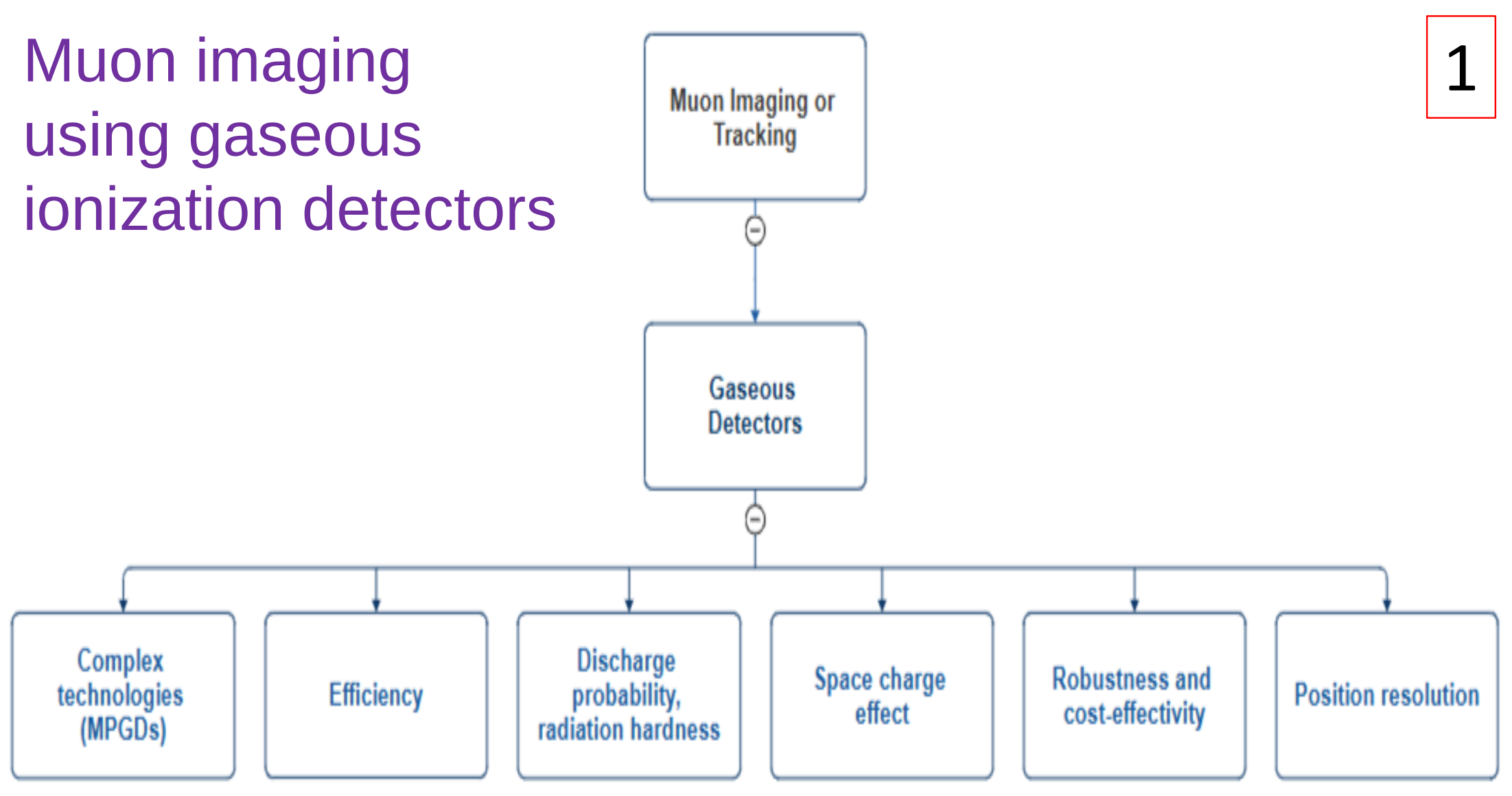
STUDY OF CHARGE DYNAMICS IN THGEM-BASED DETECTORS – A NUMERICAL APPROACH

Purba Bhattacharya[a], Rishabh Gupta[a], Shounok Guha[a], Prasant Kumar Rout[b], Jaydeep Datta[c], Nayana Majumdar[d], Supratik Mukhopadhyay[d]
[a]Department of Physics, School Of Basic And Applied Sciences, Adamas University, Kolkata, India
[b]National Central University, Taiwan
[c]Stony Brook University, United States
[d]Applied Nuclear Physics Division, Shah Institute of Nuclear Physics, Kolkata, India, a CI of HBNI
Presented by: Maxim Titov, CEA, Saclay

Muon imaging using gaseous ionization detectors

1

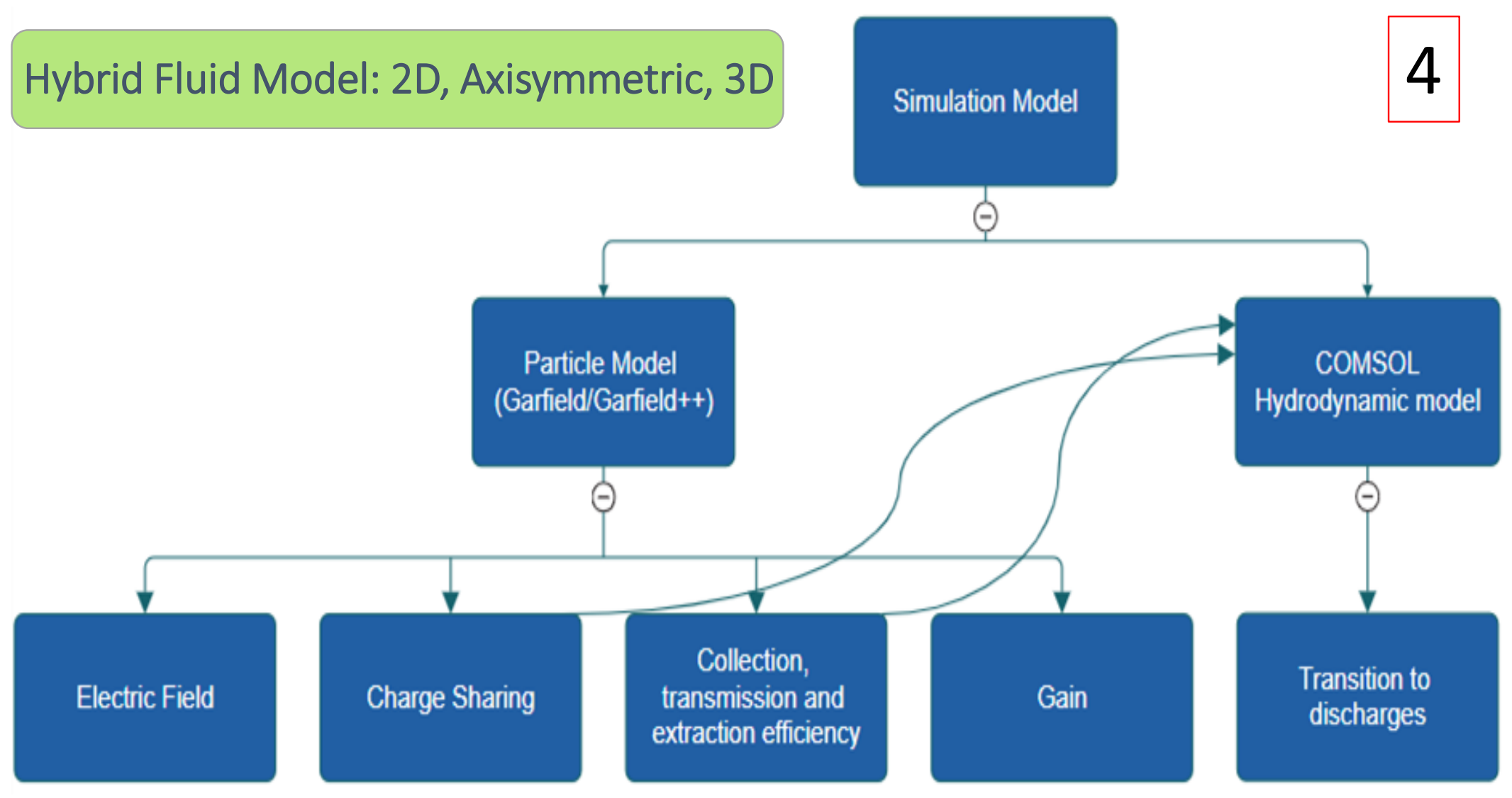


Requirements

- Good position resolution to distinguish medium and high Z material
- High detector efficiency
- Good timing resolution
- Portable, robust, cost-effective
- Low or zero electrical power consumption
- Easily manageable fabrication complextities

Opted for THGEM based on above requirements.

4



- **Several inputs from the particle model are necessary:** primary ionization [HEED], transport properties [Magboltz], charge sharing, collection, transmission and extraction efficiencies [Garfield].

Results in a hybrid model

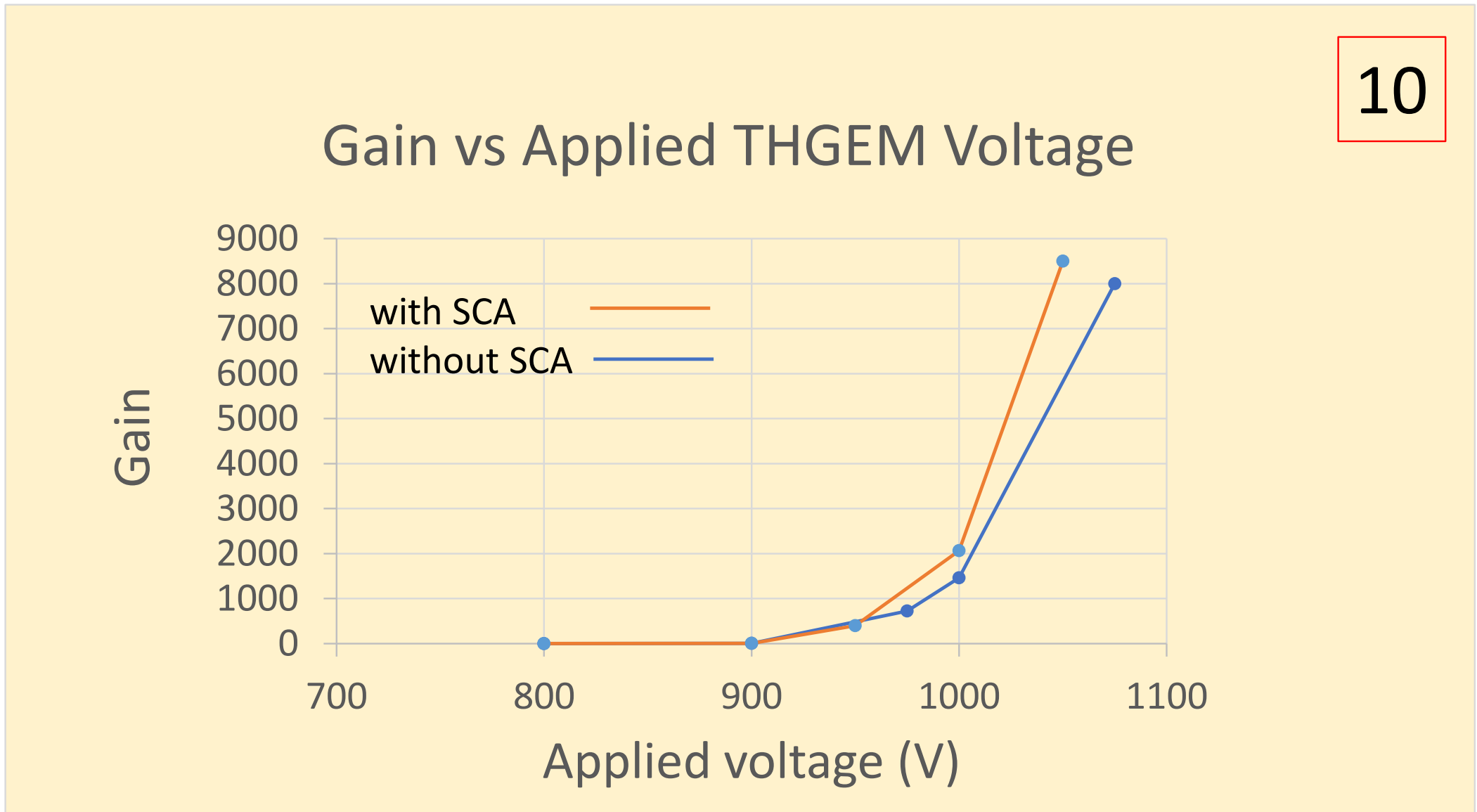
7

Hybrid COMSOL model using the MPh package

- MPh is a Pythonic scripting interface for Comsol Multiphysics software.
- Streamlines the integration of Comsol Multiphysics with Python for automated simulations and data processing.
- Found to be particularly useful in workflows involving HEED, Magboltz, Garfield++, and Comsol, enabling efficient coupling of electric field calculations and particle tracking.
- Code written in python using MPh module as a wrapper to simplify multiple simulation tasks.

Effect of surface charge accumulation (SCA) on Gain

10



Conclusions

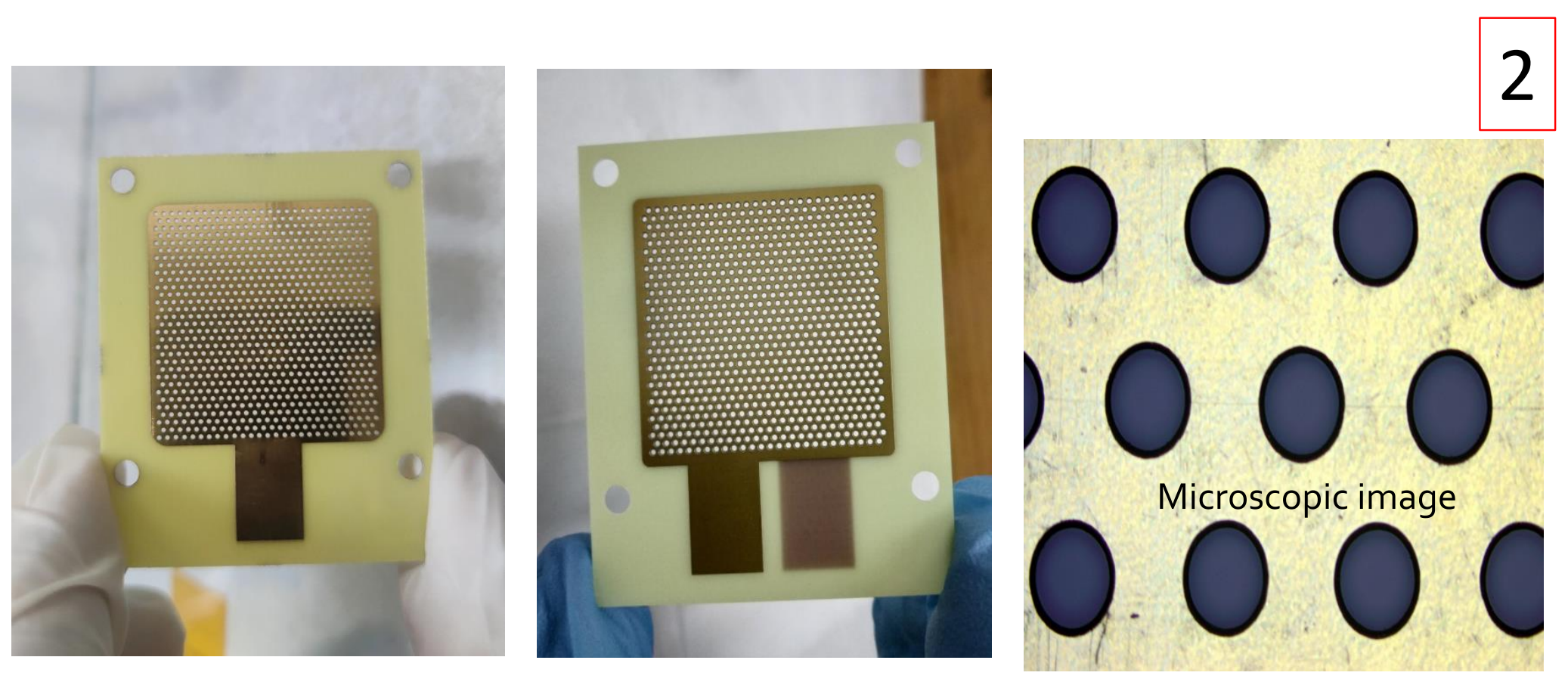
1. A hybrid model based on inputs from particle models to transport charged particles as dilute fluids is found to work well, with few obvious limitations due to mathematical modeling.

1. A Python code, developed utilizing the MPh package, played a key role in automating simulations and analyzing THGEM performance by efficiently varying parameters and generating models as needed. It has the potential of automating studies related to detector optimization.

2. Initial studies on effects of surface charge accumulation, streamer transition and negative ion accumulation have been carried out.

3. The results need further refinement.

2



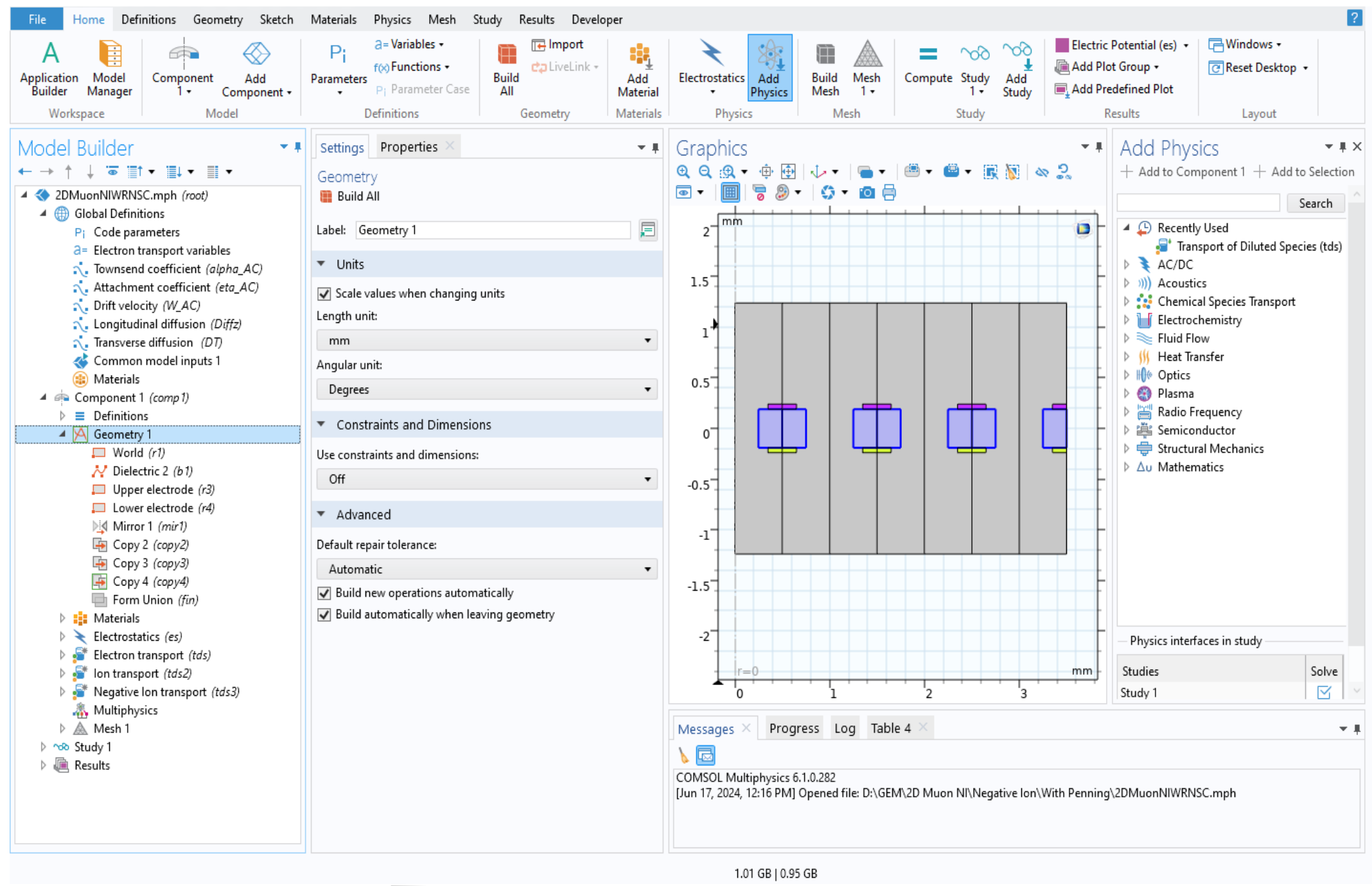
THGEMs fabricated in India

- Gains > 3 x 10^3 achieved with a single THGEM
- Thicker foils: stability and radiation hardness
- Simplified production process
- Focus on cylindrical holes for easy fabrication
- Hole diameter: 500 μm.
- Two variants: with & without rim. (Rim ~ 100 μm)
- Pitch: 1000 μm.
- Characterized using argon-based gas mixtures (Ar:CO2= 70:30 and Ar:isobutane = 95:5)

5

Simulation with COMSOL

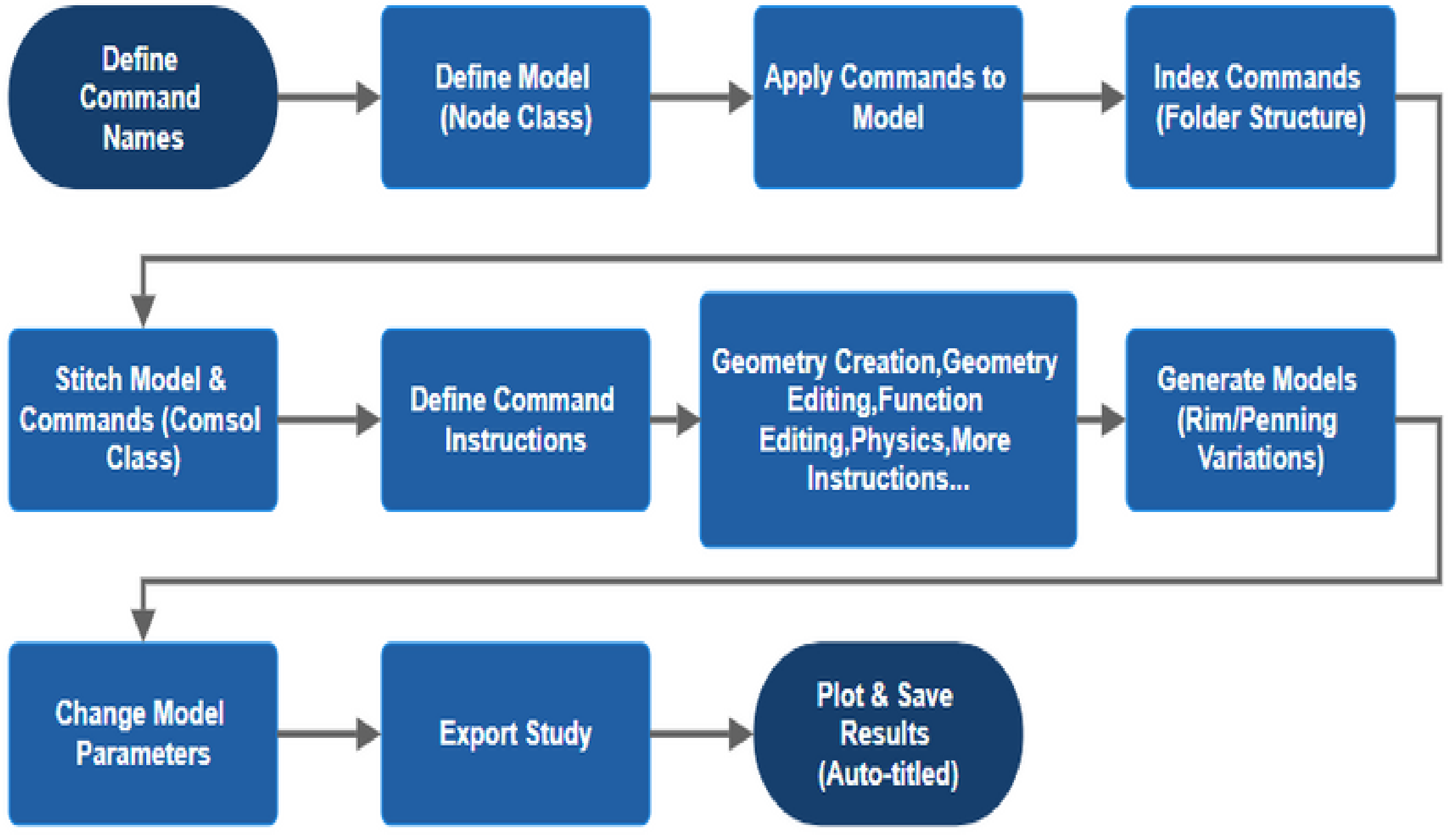
- Commercial FEM package.
- Integrates various physical phenomena for comprehensive analysis.



COMSOL Multiphysics 6.1.0.282
[Jun 17, 2024, 12:16 PM] Opened file: D:\GEM\2D Muon NI\Negative Ion\With Penning\2DMuonNIWRNSC.mph

1.01 GB | 0.95 GB

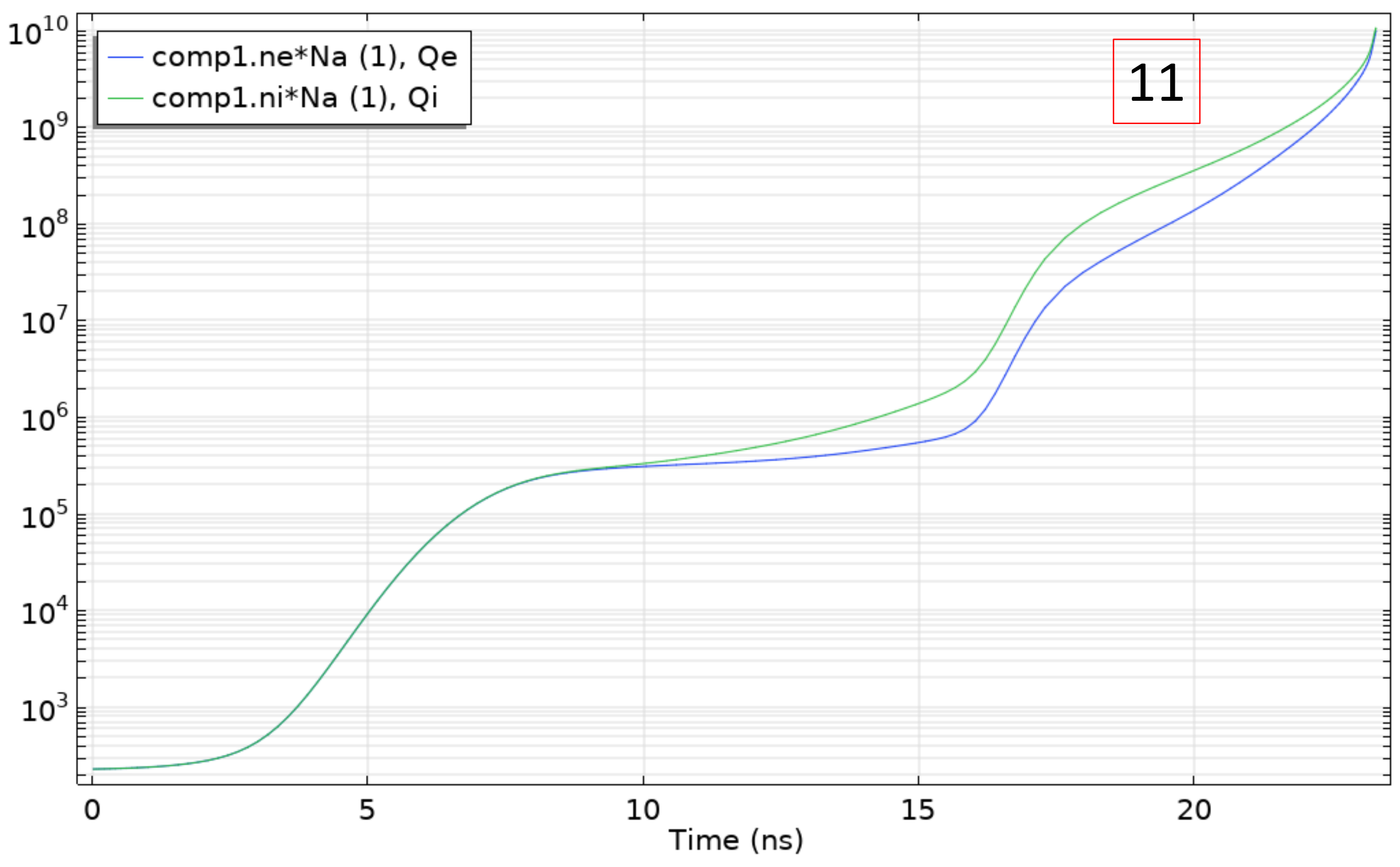
8



- Developed code utilizes MPh's Java connection via JPype
- Achieves complex simulations with minimal code.

Streamer transition at 1800V

11



Acknowledgements

- The authors are deeply indebted to Dr. Maxim Titov for making this poster presentation possible.
- All the authors acknowledge support from their respective Institutes and Universities
- The authors acknowledge the funding received from the Science and Engineering Research Board, Government of India, No. SRG/2022/000531.

Importance of numerical simulation

3

- **Optimization, Cost-Effective, Insightful, Predictive**

1. Simulation Approaches:

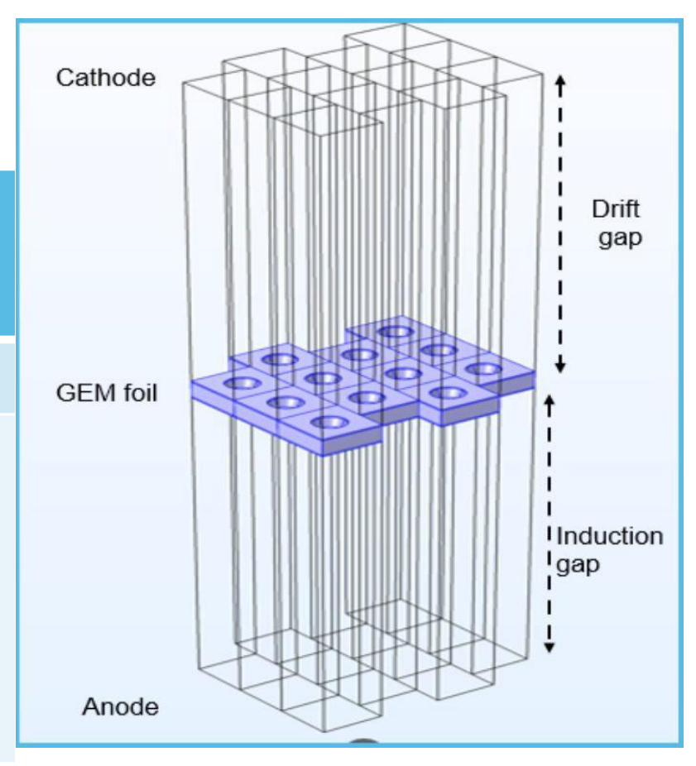
i. Particle Simulation: Based on Lagrangian mechanics, may use Garfield++ simulation framework. Very detailed, but resource hungry. Simulation of streamer, space charge effects can be quite demanding.

ii. Hydrodynamic Simulation: Based on Eulerian mechanics. Easy on computational resource. Handles complex physics processes such as streamer transition, space charge accumulation and charging up effects; Lacks in detail, provides averaged out properties.

Simulation details

6

Boundary conditions	Electron transport	Ion transport
No-flux	Drift cathode	Readout anode
Open boundary	THGEM top Cu, THGEM bottom Cu, anode and outer surface	THGEM top Cu, THGEM bottom Cu, cathode and outer surface



Drift-diffusion equations

Electrostatics $\nabla \cdot \mathbf{D} = \rho_v$ and $\mathbf{E} = -\nabla V$

Transport of diluted species $\nabla \cdot (\mathbf{J}_i + \mathbf{u} c_i) = R_i$ and $\mathbf{J}_i = -D_i \nabla c_i$

Reactions $\nabla \cdot (\mathbf{J}_i + \rho \mathbf{u} \omega_i) = R_i + S_i$

Surface charge accumulation $\frac{\partial \rho_s}{\partial t} = \mathbf{n} \cdot \mathbf{J}_i + \mathbf{n} \cdot \mathbf{J}_e$ and $-\mathbf{n} \cdot (\mathbf{D}_1 - \mathbf{D}_2) = \rho_s$

Initial Conditions:

- Identical initial concentrations for ions and electrons.

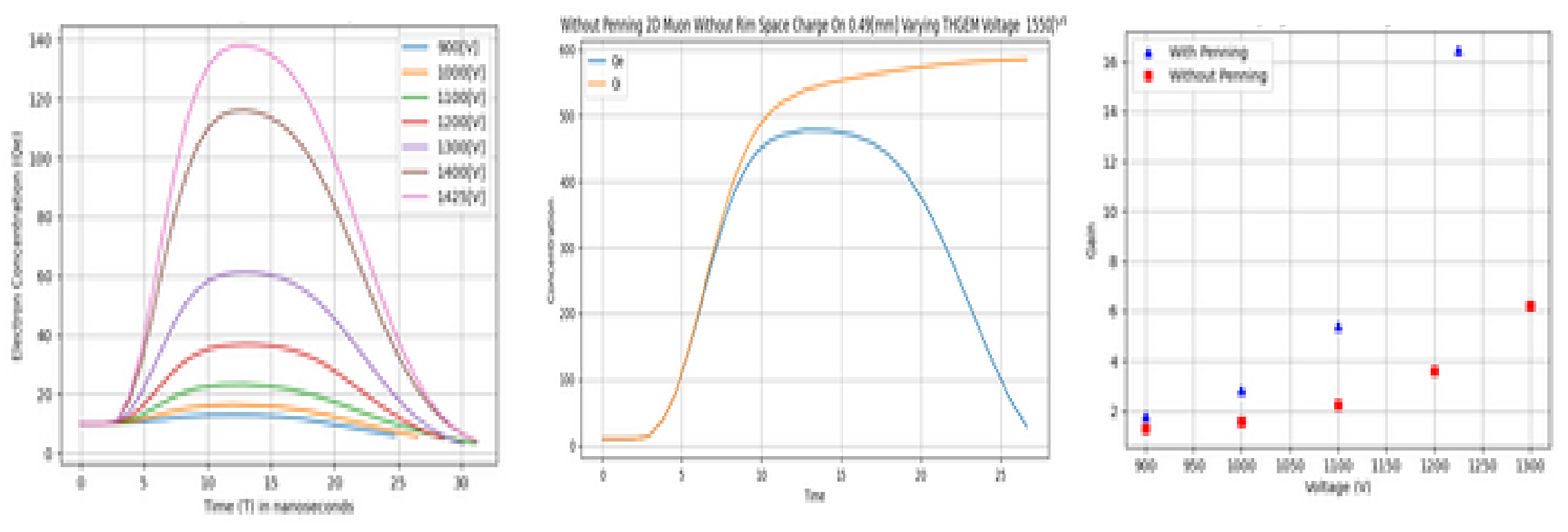
Boundary Conditions:

- Conducting electrodes maintain specific potentials.
- Conducting electrodes and symmetry boundaries allow passage of charged particles.
- Material properties of non-conducting boundaries determine interaction behavior.

Use of codes based on MPh

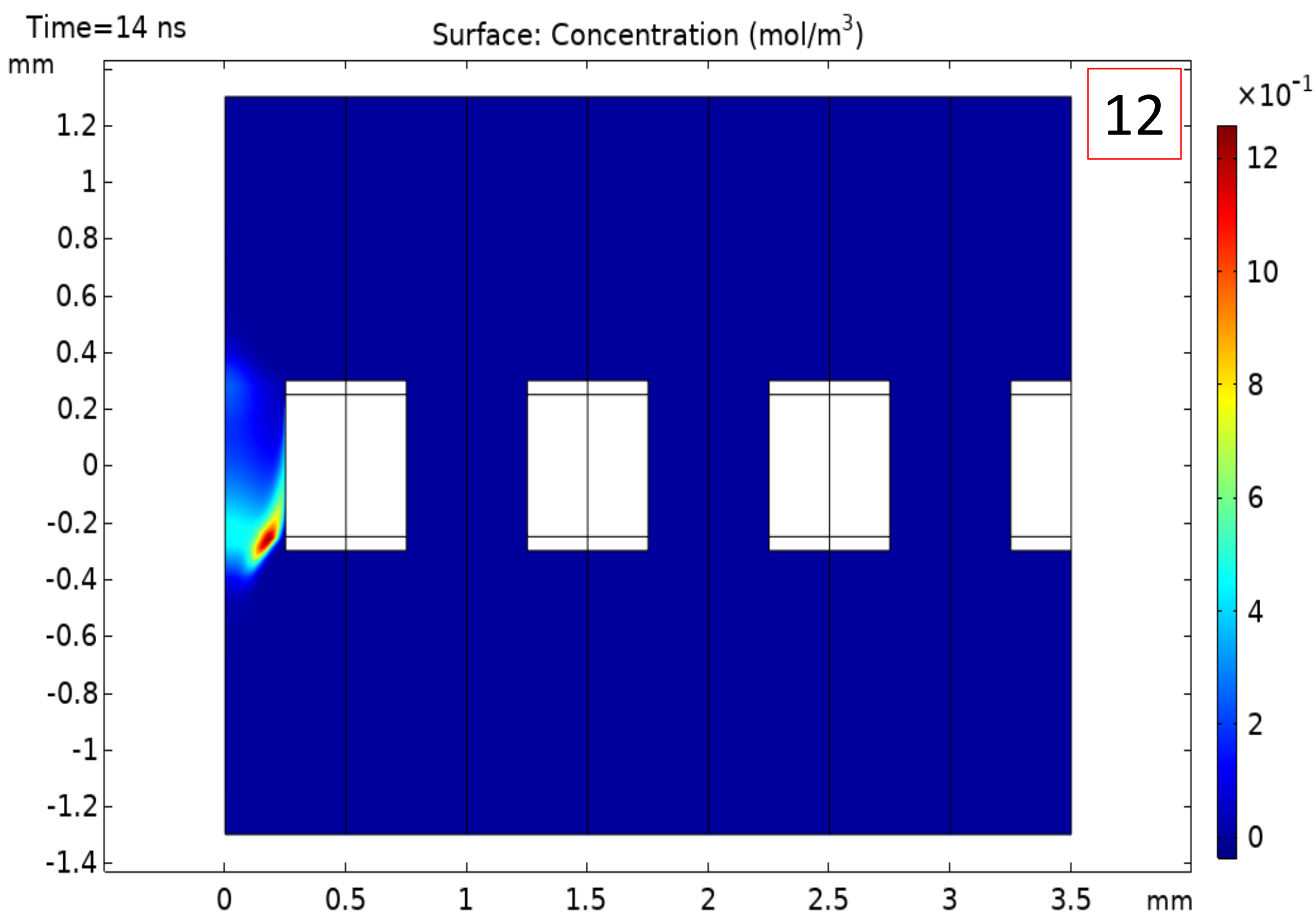
9

- Simultaneous calculations and data plotting based on user requirements.
- Can also create new models if needed.
- Following graphs obtained by varying some parameters of the Thick GEM module to test it under different conditions.



Accumulation of negative ions

12



References

Muon imaging: Sebastien Procureur et al. , *Nat Commun* (2023). doi: https://doi.org/10.1038/s41467-023-36351-0
THGEM: Shikma Bressler et al., Progress in Particle and Nuclear Physics (2023). doi: https://doi.org/10.1016/j.ppnp.2023.104029
Garfield: R. Veenhof. , Journal of Instrumentation 4 (2009), P12017 [https://garfieldpp.web.cern.ch/garfieldpp/]
Heed: I.B. Smirnov. , Nucl. Instrum. Meth. A 554 (2005), p. 474.
Magboltz: S.F. Biagi. , Nucl. Instrum. Meth. A 421 (2005), p. 234
Comsol: https://www.comsol.com/
MPh: https://mph.readthedocs.io/en/1.2/