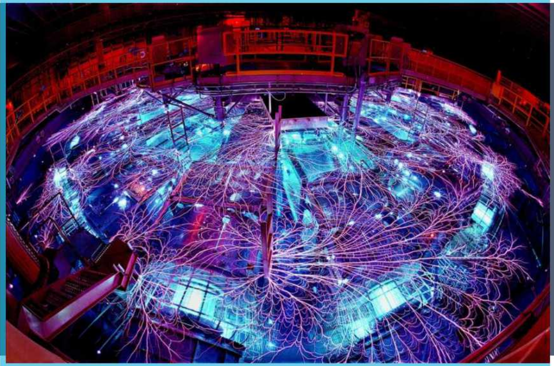
SAND2019-12952C

Cross-code Verification for Simulations of a Planar MITL



PRESENTED BY

Nathaniel D. Hamlin, Evstati Evstatiev, Nichelle Bennett

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

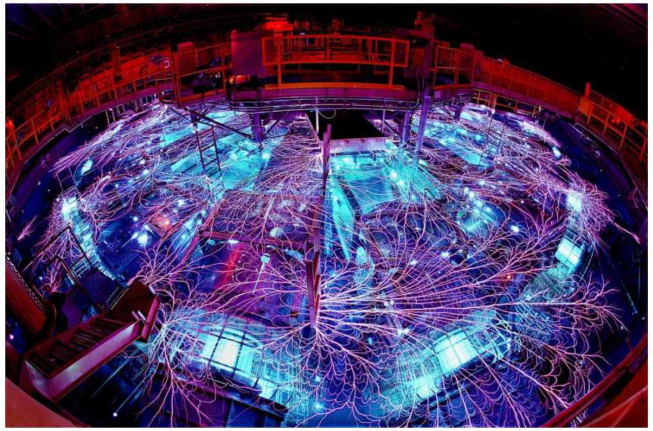
SAND number:

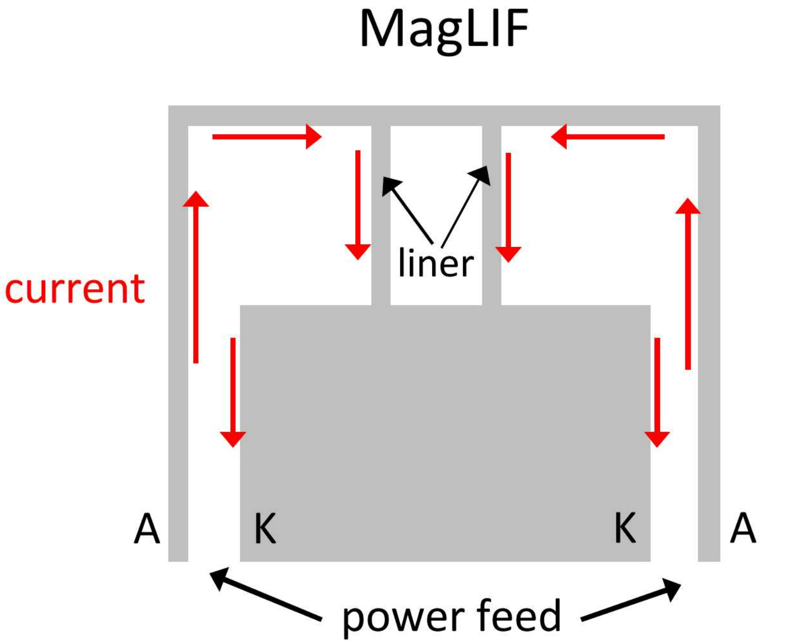
Motivation for power-flow modeling

High-fidelity power-flow modeling is critical to improving the performance of experiments on present and future pulsed-power facilities. [x]

- Power-flow modeling incorporates a wide range of length/time scales:
  - **Load region:** dense plasma, suitable for **fluid modeling** (MHD)
  - **Outer MITL:** low-density plasma, suitable for PIC modeling
- Power-flow modeling stands to benefit from **hybridization** of PIC and fluid codes.
  - EMPIRE: PIC, fluid, hybrid (Sean Miller, poster: **NP10.00019**)
  - Chicago: PIC, fluid, hybrid (Nichelle Bennett, invited talk: **GI3.00006**)
- Drive toward **reproducible science** to inform hybridization:
  - **PIC vs PIC:** When, and how well (quantitatively), do different PIC codes agree?
  - **PIC vs fluid:** When do we expect kinetic and fluid modeling to agree vs disagree?
- Provides important feedback for code developers.
  - Testing of new capabilities.

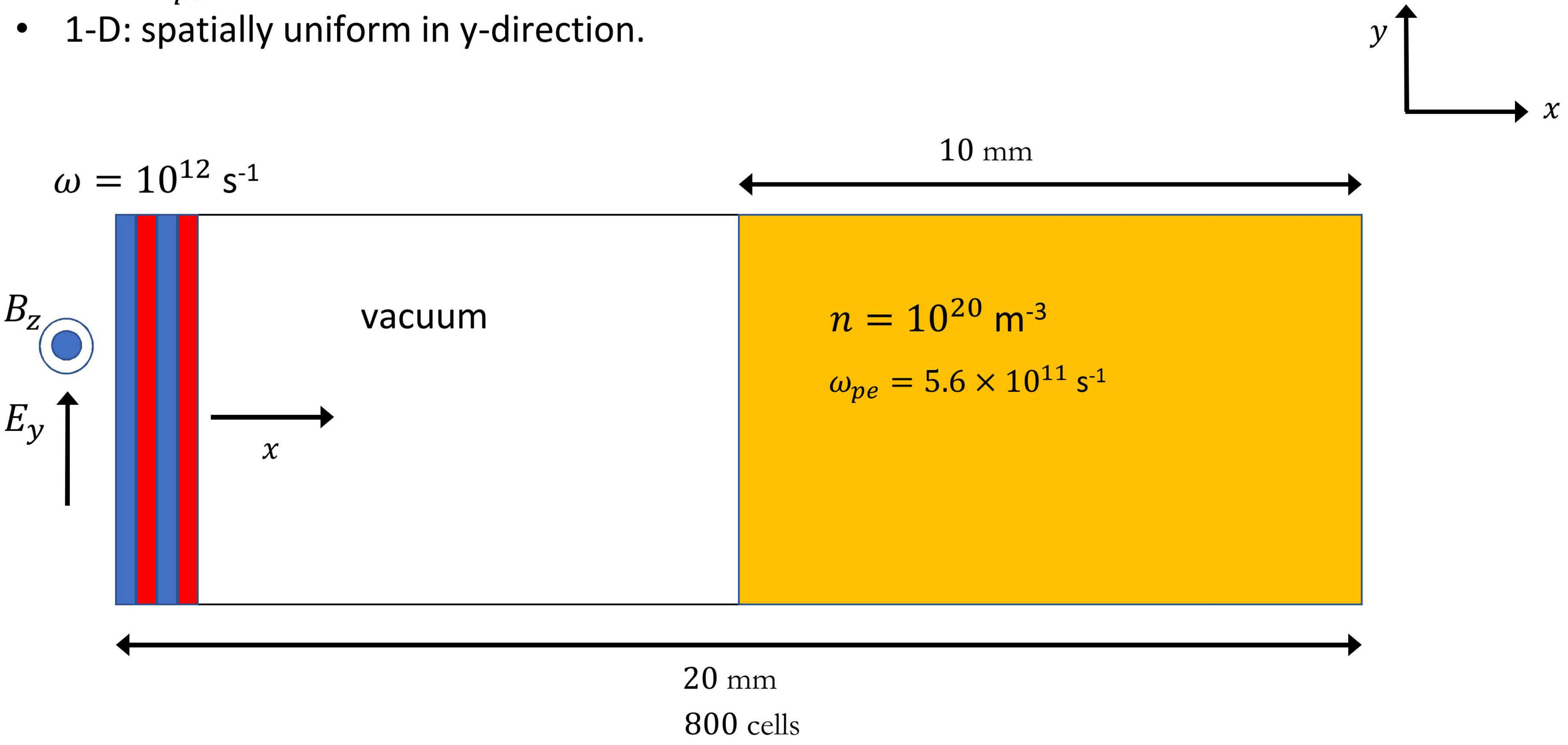
[x] For more information, see
- Daniel Sinars' plenary: **FR1.00001**
- https://www.sandia.gov/pulsed-power/





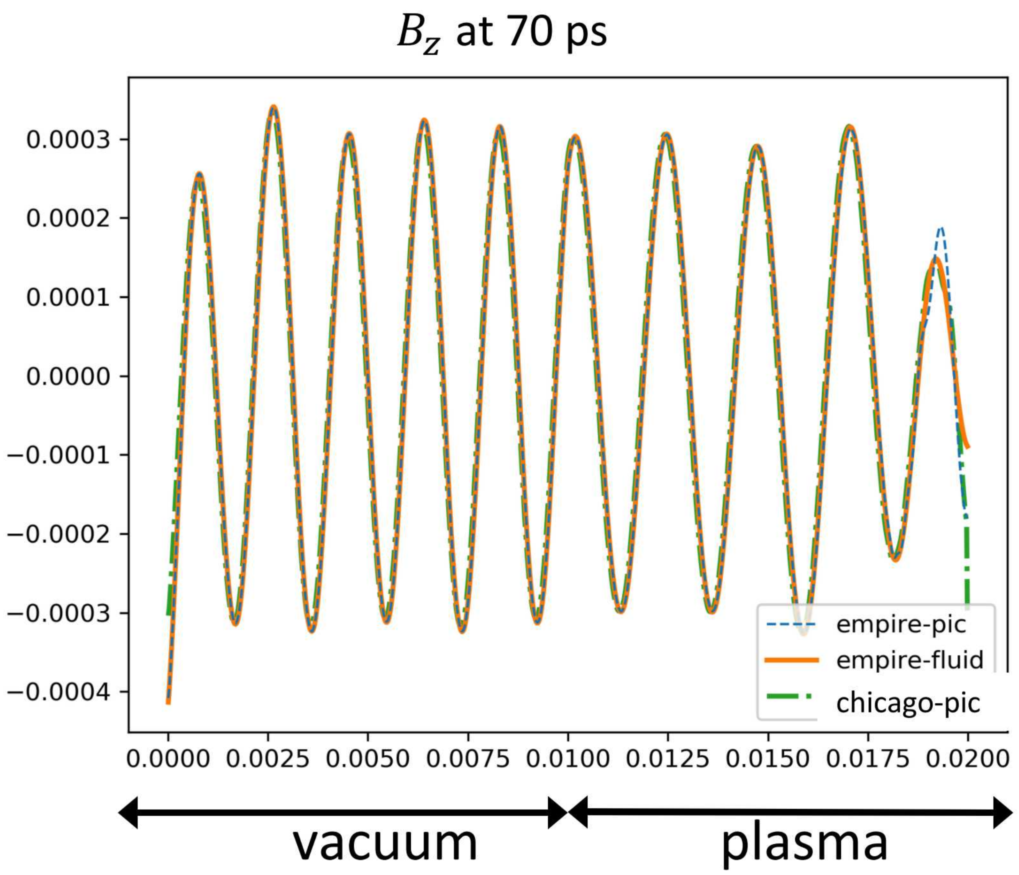
EMPIRE vs Chicago: 1-D TEM-wave

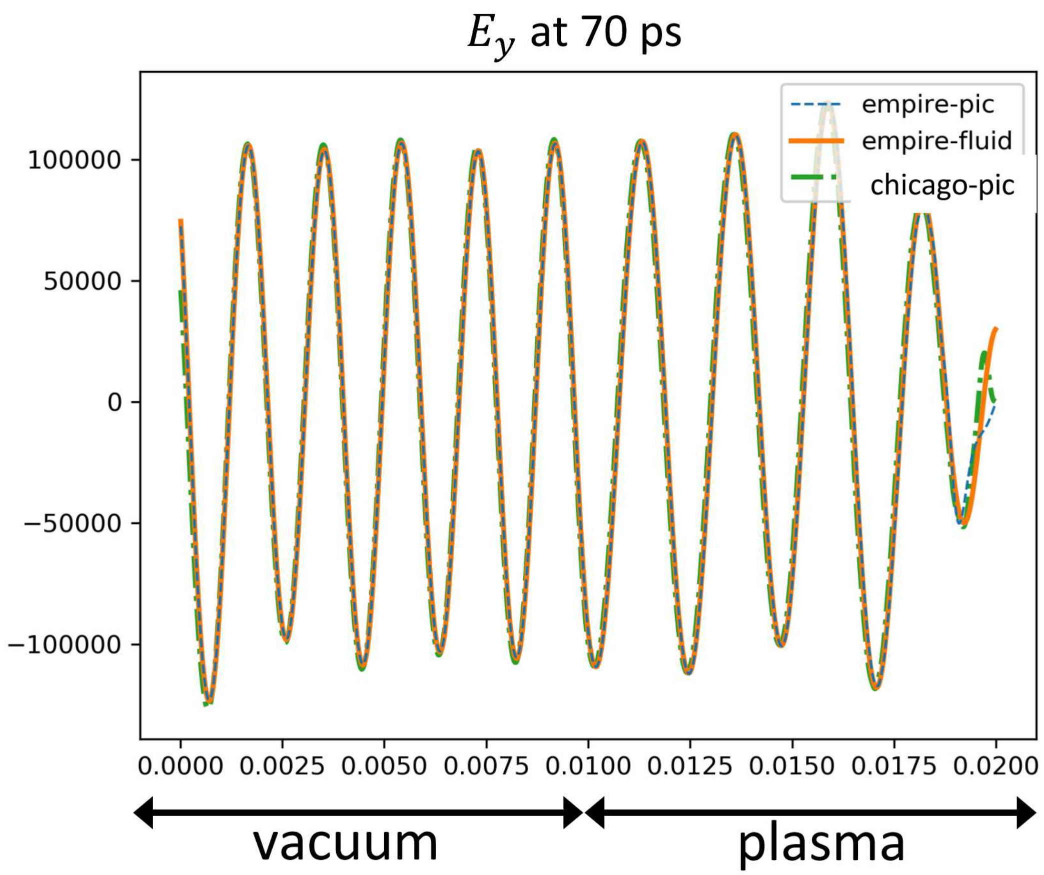
- $\omega > \omega_{pe}$: EM wave should penetrate plasma with minor perturbations.
- 1-D: spatially uniform in y-direction.



EMPIRE-PIC vs EMPIRE-Fluid vs Chicago-PIC: 1-D TEM-wave

- Cold plasma results
- Until 70 ps, close agreement between all three codes in E and B fields.





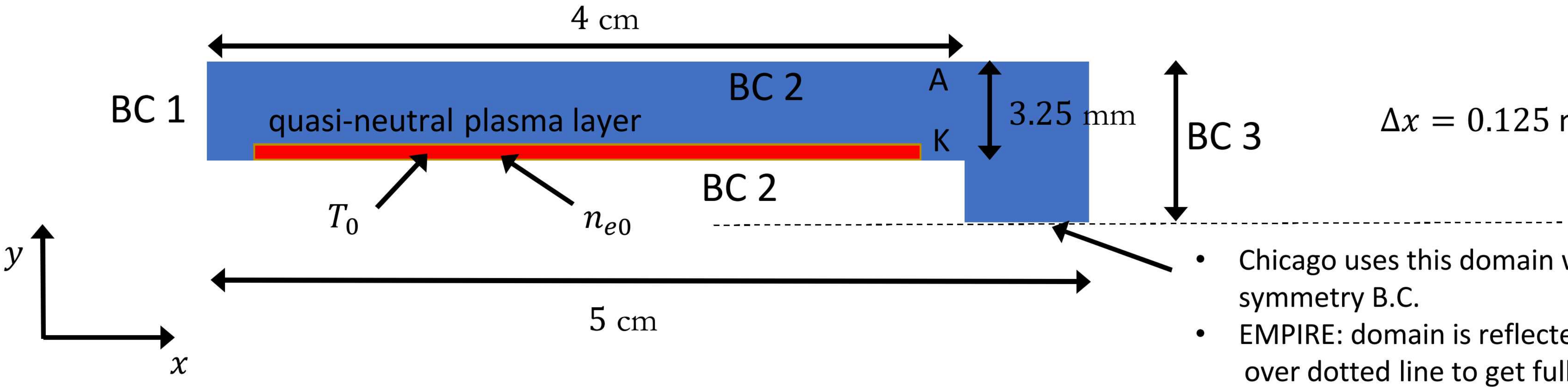
Planar MITL: Initialization and boundary conditions

Initialization

- A quasi-neutral electron-proton plasma layer is initialized against the cathode.
  - By starting with **same initial plasma state**, we can isolate discrepancies in **plasma evolution** from discrepancies in **plasma production.**
- Compare EMPIRE and Chicago for two cases:
  1. Cold plasma ($T_0 = 0.1$ eV), $n_{e0} = 10^{15}$ m^{-3}
  2. Hot plasma (T_0 = 10 keV), $n_{e0} = 10^{15}$ m^{-3}

Boundary conditions

- **BC 1:** Drive voltage V(t) = (10 kV)*time/(0.2 ns), which launches TEM wave propagating in x-direction.
- **BC 2:** Absorbing for particles; conducting EM ($E_x = E_y = 0$)
- **BC 3:** Same as BC2; EMPIRE-PIC adds impedance feature, which has minimal influence over simulation times examined.



$\Delta x = 0.125$ mm

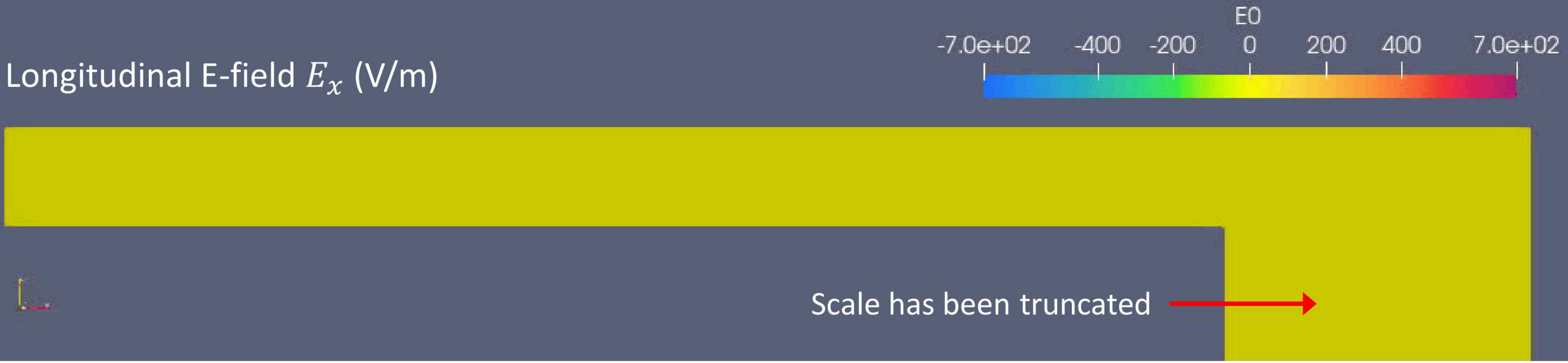
- Chicago uses this domain with symmetry B.C.
- EMPIRE: domain is reflected over dotted line to get full domain

Cold plasma (0.1 eV): Evolution of plasma layer

EMPIRE-PIC simulations

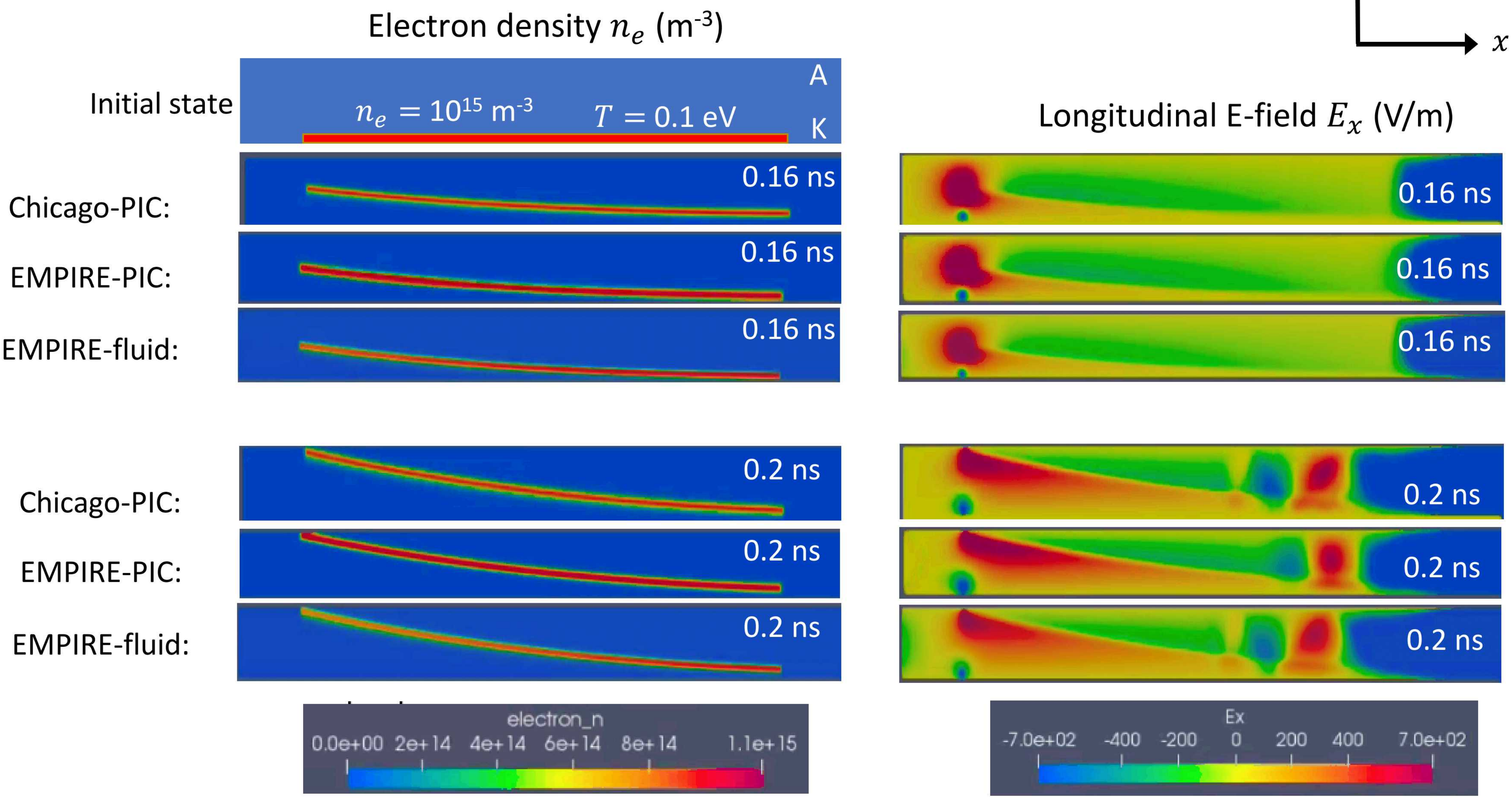
Electron density n_e (m^{-3})

Longitudinal E-field E_x (V/m)



Cold plasma (0.1 eV): EMPIRE-Fluid vs EMPIRE-PIC vs Chicago

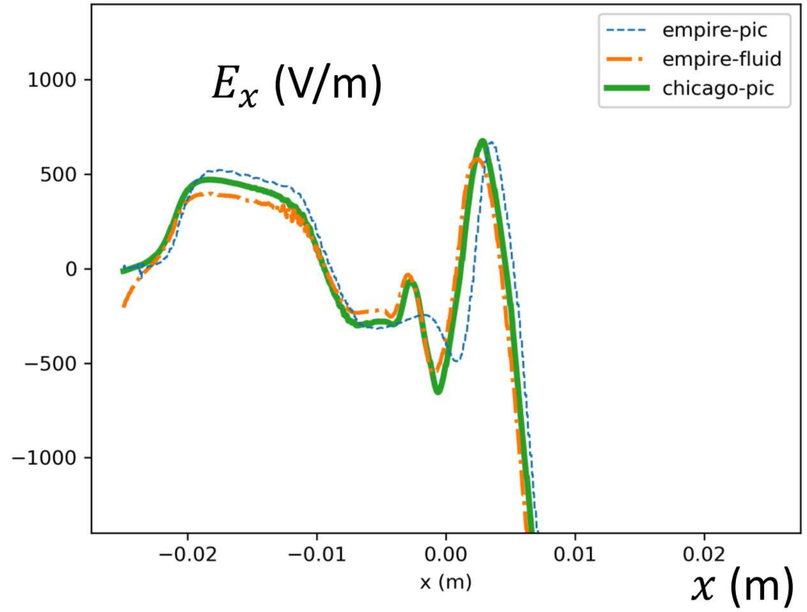
Electrons accelerate; protons remain stationary.



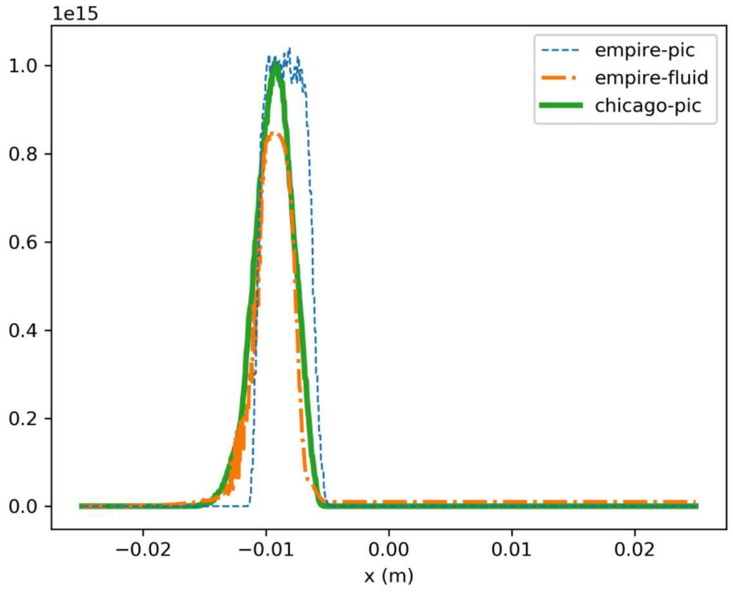
Cold plasma (0.1 eV): line-outs

Relative differences (L1 norm) across line-out:

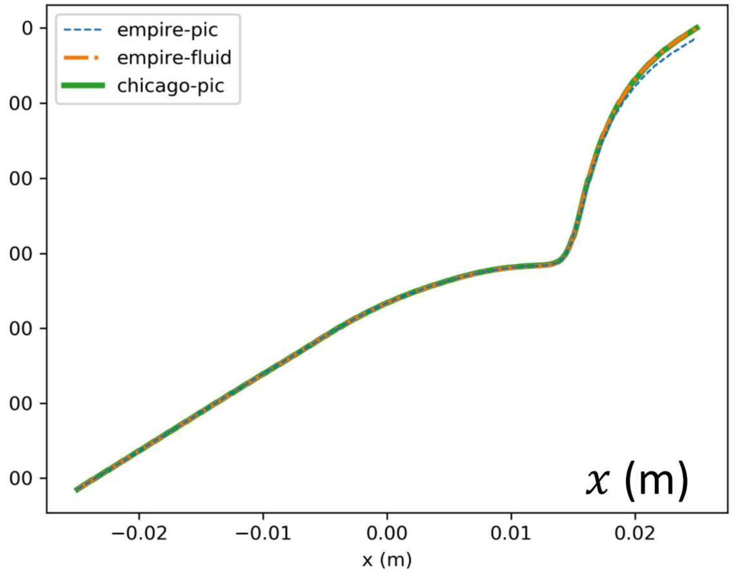
	EMPIRE-PIC vs EMPIRE-Fluid	EMPIRE-PIC vs Chicago-PIC
n_e	2.39×10^{-1}	1.49×10^{-1}
E_x	3.90×10^{-2}	5.10×10^{-2}
E_y	4.50×10^{-3}	4.95×10^{-3}

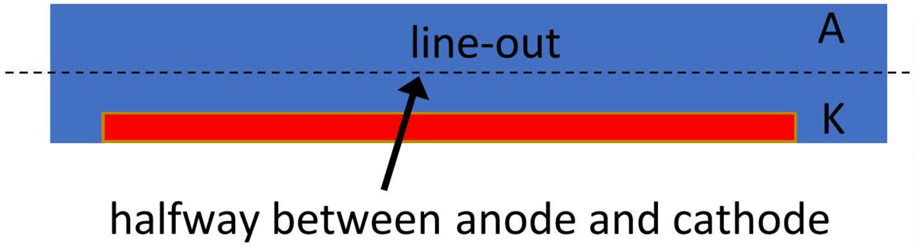


n_e (m^{-3})



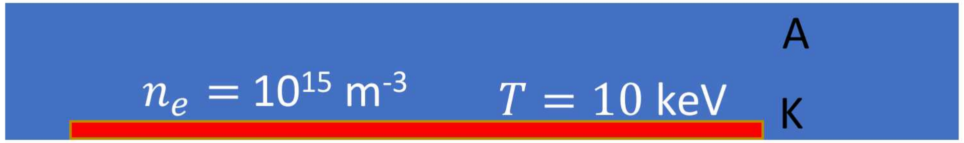
E_y (V/m)



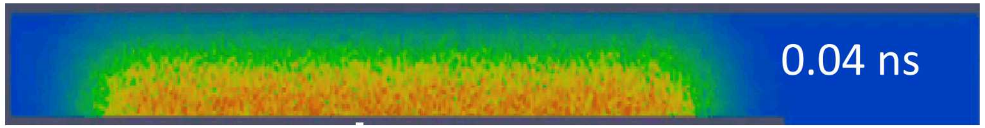


Hot plasma (10 keV): fluid code doesn't agree as closely with PIC codes

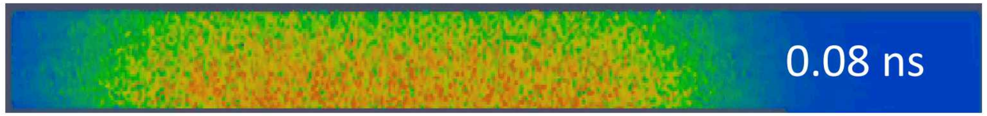
Initial state



thermal expansion



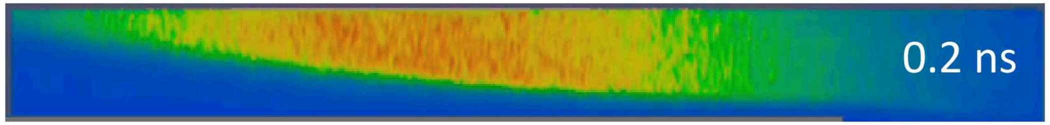
thermal expansion



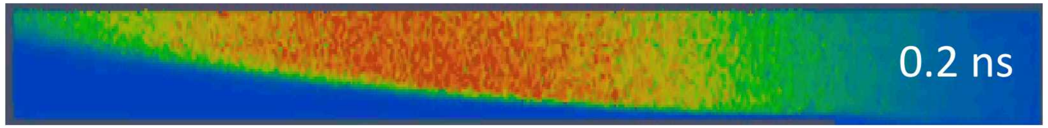
Penetration by EM pulse

Electron density n_e (m^{-3})

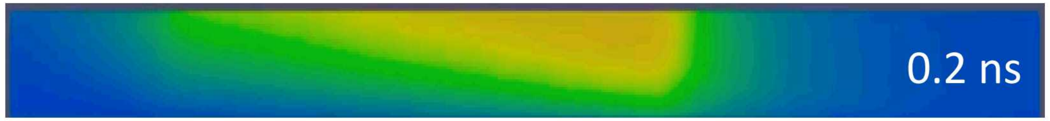
Chicago-PIC:



EMPIRE-PIC:



EMPIRE-fluid :

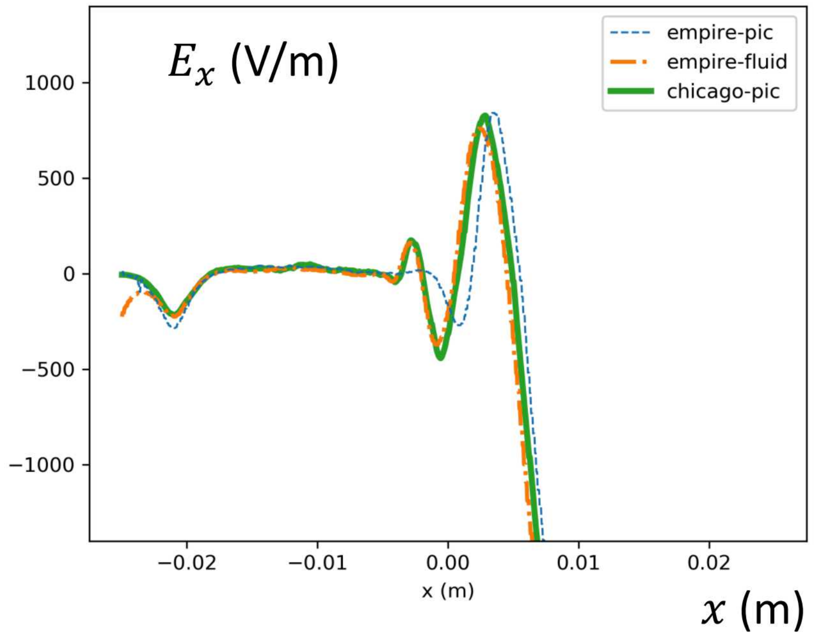


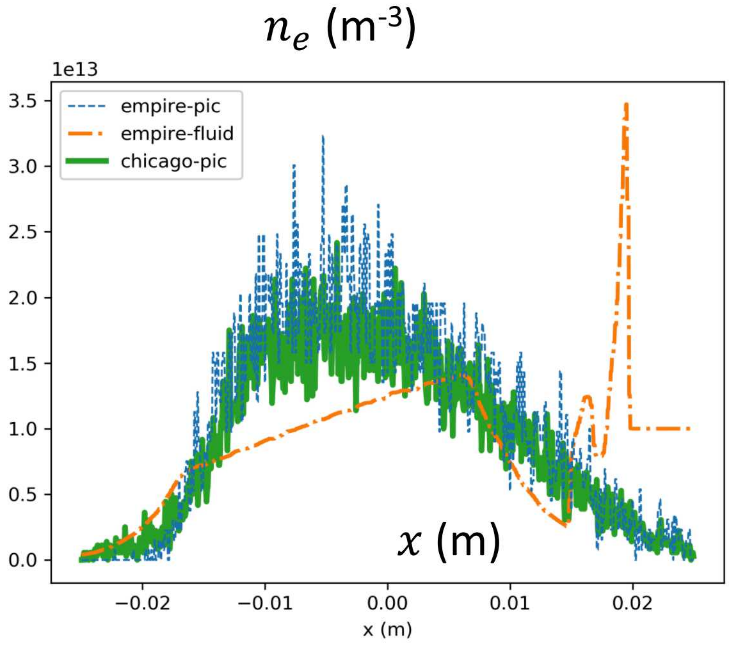
Should EMPIRE-Fluid compare more closely with PIC codes?
A Chicago-Fluid comparison would provide insight.

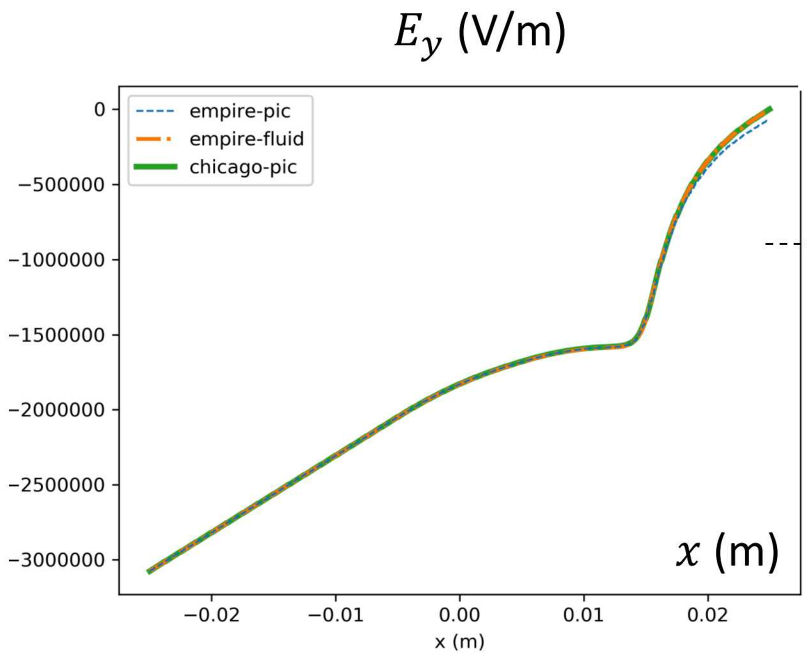
Hot plasma (10 keV): line-outs

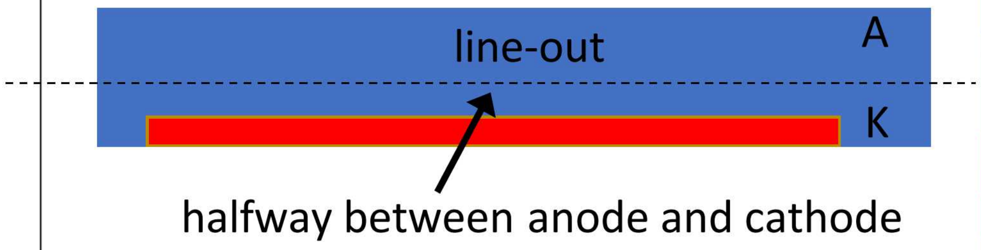
Relative differences (L1 norm) across line-out:

	EMPIRE-PIC vs EMPIRE-Fluid	EMPIRE-PIC vs Chicago-PIC
n_e	1.53x10^{-1}	1.30x10^{-1}
E_x	3.90x10^{-2}	5.05x10^{-2}
E_y	4.54x10^{-3}	5.28x10^{-3}



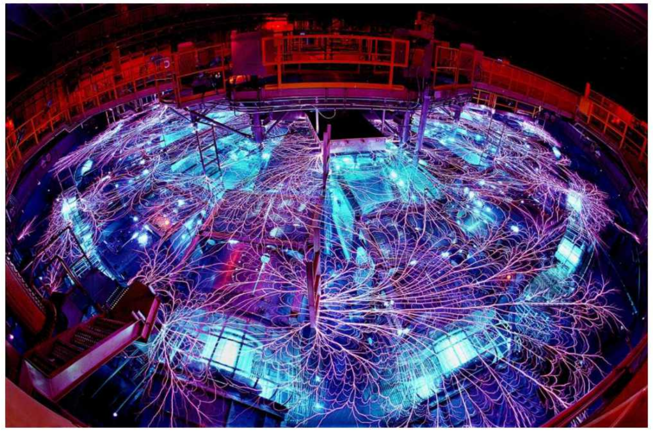






Should EMPIRE-Fluid compare more closely with PIC codes?
A Chicago-Fluid comparison would provide insight.

Conclusions



- 1-D O-wave: Chicago and EMPIRE agree to within 1% at early times, before reflections from boundary.
- 2-D planar MITL:
  - Agreement in n_e to within ~ 20%.
  - Agreement in E_x to within ~ 5%.
  - Agreement in E_y and B_z to within ~ 0.5%.
- Future directions:
  - Comparison between EMPIRE-Fluid and Chicago-Fluid.
  - Comparison with collisional PIC.
  - Hybridization of EMPIRE-Fluid, PIC in delta-f scheme.
  - Extension to 3-D geometries, e.g. relevant to Z-accelerator