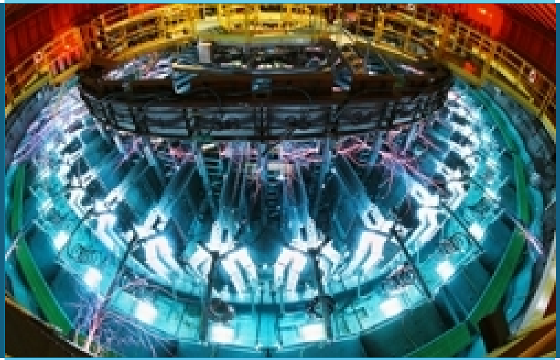
Sandia National Laboratories

SAND2020-13093C

Simulating High Energy Beam Transport Through a Collisional Gas Cell with EMPIRE



Presented By: ***Brandon M. Medina***

SNL: K. Bell, C. H. Moore, M. Bettencourt, K. Cartwright

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Outline

- Motivation
- RKA Overview
- Problem Description
- Results
- Conclusion

Motivation

EMPIRE is a “new” code with the lofty goal of solving plasma problems across a large range of density ranges on unstructured meshes

- Goal to have PIC, Fluid, and Hybrid capability
- Built to be scalable from the start (Bettencourt’s talk)
- Electrostatic and Electromagnetic Maxwell solvers
- Transmission line model (Edward and Duncan’s talk)
- DSMC and MCC collisional models: e.g. ionization, excitation (Andy’s talk)
- Surface physics: e.g. thermal desorption (David and Nick’s talk), ion-induced SEE (Andy’s talk)

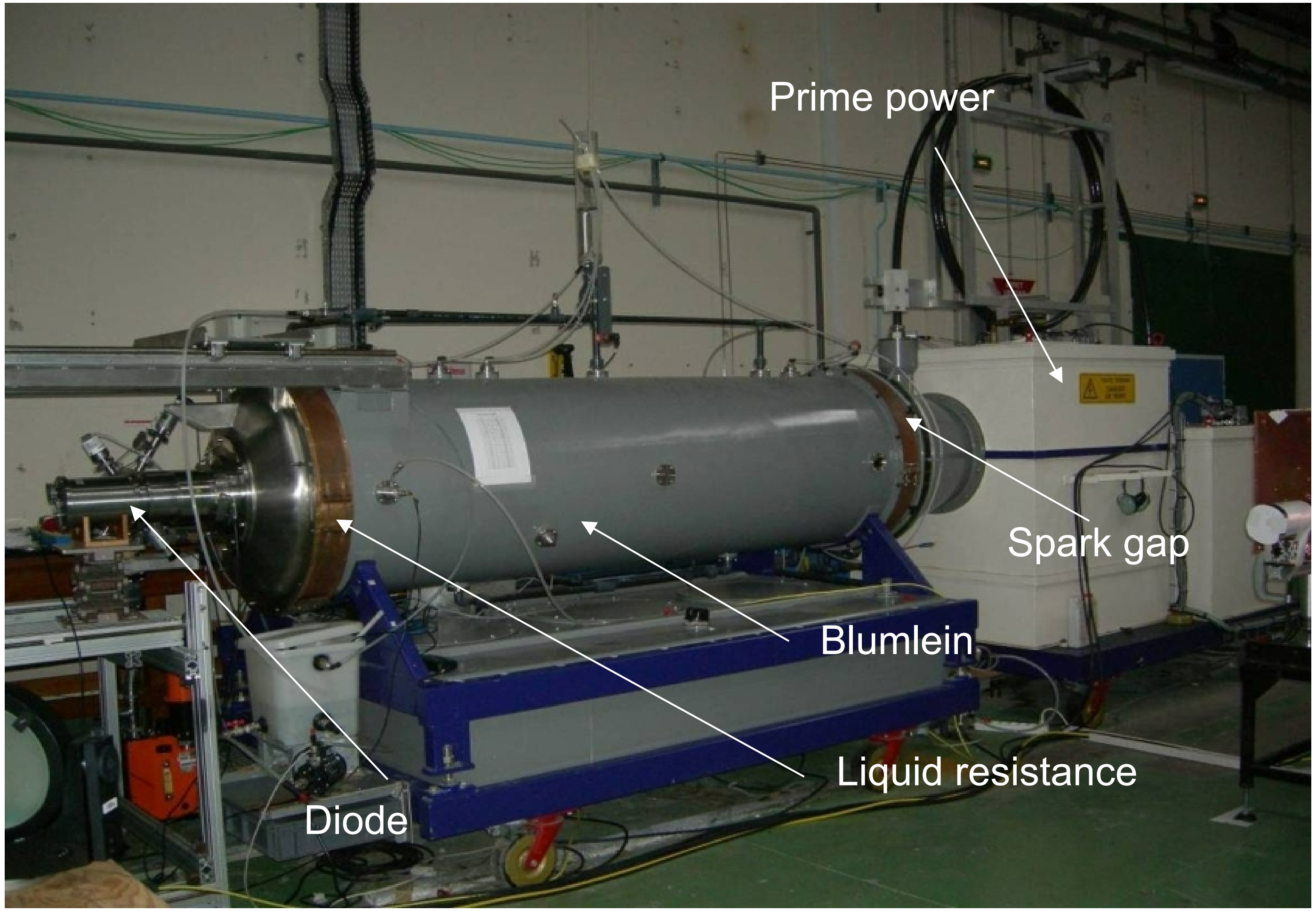
We have a collaboration with CEA for validation data using RKA

- Increase confidence in EMPIRE’s capability to simulate pulsed power systems and high energy beams

RKA Overview

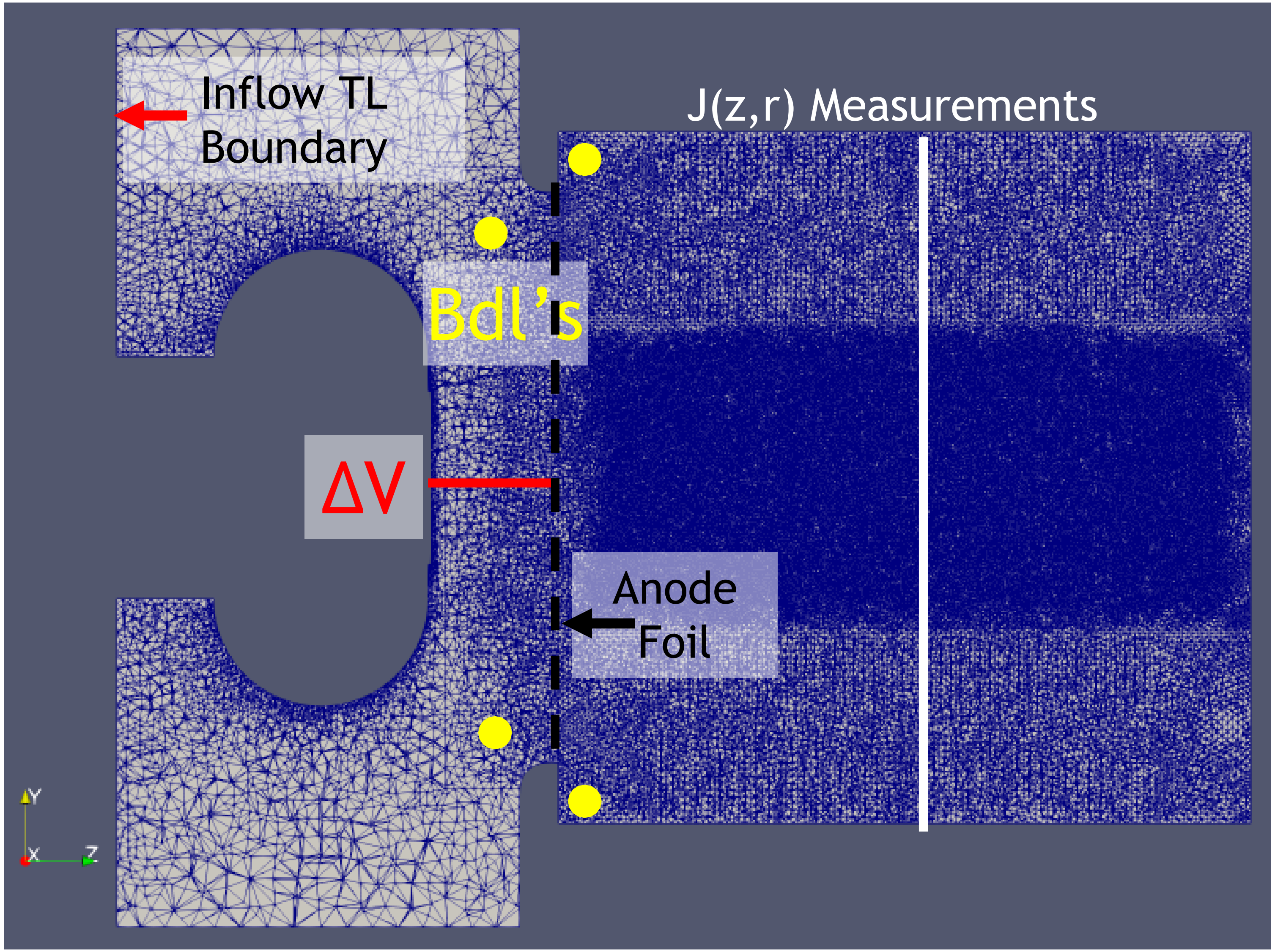
What is the RKA?

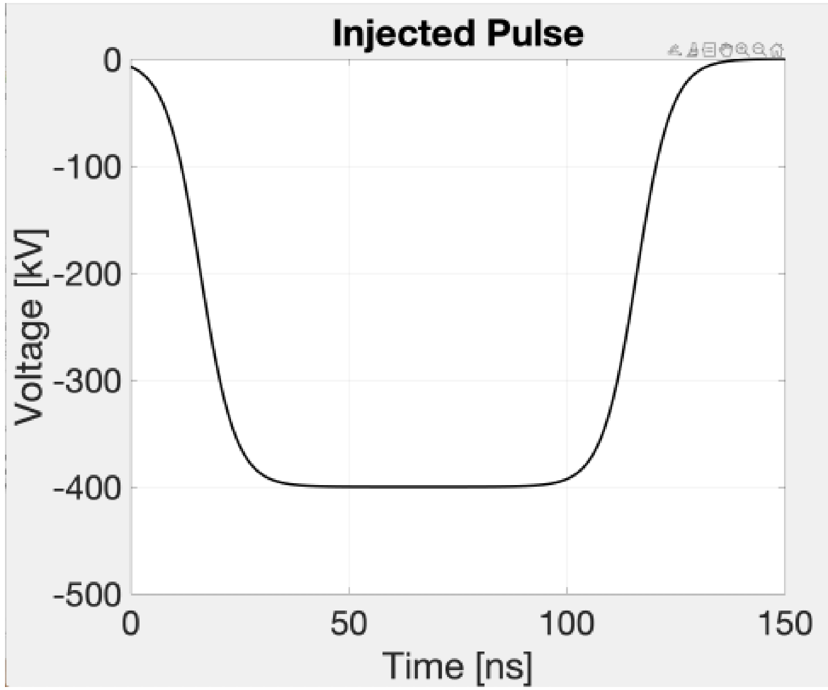
- Pulsed Power Machine
  - Located in Bordeaux
- Electrical characteristics :
  - Beam energy : $V < 500$ kV
  - Beam current : $1 < I < 30$ kA
  - Pulse length (FWHM) : $\tau \approx 100$ ns
  - Fluence : $0.5 < \phi < 10$ cal/cm²
- Can attach a gas cell with various diagnostics to study the electron transport from vacuum to <10mbar.



PROPAGATION OF ELECTRON BEAMS IN GAS CELLS B. Cassany, D. Hebert, J. Gardelle, P. Modin, N. Szalek, K. Bell, C. H. Moore, B. Medina, M. Bettencourt, ICOPS 2019

Simulated Geometry and Pulse





Variable mesh size

Δx = 1mm in beam region in gas cell

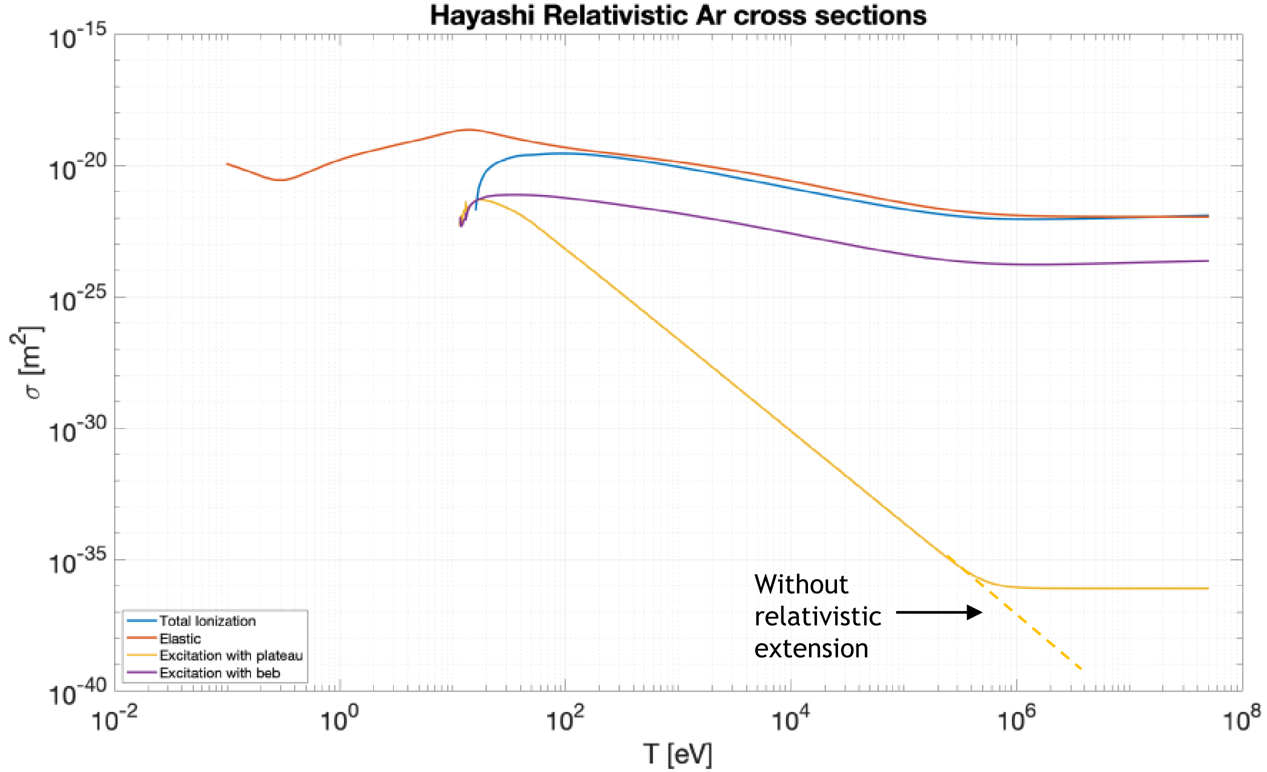
Δx = 8mm in far-field region

$\Delta x/\lambda_D < 1 \rightarrow$ plasma density < 5e16 m^{-3} assuming that T~1keV for dense return current

Problem Description

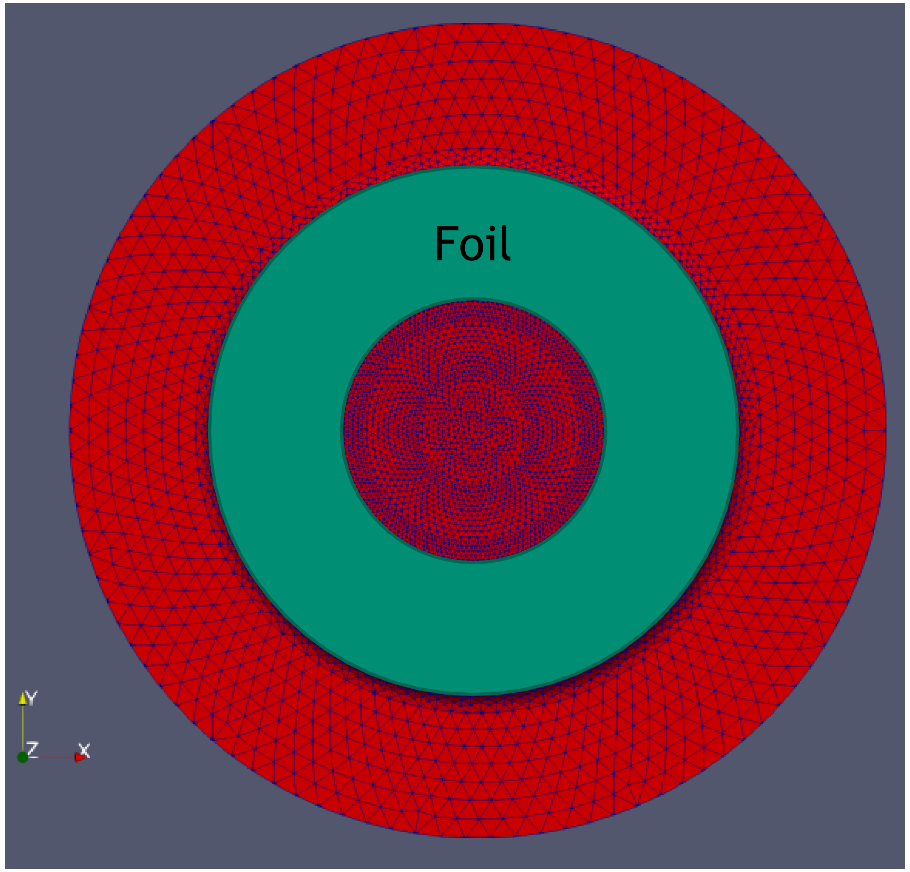
Cross Sections

- Hayashi Cross sections
  - Non-relativistic
  - With relativistic extensions
- We want to understand the sensitivity of RKA dynamics to the cross sections
  - How different are the properties of the beam?
  - Are the electron dynamics drastically different?
  - How much is the ionization rate affected?
- All elastic and excitation collisions are still isotropic: Adding Okhrimovskyy model in near future.



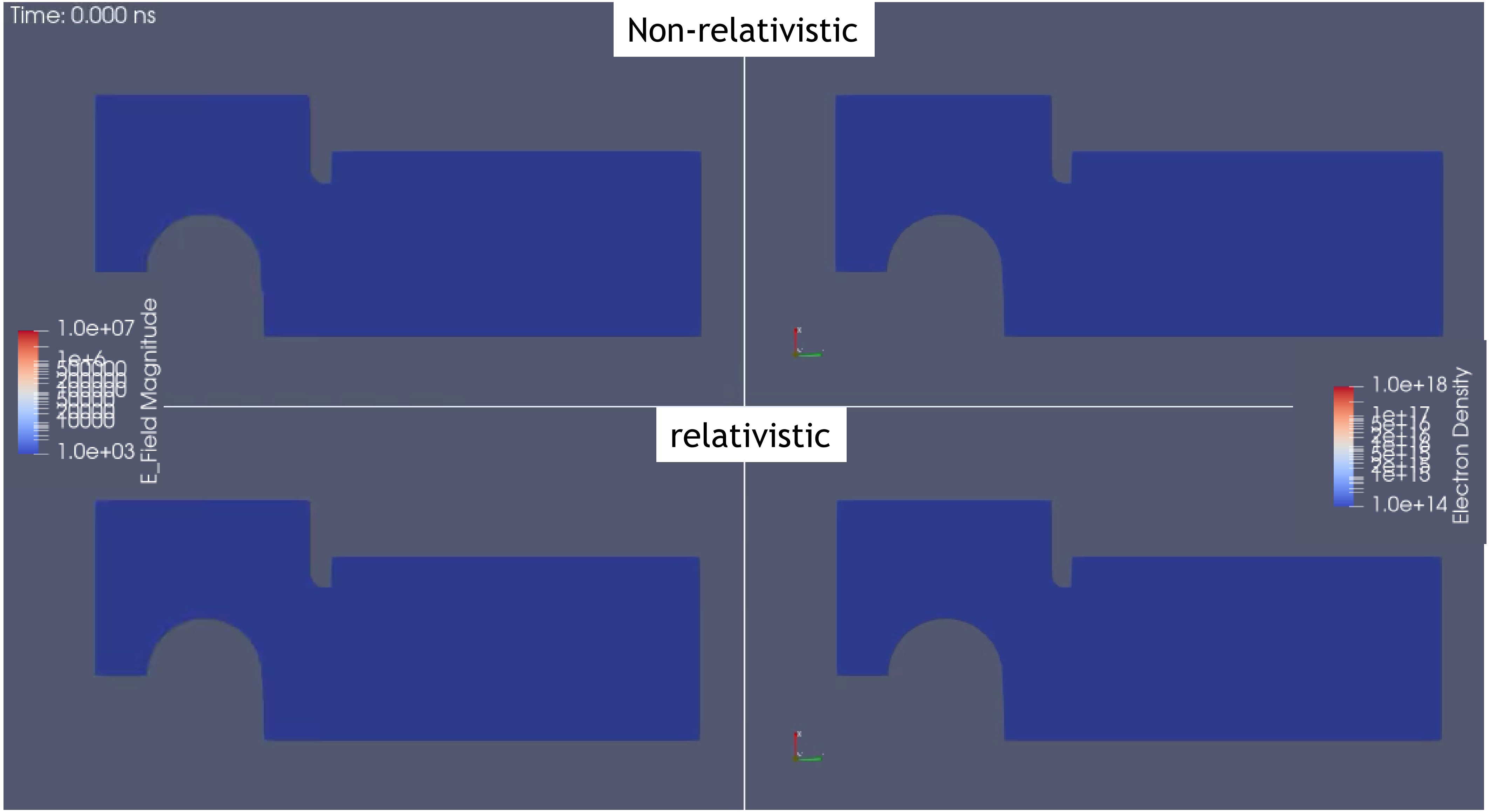
Foil

- No Foil
  - BC shorts the fields and is transparent to particles.
- Partial Foil
  - BC is separated into two regions; inner and outer sections
  - Outer section shorts the fields and doesn't allow particle passage
  - Inner section shorts the fields and is transparent to particles.
- What we hope to understand better
  - Does this partial foil BC improve results?
  - How important is the level of foil physics fidelity: Do we need to model the foil with ITS or can we use more simple scattering and energy loss models?

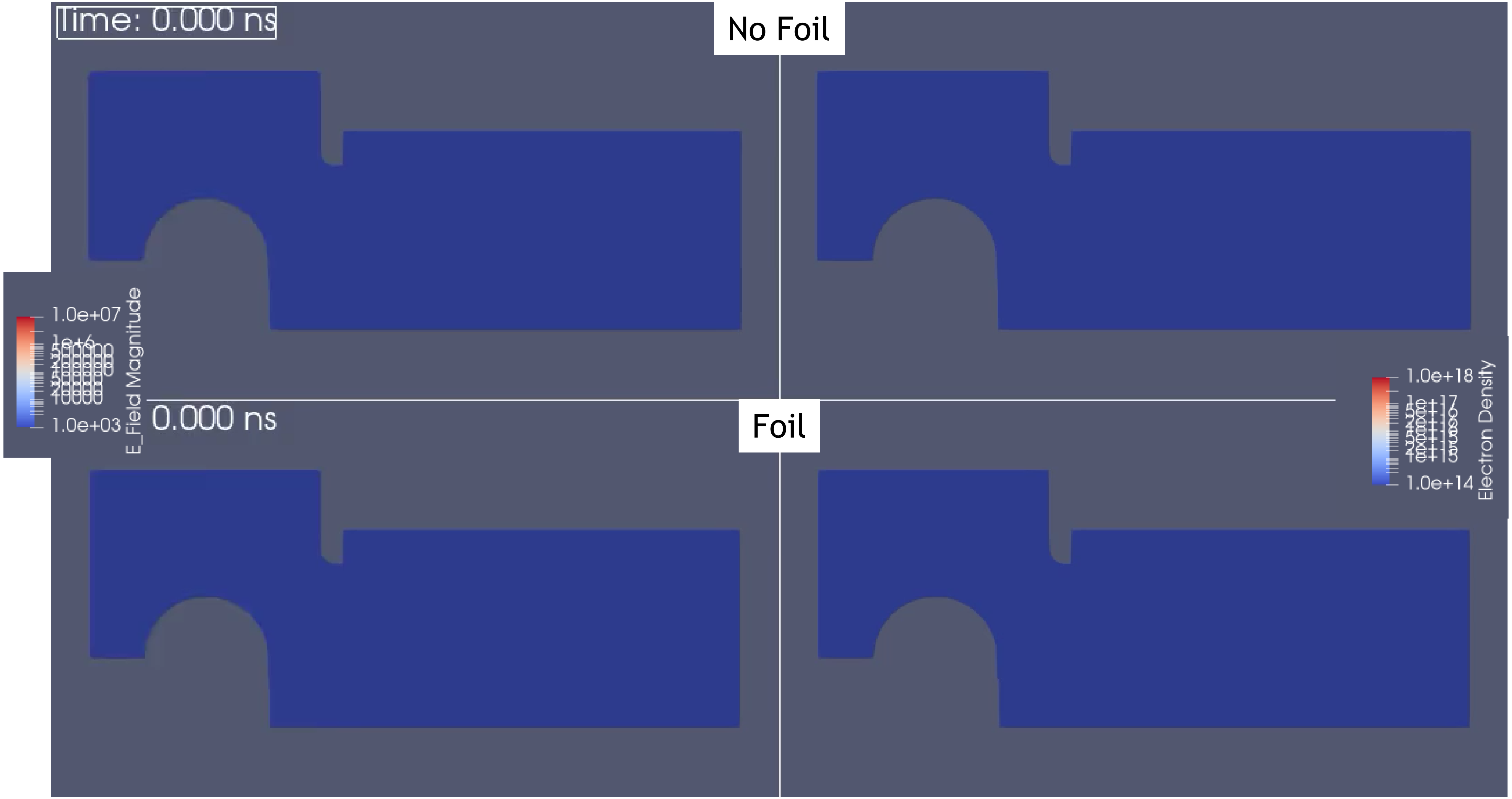


Results

Comparing Cross Sections (with Foil BC)



With and Without Foil (relativistic xsections)



Conclusions

- The relativistic cross section corrections drastically alter the beam transport and focusing.
  - More collisions and ionization.
  - Affects the beam focusing location and magnitude.
  - The ionization Knudsen number is <1 with relativistic cross sections which leads to very different electron dynamics.
  - Future work: Add anisotropic scattering and scan across gas cell pressures → eventually the additional collisionality due to the relativistic corrections won’t matter as much?

- Partial Foil
  - No foil leads to unphysical build-up at the gas cell boundary. This is due to scattered electrons oscillating in and out of the diode region and ExB drifting radially outward.
  - There is still a build up of electrons in the inner region due to the unphysical nature of the boundary.
  - These simulations can benefit from a more advanced foil BC. We need a BC that transmits and scatters incident electrons with some probability. The scattering should be anisotropic, with forward scattering being the most probable. The BC should also include energy transfer and conservation and even possibly have a foil deterioration factor to simulate foil weakening.