Hydrodynamic Approach
to
Simulate Avalanche and Streamer
in
Gaseous Detectors

PRESENTED BY

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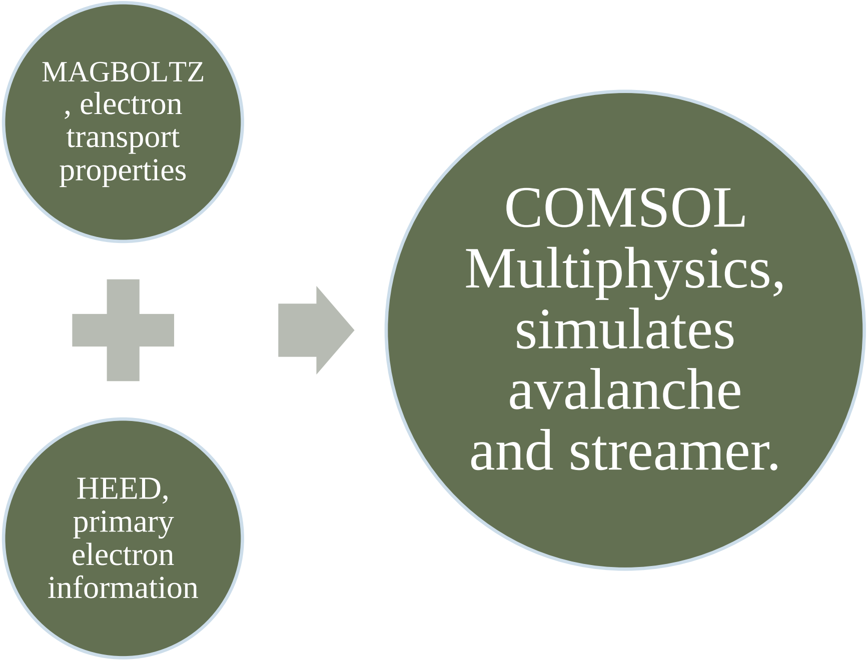
Motivation

1. The gaseous detectors are known for their excellent time resolution, good spatial resolution. They have large area coverage and small response time. These advantages have made them an important tool of many present and future experiments.
2. Understanding the governing physics of these detectors help to improve them.
3. Moreover if one can simulate avalanche and streamer probability of the gaseous detectors it will help identifying potential alternative gas mixtures without carrying out experiments.
4. Many attempts have been made to simulate these detectors following Monte Carlo method or hydrodynamic approach.[W. Riegler et al *NIM A* **500** (2003) 144; D. Bosnjakovic et al., 2014 *JINST* **9** P09012; A. Moshaii et al, *NIM A* **661** (2012) S168; D. Bošnjakovic et al, *J. Phys. D* **49** (2016) 405201.]
5. Here a hydrodynamic approach will be described to simulate RPC and GEM. The simulated results have been compared with experimental data to validate the model.

Simulation Framework

1. The basic idea was followed from the model described in RD51 –NOTE-2011-005, by P. Fonte. The simulation framework utilizes hydrodynamic approach. The gas molecules, ions and electrons are considered as fluids.



$$\frac{\partial n_e}{\partial t} + \vec{\nabla} \cdot (-D\vec{\nabla} n_e + \vec{u}_e n_e) = S_e + S_{ph}$$

$$\frac{\partial n_i}{\partial t} + \vec{\nabla} \cdot (-D\vec{\nabla} n_i + \vec{u}_i n_i) = S_e + S_{ph}$$

$$S_e = (\alpha(\vec{E}) - \eta(\vec{E}))|\vec{u}_e| n_e(\vec{x}, t)$$

$$S_{ph} = Q_e \mu_{abs} \psi_0$$

Hydrodynamic equations

$$\vec{\nabla}(-c\vec{\nabla}\psi_0) + a\psi_0 = f$$

$$c = \frac{1}{3\mu_{abs}}$$

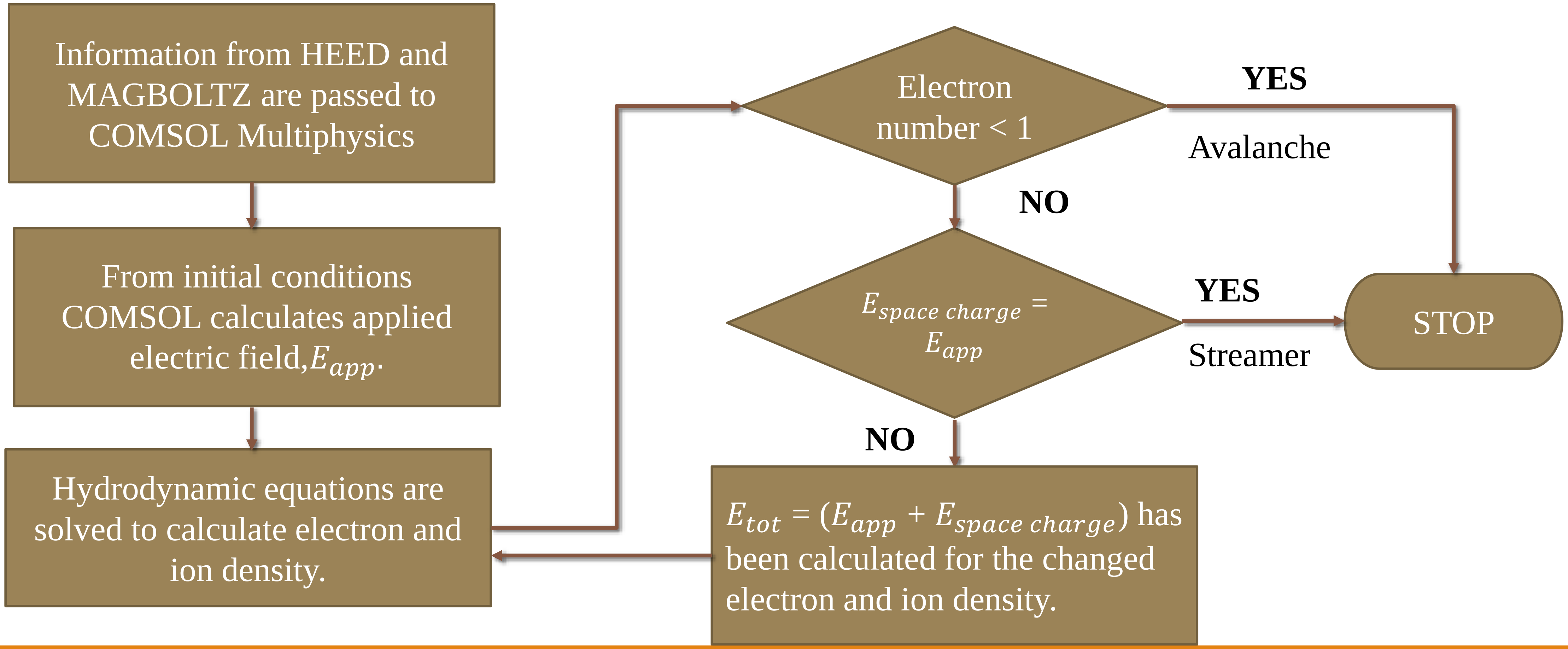
$$f = \delta S_e$$

$$a = \mu_{abs}$$

Equations for photon propagation

Ref:
1. J. Datta et al, *JINST* **15** C12006 (2020)
2. J. Capeillere et al, *J. Phys. D* **41** (2008) 234018.

Simulation Flowchart



Simulation for RPC

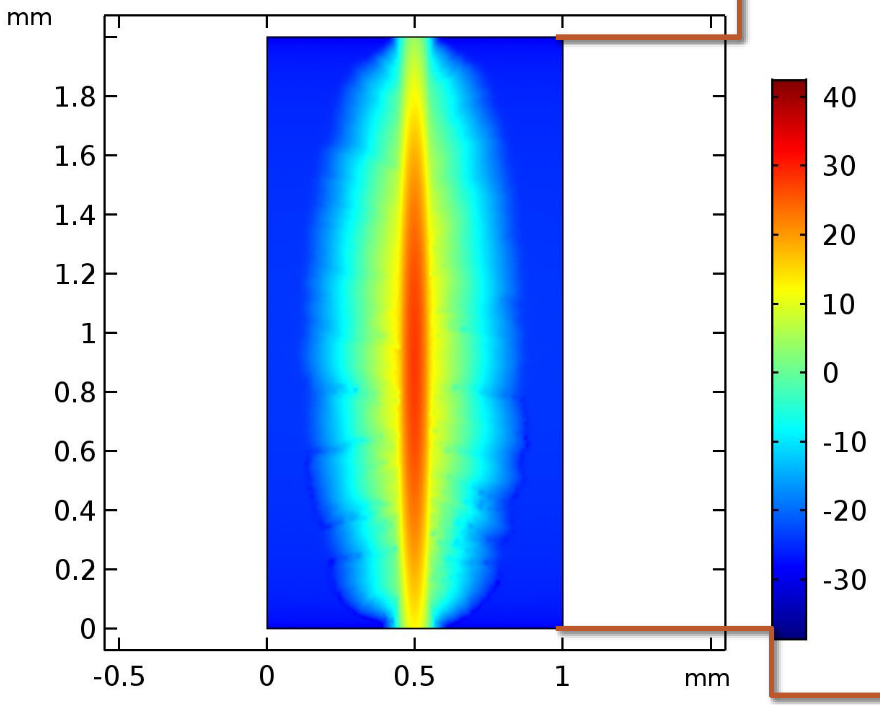
Ref: “*Study of Streamer Development in Resistive Plate Chamber*”, J. Datta et al 2020 *JINST* **15** C12006

Avalanche and Streamer Event

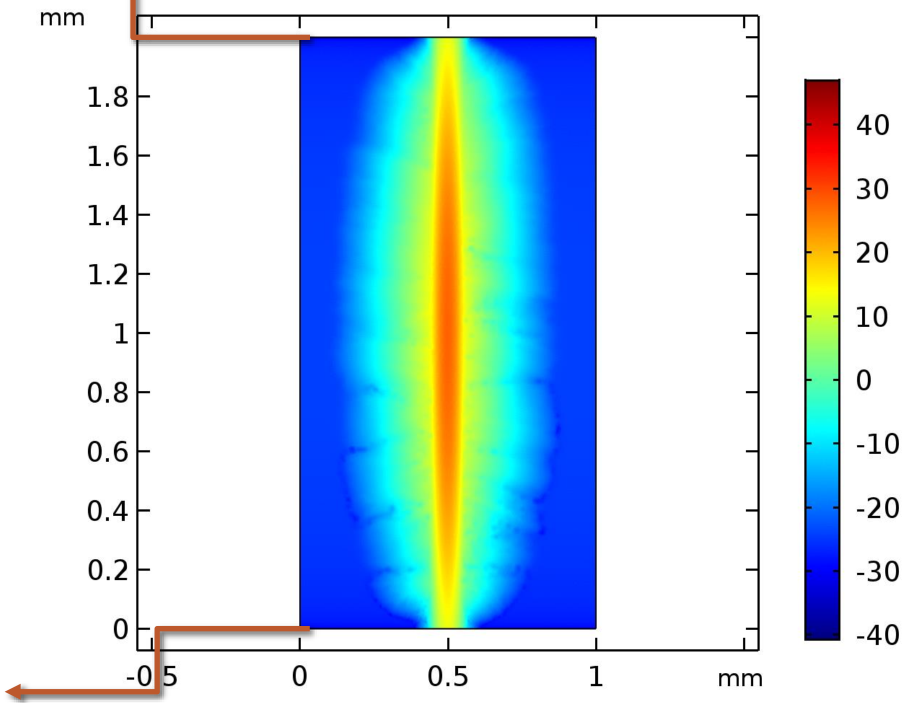
AVALANCHE EVENT

Cathode

STREAMER EVENT



Electron density in logarithmic scale



Anode

41 kV/cm, number of primaries 60, mean Z position 1 .0 mm

47 kV/cm, number of primaries 60, mean Z position 1 .0 mm

Calculation of Streamer Probability and Efficiency

1. 10000 muon events, following cosmic muon flux have been simulated using HEED.
2. Number of primary electrons has been varied in steps of 5 between 10 to 60.
3. Position of the primary electrons has been varied in step of 0.1 mm between 0.1 mm and 1.9 mm.
4. From simulation it was found out, for each applied voltage, for what value of initial position and primary electron number, streamer occurs and the induced current crosses the threshold mark.
5. The induced current is calculated using Ramo's theorem.

Gas mixture R134a : butane = 97 : 3

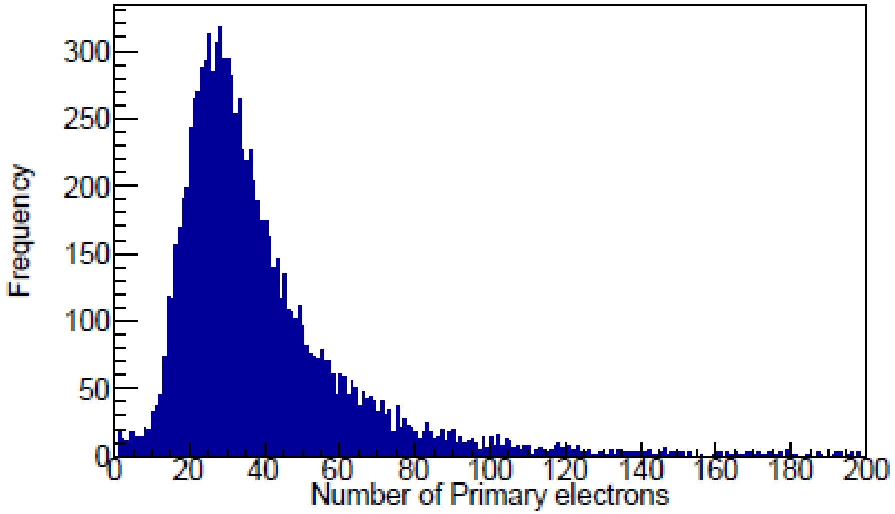


Figure: 1 Number of primary electrons obtained from HEED

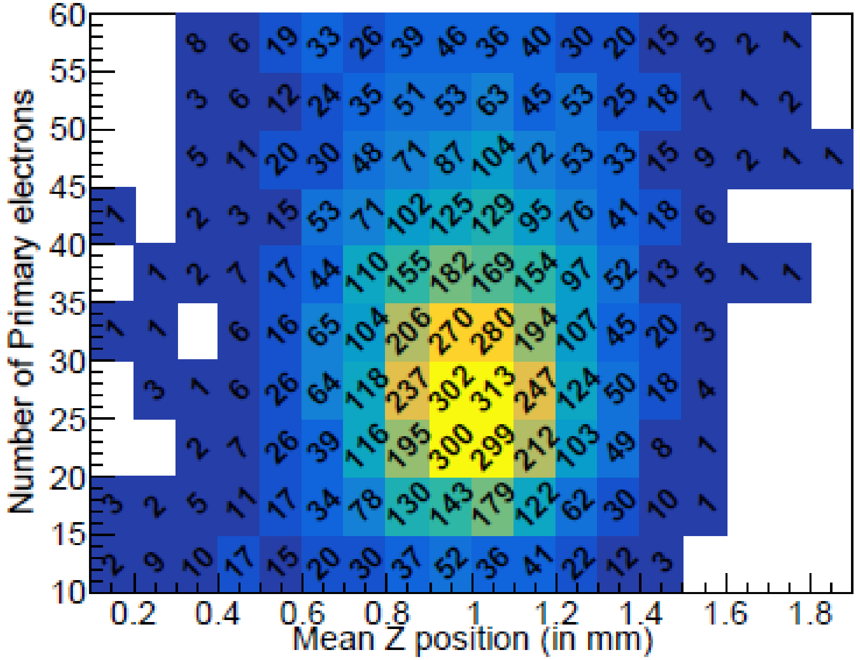
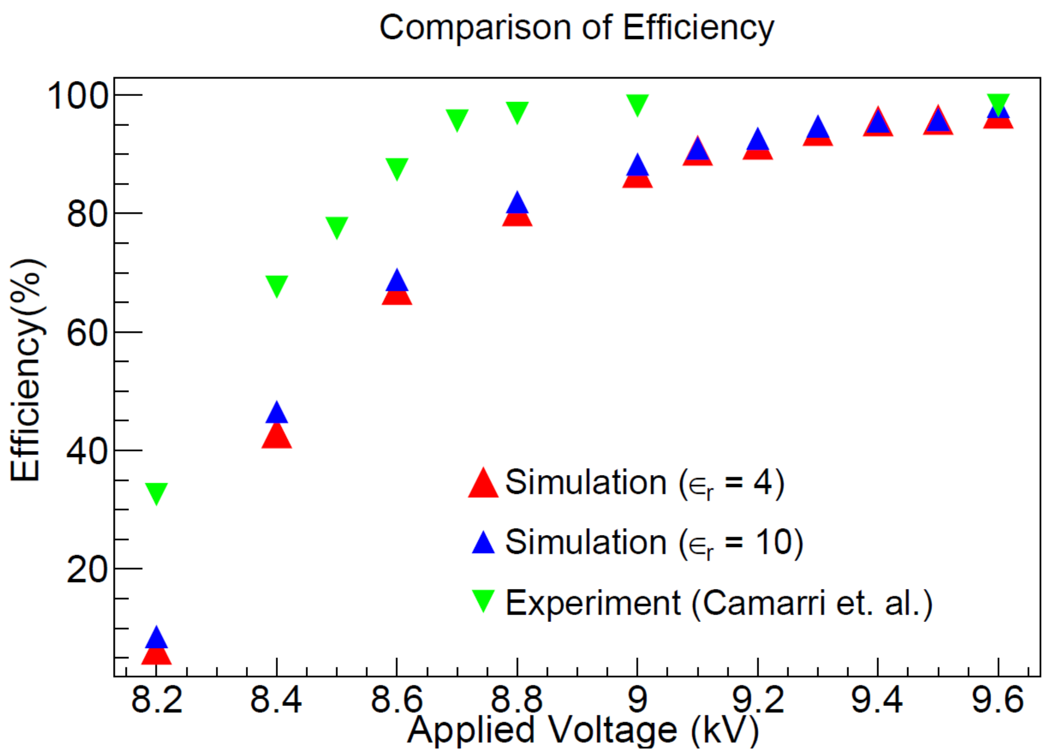
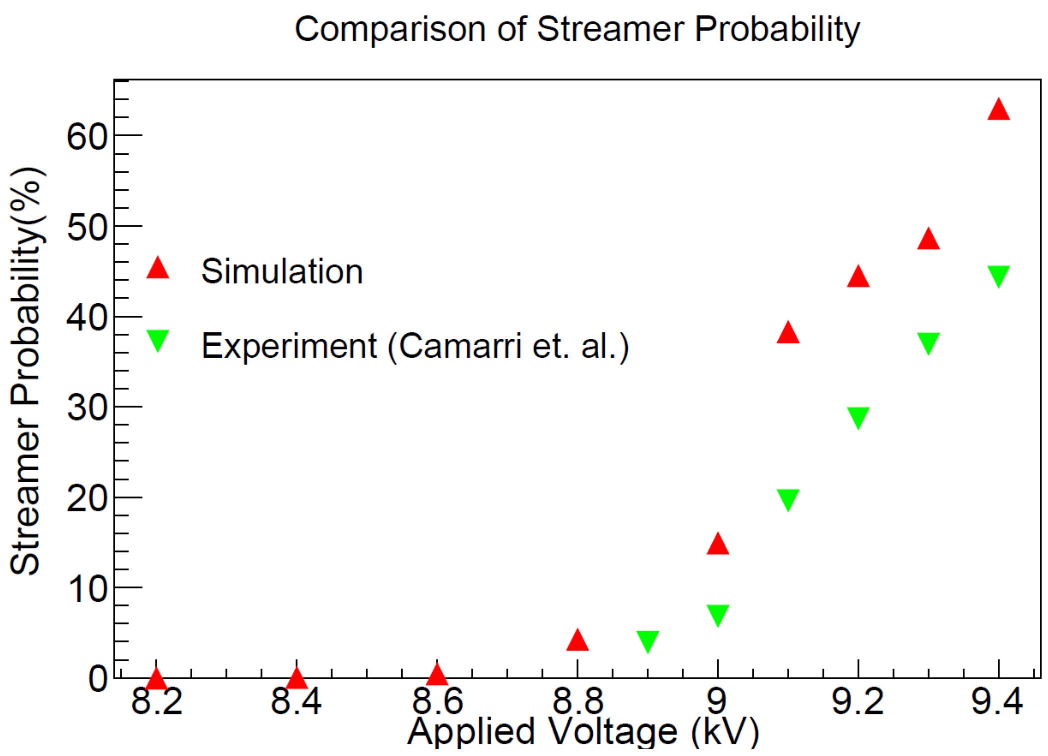


Figure 2: Variation of primary electron number with mean Z-position

Ref: "*Study of Streamer Development in Resistive Plate Chamber*", **J. Datta**, S. Tripathy, N. Majumdar, S. Mukhopadhyay, *JINST* **15** C12006 (2020)

Result for R134a : butane = 97 : 3



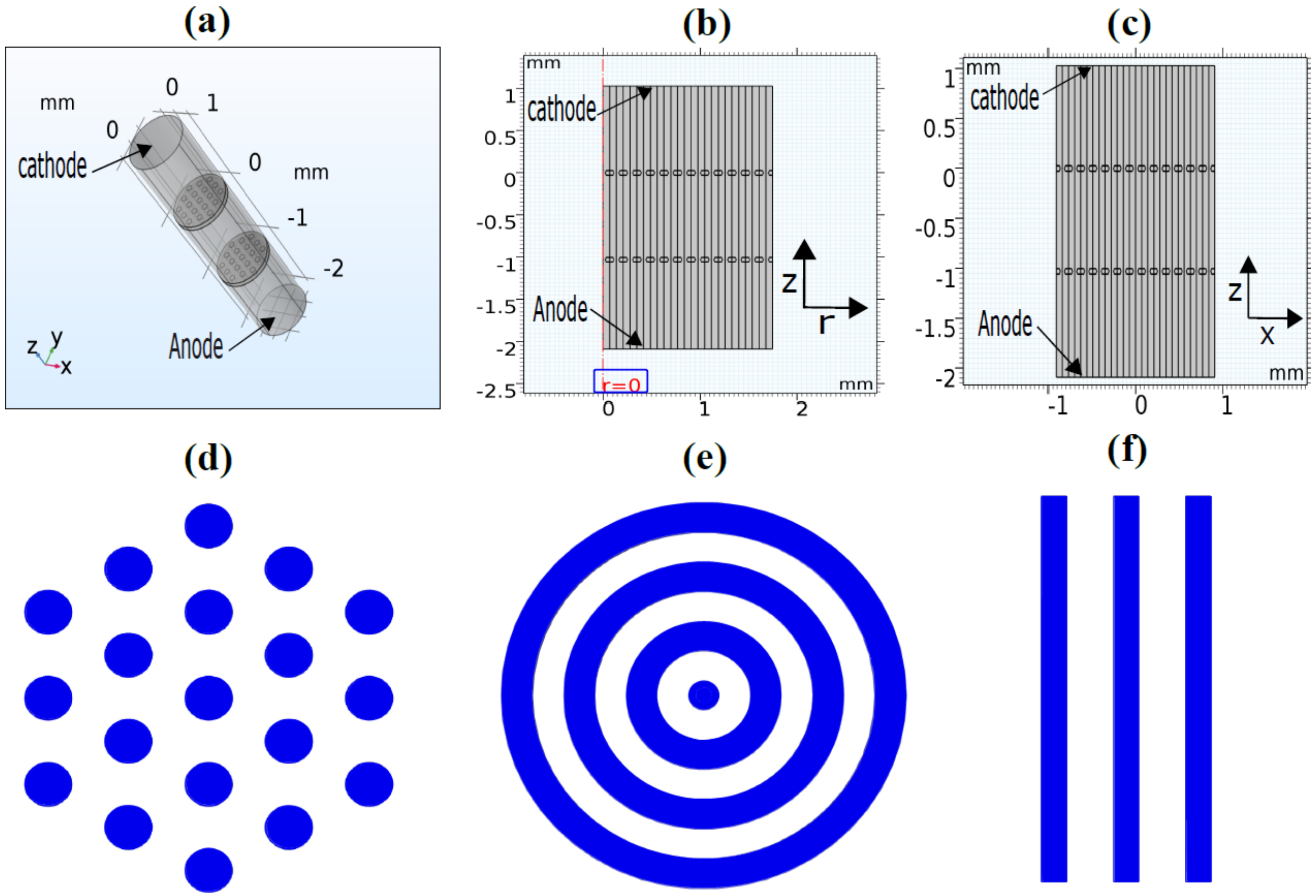


References:
1. P. Camarri et al., *NIM A*, **414**,(1998), 317.
2. **J. Datta**, S. Tripathy, N. Majumdar, S. Mukhopadhyay, *JINST* **15** C12006 (2020)

Simulation for GEM

Ref: *"Fast simulation of avalanche and streamer in GEM detector using hydrodynamic approach"* P.K. Rout *et al* 2021 *JINST* **16** P02018

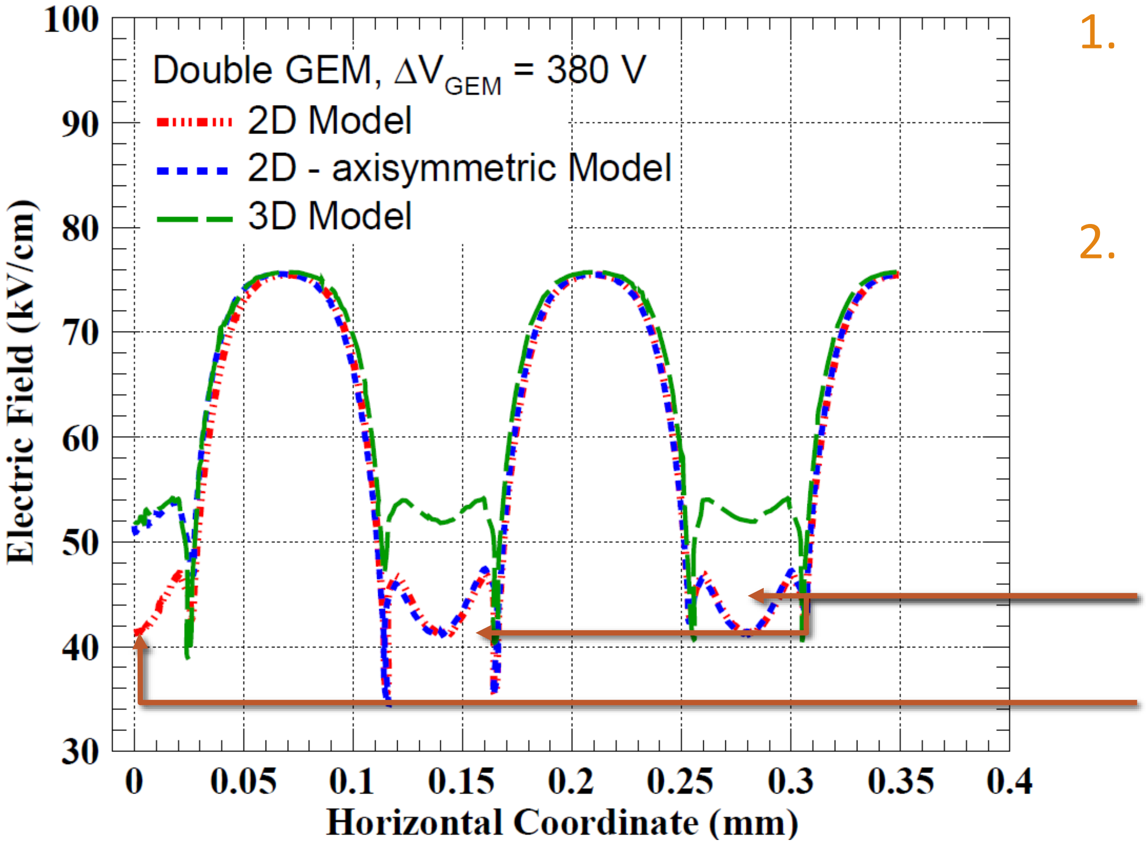
Choice of GEM Simulation Geometry



a) 3D geometry of GEM
b) 2D axisymmetric geometry
c) 2D geometry of GEM
d) Top view of 3D GEM foil
e) Top view of 2D axisymmetric model
f) Top view of 2D model.

Ref: "Fast simulation of avalanche and streamer in GEM detector using hydrodynamic approach" P.K. Rout *et al* 2021 *JINST* **16** P02018

Electric Field configuration of different model



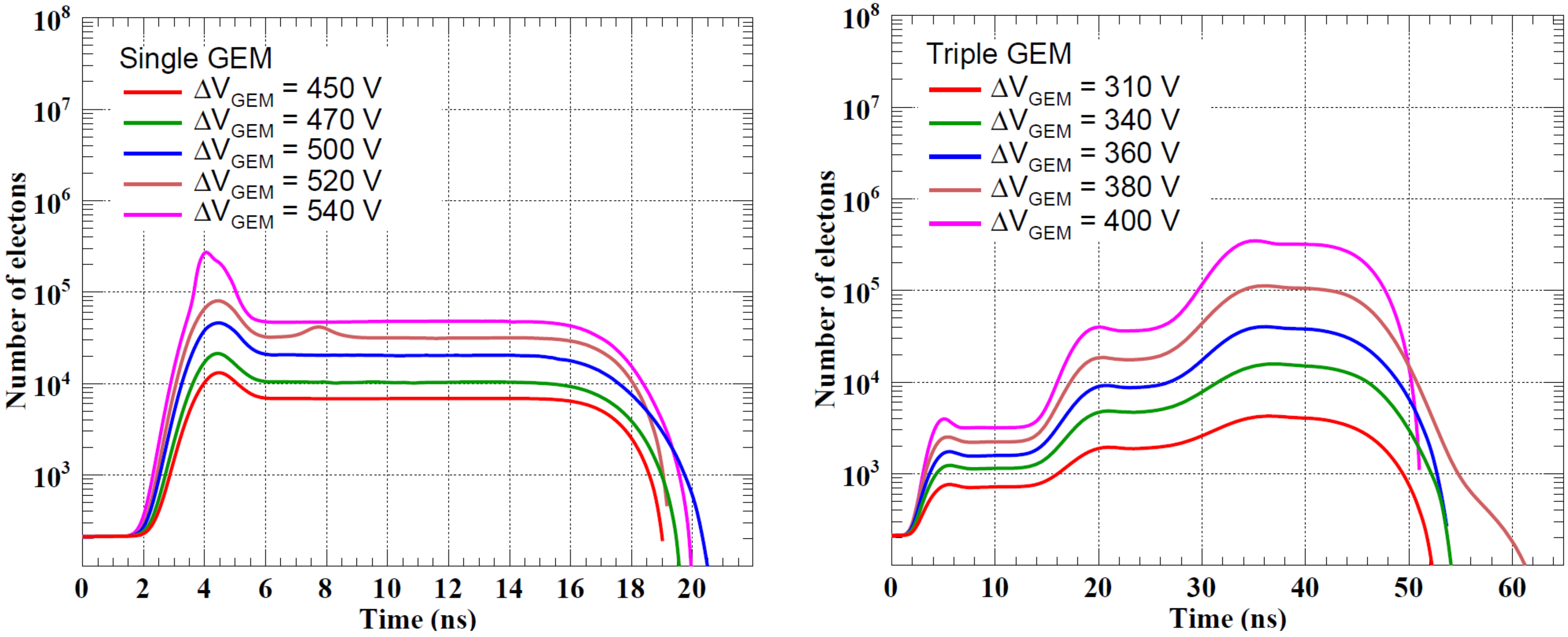
1. Using COMSOL Multiphysics the electric field for different configuration have been calculated.
2. For the Central hole of 3D and 2D-axisymmetric model the electric field configuration are in accordance but that of 2D model is far off.

Side holes (3D model)/ Channels (2D axisymmetric model, 2D model)

Central hole (3D, 2D axisymmetric model)/ Channel (2D model)

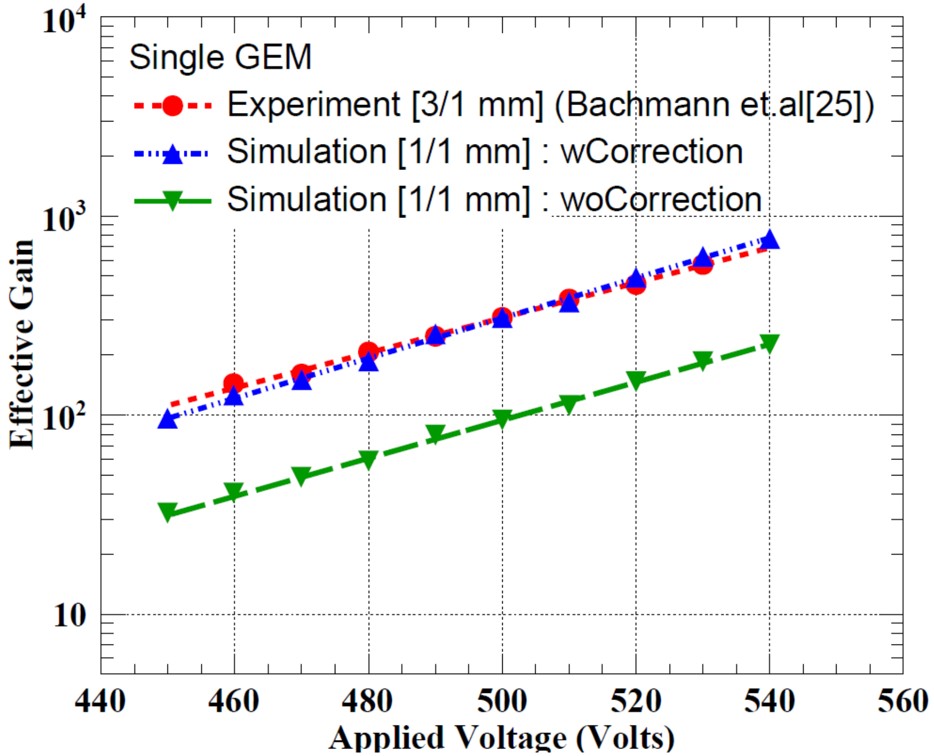
Ref: "Fast simulation of avalanche and streamer in GEM detector using hydrodynamic approach" P.K. Rout *et al* 2021 *JINST* **16** P02018

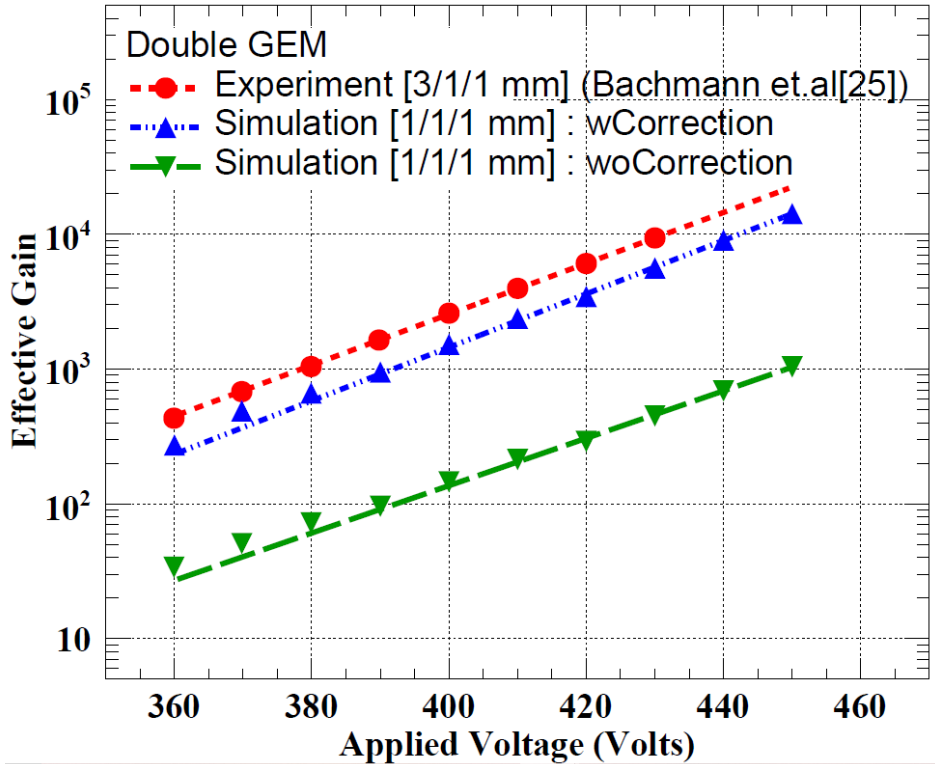
Variation of Electron Numbers with Time in Avalanche



Ref: "Fast simulation of avalanche and streamer in GEM detector using hydrodynamic approach" P.K. Rout *et al* 2021 *JINST* **16** P02018

Gain Comparison for Single and Double GEM



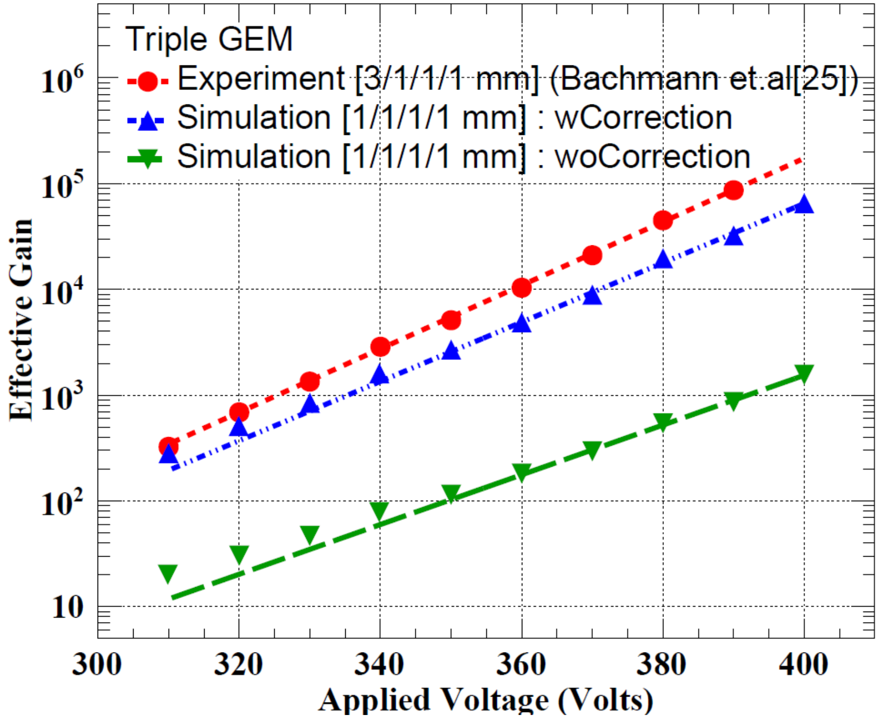


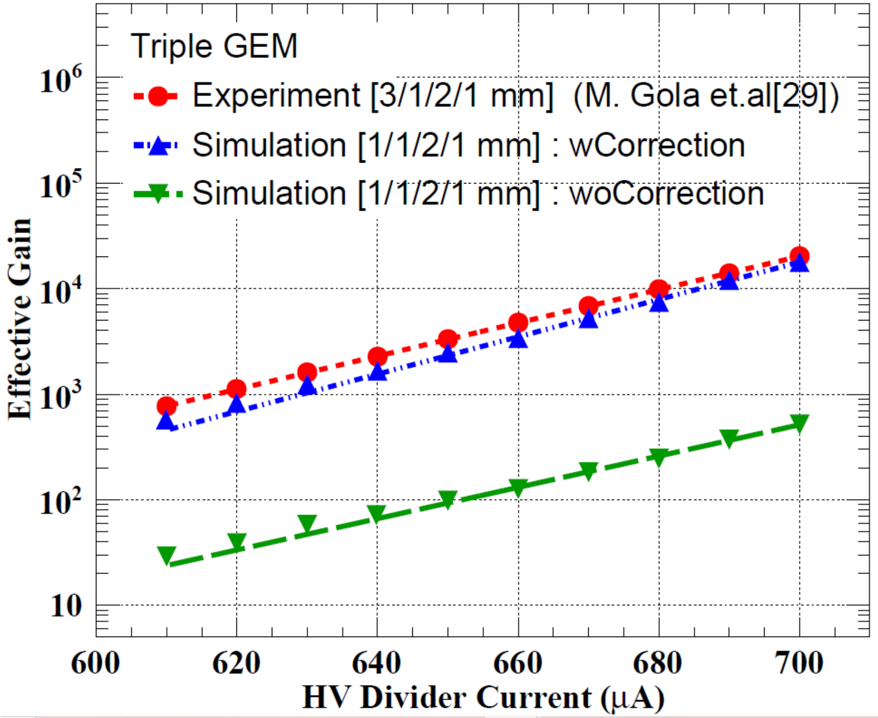
Ref:

"Fast simulation of avalanche and streamer in GEM detector using hydrodynamic approach" P.K. Rout *et al* 2021 *JINST* **16** P02018

"Discharge mechanisms and their prevention in the gas electron multiplier (GEM)", S. Bachmann et al.,NIM A479(2002) 294.

Gain Comparison for Triple GEM





Ref: "Fast simulation of avalanche and streamer in GEM detector using hydrodynamic approach" P.K. Rout *et al* 2021 *JINST* **16** P02018
"Discharge mechanisms and their prevention in the gas electron multiplier (GEM)", S. Bachmann et al.,NIM A479(2002) 294
"Performance of the triple GEM detector built using commercially manufactured GEM foils in India", M. Gola et al,NIM A951(2020) 162967

Conclusion

1. The hydrodynamic approach to simulate avalanche and streamer have been discussed.
2. Space charge effect has been included.
3. This method is fast and in reasonable time one can simulate both RPC and GEM characteristics with acceptable accuracy.

Our Group

These works have been carried out with

Prasant Kr. Rout[1, 2], Sridhar Tripathy[1, 2], Promita Roy[1, 2], Purba Bhattacharya[3], Sandip Sarkar[1, 2], Supratik Mukhopadhyay[1, 2], Nayana Majumdar[1, 2]

1. Saha Institue of Nuclear Physics, Kolkata, India

2. Homi Bhabha National Institute, Mumbai, India

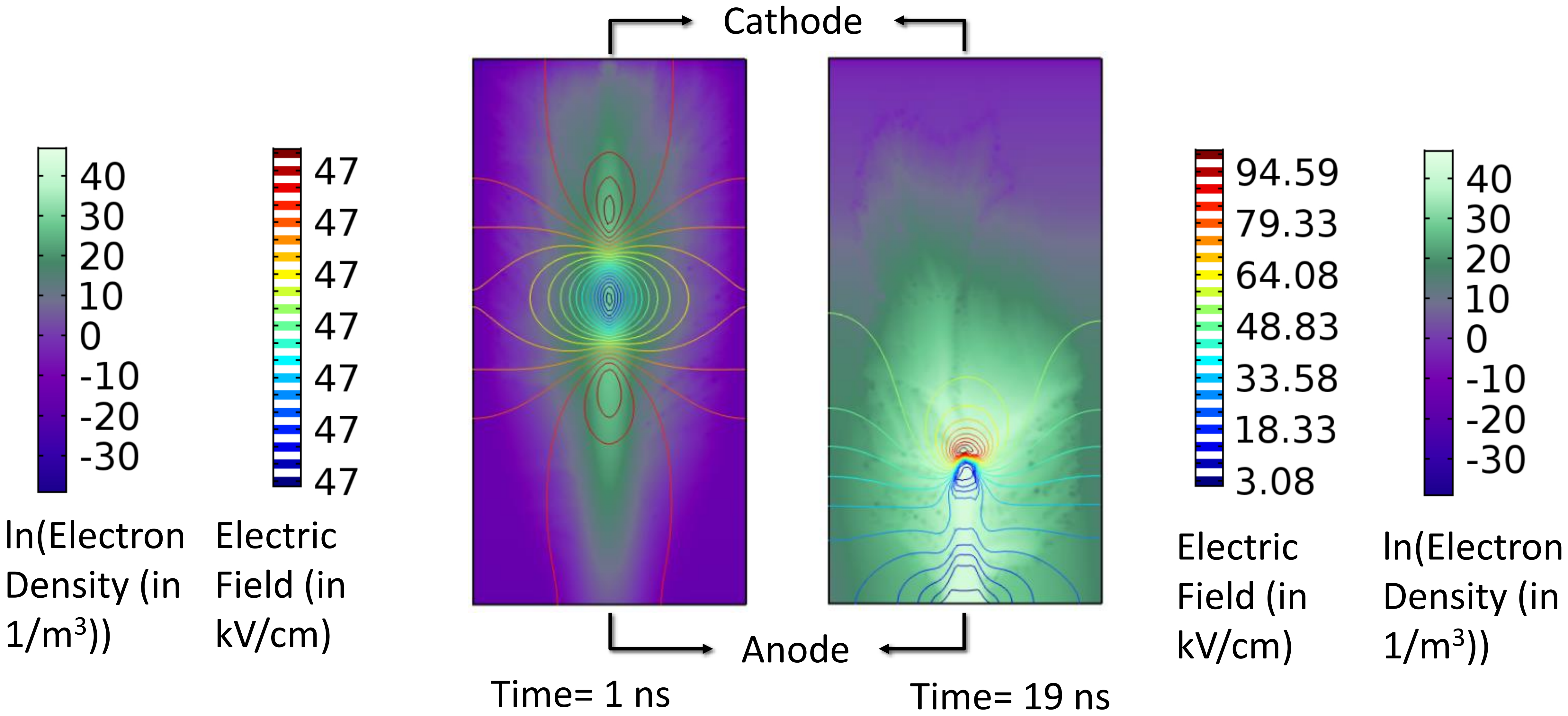
3. Department of Physics, University of Calcutta, 92 A.P.C Road, Kolkata 700009, West Bengal, India

Thank you

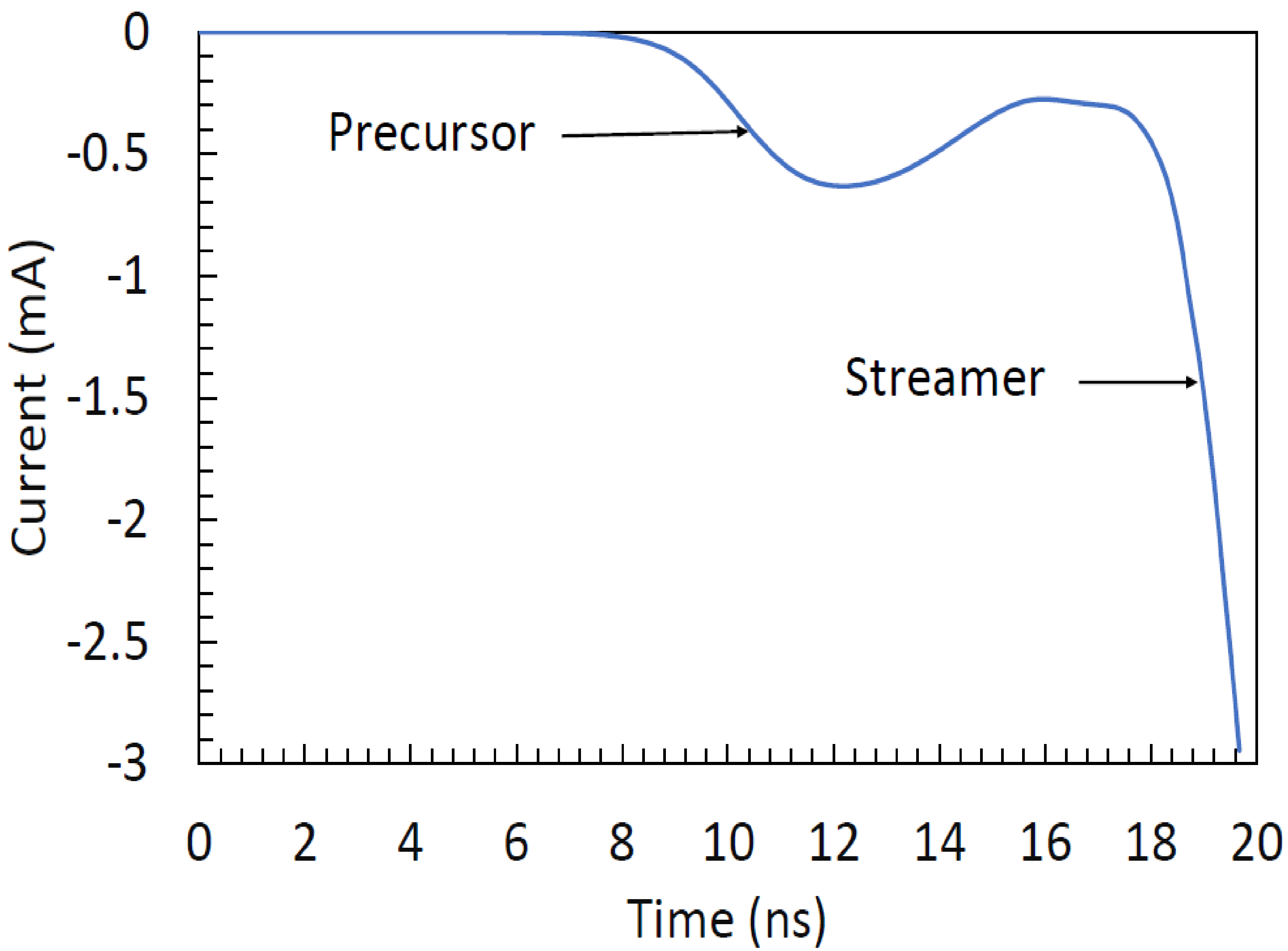
Back up slides

Boundary Conditions for RPC

1. The outflow of electrons through anode and that of positive ions through cathode has been taken care of by assuming that there drift of these charged species through respective electrodes.
2. The dimension of the simulation volume was chosen such a way that it can contain the whole avalanche and streamer.
3. The electrodes are made of Bakelite or glass, none of which have scintillation property, so the photon flux from the electrodes has been set to zero.



Ref: "*Study of Streamer Development in Resistive Plate Chamber*", **J. Datta**, S. Tripathy, N. Majumdar, S. Mukhopadhyay, *JINST* **15** C12006 (2020)

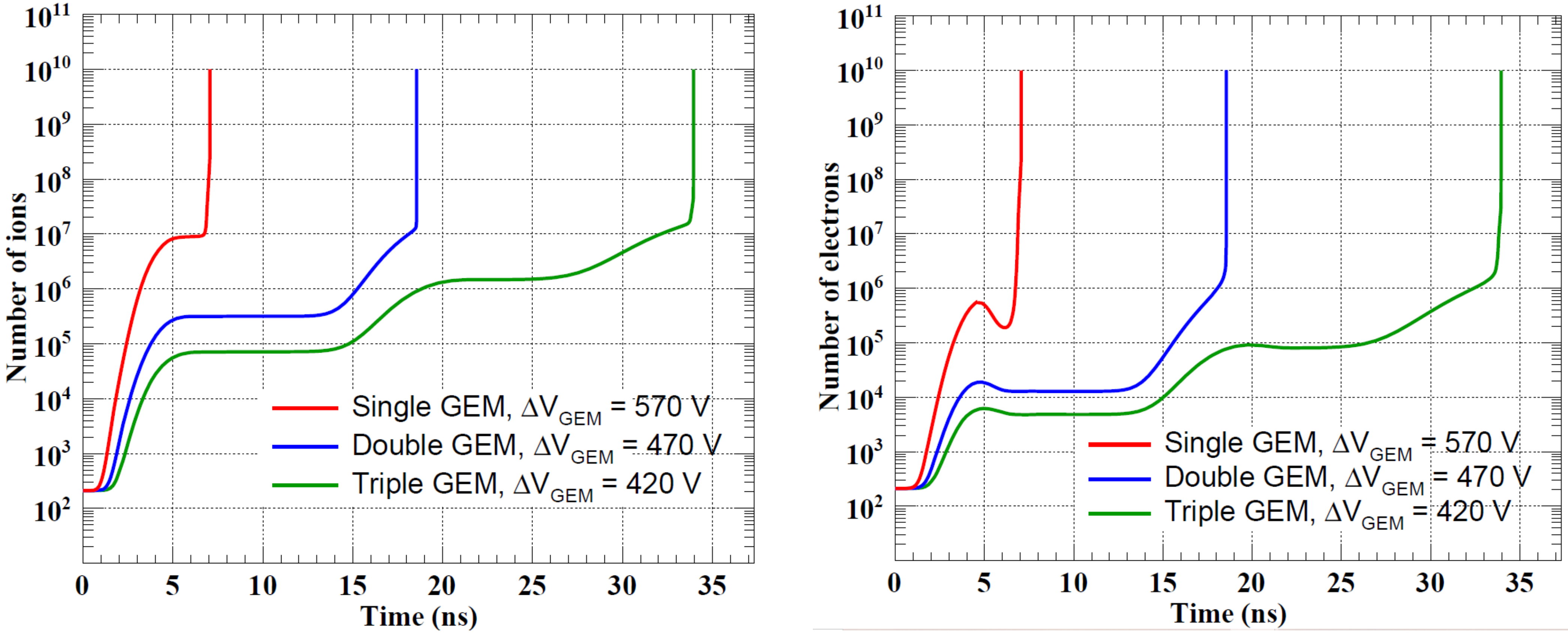


Ref: “*Study of Streamer Development in Resistive Plate Chamber*”, **J. Datta**, S. Tripathy, N. Majumdar, S. Mukhopadhyay, *JINST* **15** C12006 (2020)

Boundary Conditions for GEM

1. To incorporate the loss of charged species through the electrodes, it was assumed that the electrode boundaries, that are drift cathode, anode, GEM cathode, GEM anode, are open boundaries.
2. The dimension of the simulation volume was chosen such a way that it can contain the whole avalanche and streamer.
3. The charged species get accumulated on the surface of the dielectric material. So the dielectric boundaries were chosen to be opaque for them.

Streamer in GEM



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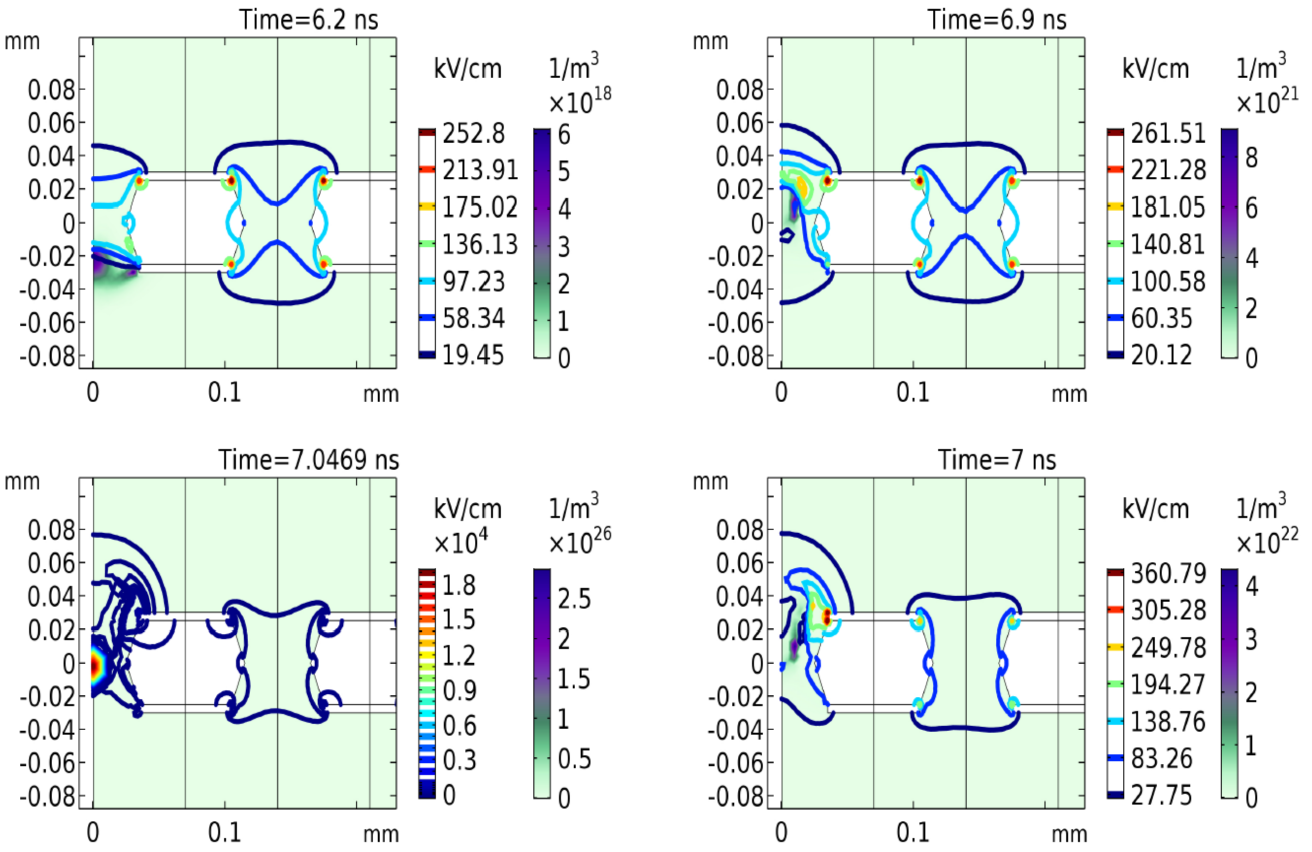
Streamer in GEM



This figure shows the streamer propagation in a single GEM. The plots are clockwise in time starting from top left corner.

Ref: "Fast simulation of avalanche and streamer in GEM detector using hydrodynamic approach" P.K. Rout *et al* 2021 *JINST* **16** P02018