Numerical Investigation on Electron and Ion Transmission of GEM-based Detectors

Purba Bhattacharya

NISER, Bhubaneswar, India

Group Members:

Sumanya Sekhar Sahoo, Saikat Biswas, Bedangadas Mohanty, (NISER, India)
Nayana Majumdar, Supratik Mukhopadhyay (SINP, India)

4th International Conference on Micro-Pattern Gaseous Detectors & RD51 Meeting, 12 – 17th October, 2015, Trieste, Italy

Applications of Micro-Pattern Gas Detectors in High-Rate Experiments

ALICE GEM-TPC Upgrade

•Major issues for the GEM-TPC upgrade

- $< 0.25\%$ Ion back flow to avoid space charge distortion

- Better electron transmission -- dE/dx resolution for the particle identification

- Stability of GEM (gain, charge up, discharge, P/T)

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

Motivations

- Electron Transmission and Ion Backflow with and without magnetic field for different GEM-based detectors under various field configuration

Today's Discussion:

- Transport Property of Ne/ CO_2 /N_2 (90/10/5) gas mixture

- Single GEM detector: Variation of Electron Transmission, Gain and Ion backflow with V_{GEM}, E_{Drift}, $E_{Induction}$ with and without magnetic field for two different hole pitch of GEM foil

- Triple GEM detector: Electron and Ion Transmission for a particular geometry and field configuration, Comparison with previous experimental and numerical results

- Quadruple GEM detector: Electron and Ion Transmission for different geometry, two field configuration, with and without magnetic field

: 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**

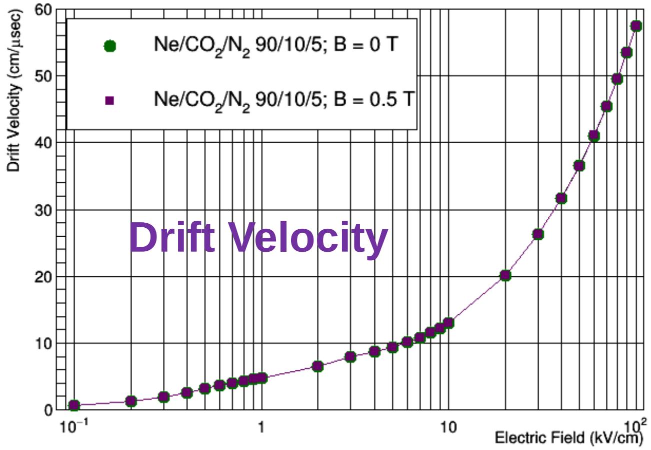
- **Electrical Solver: neBEM (nearly exact Boundary Element Method** – charge distribution on a geometry for a given voltage configuration; both potential and field computed using the charge distribution

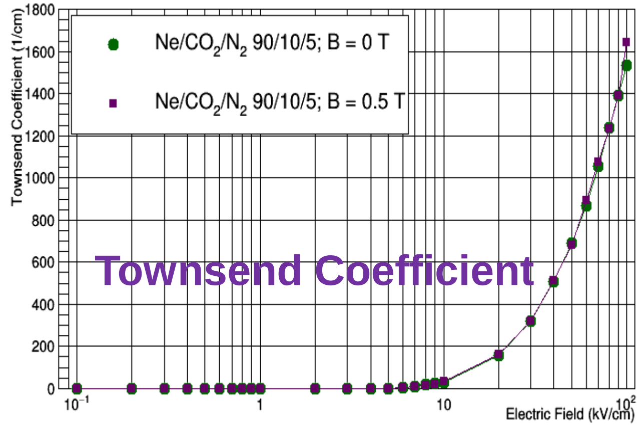
neBEM developments that were crucial for the study:

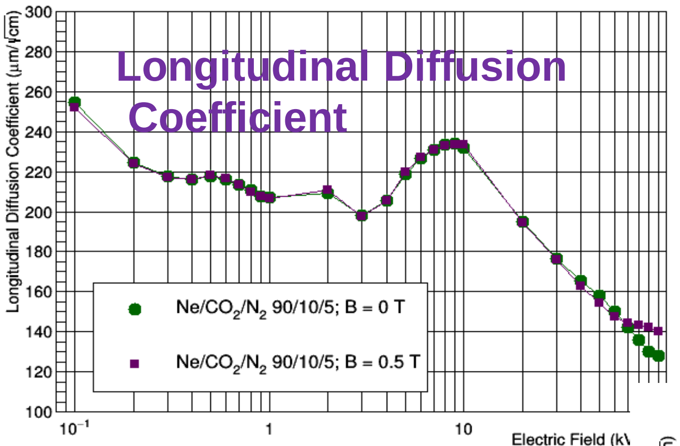
•Optimization of field calculations to achieve a large range of fields

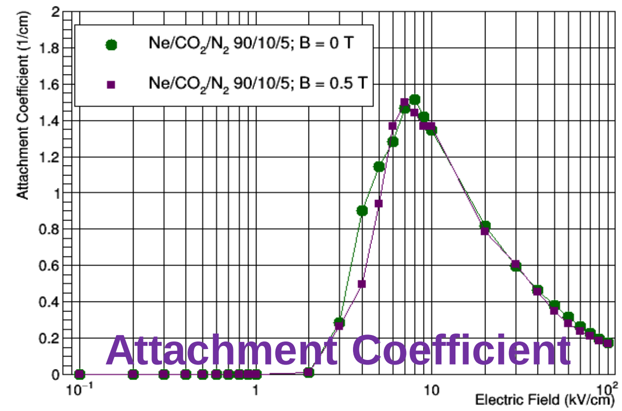
•Extensive use of the recently developed fast-volume approach, code parallelization, reduced order modelling so that a reasonable statistics is maintained in all the studies

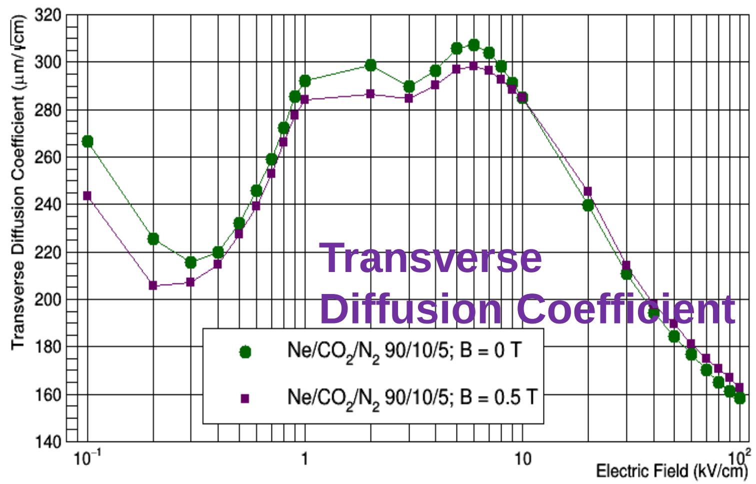
Transport Property of Ne / CO_2 /N_2 (90/10/5)







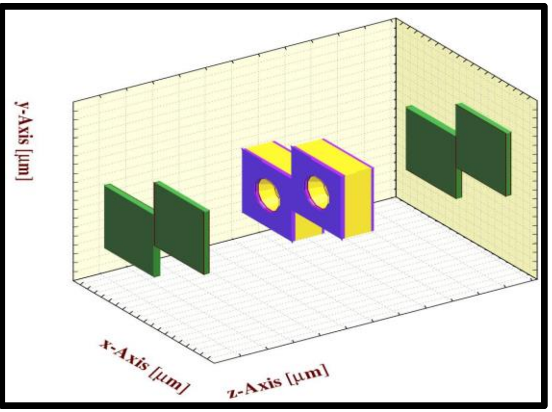


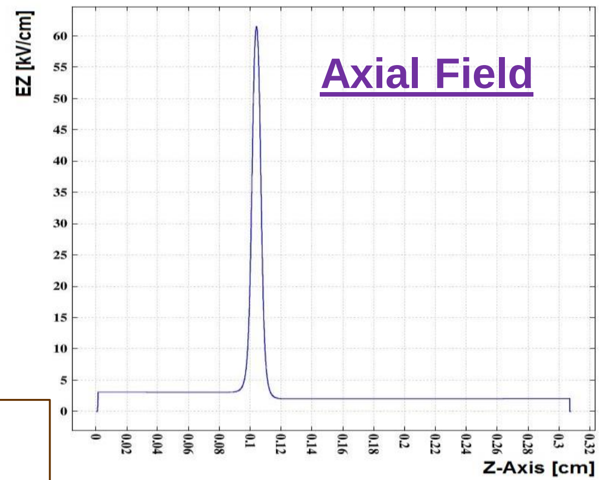


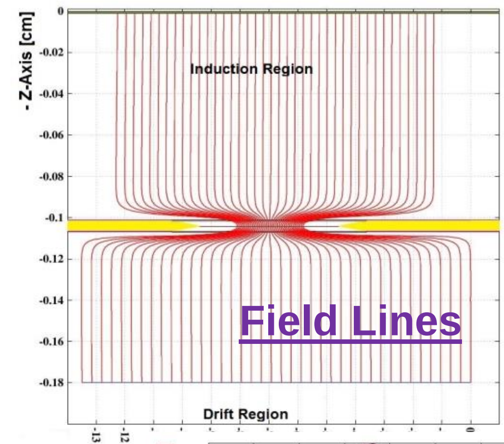
Magnetic field mainly affects transverse diffusion coefficient, but for 0.5 T magnetic field, this effect is not significant

Device Geometry of Single Detector

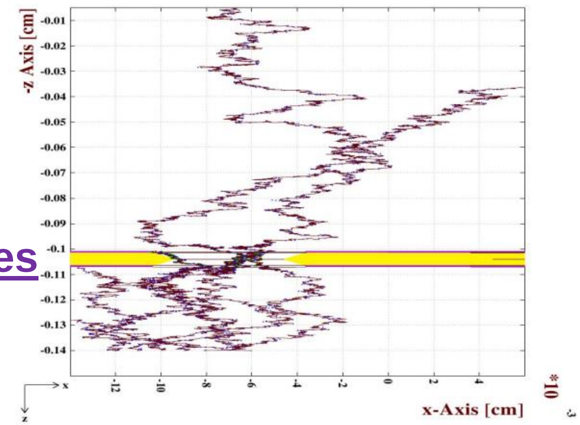
➢**Numerical simulation (using Garfield) was conducted to understand its working principle in Ne / CO_2 / N_2 (90/10/5) gas mixture.**







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



Electron Drift Lines

- ✓ **The basic unit of two bi-conical holes, placed between two parallel conductors**
- ✓ **The whole basic unit was repeated in both x, y directions to model the detector.**
- ✓ **Due to transverse diffusion some electrons are lost on the GEM foils**
- ✓ **With proper field configuration between drift, GEM foil and induction region, the ultimate electron collection on the anode can be increased**

Electron Transmission

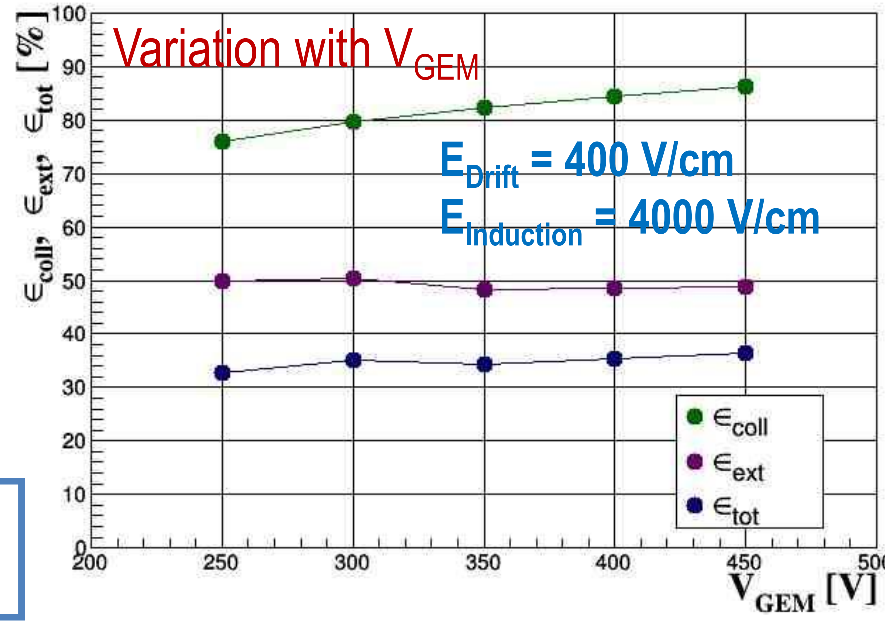
$$\varepsilon_{tot} = \frac{N_{anode}}{N_{drift}} = \varepsilon_{coll} \times \varepsilon_{ext}$$

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

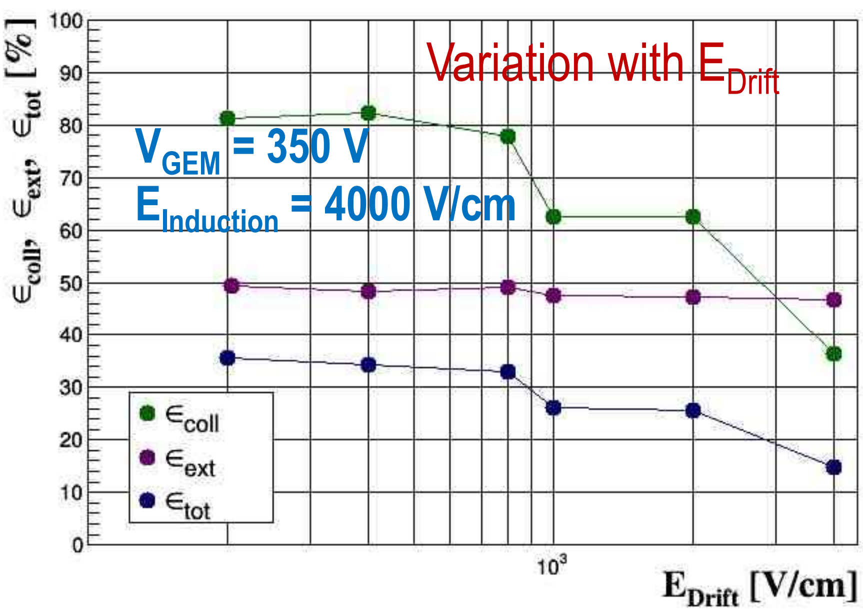
$$\varepsilon_{ext} = \frac{N_{anode}}{N_{GEM}}$$

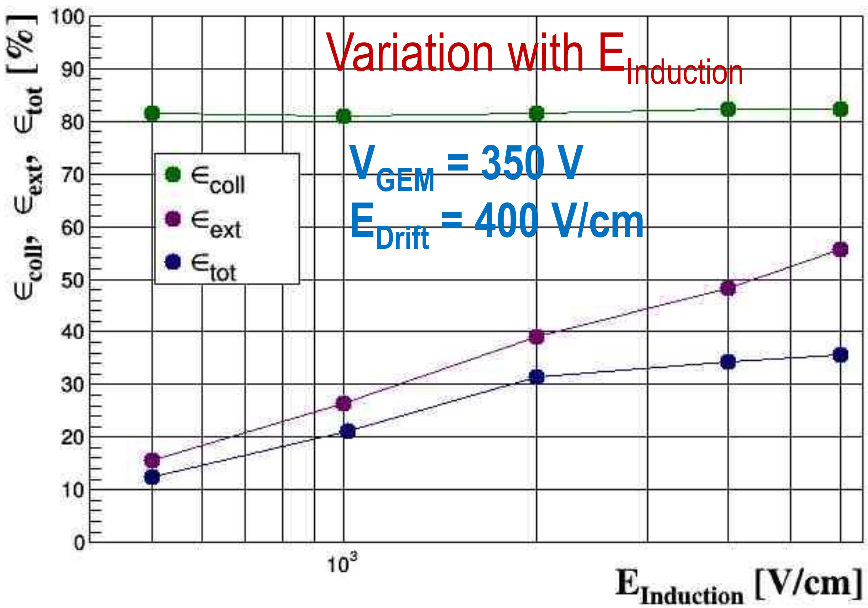
Microscopic tracking of electrons from randomly distributed points;

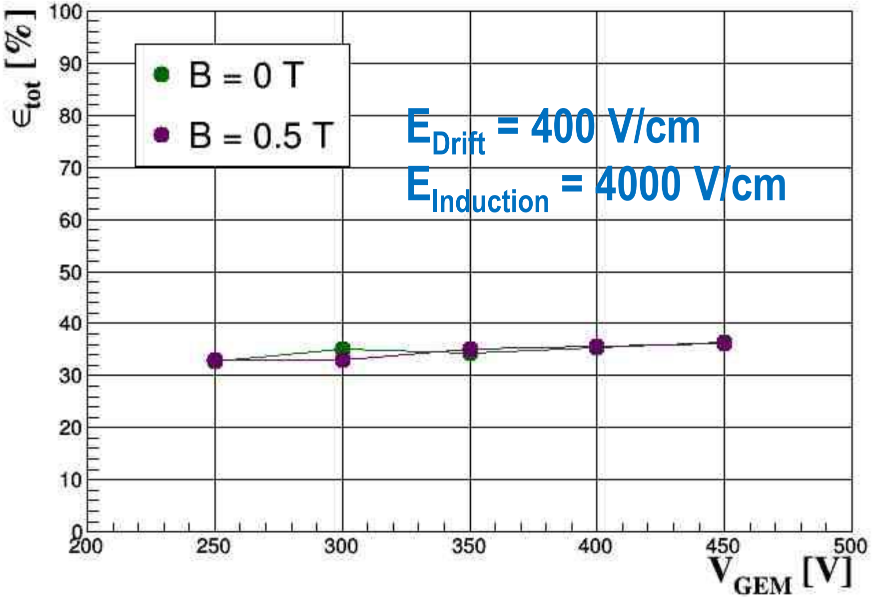
Gas mixture of Ne / CO_2 / N_2 (90/10/5)



- ➢ V_{GEM} affects ε_{coll} and thus ε_{tot}, E_{Drift} affects ε_{coll} and thus ε_{tot}, $E_{Induction}$ affects ε_{ext} and thus ε_{tot}





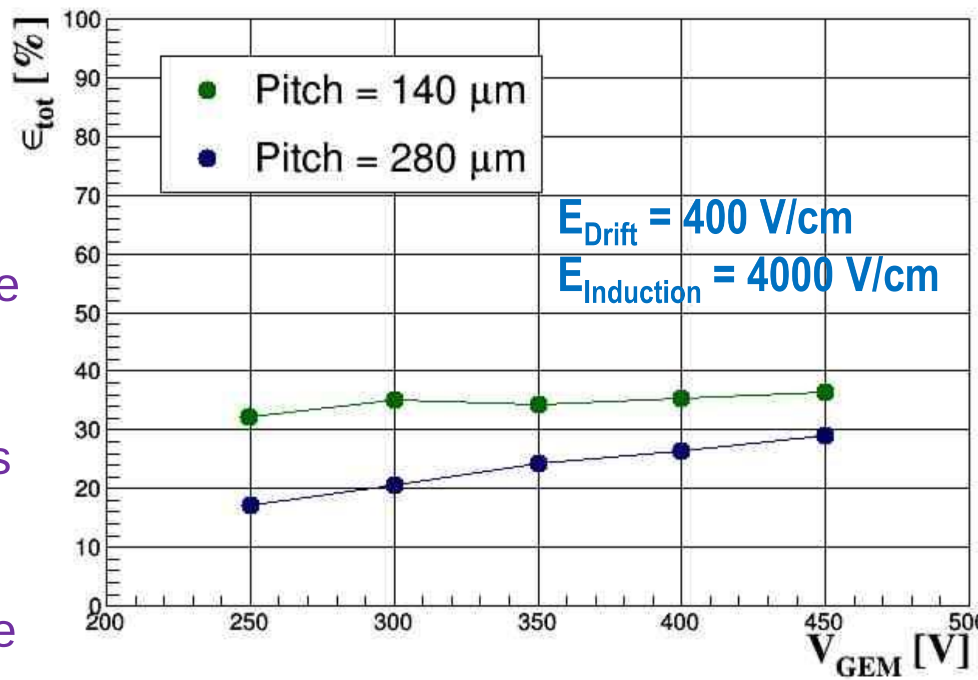


<u>Gas mixture of Ne / CO_2 / N_2 (90/10/5)</u>

Effect of 0.5 T magnetic field
--Variation with V_{GEM}

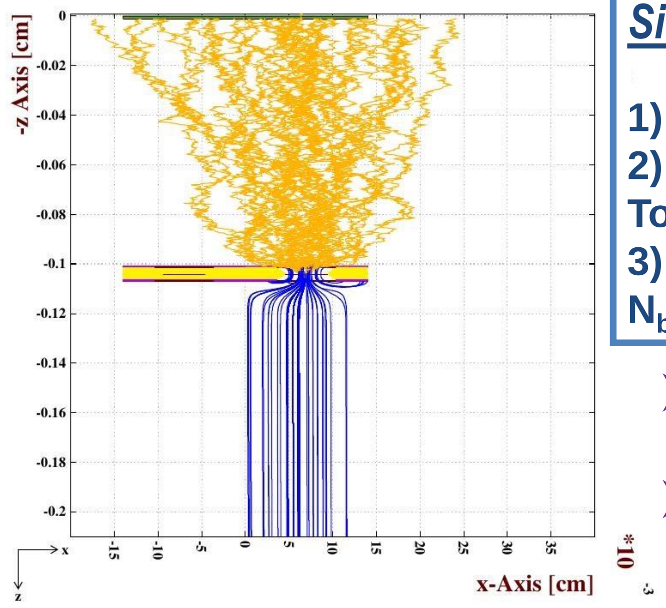
Effect of hole pitch
--Variation with V_{GEM}

- Variation with E_{Drift} and $E_{Induction}$ have been also studied
- No effect of 0.5 T magnetic field has been observed
- In all of the cases, smaller pitch give better result



Electron Gain and Ion Backflow

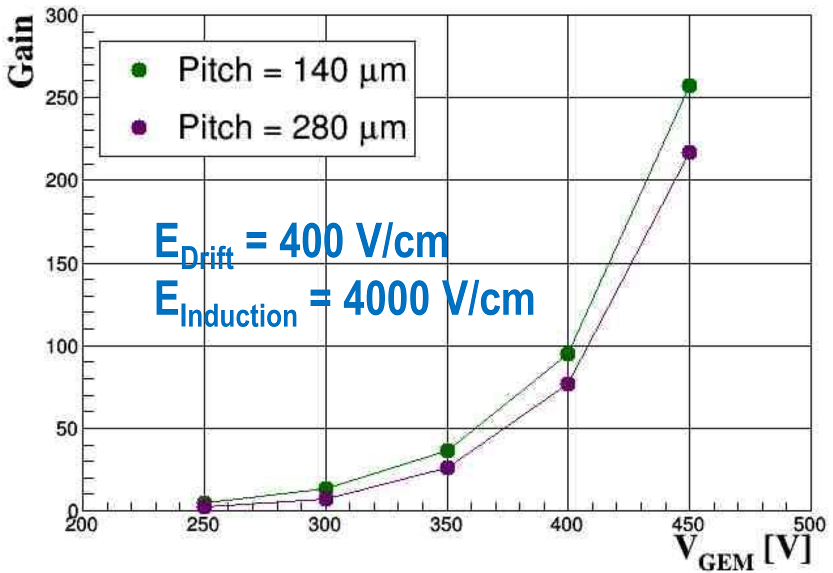
Gas mixture of Ne / CO_2 / N_2 (90/10/5)

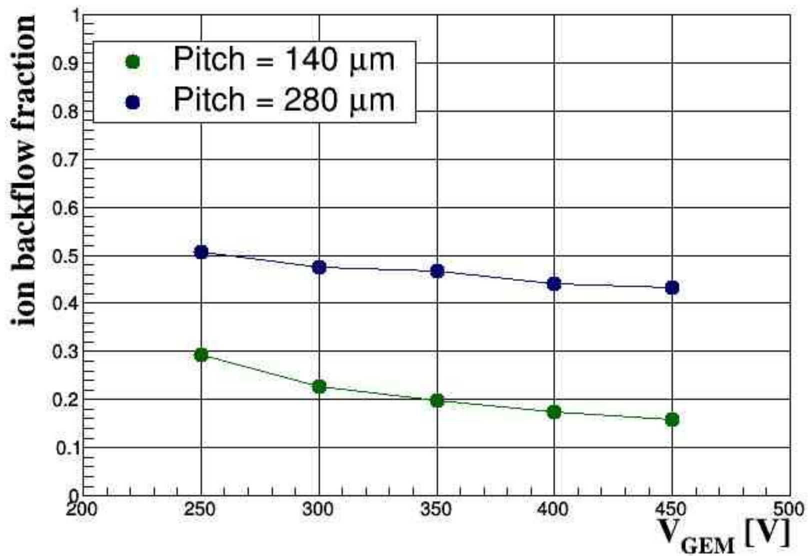


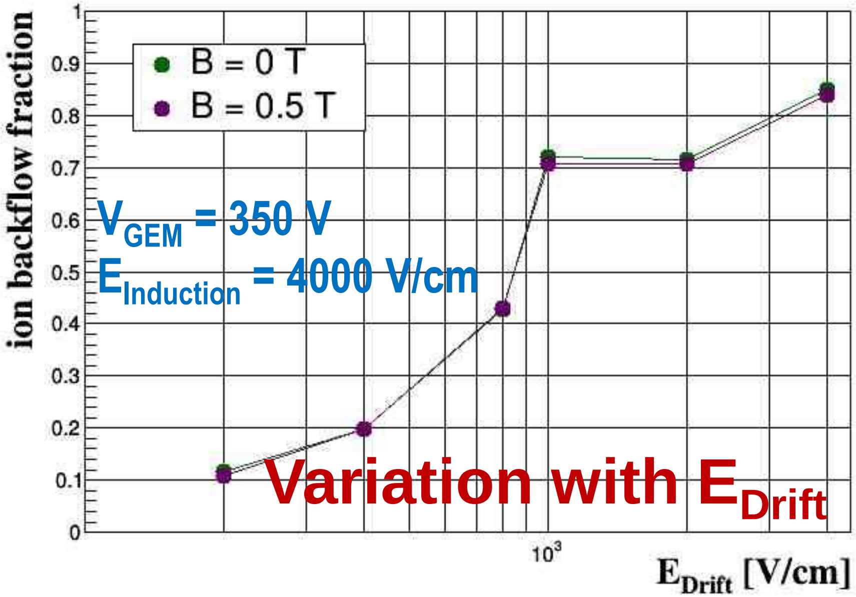
Simulation (Monte Carlo Method):

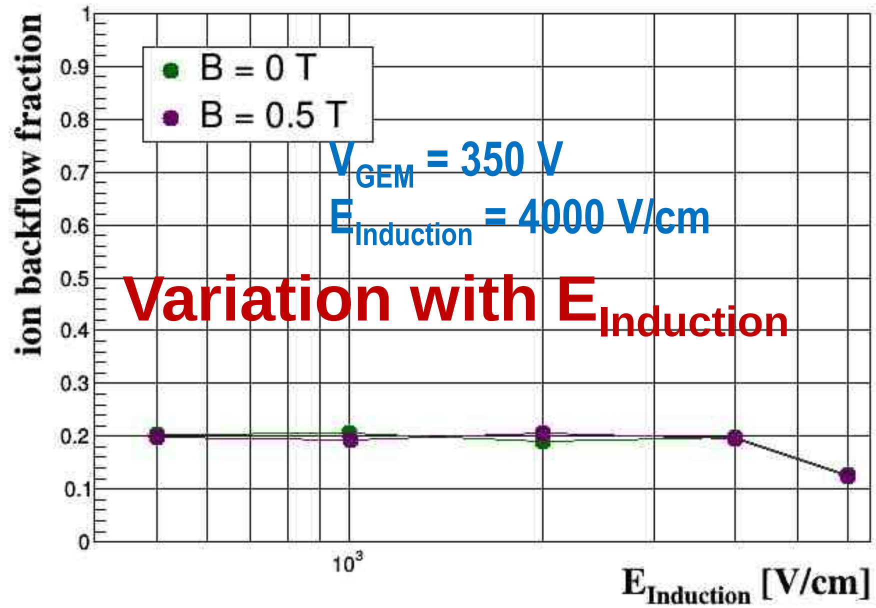
1) drifting of initial electron from specified point
2) creation of secondary electrons for each step according to Townsend and attachment coefficient
3) Ion drift lines are followed and fraction has been calculated as N_b/N_T

- Variation with V_{GEM}
- Higher V_{GEM} is required for less backflow
- Smaller pitch shows higher gain and less backflow fraction at same voltage

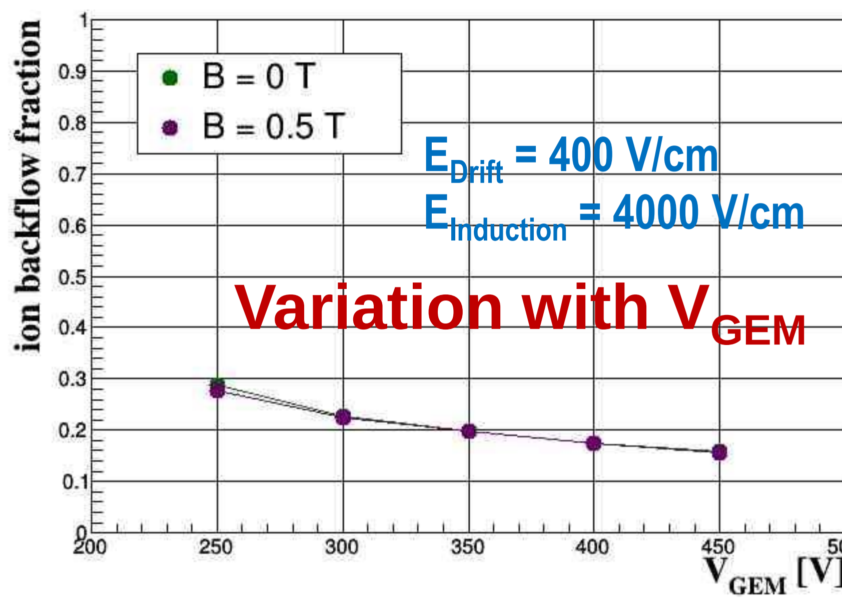






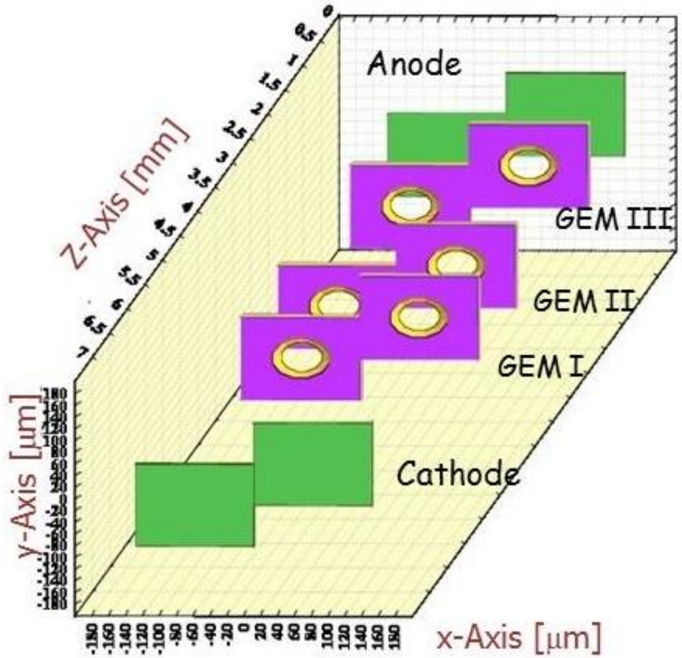


- Lower E_{drift} is required for less backflow
- No significant effect of $E_{induction}$ on backflow except at very high induction field
- No effect of 0.5 T magnetic field has been observed
- In all of the cases, smaller pitch give better result



<u>Study of single GEM will be helpful to understand complicated physics process in multi-GEMs, to choose optimized field configuration, detector geometry etc..</u>

Triple GEM Detector



Foil thickness: 50 µm

Copper thickness: 5 µm

Hole dia (outer): 70 µm

Hole dia (inner): 50 µm

Hole pitch: 140 µm

Gap Configuration: 3:2:2:2 (mm)

Drift Field: 400 V/cm

V_{GEMI}: 250 V

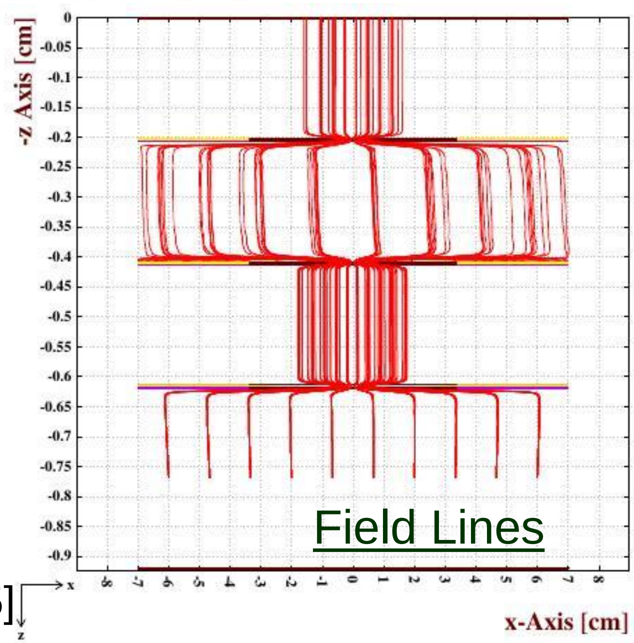
Transfer Field I: 5 kV/cm

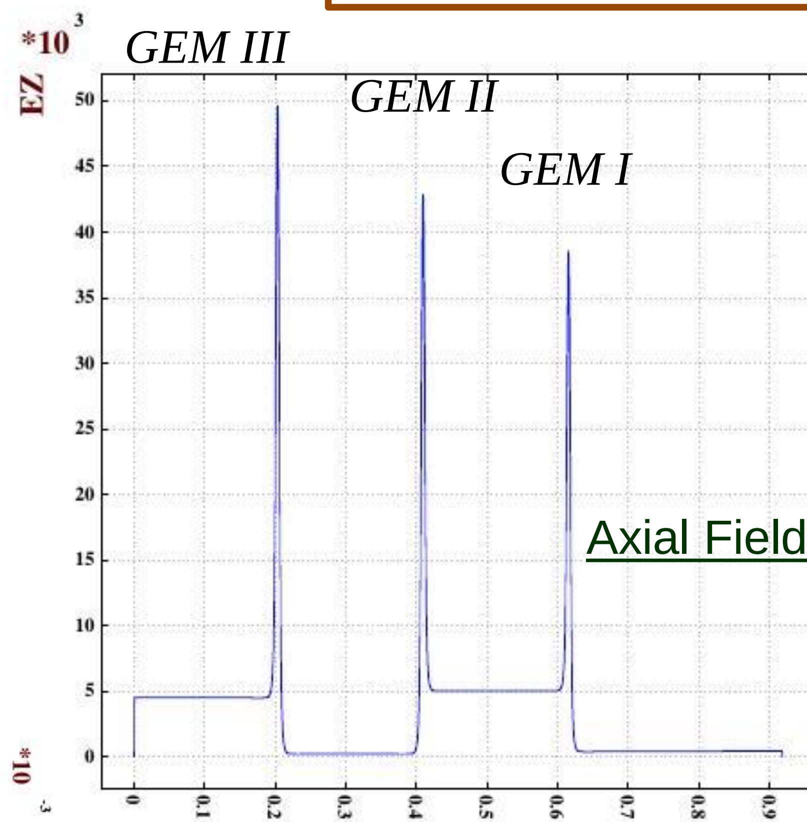
V_{GEMII}: 280 V

Transfer Field II: 200 V/cm

V_{GEMIII}: 325 V

Induction Field: 4.5 kV/cm





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

Electron Transmission

- Electron Transmission using Microscopic drift method
- No multiplication has been considered
- 1000 electrons are injected in the drift volume
- Gas mixture: Ne/ CO_2 / N_2 (90/ 10/ 5)

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

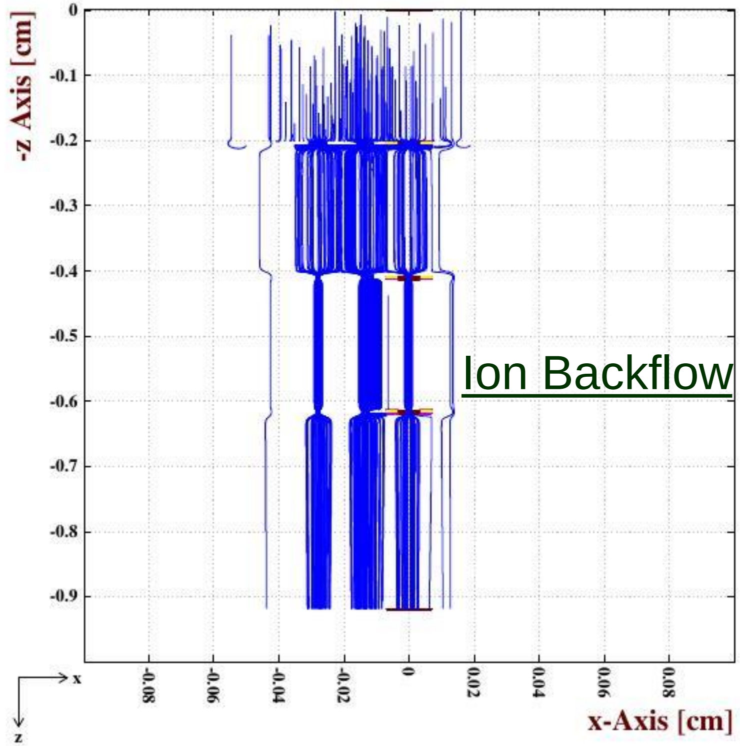
Individual efficiencies of GEM foils:

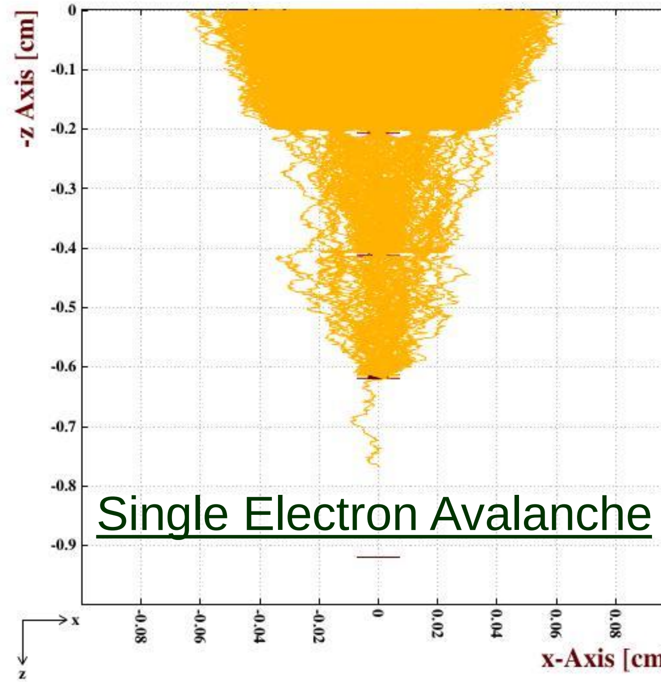
GEM I		GEM II		GEM III	
ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}
90.5%	50.5%	31.95%	8.904%	92.31%	33.33%

- ✓ ε_{tot} is significantly low. Only 0.4% primary electrons are able to reach anode
- ✓ But during its drift, electron multiplication increase number of electrons
- ✓ Future calculation will consider this effect

Electron Avalanche and Ion Backflow

- 3 stages of multiplication, simulated value of ~1940 with 35% Penning transfer rate, close to the previous results





- Most of the ions are collected on the 3rd GEM foil

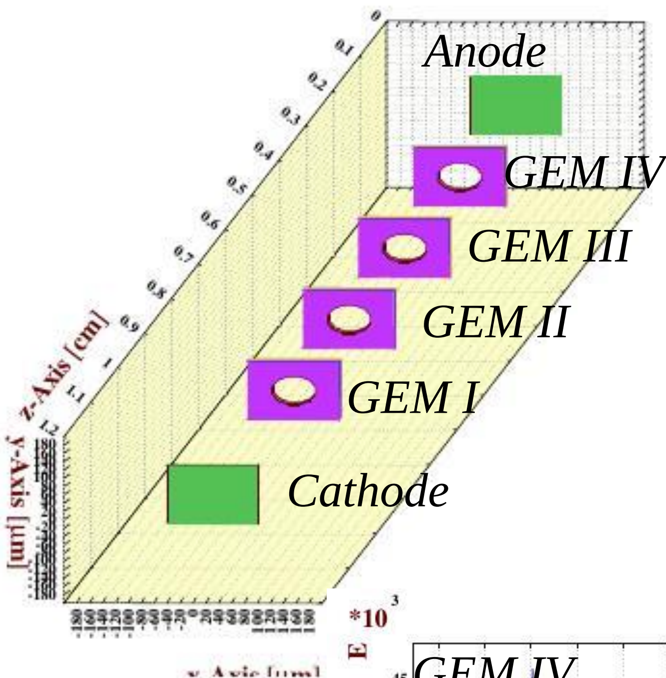
- Ion backflow Fraction: 5.4%, which is close to the reported values (~4%)

Collection of ions on individual GEM foils:

GEM I	GEM II	GEM III
1.48%	0.43%	92.51%

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

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



Foil thickness: 50 µm

Copper thickness: 5 µm

Hole dia (outer): 70 µm

Hole dia (inner): 50 µm

Hole pitch: 140 µm

Gap Configuration: 3:2:2:2:2 (mm)

Drift Field: 400 V/cm

V_{GEMI}: 275 V

Transfer Field I: 2000 V/cm

V_{GEMII}: 240 V

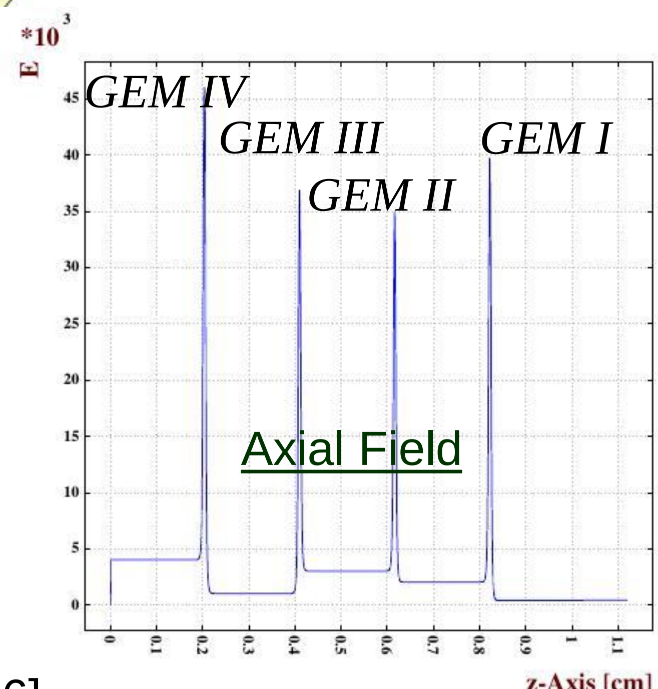
Transfer Field II: 3000 V/cm

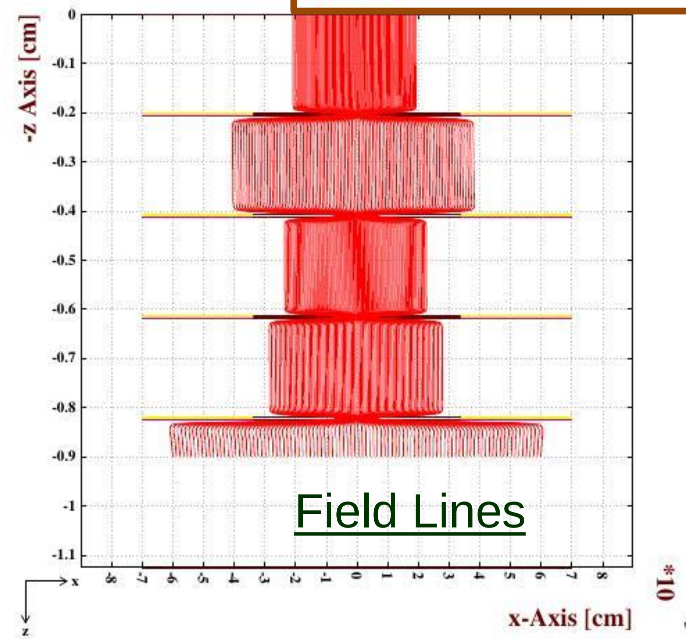
V_{GEMIII}: 254 V

Transfer Field III: 1000 V/cm

V_{GEMIV}: 317 V

Induction Field: 4000 kV/cm





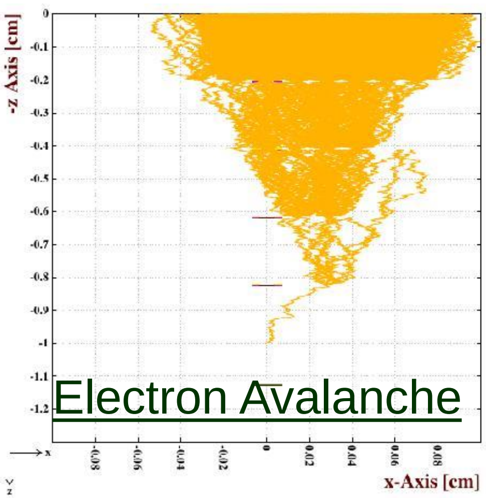
[ALICE-TDR-016]

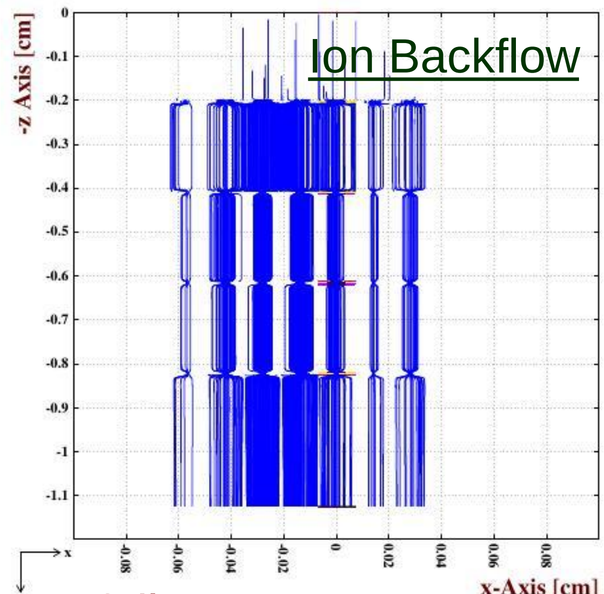
Electron Transmission, Avalanche and Ion Backflow

Individual efficiencies of GEM foils:

GEM I		GEM II		GEM III		GEM IV	
ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}	ε_{coll}	ε_{extr}
99.03%	46.41%	61.36%	50.67%	48.28%	29.71%	97.07%	58.79%

✓ Only 1.2% primary electrons are able to reach anode



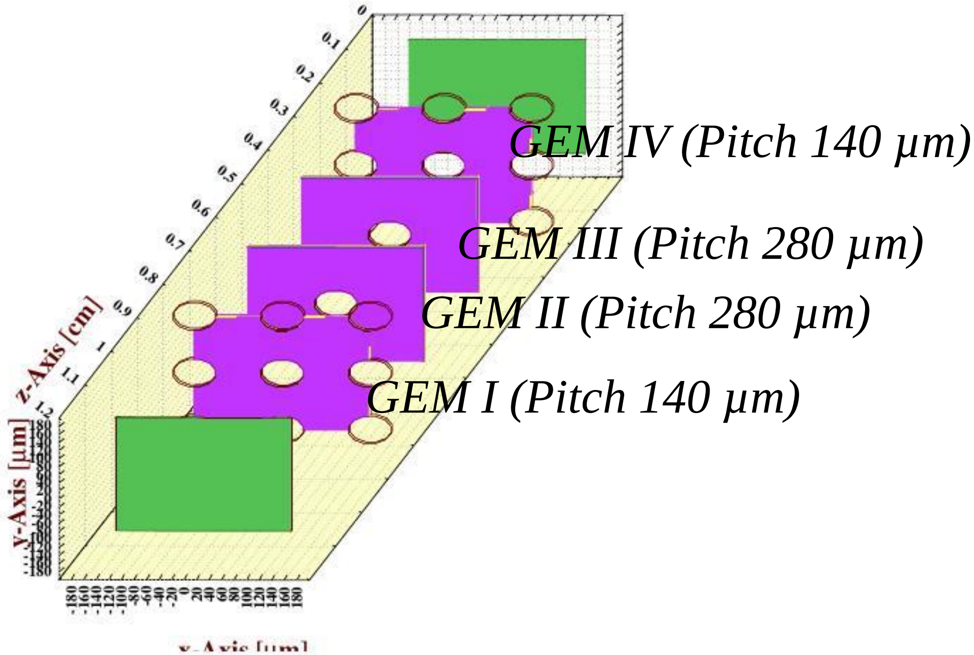


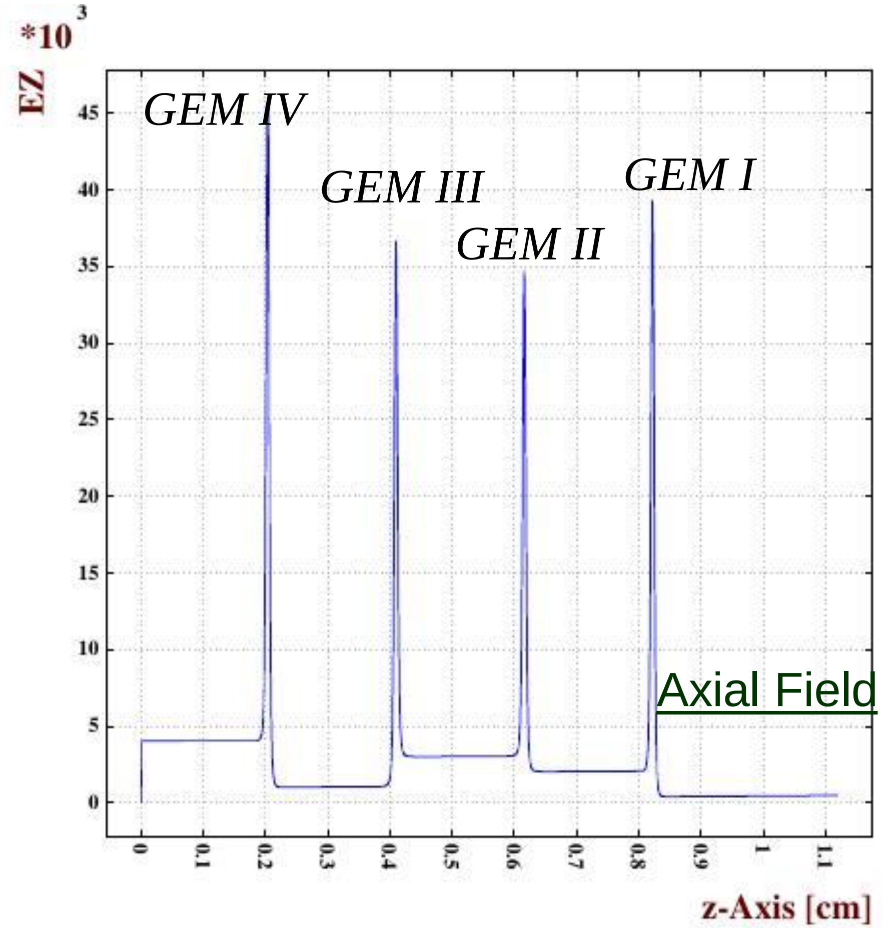
- Gain: ~3000 with 35% Penning transfer rate
- Most of the ions are collected on the 1st and 4th GEM foil
- Ion backflow Fraction: 11.73%

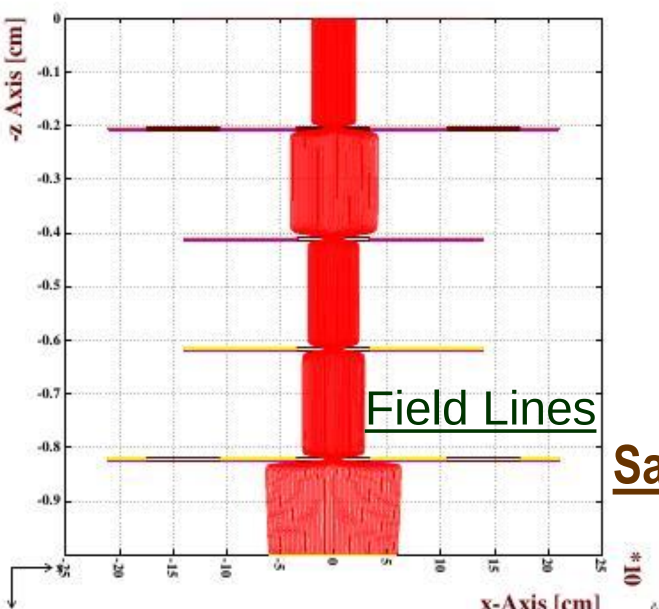
Collection of ions on individual GEM foils:

GEM I	GEM II	GEM III	GEM IV
34.27%	0.081%	0.517%	53.65%

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







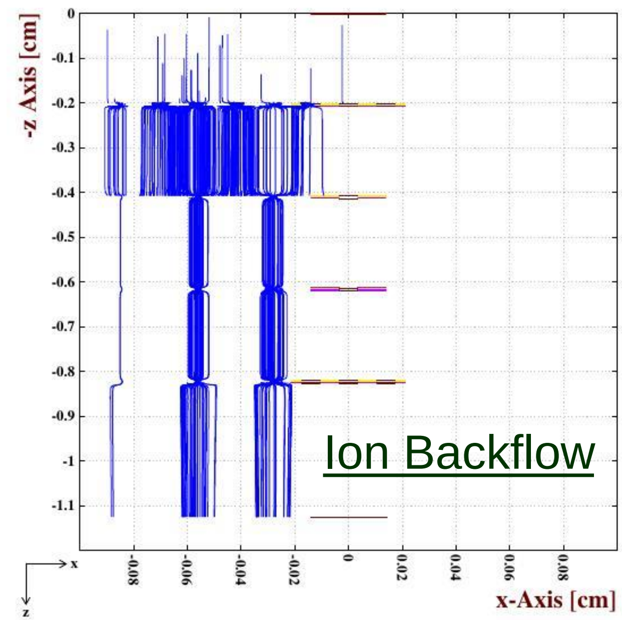
Same Voltage Configuration as S-S-S-S Configuration

Electron Transmission and Ion Backflow

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	99.18%	47.09%	16.91%	52.98%	14.59%	29.51%	100%	50%
B = 0.5T	99.05%	49.14%	16.15%	52.29%	13.87%	35.09%	95%	63.16%

- ✓ Only 9 (B = 0T) and 13 (B = 1 T) primary electrons out of 10000 are able to reach anode
- ✓ Most of the ions are collected on the 3rd and 4th GEM foils
- ✓ Ion backflow fraction: 1.69% (B = 0 T) and 1.51% (B = 0.5T)



Collection of ions on individual GEM foils:

Magnetic Field	GEM I	GEM II	GEM III	GEM IV
B = 0T	5.85%	0.154%	22.53%	70.20%
B = 0.5T	4.95%	0.24%	32.68%	63.53%

Quadruple GEM Detector (S-LP-LP-S)
(Same Geometry, Different Voltage Configuration)

Drift Field: 400 V/cm

V_{GEMI}: 270 V

Transfer Field I: 4000 V/cm

V_{GEMII}: 250 V

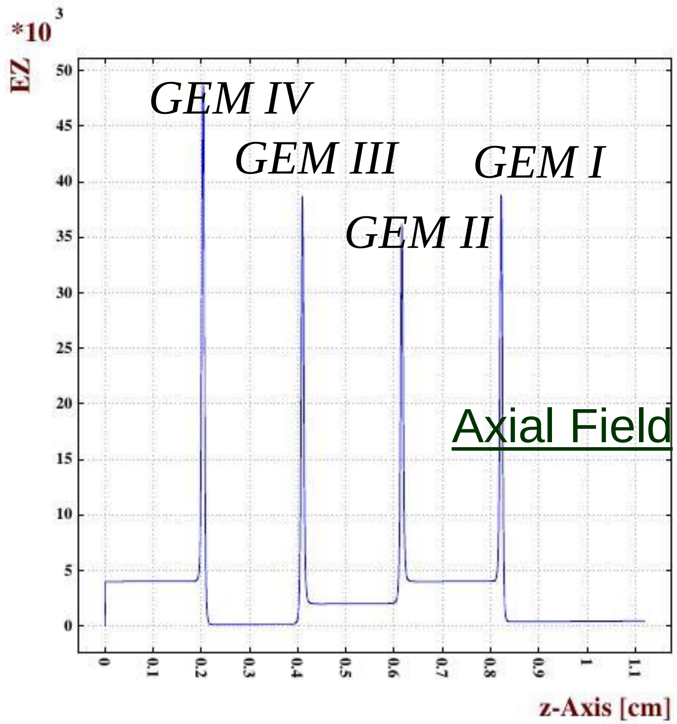
Transfer Field II: 2000 V/cm

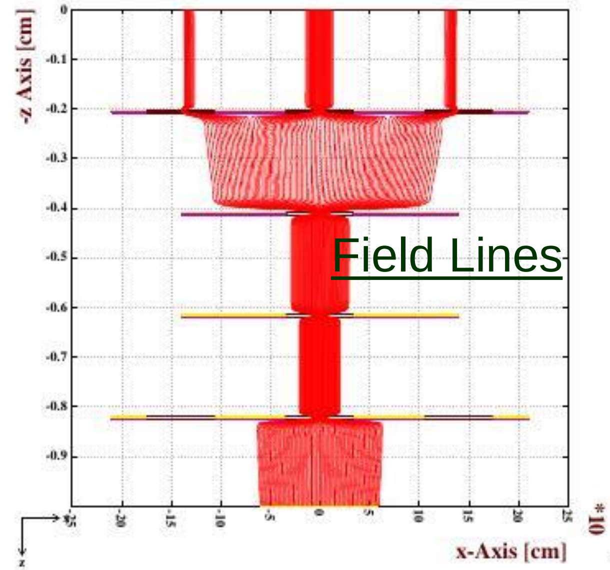
V_{GEMIII}: 270 V

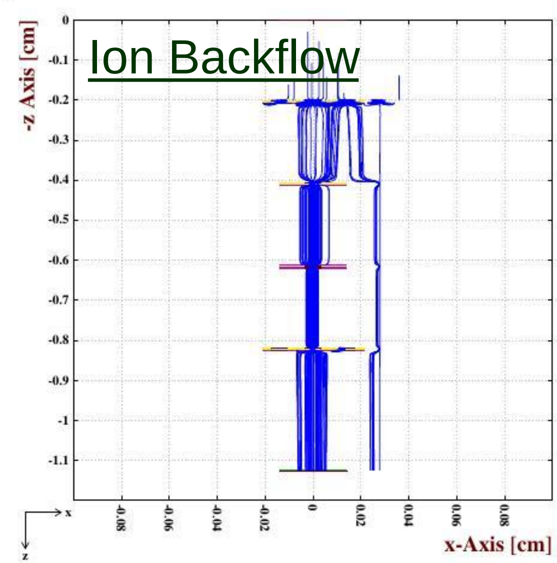
Transfer Field III: 100 V/cm

V_{GEMIV}: 340 V

Induction Field: 4000 kV/cm







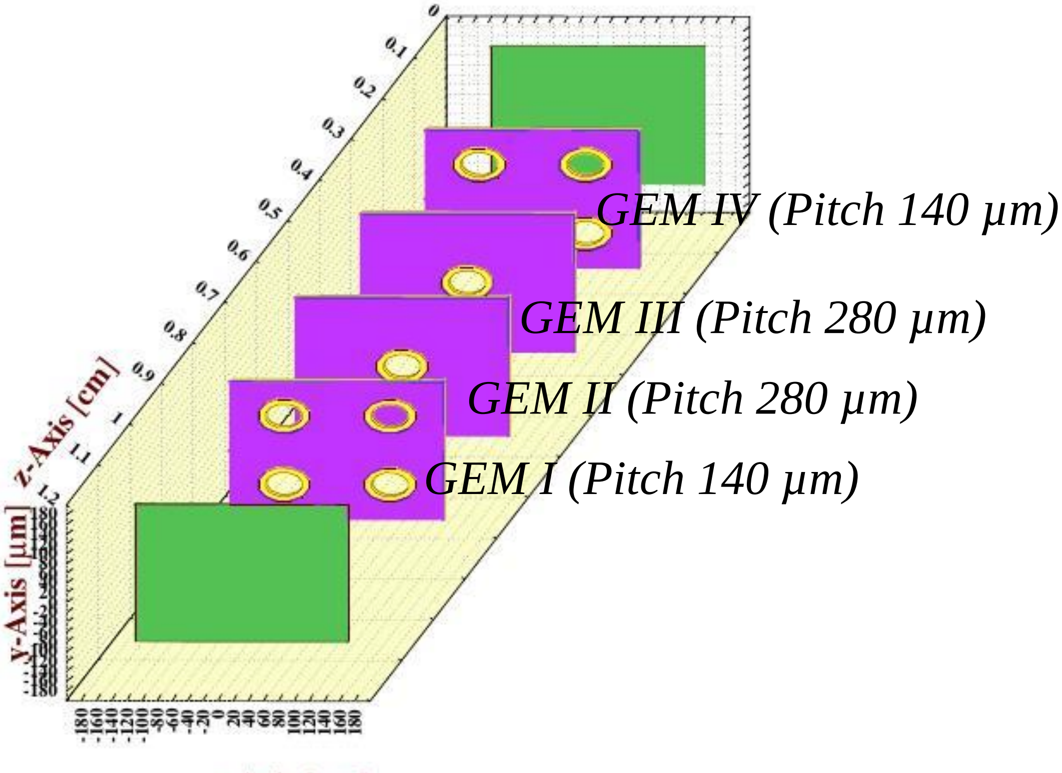
Collection of ions on individual GEM foils:

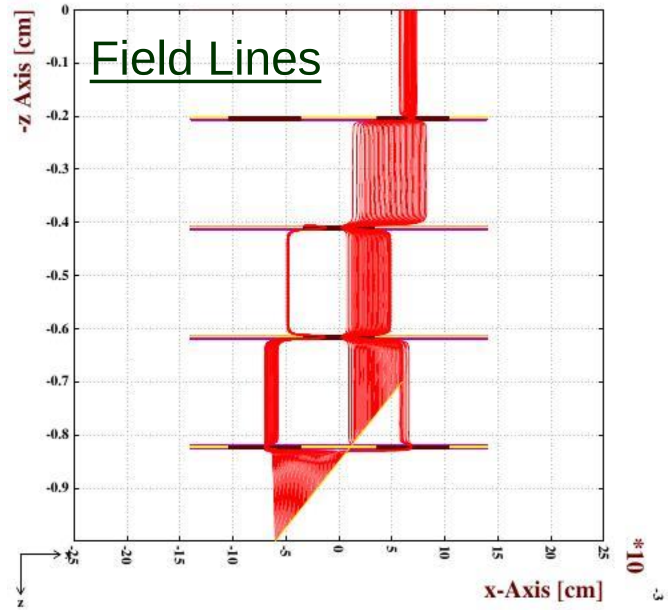
GEM I	GEM II	GEM III	GEM IV
0.1%	0.15%	0.75%	97%

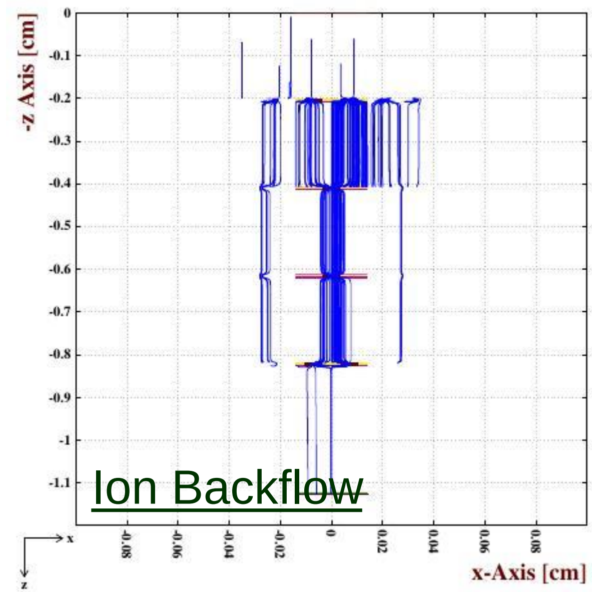
✓ Ion backflow fraction: 2% (B = 0 T)

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

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







- ✓ Only 6 primary electrons out of 10000 are able to reach anode
- ✓ Most of the ions are collected on the 1st (15.36%) , 3rd (25.65%) and 4th GEM (58.486%) foils
- ✓ Ion backflow fraction: 0.2% (B = 0T)

Summary:

- Numerical simulation for different GEM-based detectors has been carried out to estimate electron transmission and ion backflow.

- Study of single GEM detector has helped us to understand the complicated physics process in multi-GEM structure and to choose optimized field configuration, detector geometry etc. 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.

- Numerical simulation for a triple GEM detector (S-S-S) having gap configuration 3:2:2:2 has been performed. Loss of electrons on different GEM foils, also due to attachment have been observed; Only ~1% of primary electrons are able to reach anode. Backflow fraction ~ 5 %.

- Numerical simulation for a quadruple GEM detector having gap configuration 3:2:2:2:2 has been performed with different voltage configuration, geometry configuration has been performed in presence and absence of magnetic field. Electron transmission affected significantly. Backflow fraction ~ 1 %. It can be made better with a proper optimization of aforesaid parameters.

Future Plan:

1. Statistics of each run will be increased.

2. Electron transmission including multiplication process will be calculated.

3. Energy resolution will be estimated.

4. Effect of different gas mixtures will be carried out.

5. Space charge effect will be considered.

6. The behaviour of electron and ion transmission on detector edge will be also simulated

7. In addition to the further improvement in the numerical work, at SINP and NISER development of a setup for measuring the backflow fraction has been planned.

Acknowledgement:

Rob Veenhof, RD51 Collaboration

ALICE TPC Collaboration

Satyajit Saha

Saha Institute of Nuclear Physics, National Institute of Science, Education and Research

THANK YOU ALL !!

Computation

Efficiency of neBEM-GARFIELD improved with implementation of
‘

- Fast Volume Algorithm
- Reduced Order Modelling
- OMP Threading

Field calculation	RKF-Drift	Microscopic-drift	MC-avalanche (for higher gain)
1 week	15 minutes	1 day (10,000 statistics)	1-2 days (100 statistics)

- Resource used is one DELL Precision T7500 Workstation, 6 threads