Simulating Plasma Sheaths with Commercial PIC Code

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Introduction

Plasma sheaths occur in any apparatus where plasma comes in contact with material boundaries. Understanding sheath structure is key to the development of tokamak science, Hall thrusters and other plasma technologies.

Electron temperature in plasmas tends to be larger than ion temperature[1]. Since electron mass is also significantly smaller than ion mass, electrons will travel at velocities much higher than plasma ions. High velocity electrons can leave the plasma for material surfaces and accumulate negative charge on these boundaries[3]. Plasma sheaths form around negatively charged boundaries.

Particle-in-cell codes such as Large Scale Plasma (LSP) are powerful tools for the analysis of sheath formation.

LSP provides a complete framework to create, manipulate and analyze a collisionless 1D plasma. The software includes:

- Particle generation, injection and emission
- Complex boundary conditions
- Detailed diagnostics

We will model and analyze sheath structures using these tools.

Methods

Intermediate simulations were run with a variety of parameter sets. The primary quantities that varied were:

Electron flux magnitude
Changes in electron flux affect overall particle density in the chamber. Net density determines the maximum cell size for the simulations: no cell could be larger than the Debye radius[2].

Electron/Ion flux ratio
While our goal is a quasi-neutral plasma, the boundary conditions are such that an excess of charge in the chamber will propel particles out and maintain neutrality. We were able to adjust the electron to ion flux ratio to change our potential structure without disrupting the charge balance. We attempted to use different flux ratios to compensate for any unintentional charge buildup at the boundaries or the chamber.

Simulation Parameters

General

Chamber	0.5 cm
Time step	0.01 ns
Cell size	0.001 cm
Debye length	0.02 cm

Injections

	Electron	Ion
Drift velocity	0 c	0 c
Thermal Energy	1.0 eV	0.025 eV
Flux	5e5 $cm^{-2} s^{-1}$	1e6 $cm^{-2} s^{-1}$
Mass	9.109 e-31 kg	1.661 e-27 kg
Charge	-1 e	1 e

Boundary conditions

	x = 0.0 cm	x = 0.5 cm
Wall	conductive	conductive
Electric potential	0.0 V	floating

Particle Density and Potential

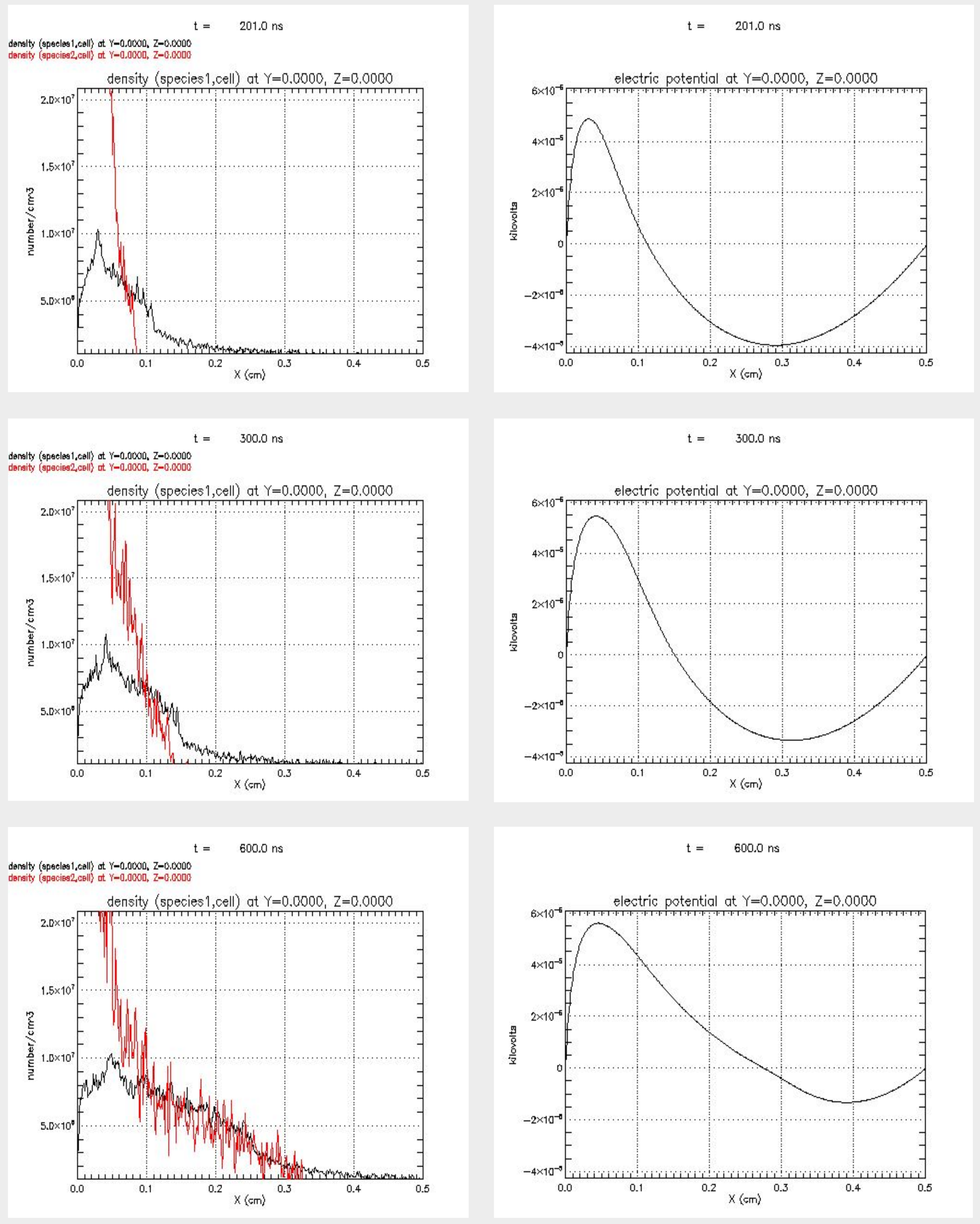

Figure 1. Particle density and electric potential in chamber at 201 ns, 300 ns and 600 ns. At left, electron density shown in black, ion density shown in red.

Simulation Analysis

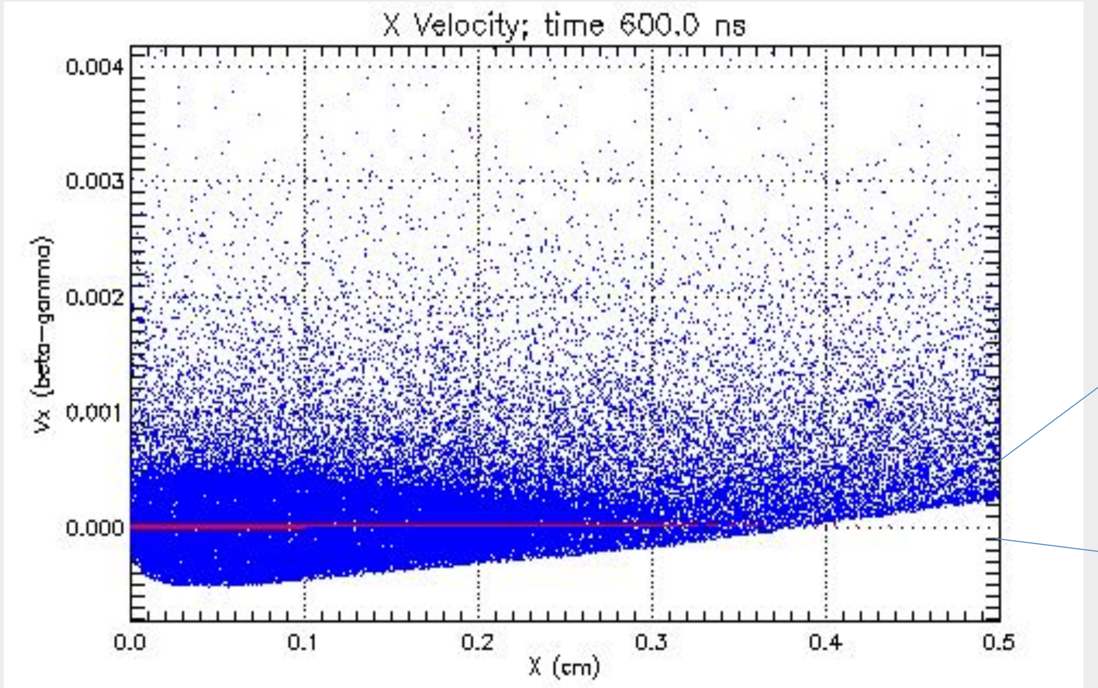

Figure 2. Particle velocity in chamber at 600 ns. Electrons shown in blue, ions in red.

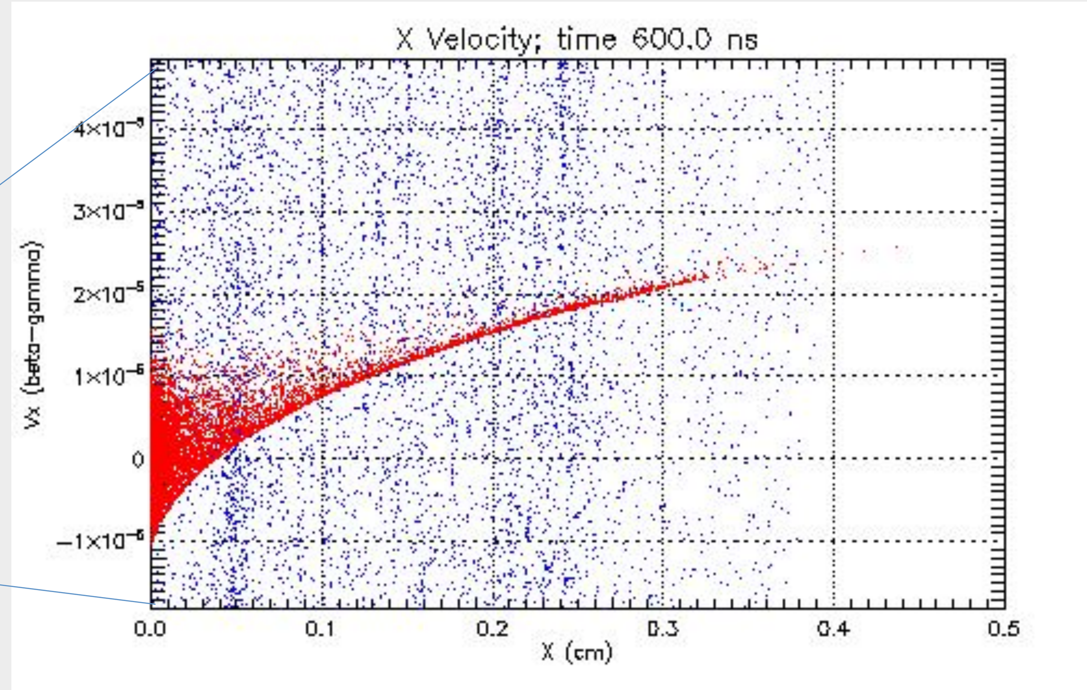

Figure 3. Particle velocity in chamber at 600 ns, small velocity range. Electrons shown in blue, ions in red

- 0 ns, ions and electrons begin entering the chamber
- 600 ns, a steady-state particle distribution is reached (Fig.1)

At all points x > 0.1 cm the ion density is very close to the electron density, but for x < 0.1 cm the densities diverge in an unbalanced pattern, possibly the result of LSP's injection process. If this is the case, this region can be discounted as a non-physical result. While it is not clear what causes this divergence, our steady state sheath (which we look for at x > 0.4) will not be affected.

The electric potential evolves with the distribution of particles but never reaches a steady-state plasma sheath. Where we hope to see a flat potential with a valley at x = 0.5 cm there is a concave-up curve.

The magnitude of this potential curve is inconsistent with our expectations. It reaches a maximum of 0.006 V while we expect it to exist in the neighborhood of 1 V. Our simulation potential is at odds with the electric field in the system at 600 ns (Fig. 4). When integrated, this electric field curve shows a potential on the order of 1 V.

The x-velocity of particles in the chamber at 600 ns is plotted above (Fig. 2, Fig 3). Electrons show Maxwellian distribution above a minimum velocity and ions accelerate to ~0.4 as expected. These results are qualitatively consistent with our potential curve at 600 ns.

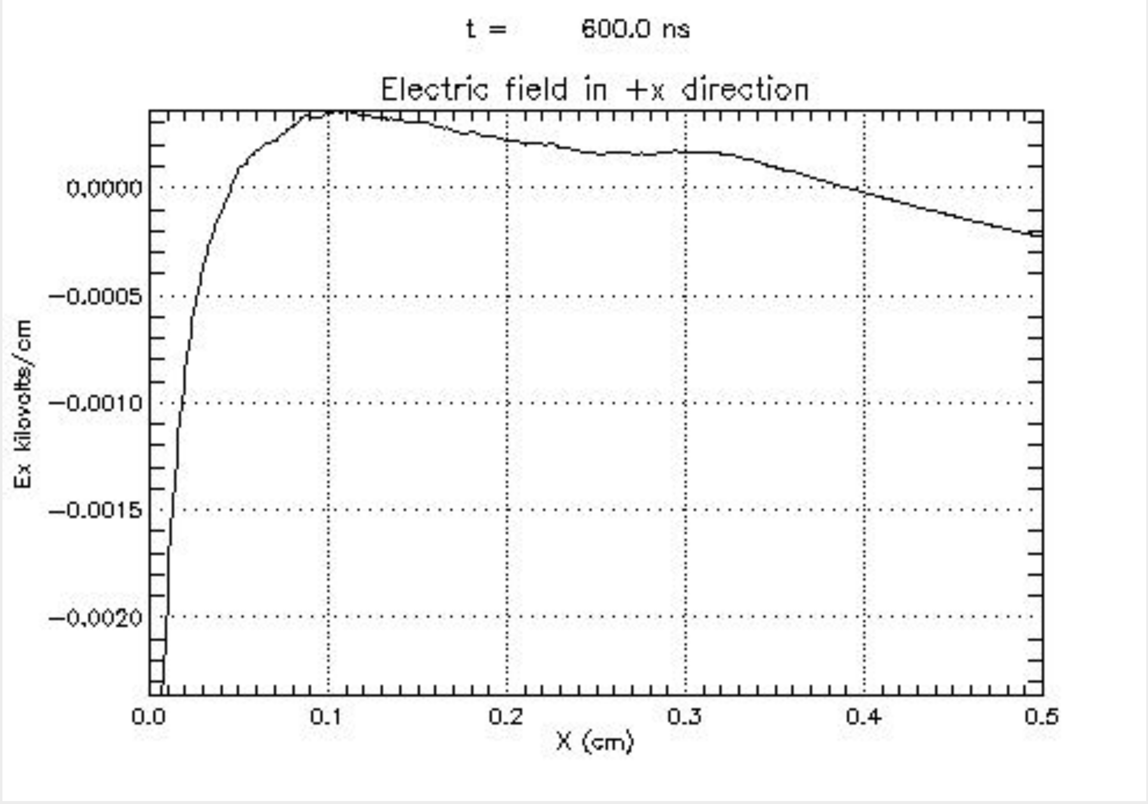

Figure 4. Electric field in chamber at 600 ns.

Conclusion

Our simulations do not produce a steady state plasma sheath. There are inconsistencies between the potential curve produced by our simulations and the potential curve of a steady state sheath. The boundary conditions of our simulation do not interact with the plasma as we expect. We created a floating boundary at x = 0.5 cm, but the electric potential near this boundary indicates that this region may not be acting as we planned.

It is possible to create a steady state sheath using two particle injections in LSP. We arrived at a set of parameters which are appropriate for sheath simulation. Through further investigation into floating potential boundary models we will develop a working model of sheath formation.

Acknowledgements

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