Standard GEM Charging Up Simulation

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Simulated Setups

- Standard GEM:
  - Thickness 50 µm kapton + 5 µm copper (up & down)
  - Pitch 140 µm
  - Cu diametre: 70 µm; kapton diametre 50 µm
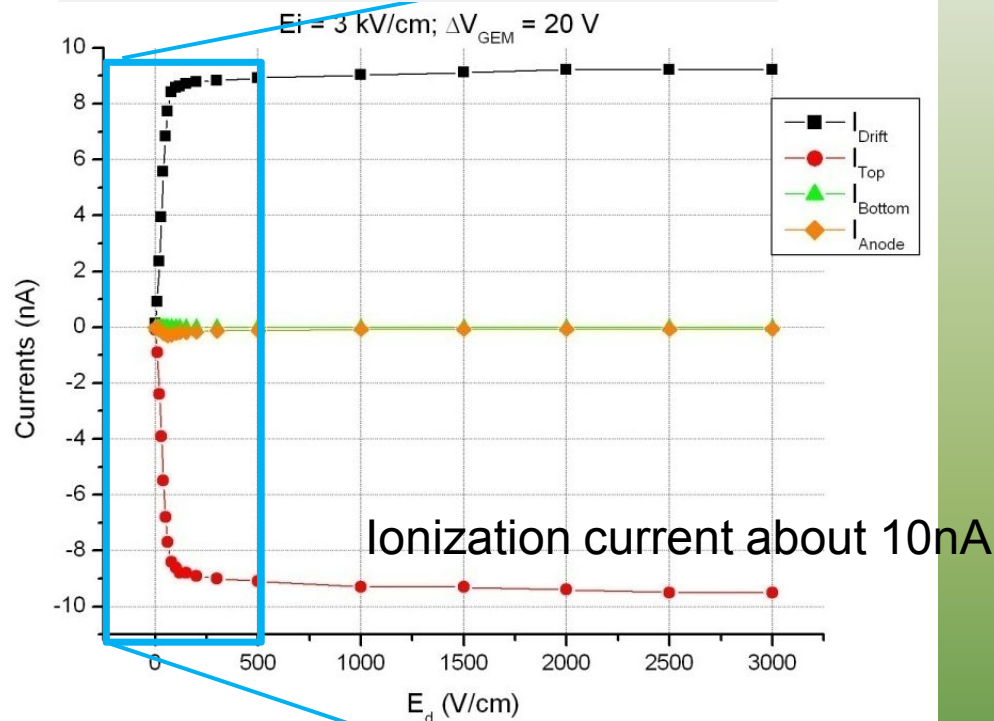
NO GAIN Setup

- Drift Field = 0.1 kV/cm
- GEM Potential Difference = 20 V (NO GAIN)
- Induction Field = 3 kV/cm

GAIN Setup

- Drift Field = 0.1 kV/cm
- GEM Potential Difference = 500 V (GAIN)
- Induction Field = 3 kV/cm

ΔV$_{GEM}$= 20 V: The measurements

Drift Scan (current vs drift field)

E$_i$ = 3 kV/cm; ΔV$_{GEM}$ = 20 V

Ionization current about 10nA

8.9 keV X-Rays collimated beam shot from the side to be sure to have conversion only in the drift gap

Drift Current

X-Rays ---->

Top GEM Current

Bottom GEM Current

Anode Current
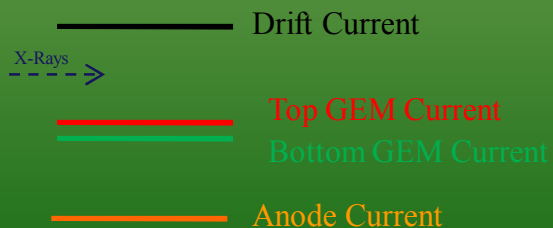
G. Croci et al: GEM Transparency Studies: electrons and ions measurements, 2nd RD51 Collaboration Meeting Paris 13-15 October
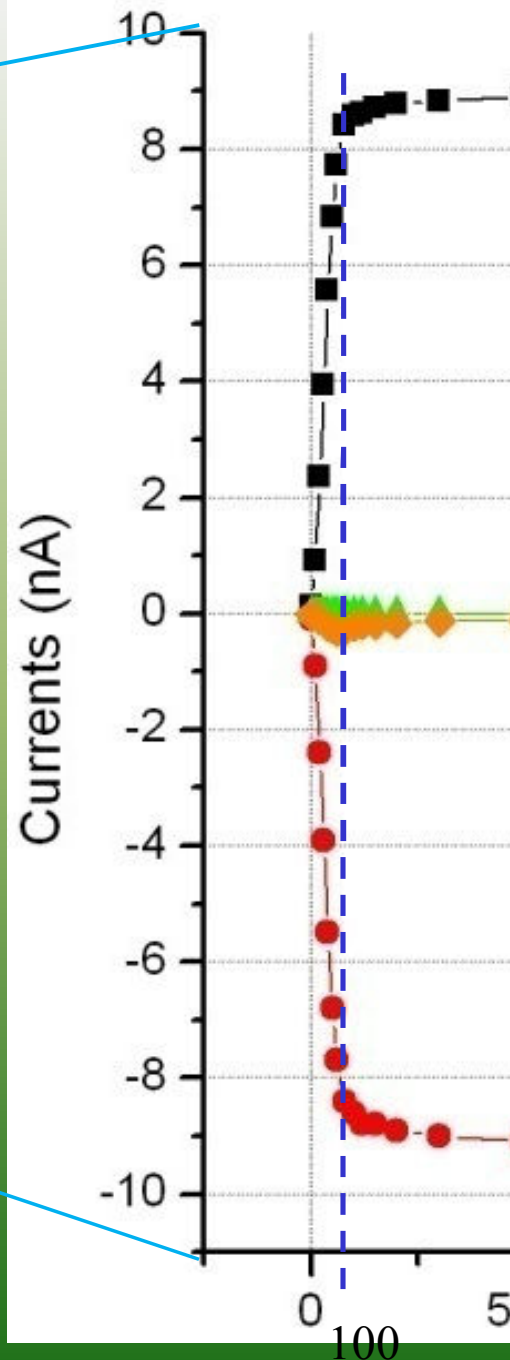
Simulation Method

a) Start with map **without** charges on kapton

b) Simulate **2000 electrons** starting 290 μm above the top copper and record their end position (x-end,y-end,z-end). Simulation uses new *microavalanche* procedure introduced last year by Rob Veenhof

c) Calculate the **number of electron** ending on Anode, Bottom Electrode, Bottom Half Kapton, Top Half Kapton, Top Electrode ($N\%_{\{electrode\}}$)

d) We calculated which is the **current per hole** knowing the ionization current and the irradiated area (we shot from the side) and this gives us a ionization-geometrical factor (f_{ig}) that has [A] as units

e) The charge to be added to top or bottom kapton (q_{add_tk}, q_{add_bk}) for a time step (t_{step}) is calculated as follows:

$$q_{add\_t(b)k} [C] = N\%_{t(b)k} * f_{ig} [A] * t_{step} [s]$$

f) We add the calculated charge on top (bottom) Kapton and **create a charged map**

g) We **restart** another simulation of **2000 electrons** considering the new charge deposited

# ANSYS : definition of the geometric, electrostatic properties and resolution of Maxwell equation
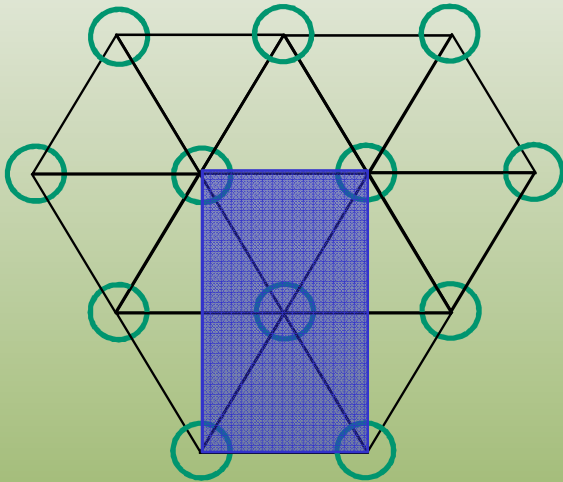
The elementary cell simulated is the one in the square
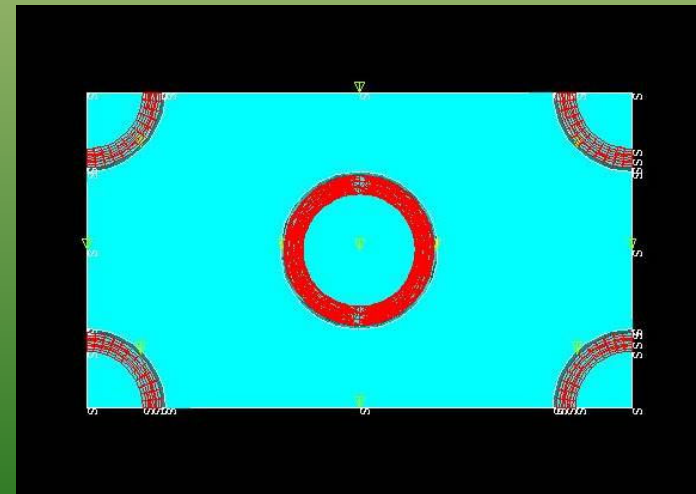
Geometric properties:
- kapton thickness = 50 µm
- copper thickness = 5 µm
- drift gap thickness = 800 µm
- induction gap thickness = 800 µm
- holes pitch = 140 µm
- hole copper diameter = 70 µm
- hole kapton diameter = 50 µm

Electrostatic properties:
- drift field = 0.1 kV/cm
- GEM voltage = 20 V / 500 V
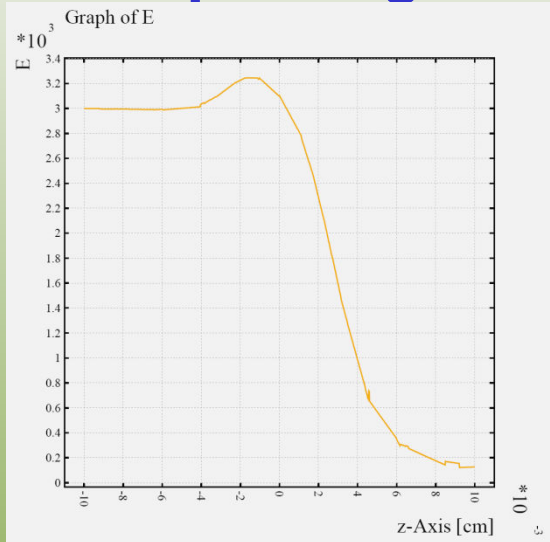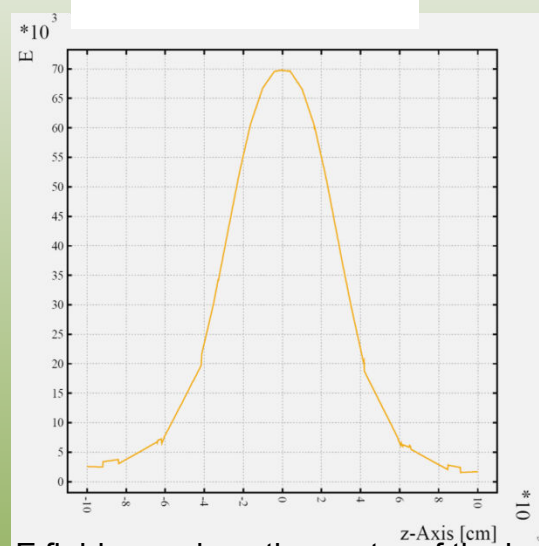- induction field = 3 kV/cm
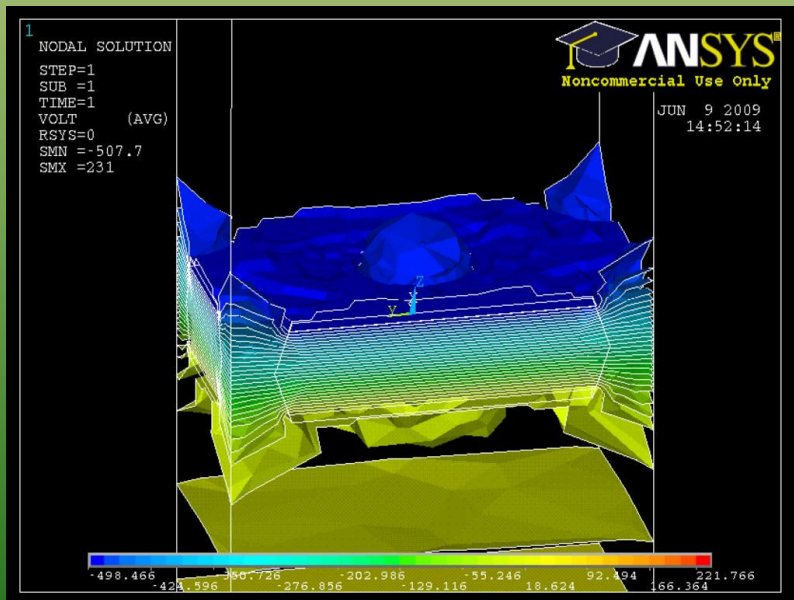
Equipotential planes in Ansys Solution

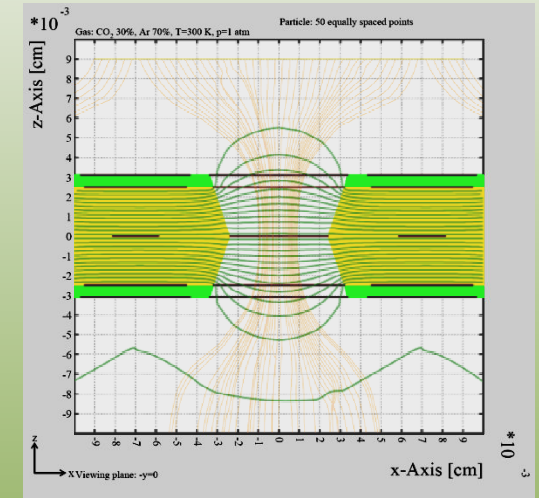Surface charge application onto the Kapton walls

Garfield: Map Conversion, Field checking, electrons drift lines plotting and execution of microavalanche procedure
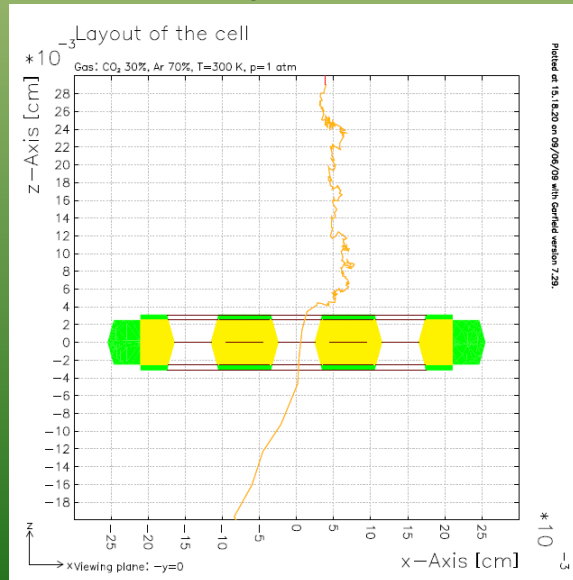

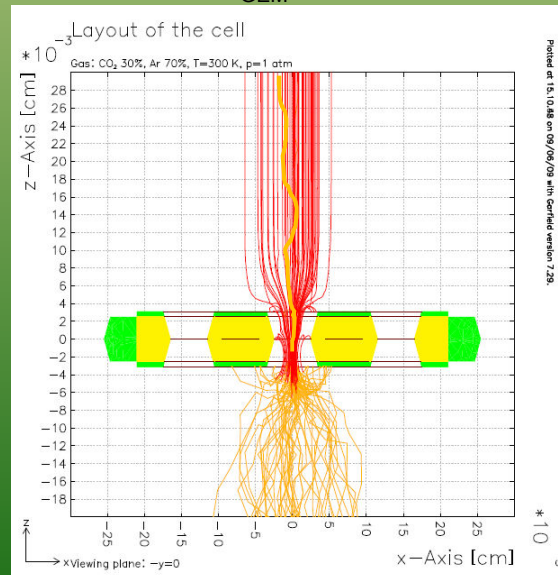E field vs z along the centre of the hole for ΔV_{GEM} = 20 V

E field vs z along the centre of the hole for ΔV_{GEM} = 500 V
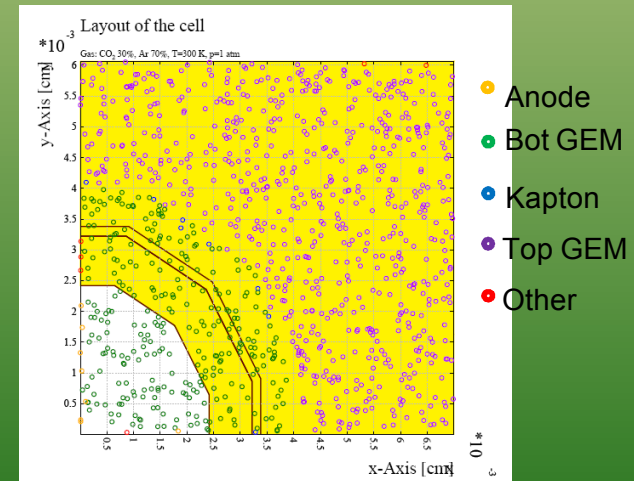

Equipotential lines and electron drift lines for ΔV_{GEM} = 500 V

One electron started form z=290 μm drifts in the GEM foil powered at ΔV_{GEM}=20V
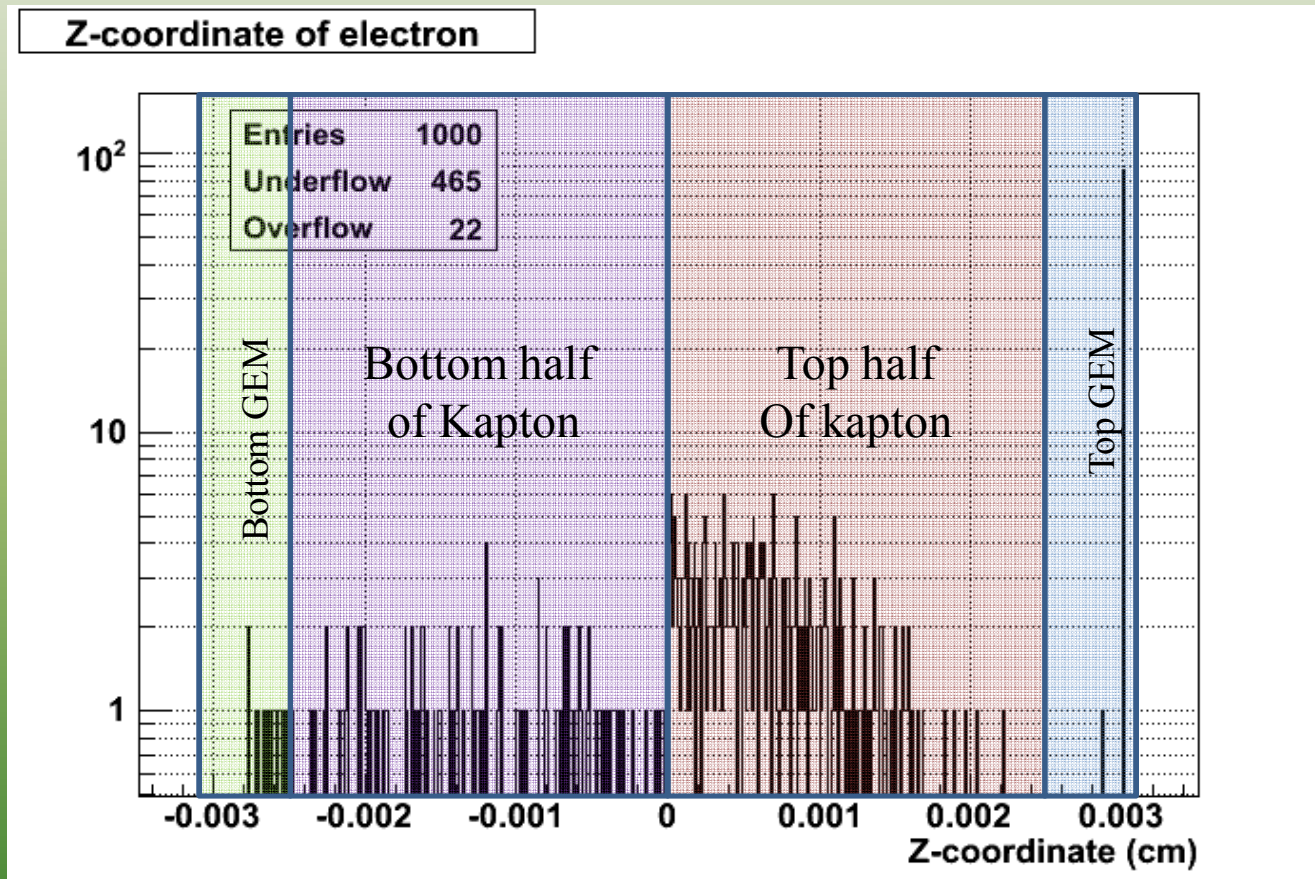

One electron started form z=290 μm is multiplied in the GEM foil powered at ΔV_{GEM}= 500V

Electrons starting points shown.
Z-start = 500 μm
Color represents the ending place

6

ROOT Analisys: example of electron z-end histogram for ΔV_{GEM} = 20 V

We divided the Kapton in two halves without taking into account the precise z-end position of each charge

ΔV_{GEM} = 20 V: which is the optimum *iteration step*?
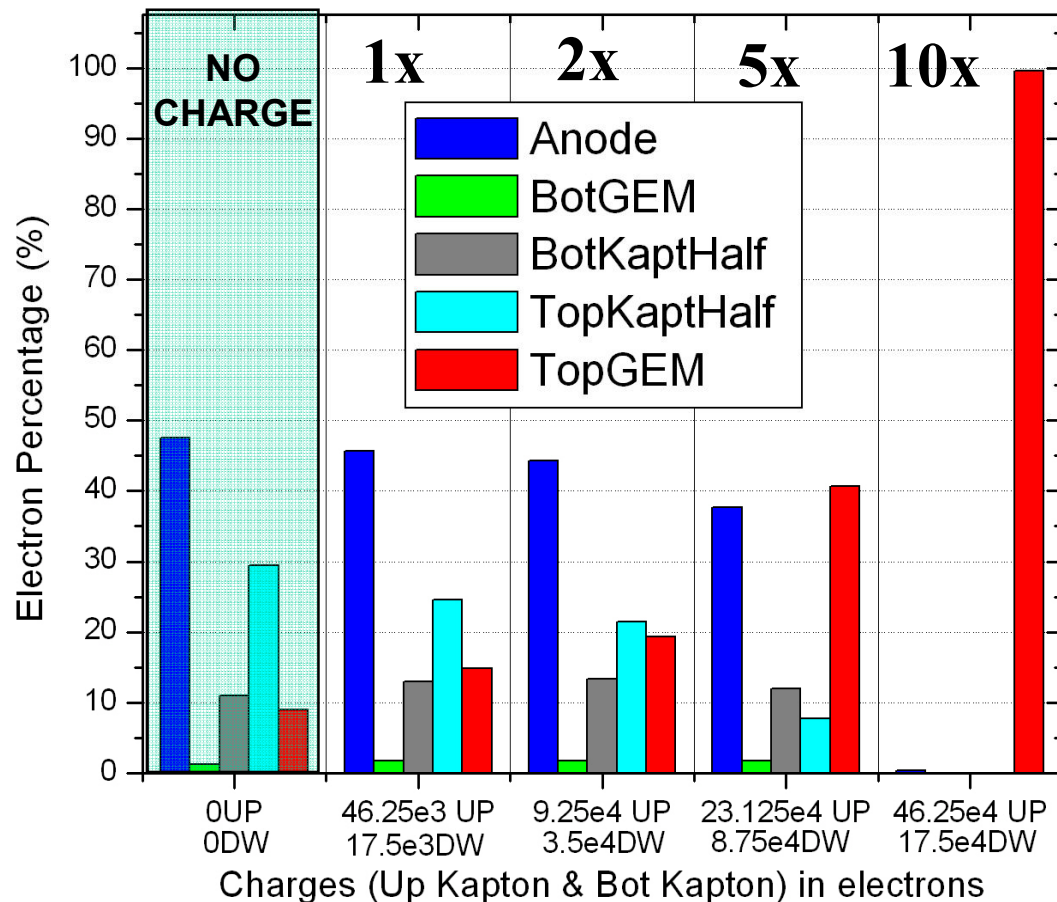
First "manual" iterative method simulation with "0.1s equivalent" charge step
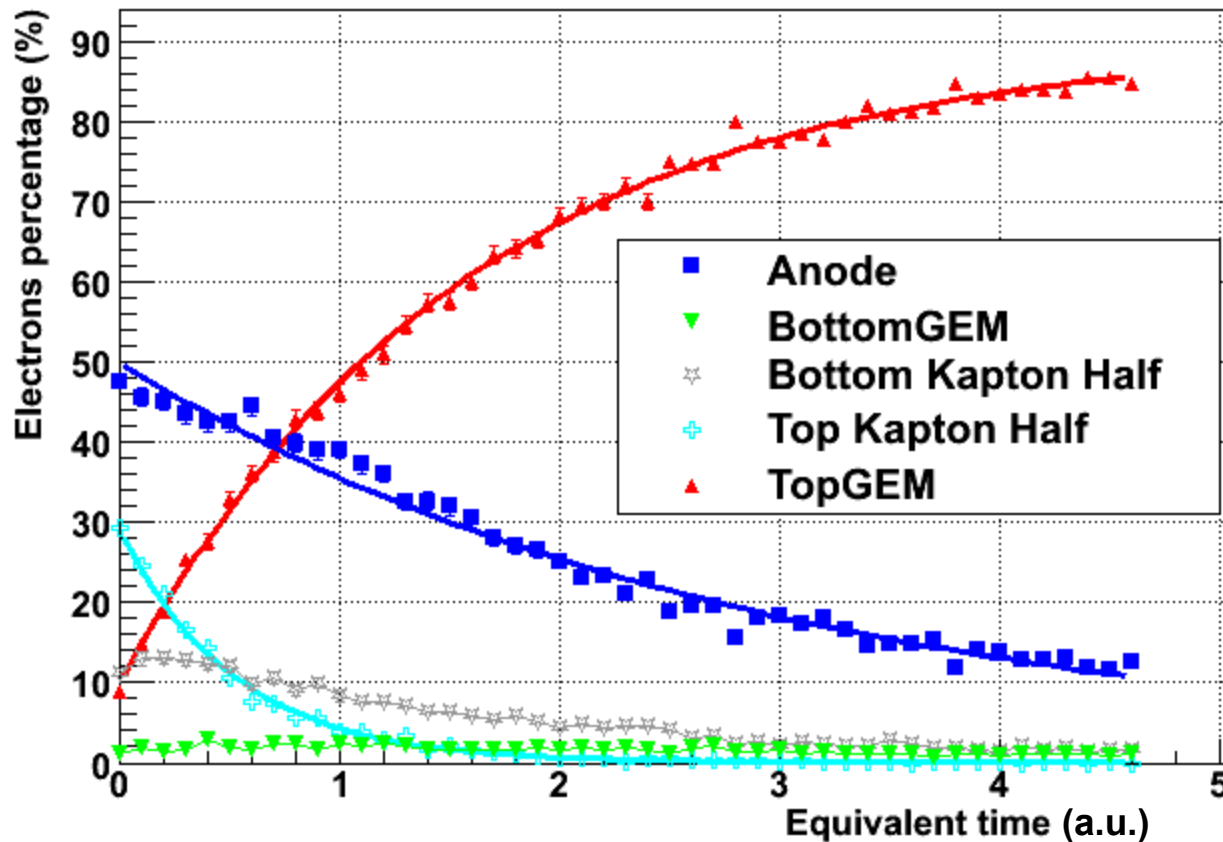
Iterative method with "0.1s equivalent" charge step

First "manual" iterative method simulation with "0.1s equivalent" charge step

Iterative method with "0.1s equivalent" charge step

- Anode
- BottomGEM
- Bottom Kapton Half
- Top Kapton Half
- TopGEM

First "manual" iterative method simulation with "0.1s equivalent" charge step
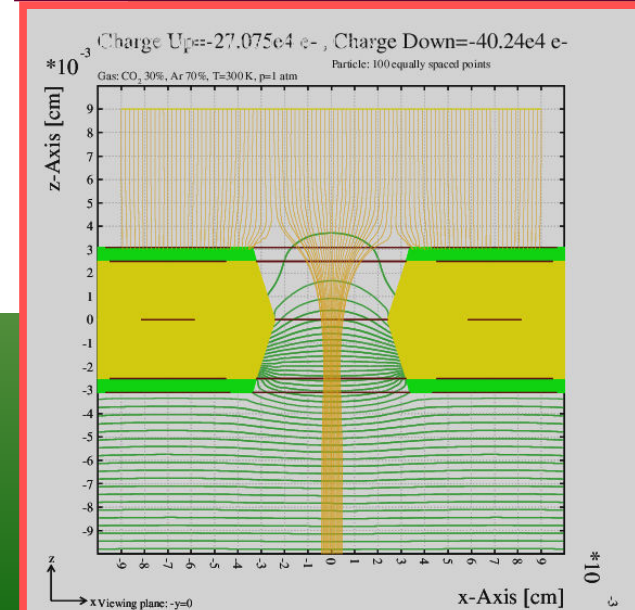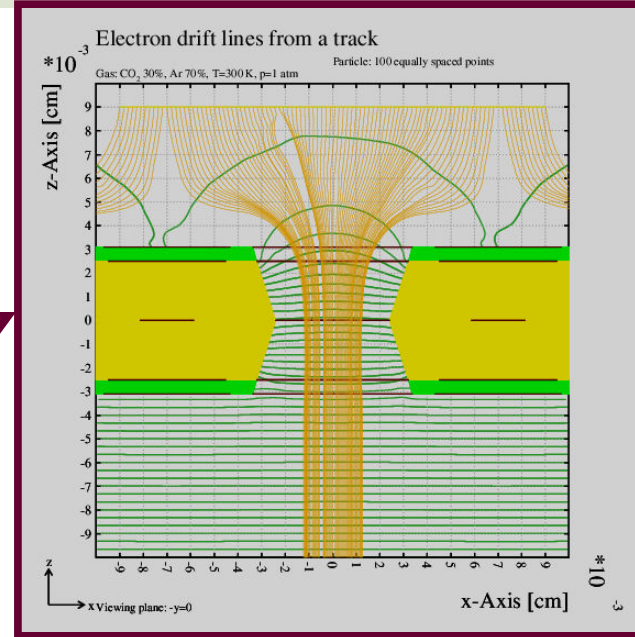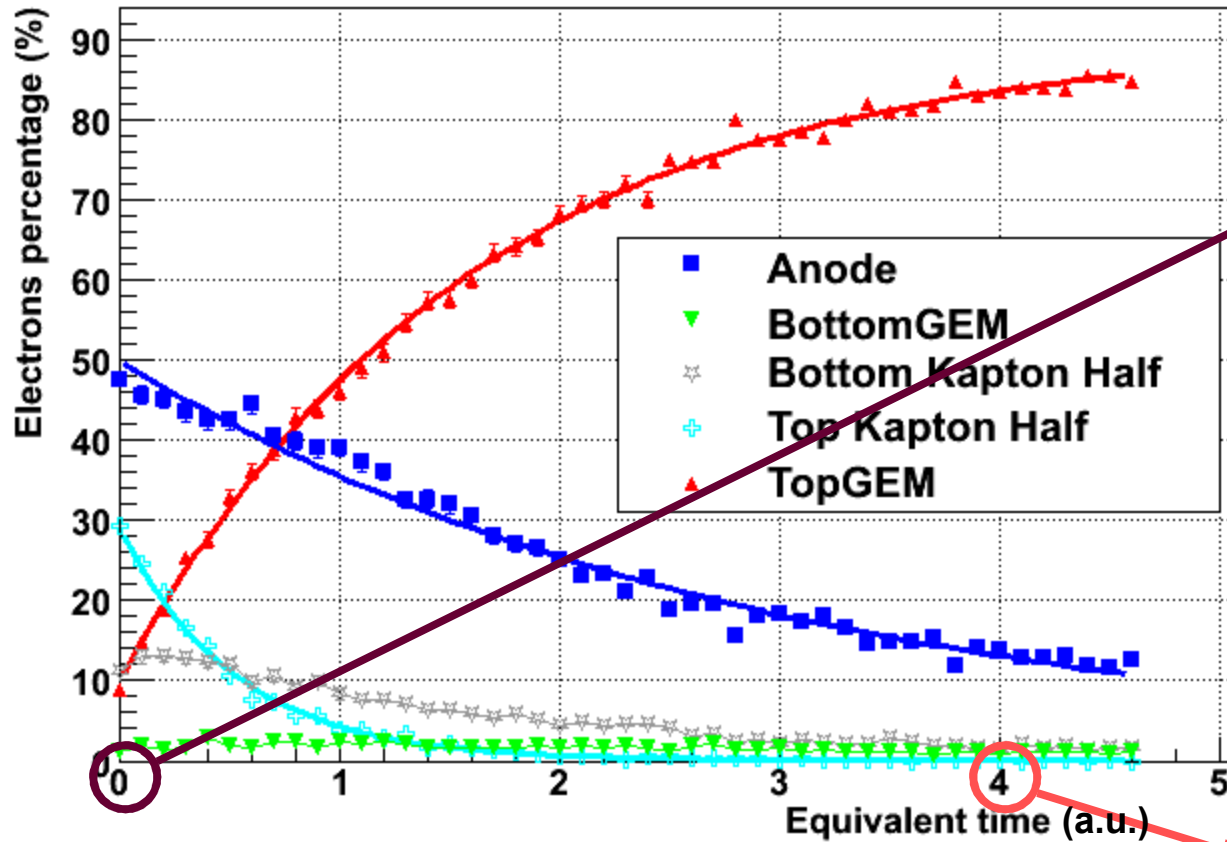

Iterative method with "0.1s equivalent" charge step
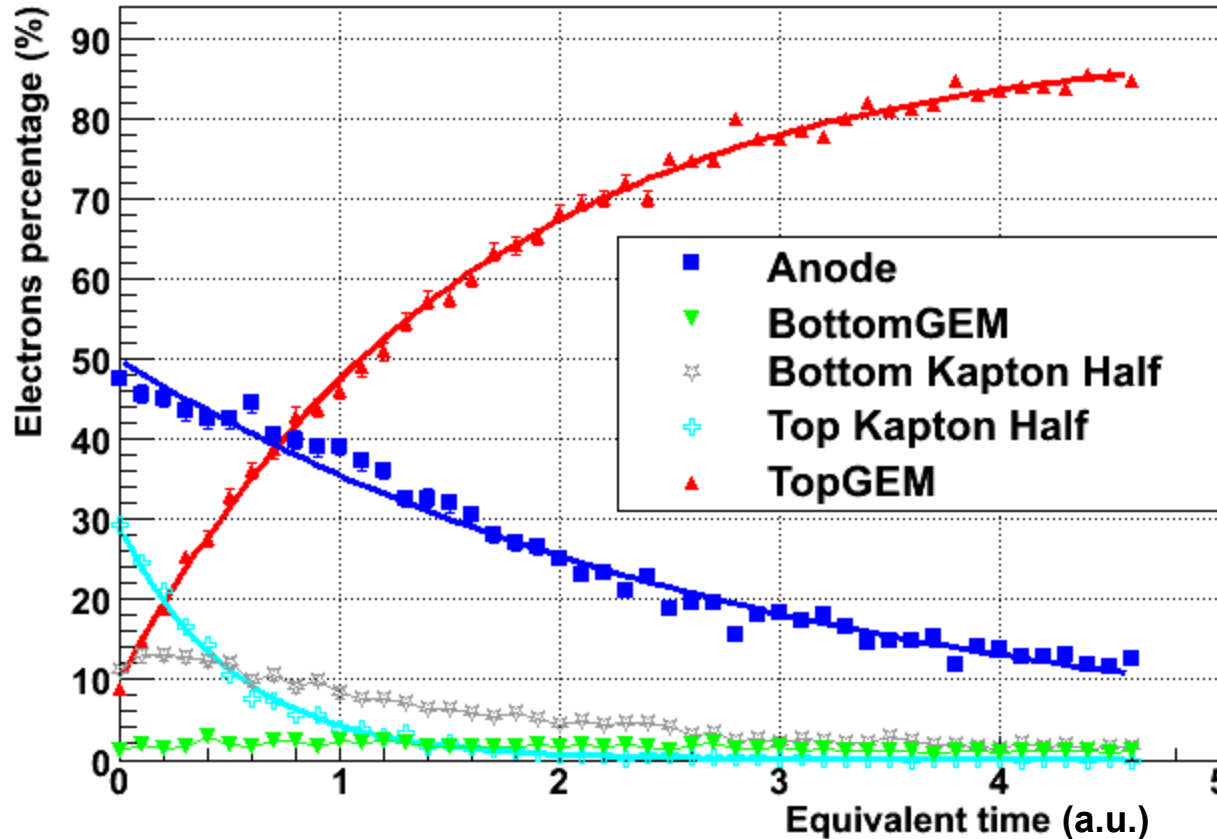
Equiv Time	Kapt Top Half Charge (e-)	Kapt Bot Half Charge (e-)
0.1	4.625e4	1.75e4
0.5	18.39e4	11.8e4
1	23.2e4	19.32e4
2	26.26e4	29.1e4
3	26.85e4	35.14e4
4	27.04e4	38.63e4

Place	Fit Function	P0	P1	P2
TopGEM	P0 – P1*exp(-x*P2)	90.1± 0.5	80.3± 0.5	0.634 ± 0.013
Anode	P0 + P1*exp(-x*P2)	0.646 ± 0.02	49.4 ± 1.1	0.344 ± 0.02
Top Kapt Half	P0 + P1*exp(-x*P2)	0.07 ± 0.02	29.4 ± 0.6	1.93 ± 0.04

Recent developments

The simulation took about 2 weeks!!!!!!

→ We managed to write a shell script that automatizes all the required steps and is submitted to lxbatch.cern.ch:

- Creates a map with no charges (Ansys) and converts it to Garfield

- Launches a Garfield script that starts 2000 e- 290 μm before the top GEM, executes the *microavalanche* procedure and writes an output file with x-end, y-end, z-end and t-end for each electron and ion in the simulation. To use multi-processor capability many Garfield sessions are started at the same time

- Starts a ROOT macro that analyzes the output file and computes the electrons/ions ending place percentage, the real gain and the effective gain (if any)

- Creates another Ansys macro applying to the kapton wall charges proportional to estimated percentages

- Reconverts the Ansys solution to Garfield map, starts another simulation of 2000 e- and continue

Specific features of the script

- The script saves all the data (Ansys macro & outputs, Garfield macros & outputs, ROOT outputs) in each iteration and thus, if the script is stopped or killed, it is possible to restart from the last performed iteration

- If the relative error on number of electrons on top (bottom) Kapton is too high, other 2000 primary e- are started for the same condition in order to increase statistics

- There is a range for the charge to be added : if the calculated charge is not inside this range, it is scaled by increasing or reducing the time step
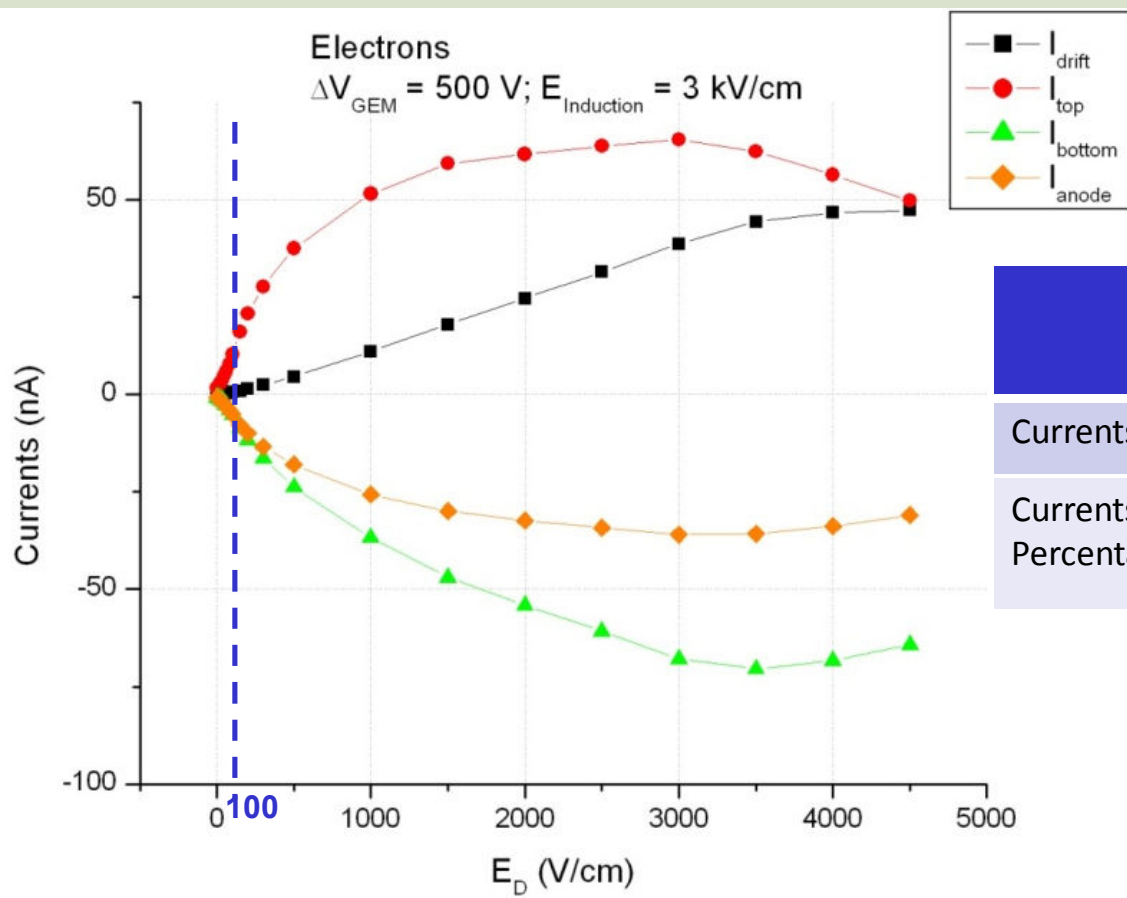
Results

Iterative Method
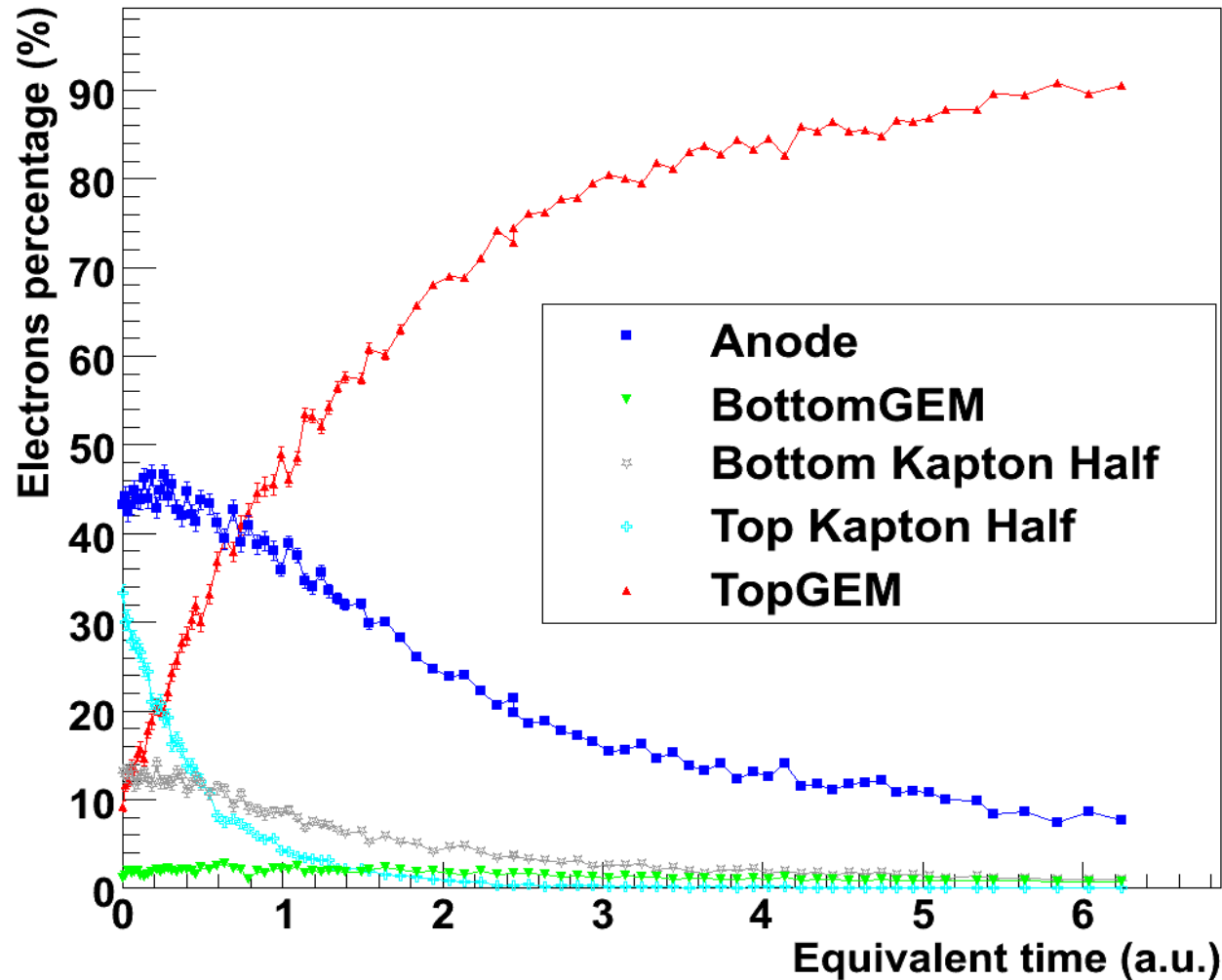
- The results is the same as the one got with the *manual* procedure.

- The time steps at the beginning are smaller to avoid too steep variation.

- The time needed to get this results was 2 days of waiting time and 2 days of calculation time.

GAIN Setup Simulation

Very Preliminary Results
(Still going on)

$\Delta V_{GEM} = 500$ V: The measurements

Drift Scan (current vs drift field)

Electrons
$\Delta V_{GEM} = 500$ V; $E_{Induction} = 3$ kV/cm

Legend:
- I_{drift} (black squares)
- I_{top} (red circles)
- I_{bottom} (green triangles)
- I_{anode} (orange diamonds)

Axes: Currents (nA) vs E_D (V/cm)

Currents values @ Ed = 0.1 kV/cm

	I_{drift}	I_{top}	I_{bottom}	I_{anode}
Currents	0.7nA	10.4nA	-5.5nA	-5.5nA
Currents Percentage	I^+ 6.3%	I^+ 93.7%	e^- 50%	e^- 50%

G. Croci et al: GEM Transparency Studies:
electrons and ions measurements,
2nd RD51 Collaboration Meeting Paris 13-15 October

8.9 keV X-Rays collimated beam shot from the side
to be sure to have conversion only in the drift gap

Drift Current

X-Rays >

Top GEM Current

Bottom GEM Current

Anode Current
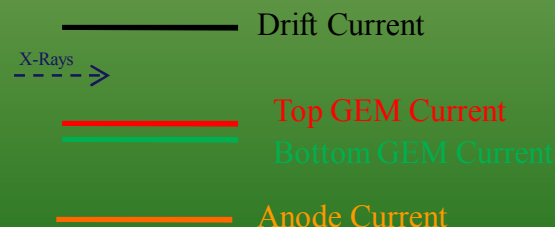
Additional problems when dealing with ions as well as electrons

- Now there are two charged species that play a role: it is important to understand how to deal with them.
- The sign of the charge added to top (bottom) Kapton defines which one of the two electrical species is the majority in that place. It is not payed attention to the precise z-end: if one electron and one ion end up in the same place (top/bottom kapton) they are considered to be neutralized.
- So that, the equilibrium can be reached when no charge goes into the dielectric as well as the number of electrons and ions, going to the Kapton, is the same.
- In this preliminary study the feature of the minimum addable charge is kept: as you will see this is a bad strategy because it avoids to arrive to an equilibrium given by the equal amount of negative and positive charges on dielectric.
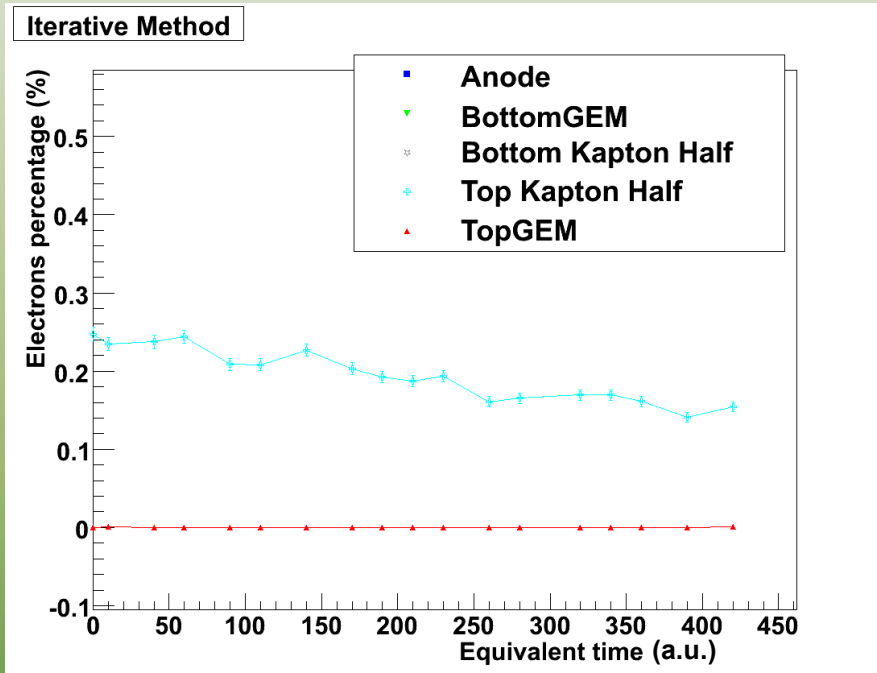
Electrons percentages
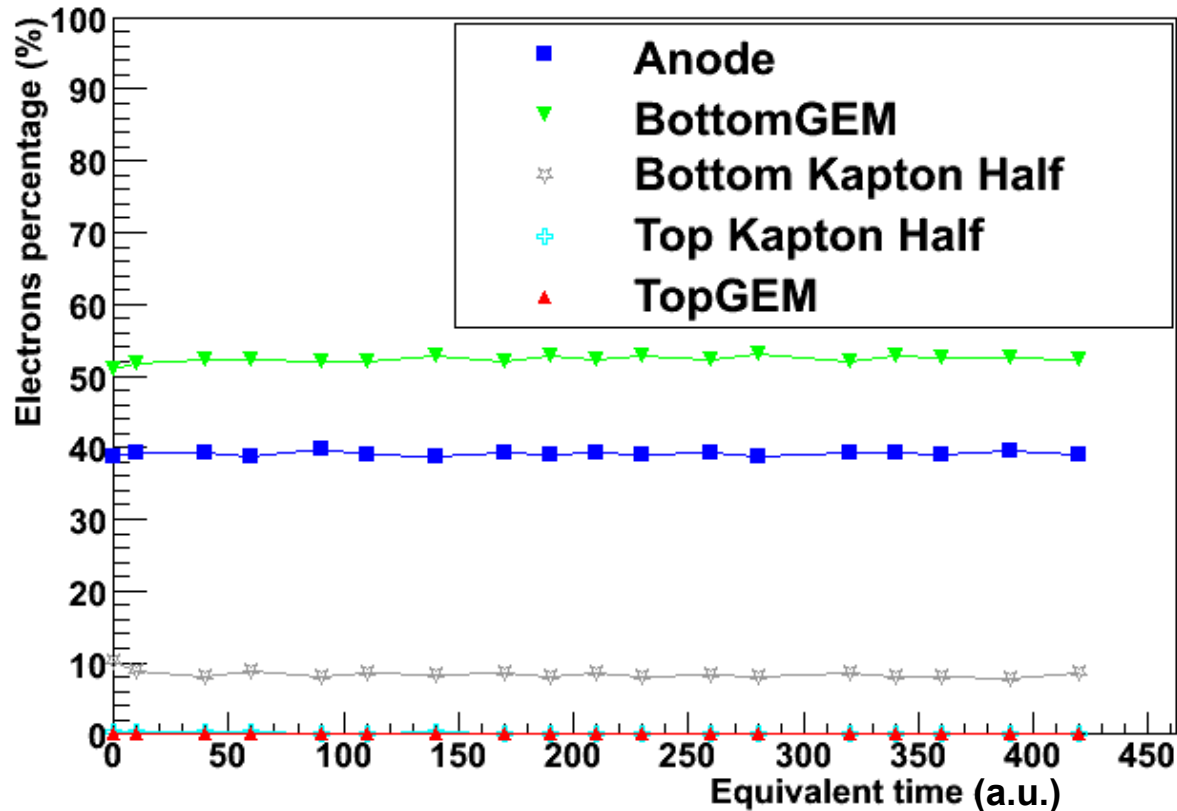
Equiv Time	Kapt Top Half Charge (e-)	Kapt Bot Half Charge (e-)
40	-1.145e5	-7.733e5
110	-2.844e5	-5.253e5
190	-4.671e5	-7.825e5
260	-5.844e5	-5.400e5
340	-6.802e5	-8.054e5
420	-7.573e5	-5.024e5

Since the beginning, the percentages are compatible with what we measured but the simulated gain (see later) is still lower (factor 4-5) then the measured one
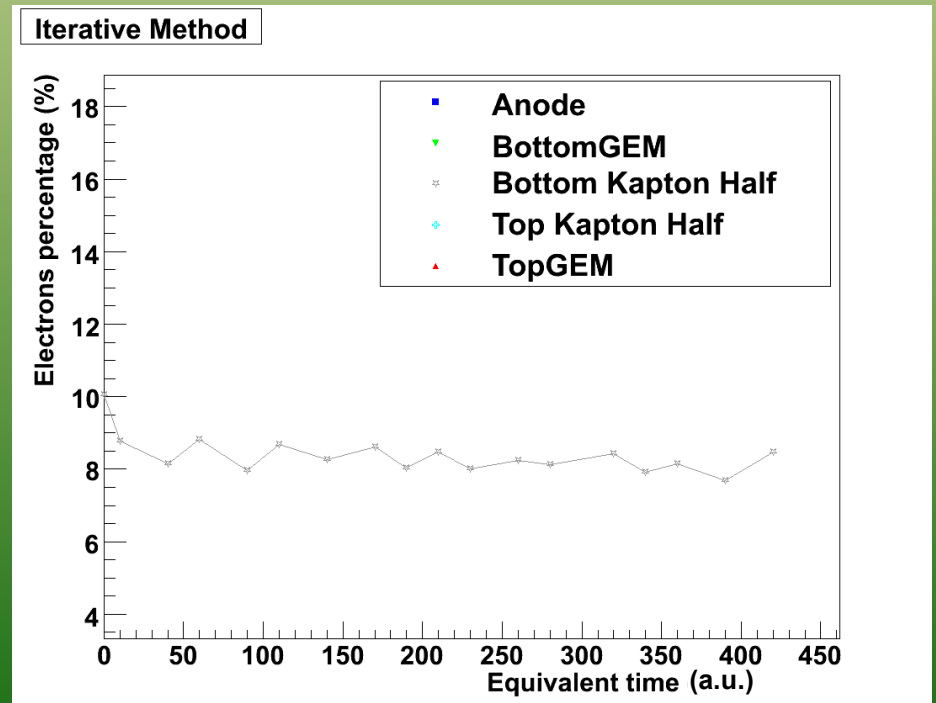The percentages seems not to change by applying more charge, they seems to oscillate:
this can be due to the minimum time step used in this preliminary test that could be too large

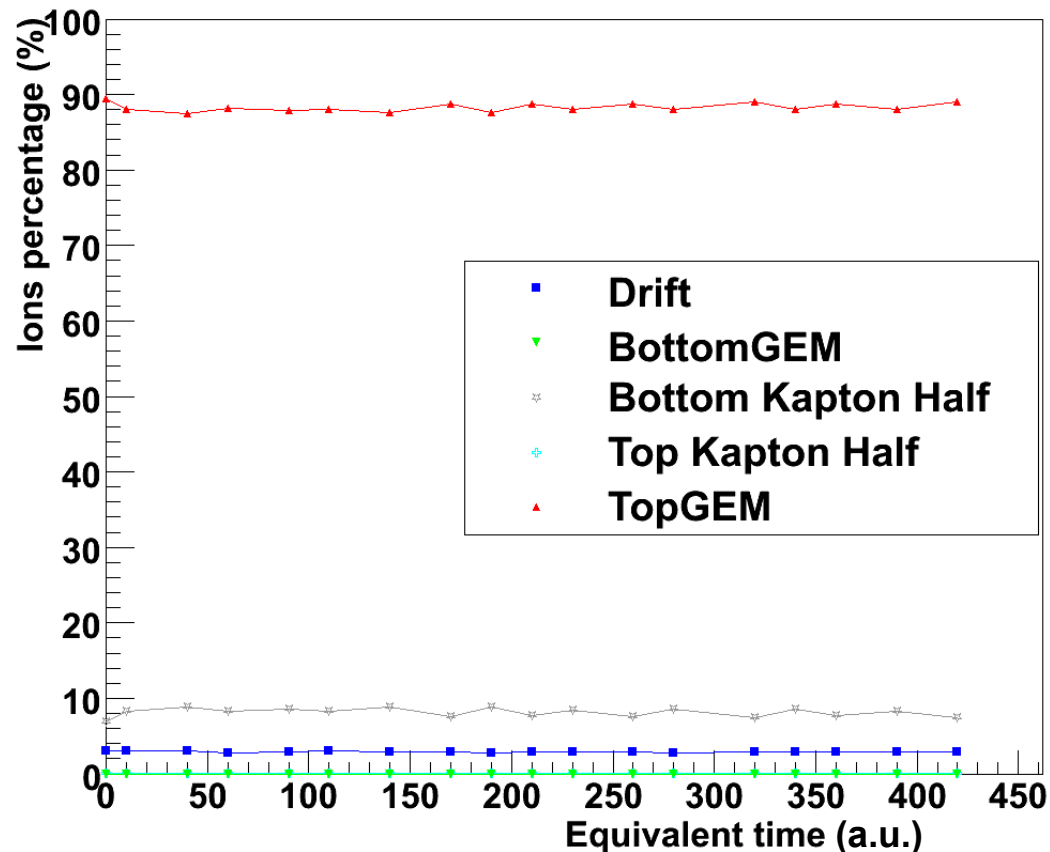# Electrons percentages: zoom into the kapton curves

Bottom Kapton electron percentage seems to stay constant

Top Kapton electron percentage seems to decrease when more and more electrons are deposited there

Ions percentages

| Equiv Time	Kapt Top Half Charge (e-)	Kapt Bot Half Charge (e-)
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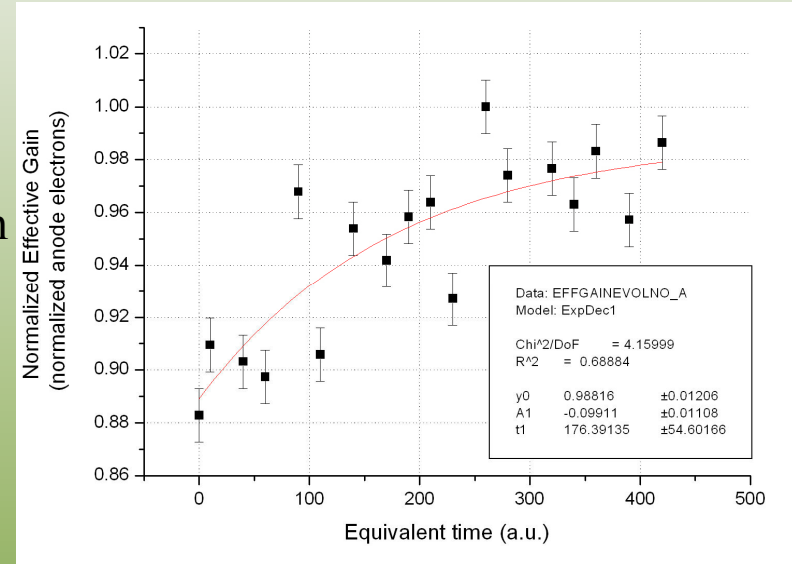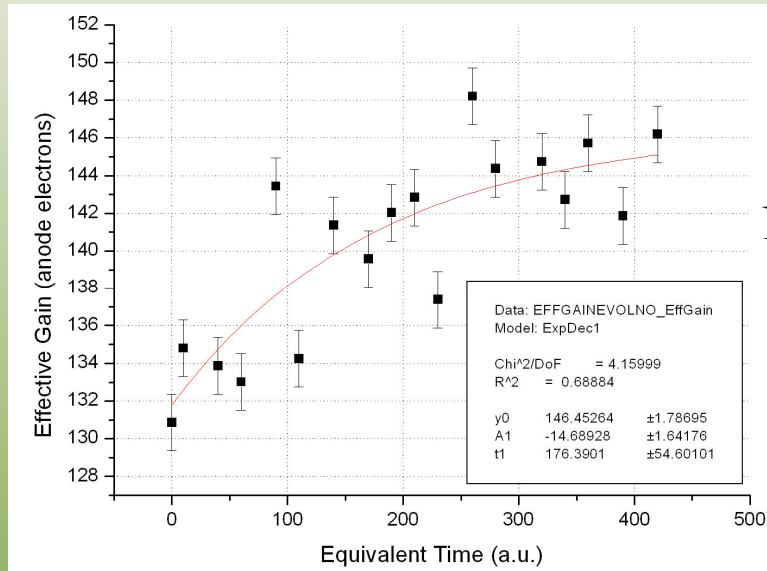
Ions percentages: zoom into kapton curves

Iterative Method

Bottom Kapton ions percentage seems to decrease
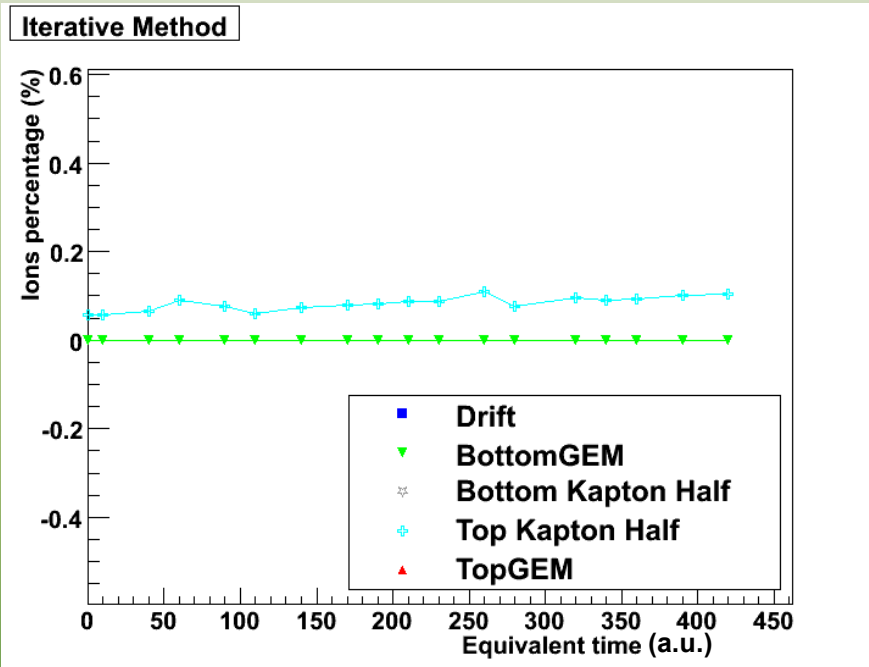
Top Kapton ion percentage seems to increase when more and more electrons are deposited there
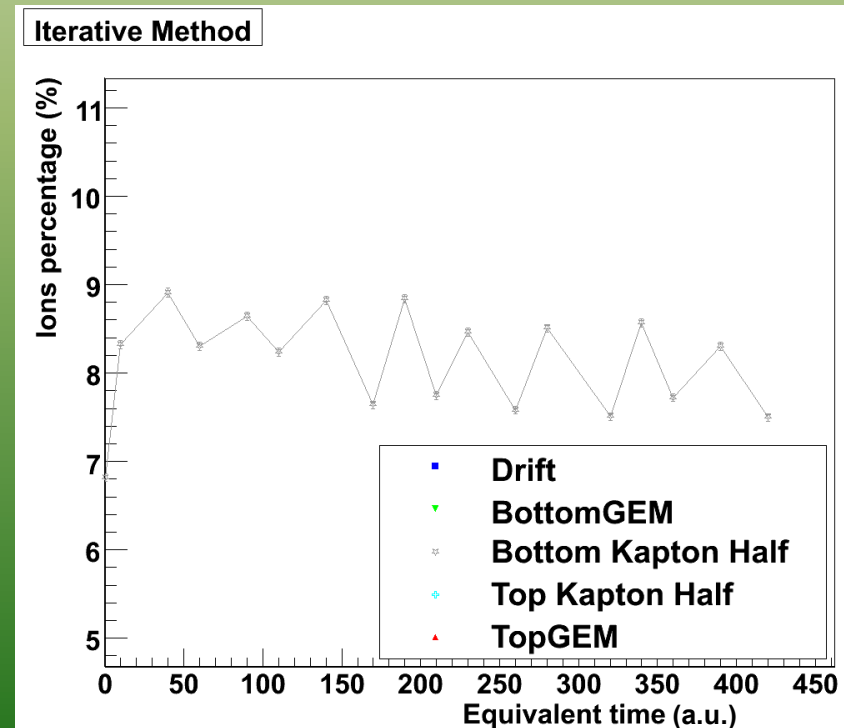
Gain Evolution: a first look (1)

Effective Gain (only anode electrons)

Normalization
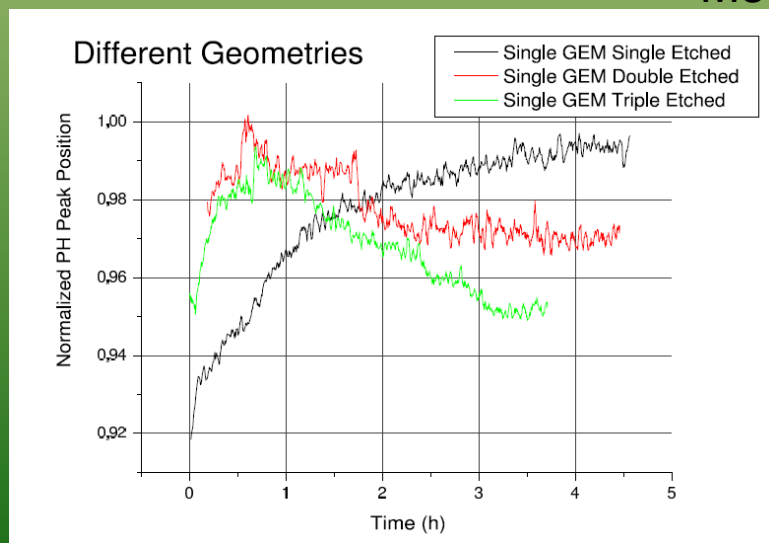
Real Gain (anode + bottom electrons)

Normalization
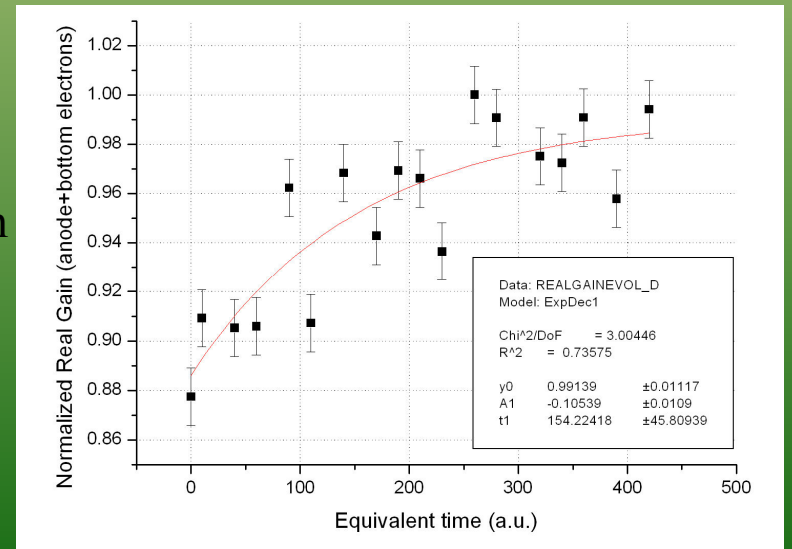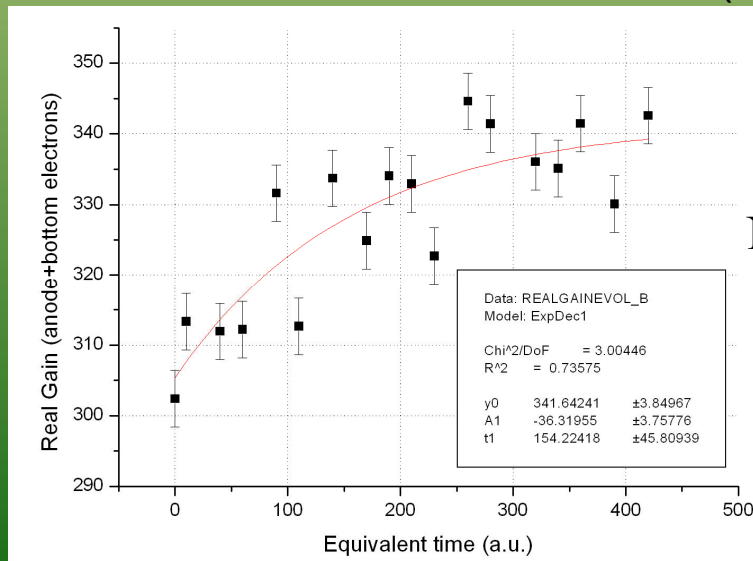
Gain Evolution: a first look (2)

Simulations
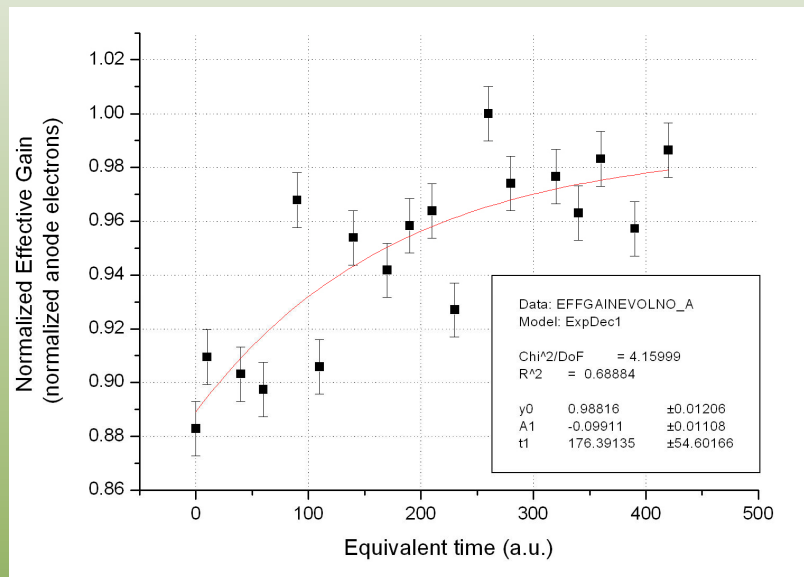
Gain Variation ~ 10 %

Measurements

Standard GEM is the black curve
Gain variation ~ 5-10%
The simulated gain is always a factor 4-5 less than the measured one

The green and red curve represents other geometries (not related to the present work)

G. Croci, "**Study of relevant parameters of GEM-based detectors**", Master thesis 2007

Conclusions and future plans

• In the NO GAIN setup we were able to reproduce the measurements results with the charging up simulation

• The automatic procedure speeds up the simulation by a huge factor

• For the GAIN setup we still have to get more data to have a better understanding:
- The currents distribution seems to be correct
- The gain is still too low even if it seems to increase

• In the future:
- ❖ we will try to understand all the systematics in the simulation:
  - it seems that the simulation is biased by the minimum charge threshold
  - Ansys mesh refinement may give better results
  -
- ❖ the recently introduced NeBEM field solver will be tried
- ❖ other GEM geometries will be simulated

Spare Slides

Simulations: Field Map Creation

Simulation

➤ *ANSYS PACKAGE*

Ansys is used to define:
1) the geometry;
2) the material properties;
3) the electrodes voltage;
4) the e.m. boundary conditions;
and to solve the e.m. equations with a finite elements analysis method

➤ *GARFIELD PACKAGE*

Garfield is used to:
1) read the Ansys fieldmaps;
2) define the gas properties;
3) simulate the behavior of electrons in the gas

ΔV_{GEM} = 500 V: **which is the optimum *starting iteration step*?**