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EMPIRE Simulation of the RKA Electron Beam in a Gas Cell

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Abstract

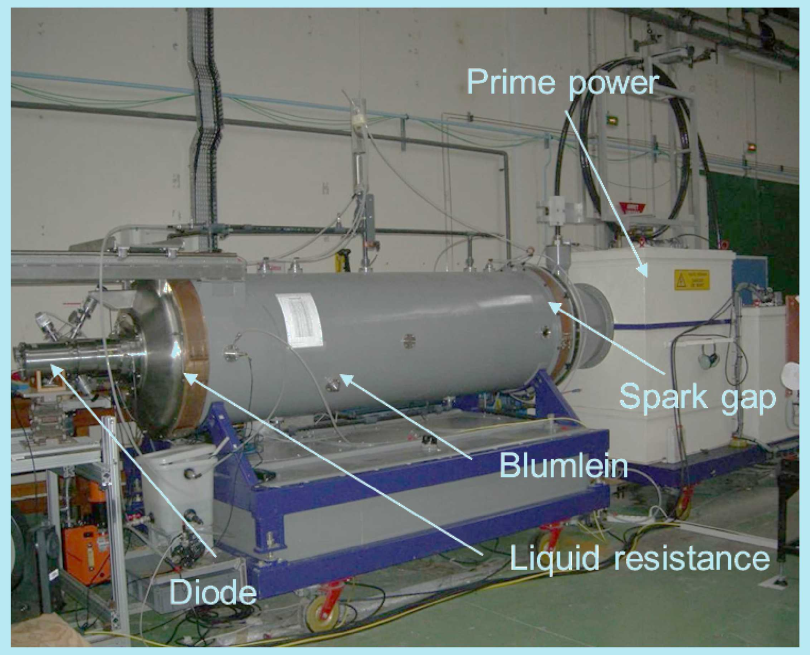
As part of a continued validation effort for Sandia's new plasma code, EMPIRE, we have modeled and are simulating the RKA beam experiment. Specifically, we have begun simulations of the RKA diode into the gas cell. The current EMPIRE (informal) validation effort is ultimately concerned with the electron-beam transport (e.g. electron-neutral chemistry) through an Ar-filled gas cell at various pressures from vacuum to ~1 Torr. In the current work, we will compare our simulations to CEA results and test a possible explanation for why the CEA/CESTA is seeing asymmetric burn-through on their cathode foil.

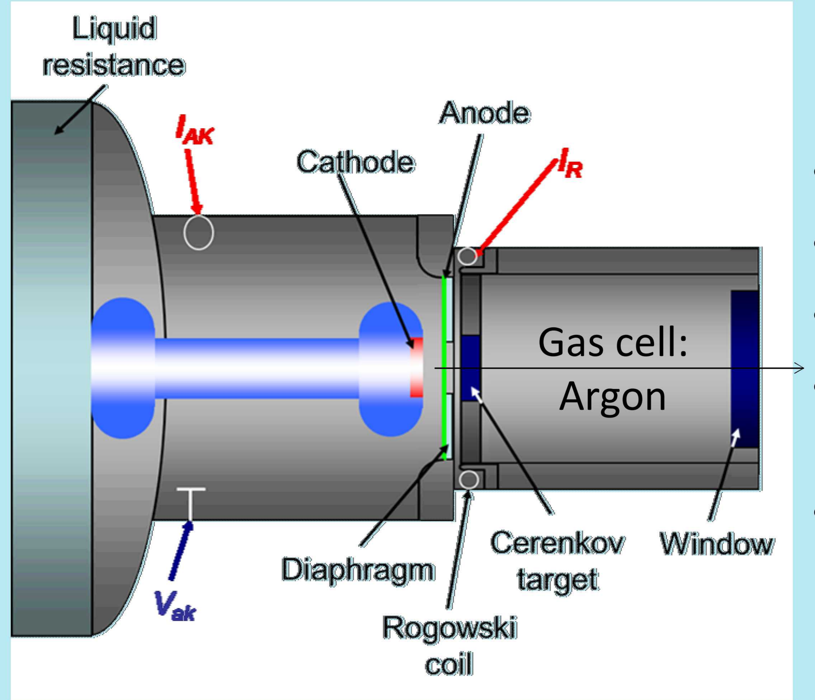
EMPIRE Overview

- EMPIRE is a 3D EM Finite Element plasma code on unstructured mesh.
- EMPIRE has a breadth of physics capable of modeling low temperature discharge plasmas to high energy e- beam transport including complex gas chemistries and plasma-surface interactions.
- Electron-neutral collisions modeled using the Direct Simulation Monte Carlo (DSMC) method.

The RKA Pulsed Power Machine and Simulation Setup

RKA is a 500 kV, 30 kA, 100 ns FWHM generator for electron beam studies



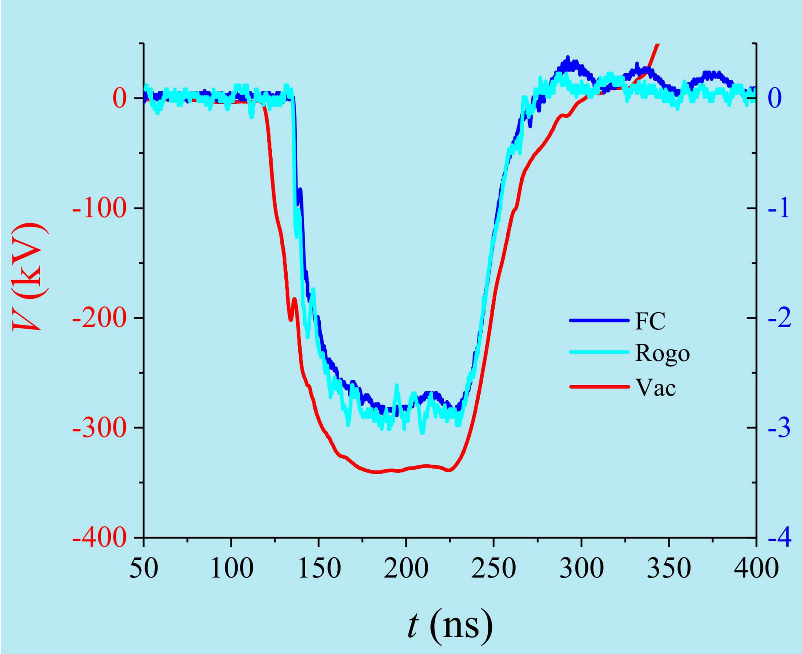


Diagnostics:

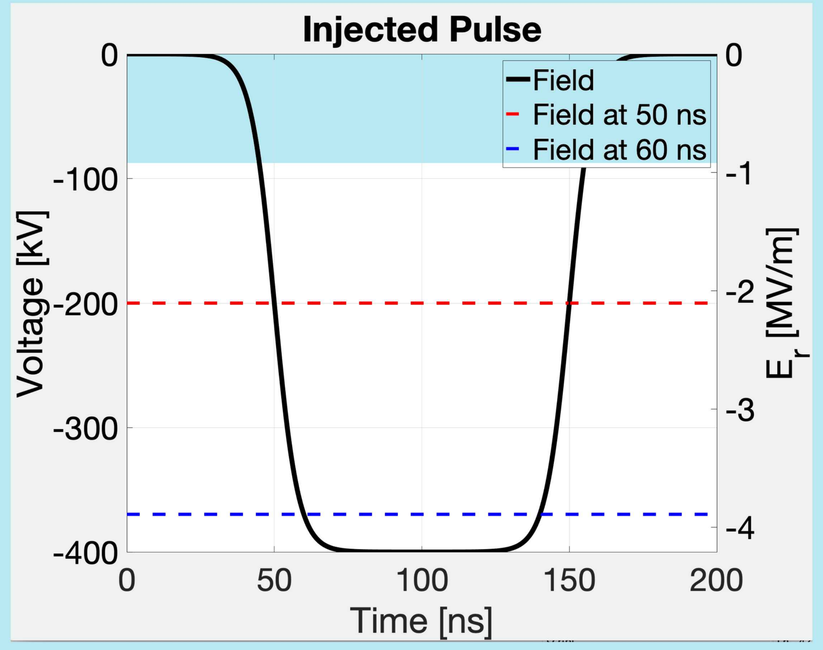
- Capacitive dividers: diode and gap voltage
- Bdots: diode current
- Rogowski coil: emitted current
- Cerenkov target: time dependent beam imaging along z
- Faraday cup: beam current along z

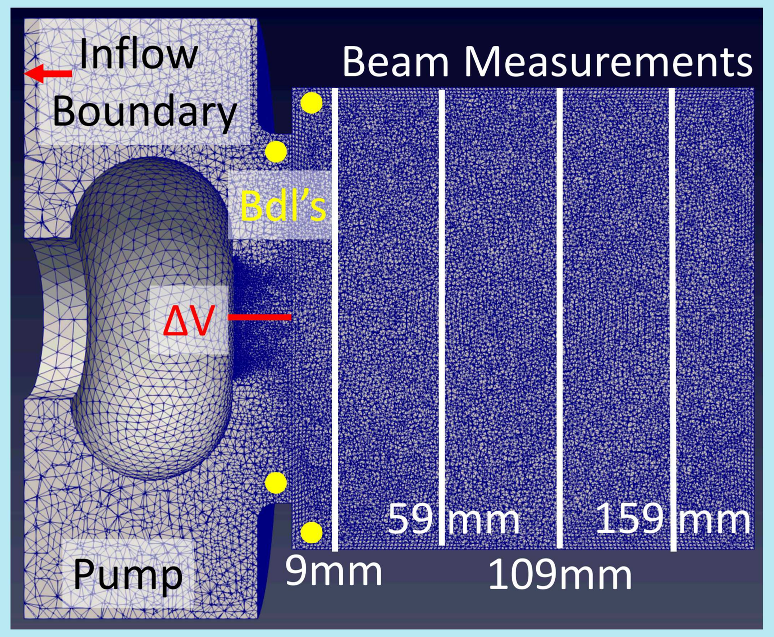
Variable mesh size in diode
Δx = 1mm near cathode
Δx = 2mm in the gas cell

Typical Voltage and Current Waveforms

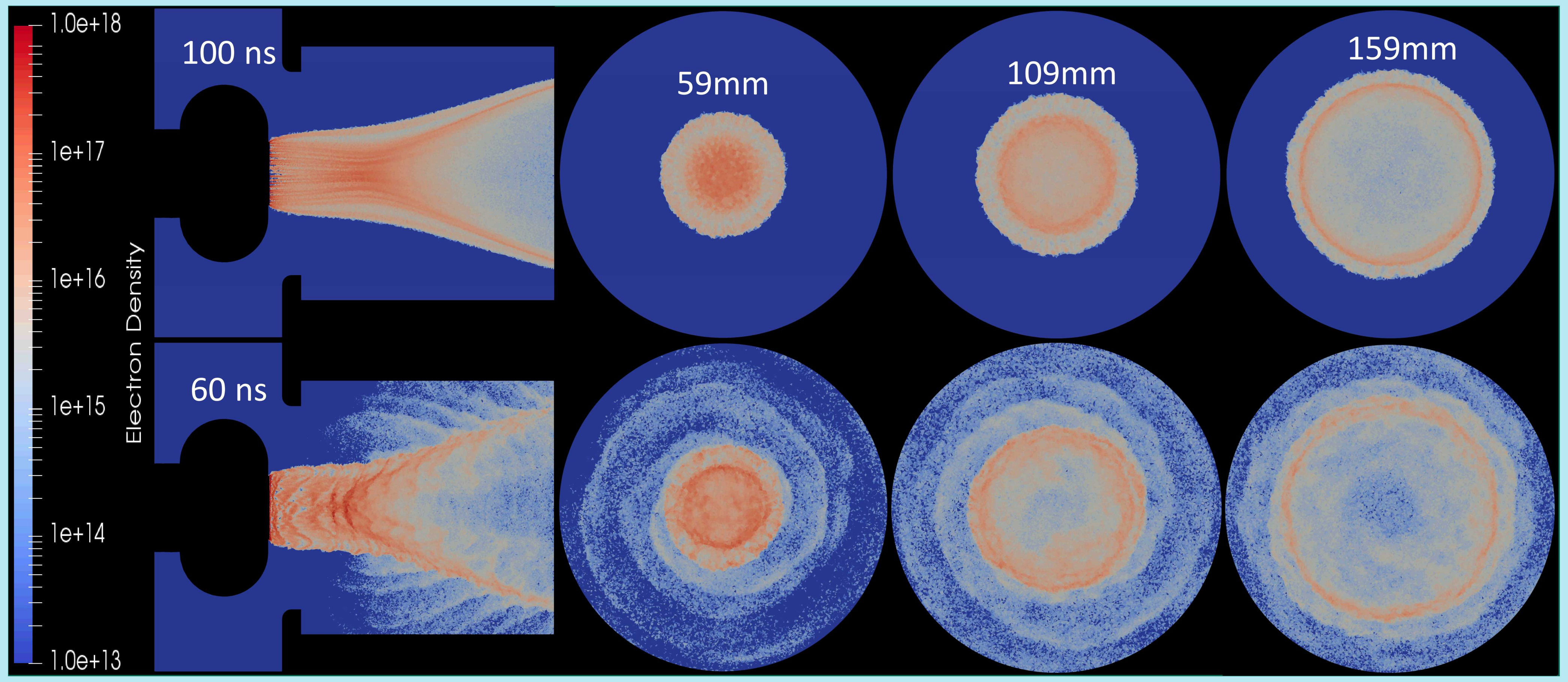


Representative Driver Waveform





Vacuum Simulations (No Leak)



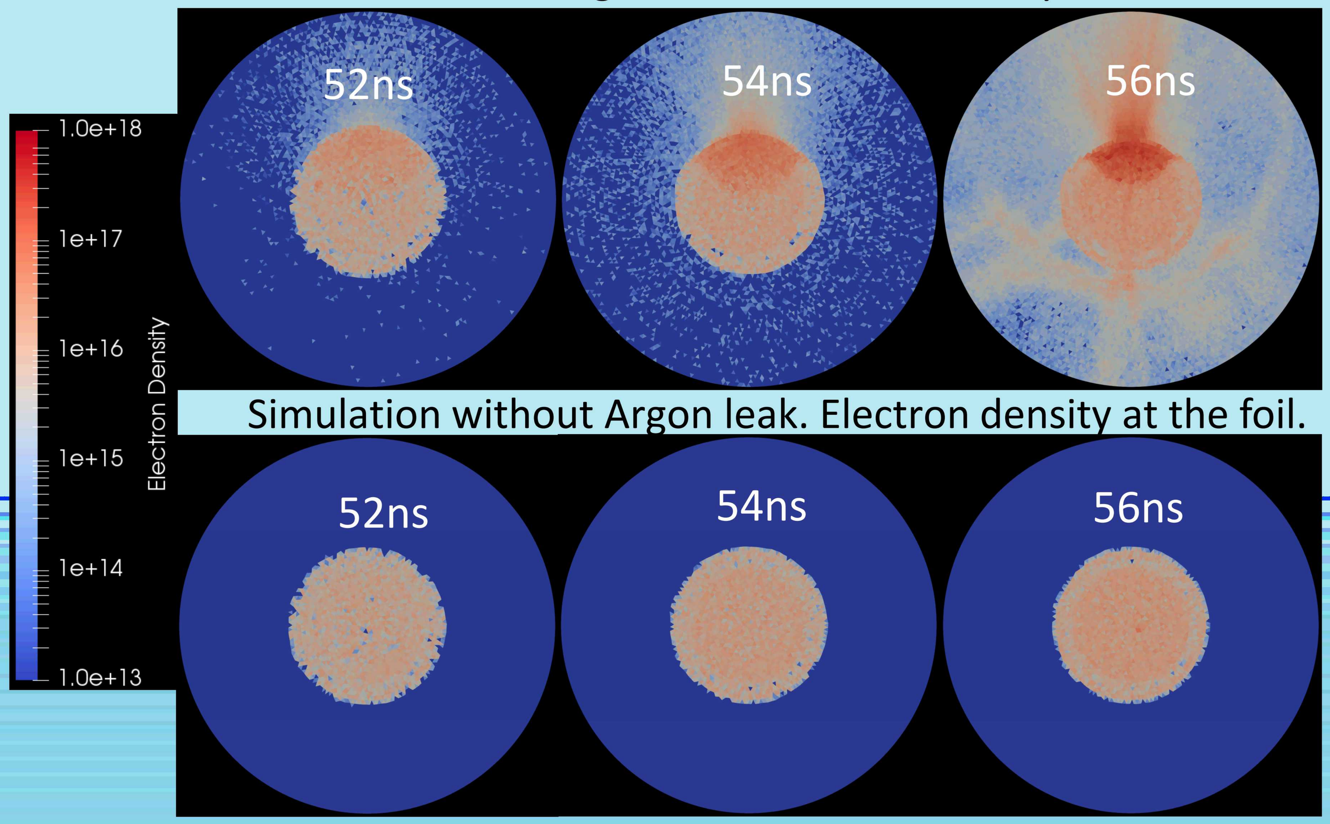
Takeaways

- Beam space charge sufficient to spread the beam
- Lack of scattering model for the anode foil results in sharp beam profile
- Investigating whether the simulated instability is due to noise or numerical error

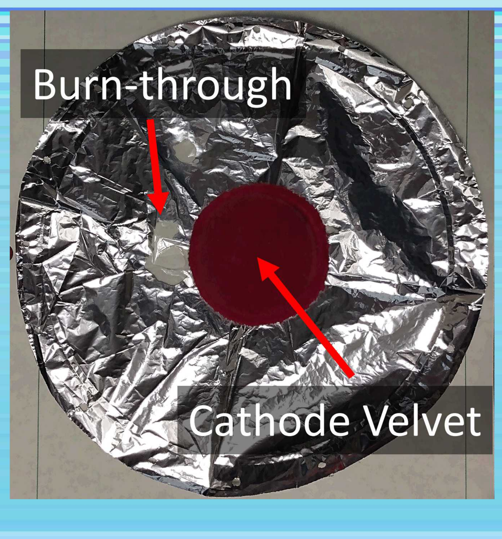
Vacuum Simulations (Argon Leak)

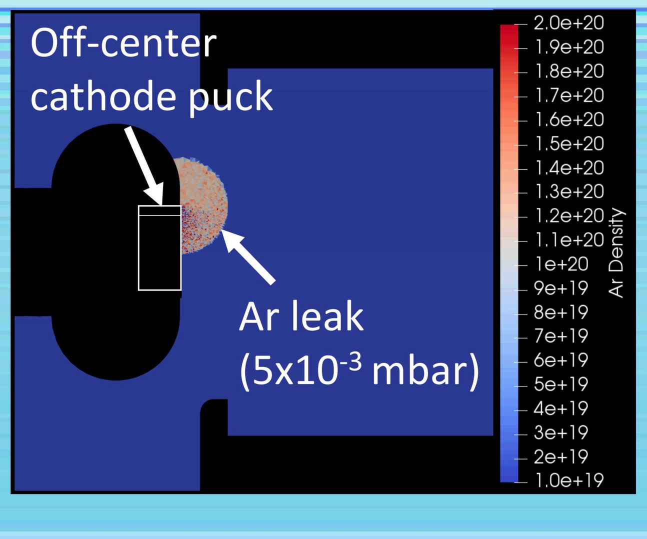
- Under ideal conditions RKA is capable of multiple shots without breaking vacuum.
- Occasionally small holes appear in the mylar/Al anode foil which require RKA to be opened.
- It was hypothesized that the interchangeable puck holding the cathode velvet could potentially trap air resulting in a virtual leak which we model here as an off-center cathode puck.
- Simulating a leak near the cathode produces a "hot-spot" at the foil.

Simulation with Argon leak. Electron density at the foil.

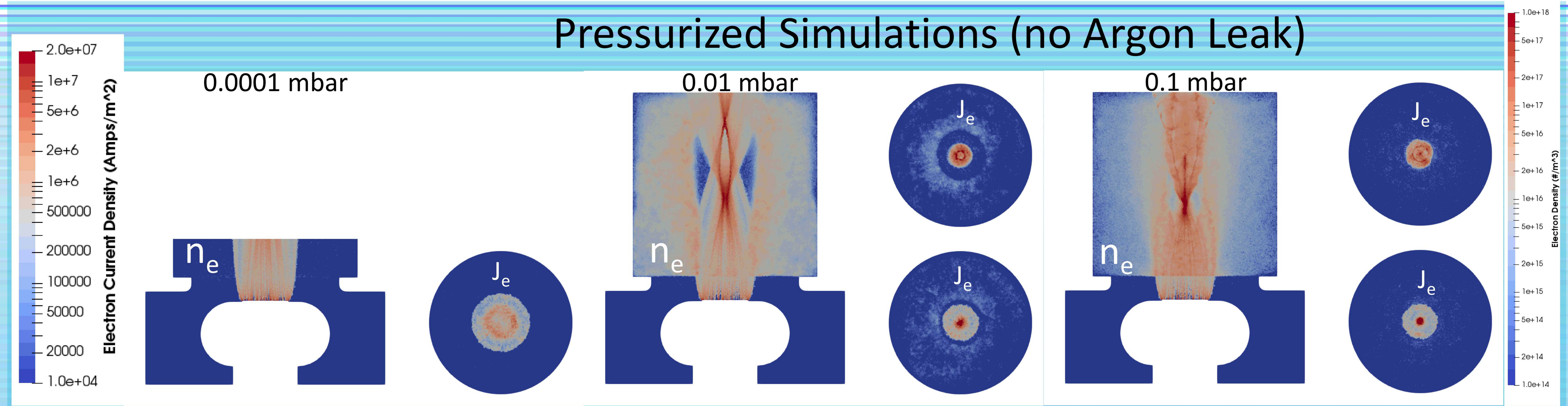


Simulation without Argon leak. Electron density at the foil.





Pressurized Simulations (no Argon Leak)



- Lack of foil scattering in the model allows for exaggerated observation of:
  - Cathode imprint, Beam spreading, Beam-gas interactions
- Beam transport through 10^{-4} mbar background pressure virtually the same as through vacuum. Not surprising as the mean free path is ~100m (500x the gas cell length)
- Significant changes to the beam profile occurs with background pressure as low as 10^{-2} mbar.
  - Surprising as the mean free path is ~5x the gas cell length. Increased diffusion in the model due to isotropic scattering likely exaggerates the pressure effect.

Future Work

- Add scattering boundary condition at the anode foil.
- Add relativistic, anisotropic collisions.
- Simulate RKA beam transport with MCC and EMPIRE-hybrid collision models as part of each algorithm's verification & validation.

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