

2.xD Simulation of Radio-frequency Ion Thruster (RIT-2.5)

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Motivation

- We wanted to develop our own particle-based code for plasma simulation in large devices.
- Collaboration with experimentalist working on RF- Ion thrusters at JLU.
- Research on plasma in non-thermal state as seen from the example of RIT-1.0 simulations.

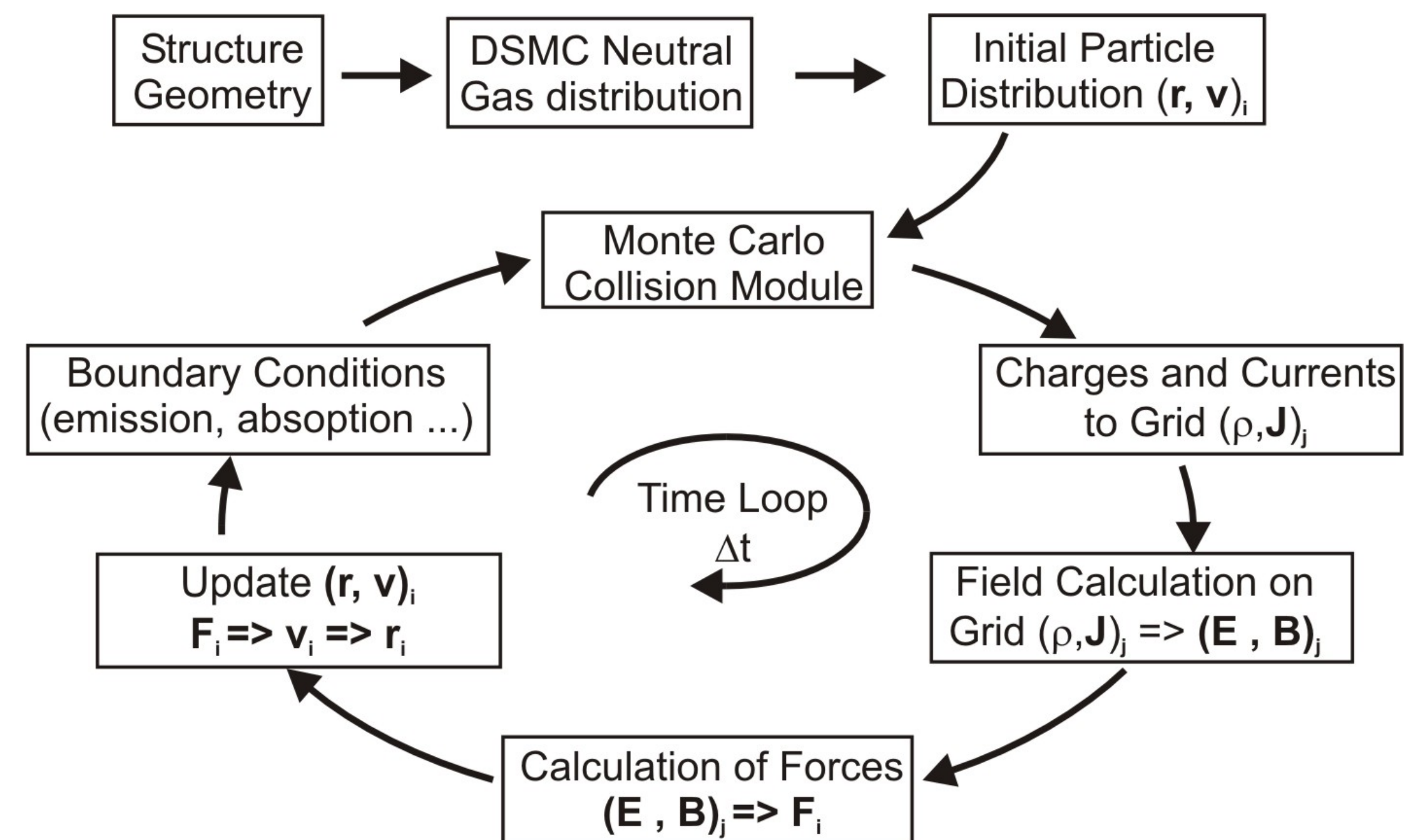


Particle-in-Cell (PIC) method

- Developed by Buneman, Dawson, Hockney, Birdsall, Morse
- The particles in a Lagrangian frame are tracked in continuous phase space, whereas fields are computed simultaneously on Eulerian mesh.

- Time loop

- Integration of the equations of motion.
- Interpolation of charge and current source terms to the field mesh.
- Computation of the fields on mesh points.
- Interpolation of the fields from the mesh to the particle locations.





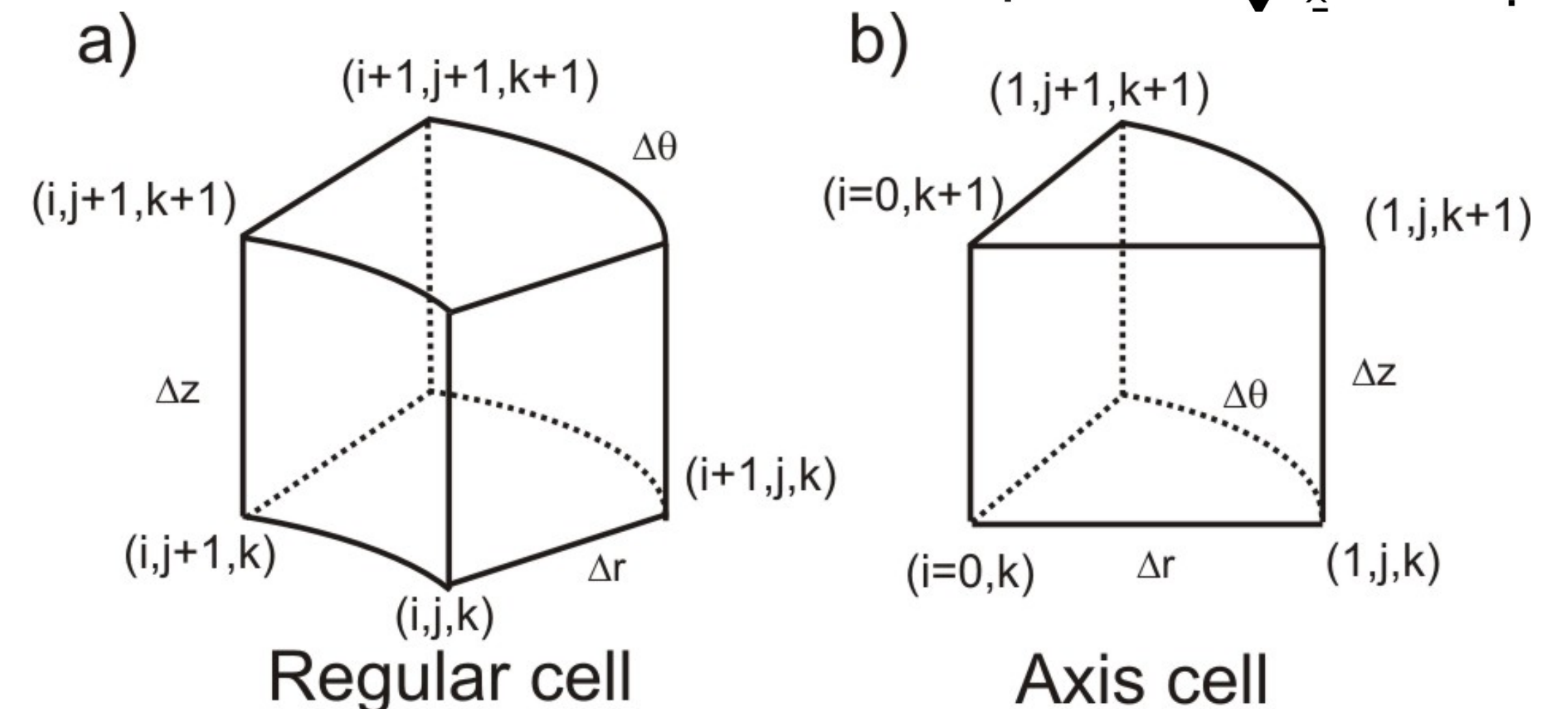
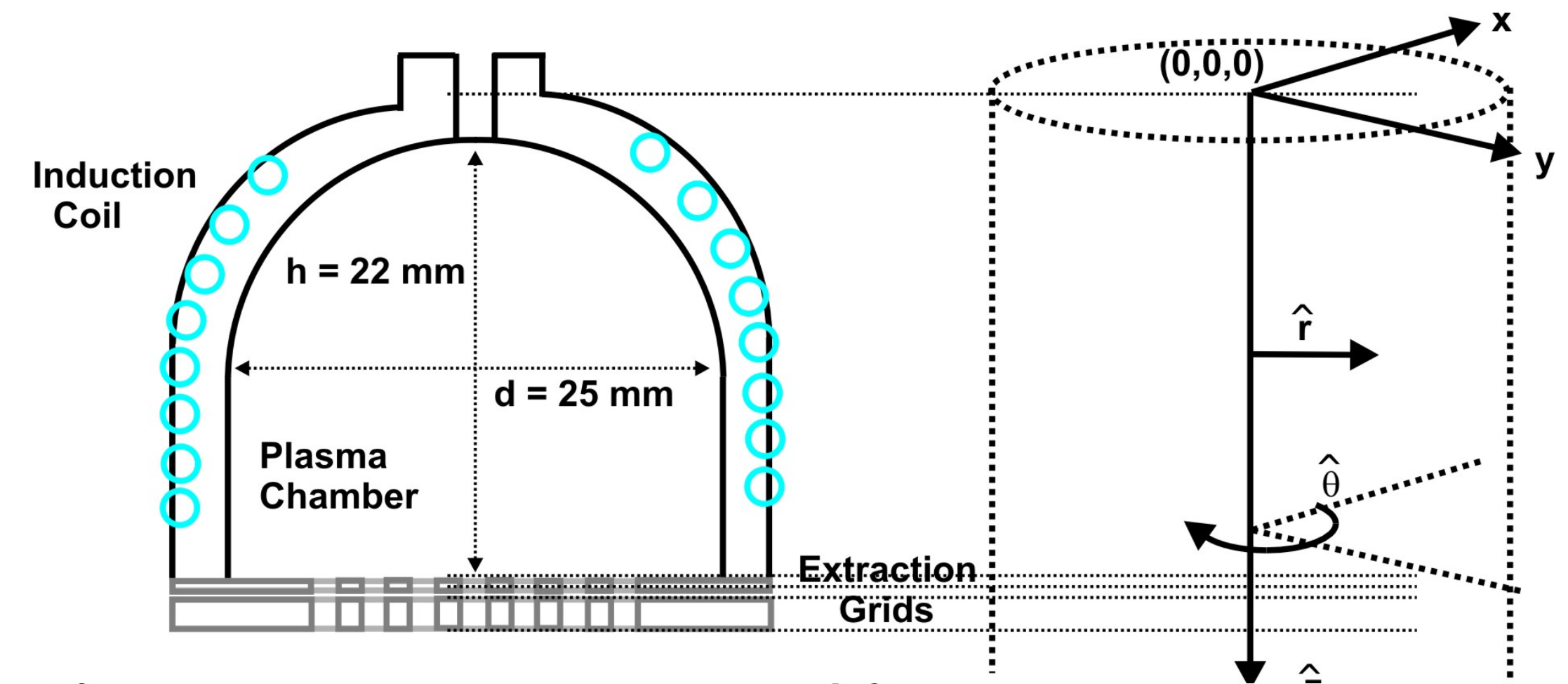
PIC limitations

- Grid size and time step $\Delta t < 2\omega_{pe}^{-1}$
 $\Delta x < 3.4\lambda_D$
- Example: Plasma density $n = 10^{16} /m^3$, $T_e = 10$ eV corresponds to Debye length of 0.23 mm : 0.1 mm grid size leading to 100 points for RIT-1.0 in each direction
- If grid thickness 1 mm we need at least 6 points for resolution : that corresponds to 0.16 mm in spatial direction
- Typical plasma frequency leads to time scale of 10^{-11} s



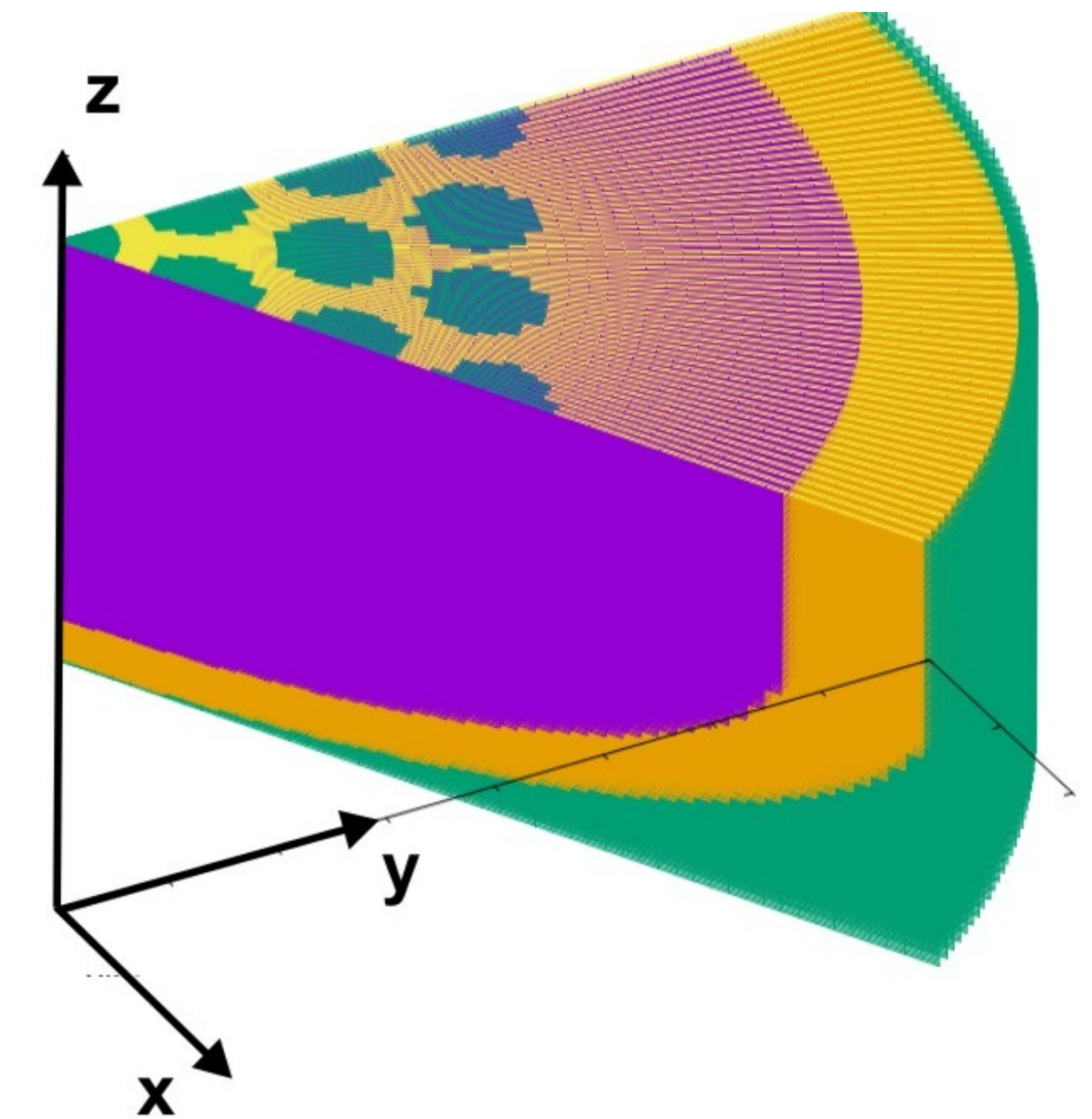
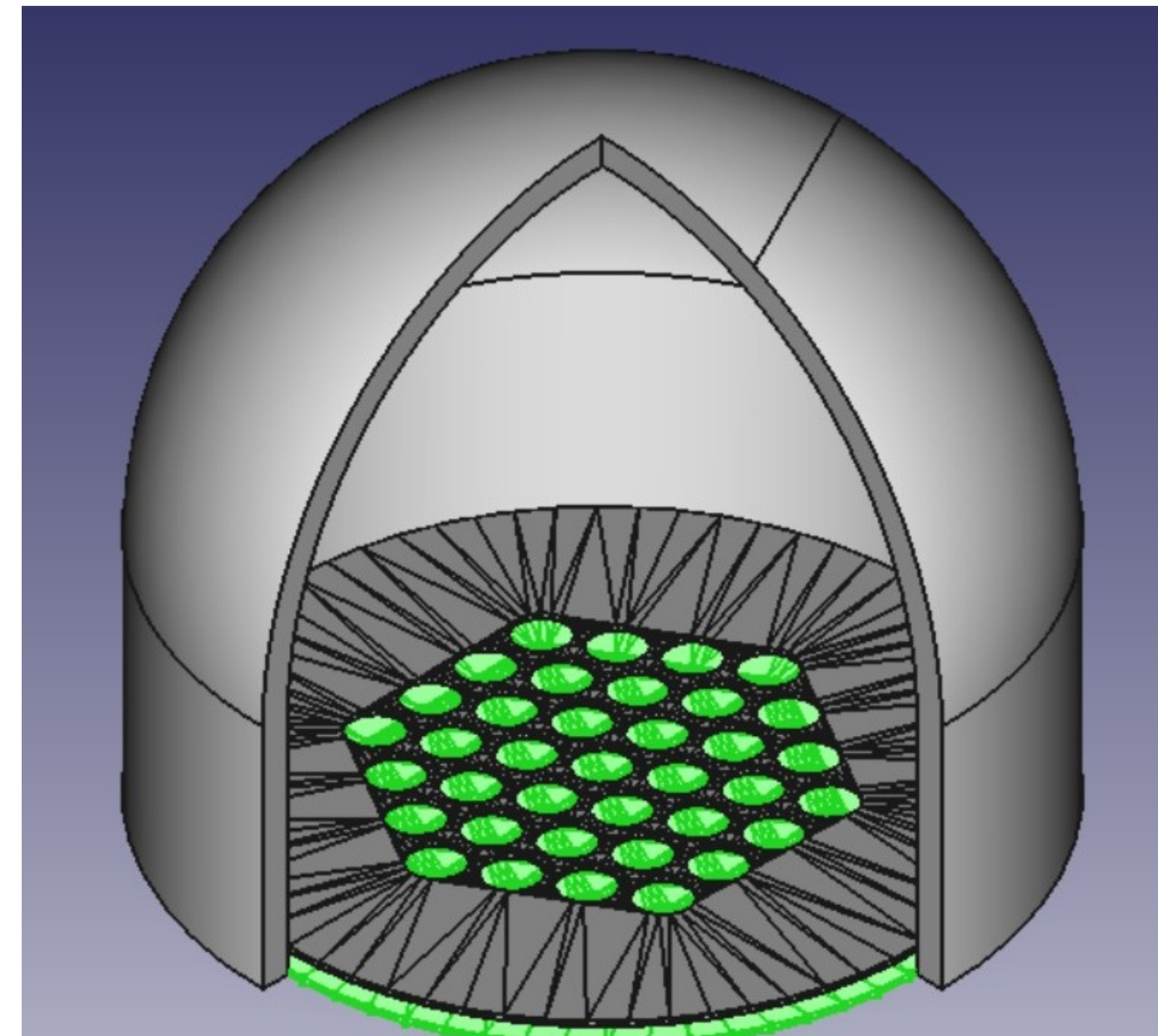
Cylindrical Coordinates

- Grid/Mesh is created in cylindrical coordinates
- Unlike cartesian coordinates the volume elements differ
- Separate central cells needed to be defined
- Gauss law for axis cells



2.xD approach

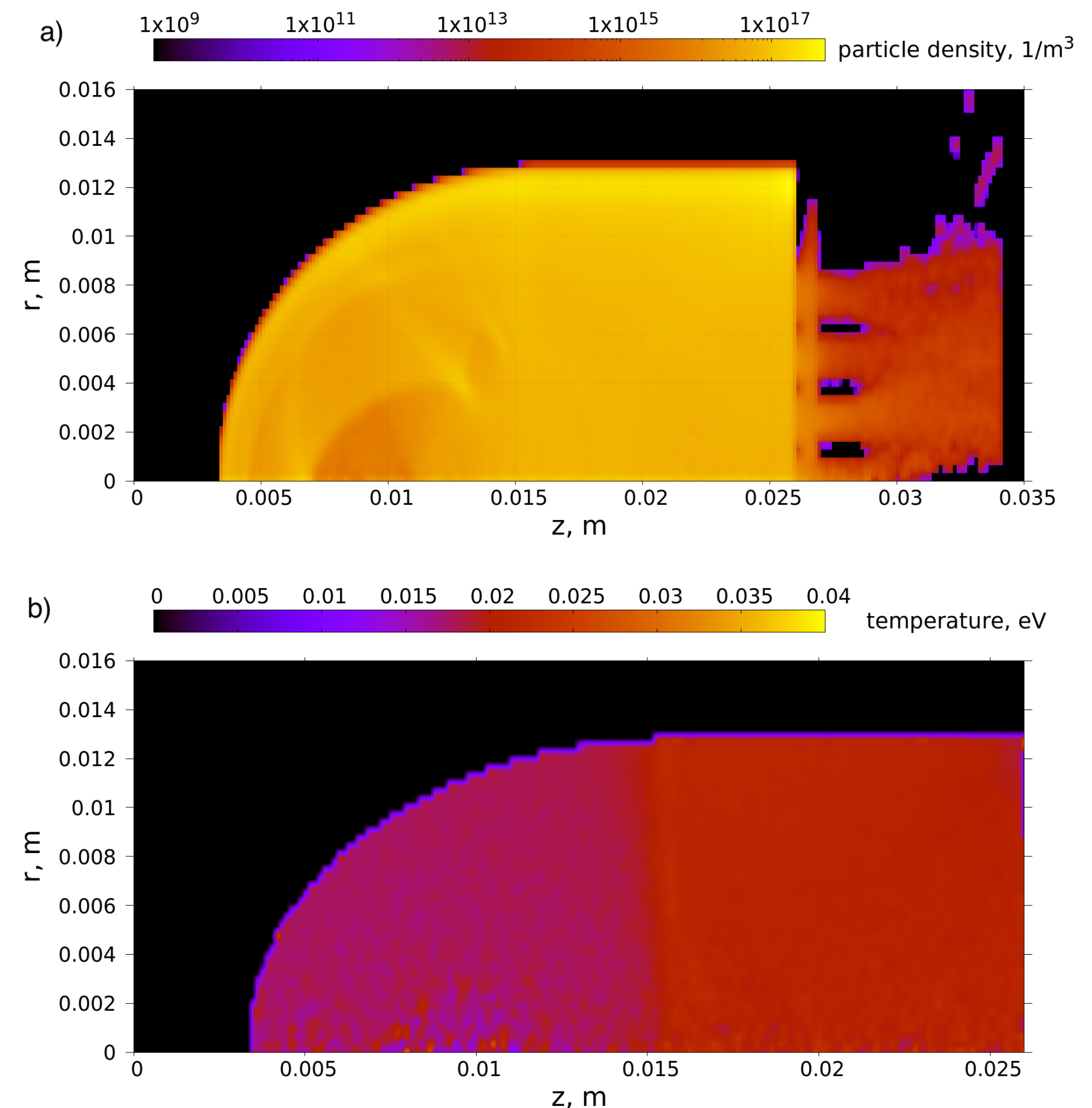
- The size of the simulation domain can be selected by choosing angular extent
- In case of partial pie domain periodic boundaries are applied
- Simulation domain is decomposed in only longitudinal z-direction
- Induction coil is always 3d





DSMC Simulation

- Domain with a radius of 16.0 mm and a length of 35.0 mm.
- At a distance of 34.0 mm is a detector
- Xenon (Xe0) particles with the inlet gas flow of 1.816×10^{-11} kg/s
- Cylindrical domain 51x2x251 grid points, time step 1×10^{-8} s, using 240 cores over a time of 16639 s

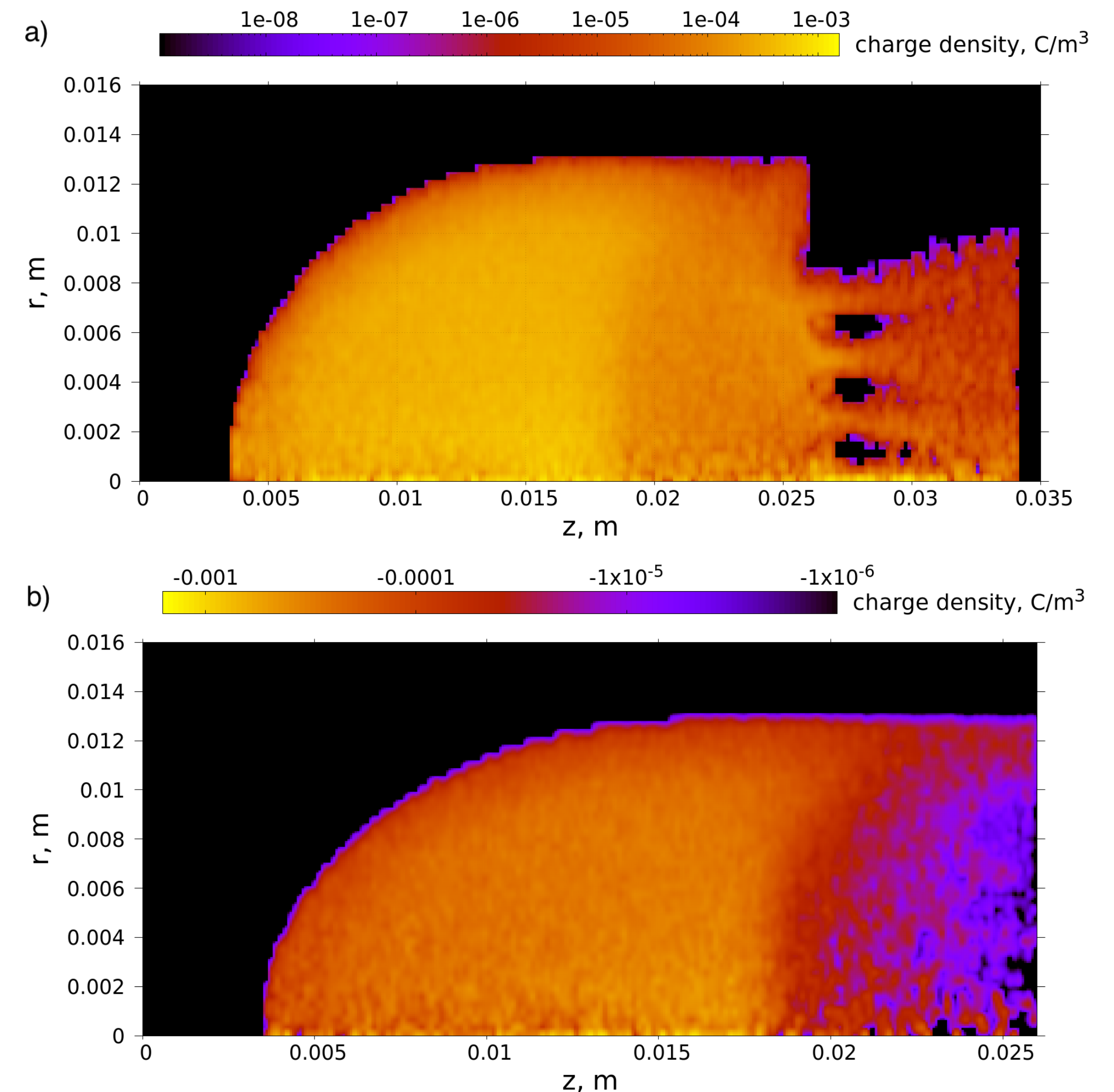


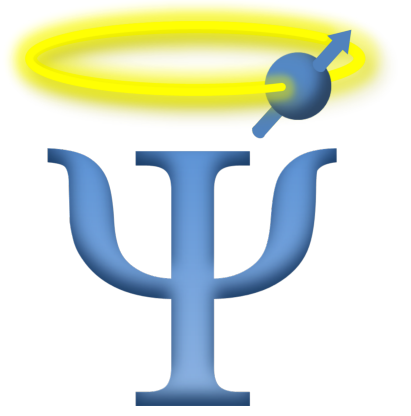


Plasma simulation

- Xe⁺ ions with the density $1 \times 10^{15} / \text{m}^3$ along with electrons are initialised
- Power is deposited through coil at frequency of 2.2 MHz
- Monte-Carlo Collisions include electron-neutrals, ion-neutrals
- 4545 steps per rf-cycle
- Example with 10-degree pie section

Dr. Ninad Joshi, IEPC 2024, Toulouse, France

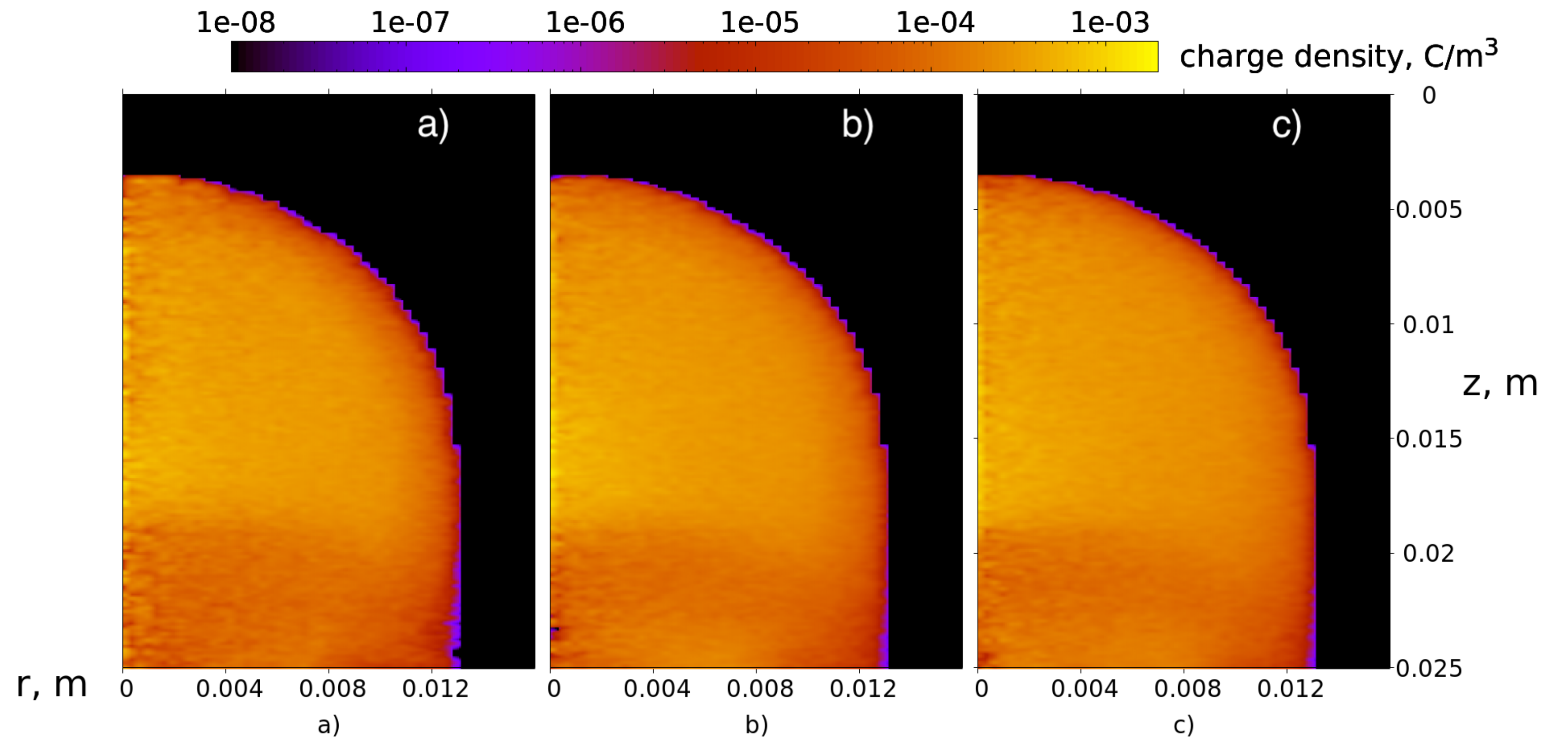




Comparison of Pie sections

Ion density

- Comparison with different pie sections: 10-degree, 30-degree, 60-degree
- Ion densities inside chamber are plotted

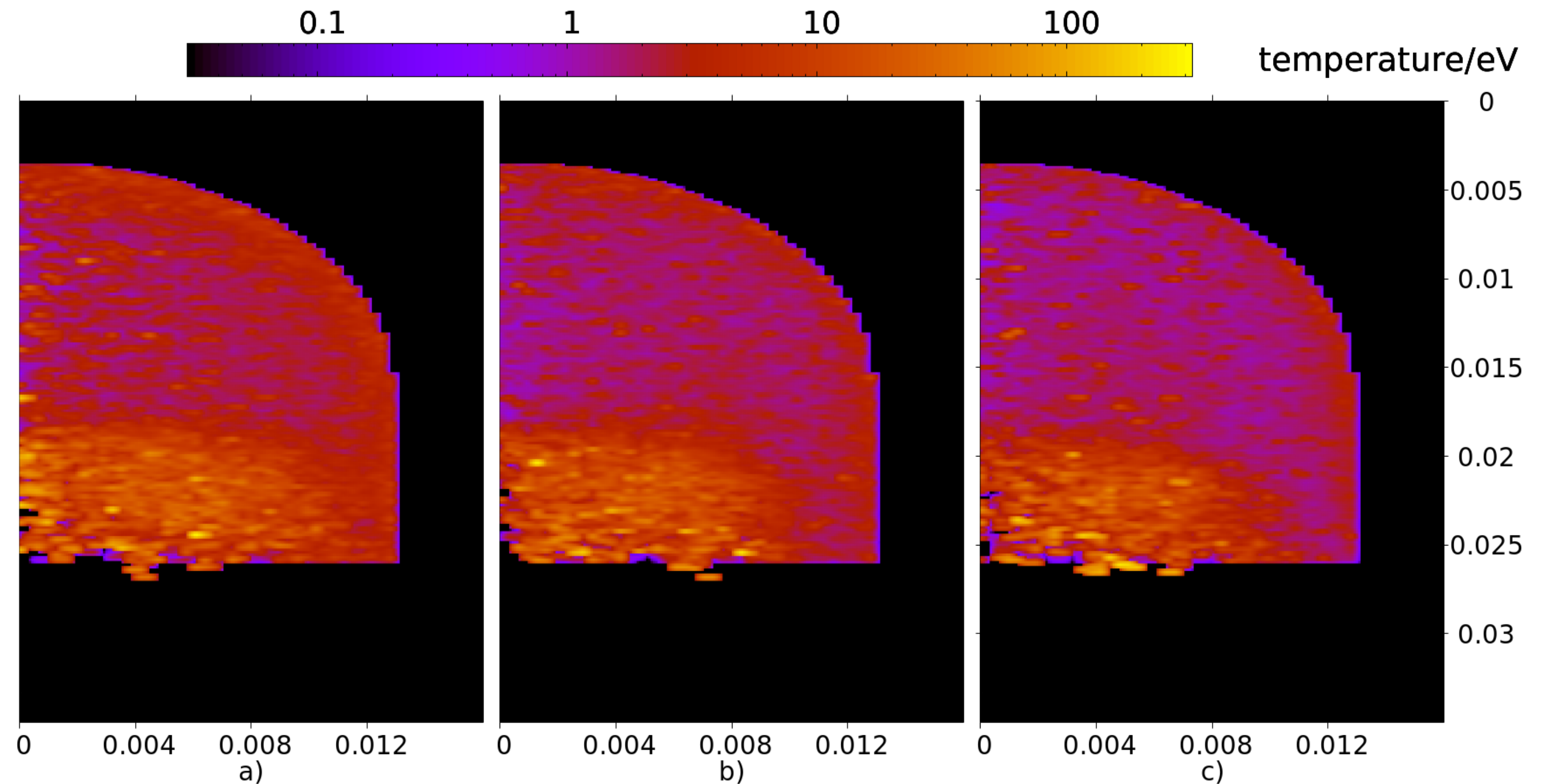




Comparison of Pie sections

Electron Temperature

- Comparison with different pie sections: 10-degree, 30-degree, 60-degree
- Electron temperature inside chamber are plotted

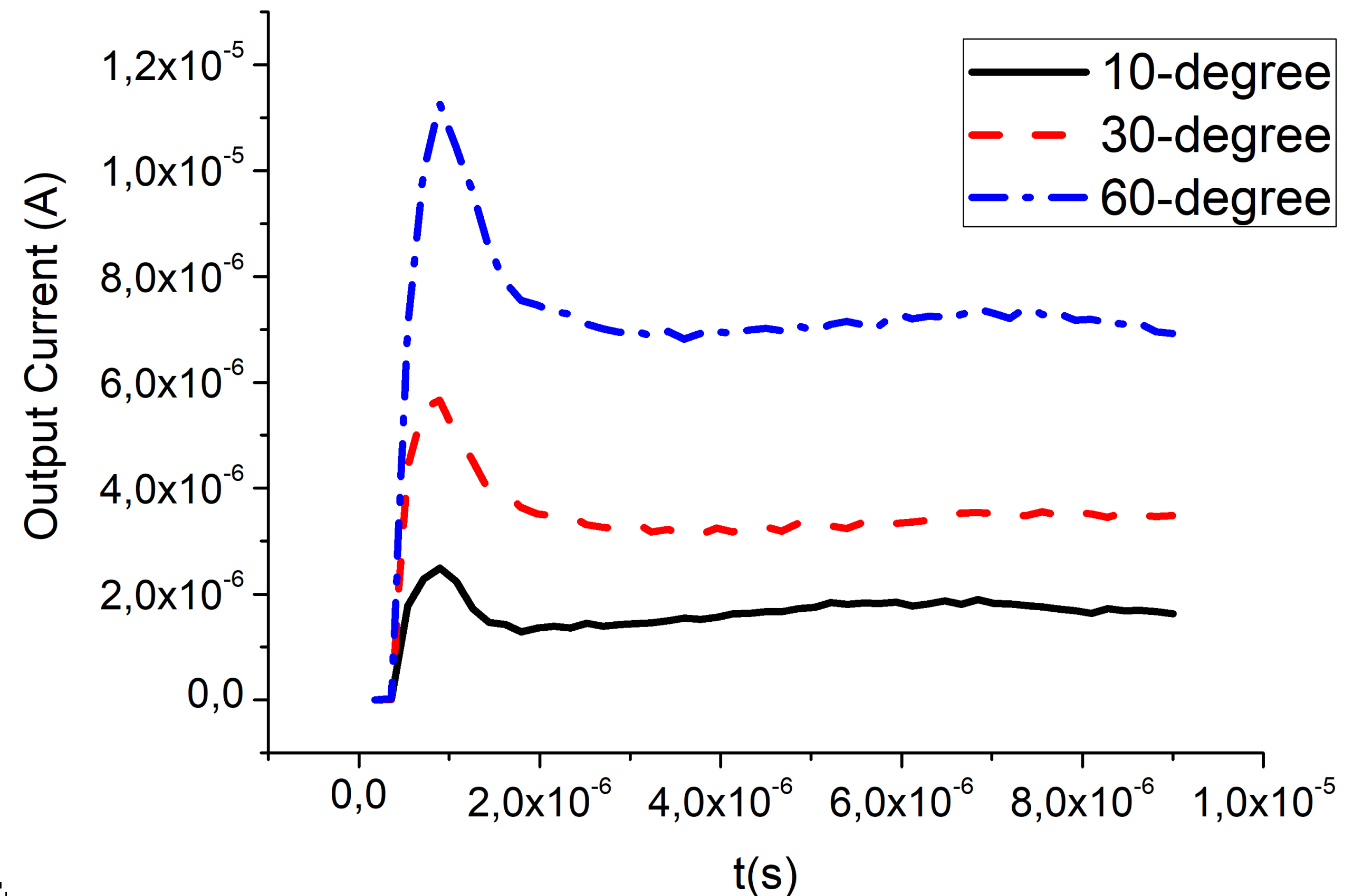




Comparison of Pie sections

Ion Extraction

- Comparison with different pie sections: 10-degree, 30-degree, 60-degree
- Extracted currents are compared in this case
- 30-degrees and 60-degrees show higher current as expected

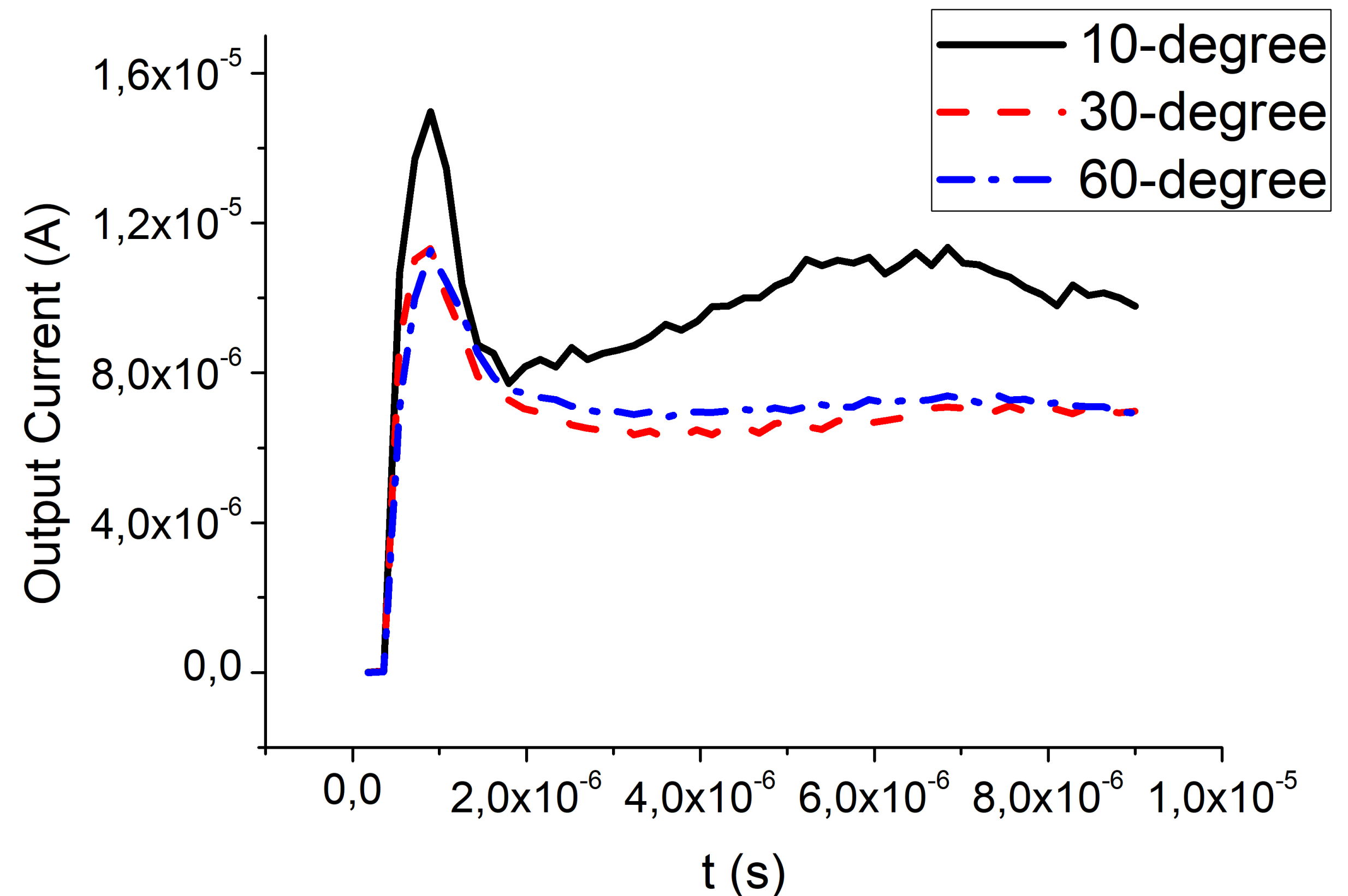




Comparison of Pie sections ..

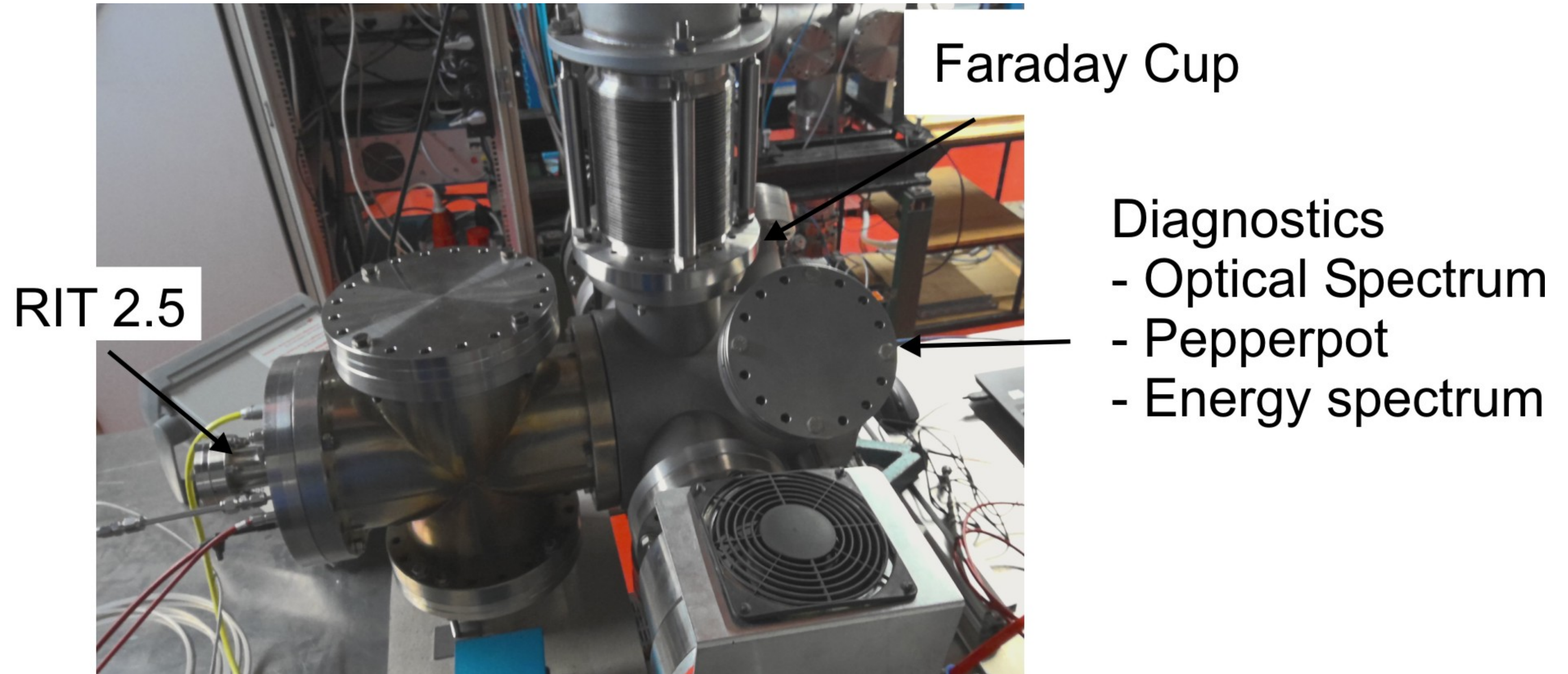
Ion Extraction

- Comparison with different pie sections: 10-degree, 30-degree, 60-degree
- 30-degrees and 60-degrees show similar behaviour when normalized as opposed to 10-degree



Validation

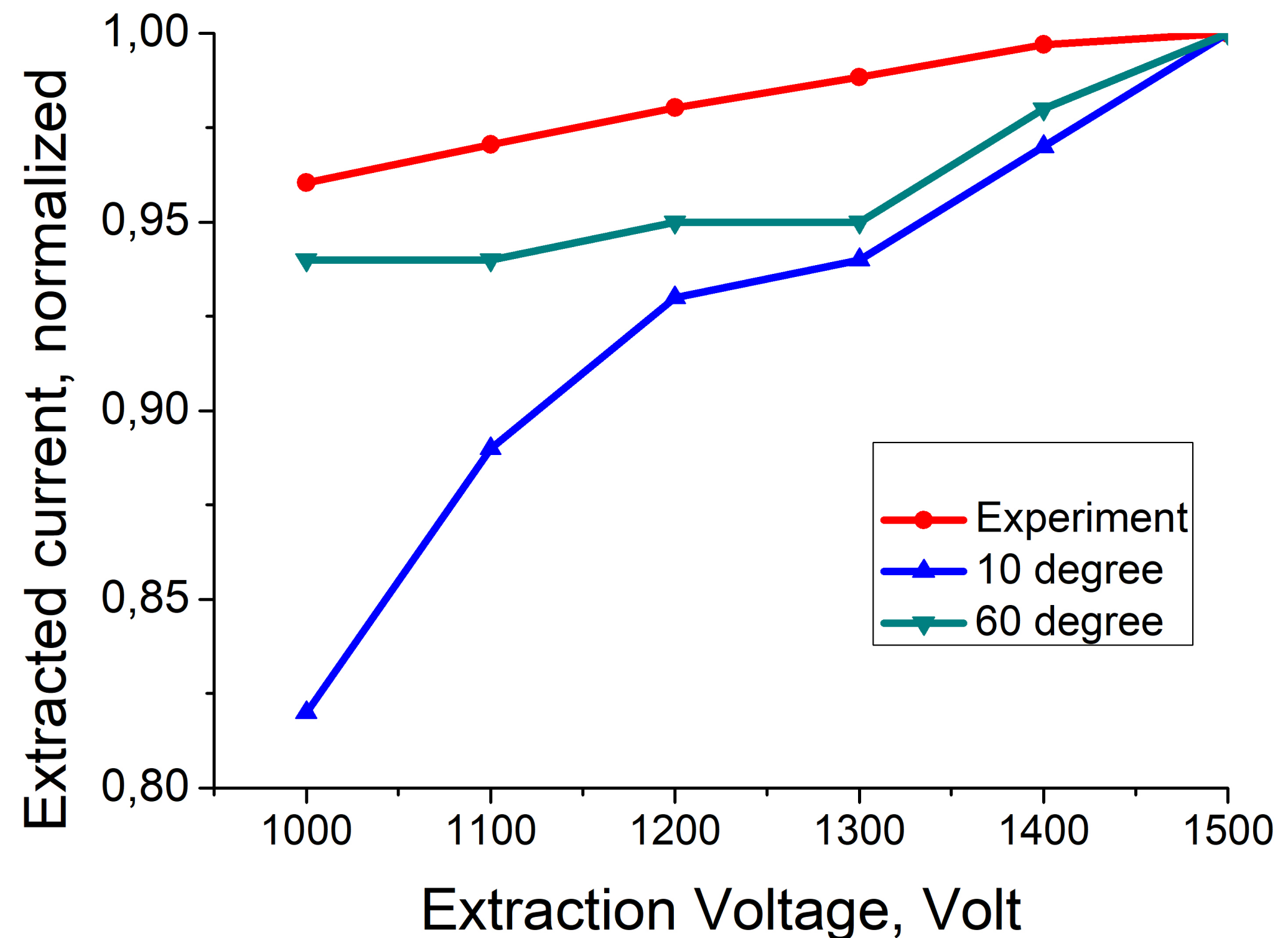
Experimental setup





Preliminary Results

- Estimated density $10^{16}/\text{m}^3$, temperature 12 eV
- Here we compare experimental results with simulations.
- Two different cases of pie sections are compared.
- 60-degree simulation show more similar rise in current as a function of extraction voltageage.





Applications of PIC-Cyl

- Currently being used for RF-ion thrusters.
- We can simulate plasmas in other devices like gas discharge in glass tube, magnetic mirrors for fusion research etc.
- We also have developed PIC code in 3d cartesian coordinates and results can be compared independently.

Thank you!