*Exceptional service in the national interest*

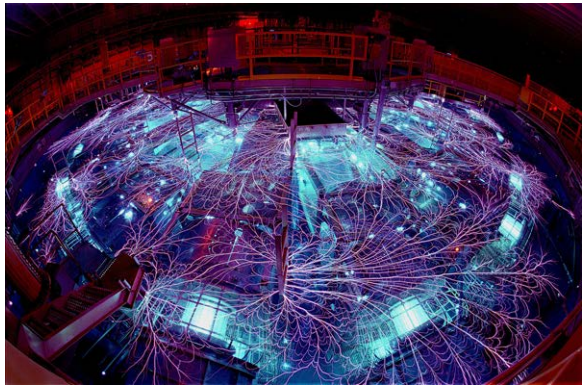
Sandia National Laboratories

# Z-Beamlet laser preheat and experimental capabilities

Daniel B. Sinars, Eric Harding, Adam Sefkow, Matthias Geissel, David Montgomery*

*MagLIF Workshop*

*Albuquerque, NM, Feb. 5-8, 2012*



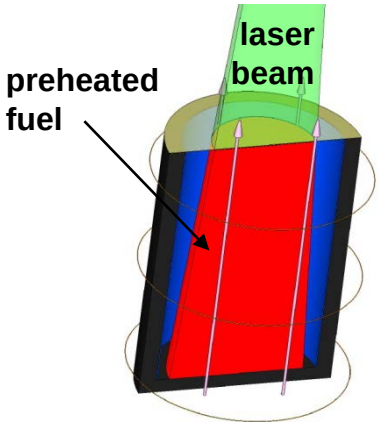
U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

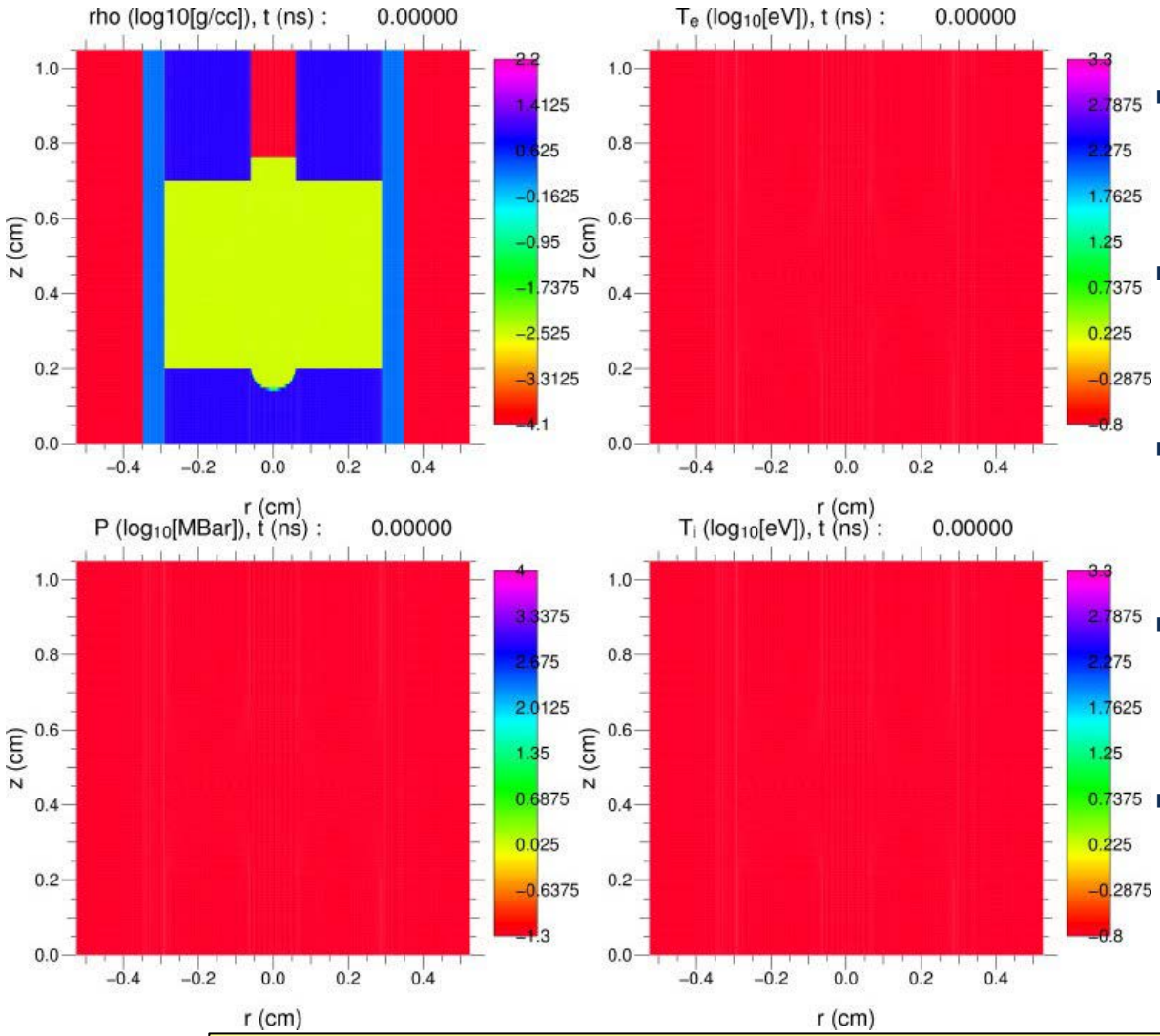
* Los Alamos National Laboratory

# The current plan for preheating the fusion fuel on Z is to use the Z-Beamlet laser during the implosion




- **Main technical challenges**
  - How do we heat an ICF target in the center of the machine with the on-axis Z-Beamlet Final Optics Assembly without damaging it?
  - Can we deliver >2 kJ of energy from the laser?
  - How much benchmarking of the LASNEX and HYDRA simulations is needed? Are they providing reasonable answers? Are there important phenomena that are not being properly modeled? (e.g., non-uniform focusing effects)
  - Do we need in situ diagnostics on Z to measure the preheating, or can we rely on extrapolations of standalone Z-Beamlet experiments?
  - Are we better off doing standalone target chamber experiments or making measurements on Z?

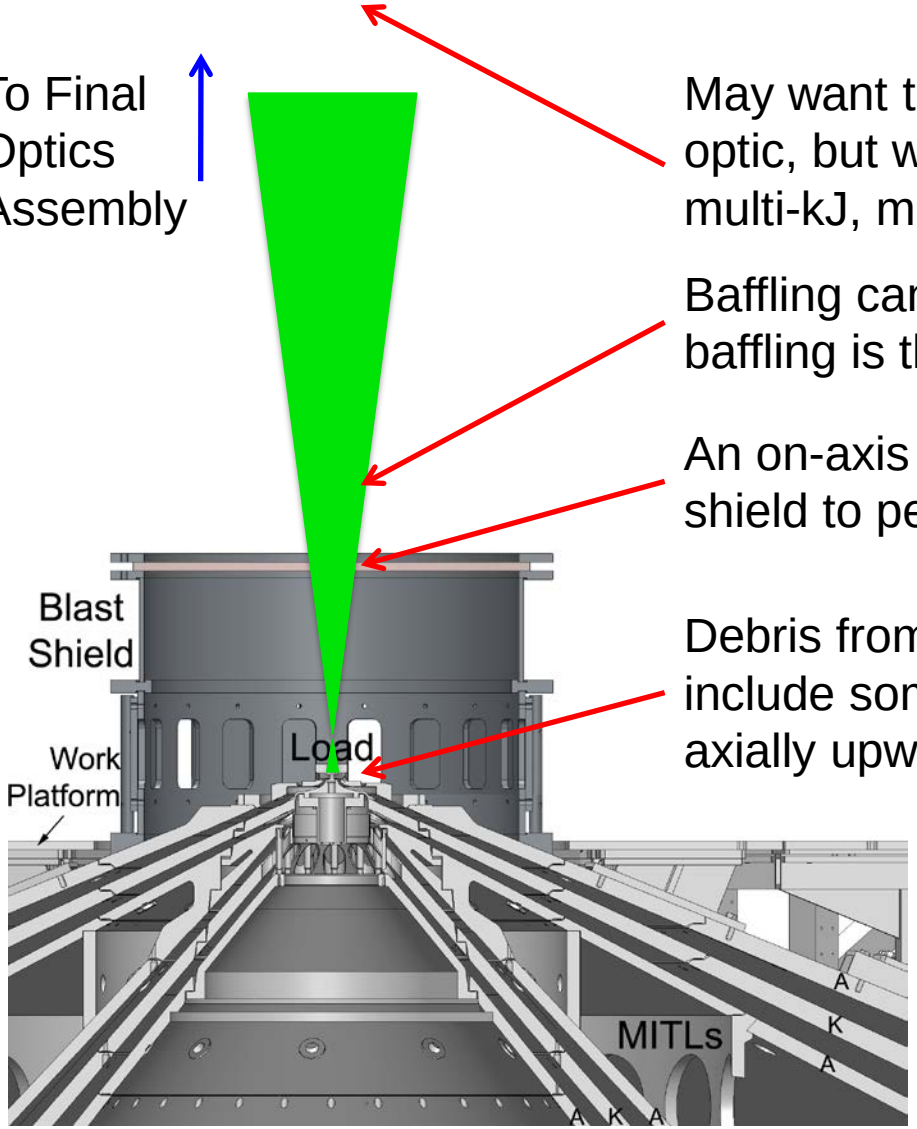
# An example HYDRA simulation of a MagLIF target illustrates some key issues to be evaluated




- What is ideal geometry for laser, target, and apertures?
- Can we predict the temperature increase of the fuel correctly?
- Are we getting the dynamics of the bleaching wave correct?
- Will non-uniform focusing of the laser at different heights cause issues?
- How will the axial and any spontaneously-generated B-fields affect the results?

A 6.5 kJ, 4-ns laser pulse applied at t=120 ns (liner moved in ~1/3). In this example the LEH is 1.2 mm, laser spot size about 0.8 mm

# A major engineering challenge for preheating is preventing debris damage to Z-Beamlet optics from MJ energy source




May want to use extra in-line shielding near the optic, but what will effects be on backscatter for a multi-kJ, multi-ns laser pulse?

Baffling can be used, but the higher up the baffling is the larger the beam size gets

An on-axis hole will be needed in the blast shield to permit the laser to reach the targets

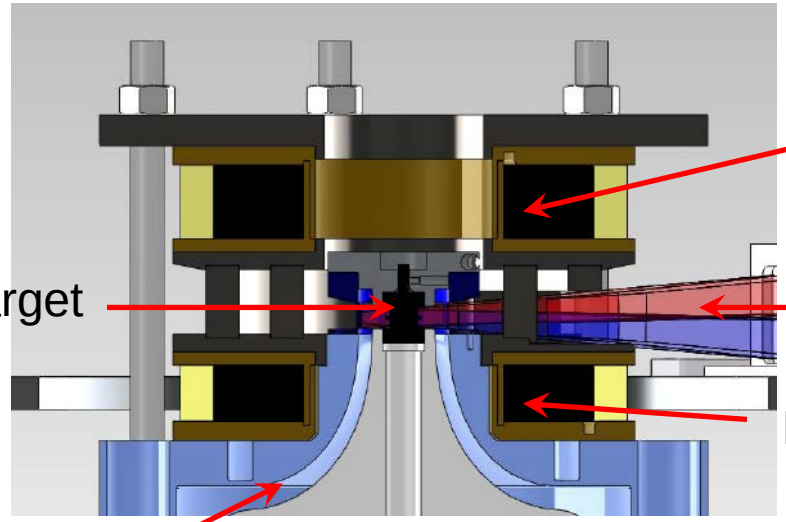
Debris from the load will include some directed axially upward

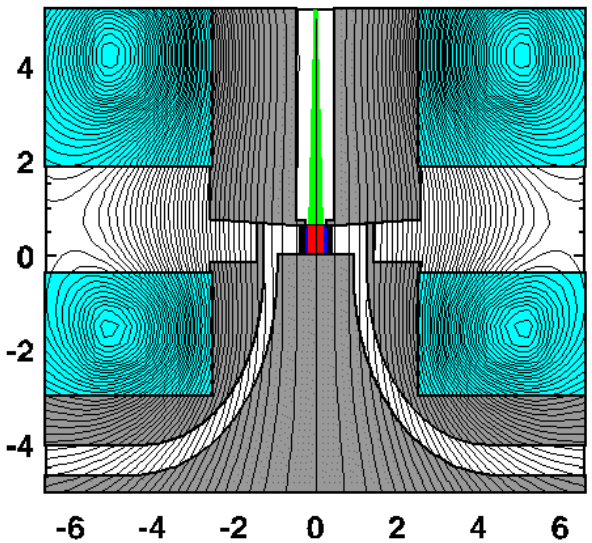
# First integrated tests of MagLIF on Z can use existing ~2 kJ capability, but 5-7 kJ may be of long-term interest

Sandia National Laboratories

- Based on preliminary discussions, the existing amplifiers limit the available energy for extraction to 2 kJ.
- If booster amps were added this might be increased to more like 5 kJ, but it would also require longer laser pulse lengths
- Laser pulse lengths approaching 10 ns may require phase modulators to be installed to prevent backscattered light from damaging the optics
- Anticipate first integrated MagLIF experiments on Z would use the existing capability of Z-Beamlet
- We don't have a clear picture at this point what the cost, schedule, or scope of the project is for obtaining >2 kJ

# Measuring and benchmarking the preheating in situ during a full Z experiment seems impractical, so we originally considered requesting separate preheat experiments




Geometrically, the only access for optical or sub-keV photon diagnostics will be along the axis (up or down), but this is along the laser beam path…

Standalone preheat experiments using Phase C area of 983 were first idea. In situ experiments in Z chamber could be considered if the team deems extrapolation from chamber tests too uncertain. Z may have diagnostic advantages in that many diagnostics already exist (imaging & spectroscopy)

# Example fuel preheating questions

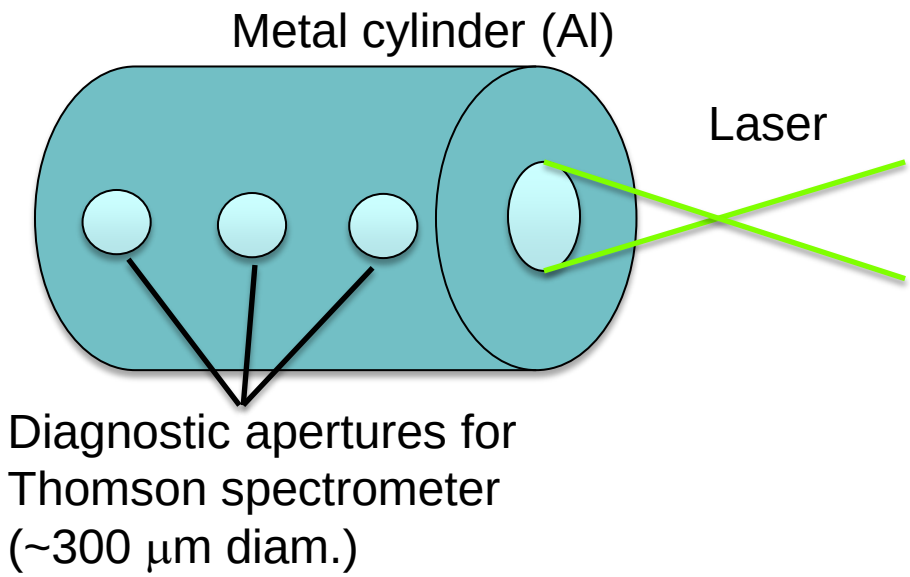
- What are the requirements for the preheated plasma?
  - How much preheat energy do we actually need?
  - How axially and radially uniform does the preheated plasma need to be? How does the uniformity depend on the laser parameters (e.g., focus, diameter, uniformity?)
  - How do we prevent the preheating from ablating the end caps?
- How do we characterize the preheated plasma?
  - How uniform will the preheated plasma be? What will the temperature of the preheat be in experiments? (Laser energy needs to go to the fuel, not end caps or laser entrance hole)
  - Do we need to measure/understand the redistribution of the axial magnetic field in a preheated plasma? If so, how?
  - How will the preheat plasma interact with and affect the liner?
  - Do we need to do early-time axial spectroscopy to diagnose the preheating in situ? (Assuming radial diagnosis is hard)

# Possible objectives for preheat experiments

- Primary experimental objectives
  - Measure D2 fuel ion and electron temperature increase in a MagLIF-relevant mockup target that is heated using 527-nm Z-Beamlet laser light, and compare the results to HYDRA simulations being used to predict MagLIF target performance on Z.
  - Measure the propagation velocity, efficacy, and spatial extent of the heating through the fuel volume, and compare the results to HYDRA simulations.

- A pre-conceptual design team has begun examining potential target designs, diagnostic techniques, laser issues, and key physics issues.
  - Eric Harding, Matthias Geissel, Adam Sefkow, David Montgomery (LANL), and Daniel Sinars
  - Additional support is desirable

# Pre-conceptual ideas for target geometry and gas fill

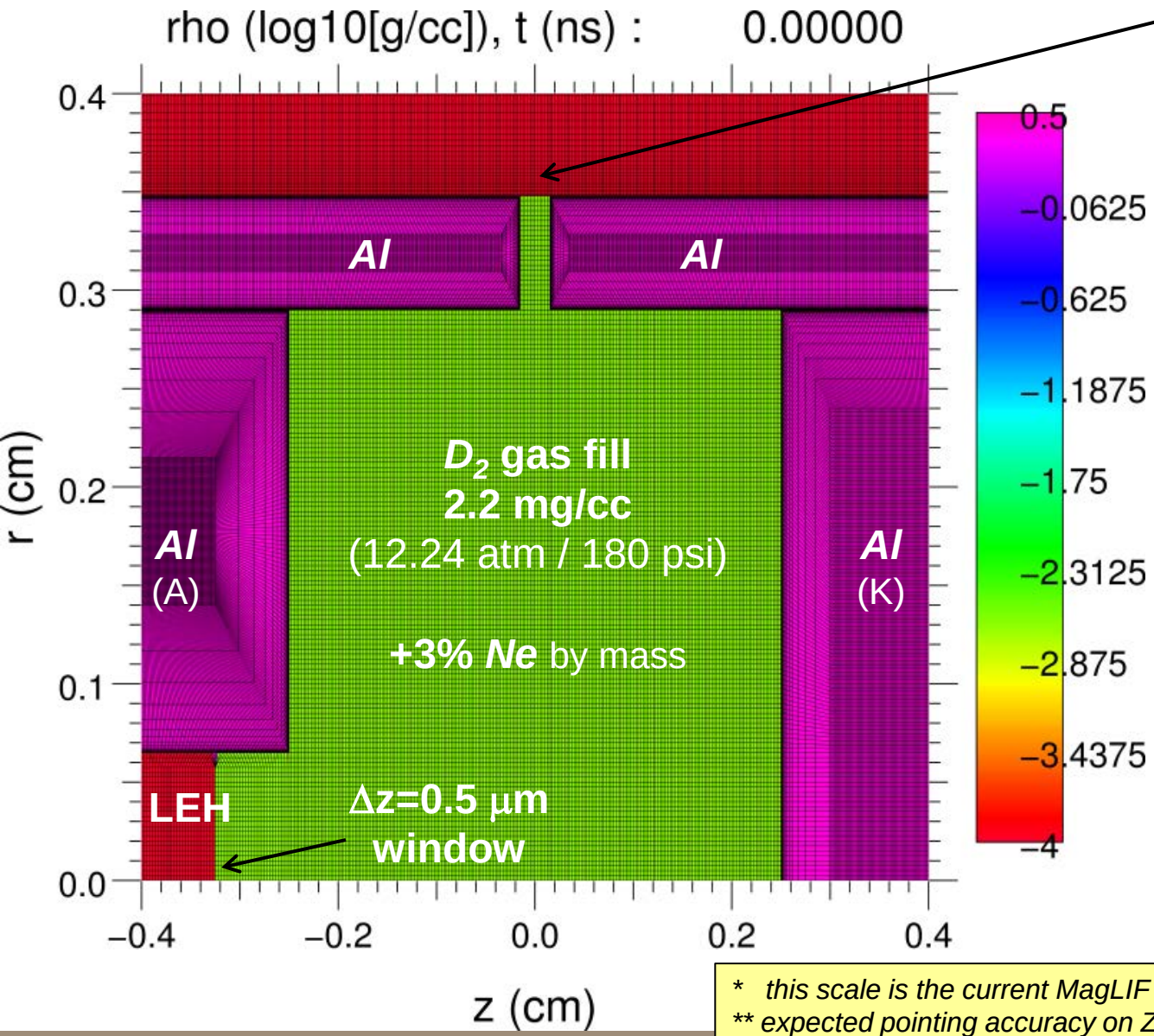



- Gas fill:
  - D2 gas doped with 3% Ne (by atomic number)
  - 2.2 mg/cc (180 psi) fill
- Liner:
  - Material is Al
  - 5 mm tall, 5.8 mm diameter
- Diagnostic apertures
  - 3x300 μm holes for optical Thomson spectrometer
  - 300-μm-wide slit opposite holes to reduce scatter for Thomson and provide imaging and x-ray spectrometer access

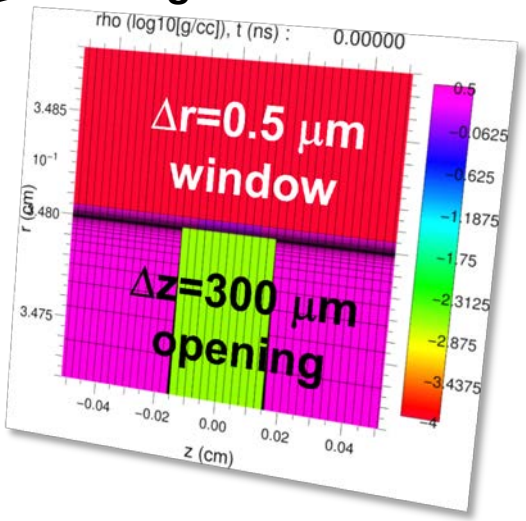
David Montgomery (LANL) is willing to provide his Thomson spectrometer from Trident for these measurements.

Time-integrated x-ray spectrometer and time-gated x-ray/optical camera would view slit on opposite side to provide information on spatial extent and velocity of preheat bleaching wave.

# HYDRA simulations are being run to design and predict MagLIF preheat ZBL experiments




**Diagnostic Port**

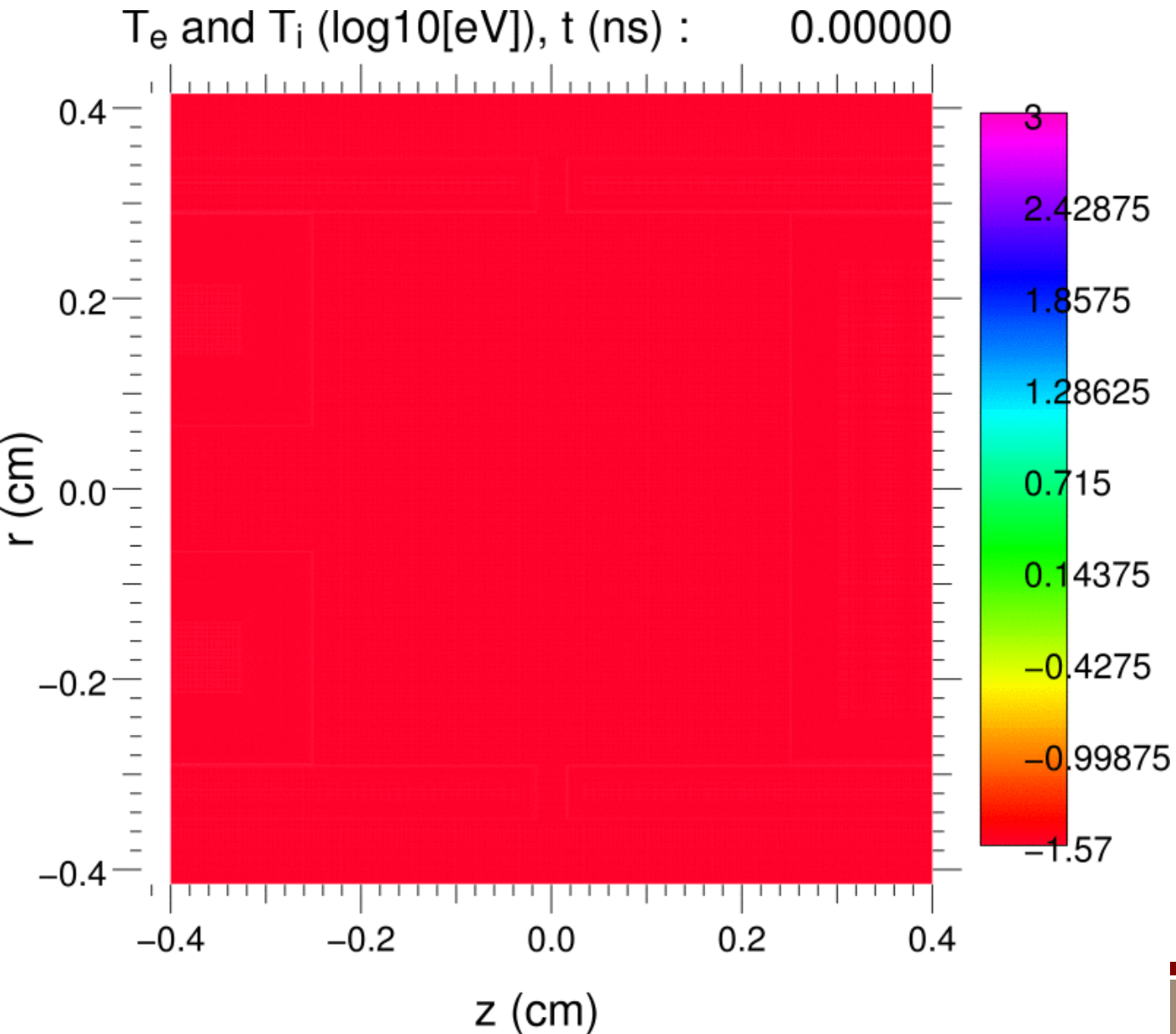



**Laser Entrance Hole**
1.3 mm diameter

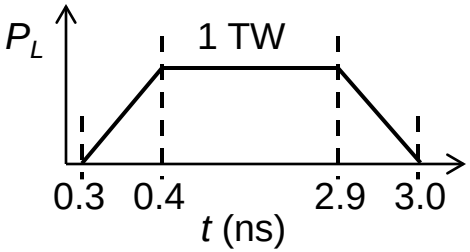
**Laser Parameters**
2.5 kJ of 2ω
2.5 ns duration (1 TW)
0.1 ns rise/fall time
0.4 mm FWHM ($\sim e^{-(r/spot)^2}$)
f/10 lens (cal chamber)
$I_L \approx 3e14$ W cm$^{-2}$

* *this scale is the current MagLIF point design*
** *expected pointing accuracy on Z is 0.015 cm*

# HYDRA predictions for MagLIF preheat Z-Beamlet experiments



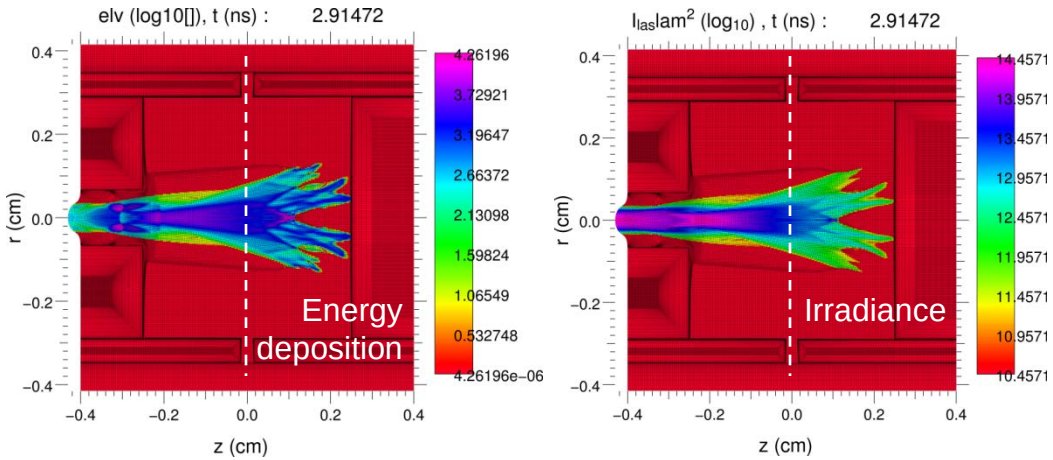

2.5 kJ of 2ω in 2.5 ns




The laser pulse ends just as it reaches the far wall in this example.

The higher energies and powers typical of MagLIF will ablate far wall material (end cap); we should also try to measure this, since it mixes with fuel and critically impacts the target design.

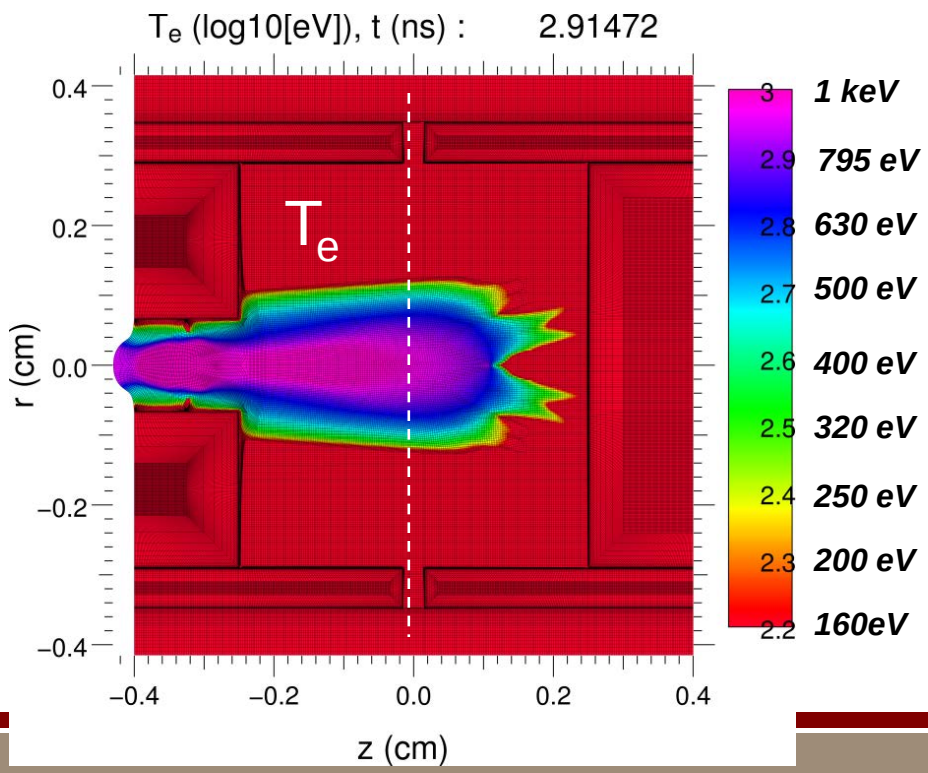
# Experiments may measure $T_e$~800 eV and $T_i$~400 eV

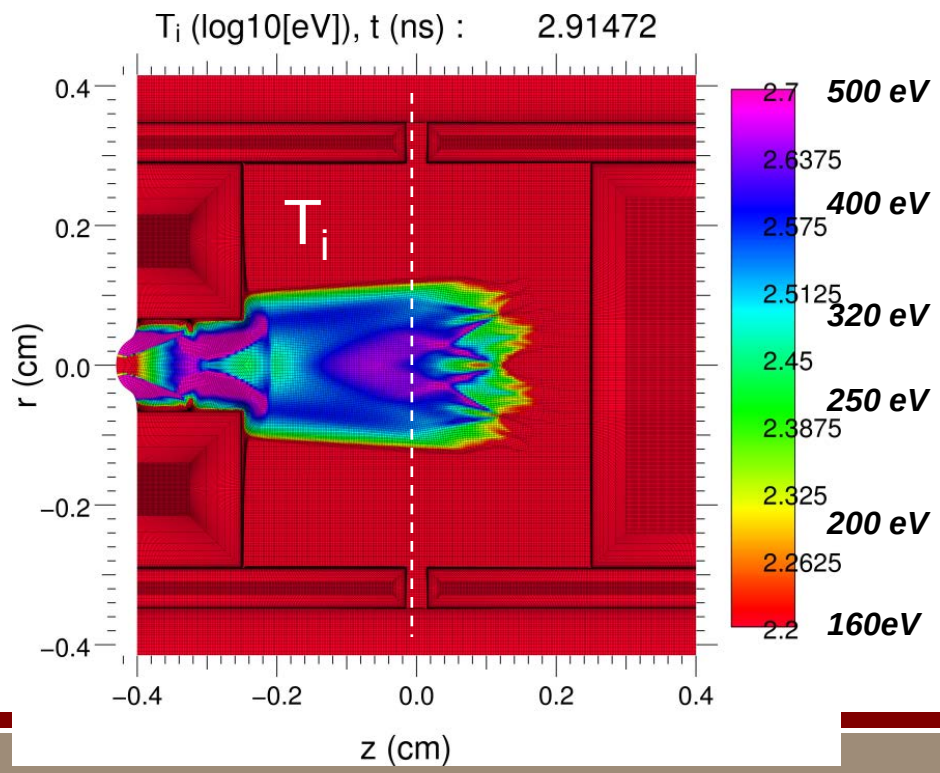



**Self Thomson scattering**

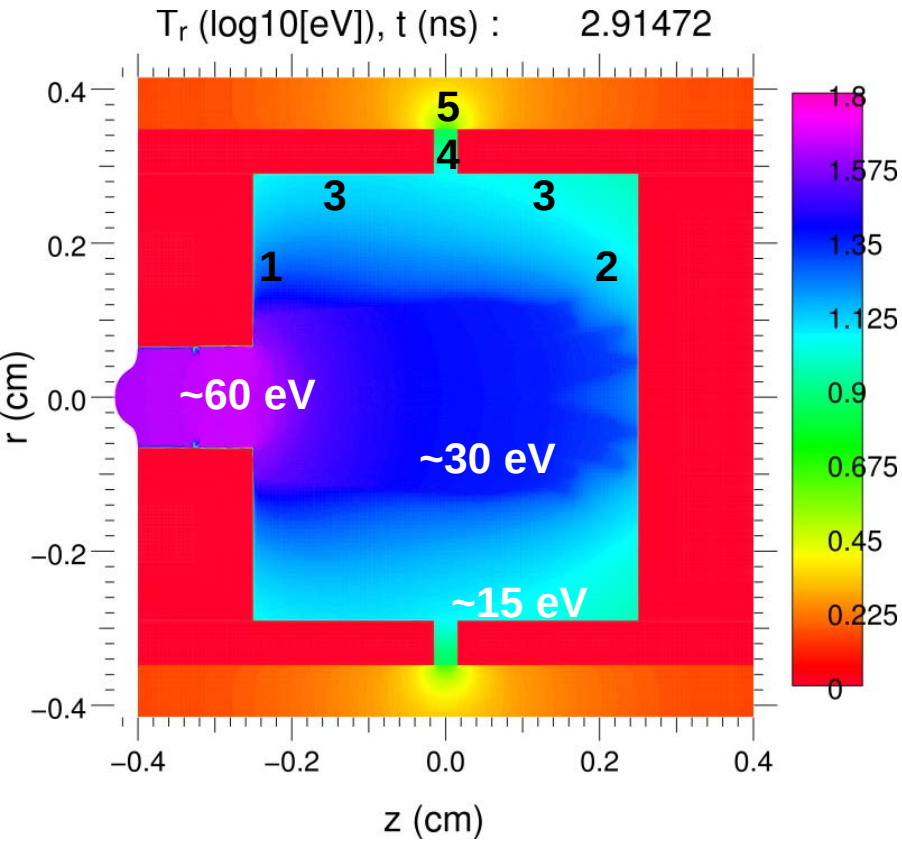
Snapshot diagnosis of $T_e$ and $T_i$ only occurs during laser pulse

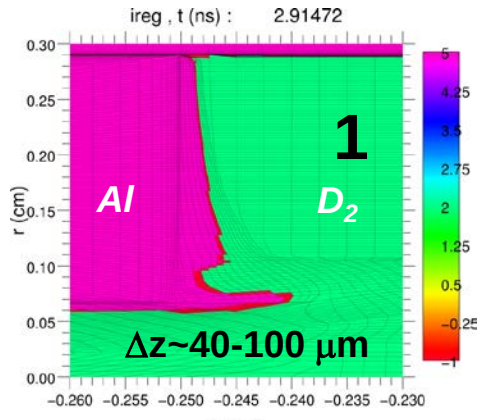
Axial resolution only through positioning of diagnostic port, and no radial resolution

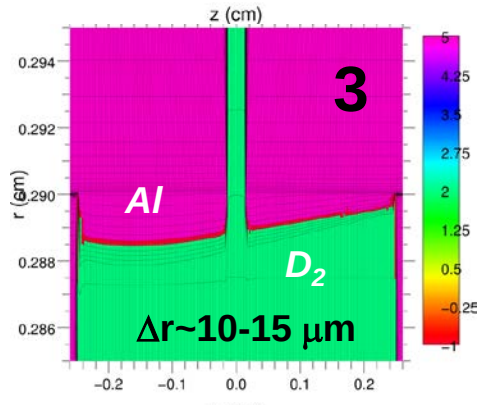


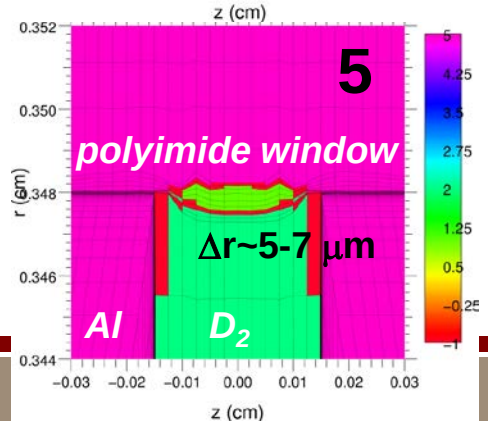



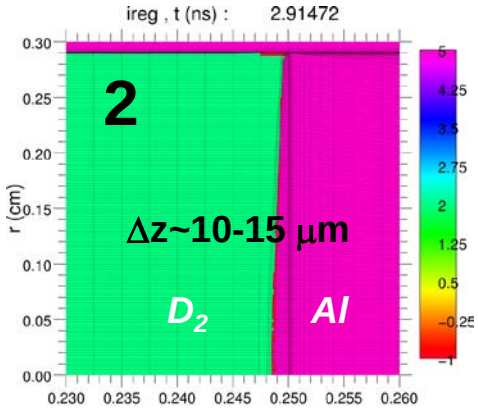
# The $T_{rad}$ field does not close the diagnostic port or ablate much of the *Al* wall material

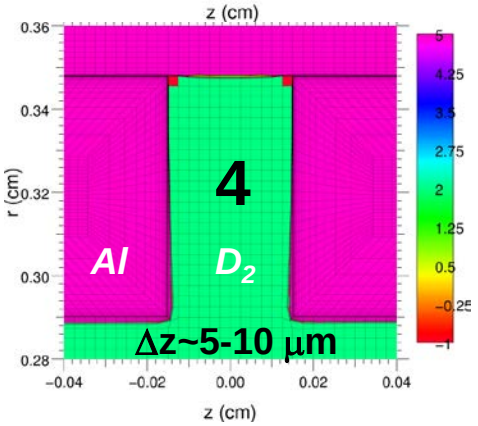


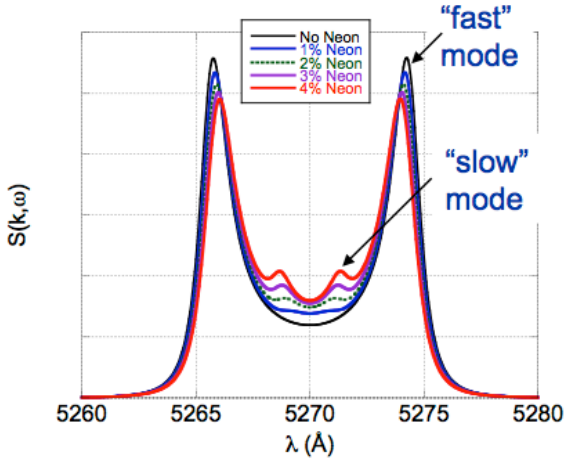



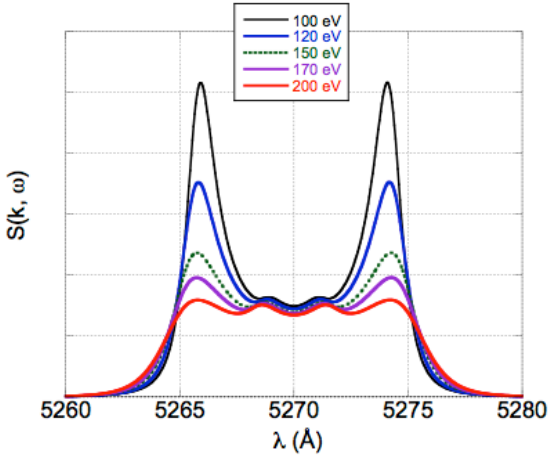
# Optical Thomson scattering using Z-Beamlet heating laser and Ne dopants can provide Ti and Te (next talk)

## Trace amounts of Neon dopant in $D_2$ plasma may help determine ion temperature

$T_e$=300 eV, $T_i$ = 100 eV
$n_e$ = 2e20 e/cm$^3$, $\theta_s$ = 90°
Neon varying (atomic %)




$T_e$=300 eV, $T_i$ varying, 2% Neon, $\langle Z_{ne} \rangle$ = 8
$n_e$ = 2e20 e/cm$^3$, $\theta_s$ = 90°

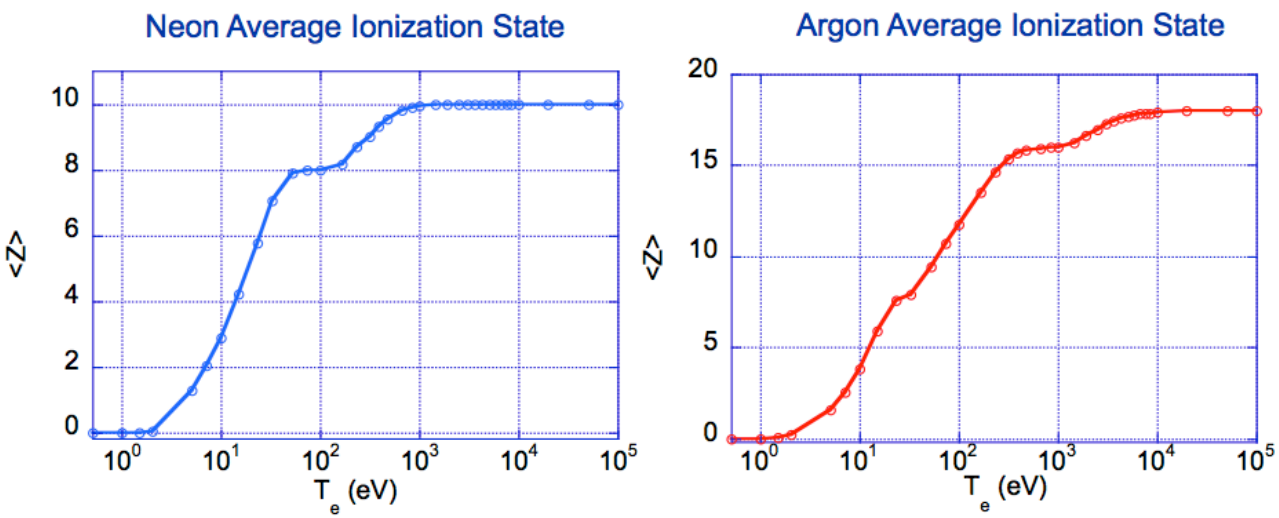



Presence of "slow mode" due to coupling between light and heavy ions

"Fast" mode damps with increasing $T_i/T_e$, providing a sensitive measure of $T_i$

# Neon dopants may provide useful spectroscopic diagnosis of plasma conditions

## Average ionization of Neon and Argon vary over temperature range of interest




* <Z> obtained using FLYCHK non-LTE calculations, $n_e = 10^{20}$ e/cm$^3$

# We propose to implement preheat capabilities on Z over several years

- CY2012:
  - Standalone Z-Beamlet preheat experiments for benchmarking of key physics predictions of HYDRA code
  - In tandem with X-ray Thomson Scattering project, work on characterization of axial debris and strategies to protect the on-axis Final Optics Assembly
  - Work with Z-Beamlet facility to understand the hazards posed by a multi-ns, multi-kJ laser pulse (e.g., backscatter from a ~5 kJ, ~5 ns pulse)
- CY2013:
  - Continue standalone Z-Beamlet preheat experiments as needed
  - Implement laser preheat capability on Z during first integrated MagLIF experiments using existing laser capability (~2.5 kJ in ~2.5 ns)
  - Begin design work on Z-Beamlet for expanding the energy capability of the laser (e.g., phase modulators, booster amplifiers)
- CY2014:
  - Implement expanded capabilities of laser

# Backups