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NNSA Laboratory Directed Research & Development

Materials in Extremes: Innovation for Qualification and Certification

Implementing and Diagnosing Magnetic Flux Compression on Z

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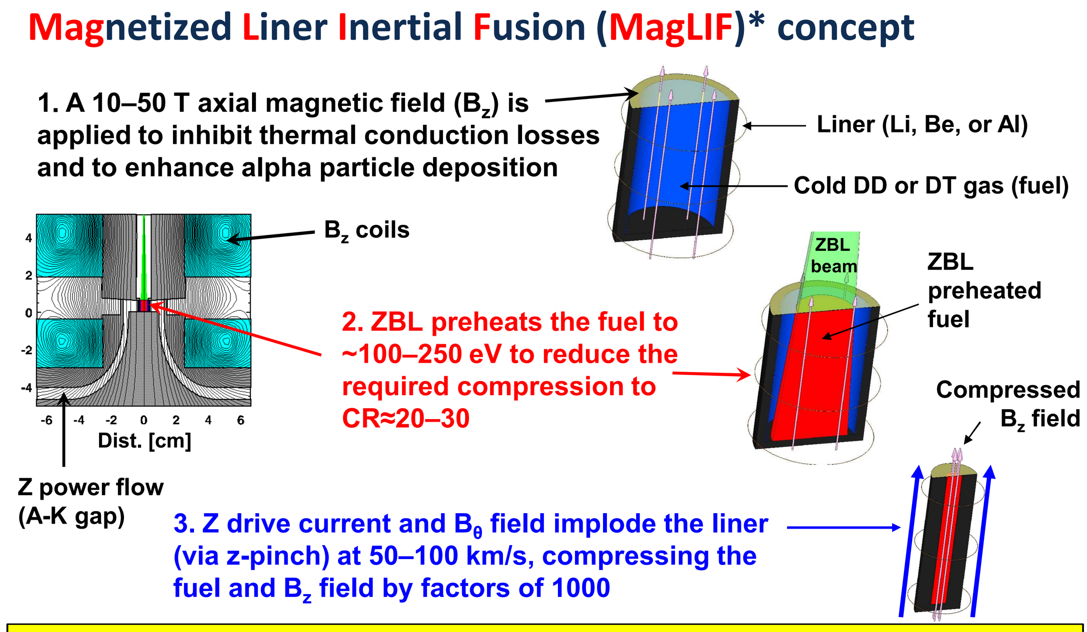
What is the challenge?

The Z pulsed-power facility offers a unique platform for producing very large magnetic fields (10's–100's MGauss) coupled to very high-energy-density plasmas (>>1 Mbar). These extreme states of magnetized matter offer many rich and exciting phenomena for scientific inquiry, as highlighted by the recent Research Needs Workshop (ReNeW) on high-energy-density laboratory physics (HEDLP).

One method to achieve very large magnetic fields on Z is magnetic flux compression. In principle, an axial seed field, B_{z0}, of about 30 T can be trapped and compressed (amplified) to more than 10,000 T by a fast imploding liner on Z. This phenomenon is exploited by the Magnetized Liner Inertial Fusion (MagLIF) concept currently under development at Sandia.

We are working toward the evaluation of a new Magnetized Liner Inertial Fusion (MagLIF)* concept



With DT fuel, simulations indicate scientific breakeven may be possible on Z (fusion energy out = energy deposited in fusion fuel)

*S. A. Slutz *et al.*, PoP 17, 056303 (2010); S. A. Slutz and R. A. Vesey, PRL 108, 025003 (2012).

Our ability to compress flux remains unclear, however, due to poorly understood physics. For example, the Nernst thermo-electromagnetic effect can cause significant flux loss across strong temperature gradients in the fuel. The Nernst effect is included in higher-order magnetohydrodynamics theory, but the physics needs to be validated experimentally.

Developing diagnostics to measure these compressed fields is required to assess whether or not adequate compression is achieved.

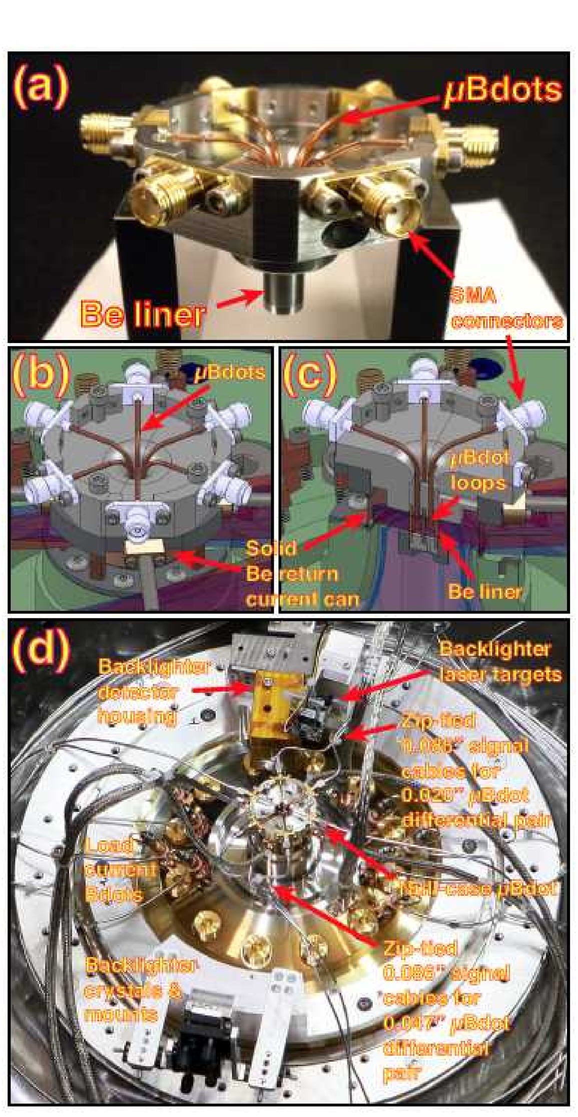
Why is this important for our nation?

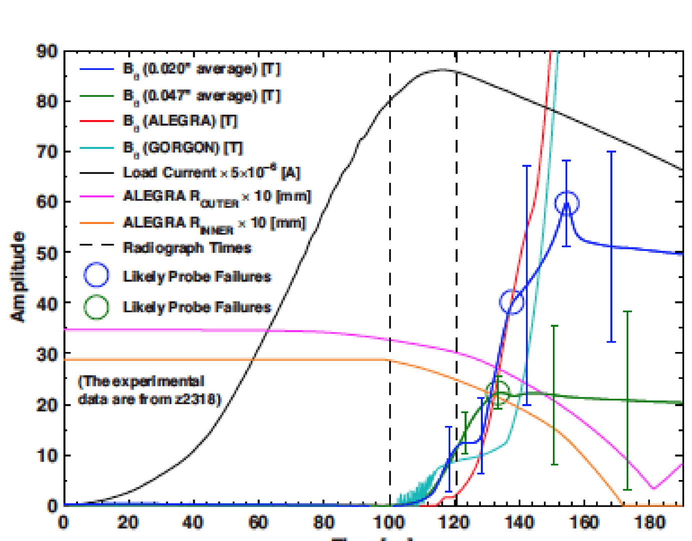
Understanding the fundamental physics of magnetic flux compression will have a direct impact on our magnetized inertial-confinement fusion program (e.g., MagLIF) and our radiation effects program (e.g., neutron sources, radiation sources, etc.), and thus impact related national security missions (e.g., stockpile stewardship), as well as possibly provide a viable future fusion energy source.

What is our innovation?

Producing and diagnosing such intense magnetic fields in the harsh HEDLP environment on Z is nontrivial. We are therefore testing on Z the most promising diagnostic methods that have been proven on smaller-scale facilities (e.g., Zeeman spectroscopy, miniaturized "micro B-dots", and Faraday rotation). We are also evaluating new diagnostic possibilities (e.g., on-axis PDV).

Micro-Bdot Measurements of B_θ on Z





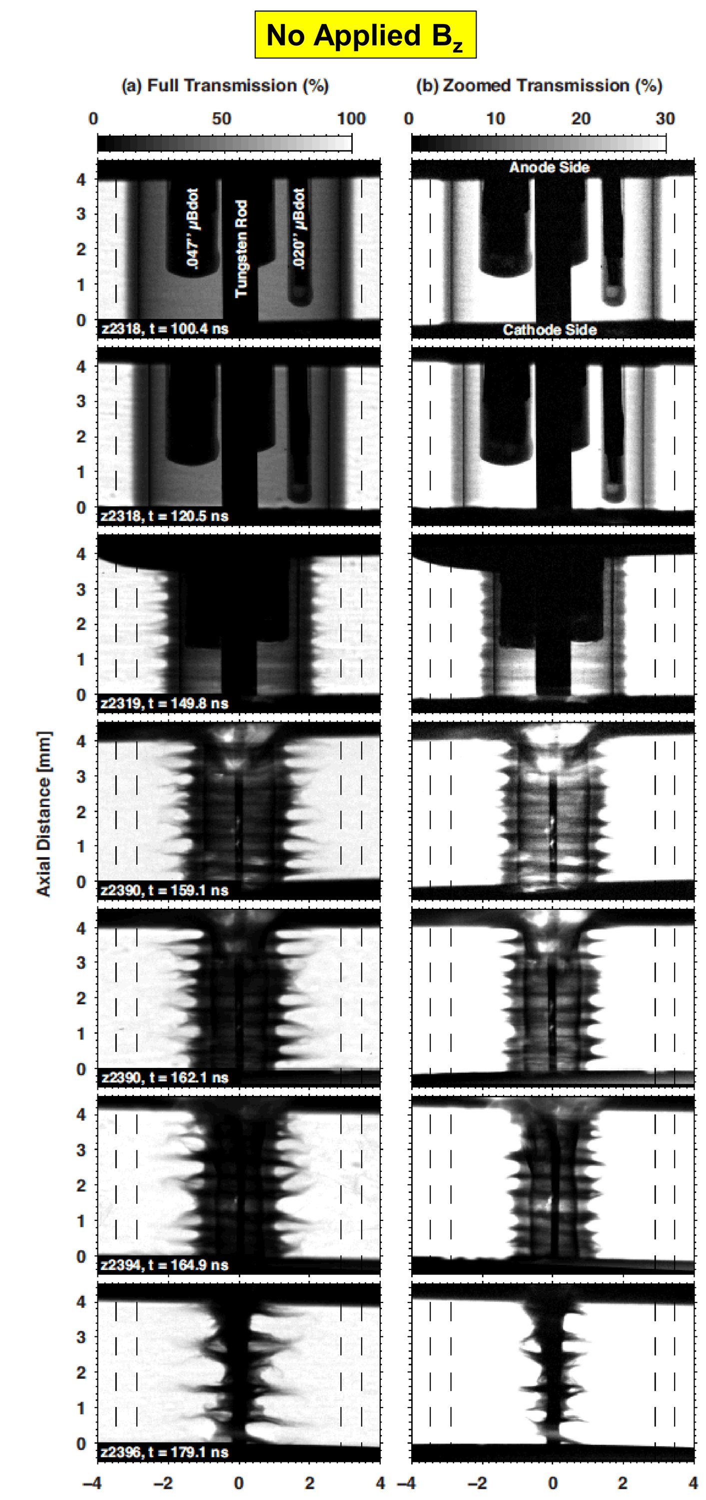
- µBdot development & fielding on Z
- In collaboration with John Greenly at Cornell University
- Successfully detected (and measured) B_θ prior to bulk implosion of liner (in good agreement with that predicted by ALEGRA simulations)
- µBdots have recently been used to measure B_z in first flux-compression experiments on Z; analysis is underway

R. D. McBride *et al.*, Phys. Plasmas 20, 056309 (2013).

What have we learned so far?

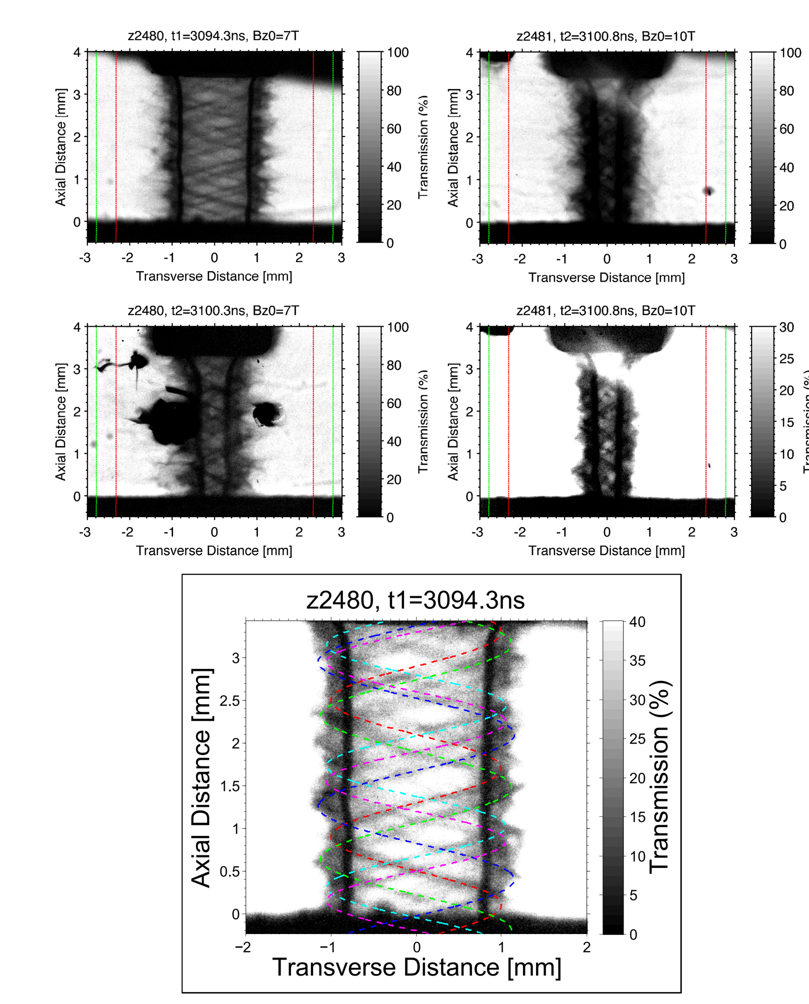
We are presently in the first 6 months of this 3-year LDRD. So far, we have performed 4 experiments on Z that involved flux compression (2 dedicated flux compression experiments and 2 ride-along/MagLIF-development experiments), and we have already found very exciting and surprising results. We have found that the applied B_z field dramatically alters the structure caused by the Magneto-Rayleigh-Taylor (MRT) instability, changing it from ring-like structure to helical-like structure:

No Applied B_z

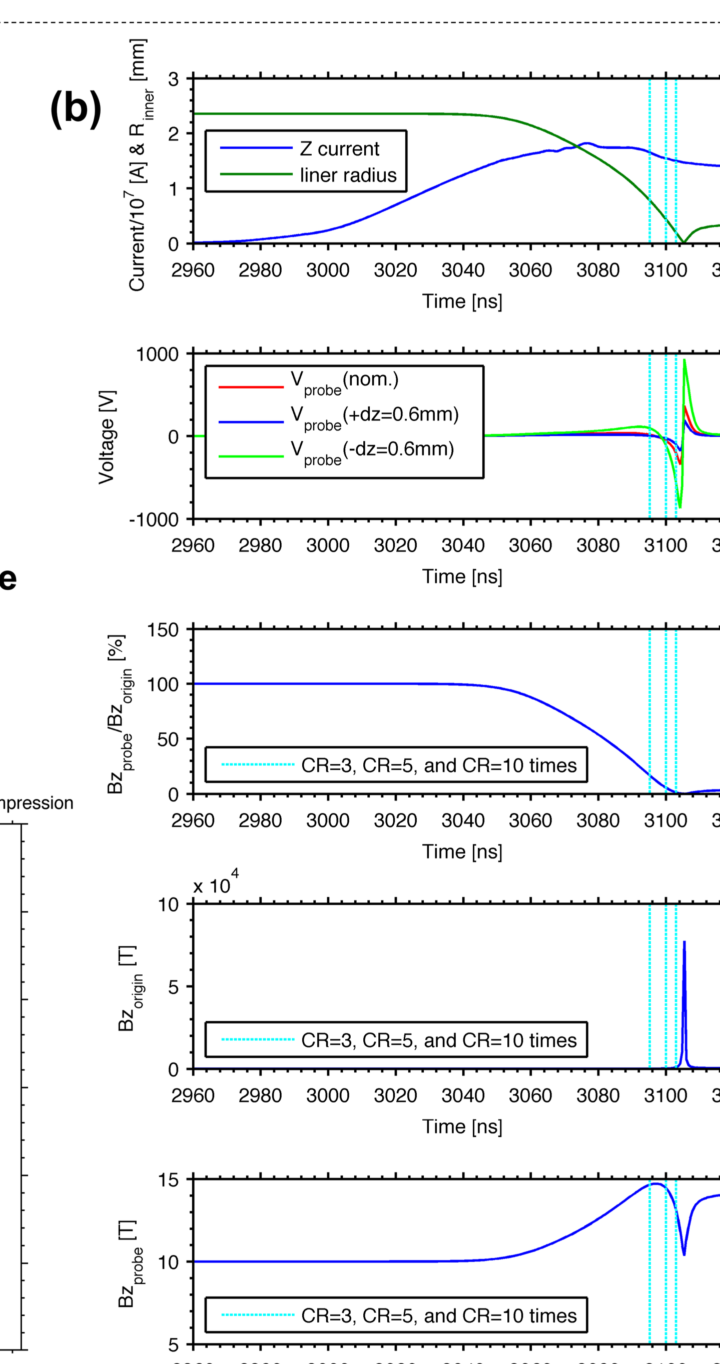


R. D. McBride *et al.*, Phys. Plasmas 20, 056309 (2013).

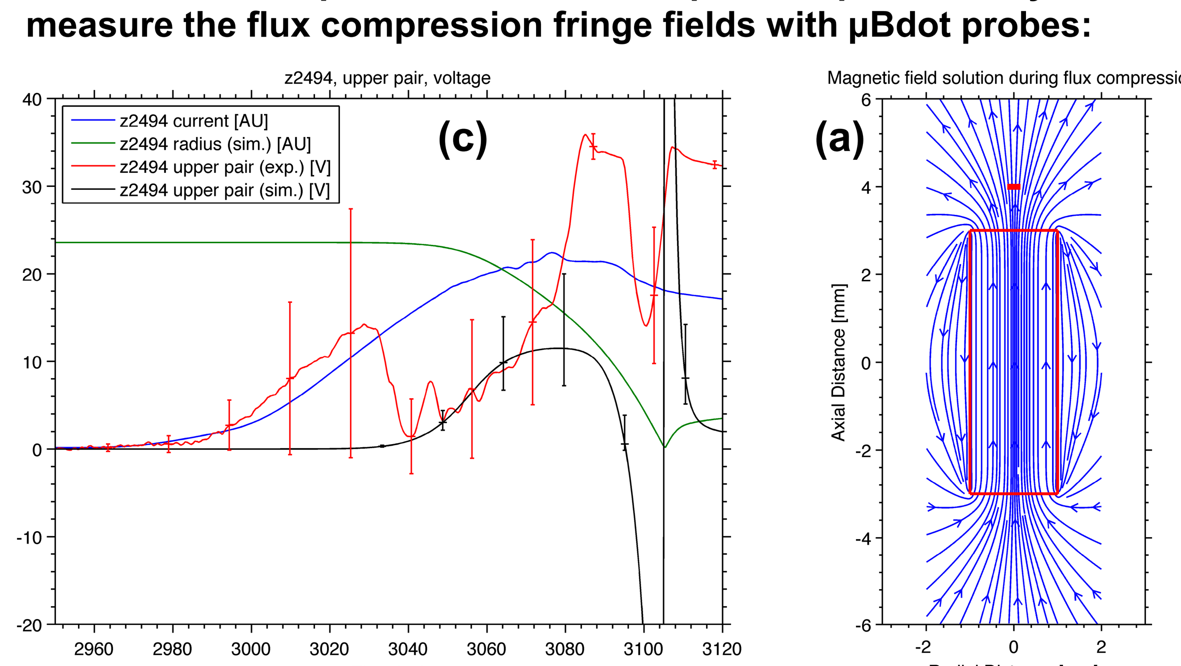
With Applied B_z



T. J. Awe *et al.*, manuscript in preparation for PRL

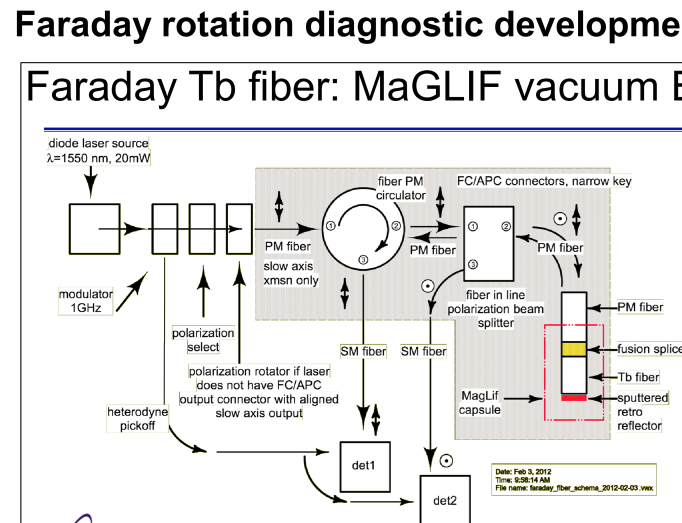


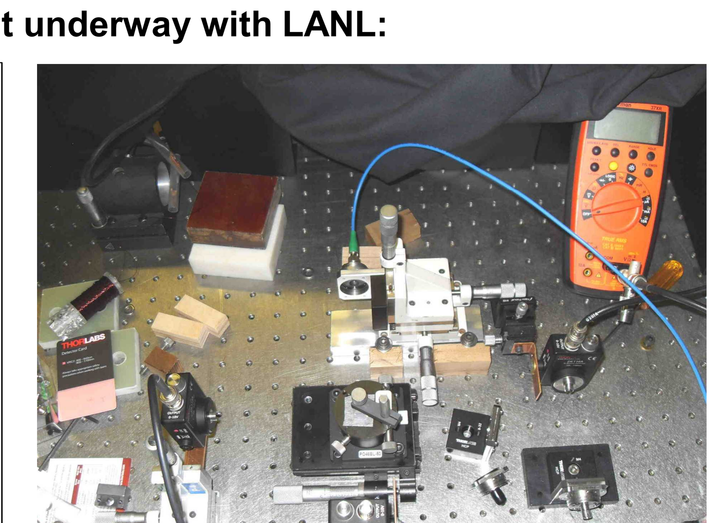
(a) We have developed simulation codes to calculate the magnetic fields during flux compression. (b) We have used these simulations to estimate the expected signal responses from µBdot probes in the fringe fields. (c) We have used these estimates to compare to our first attempts to experimentally measure the flux compression fringe fields with µBdot probes:



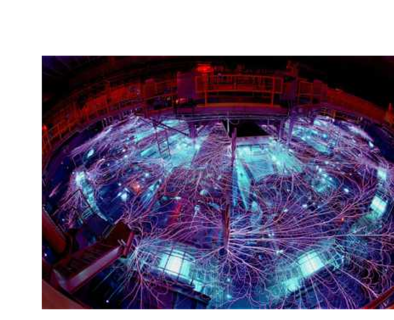
We have already successfully detected flux compression signals, but we have also learned that it will be very difficult to infer the amplified B_z field within the liner at CR=3, 5, or 10 (our measurement goals) without very precise characterization of the probe loop positions and better electrical shielding

Faraday rotation diagnostic development underway with LANL:





Much work and many challenges remain!



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