A study of Avalanche and Streamer simulation in GEM detector using hydrodynamic approach

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Introduction

- Gas Electron Multiplier (GEM) detectors belong to the family of MPGDs.

- These detectors have been able to operate in the high rate experiments like ALICE, CMS, COMPASS and LHCb for their high rate handling capability and radiation hardness.

- The improvement of readout technology and related electronics so far helps to achieve good spatial ($\sim 100$ um) and time resolution (4ns) through the use of these detectors.

How does the numerical simulation help?

- The optimization of design parameters of the GEM, the gas mixture used are different for each experiment due to the nature of tracking and timing precision required by the experiment.

- A suitable numerical simulation tool can help to facilitate the study significantly here.

Numerical simulation in gaseous ionization detectors

- Particle Simulation approach: Lagrangian description

- Hydrodynamic simulation approach: Eulerian description
Particle simulation approach :-

- Garfield++ simulation framework utilizes the Lagrangian description to simulate the evolution of charged particles within the gaseous ionization detectors and signal generation.

- It incorporates generation of primaries using HEED framework, a suitable gas mixture for charge transport utilizing different transport parameters from MAGBOLTZ in the presence of electric field which can be calculated from neBEM package.

- This approach is most realistic and requires significant computational resources.

- As a result, the problems involving space charge effects, development of streamers/discharges are difficult to address here.

Hydrodynamic simulation approach :-

- This approach, follows the Eulerian description. The charged particles are considered as charged fluids in the gas volume.

- The mathematical model incorporates the effects of space charge and is possible to study the development of streamers/discharges in a reasonable less time than the particle model.

- This simulation framework can be built on the platform of a commercial Finite Element Method (FEM) package, COMSOL Multiphysics.

- It utilizes the primary ionizations from HEED and the transport parameters from MAGBOLTZ to perform the simulation.
### Mathematical model of hydrodynamic simulation:

- The model represents the mass transport of solute species in a background solvent gas mixture.
- The positively and negatively charged particles are considered to be charged fluid in the gas volume.
- The transport of charged fluids occurs by the convection and migration mechanism.
- The hydrodynamics is governed by the Drift-diffusion-reaction equations below.
- The applied electric field has a significant influence on the system dynamics and is modified by the charged particles by themselves during the simulation.

\[
\frac{\partial c_i}{\partial t} + \nabla \cdot \left( -D_i \nabla c_i + \vec{u}_i c_i \right) = R_i
\]

\[
\vec{E} = -\nabla V
\]

\[
\nabla \cdot D = \rho_v
\]

Where \( C_i, D_i, \vec{u}_i \) and \( R_i \) represents concentration, diffusion coefficient, drift velocity and rate of production of charged species in the simulation volume respectively.

- \( V \) = Electric potential
- \( \vec{E} \) = Electric field
- \( D \) = Electric displacement vector
- \( \rho_v \) = Volume space charge density
Geometry of GEM detector: Two dimensional axisymmetric model

- GEM hole has natural axisymmetry in it.
- Standard double mask biconical GEM hole has been used in the simulation.
- Inner hole diameter = 50 µm, Outer hole diameter = 70 µm, Copper thickness = 5 µm
- \( r = 0 \) corresponds to the symmetry axis
- Drift gap = 1 mm
- Transfer gap 1 = Transfer gap 2 = Induction gap = 1 mm
Electric field calculation: -

Field along the symmetric axis $r = 0$ For a single GEM

Field at $z = 0$ along the middle of the dielectric for a Single GEM

Field along the symmetric axis $r = 0$ For a double GEM

Field along the symmetric axis $r = 0$ for a triple GEM

- The electric potential and field is calculated by the FEM solver in the gas volume by utilizing fine meshing in the detector geometries.

- The charge transport occurs in the presence of the applied electric field and also gets modified due to space charges build up during simulation.
Avalanche formation:

- The evolution of electronic and ionic fluids in Ar + CO$_2$ (70:30) gas volume have been simulated.

- The primary charge cluster is used from Fe$^{55}$ radioactive source, which emits 5.9 keV photons into the gas volume.

- In the avalanche mode operation of the detector, the electron avalanche proceeds in the gas volume until it reaches the anode.
Effect of Space charge and Streamer formation:

- Positive streamers have been observed.
- Ion density builds up near GEM anode and grows sufficiently high.
- Strong distortion of applied electric field observed due to space charge.

Distortion of total electric field and evolution of ion concentration during streamer formation

Distortion of total electric field and evolution of electron concentration during streamer formation

Evolution of electrons and ions during streamer transitions
Effective Gain measurement:

- The numerical estimates of the effective gain are obtained from the induced current in the anode.
- The effective gain values from simulation follows the experimental trend, however the values are different.
- The gain values are scaled with an approximate scaling factors calculated using the charge sharing informations and gives a reasonable agreement.

**References:**
Summary:

- Presented the hydrodynamic simulation model using the GEM detectors.
- Avalanche formation and computationally difficult transition from avalanche to streamer is modelled reasonably well using this simulation approach.
- Effect of space charge and its relation to the formation of streamers have been studied.
- Evolution of positive streamers dominated by ions have been observed.
- The numerical estimate of effective gain values with and without correction have been obtained and compared with the experimental values.
- The results of the studies have been communicated to JINST recently and is accepted for publication. More information about the studies can be found here: https://arxiv.org/pdf/2011.02988.pdf
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************************** Thank You ****************************