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Design and simulation of dynamic screw pinch experiments on the Z Facility

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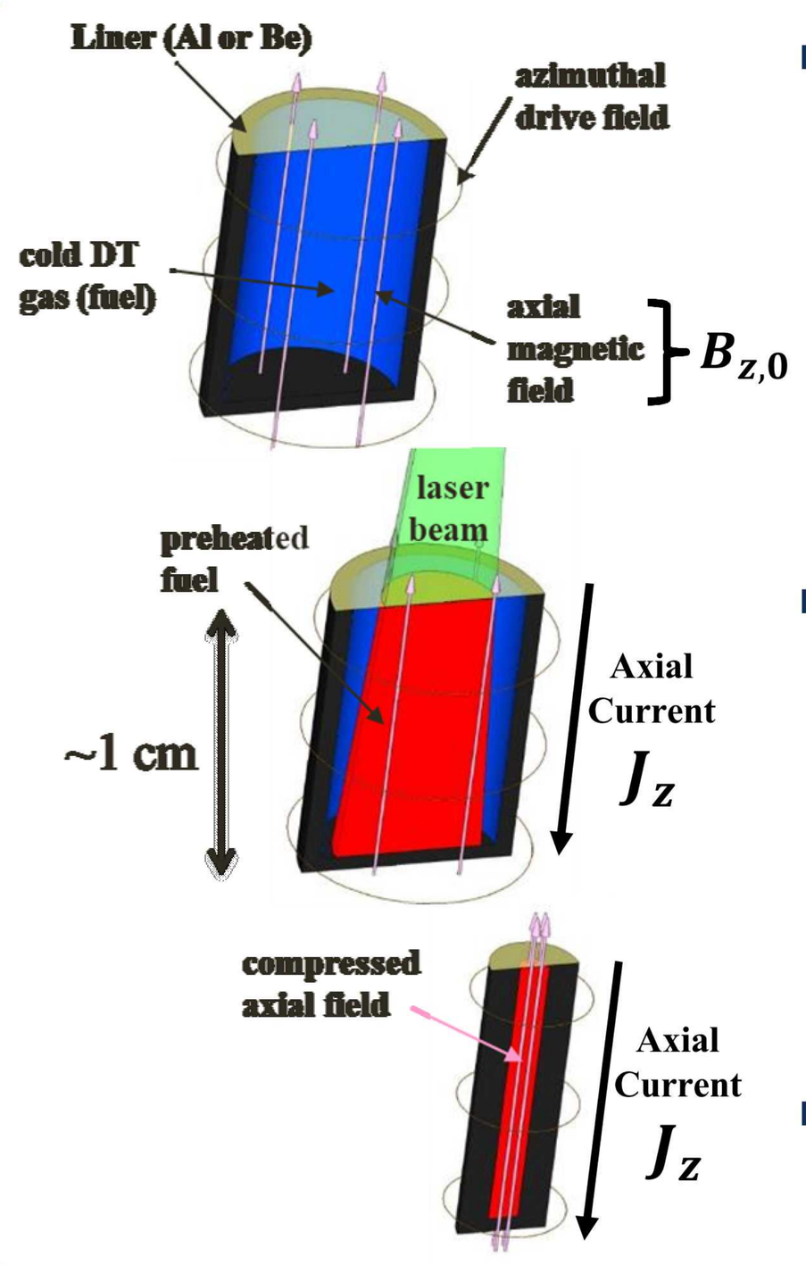
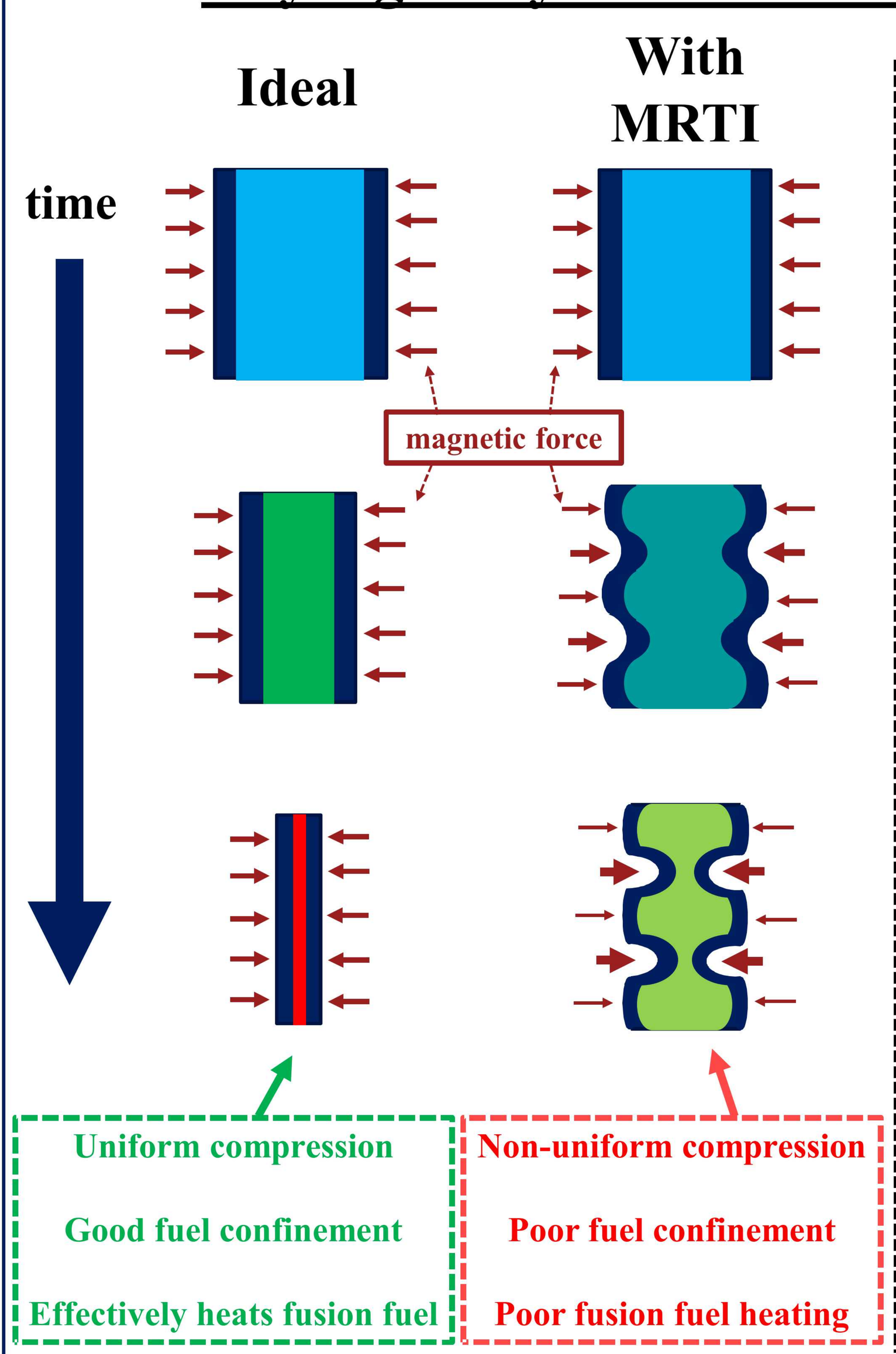
STEWARDSHIP SCIENCE GRADUATE FELLOWSHIP

Magnetized Liner Inertial Fusion (MagLIF[1]): Magnetic Compression of Premagnetized, Laser-Preheated Fusion Fuel

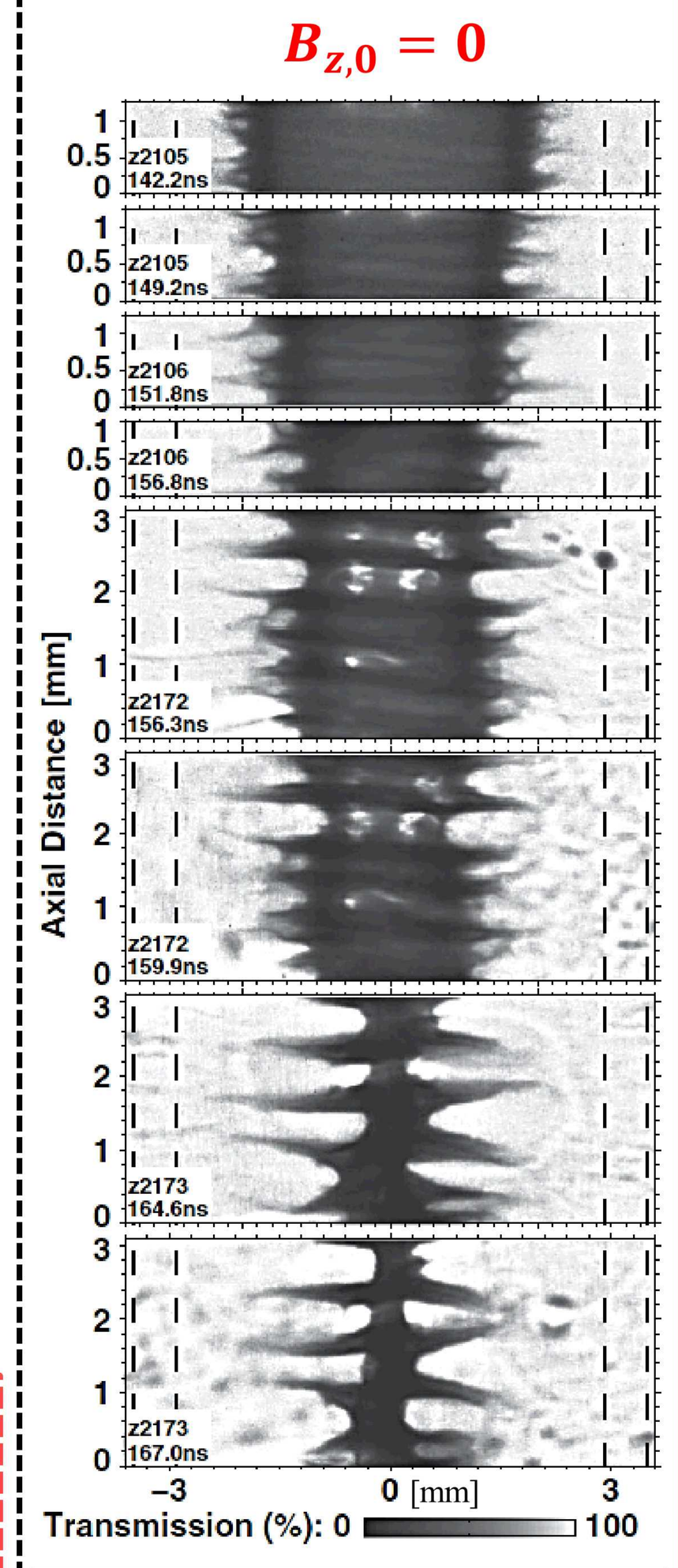


- An initial 10-30 T axial magnetic field is applied by external coils
  - Inhibits thermal conduction losses
  - May help stabilize implosion at late times
- The Z-Beamlet Laser (~ 4 kJ) heats the fuel
  - Reduces compression and implosion velocity needed for significant fusion yield
- Z Machine implodes the liner with ~ 18 MA of current in 100 ns

Imploding Liners Suffer From Magnetized Rayleigh-Taylor Instabilities (MRTI)



Radiographs



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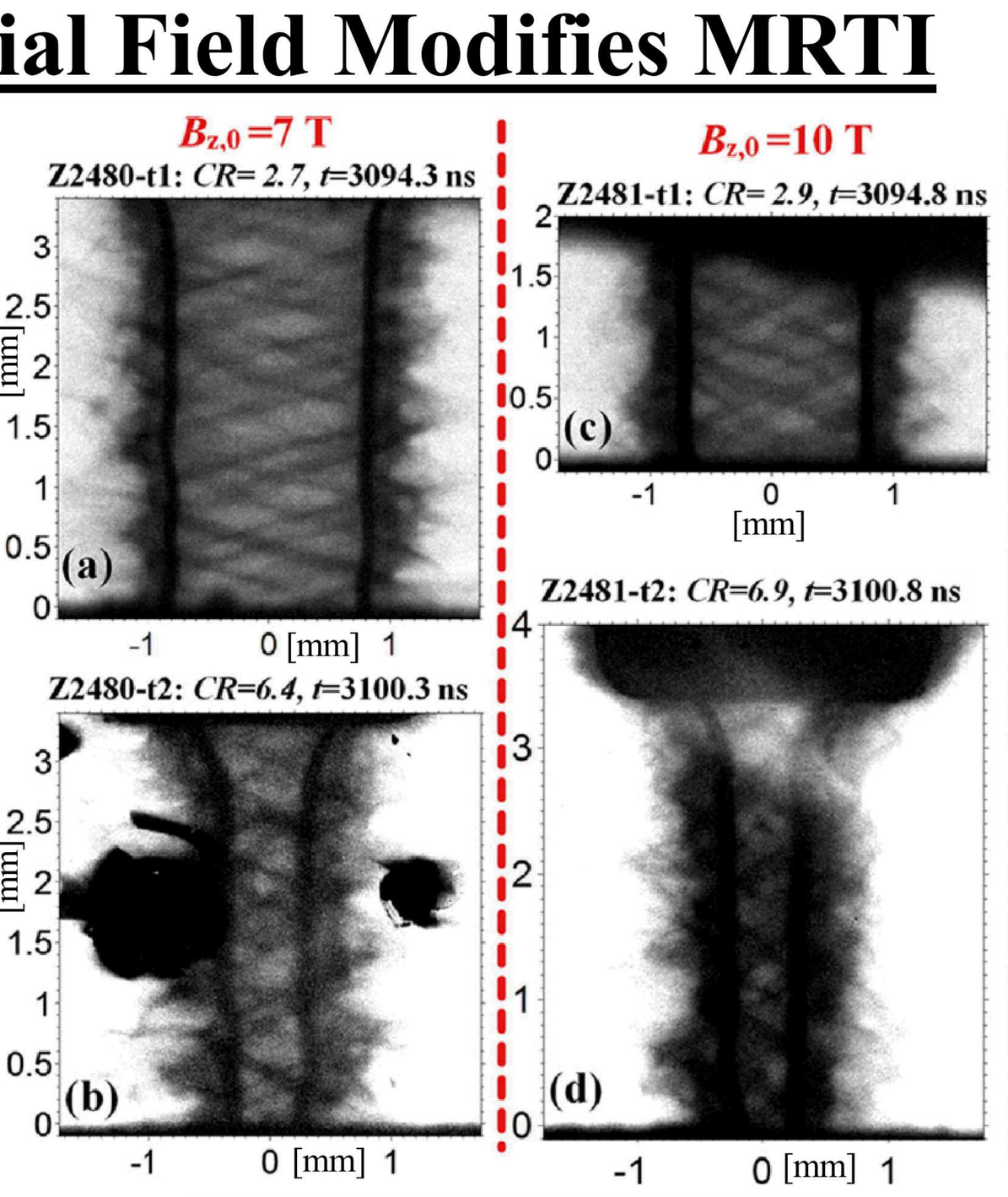
Background, Static Axial Field Modifies MRTI

$B_{z,0}$ improves liner implosion stability compared to unmagnetized implosions.

MRTI growth is modified, ***not eliminated***

Origin and evolution of helical MRTI apparent in MagLIF is not well understood



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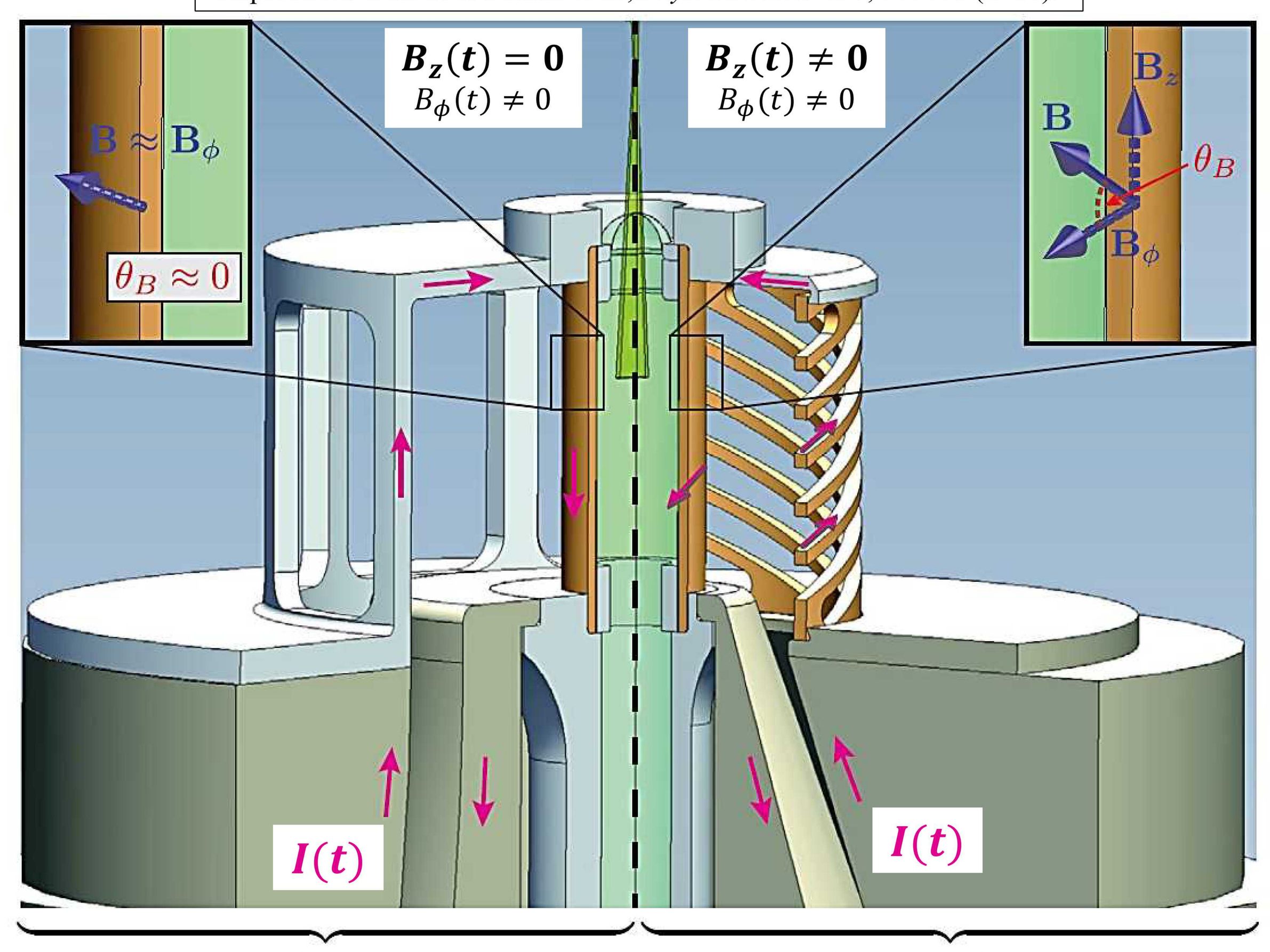
Addition of Dynamic Axial Magnetic Field Component Results in a Helical Drive Field

Reproduced from P. F. Schmit et al., *Phys. Rev. Lett.* **117**, 205001 (2016).



Drive Field Polarization

$$\theta_B(t) = \tan^{-1}[\Pi(t)] = \tan^{-1}\left[\frac{B_z(t)}{B_\phi(t)}\right]$$

$B_z(t) \propto I(t)$

$B_\phi(t) \propto \frac{I(t)}{r_l(t)}$

Drive Field Ratio

$$\Pi(t) = \frac{B_z(t)}{B_\phi(t)}$$

$I(t)$ = current flowing through liner
$r_l(t)$ = liner outer radius at time t

As liner implodes ($r_l(t)$ decreases), the drive magnetic field rotates, shifting the fastest growing MRTI modes as a function of time.

MRTI growth is reduced via a Solid Liner Dynamic Screw Pinch[2] (SLDSP)

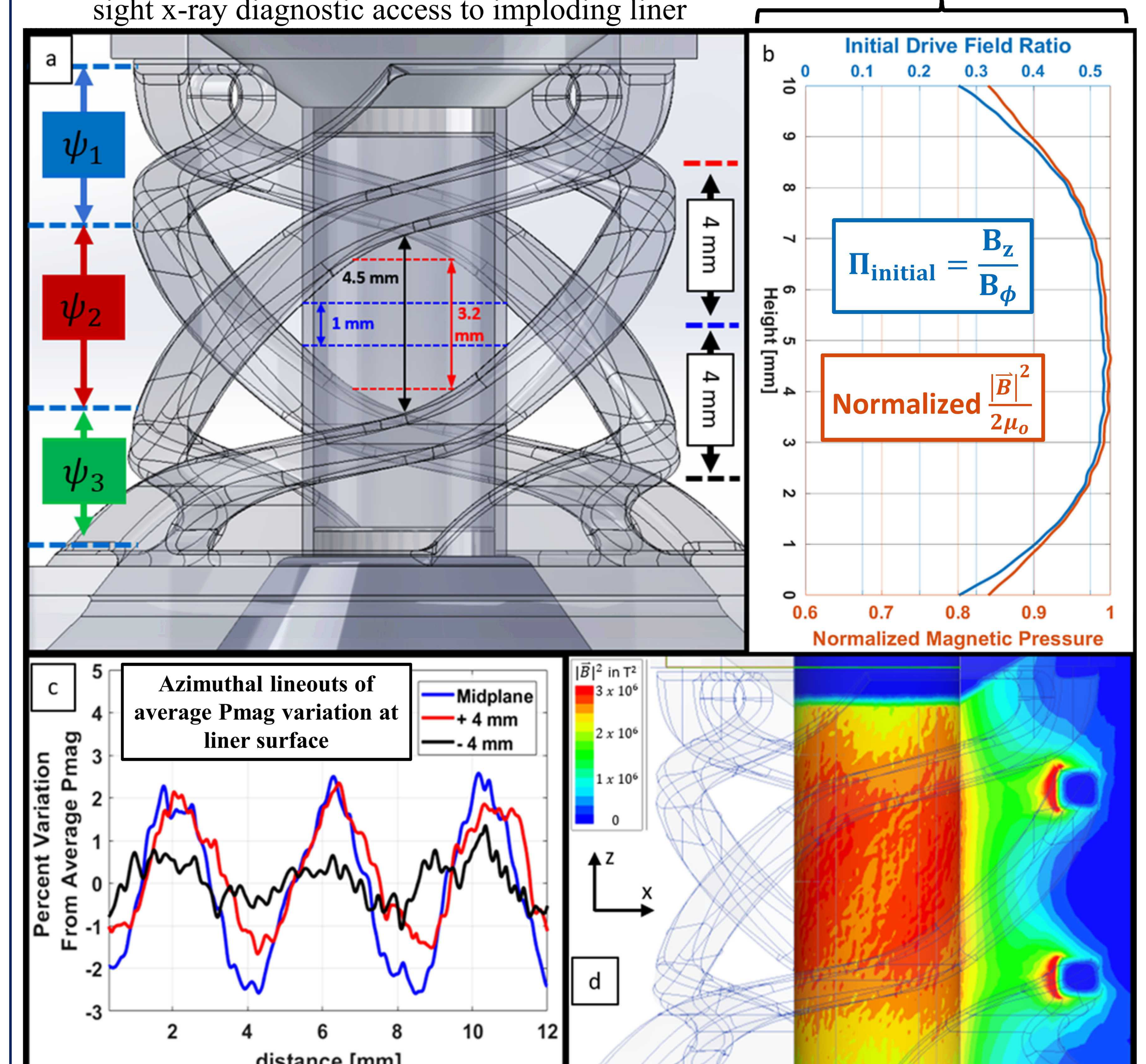
3D Simulations Have Helped to Establish the Physics Design Basis[3] for MagLIF-based Experiments on the Z Facility

Transient Magnetic ANSYS Maxwell Simulations

Candidate Design for MagLIF

Multiple-pitch angle helical posts provide line of sight x-ray diagnostic access to imploding liner

Drive field ratio and magnetic pressure have axial dependence

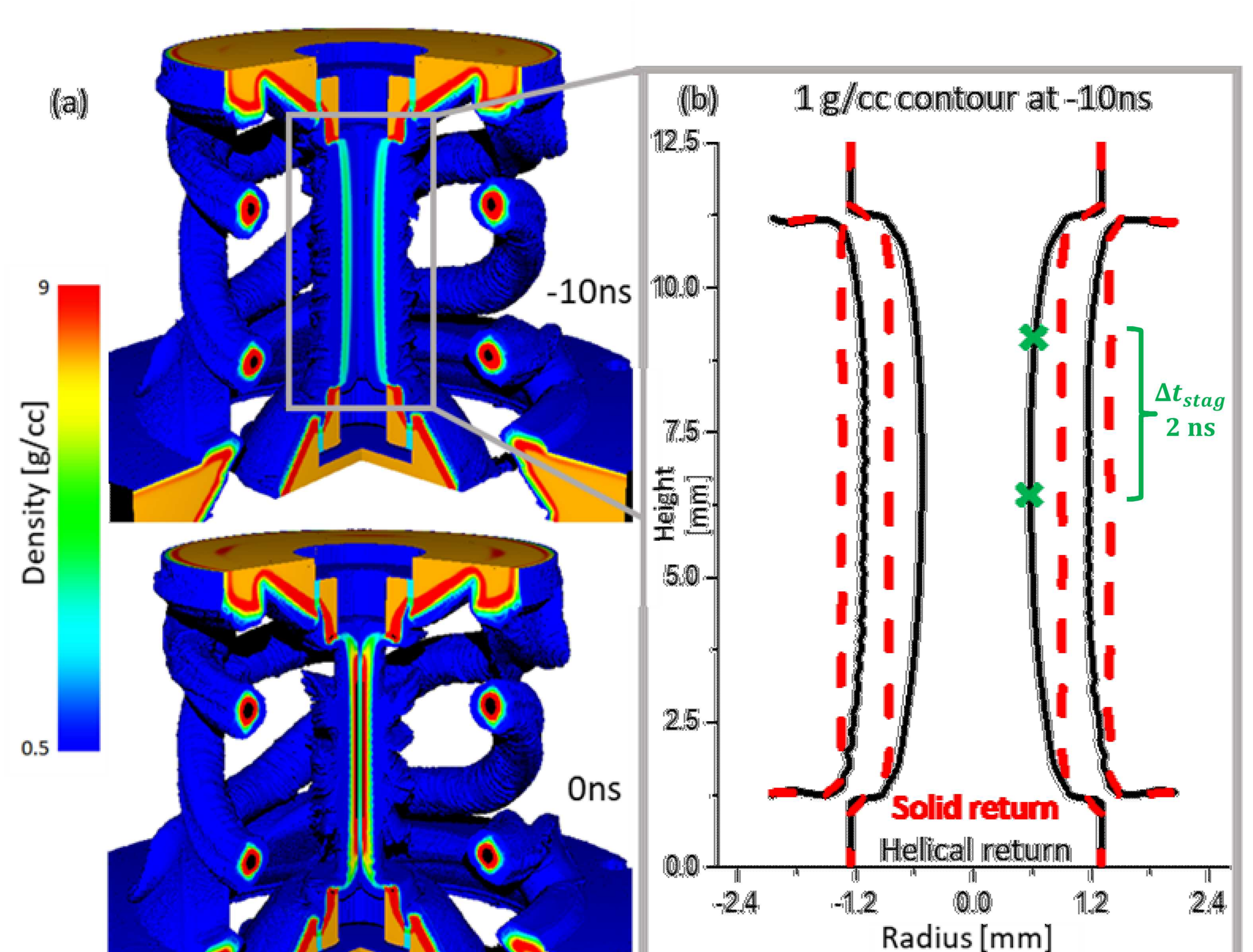


Distribution of magnetic pressure at the liner outer surface suggests that SLDSP experiments will drive helical MRTI modes.

Axial non-uniformity of magnetic pressure will drive the midplane harder than the ends of the liner.

Implosion Simulations in GORGON

3D radiation-magnetohydrodynamic (rad-MHD) simulations indicate that the liner is effectively imploded when helical return posts are used.



Helical posts experience substantial magnetic force throughout the experiment.

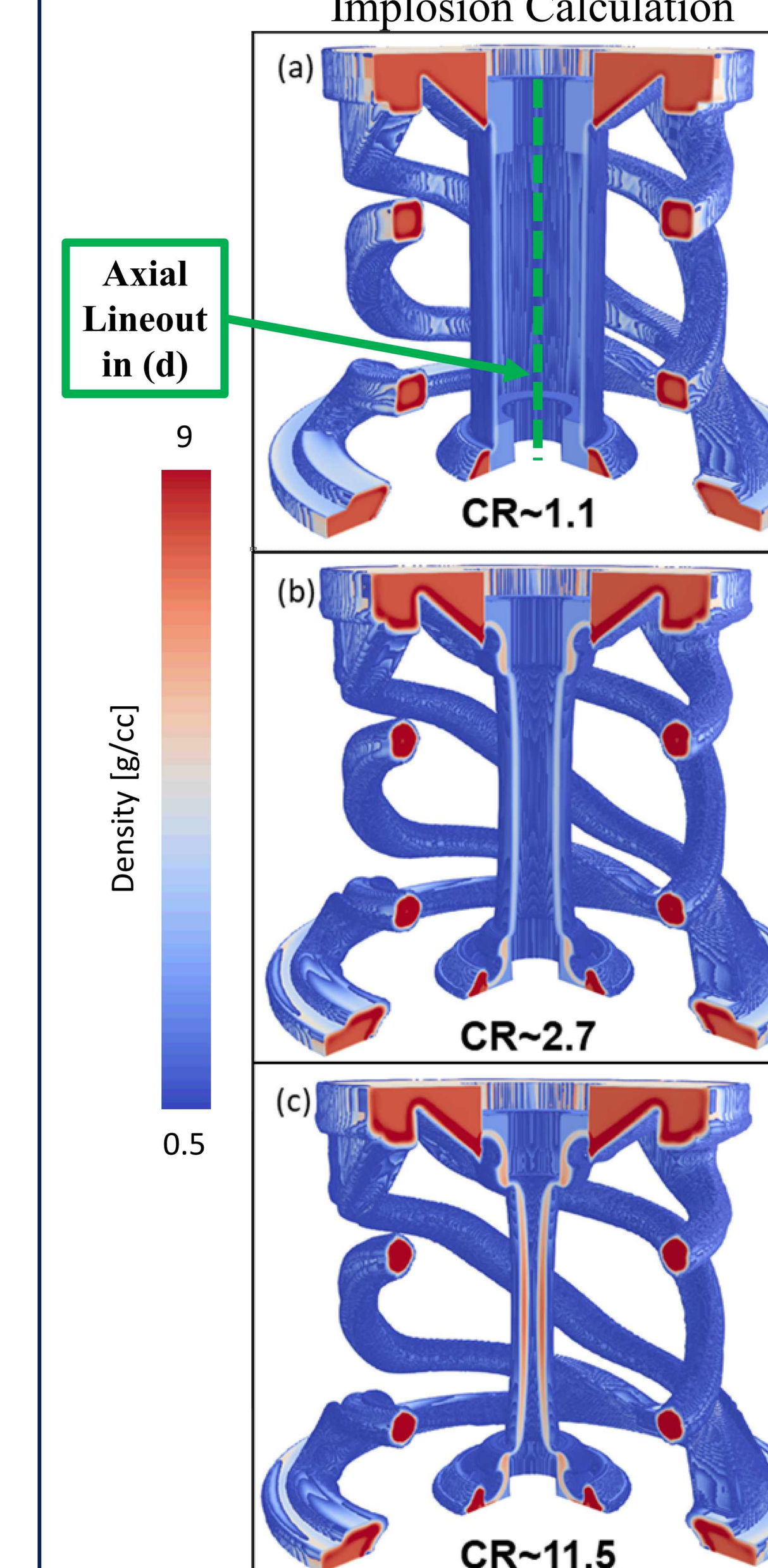
If a dense, low conductivity metal is used (stainless steel), simulations indicate that helical posts remain intact throughout the course of the experiment.

Non-uniformity of magnetic pressure results in a bowing effect in the imploding SLDSP liner compared to normal MagLIF.

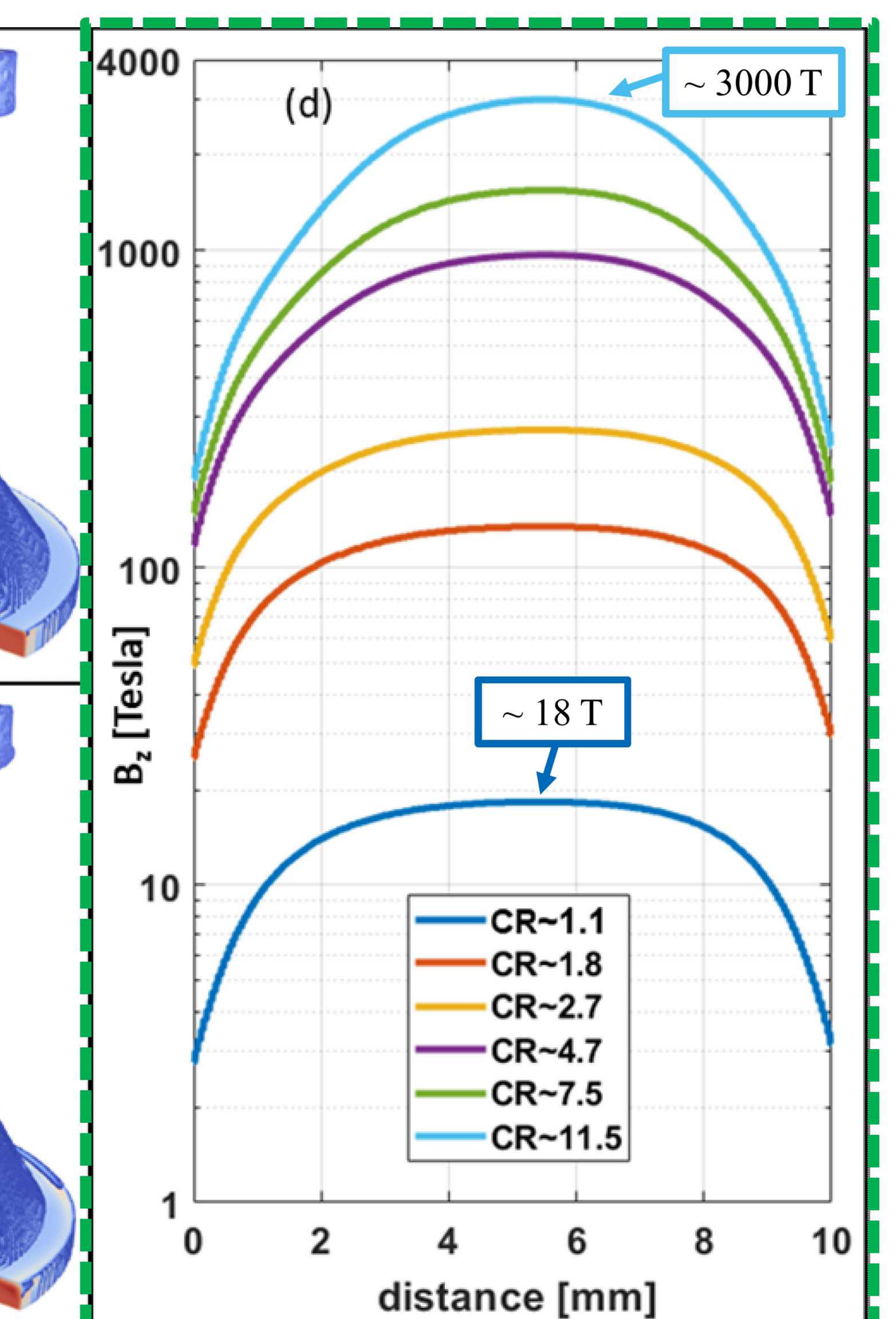
2 ns difference in stagnation time (t_{stag}) between liner midplane and 3 mm above midplane (marked with x)

3D ALEGRA Simulations[3] Enabled Study of Dynamic Field Distribution and MRTI Growth

Resistive MHD ALEGRA Implosion Calculation



Lineouts of Axial Field on Axis

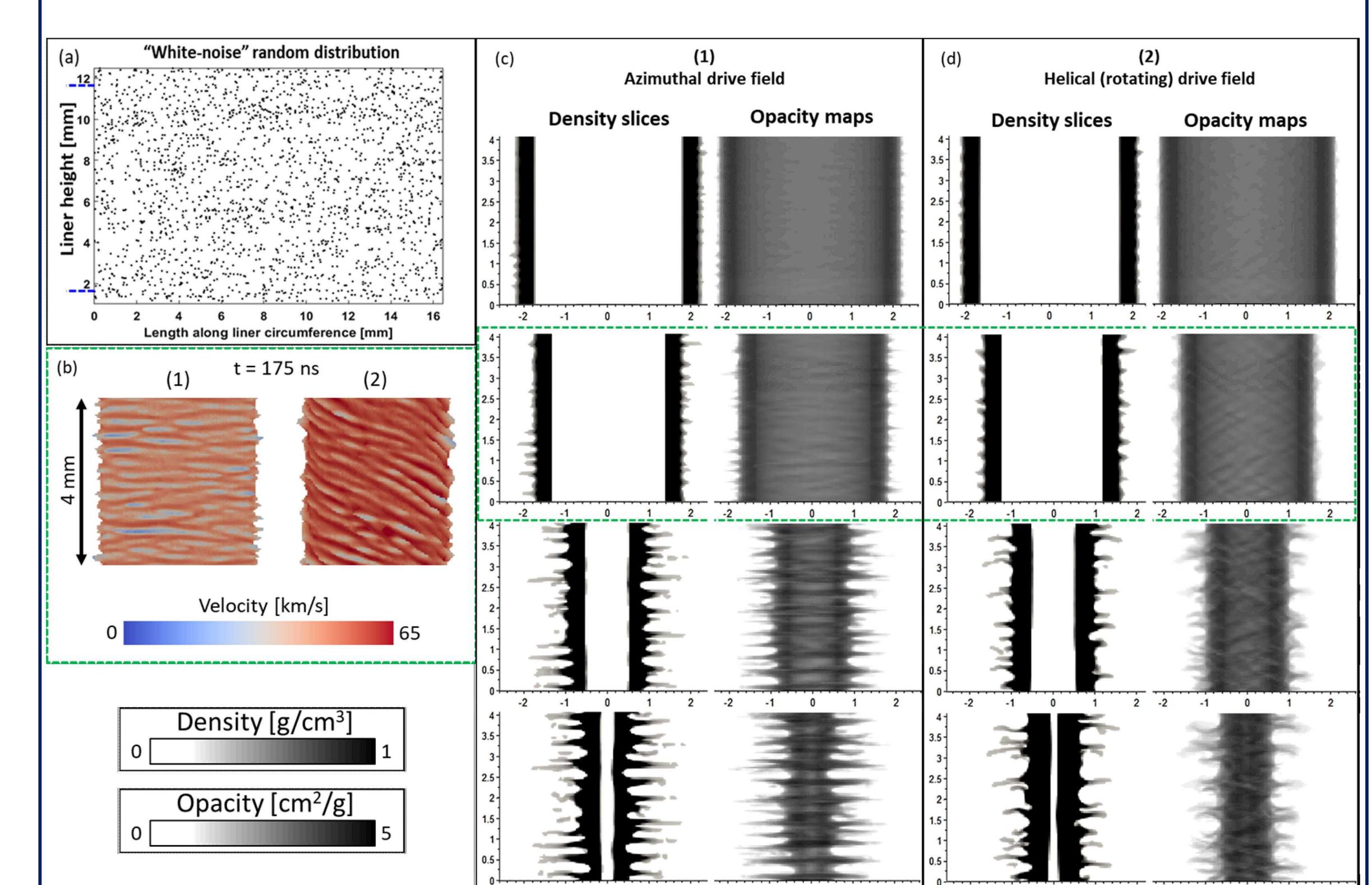


$$\text{CR} = \frac{r_{l,in}(0)}{r_{l,in}(t)}$$

$r_{l,in}(0)$ = initial inner liner radius
$r_{l,in}(t)$ = liner inner radius at time t

Significant axial magnetic field is injected inside of the liner and compressed during implosion.

This mechanism[4] could potentially premagnetize the fuel in MagLIF.



ALEGRA simulations demonstrate expected orientation of MRTI (azimuthal and helical) and an ~XX reduction in MRTI amplitude near stagnation for the helical (rotating) drive field case

References

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[2] P. F. Schmit, A. L. Velikovich, R. D. McBride, and G. K. Robertson, Phys. Rev. Lett. **117**, 205001 (2016).

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[4] P.-A. Gourdain, M. B. Adams, J. R. Davies, and C. E. Seyler, Physics of Plasmas **24**, 102712 (2017).

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