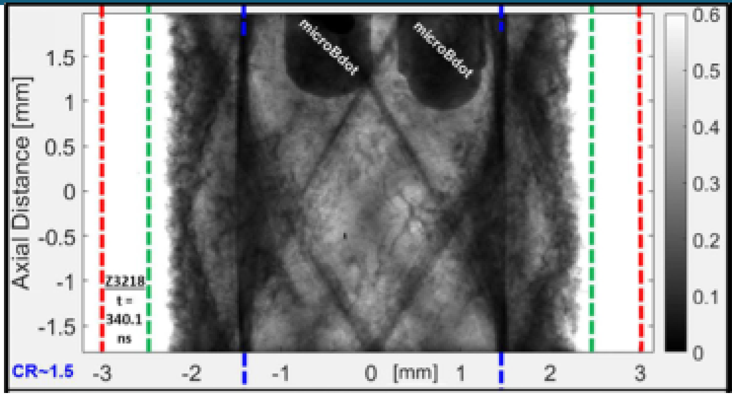
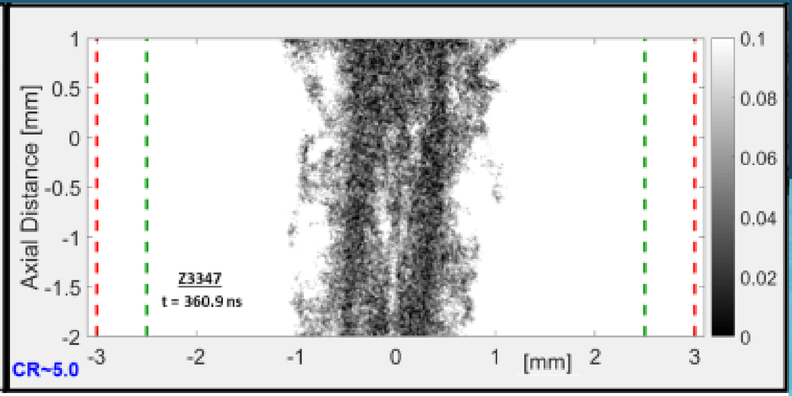
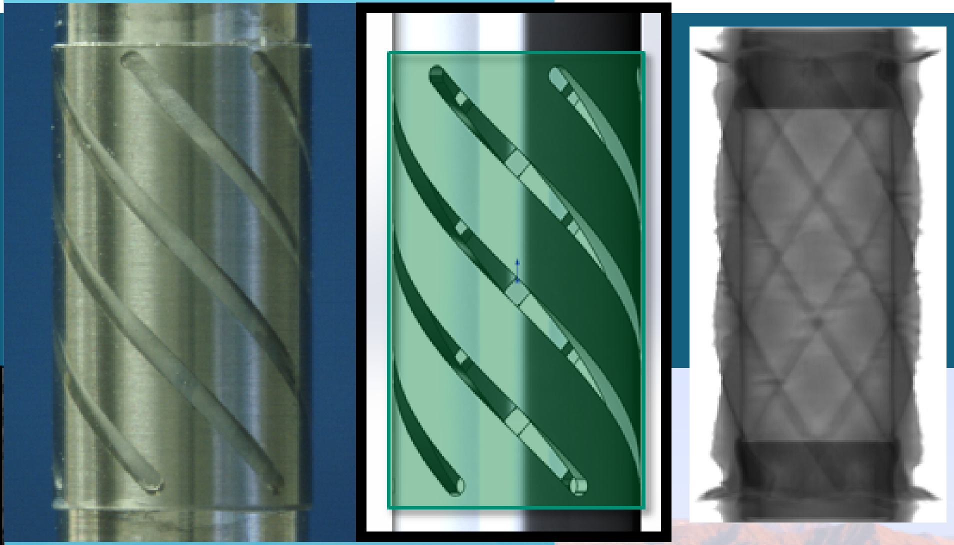
SAND2021-10047C

Sandia National Laboratories

Three-dimensional magnetohydrodynamic modeling of auto-magnetizing liner implosions







PRESENTED BY

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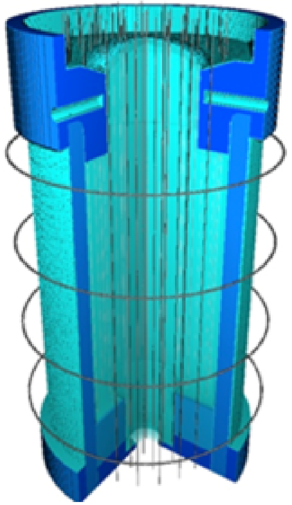
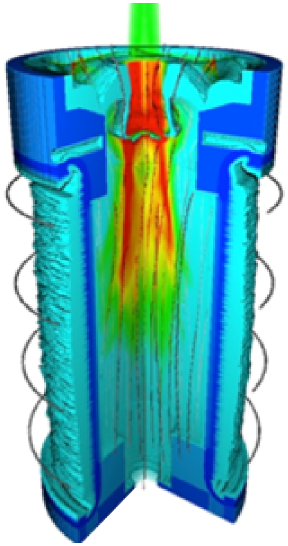
SAND2021- XXXX

Magnetized Liner Inertial Fusion (MagLIF[1]): Magnetic compression of premagnetized, laser-preheated fusion fuel



- **Premagnetization[2]: 10-20 T quasi-static axial magnetic field, $B_{z,0}$, is applied to thermally insulate fuel**

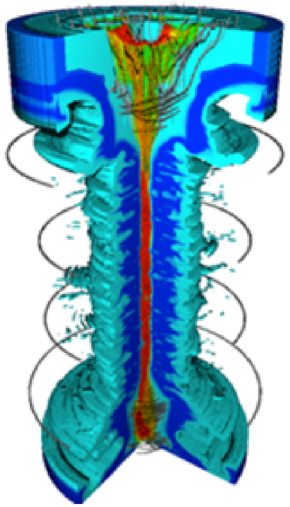
Reduces required implosion velocity compared to laser ICF



- **Laser preheat[3]: The fuel is pre-heated using the Z-Beamlet Laser (4 kJ)**

Reduces required compressive heating compared to laser ICF

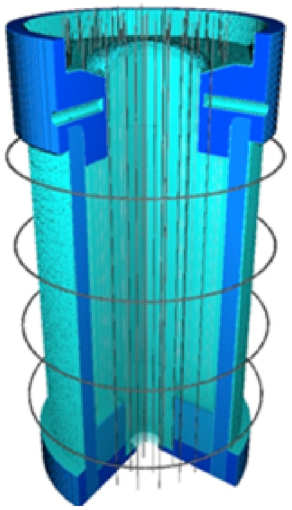
Deuterium-gas-filled beryllium liner (cylindrical tube)



- **Compression: Z Machine drive current implodes liner, ~18 MA in 100 ns**
  - **Adiabatically compresses fuel to thermonuclear conditions**

[1] S. A. Slutz et al., Phys. Plasmas **17**, 056303 (2010). [2] Rovang et al., Rev. Sci. Instrum. **85**, 124701 (2014). [3] Harvey-Thompson et al., Phys. Plasmas **26**, 032707 (2019).

Magnetized Liner Inertial Fusion (MagLIF[1]): Magnetic compression of premagnetized, laser-preheated fusion fuel

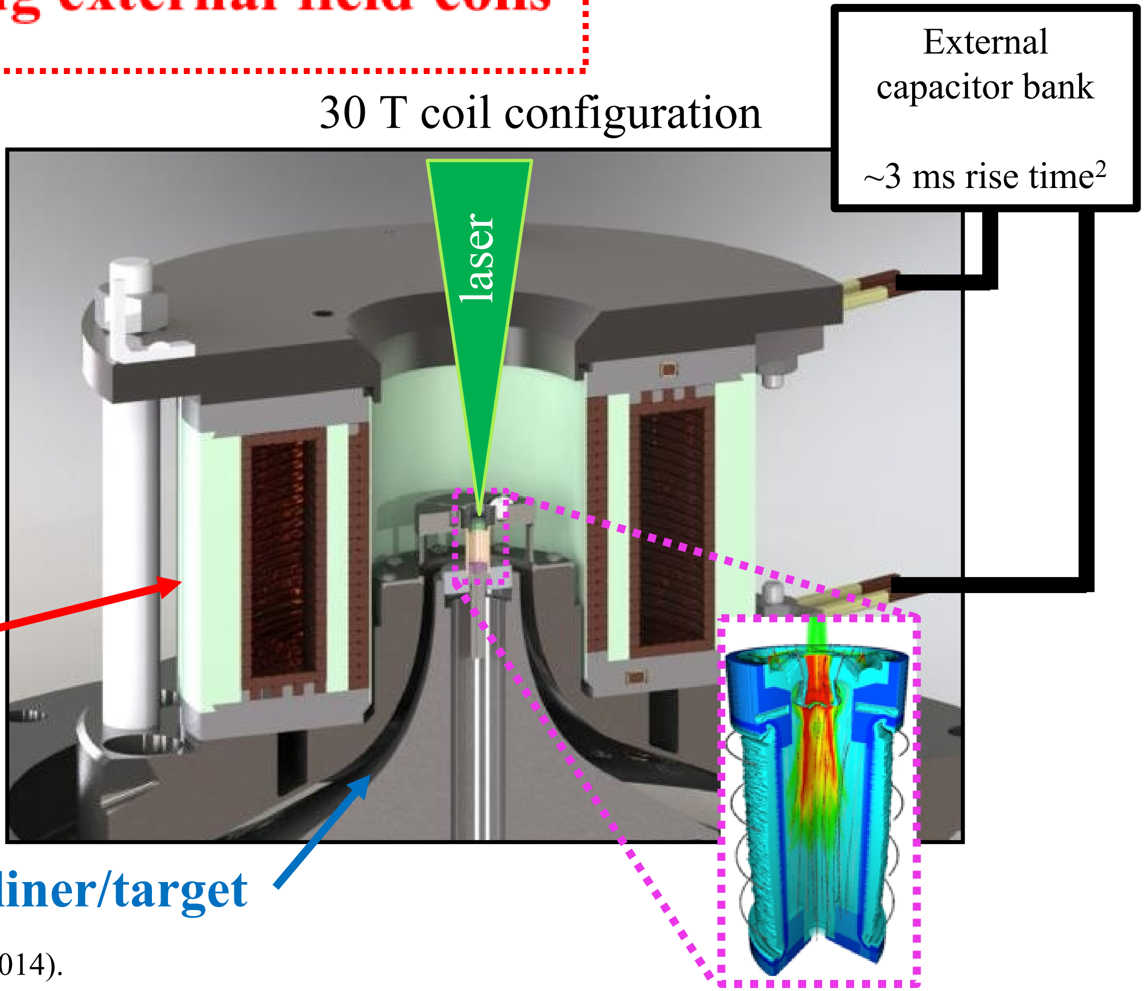


Nearing upper limit using coils

- **Premagnetization[2]: 10-20 T quasi-static[2] axial magnetic field, $B_{z,0}$, is applied using external field coils**

Calculations[1] indicate that $B_{z,0}$ = 30-50 T would improve thermal insulation of fuel and increase fusion yield

30 T coil configuration



Copper coils block radial x-ray diagnostic access

Extended pulsed power feed reduces current coupling to liner/target

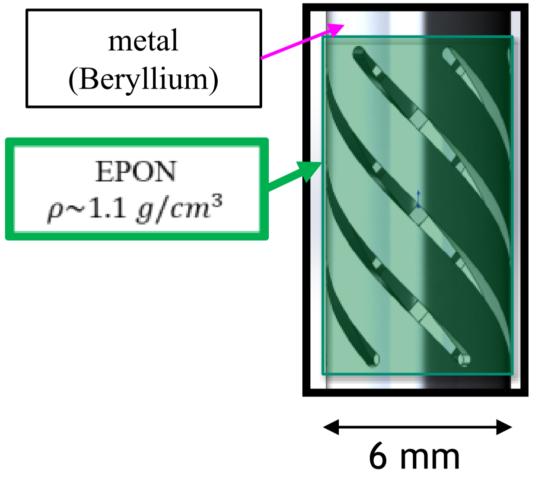
[1] S. A. Slutz et al., Phys. Plasmas **17**, 056303 (2010). [2] Rovang et al., Rev. Sci. Instrum. **85**, 124701 (2014).

Auto-magnetizing (AutoMag) liners offer an alternative to external coils with several potential advantages

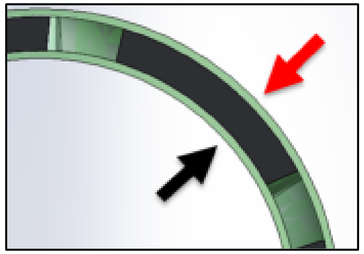
Eliminate coils

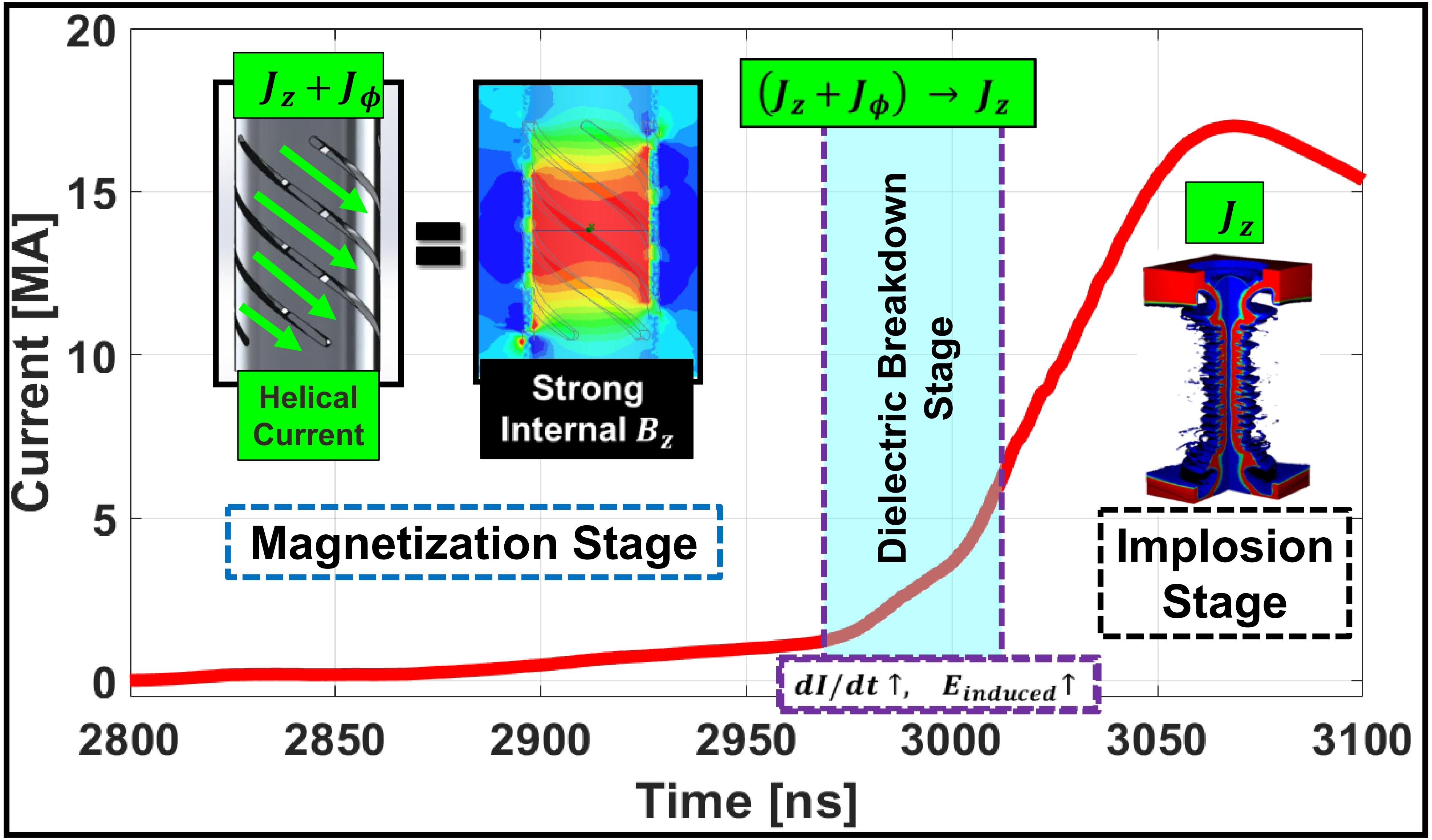
Magnetize the target using the pulsed power driver

AutoMag liner



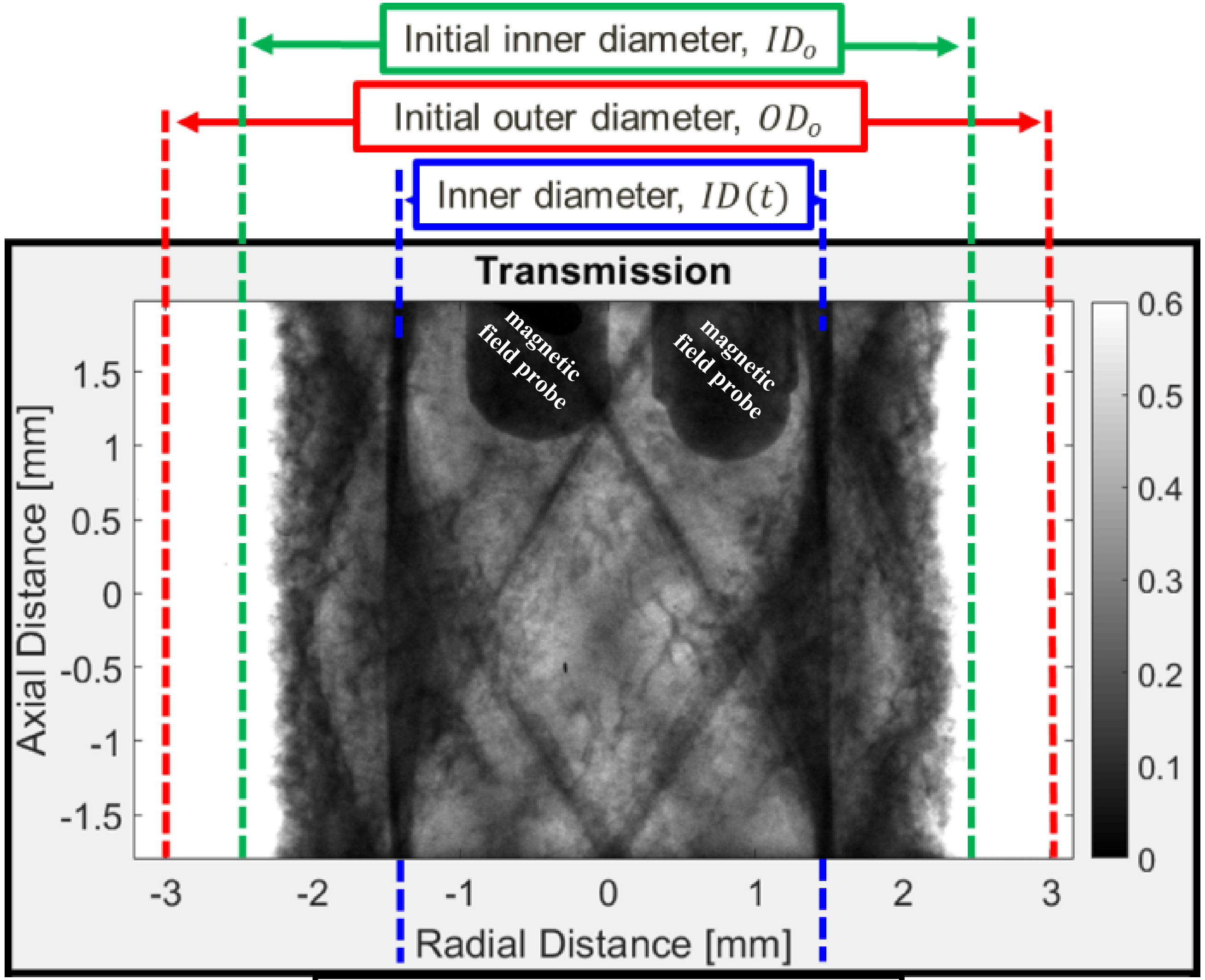
top view



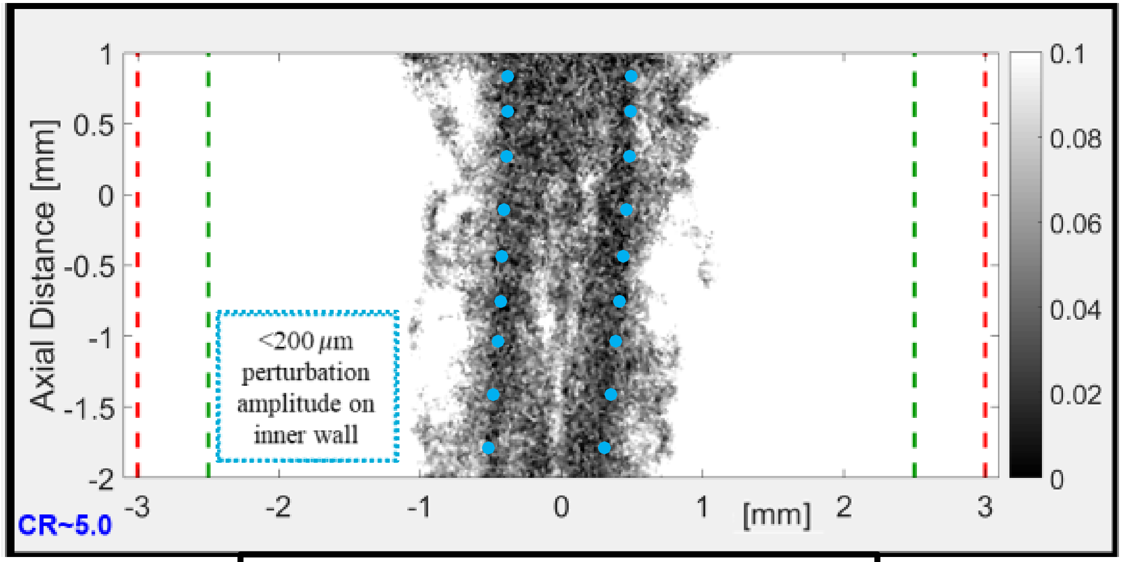


G. A. Shipley et al., *Physics of Plasmas* **25**, 052703 (2018). S. A. Slutz et al., *Phys. Plasmas* **24**, 012704 (2017).

Radiography* diagnosed implosion dynamics of first ever AutoMag liners on Z - *a unique dataset for multi-physics code comparisons*



Z3218 Frame 1, CR ~ 1.5



Z3347 Frame 2, CR ~ 5

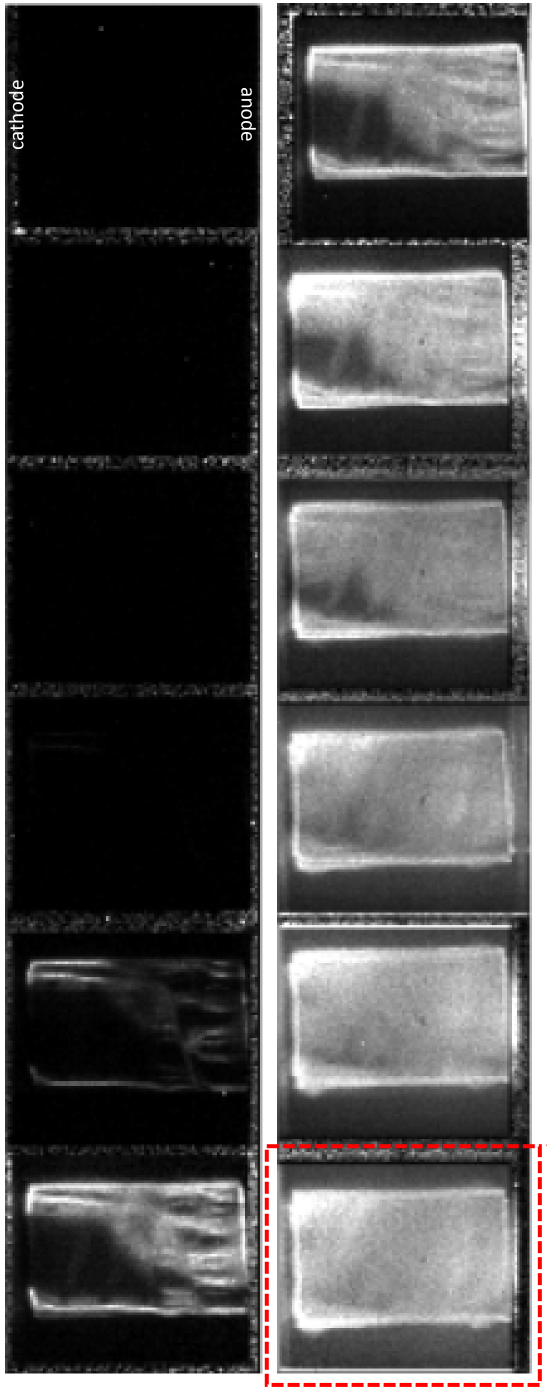
Convergence Ratio

$$CR = \frac{ID_o}{ID(t)}$$

Lower CR radiographs display complex 3D helical structures

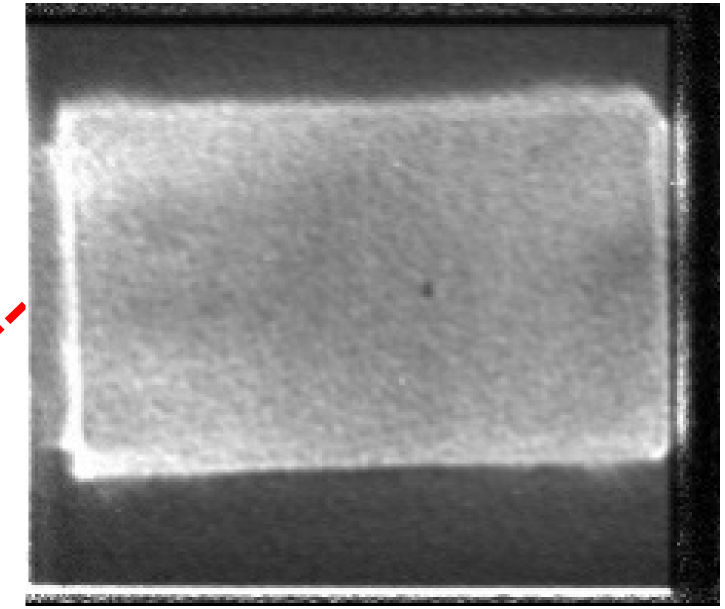
Higher CR radiographs demonstrate impressive level of cylindrical implosion stability and lack of Time Integrated x-ray Self-Emission (TISE)

<1 MA experiments on Mykonos have informed “initial” conditions for 3D implosion simulations



5 ns frames | ~50 micron resolution

12-frame visible spectrum gated imaging



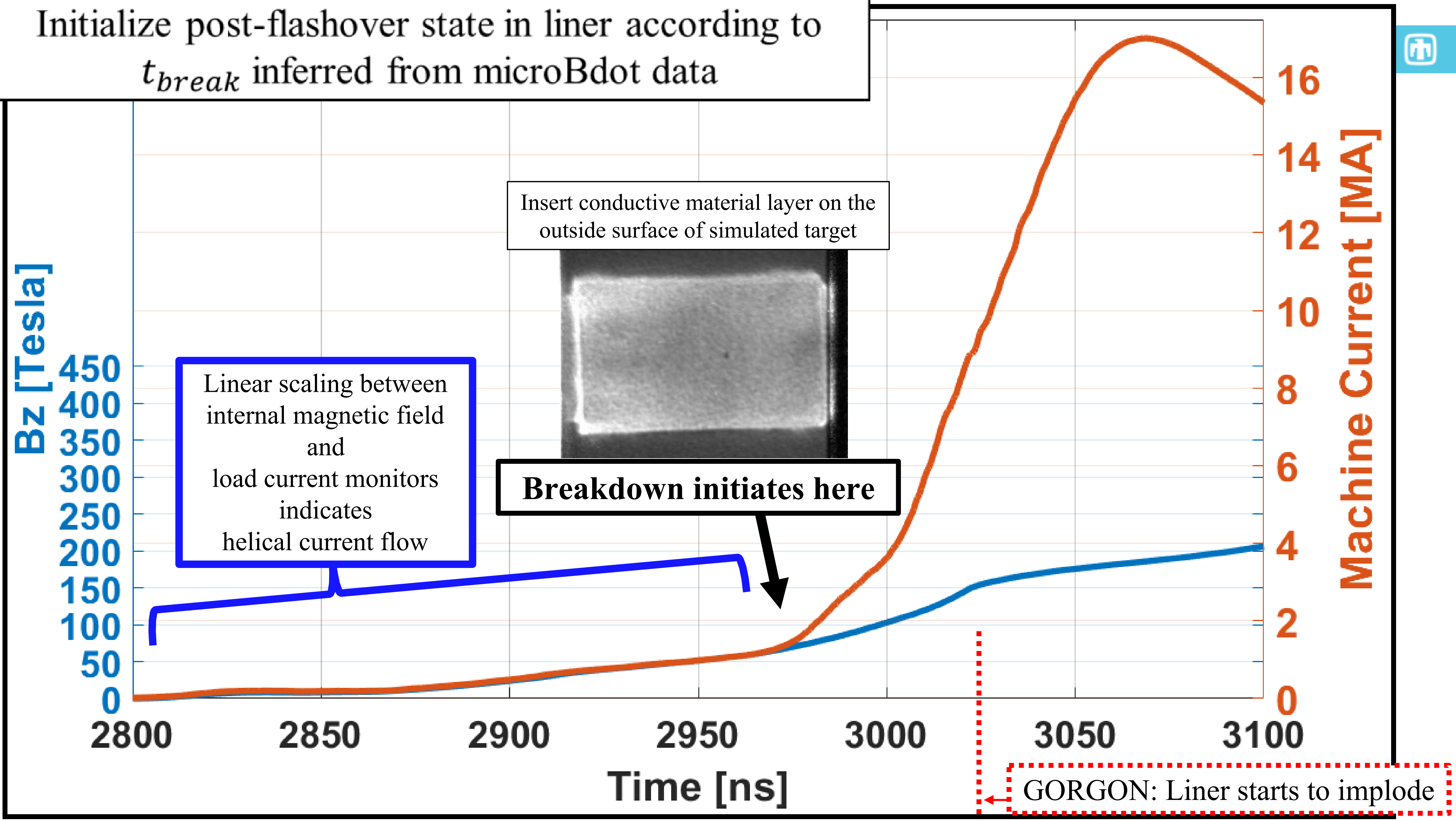
The “end state” of the flashover process

Quasi-uniform photoemission from outer surface of target indicates:

Surface flashover

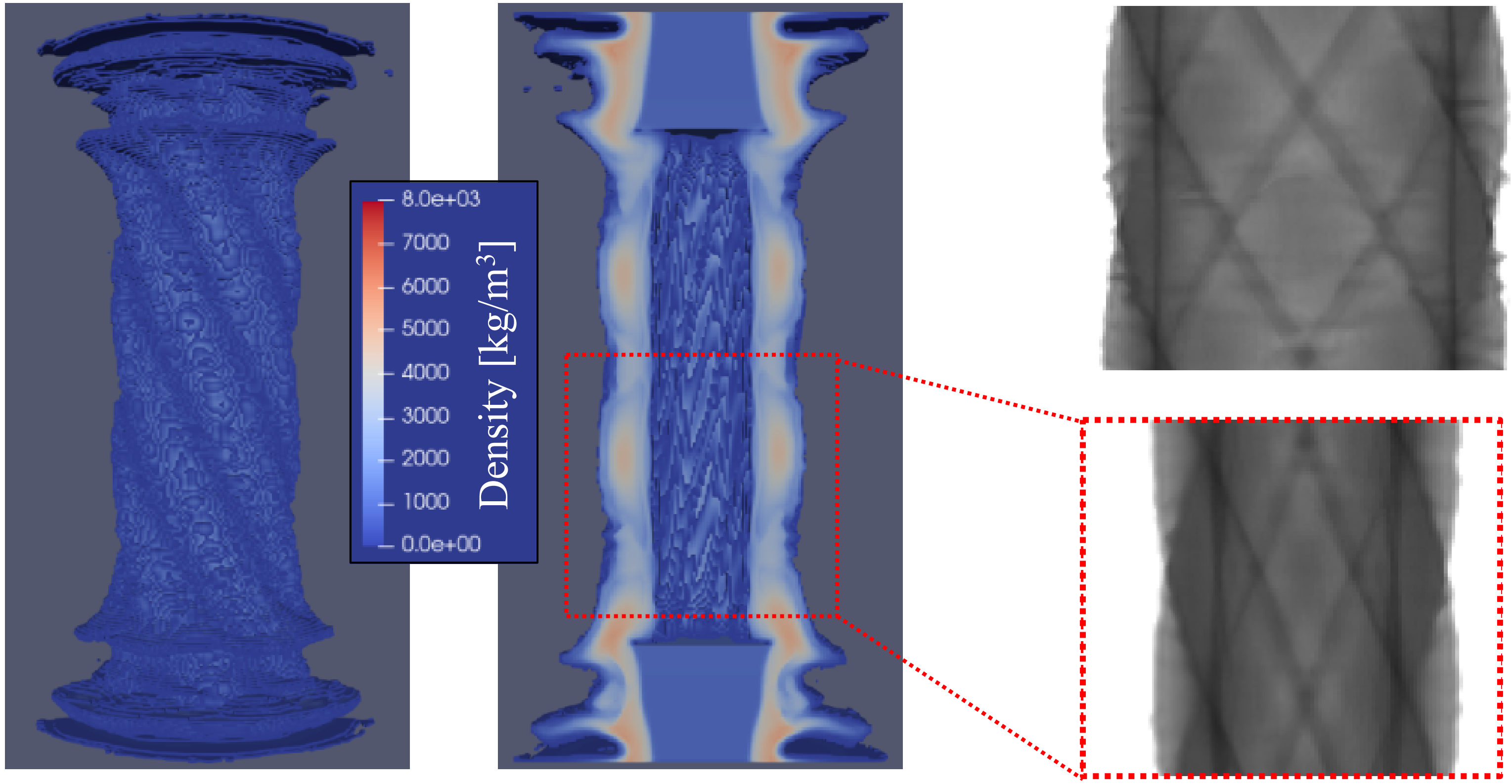
Insert a conductive, post-breakdown layer of material on the outside surface of the target at experimentally-inferred time of flashover

Initialize post-flashover state in liner according to t_{break} inferred from microBdot data



Initialization of post-flashover state has resulted in improved comparison with experimental data

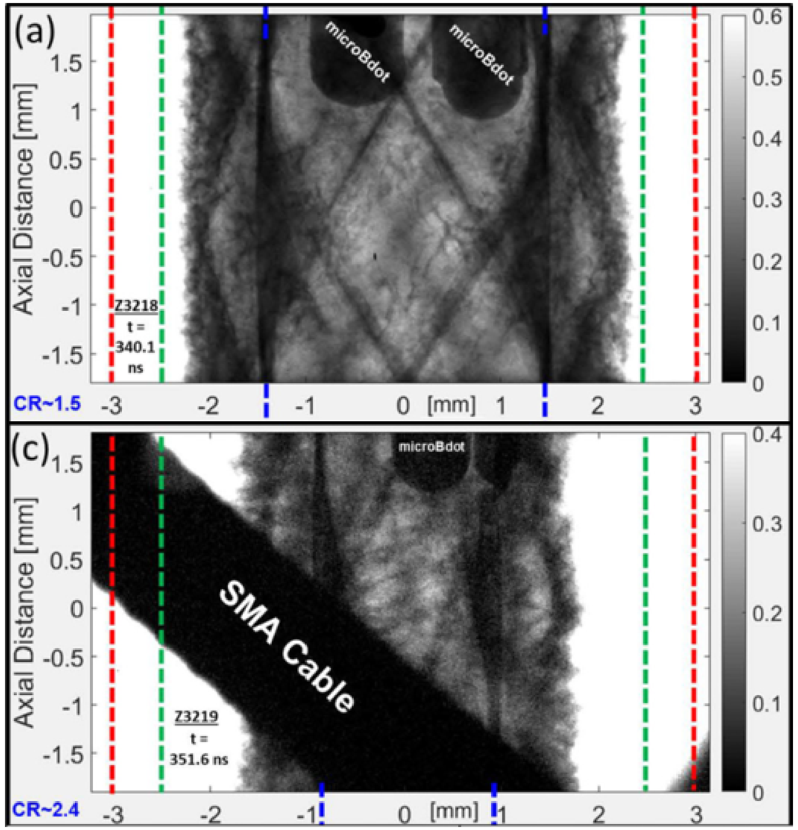
Post-shot 3D ALEGRA



density maps

opacity maps

Z Radiography Data



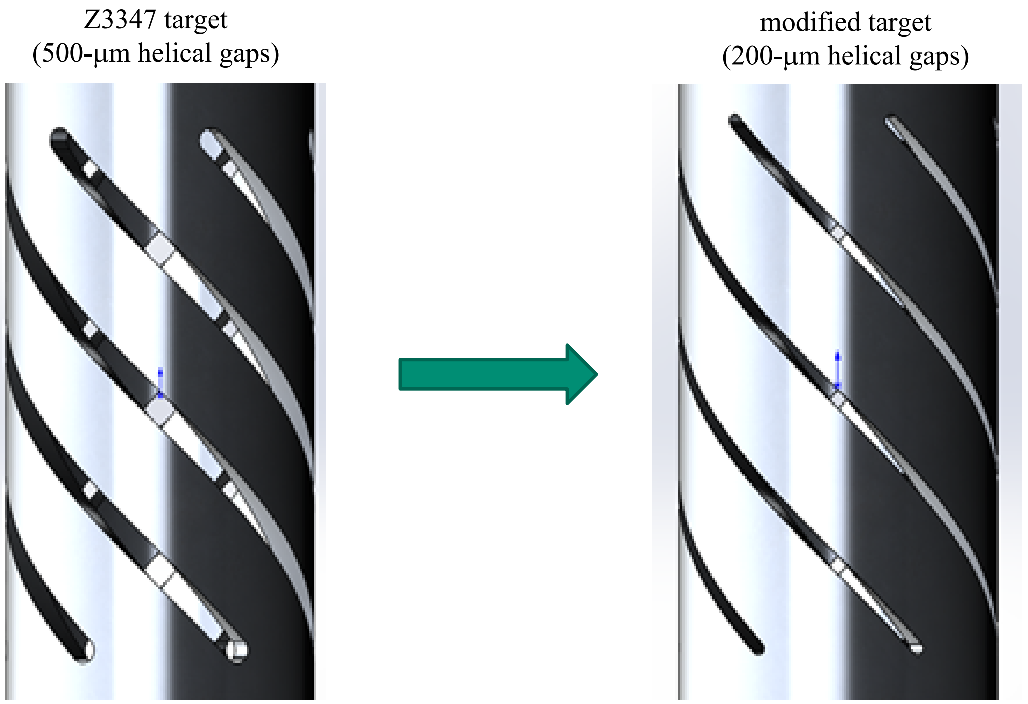
Compression of insulator-filled helical gaps (the “primary helices”) is captured in simulations

Secondary helical structures are apparent, but appear broader than in data

→ Replication of “secondary helices” in radiography data has not yet been accomplished

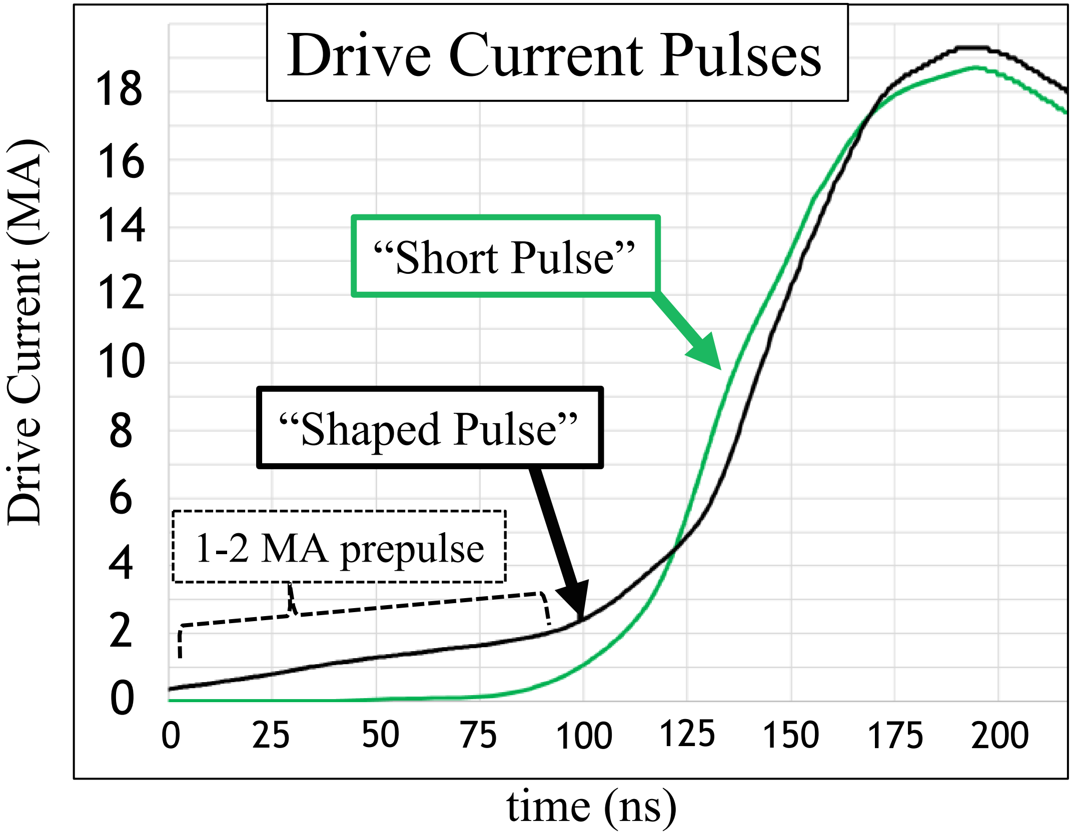
3D MHD simulations suggest that driver-target changes can improve field production and implosion dynamics

Increased metal fraction in the target



- 3D simulations: decreasing the size of the insulator filled gaps improves cylindrical implosion uniformity
  - Makes target "look more like a normal cylindrical liner"
- <1 MA experiments and MHD simulations suggest:
  - Very minor reduction in $B_{z,in}$ per unit drive current (<10%)
  - Flashover initiates at similar time and in the same fashion

Access higher dI/dt earlier in the pulse (at lower current)

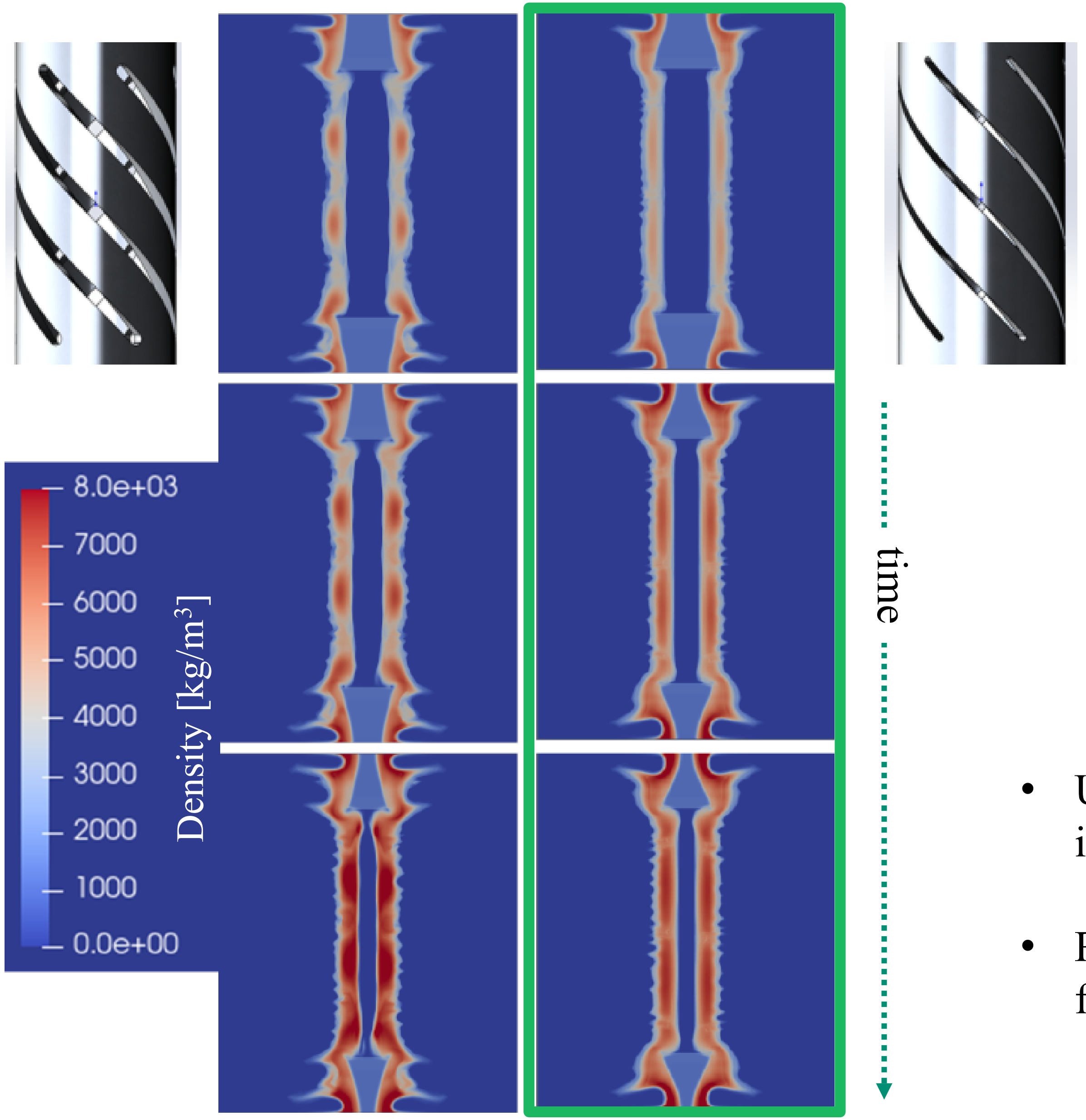


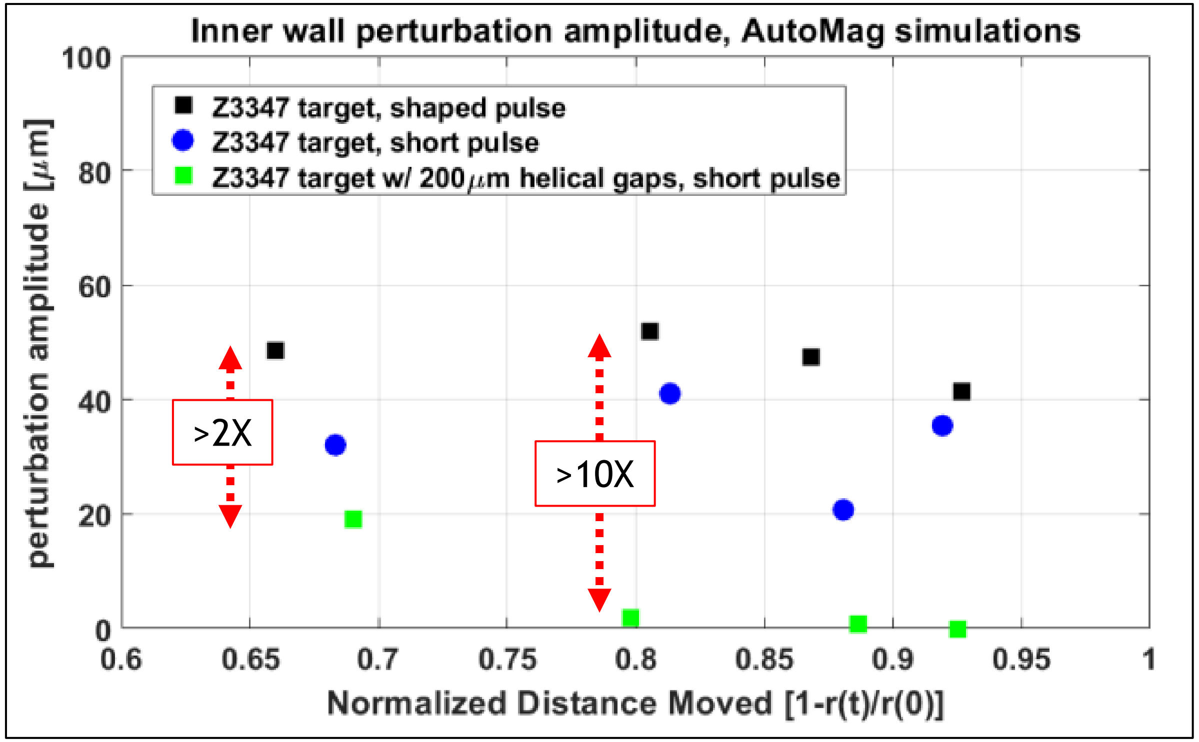
- Reaching the threshold dI/dt for flashover at lower current promotes flashover initiation at lower $B_{z,in}$
  - Recall: AutoMag on Z produced >150 T **but 30-50 T is ideal for MagLIF**

3D MHD simulations suggest that driver-target changes can improve field production and **implosion dynamics**

Z3347 (shaped) pulse

Short Pulse, 200-µm gaps

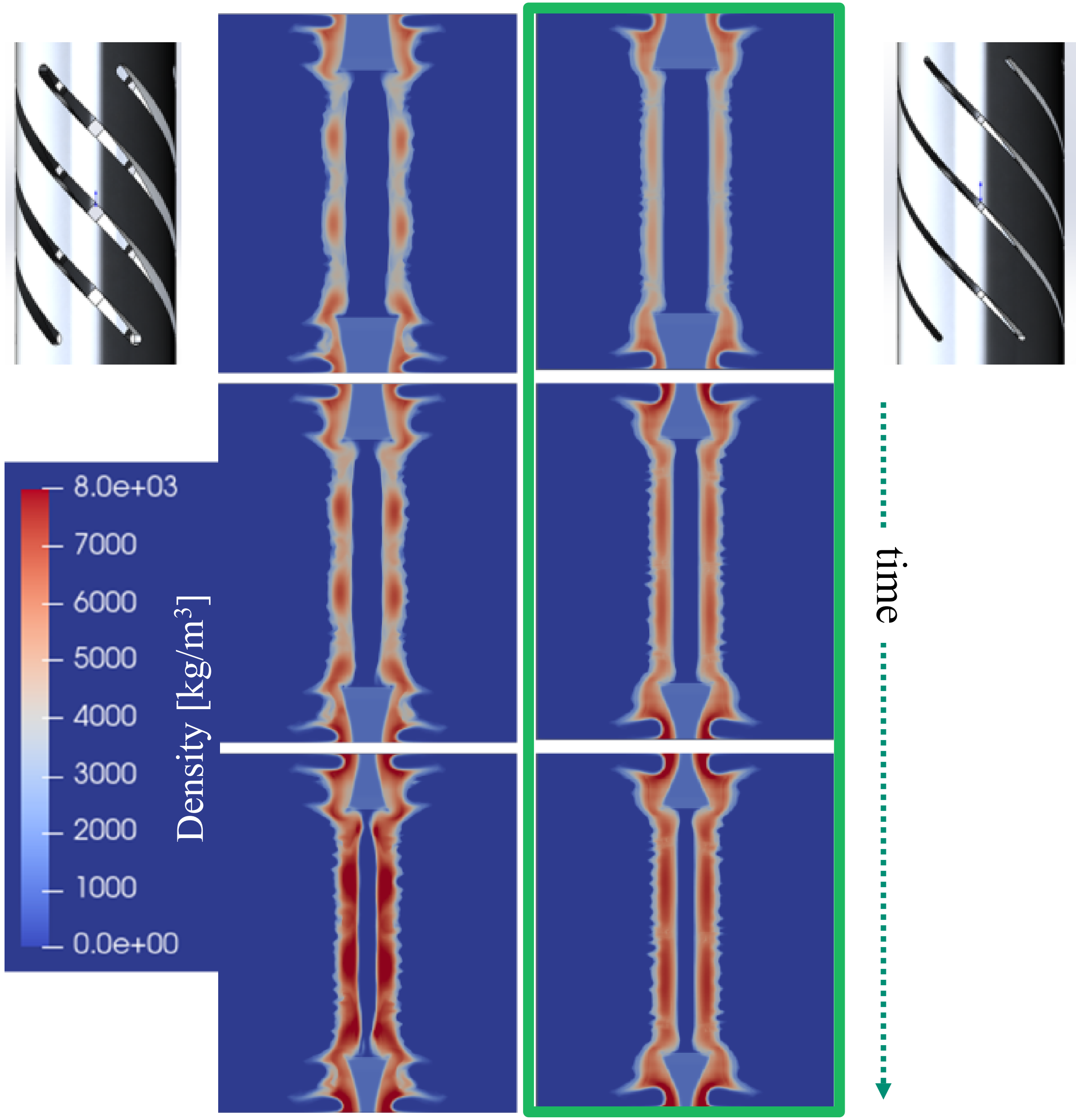


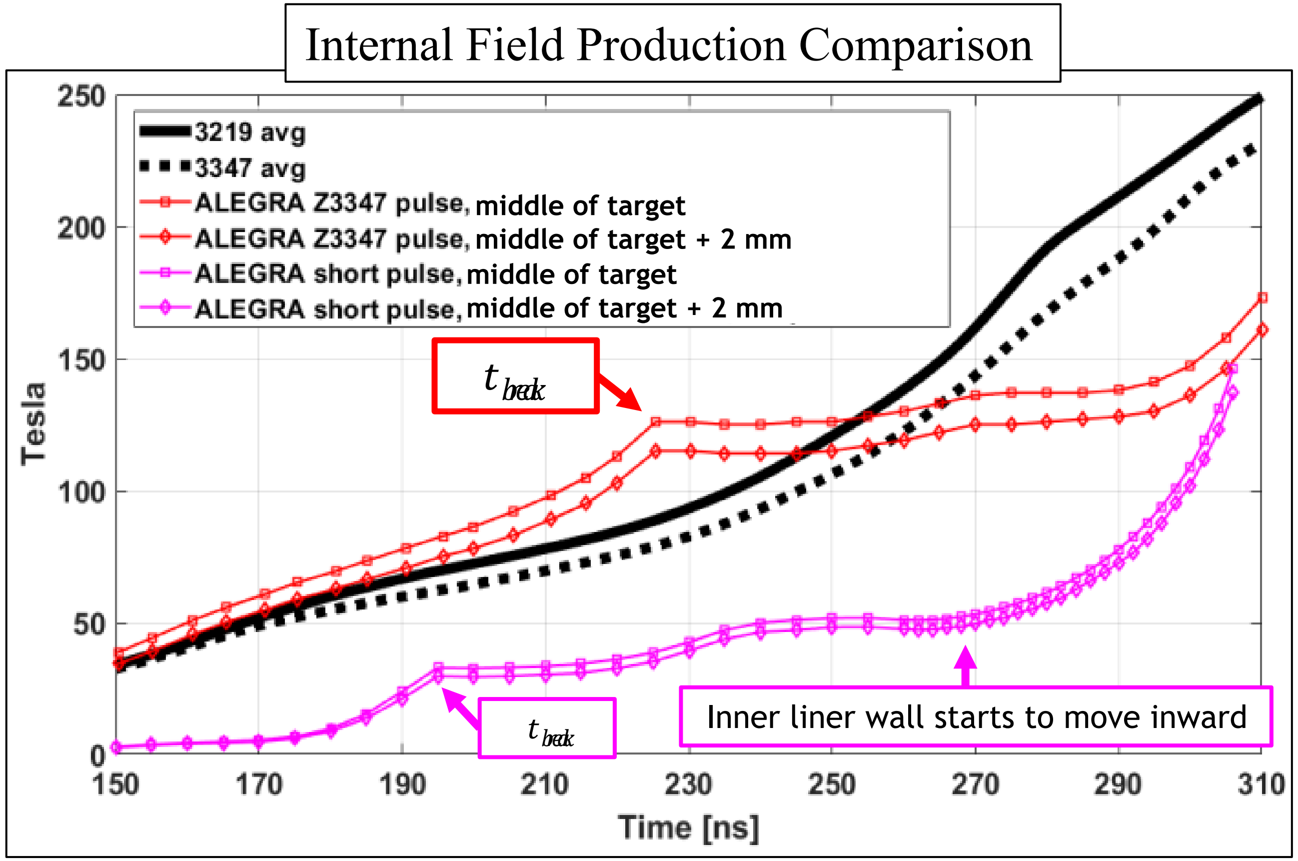


- Use of short pulse instead of shaped pulse reduces perturbation on inner wall (black squares vs. blue circles)
- Reducing helical gaps (increased beryllium fraction in target) further decreases inner wall perturbation amplitude

3D MHD simulations suggest that driver-target changes can improve **field production** and implosion dynamics

Z3347 (shaped) pulse   Short Pulse, 200-µm gaps





- Higher dI/dt accessed earlier in short pulse indicates that flashover would initiate near ~35 T
  - Compare to predicted ~120 T for shaped pulse
- ALEGRA simulations suggest ~50 T precompressed field
  - Compare to predicted ~130 T for shaped pulse

Summary and conclusions

- 3D MHD simulations (ALEGRA) can be initialized based on multi-frame gated imaging data captured in <1 MA, 100 ns flashover experiments
  - Improved comparability with ~20 MA, 100 ns implosion experiments

- Simulations indicate opportunities to improve magnetic field production
  - Use of 100 ns "short pulse" (eliminating 1-2 MA, 100-200 ns prepulse) results in flashover at lower internal field (30-50 T) better suited to MagLIF

- Simulations indicate opportunities to improve implosion dynamics
  - Increased Be fraction in target (reduce helical gap width) combined with "short pulse" results in increased cylindrical implosion uniformity

Thank you for your attention! Questions?