Status of GEM Characterization Studies at NISER

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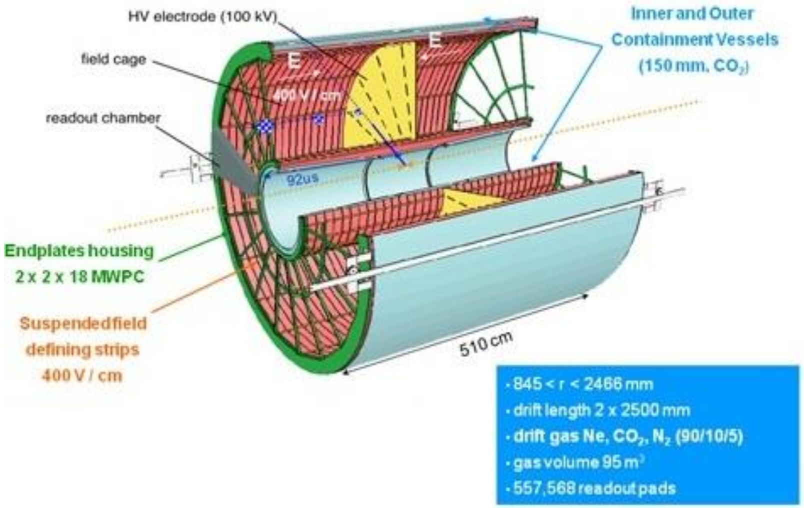
ALICE GEM-TPC Upgrade



- High rate capability
  - Target: 2MHz in p-p and 50kHz in Pb-Pb collisions
- Plan for the ALICE-TPC upgrade
  - No gating grid and continuous readout
  - MWPC readout will be replaced with other device

Recent Fundamental Innovations in Gas Detectors– Micro Pattern Gas Detectors

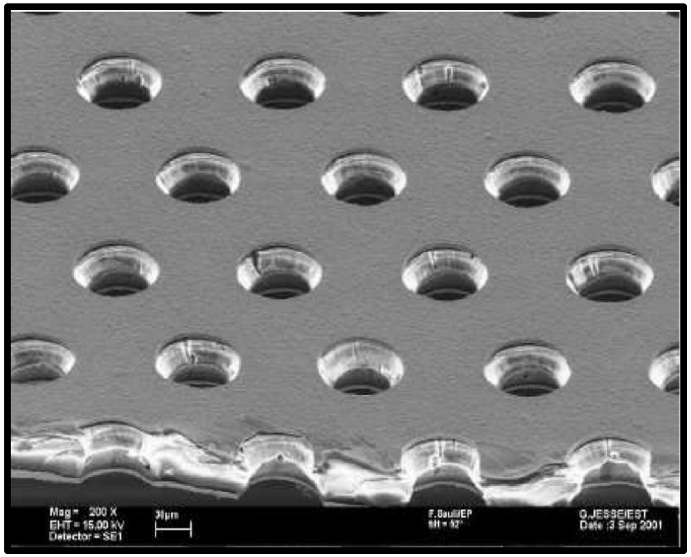
- GEM will replace MWPC
- Major requirements for the GEM-TPC upgrade

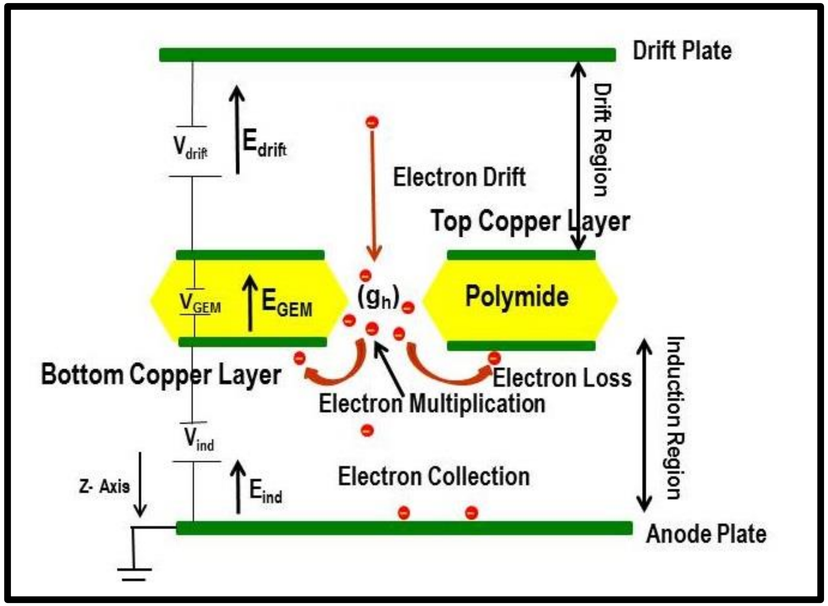
- < 0.25% Ion back flow to avoid space charge distortion
- Good electron transmission -- dE/dx resolution for the particle identification
- Better Stability of GEM (gain, charge up, discharge, P/T)

These parameters are known to depend on geometry of the detector, electrostatic configuration within the detector, gas composition, pressure ...

Single GEM)

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

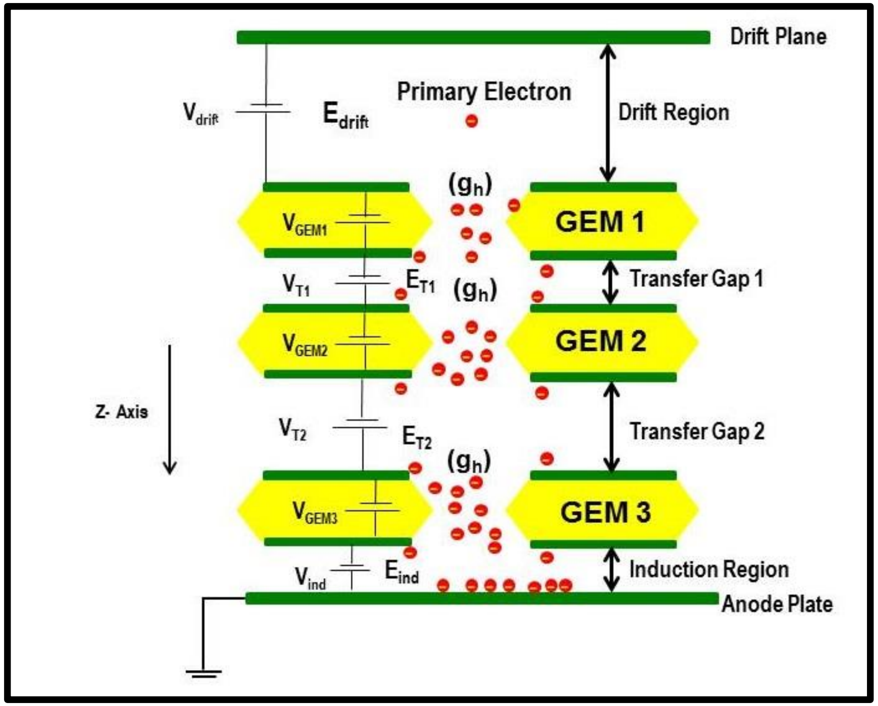




- The novel idea of stand-alone electron multiplier invokes physically separate conversion, multiplication and induction regions.
- Single GEM foil inserted between two parallel electrodes. The upper electrodes acts as cathode while the lower plays role as anode readout.
- A potential difference is created between the two sides by application of high voltages (~ 400 – 500 V) on the copper layers to develop a high amplification field (~ 70 kV/cm) inside the holes.
- 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.

Stack of GEM foils

- **Multiple GEM foils are inserted between drift and induction plane**
- **Dividing multiplication in more than one stages – higher value of gain, reduction of discharge**
- **Reduce ion backflow fraction**



Earlier Test with triple GEM detectors

- Measured Ion backflow Fraction ~ 5.4%,

[Ref: *JINST* **9** C04025]

Current Design of GEM detectors for ALICE

- **Quadruple GEM detectors**
- **Two foils, outer hole diameter of 70 µm and pitch of 140 µm (denoted as S i.e standard)**
- **Two foils, outer hole diameter of 70 µm and pitch of 280 µm (denoted as LP i.e Large Pitch)**
- **Drift Field ~ 400 V/cm, V_{GEM} ~ 250 – 360 V, Transfer Field I and II ~ 1 - 4 kV/cm, Transfer Field III ~ 100 V/cm, Induction Field ~ 4 kV/cm**
- **Gas mixture: Ne/ CO_2/ N_2 90/10/5**

Motivation -- Electron Transmission, Energy Resolution, Ion Backflow for GEM-based detectors

Earlier Results from single and triple GEM simulation:

- ❑ Higher electron transmission and lower backflow fraction can be obtained with higher V_{GEM}, lower E_{Drift}, higher $E_{Induction}$
- ❑ GEM foil with smaller hole pitch is better in terms of higher electron transmission and less backflow fraction
- ❑ No significant effect of 0.5 T magnetic field has been observed
- ❑ Triple GEM detector with foil having 140 μm pitch gives backflow fraction ~ 5.4%, but the electron transmission is affected adversely.

Today's Discussion:

- ➢ Quadruple GEM detector: Electron and Ion Transmission for different geometry, field configuration, with and without magnetic field
- ➢ Triple GEM detector having a configuration of LP-S-SP (SP stands for smaller pitch of 80 μm)
- ➢ Effect of geometrical inhomogeneity on electron and ion transmission

: Simulation tools :

Garfield + neBEM + Heed + Magboltz *combination*

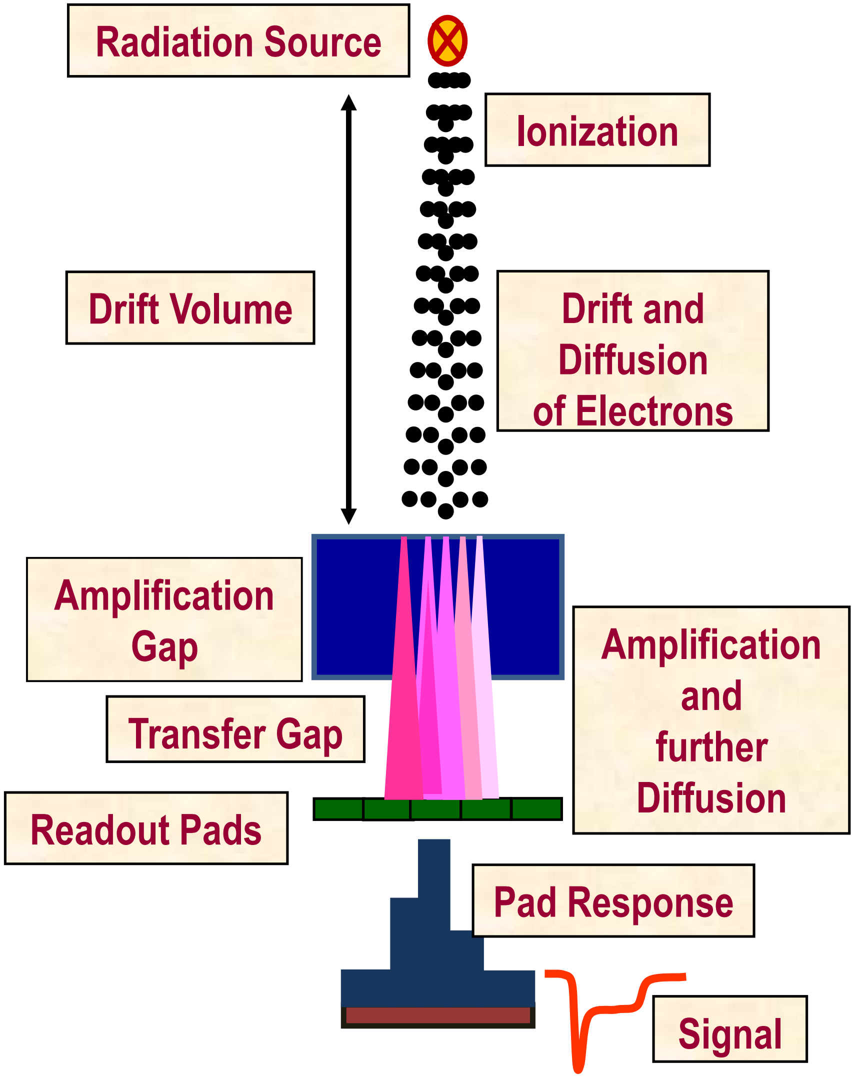
- **Detector Modelling: GARFIELD**

- **Ionization:** energy loss through ionization of a particle crossing the gas and production of clusters – **HEED**

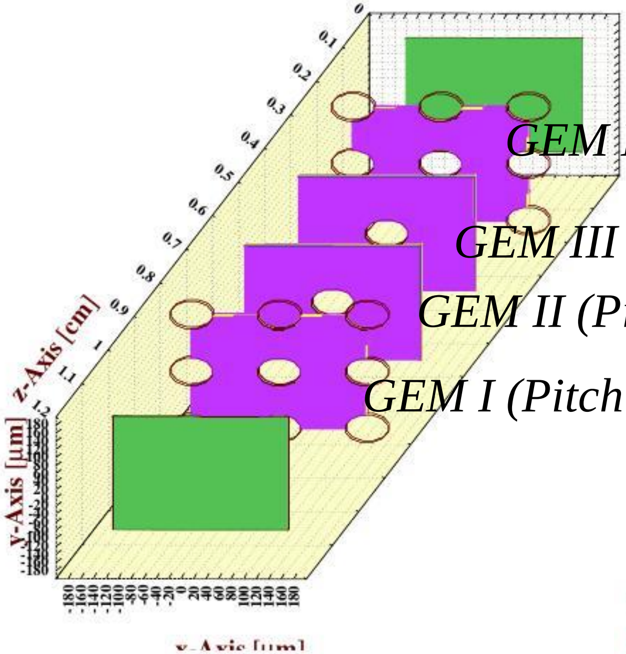
- **Transport and Amplification:** electron drift velocity and diffusion coefficients (longitudinal and transverse), Townsend and attachment coefficients – **MAGBOLTZ**

- **Detector Response:** charge induction using Reciprocity theorem (Shockley-Ramo's theorem), particle drift, charge sharing (pad response function), charge collection – **GARFIELD**

- **Electrical Solver: neBEM (nearly exact Boundary Element Method** – A formulation based on green's function that allows the use of exact close-form analytic expressions while solving 3D problems governed by Poisson's equation.



Quadruple GEM Detector (S-LP-LP-S)



GEM IV (Pitch 140 µm)

GEM III (Pitch 280 µm)

GEM II (Pitch 280 µm)

GEM I (Pitch 140 µm)

Drift Field: 400 V/cm

V_{GEMI}: 275 V

Transfer Field I: 4000 V/cm

V_{GEMII}: 235 V

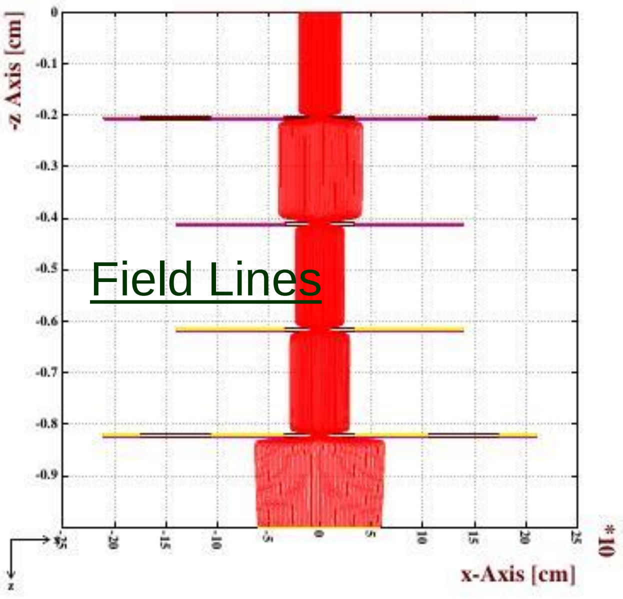
Transfer Field II: 2000 V/cm

V_{GEMIII}: 284 V

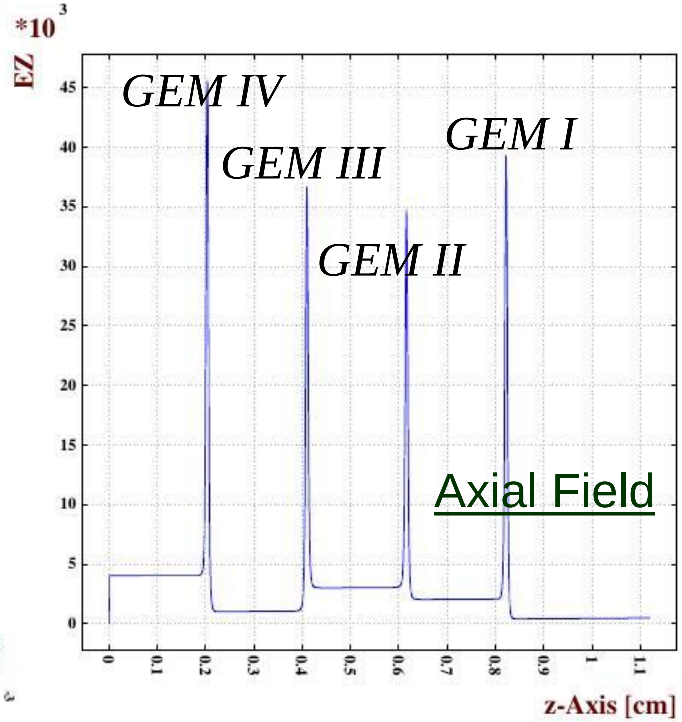
Transfer Field III: 100 V/cm

V_{GEMIV}: 345 V

Induction Field: 4000 kV/cm



Field Lines



GEM IV

GEM III

GEM II

GEM I

Axial Field

Electron Transmission

- Electron Transmission using Microscopic drift method
- No multiplication has been considered
- 10000 electrons are injected in the drift volume
- Gas mixture: Ne/ CO_2 / N_2 (90/ 10/ 5)

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

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

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

$$\boxed{\varepsilon_{tot} = \varepsilon_{coll1} \times \varepsilon_{ext1} \times \varepsilon_{coll2} \times \varepsilon_{ext2} \times \varepsilon_{coll3} \times \varepsilon_{ext3} \times \varepsilon_{coll4} \times \varepsilon_{ext4}}$$

Individual efficiencies of GEM foils:

Magnetic Field	**GEM I**		**GEM II**		**GEM III**		**GEM IV**	
	ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}
B = 0T	**99.85%**	**34.19%**	**9.84%**	**25.0%**	**29.76%**	**16.0%**	**100%**	**25%**
B = 0.5T	**99.76%**	**34.12%**	**10.17%**	**25.43%**	**32.95%**	**10.34%**	**100%**	**33%**

✓ Only 1 primary electrons out of 10000 are able to reach anode

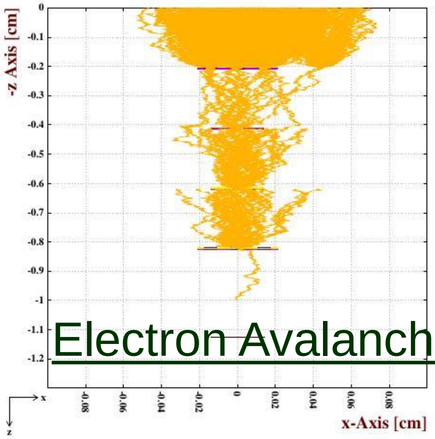
✓ No significant of magnetic field of 0.5 T has been observed on ε_{tot}

✓ Change of transfer field also does not affect ε_{tot}

Ion Backflow

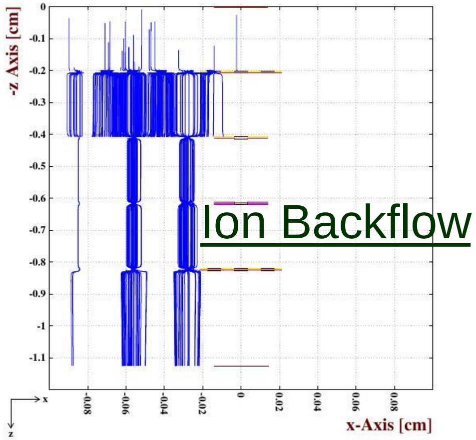
Monte Carlo Method:

1) drifting of initial electron from specified point
2) creation of secondary electrons for each step according to Townsend and attachment coefficient
3) Ion drift lines are followed and fraction has been calculated as N_b/N_T



Electron Avalanche

Gain ~ 1600 in Ne/ CO2/ N2 (90/10/5) considering Penning transfer rate of 65%



Ion Backflow

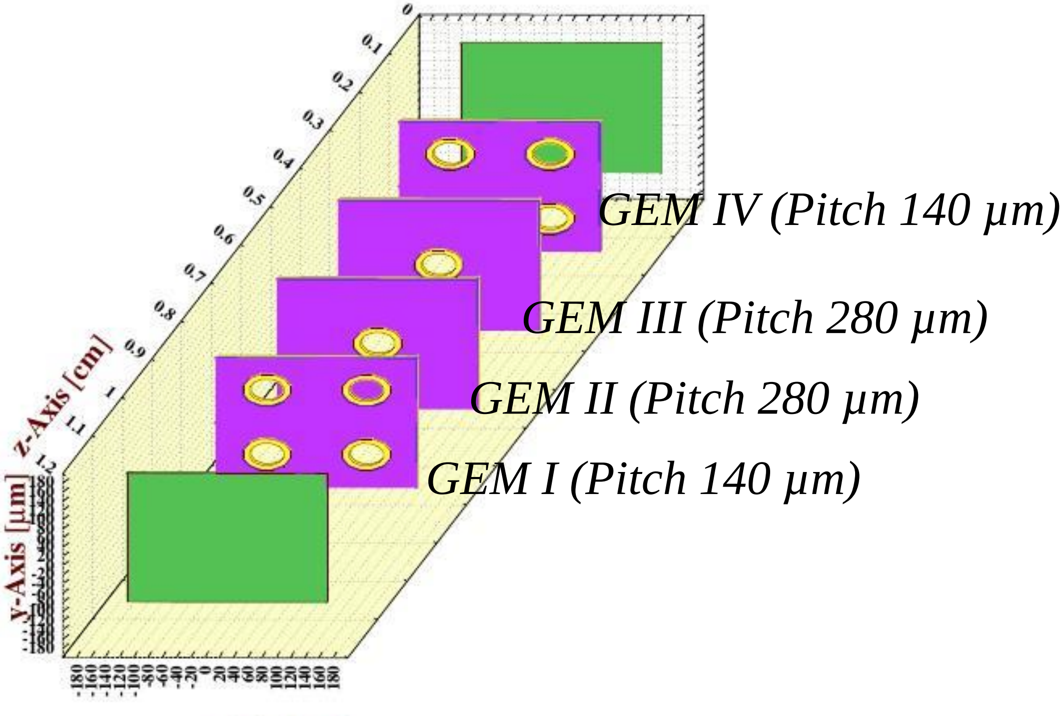
Collection of ions on individual GEM foils:

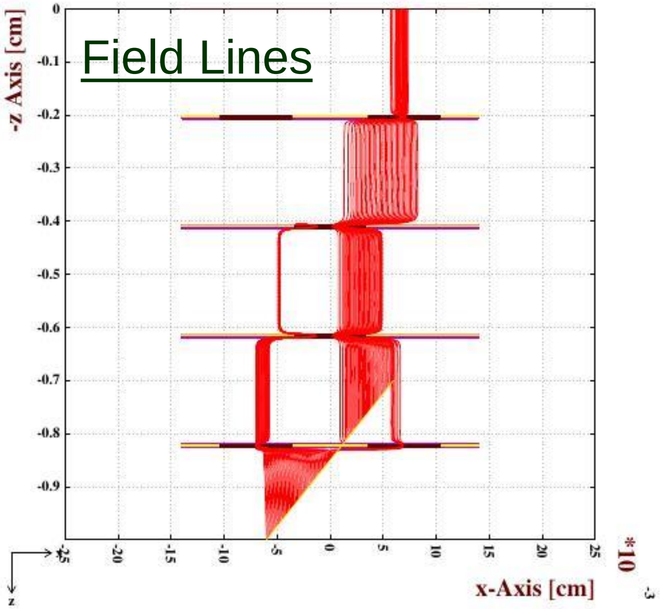
Magnetic Field	GEM I	GEM II	GEM III	GEM IV
B = 0T	2.45%	0.42%	1.29%	93.20%

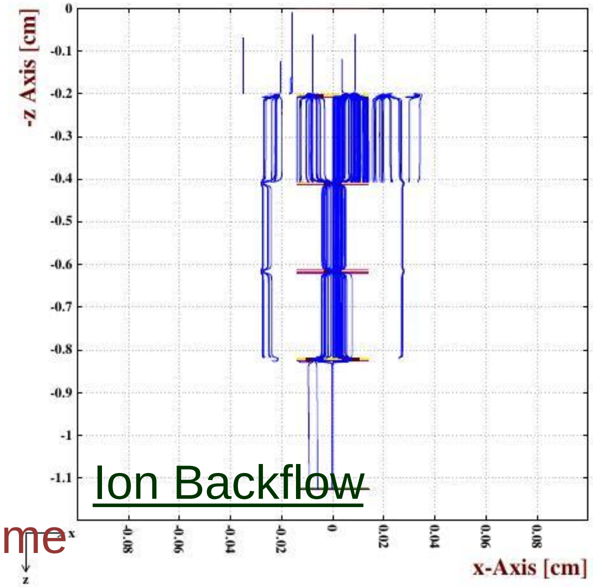
- Most of the ions are collected on the IVth GEM foil.
- Only 2.64% of ions are able to drift back to the drift volume
- No significant effect of 0.5T magnetic field has been observed on backflow fraction
- Increase of Transfer field II improves backflow fraction ~ 15%

Quadruple GEM Detector (S-LP-LP-S)

(Another Geometry, Different Placement of Holes, Same Voltage Configuration)







Collection of ions on individual GEM foils:

Magnetic Field	**GEM I**	**GEM II**	**GEM III**	**GEM IV**
B = 0T	**6.02%**	**0.49%**	**1.26%**	**92.10%**

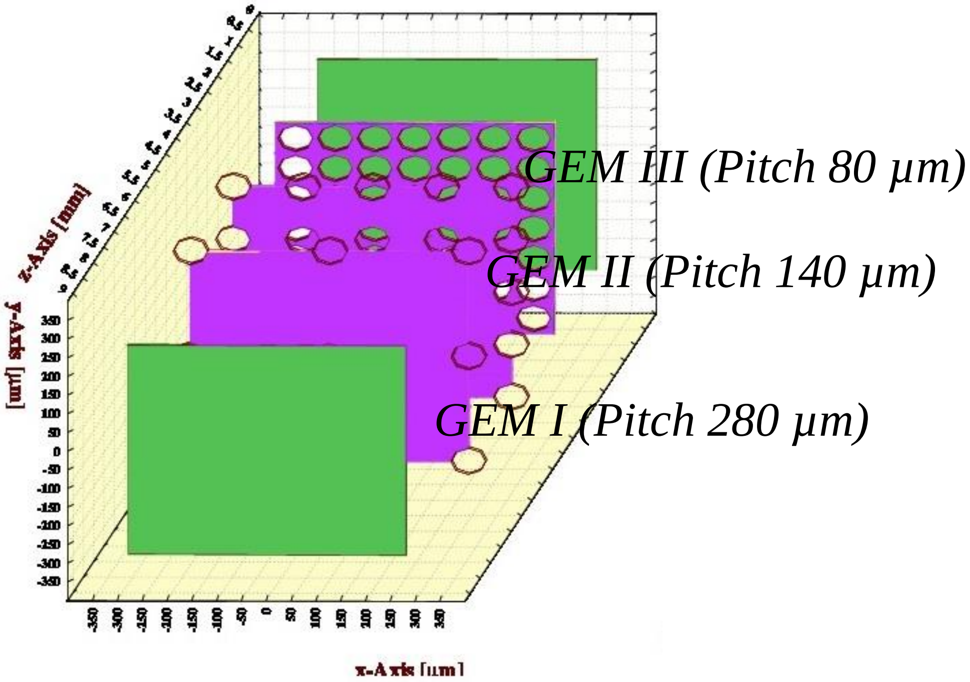
- Ions collected on the Ist GEM foil increases.
- Only 0.14% of ions are able to drift back to the drift volume

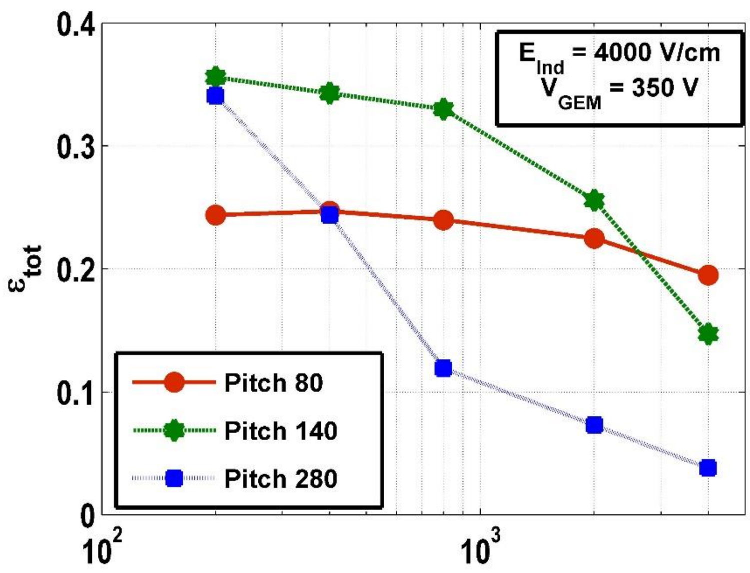
Another Geometry -- Triple GEM Detector (LP-S-SP)

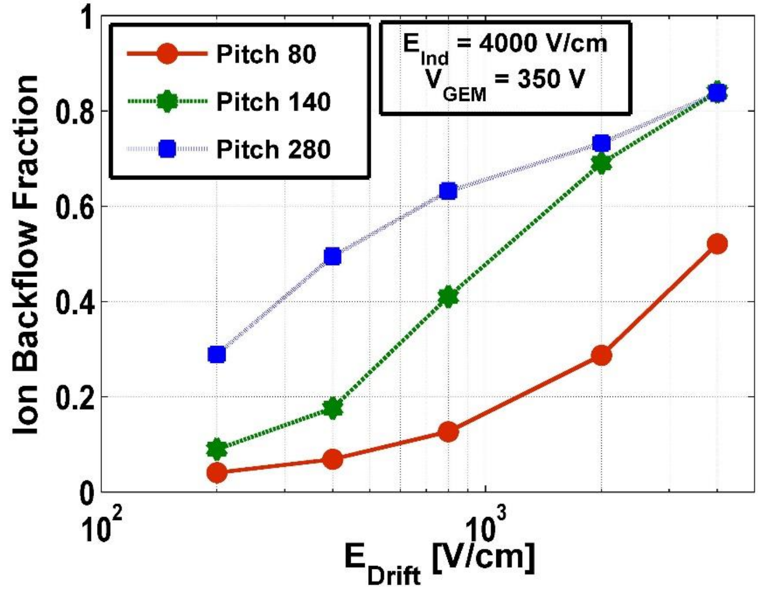
- A new proposal from ALICE group from Sao Paulo, Brazil -- Use of triple GEM detector having a configuration of LP-S-SP from top to bottom direction (here SP is the smaller pitch of 80 μm)

- Numerical simulation has been initiated -- Study of single GEM foil shows that SP is better in terms of lower backflow fraction though for this case, electron transmission is affected.

- Field calculation with 3 GEM foils is going on

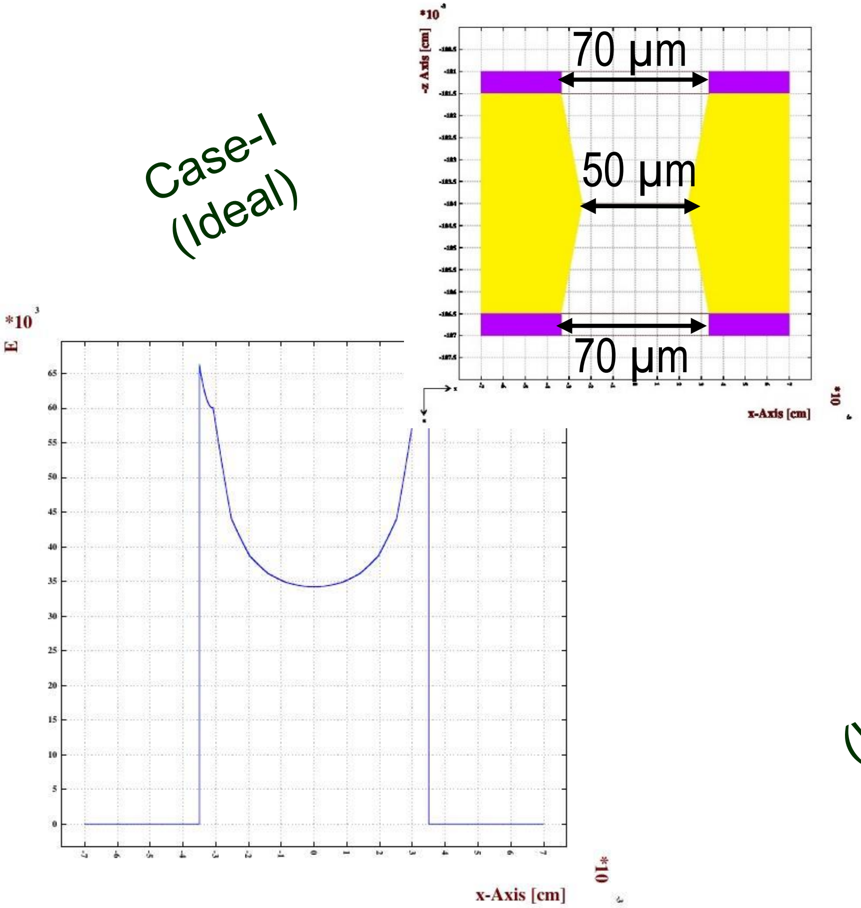




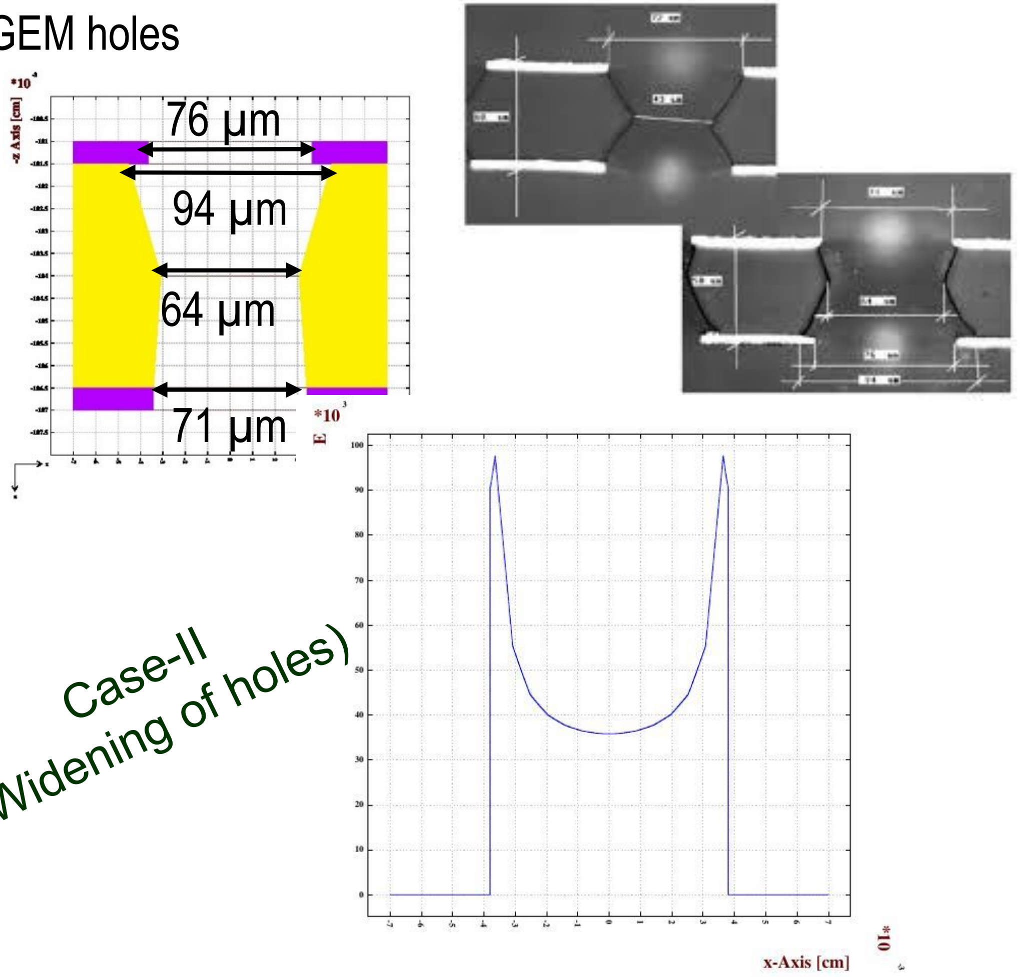


Effect of Geometrical Inhomogeneity

- ☐ Manufacturing tolerances, defects, asperities affect local field -- local discharge and related fluctuations.
- ☐ SEM analysis gives evidence of widening of GEM holes



Case-I (Ideal)

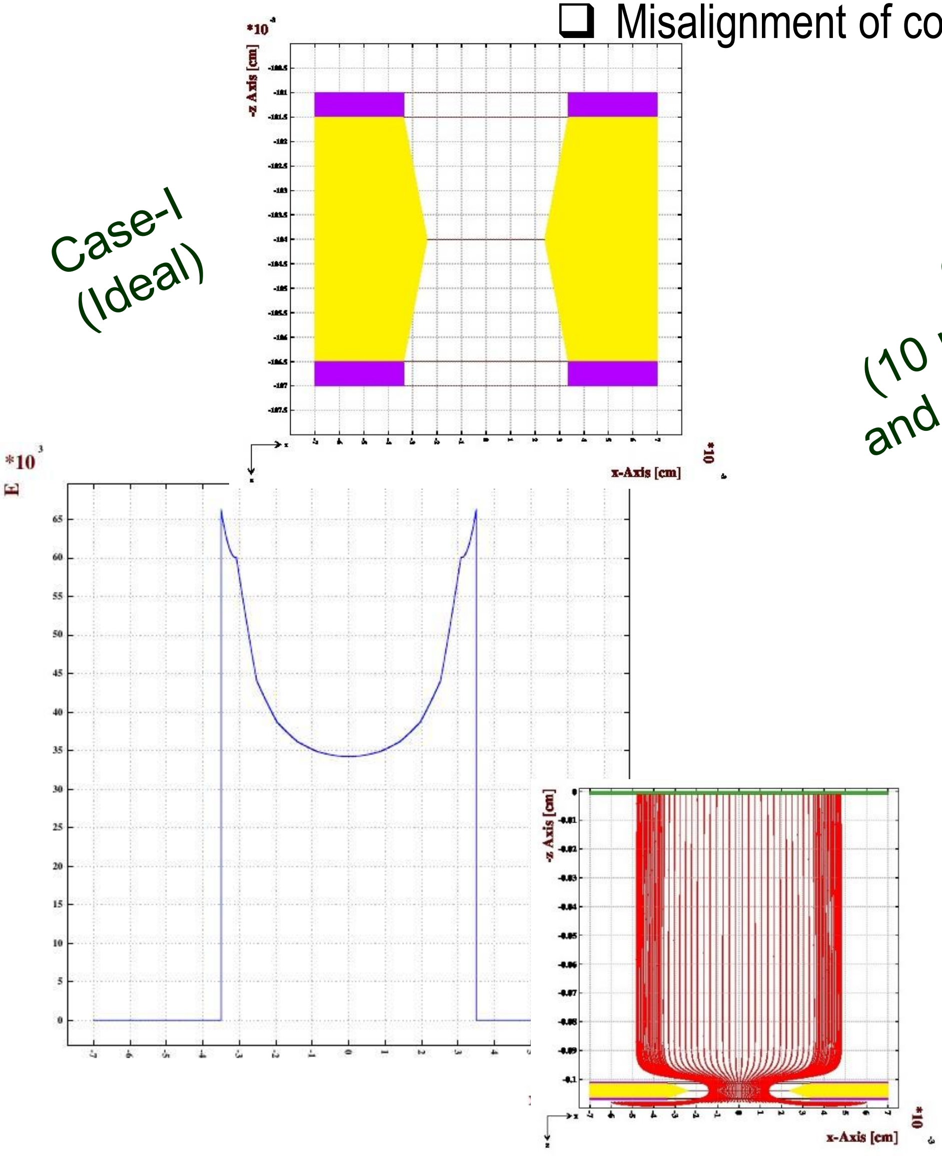


Case-II (Widening of holes)

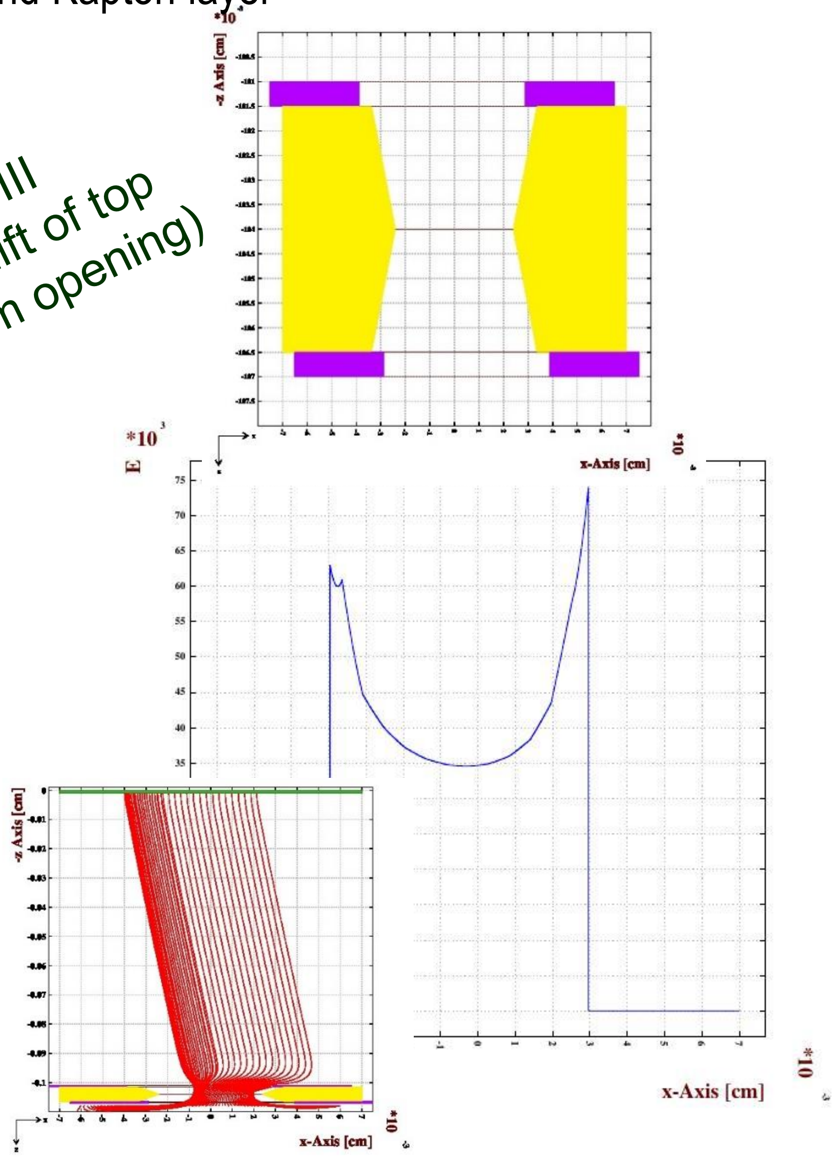
Detector	Gain	ε_{coll}	ε_{ext}	ε_{tot}	Energy resolution	Ion collection (top)	Ion collection (middle)	Ion collection (bottom)	IBF
Case - I	80	0.79	0.48	0.36	7.59%	0.744	0.061	0.011	0.19
Case - II	84	0.94	0.55	0.46	6.78%	0.782	0.086	0.009	0.13

❑ Misalignment of copper and Kapton layer

Case-I
(Ideal)



Case-III
(10 µm shift of top
and bottom opening)



Detector	Gain	ε_{coll}	ε_{ext}	ε_{tot}	Energy resolution	Ion collection (top)	Ion collection (middle)	Ion collection (bottom)	IBF
Case - III	56	0.72	0.39	0.25	9.18%	0.665	0.095	0.010	0.232

Summary:

1) Garfield simulation framework, that combines packages such as neBEM, Magboltz and Heed has been used as a tool of exploration to evaluate the fundamental features of GEM-based detectors. Several modifications have been made in the framework to make it significantly more efficient and as a result, more suitable for complicated geometry.

2) Numerical simulation to estimate electron transmission, energy resolution and ion backflow have been performed.

3) Study of single GEM detector has helped us to understand the complicated physics process in multi-GEM structure and choose field configuration, detector geometry etc. Multi-GEM device is suitable in terms of less backflow fraction but it affects electron transmission adversely. Numerical simulation for a quadruple GEM detector has been performed with different voltage configuration, geometry configuration has been performed in presence and absence of magnetic field.

4) Investigation of a triple GEM detector having configuration of LP-S-SP has been initiated to achieve a backflow fraction ~1%.

5) A numerical simulation has been carried out to investigate the role of geometrical inhomogeneity and surface asperities on electron and ion transmission. Ideally perfect, as well as single GEM detector with such imperfections have been considered here in order to achieve a comprehensive understanding.

Future Plan:

1. Electron transmission including multiplication process will be calculated.
2. Space charge effect will be considered.
3. The behaviour of electron and ion transmission on detector edge will be also simulated.

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