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Modeling of Laser Heated Gases Including MHD

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MagLIF preheat strives for high density, high energy preheat to optimize performance at reasonable convergence ratio

With 1.1 mm spot, laser deposition is

- Larger spot reduces penetration depth

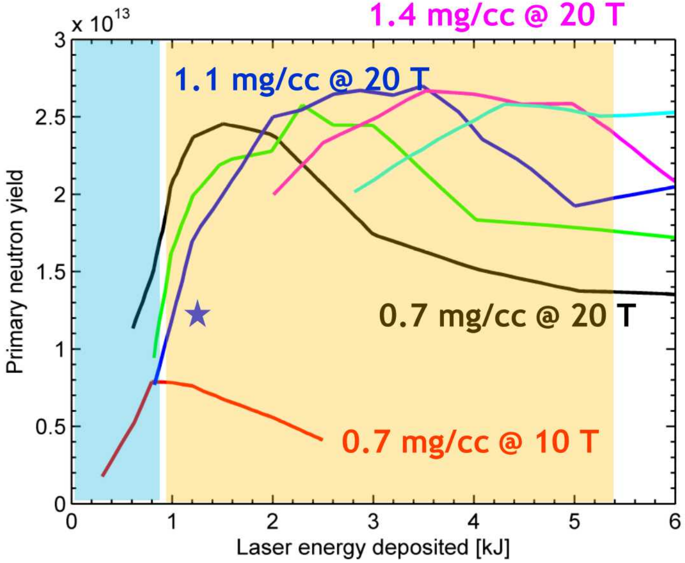
Higher densities benefit from larger spot to minimize LPI

Higher density and larger spot introduce larger energy loss to polyimide window

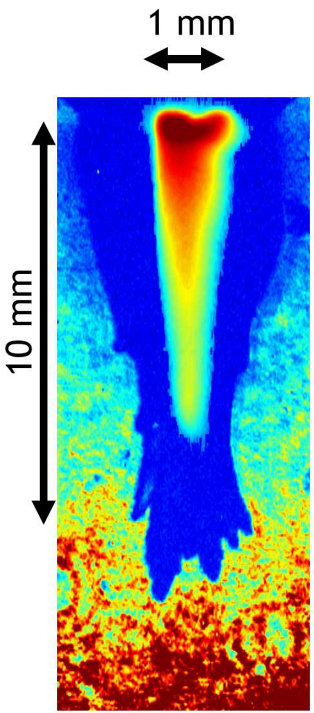
- Simulations that follow assume 1.5 mm spot combined with cryo cooling to achieve 500 nm polyimide windows

Laser only experiments do not include applied magnetic fields

- Are there new design considerations?



1.0 mg/cc
~1.2 kJ in gas
1.1 mm spot
No Bz

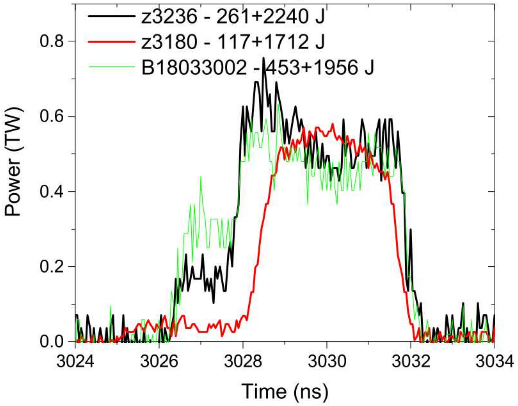


MagLIF Preheat has been studied in detail in laser-only experiments and shows 3D features

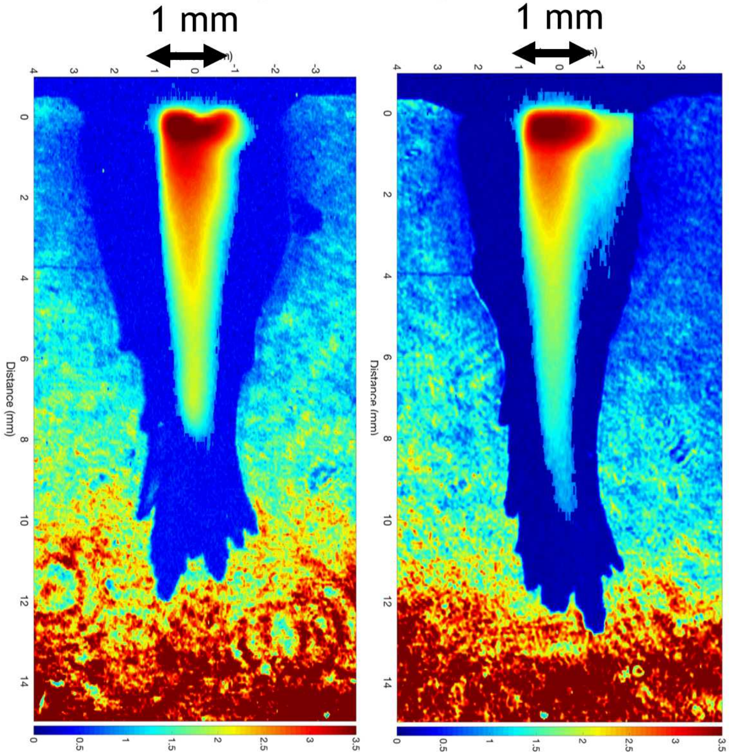
Simulations do not account for backscatter losses which can truncate laser propagation
- Also did not include Ar dopant

Pecos Experiments do not include Bz

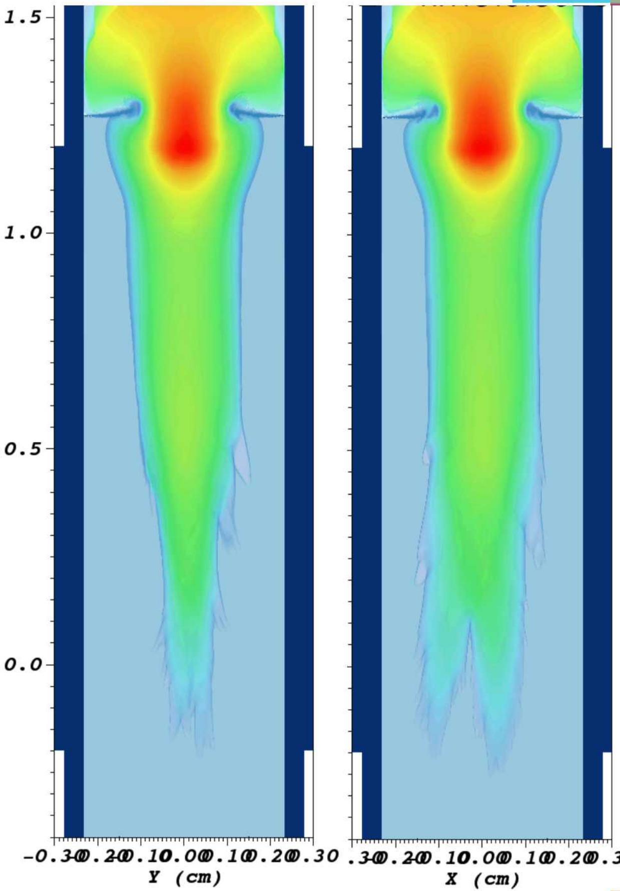
Energy is in foot + main pulse assuming 85% transmission
Both shots had 20-30 J co-injection at -20 ns



z3236 Repeat Attempts in Pecos



Propagation is consistent with ~ 1.2 kJ coupled to the gas



Slice in X

Slice in Y

Applied magnetic fields affect energy distribution during laser preheat primarily by thermal flux inhibition; Fuel also pushes around the field

Hall Parameter (> 1) controls most B-field effects

$$\omega_e \tau_e = 1.21 \times 10^{16} \frac{T_e^{3/2} |\underline{B}|}{n_e \lambda Z_{\text{eff}}}$$

**Magnetization increases with: B and T_e
Collisionality reduces magnetization**

Nernst advects magnetic field down strong temperature gradients:

$$\frac{dB_z}{dt} = \nabla \times \left(B_z \frac{\partial}{\partial r} T_e \hat{\theta} \right) / (e|\boldsymbol{B}|\boldsymbol{\omega_e \tau_e})$$

Nernst reduced by strong magnetization

Magnetic fields generate anisotropic heat fluxes

$$\underline{q} = \kappa_{\perp} \frac{\partial}{\partial r} T_e \hat{r} + \kappa_{\wedge} \frac{\partial}{\partial r} T_e \hat{\theta} + \kappa_{||} \frac{\partial}{\partial z} T_e \hat{z}$$

Perpendicular conductivity — Righi-Leduc heat flow — Parallel conductivity

A key feature of MagLIF is the applied axial magnetic field, currently not available in laser only experiments in Pecos chamber

The 3D Hydra simulation code is a primary tool for modeling laser preheat and the MagLIF implosion and is able to assess magnetic field effects

- Key concerns are detrimental distribution of deposited energy or loss of magnetic flux

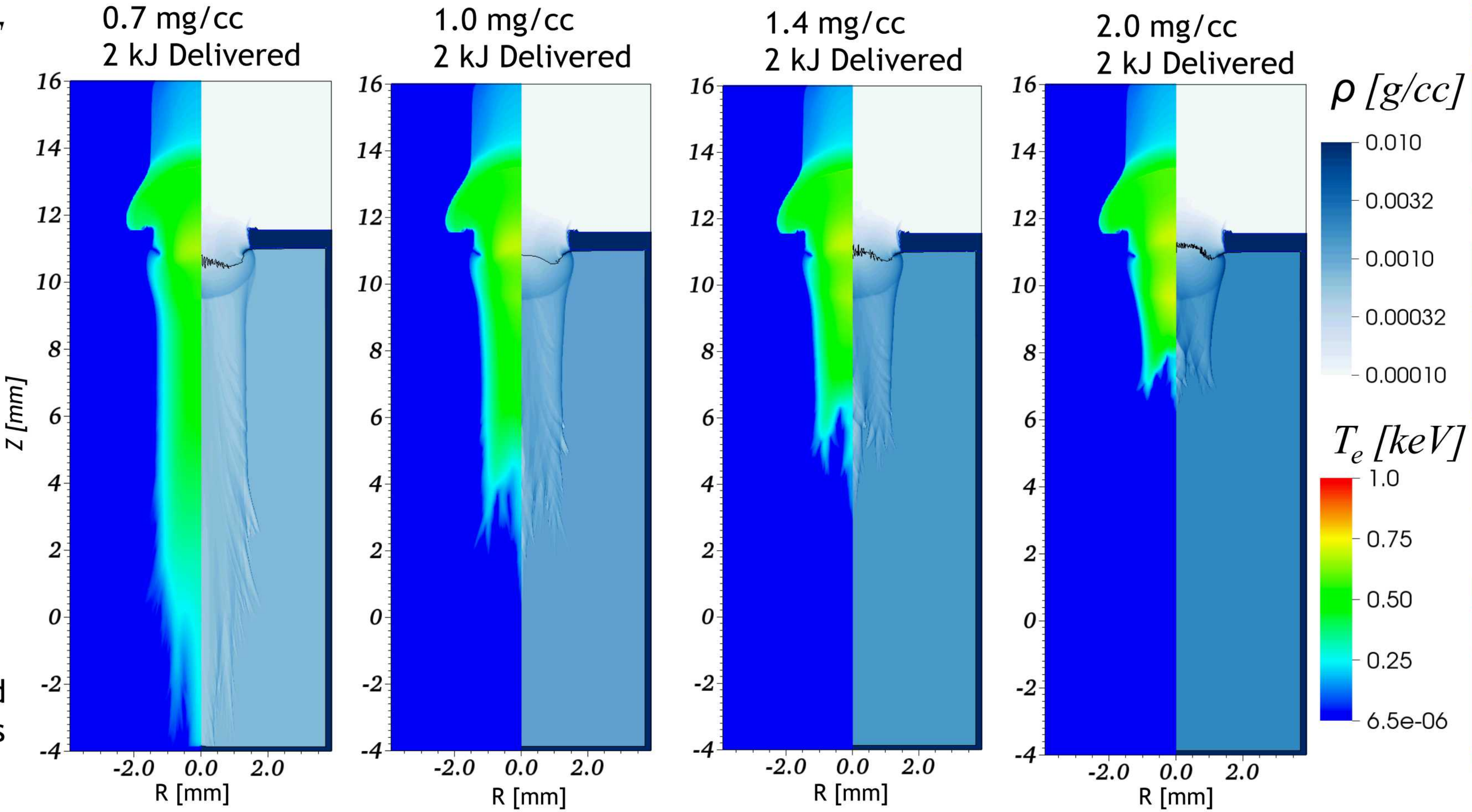
MHD effects in preheat:

- Advection of field by the fluid
- Advection of field by Nernst
- Biermann generated fields in the window and gas (B_θ in 2D)
- Modification of heat flow due to magnetized transport with B_z (helical heat flow in 3D with Righi-Leduc)

* 2D simulations shown here do not include R-L, 3D do

Laser penetration depth is highly sensitive to fuel density for fixed spot size

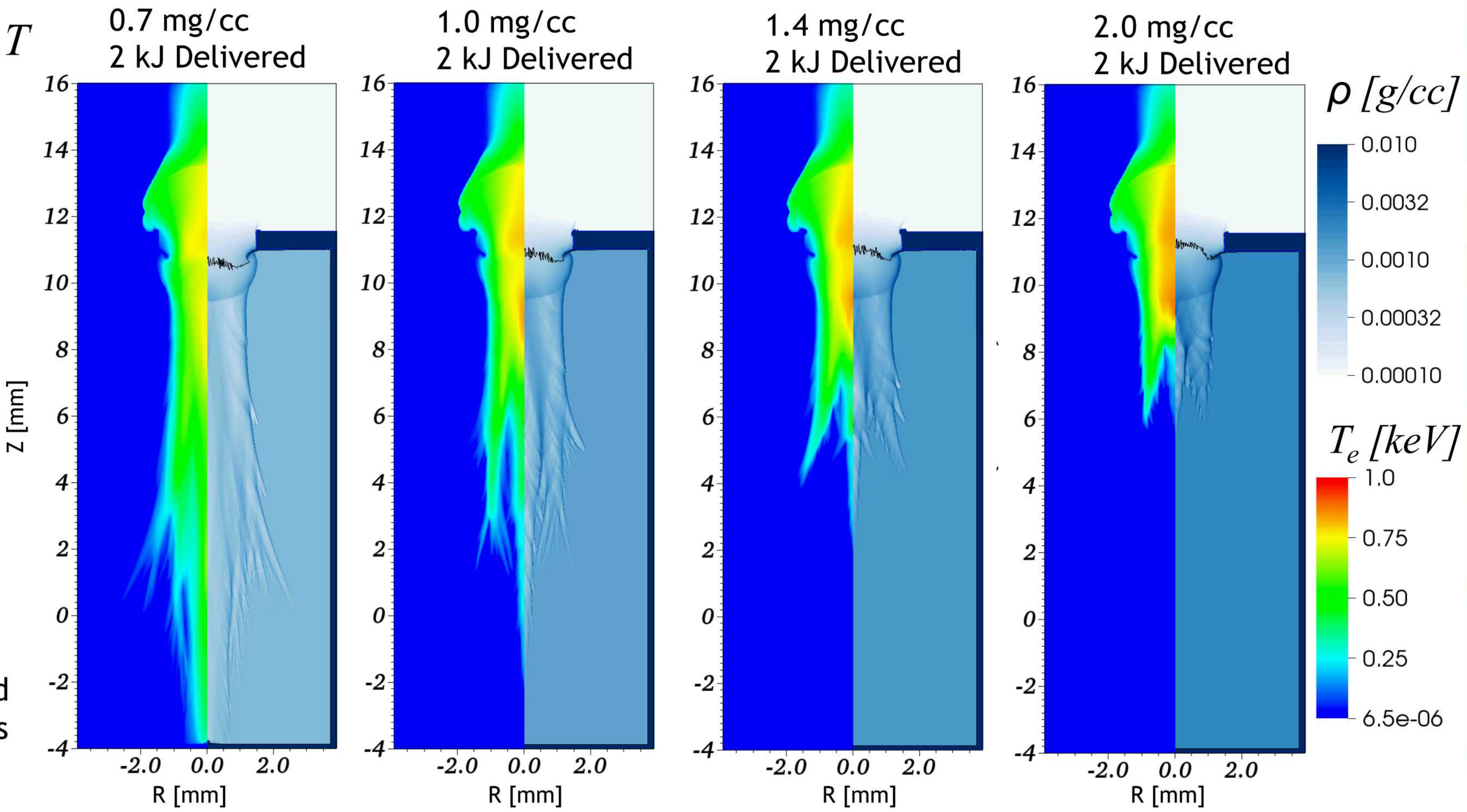
$B_z = 0\ T$
1.5 mm spot



~ 1.6 kJ deposited in the gas

Axial magnetic fields increase T_e and filamentation

$B_z = 15\ T$
1.5 mm spot



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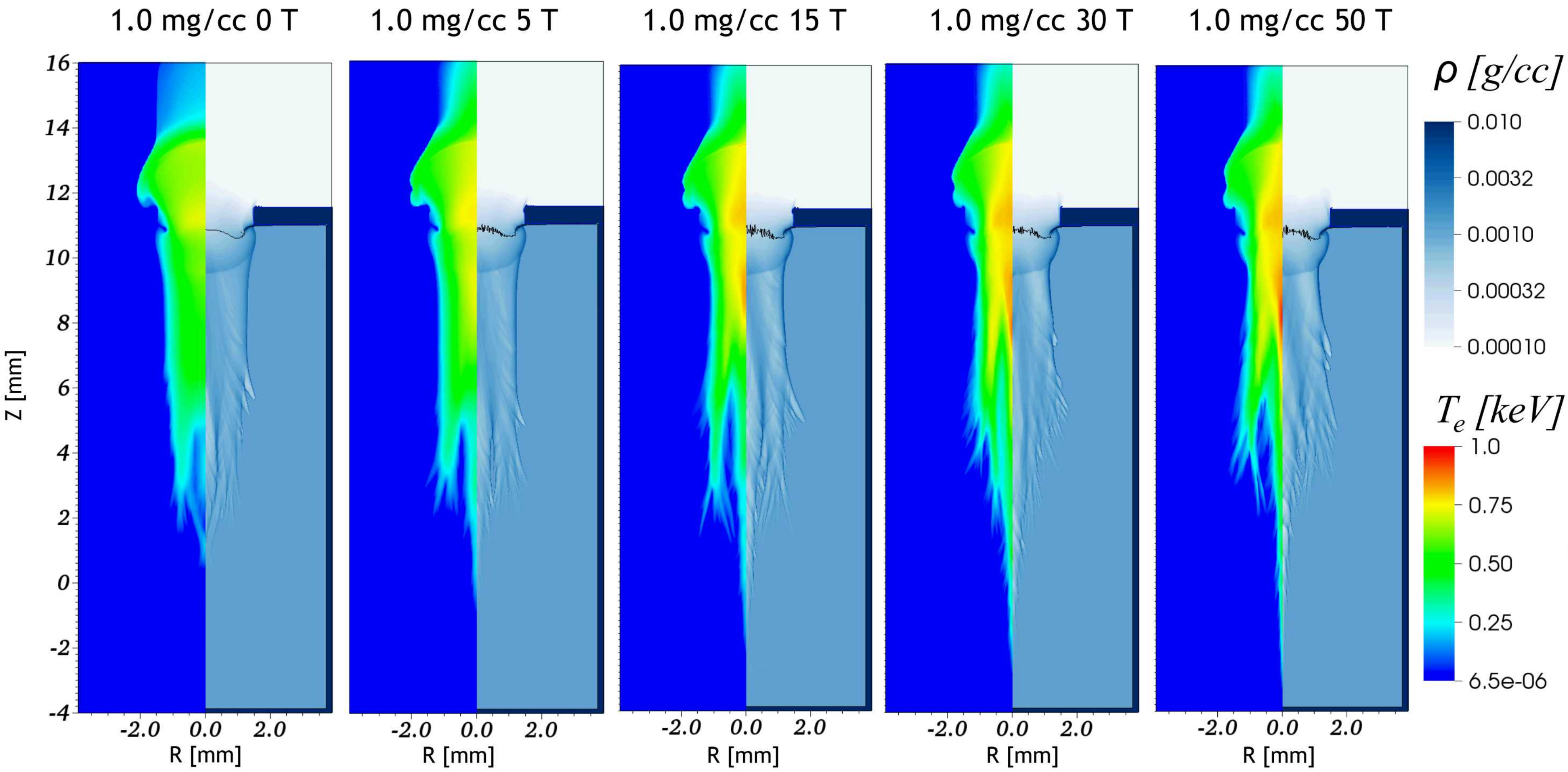
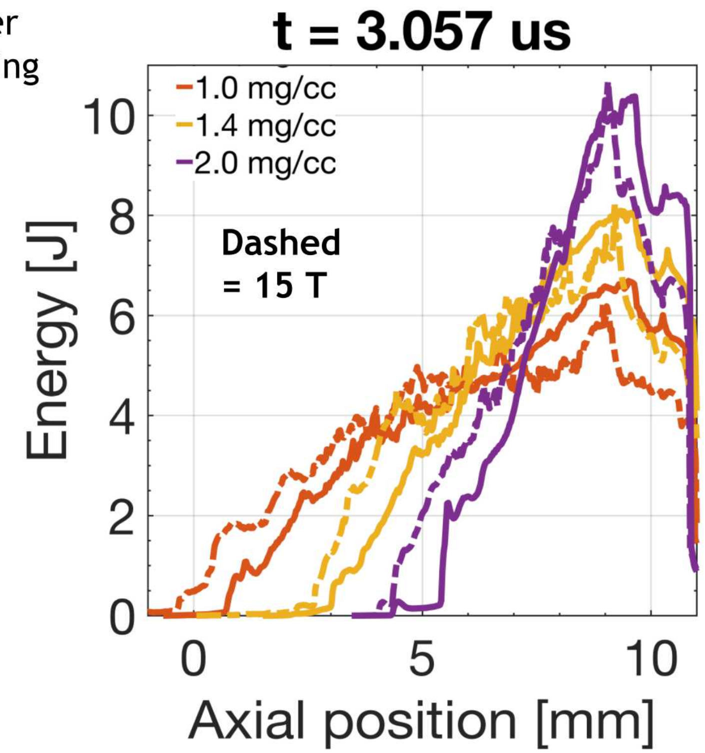
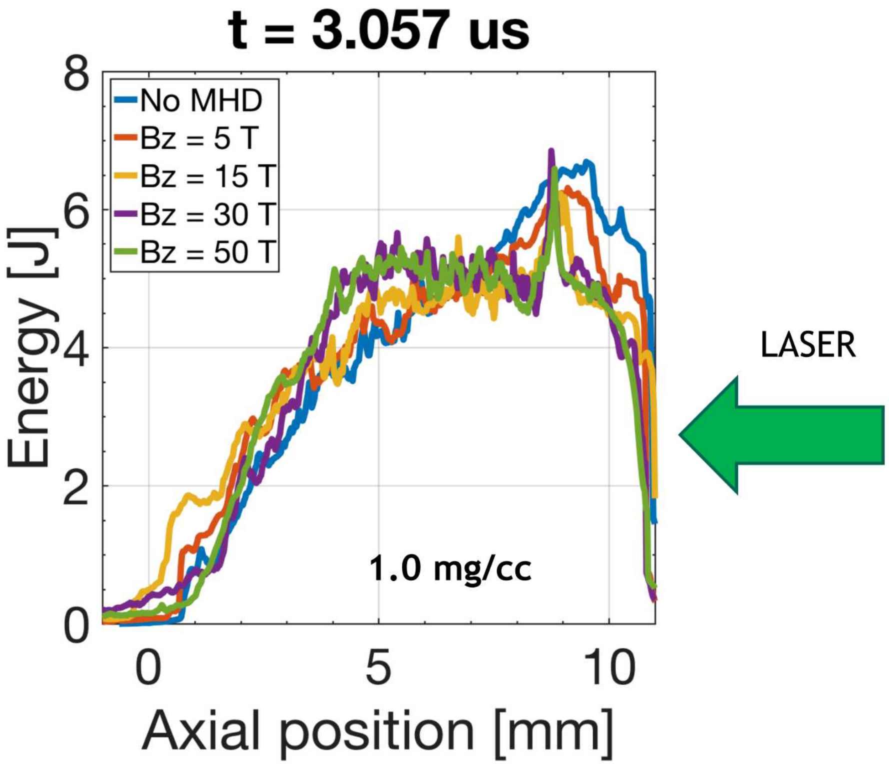
Axial magnetic fields increase T_e and filamentation



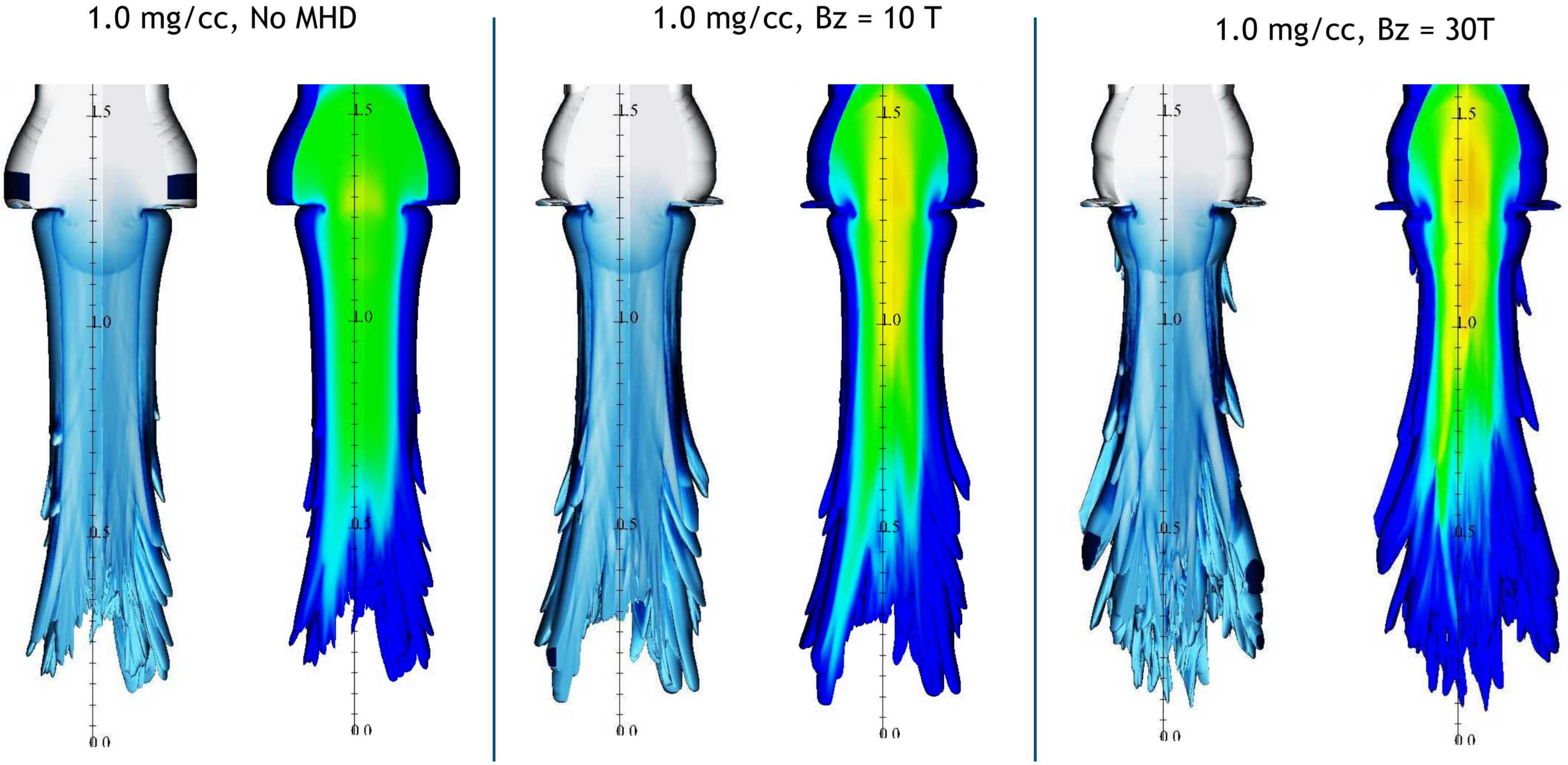
Axial magnetic field leads to deeper deposition of energy that persists after laser heating

10 ns after laser heating





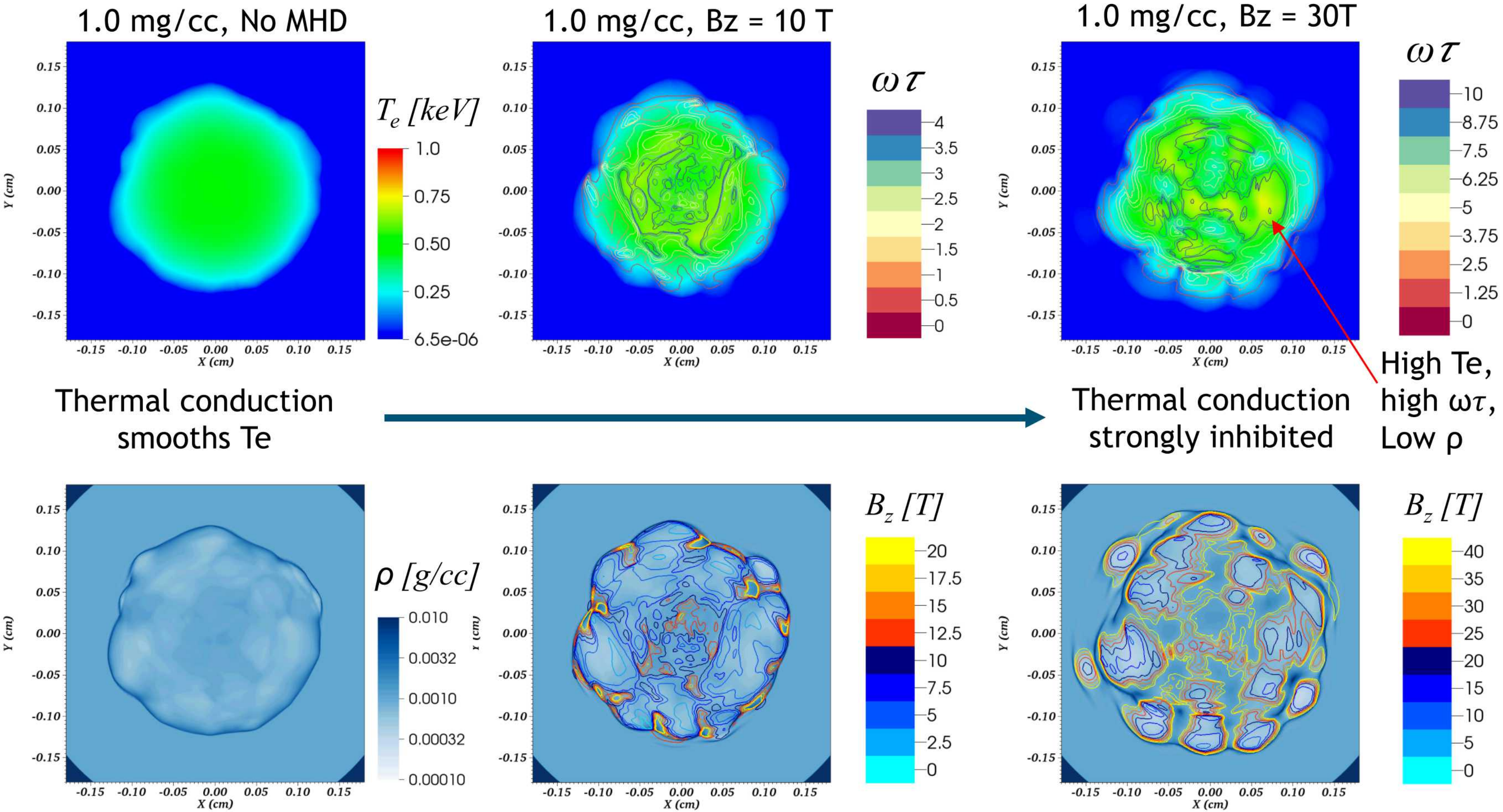
Filamentation is far more complicated in 3D but increases with increasing B_z as in 2D



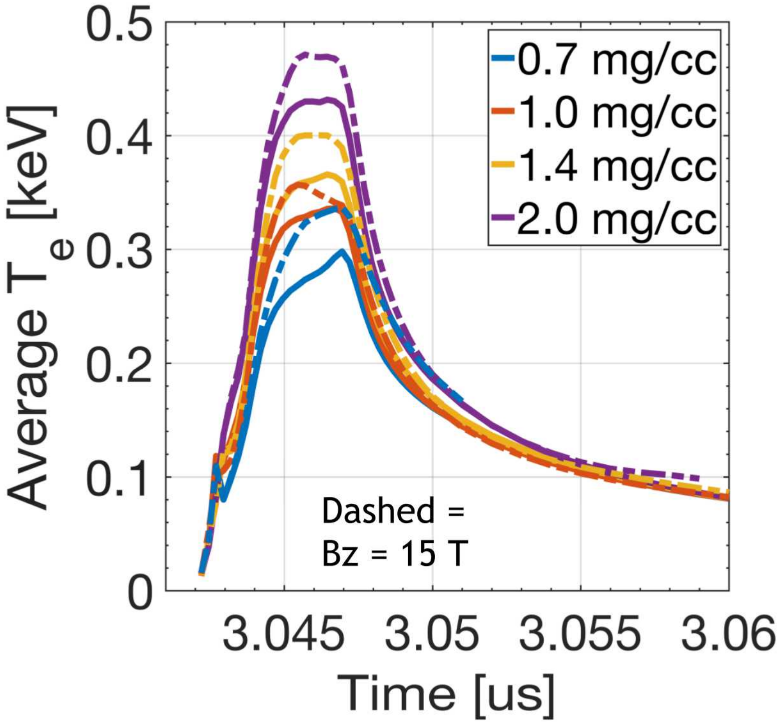
2 kJ delivered

Peak T_e still increases

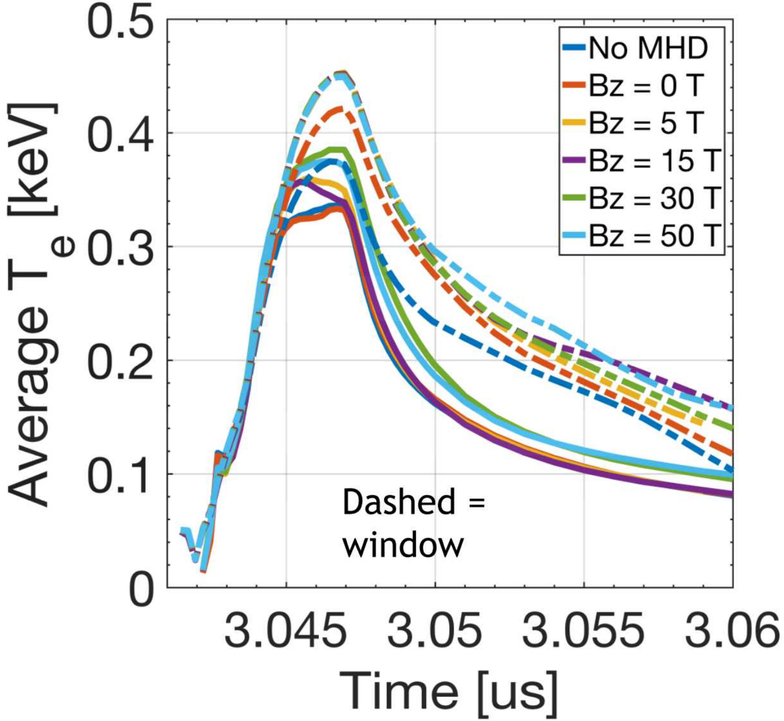
Magnetic field advected out of hottest portions; thermal conduction is substantially reduced, eliminating Te smoothing during laser pulse



Magnetic field insulation raises the average electron temperature by ~ 50 eV, effect tends to saturate at high fields

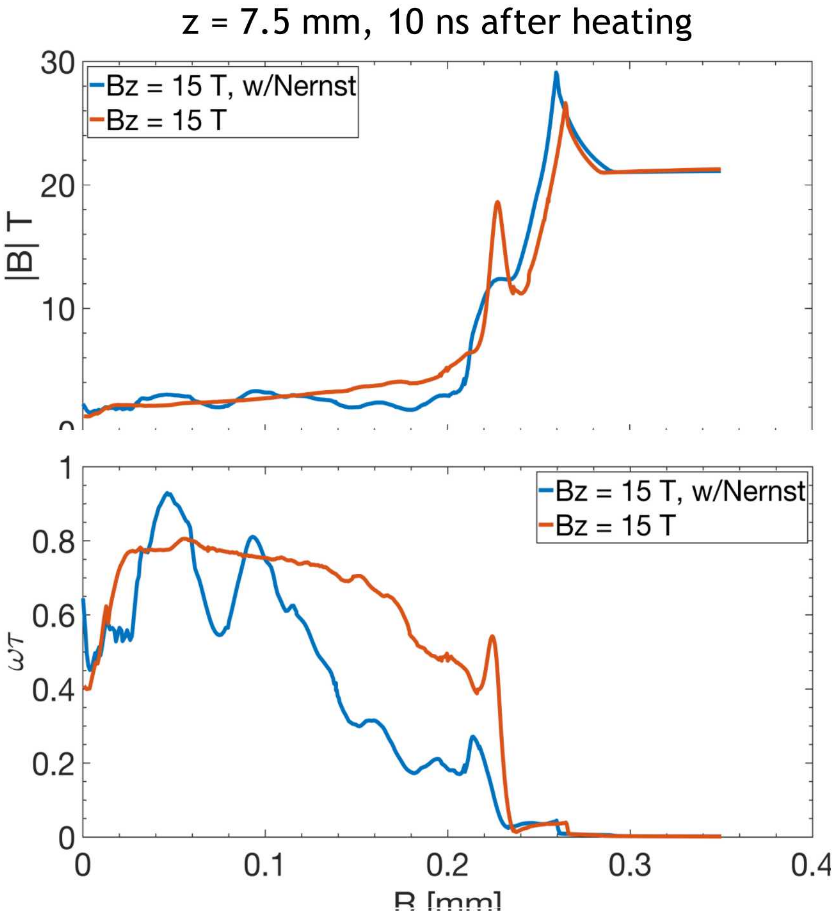


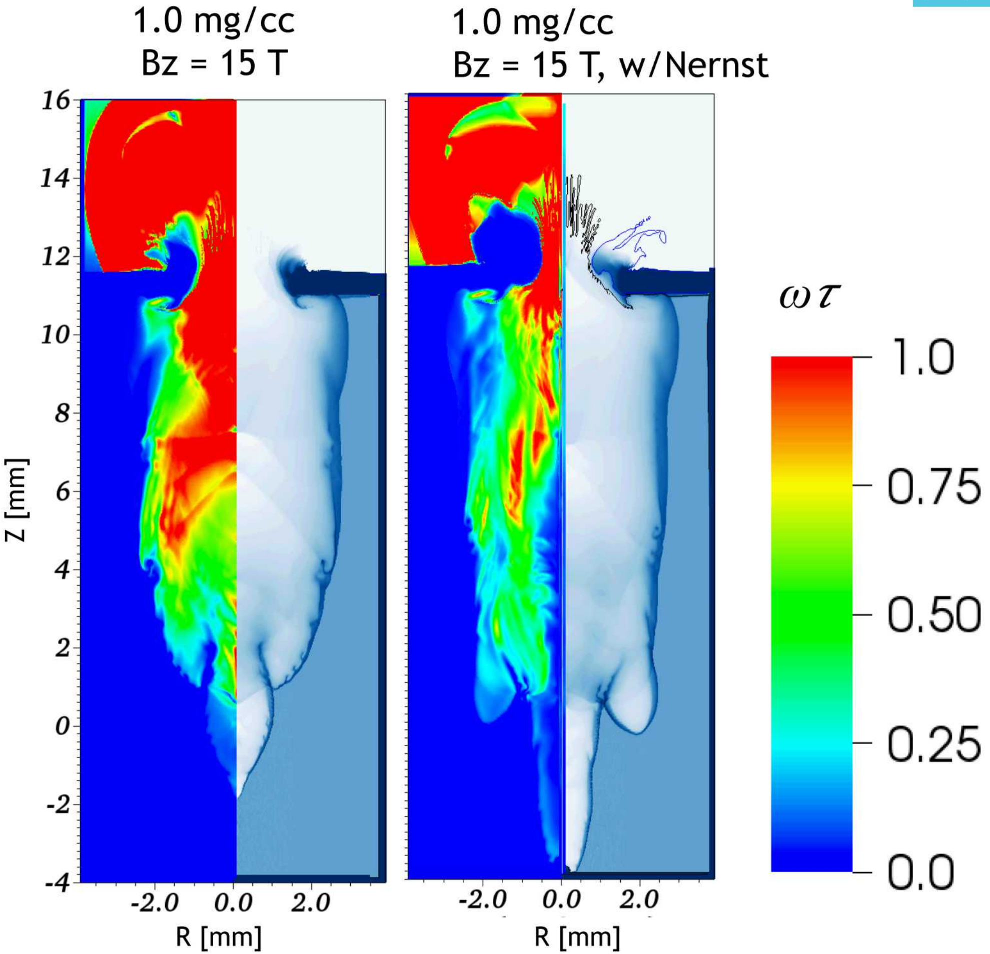
1 mg/cc



Hotter window temperatures do not lead to substantial increase in energy coupled to fuel ~ 5%

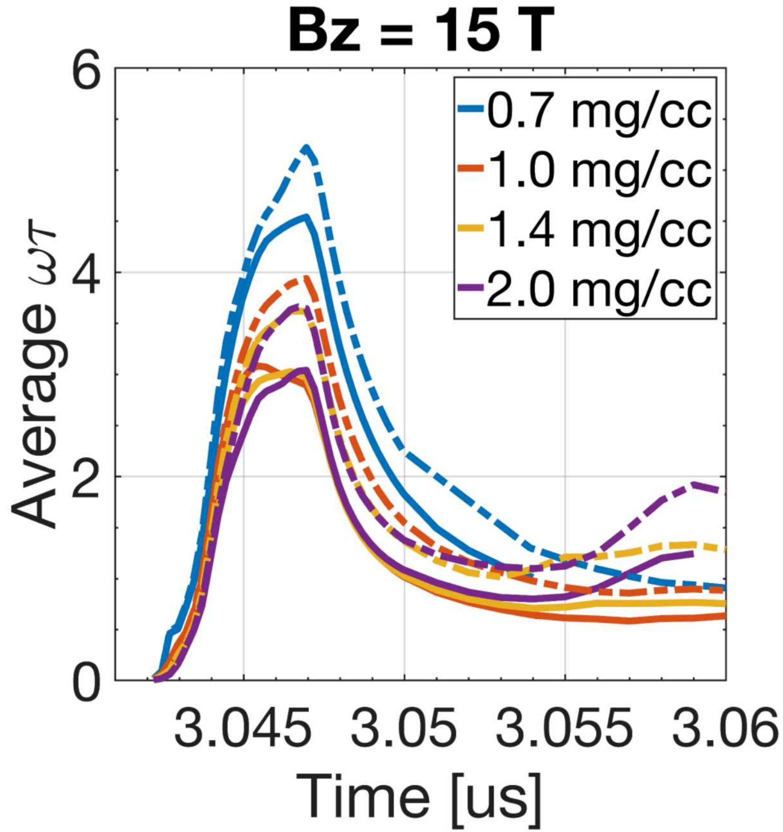
Nernst advects magnetic flux from core of the heated plasma

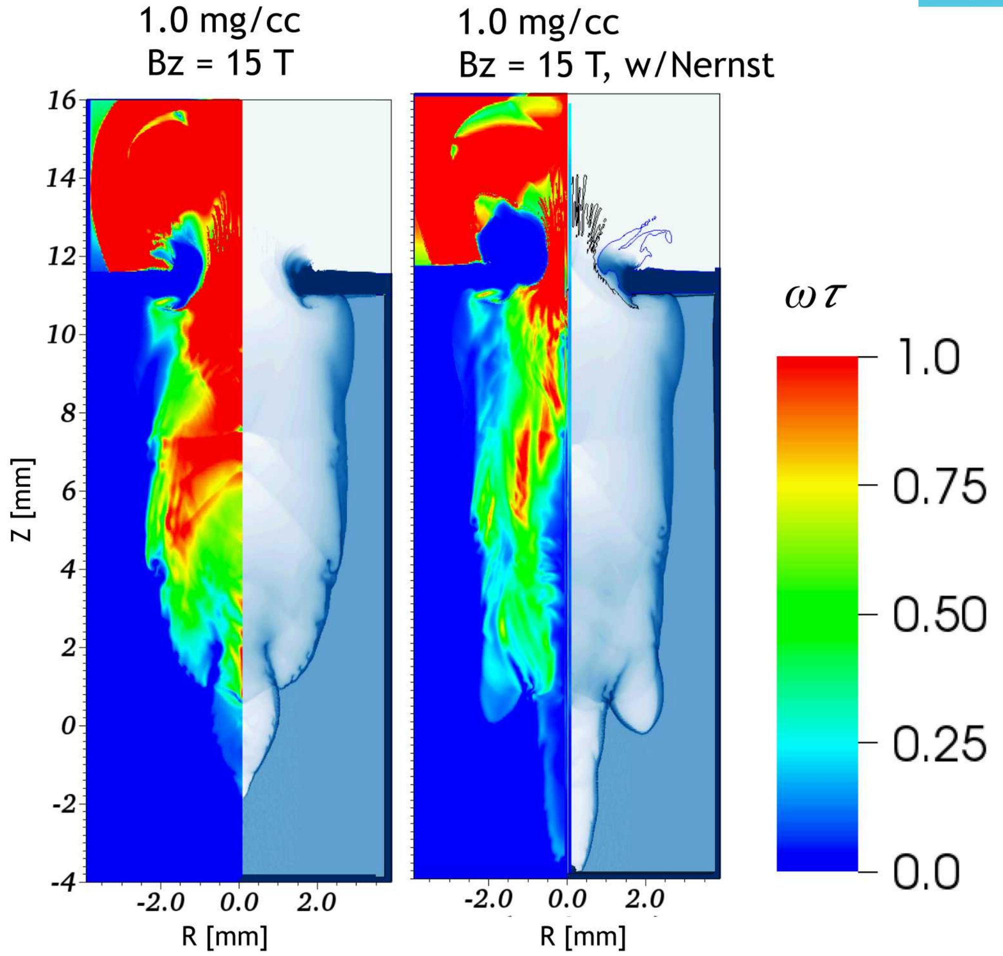




Nernst advects magnetic flux from core of the heated plasma

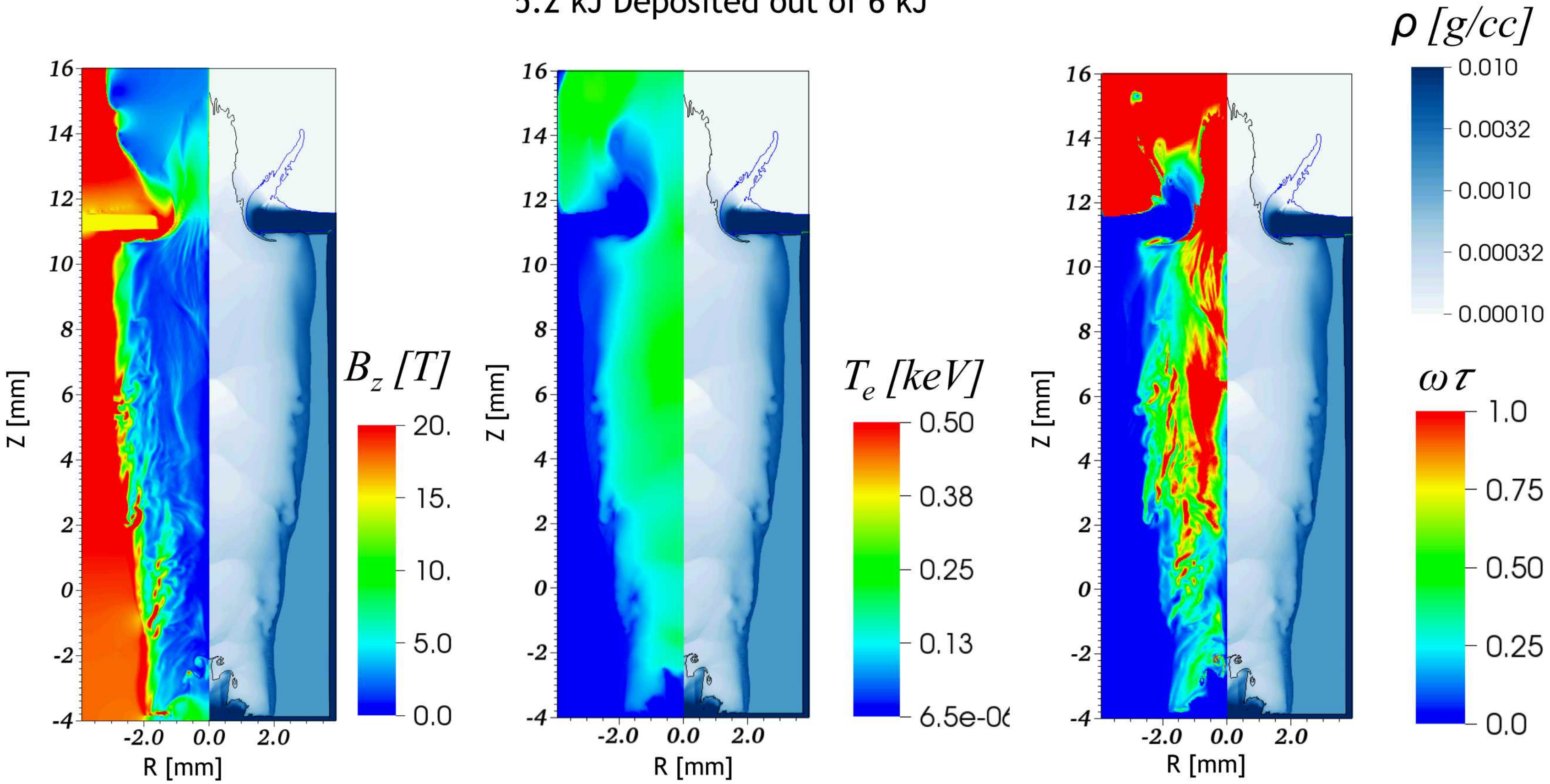
z = 7.5 mm, 10 ns after heating



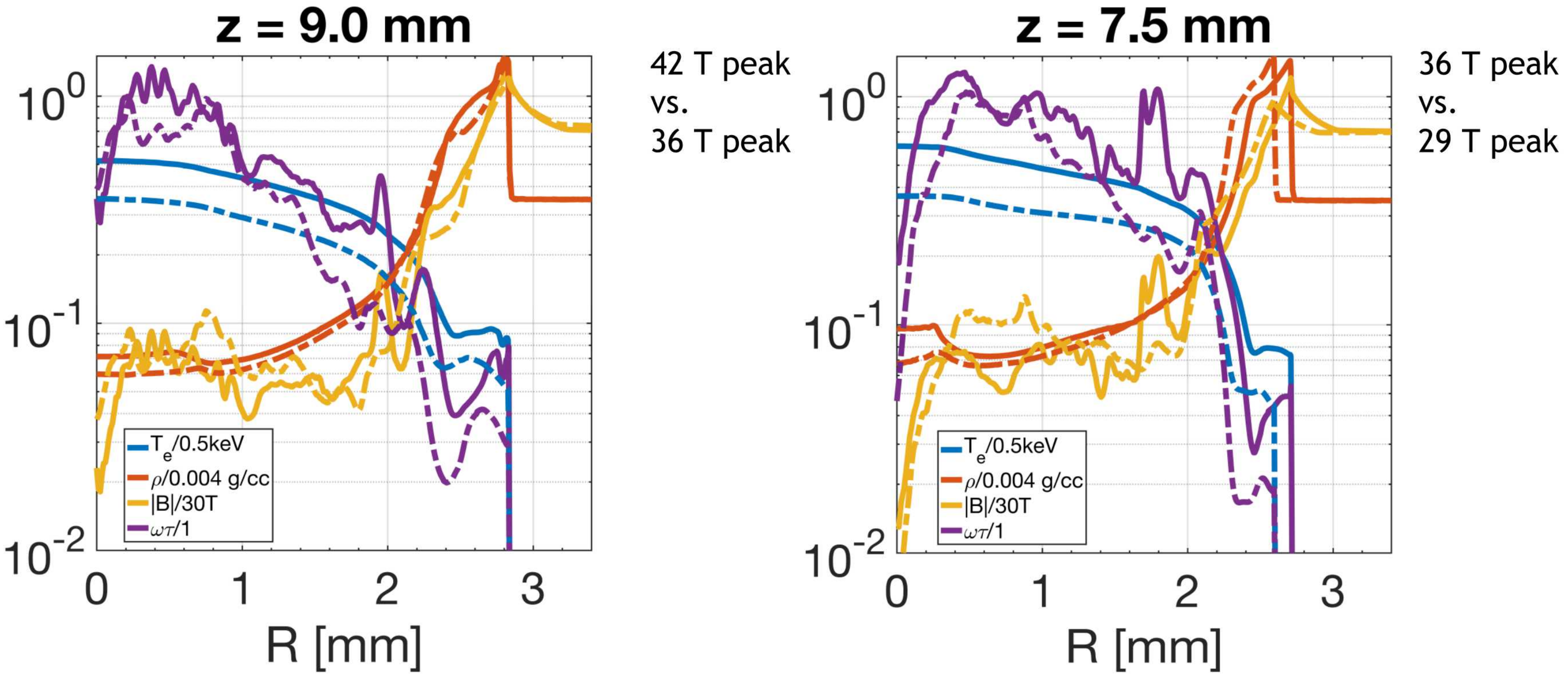


High energy preheat configurations show similar post-preheat magnetization

1.4 mg/cc, 15 T,
5.2 kJ Deposited out of 6 kJ

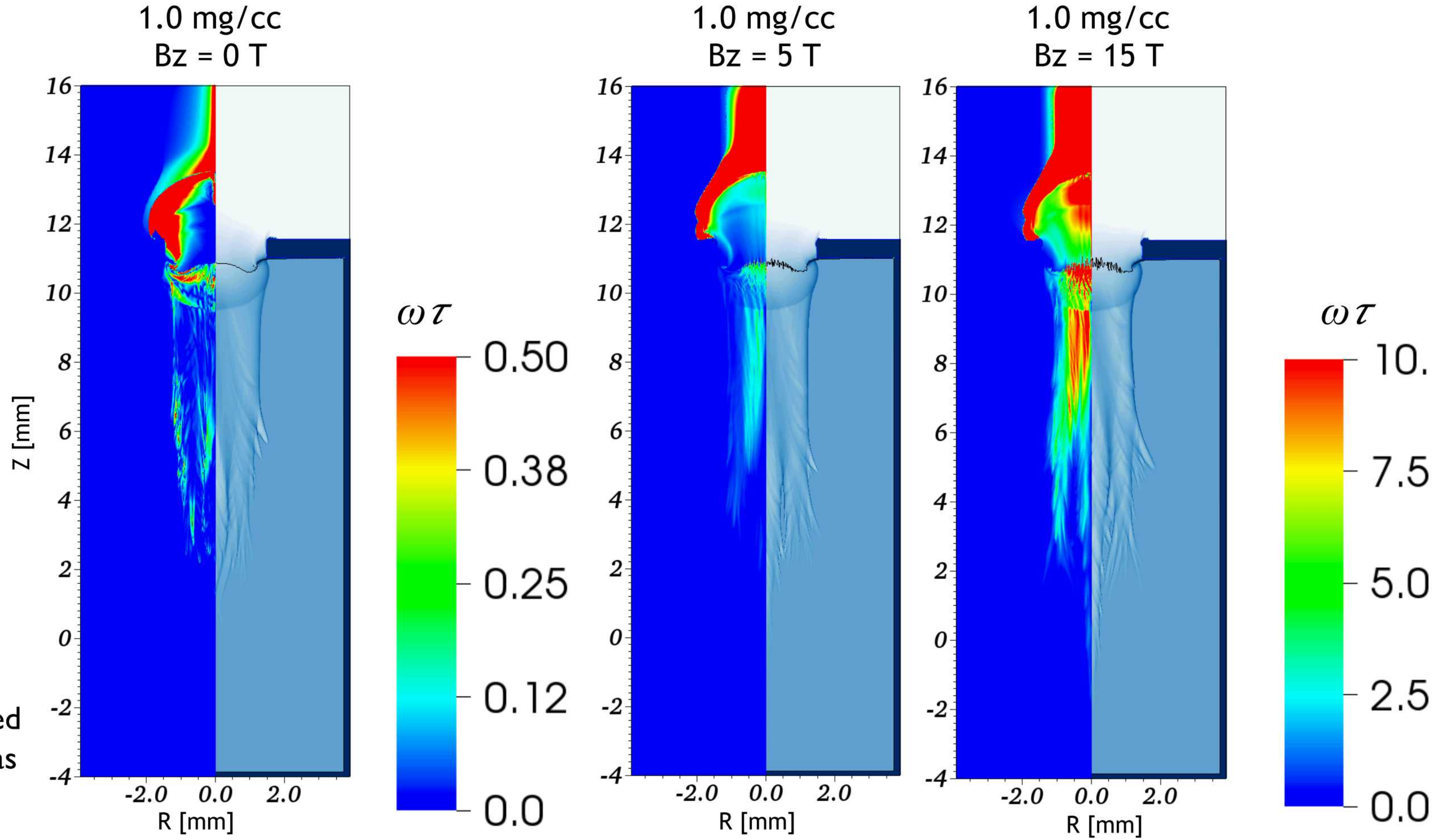


High preheat case has hotter temperatures => higher magnetization, thermal conductivity; higher peak field in the blast wave



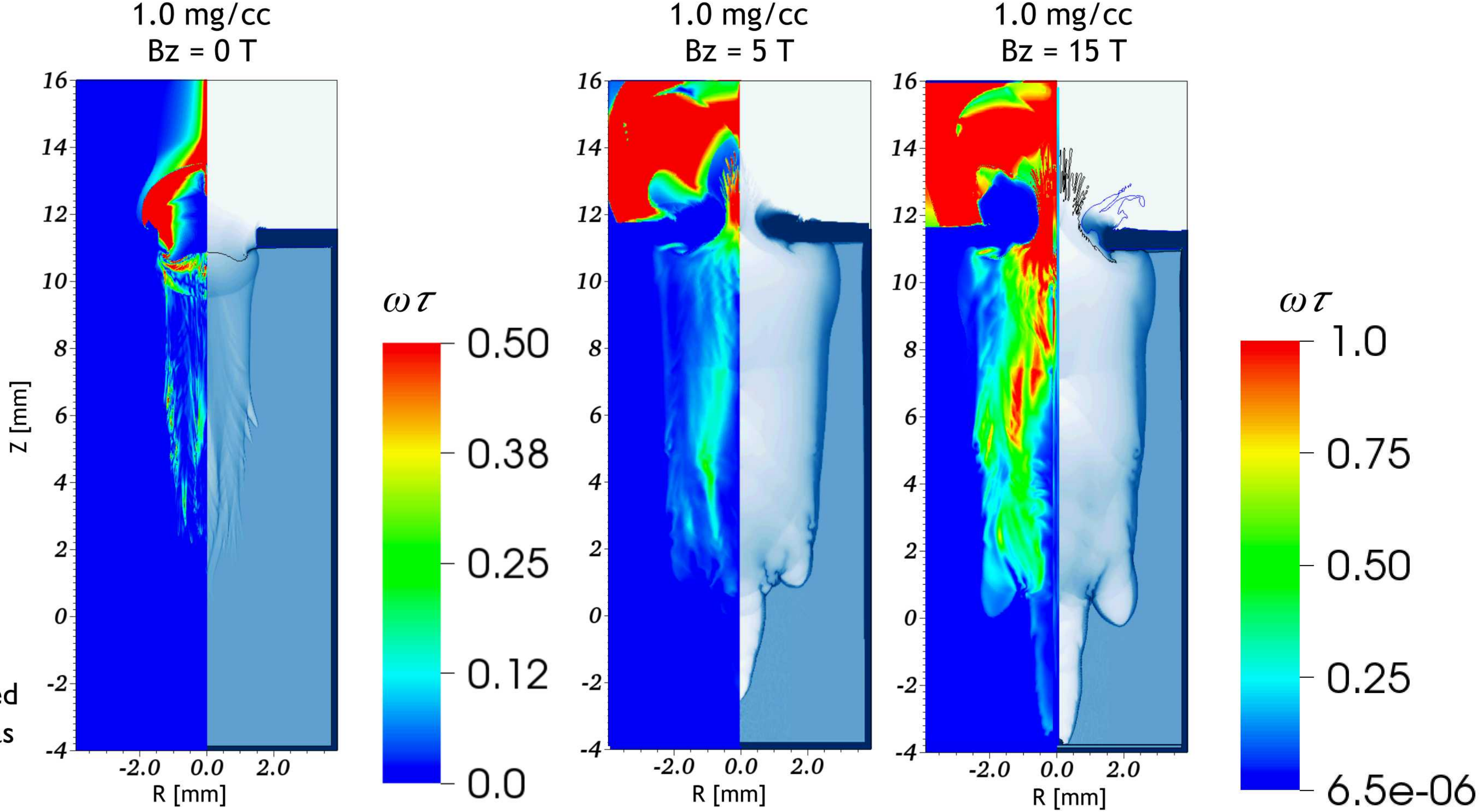
Solid curves are for high 5.2 kJ case at a time matched to the blast wave position for the 2 kJ case

At ZBL, the Biermann battery source is not expected to produce significant magnetization in deuterium



~ 1.6 kJ deposited in the gas

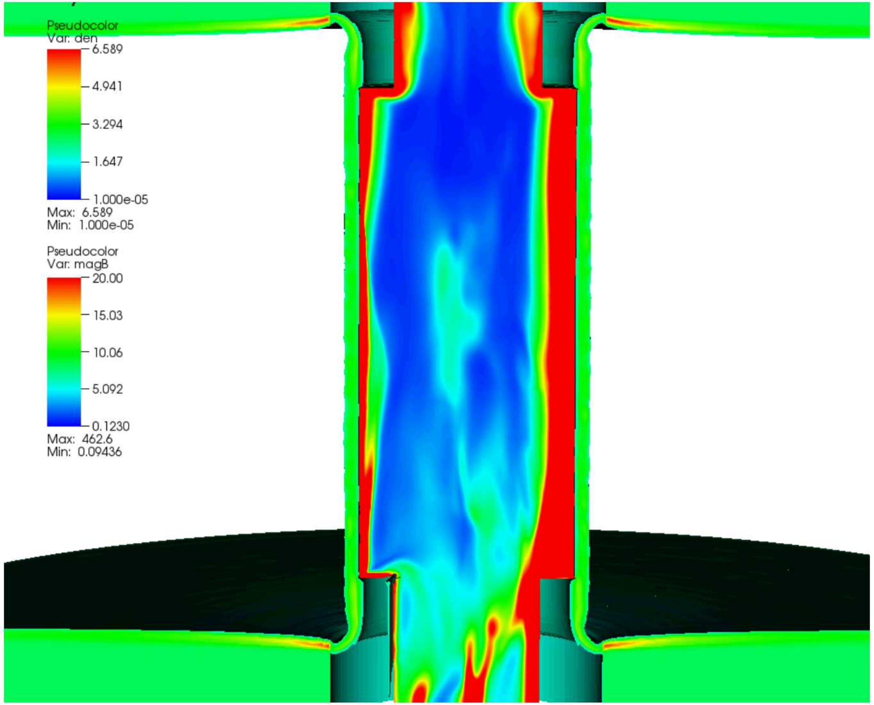
10 ns after ZBL heating, mild magnetization persists in the low density plasma and still exceeds peak magnetization from self-generated fields

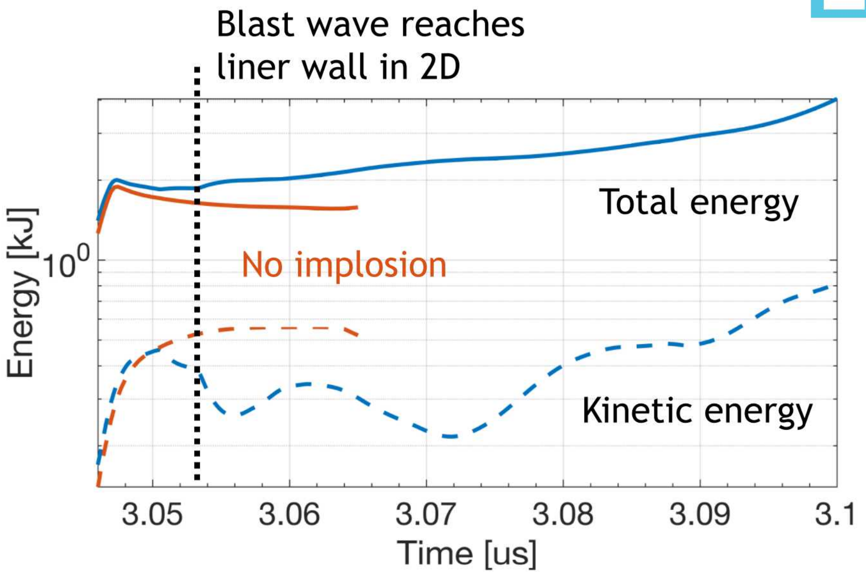


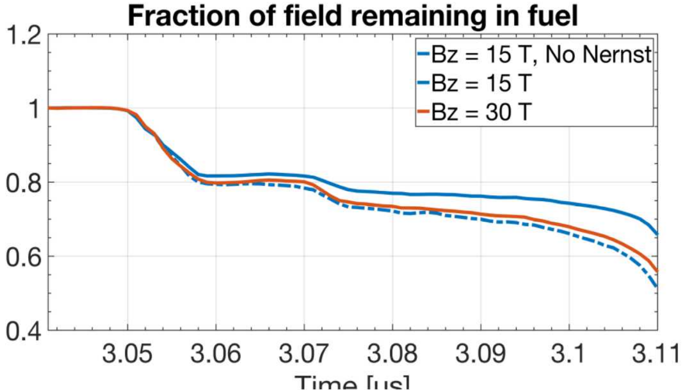
~ 1.6 kJ deposited in the gas

Laser only simulations were run past when the blast wave is expected to interact with the imploding liner wall

3D simulations show azimuthal asymmetry, but loses 5% more field than 2D after preheat but 300 J higher preheat

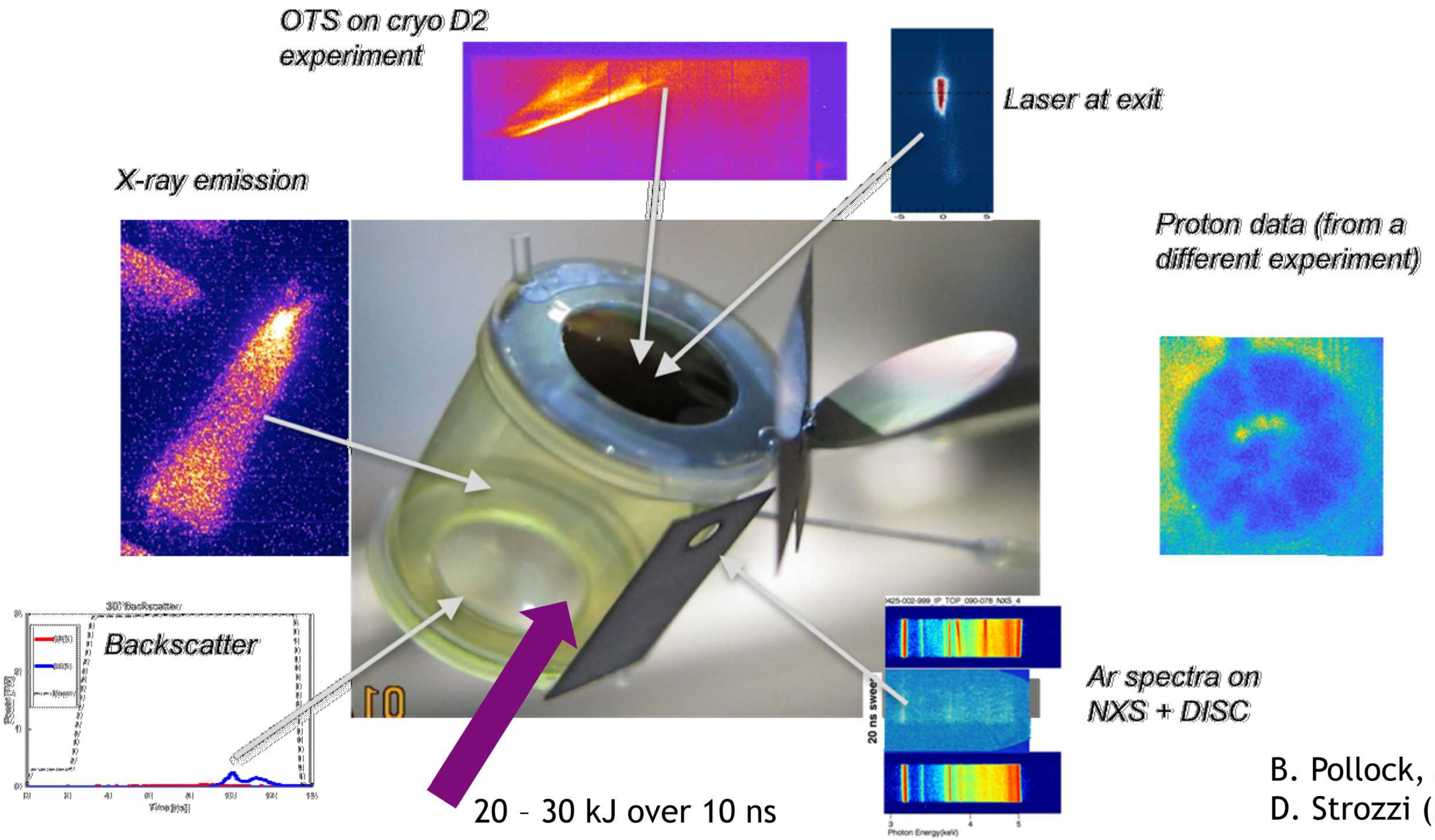






Open question: Does additional loss by Nernst ”seed” later losses during the implosion?

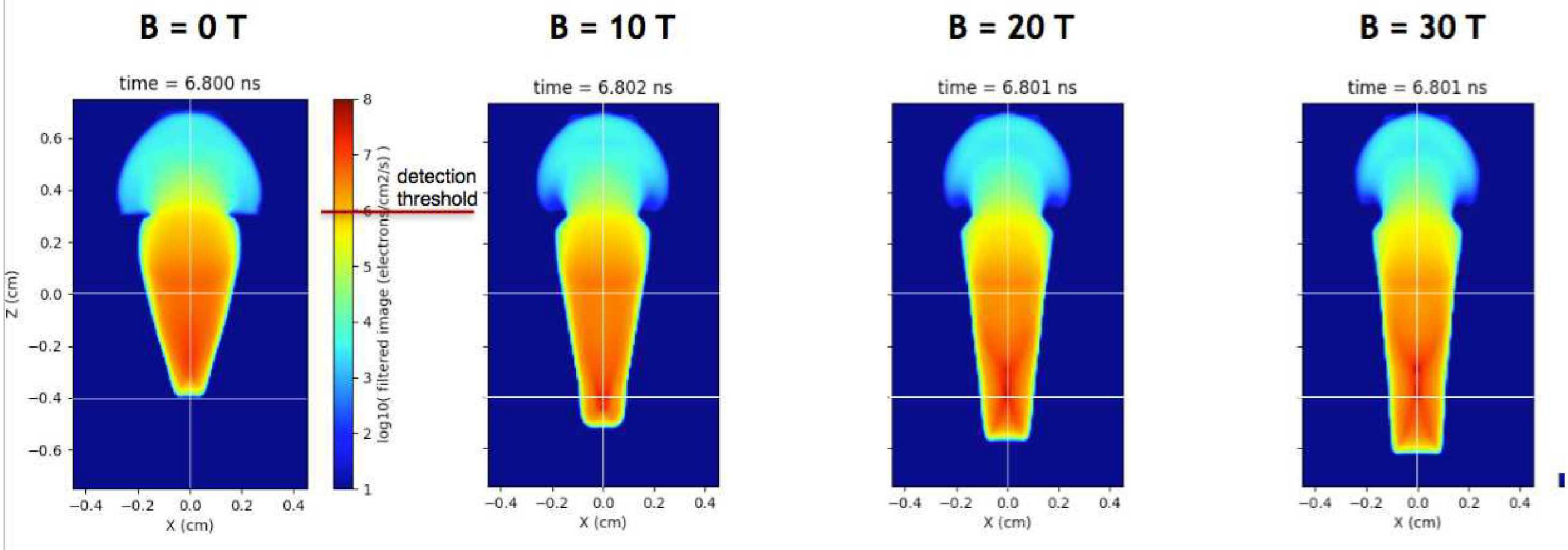
Building off 10 successful gas cell experiments, ***magnetized*** gas cell experiments are planned on the NIF by end of 2018 with warm hydrocarbon gas



B. Pollock, J. Moody, D. Strozzi (LLNL)

Building off 10 successful gas cell experiments, ***magnetized*** gas cell experiments are planned on the NIF by end of 2018 with warm hydrocarbon gas

Applied Bz is expected to have similar impact on the NIF experiments, as observed in ZBL simulations
Neopentane exaggerates the radial constricting effect of Bz



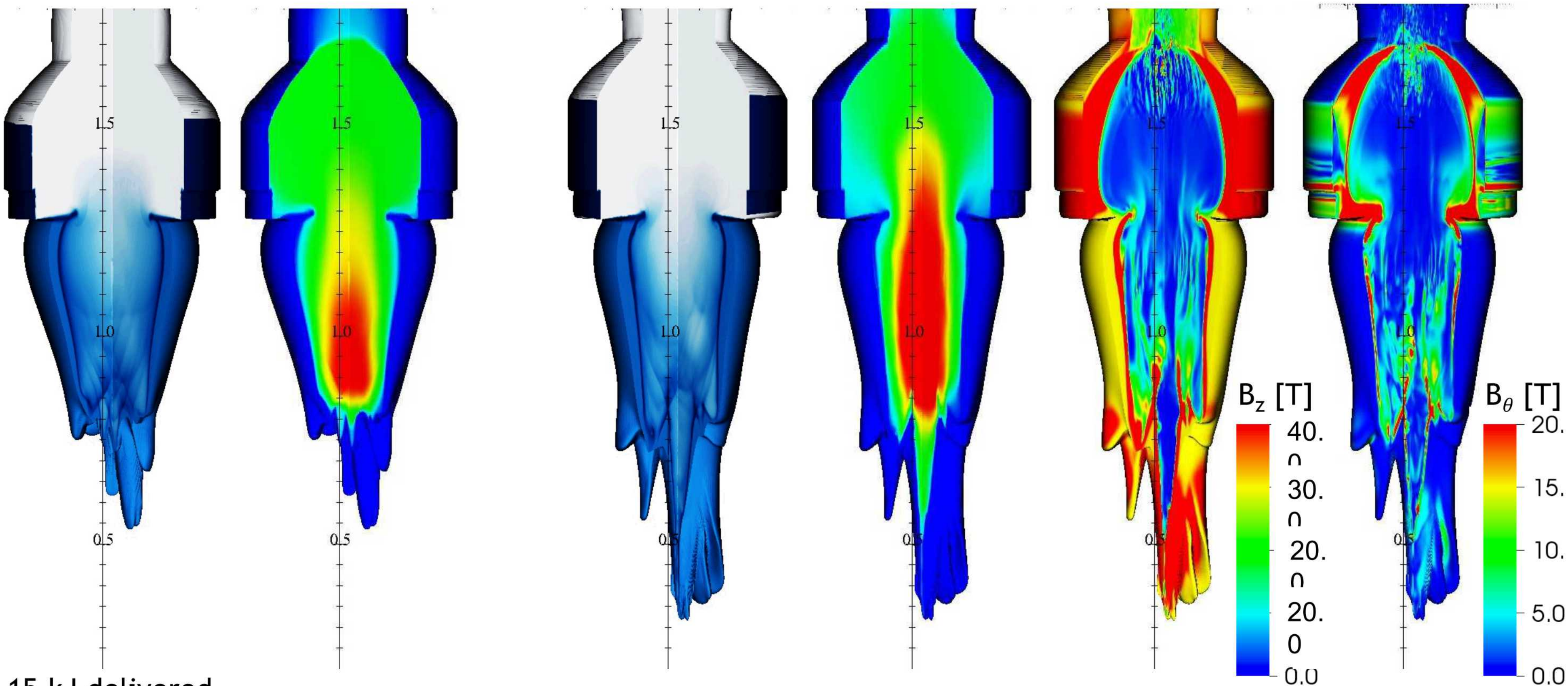
2.9 mg/cc C5H12

Simulations. by M. Glinsky

Similar effects are predicted on the NIF scale

12 % ncrit Neopentane, no MHD

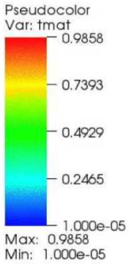
12 % ncrit Neopentane, Bz = 30T

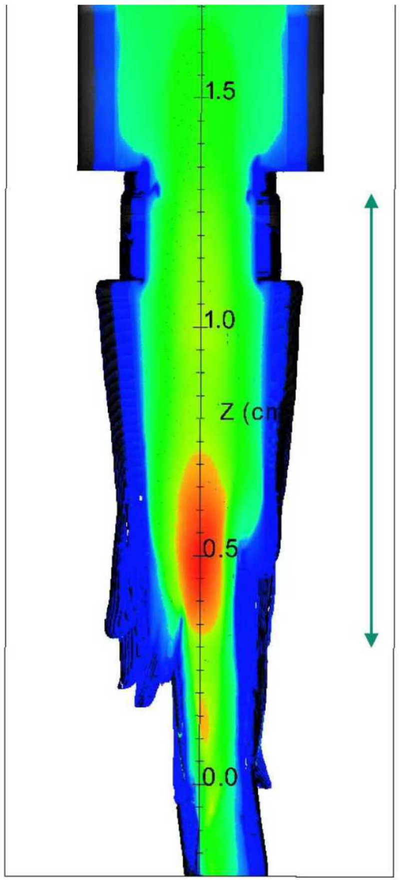


15 kJ delivered

Deuterium exhibits less beam break up and more whole beam focusing without magnetic fields

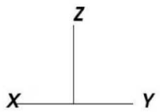
No MHD cases

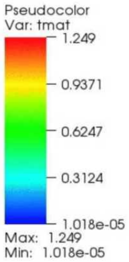


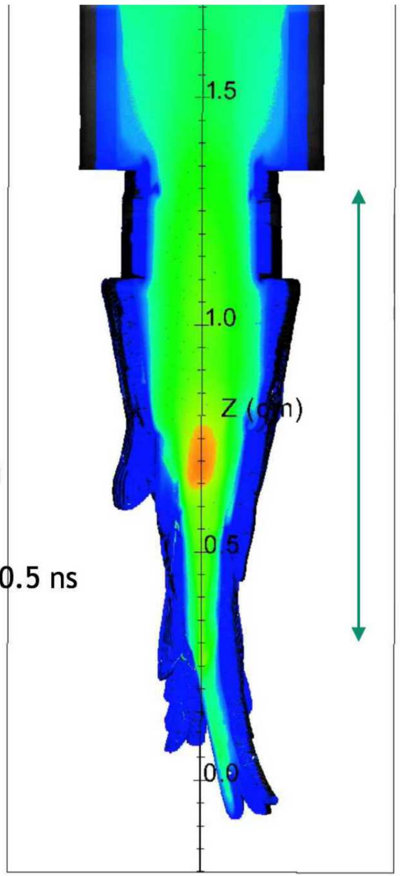


1 cm

Deuterium
2 atm
Burn thru
~ 6 ns +/- 0.5 ns

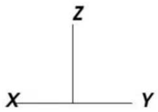






1 cm

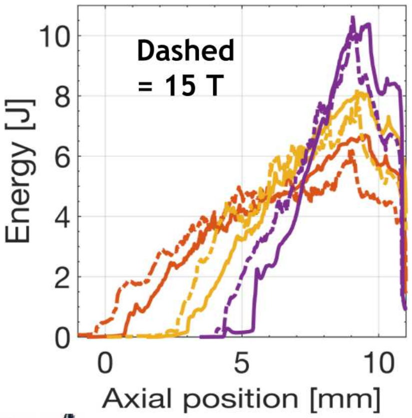
Deuterium
3 atm
Burn thru
~ 8 ns +/- 0.5 ns



Conclusions

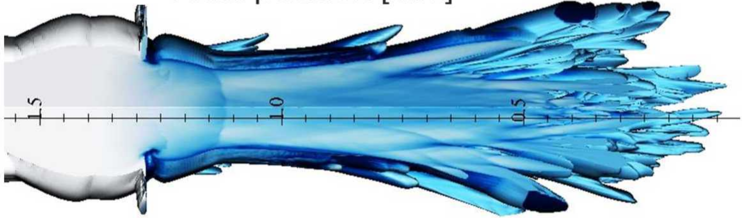
Applied magnetic fields extend the axial deposition of preheat energy by approximately 15 % compared to un-magnetized targets by restricting radial heat flow

- Leads to higher average and peak electron temperature



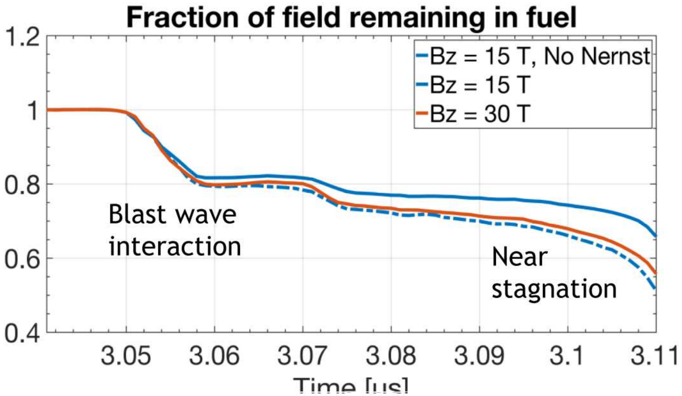
Reduction of thermal conduction and Nernst generate more thermal filamentation of the laser

- Higher intensities and shorter wavelengths can mitigate effect to some extent
- NIF will test this to some extent



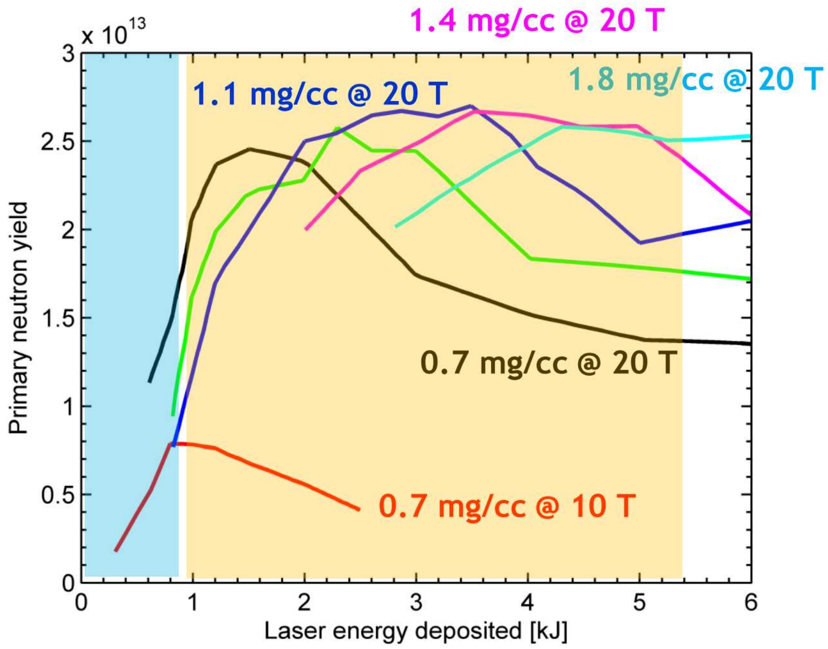
Nernst field loss to the liner is small during the blast wave phase both in 2D and 3D

- Very little experimental evidence models are accurate but MagLIF currently shows sufficient flux remains to magnetize fusion products



Summary

- 2D and 3D HYDRA simulations were performed over a range of densities and deposited energy to identify the impact of magnetic fields on preheat performance
- Design considerations:
  - Applied magnetic fields extend the axial deposition of preheat energy by approximately 15 % compared to un-magnetized targets by restricting radial heat flow
    - Leads to higher average and peak electron temperature
  - Applied magnetic fields enhance thermal filamentation of the laser by reducing thermal conduction
    - Associated problems are beam interaction with the liner wall and intensification leading to backscatter
  - Magnetic field is expelled from the core of the preheated plasma by Nernst and advection by the fluid motion
    - For the cases considered here, gradients are too small for Nernst to cause substantial loss of magnetic field to the liner
- NIF neopentane simulations show strong generation of Biermann fields in the gas and less beam break-up
- NIF deuterium simulations also show less beam break-up but more pronounced whole beam steering



Backups

General Simulation Input Parameters

ZBL gas fill is deuterium

NIF gas fills are deuterium and C5H12

ZBL polyimide window is 0.5 um thick

NIF polyimide window is 1.0 um thick

NIF Laser pulse is 0.25 TW 2 ns foot and 3 TW main pulse for 30 kJ on target

ZBL Laser Pulse