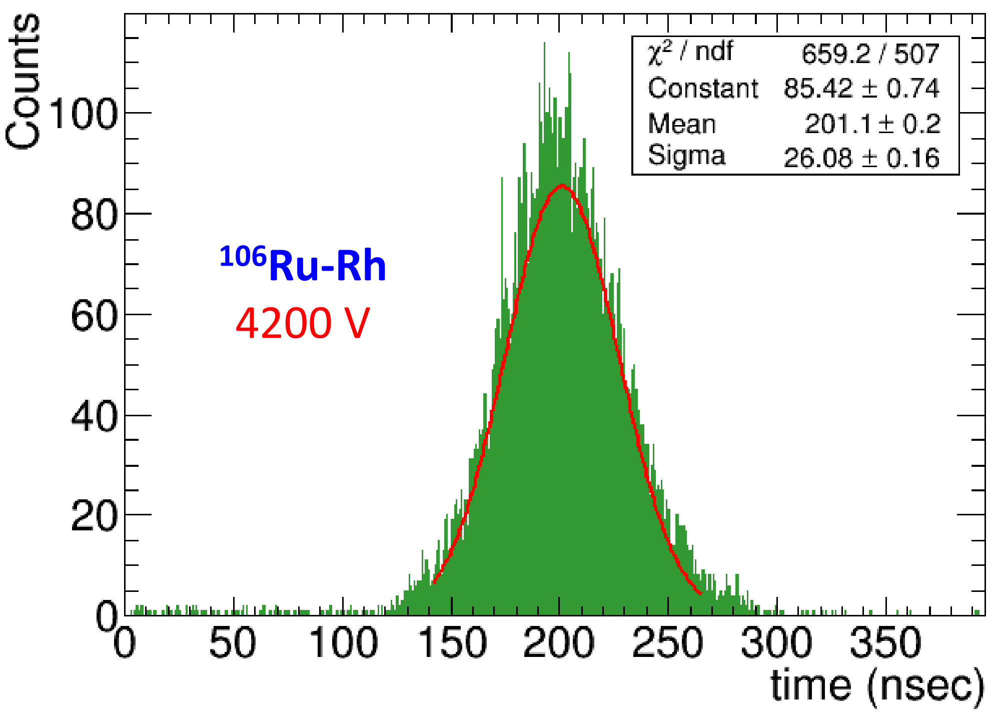
- Gain of the GEM detector is measured for 16 zones of equal area at 4100 V.
- RMS variations of gain is found to be 4% only.

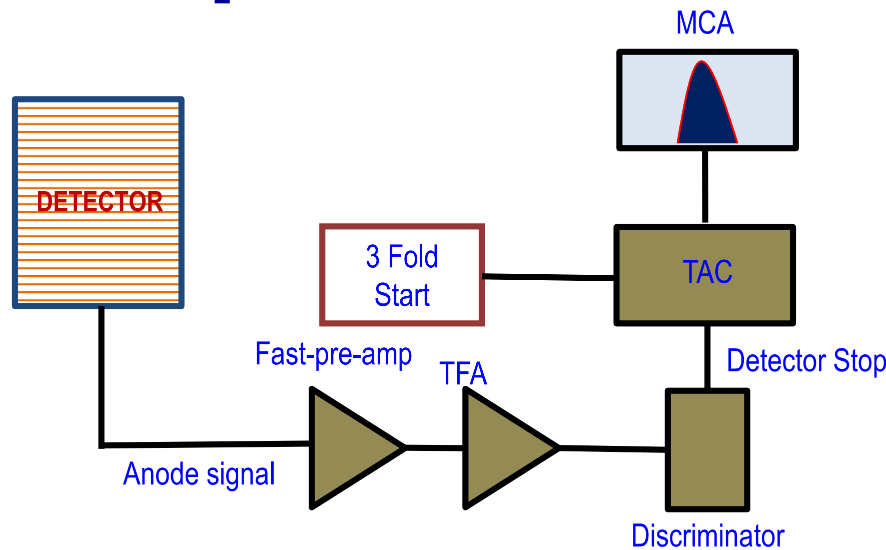




Time resolution of triple GEM







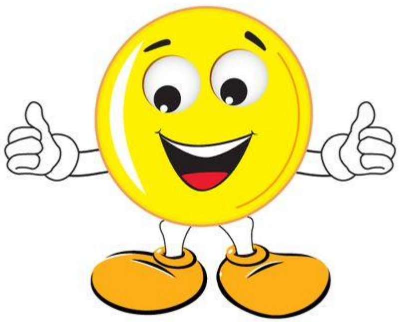
Very first attempt to get time spectrum

Summary

- Tests of a 4GEM detector has been performed using ^{55}Fe, ^{106}Ru-Rh and ^{90}Sr radio active source.
- Characteristic of the detector is done in terms of gain, energy resolution and efficiency with help of Ar/CO2 90:10 gas mixture.
- Gain uniformity test is also performed.
- Time spectrum of the detector is obtained.

Special thanks to Ganesh da

THANK YOU



Backup slides

Ionization of gas detector

- Ionisation in medium is statistical nature.

In a gas mixture, $W = \sum w_i . W_i$

Average no of electron-ion pairs from all mechanism are created for ΔE energy loss,

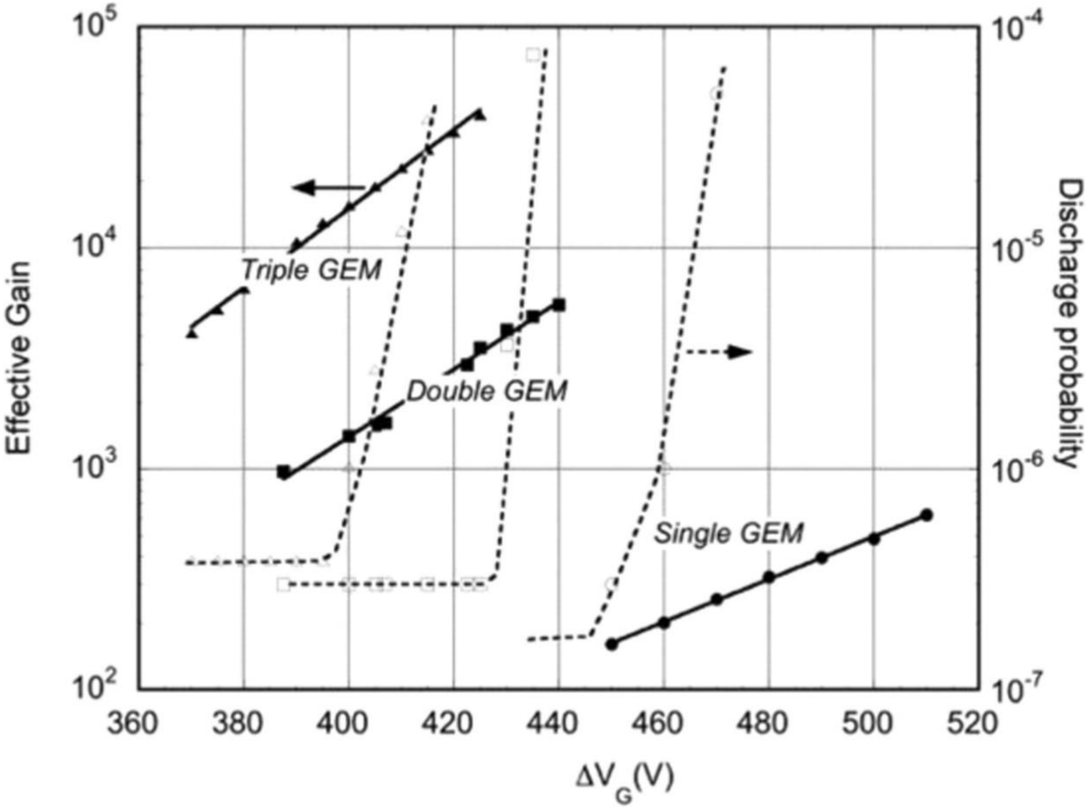
$$N = \frac{\Delta E}{W}$$

in Ar/CO_2(70:30) mixture 5.9 keV X-ray will produce ~**212** electron-ion pairs and for cosmic ray ~**100**/cm.

Gas	I [eV]	W [eV]
Ar	15.8	26
He_2	24.6	41
H_2	15.4	37
N_2	15.5	35
O_2	12.2	31
Air		33.8
CO_2	13.7	33
CH_4	13.1	28

I-first ionization potential
W-average energy for electron-ion pair production

GEM: Gain and discharge



Ref: F. Sauli NIM A 805(2016)2–24

Discharge probability

$$P_{Disch} = \frac{N_{Disch}}{R_{meas} \cdot \Delta T_{meas}} \qquad (2)$$

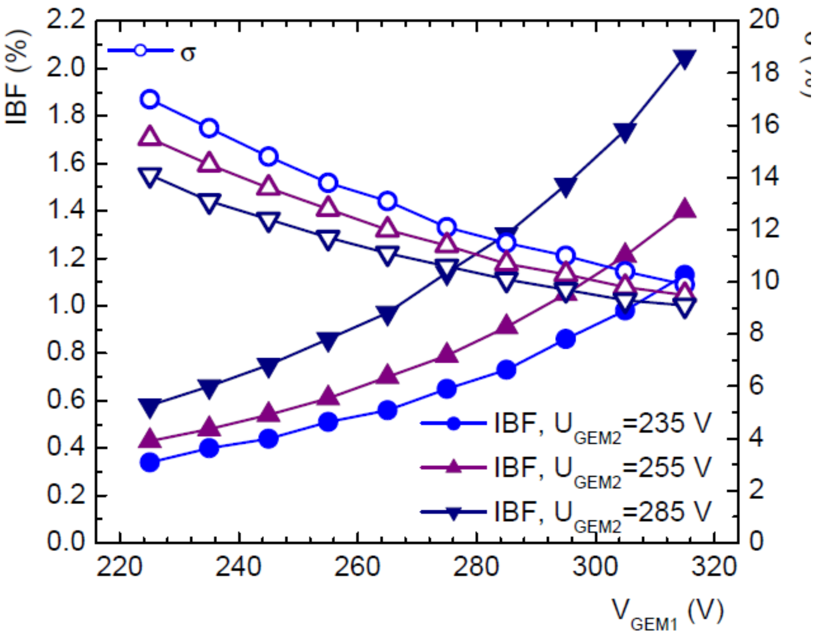
where R_{meas} is the measured neutron interaction rate and ΔT_{meas} is the measurement period.

In the case of the maximum gain used in the measurement, since $R_{meas} = 7260$ Hz (see Section 2.4), $N_{Disch} = 1$ and $\Delta T_{meas} = 1000$ s, $P_{Disch} = 1.37 \times 10^{-7}$ at $G = 5 \times 10^4$.

This result shows that in GEM-based detectors neutrons induced discharge probability is lower than alphas induced discharge probability [4].

Ref: G. Croci et al. / Nuclear Instruments and Methods in Physics Research A 712 (2013) 108–112

IBF ALICE TPC TDR



Ref: ALICE TPC Upgrade TDR

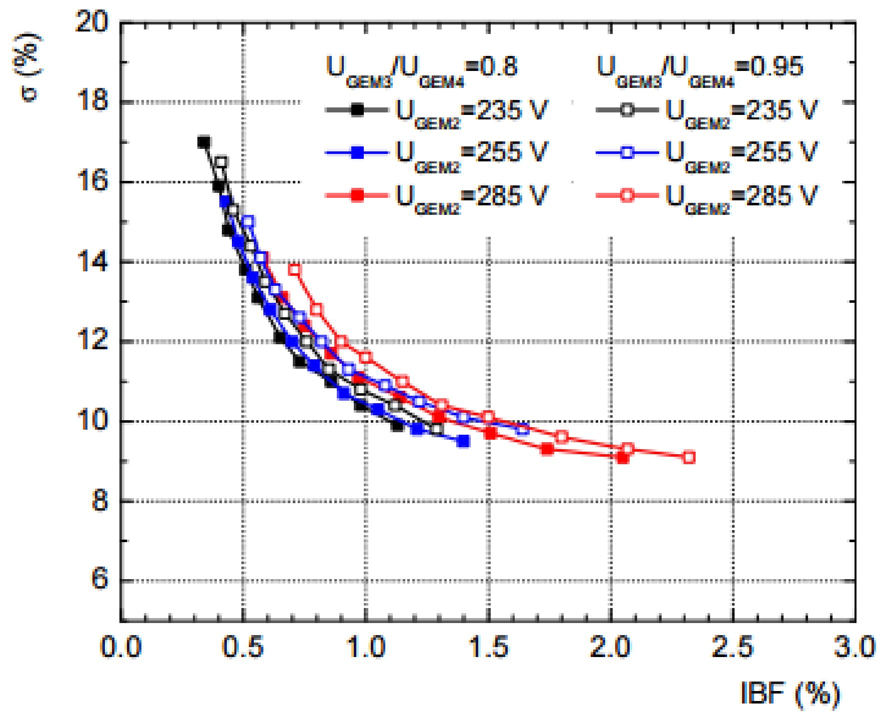


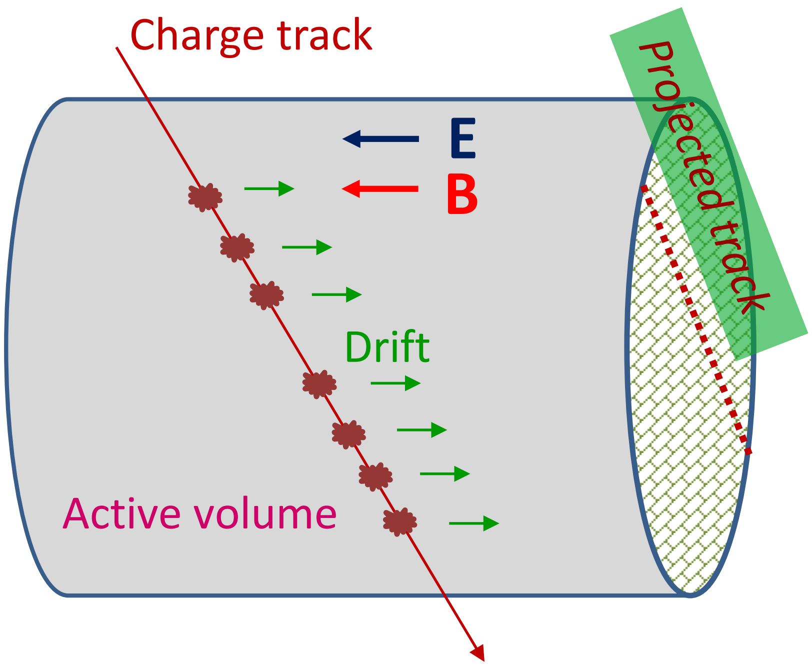
Figure 1. Correlation between IBF and energy resolution at 5.9 keV in a 4 GEM setup (S-LP-LP-S) in Ne-CO_2-N_2 (90-10-5) for various settings of voltage of GEM2.

Ref:T. Gunji, arxiv.org/pdf/1408.3484.pdf

Operating principle of Time Projection Chamber (TPC)

- TPC: introduced by *D.R.Nygren,* 1976

- E and B fields are parallel
  - Strong and uniform B field for momentum measurement and limit to electron diffusion
- Main task:
  - Track finding
  - Momentum measurement
  - PID by dE/dX



Time resolution: Basic principle

Time resolution of a detector determines how accurately two closed time incidents are separable.

Time resolution of any gas detector depends on many factors like detector geometry, gas mixtures, electric field, diffusion of the electron, cluster formation and also electronics