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Benchmark of Particle-In-Cell Simulations of a Penning-Type Discharge: Preliminary Results

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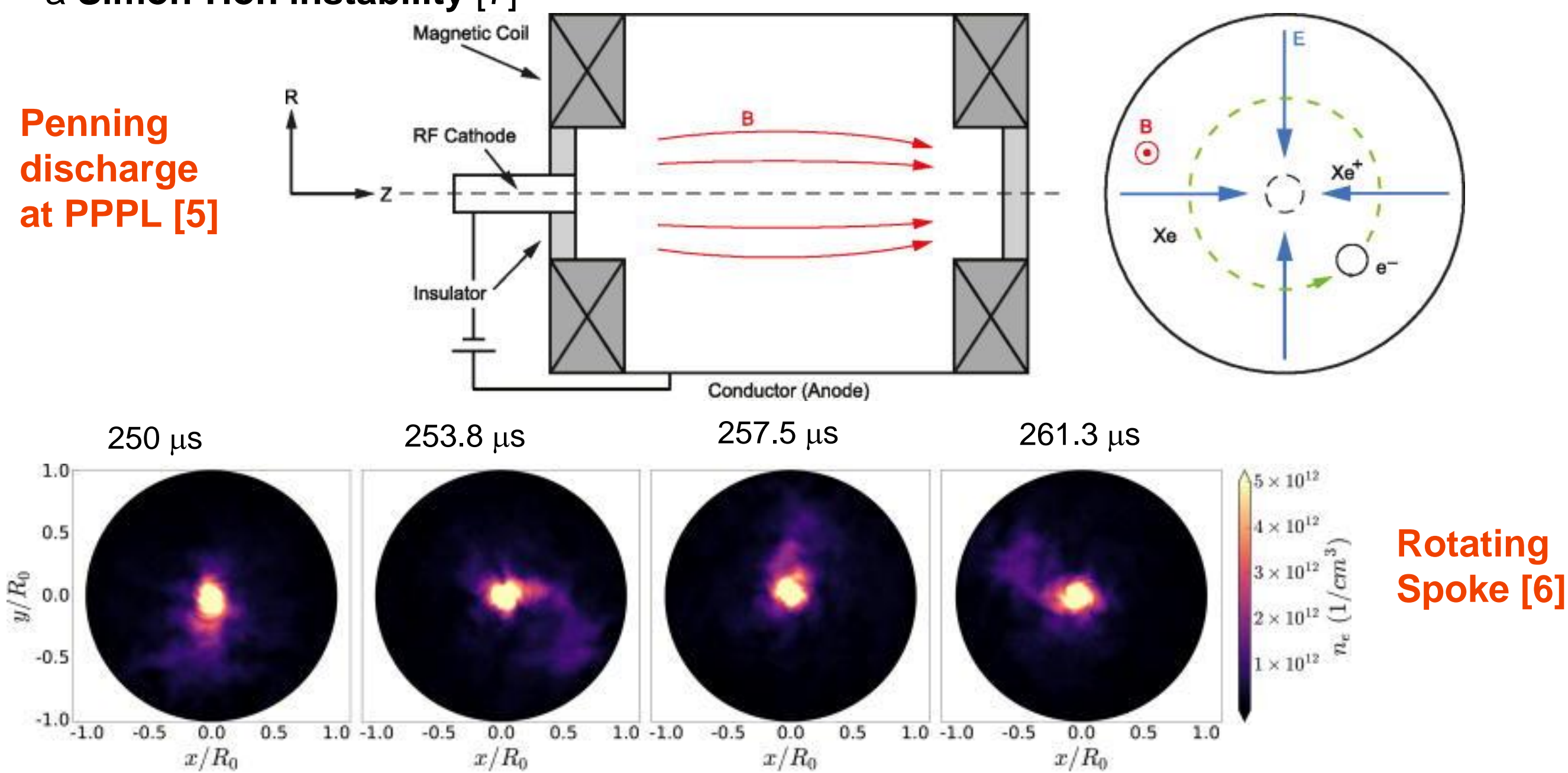
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OBJECTIVES

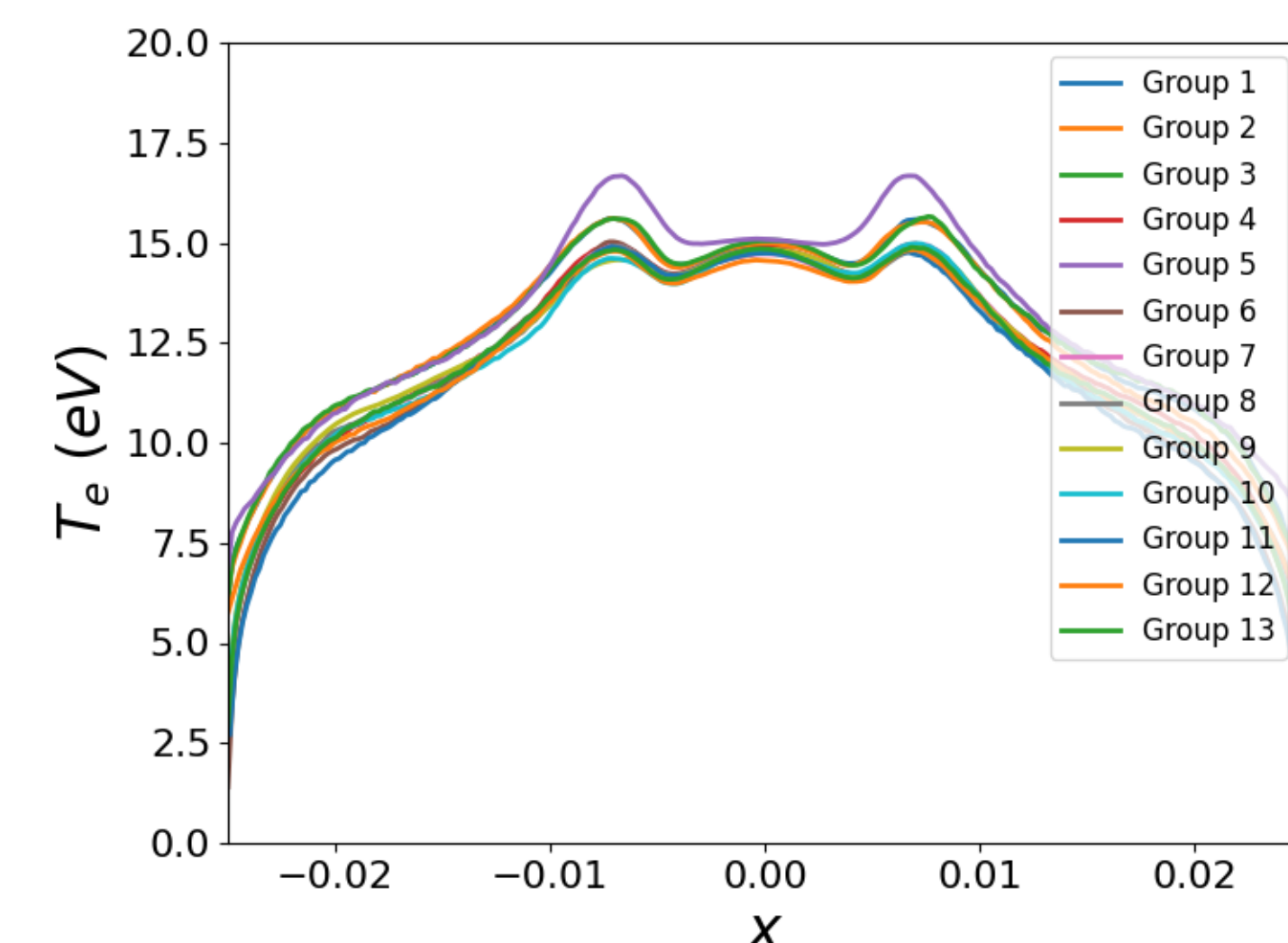
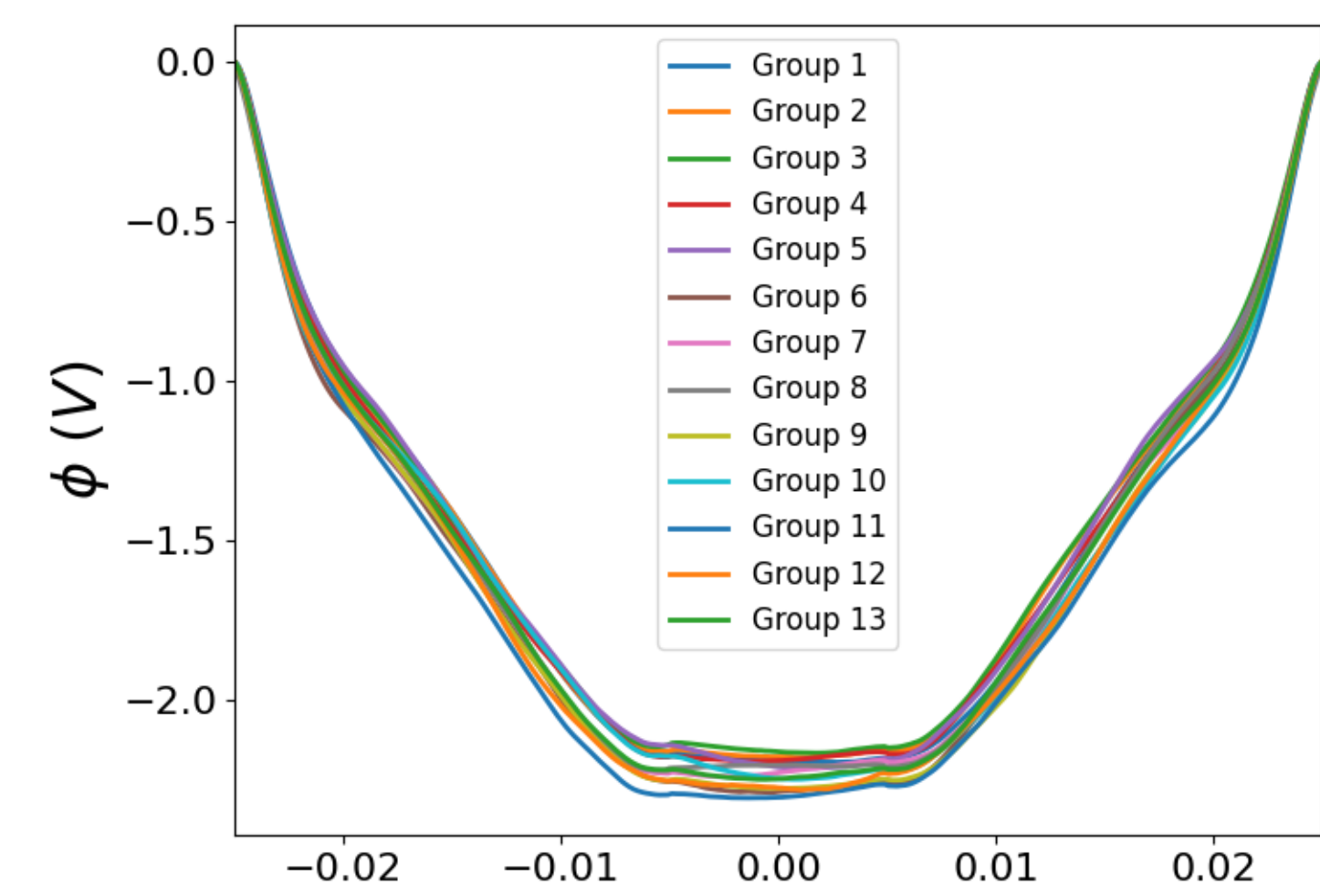
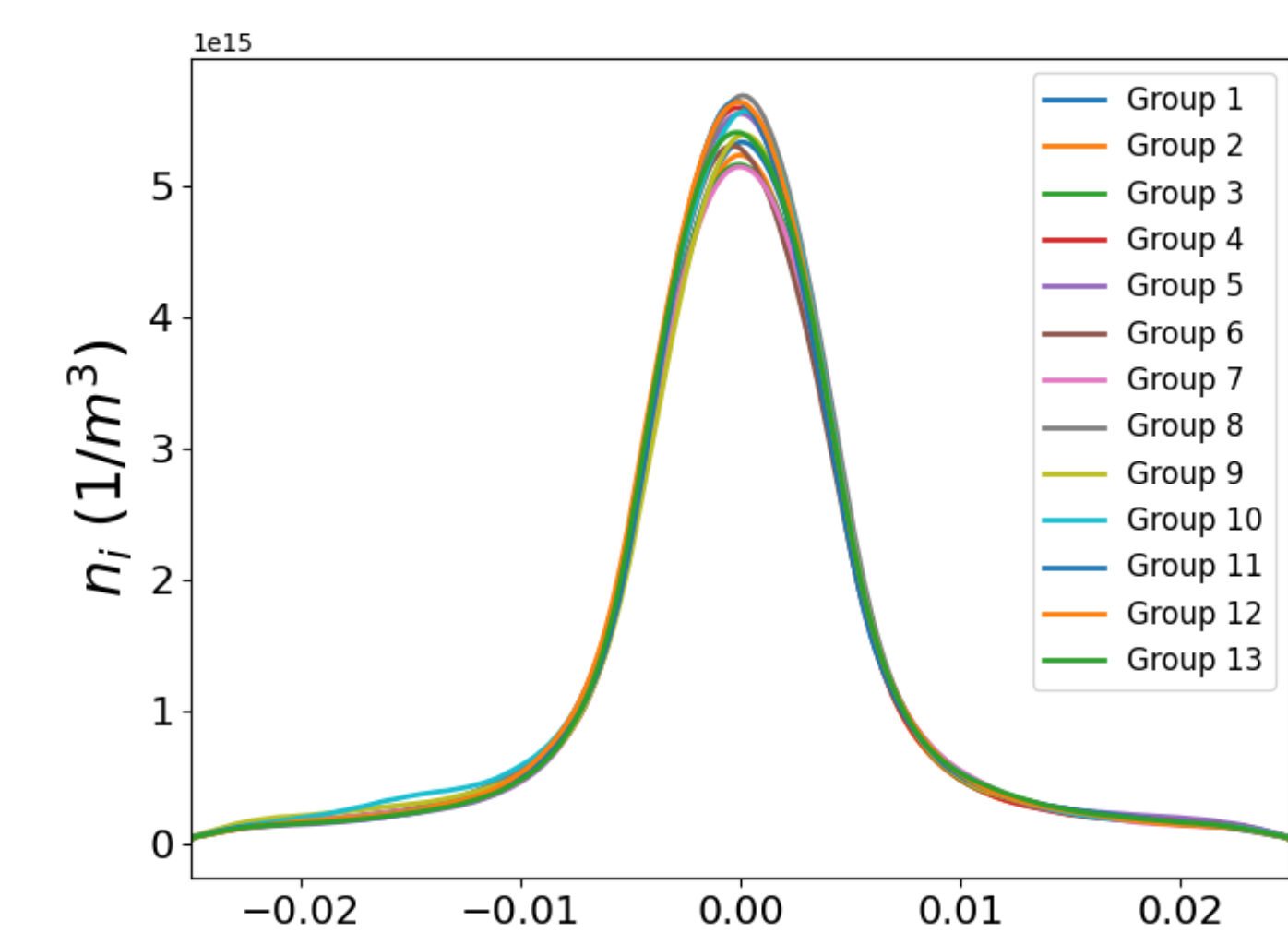
- The physics of magnetized plasmas and E x B devices is complex and very non-linear
- Numerical simulations can bring a better understanding of the phenomena
- One of the most fundamental aspects of any numerical approach (beyond validation by comparison with experiment) is the **verification** of the method's implementation
- In the context of partially magnetized E x B discharges (only the electrons are magnetized), two 2D benchmarks have already been published using **particle-in-cell (PIC) simulations** in the context of the Hall thruster [1], [2]
- These benchmarks have proved very popular with the community
- We propose a **new test case in 2D** and corresponding to the radial-azimuthal simulation plane of the rotating spoke in a **collisionless Penning discharge**

PENNING DISCHARGE

- Penning discharges are E x B plasma column [4-6]
- Axial magnetic field [few hundreds of Gauss] + DC electric field
- Primary electrons are injected at one end of the column
- Pressure [a few mTorr]
- Plasma densities [$10^{16} - 10^{18} \text{ m}^{-3}$]
- Electron temperature [1 - 10 eV]
- Coherent structures in the azimuthal direction ($f \sim$ a few kHz, $\lambda \sim$ a few centimeters) induced by a **Simon-Hoh instability** [7]

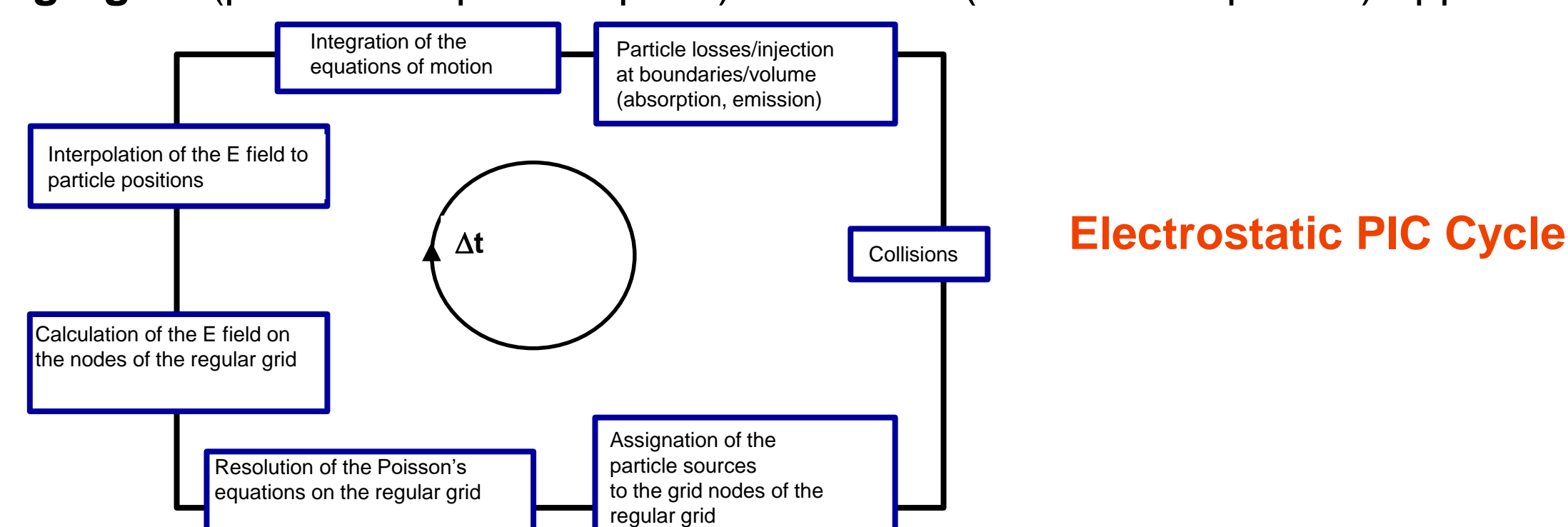


PRELIMINARY RESULTS



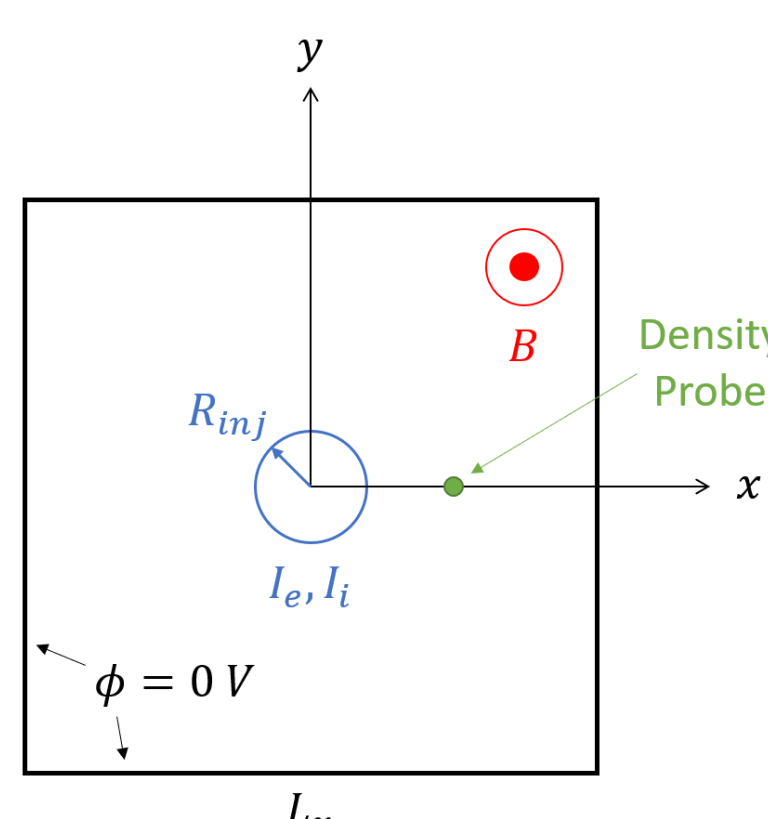
PIC ALGORITHM/INPUT DATA

- Lagrangian** (particles in phase-space) and **Euler** (Poisson's equation) approaches [8], [9]



- Initial conditions** [3]
<https://www.landmark-plasma.com>, test Case 4

- 0V BC
- No SEE
- No collision
- Maxwellian distributions
- $I_e/I_i=0.4$
- He ions



Parameter	Symbol	Value	Units
Helium-4 Ion mass	m_i	7291.712	m_e
Time step size	Δt	4.0×10^{-11}	s
Number of time steps	N_t	12,500,000	-
Total simulation time	t_{sim}	500.0	μs
Steps between diagnostic print	N_{print}	1,250	-
Time between diagnostic print	Δt_{print}	0.05	μs
x-minimum	x_{min}	-2.5×10^{-2}	m
x-maximum	x_{max}	2.5×10^{-2}	m
Domain length in x-direction	L_x	5.0×10^{-2}	m
y-minimum	y_{min}	-2.5×10^{-2}	m
y-maximum	y_{max}	2.5×10^{-2}	m
Domain length in y-direction	L_y	5.0×10^{-2}	m
Cells in x-direction	N_x	256	-
Cell length in x-direction	Δx	1.953×10^{-4}	m
Cells in y-direction	N_y	256	-
Cell length in y-direction	Δy	1.953×10^{-4}	m
Applied magnetic field strength	B	1.0×10^{-4}	T
Injection radius	R_{inj}	5.0×10^{-3}	m
Electron injection current	$I_{e,0}$	-20.0×10^{-3}	A/m
Electron injection temperature	T_e	15.0	eV
Ion injection current	$I_{i,0}$	8.0×10^{-3}	A/m
Ion injection temperature	T_i	0.025	eV
Macro-particle weight	N_{mp}	1.0×10^5	-
Electron macro-particles injected per time step	$\Gamma_{e,t,\Delta t}$	49.932	-
Ion macro-particles injected per time step	$\Gamma_{i,t,\Delta t}$	19.973	-

ONGOING WORK

- Effect of time-varying averaging on the results?
- Reduce the ion mass to accelerate the spoke rotation, $v_{rot} \propto 1/\sqrt{m_i}$ [6]
- Include self-consistent ionization through electron-atom collisions (only injecting electrons)
- Include ion-atom collisions
- Construction of a modular and transportable Penning experimental device in Toulouse, France

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