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Auto-Magnetizing Liners for MagLIF Experiments

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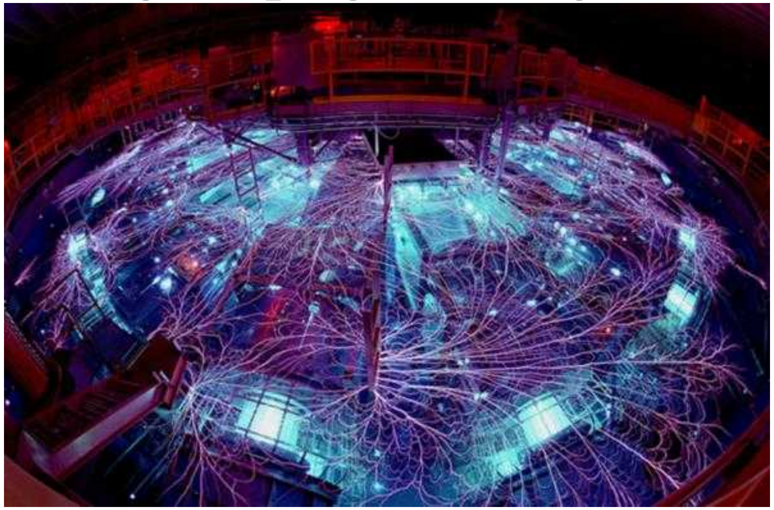

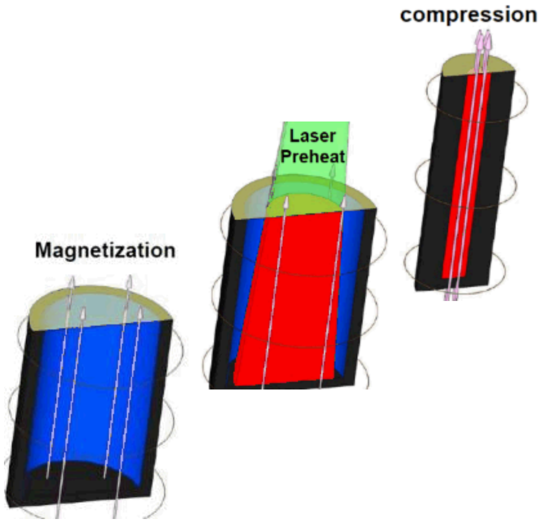

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“Magnetic Direct Drive” uses large currents to implode liners via magnetic pressure

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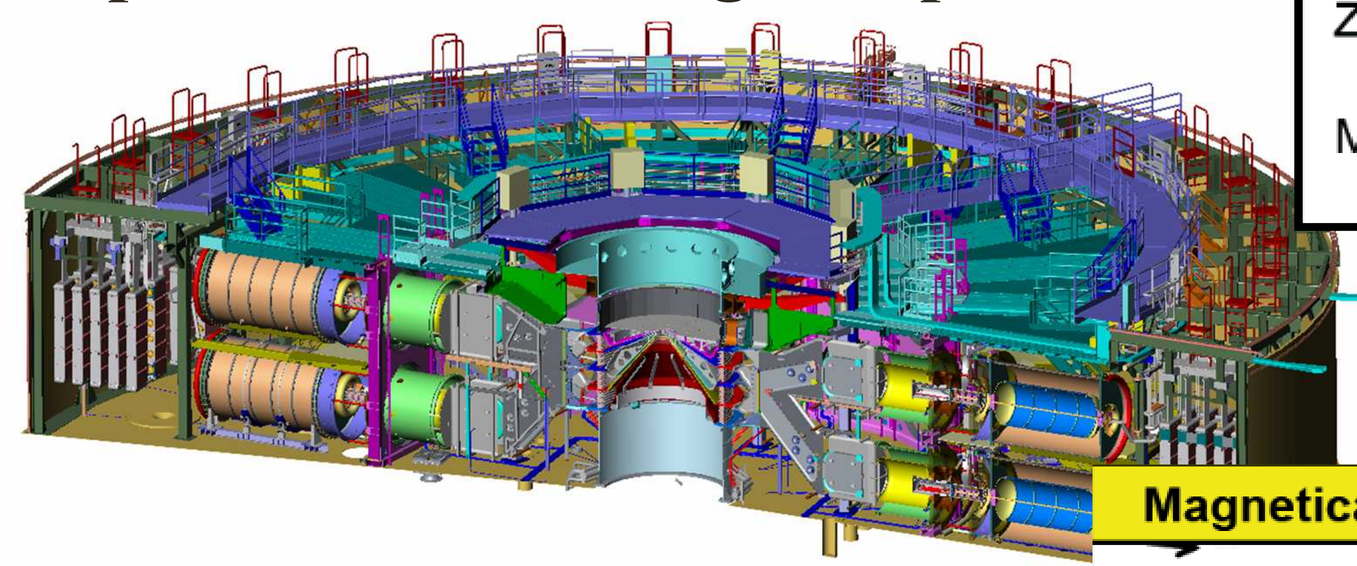
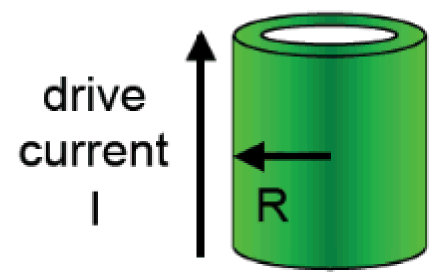


Z today couples ~0.5 MJ out of 20 MJ stored to MagLIF target (0.1 MJ in DD fuel).

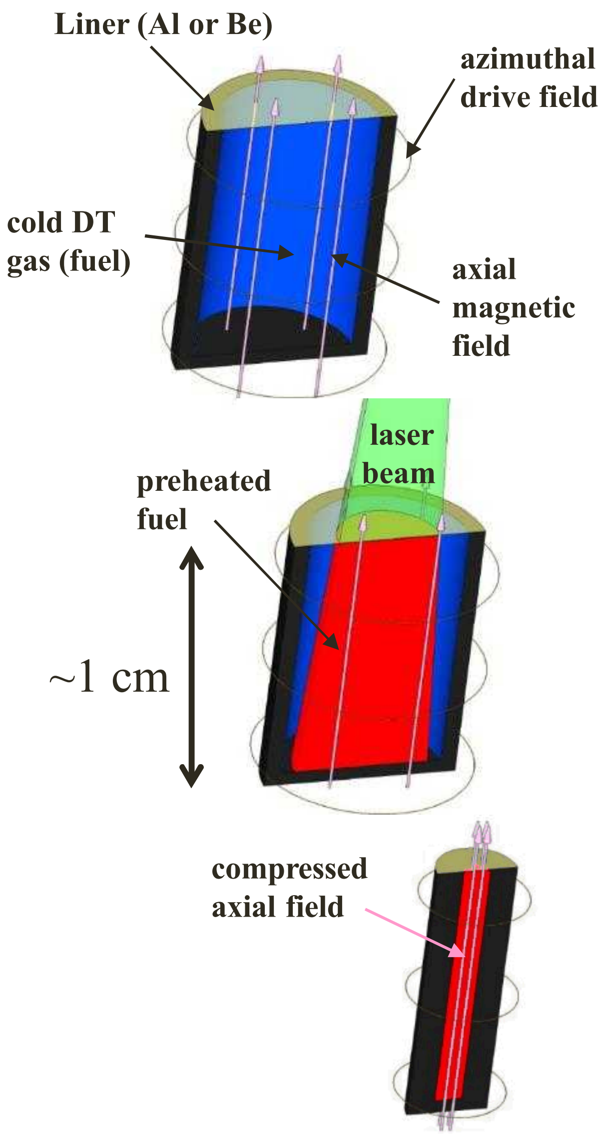
Magnetically-Driven Implosion

$$P = \frac{B^2}{8\pi} = 105\left(\frac{I_{MA}/26}{R_{mm}}\right)^2 \text{ MBar}$$



100 MBar at 26 MA and 1 mm

MagLIF* (Magnetized Liner Inertial Fusion): Fuel premagnetization + fuel preheat + fuel compression

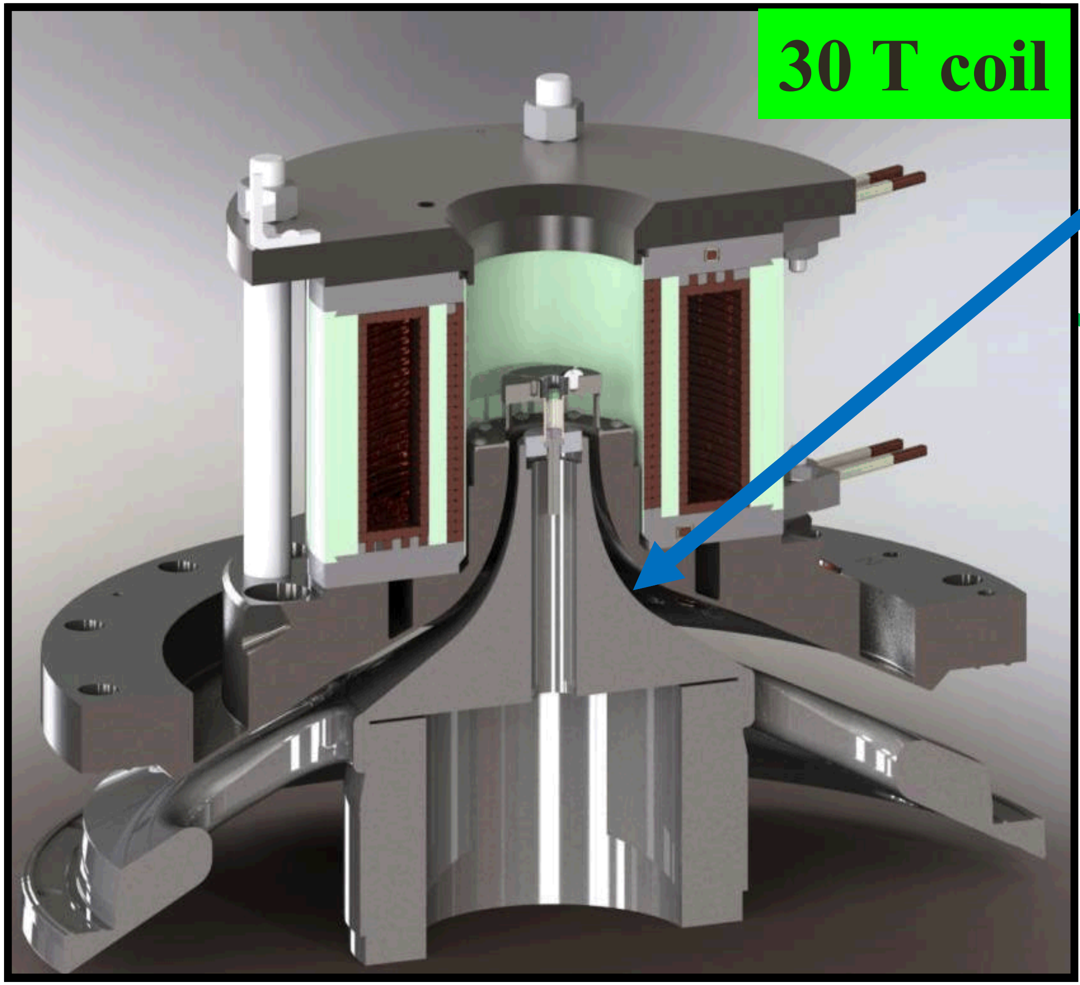


- **An initial 10-30 T axial magnetic field is applied**
  - **Compressed field inhibits thermal conduction losses**
  - **May help stabilize implosion at late times**
- **During the ~100 ns implosion, the fuel is heated using the Z-Beamlet Laser (~ 4 kJ)**
  - **Reduces compression requirements**
  - **Reduces the implosion velocity requirements**
- **Z Machine drive current compresses liner**

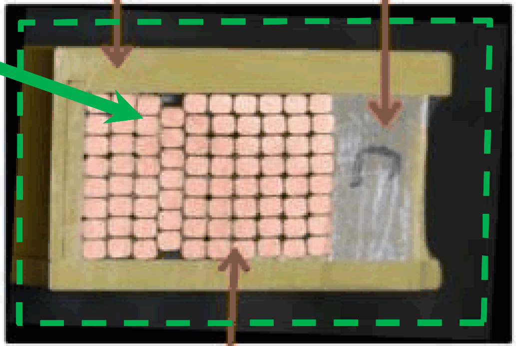
*S.A. Slutz *et al.*, Phys. Plasmas **17**, 056303 (2010); Slutz and Vesey, Phys. Rev. Lett. **108**, 025003 (2012)

External Helmholtz-like coil assembly premagnetizes the fuel and liner in MagLIF

Coils generates slow rising (3 ms) B_z field which diffuses through the liner and surrounding hardware before Z fires



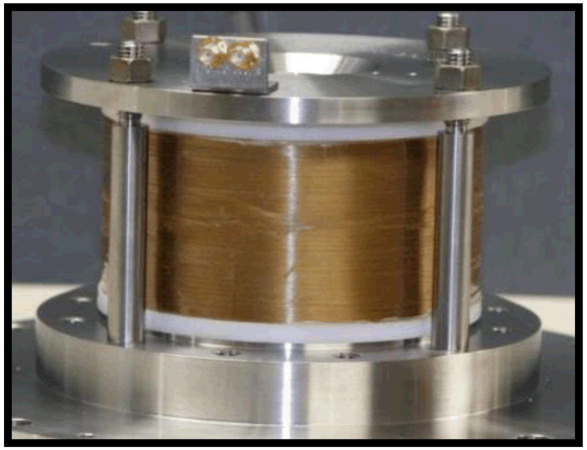
To generate a uniform B_z field, one coil sits lower than liner requiring use of a **high-inductance extended power feed**



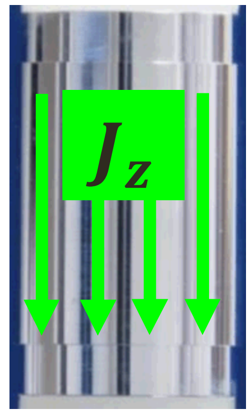
Copper coils absorb X-Rays—**diagnostic access is limited**

Auto-Magnetizing Liners (AutoMag) enforce helical current flow through the liner to eliminate external coils

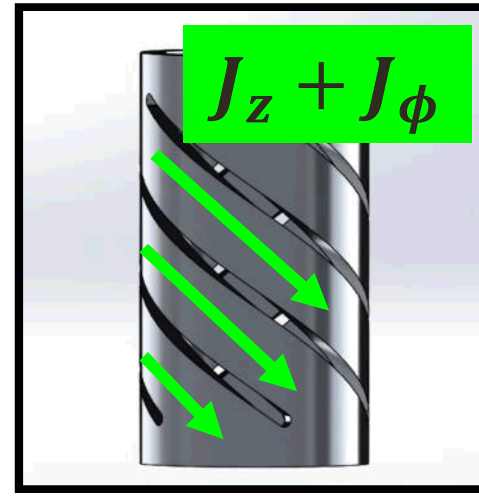
External Coils



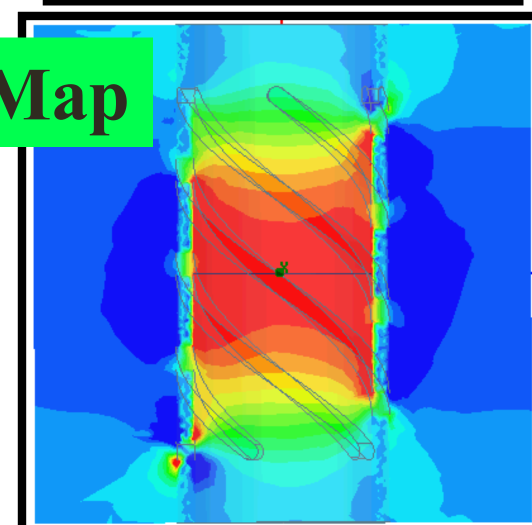
MagLIF Liner



AutoMag Liner



Axial Field Map



No external field coils

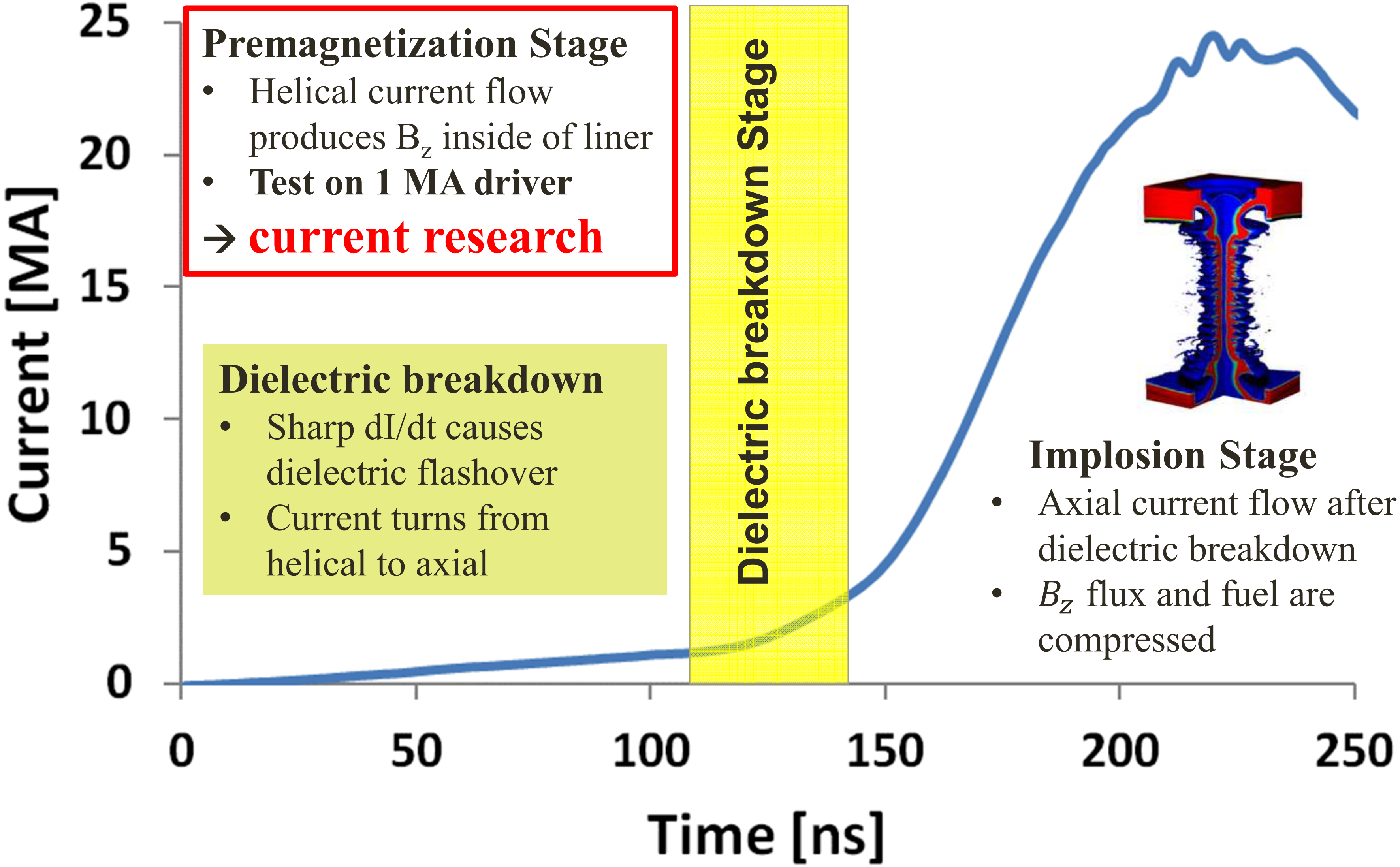
→ No extended current feed

  → Lower transmission line inductance

    → Higher current to target

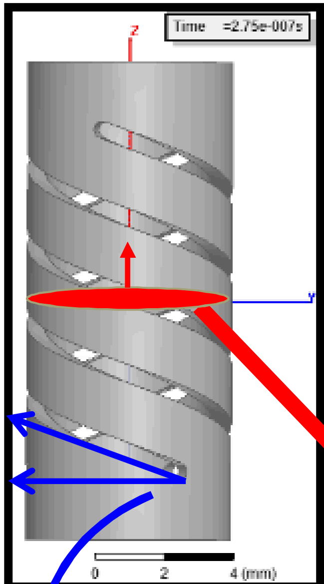
→ Unimpeded X-Ray diagnostic access

AutoMag involves three distinct stages each with unique research challenges

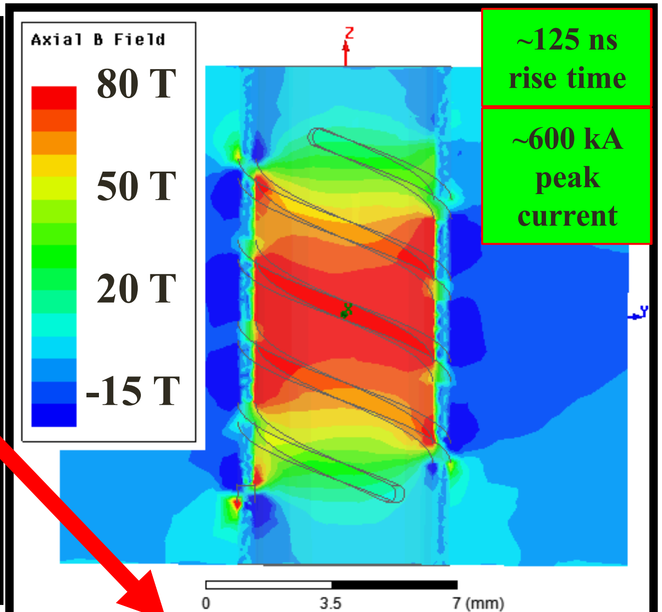


ANSYS Maxwell* simulations support the experimental design

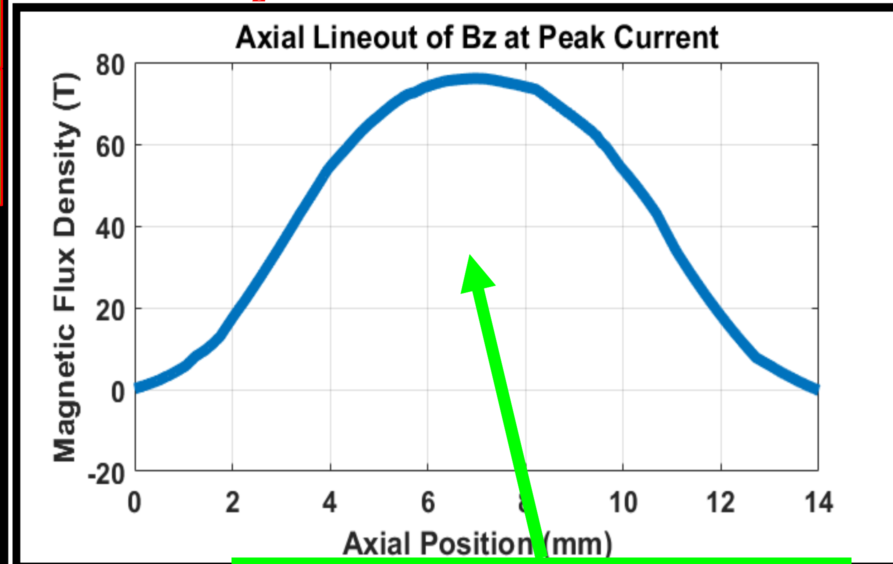
Al tube (6mm OD, 5mm ID) with 20 degree (from horizontal) helical cuts



$\Theta = 20°$



76 T B_z at Peak Driver Current



Axial gradients exist inside of liner

$$\oint E_\phi dl = -\iint \frac{dB_z}{dt} dA$$

ANSYS Maxwell Field Calculator

Induced breakdown field

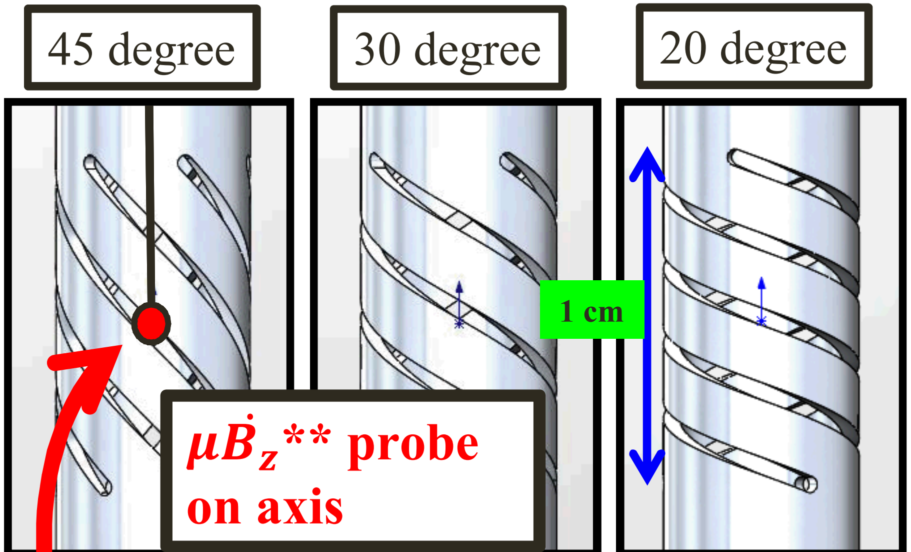
- If dB_z/dt is too high, breakdown between helical conductors will occur

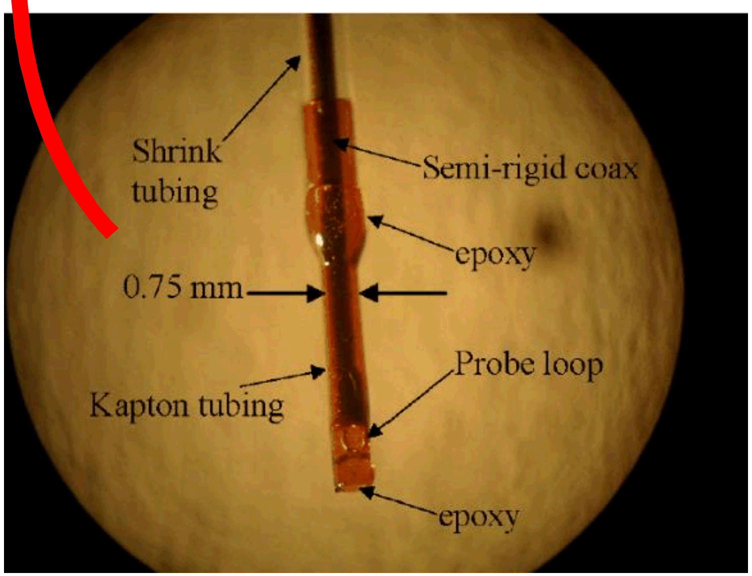
Dielectric strength of liner fill materials
Typical Epoxy → 15 MV/m
Vacuum → 20 – 40 MV/m

First experiments:
Measure $B_z(t)$ inside liner
Determine if helical current shorts out

*3D Transient Magnetic field solver

Three baseline premagnetization experiments are planned in summer 2016





ANSYS Maxwell Results

	Peak B_z	Peak E_ϕ	Peak $\frac{dB_z}{dt}$
45 degree	27 T	1.8 MV/m	4.6e8 T/s
30 degree	46 T	5.7 MV/m	5.6e8 T/s
20 degree	76 T	12.5 MV/m	9.2e8 T/s

X-Ray diagnostic access is lost for $B_z > 20\ T$ using Helmholtz-like coils

Dielectric strength
Typical Epoxy → 15 MV/m
Vacuum → 20 – 40 MV/m

Conventional probes are too large
→ Specialized microBdot probes are required**

These three designs will be tested on MYKONOS* (~125 ns, 0.6 MA)

*M. G. Mazarakis, Proceed. of the 17th IEEE Pulsed Power Conf. (2009)

**John Greenly *et al.*, AIP Conference Proceedings, 1088(1):53–56, 2009

Simulations and **experiments** indicate that implosion dynamics are robust to helical asymmetry

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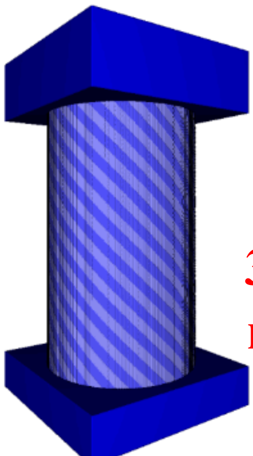
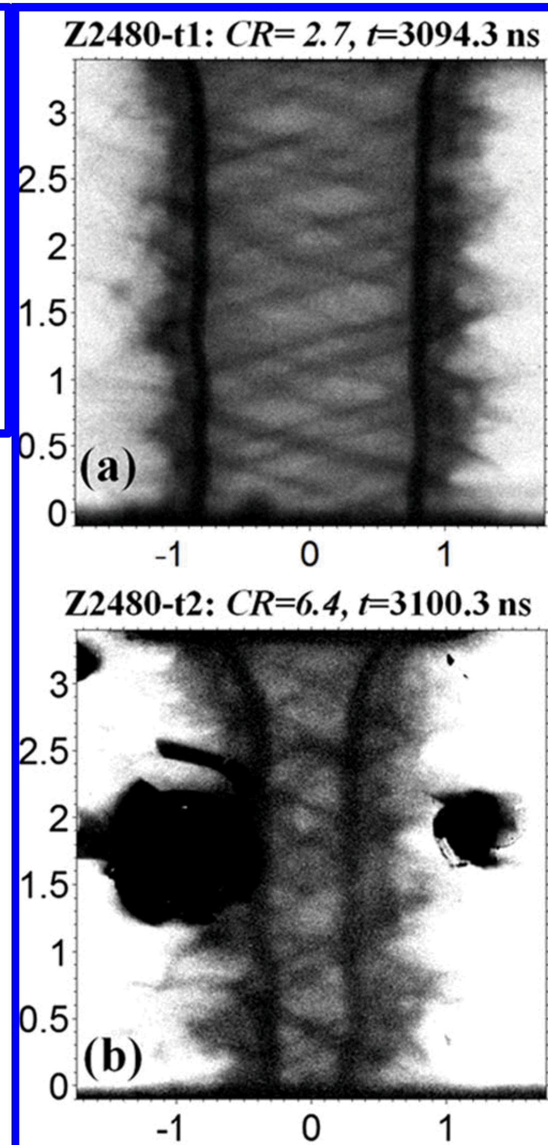


45 degree pitch angle helical Be winding with nylon spacers.

30% difference in material densities

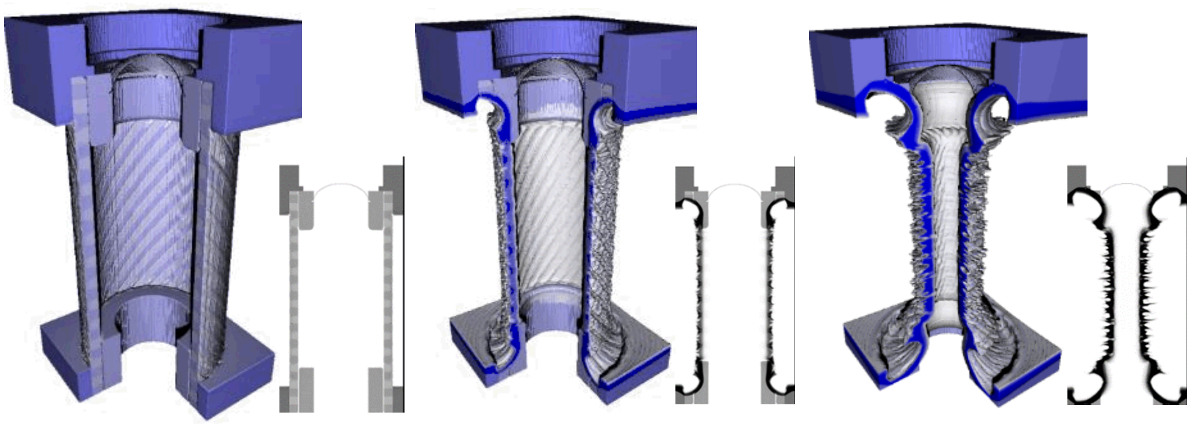
Radiographs of premagnetized MagLIF liners show implosion stability with helical structure**

No hard photon "hot spots"



3D GORGON* simulations show implosion is robust to macroscopic helical mass perturbations

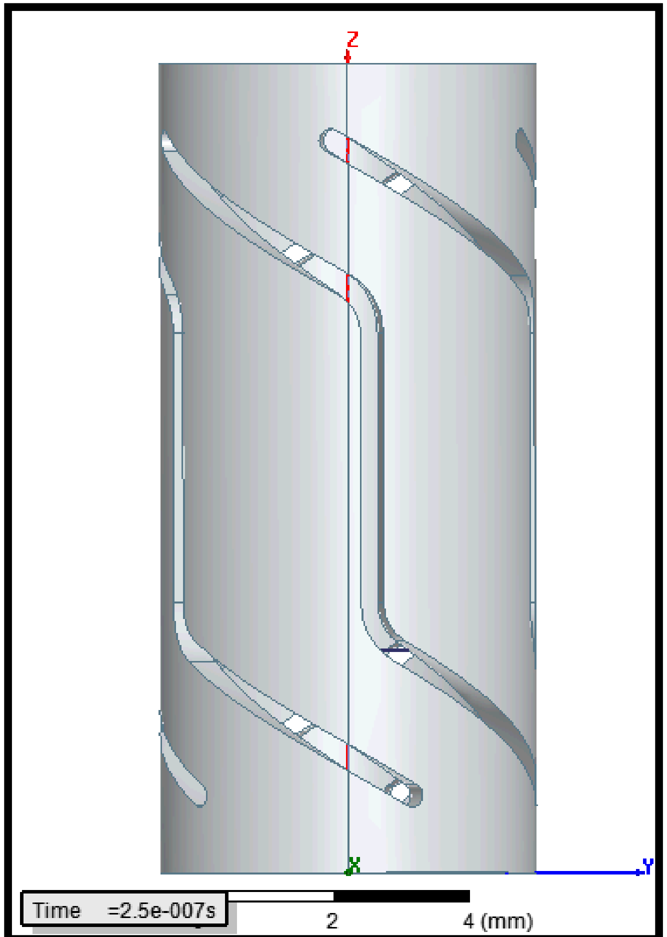
Simulated implosion on Z in ~100ns →

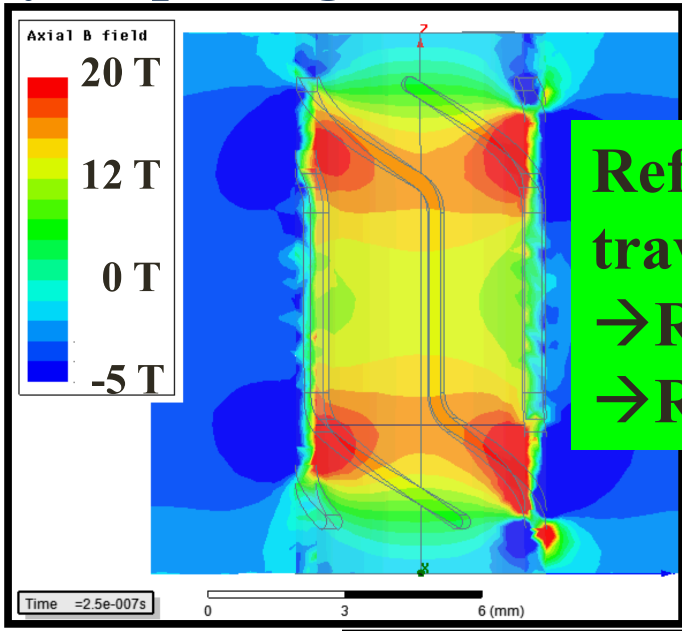


*GORGON simulations by C. A. Jennings

** T.J. Awe *et al.*, Phys. Rev. Lett. **111**, 025005 (2013)

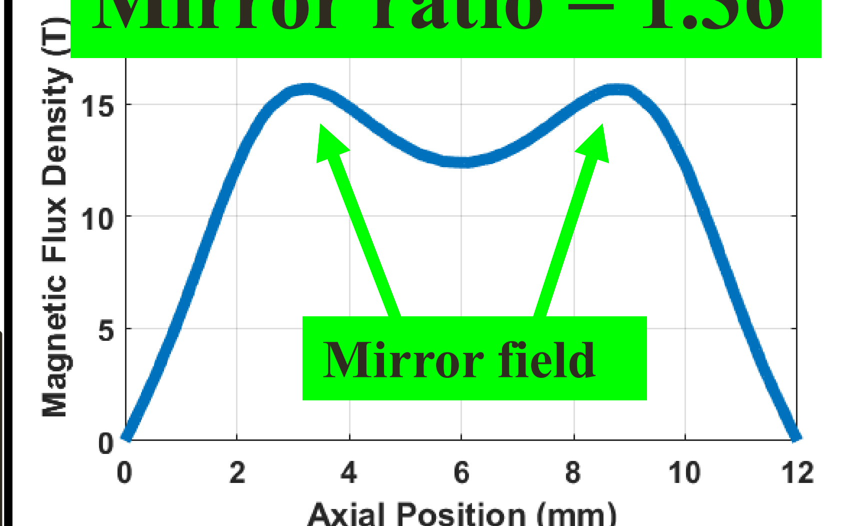
Mirror field topology may help mitigate end losses in MagLIF





Reflection of axially travelling particles
→Reduce fuel loss
→Reduce thermal loss

Mirror ratio = 1.36



Radial confinement from B_z
+ axial confinement from ∇B_z

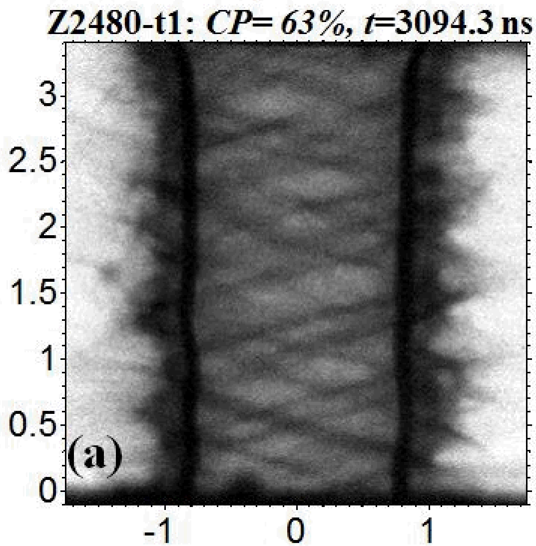
Conclusions and future work

- AutoMag can potentially provide axial field levels immediately relevant to MagLIF (**20-30 T**) and field levels beyond present capabilities (**30-100 T**)
  - **No loss of X-Ray diagnostic access**
  - **No need for high-inductance extended feed**

- First AutoMag experiments are imminent!
  - Diagnose $B_z(t)$ and liner failure mechanisms
- If premagnetization experiments prove successful, we will next evaluate implosion stability of an AutoMag liner on the Z facility

Back ups

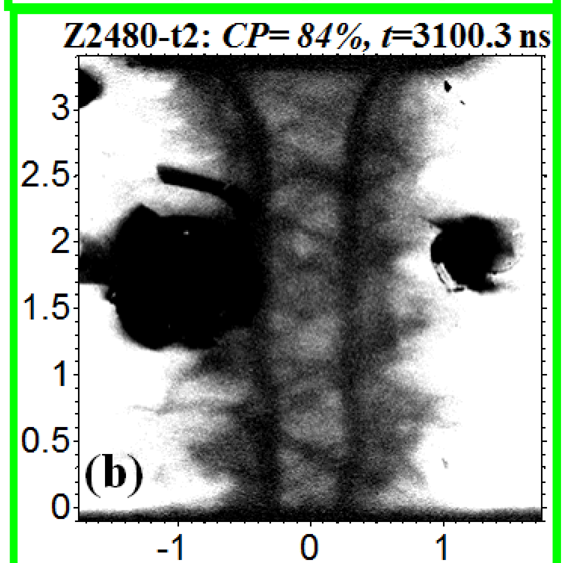
Experiments support that implosion dynamics are not damaged by helical asymmetry *

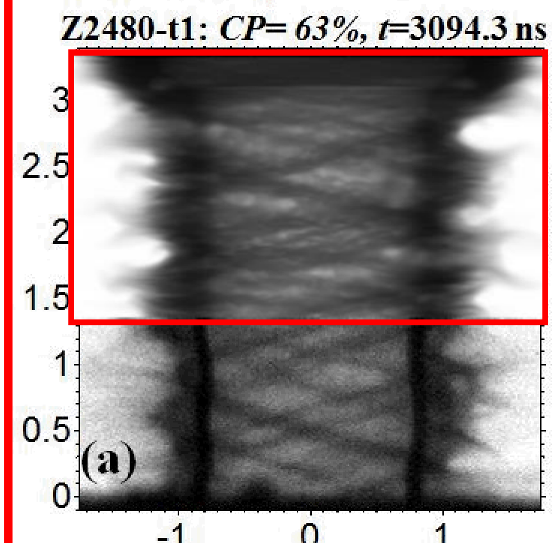


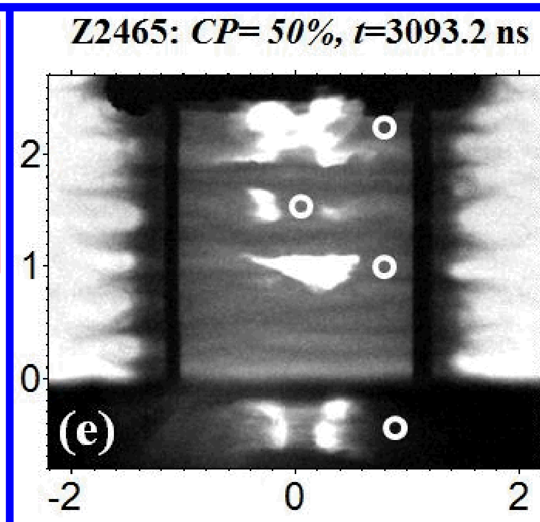
May help to prevent development and feedthrough of azimuthally correlated MRT

Radiograph of implosion without helical structure shows "hot spots" indicative of MRT bubbles impacting the center axis

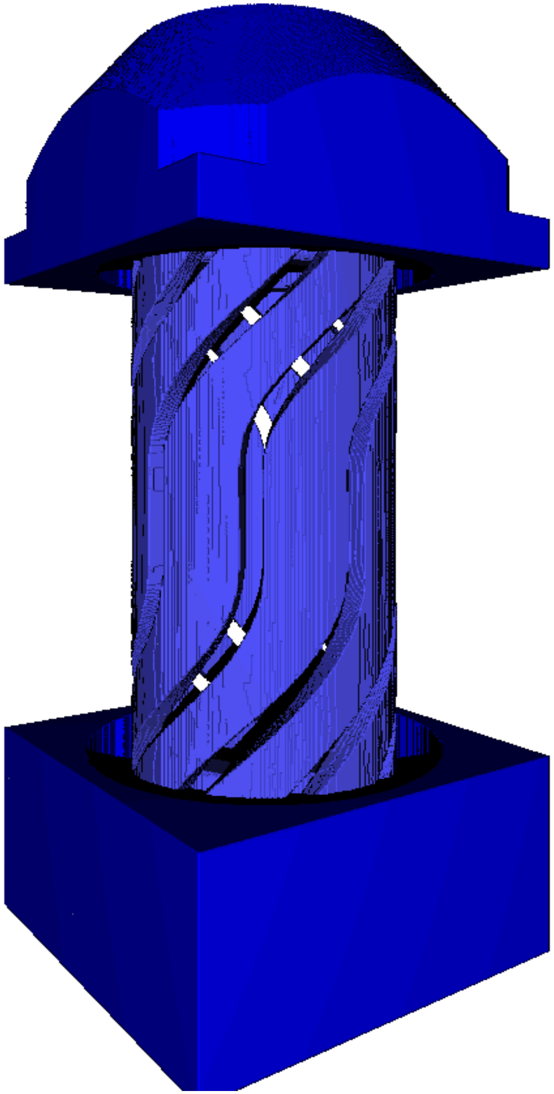
GORGON simulation (top) of Z2480 with seeded initial helical mass perturbation overlaid with radiograph (bottom)

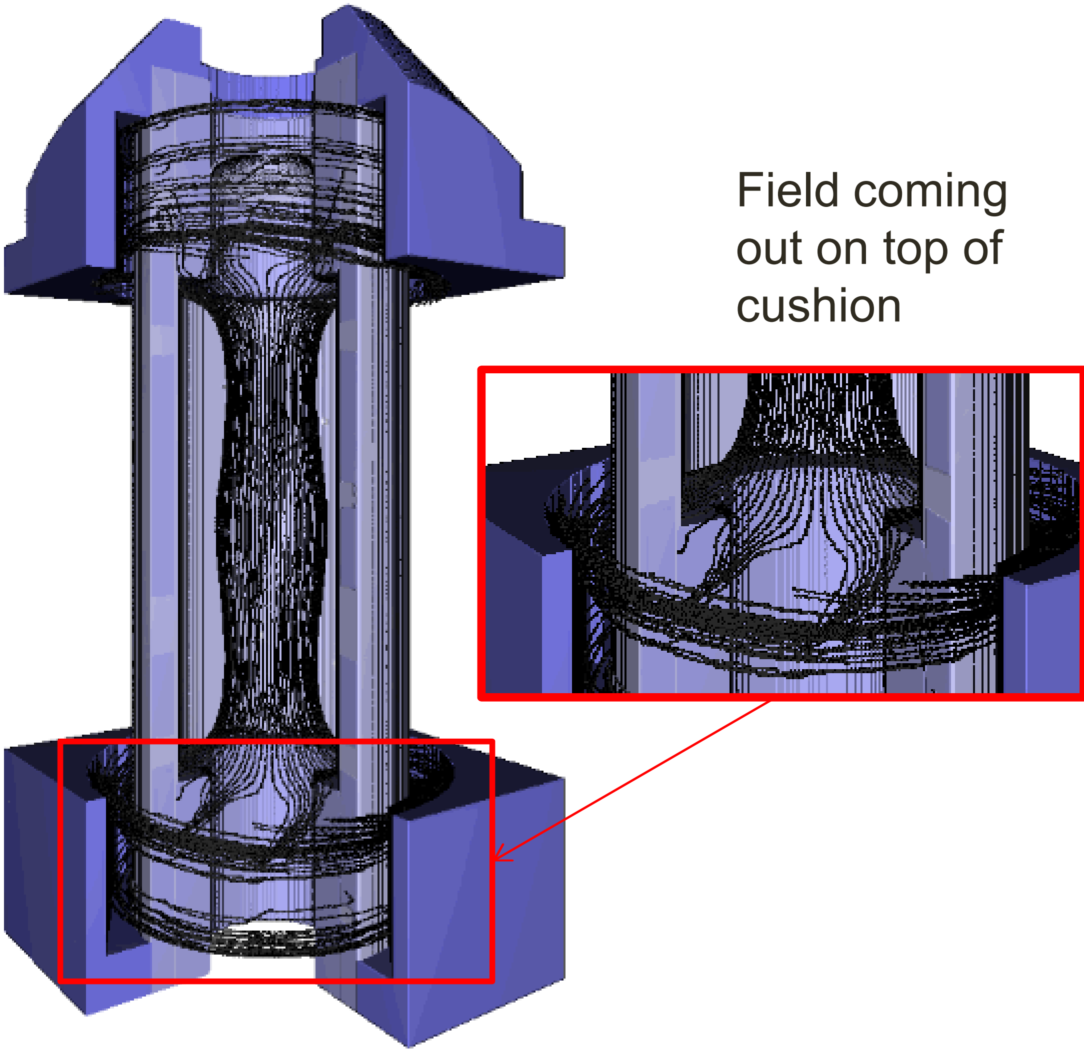




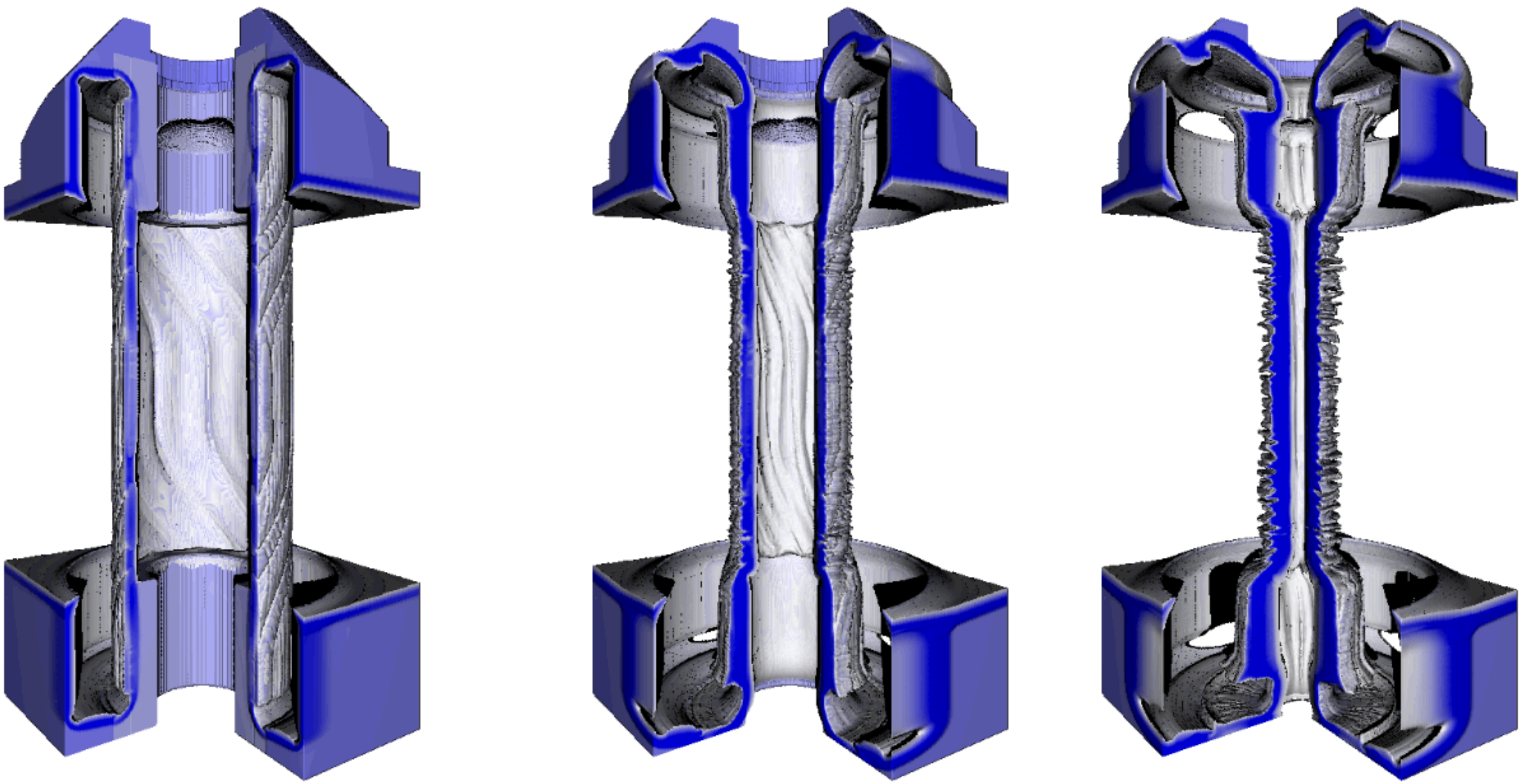


*T.J. Awe *et al.*, Phys. Plasmas **21**, 056303 (2014)

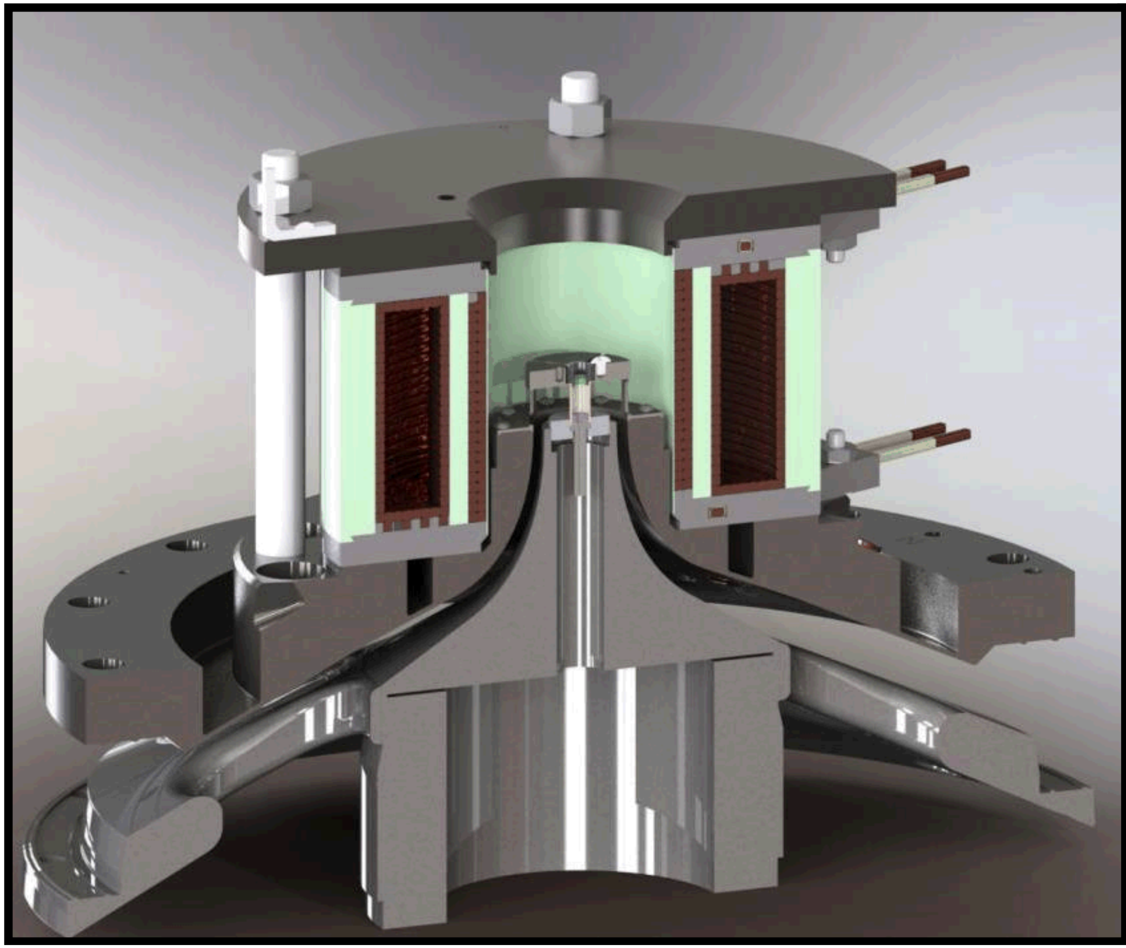


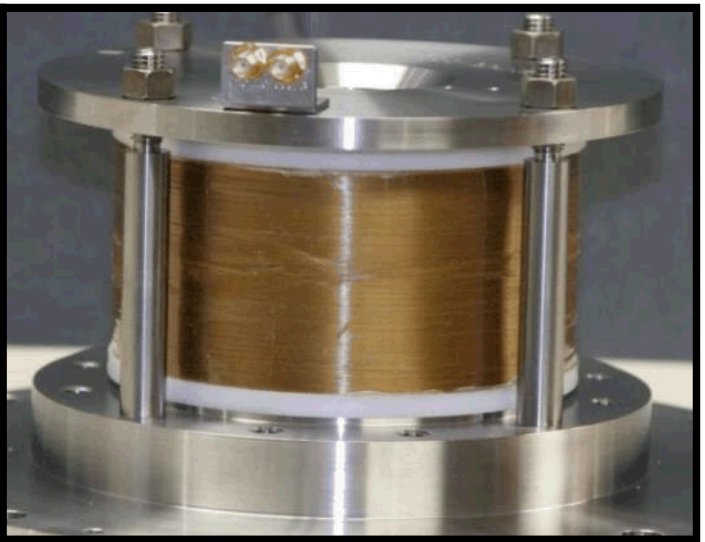


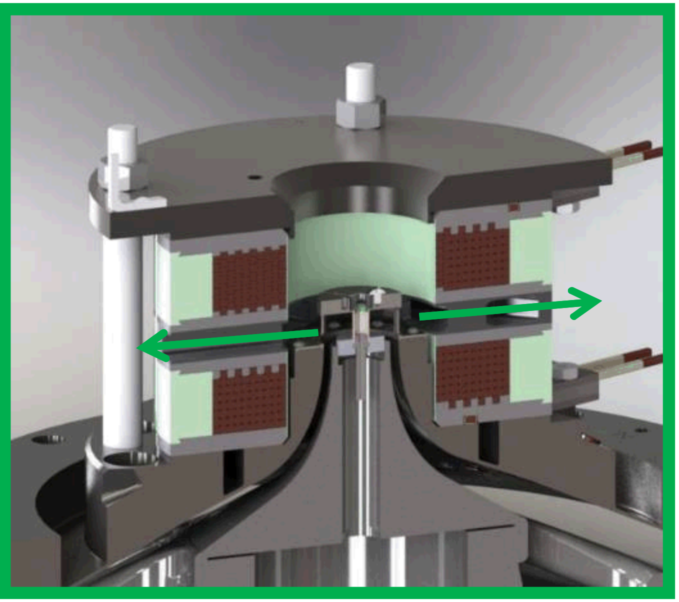
Field coming out on top of cushion



All radial x-ray diagnostic access is blocked by 30 T coils







Limited (0 degree) diagnostic access preserved for 20 T coils