GEM simulations: a flexible and efficient microscopic model based on Garfield++

CERN RD51 Collaboration Meeting
21 / Oct / 2019

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- **Experimental Context**
- **Simulation tools**
- **Models/Approaches**
- **Results**

SuperBigbite Spectrometer for HallA @ JLab

Physics:
Nucleon Form Factors at high Q^2
Neutron spin and TMD's, high statistics, high xB
Pion structure functions
… an experimental tool for hadron structure investigation

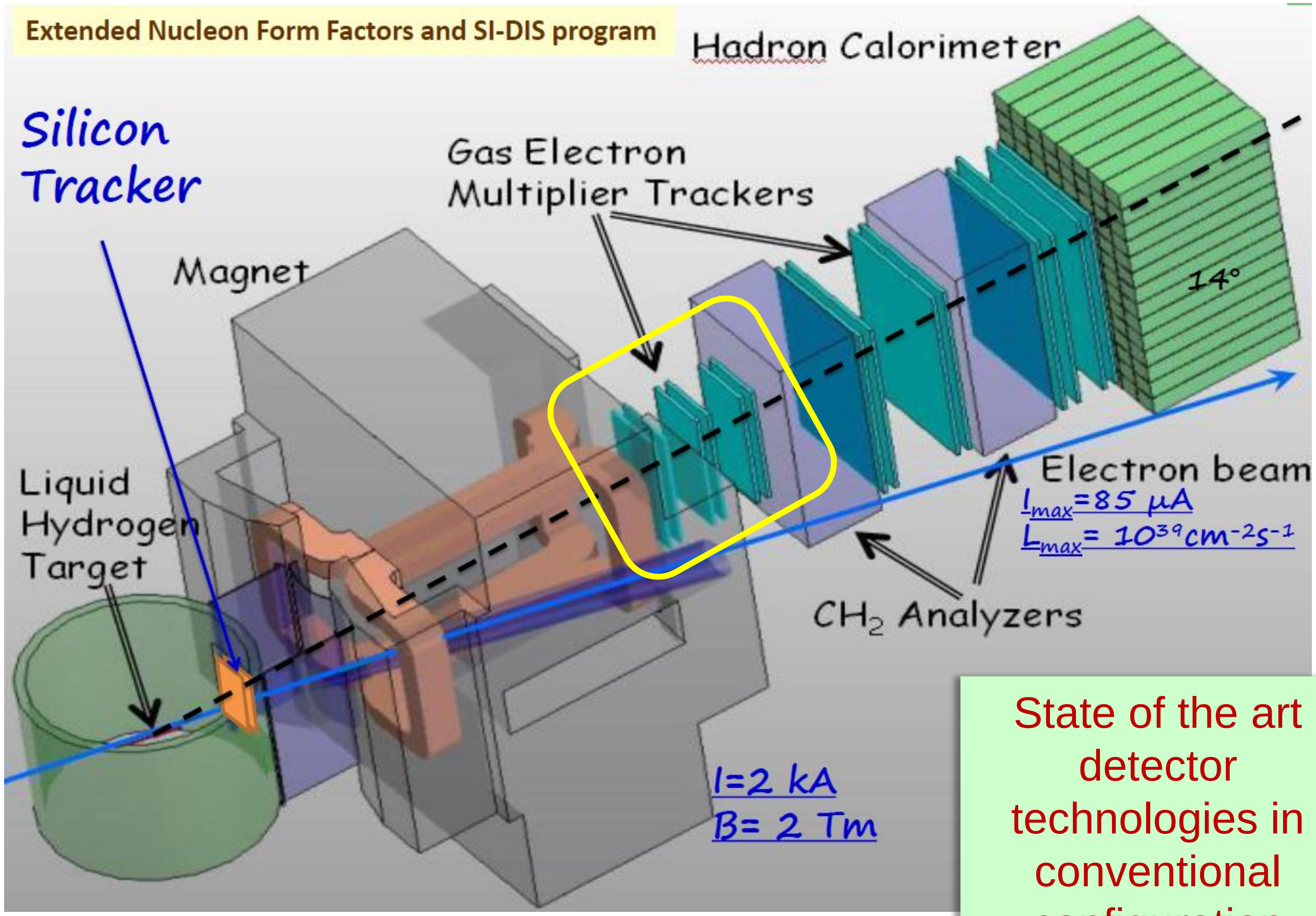
- **Large luminosity**
- Moderate acceptance
- Forward angles
- Reconfigurable detectors

Expected Background:

photon (250 MHz/cm2)

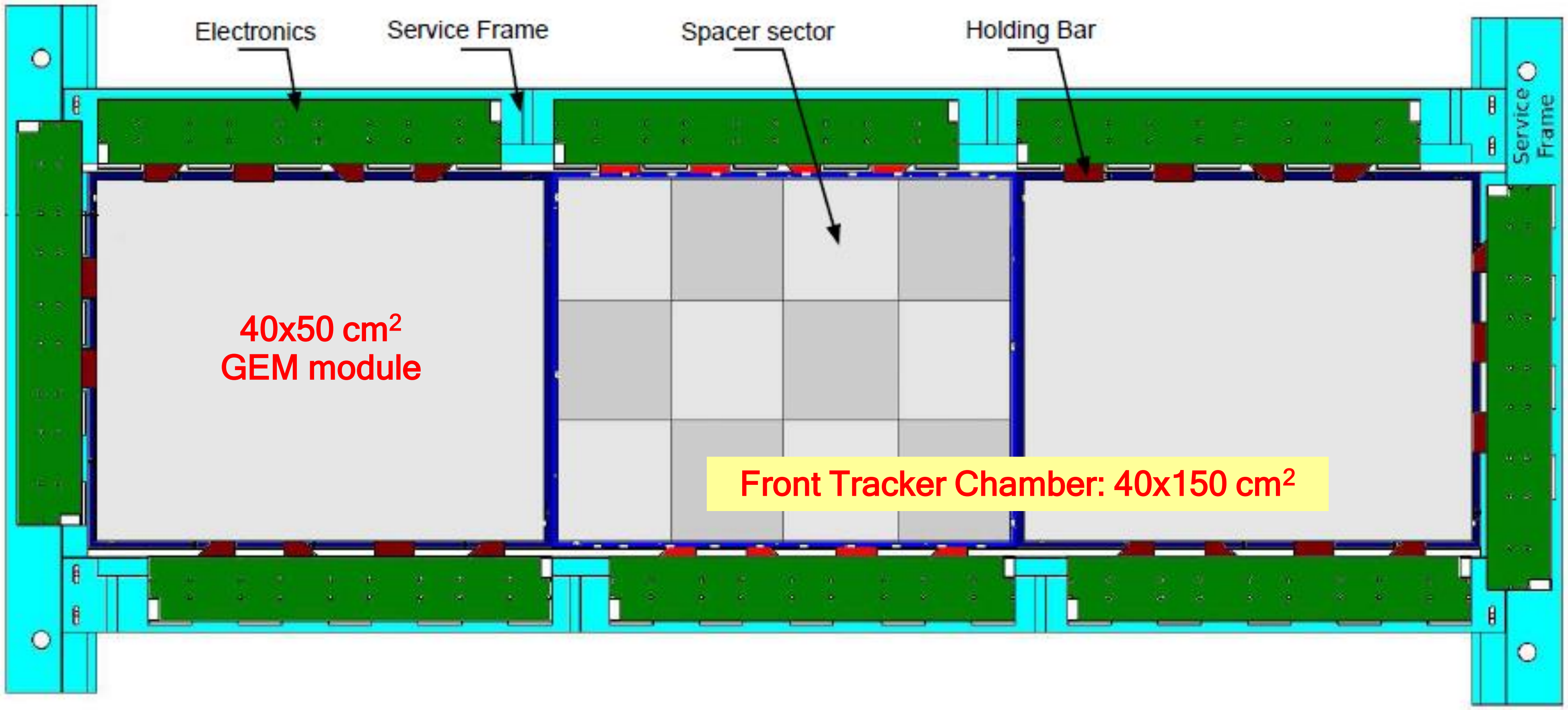
charged (160 kHz/cm2)

Kondo GNANVO talk (tomorrow on SBS GEMs Commissioning)



State of the art detector technologies in conventional configuration

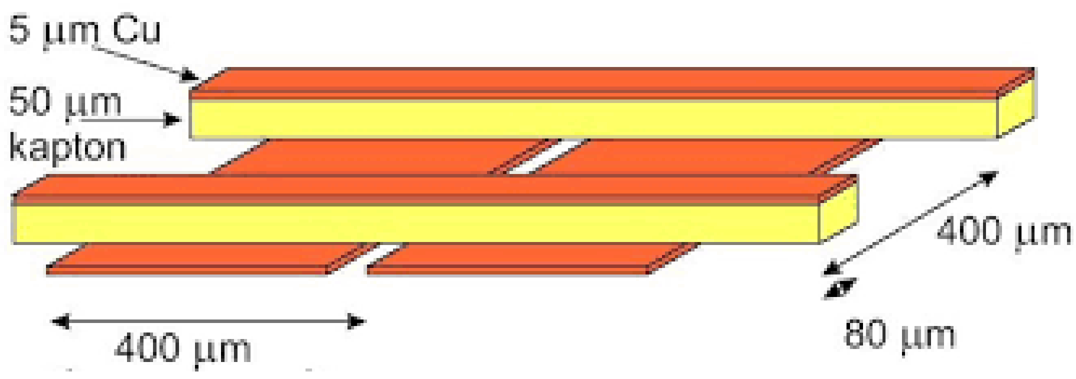
Front Tracker GEM for SBS



3xGEM: single mask GEM foil production

x/y Strip Readout Plane (a la COMPASS)

Double strips with 90° angle



Main Tools / Libraries

Two years ago we decided to implement a «microscopic» GEM simulator to better model the real behavior of the tracker and to prepare for the physics experiments

<table>
<tr><td>Geometric Model Definition</td><td rowspan="2">GMSH (3.05 and 4.0.7)
OpenCascade</td><td rowspan="3">ANSYS
Multiphysics
(R17-19)</td></tr>
<tr><td>Mesh Generation</td></tr>
<tr><td>Electrostatic Field Solution</td><td>ELMER (2018)</td></tr>
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Photoabsorption ionization</td><td colspan="2">HEED</td></tr>
<tr><td>Microscopic Gas Simulator</td><td colspan="2">Garfield++ (v3)</td></tr>
<tr><td>Automate and parallelize
multiple simulations</td><td colspan="2">Bash scripts</td></tr>
<tr><td>Analysis/Visualization</td><td colspan="2">ROOT</td></tr>
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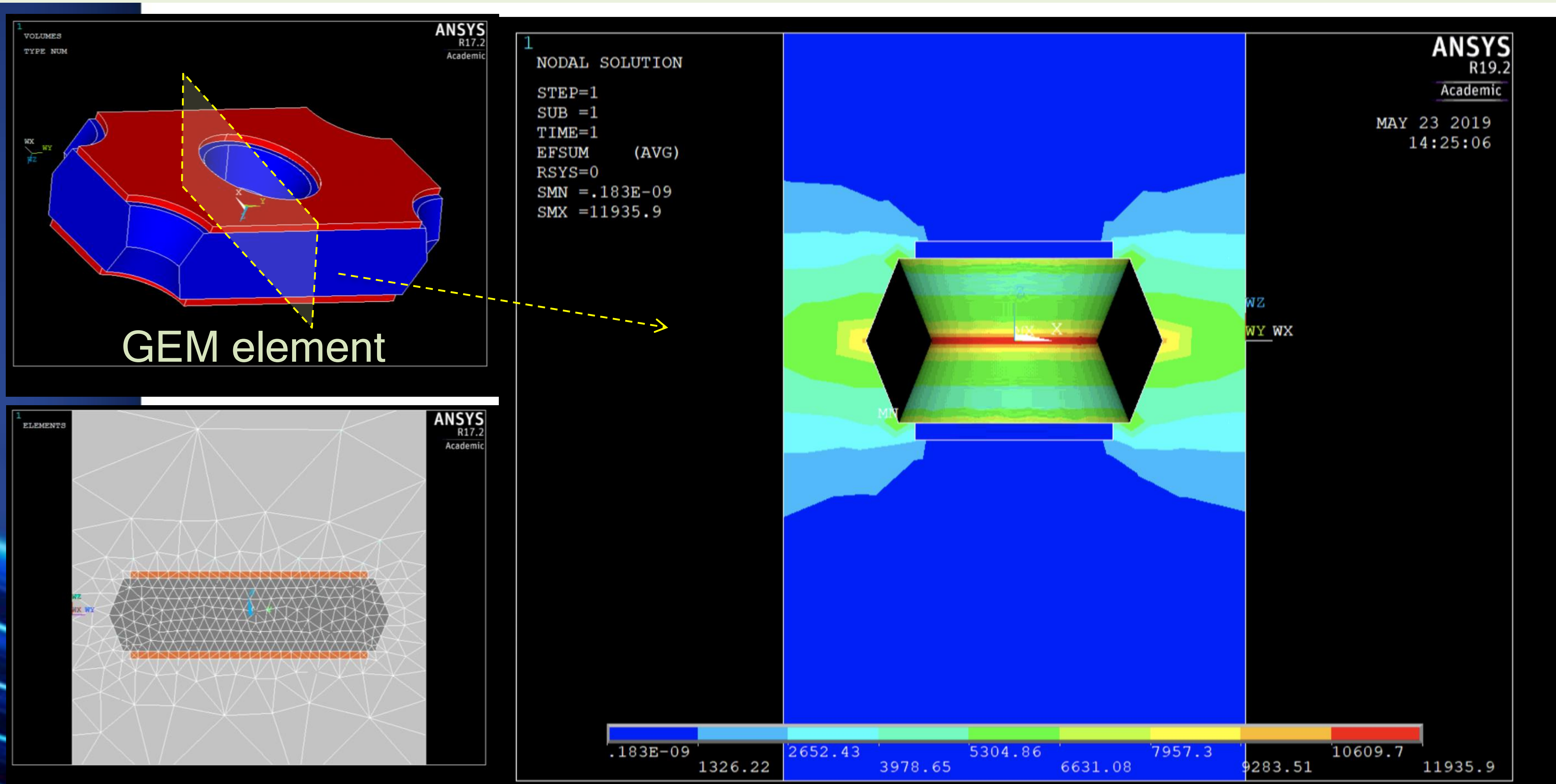
All steps are implemented programatically

ANSYS Mechanical APDL software

Engineering software useful to create complex geometries, assign materials to different volumes and create electrostatic field solutions.

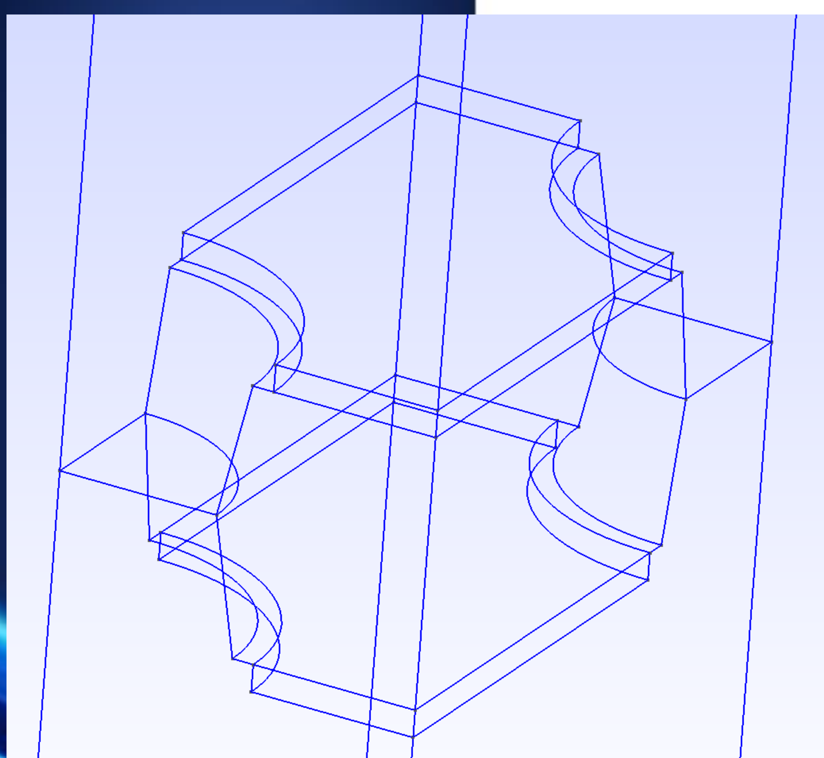
Model design, mesh generation and electrostatic field within a reasonably coherent framework; mesh generation is well optimized; better visualization tools; need license

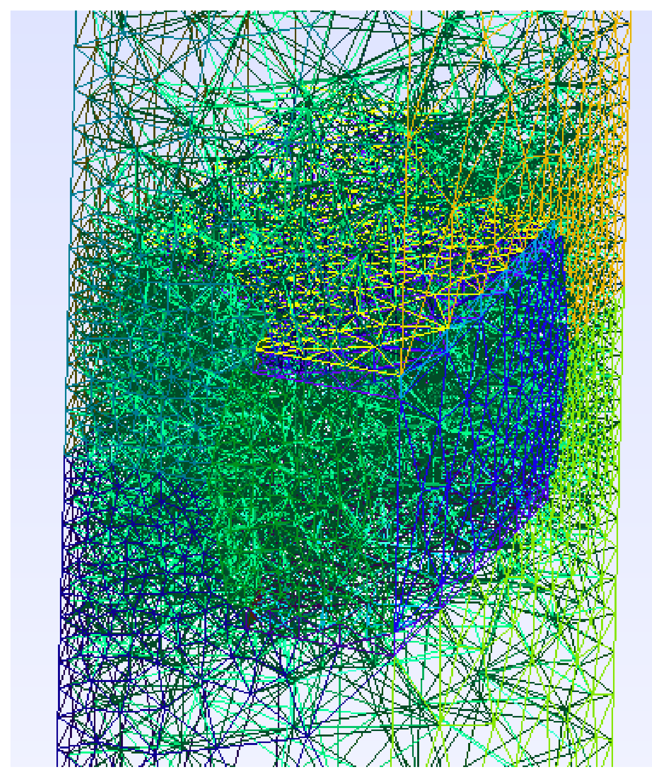


GMSH + ELMER

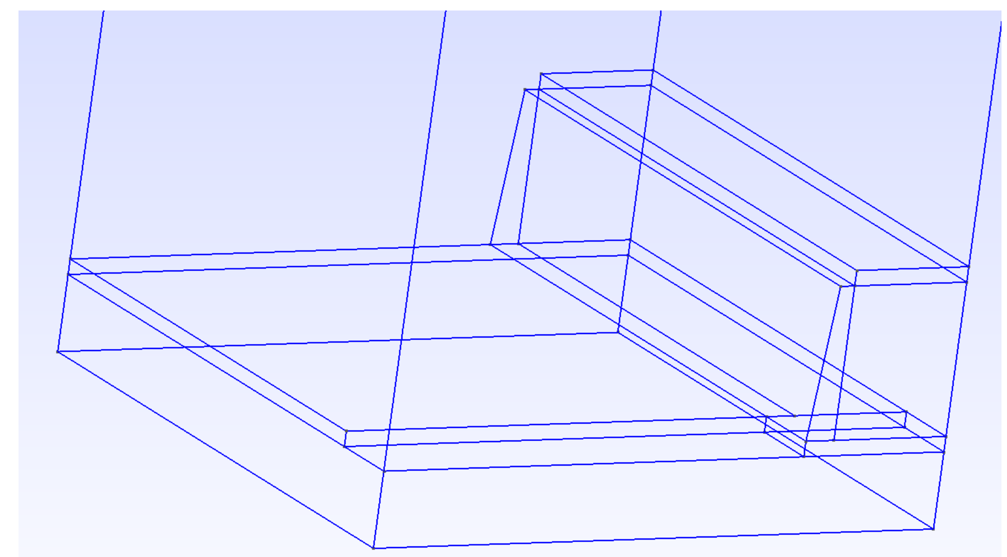
Open source software; reasonably well documented; somehow more flexible scripting language (c/c++ oriented) than in ANSYS
GMSH versions incompatibility, decent mesh generation (and field solution) is not straightforward as in ANSYS

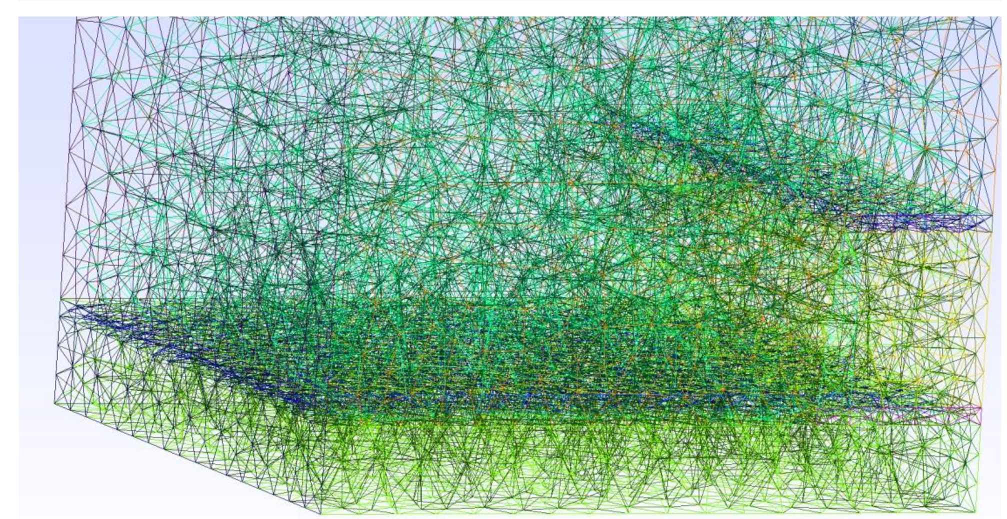
GEM foil element





x/y strip readout





Denser mesh nodes near foil parts

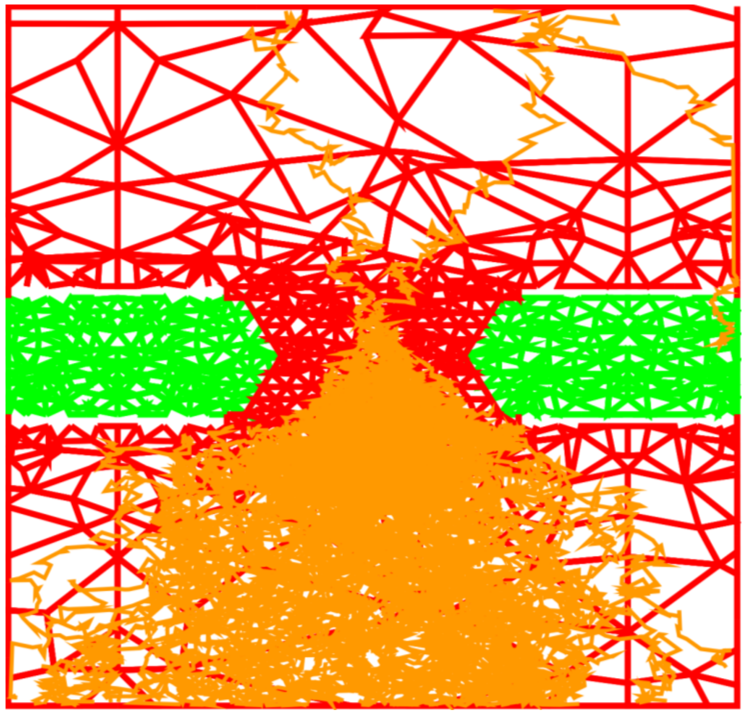
Garfield++ tool

HEED: simulate the photoabsorption ionization of the high energy particles (GeV electrons and protons)

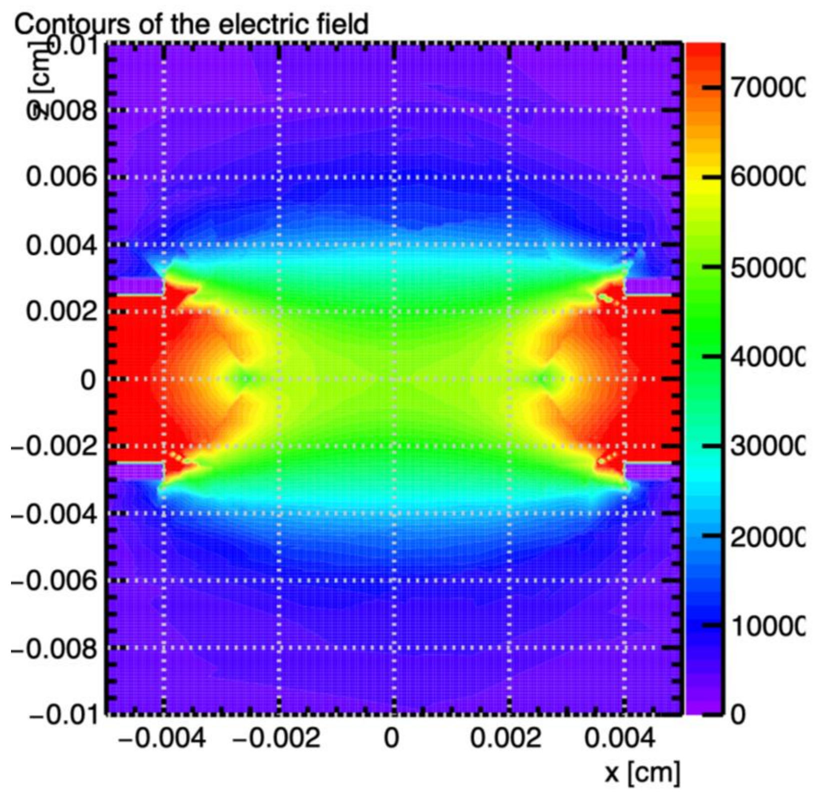
Magboltz: define the atomic and thermodynamic characteristic of the gas: Mixture **70% Argon** and **30% CO_2** (at STP); Penning Transfer ON

Garfield++: AvalancheMicroscopic for e- and AvalancheMC for ion

ROOT: for analysis and visualization



Avalanche creation and its protagation

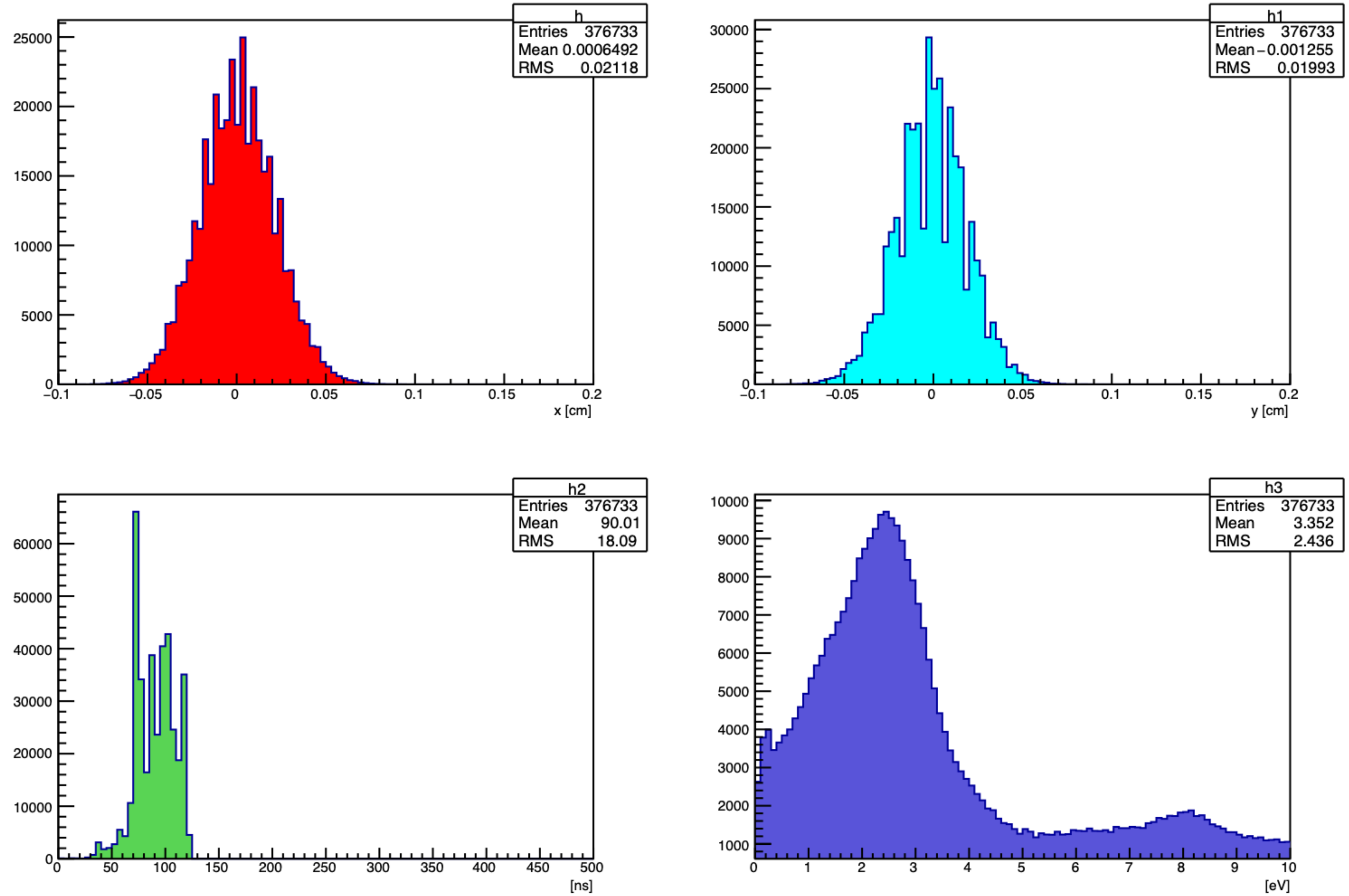


Electric Field map

Microscopic Simulations

Systematic study to verify the consistency of the simulations:

- Number of secondary electrons reaching the readout plane (strips)
- Spatial distribution of the avalanche (x and y axes)
- Secondary electrons drift time
- Energy of the particles in the readout plane



Simulations models

Single GEM foil

Simulate 2.8 GeV protons passing trough a single GEM chamber with ideal readout plane. Used to compare GMSH+ELMER and ANSYS models

Multistep 3xGEM+RD

Microscopic simulations are carried on each GEM layer in a sequential way: simulation outcome of the previous layer is the input of the next.

It's a flexible multistep model that easily allows to simulate different schemes, imperfections, foil misalignment, by decomposing the 3xGEM+Readout chamber in 4 adjacent layers.

Full 3xGEM

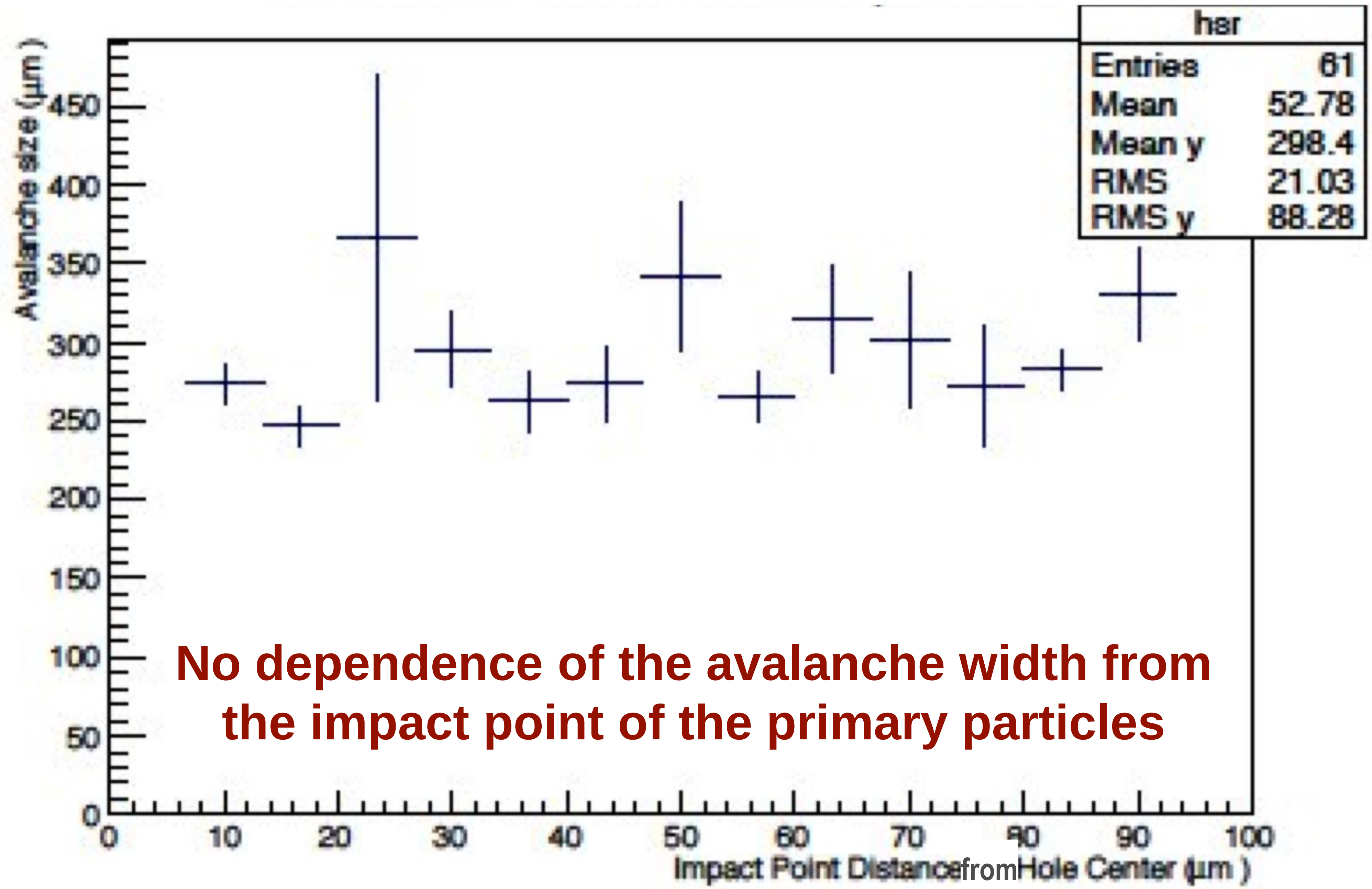
Microscopic simulations are carried from the drift plane, trough the 3 GEM foils, to an ideal readout plane.

Segmentation of the readout plane is performed on the collected electrons (no readout structure in the simulation)

Somehow used as reference and comparison for the multistep model.

Simulation - some consistency checks

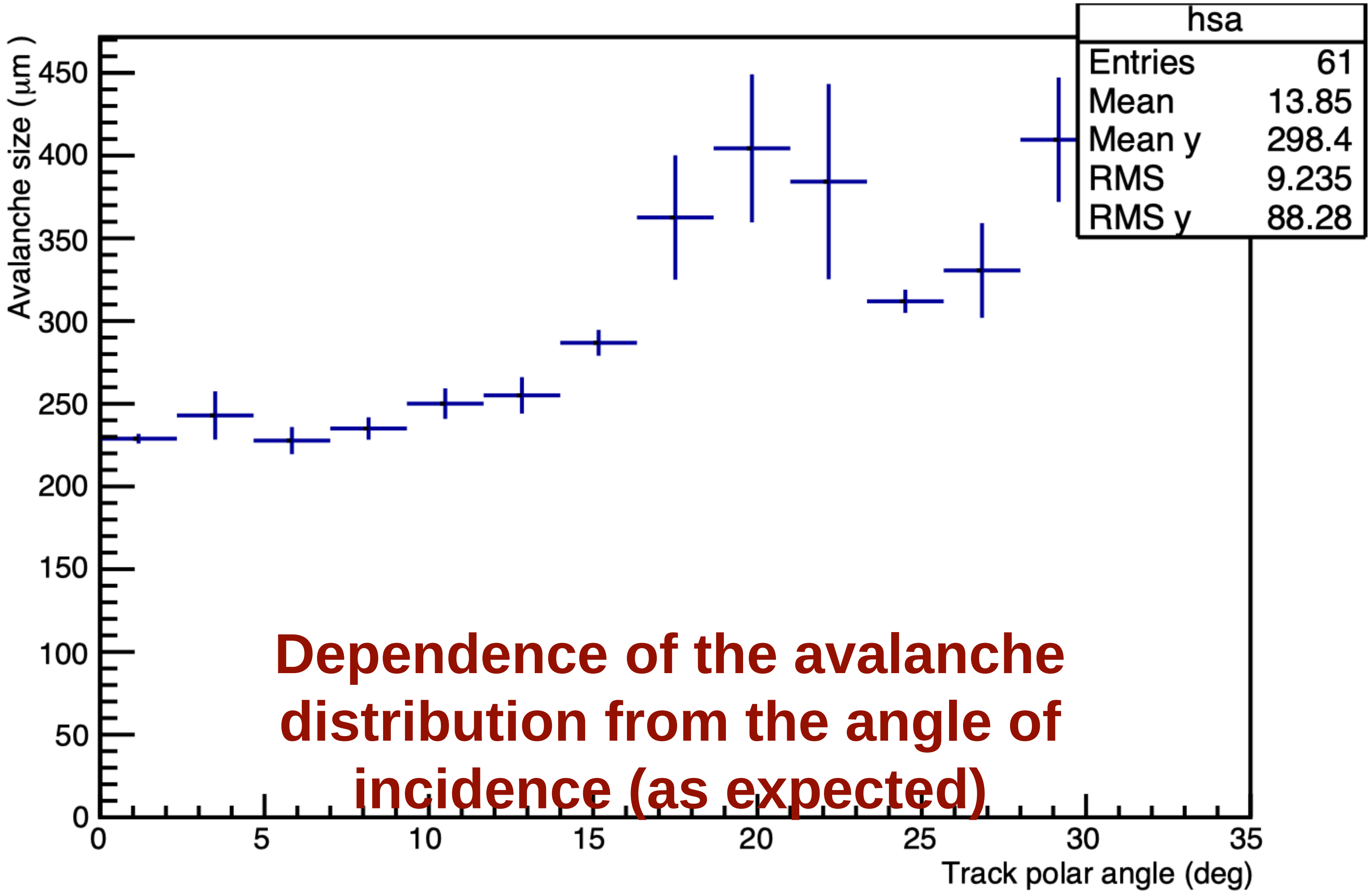
Avalanche width VS impact point of primary particles



No dependence of the avalanche width from the impact point of the primary particles

Simulation - some consistency checks

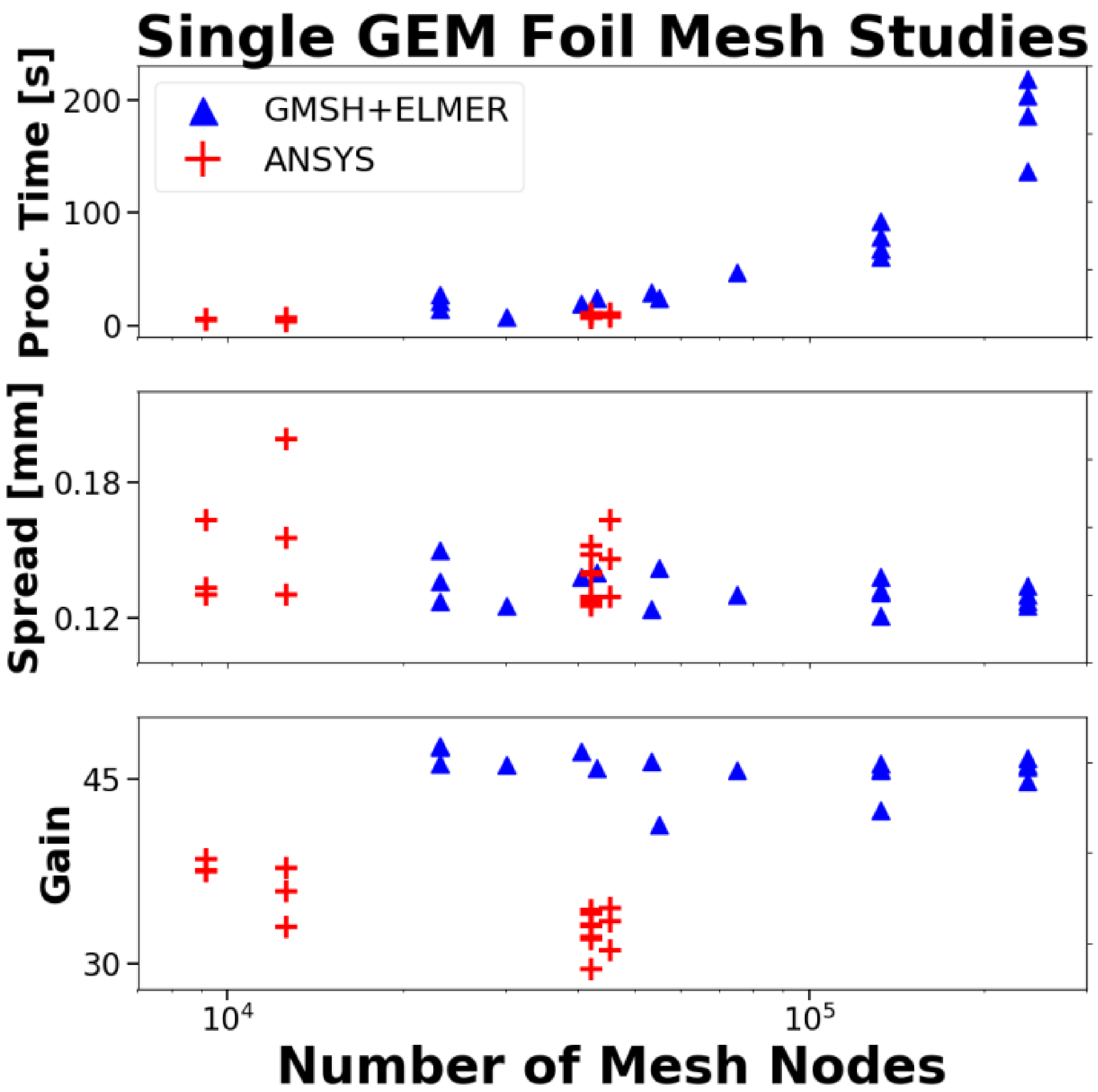
Avalanche width VS incidence angle of primary particles



Incidence Angle	0°	10°	30°
RMS	233 µm	295 µm	381 µm

Single GEM: GMSH+ELMER vs ANSYS

We compared response of single GEM foil simulation from both modellers/solvers at different mesh sizes



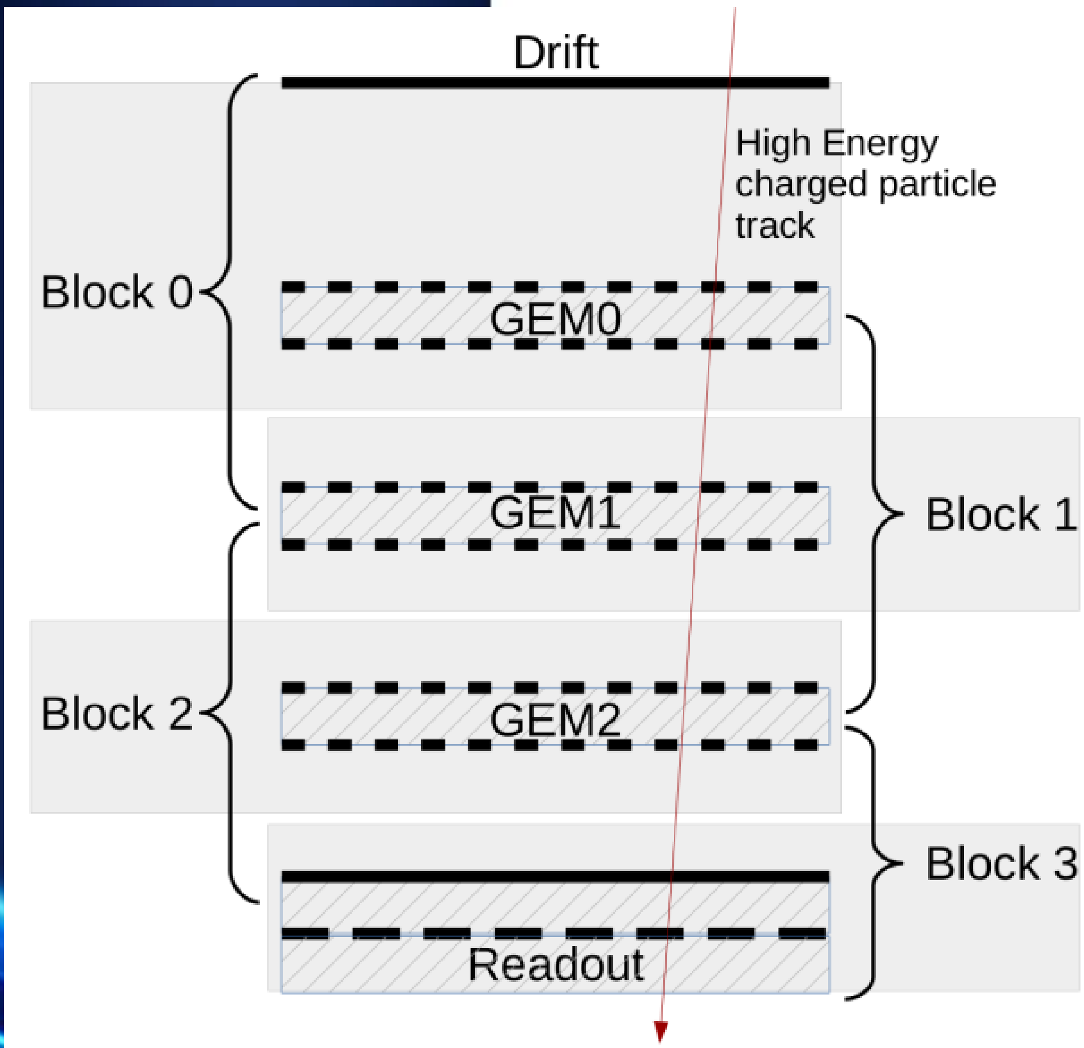
2.8 GeV protons, 0 incidence angle on Drift [-1836 V] +3 mm + [-1116 V] GEM [-721 V] + 2 mm + [0 V] ideal readout

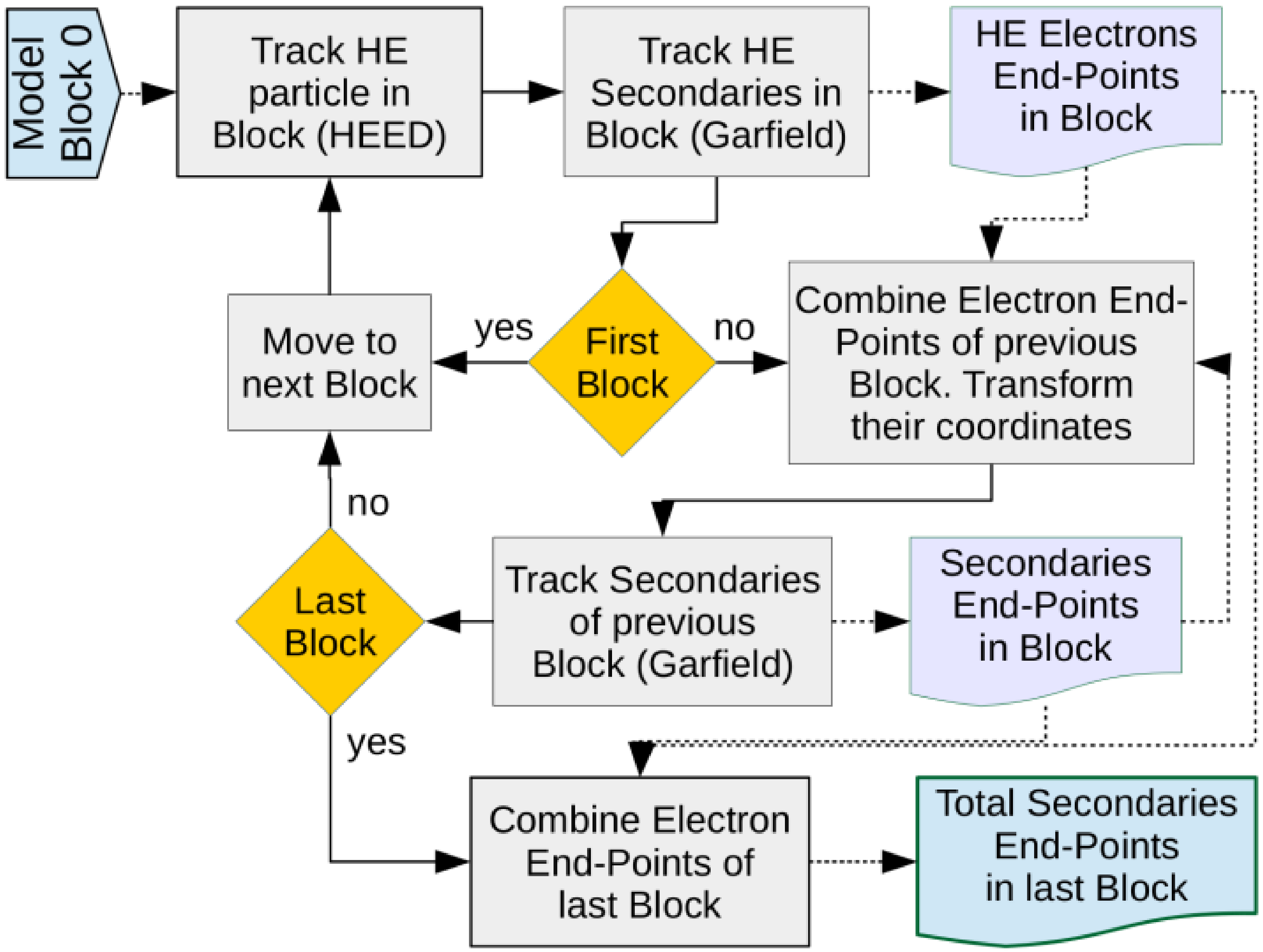
- Processing times and Avalanche spread consistent between G+E and A
- Avalanche spreads (x/y show similar spreads) reasonably constant over mesh size, but larger meshes produce more stable results
- Gains discrepancy between G+E and A; G+E based simulations look more stable over mesh size

Gain = average number of electrons collected after the GEM foil on an ideal readout plane, for each primary ionized electron

Multistep - 3xGEM+RD approach

Assume approximate independence of each GEM foil response:
the 3×GEM+Readout is decomposed into 4 overlapping simulation blocks





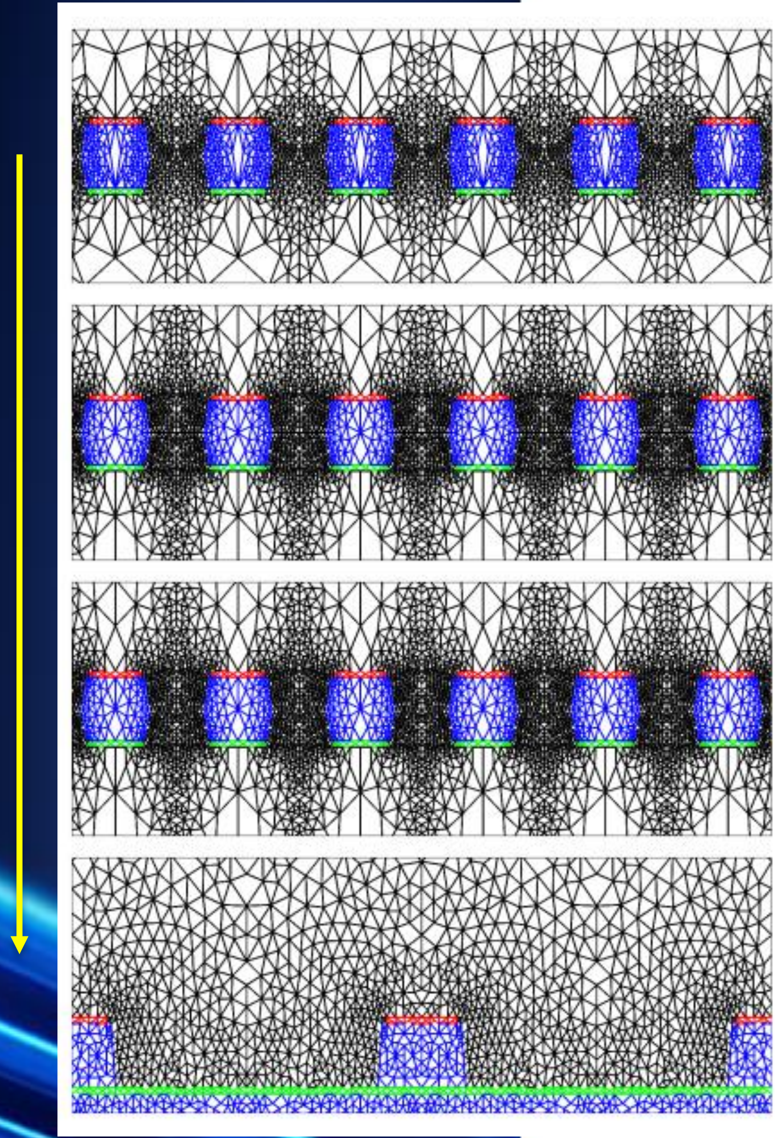
Flexible approach, easy integration of readout plane, allows to simulate different schemes, imperfections, foil misalignment

DO NOT CONSISTENTLY HANDLE ions drift on different blocks (YET)

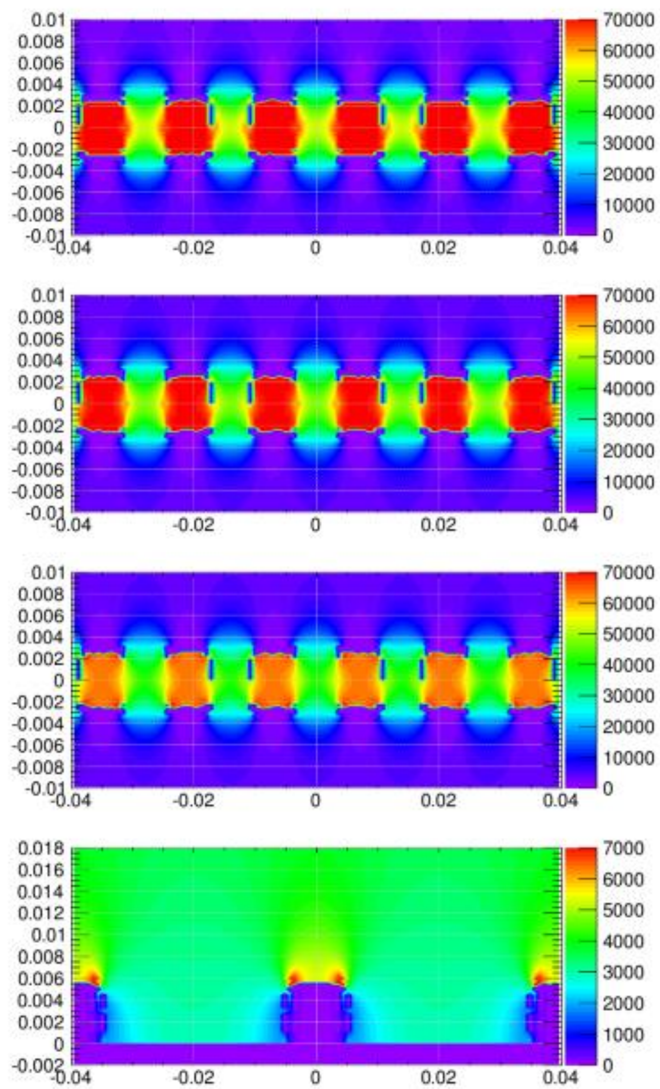
Multistep – 3xGEM+RD model and simulation

GMSH + ELMER models simulated

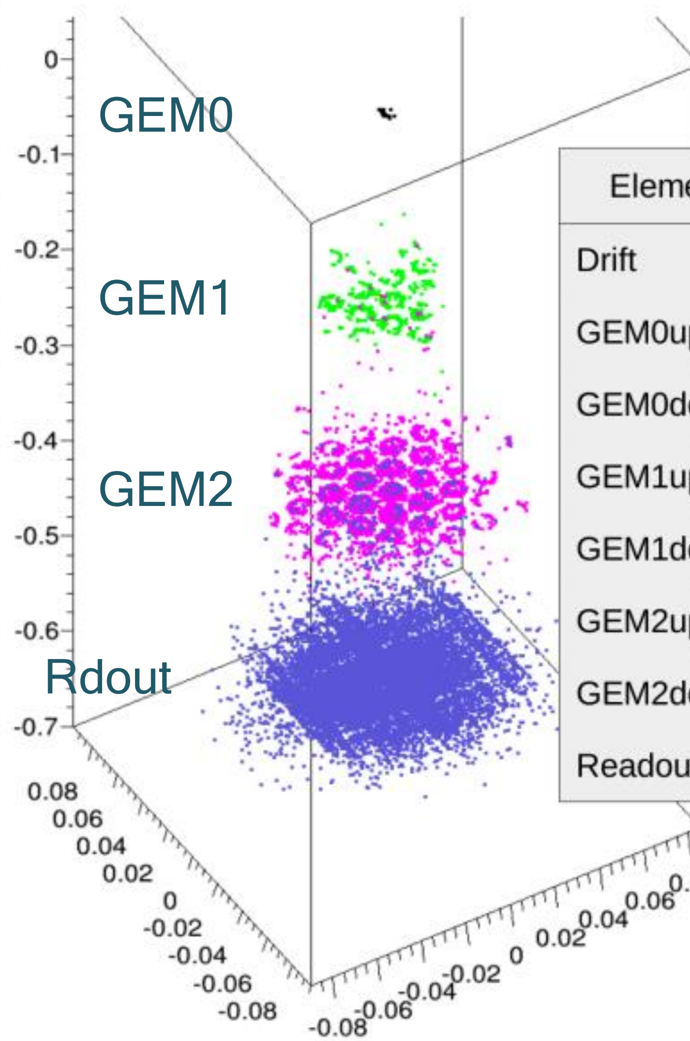
Mesh



Electrostatic Field



Garfield e- endpoints

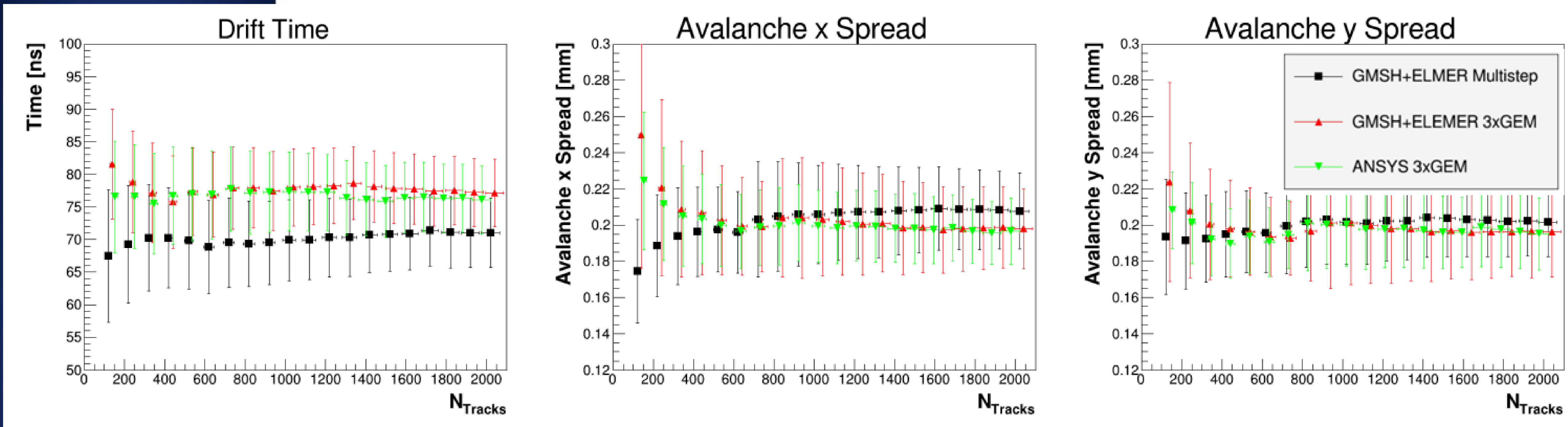


Element	Bias (V)	Block			
Drift	-3955	0			
GEM0up	-3235	0			
GEM0down	-2840	0	1		
GEM1up	-2119	0	1	2	
GEM1down	-1760		1	2	
GEM2up	-1039		1	2	
GEM2down	-721			2	3
Readout	0				3

Each block is simulated in sequence (following avalanche development)

Different approaches comparison

GMSH+ELMER multistep approach and full 3xGEM
ANSYS on full 3xGEM

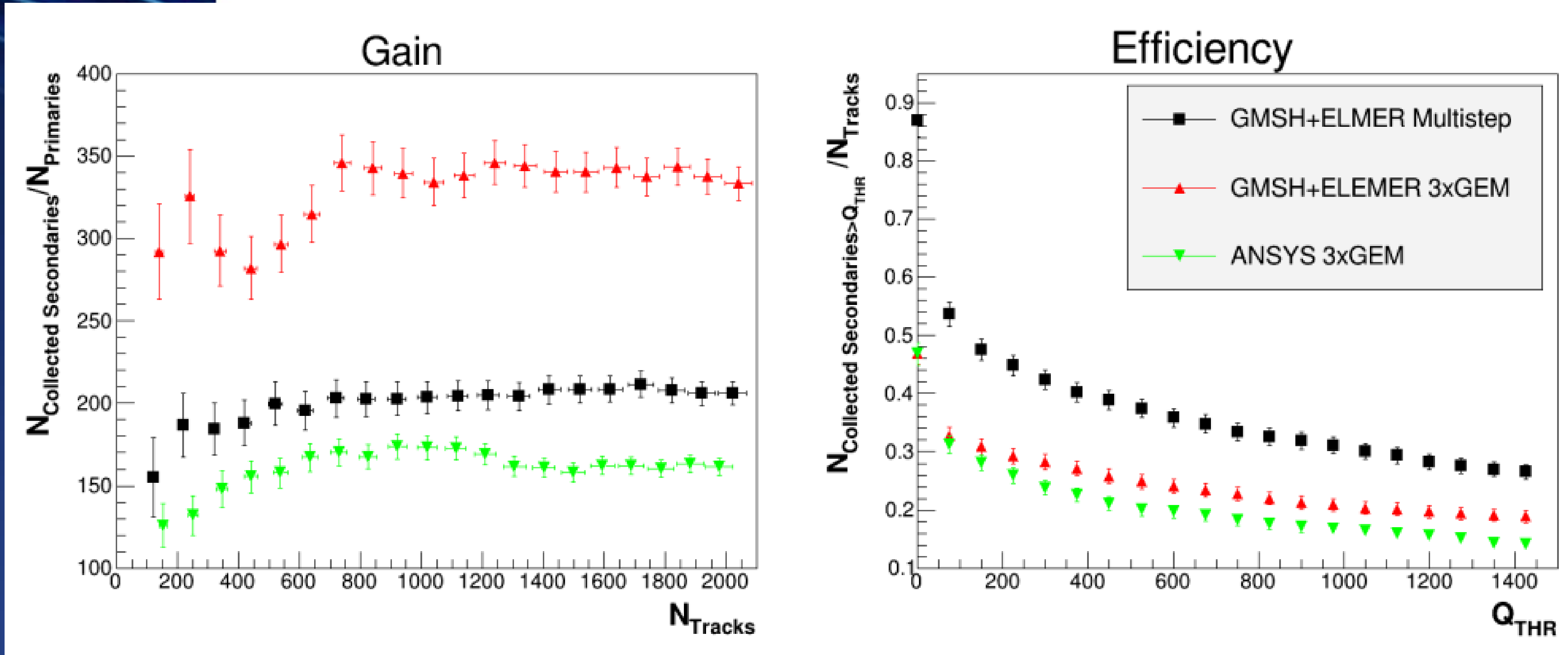


Cumulated plots (increasing number of simulated tracks)

All quantities tend to reach rather stable estimates when averaged above ~800 tracks

e- drift time and avalanche x/y spreads consistent within statistical uncertainties

Different approaches comparison



Efficiency = fraction of high energy tracks producing a number of secondaries collected on the readout plane larger than the given threshold Q_{THR}

Gain and Efficiency show discrepancies between models

Gain differences between G+E and A qualitatively consistent with single foil results

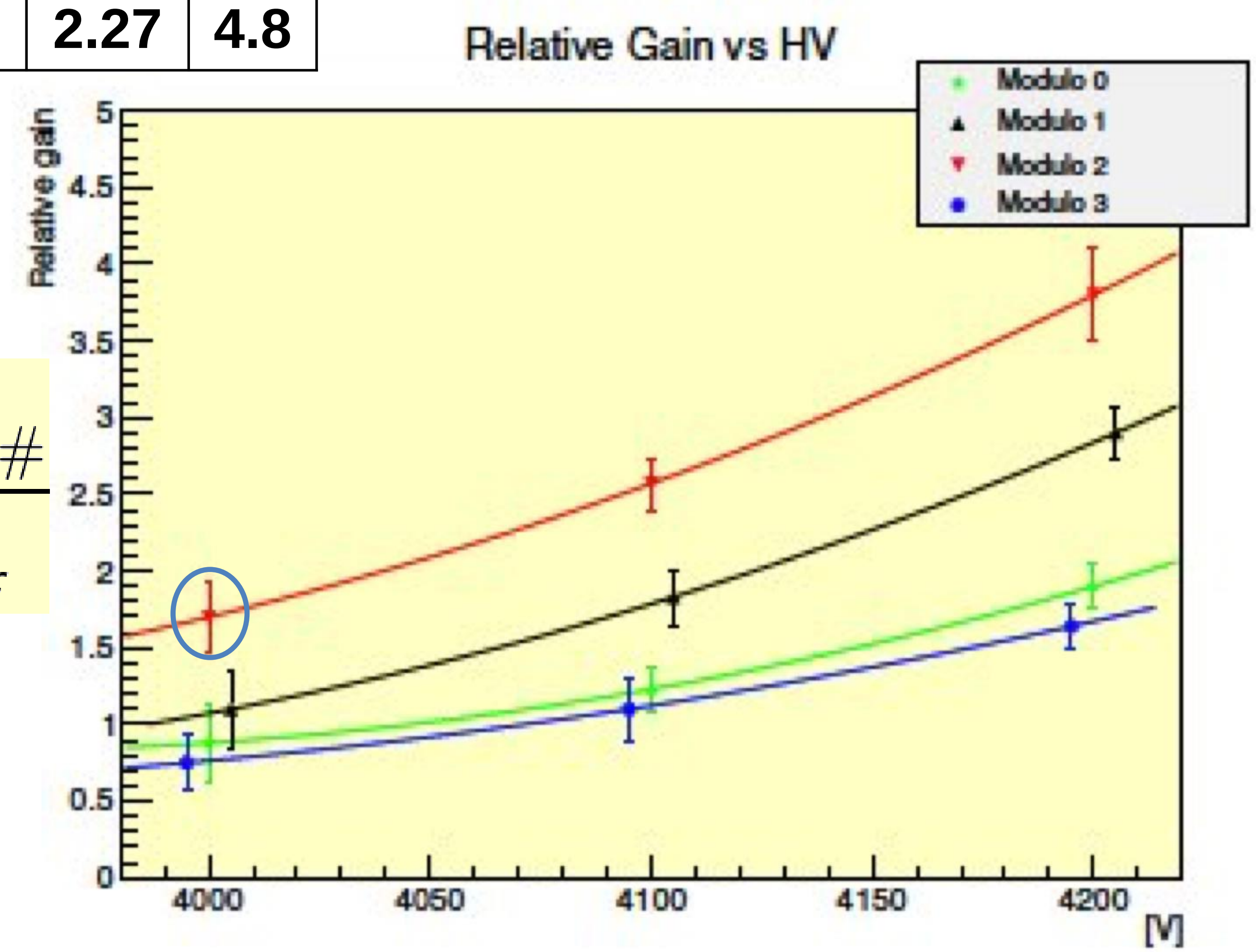
→ Discrepancy most likely related to the different meshes

Preliminary comparison with real data

We have quite detailed test-beam (2.8 GeV p) data of 5 GEM modules

	HV Divider Resistors [MΩ]							
Module	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
0	0.441	7.2	3.76	7.2	3.63	7.2	2.98	7.2
1	0.441	7.2	3.92	7.2	3.57	7.2	3.57	7.2
2	**0.441**	**7.2**	**3.92**	**7.2**	**3.92**	**7.2**	**3.92**	**7.2**
3	0.441	7.2	3.76	7.2	3.66	7.2	2.98	7.2
Reference	**0.441**	**4.8**	**2.66**	**4.8**	**2.66**	**4.8**	**2.27**	**4.8**

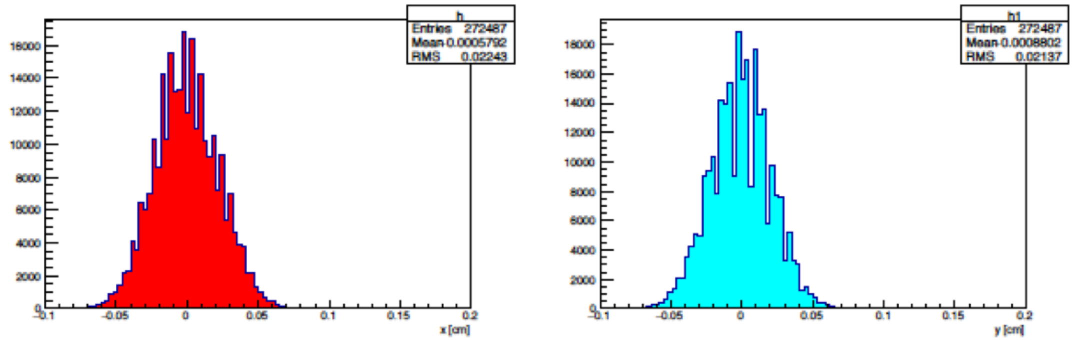
$$RelativeGain = \frac{\left[I_{HV}^{Beam} - I_{HV}^{NoBeam}\right]_{Mod\#}}{\left[I_{4100}^{Beam} - I_{4100}^{NoBeam}\right]_{Ref}}$$

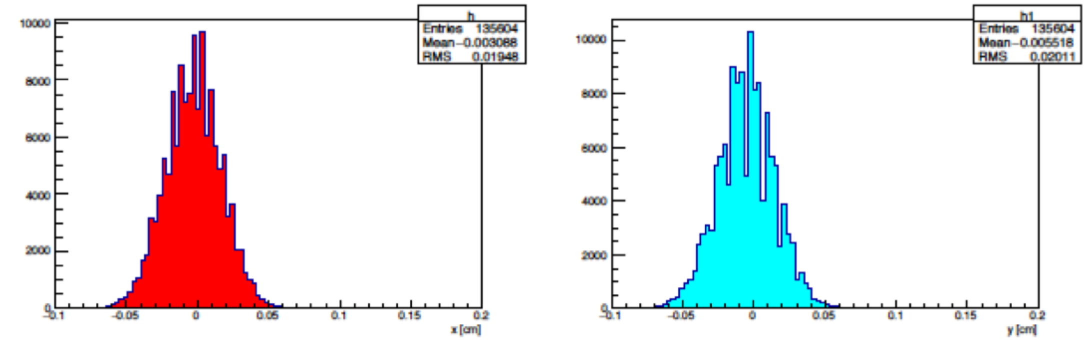


Preliminary Garfield++ prediction vs real data

ANSYS-Model

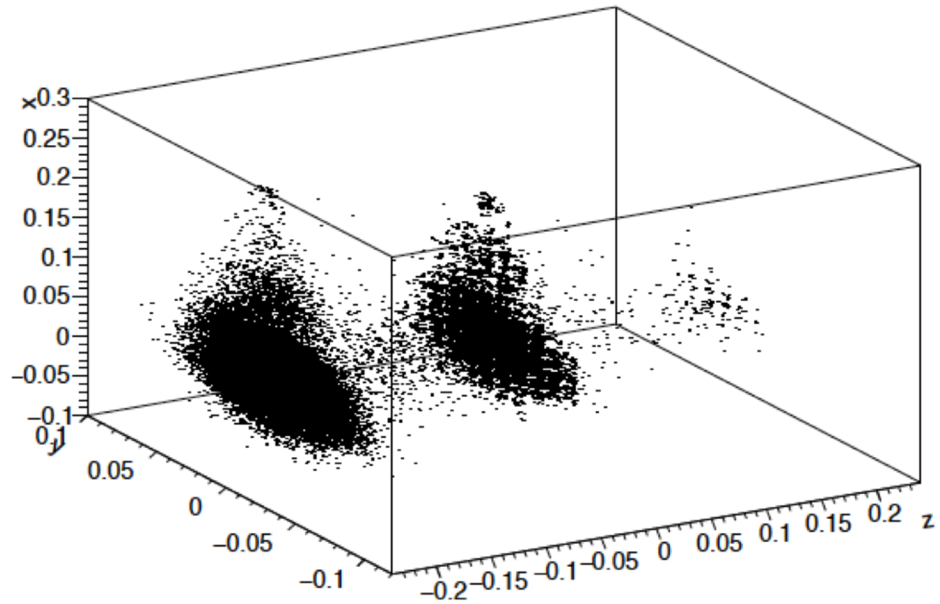
HV=4000 - Module 2 - Relative Gain
Predicted : 2.000 ± 0.013
Real data : 1.70 +/- 0.25

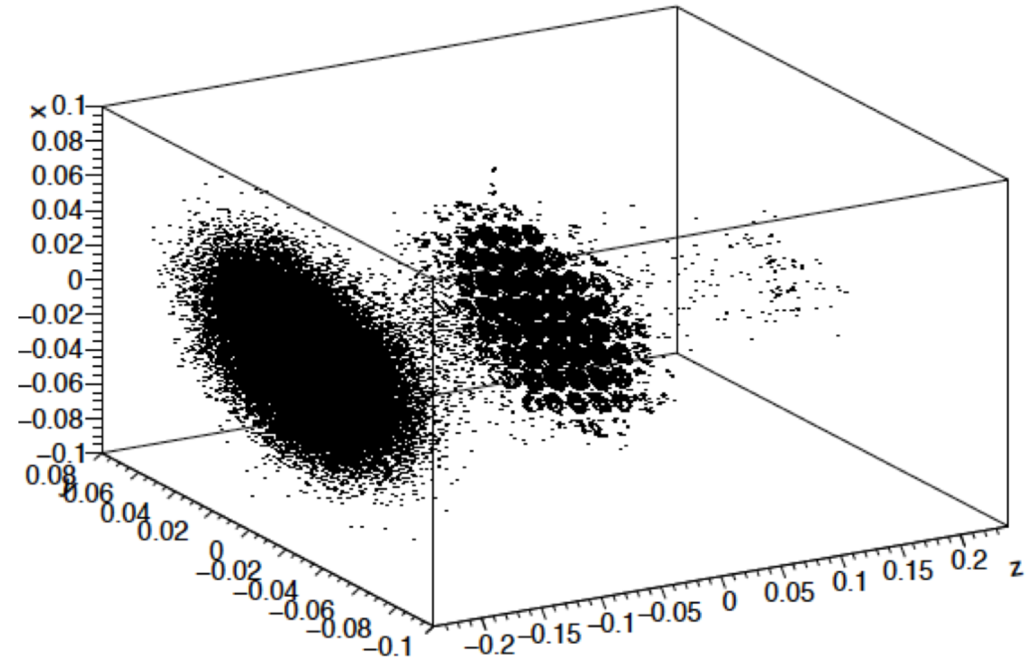




Module 2 - Entries: 272487

Ref Module - Entries: 135604





Summary

Implemented GEM simulations based on:

- Garfield++ (& Heed & Magboltz)
- Programmatic models from both ANSYS Multiphysics and GMSH+ELMER

Compared ANSYS and G+E on single foil response vs mesh size → show different gain predictions (related to how the mesh is generated ?)

Implemented two different GEM chamber models:

- Multistep 3xGEM+x/y Readout: flexible, permit an easy integration of the readout plane; no consistent ion drift simulation yet
- Full 3xGEM: ideal readout only

Comparison shows:

- good agreements on drift time, avalanche spread
- discrepancy on gain prediction (but consistent with single foil)
- The multistep approach seems to work similar to the Full GEM; discrepancy likely related to mesh generation (and/or field solution) (?)

Very preliminary, limited, comparison of relative gain with real data of the 3xGEM model is encouraging