SAND2019-5985PE

P203 Studies of Intense Electron Beam Propagation in Gas-Filled Cells

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Objectives

- SNL
  - Obtain model validation data for EMPIRE code suite
  - Platform comparison at SPHINX
  - Implementation of CESTA diagnostics at SPHINX

- CEA/CESTA
  - Optimize CESAR beam performance
  - Dedicated experiments at RKA to improve simulation models (EMPIRE & CALDER)
  - Implement electron density diagnostic on RKA

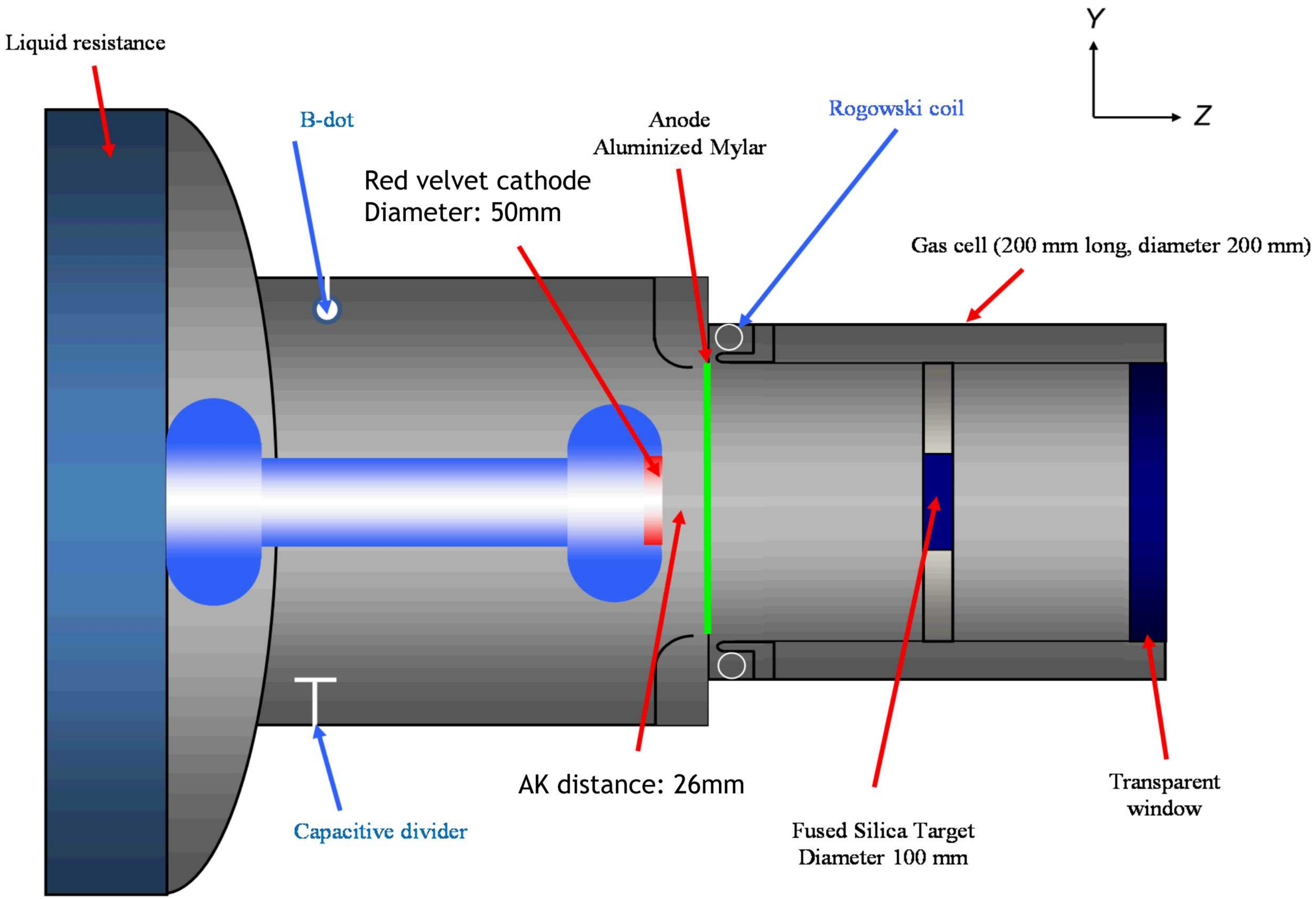
EMPIRE details

- EMPIRE is Sandia's next generation EM plasma
  - Code began significant development in 2017

- What makes EMPIRE special?
  - 3D EM Finite Element plasma code on unstructured mesh
  - EMPIRE runs on modern HPC architectures (CPUs, GPUs, ARMs, …) via Kokkos abstraction layer
  - EMPIRE has a breadth of physics capable of modeling low temperature discharge plasmas to high energy e- beam transport including complex gas chemistries
  - EMPIRE will have hybrid fluid-kinetic capabilities

- Currently developing and testing many physics models including:
  - Energetic, relativistic collisions (including anistropic scattering)
  - Charged particle transport through a foil

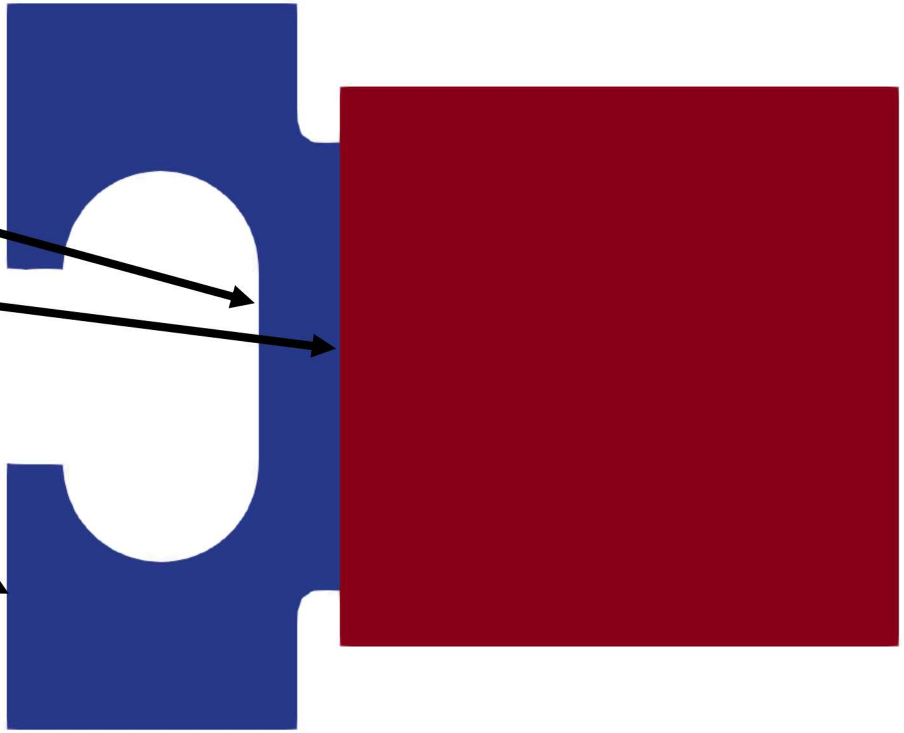
Relativistic Klystron Accelerator (RKA)

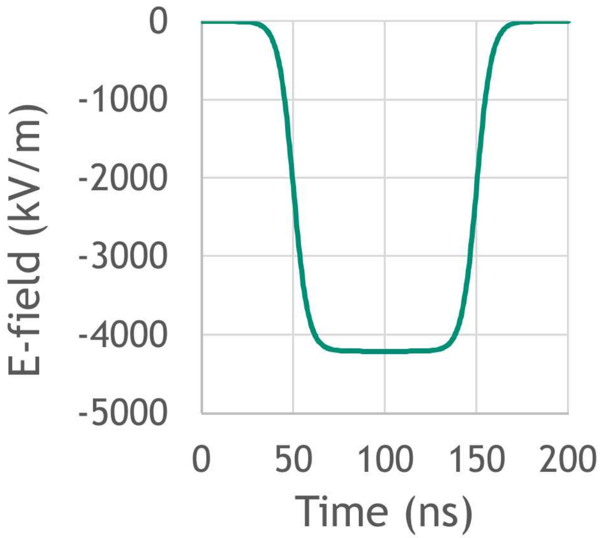


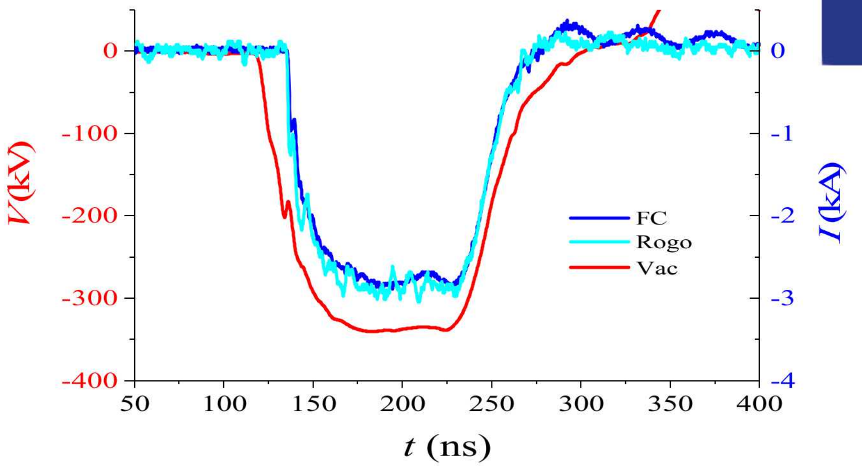
Domain & Boundary Conditions

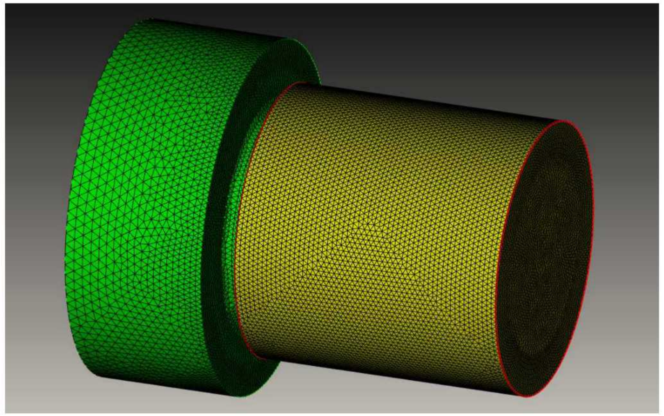
- SCL emission from the cathode
- The anode foil shorts the fields, but allows particles to pass through (no interaction)
- Representative driver waveform imposed as a Dirchlet BC:

$$\vec{E}(\vec{x},t) = -2.105 \times 10^{6} \left[tanh\left(\frac{t-t_0}{80 \times 10^{-9}}\right) - tanh\left(\frac{t-t_f}{80 \times 10^{-9}}\right) \right] \frac{\vec{x}}{r}$$



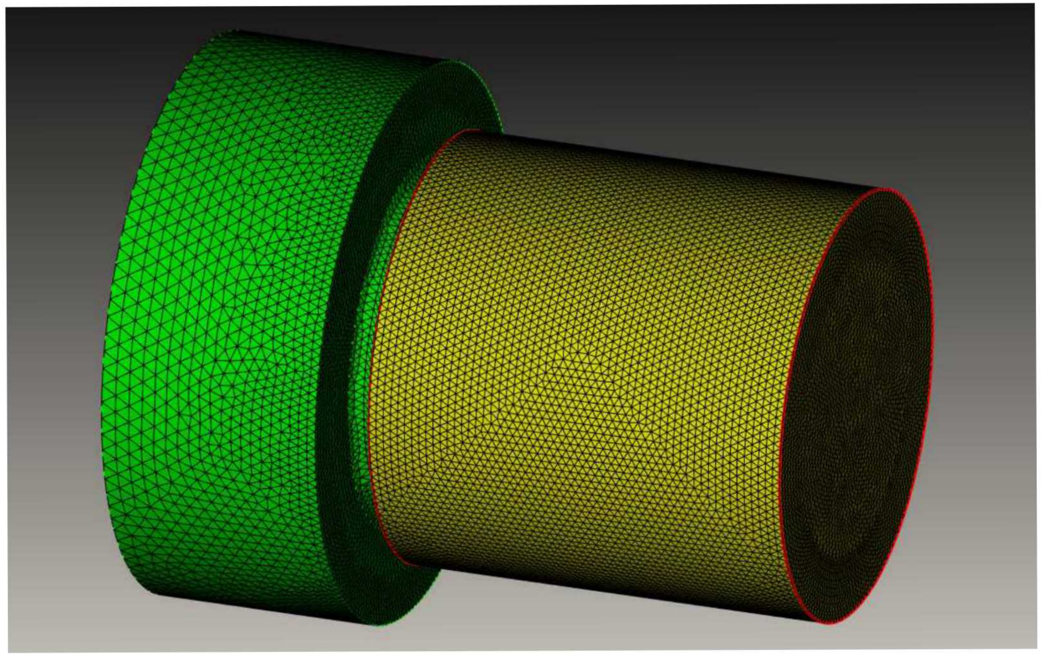


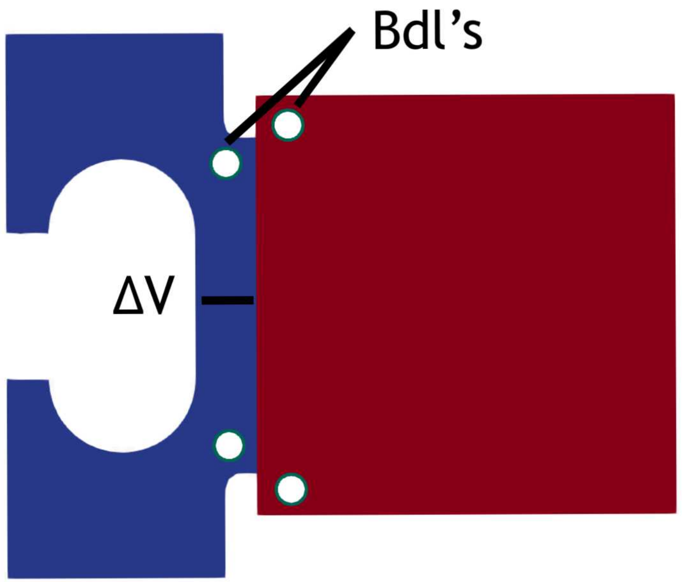




Mesh & Diagnostics

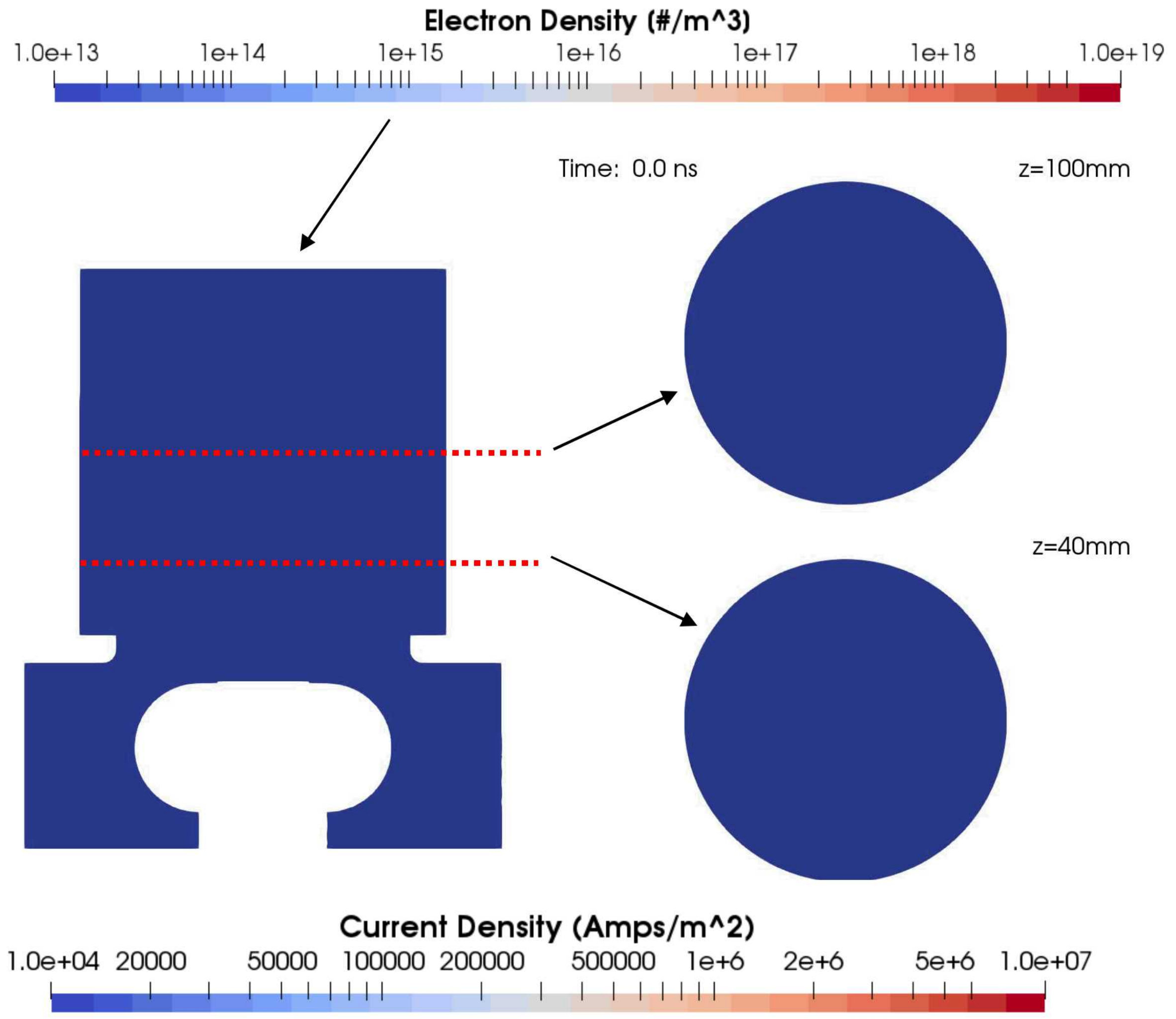
- Perfect conductor metal BCs
  - Dirchlet BCs ($E_{\perp}$=0)
  - Currently e^- and Ar^+ that impact surfaces are absorbed -- no Secondary Electron Emission or sputtering
- Variable mesh size in diode
  - Δx = 1mm near cathode, 4mm far field
  - Δx = 2mm in the gas cell
- Diagnostics:
  - Element-based species & current densities
  - Bdl loops at halfway across the A-K gap, just in front of the anode, and 5mm after the anode
  - Voltage across the A-K gap

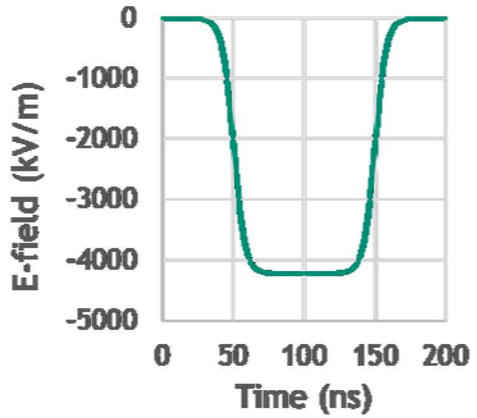




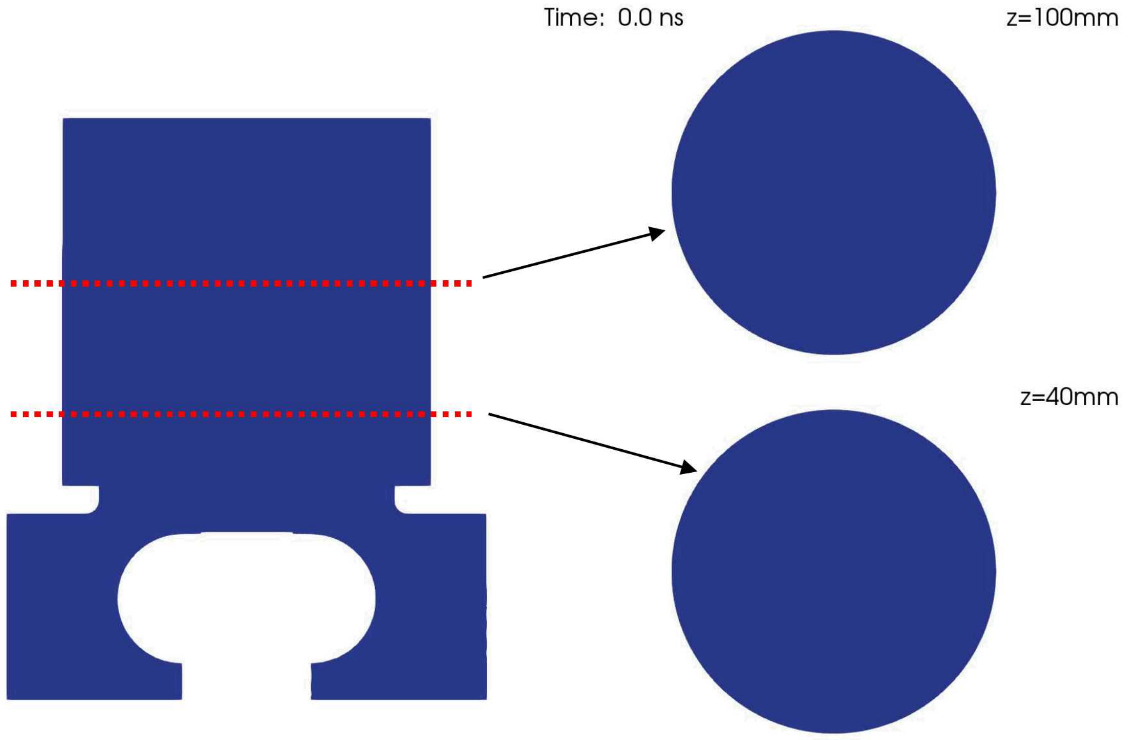
RKA results

Vacuum



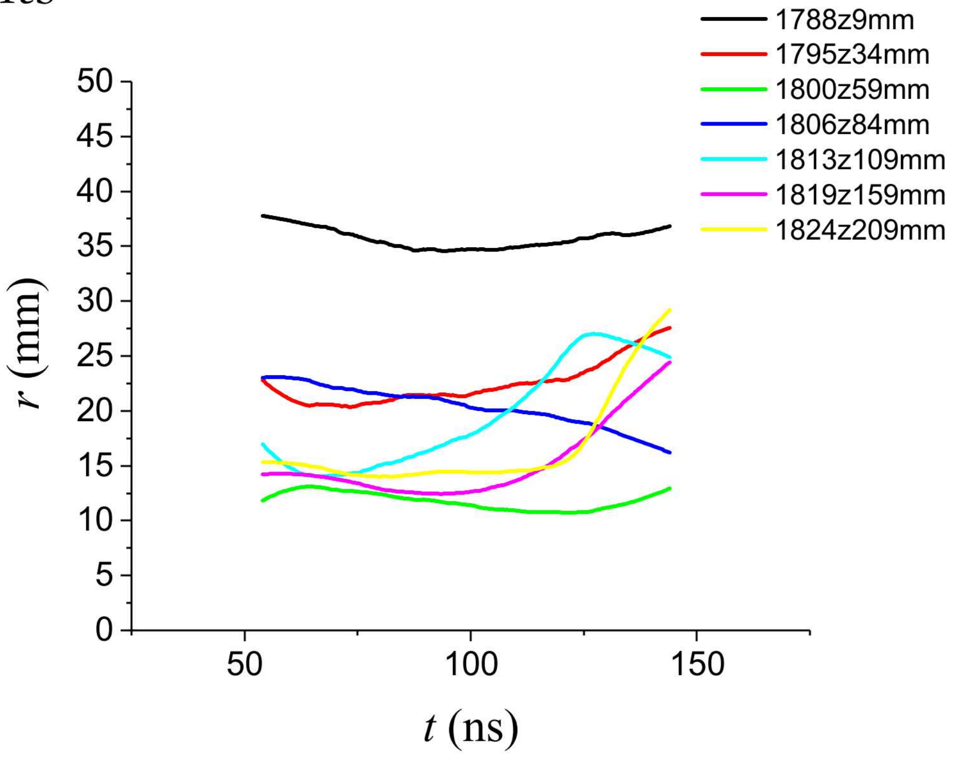


0.1 mBar

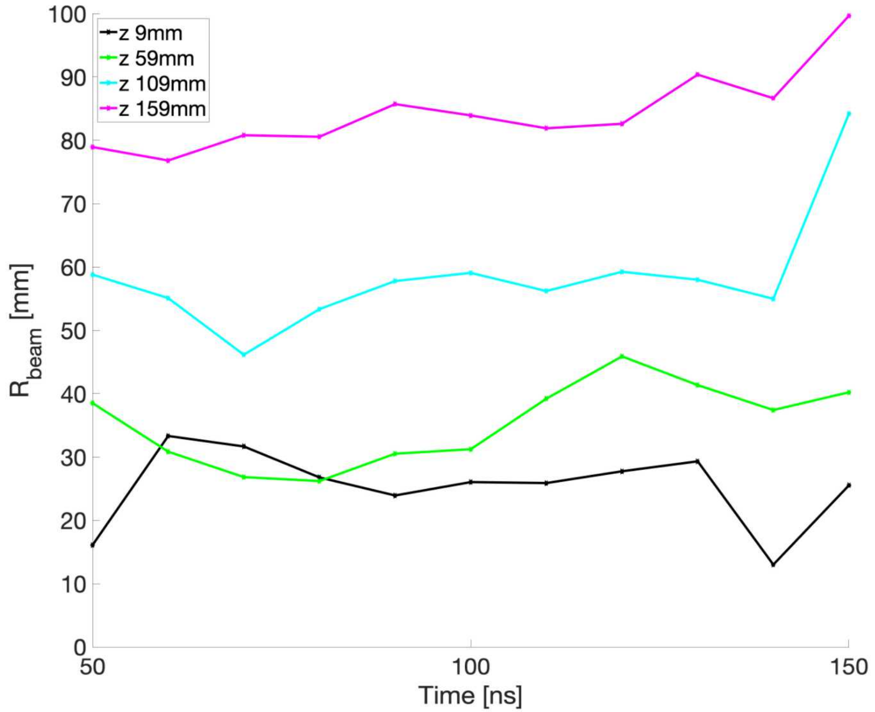


RKA sims vs. exp. results

- We can post-process the EMPIRE output to obtain the beam radius vs. time at several locations along the gas cell z-axis. New RKA shots will be compared with simulation results



Representative RKA data from streak camera (different diode gap & cathode, 3 mBar)



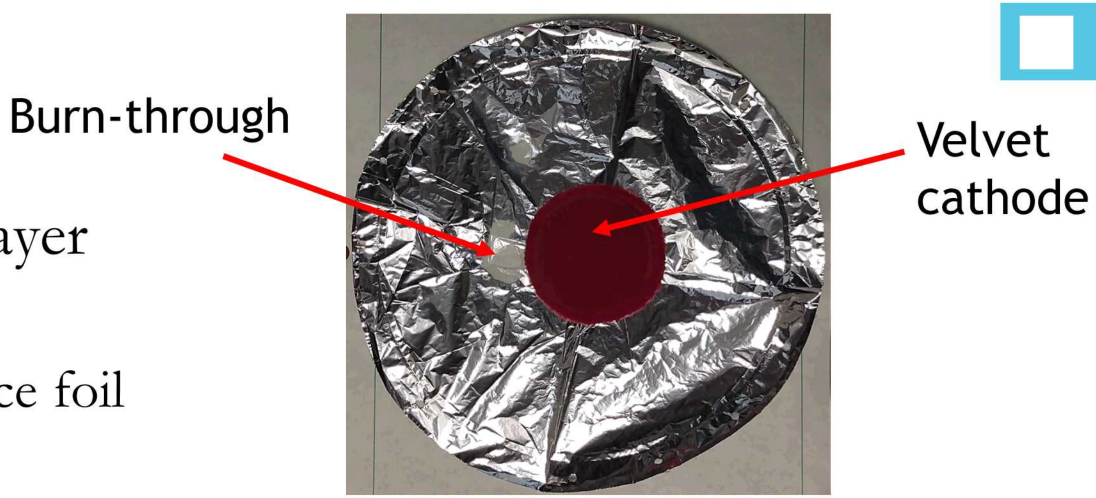
EMPIRE simulation of RKA at vacuum

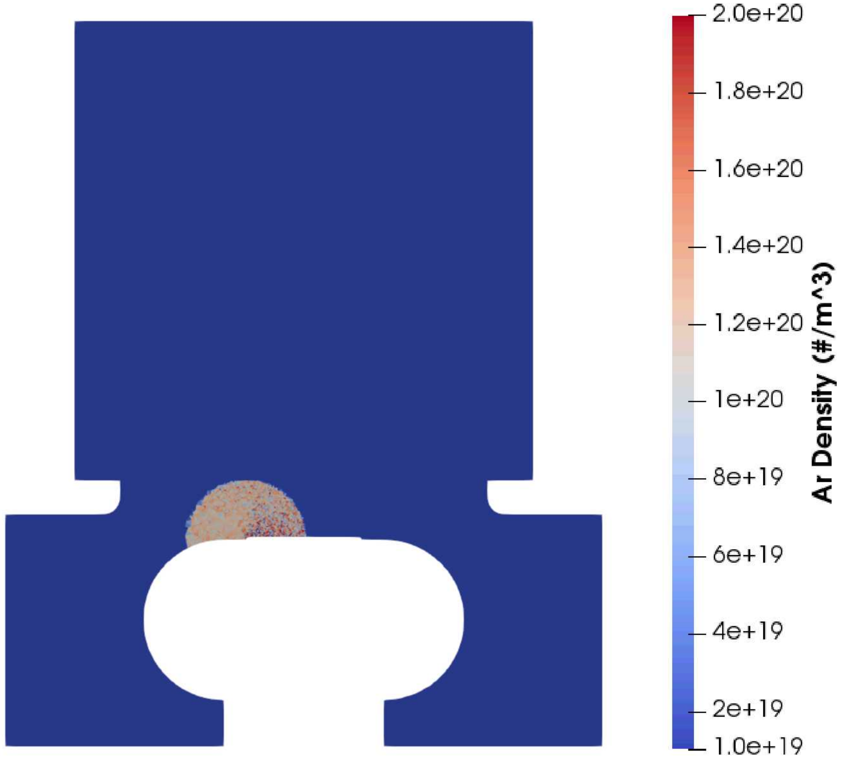
RKA foil burn-through

- After several shots small holes in the aluminum layer appear in the anode foil
  - Eventually the foil breaks → Must open RKA to replace foil

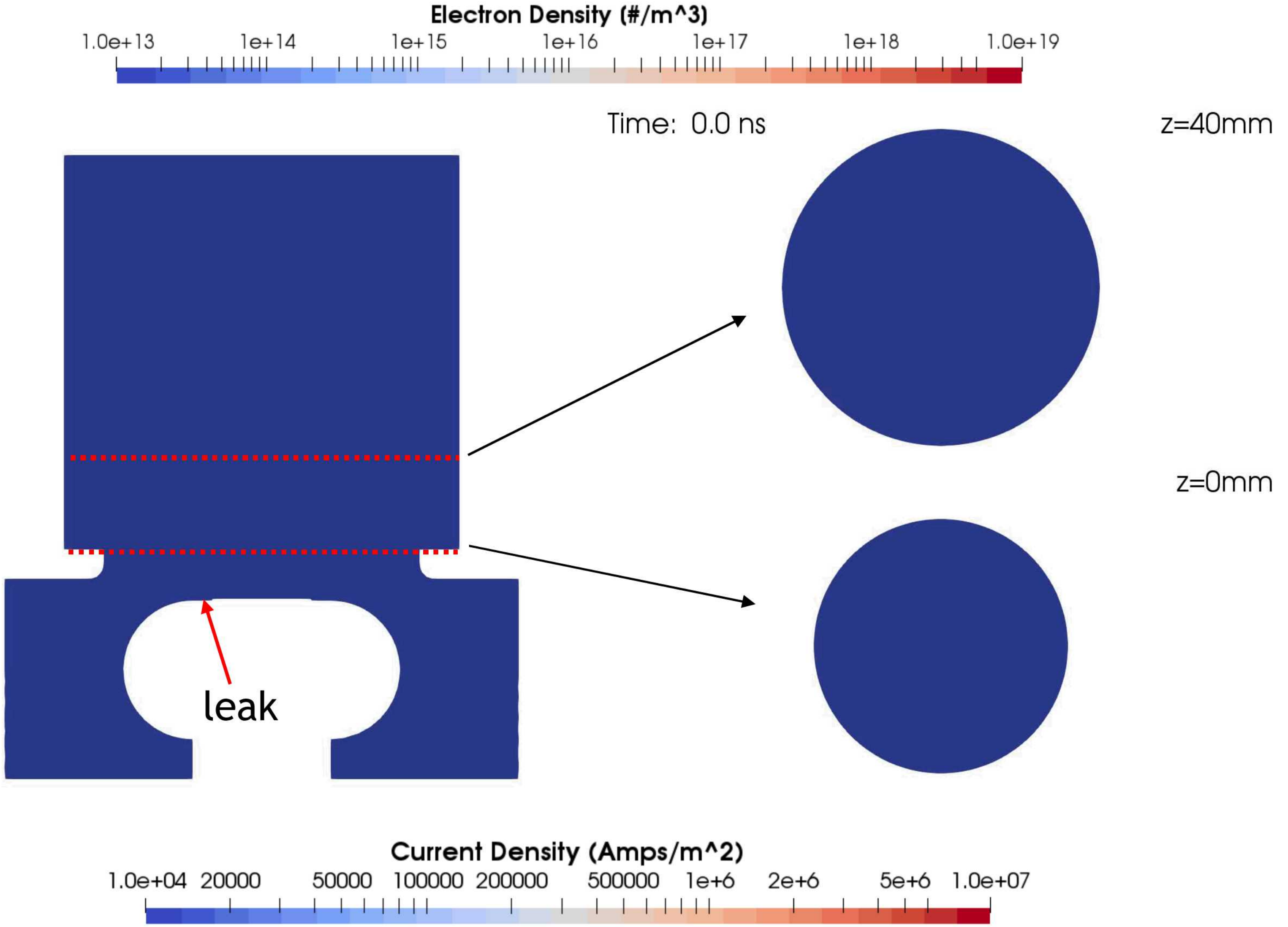
- During March visit to CESTA it was realized that a small amount of gas may be leaking from between the inserted cathode puck and the cathode stem.

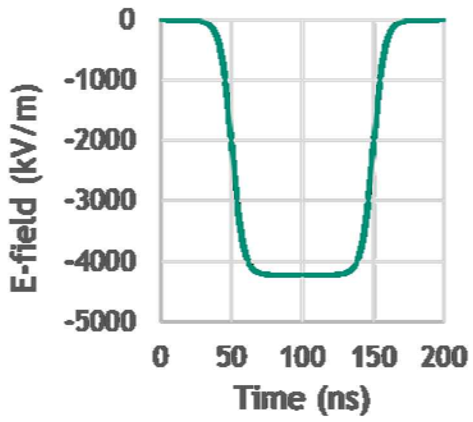
- To test this possibility we added a small region of higher gas pressure ($5*10^{-3}$ mbar) in the nominally vacuum diode region



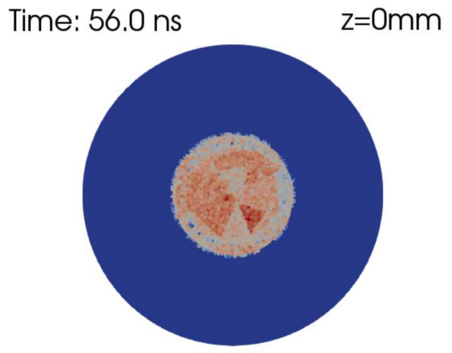


RKA foil burn-through

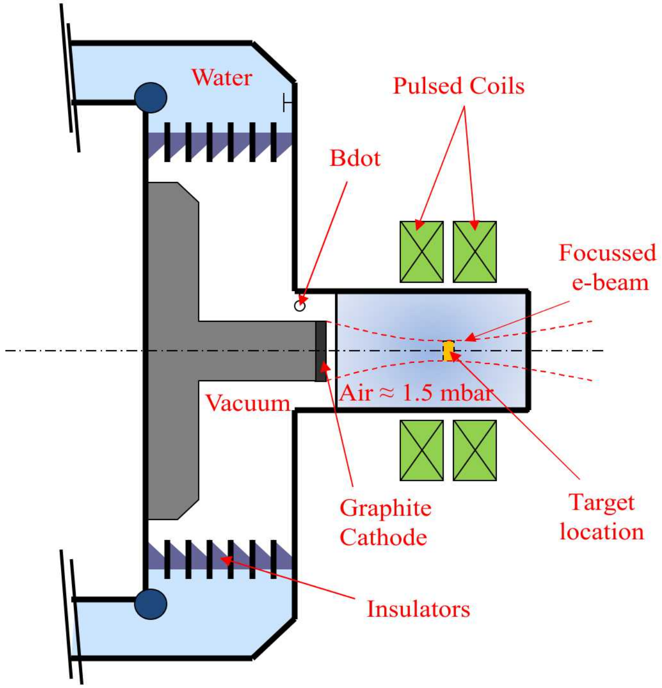


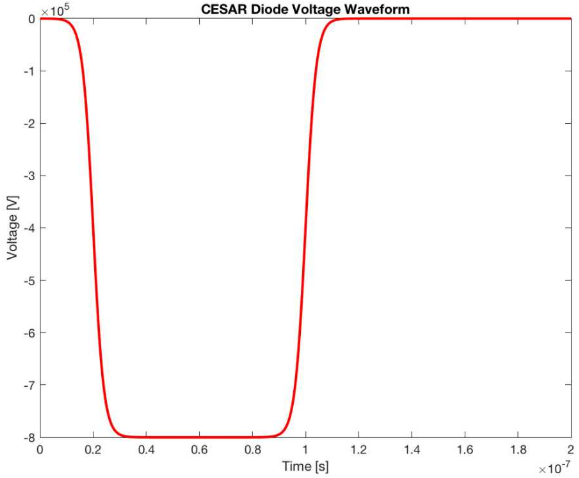


Without gas leak:

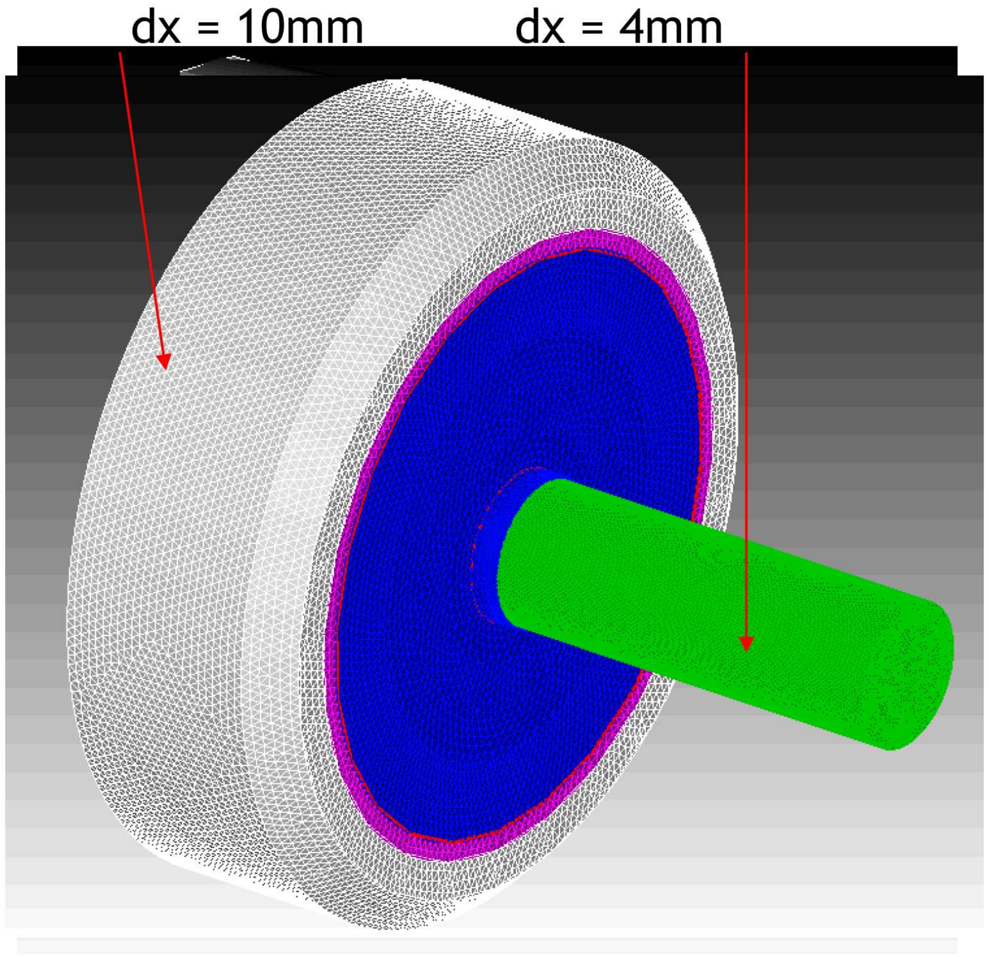


CESAR setup

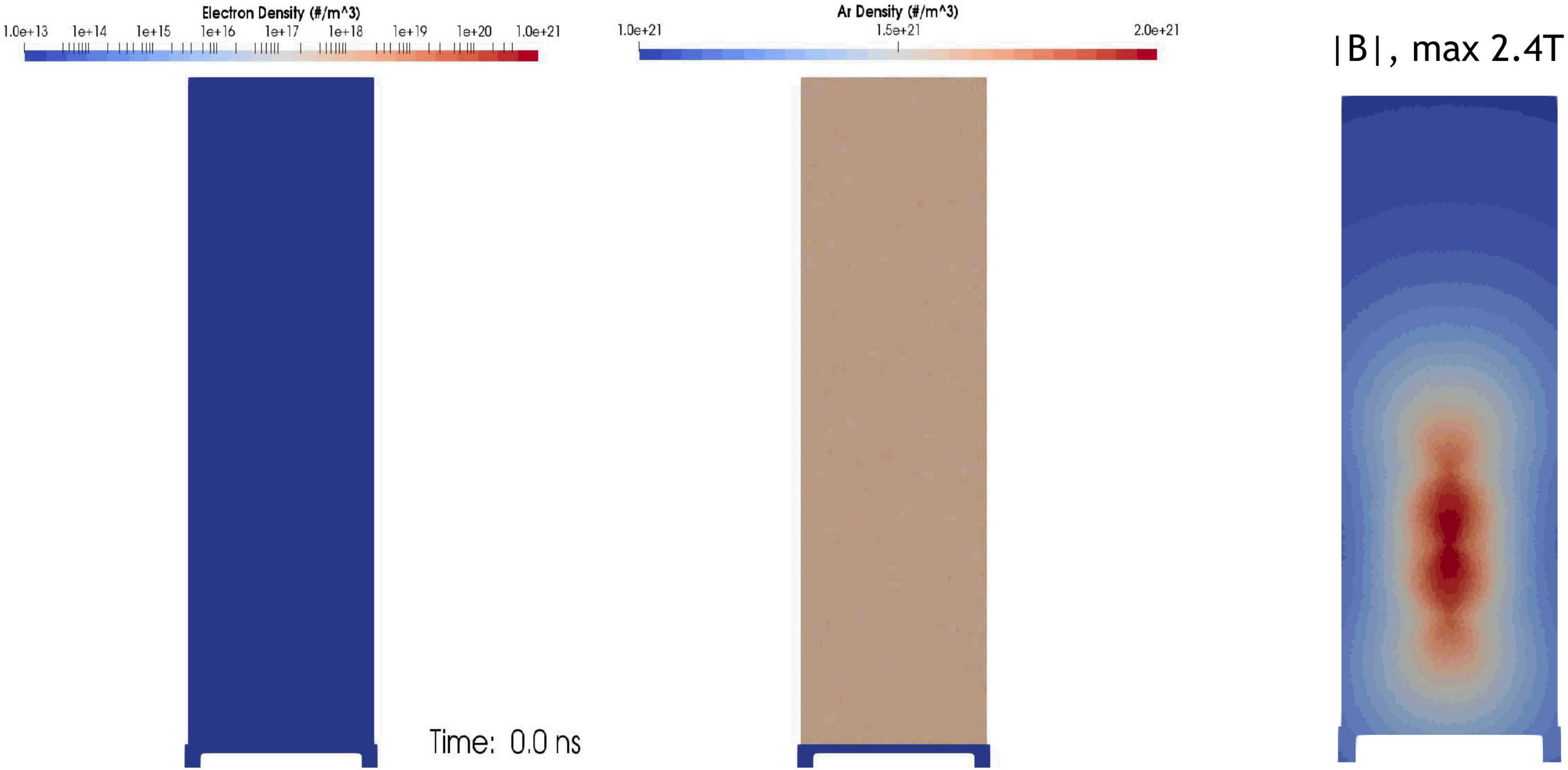




- AK gap: 6mm
- Aluminum/mylar foil anode
- Helmholtz coils : 3T+ fields
- Fluence target at 127mm from foil
- Graphite cathode
- Water line: ε_r = 80
- Insulator: ε_r = 2
- Argon pressure: 50 mTorr



Initial CESAR results



Simulation Summary

- Rapid development of EMPIRE's capability to simulate e- beam transport
- Starting benchmark collaborations with CALDER
  - EMPIRE implementing additional ionization physics present in CALDER
- Starting informal validation of EMPIRE model for e- beam transport
- EMPIRE simulations indicate that small gas leak near cathode velvet is possible explanation for foil burn-through
- SNL present for first RKA shots
- New chamber for RKA
- Planning experiments on SPHINX guided by RKA results & simulation

→Progression towards predictive simulations of CESAR for beam optimization