THGEM simulations

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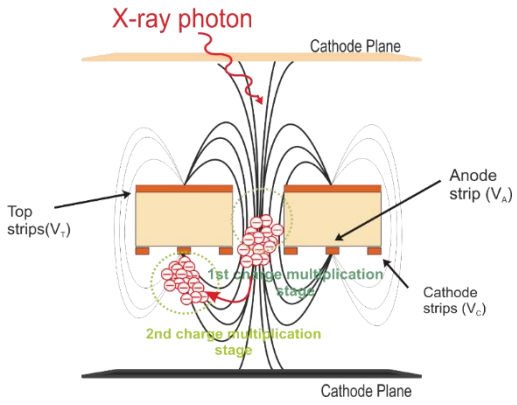
Outline

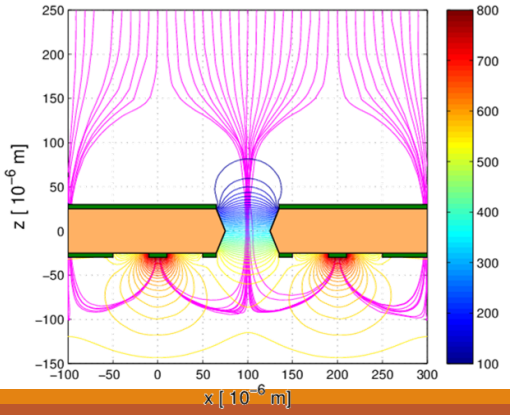
- Background
- Simulations software in MPGDs - THGEM
- Building the Electrostatic field maps
- Particle transport using Garfield++
- Some examples (explaining differences between simulation and measurements, gain evolution over time)
- Main conclusions

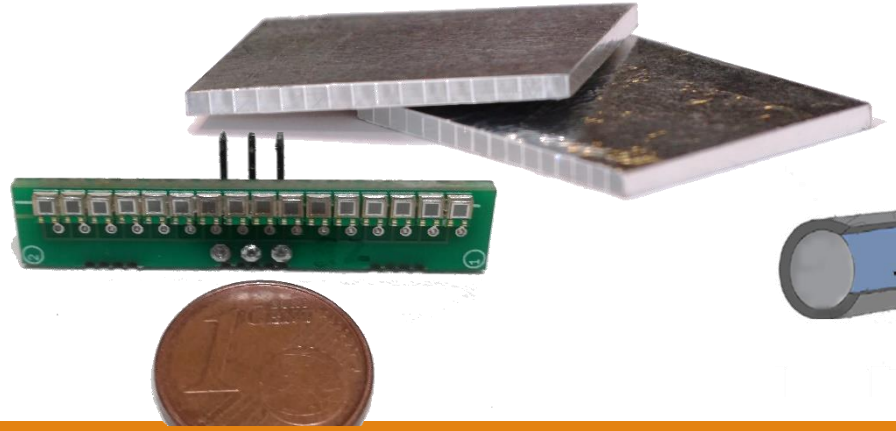
Investigation group – DRIM University of Aveiro

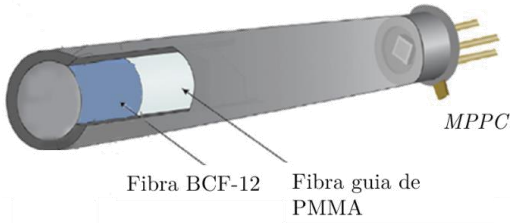
Deteção de **R**adiação e **I**magiologia **M**édica - Radiation detection and Medical Imaging

- Medical Physics (CT, PET);
- Physics Instrumentation;
- Applied Physics
- Strong research in new systems and devices with application in Medical Physics / Biomedical Engineering





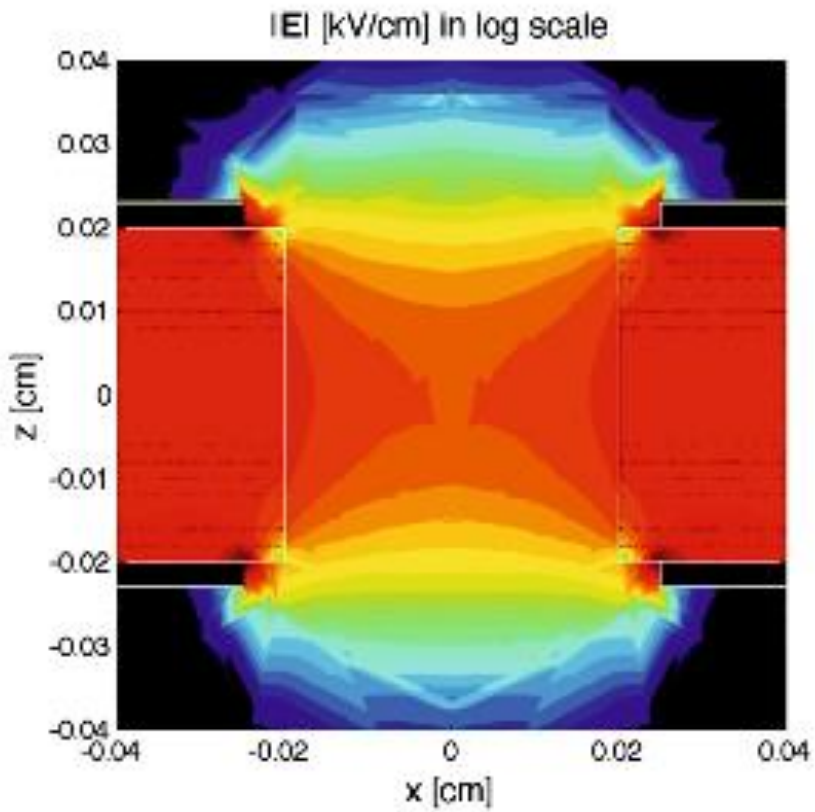




Background

Typical MPGDs (and THGEM in particular) simulations rely in two types of calculations:

- **Electrostatic fields (FEM calculations)**

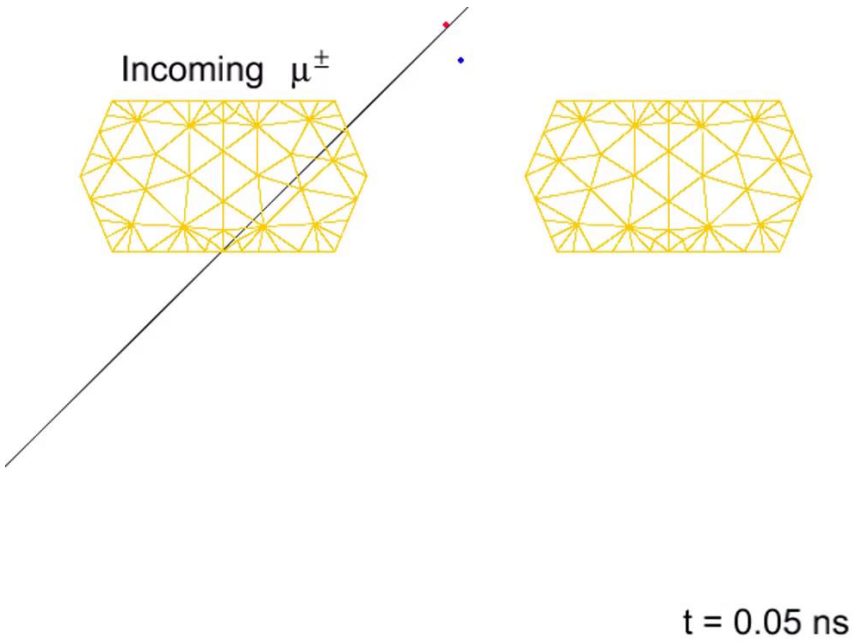


Correia et al, GEM Electrostatic Field Map
MPGD CB Zaragoza 2013

Background

Typical MPGDs (and THGEM in particular) simulations rely in two types of calculations:

- Electrostatic fields (FEM calculations)
- **Particle transport in gaseous or liquid materials**

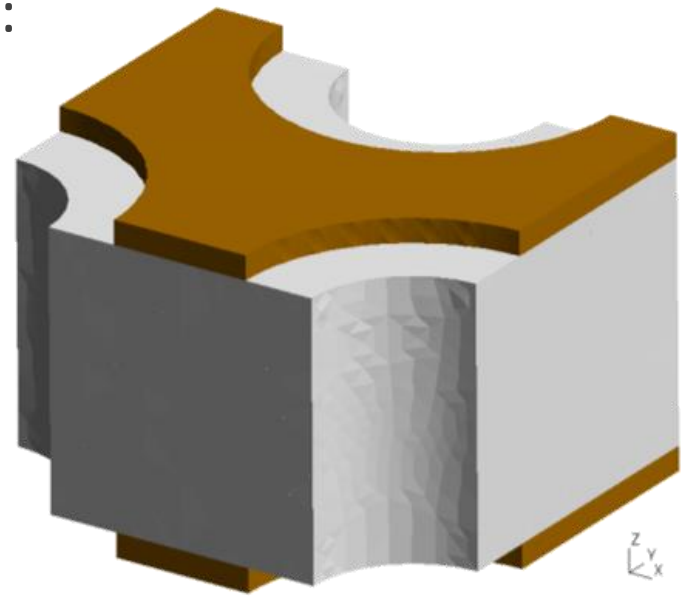


Dildick et al, MPGD CB CERN 2011

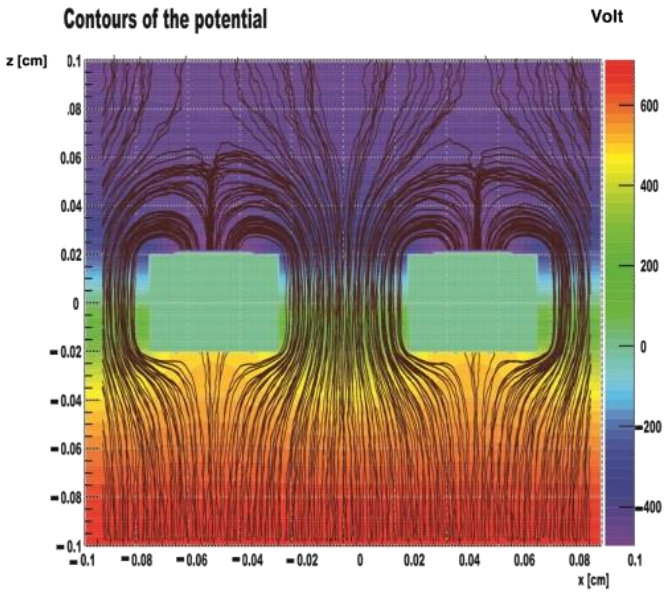
Electrostatic fields

The calculation of the Electrostatic Field Maps, needed for the calculations of the particle's trajectories in the detector medium, are often based in Finite Element Methods software:

- Ansys
- ELMER+GMSH
- Synopsys Sentaurus
- COMSOL
- neBEM
- CST Studio
- …



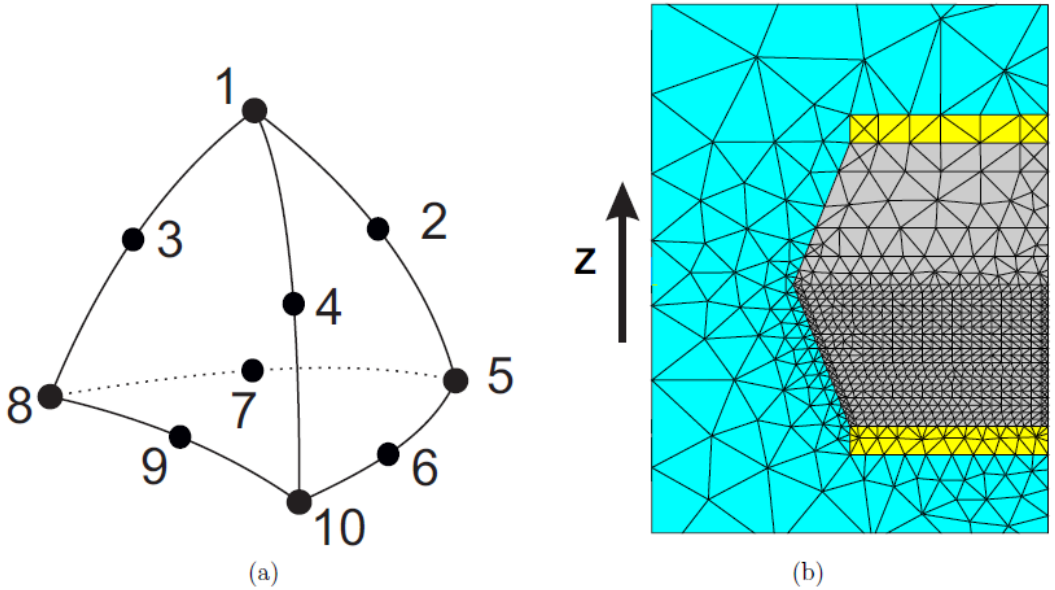
Josh Renner - THGEM cell from "Open-source finite-element field calculations with Elmer and Gmsh"



THGEM. Potential map and field lines.

Using Ansys

- Based in Finite Element methods
- Potential is calculated for specific points in space, and interpolated for the remaining
- Can be accessed from Lxplus (Cern accounts)



Ansys SOLID123 typical element. These elements fill the space and the electric potential is calculated in each node. Needs bondary conditions (usually the potential applied to electrodes. B) Example of a GEM mesh simulation using SOLID123 elements.

Source: RD51 simulation school - Modeling the GEM Efield using finite elements
Studies in gaseous radiation detectors: GEM, THGEM and Compton camera

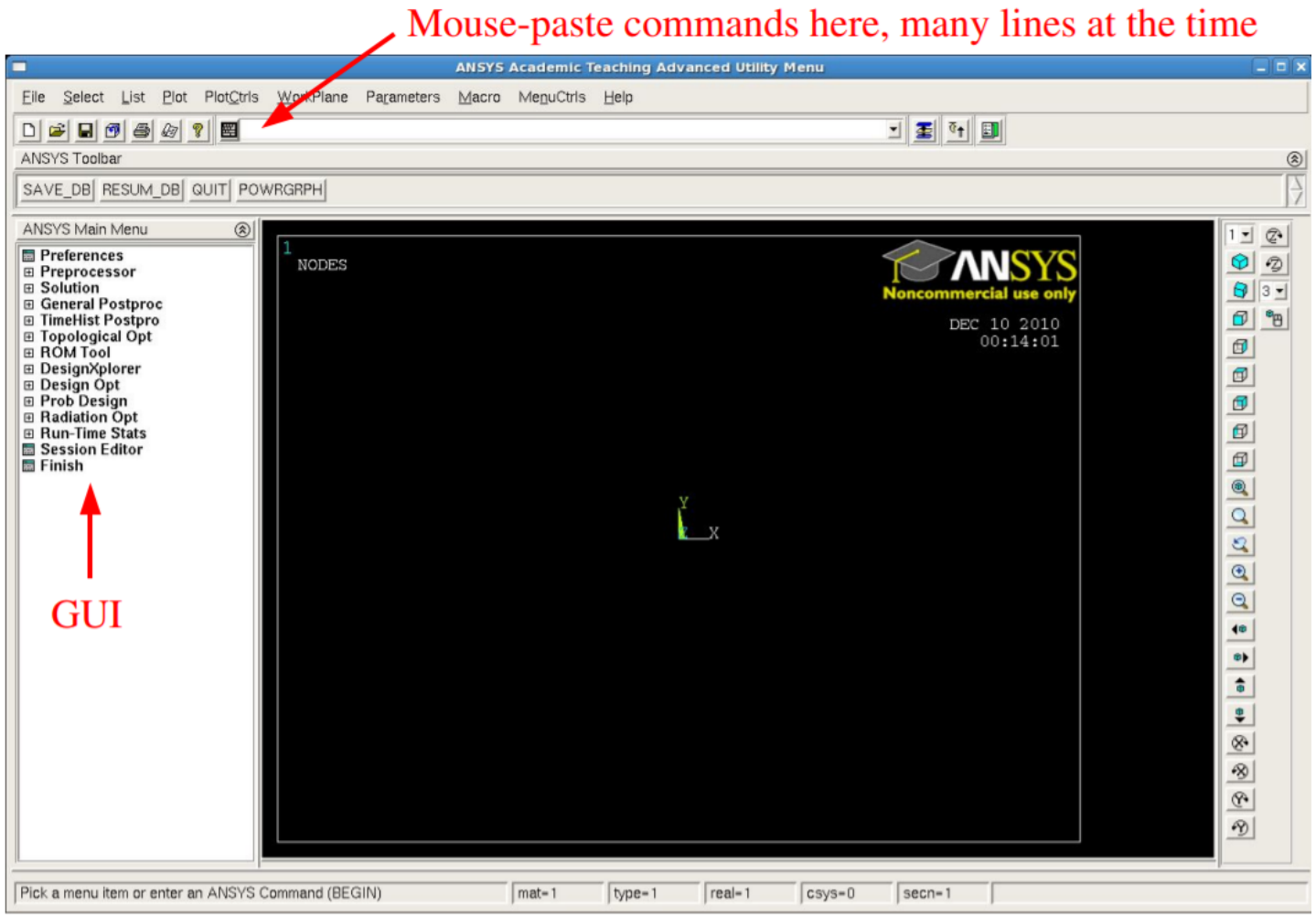
Using Ansys by GUI

Users can do simulations by:

- **User Interface** (not so user friendly…)

  Usually, the UI is preferred during the geometry development

- A **script (text) file**



Source: [RD51 simulation school - Modeling the GEM Efield using finite elements]

Using Ansys by script

- The scripting method is used when an established geometry is already available and only simulations parameters are to be studied
- Examples:
  - Electrode voltages
  - Drift fields
  - Geometry dimensions
  - Material Properties
  - Charge in insulators

```
! Material properties
MP,PERX,1,1e10   ! Metal Permittivity
MP,RSVX,1,0.0    ! Metal Resistivity
MP,PERX,2,1.0    ! Gas Permittivity
MP,PERX,3,3.9    ! Permittivity of kapton

! Construct the GEM
pitch =  0.140   ! Distance between holes, in mm
kapton = 0.05   ! Thickness of the kapton layer, in mm
metal =  0.005   ! Thickness of the metal layers, in mm
outdia = 0.07   ! Hole outer diameter, in mm
middia = 0.05   ! Hole diameter in the centre, in mm
drift =  1.0     ! Position of the drift plane in mm
induct = -1.0    ! Position of the induction plane in mm
rim =    0.07   ! Rim diameter, in mm
v = 350     ! Voltage difference across the GEM
e_d = 200        ! Electric field between drift plane and upper metal (abs,V/mm)
e_i = 300        ! Electric field between lower metal and inductive plane (abs,V/mm)
unit = 1000      ! Units: 1000 for mm, 100 for cm, 1 for m
pi = 3.14159265  ! pi
qe = 1.60217646e-19      ! Electron charge [C]
n = 24         ! Number of slices

! Make the plastic (1-n), lower metal (n+1), upper metal (n+2) and gas (n+3)
*do, i, 1, n-4
*if, i,lt,21,then
    BLOCK, 0, pitch/2, 0, sqrt(3)*pitch/2, -kapton/2+(i-1)*(kapton/2)/(n-4), -kapton/2+
*endif
```

Using Ansys

- Output files are:
  - ELIST.lis
  - MPLIST.lis
  - NLIST.lis
  - PRNSOL.lis

```
LIST MATERIALS       1 TO       3 BY       1
 PROPERTY= ALL

MATERIAL NUMBER       1

     TEMP        RSVX
               0.000000

     TEMP        PERX
             0.1000000E+11
```

```
NODE        X                    Y                    Z
     1    0.700000000000E-01   0.00000000000      -0.250000000000E-01
     2    0.700000000000E-01  0.862435565298E-01 -0.250000000000E-01
     3    0.340000000000E-01   0.00000000000      -0.225000000000E-01
     4    0.700000000000E-01   0.00000000000      -0.225000000000E-01
     5    0.700000000000E-01  0.862435565298E-01 -0.237500000000E-01
```

These files contain information about the materials, elements, nodes and the correspondent potential solution obtained

```
***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

LOAD STEP=     1  SUBSTEP=     1
 TIME=    1.0000      LOAD CASE=   0

  NODE      VOLT
     1    175.00
     2    175.00
     3    144.97
     4    157.43
     5    157.40
```

Particle transport in MPGDs

- Within the MPGD community, the software used for simulating microscopic drift of charged particles in gaseous or liquid volumes is **Garfield**:
  - **Garfield** (Fortran version developed by Rob Veenhof, last update 2010)
  - **Garfield++** (C++ version) currently maintained by a collaboration headed by Heinrich Schindler - https://garfieldpp.web.cern.ch/garfieldpp/

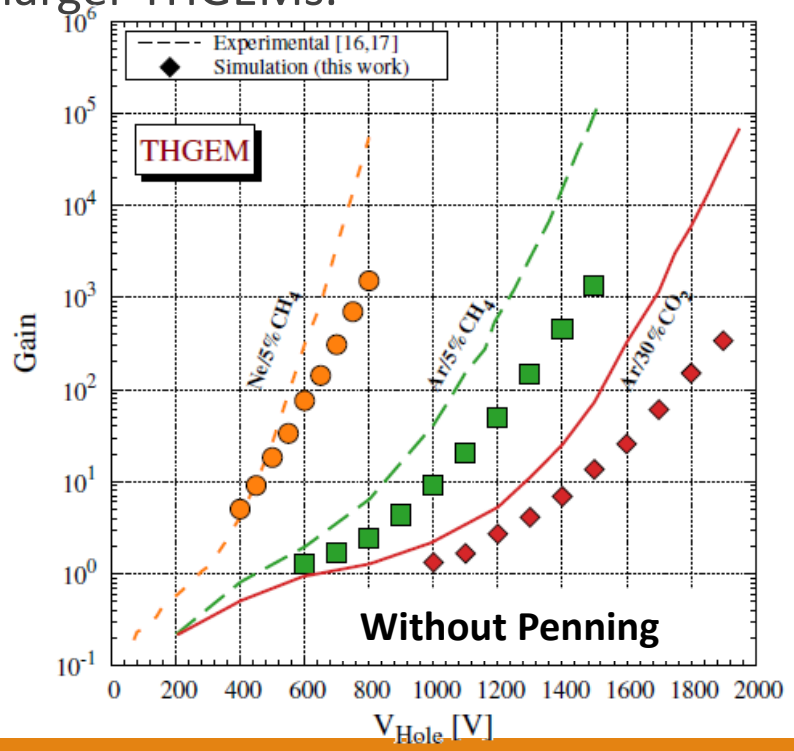
  Interfaces with other software:
  - **Heed** (for simulation of primary ionizing particles patterns)
  - **Magboltz** (for computing electron transport and avalanches)
  - **GEANT4** (integration with larger experiments at CERN)
  - **Field maps calculators**

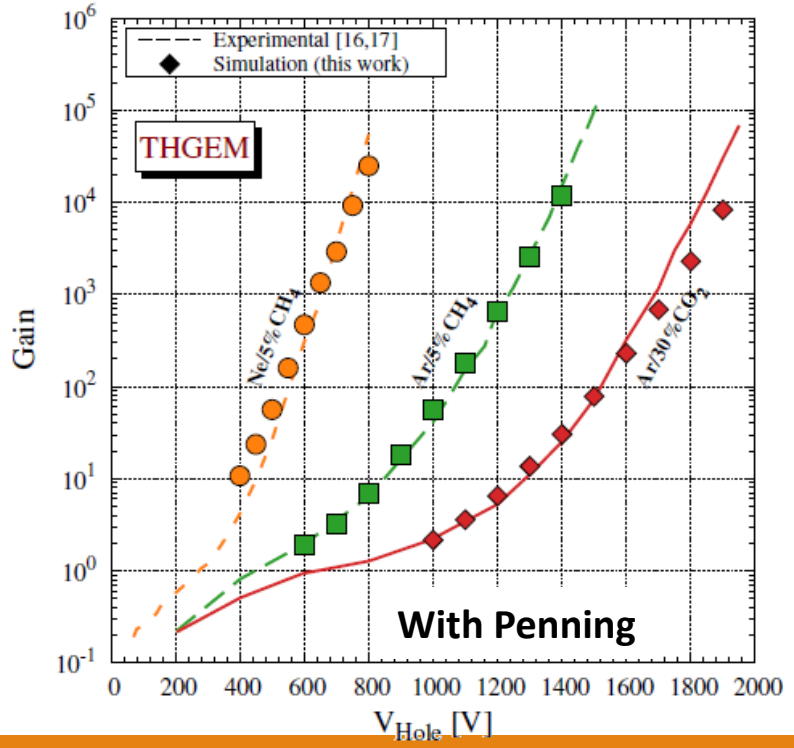
Garfield++

- Documentation available: User Guide
- For simple geometries, where electric field can be calculated analytically, geometries and medium parameters are enough for avalanches simulations
- However, for most cases the field maps needs to be calculated previously (either in ANSYS, ELMER, COMSOL, ….).

Differences between simulated and experimental gain

- Very often results from simulations differ from experiments by orders of magnitude. Previous works demonstrated that gas parameters, such **Penning effects**, can explain such differences – it assumes higher importance for larger drift trajectories due to the number of excitations in gas mixtures – therefore more important for larger THGEMs.

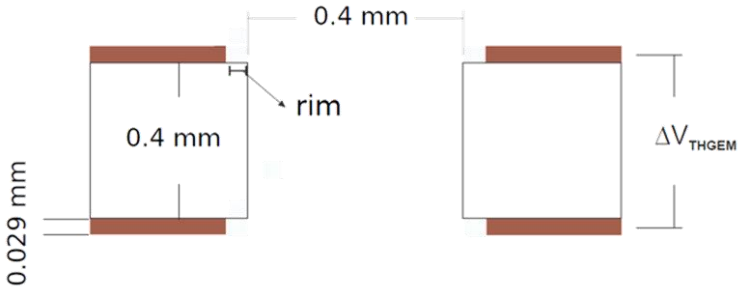


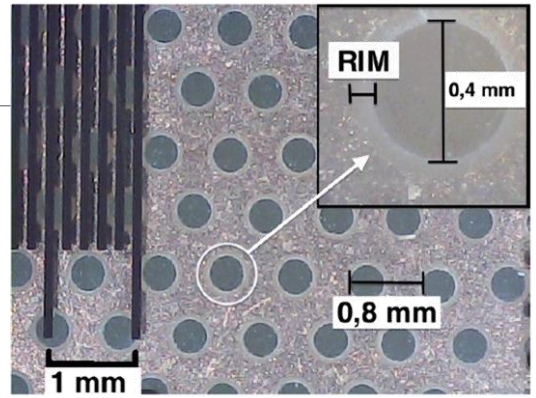


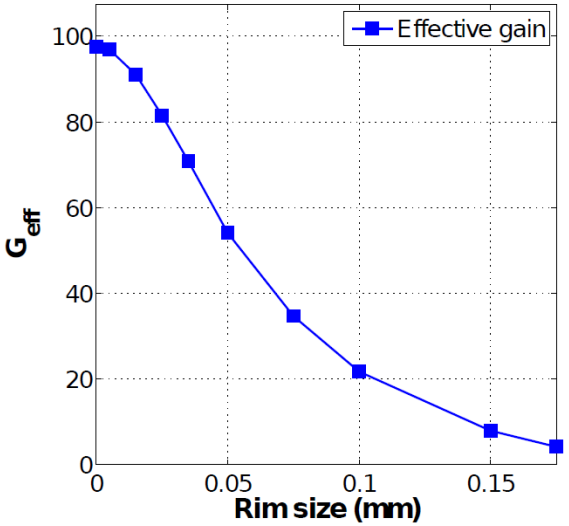
CDR Azevedo et al, [THGEM gain calculations using Garfield++: solving discrepancies between simulation and experimental data](), JINST 2016

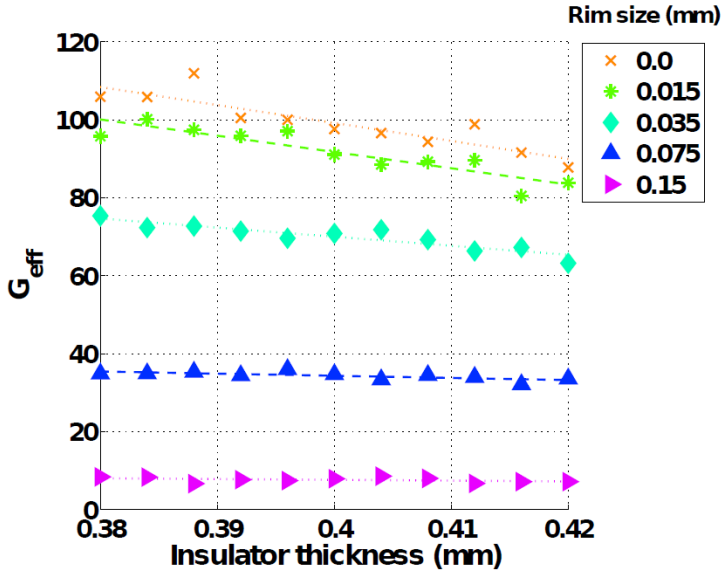
Parameters affecting the gain

- Geometric parameters to simulate:
  - **Insulator Thickness** increase -> avalanche gain decrease.
  - **RIM size** increase -> avalanche size decrease.
  - Pitch? Hole shape? Insulator materials?...
- Previous results are for static simulations - “snapshots” of a “clean” structures - what about **gain stability**?









Gain stability over time

- Environmental factors can affect the avalanche gain - temperature, pressure, gas purity, irradiation rate – probably not so interesting to simulate.

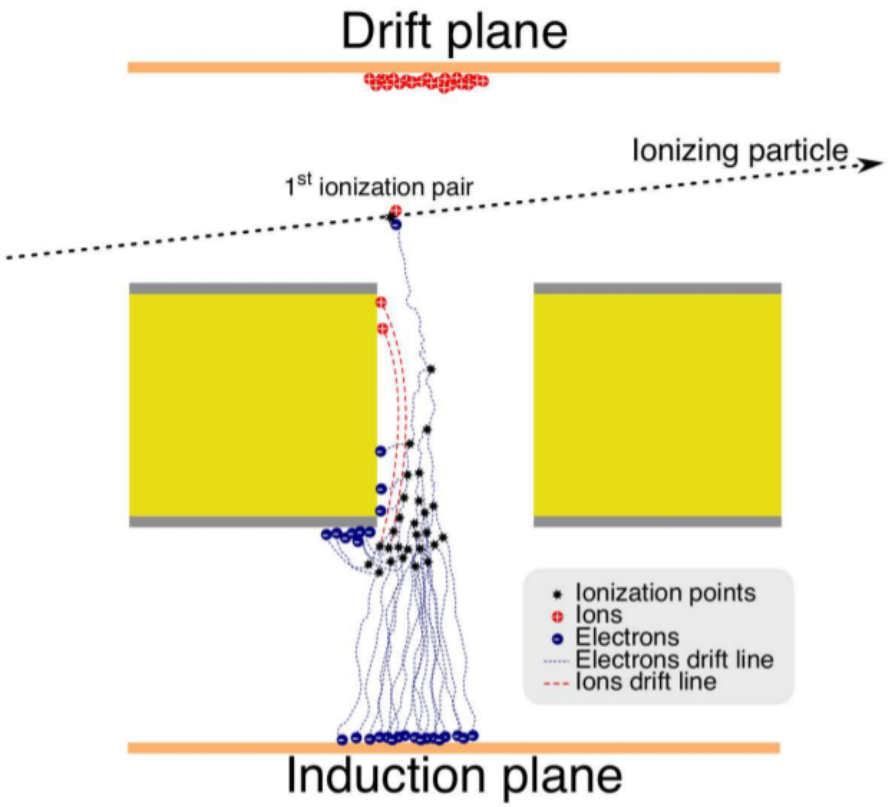
- Some works focused on gain variations due to **insulator charging-up** in MPGDs
  - M. Alfosi et al, NIMA 2012 "Simulation of the dielectric charging-up effect in a GEM detector"
  - Correia et al, JINST 2014 "A dynamic method for charging-up calculations: the case of GEM"
  - S. Dalla Torre JINST 2015 "The gain in Thick GEM multipliers and its time-evolution"
  - Correia et al, JINST 2018 "Simulation of gain stability of THGEM gas-avalanche particle detectors"
  - M. Pitt et al, JINST 2018 "Measurements of charging-up processes in THGEM-based particle detectors"

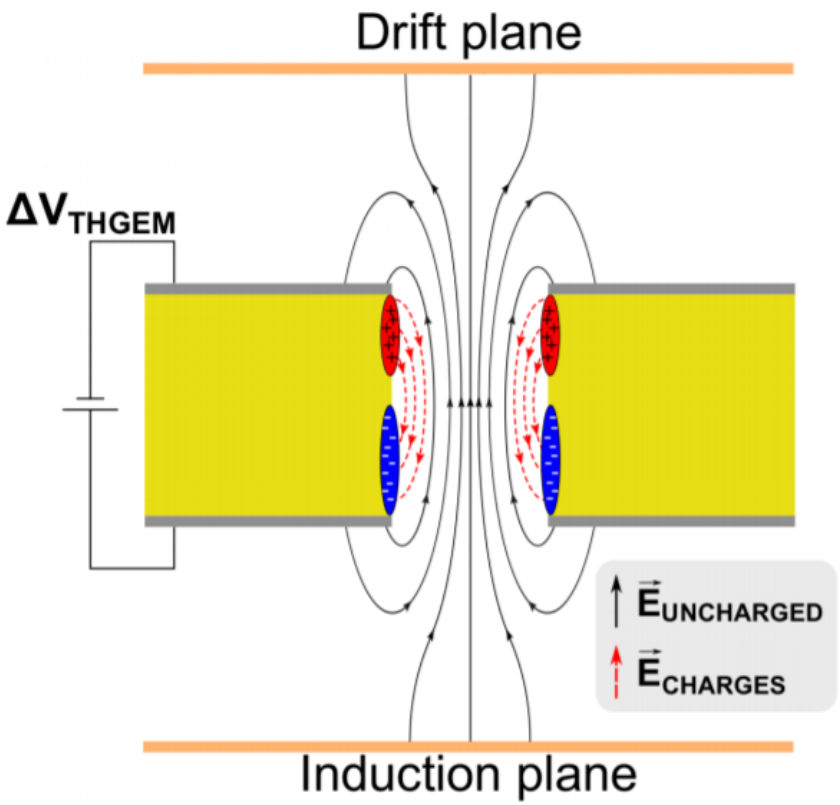
- **Discharges** are also known to change gain behavior on MPGDs and have also been investigated (I will not develop this topic on this talk):
  - P. Fonte et al "The physics of streamers and discharges" 2nd RD51 Collaboration Meeting
  - F. Resnati "Modelling of dynamic and transient behaviours of gaseous detectors", RD-51 Open Lectures 2017

Gain stability over time

- Insulator charging-up during avalanches:

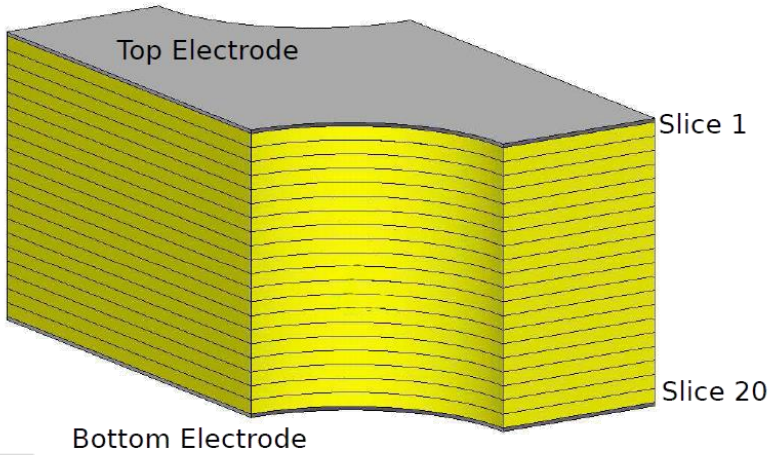
Correia et al, JINST 2018 "Simulation of gain stability of THGEM gas-avalanche particle detectors

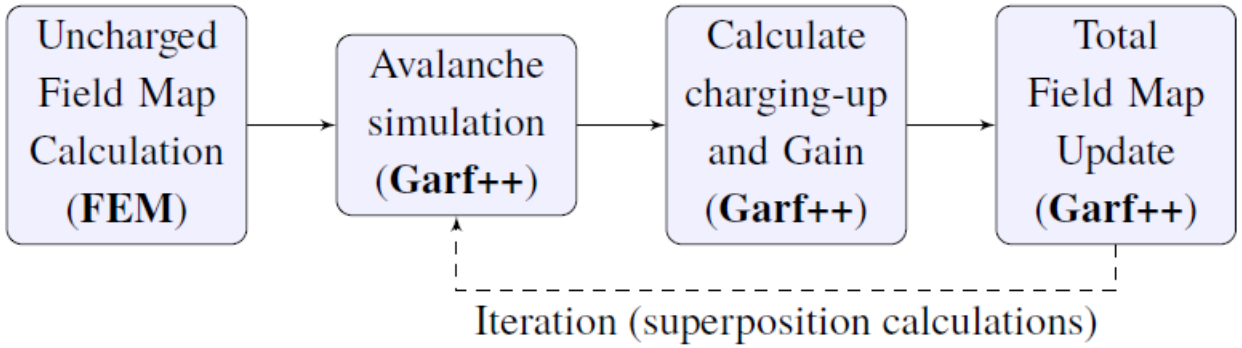




Gain stability over time

- Insulator charging-up during avalanches – The **algorithm**
- Starting point – Few initial field maps:
  - 1 for voltage applied to electrodes (*Uncharged* field map)
  - *N* for the insulator surfaces, divided in thin slices.
- Algorithm runs **entirely** inside Garfield++ (https://github.com/pmcorreia/Garfpp-chargingup and "How charging up affects THGEM detectors gain"

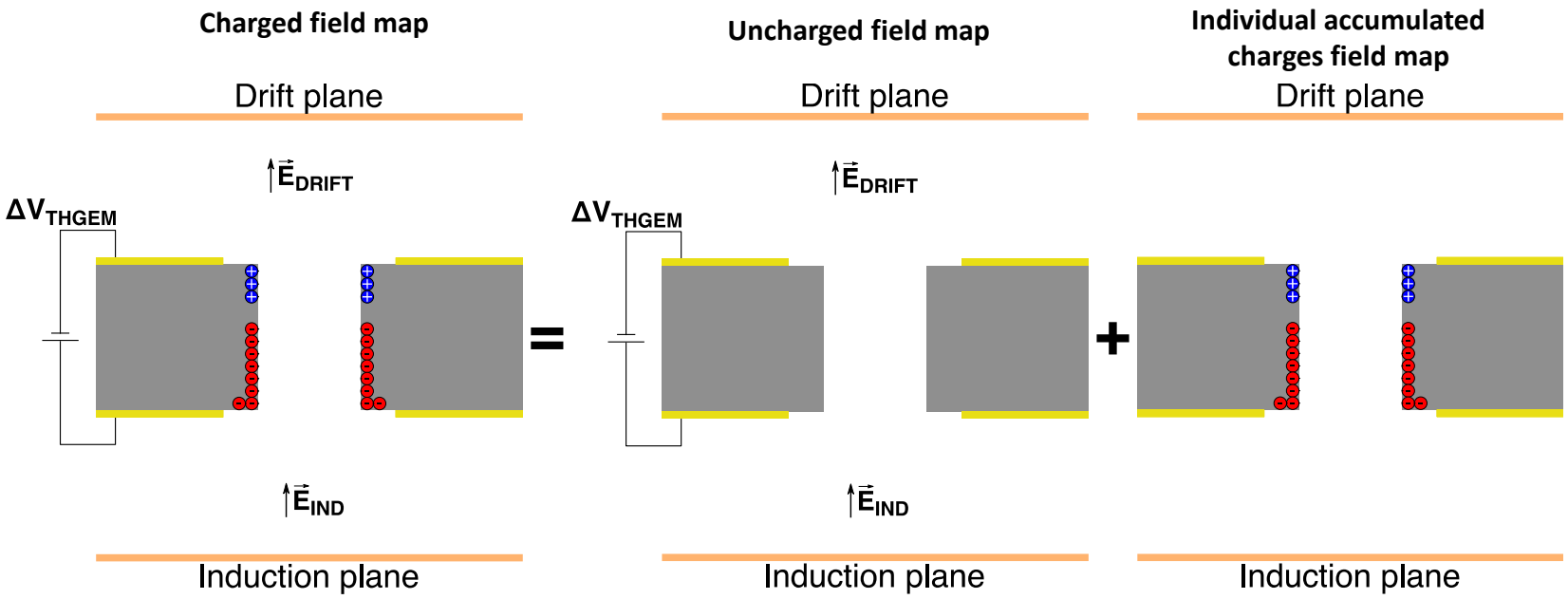


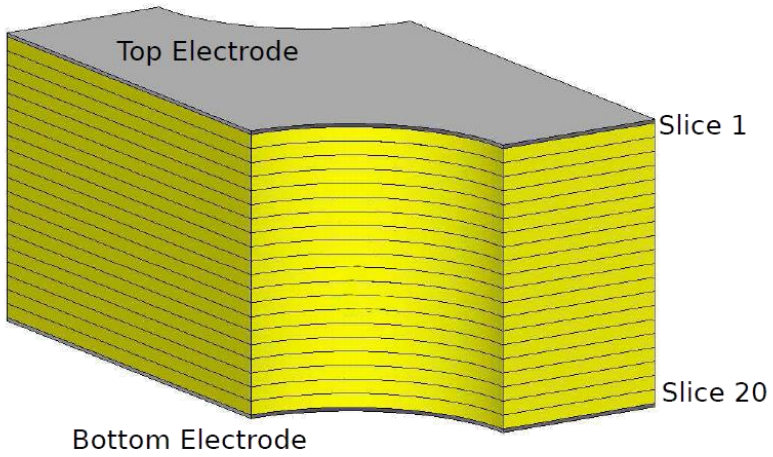


Gain stability over time

- Insulator charging-up during avalanches – The **algorithm**

$$V(charges, i) = V\ (uncharged, i) + N\ \times s \times V(j, i)$$





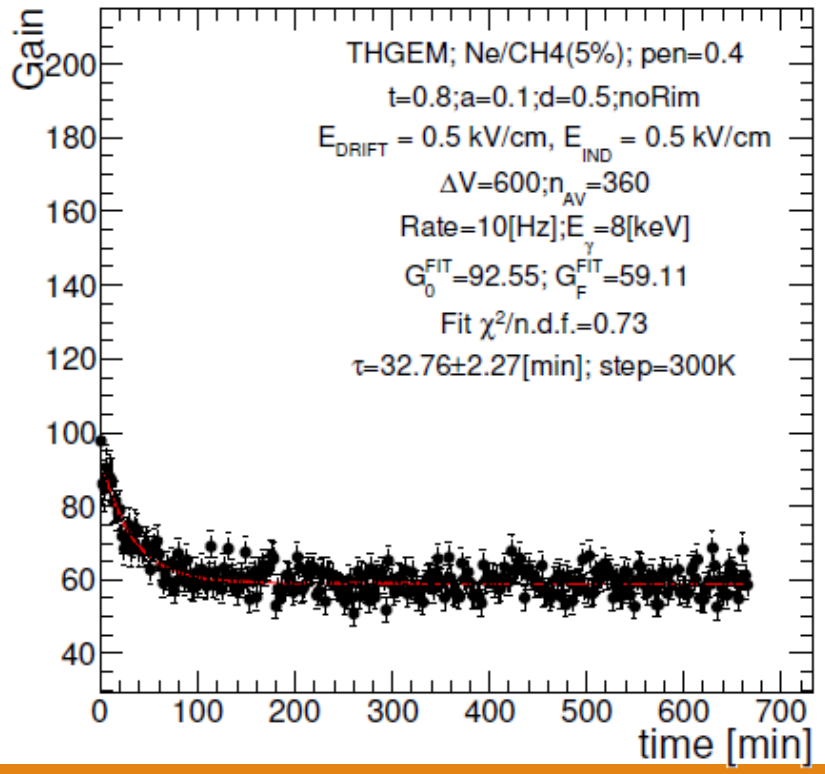
$\boldsymbol{V(j,i)}$ is the electric potential on node i due to the presence of a unitary charge in the surface of slice j

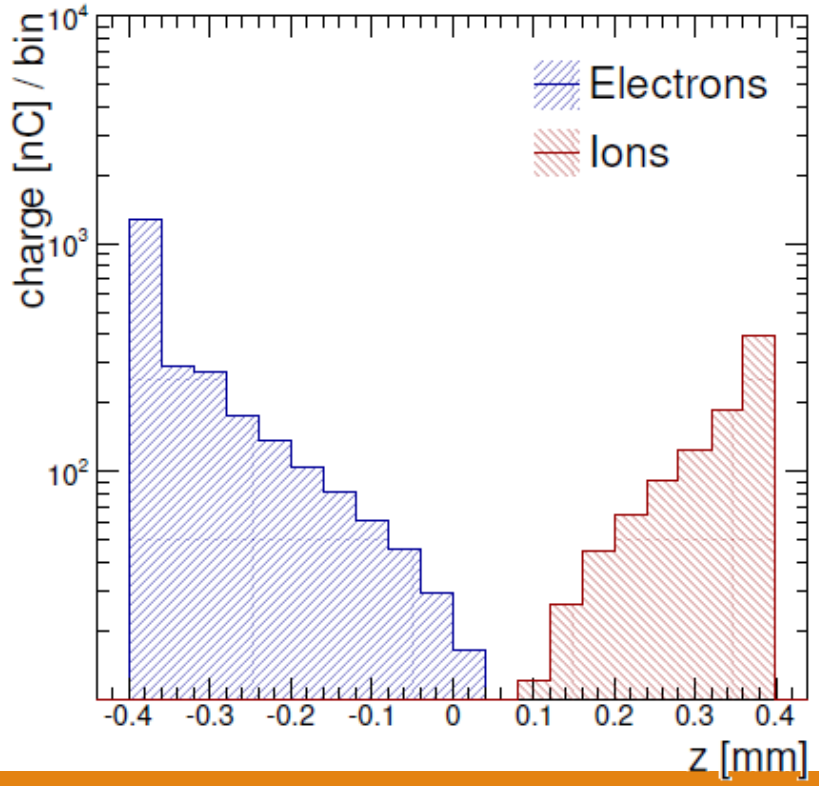
$\boldsymbol{N}$ is the number of accumulated charges on a given surface and iteration

$\boldsymbol{s}$ is a speed-up parameter for convergence

Gain stability over time

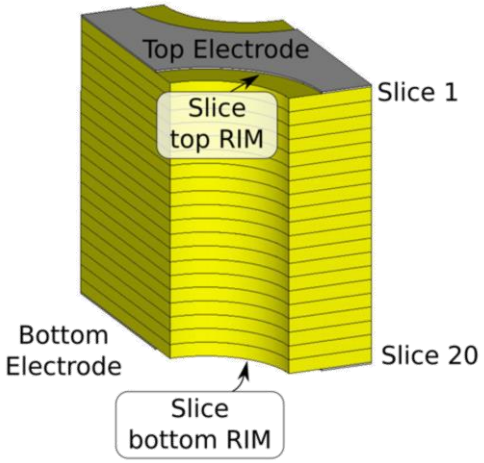
- Typical results (for THGEM without RIM): Gain drops and stabilizes after few minutes to few hours – **fast component**.
- Charge accumulation on the surface holes is not symmetric (neither constant during iterations)



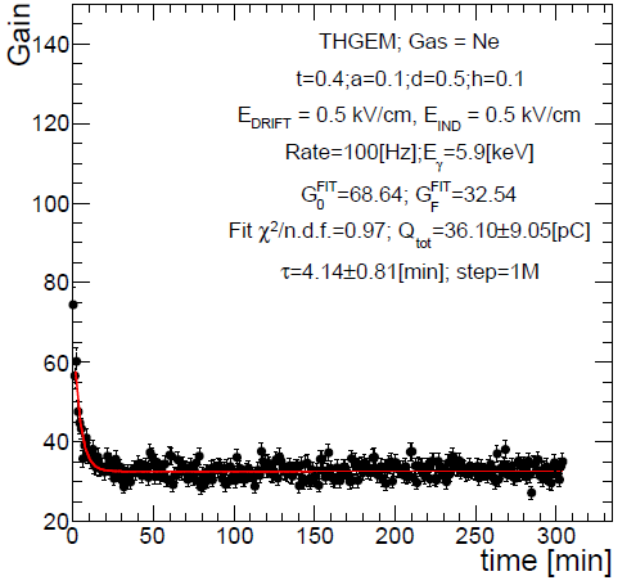


Gain stability over time

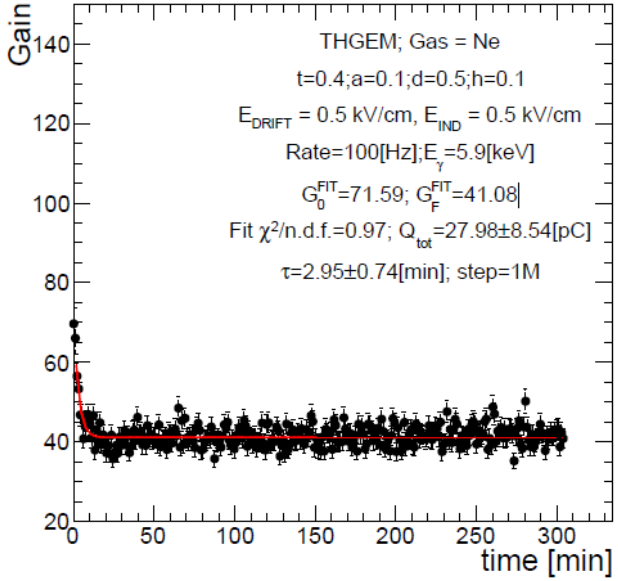
- Now considering the charge on the RIM (M. Pitt et al, JINST 2018 "Measurements of charging-up processes in THGEM-based particle detectors" - **Longer component appears, apparently due to TOP RIM charge accumulation.**
- Defined Total charge (Q_{tot}) as the charge accumulated during relaxation period.



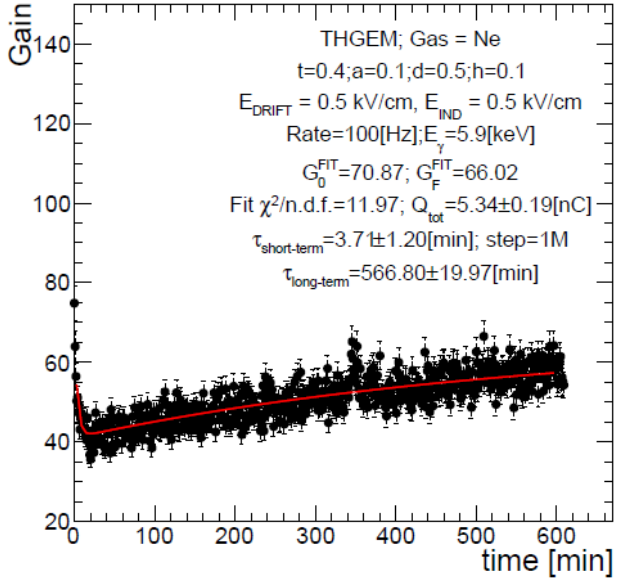
None of the RIMs charged up



Only BOT RIM charged up

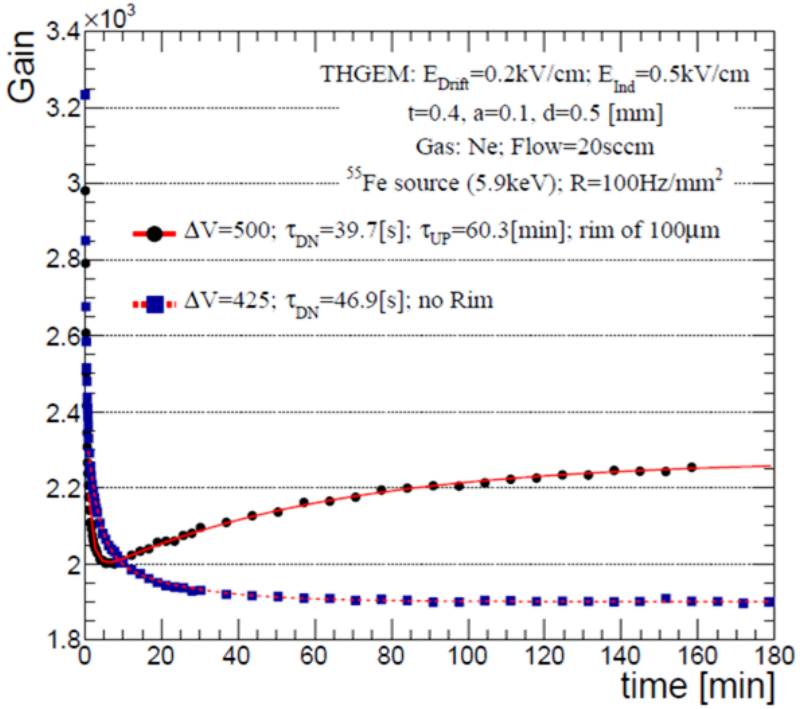


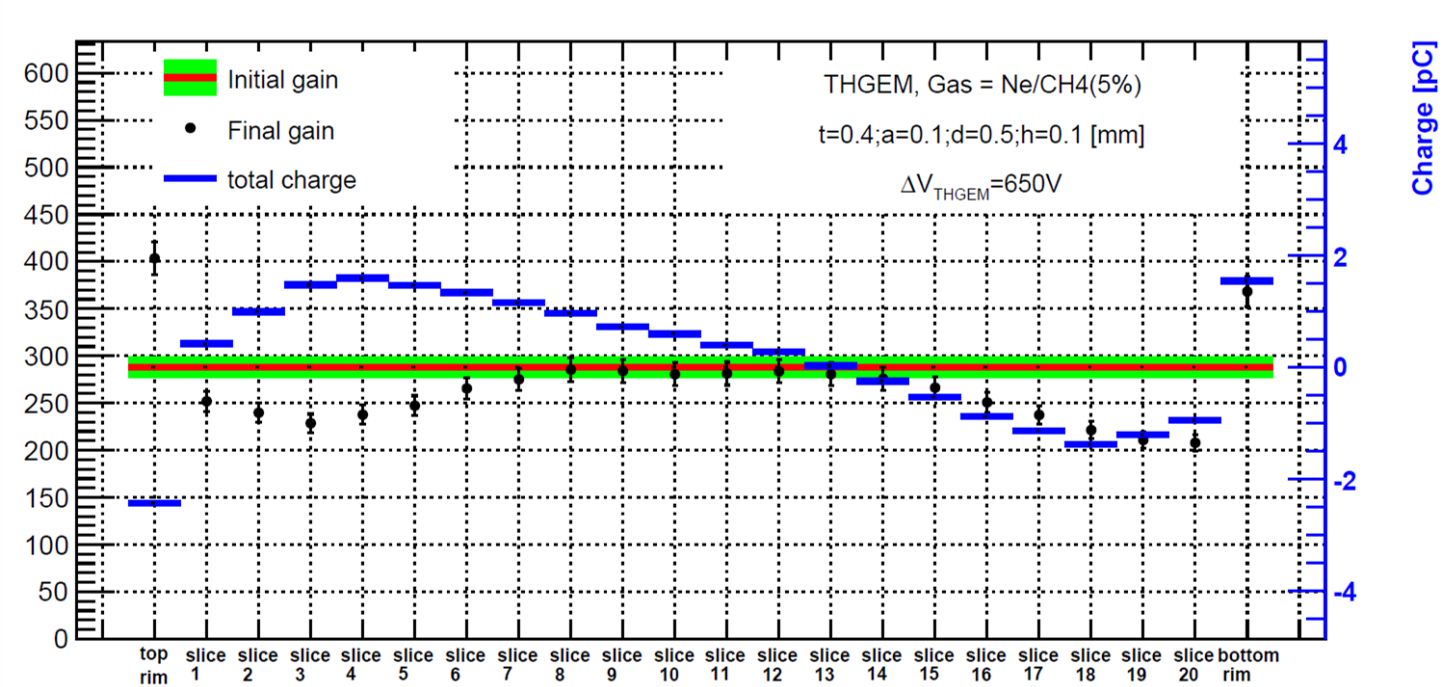
Both RIMs charged up



Gain stability over time

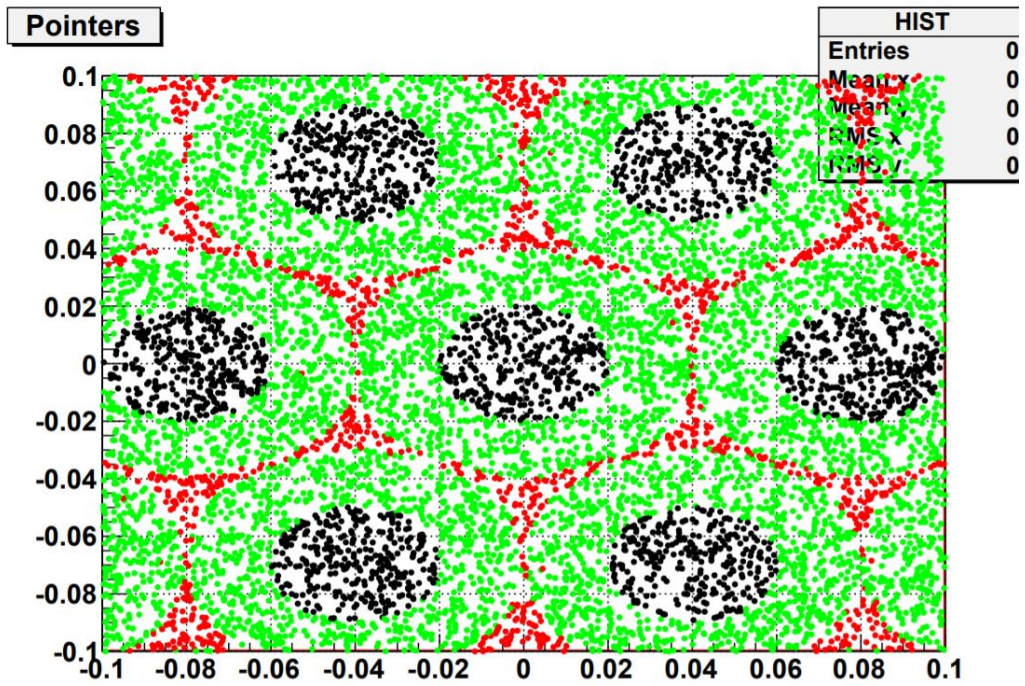
- Now considering the charge on the RIM (M. Pitt et al, JINST 2018 "Measurements of charging-up processes in THGEM-based particle detectors" - Comparison between **No RIM** and **100 µm RIM (left)** and effect on the gain due to the **accumulated charge on each insulator slice** (right).

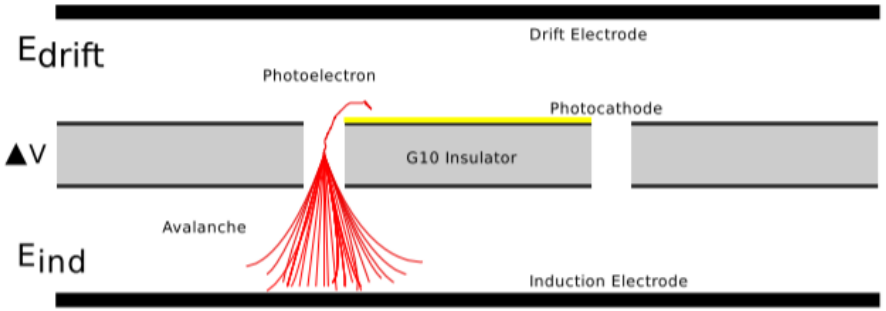


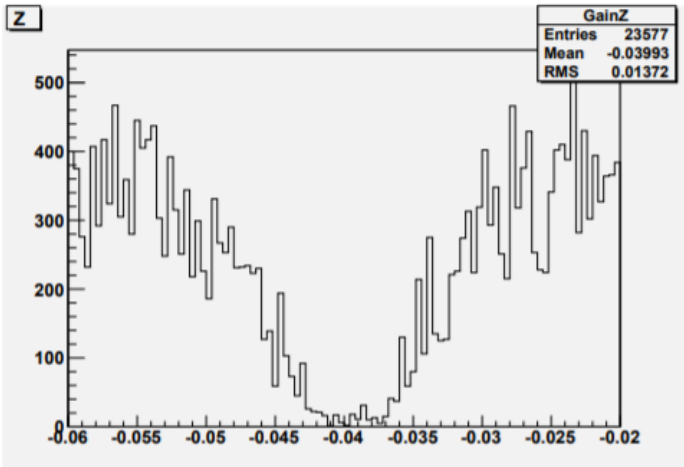


Another application: Photoelectron extraction

- When using a photocathode on top of the THGEM, some extracted photoelectrons doesn't produce avalanches.
- Photoelectrons originated in the effective area (green) are more likely to produce avalanches, therefore contribute to the signal amplification.
- The avalanche gain is also not constant along the **pitch** – depends on **drift field**.
- (Parameters not considered in this study – different RIM, thickness, charging-up,…)







Martinez et al, "Photon DetectionWith a Thick GEM", CERN summer student 2012

Main conclusions

- Simulation of MPGDs has been an important tool in the design and understanding of the detectors.
- Often rely in the use of **Garfield/Garfield++** interfaced with other software.
- Geometric parameters of the detectors and the gas mixture properties can be responsible for different results if not used properly (eg: not considering **Penning effect** in gas mixtures).
- Gain variation over time due to charging-up simulation can be simulated and match experimental results, quantitatively:
  - Accumulated charge Q_{tot} needed for stabilization increases with the decrease of insulator thickness or increase of V_{THGEM} – usually within few minutes to hours.
  - RIMs play an important rule in the effect, specially the TOP RIM responsible for a **long term component** of the gain variation, while the BOTTOM RIM **increases** the total gain.
- These studies didn't consider charges **flow in the insulator surface and bulk**, neither **insulator polarization** due to potential applied to electrodes - should be related with even longer components of gain variation (**up to days**).

Acknowledgments

Many thanks to

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