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A flexible and efficient microscopic simulation of multiple GEM chamber based on Garfield++

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Abstract. Microscopic simulations may bring a better understanding of the response of gaseous detectors. Such simulations are computationally demanding, due to the modelling of the low energy processes and to the high segmentation required for the 2D/3D field maps. In MPGD such maps can be much more complex than those of traditional multiwire chambers, due to the heterogeneous materials and more involute geometries, which break the simplifying symmetries featured in the latter. In order to investigate the performance of the triple GEM 2-dimensional tracking chambers being developed for high luminosity experiments with the Super BigBite Spectrometer at Jefferson Laboratory, we have set up a flexible and rather efficient multistep simulation processor based on either ANSYS or GMSH+ELMER for 3D CAD and electrostatic field modelling and then combined to Garfield++. Potential systematic effects from the 3D CAD modellers, the mesh generators and the electrostatic field solvers have been estimated with dedicated simulations; once these effects have been assessed, the results of the multistep approach have been compared to a simplified whole GEM chamber model.

1. Introduction

A new series of high luminosity experiments are going to be performed at Jefferson Lab [1] with the recently upgraded CEBAF multi–GeV electron beam. These experiments will investigate the structure of the nucleons measuring their electromagnetic form factors at unexplored high momentum transfer [2]: since the cross section decreases with the momentum transfer by several orders of magnitude, high luminosity measurements are mandatory. However high luminosity implies a large background and therefore needs highly segmented detectors.

For such physics program, dedicated, conventional spectrometers (SBS and BigBite) with state of the art detector technologies have been designed or refurbished [3] and are now being finalized. These spectrometers will include highly segmented, large size GEM chambers for

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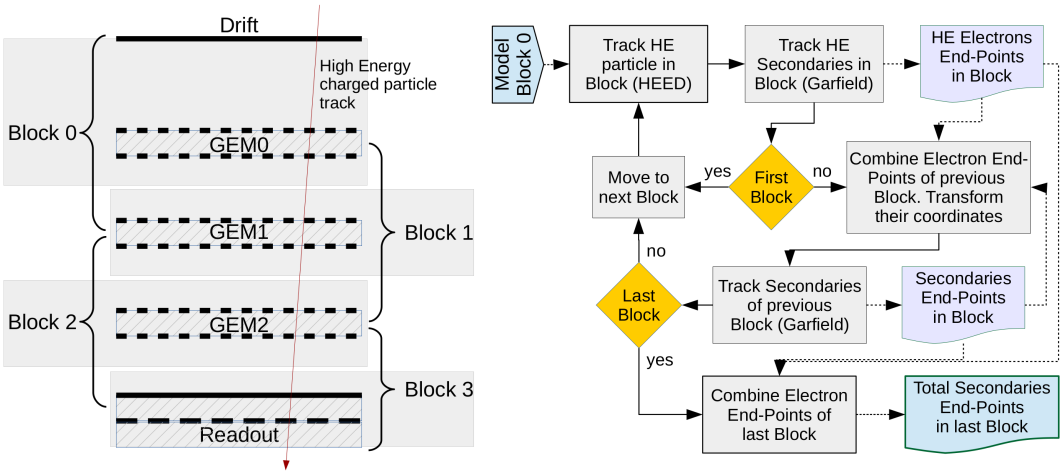

Figure 1. Left: the 3×GEM+Readout schematic view (not to scale) with the definition of the different blocks of simulation (curly brackets) used in the multistep approach and the respective, not overlapping, sensitive volumes (grey highlighted boxes). Right: the high level flow diagram of the multistep algorithm (HE stands for High Energy).

precise tracking of the charged particles directly produced by the scattering processes (front tracker) or in specialized recoil polarimeters [5].

1.1. Front Tracker GEM chambers

The front tracker will consist of up to 6 GEM chambers [4], designed to provide hit spatial resolution < 100 μm by simultaneous x/y strip readout (with 400 μm pitch), to stand large background flux (up to 500 MHz/cm^2 photons) and to offer an active area of 150×40 cm^2. The GEM strips are readout by the MPD [4] flexible electronics developed around the APV25 chip [6], compliant with the VME-VXS JLab standard and able to transfer data over fast optical link. Four chambers are currently under cosmic test at JLab, before installation in the BigBite spectrometer.

2. Microscopic Simulations

Understanding GEM detectors' behavior and performance can be supported by the simulation of the expected detector response. Key parameters such as gain, spatial resolution and timing can be evaluated by using the Garfield++ library [8] and then validated by cosmic and beam tests. Such simulations are computationally demanding, due to the modelling of the low energy processes and to the relatively high segmentation (meshing) required for the accuracy of field maps.

In GEM, and in MPGD detectors in general, field maps are typically more complex than those of traditional multiwire chambers, due to the heterogeneous materials and more involute geometries, which break the simplifying symmetries featured in the latter. In fact, a comprehensive simulation of the multi GEM chamber, in a straightforward implementation, requires a large 3D model due mainly to the relatively large distance between foils (few cm) with respect to the pitches of the GEM holes (typical 140μm) and of the strip or pad readout (few hundreds of μm). Moreover, offsets and/or misalignment between foils require new models and corresponding new computationally intensive simulations for each configuration.

This complexity has been largely mitigated exploiting the approximate independence of each GEM foil response: the 3×GEM+Readout chamber is decomposed into 4 overlapping blocks

[7] that easily allow to merge the different GEM foil and readout symmetries and to analyze different schemes, imperfections and foil misalignment using the same microscopic simulations (with appropriate considerations on the potential systematic errors that can be introduced). As schematically represented by the left drawing of Fig. 1, the single block model includes a central foil and the border of the previous and following foils while the sensitive volume where the particles are simulated, is limited by the mid-planes of the gaps between foils[9]. Each block is simulated separately as summarized by the flow chart in the right part of Fig. 1: the outcome (electrons end-points) of the previous block is fed into the next block, which can be rotated and shifted with respect to the previous one by an appropriate coordinate transform. Currently ions are not fully tracked back to the drift and weighting fields are not included.

This multistep approach has been implemented, in the Garfield++ framework, using either the open-source GMSH [9] and ELMER [10] packages or the commercial ANSYS Multiphysics [11] application as 3D CAD, mesh generator and electrostatic field solver. The Heed [12] and Magboltz [13] built in Garfield++ libraries have been used for high energy particles ionization and gas properties, respectively.

Main inputs to the simulation program are the geometry and electrostatic model (depending on the high voltage biases), the gas mixture, the primary particle type, starting point, direction and momentum. The ionization electrons (ions) end points are then generated within the sensitive volume either along the track of the primary ionizing particle or by successive ionization processes during avalanche multiplication. End-point information include: 3D position, energy, time of drift and status of the electron (ion).

An example of the foil models and simulation is presented in Fig. 2: mesh nodes into the holes, where the electrostatic field is changing rapidly, have much more detail than in the gaps between foils; similarly in the bottom readout plane with double x/y strip layers, more thick mesh surrounds the sharp edges. The readout strip pattern is barely visible in the electron avalanche end-points on the bottom right of the figure.

3. First results

As described in the following subsections, the above implemented framework has been initially tested on single GEM foil simulations against systematic effects of the adopted CAD modelers, mesh generators and electrostatic field solvers; the results of this preliminary analysis has driven the choice of the optimal procedure and parameters for to generation of the whole GEM chamber model mesh and the electrostatic field that are then used by Garfield++. Simulations of different whole GEM chambers have been carried on to evaluate the robustness of the multistep approach.

3.1. Single foil analysis

Mesh sizes and corresponding electrostatic field effects from both GMSH-ELMER and ANSYS have been evaluated on a single GEM foil[10] looking at the gain, avalanche spread and processing time; results are summarized in Fig. 3. The gain is defined as the average number of electrons collected after the GEM foil on a hypothetical readout plane, for each primary ionized electron generated by a high energy charged particle (2.8 GeV/c proton in the specific study); the avalanche spatial spread is estimated as the standard deviation of the x or y distribution of the overall collected electrons on the hypothetical readout plane, which typically appear as nearly Gaussian.

[9] The first GEM and last Readout blocks present straightforward differences with respect to the two central GEM blocks.

[10] The single GEM foil model correspond to the Block 0 in Fig. 1; it consists of a drift plane at 3 cm from the central GEM foil and a ground plane at 2 cm on the other side of the central foil; relative potentials are set at -1836.09 V, -1115.56 V, -720.53 V and 0 V respectively.

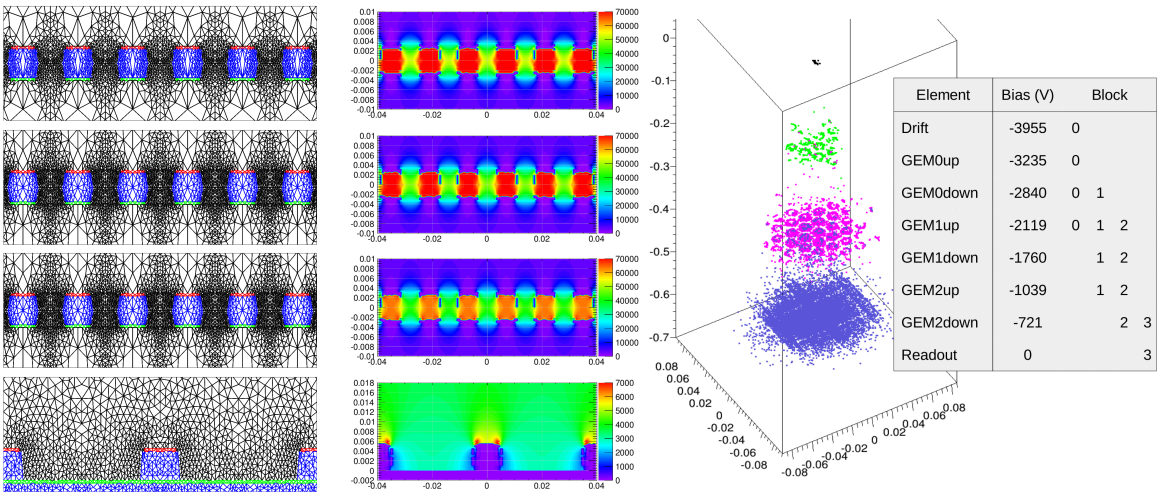

Figure 2. The 3×GEM+Readout model meshed (left), electrostatic field (middle) and one typical avalanche (electrons end-points) from a 2.8 GeV proton track in the multistep approach together with applied bias voltages (right). Units are cm and V/cm for linear space and electrostatic field respectively; drawings are not to scale. Note, the electrostatic field range of the readout (bottom-middle map) is 10 times smaller than the GEM foils (middle maps above readout).

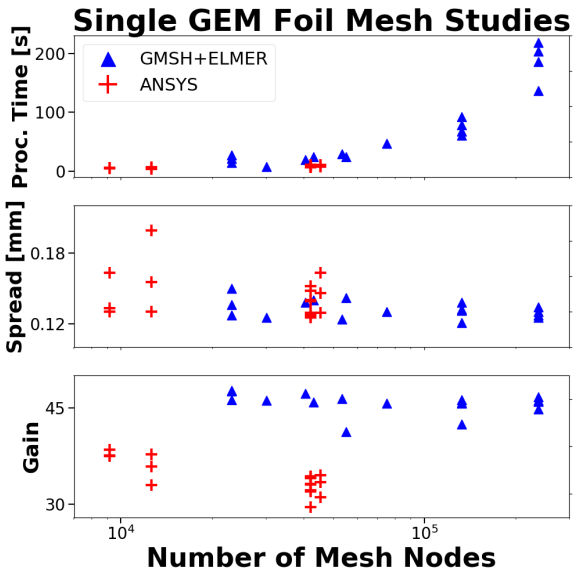

Figure 3. Single GEM foil simulations; the x axis, in log scale, represent the size of the generated mesh. Gain is defined in the main text, Spread is Avalanche x axis spread (y axis show identical patterns), Proc. Time is the average processing time for a single track. Several runs have been performed at the same or very similar conditions and can be used to estimate the typical reproducible variability.

From Fig. 3 it is evident that the simulation processing time depends on the number of mesh nodes, as one can naively expect; in general ANSYS default settings appear to provide size-optimized and model adapted meshes while GMSH requires the implementation of specific strategies (programmatic instructions) to get similar results. The gains predicted by the ANSYS and GMSH+ELMER models differ by about 15% (larger than the fluctuations between runs), probably due to the slightly different electrostatic fields generated by the two solvers on the generated meshes; ANSYS models suffer of a noticeable dependence of the gain from the mesh size, while GMSH+ELMER provides more uniform results in the explored range. The spatial spreads predicted by the different codes are in fair agreement, without any noticeable dependence from mesh size.

3.2. Whole Chamber models comparison

From the previous single foil results, the best mesh size ($\sim 10^4$ nodes per foil) has been chosen as trade-off between stable results and computational speed and then used in the implementation of either the whole 3×GEM chamber with simplified flat surface Readout (W-3G) using both ANSYS and GMSH-ELMER or the above multistep approach for the 3×GEM+Readout (MS-3GR) using the latter packages.

All simulations have been performed for high energy protons at 2.8 GeV traversing the GEM with a uniformly distributed incident angle between 0 and 30 degree; the high voltage biases have been set to the realistic values used in the SBS Front Tracker GEM described above and reported in the table of Fig. 2.

The results are summarized in Fig. 4, where the most relevant quantities are cumulatively plotted as a function of the number of simulated events (number of high energy tracks), except the efficiency which is function of the collected charge threshold (secondaries) with full statistics (all simulated tracks). The efficiency shows, quite surprisingly, the largest discrepancy between the two MS-3GR and the W-3G simulation approaches; this quantity is defined as the fraction of high energy tracks producing a number of secondaries collected on the readout plane larger than the given threshold Q_{thr}: the MS-3GR efficiency is twice the other two models, but still largely lower than reasonably expected.

The gain normalized to the number of primary electrons generated by the high energy charged track, as defined above, also shows a noticeable discrepancy between the three approaches and especially for the GMSH-ELMER W-3G with respect to the others: this can be only partially explained by different electrostatic field maps, as already mentioned in the single foil analysis; the GMSH-ELMER W-3G seems to have a larger fluctuation on the primary and secondary ionized electrons.

All other estimated mean quantities are pretty consistent with different models/simulations within statistical uncertainties; all quantities tend to reach rather stable estimates when averaged above ~ 800 tracks.

4. Conclusions and outlook

The above results represent the first steps toward a solid methodology for microscopic GEM (and more in general MPGD) simulations within the Garfield++ framework: different 3D CAD modellers and electrostatic field solvers and various simulation approaches have been compared, showing noticeable discrepancies mainly on gain and efficiency (as defined in the paper); part of those discrepancies are probably unavoidable due to the difficulty to have a very fine tuning of the generated electrostatic maps and can be resolved introducing suitable tuning factors.

Work is however in progress to better understand the origins of the most noticeable discrepancies, and to better characterize the multi–step approach; further development will possibly extend the capability of this method to fully include ion effects.

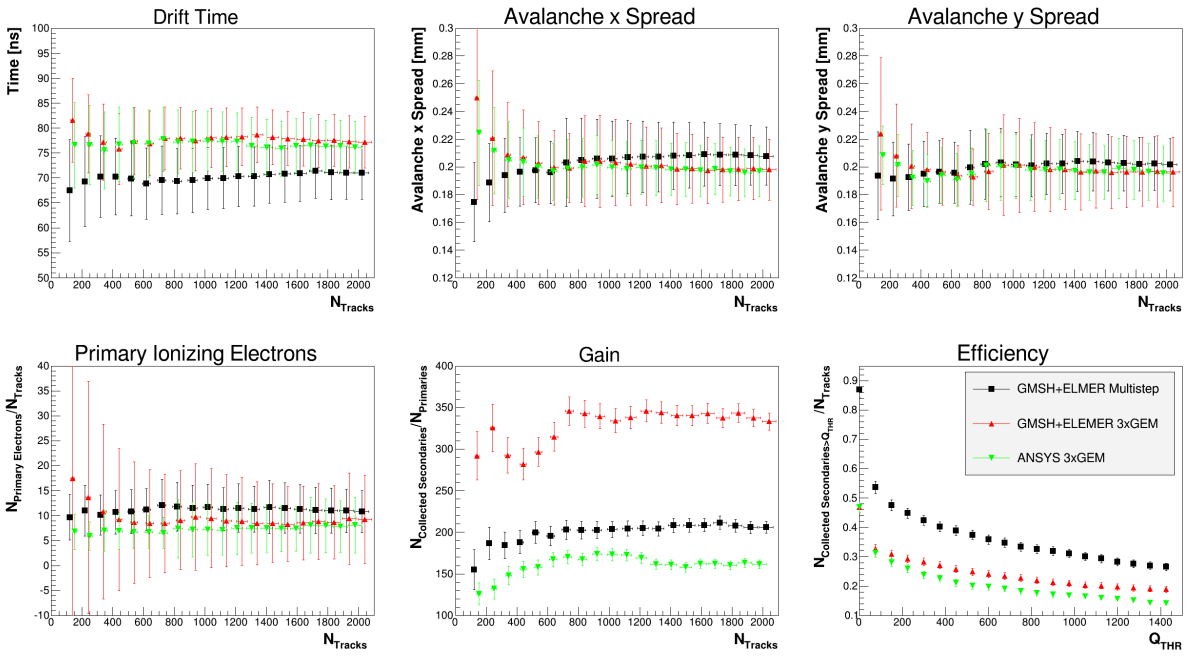

Figure 4. Full GEM chamber simulations versus the cumulated number of tracks simulated, except the Efficiency bottom-right plot; the error bars represent statistical only uncertainties.

Validation of the simulator by means of real beam test data, already available to the SBS GEM group, has also started.

5. References

[1] Thomas Jefferson National Accelerator Facility, Science web page https://www.jlab.org/research/science
[2] B. Wojtsekhowski, "Nucleon form factors program with SBS at JLAB", arXiv:1401.0859v3 [nucl-ex]
[3] SBS project web page https://hallaweb.jlab.org/12GeV/SuperBigBite/
[4] V. Bellini et al., "GEM tracker for high luminosity experiments at the JLab Hall A", 2012 JINST 7 C05013
[5] K. Gnanvo et al., "Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab", NIM A 782 (2015), arXiv:1409.5393 [physics.ins-det]
[6] M. French et al., "Design and Results from the APV25, a Deep Submicron CMOS Front-End Chip for the CMS Tracker", NIM A 466 (2001) 359-65
[7] V. Brio Master Thesis "Simulation of the Triple-GEM tracker for Jefferson Lab experiments", Catania University, 2017
[8] Garfield++ - simulation of tracking detectors web site https://garfieldpp.web.cern.ch/garfieldpp
[9] C. Geuzaine and J.-F. Remacle, "Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities." International Journal for Numerical Methods in Engineering 79(11), pp. 1309-1331, 2009, web site http://gmsh.info
[10] ELMER web page https://www.csc.fi/web/elmer/elmer
[11] ANSYS web page https://www.ansys.com/
[12] D. Pfeiffer et al., "Interfacing Geant4, Garfield++ and Degrad for the Simulation of Gaseous Detectors", arXiv:1806.05880v3 [physics.ins-det] 26 Feb 2019
[13] S.F. Biagi, "A description of the Magboltz program, with results compared to experiment", Nucl. Instr. and Meth. A 421 (1999) 234-240 .