Experimental & Numerical Investigations on GEM Detectors

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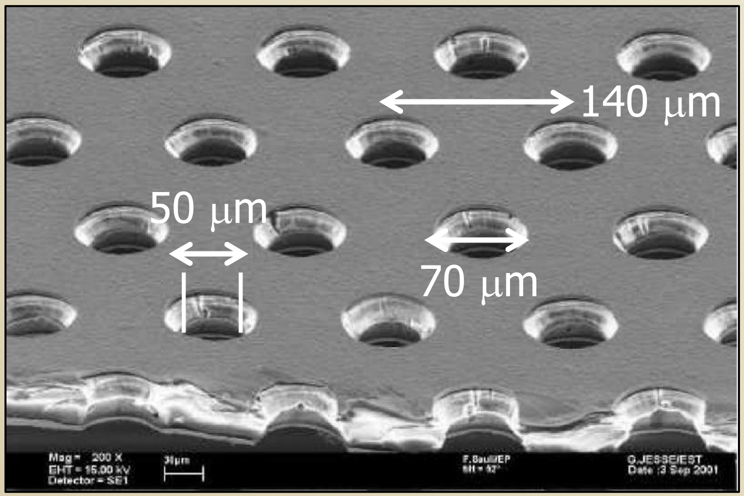
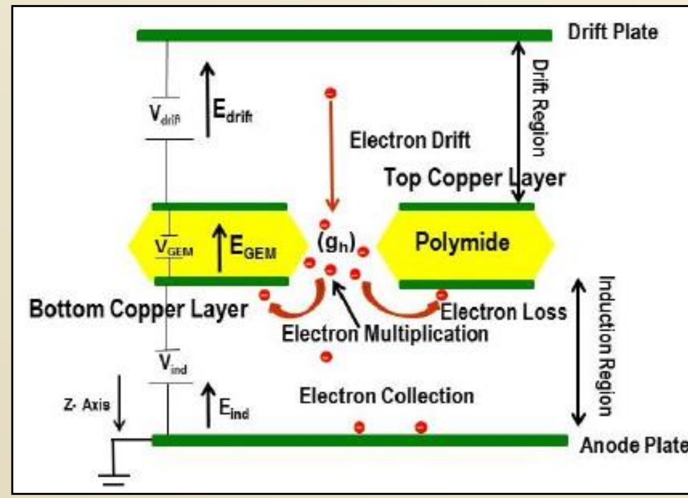
Gas Electron Multiplier (GEM)

A miniscule structure for charge (electron/ion) multiplication introduced in 1996 by Sauli.

- Thin insulating polymer foil (thickness ~ 50 μm) clad with copper (thickness ~ 5 μm) on both sides.
- Chemically etched for a regular matrix of holes (pitch ~ 180 μm) with bi-conical shape (external dia ~ 70 μm, internal dia ~ 50 μm).

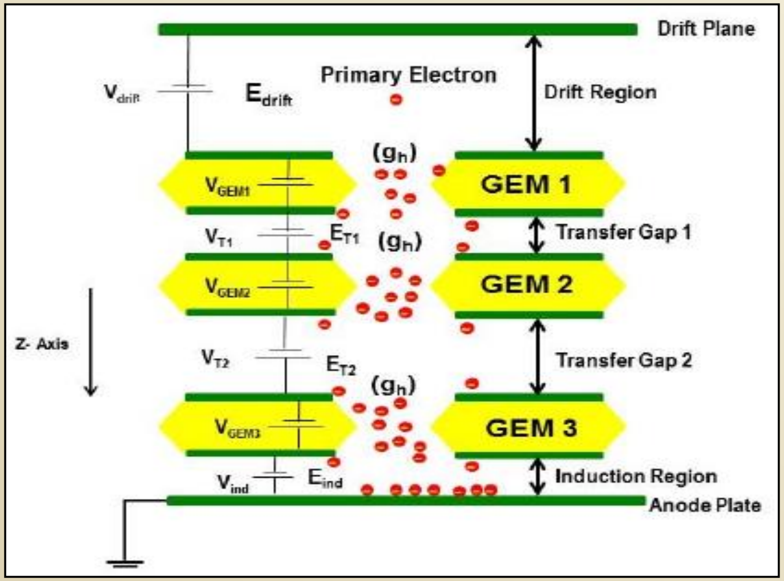




- A potential difference is created between the two sides by application of high voltages (~ 400-500 V) on the copper layers to develop a dipole field (~100 kV/cm) in the hole.
- The holes act as the multiplication channel for the electrons (gain ~ 10^3) released by the ionization of gaseous medium by some charged particle or radiation.

Gas Electron Multiplier (GEM)

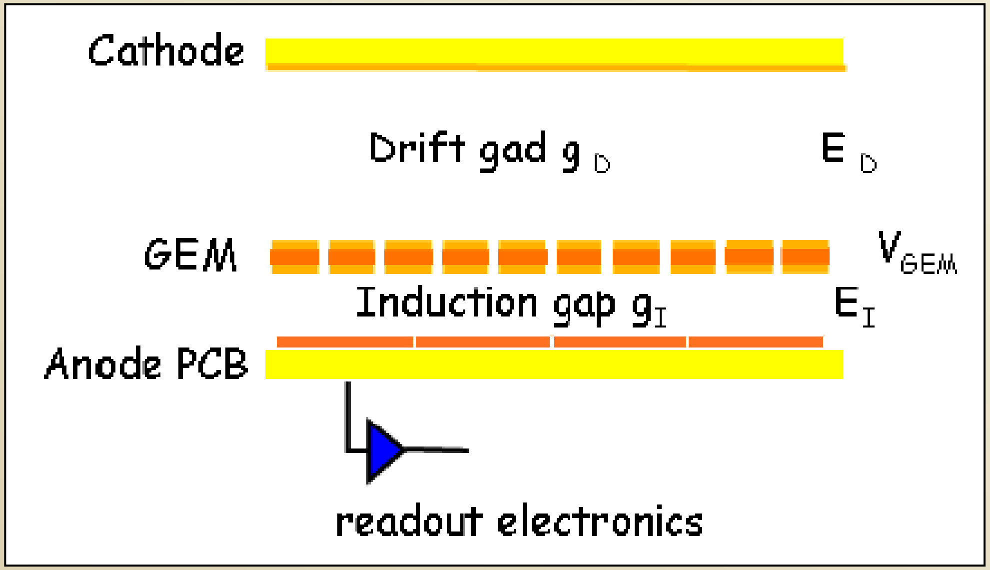
- The novel idea of stand-alone electron multiplier invokes physically separate conversion, multiplication and induction regions.
- Greater freedom in readout design leading to cost-effective solutions.
- Possibility of dividing multiplication in more than one stages.
- Augmentation of gain (~ $10^3 - 10^4$) by using multiple foils.
- Reduces discharge and ageing problems.



- The integration capability with other detectors paves the way of new hybrid detection devices.

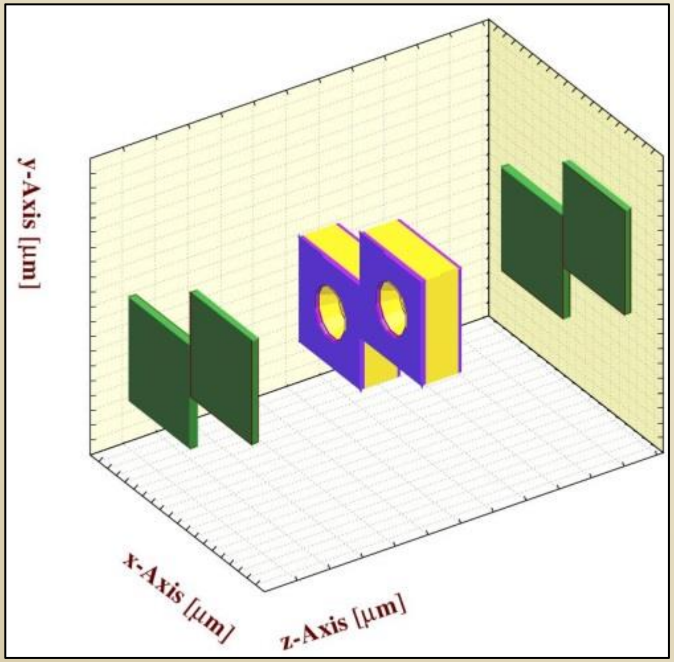
Single-GEM Detector

- Single GEM foil inserted between two parallel electrodes.
- The upper electrode acts as cathode while the lower plays role as anode readout.
- Electrons produced by ionization in drift gap drift towards holes and multiply inside.
- The fraction transferred to induction gap induces current signal on the anode.
- The multiplication ions are collected on the upper surface of the foil.



Device Geometry

- Numerical simulation (using GARFIELD) of single-GEM detector was conducted to understand its working principle.
- Gas mixture of Ar (70%) + CO_2 (30%) was considered.



Foil thickness :	**50 μm**
Copper thickness :	**5 μm**
Hole dia (outer) :	**70 μm**
Hole dia (inner) :	**50 μm**
Hole pitch :	**140 μm (staggered)**
Gap configuration :	**2:1 (mm)**

- The basic unit of two bi-conical holes arranged in staggered manner, placed between two parallel conductors.
- Each of the conductors consists of two staggered plates.
- The whole basic unit was repeated in both x, y directions to model the detector.

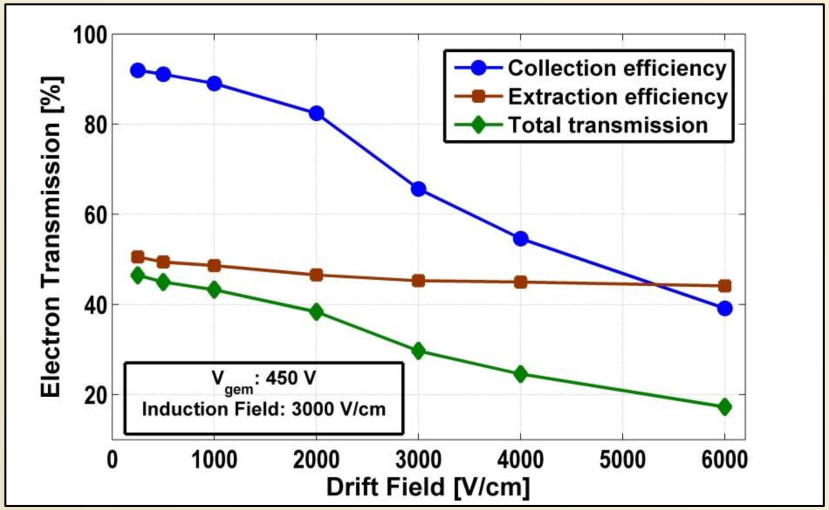
Electron Transmission

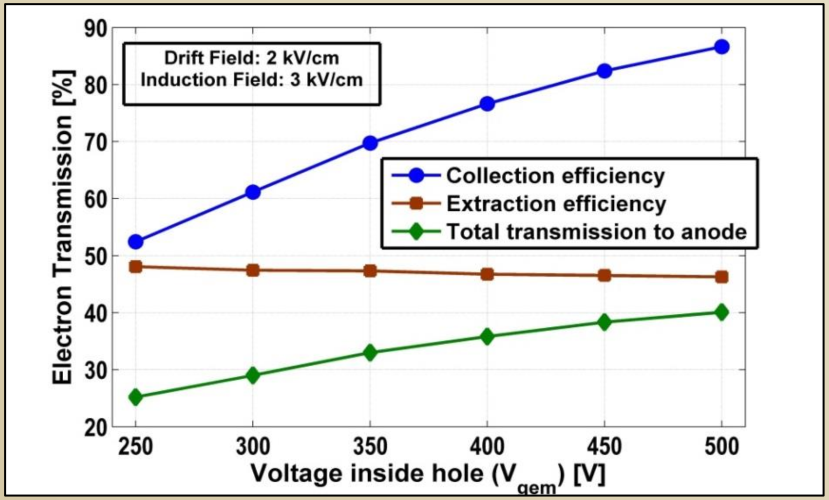
- A 5.9 keV photon track was considered in drift volume for primary ionization.
- No multiplication considered.

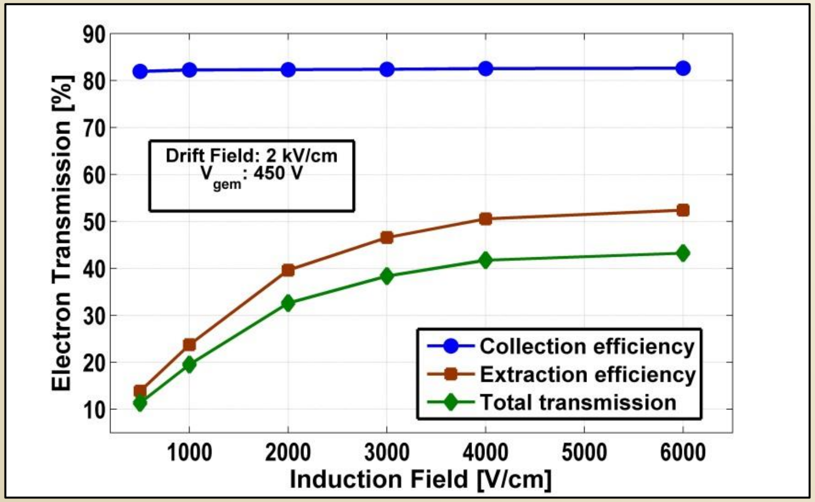
$$\epsilon_{tot} = \frac{N_{anode}}{N_{drift}} = \epsilon_{coll} \times \epsilon_{ext}$$

$$\epsilon_{coll} = \frac{N_{GEM}}{N_{drift}}$$

$$\epsilon_{ext} = \frac{N_{anode}}{N_{GEM}}$$



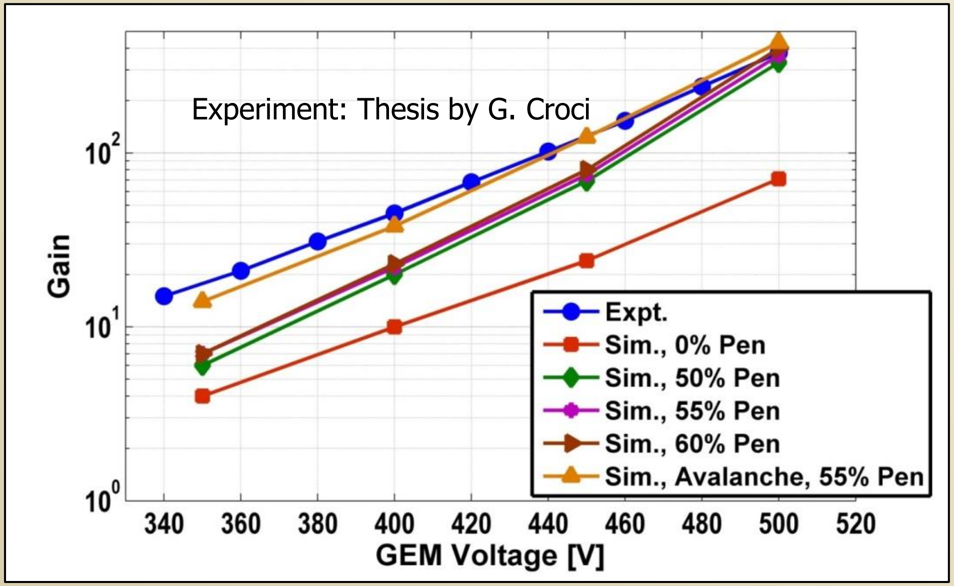


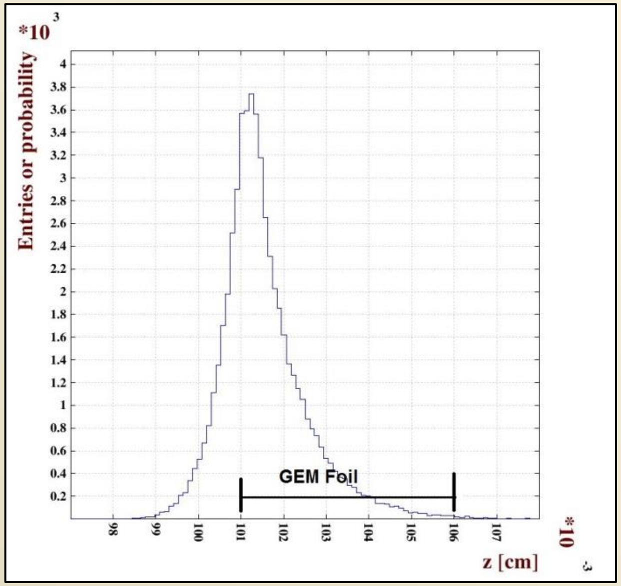


Electron Gain

Gain estimates were made following:

$$G_{int} = e^{<\alpha> V_{GEM}}$$
$$G_{eff} = \epsilon_{tot} \times G_{int}$$



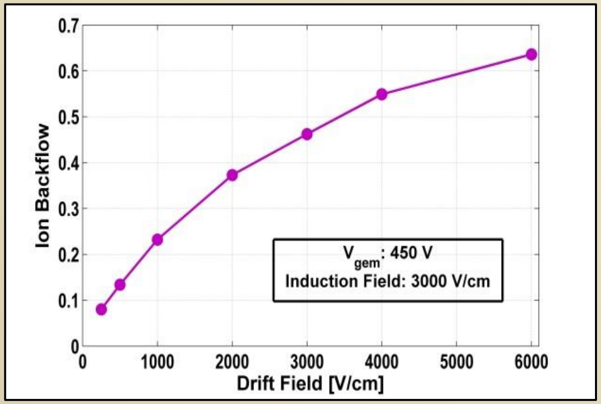


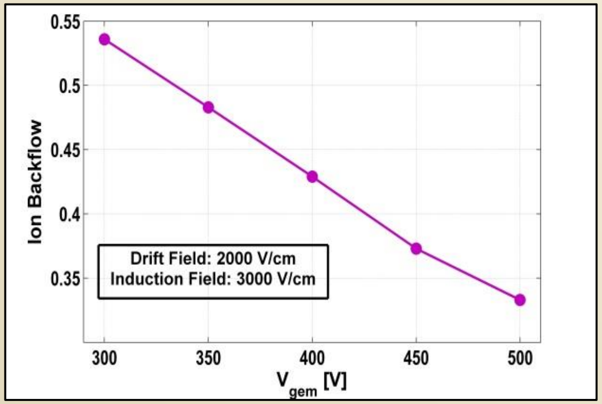
- Simulation following the said approach with 50-60% Penning transfer underestimates the experiment.
- Simulation considering the actual avalanche process with 55% Penning transfer agrees closely.
- Maximum of the probability distribution of creation point of secondary electrons is located at the lower edge of the foil.

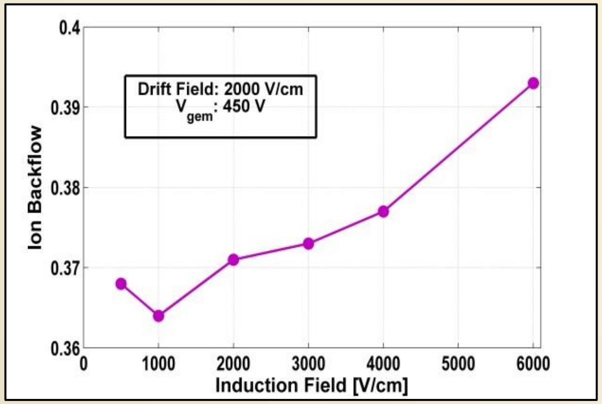
Ion Backflow

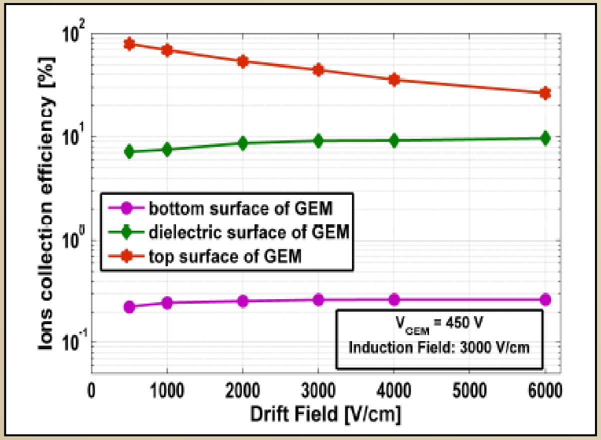
- Ion backflow is the process of spilling over of ions in the drift region.
- Disturbs the homogeneity of the drift field and thus the operation of the detector.
- Ions are to be absorbed on the top surface of the GEM foil.

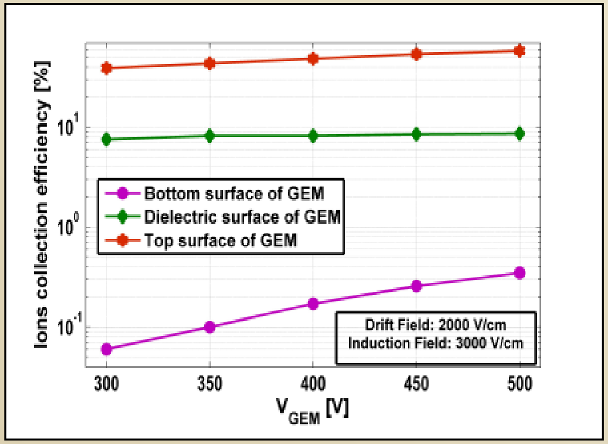
$$IBF = \frac{N_b}{N_t}$$

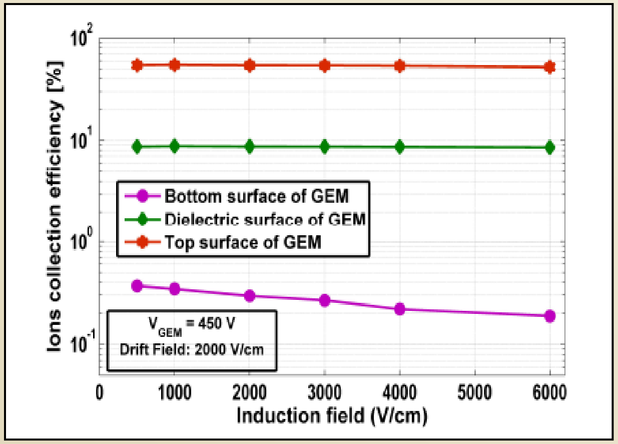






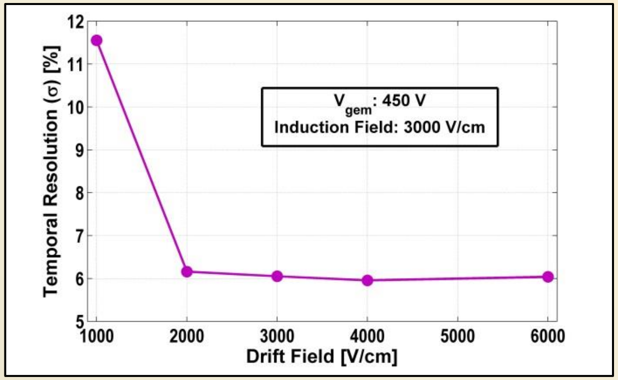


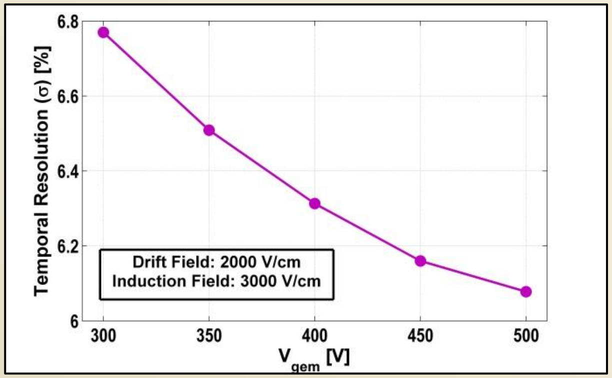


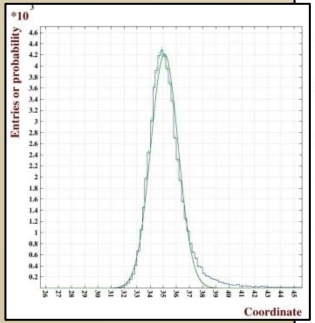


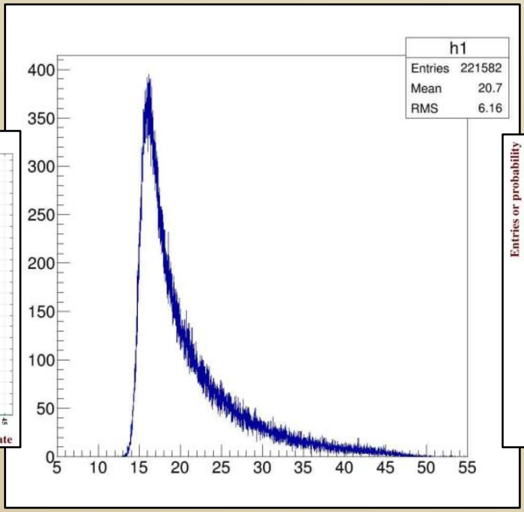
Time Resolution

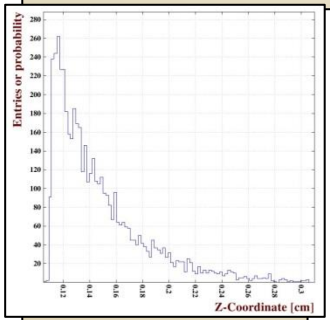
- Primary ionization and diffusion determine the time resolution.
- Position of first hit electrons is decreasing exponential.
- Reaching time distribution of single electron is gaussian due to diffusion.
- Cosmic muon (1-3 GeV) track was considered at different inclinations.
- First hit on the anode was recorded to produce a time spectrum assuming it generated considerable signal.
- No multiplication was considered.

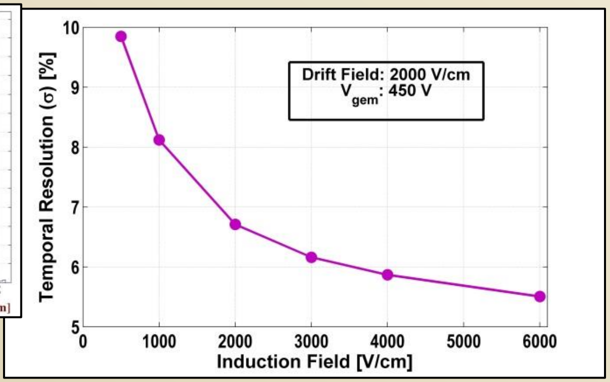






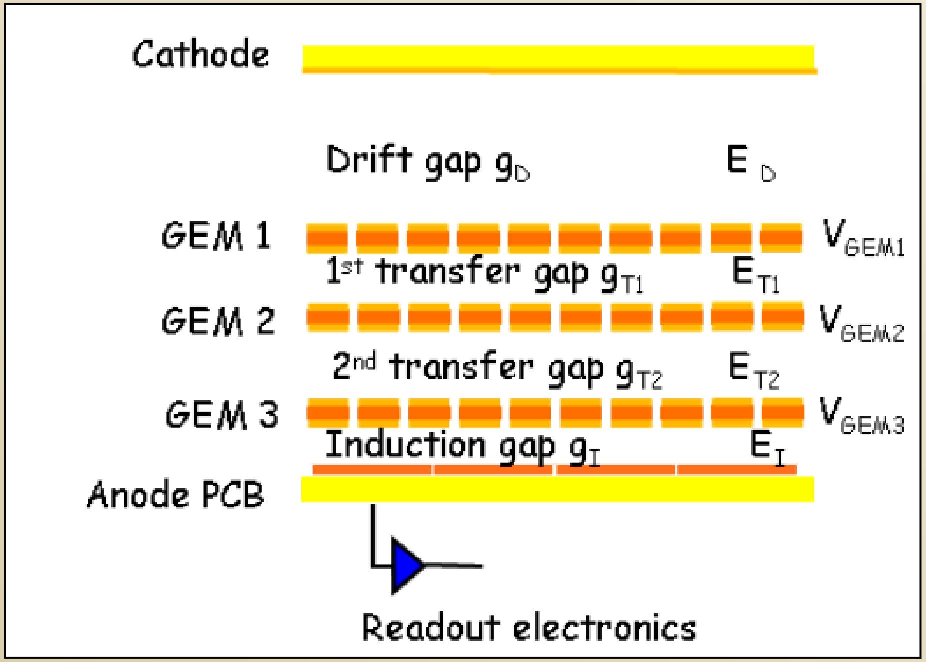






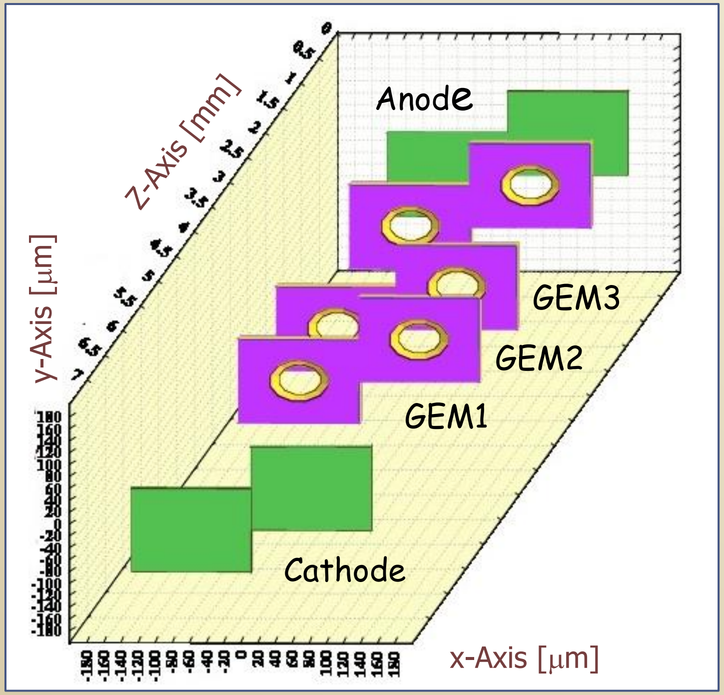
Triple-GEM Detector

- Three GEM foils are inserted between two parallel electrodes.
- The upper electrode acts as cathode while the lower plays role as anode readout.
- Electrons produced by ionization in drift gap drift towards holes and multiply inside.
- The fraction transferred to the first induction gap transport to the next foil and the process continues.
- The fraction transferred to the induction gap from the third foil induces current signal on the anode.
- The multiplication ions are collected on the upper surface of the foil.



Device Geometry

- Numerical simulation (using GARFIELD) of triple-GEM detector was conducted to understand its working principle.
- Gas mixture of Ar (70%) + CO_2 (30%) was considered.



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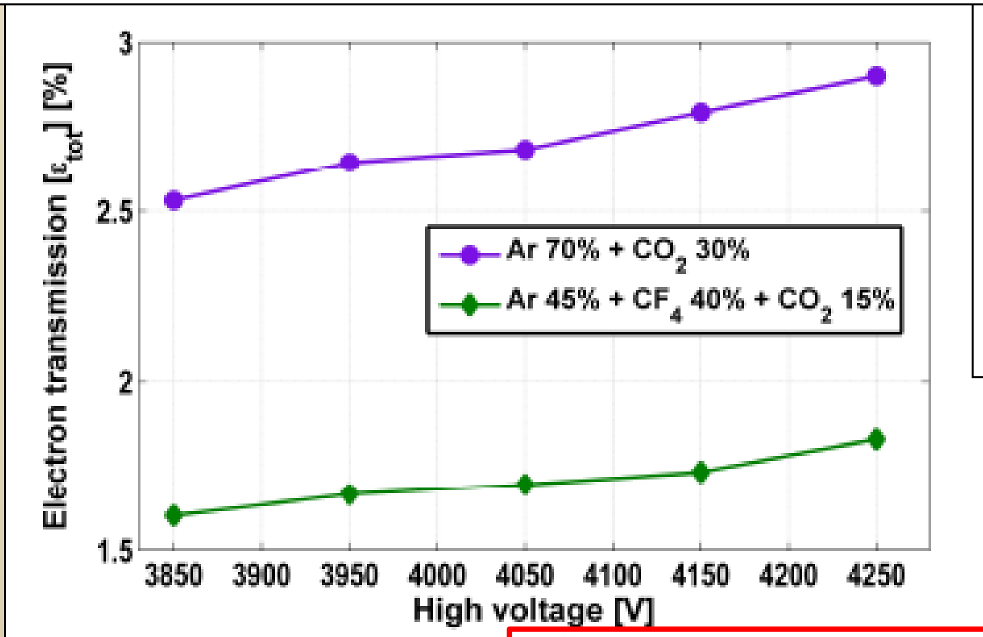
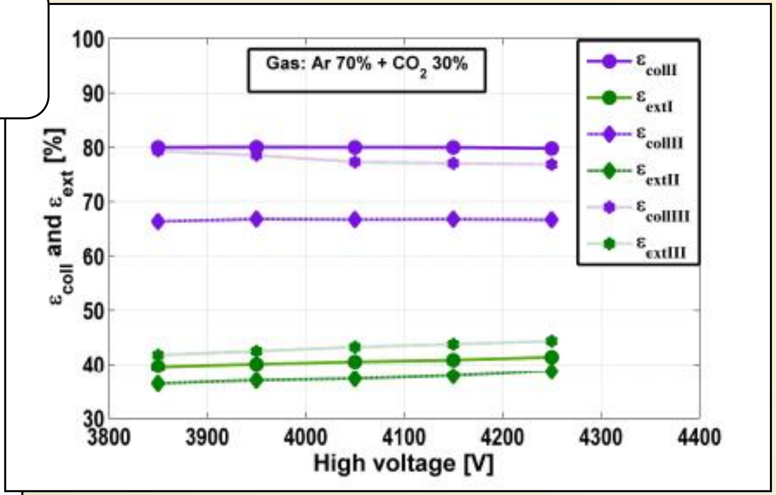
Gap configuration :	**3:1:2:1 (mm)**

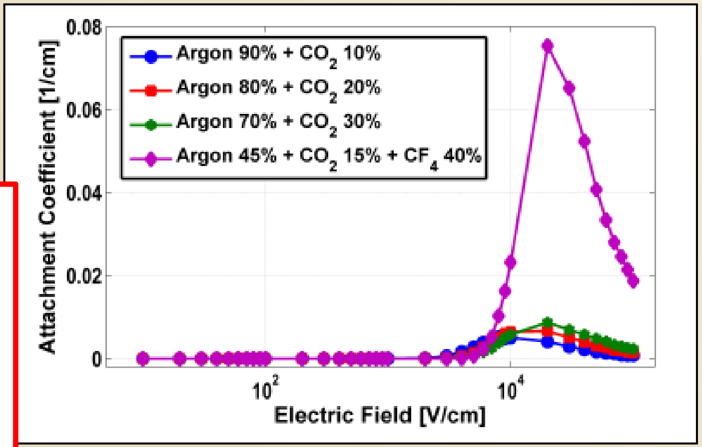
- The basic unit of three foils of two bi-conical holes arranged in staggered manner, placed between two parallel conductors.
- Each of the conductors consist of two staggered plates.
- The whole basic unit was repeated in both x, y directions to model the detector.

Electron Transmission

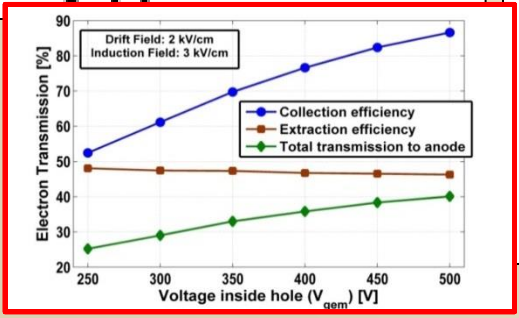
$$\epsilon_{tot} = \epsilon_{coll1} \times \epsilon_{ext1} \times \epsilon_{coll2} \times \epsilon_{ext2} \times \epsilon_{coll3} \times \epsilon_{ext3}$$





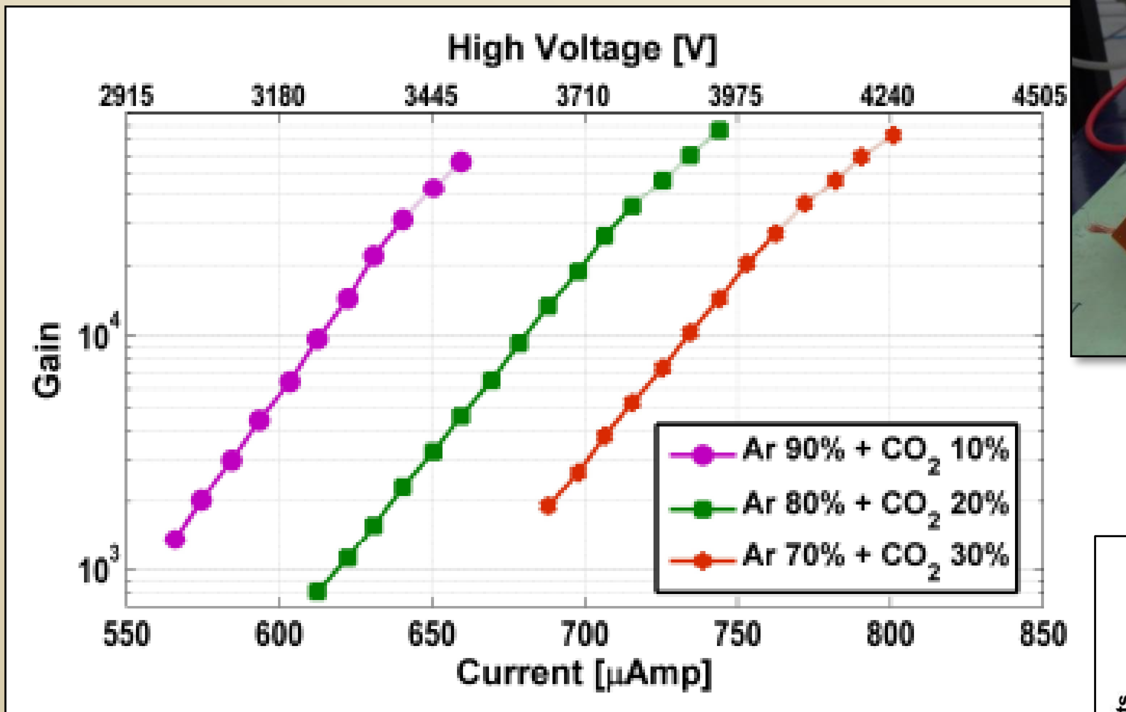


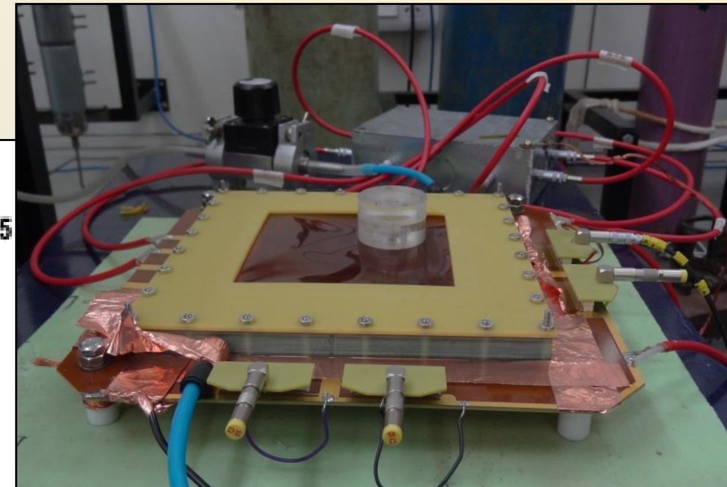
Single-GEM

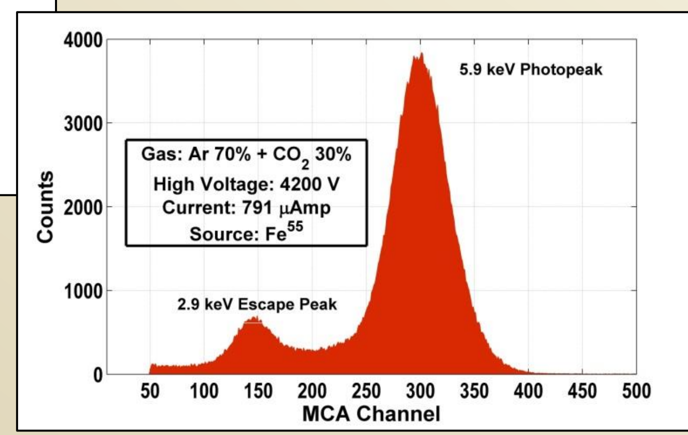


- Due to higher attachment in Ar-CO2-CF4, the transmission is even less.

Gain Measurement





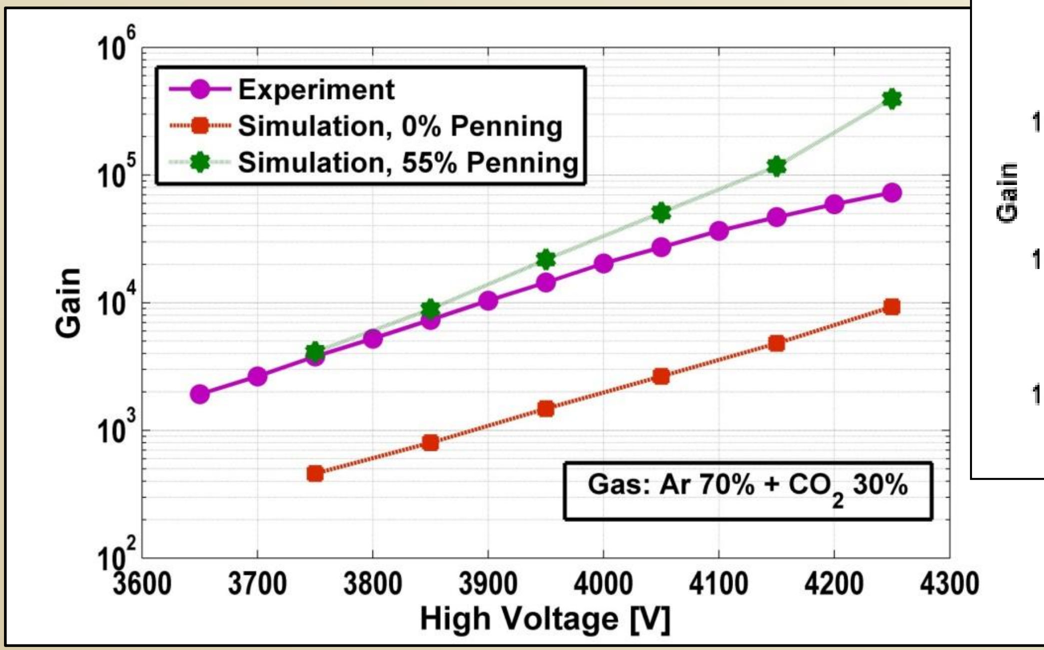


- Test was done with an ^{55}Fe source
- Gas mixture Ar/CO_2 (70:30/80:20/90:10) at STP

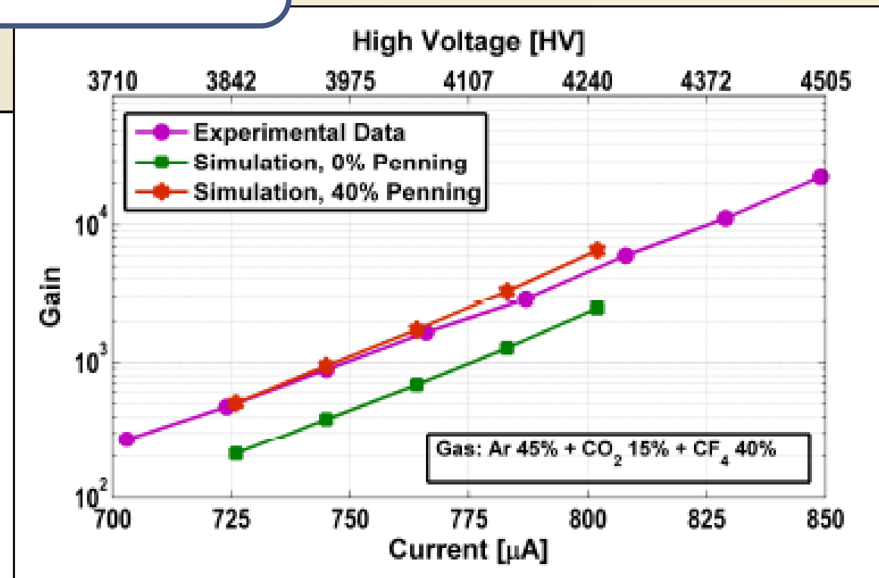
Electron Gain

Gain estimates were made following:

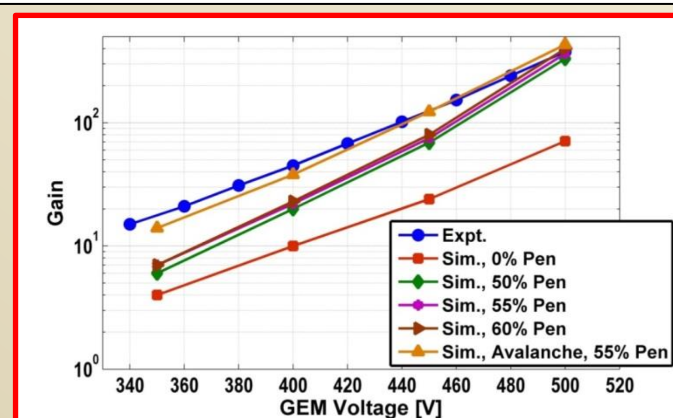
$$G_{eff} = \epsilon_{tot} \times G_{int}$$
$$G_{int} = e^{<\alpha> V_{GEM}}$$



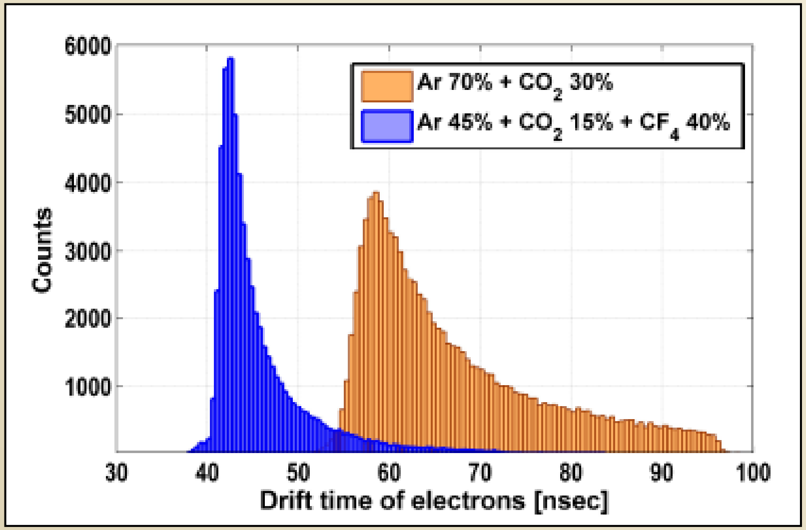
Experiment: CMS-GEM Collaboration

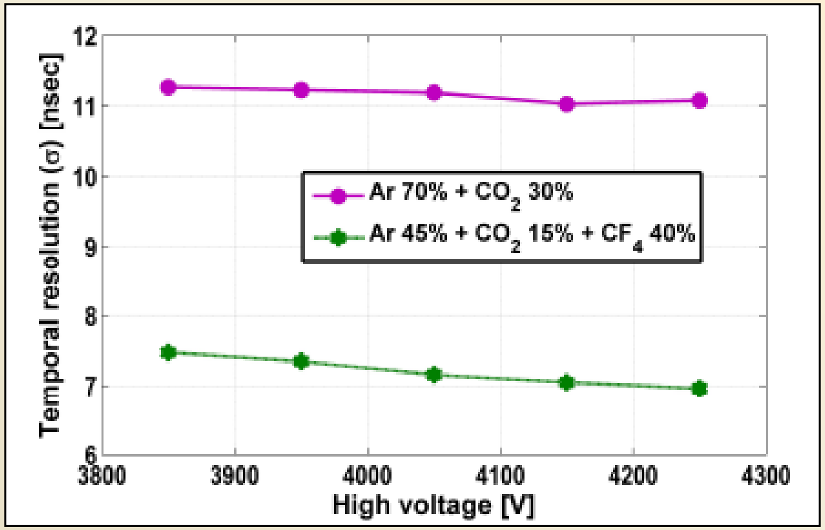


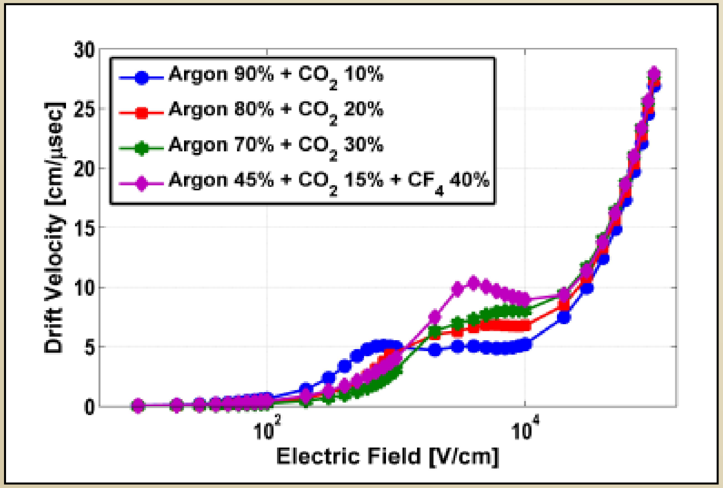
Single-GEM

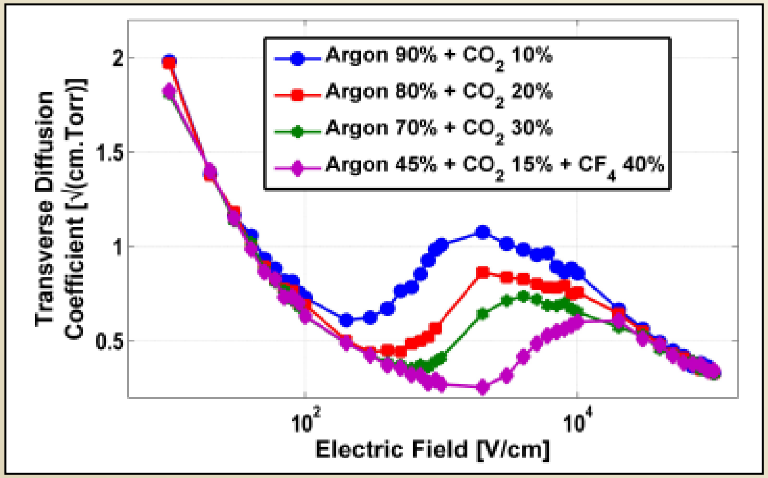


Time Resolution









- Due to higher drift velocity and lower transverse diffusion in Ar-CO2-CF4, the time resolution improves.

Remarks

Final Remarks

- Detailed numerical simulation and experimental studies have been carried out to investigate the characteristics of GEM detectors.
- Most of the numerical studies on single-GEM characteristics have been completed. A few for the triple-GEM are still being executed.
- Experimental measurements of some of the important characteristics of triple-GEM have been completed. We plan to extend the test setup for a few more measurements like time resolution, space resolution etc.
- Also we are in the process of procuring CF_4 gas so that can start measurements with new gas mixture, relevant for CMS GEM collaboration.
- We also hope to start experimenting with single-GEM and double-GEM devices in near future.

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- Pradipta Das, Chandranath Marick (SINP)
- Subhasis Chattopadhyay, Ganesh Das (VECC)
- Saikat Biswas (NISER)
- Rui De Oliveira, Archana Sharma, Leszek Ropelewsky, Eraldo Oliveri, Miranda Van Stenis (CERN)
- RD51 Collaboration
- CMS-GEM Collaboration

Thank You All !!