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Liner stability, fuel assembly, and stagnation physics

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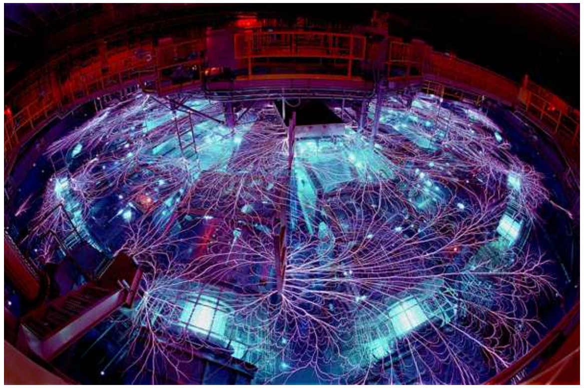
with thanks to the MagLIF working group

MagLIF Workshop

Albuquerque, NM, Feb. 5-8, 2012



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NNSA National Nuclear Security Administration

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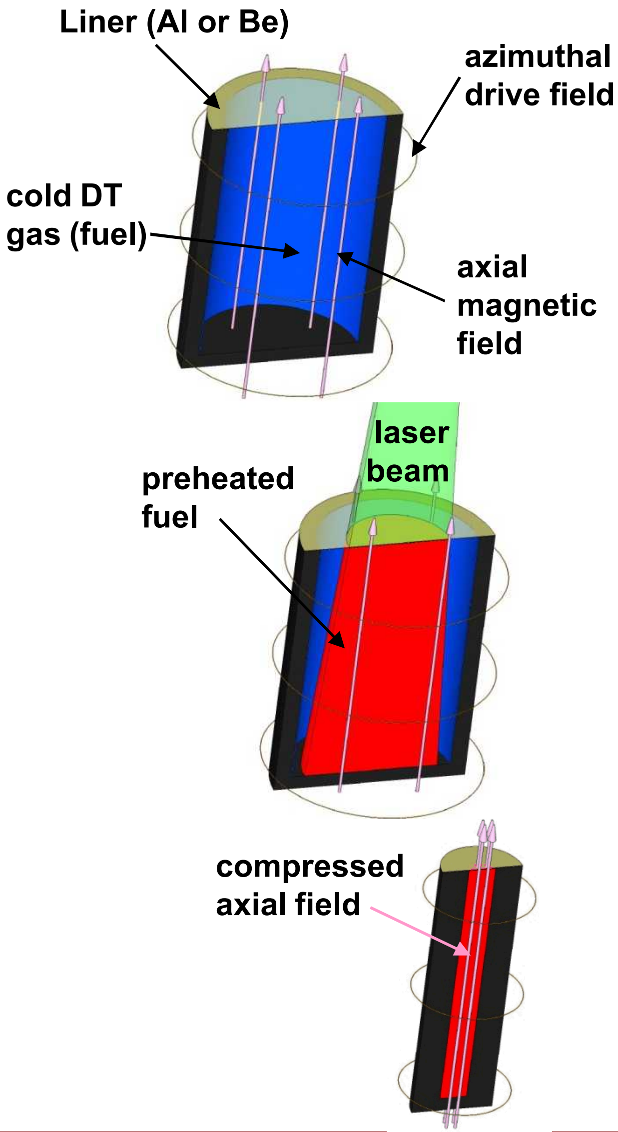
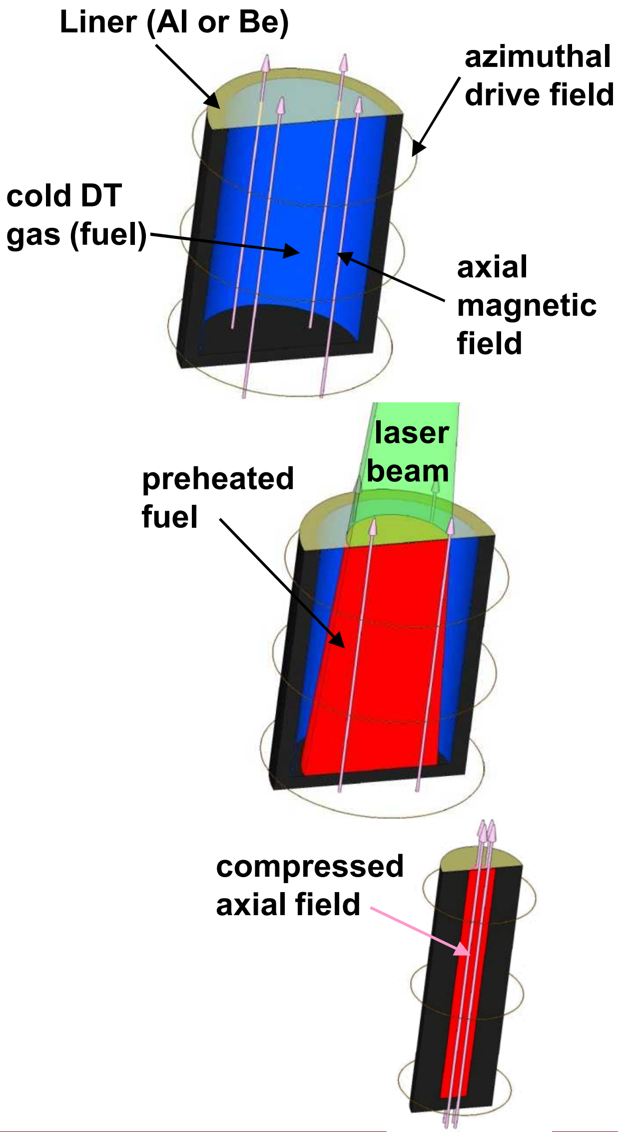
We are working toward the evaluation of a new Magnetized Liner Inertial Fusion (MagLIF)* concept



- An initial ~10 T axial magnetic field is applied
  - Inhibits thermal conduction losses
  - Enhances alpha particle energy deposition
  - May help stabilize implosion at late times
- During implosion, the fuel is heated using the Z-Beamlet laser (<10 kJ needed)
  - Preheating reduces the compression needed to obtain ignition temperatures to 20-30 on Z
  - Preheating reduces the implosion velocity needed to “only” 100 km/s (slow for ICF)
  - Stagnation pressure required is few Gbar, not a few hundred Gbar

*S.A. Slutz *et al.*, Phys. Plasmas 17, 056303 (2010); Slutz and Vesey, Phys. Rev. Lett. 108, 025003 (2012).

This discussion section is aimed at three issues…



- Liner dynamics
- Fuel preheating
- Stagnation and fuel assembly
- Integration and fielding
- Modeling & simulation

A great attraction of MagLIF is the possibility of relaxing ρR in the fuel

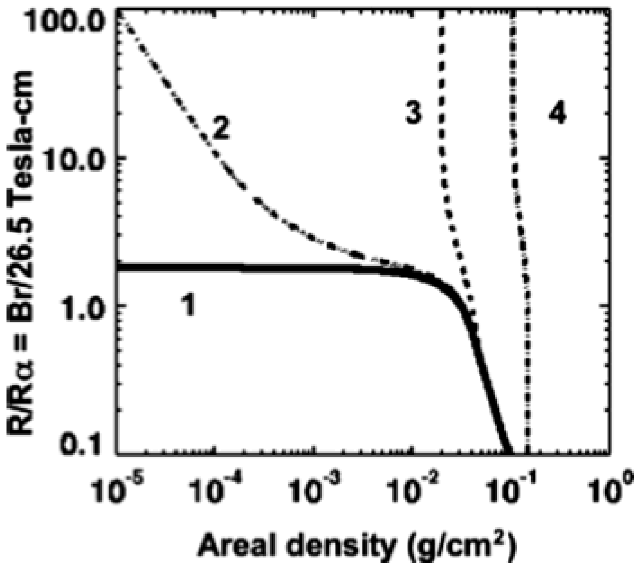


FIG. 2. Magnetized fuel ignition space contours are plotted as a function of fuel areal density and the ratio of the cylinder radius over the cyclotron radius of a fusion α-particle with its initial energy as calculated with the following assumptions, (1) α transport including B-field effects and classical magnetic conductivity inhibition, (2) α-transport including B-field effects and Bohm magnetic conductivity inhibition, (3) α transport ignoring B-field effects and classical magnetic conductivity inhibition, and (4) α transport including B-field effects and conductivity ignoring B-field.

Fig. 2 from Slutz et al. (2010)

- Usual ablatively-driven capsules get inertial confinement from the fuel (ρR ~1 or 2 g/cm^2)
- MagLIF trades liner ρR for fuel ρR
- How can we build confidence in the validity of this tradeoff?
  - What are the limitations of the theory? How sensitive is this conclusion to theoretical uncertainties?

Are theoretical improvements needed to understand the final fuel configuration we need to achieve?

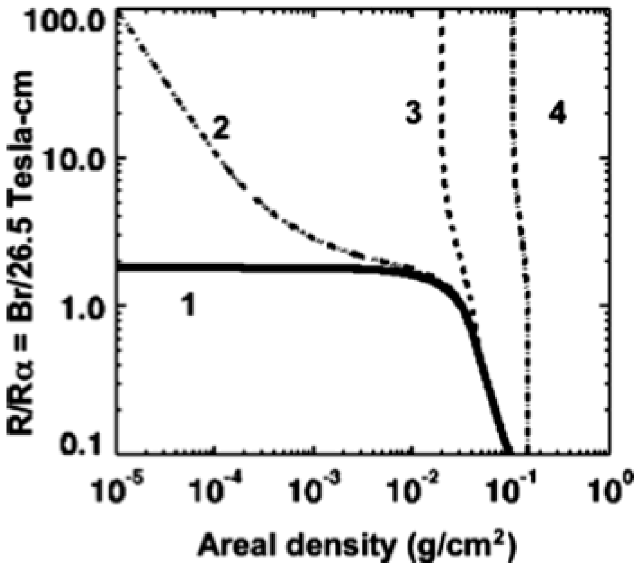


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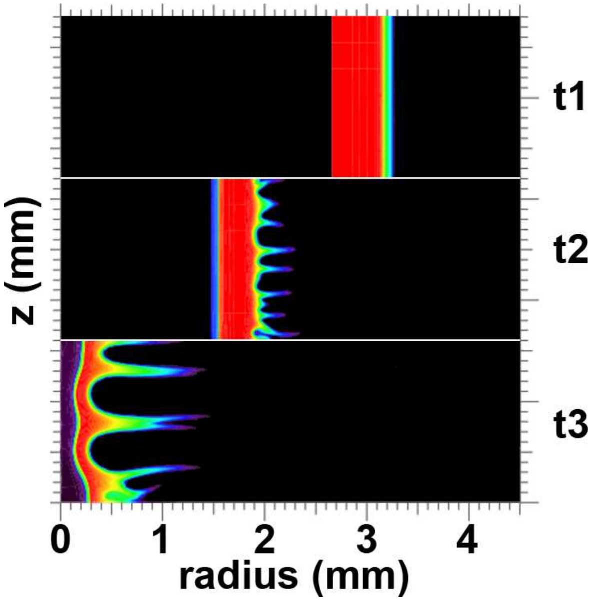
Fig. 2 from Slutz et al. (2010)

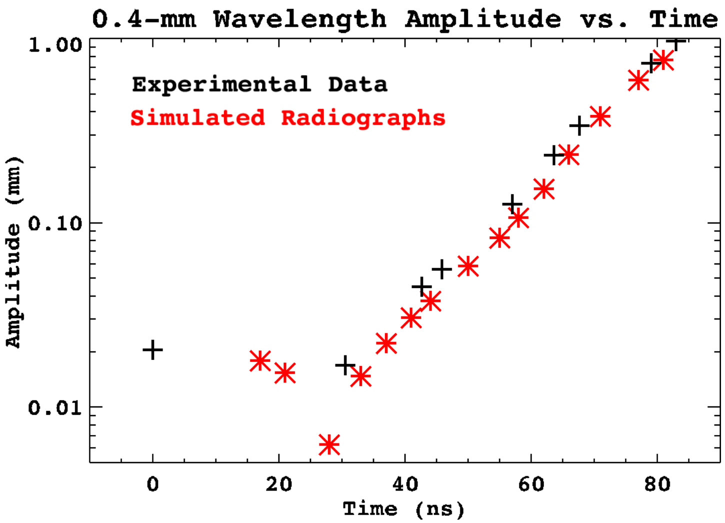
- Is the final fuel/liner plasma strongly coupled?
  - Fuel probably not
  - Liner may well be
- Do we need to model strong-coupling effects well?
- How are these conclusions affected by the presence of liner material in the fuel?
- How are these conclusions affected by the addition of a magnetic field?

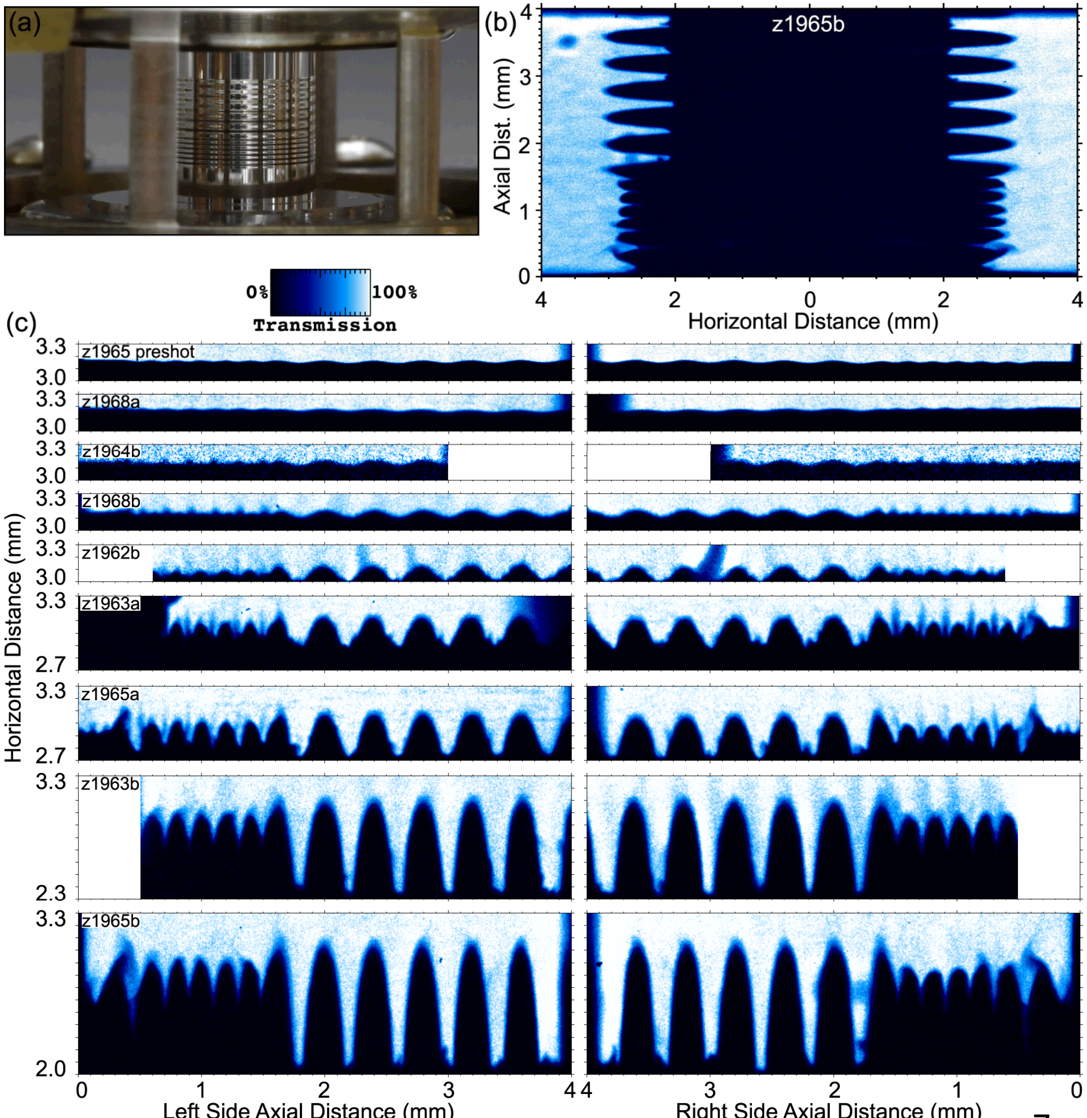
A large threat to achieving any compression at all is the growth of liner instabilities

- What are all the issues?
  - Electrothermal phase (cf. Kyle Peterson’s talk)
  - Initial magnetic Rayleigh Taylor (MRT) (cf. Dan Sinars’ data and paper)
  - Late time MRT (cf. Ryan McBride’s data)
  - Deceleration phase instability growth
- What data do we have? What data do we need?
- How well does “Code (fill in the blank)” match that data?
- Short of a perfect code, what are *useful,* practical computational strategies for this problem?

Initial phase data* are already available for anyone with an Rad-MHD code—a challenge to all!







*D.B. Sinars, S.A. Slutz *et al.*, Phys. Rev. Lett. (2010); D.B. Sinars, S.A. Slutz *et al.*, Phys. Plasmas (2011).

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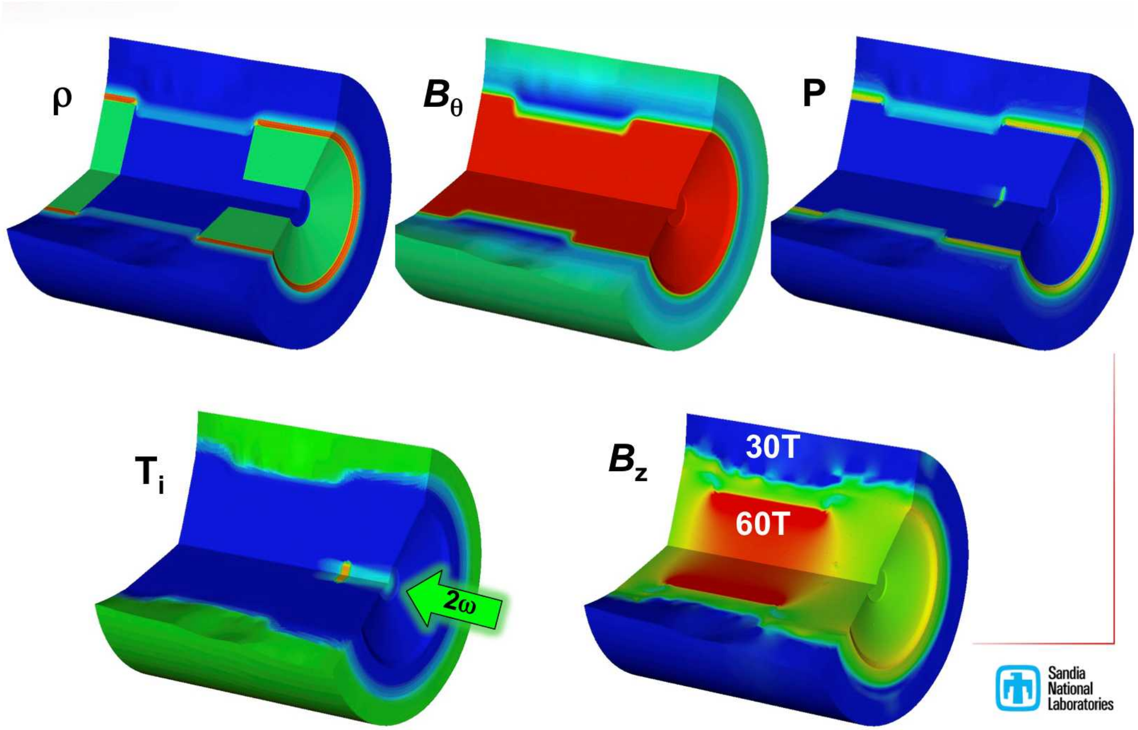
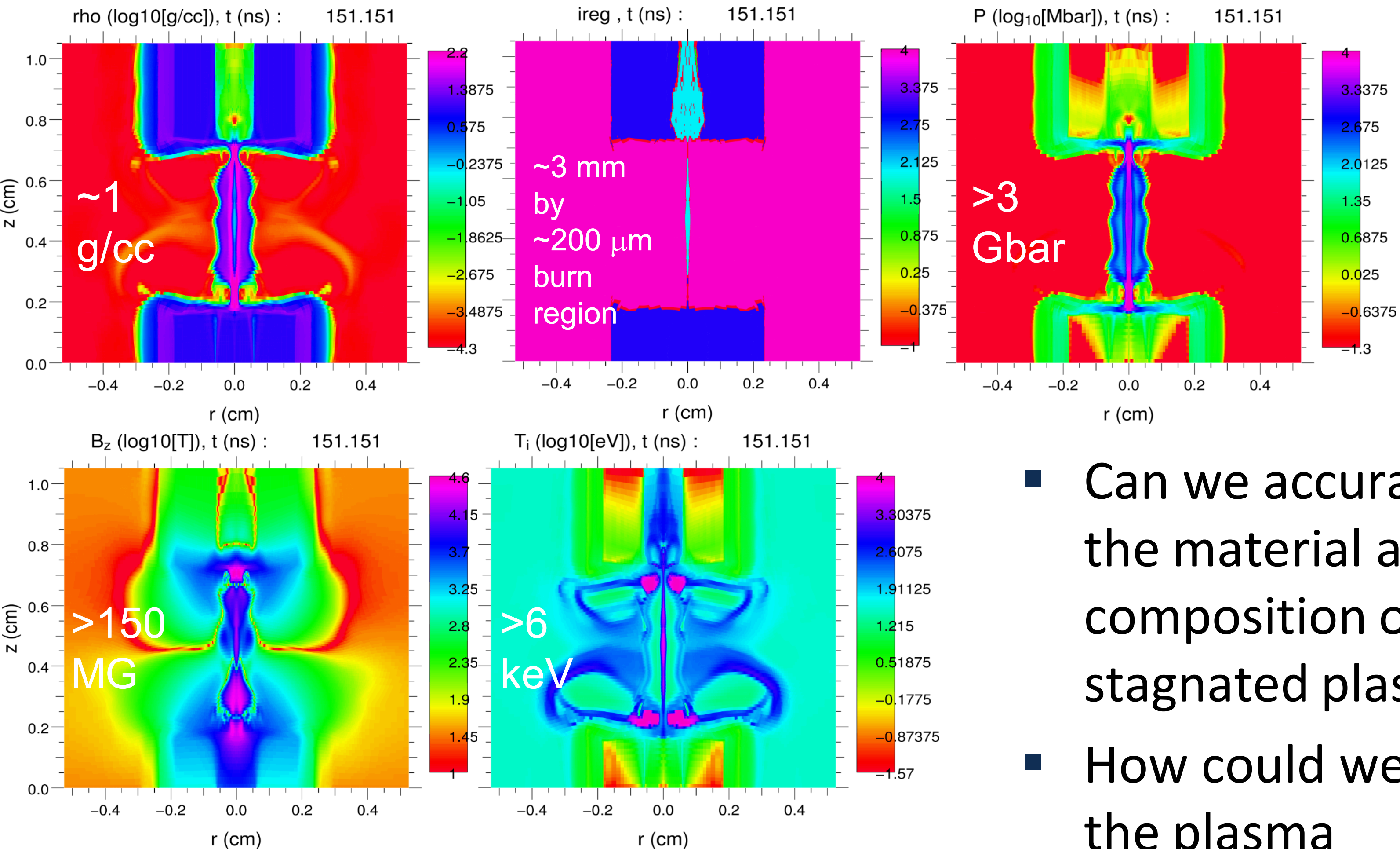
How well do the codes simulate the dynamics of the magnetic field within a compressing liner?



HYDRA simulation from Joe Koning, Adam Sefkow

- Simulation predictions for MagLIF clearly depend on plasma effects that are sometimes neglected
- Even if included, are the assumptions behind the theory valid in the MagLIF regime?
- Especially important is the distribution of magnetic flux at stagnation

How well do the codes simulate the stagnation phase?



HYDRA simulation from Joe Koning, Adam Sefkow

- Can we accurately model the material and field composition of the stagnated plasma?
- How could we diagnose the plasma experimentally?

The purpose of this discussion…

- …A free and informal interaction that engages you on what you think the fundamental simulation, prediction, and validation issues are that we face in the general areas of:
  - Liner stability
  - Fuel assembly
  - Stagnation physics
- Discuss!

Backups

Example liner dynamics questions

- What are the design requirements that maintain sufficiently low instability levels to allow MagLIF to succeed?
  - Is there a liner surface roughness specification?
  - How do we account for the effect of electro-thermal instabilities? Do they vary significantly with material (e.g., Be, Al)?
  - Do we have azimuthal asymmetries in the power flow on Z that can seed damaging levels of liner instabilities?
  - How uniformly does the current need to initiate on the liner?
  - How uniform does the liner have to be at a convergence ratio of 10?
- Do we understand how the magneto-Rayleigh-Taylor instability correlates azimuthally even with random surface roughness?
- Are 3D simulations required to capture MRT growth?
- Is there blowoff from the inside liner surface due to ablation or spall from combined rarefaction waves that leads to mix?
- Is isentropic compression (current pulse shaping) of benefit for MagLIF?
- What can we do to mitigate wall instabilities at the liner top/bottom?

Example stagnation & fuel assembly questions

- What are our key performance metrics?
  (Yield, T_ion, flux compression, convergence ratio, etc.?)
  Can we identify and pull out important empirical variables?
- Can we use x-ray spectroscopy as an alternative method for diagnosing fuel conditions rather than neutron diagnostics?
  What types of fuel dopants do we want? (Cl, Ar, Ne, Kr, Xe, Rn)
- What is the magnetic field doing in our experiments?
  - How do we measure magnetic field flux compression?
  - How much of the axial Bfield remains in the fuel (Nernst)? What are the maximum and average values of the Bfield?
  - Is there a metric other than yield that will allow us to measure the impact of the magnetic field on the target performance?
- Does MagLIF work if there is a larger distribution of r-Btheta than expected, so that the magnetic compression is weaker?