Progress report on Staged Z-pinch modeling/comparison with the HYDRA and MACH2 codes

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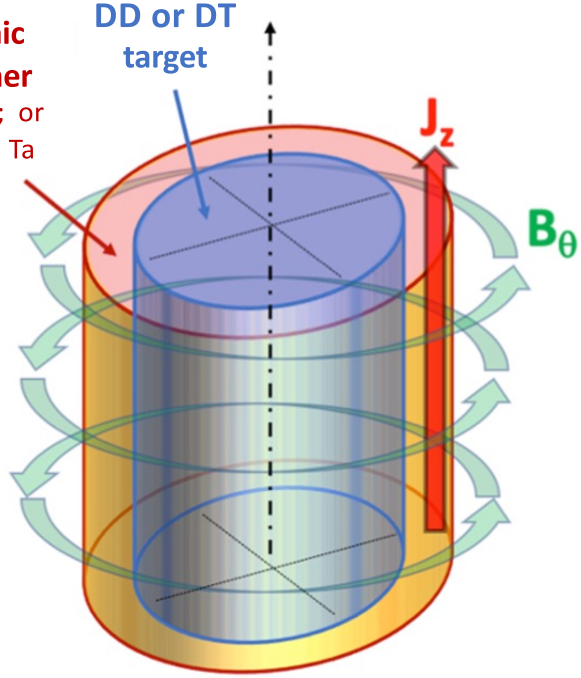
INFUSE Workshop
Dec.16, 2021

Prepared by LLNL under Contract DE-AC52-07NA27344

The Staged Z-Pinch (SZP) concept



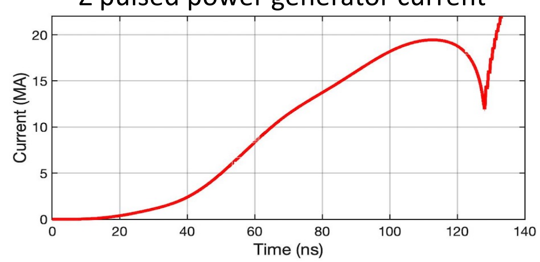
- High atomic number liner compresses fusible target.
- Shock preheating of target plasma to ~ 100 eV.
- Compression of B_θ at the liner/target interface near stagnation time creates very high (10^3 - 10^4 T) magnetic field which "freezes" electrons along the B_θ lines. Mass accumulation at the interface creates large P_{RAM} and very strong adiabatic compression.
- MIFTI models SZPs with the multi-material, single fluid, three-temperature resistive MHD code MACH2.
- Key SZP model feature in MACH2 is setting a limit on the liner plasma temperature either explicitly, or via a cap on the electron internal energy in the liner.

In this study:

R_{liner} = 3 mm
R_{fuel} = 2 mm
H =15 mm

9.8mg/cc 50-50% DT fuel
600mg/cc Ag liner

Z pulsed power generator current



E_{fusion} > 4 MJ

Calculated* without α-heating for Ag-liner on DT target in Sandia's Z-machine

* IEEE Trans. Plasma Sci. **43**, 2463 (2015)
Phys. Plasmas **27**, 042709 (2020)

1-D HYDRA simulations and checks done so far

HYDRA is a multi-physics radiation hydrodynamics code developed at LLNL [M. Marinak et al., Phys. Plasmas 5, **1125** (1998)]

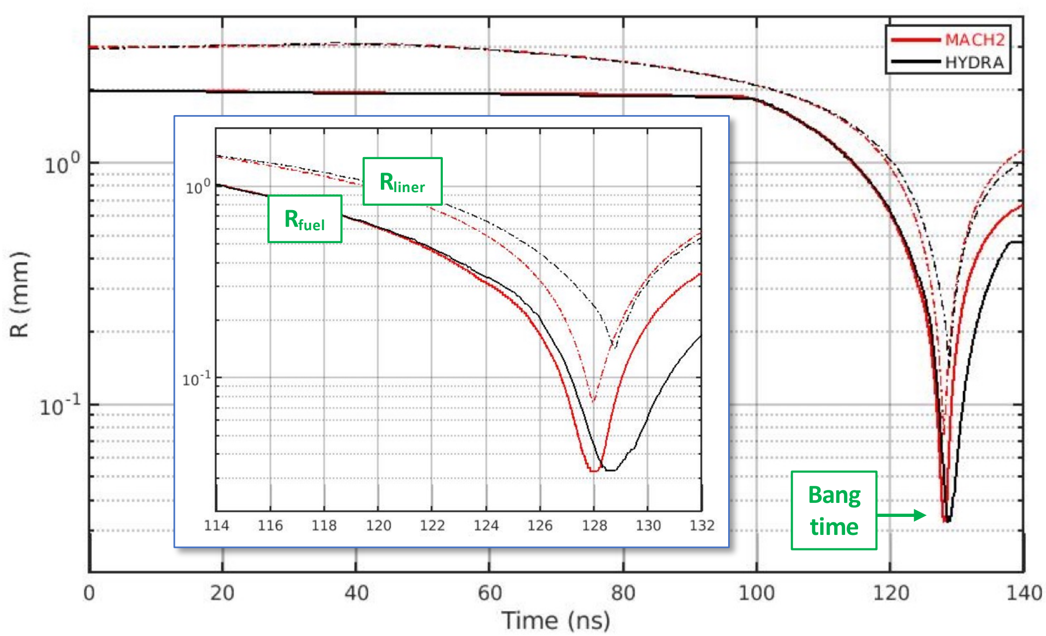
Range (mm)	Eulerian Grid ΔR (μm)
0.0 - 0.2	1.56
0.2 - 1.0	6.25
1.0 - 3.0	15.62
3.0 - 4.0	31.25

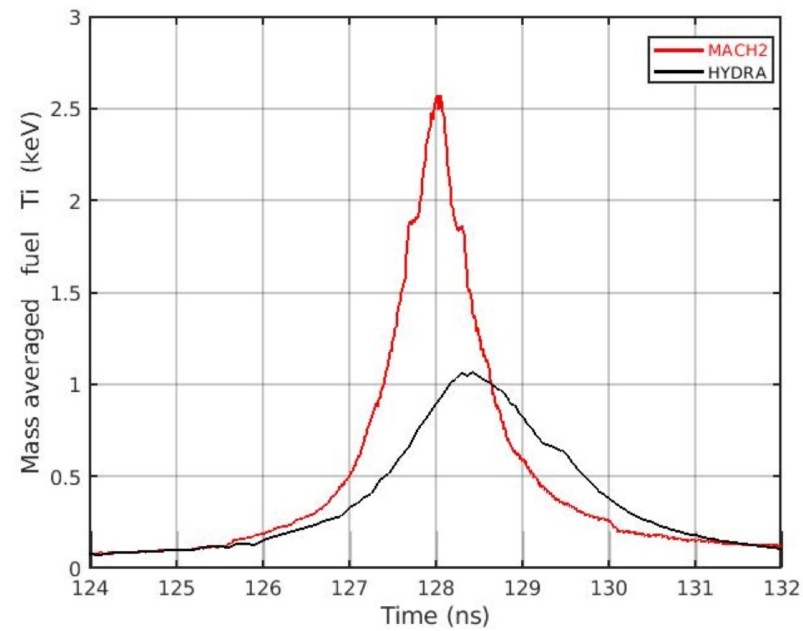
- Different Grids (ALE and Eulerian Approaches)
- Different Treatments of the Vacuum
  - Suppressing artificial shocks in vacuum
  - Capping air mesh temperature
- Different Conductivity Models for both Liner and Fuel
  Compare semi-analytic vs SESAME tables
- Different Number of Spectral groups for Radiation Modeling (1 vs 36 vs 100 vs 240 vs 400)
  Currently Single Group with a max 10 keV
- Different Approaches for Radiation Transport
  Diffusion vs Monte Carlo
- Magnetic Diffusion vs Current Volume Source

➢ Over 150 HYDRA SZP simulations completed by the LLNL team

Next slides will compare a nominal MACH2 simulation with a HYDRA model with the red features

Comparison of three essential parameters: $R_{fuel}(t)$, $R_{liner}(t)$, $\overline{T}_{i,\,fuel}(t)$

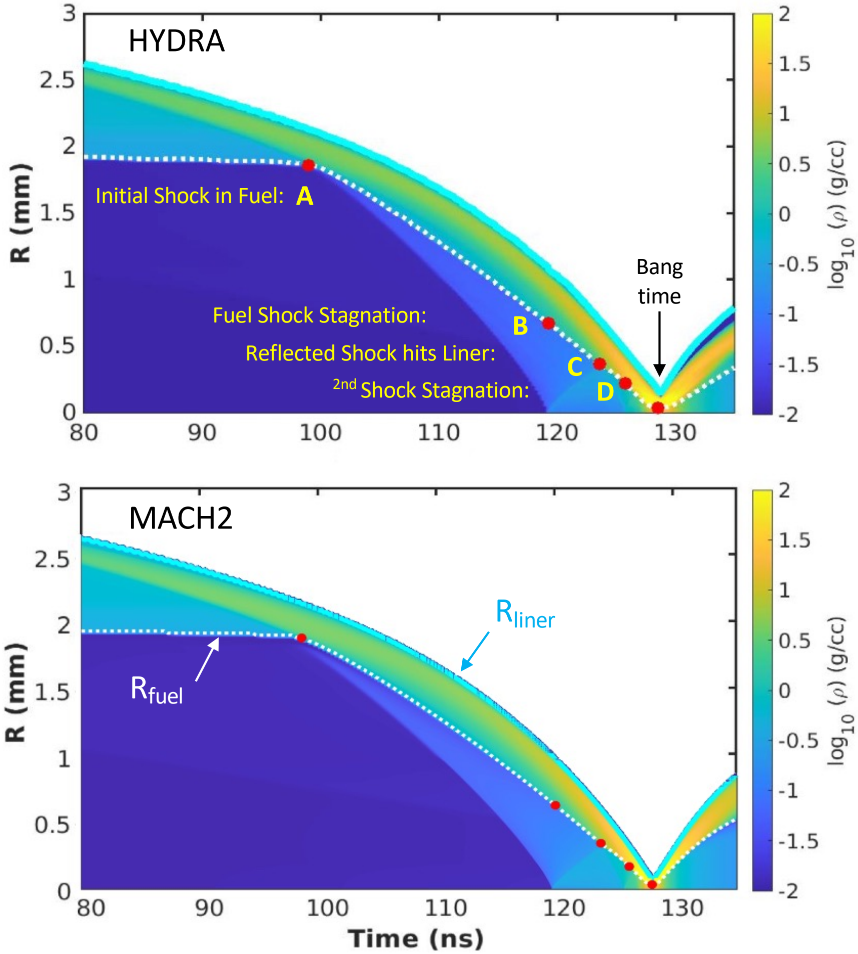


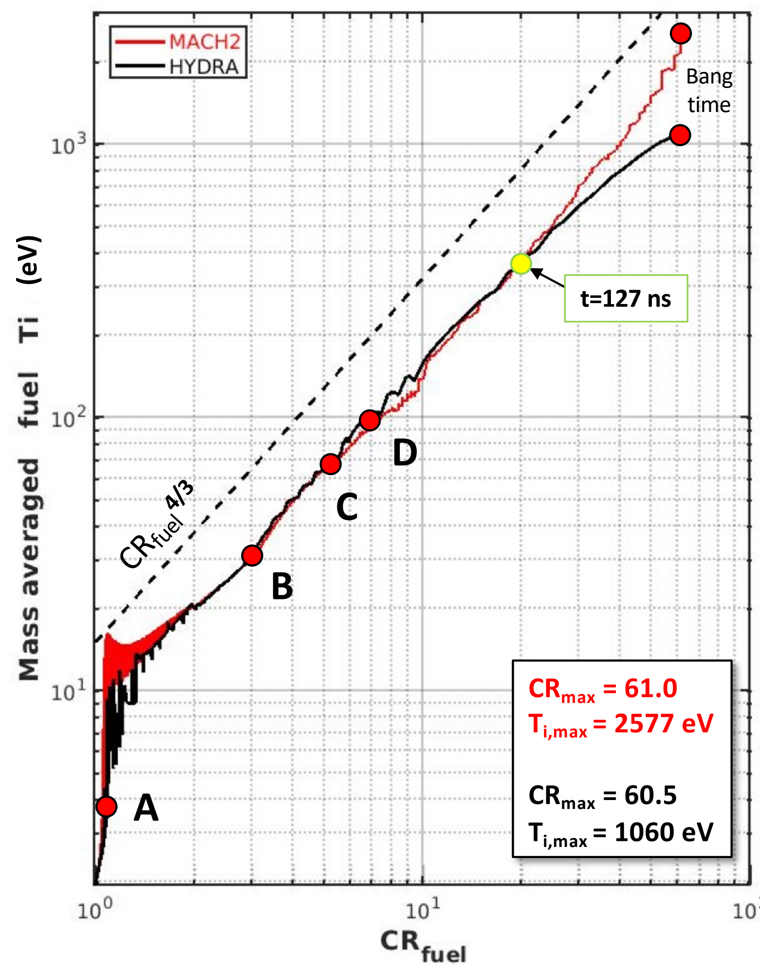


Excellent agreement up to:

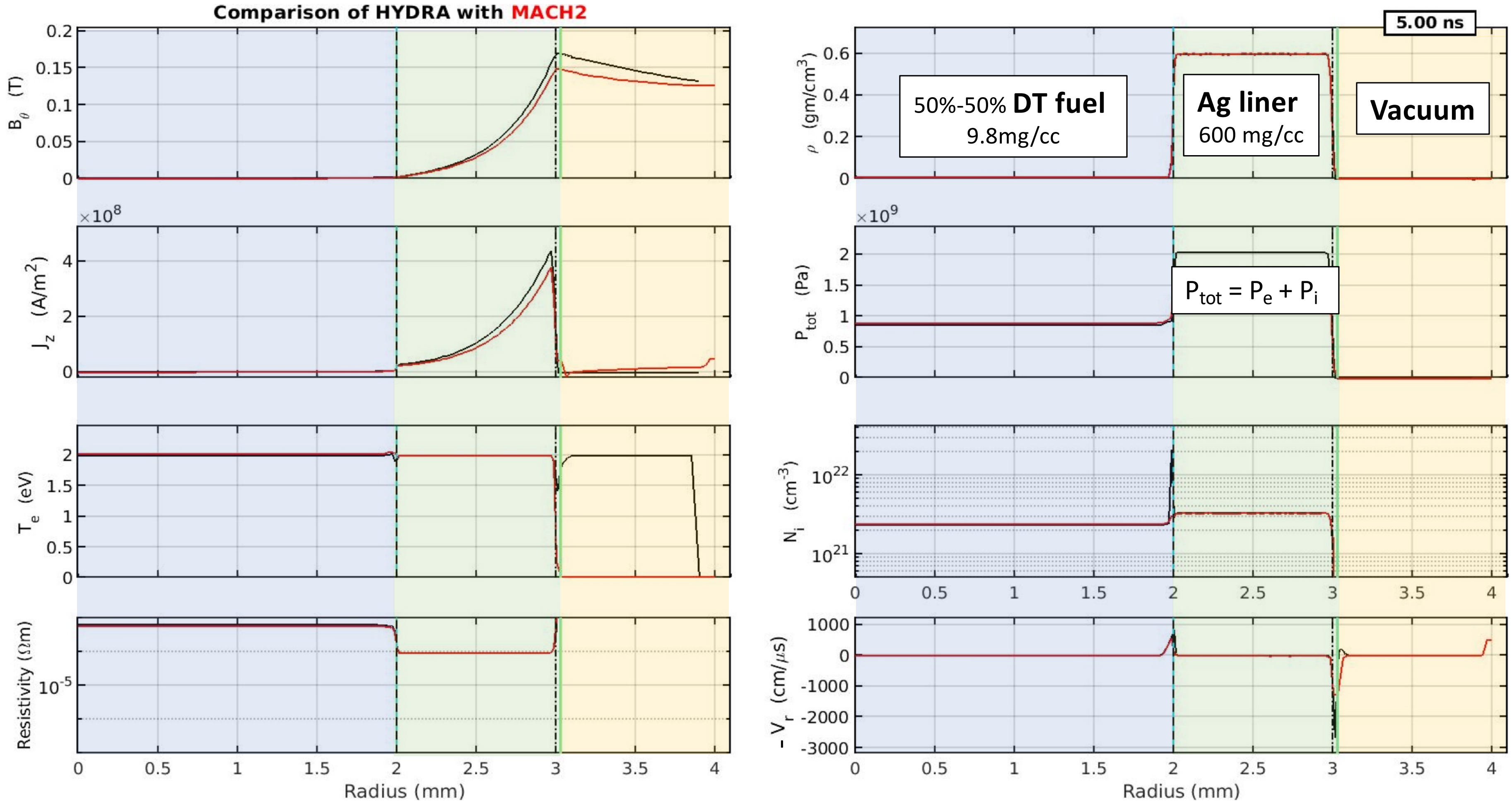
6 ns before bang time **for $R_{fuel}(t)$**
12 ns before bang time **for $R_{liner}(t)$**
2.5 ns before bang time **for the mass averaged fuel Ti;** but this is the key discrepancy.

Comparison of MACH2 and HYDRA compression trajectories

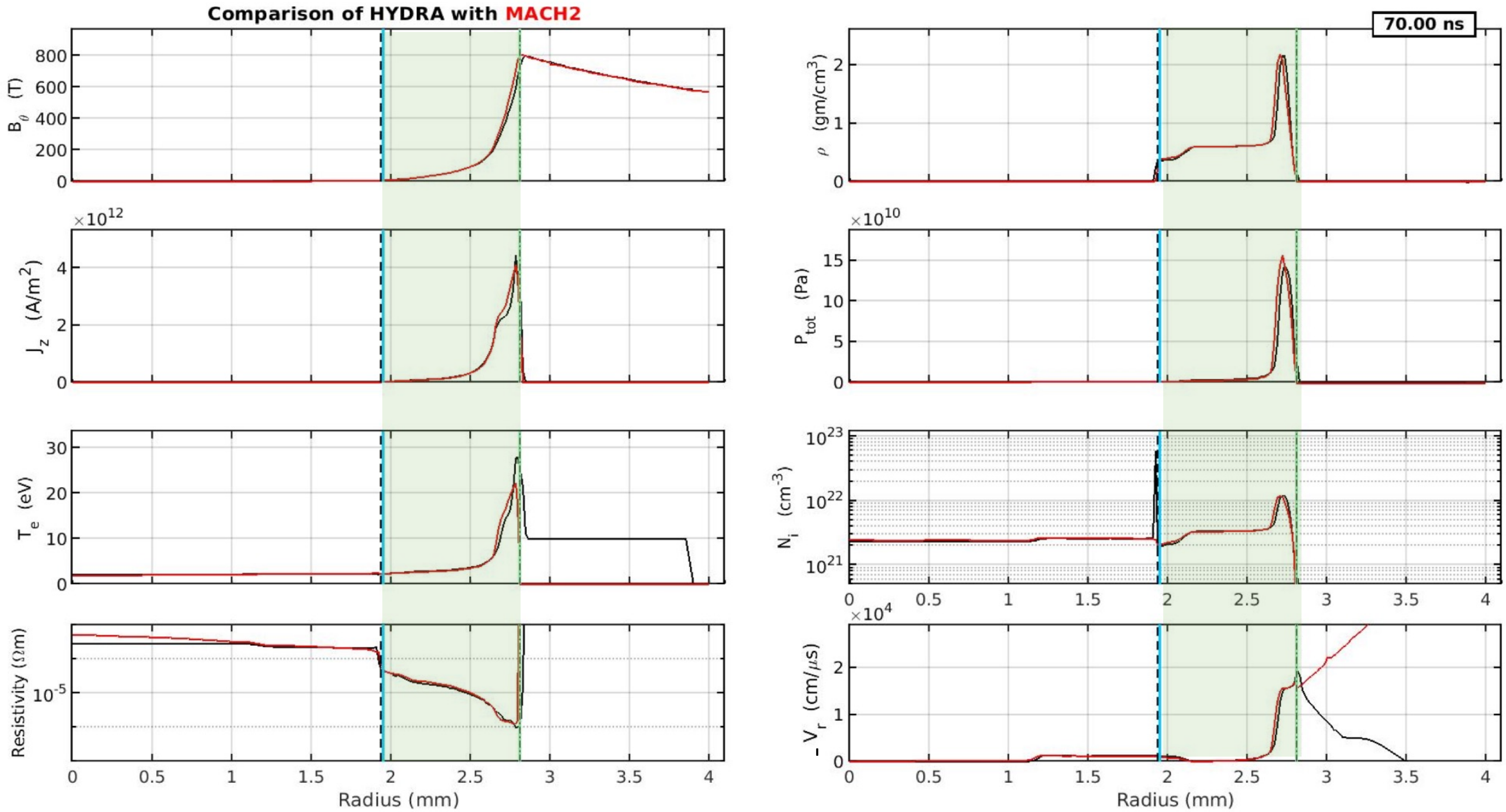




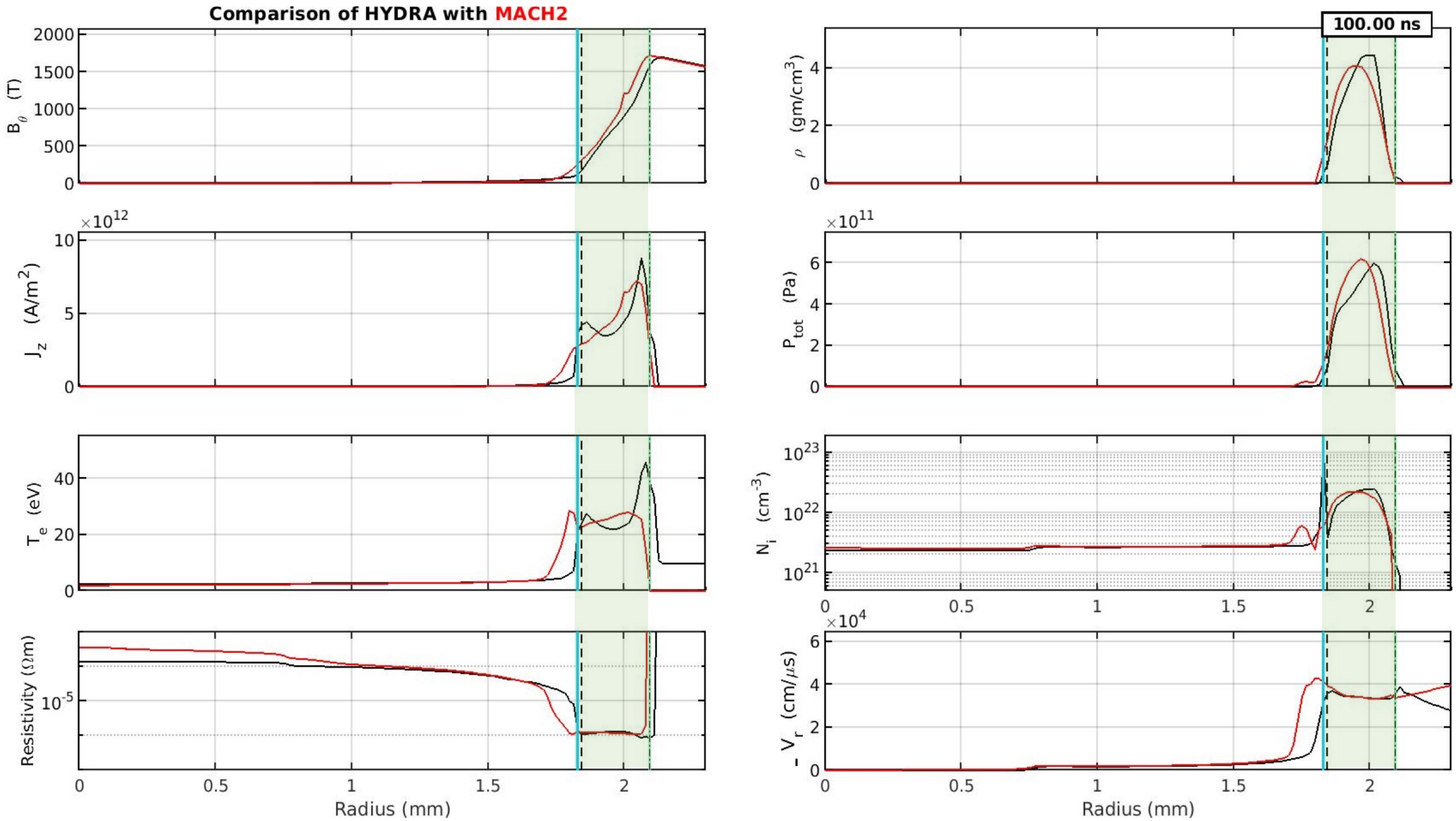
Important tool for analyzing plasma dynamics: movies



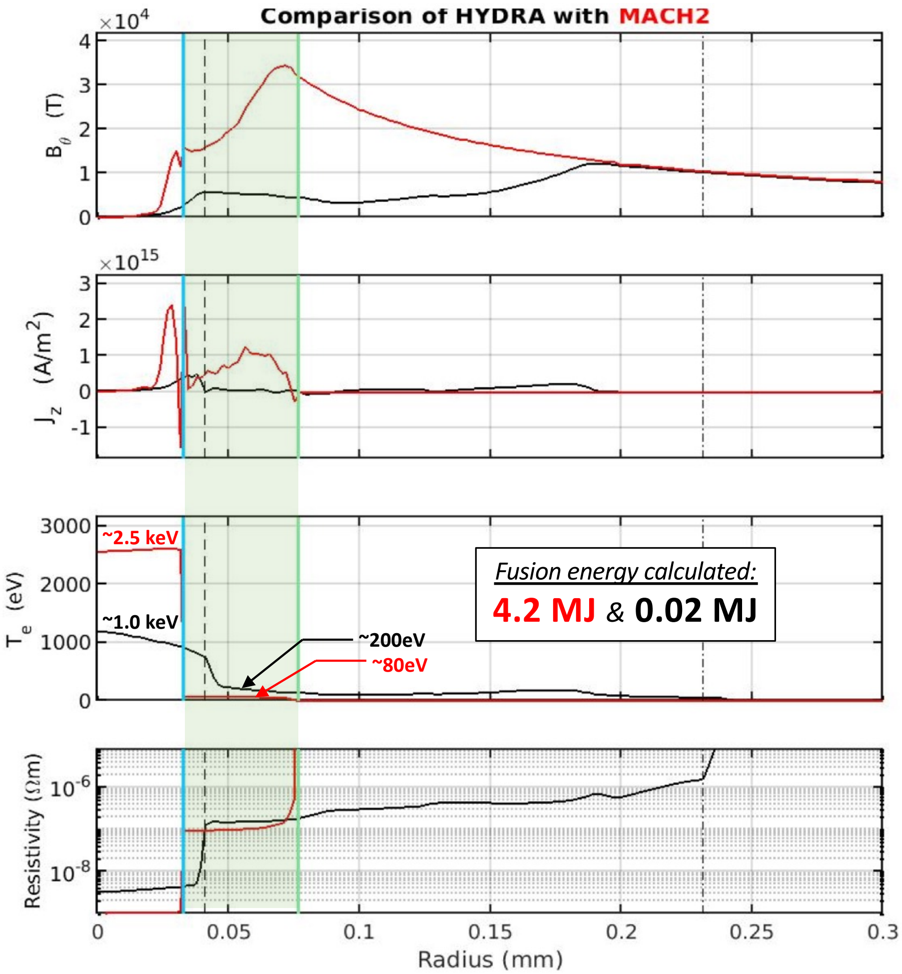
Nearly identical profiles at 70 ns

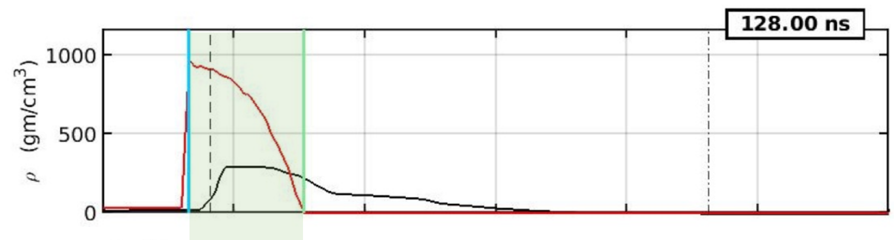


Slight variations at 100ns



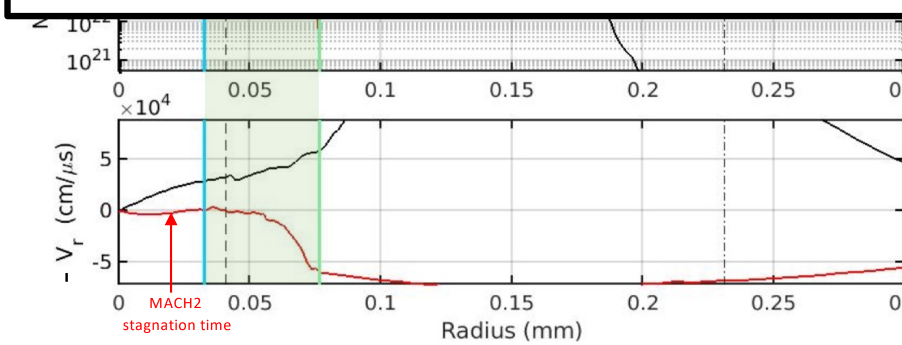
At or near stagnation time there is large difference in T-profiles





Possible sources of discrepancy will be analyzed:

- **Thermal transport**
- **Radiative transport**
- **Energy coupling to the system**



Summary

- **The INFUSE collaboration with LLNL allows MIFTI to:**
  - Benchmark the MACH2 code with HYDRA for high current Staged Z-pinches.
  - Provide more realistic α-particle heating models.
  - Learn how to use the HYDRA code and software tools needed to analyze its results.
  - Gain confidence in the SZP modeling with the MACH2 code for a proposed 10 MA pulsed power generator based on Liner Transformer Driver (LTD) technology.

- **The benchmarking efforts so far show excellent agreement between the two codes, except for the last 10ns of the compression. We are investigating the factor of ~2.5 difference between the final fuel temperatures, which is critical for high gain fusion.**

- After the benchmarking phase we'll focus on modeling the SZP α-particle heating.
- Start hybrid kinetic simulations with the CHICAGO code.
- Study the effects of the MRT instability with 2-D models with increasing axial resolution.