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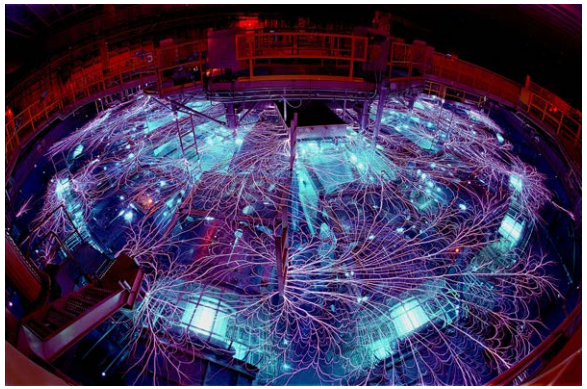
Sandia National Laboratories

Scientific uncertainties and opportunities in MagLIF

Daniel B. Sinars
with thanks to the MagLIF working group

MagLIF Workshop
Albuquerque, NM, Feb. 5-8, 2012



U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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We are excited to have a diverse group!

- Sandia National Laboratories
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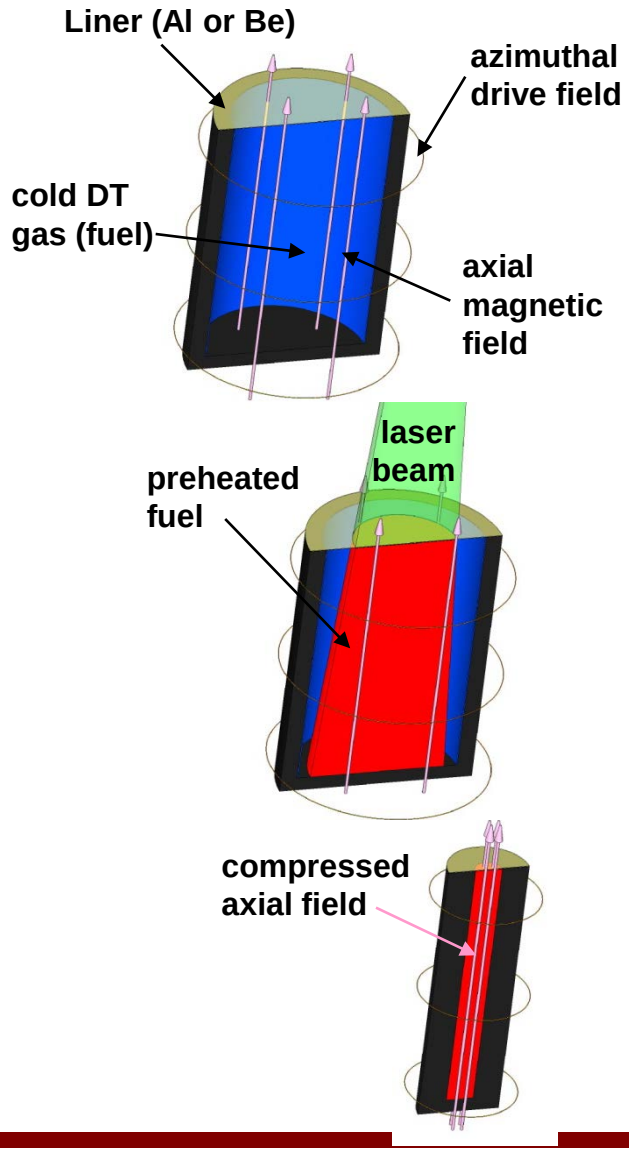
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- Naval Research Laboratory
- Cornell University
- Imperial College
- Princeton
- UCSD
- U. Michigan
- U. Nevada-Reno
- U. Rochester
- UT-Austin
- U. Washington
- National Nuclear Security Administration

The pulsed power ICF program is assessing the potential of magnetically-driven targets to provide a path to high fusion yield

- Magnetic fields can be used to create extreme pressures needed for fusion & comparable to those available on the National Ignition Facility (~100 Mbar).
- Magnetic fields may make laboratory fusion easier by suppressing electron conduction losses and confining alpha particles in burning plasmas.
- Liner targets directly driven by current and magnetic fields can couple large fractions of the driver's stored energy to fusion fuel (~0.5%). High-yield (GJ-class), high-gain (>500) target designs appear feasible with today's technology.
- Our strategy at Sandia for assessing the potential of magnetically-driven fusion targets is based on three main elements
  - Demonstrate understanding of key target physics and design control over target performance on Z, validating key aspects of our simulation tools.
  - Demonstrate scientific breakeven on Z, where breakeven is defined as obtaining as much fusion yield out as the energy deposited into the fuel.
  - Assemble a compelling argument for high-yield inertial confinement fusion.
    - Validated target designs capable of GJ-class yields
    - Developing facility requirements to drive such targets
    - Motivating the stockpile stewardship applications of high yields

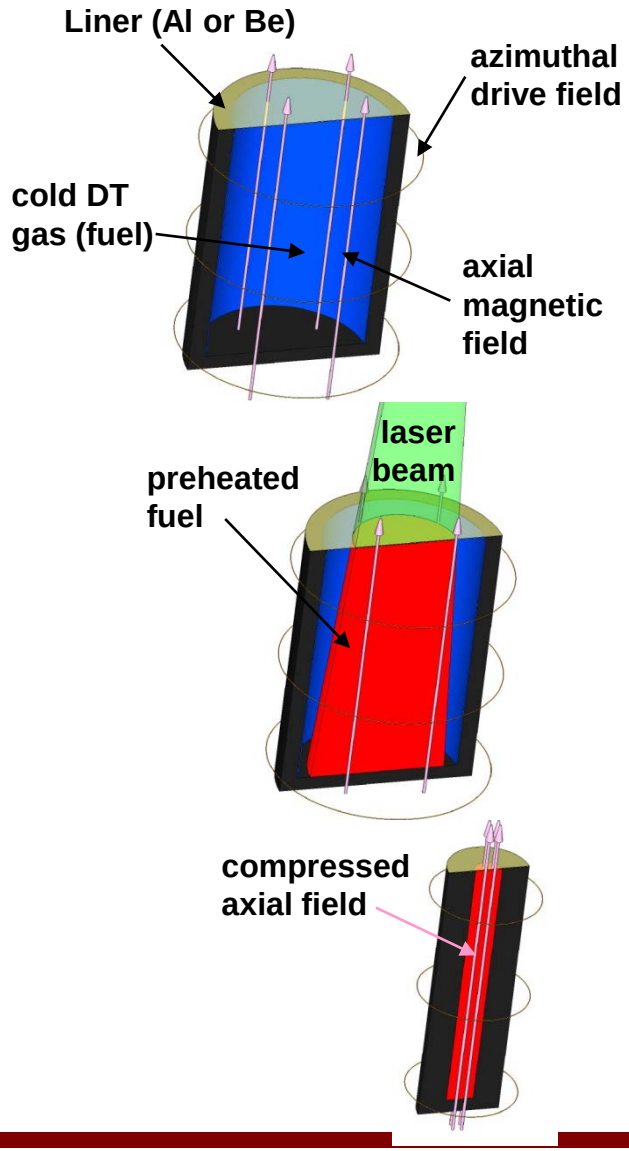
We are working toward the evaluation of a new Magnetized Liner Inertial Fusion (MagLIF)* concept



- An initial ~10 T axial magnetic field is applied
  - Inhibits thermal conduction losses
  - Enhances alpha particle energy deposition
  - May help stabilize implosion at late times
- During implosion, the fuel is heated using the Z-Beamlet laser (<10 kJ needed)
  - Preheating reduces the compression needed to obtain ignition temperatures to 20-30 on Z
  - Preheating reduces the implosion velocity needed to "only" 100 km/s (slow for ICF)
  - Stagnation pressure required is few Gbar, not a few hundred Gbar
- Scientific breakeven may be possible on Z (fusion yield = energy into fusion fuel); something not yet achieved by any laboratory

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

There are many opportunities for science and engineering research related to MagLIF



- Issues can be subdivided into several categories:
  - Liner dynamics
  - Fuel preheating
  - Stagnation and fuel assembly
  - Integration and fielding
  - Modeling & simulation
  - Effectively collaborating

Example liner dynamics questions

- **What are the design requirements that maintain sufficiently low instability levels to allow MagLIF to succeed?**
  - Is there a liner surface roughness specification?
  - How do we account for electro-thermal instabilities? Can we suppress them by using coatings or layering on the liner surface?
  - Do we have azimuthal asymmetries in the power flow on Z that can seed damaging levels of liner instabilities?
  - How uniformly does the current need to initiate on the liner?
  - How uniform does the liner have to be at a convergence ratio of 10?
- Do we understand how the magneto-Rayleigh-Taylor instability correlates azimuthally even with random surface roughness?
- Are 3D simulations required to capture MRT growth?
- Is there blowoff from the inside liner surface due to ablation or spall from combined rarefaction waves that leads to mix? Can we mitigate this?
- How does isentropic compression (current pulse shaping) benefit MagLIF?
- What can we do to mitigate wall instabilities at the liner top/bottom?

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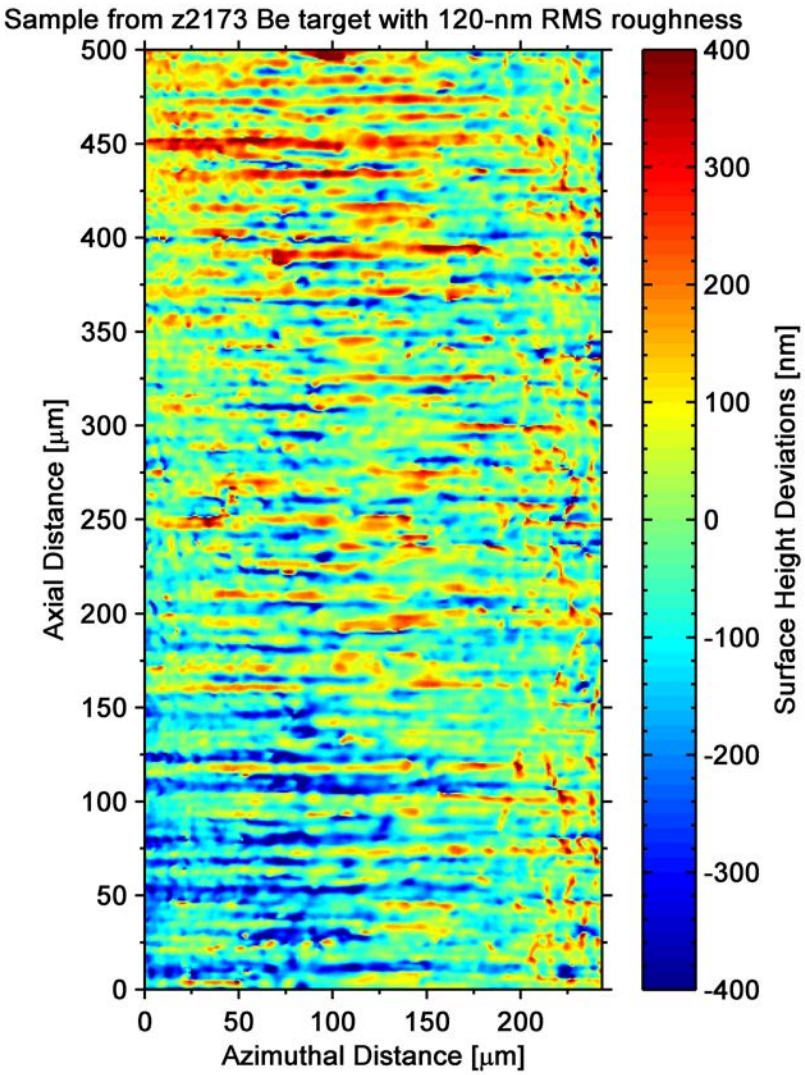

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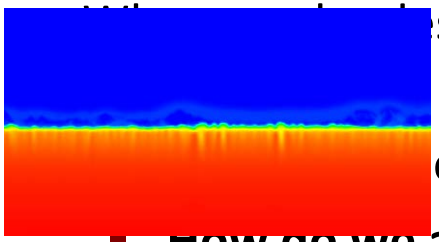

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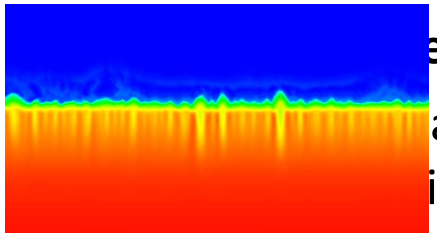

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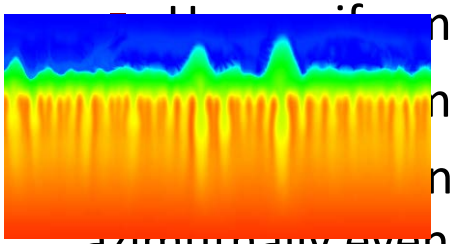

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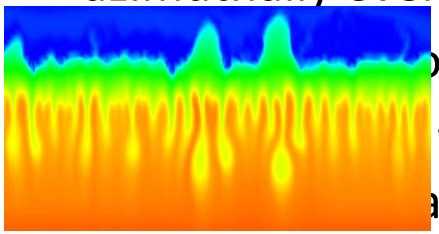

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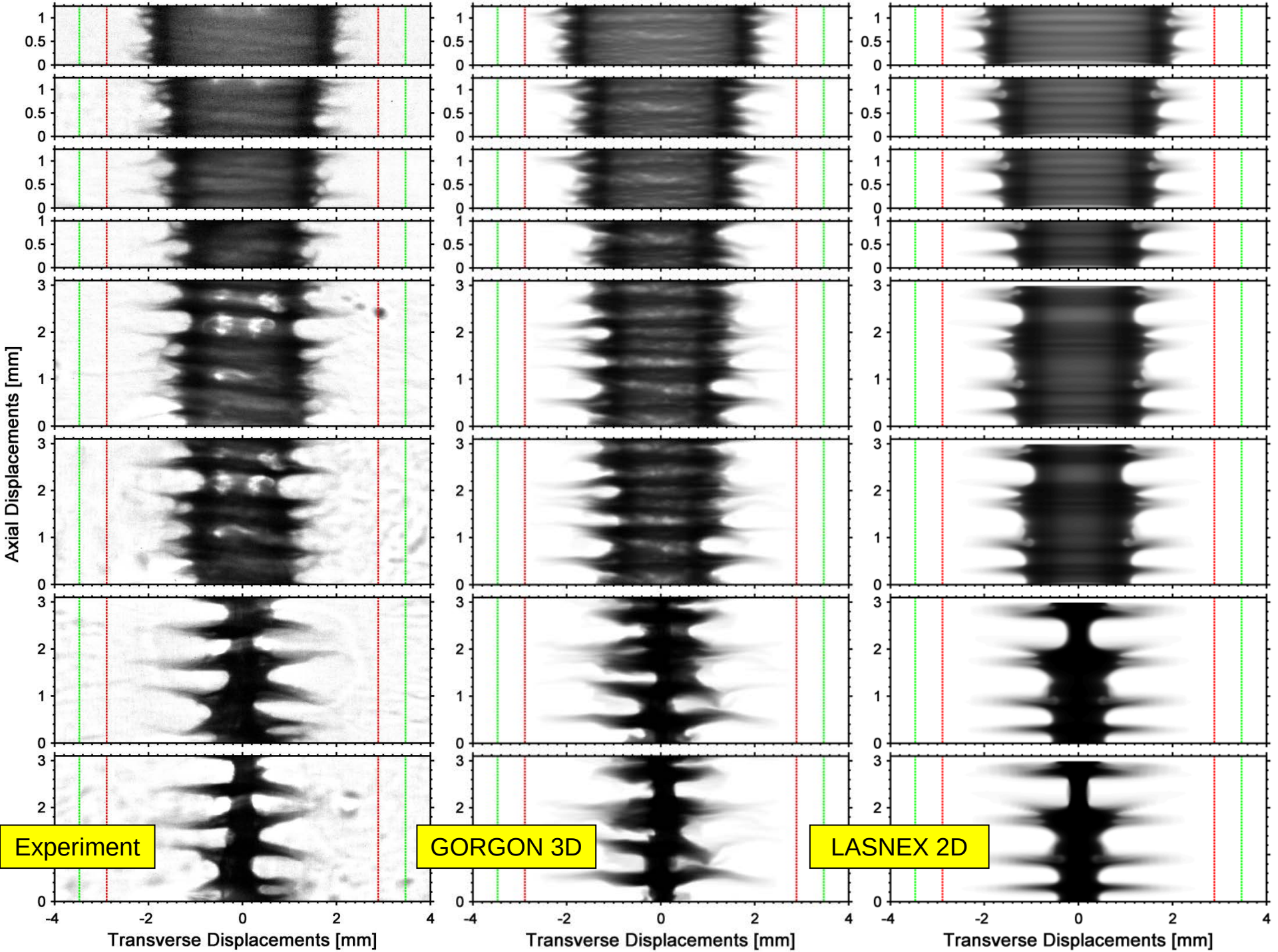
Experiment
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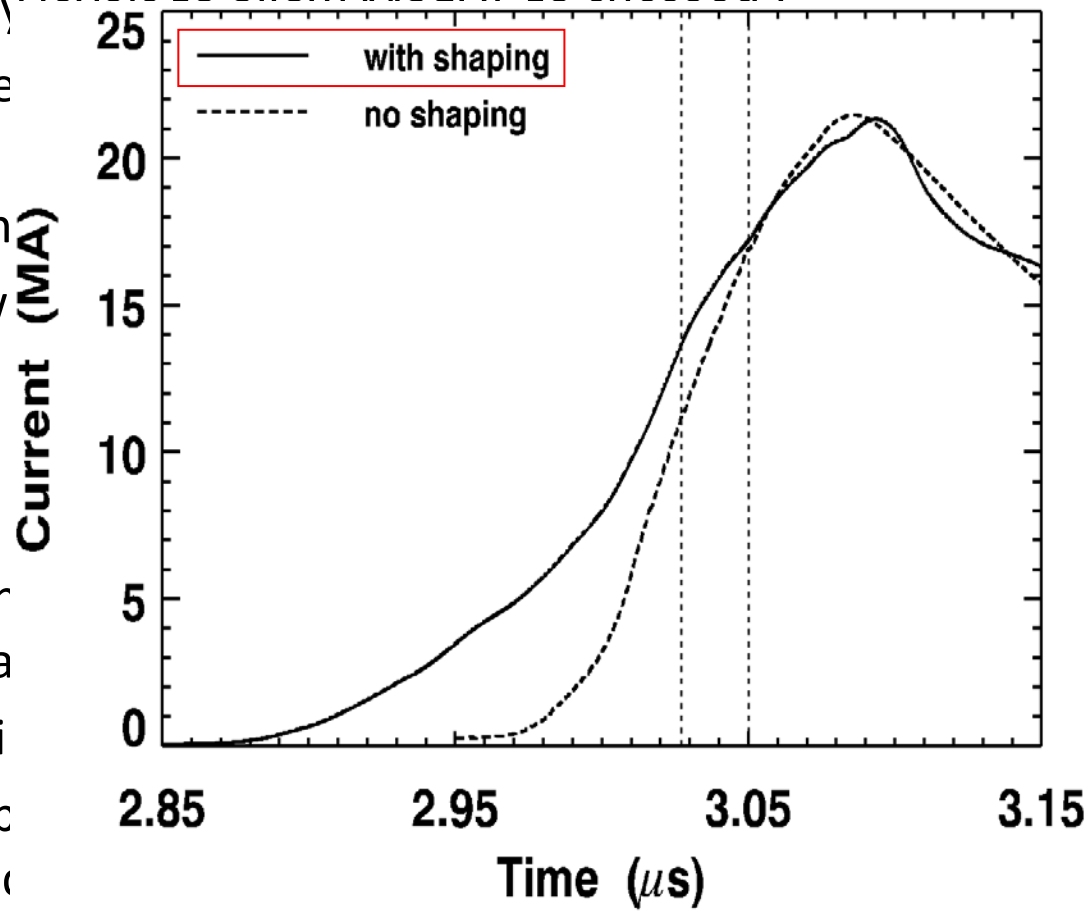

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Example fuel preheating questions

- **What are the requirements for the preheated plasma?**
  - How much preheat energy do we actually need?
  - How axially and radially uniform does the preheated plasma need to be? How does the uniformity depend on the laser parameters (e.g., focus, diameter, uniformity?)
  - How do we prevent the preheating from ablating the end caps?
- How do we characterize the preheated plasma?
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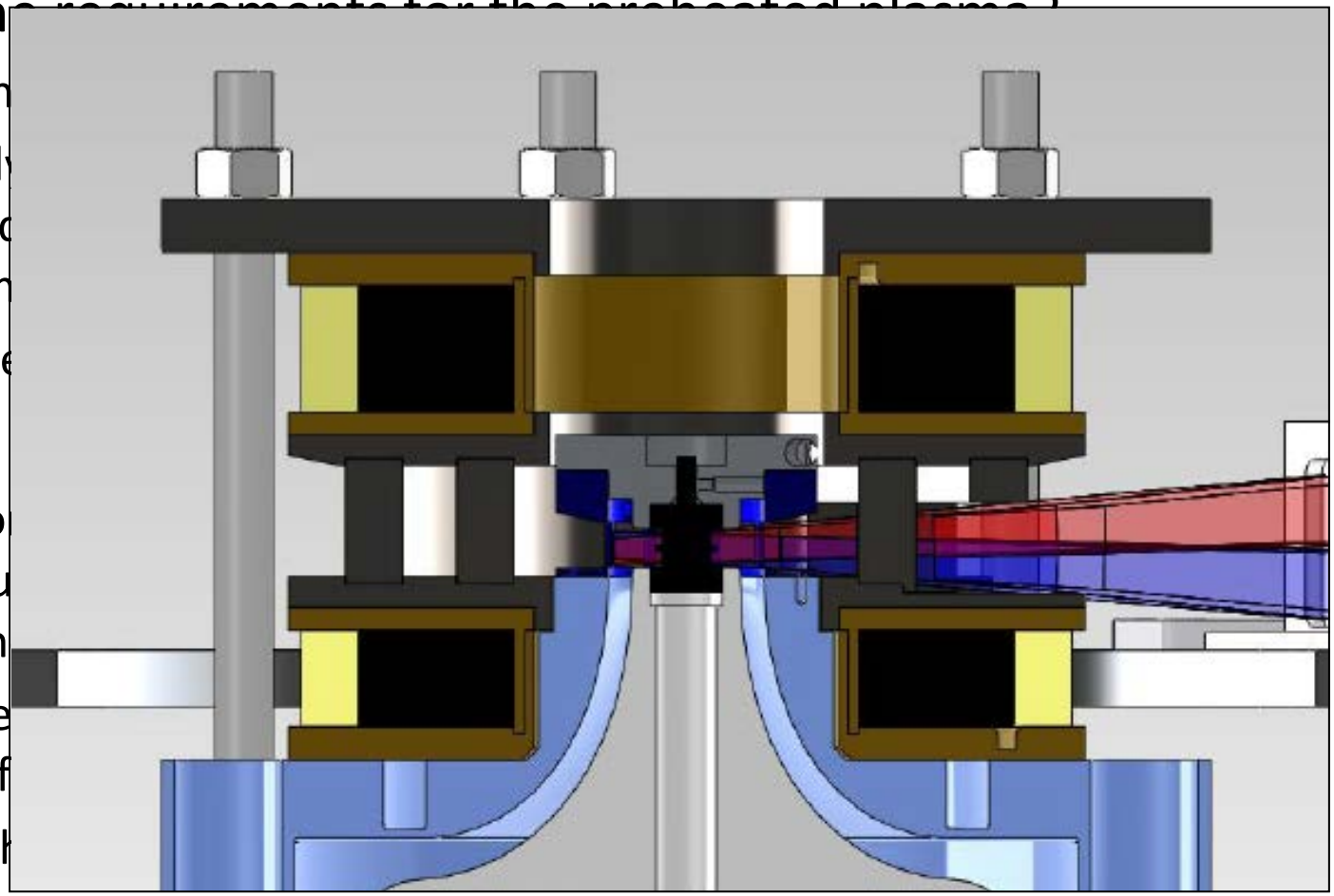

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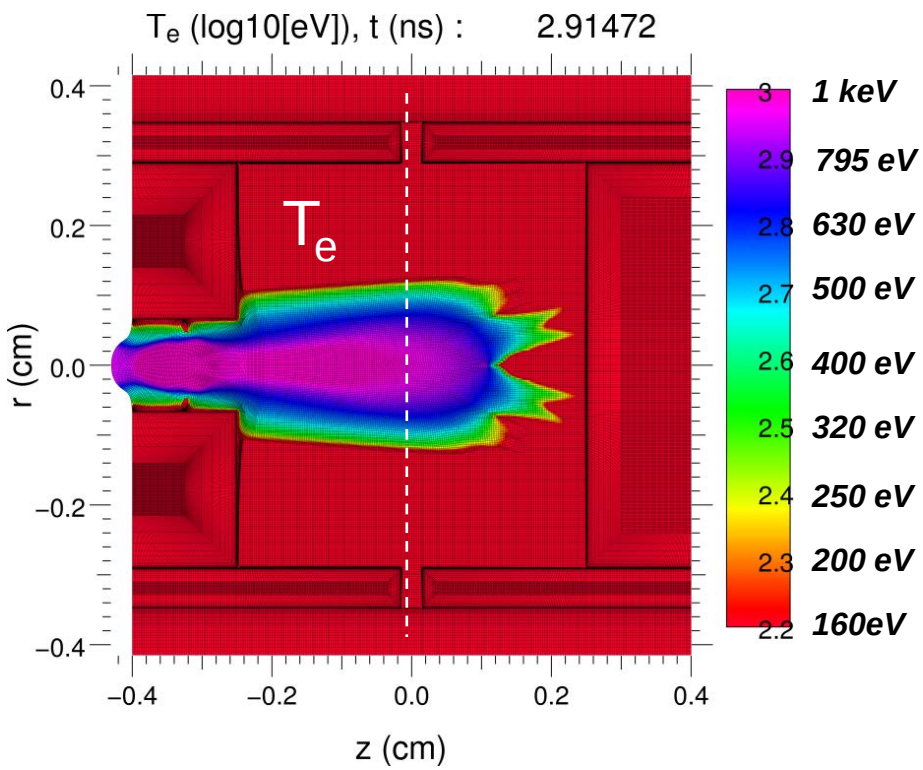

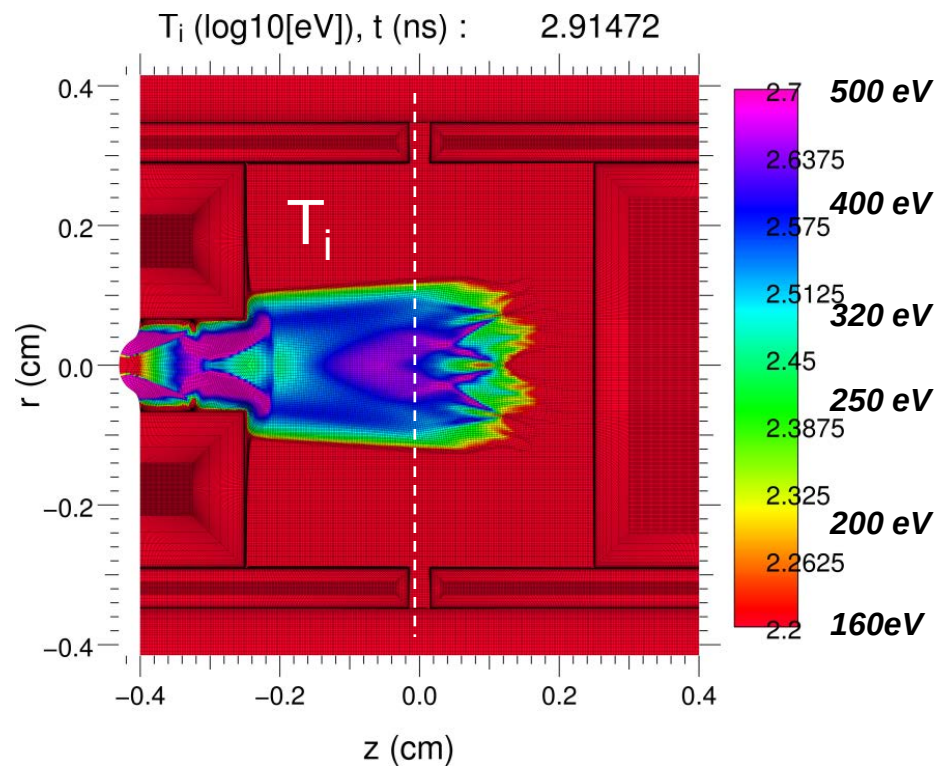

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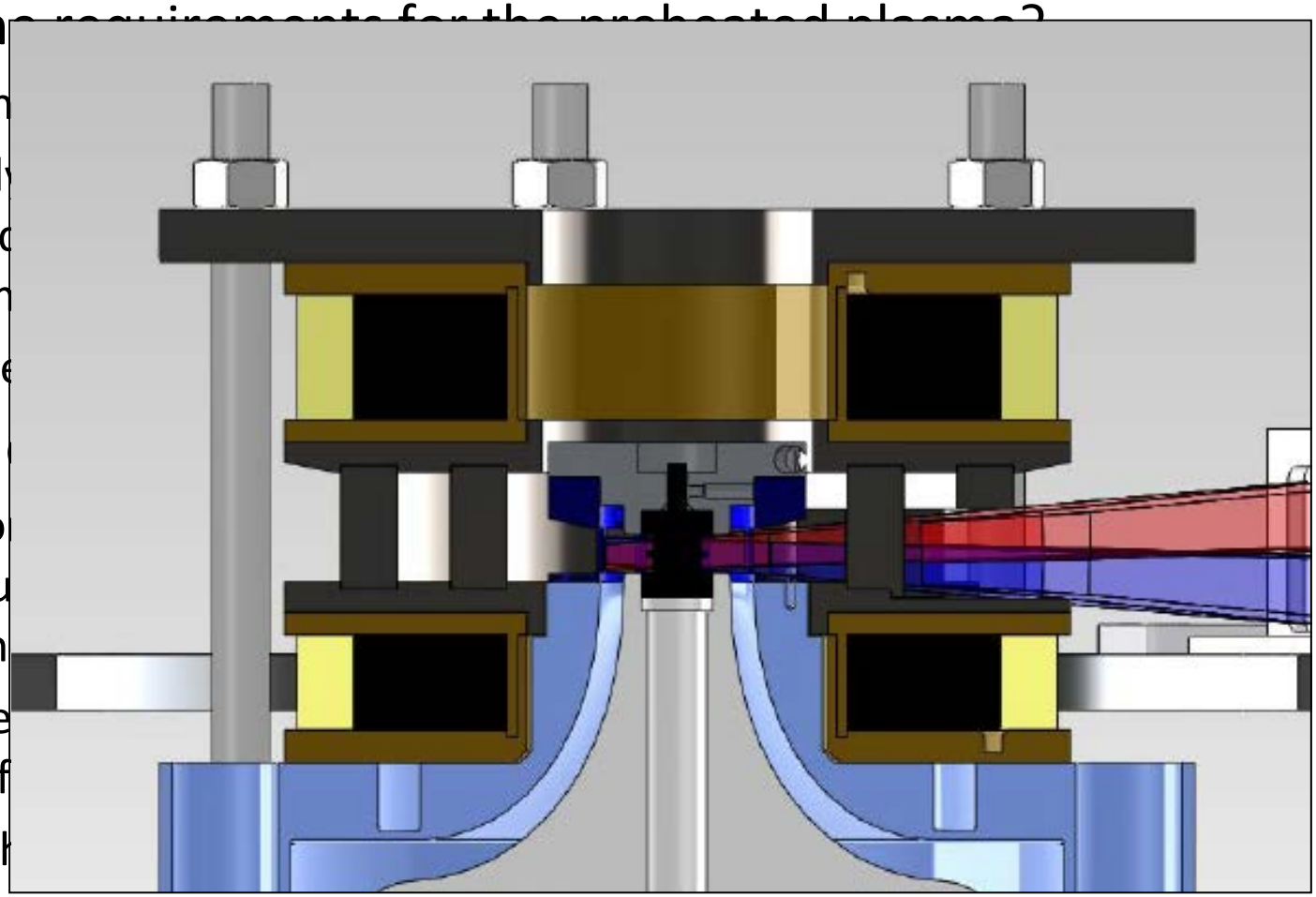

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Example stagnation & fuel assembly questions

- **What are our key performance metrics?**
  (Yield, T_ion, flux compression, convergence ratio, etc.?)
  Can we identify and pull out important empirical variables?
- Can we use x-ray spectroscopy as an alternative method for diagnosing fuel conditions rather than neutron diagnostics?
  What types of fuel dopants do we want? (Cl, Ar, Ne, Kr, Xe, Rn)
- What is the magnetic field doing in our experiments?
  - How do we measure magnetic field flux compression?
  - How much of the axial Bfield remains in the fuel (Nernst)? What are the maximum and average values of the Bfield?
  - Is there a metric other than yield that will allow us to measure the impact of the magnetic field on the target performance?
- Does MagLIF work if there is a larger distribution of r-Btheta than expected, so that the magnetic compression is weaker?

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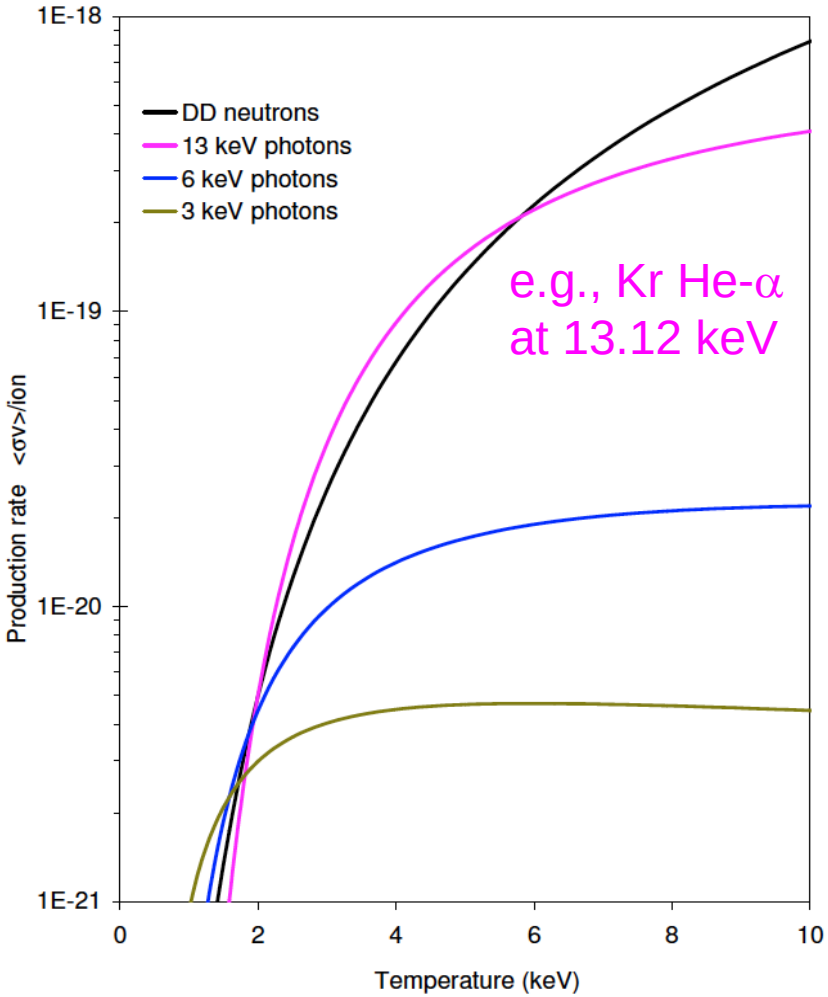

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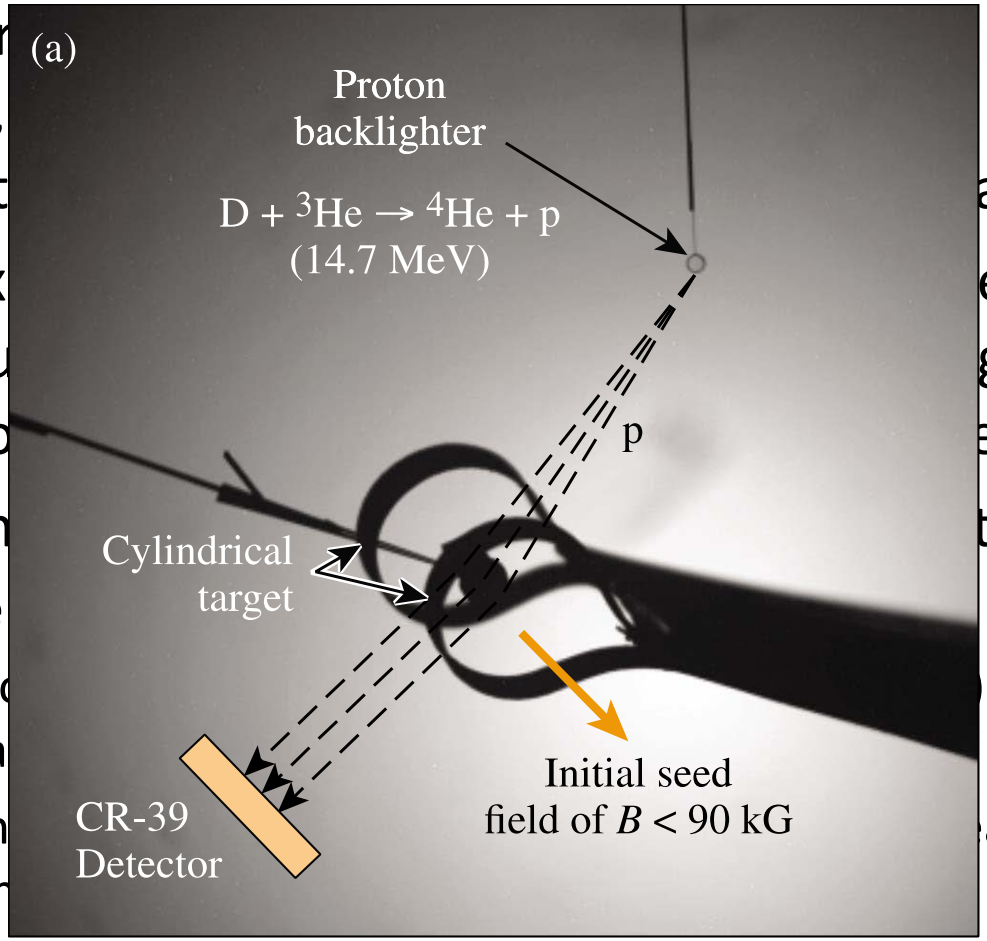

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Example stagnation & fuel assembly questions

- What are our key performance metrics?
  (Yield, T_ion, flux compression, convergence ratio, etc.?)
  Can we identify and pull out important empirical variables?
- Can we use x-ray spectroscopy as an alternative method for diagnosing fuel conditions rather than neutron diagnostics?
  What types of fuel dopants do we want? (Cl, Ar, Ne, Kr, Xe, Rn)
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  - How do we measure magnetic field flux compression?
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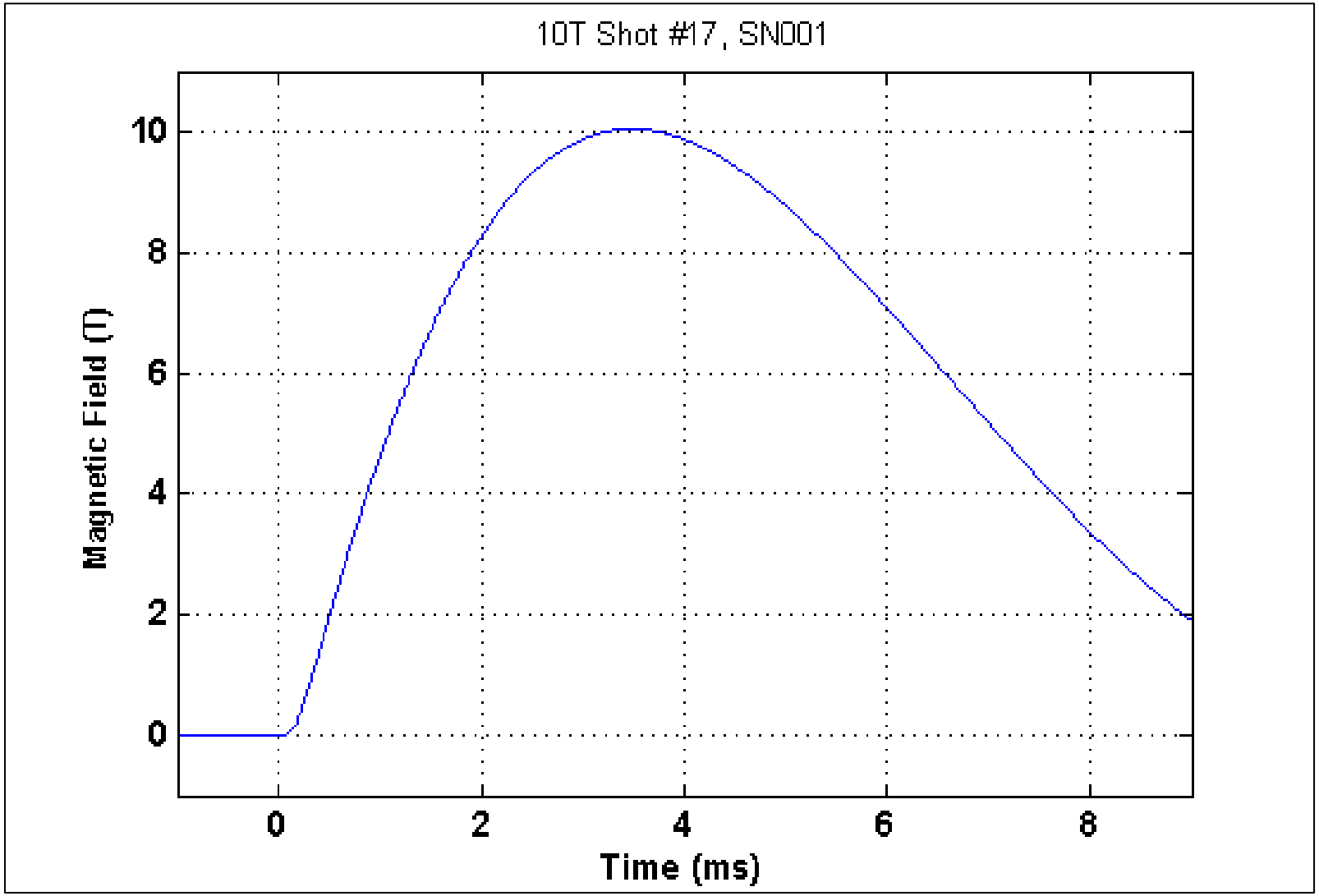
Example integration & fielding questions

- **Will the seed field (10-30 T) deform or perturb the liner?**



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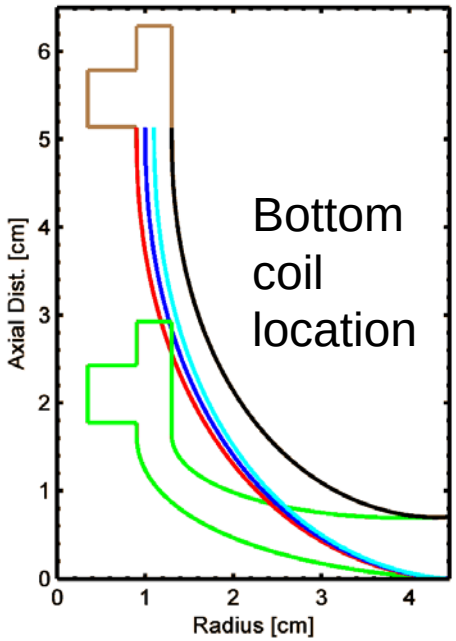

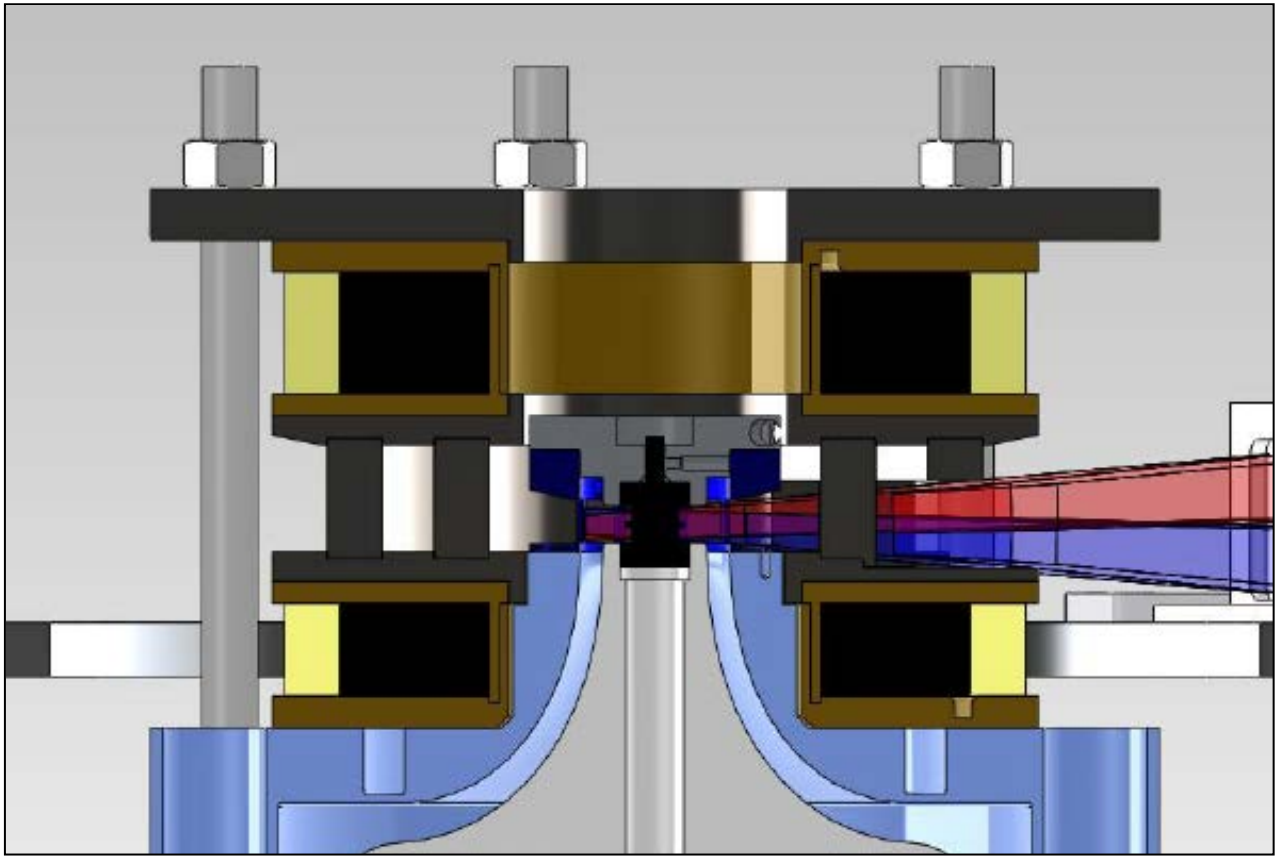

<u>MagLIF inductance</u>
5.52 nH (7 mm to 4 mm)
4.82 nH (7 mm to 3 mm)
4.18 nH (7 mm to 2 mm)
<u>Standard inductance</u>
3.97 nH (7 mm to 4 mm)

High L → Convolute losses?
Small gaps → feed losses?

Example integration & fielding questions

- Will the seed field (10-30 T) deform or perturb the liner?
- How good is the current delivery in the raised power feed geometry that is compatible with the Bfield coils?
- **What do we need to diagnose in situ on Z and what can we safely extrapolate from standalone or offline tests?**
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- What diagnostic access is needed for the initial tests? Would we be better off doing higher-field tests with less access?
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- When is the earliest that Sandia can field a fully-integrated experiment of any kind on Z?

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Example modeling & simulation questions

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Questions about effectively collaborating

- **How do we effectively collaborate with our university colleagues and their work?**
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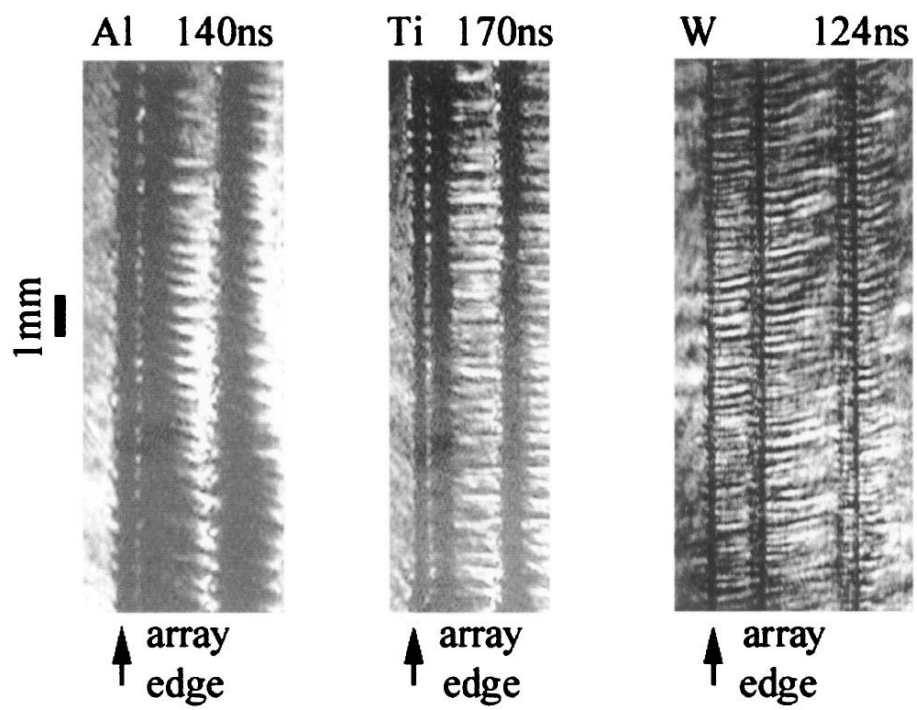

FIG. 3. Laser probing showing periodic structures in the coronal plasma for Al, Ti, and W wire arrays.

Questions about effectively collaborating

- How do we effectively collaborate with our university colleagues and their work?

- **What experiments can be done on university-scale facilities that will either inform us on key physics issues or be scaled tests of MagLIF conditions?**

- Are there diagnostic ideas that can be demonstrated on university facilities that would ultimately be relevant to Z?

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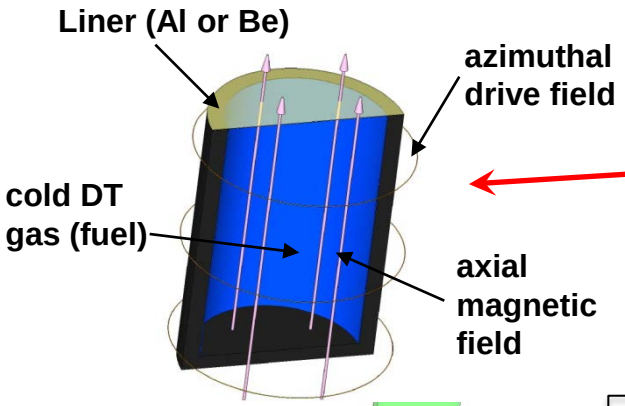
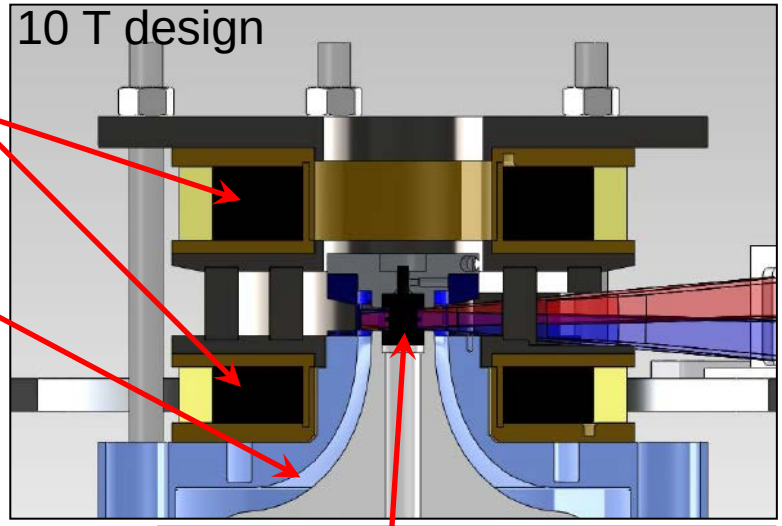
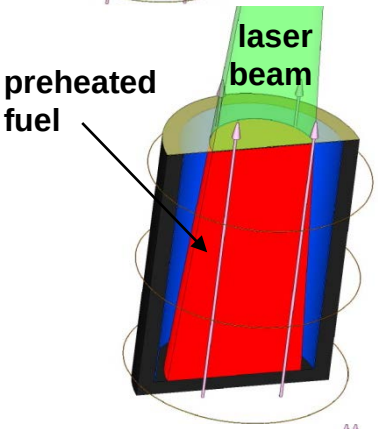
Moving from concept to actual implementation requires new experimental capabilities for Z



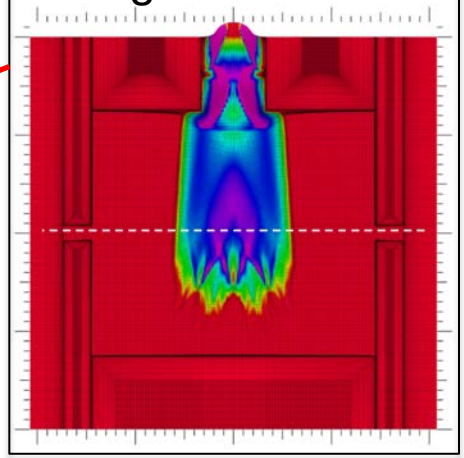
External Coils for Bz

Extended power feed in presence of Bz

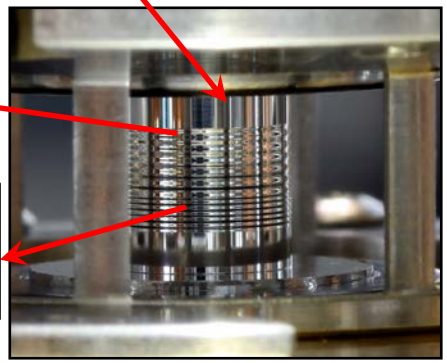




Preheat capability using Z-Beamlet

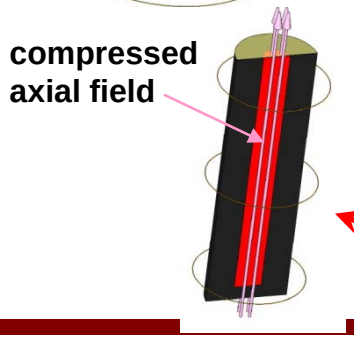


Target fabrication and MRT growth characterization



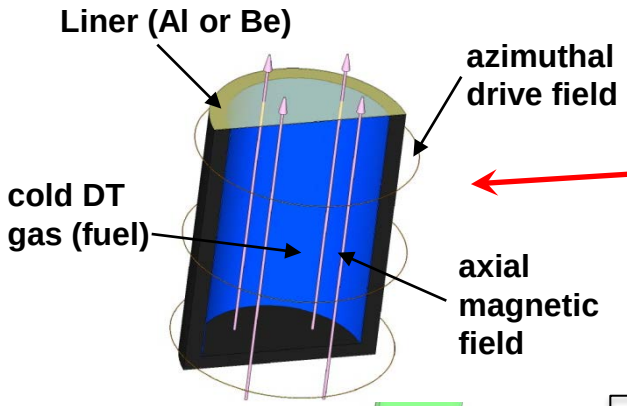
Adv. neutron diagnostics

>10 keV x-ray diagnostics



Magnetic flux compression diagnostics

We think an integrated test in 2013 is possible



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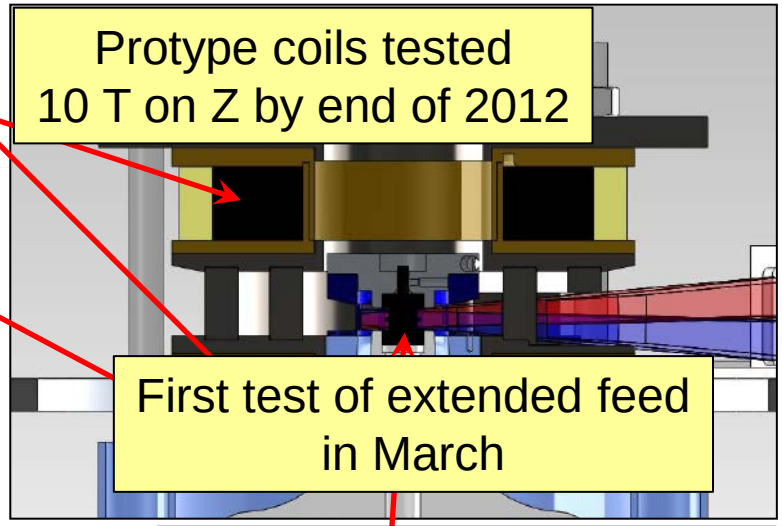
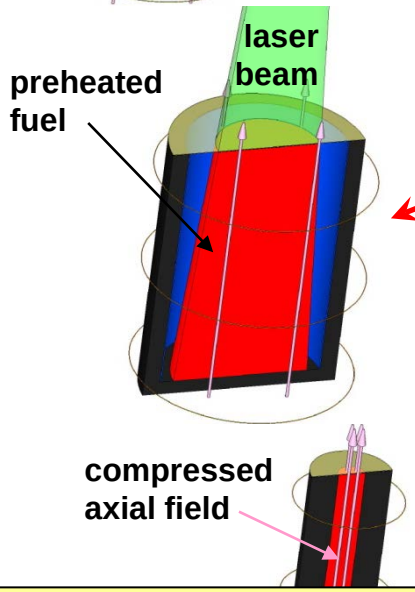


Protype coils tested 10 T on Z by end of 2012

First test of extended feed in March

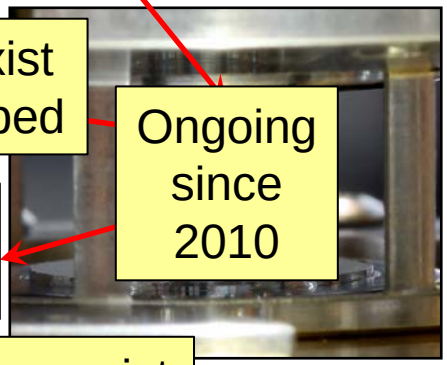


Preheat capability using Z-Beamlet

Working on test objectives Standalone test on Z by end of 2012? Preheat test on downline in 2013

Target fabrication and MRT growth characterization

Yield, nTOF exist Imager prototyped



Ongoing since 2010

>10 keV x-ray diagnostics

Micro-Bdots tested in March Conceptual ideas needed

Time-integrated >10 keV spectrometers exist Time-resolved ideas in conceptual stage

We would like your help with MagLIF!

- The goal of this workshop is not to convince you that Sandia has all of the answers…
- …or all of the right questions!

- Our goal is to engage you on what we are doing and thinking so that we can get feedback from you.

- We hope that there are opportunities for collaboration and that you leave with ideas for scientific proposals that you can carry out at your home institutions

The workshop agenda is designed to help facilitate these goals

- **Monday**
  - Presentations on integrated calculations and theory
  - Presentations on liner stability questions
  - Presentations on measuring and generating magnetic fields
- **Tuesday**
  - Presentations on preheat measurements
  - Presentations on target fabrication capabilities
  - Parallel Discussion Sessions
    - Discussion session on measuring magnetic fields, flux compression, preheat
    - Discussion session on stability, fuel assembly, & stagnation physics
- **Wednesday morning**
  - Report to large group the results of the discussion sessions
  - General discussion session
- You are invited to make short presentations during the discussion sessions—please contact the moderator (Nakhleh or Cuneo)