# Characteristic simulations of stack of four Gas Electron Multipliers (GEMs)

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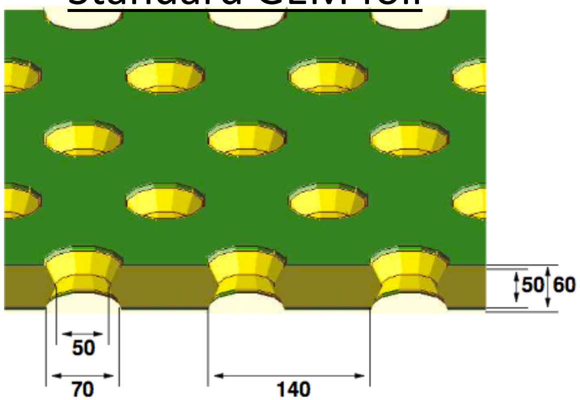
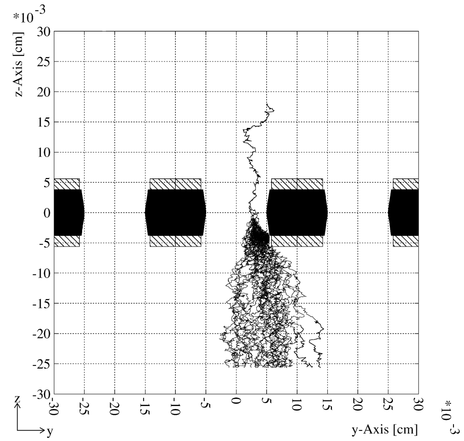
# Outline

- GEM detector and their application
- Garfield++ Simulations
- TUNING DETECTOR
  - Fixing gain and tuning various fields
  - Gains, Transparency, and Ion backflow
- DETECTOR CHARACTERIZATION
  - Induced signals and time resolution
  - Position and energy resolutions

# GEM

## Standard GEM foil



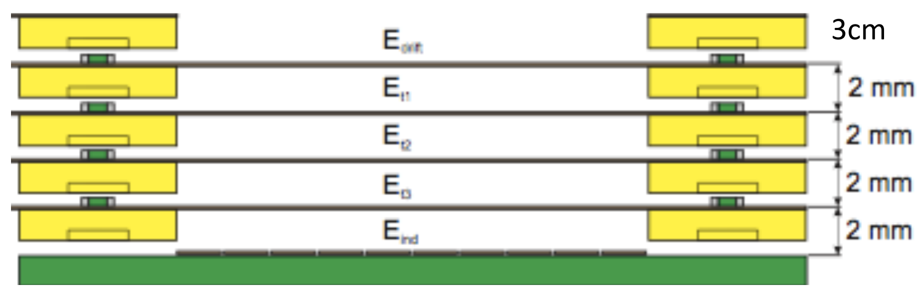




## GEM in large scale experiments

- STAR forward tracking
- ALICE TPC readout
- CBM muon tracker

- Main objective: Retain physics performance in high rate operation
  - continuous read-out of Pb-Pb events at 50 kHz collision rate
- Operation of MWPC without gating grid would lead to massive space-charge distortions due to back-drifting ions
- Instead: Continuous read-out with micro- pattern gaseous detectors
- Advantages:
  - reduced ion backflow (IBF)
  - high rate capability
  - no long ion tail

## Standard pitch four layer GEM in IOP Lab




IOP Looking for :

- GEM behavior with gas flow rate
- Long term stability

# Simulation Framework

## Garfield++

Magboltz : transport properties of electrons in gas mixtures
Heed : ionization pattern produced along the track

webpage http://cern.ch/garfieldpp

Advantage : ROOT framework

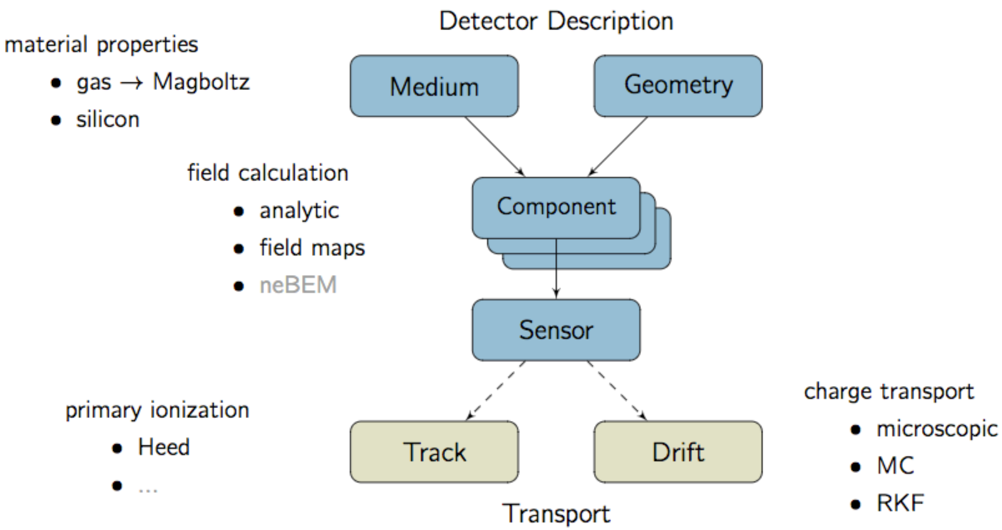


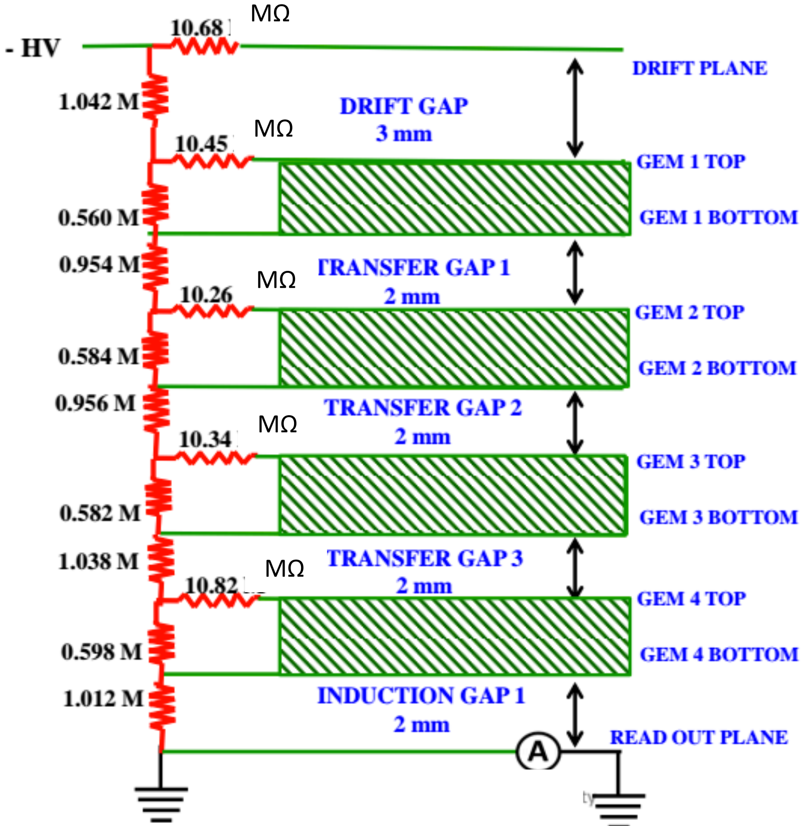

**Figure 1.1.** Overview of the main classes in Garfield++ and their interplay.

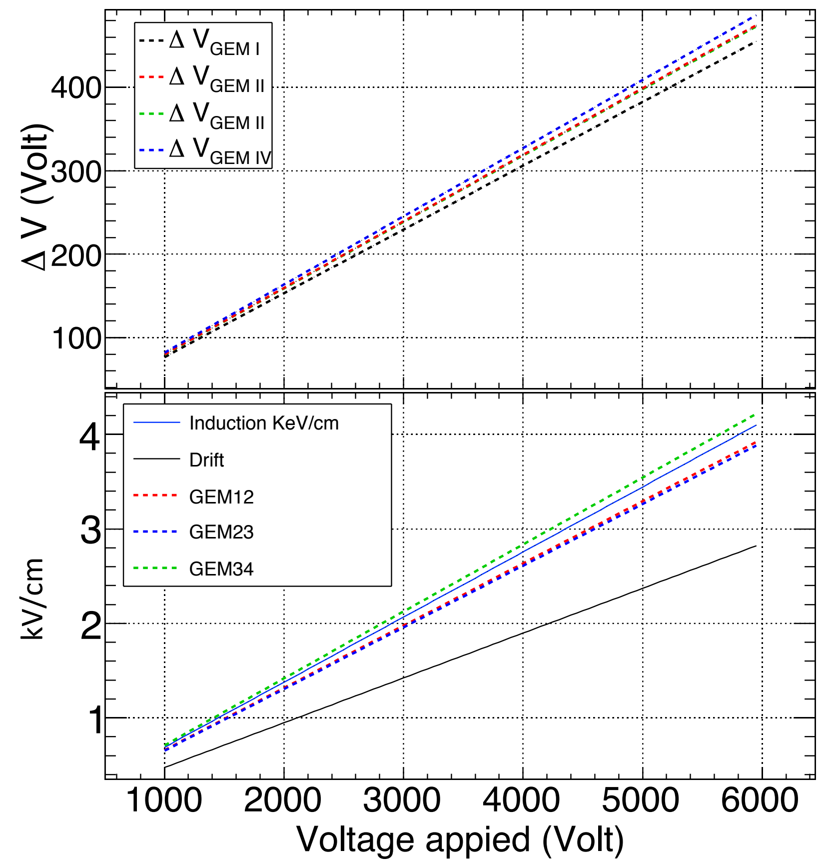
ANSYS code : external field solver

Defining : geometry, boundary conditions, initial meshing
--> Produce field maps

loading the mesh (ELIST.lis, NLIST.lis), the list of nodal solutions (PRNSOL.lis), and the material properties (MPLIST.lis);

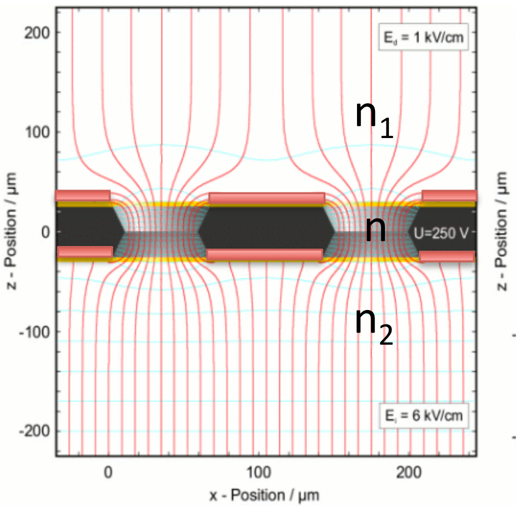
# For 4-GEM fabricated in IOP-lab



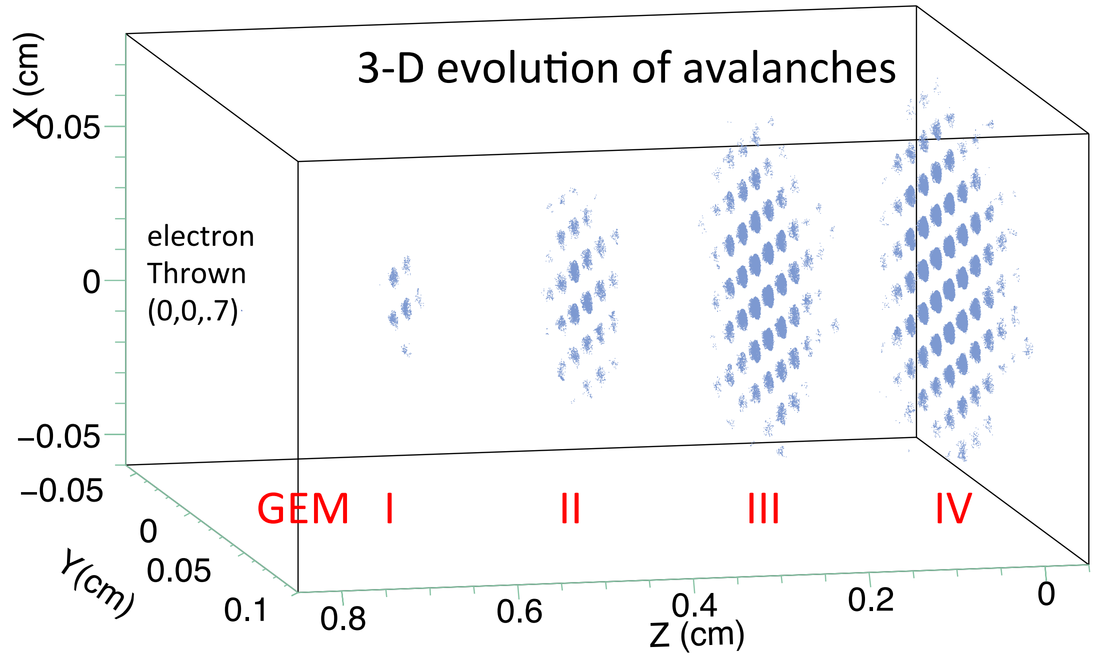




- Simulation study for the detector
- Tuning fields for proper operation region

# Simulations in Garfield++




5 micron
50micron
5micron



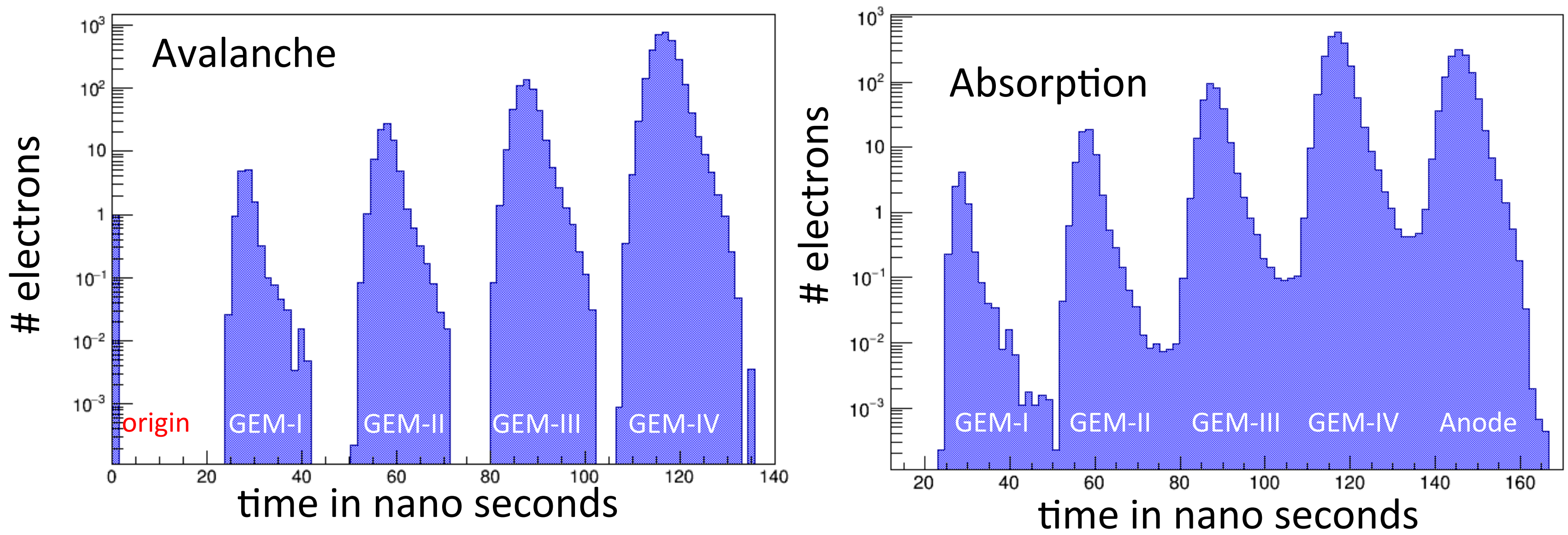

**Intrinsic gain** = $n/n_1$
**Effective gain** = $n_2/n_1$

**Transparency** = fraction of $n_1$ entering in avalanche zone
**Ion Backflow** = fraction of ions in entering the drift region
Energy/Position **Resolution**
**Induced signal** shapes

Avalanche of electrons in GEM Holes
-- single electron thrown at (0,0.0.7)
-- 4 Layers
-- Ar:$CO_2$ = 70:30

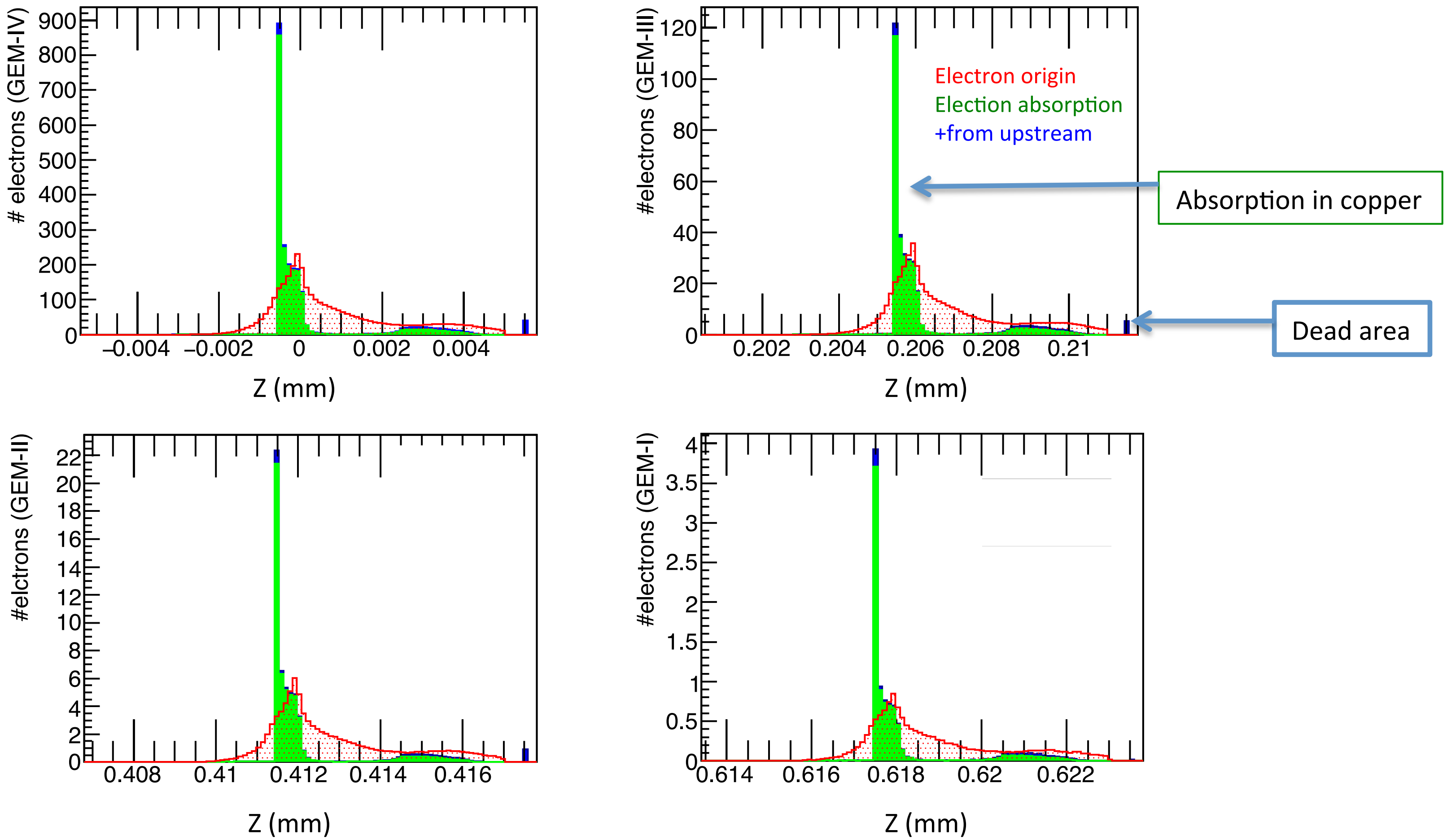
# Avalanche And Absorption in GEM

**with time**



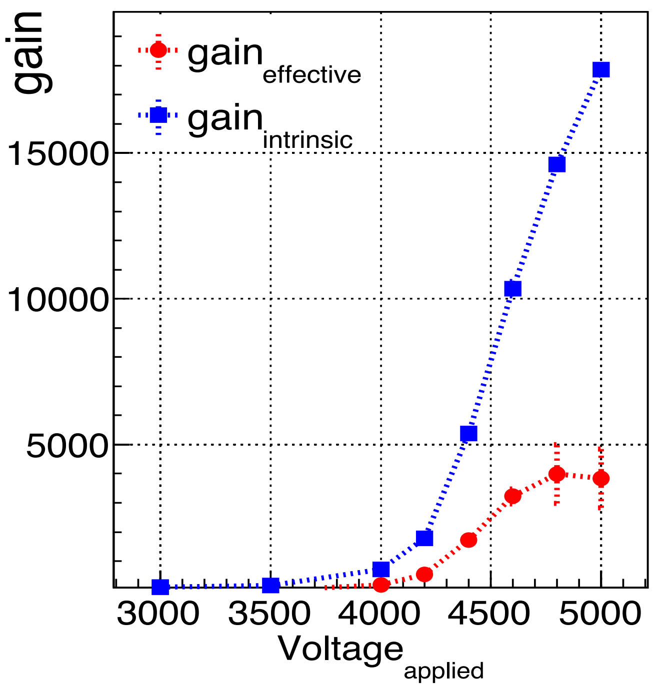

For a particular gas mixture the absorption much depend on field configuration

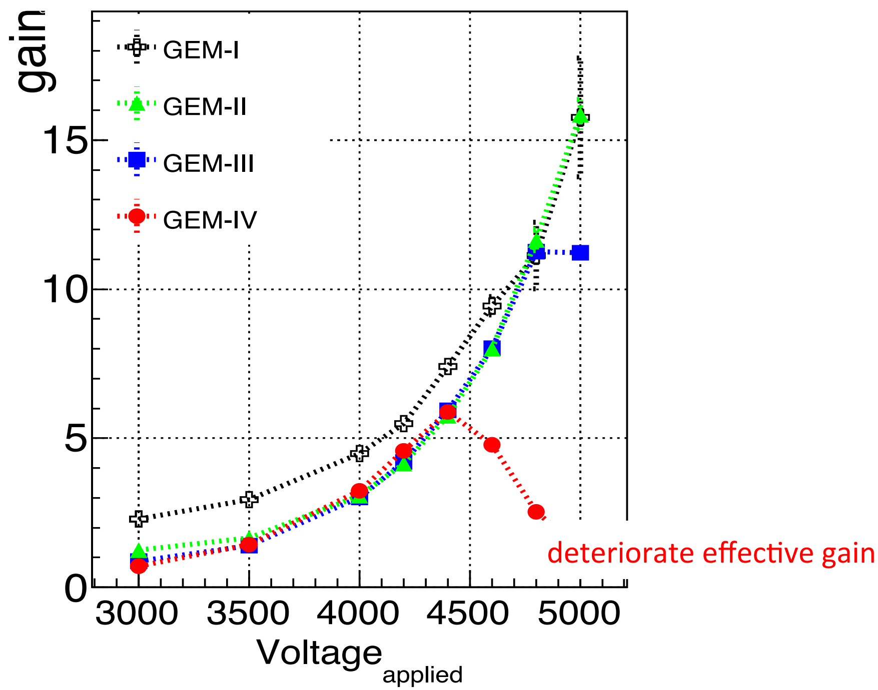
# with z position




- All four layers behaves similar way
- Avalanche grows up with increasing gem layers

# Gains for Detector




| Voltge applied | $\Delta V_{GEM\ I}$ | $\Delta V_{GEM\ II}$ | $\Delta V_{GEM\ III}$ | $\Delta V_{GEM\ iV}$ |
|---|---|---|---|---|
| 3000 | 229 | 239 | 238 | 245 |
| 3500 | 267 | 279 | 278 | 286 |
| 4000 | 306 | 319 | 318 | 327 |
| 4200 | 321 | 334 | 333 | 343 |
| 4400 | 336 | 350 | 349 | 359 |
| 4600 | 351 | 366 | 365 | 376 |
| 4800 | 367 | 382 | 381 | 392 |
| 5000 | 382 | 398 | 397 | 408 |

**Filed**

**Drift = 2.08 kV/cm**

**$Tranfer_{12}$ = 2.90 kV/cm** **gains ~1800**

**$Tranfer_{12}$ = 2.87 kV/cm**

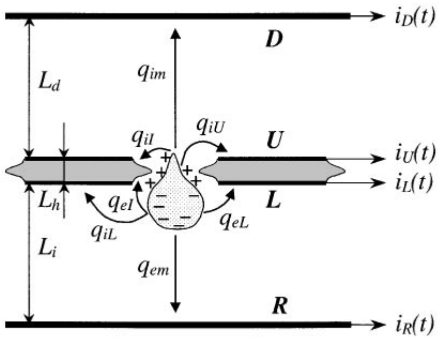
**$Tranfer_{12}$ = 3.12 kV/cm**

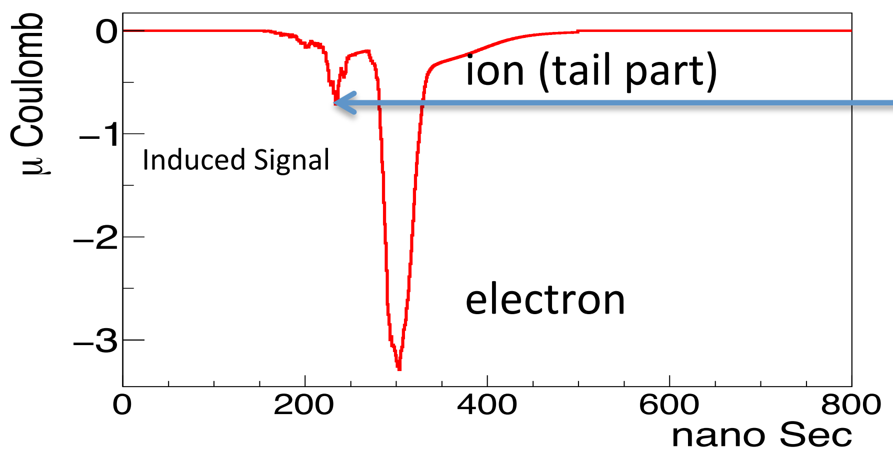
**Induction = 3.03 kV/cm**

We would play with fields :
Induction, Drift and Transfer fields at effective gains~1800

# Field Adjustment

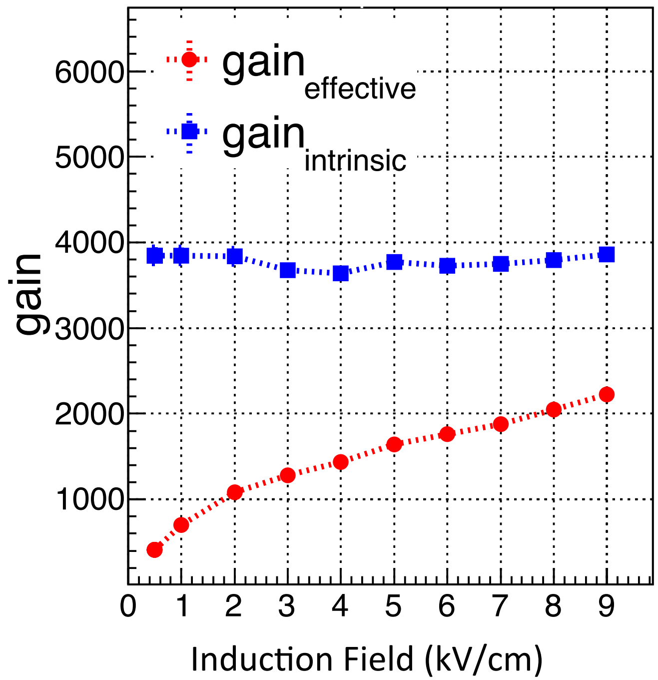
- Induction field : high→ more transport to electrons at anode
- Transfer fields timing : gains, ion backflow and resolutions of the detector

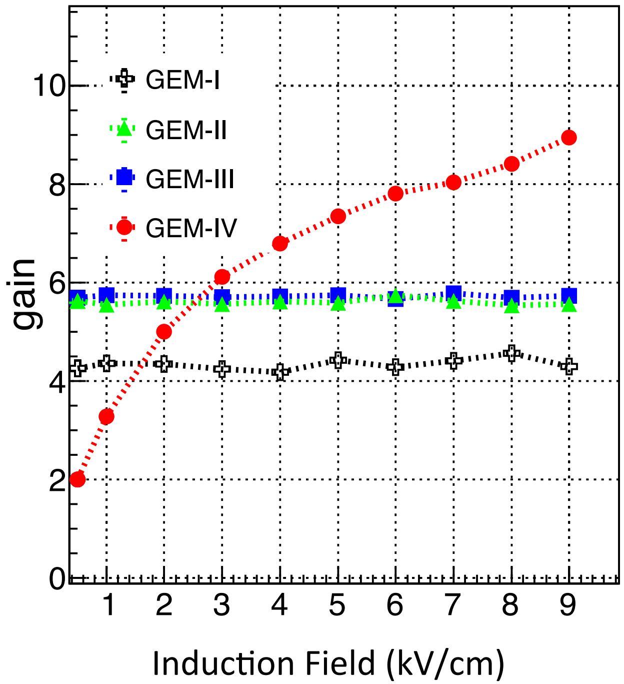



Not desirable

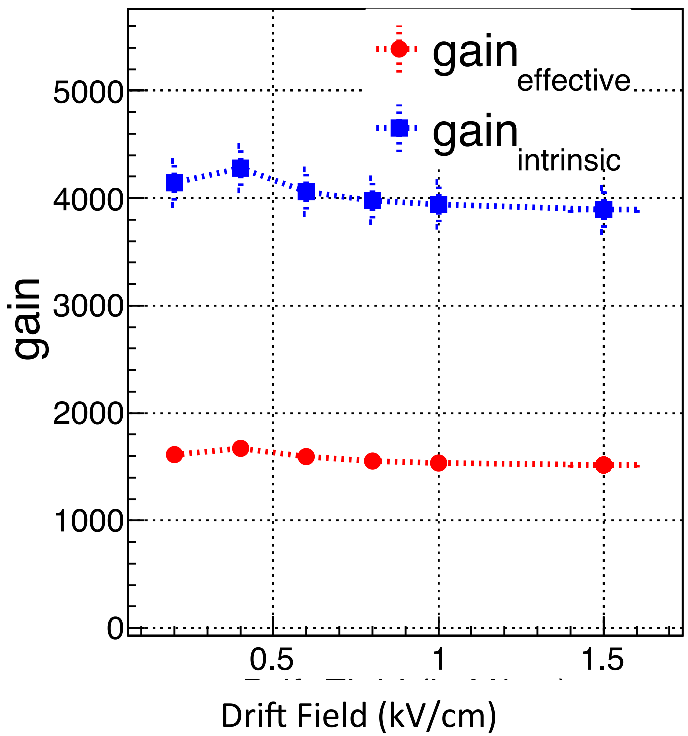
# Induction filed

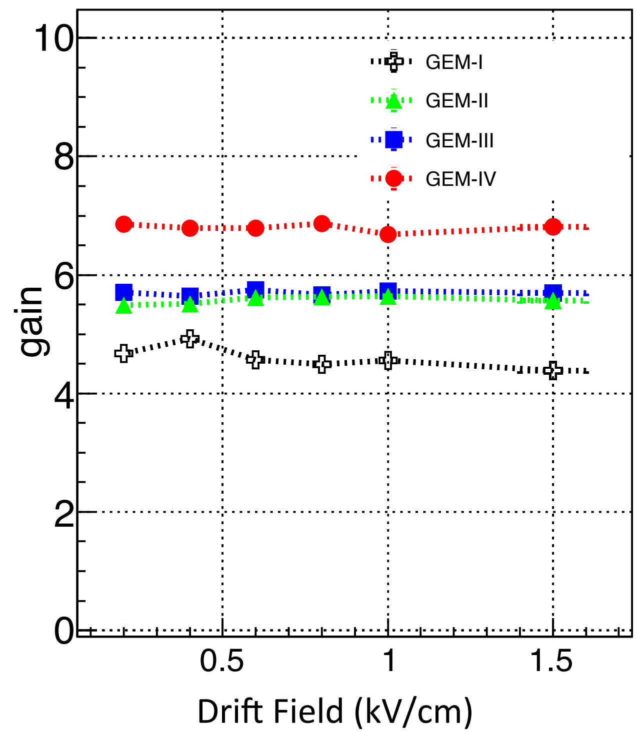



Induction field set to 4kV/cm

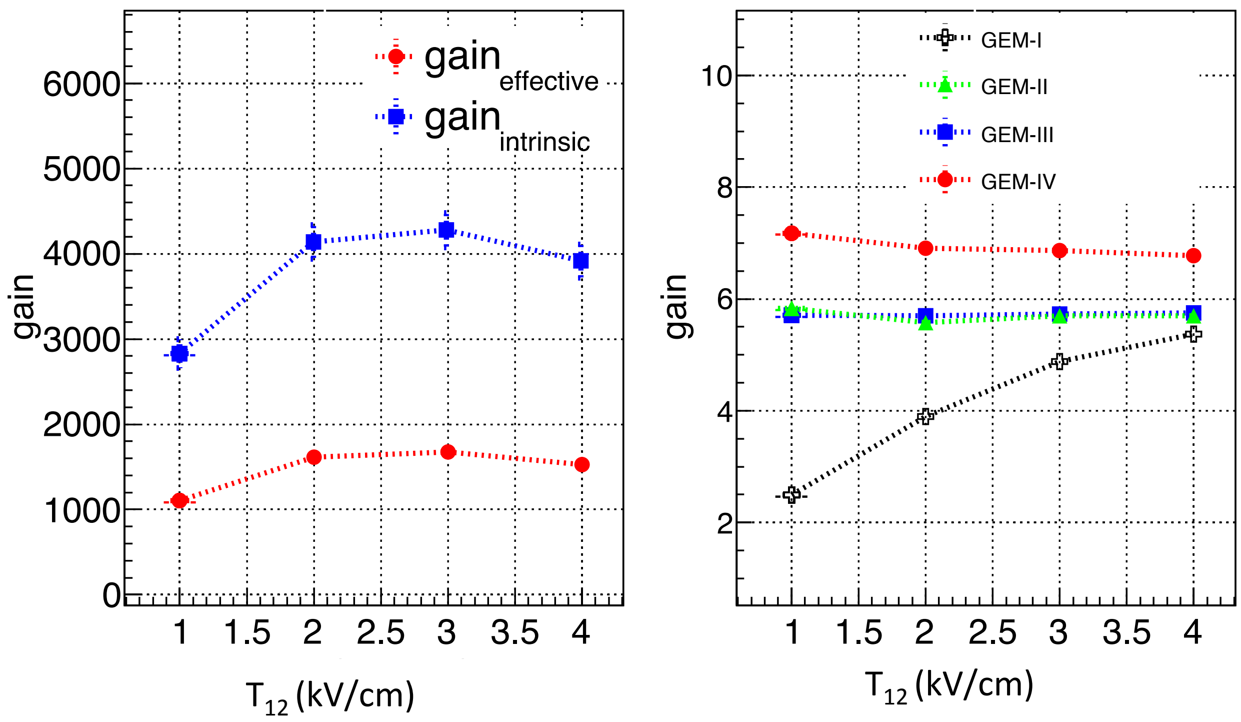
# Drift filed



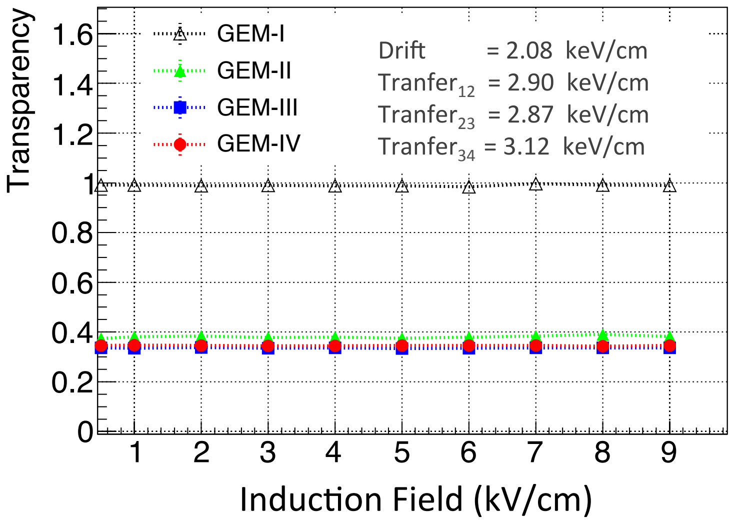

Drift field set to 0.4kV/cm

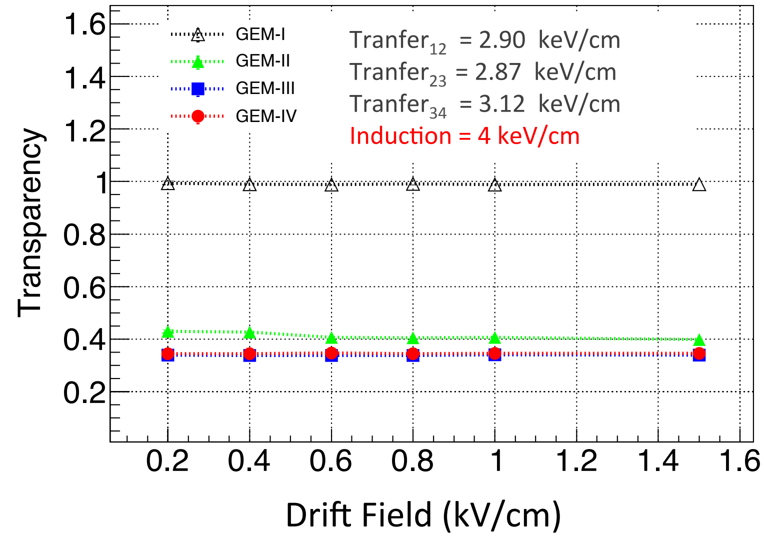
# Transfer Filed

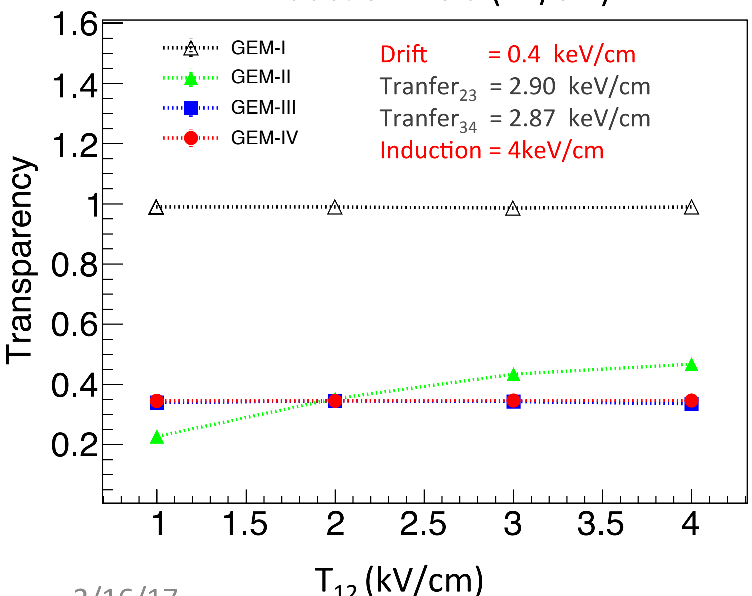



Transfer field set to 4.0kV/cm

# Transparency



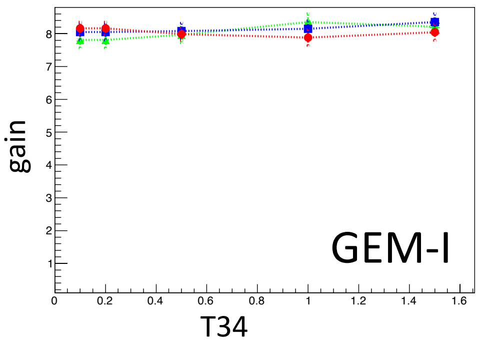



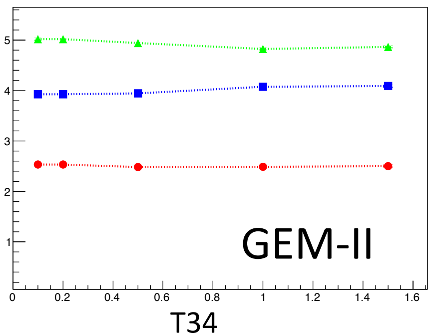

- Transparency for GEM-I ~1 since electron with a momentum in z-direction left over a hole
- Drift filed is set usually to a low value = 0.4

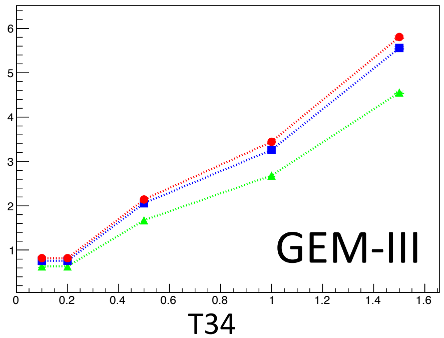
The value set relatively high transparency

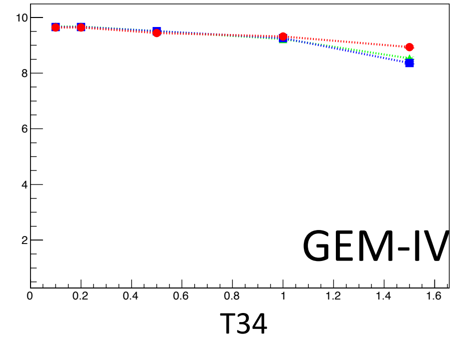
Drift = 0.4 kV/cm
Tranfer$_{12}$ = 4.0 kV/cm
Tranfer$_{23}$ = 2.90 kV/cm
Tranfer$_{34}$ = 2.87 kV/cm
Induction = 4 kV/cm

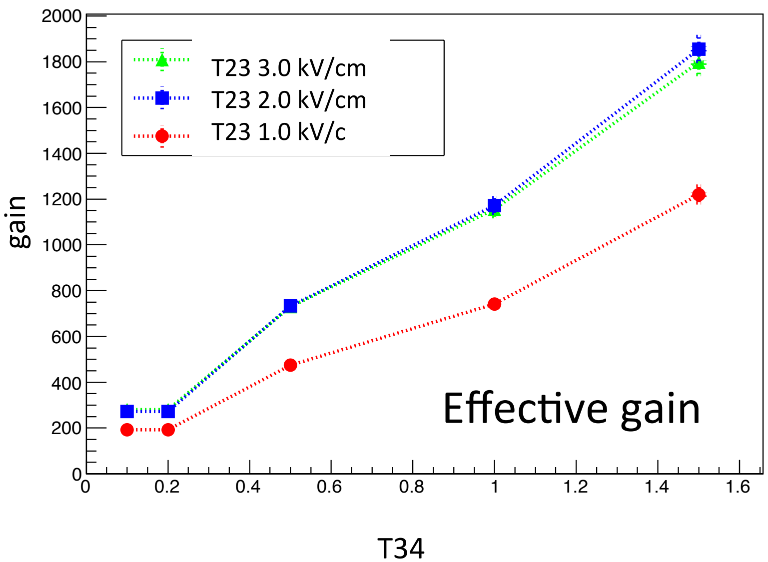
# Gains with T23 and t34



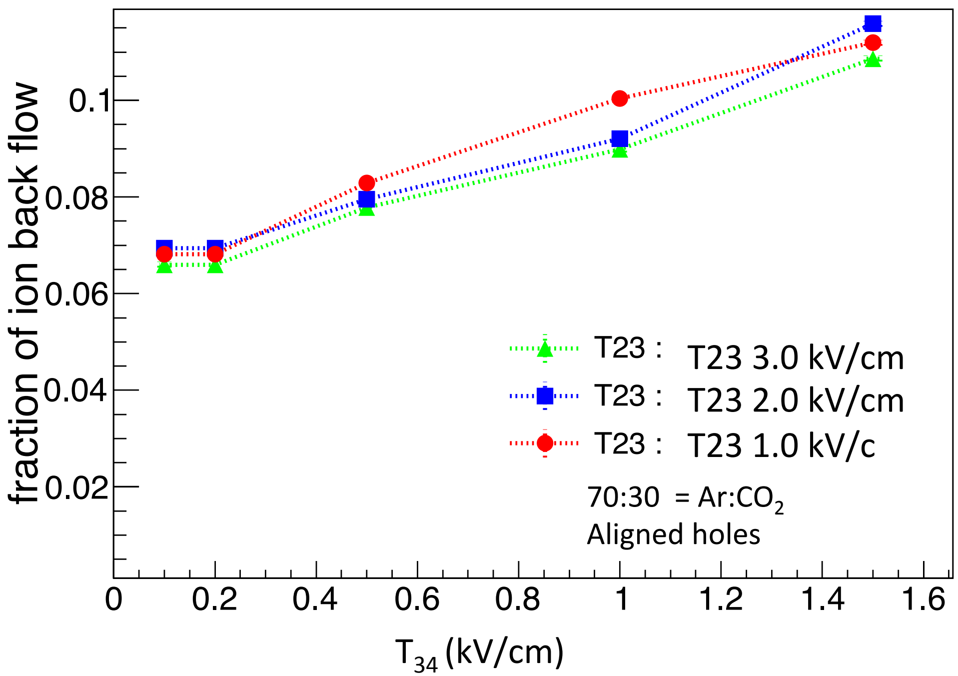




- One need to choose T34 (1-1.5 kV ) for higher gain

  BUT – we need to consider ion backflow

# Ion Backflow

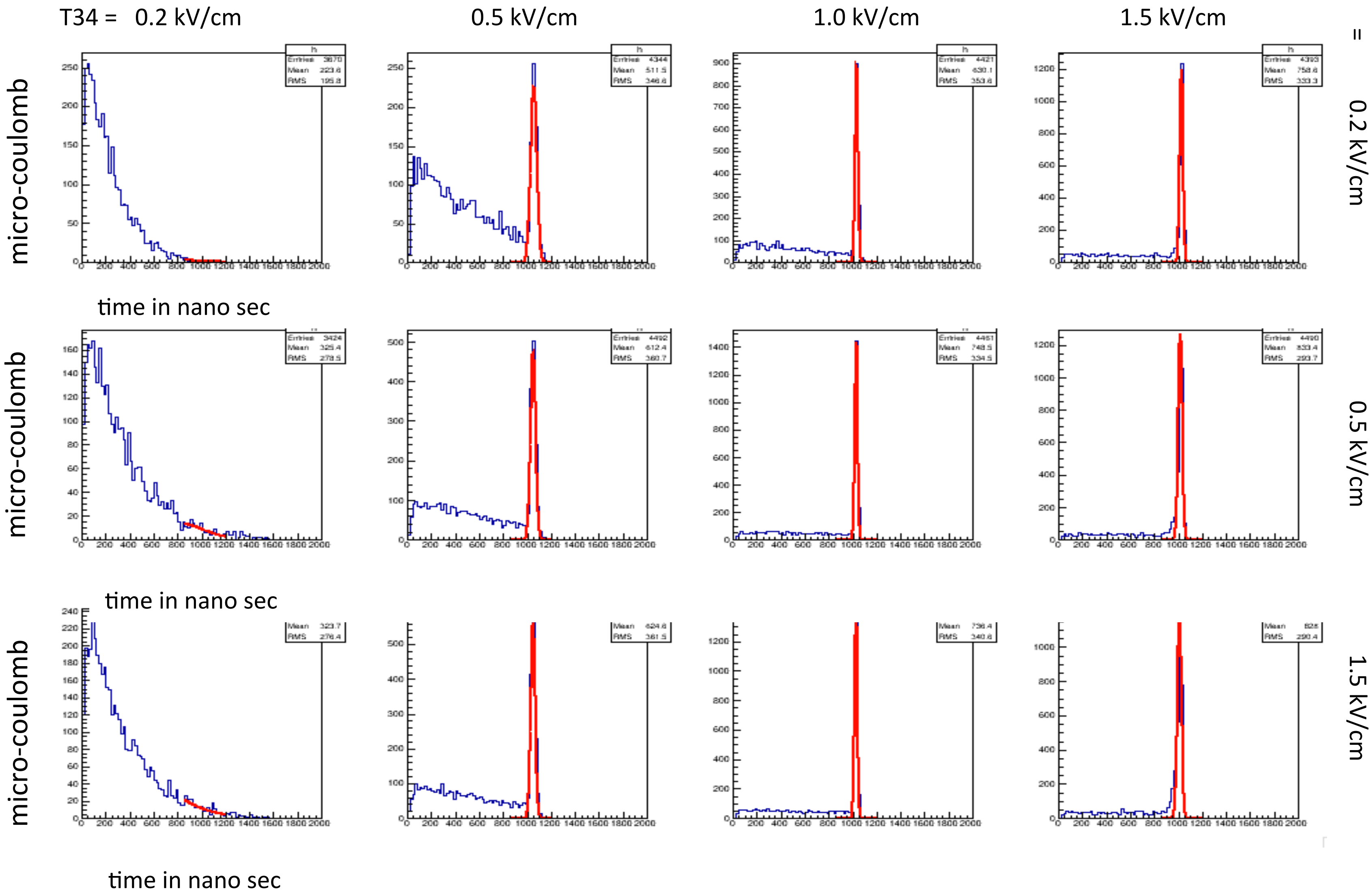



- Lower T34 significantly reduces ion backflow
- It is far above the acquired ion backflow (e.g in ALICE)

Our geometry SmP-SmP-SmP-SmP aligned hole geometry
- Large Pitch in between and misalignment can reduce ion backflow in great extent

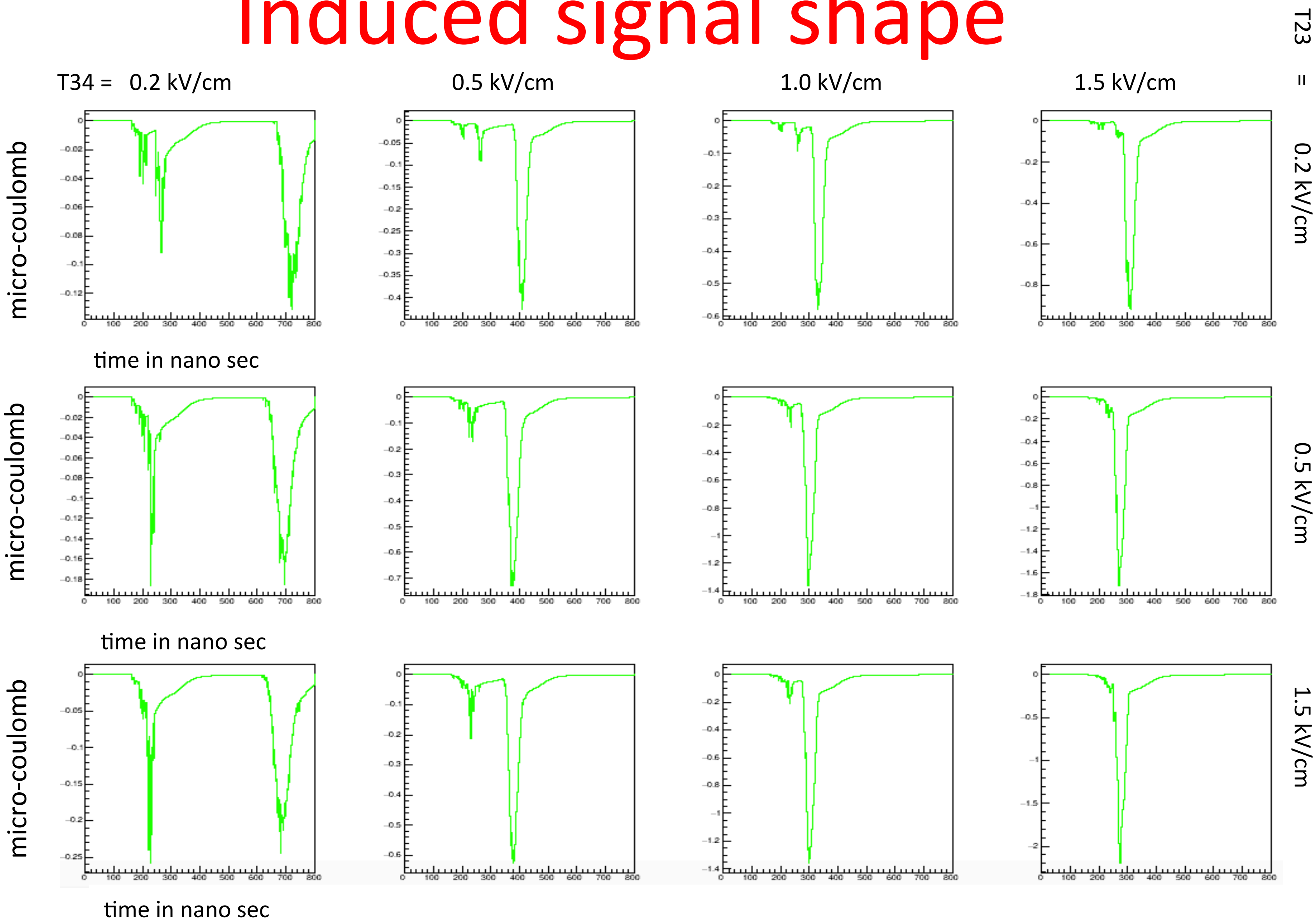
- Working on various geometry and misalignments

# Gain peaks

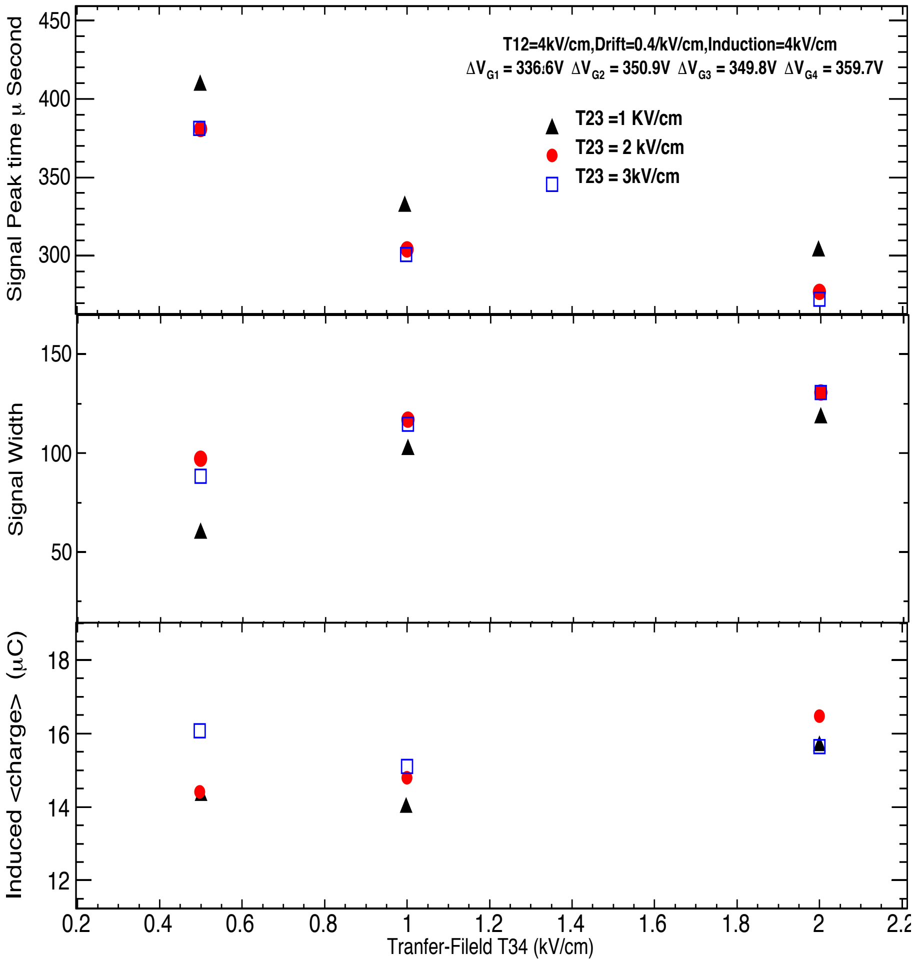


T34 = 0.2 kV/cm
0.5 kV/cm
1.0 kV/cm
1.5 kV/cm
T23 =
0.2 kV/cm
0.5 kV/cm
1.5 kV/cm
micro-coulomb
micro-coulomb
micro-coulomb
time in nano sec
time in nano sec
time in nano sec

# Induced signal shape



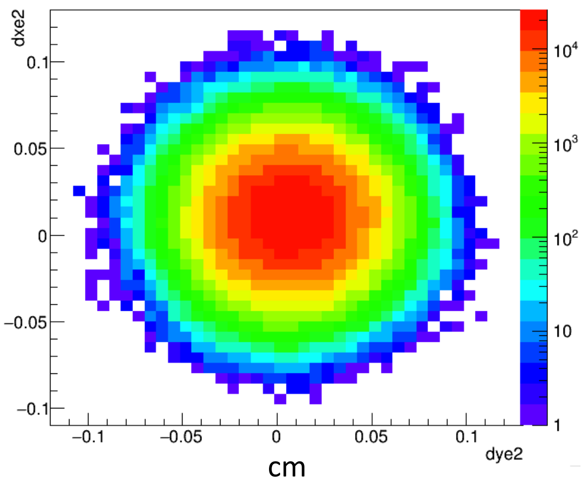
# Induced Signal timing and width

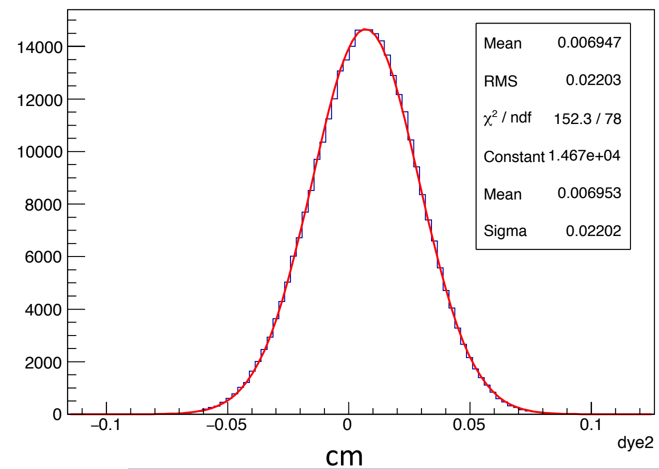


# Resolution

Position

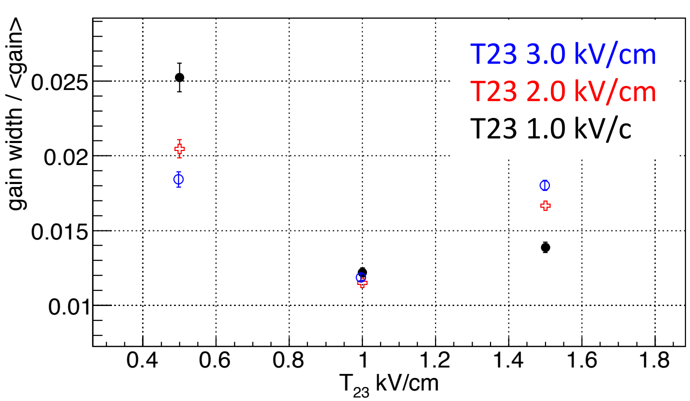
mm




Signal spread 200 micron width

Energy




Seems to be narrow

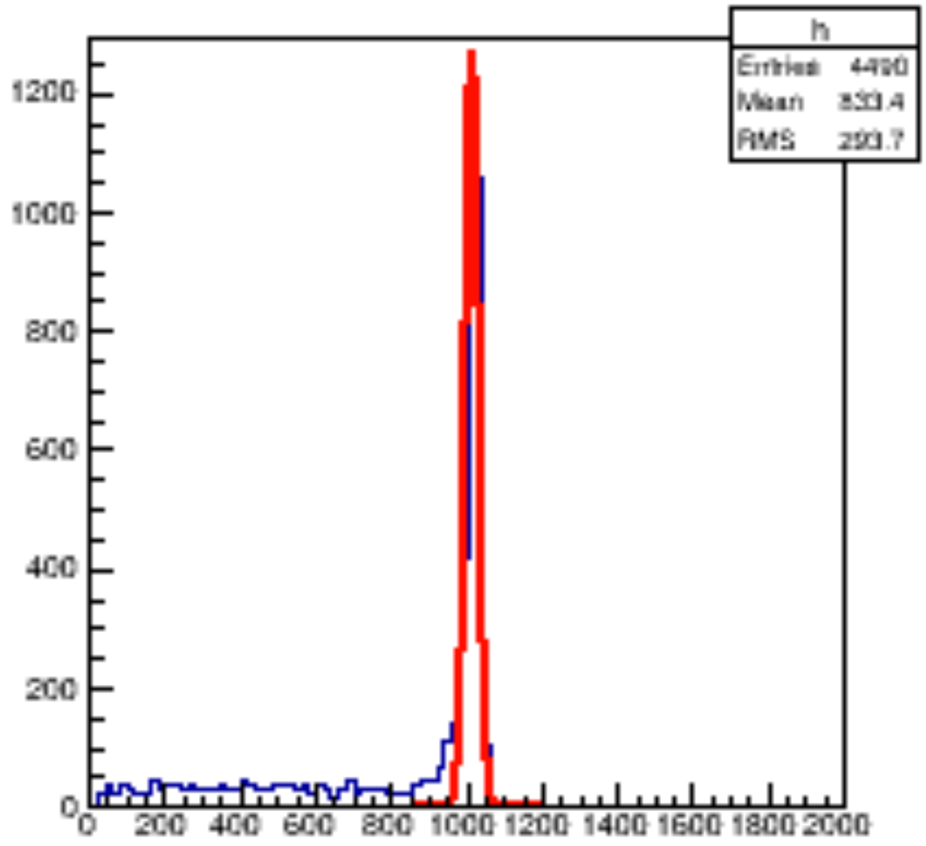
- It is single electron multiplication width
- Probably need induced signal analysis

# Summary

- GEM simulation in Garfield++ with ANSYS based field calculations is being performed.
- 4-GEM stacks is being tuned and a field configuration is set to work in a preferred gain region
- Ion backflow is in the level of 6-10% and we need misalignment and pitch variation in alternative layers to reduce the value
- Width of the signal at anode plane is about 200 micron and gain width is coming in the range of 1%-2.5%
- Need to work more on induced signals

# Backups

# Energy peak


h
Entries 4490
Mean 833.4
RMS 293.7
1200
1000
800
600
400
200
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000

*Nuclear Instruments and Methods in Physics Research A 450 (2000) 277–287*

The induced current in a readout element :

$$i = q_{\mathrm{em}} \nabla V_{\mathrm{w}}^{\mathrm{R}} \cdot \boldsymbol{v}_e$$

*weighting field* [2] of the readout electrode $V_{\mathrm{w}}^{\mathrm{R}}$ with unit potential applied

$\boldsymbol{v}_{\mathrm{e}}$ is the charge drift

For a 1 mm gap a full signal width will be about 20 ns for the drift velocity of "5cm/ micro s.

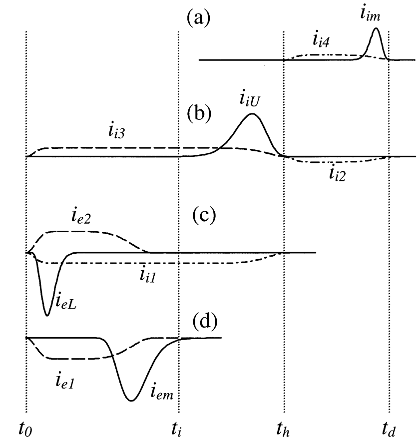



Fig. 12. Current and charge induction mechanisms on GEM electrodes: (a) drift, (b) upper GEM, (c) lower GEM, (d) readout. Note: (a) and (b) are not to the scale.

Weighting fields and induced currents

Finite Element Field Maps

which contains the nodal solutions for the weighting field configuration

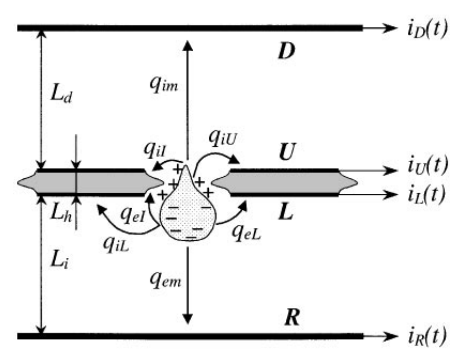
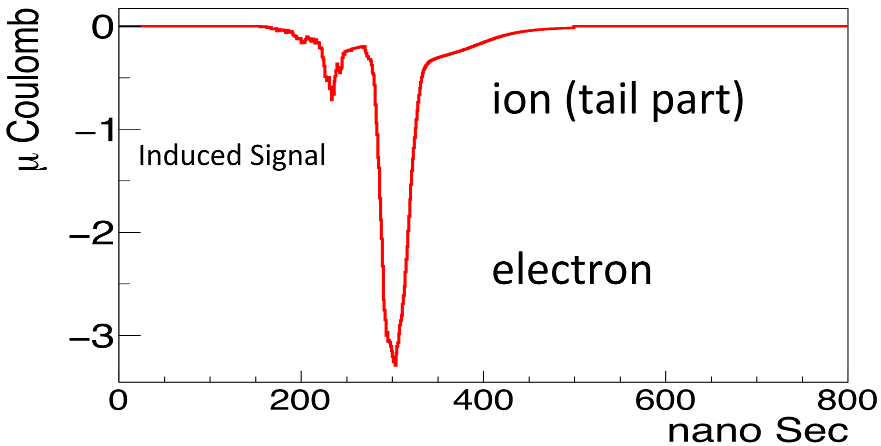
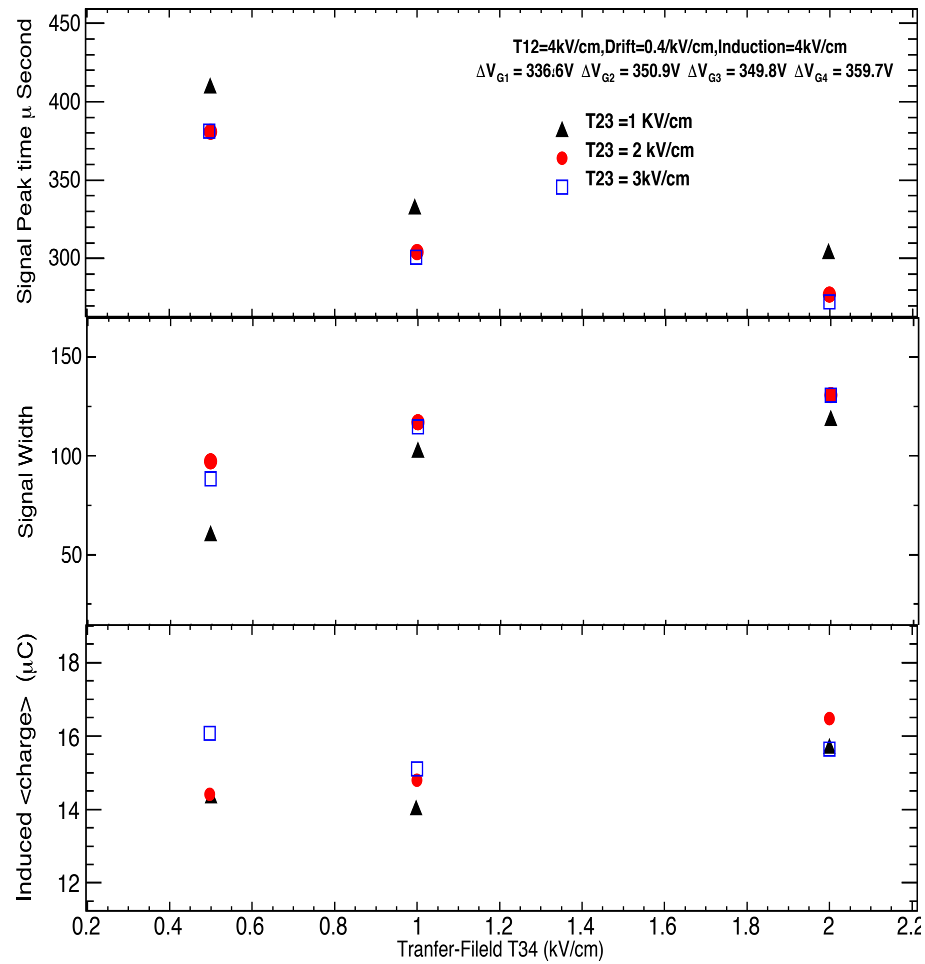



Fig. 13. Current components and their measurements.

# Induced signals from 4-GEM




A typical signal and induced signal properties in preferable working region of the detector

- **From electron collection and ion Tracking calculating : Gains, transparency, resolutions and ion backflow, etc**

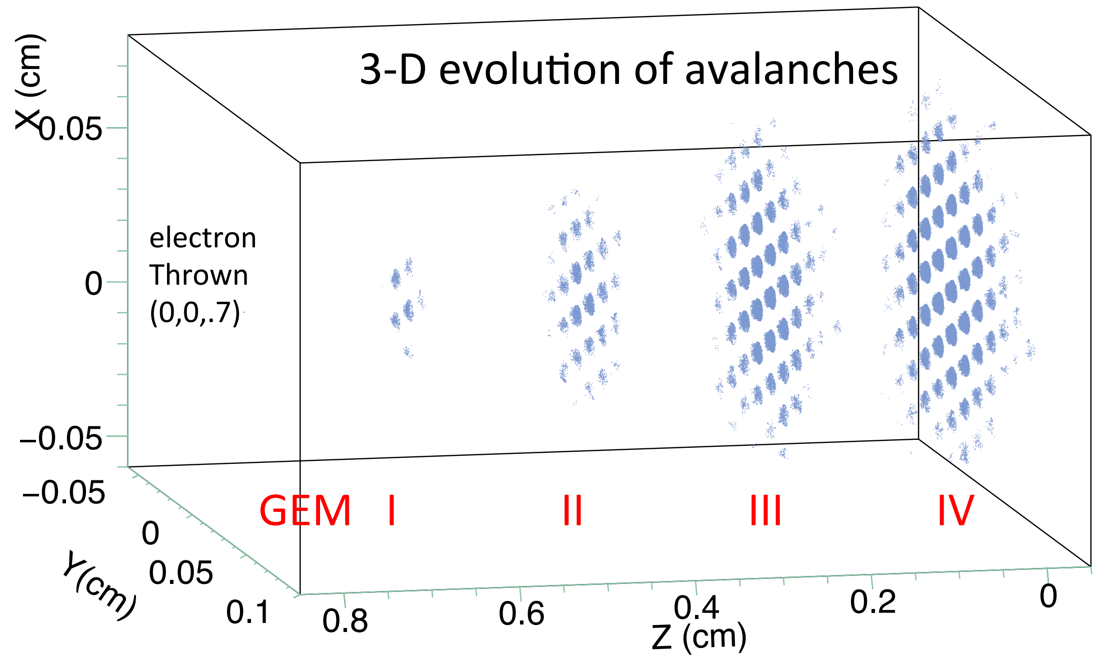
# GEM simulations with Garfield++

ANSYS code : external field solver

Defining : geometry, boundary conditions, initial meshing
--> Produce field maps

loading the mesh (ELIST.lis, NLIST.lis), the list of nodal solutions (PRNSOL.lis), and the material properties (MPLIST.lis);

**Tracking electrons in** Garfield++
**Using class :** ComponentAnsys123




Avalanche of electrons in GEM Holes
-- single electron thrown at (0,0.0.7)
-- 4 Layers
-- Ar:$CO_2$ = 70:30