Coulomb collisions and ϵ_0 scaling in the PIC code LePIC for Ion Source Applications

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Abstract

This study investigates the effects of **Coulomb collisions** and the **scaling of the vacuum permittivity constant (ε_0)** in the Particle-In-Cell (PIC) code ***LePIC***, developed for ion source applications. Plasma profiles (electron density, temperature, flux, and electric potential) remained consistent under ε_0 scaling, with deviations observed in the sheath regions.
Coulomb collisions were modeled using Nanbu's method, and simulation results were benchmarked against analytical solutions for temperature relaxation. Agreement between numerical and theoretical predictions confirms the reliability of the approach for simulating collision-dominated plasmas in ion sources.

Theory

Scaling ϵ_0

In a plasma, the Debye length is

$$\lambda_D = \left(\frac{\epsilon_0 T_e}{n_e e^2}\right)^{1/2} \quad (1)$$

Decreasing the number of cells to speed the simulation

$$\frac{\lambda_D}{\Delta x} = cst; \quad \Delta x \propto \frac{1}{nb_{cell}} \quad (2)$$

$$\Rightarrow nb_{cell} \propto \frac{1}{\epsilon_0^2} \quad (3)$$

Coulomb collisions

Nanbu's method for Coulomb collisions:

1. **Calculate the number of binary collisions between each species**
2. **Calculate the number of collisions between particles of the same species**
3. **Form the collision pairs. Compute the post-collision velocities**

Results

Scaling ϵ_0

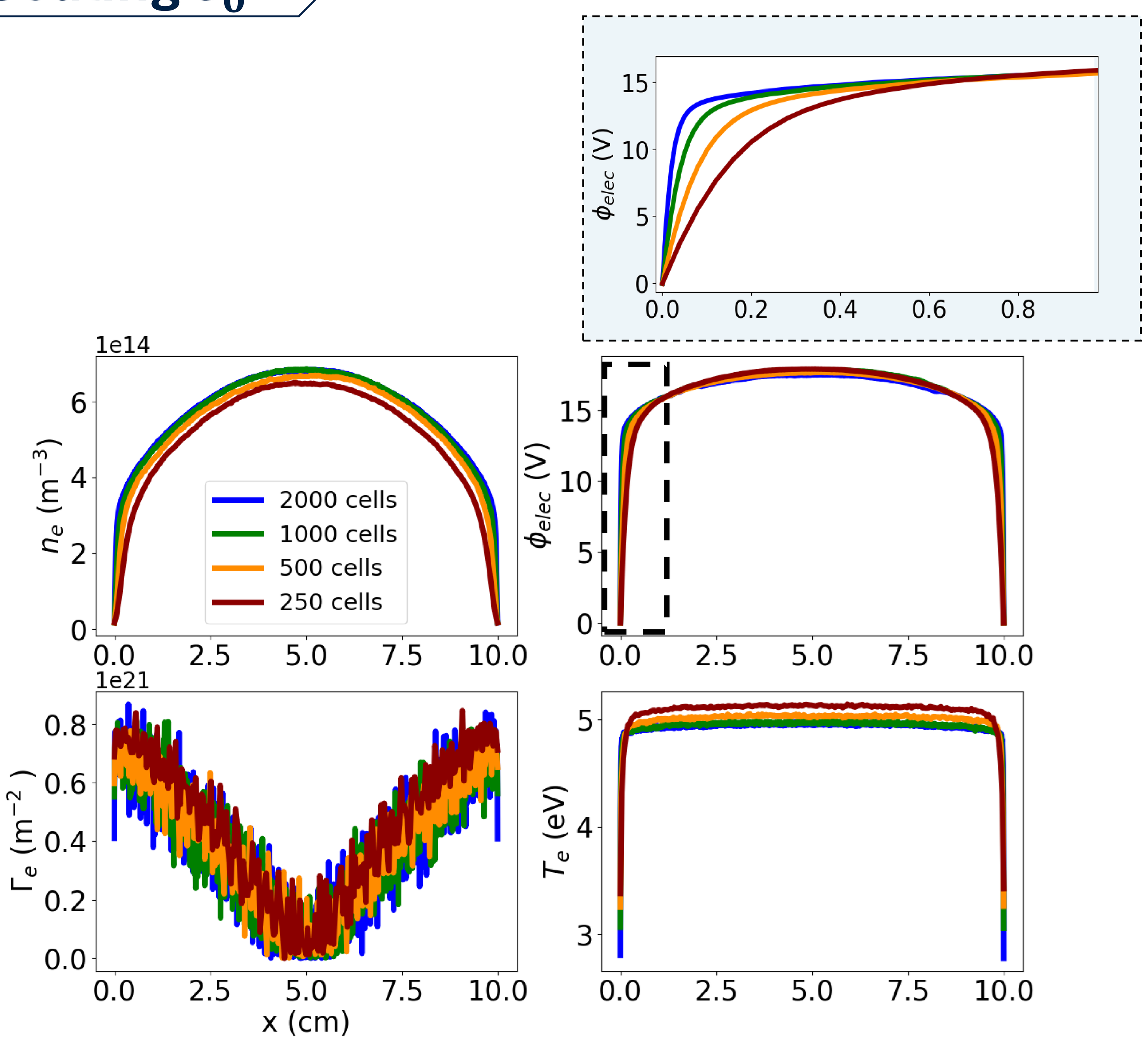

Fig. 1 Axial profiles of the **plasma density**, **electron temperature**, **electron flux**, and **electric potential** along an ambipolar discharge. The profiles are unaffected by the scaling except in the **sheath regions**.

Coulomb collisions

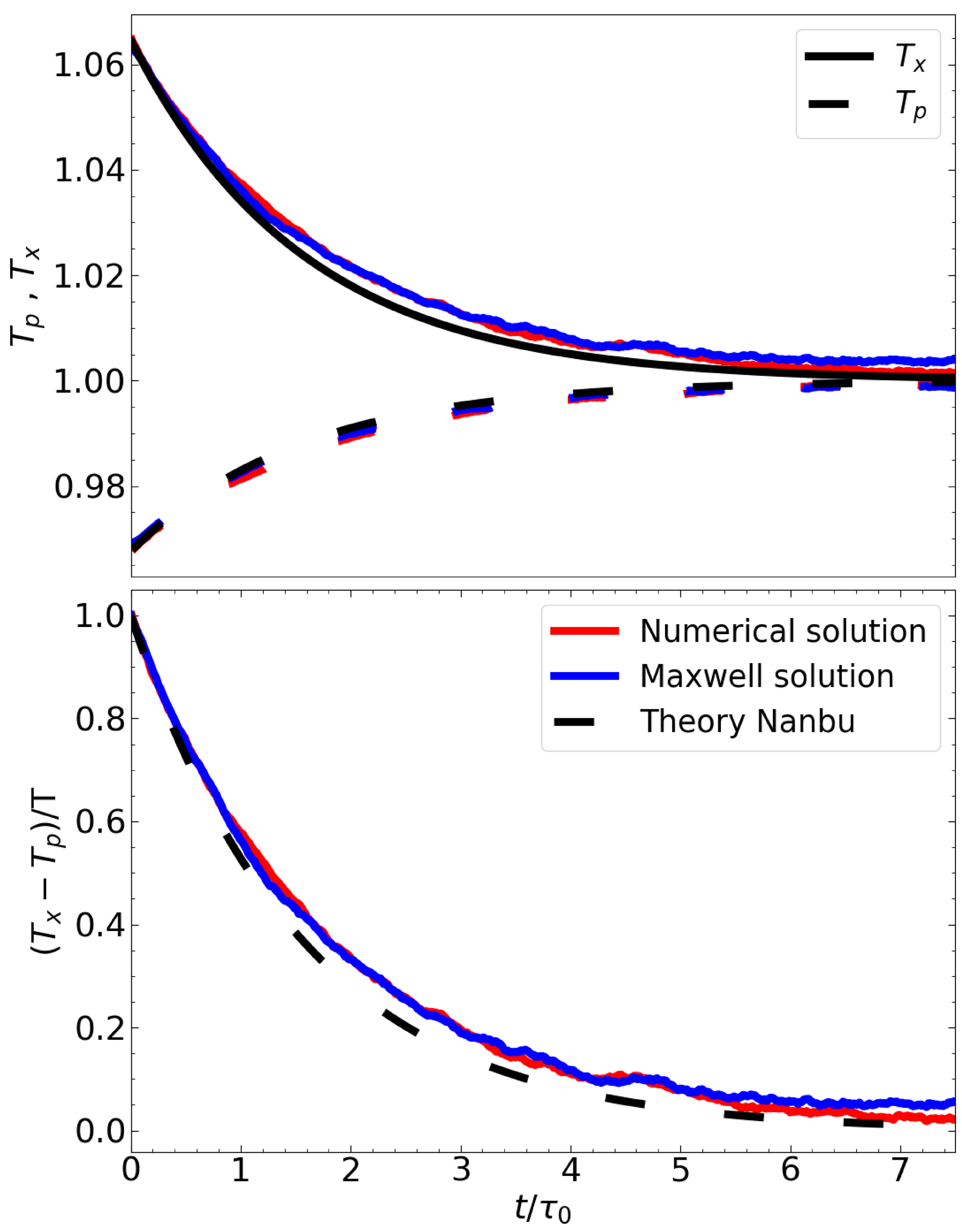

Fig. 2 Temperature Relaxation of an **ellipsoidal electron distribution**: **Simulation results** with and without re-Maxwellianization compared with **analytical solutions**.

Conclusion/Next Steps

This study demonstrates the **robustness of ε_0 scaling and Coulomb collision modeling** within the *LePIC* code for simulating collision-dominated plasmas.
Plasma characteristics remain consistent under scaling, validating the approach for efficient and accurate ion source simulations.

Next steps:

- **Modularization and modernization** of the *LePIC* PIC code to improve maintainability and flexibility.
- Integration of **energy-conserving numerical schemes** to enhance simulation stability and physical accuracy.
- Development of an **antenna model** to support future simulations involving electromagnetic wave-plasma interactions.

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LEPIC
Laplace Explicit Particle-In-Cell code