Plans for a magnetized warm hohlraum experiment on NIF

John D. Moody

April 23, 2018

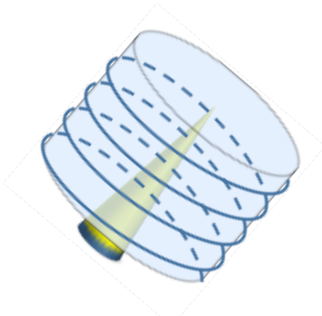
Collaborators: B. Pollock, E. Carroll, D. Strozzi, N. Meezan, G. Logan, etal

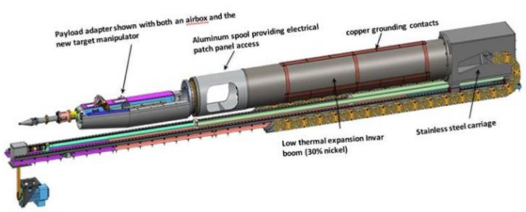
LLNL-PRES-699926
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

The NIF facility has a 3 phase plan to get to a magnetized cryo hohlraum test

Magnetized warm gas-pipe

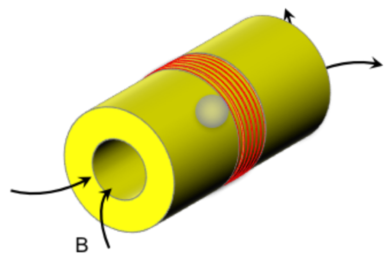


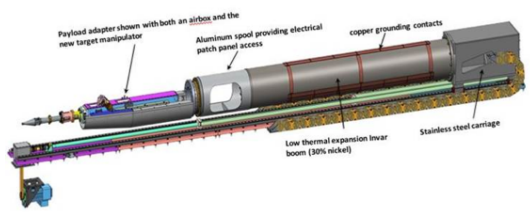


Using TanDM with power supply in DIM

First experiment: Dec 2018

Magnetized warm hohlraum

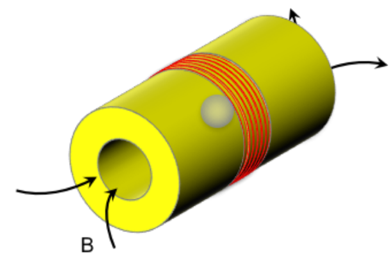


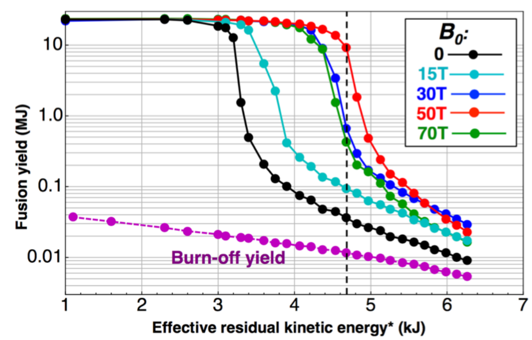


Using TanDM with power supply in DIM

First experiment: ~April 2019

Magnetized cryo hohlraum





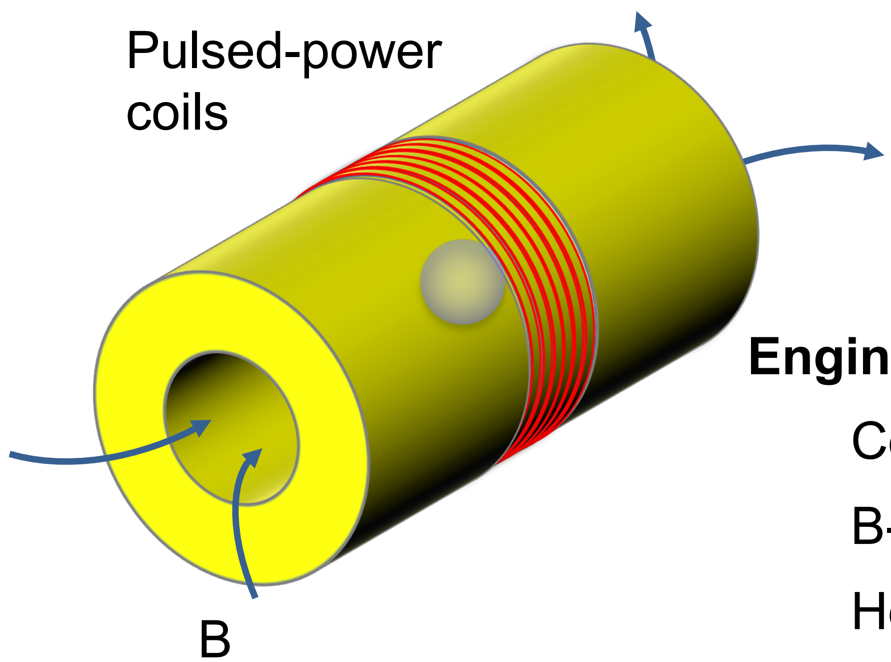
Perkins PoP 2017

Using ITIC

Top level goal for a NIF magnetized warm hohlraum implosion

Obtain experimental evidence for a *B-field induced effect* in the hohlraum and/or capsule physics in a warm gas-filled indirect drive capsule implosion

Magnetized warm hohlraum experimental considerations



Engineering considerations:

Coil – turns, location, inductance, eddy currents

B-field soak-in, slots

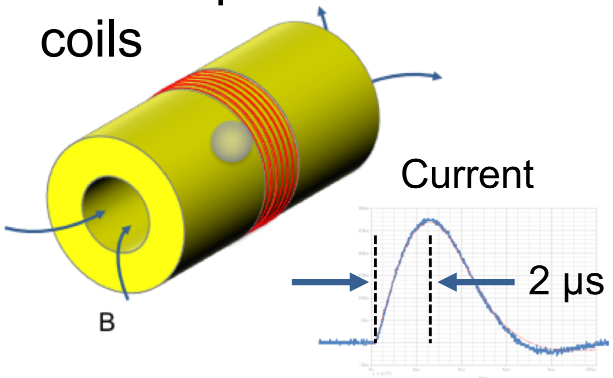
Hohlraum distortion

Physics considerations:

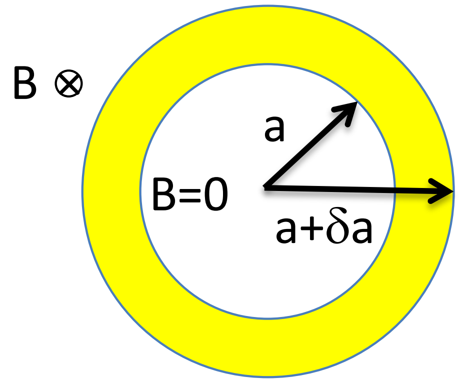
Hohlraum physics: Te, LPI, wall blow-in

Capsule physics: Yn, Ti, shape, mix, B-field amp

The outside coil requires B-field diffusion time which also applies pressure on the hohlraum



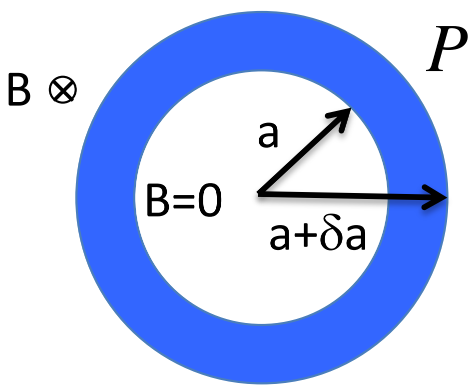
Soak-in time (1D in r)



$$\tau = \frac{\mu_0 \sigma a \delta a}{2}$$

For Au, a = 5 mm,
δa = 8 µm:
τ = 0.44 µs

B-field pressure (1D in r)



$$P[bar] = 3.9 B[T]^2$$

For hohlraum,
peak ΔB ~ 5 T:
P ~ 100 atm

How far does the wall move?

$$\Delta r = \frac{1}{2} g\, t^2$$

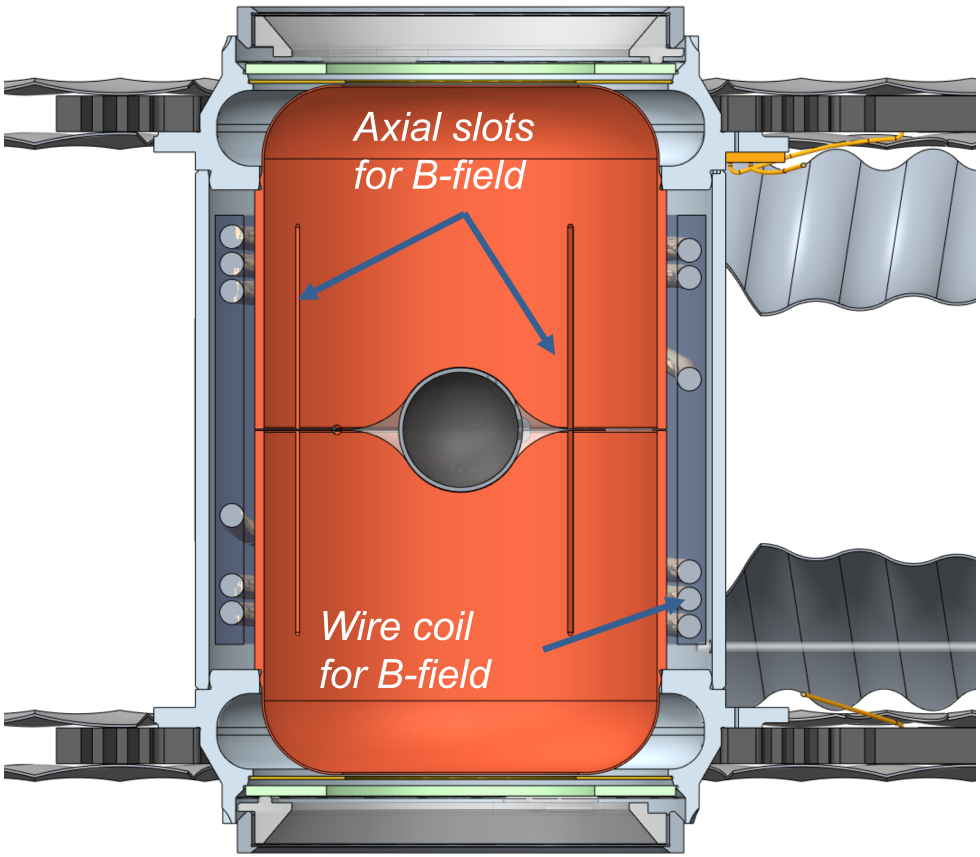
$$g = \frac{P}{\rho \delta a}$$

$$\boldsymbol{g = 6.5e7\ m/s^2}$$

Wall may move ~ 65 µm in 1 µs – this matters so need to measure it; wall will heat up too…

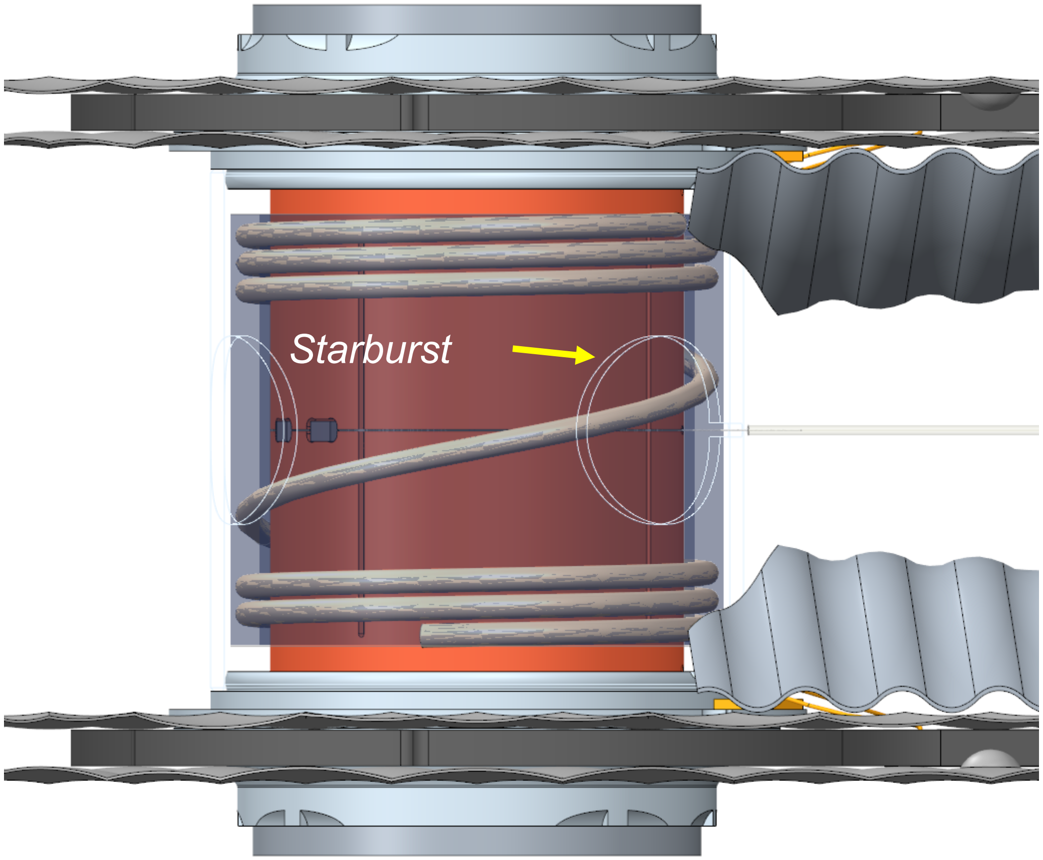
One alternative to field soak-in is axial slots

Cut-away hohlraum view



Wire wrapped on the inside of the diagnostic band

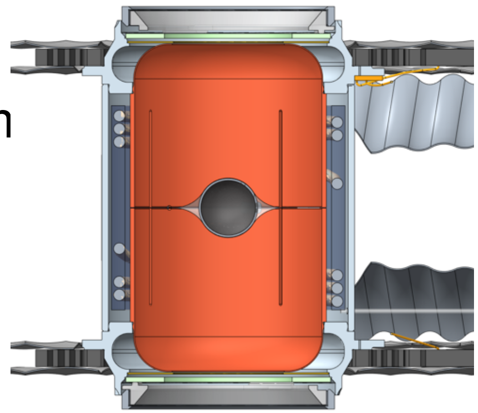
Wire wrapping scheme



Wire path avoids the starburst for future layering

The time-varying current creates a voltage across the slots

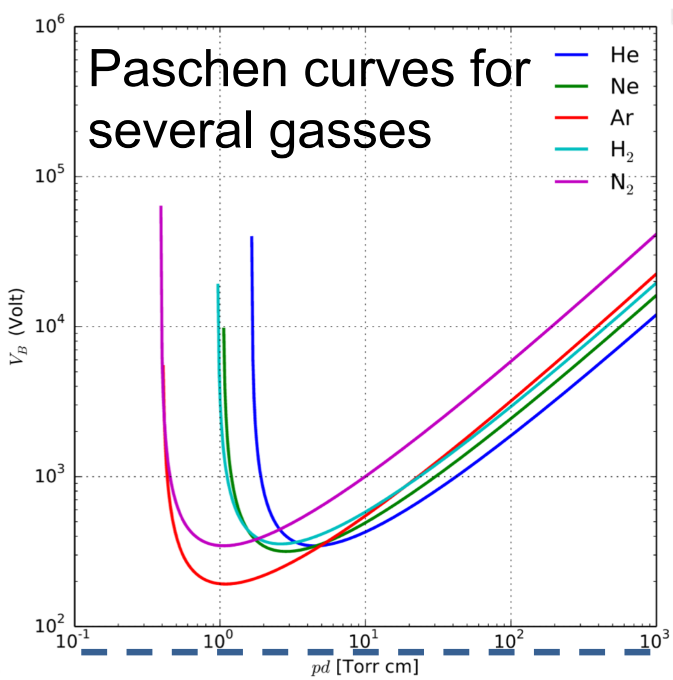
Slotted hohlraum



Ramping the current in the coil creates a voltage across the slots. Assume 4 slots of 100 µm width:

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$V_{Slot} = -\frac{1}{N_{Slots}} \frac{\partial (B \cdot A)}{\partial t} = \frac{350}{N_{Slots}} V = 90\ V$$

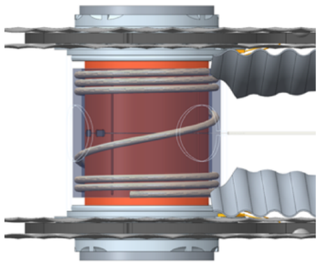


90 V

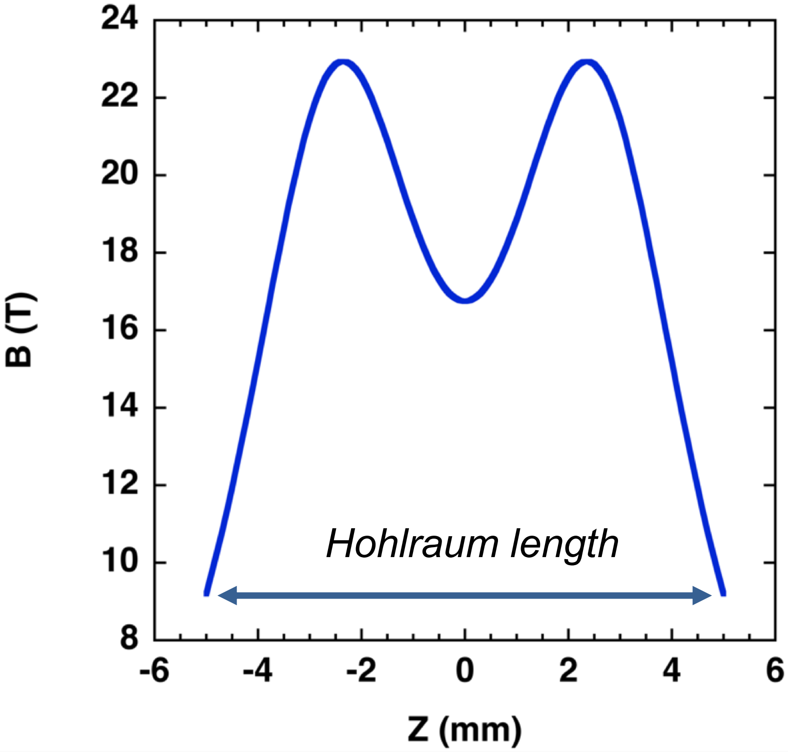
- Slot voltage is ~ 0.9 MV/m (4 slots)
- Any gas-fill (on left plot) provides needed standoff for gasses
- Needs testing for C5H12 (and 3 slots?)
- Perkins proposed a U hohlraum with 20x higher resistance than Au as alternative

We will optimize the coil path for the warm hohlraum

Wire path on the hohlraum

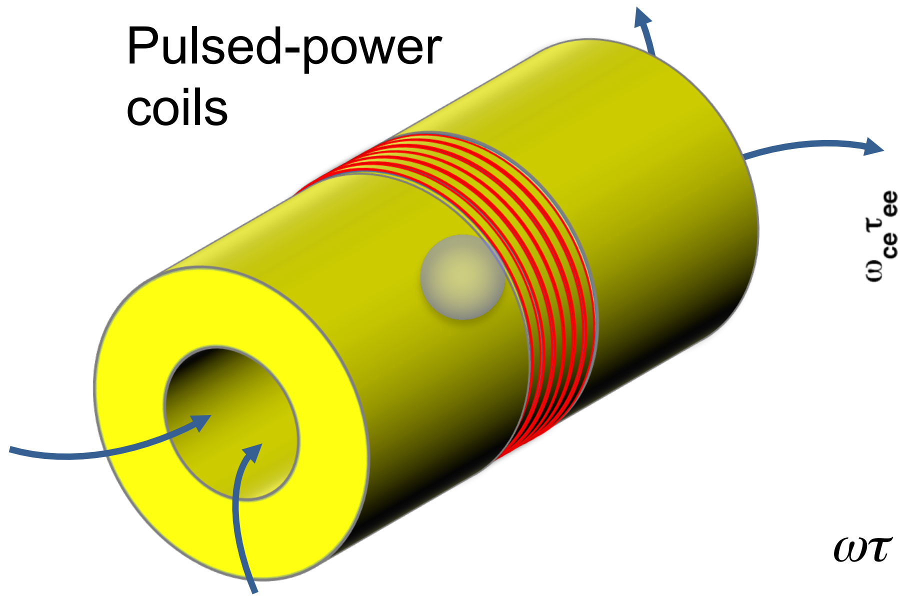


B-field for 30 kA

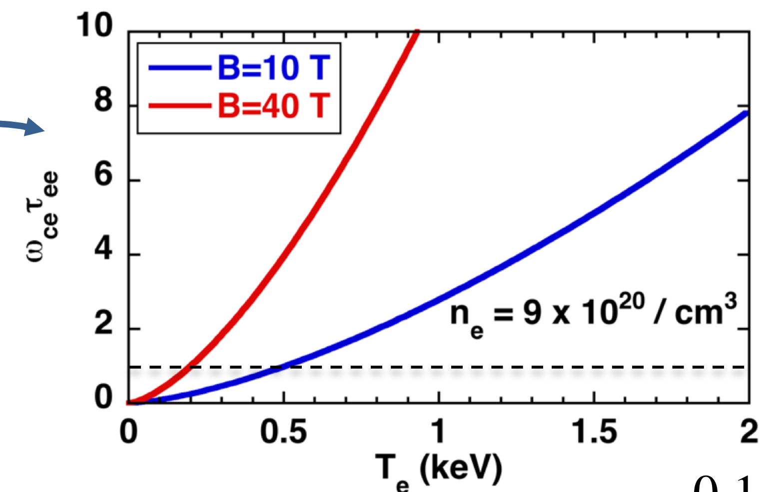


- Warm hohlraum does not use starbursts so coils can be closer together
- The central gap must accommodate the 100 μm window for core symmetry
- How does the non-uniform field affect hohlraum plasma conditions and dynamics?
- What role does the Al diagnostic band have on the resulting field?
- We will study these questions with simulations and measurements

B-field can affect electron heat conduction and alpha confinement



Hall parameter

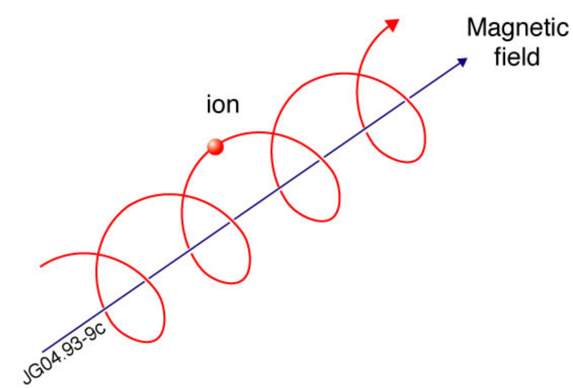


Hohlraum plasma electrons are easily magnetized

$$\omega\tau = 0.278 \bullet B[T] \bullet T_e[keV]^{3/2} \bullet \frac{0.1}{n_e / n_{cr(3\omega)}}$$

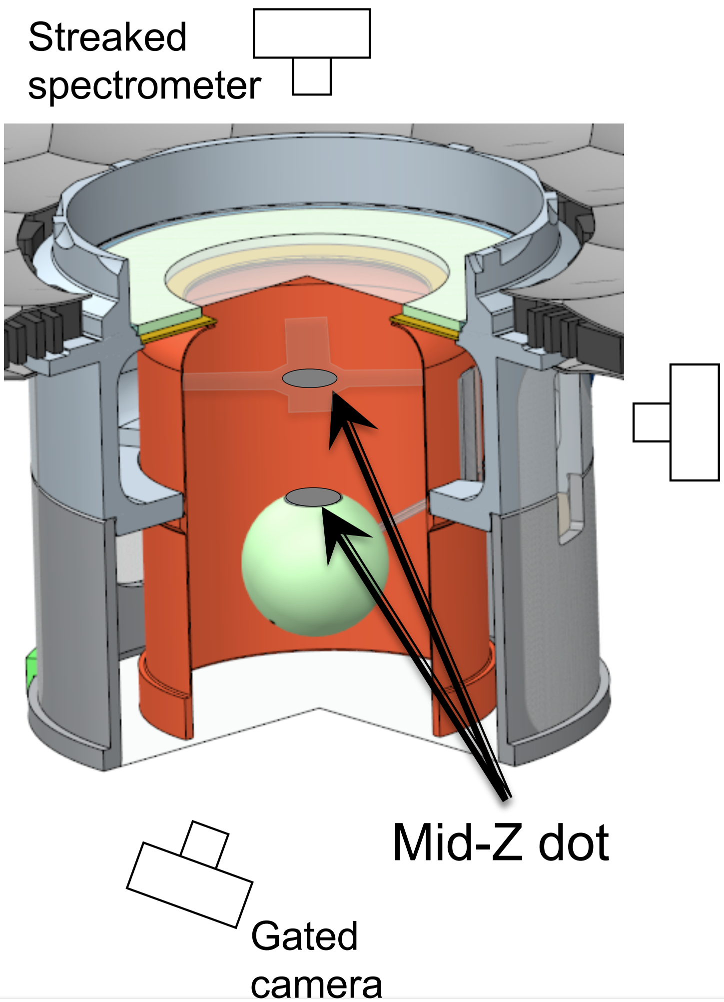
Alpha particle confinement:

- DT alpha at 3.5 MeV
- Gyro-radius of 25 – 50 μm requires B = 3.8 – 7.5 kT
- For CR = 20 this requires a seed field of 10 to 20 T



The external B-field may increase the hohlraum Te

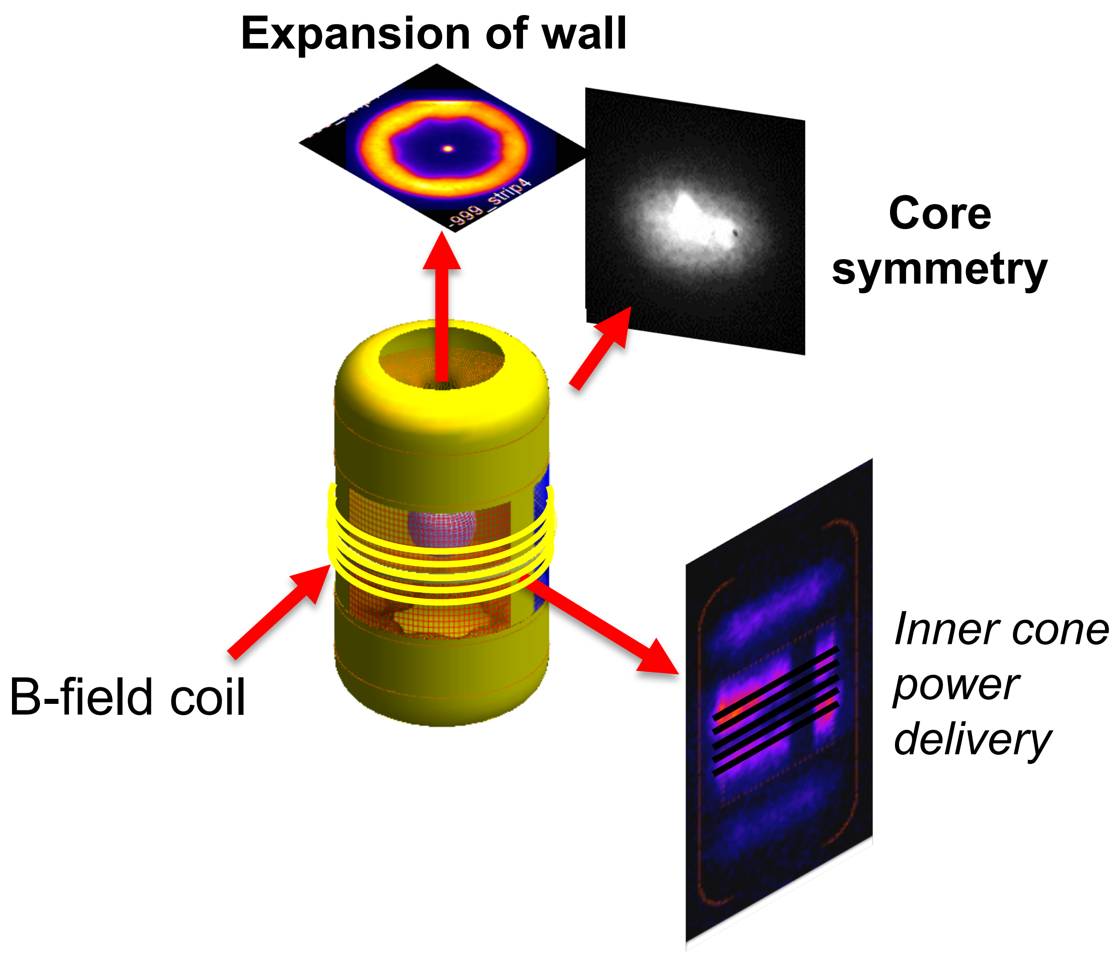
Dot spectroscopy



Te measurements can be made using mid-Z tracer spectroscopy or optical Thomson

NIF OTS

Measure hohlraum wall expansion and core shape



- Core symmetry and wall expansion from the pole has been done and may show affects due to the applied B-field
- Thin-wall measurement has been done; it can detect ~ 30% changes in inner beam propagation

Ion temperature and Yield have been observed to increase with an applied B-field

Magnetized implosions at LLE show a modest increase in Yn and Ti

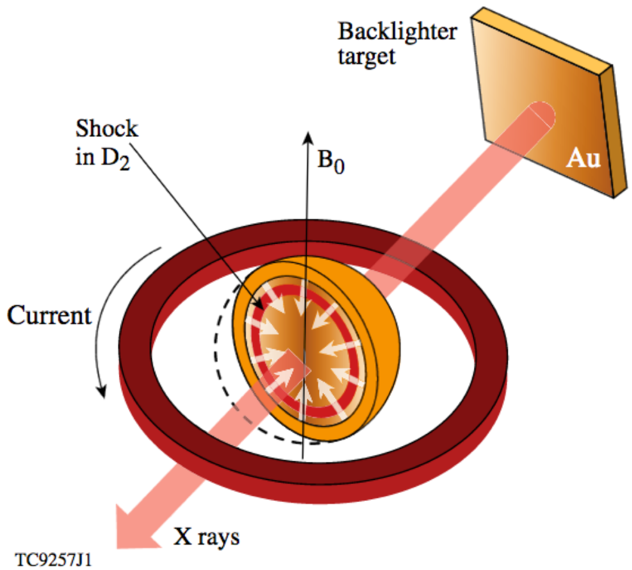
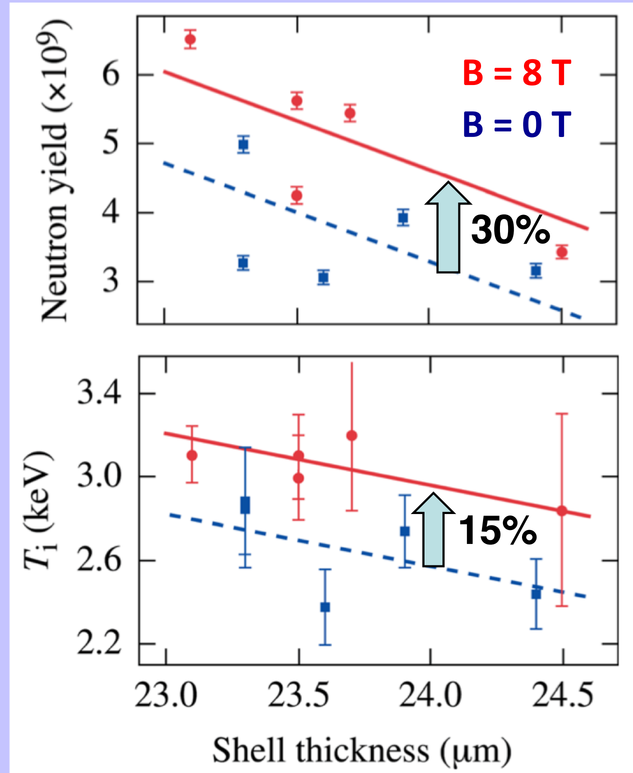


FIG. 1 (color online). A spherical ICF target is placed inside a coil generating an 80-kG magnetic field. The target is imploded by the OMEGA laser, trapping and compressing the field inside. X-ray radiography is used to assess the implosion uniformity.

B-fields have improved direct-drive capsule performance



Chang et al, Phys. Rev. Lett. 107, 035006 (2011)

Neutron spectra can help estimate the compressed B-field in the capsule

Shape and comparison of DD and DT neutron spectra may be used to quantify the compressed B-field

PRL **113,** 155004 (2014) PHYSICAL REVIEW LETTERS week ending 10 OCTOBER 2014

Understanding Fuel Magnetization and Mix Using Secondary Nuclear Reactions in Magneto-Inertial Fusion

P. F. Schmit, P. F. Knapp, S. B. Hansen, M. R. Gomez, K. D. Hahn, D. B. Sinars, K. J. Peterson, S. A. Slutz, A. B. Sefkow, T. J. Awe, E. Harding, C. A. Jennings, G. A. Chandler, G. W. Cooper, M. E. Cuneo, M. Geissel, A. J. Harvey-Thompson, M. C. Herrmann, M. H. Hess, O. Johns, D. C. Lamppa, M. R. Martin, R. D. McBride, J. L. Porter, G. K. Robertson, G. A. Rochau, D. C. Rovang, C. L. Ruiz, M. E. Savage, I. C. Smith, W. A. Stygar, and R. A. Vesey
Sandia National Laboratories, P.O. Box 5800, Albuquerque, New Mexico 87185-1186, USA
(Received 18 June 2014; published 6 October 2014)

Magnetizing the fuel in inertial confinement fusion relaxes ignition requirements by reducing thermal conductivity and changing the physics of burn product confinement. Diagnosing the level of fuel magnetization during burn is critical to understanding target performance in magneto-inertial fusion (MIF) implosions. In pure deuterium fusion plasma, 1.01 MeV tritons are emitted during deuterium-deuterium fusion and can undergo secondary deuterium-tritium reactions before exiting the fuel. Increasing the fuel magnetization elongates the path lengths through the fuel of some of the tritons, enhancing their probability of reaction. Based on this feature, a method to diagnose fuel magnetization using the ratio of overall deuterium-tritium to deuterium-deuterium neutron yields is developed. Analysis of anisotropies in the secondary neutron energy spectra further constrain the measurement. Secondary reactions also are shown to provide an upper bound for the volumetric fuel-pusher mix in MIF. The analysis is applied to recent MIF experiments [M. R. Gomez *et al.*, Phys. Rev. Lett. 113, 155003 (2014)] on the Z Pulsed Power Facility, indicating that significant magnetic confinement of charged burn products was achieved and suggesting a relatively low-mix environment. Both of these are essential features of future ignition-scale MIF designs.

DOI: 10.1103/PhysRevLett.113.155004 PACS numbers: 52.58.Lq, 52.55.Pi, 52.65.Pp, 52.70.Nc

May provide a way to verify the hot-spot B-field magnitude

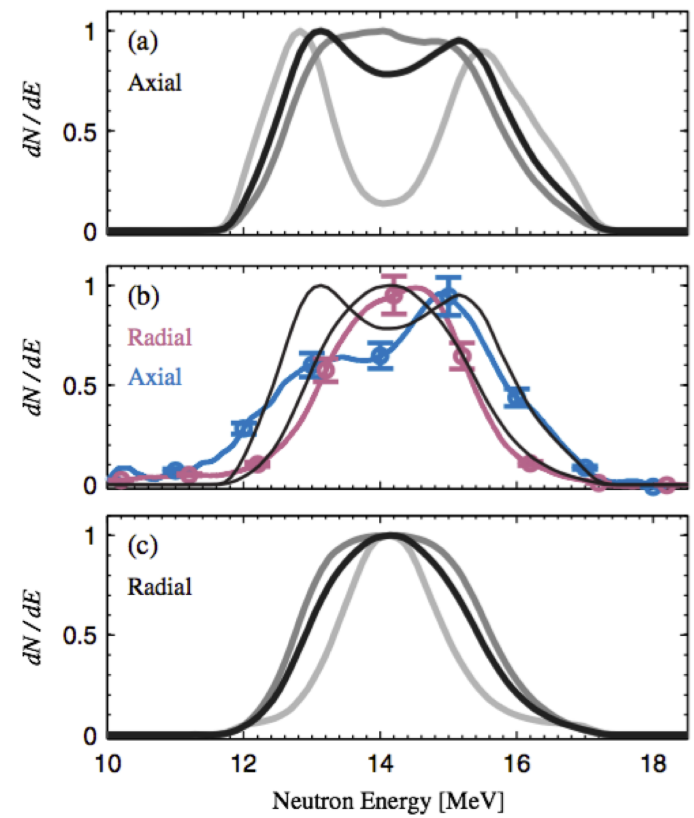


FIG. 2 (color online). (a) DT neutron spectra viewed axially calculated using $BR = 2.5 \times 10^5$ G cm (light gray curve), 4.2×10^5 G cm (black curve), and 7.0×10^5 G cm (gray curve). (b) Axially (blue) and radially (magenta) viewed DT neutron spectra from the recent MagLIF experiments, with representative error bars shown. (c) DT neutron spectra viewed radially calculated using the same values of *BR* as in (a). Black curves from (a) and (c) are overlaid on (b) for comparison.

The warm magnetized hohlraum platform is under development

Considering several options

- 3-shock HDC capsule in a gas-filled Au hohlraum
- ID exploding pusher
- 2-shock thick capsule – matches 1D simulations

Basis for the decision is which design gives the most significant and easily observable changes when applying an external B-field

Summary and plans

Summary

- Soak-in moves the hohlraum too far; slots set an upper limit on hohlraum gas-fill – need testing for C_5H_{12}
- Non-uniform B-field geometry is not optimized yet; may affect hohlraum plasma conditions
- Important to diagnose hohlraum plasma conditions and dynamics as well as diagnose the capsule behavior to develop a full understanding of the effects of magnetization

Plans

- Experimentally study limits of using slots for B-field penetration
- Simulate expected changes to hohlraum dynamics from the applied B
- Decide on the hohlraum platform

Lawrence Livermore National Laboratory

TanDM (90, 348) installed at NIF