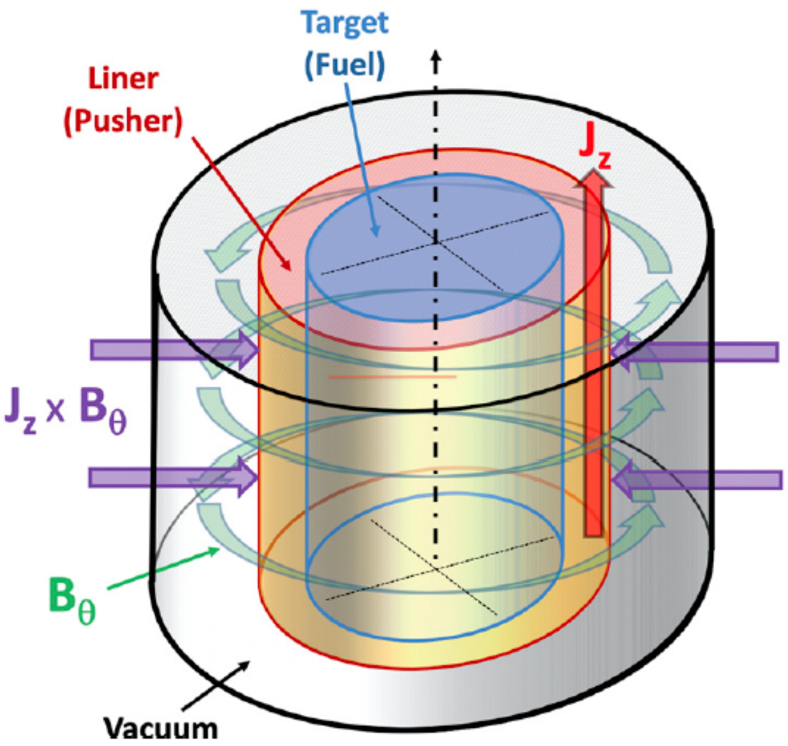
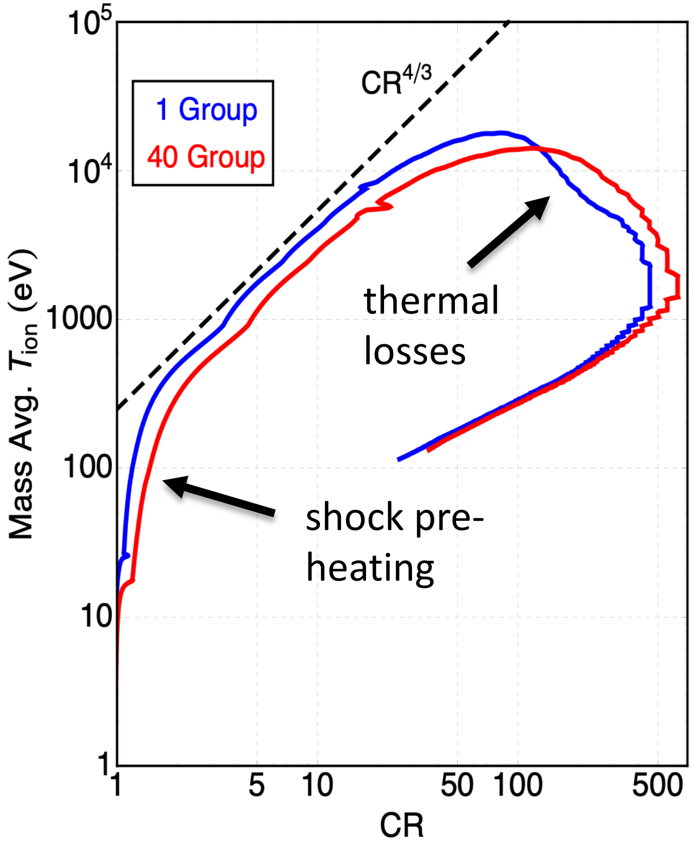
One-Dimensional *FLASH* Simulations of a Gas-Puff Staged Z-Pinch



Ruskov+ (Phys. Plasmas 2020)



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64^{th} Annual APS DPP
Spokane, Washington
17-21 October 2022

Acknowledgements

This material is based upon work supported by the Department of Energy (DOE) National Nuclear Security Administration (NNSA) under Award Numbers DE-NA0003856 and DE-NA0003842, the U.S. DOE Advanced Research Projects Agency-Energy (ARPA-E) under Award Number DE-AR0001272 and the U.S. DOE NNSA under subcontracts no. 536203 and 630138 with Los Alamos National Laboratory, subcontract B632670 with Lawrence Livermore National Laboratory.

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Summary

- *FLASH* has undergone a lot of new code development to be able to simulate Z-pinches and other problems with non-ideal MHD physics – a new release of the code is coming in the near future.

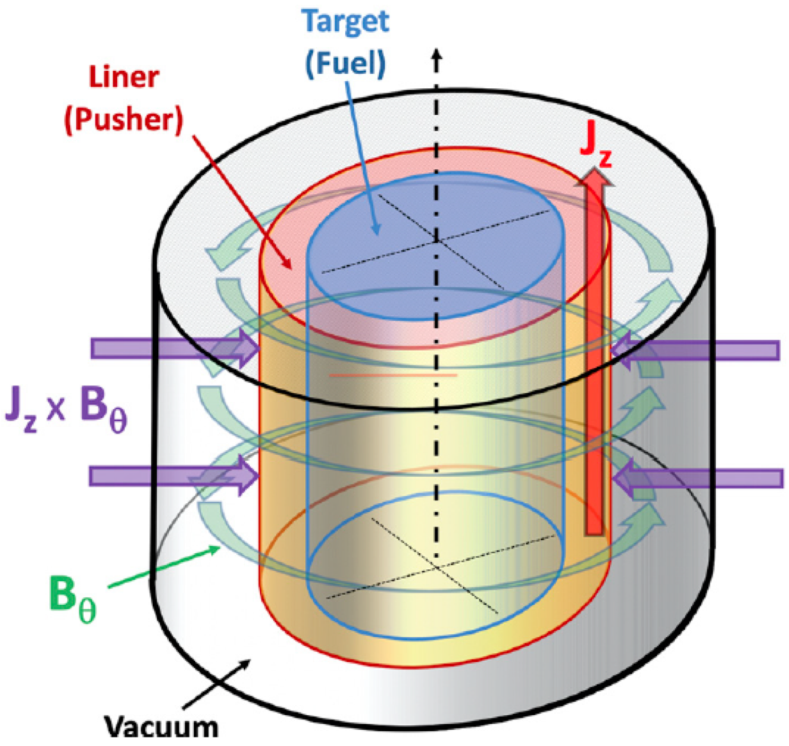
- Ideal EOS SZP model comparisons between *FLASH* and *MACH2* match well, but diverge when we use EOS, ionization, and opacity tables: *MACH2* uses SESAME while *FLASH* uses PROPACEOS.
  - CR > 100 and Tion > 10 keV are achieved in *FLASH*

- *FLASH* has newer anisotropic transport coefficients which have a relatively small effect on the 1D results.

- Discrepancies between single-group (Gray radiation) and multi-group are large → Gray radiation underestimates radiation losses.

A very brief introduction to the Staged Z-Pinch (SZP)

- There are several configurations in the literature. In this talk, we present results for a configuration similar to what has been referred to as SZP1 (a Xe gas-puff liner).
  - For details on SZP2 (solid Ag liner), see Fernando Garcia-Rubio's talk: Wed. NO04.00013



Ruskov+ (Phys. Plasmas 2020)

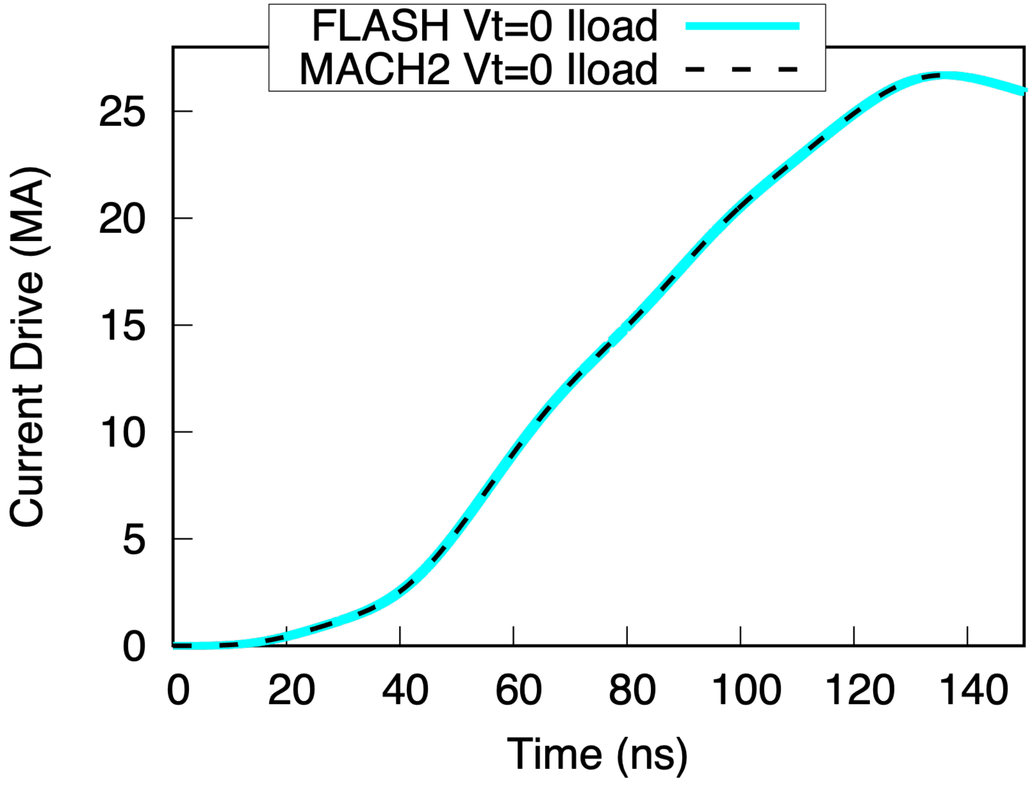
- A key feature of every SZP configuration is the use of a high atomic number liner.

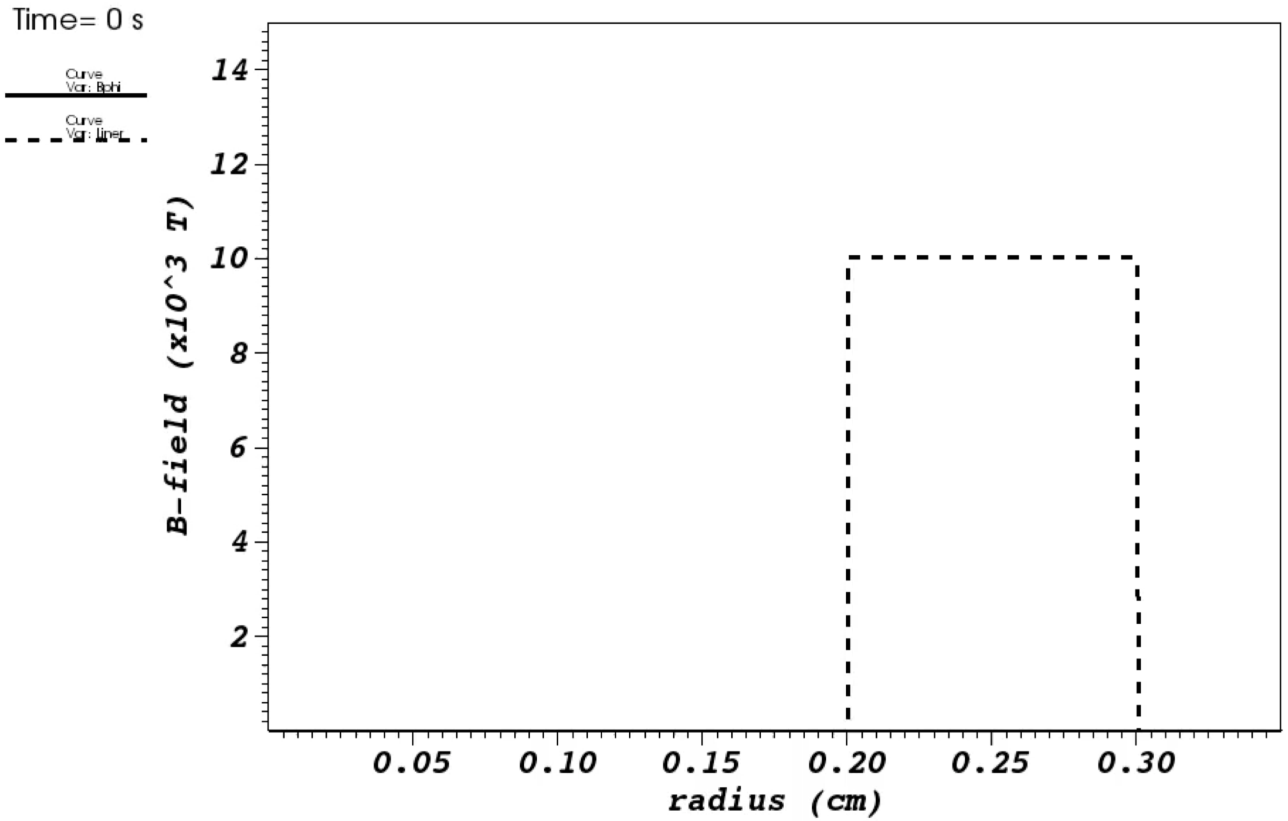
- Hypothesis is that this setup provides shock pre-heating to the target, and improved magnetized thermal insulation and stability to the target/liner interface.

- We are also actively investigating other SZP configurationx that use solid liners.

New code development in FLASH enables Z-pinch modeling

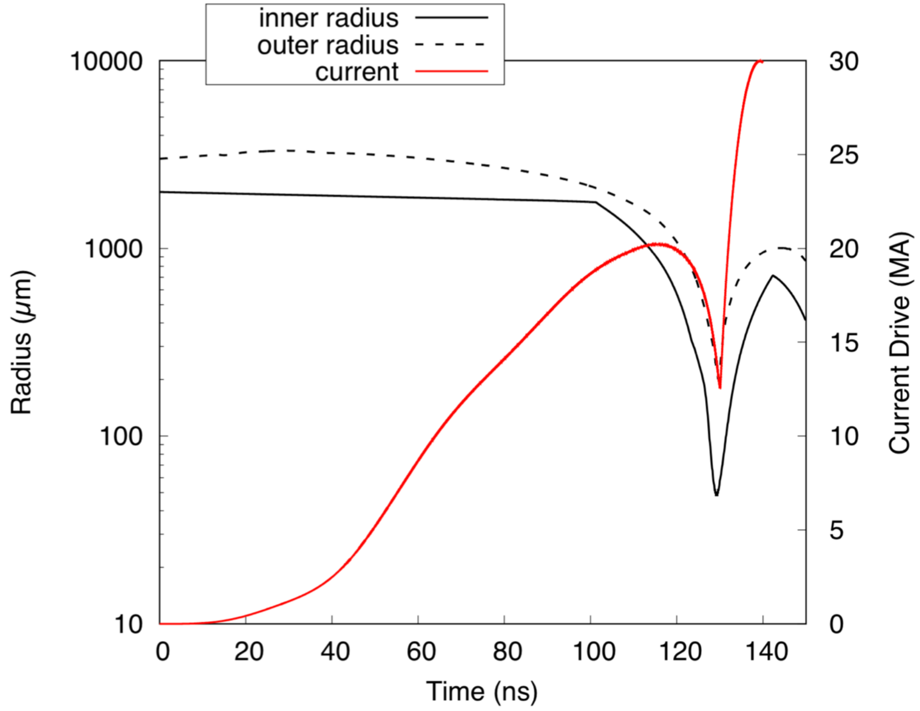
- New code development includes an implicit solver for anisotropic magnetic resistive diffusion, updated transport coefficients (Davies, et al. 2020), and a circuit model for the Z Machine (McBride, et al. 2010).
- Thermoelectric effects (e.g., Nernst) have also been implemented but have not been included in SZP studies yet.
- On the left is the load current profile from the circuit model; *FLASH* and *MACH2* match perfectly, and on the right is a quick example of a pinching B-field from a *FLASH* simulation with the circuit model.

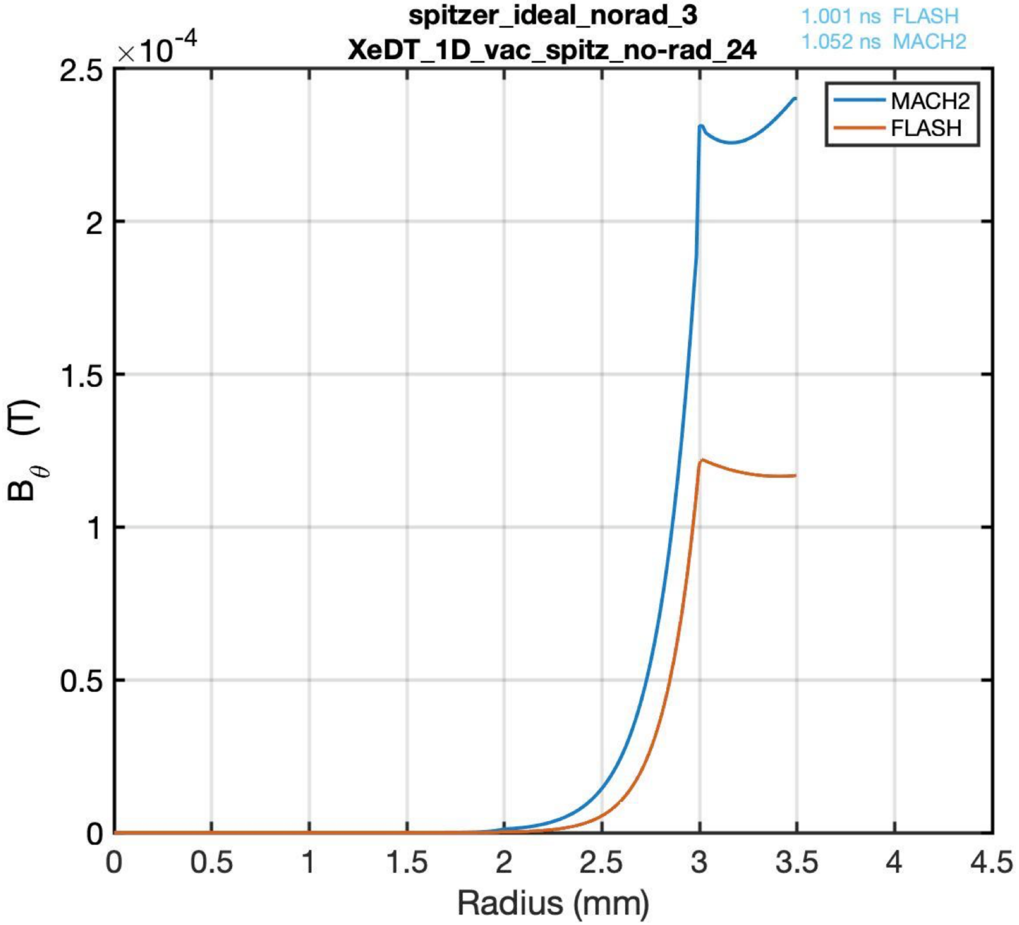




Simplified models used ideal EOS and dynamics between FLASH and MACH2 matched fairly well

- Also used current input from a file (not a circuit model)





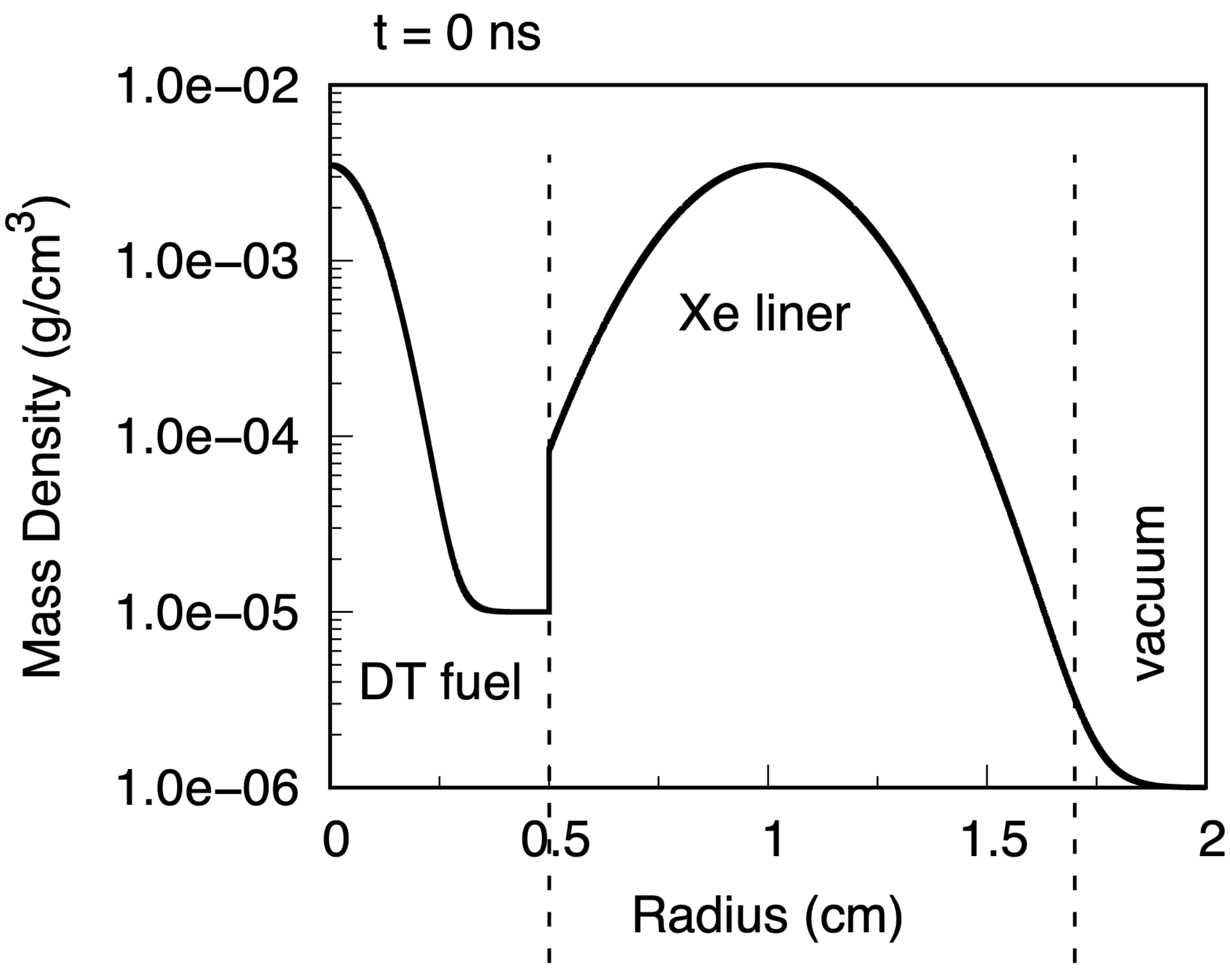
- We now typically use slightly different initial conditions and temperature floors and ceilings to keep time steps reasonable and conditions within ranges of EOS tables

Initial conditions are different than previously published SZP1 models (we refer to this new setup as SZP1)*

- DT fuel: 3.5 mg/cm^3 Gaussian peak, 0.5 eV
  - PROPACEOS
  - No temperature floor or ceiling
  - Spitzer resistivity and thermal conductivity

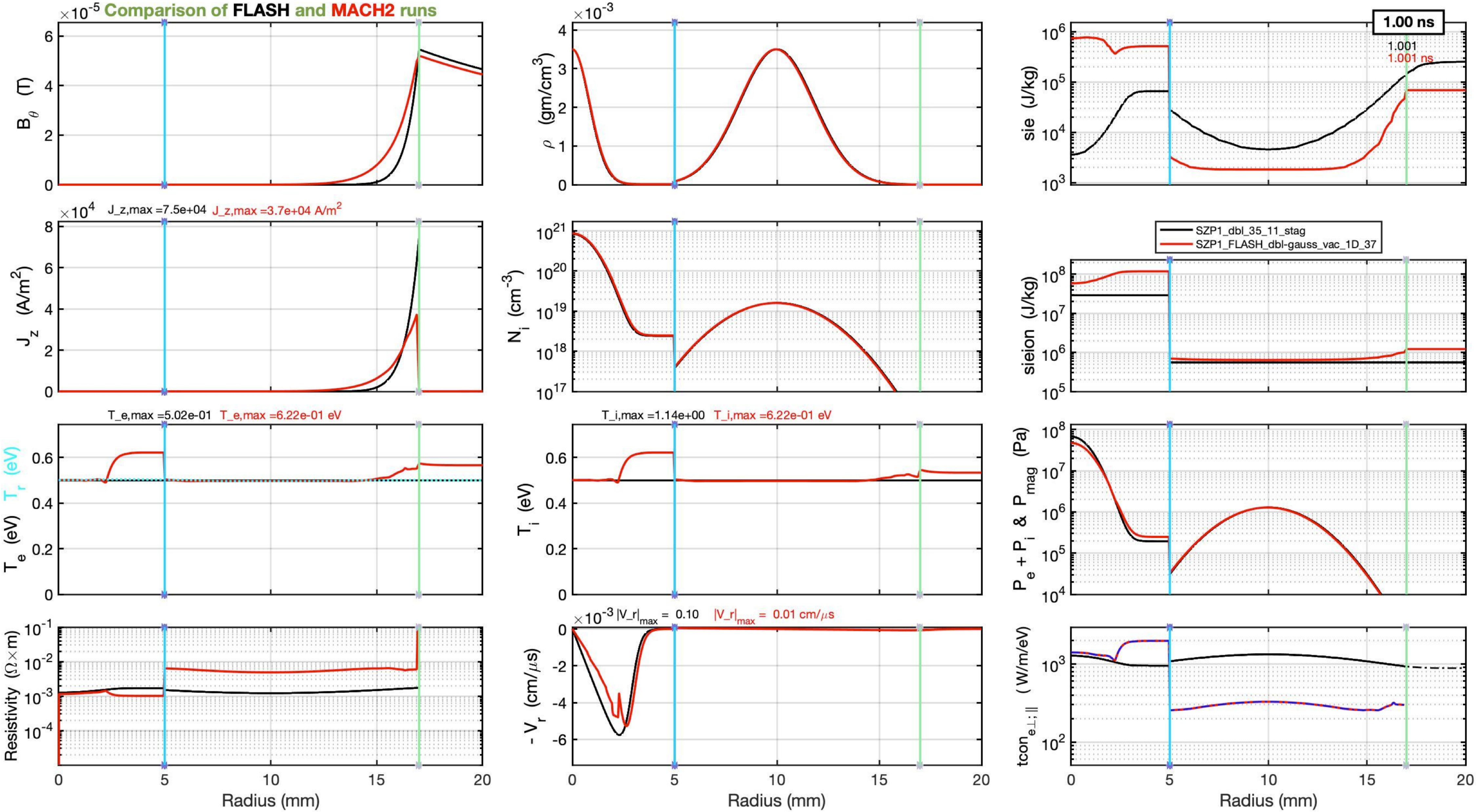
- Xe liner: 3.5 mg/cm^3 Gaussian peak, 0.5 eV
  - PROPACEOS
  - No temperature floor or ceiling
  - Spitzer resistivity and thermal conductivity

- Xe "vacuum": <= 3.25x 10^{-6} g/cm^3, 0.5 eV
  - PROPACEOS
  - Temperature forced to remain constant at 0.5 eV
  - Constant resistivity 1.e11 cm^2/s



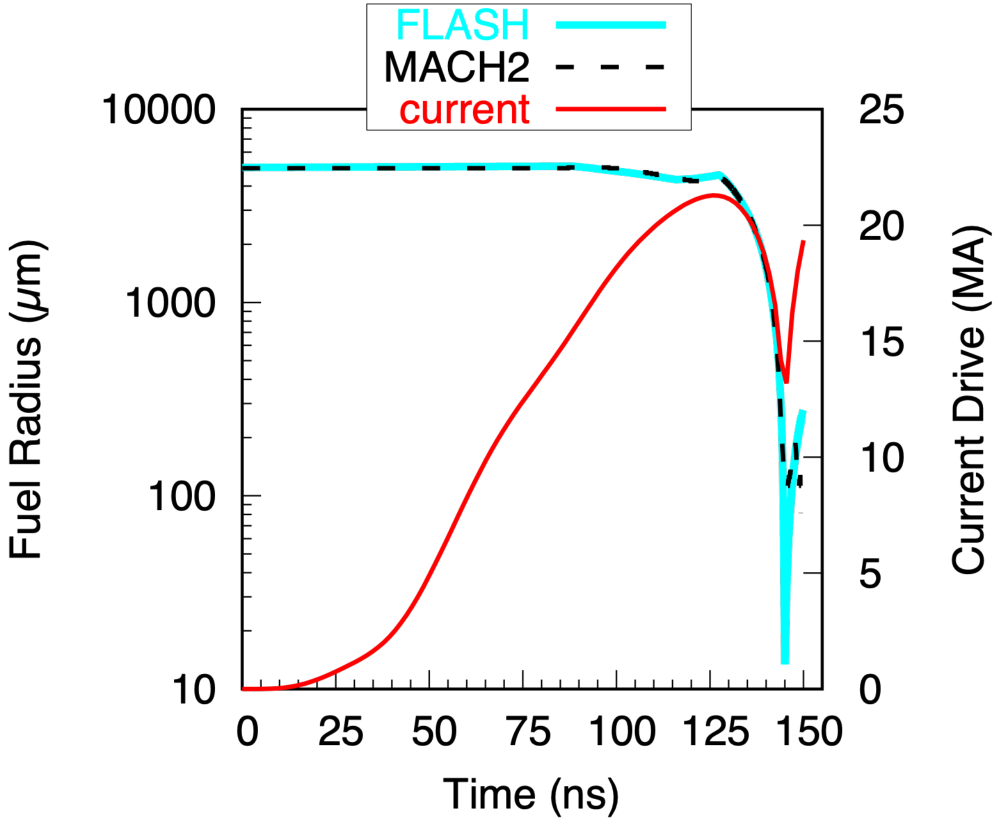
MACH2 **uses SESAME, which leads to discrepant code-to-code comparison.**

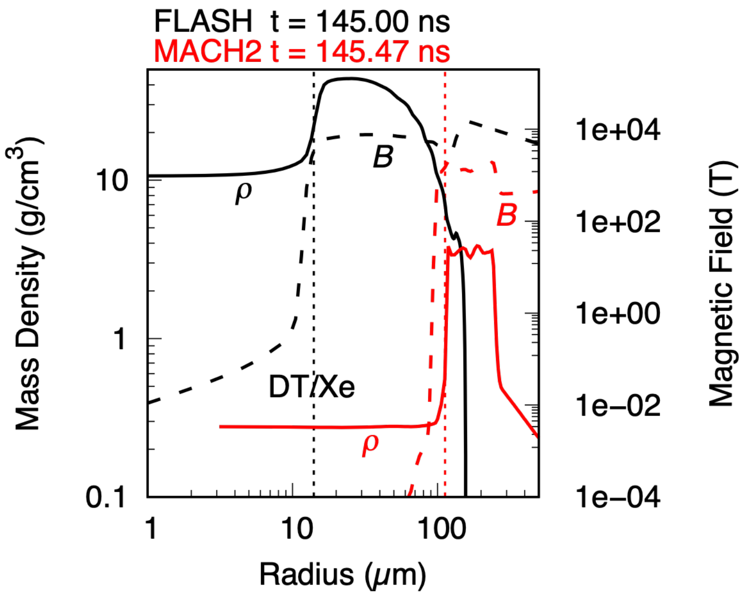
12-panel movie shows code-to-code comparison

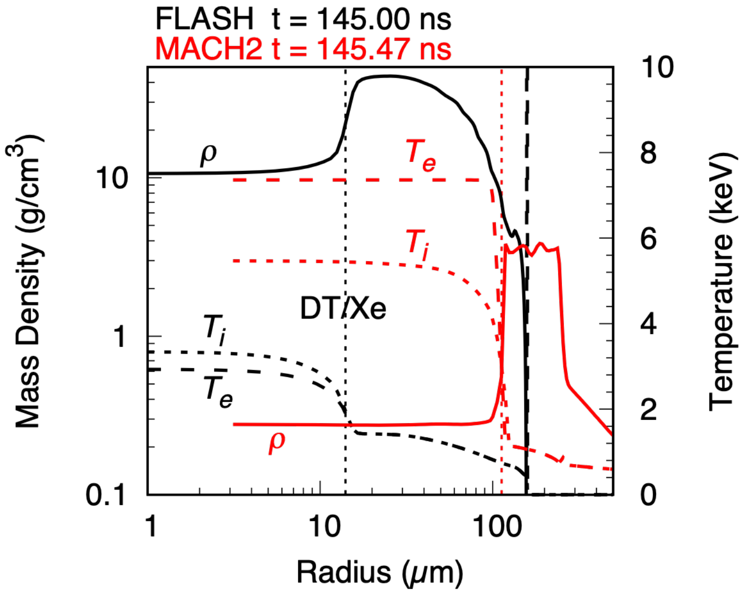


Single-group SZP1 simulations show similar dynamics between FLASH and MACH2, different stagnation*

- t_{stag} = 145 ns vs. 145.47 ns
- CR = 357 vs. 44.4
- peak $T_{i,stag}$ = 3.34 keV vs. 5.47 keV







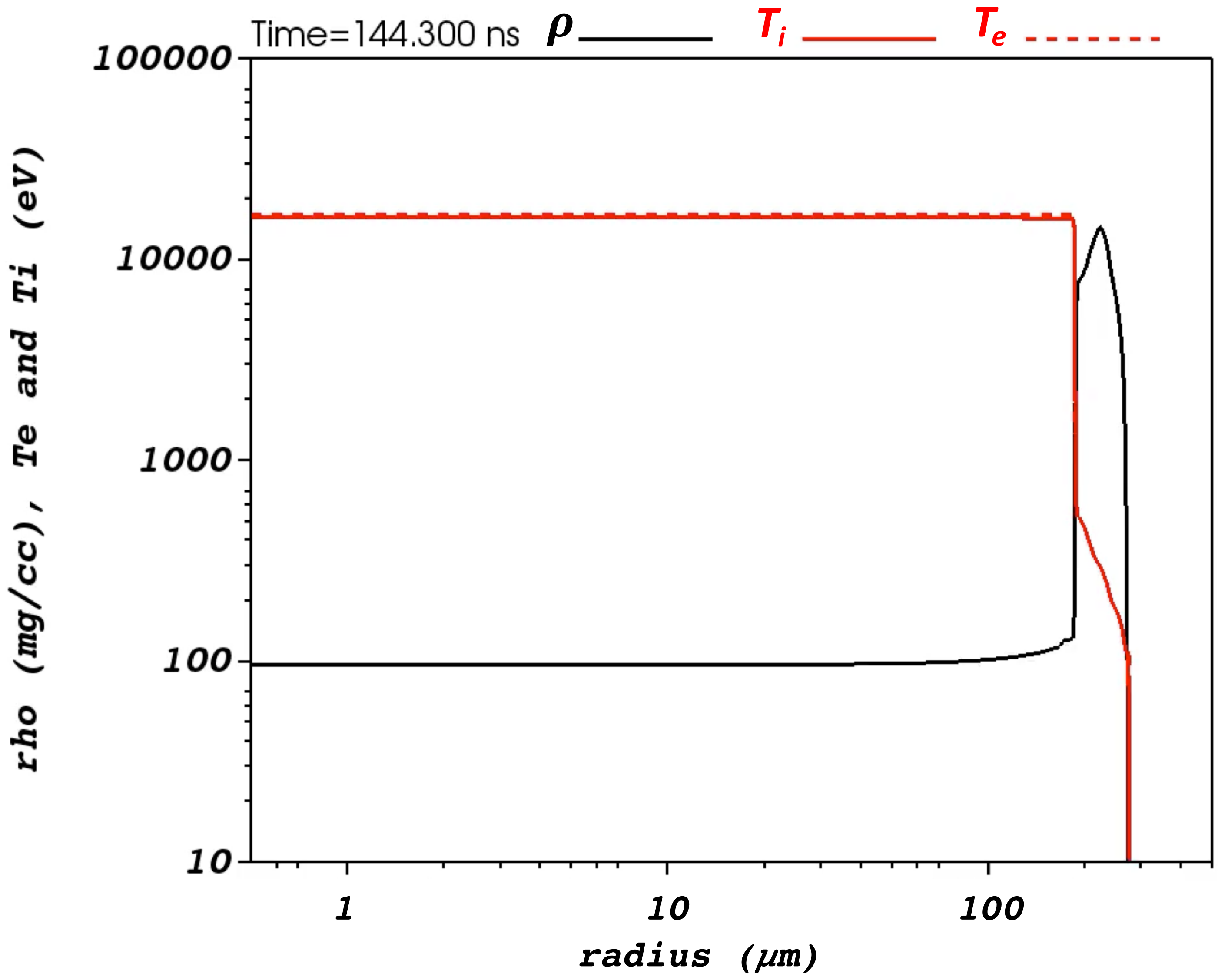
- Discrepancy comes from the fact that the two codes currently have to use different tables for EOS, ionization, and opacities.

To understand the physics just before stagnation, one must look at high-frequency output

- Peak T_i > 40 keV occurs ~ 275 ps before stagnation

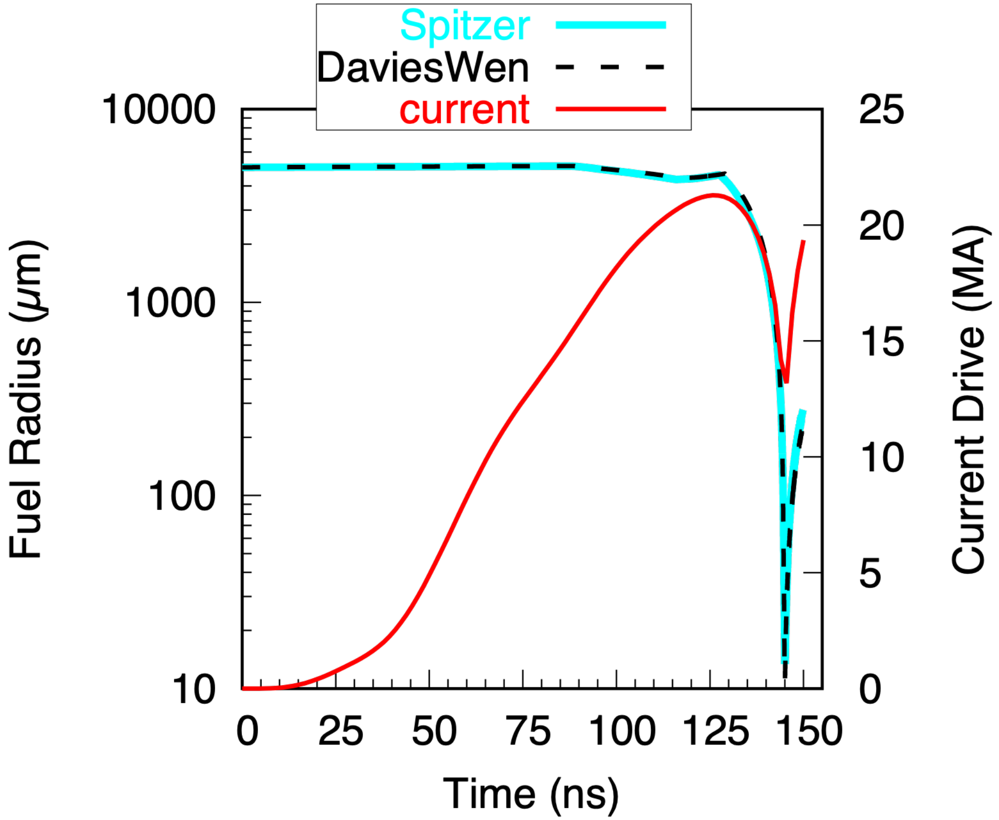
- After peak T_i thermal losses become greater than compressional heating

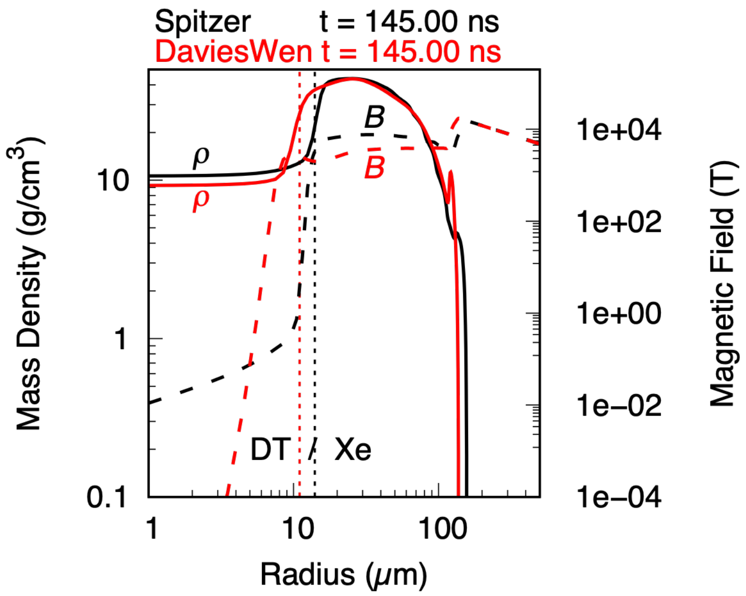
- Density increases to > 10 g/cm^3 until fuel finally stagnates

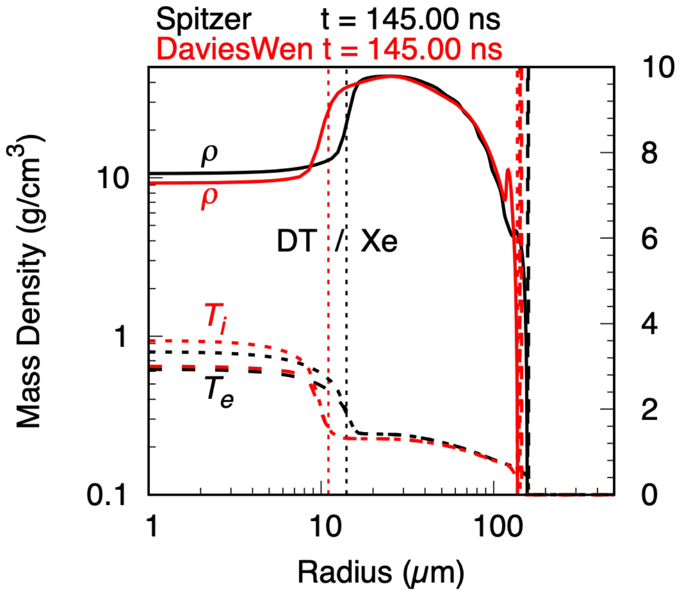


Using newer transport coefficients has a relatively minor effect on the FLASH results

- t_{stag} = 145 ns vs. 145 ns
- CR = 357 vs. 454
- peak $T_{i,stag}$ = 3.34 keV vs. 3.61 keV



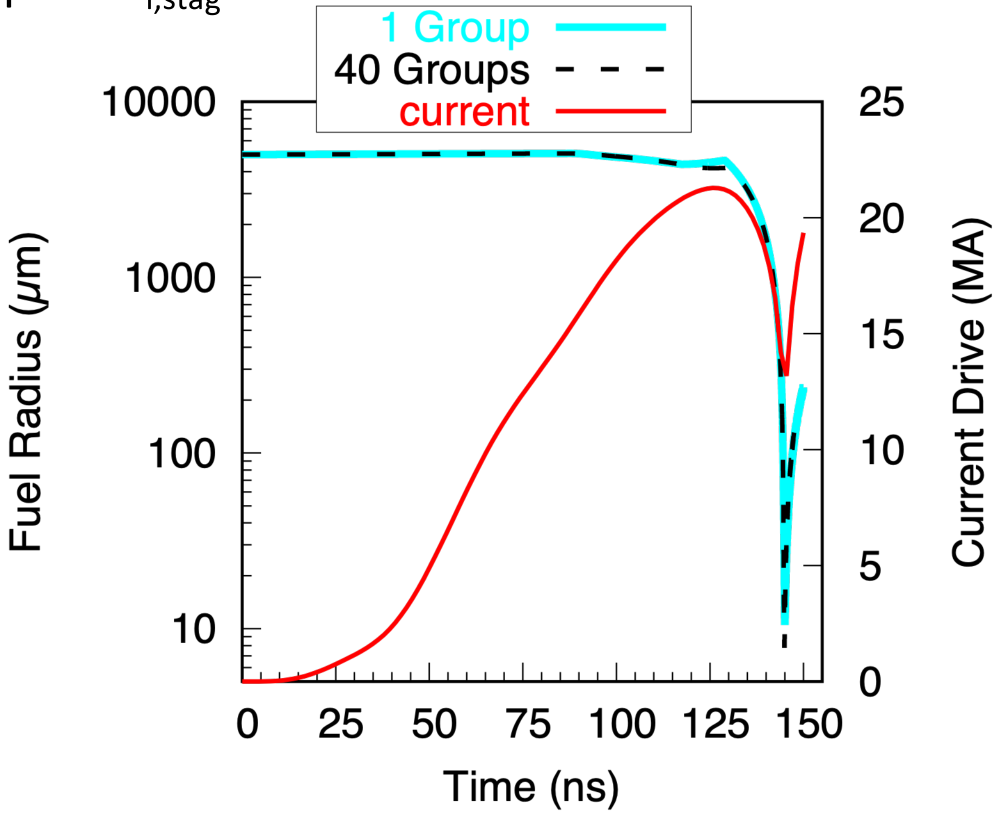


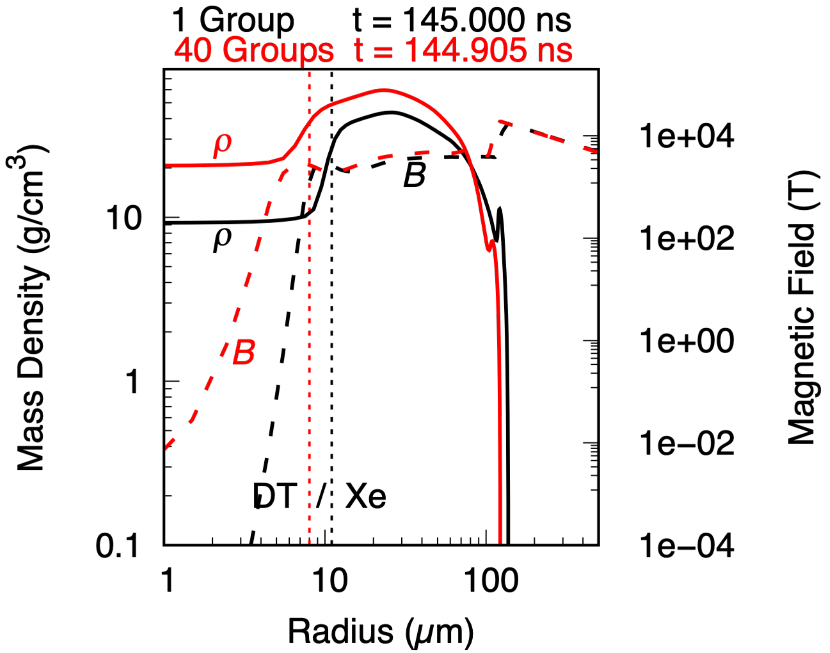


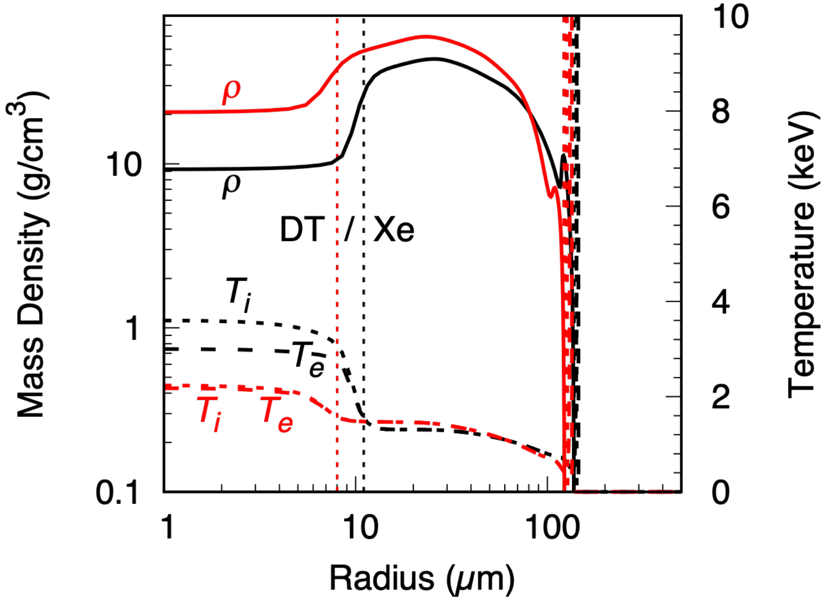
- Thermal conductivity: Spitzer → Ji and Held (2013)
- Magnetic resistivity: Spitzer → Davies, et al. (2020)

40-group SZP1 results are slightly different from the single-group (Gray radiation) case*

- t_{stag} = 145 ns vs. 144.905 ns
- CR = 454 vs. 625
- peak $T_{i,stag}$ = 3.61 keV vs. 2.24 keV



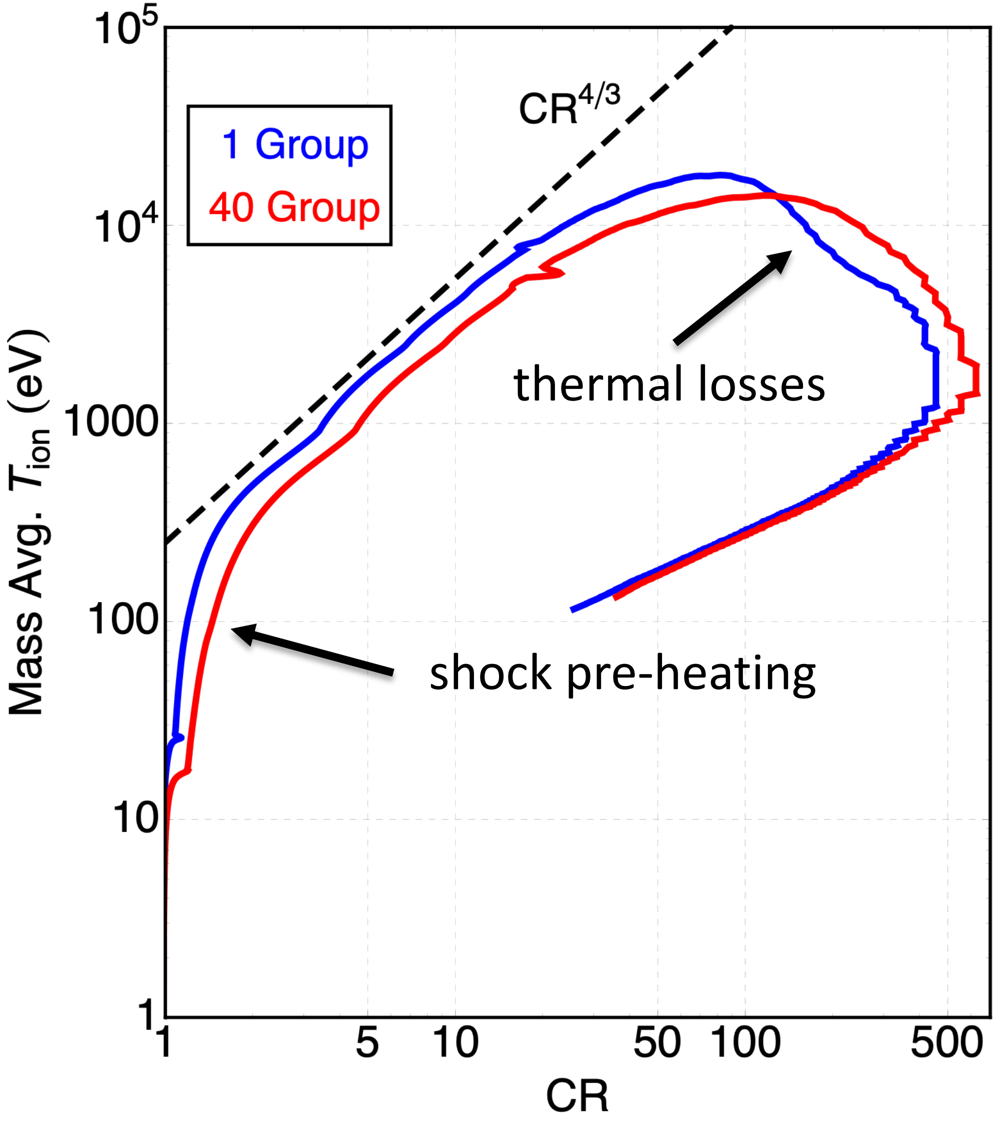




Results suggest that single-group radiation underestimates radiation losses.

Shock pre-heating is key to reaching high temperatures

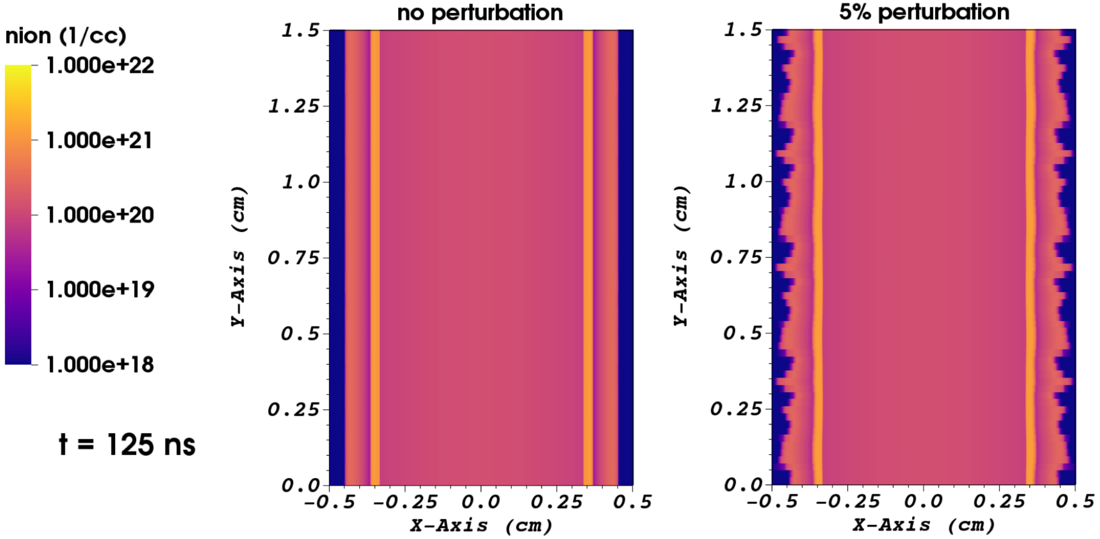
- A strong shock is responsible for the jump in temperature at the onset of fuel compression
- Fuel then undergoes adiabatic compression ($T_i \sim CR^{4/3}$)
- Thermal losses begin to limit the temperature increase from thermal compression near CR ~ 20
- After peak temperature, compression continues and thermal losses dominate until and after stagnation



These high CR's > 100 are likely to be unstable experimentally → need 2D sims.

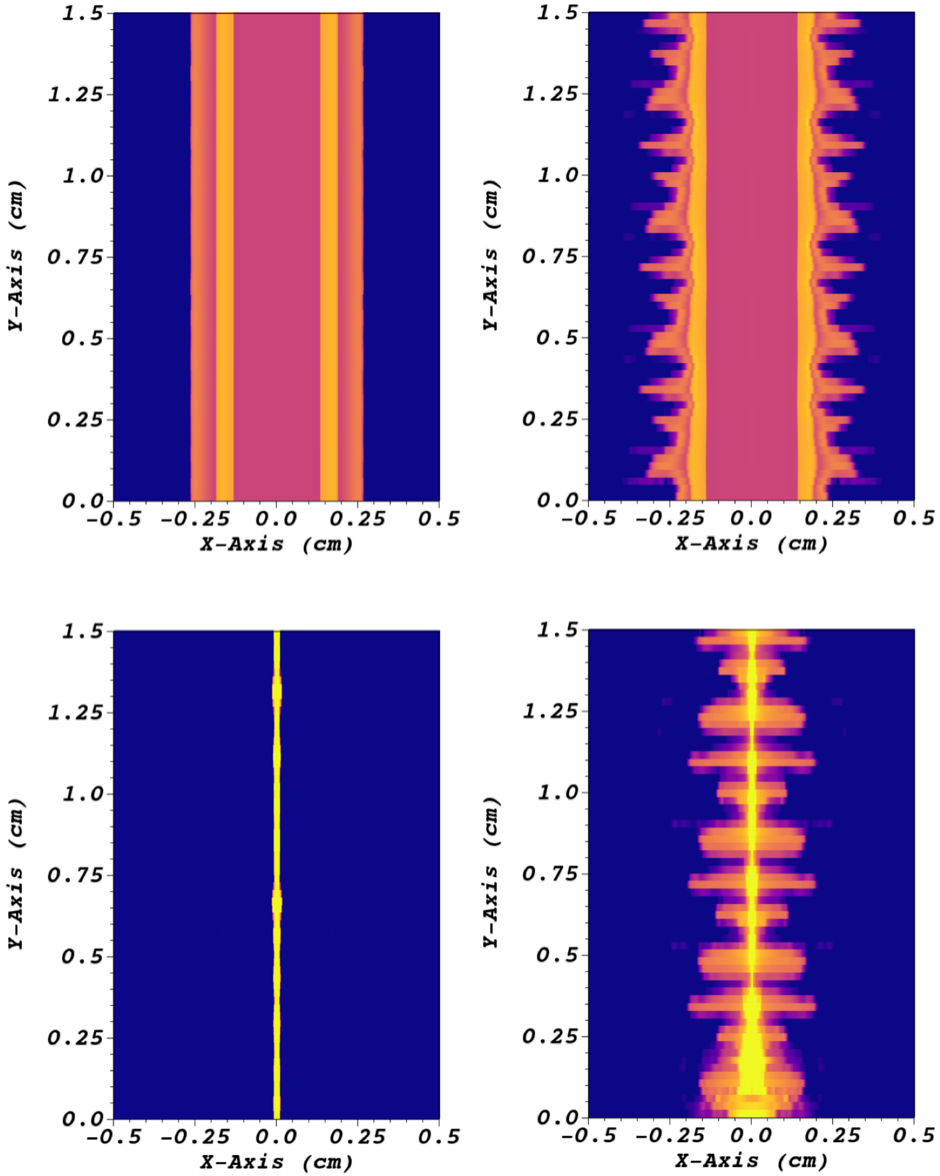
Future Work: 2D simulations (and eventually 3D) will be used to study effects from instabilities

- A hypothesis put forth by MIFTI is that while the outer liner/vacuum interface shows MRT instabilities, the inner fuel/liner interface remains stable. We can now test this with *FLASH* for various SZP configurations.



t = 131 ns

t = 137 ns



- The preliminary, low-resolution run shown here has a 5% random density perturbation in the liner

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