Exceptional service in the national interest

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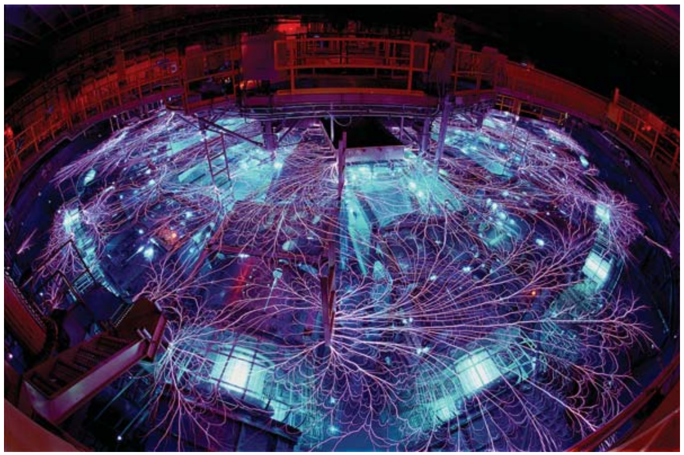

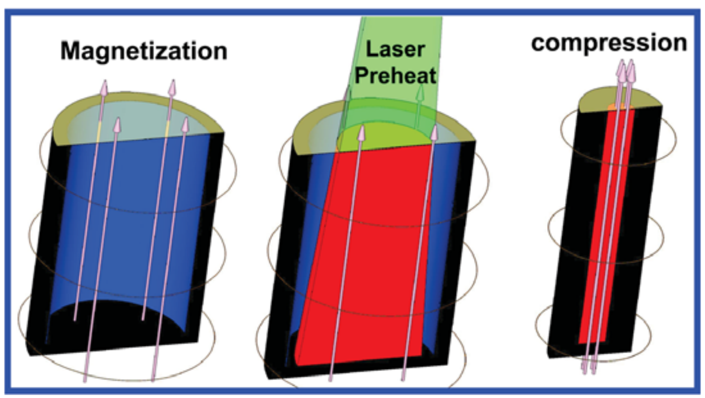

Magnetized Liner Inertial Fusion & Cylindrical Dynamic Materials Properties Experiments on the Z Pulsed-Power Accelerator

Ryan D. McBride

Physicist & Senior Member of the Technical Staff

Sandia National Laboratories

Stewardship Science Graduate Fellowship Conference

Santa Fe, New Mexico, June 25, 2013

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Thanks to many collaborators:

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[1]*Sandia National Laboratories, Albuquerque, NM*

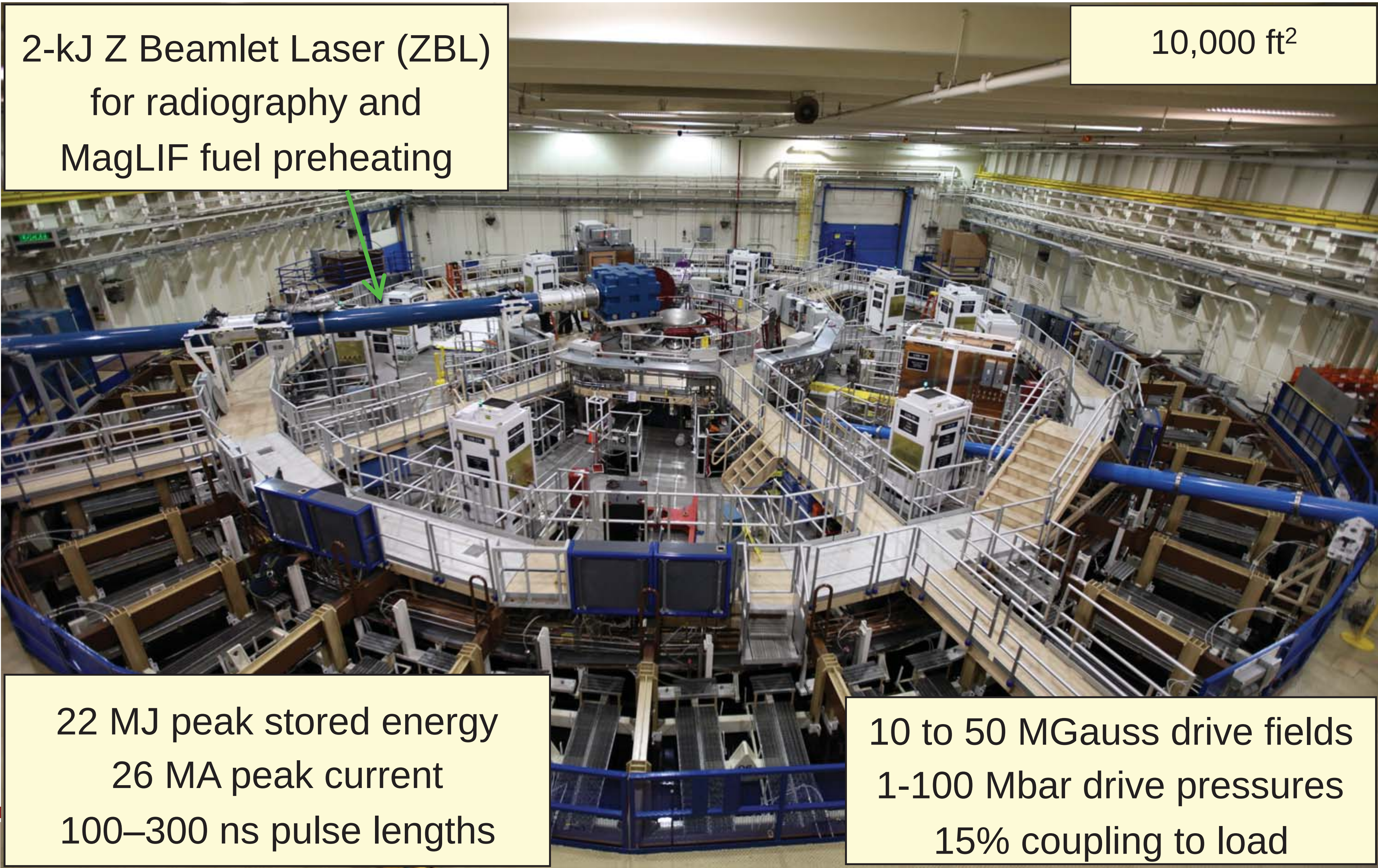
[2]*Laboratory of Plasma Studies, Cornell University, Ithaca, NY*

[3]*Lawerence Livermore National Laboratory, Livermore, CA*

[4]*General Atomics, San Diego, CA*

[5]*Raytheon Ktech, Albuquerque, NM*

The Z pulsed-power facility combines a compact MJ-class target physics platform (the Z accelerator) with a TW-class laser (ZBL)



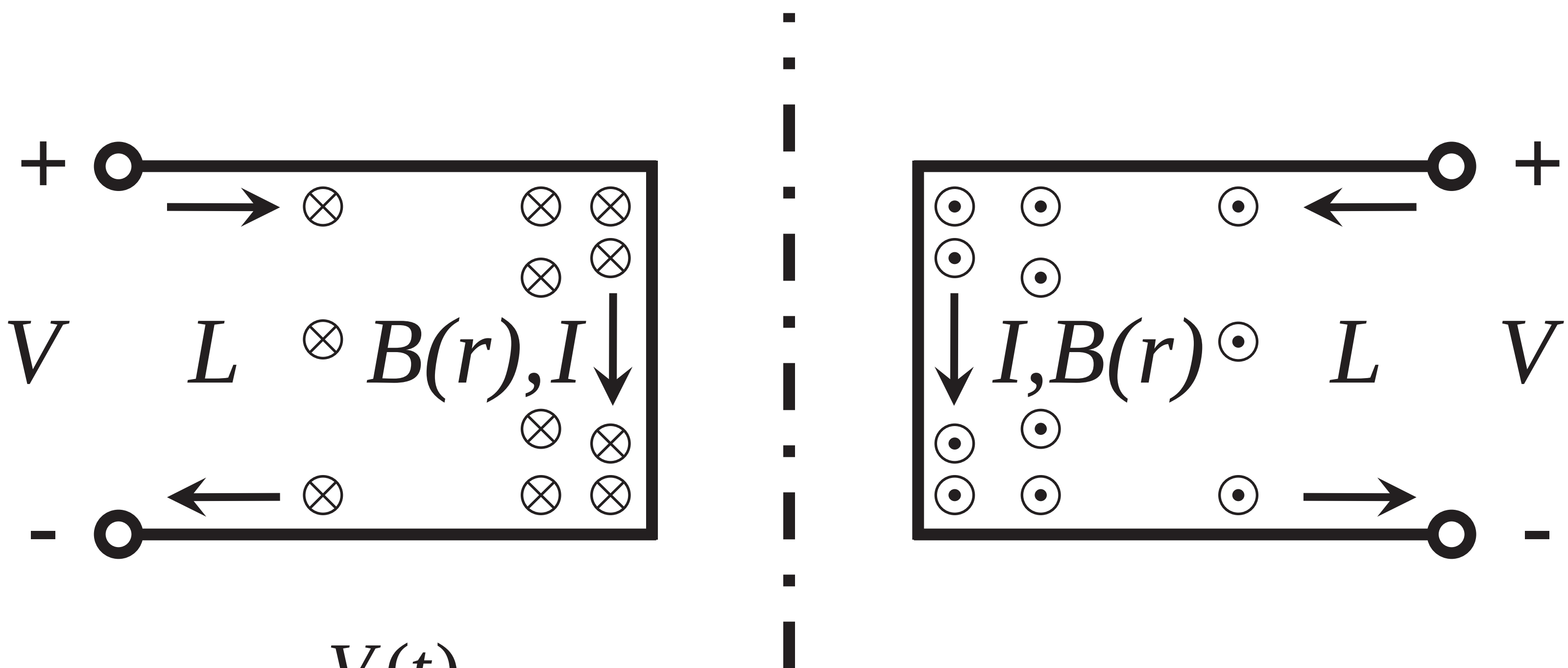
2-kJ Z Beamlet Laser (ZBL) for radiography and MagLIF fuel preheating

10,000 ft^2

22 MJ peak stored energy
26 MA peak current
100–300 ns pulse lengths

10 to 50 MGauss drive fields
1-100 Mbar drive pressures
15% coupling to load

Basic Pulsed-Power Setup



$$I'(t) = \frac{V(t)}{L}$$

℄
$(r = 0)$

$$P_{mag}(r) = \frac{B^2(r)}{2\mu_0}$$

$$B(r) = \frac{\mu_0 I}{2\pi r}$$

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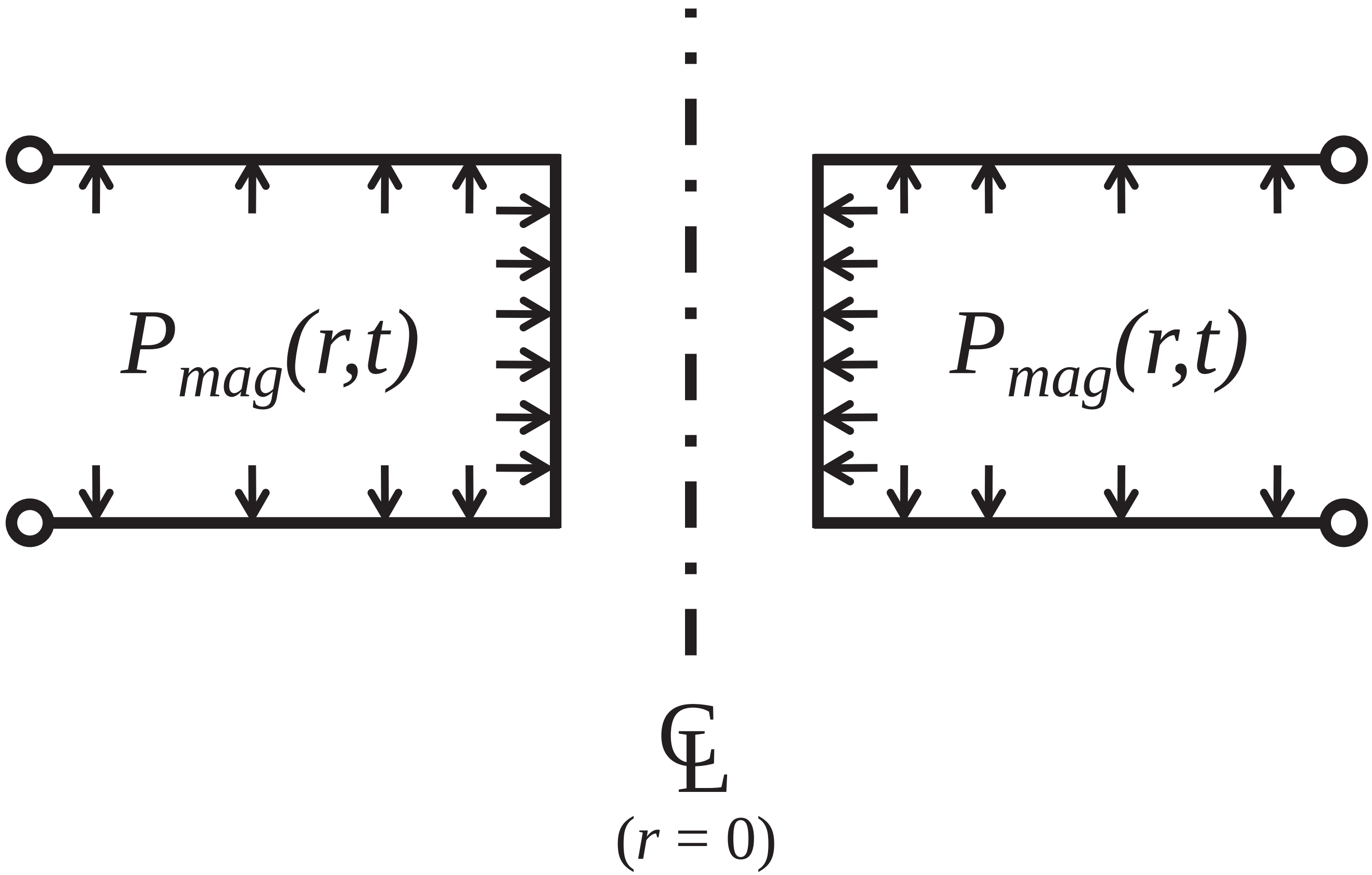
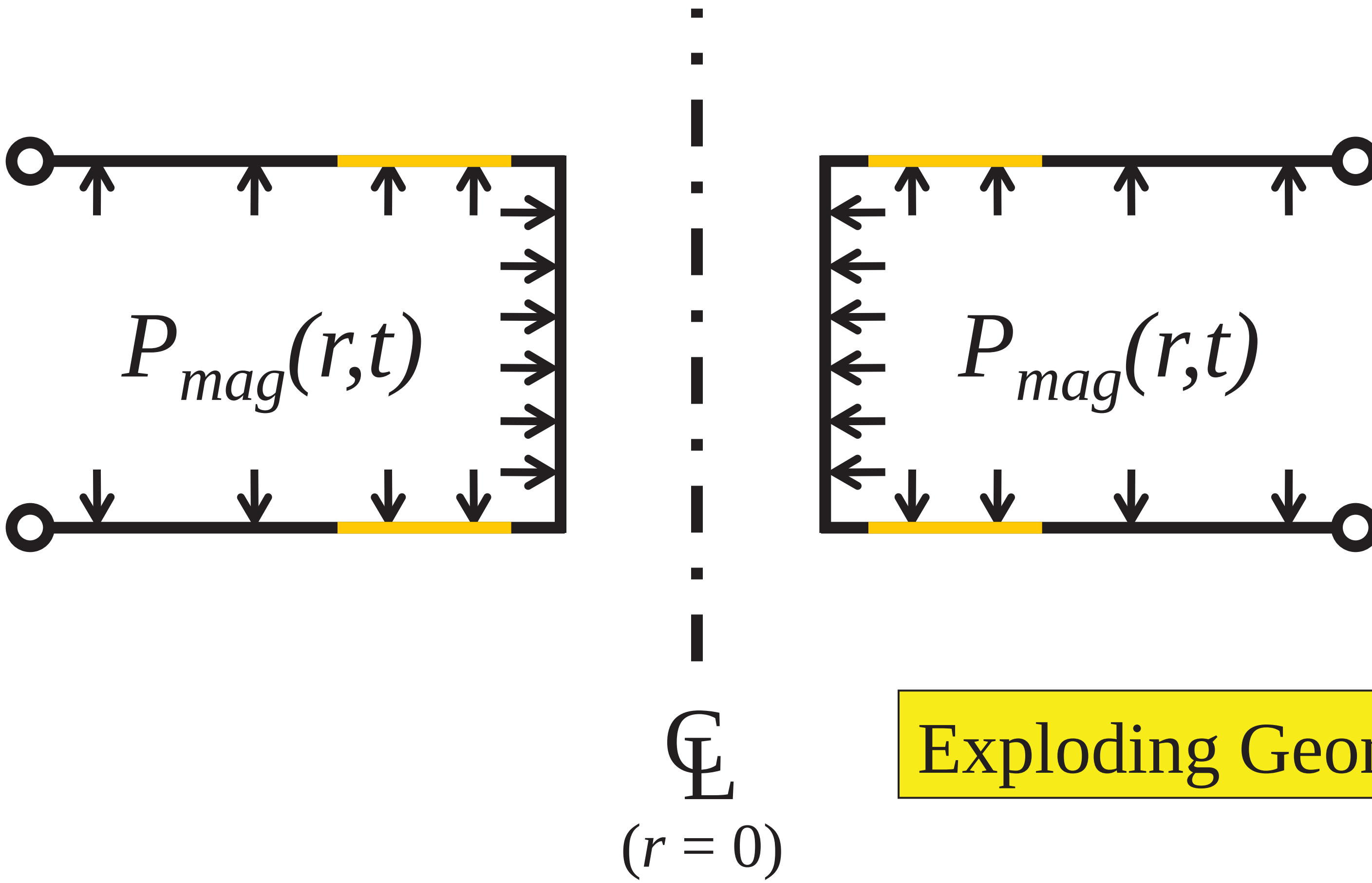
Basic Pulsed-Power Setup

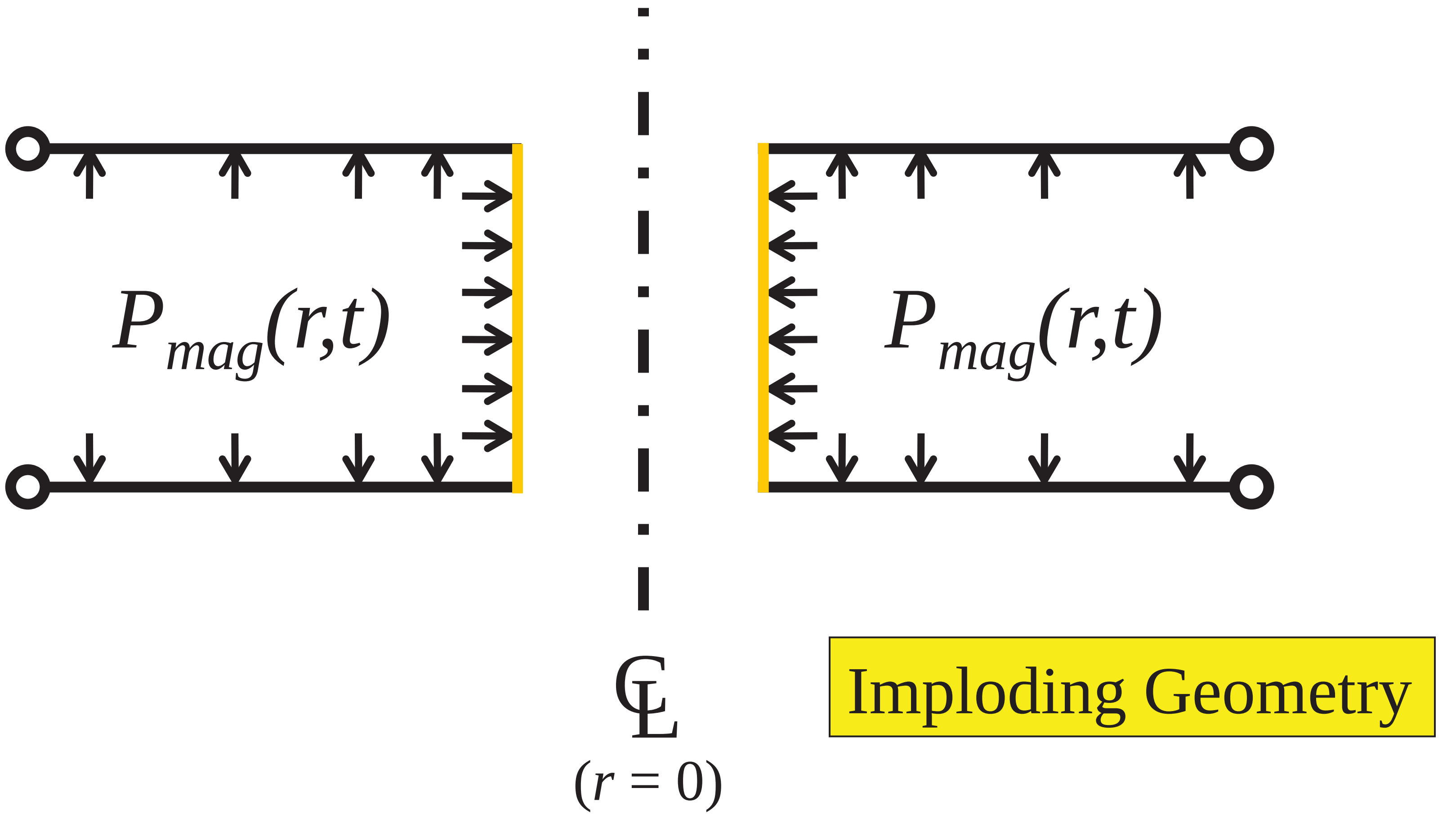


Basic Pulsed-Power Setup



Exploding Geometry

Basic Pulsed-Power Setup

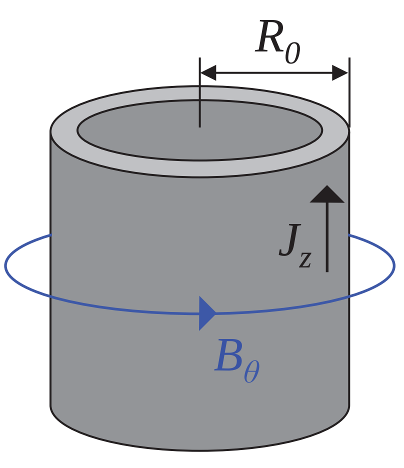


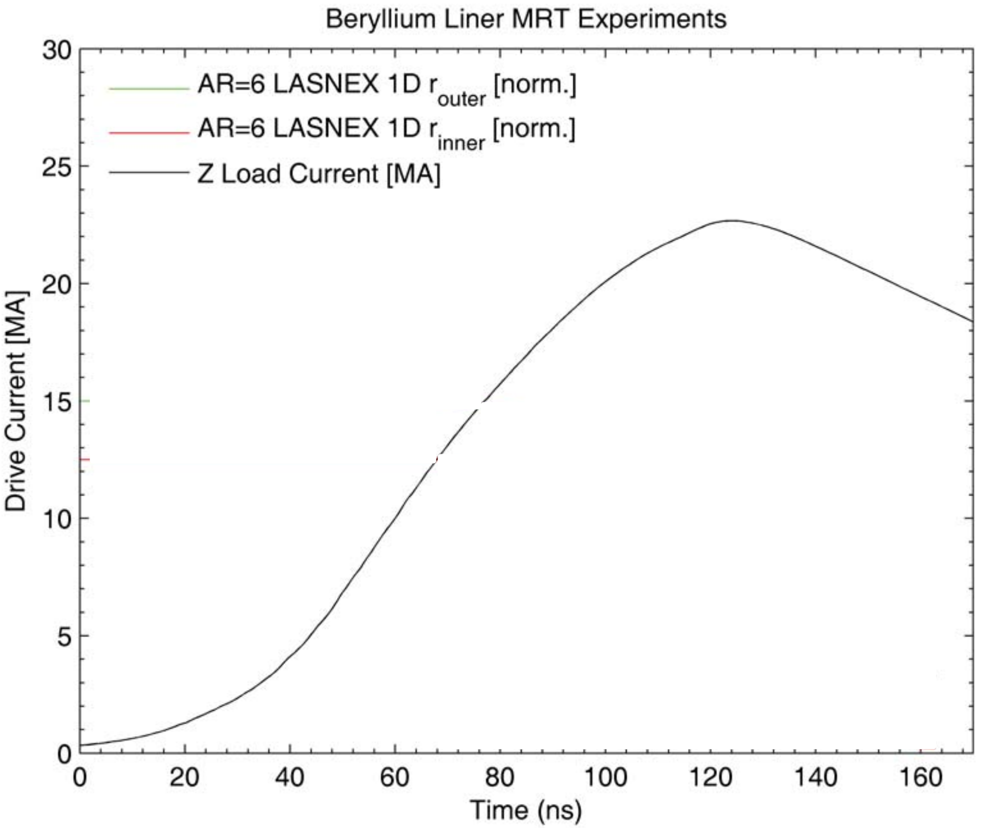
Pulsed-Power and Cylindrical Geometry for HEDP

Magnetically-Driven Cylindrical Geometry (Static Case):

$$P = \frac{B^2}{2\mu_o} = 140 \cdot \left(\frac{I_{[\mathrm{MA}]}/30}{R_{0,[\mathrm{mm}]}} \right)^2 \quad [\mathrm{Mbar}]$$

140 Mbar is generated by a 300-eV radiation drive



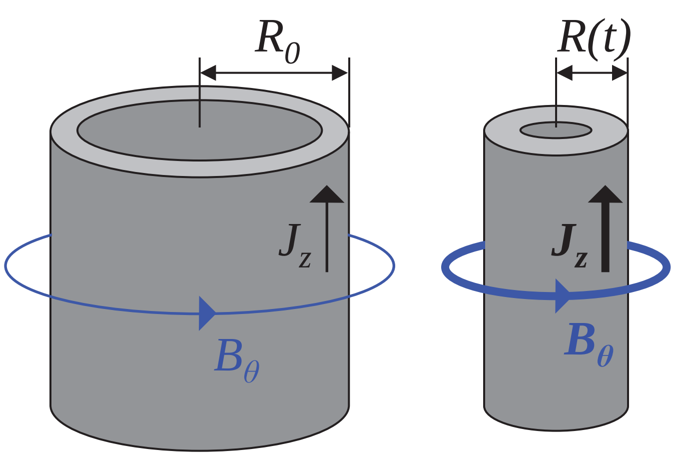


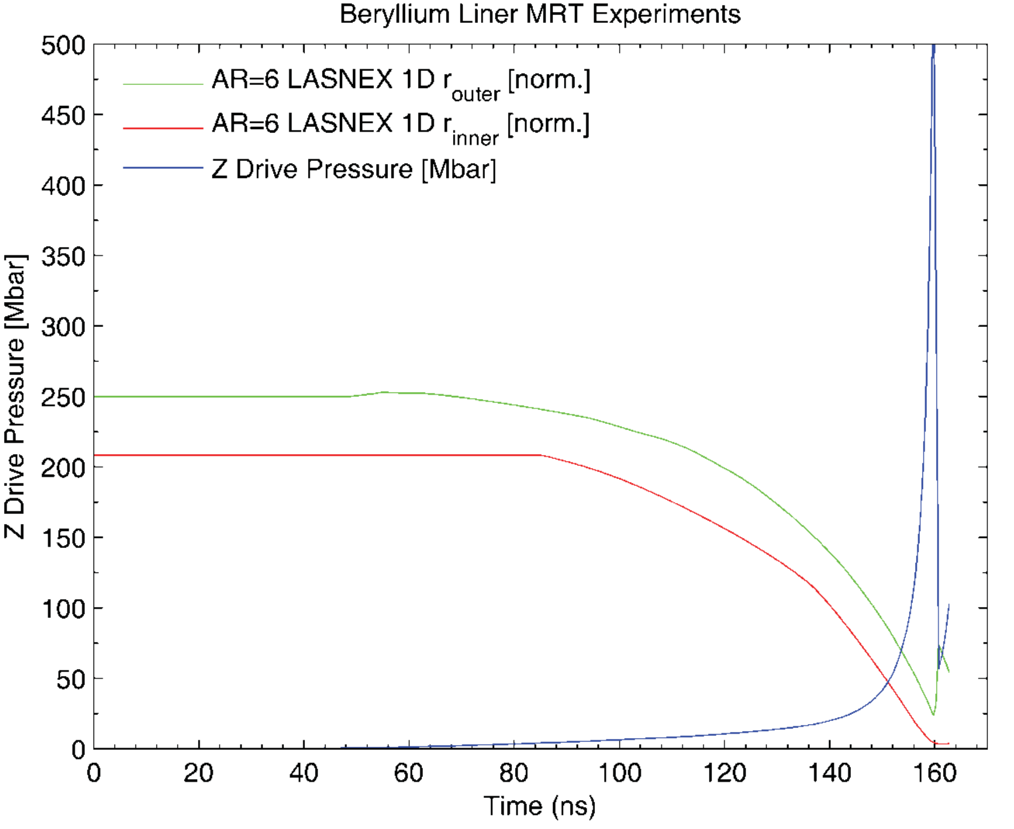
Pulsed-Power and Liner Implosions for HEDP

Magnetically-Driven Cylindrical Implosion
(Implosion Drive Pressure is Divergent!):

$$P = \frac{B^2}{2\mu_o} = 140 \cdot \left(\frac{I_{[\mathrm{MA}]}/30}{R(t)_{[\mathrm{mm}]}} \right)^2 \quad [\mathrm{Mbar}]$$

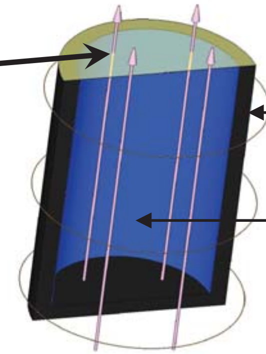
140 Mbar is generated by a 300-eV radiation drive





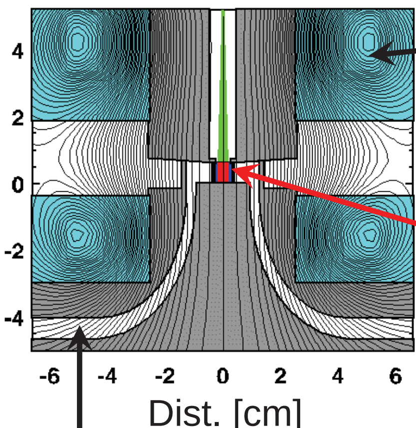
We are working toward the evaluation of a new **Magnetized Liner Inertial Fusion (MagLIF)*** concept

1. A 10–50 T axial magnetic field (B_z) is applied to inhibit thermal conduction losses and to enhance alpha particle deposition



Liner (Li, Be, or Al)

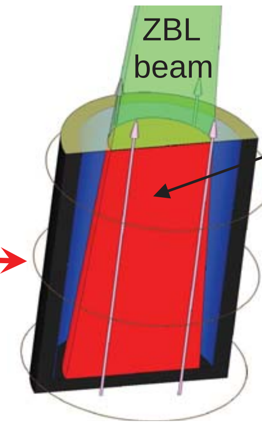
Cold DD or DT gas (fuel)



B_z coils

Z power flow (A-K gap)

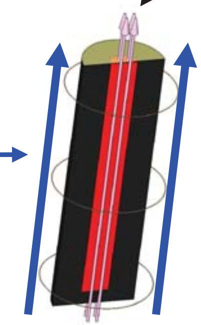
2. ZBL preheats the fuel to ~100–250 eV to reduce the required compression to CR≈20–30



ZBL preheated fuel

Compressed B_z field

3. Z drive current and B_θ field implode the liner (via z-pinch) at 50–100 km/s, compressing the fuel and B_z field by factors of 1000

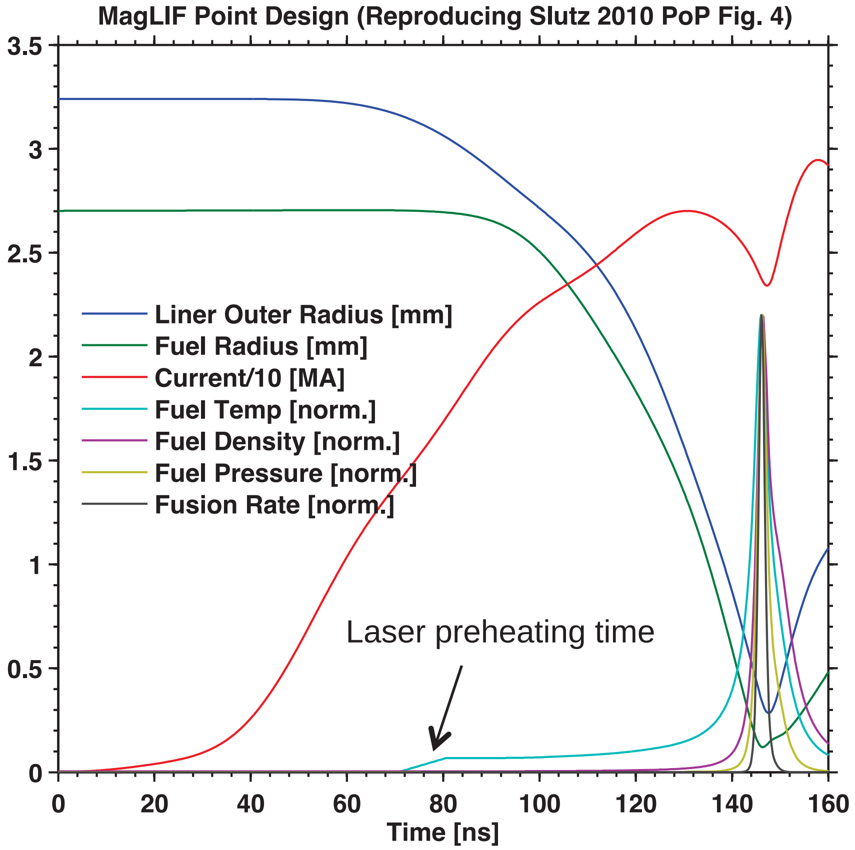


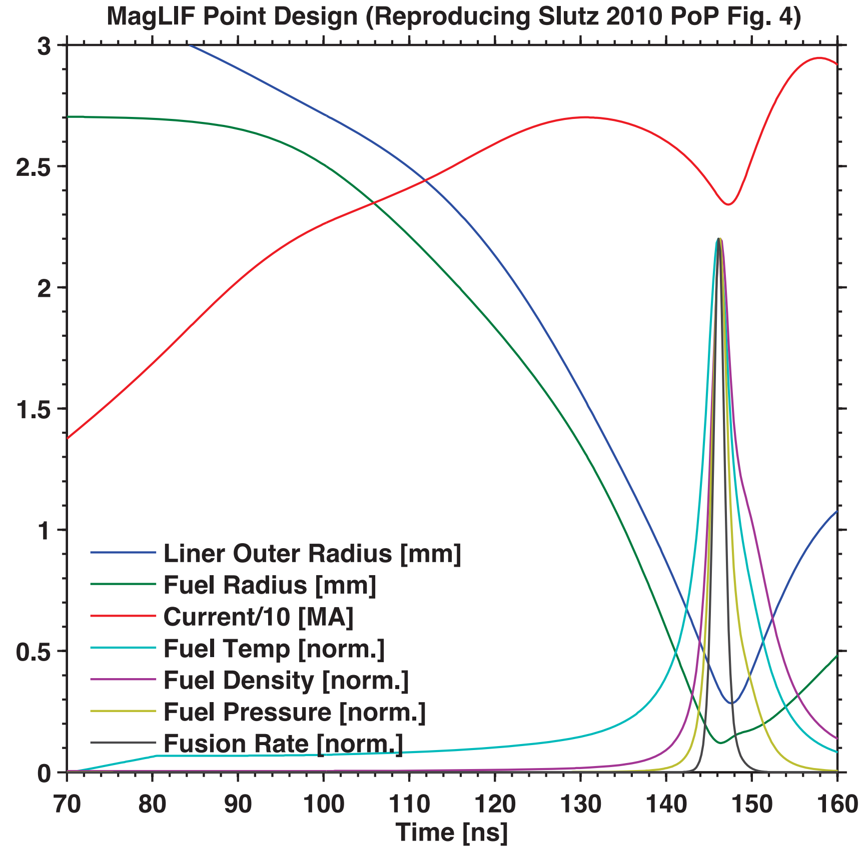
With DT fuel, simulations indicate scientific breakeven may be possible on Z (fusion energy out = energy deposited in fusion fuel)

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

MagLIF Timing Overview

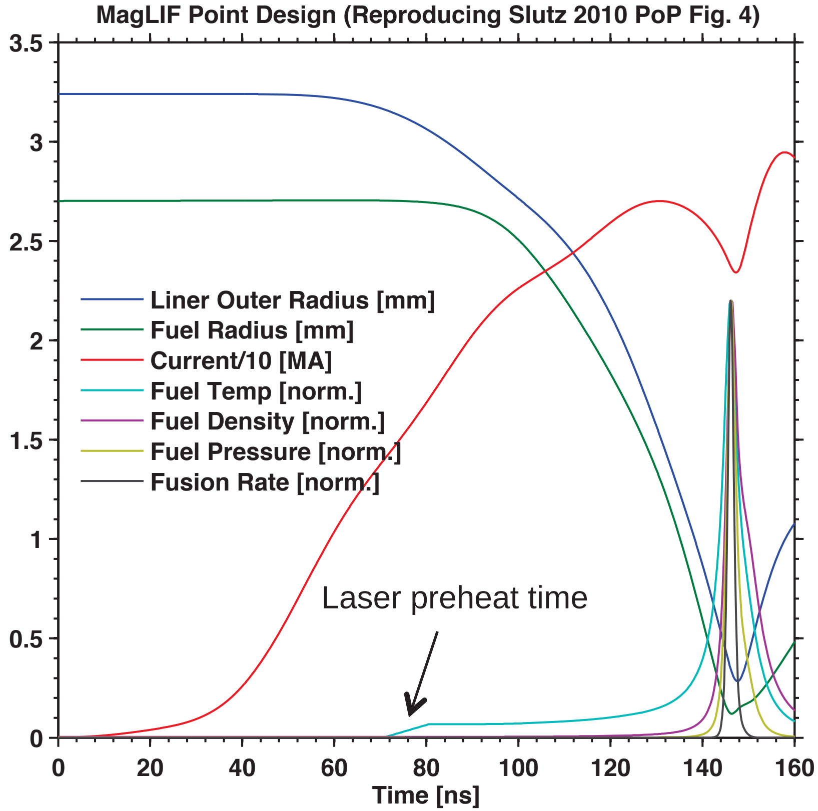
~ 100-ns implosion times
~ adiabatic fuel compression (thus preheating the fuel is necessary)
~ 5-keV fuel stagnation temperatures
~ 1-g/cc fuel stagnation densities
~ 5-Gbar fuel stagnation pressures

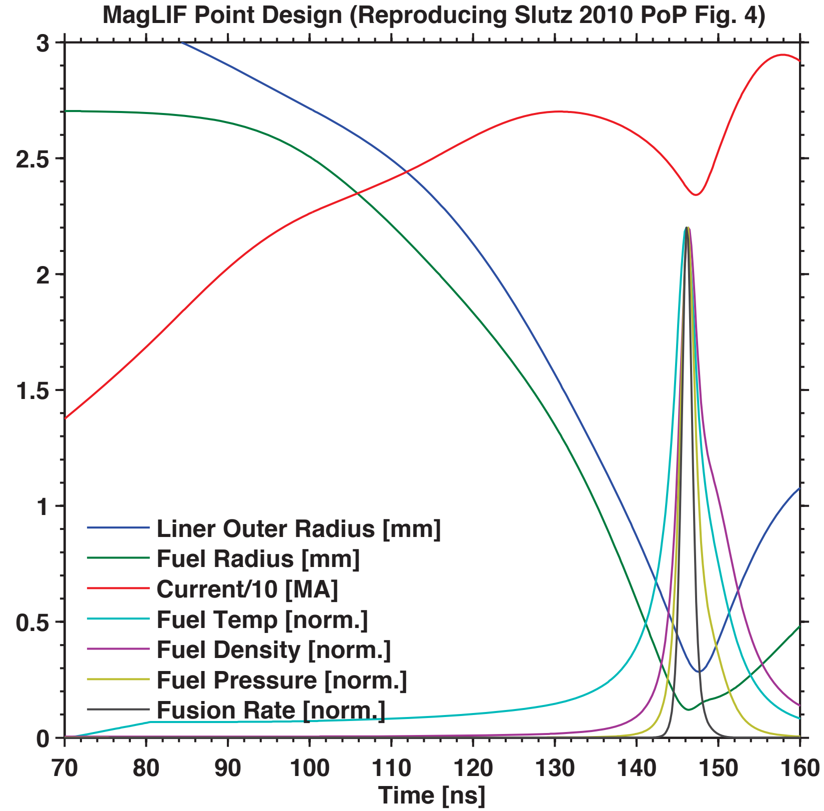




Preheat is necessary for the adiabatic compression and heating of MagLIF fuel

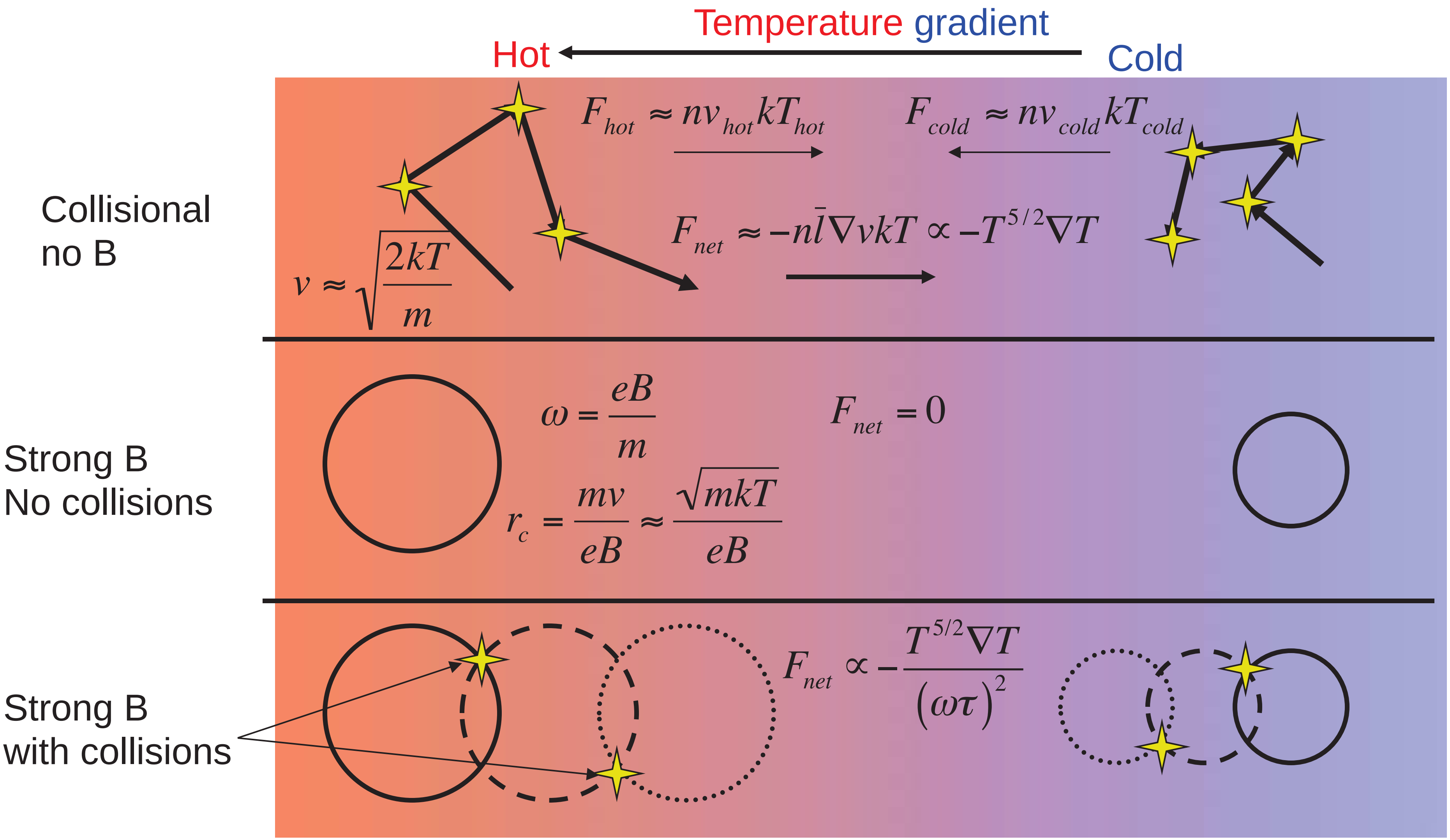
$$T \approx T_0 \left(\frac{\rho}{\rho_0} \right) \approx T_0 C_R^{4/3} \qquad (C_R = R_0 / R_{stagnation})$$





- Typically for ICF (e.g., NIF), faster implosions shock-heat the fuel, not so for MagLIF
- Magnetization is used to keep the preheated fuel from cooling off during the implosion

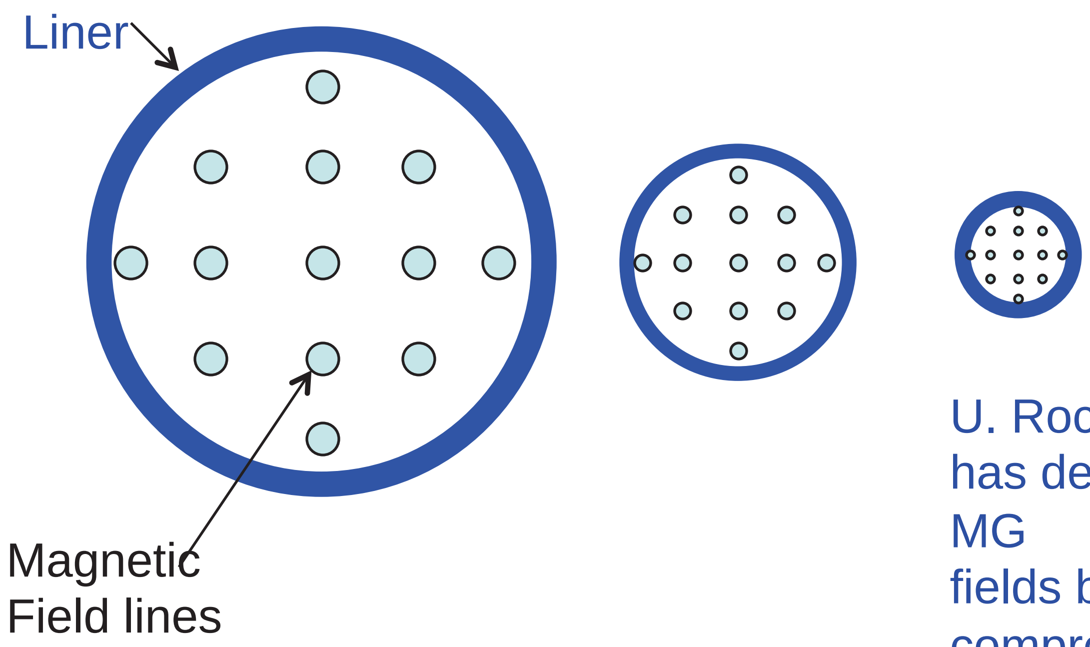
The presence of a magnetic field strongly reduces transport, e.g. heat conduction



High magnetic fields can be obtained by flux compression

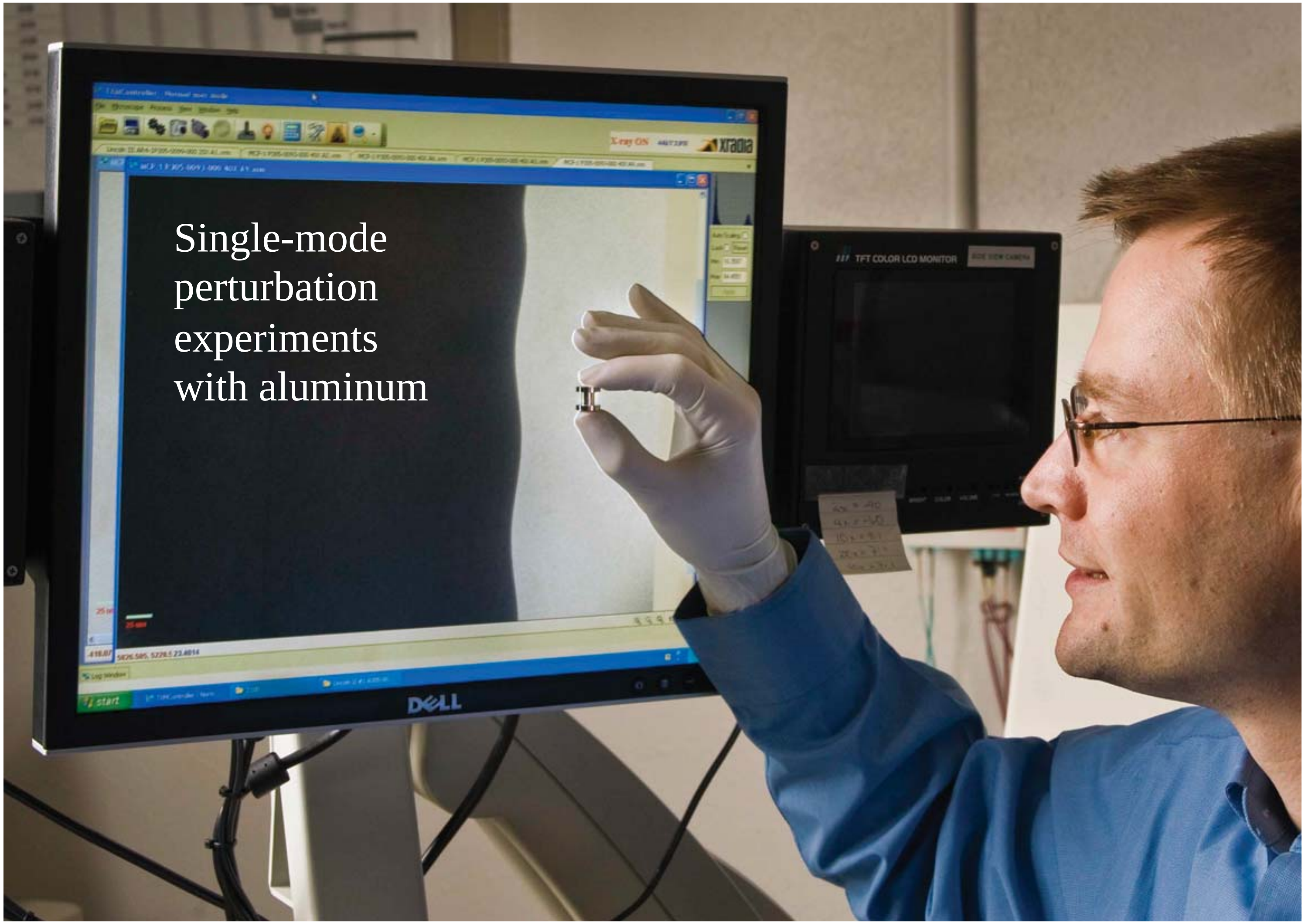
The Flux = # of field lines
Field strength = # of field lines/area
Field lines are "frozen in" for high conductivity
• Flux is conserved

Since $Area = \pi r^2$ $\quad B \approx B_0 \left(\frac{r_0}{r} \right)^2$



U. Rochester LLE
has demonstrated ~ 40
MG
fields by flux
compression

Target Scale-Size



Targets fabricated by General Atomics

Target Hardware Scale-Size

The Z pulsed-power facility combines a compact MJ-class target physics platform (the Z accelerator) with a TW-class laser (ZBL) – Accelerator Scale Size

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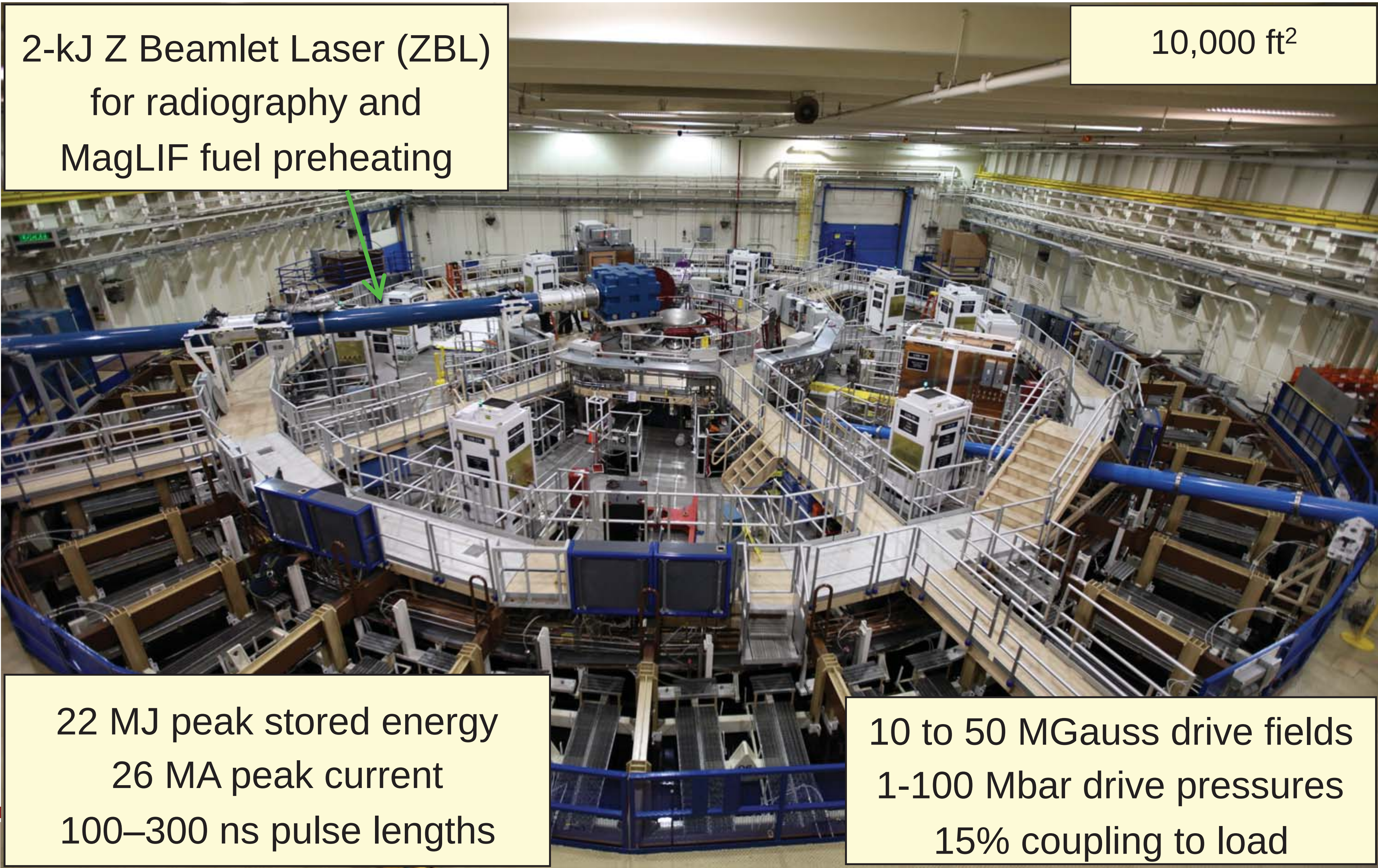


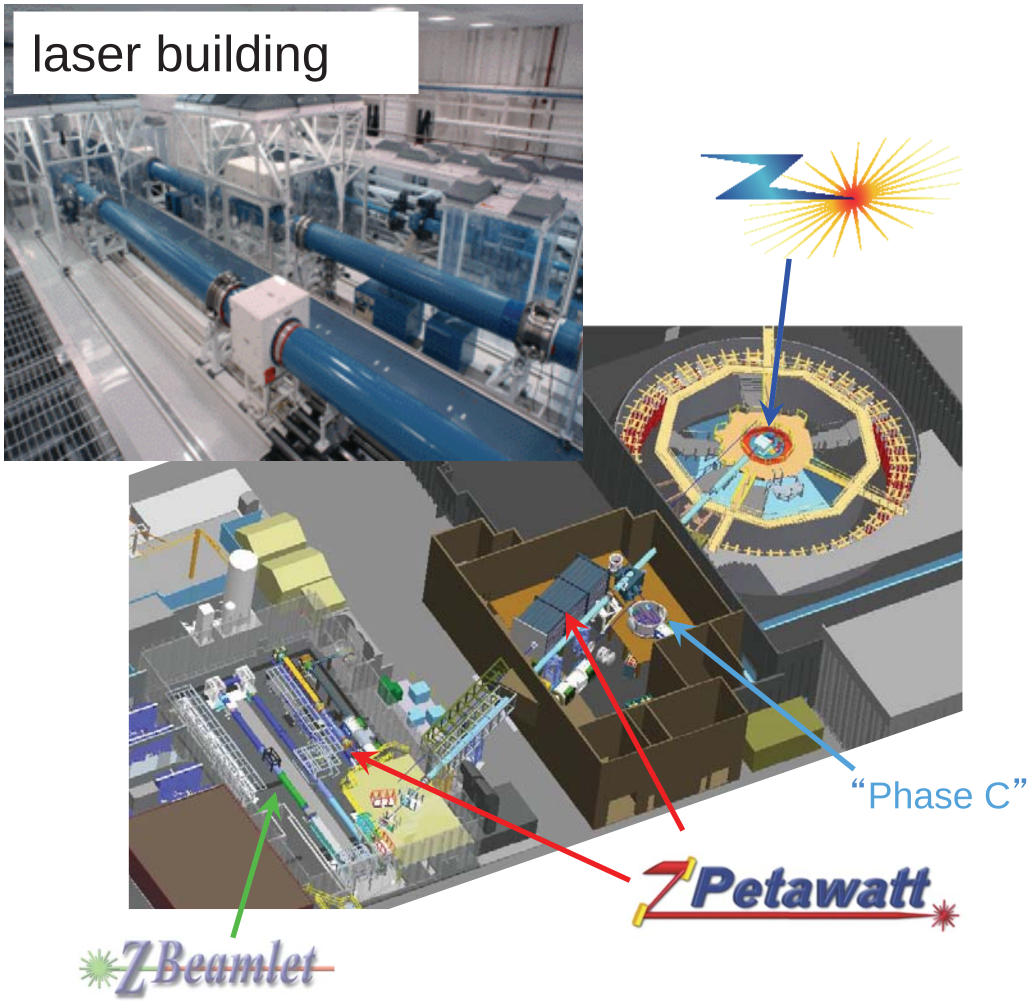
2-kJ Z Beamlet Laser (ZBL) for radiography and MagLIF fuel preheating

10,000 ft^2

22 MJ peak stored energy
26 MA peak current
100–300 ns pulse lengths

10 to 50 MGauss drive fields
1-100 Mbar drive pressures
15% coupling to load

The Z-Beamlet Laser (ZBL) at Sandia* can be used to heat fusion fuel and to radiograph liner targets – Facility Scale Size



ZBL was originally a prototype laser for the National Ignition Facility (NIF)

Today ZBL is located at Sandia and is routinely used to deliver ~2.4 kJ of 2ω light in 2 pulses for radiographing Z experiments

Filling out the booster amps would enable longer pulses (5–7 ns) which would extract up to 6 kJ of 1ω, for 4.2 kJ of 2ω. This energy could be used to heat fusion fuel to a few hundred eV.

* P. K. Rambo *et al.*, Applied Optics 44, 2421 (2005).

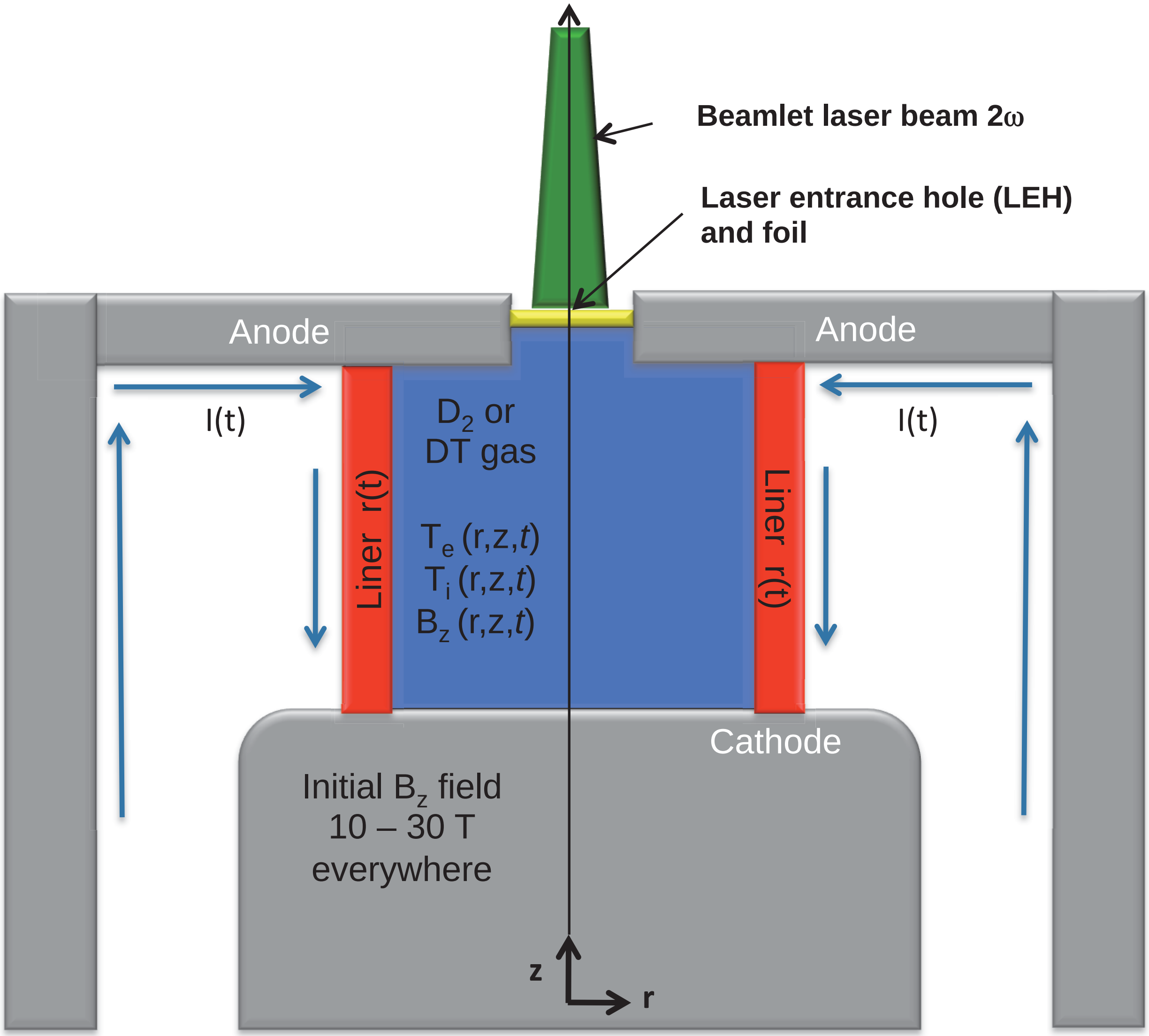
Fully integrated 2D simulations have been performed using both Lasnex and Hydra

Integrated simulations include:

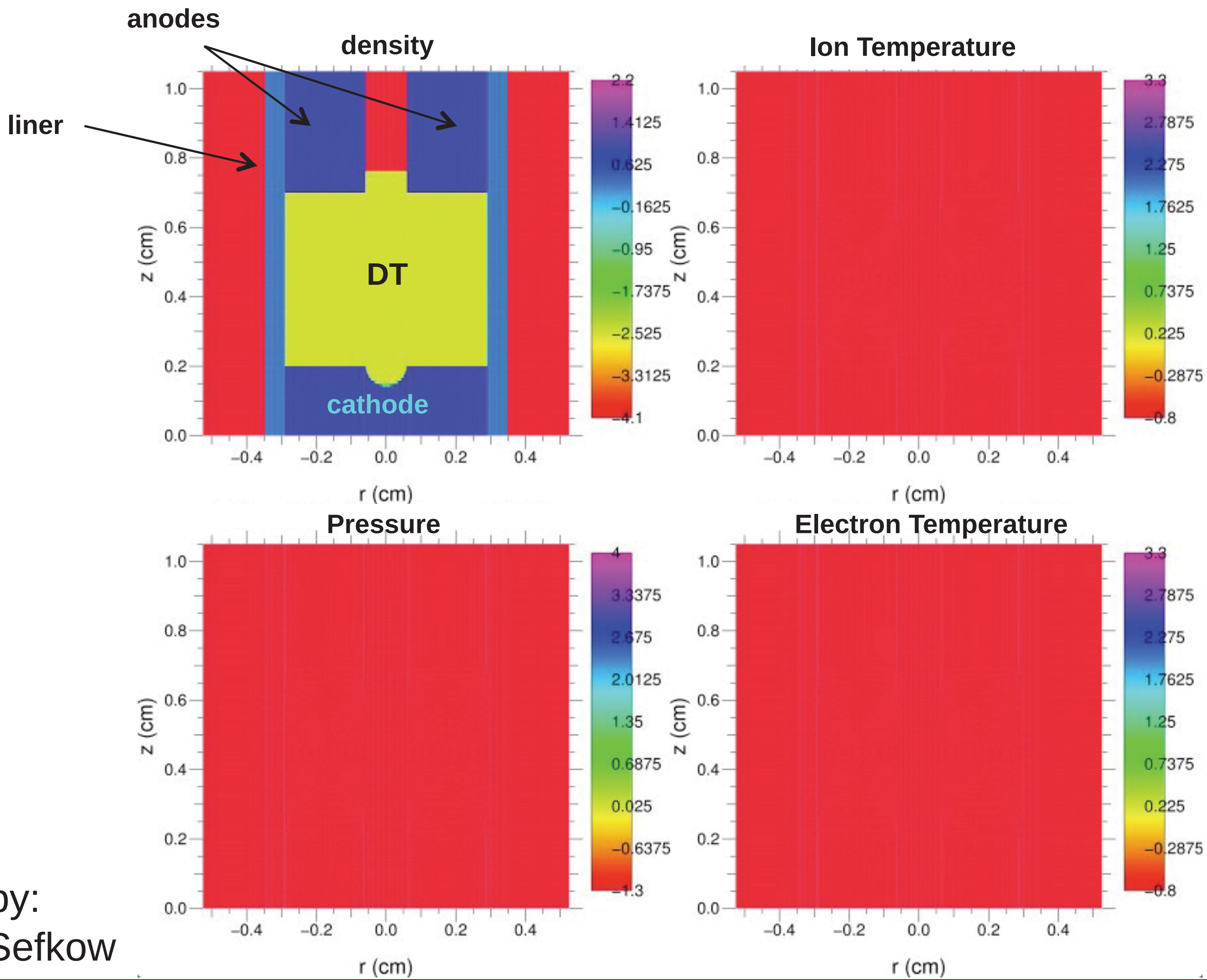
- **Laser interaction with foil and gas**
- **Axial heat loss at electrodes**
- **Loss of DT or D2 gas through LEH**
- **Liner implosion driven by Z circuit model**

Fully integrated Lasnex simulations support the point design

- **6 kJ of laser energy**
- **Lithium liner**
- **Initial field of 10 Tesla**
- **400 kJ**

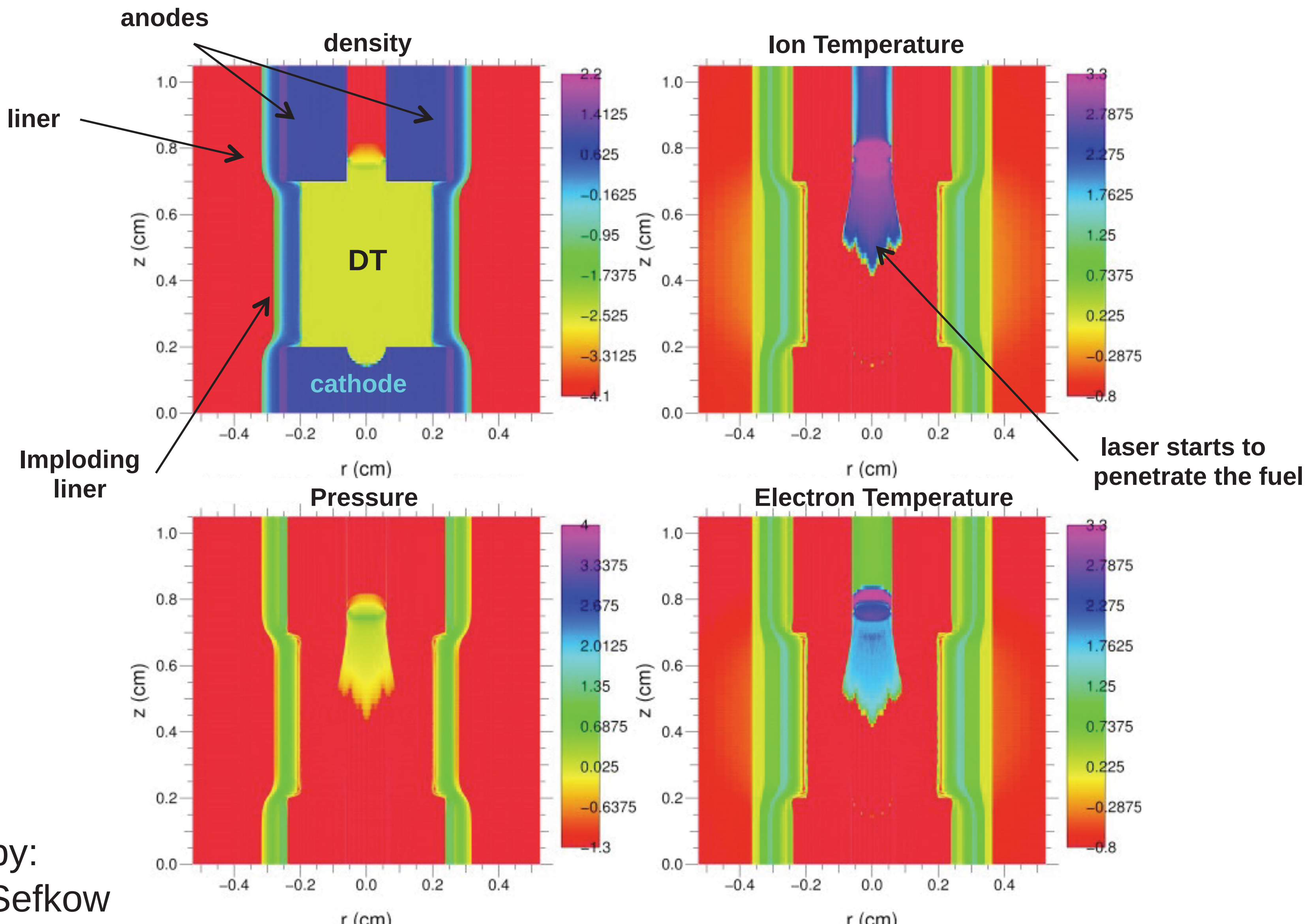


Hydra MagLIF Movie
time=0.0



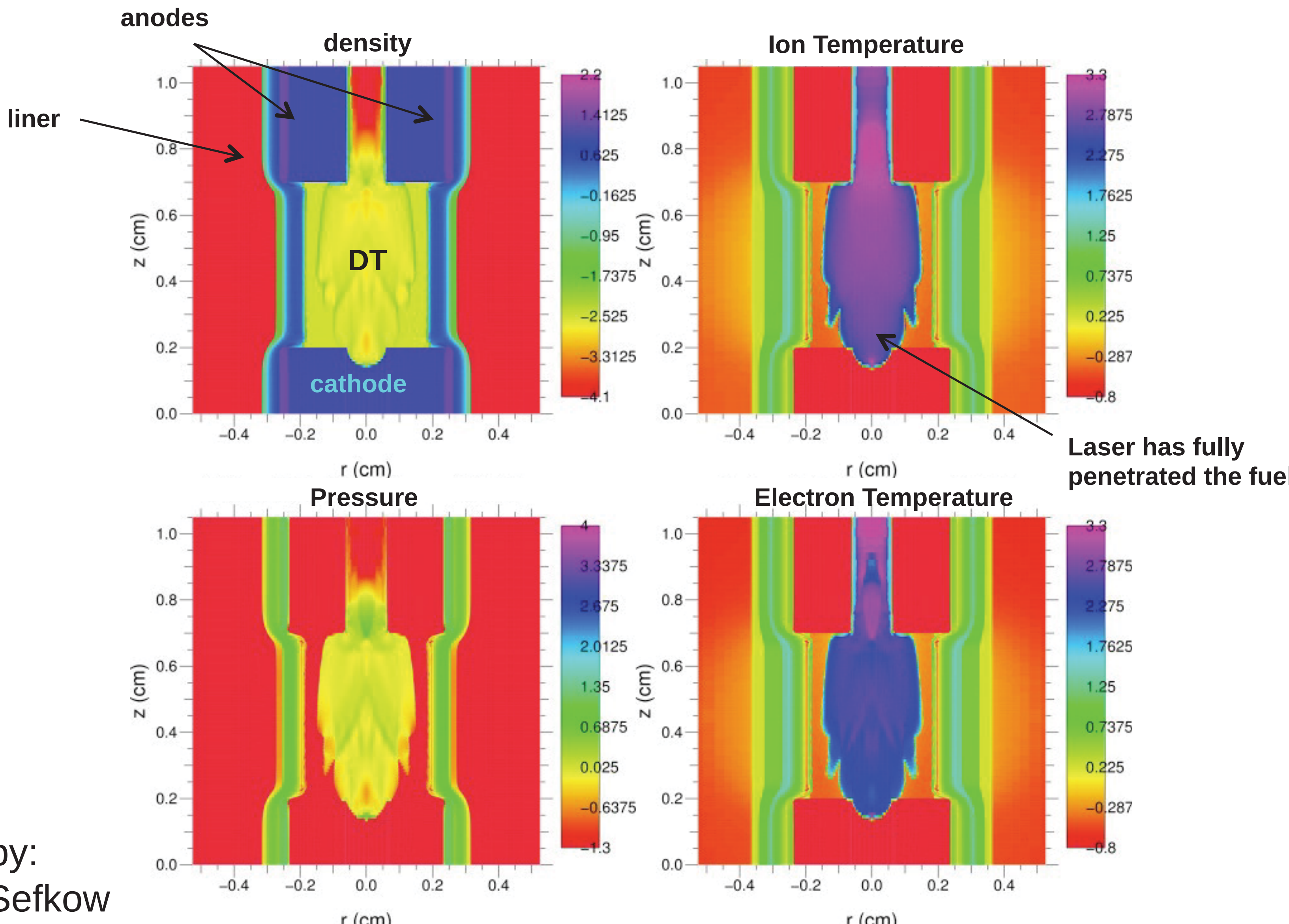
Hydra
Sims by:
A. B. Sefkow

Hydra MagLIF Movie
time=120.0



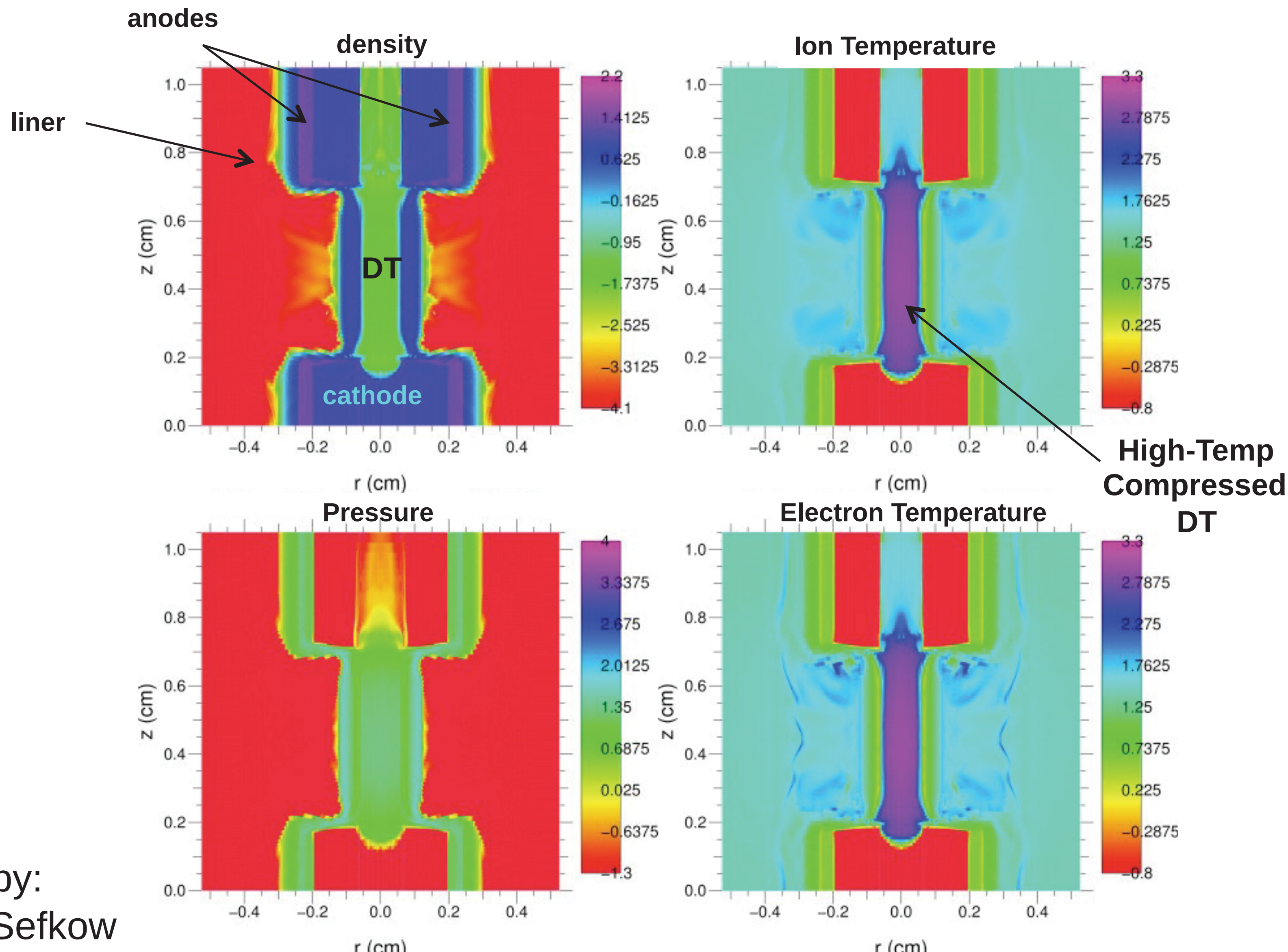
Hydra Sims by:
A. B. Sefkow

Hydra MagLIF Movie
time=123.0



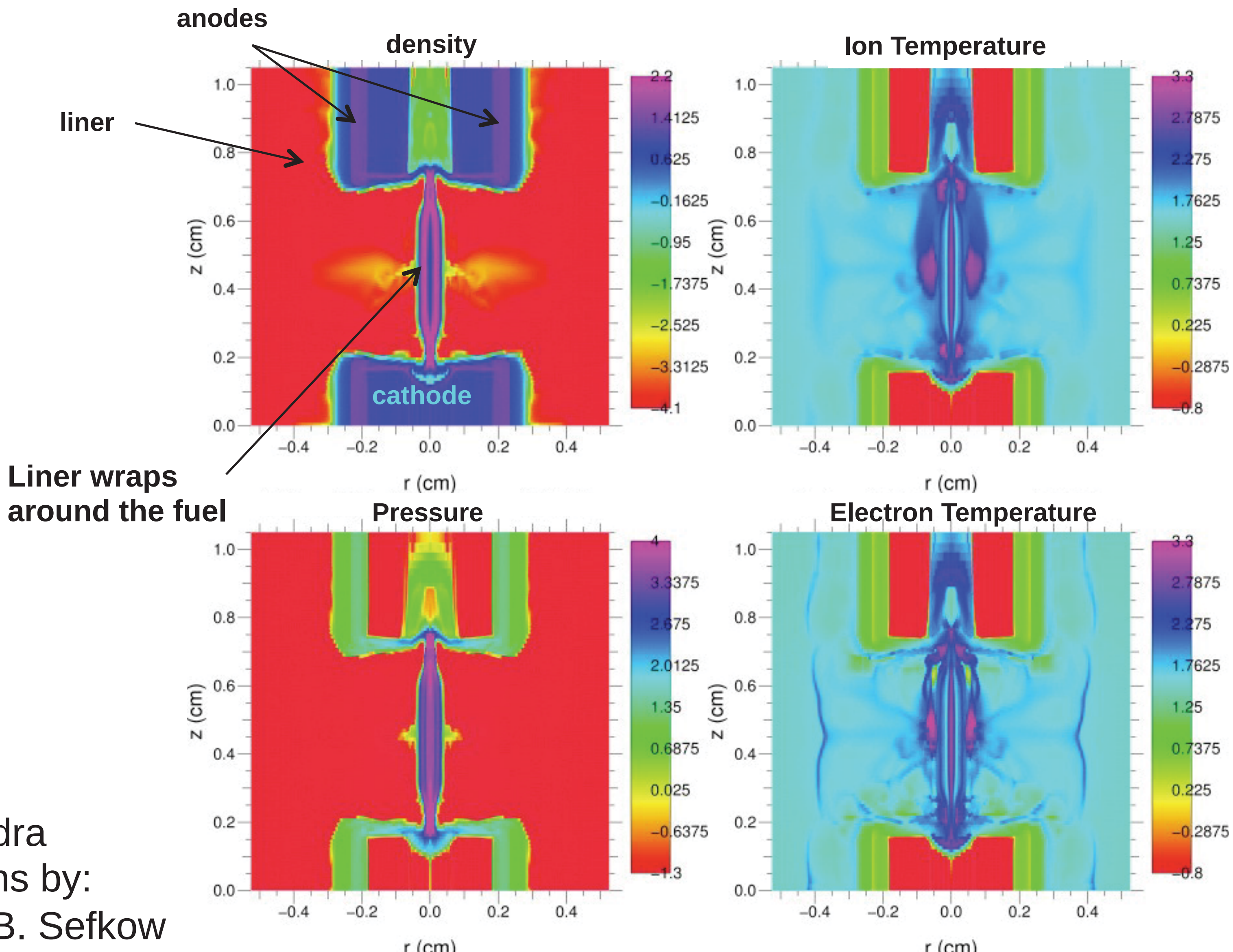
Hydra
Sims by:
A. B. Sefkow

Hydra MagLIF Movie
time=144.0



Hydra
Sims by:
A. B. Sefkow

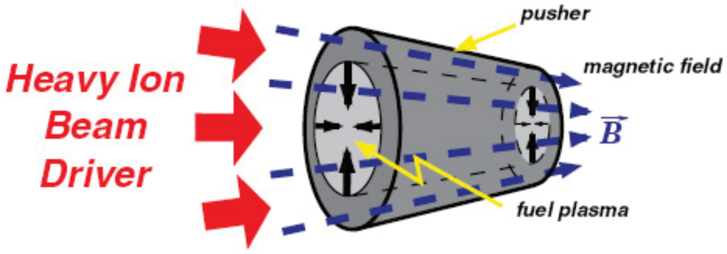
Hydra MagLIF Movie
time=153.0



Hydra
Sims by:
A. B. Sefkow

There is broad interest in magnetized fuel for several inertial confinement fusion (ICF) concepts

Max Planck / ITEP

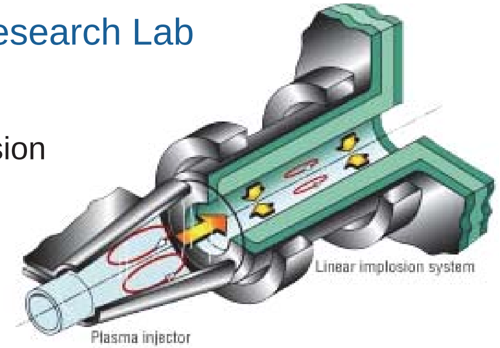


Basko, Kemp, Meyer-ter-Vehn, *Nucl. Fusion* 40, 59 (2000)
Kemp, Basko, Meyer-ter-Vehn, *Nucl. Fusion* 43, 16 (2003)

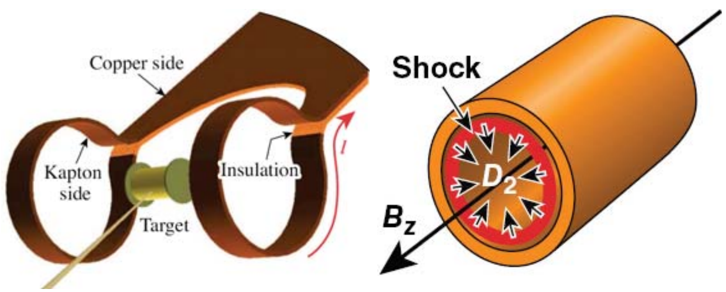
Los Alamos / Air Force Research Lab

Field Reversed Configuration
Shiva Star generator
~20 μs, 0.5 cm/μs liner implosion

Taccetti, Intrator, Wurden *et al., Rev. Sci, Instr.* 74, 4314 (2003)
Degnan *et al.*, *IEEE Trans. Plas. Sci.* 36, 80 (2008)



U. Rochester LLE



Direct drive laser implosion of cylinders
-- shock pre-heating, high implosion velocity

Gotchev *et al.*, *Bull. Am. Phys. Soc.* 52, 250 (2007)
Gotchev *et al.*, *Rev. Sci. Instr.* 80, 043504 (2009)

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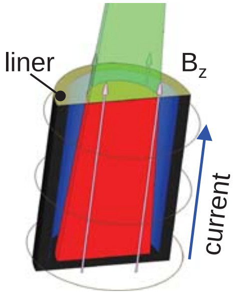
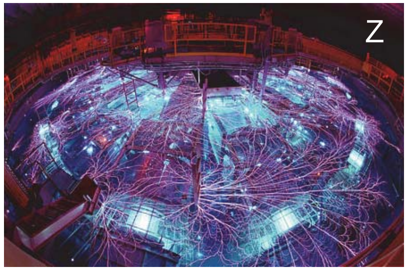
Magnetized Liner Inertial Fusion

Laser preheated magnetized fuel

Backlighting to diagnose the implosions (stability)

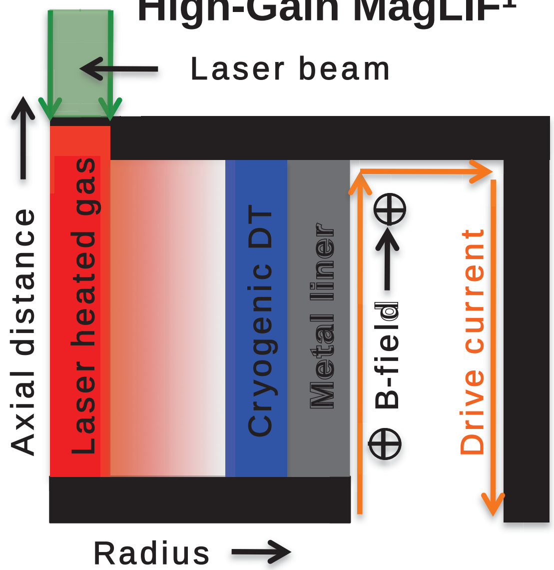
LASNEX simulations indicate interesting yields

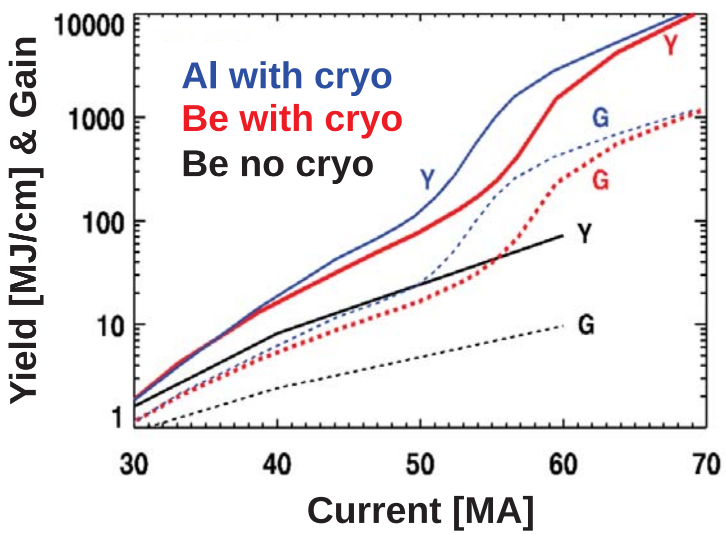




High Yields can be obtained with MagLIF

High-Gain MagLIF[1]





High yields could be used to investigate stewardship applications of ignition

High Gain (Yield) is obtained by only heating a small central portion of the fuel during compression
- minimizes compressive heating
- burn wave propagates into cold fuel as a deflagration

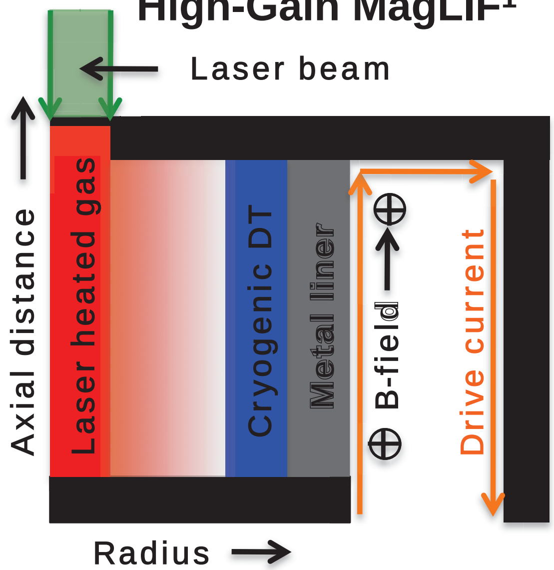
B_z decreases radial heat transport
- increases self-heating in the hot spot
- decreases burn wave propagation into cold fuel
- There is an optimal field strength
- The large ρr of MagLIF liners provides adequate burn time

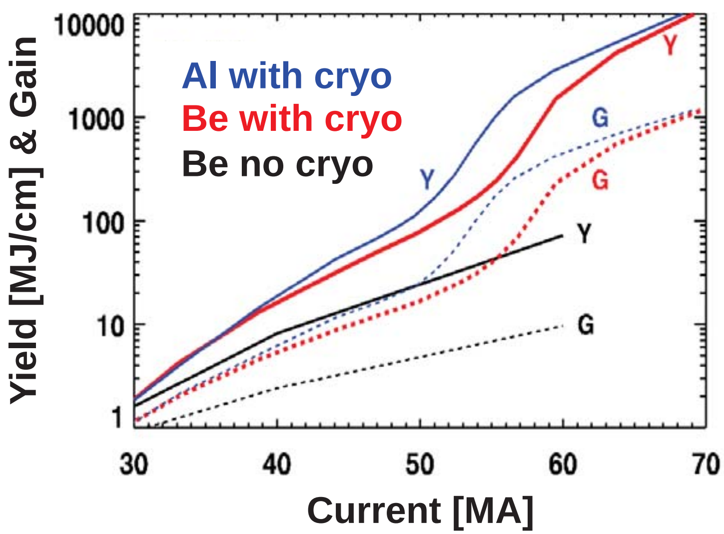
Initial gas density increases with current
- not at vapor pressure
- laser energy =>22 KJ
- pulse length => 30 ns

[1] *S.A. Slutz and R.A. Vesey Physical Review Letters 108, 025003 (2012)*

High Gain is required for Fusion Energy

High-Gain MagLIF[1]





Fusion energy requires $G\eta_E f_{RP}\eta_D = 1$

$$G > 50$$

- G **= Gain=Yield/liner absorbed energy**
- η_E **= electricity production efficiency~0.4**
- f_{RP} **= fraction of power recirculated~0.25**
- η_D **= driver efficiency ~ 0.2 for magnetic implosions**

[1] *S.A. Slutz and R.A. Vesey Physical Review Letters 108, 025003 (2012)*

The potential of MagLIF

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Fuel magnetization allows slow implosions thus greatly reducing the driver cost

Simulations indicate that MagLIF could produce significant fusion yields on Z

Simulations further indicate that High-Yield MagLIF is possible on future higher-current accelerators

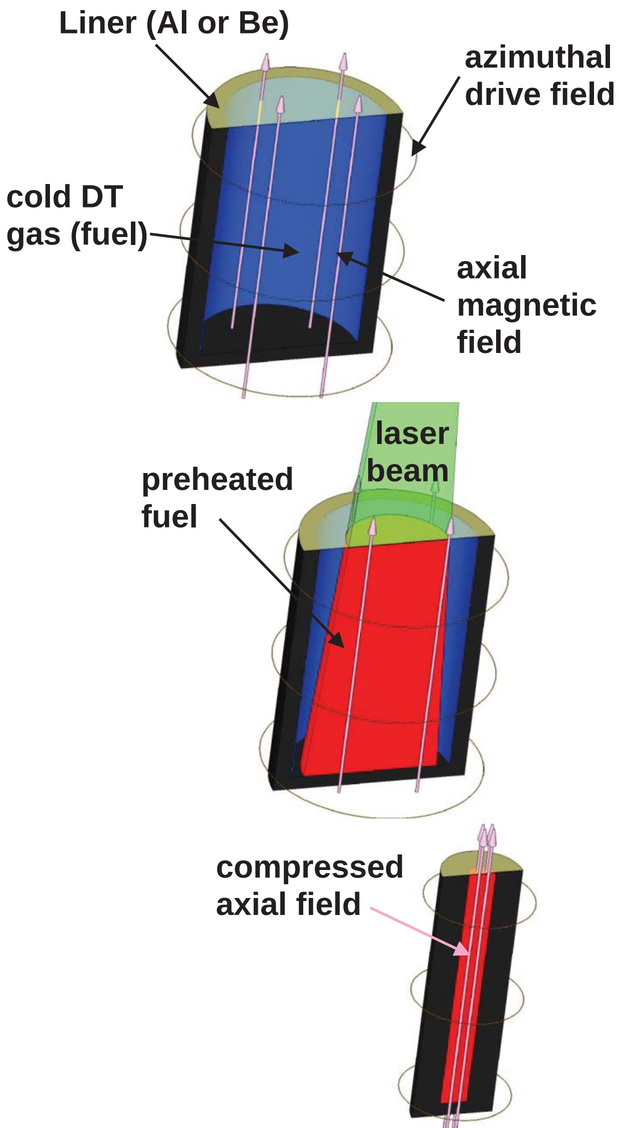
- **Gains of 1000**
- **Yields of 10 GJ/cm (useful for stockpile stewardship)**

MagLIF will provide a platform to evaluate critical physics for any magnetized inertial fusion concept:

- **Magnetic flux compression**
- **Generalized Ohms law terms such as the Nernst effect**
- **Anomalous thermal transport**
- **Cooling flows**
- **Magnetized Knudsen layers**
- **Magnetic inhibition of the Rayleigh-Taylor Instability**
- **Fusion from anisotropic ion distributions**
- **Magnetic inhibition of alpha particle transport**

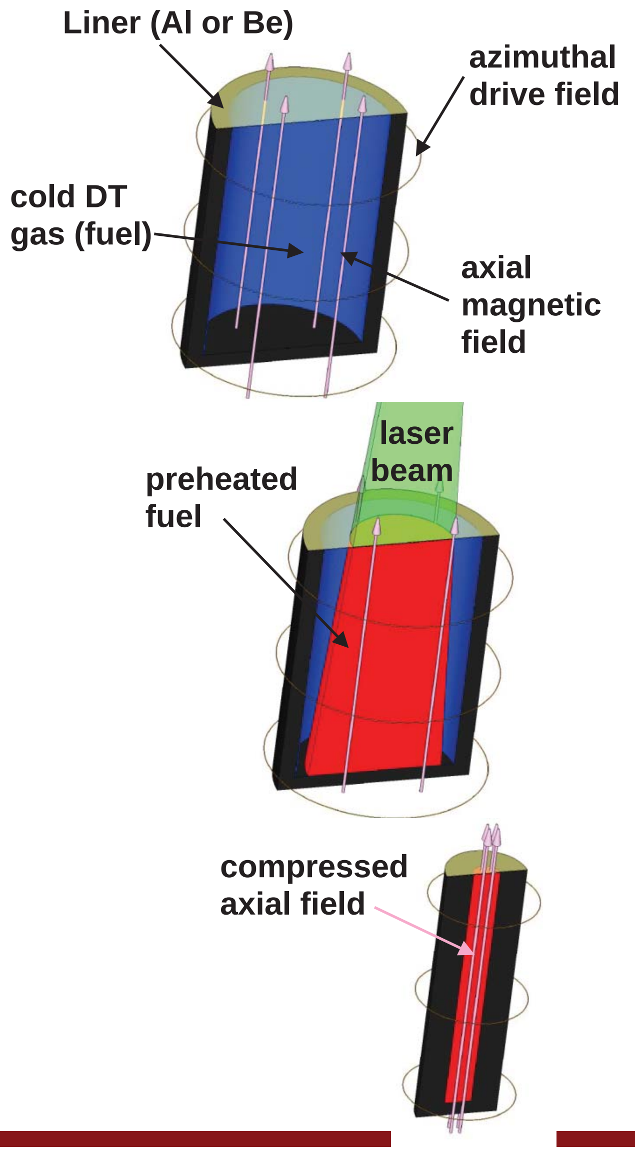
Experimental campaigns are now investigating the important physics that need to be understood and modeled to bring MagLIF from concept to reality

Sandia plans to address key science and engineering research questions related to MagLIF in the next 3-5 years



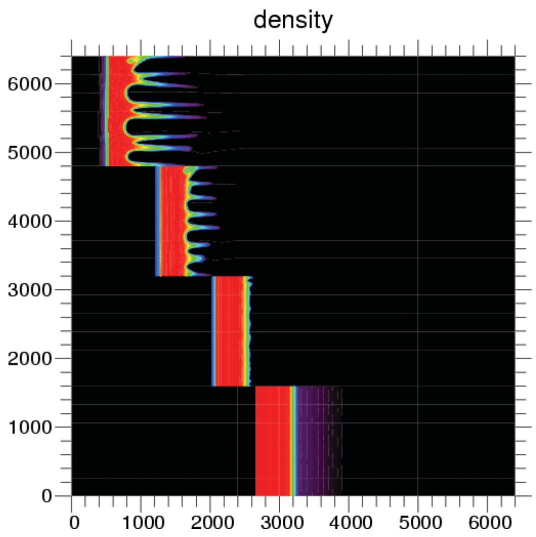
- Research can be subdivided into several broad categories:
  - Liner implosion dynamics
  - Fuel preheating
  - Impact of fuel magnetization
  - Fuel assembly & stagnation
- MagLIF requires new capabilities to address some of these issues
- MagLIF leverages and benefits ongoing ICF/Science campaign research on Z, NIF, and OMEGA

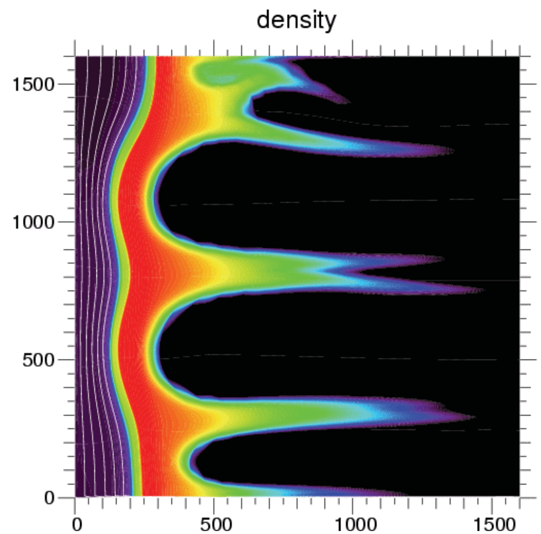
Sandia plans to address key science and engineering research questions related to MagLIF in the next 3-5 years

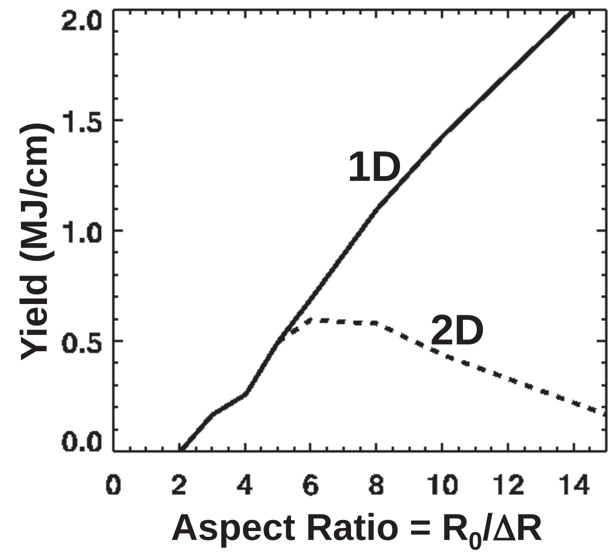


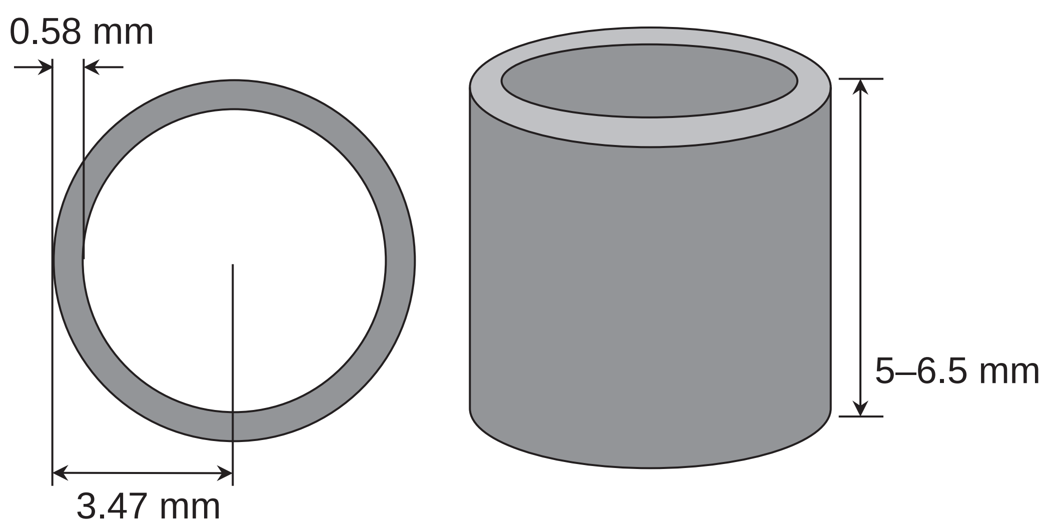
- Liner implosion dynamics
- Fuel preheating
- Impact of fuel magnetization
- Fuel assembly & stagnation

2D LASNEX simulations of MagLIF suggest an optimum at an aspect ratio (AR) of 6*









$$AR \equiv \frac{R_{outer,0}}{\Delta R_0}$$

* S. A. Slutz *et al.*, Phys. Plasmas 17, 056303 (2010).

We have already done significant work to date on liner implosion dynamics that is relevant to MagLIF

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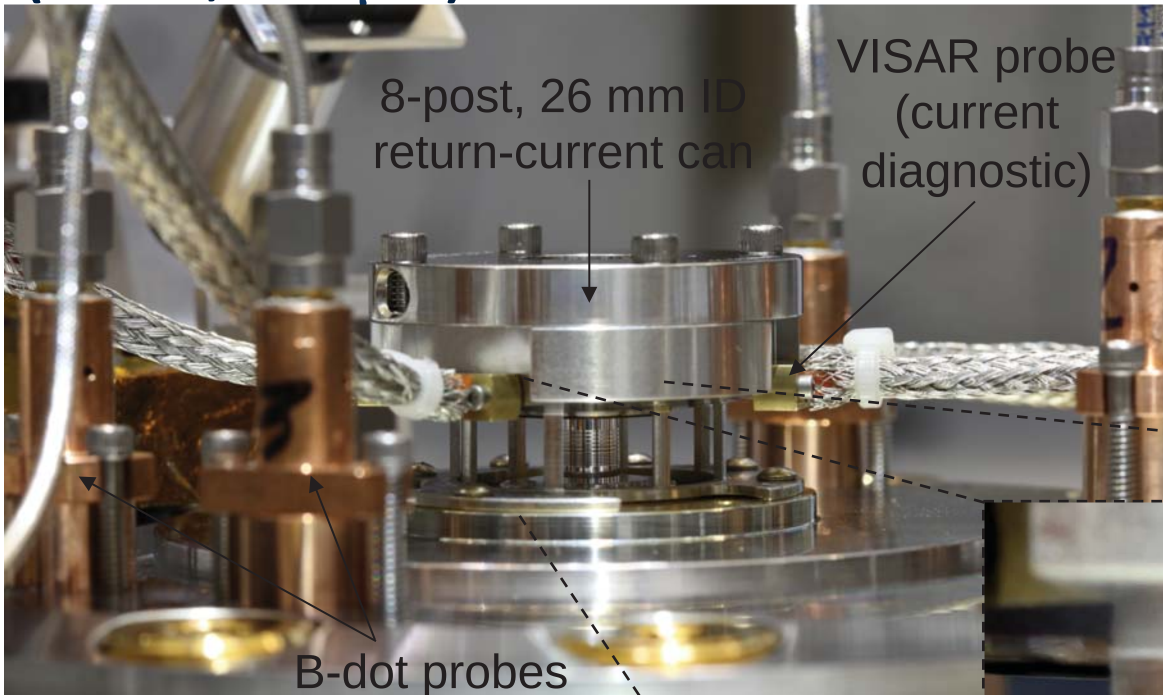
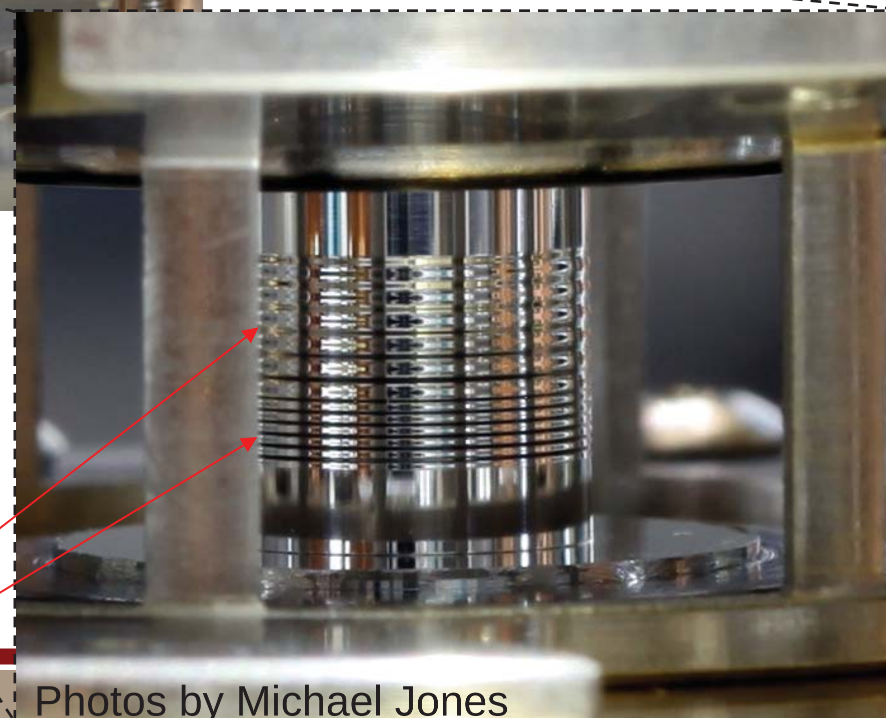
- A 3-year LDRD (Laboratory Directed Research & Development) on "*Stability of Fusion Target Concepts on Z*", (FY09-FY11) focused heavily on liner dynamics
- Dan Sinars won an OFES DOE Early Career Award (2011-2016) for "*Fundamental instability measurements in magnetically-driven z-pinch liner implosions*" which will continue to look at this
- We will now briefly summarize several recent MagLIF-relevant liner dynamics publications:
  - D.B. Sinars *et al.*, Phys. Rev. Lett. 105, 185001 (2010).
  - D.B. Sinars *et al.*, Phys. Plasmas 18, 056301 (2011).
  - M.R. Martin *et al.*, Phys. Plasmas 19, 056310 (2012).
  - R.D. McBride *et al.*, Phys. Rev. Lett. 109, 135004 (2012)
  - R.D. McBride *et al.*, Phys. Plasmas 20, 056309 (2013)
  - K.J. Peterson *et al.*, Phys. Plasmas 19, 092701 (2012)
  - K.J. Peterson *et al.*, Phys. Plasmas 20, 056305 (2013)
- The bottom line is that the original MagLIF calculations are consistent with the experimental data obtained to date, we will continue to evaluate this

We tested MRT growth predictions in controlled experiments on Z using Al liners with small sinusoidal perturbations (λ=200, 400-μm)

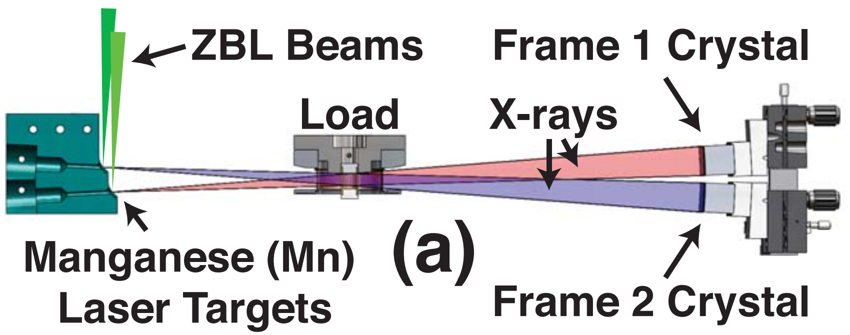


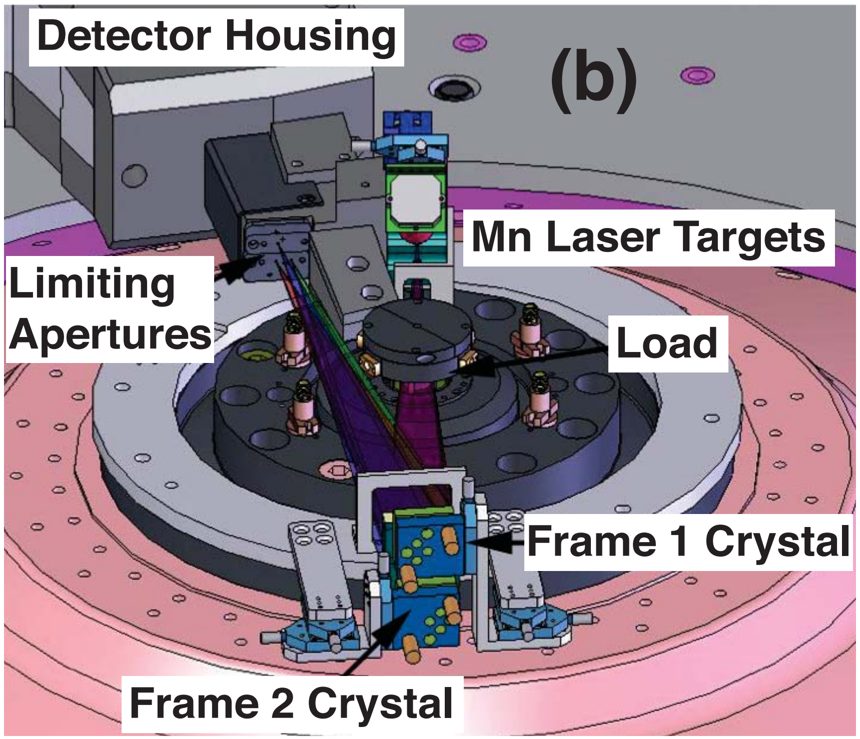


- Solid cylindrical liner (Al 1100 alloy)
- 6.5 mm tall, 6.34 mm diameter, AR=10
- 10 nm surface finish (diamond-turned)
- 12 sinusoidal perturbations

Targets made by General Atomics

Two-frame monochromatic (6151±0.5 eV) crystal backlighting diagnostic to study liner dynamics on Z*



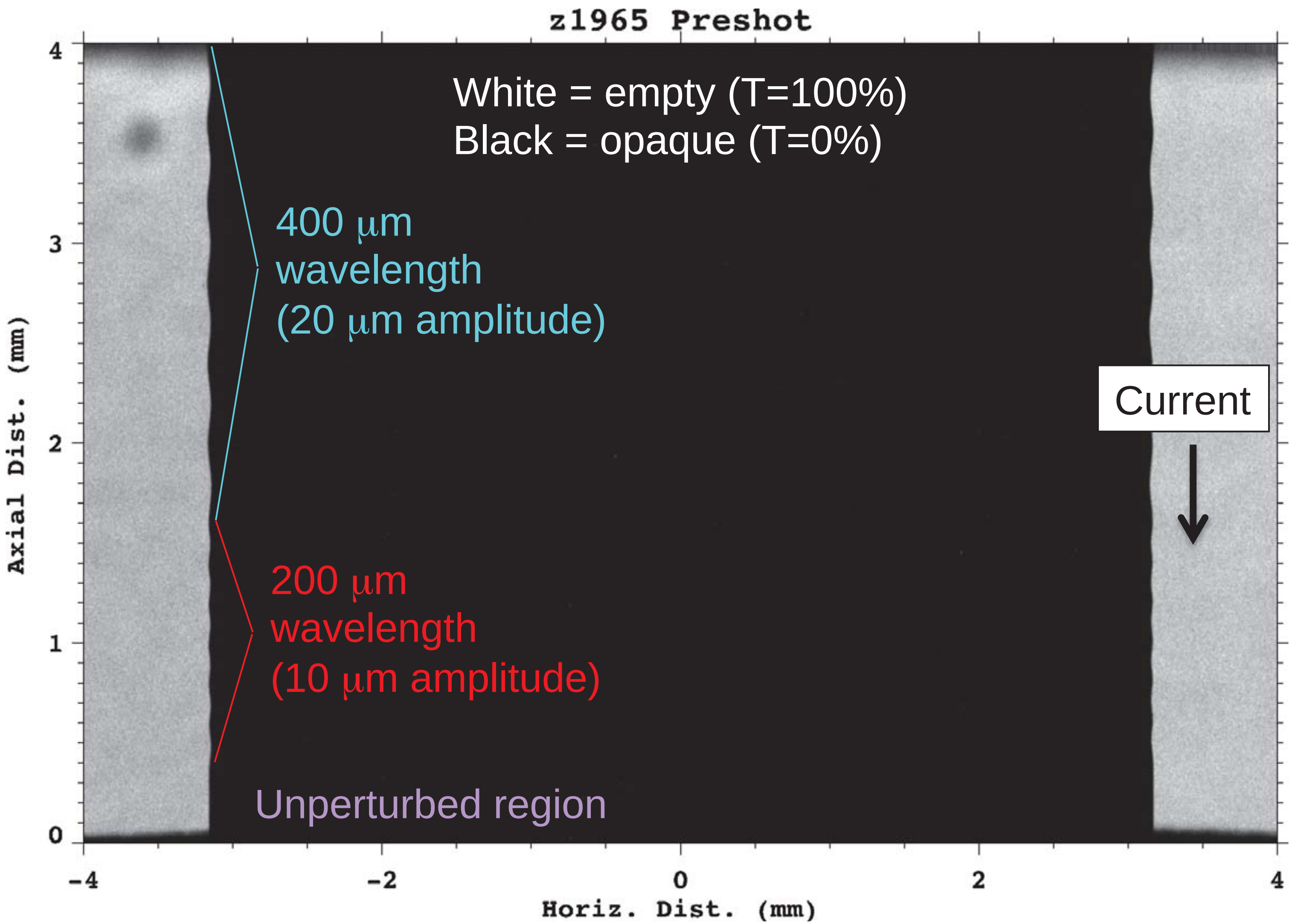


- Spherically-bent quartz crystals (22<u>4</u>3)
- Monochromatic (~0.5 eV bandpass)
- 15 micron resolution (edge-spread)
- Large field of view (10 mm x 4 mm)
- We can see through imploding beryllium (not so for aluminum and other higher-opacity materials)

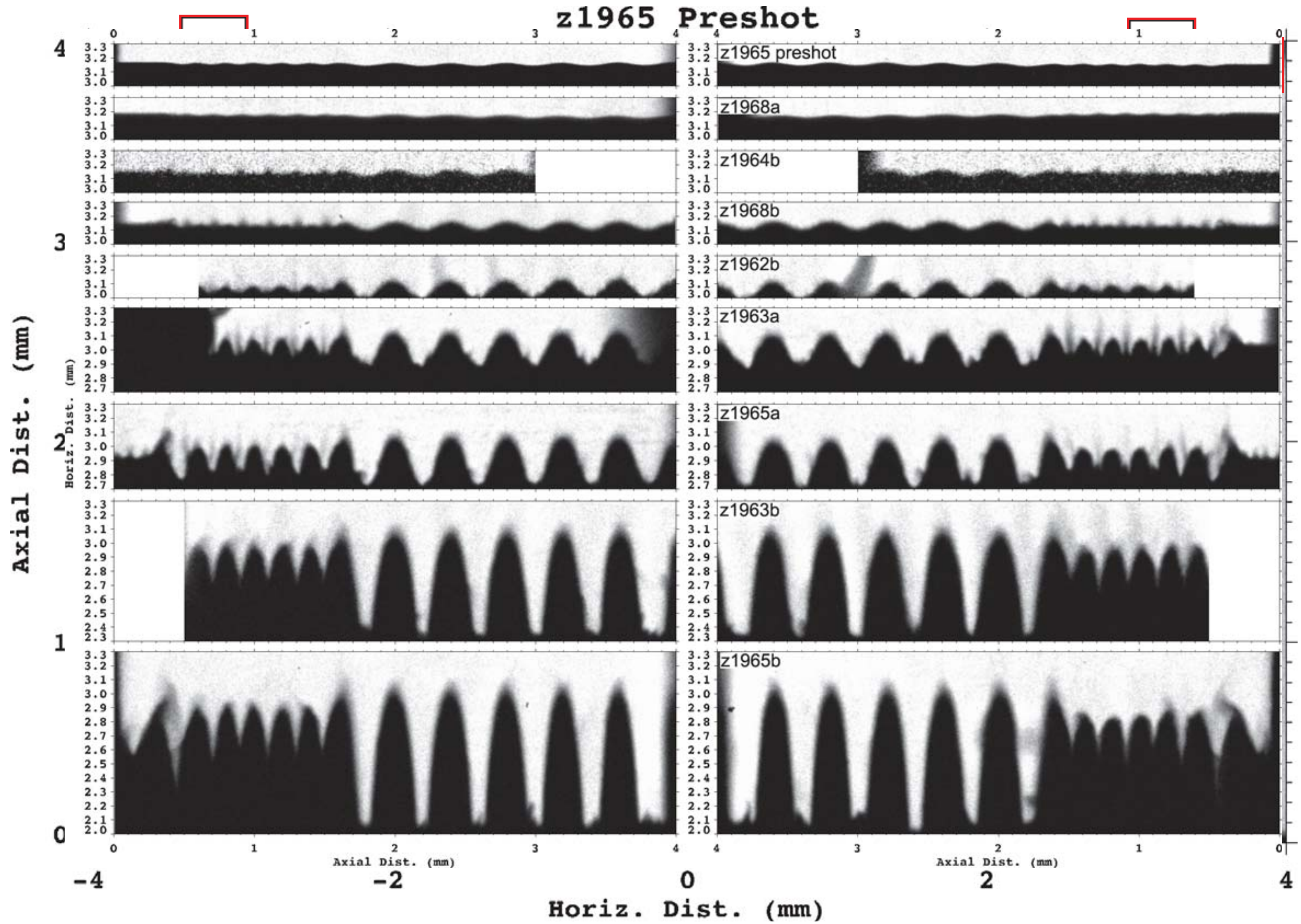
- **Original concept**
  - S.A. Pikuz *et al.*, RSI (1997).
- **1.865 keV backlighter at NRL**
  - Y. Aglitskiy *et al.*, RSI (1999).
- **Explored as NIF diagnostic option**
  - J.A. Koch *et al.*, RSI (1999).
- **Single-frame 1.865 keV and 6.151 keV implemented on Z facility**
  - D.B. Sinars *et al.*, RSI (2004).
- **Two-frame 6.151 keV on Z facility**
  - G.R. Bennett *et al.*, RSI (2008).

* G. R. Bennett *et al.*, RSI (2008).

Example 6.151 keV radiograph (Pre-shot)

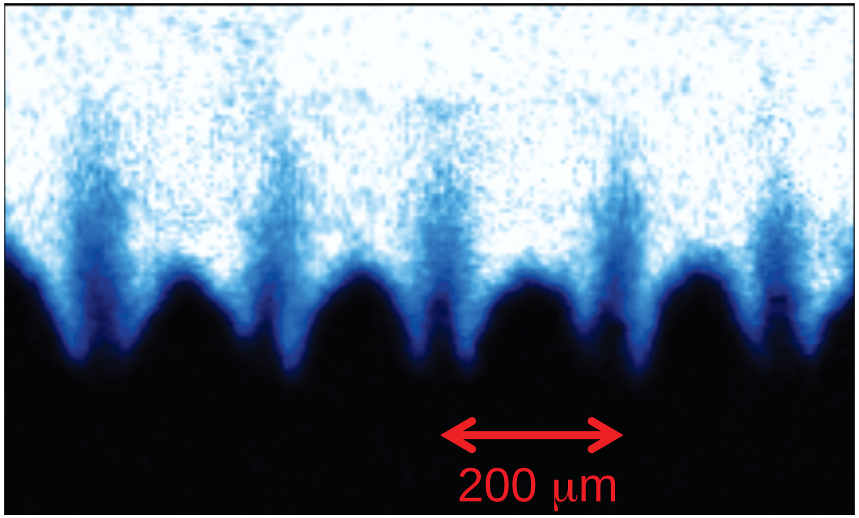


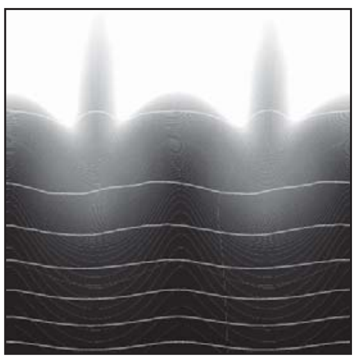
Zooming in, we see ablation, jetting, and small-scale instabilities in addition to the seeded instability growth



D.B. Sinars *et al.*, Phys. Rev. Lett. (2010); D.B. Sinars *et al.*, Phys. Plasmas (2011).

We observe excellent agreement between simulation and experiment in single-mode MRT growth experiments, *using the same methodology as used in MagLIF calculations*

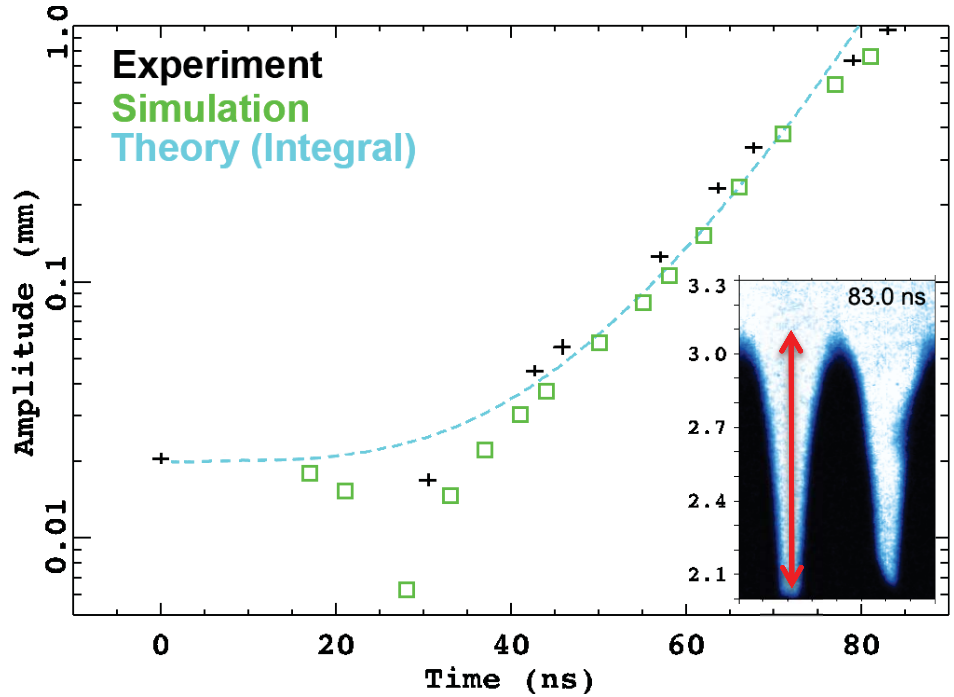




Ablated material coalesces in valleys to form jets visible in the radiographs

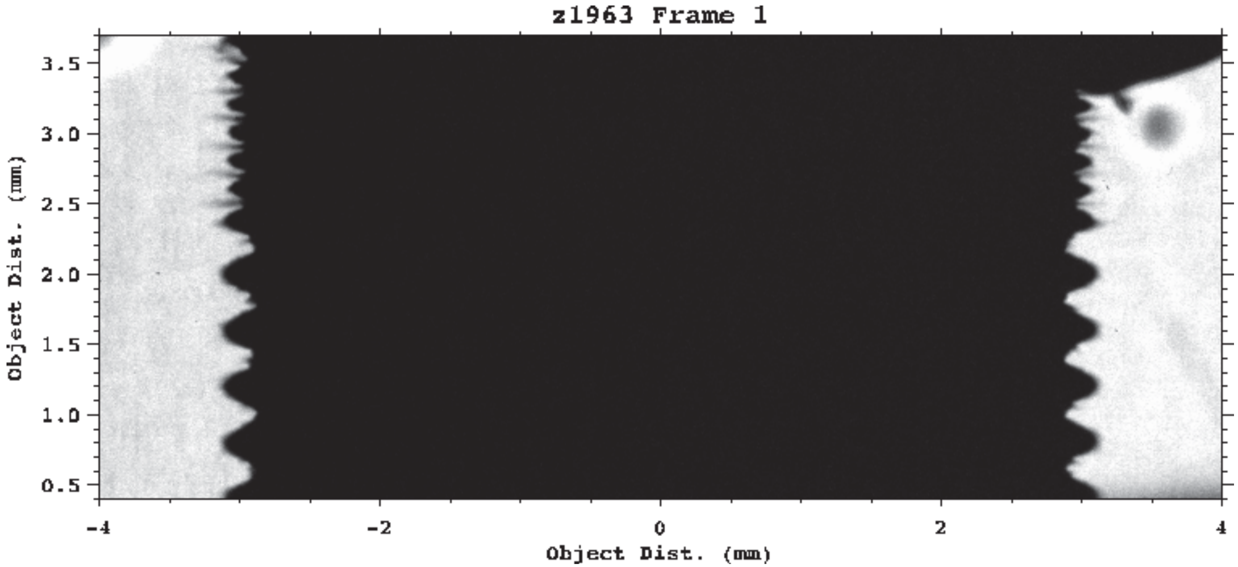
Simulated density map with rB_θ contours

LASNEX: T_{jets} ~30 eV; T_{valley} ~100 eV

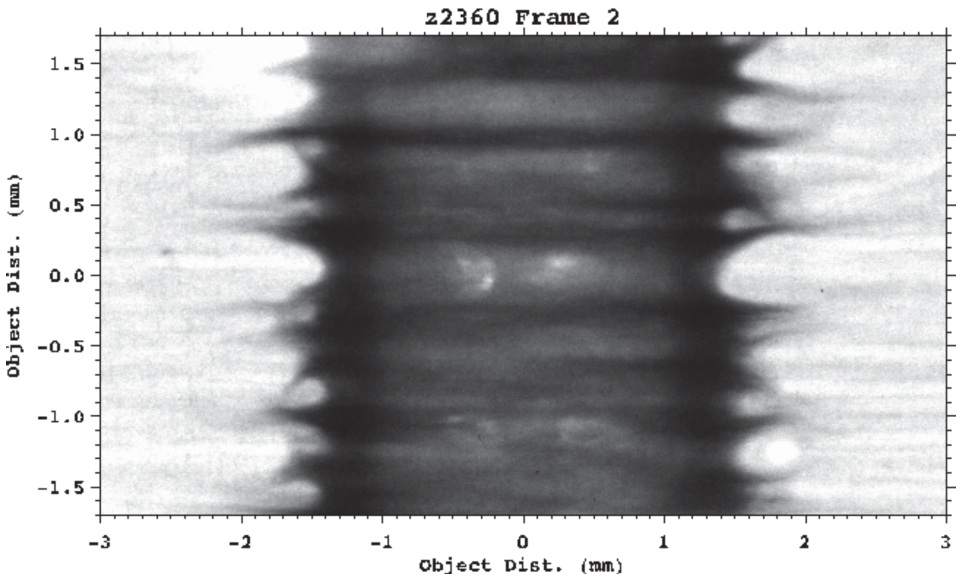


- Fine-structure details such as jetting and ablation were successfully predicted
- Amplitude of the resulting growth versus time was also predicted, and matches that expected by theory

The lower opacity of beryllium at 6.151 keV allows us to take penetrating radiographs of the liner implosions



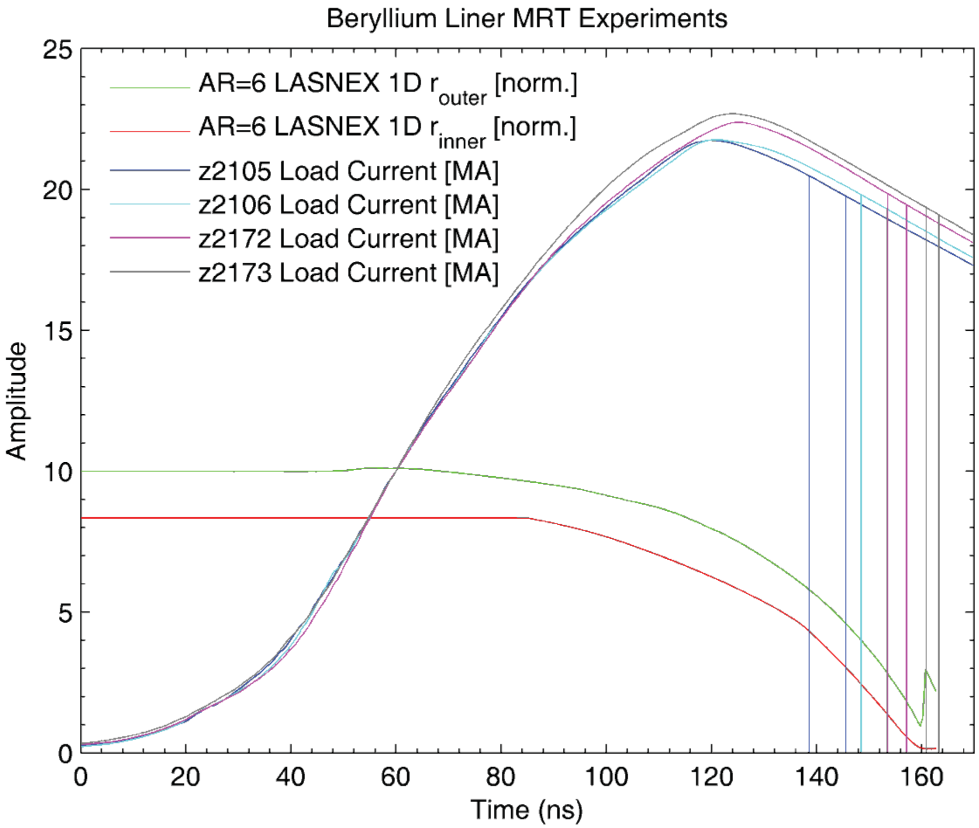
High opacity of Al means that we only see the edge of the liner

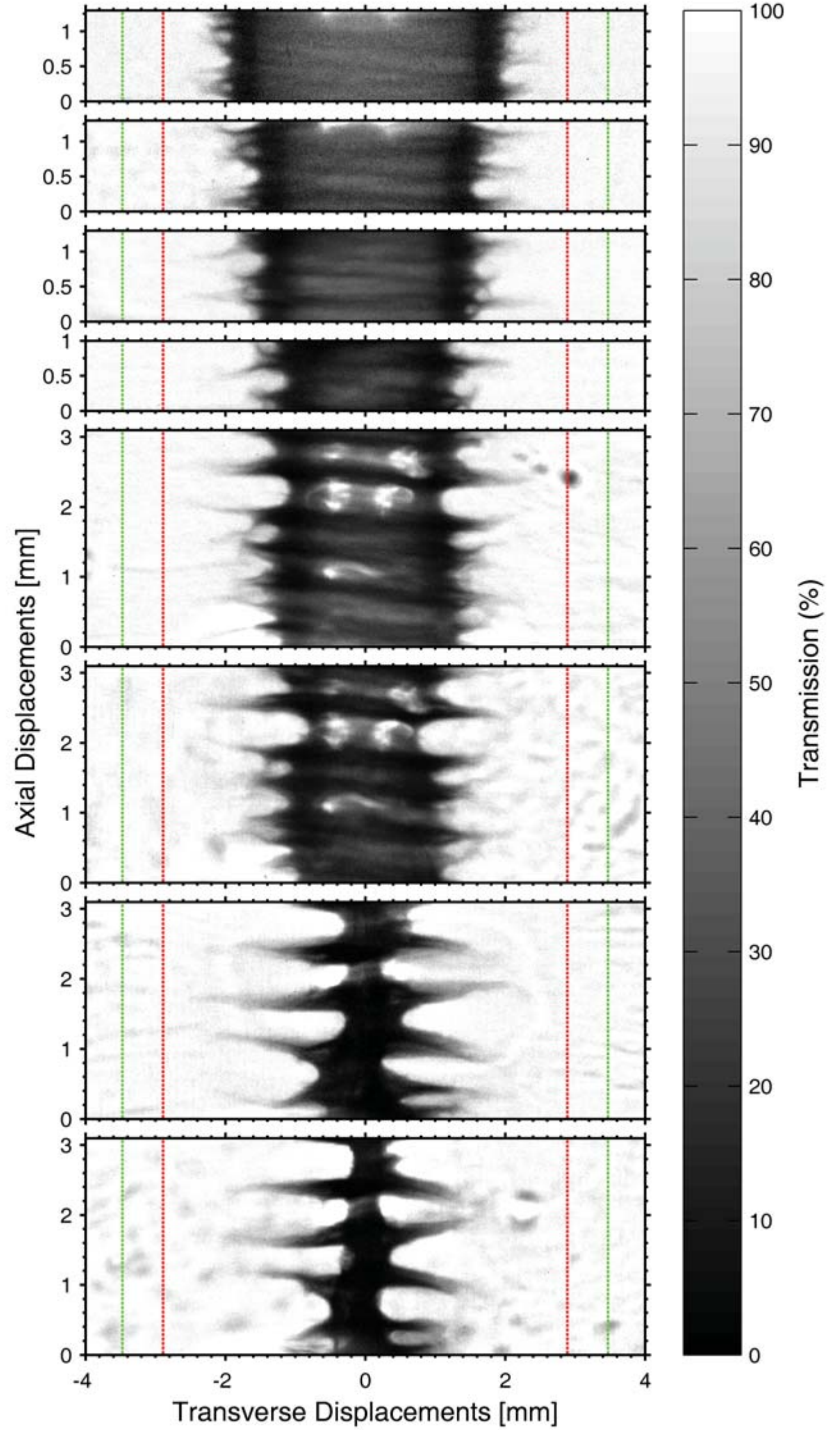


Lower opacity of Be means that we can see through the liner and the “spikes” show up as dark bands

Machining of beryllium targets is done at General Atomics in La Jolla, CA

Beryllium MRT Data

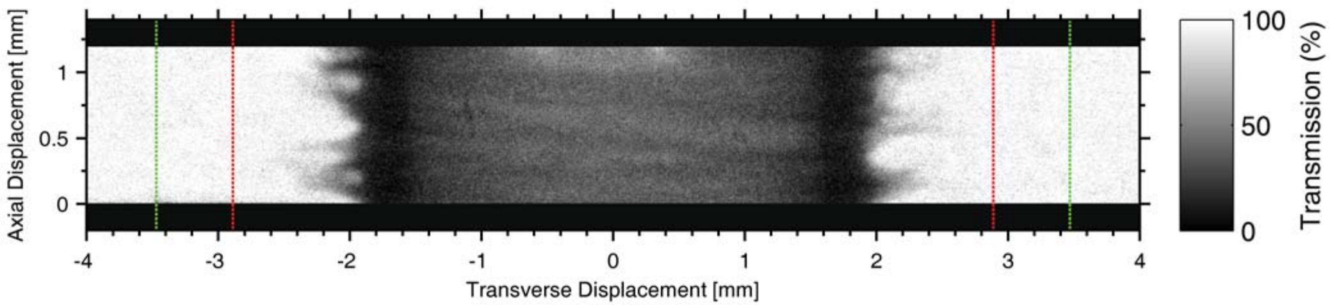




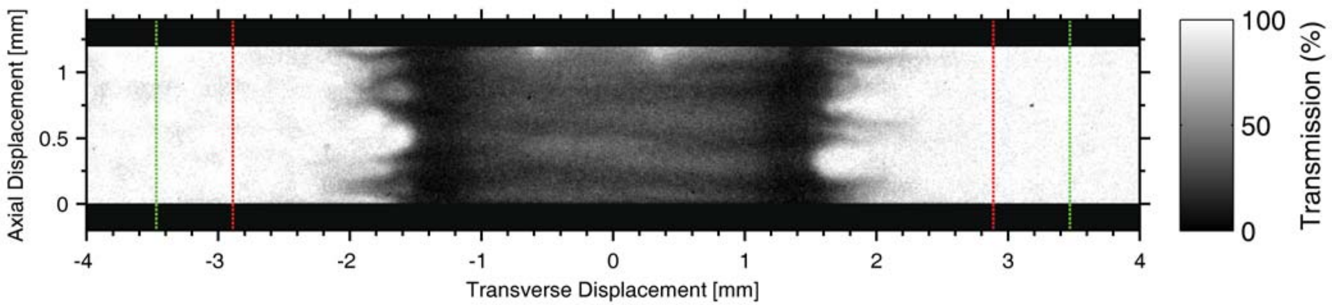
AR=6:

$r_{outer,0}$ = 3.47 mm

$r_{inner,0}$ = 2.89 mm



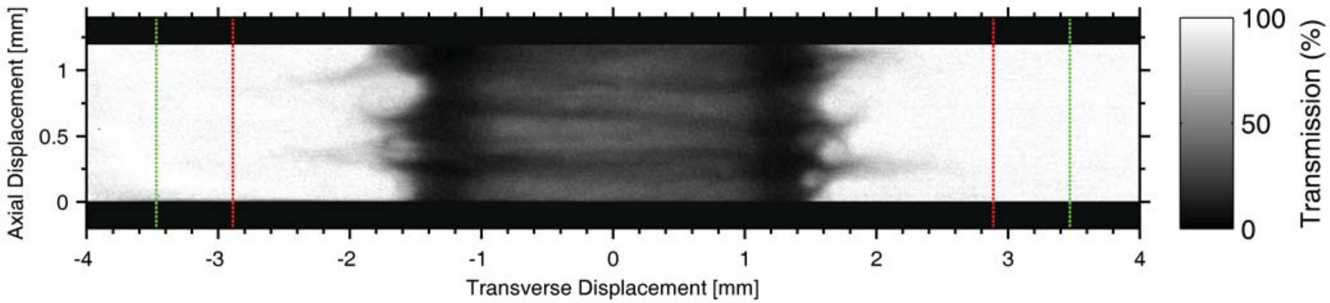
AR=6:
$r_{outer,0}$ = 3.47 mm
$r_{inner,0}$ = 2.89 mm



AR=6:

$r_{outer,0}$ = 3.47 mm

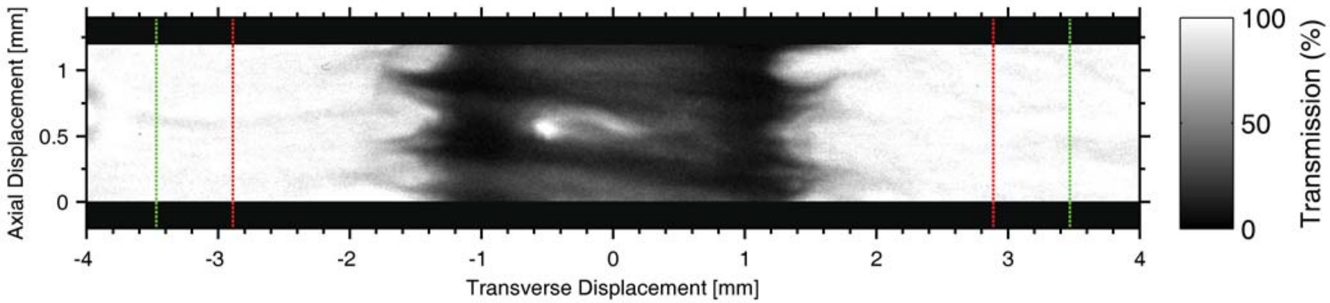
$r_{inner,0}$ = 2.89 mm



AR=6:

$r_{outer,0}$ = 3.47 mm

$r_{inner,0}$ = 2.89 mm



AR=6:

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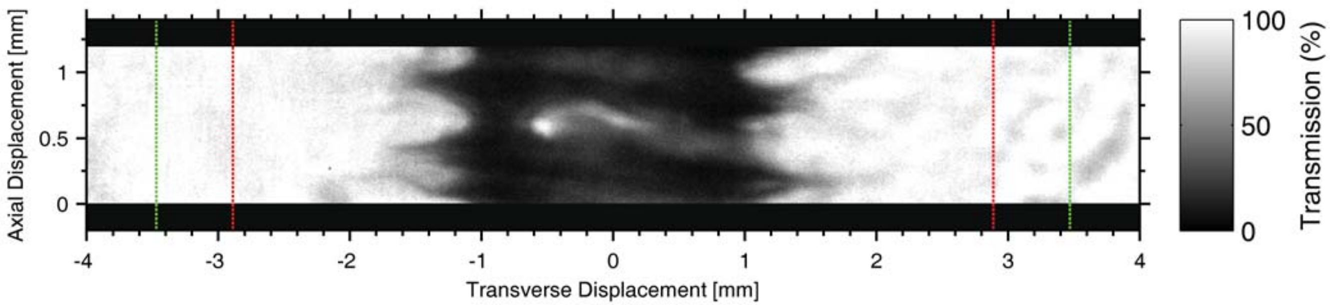
$r_{inner,0}$ = 2.89 mm



AR=6:

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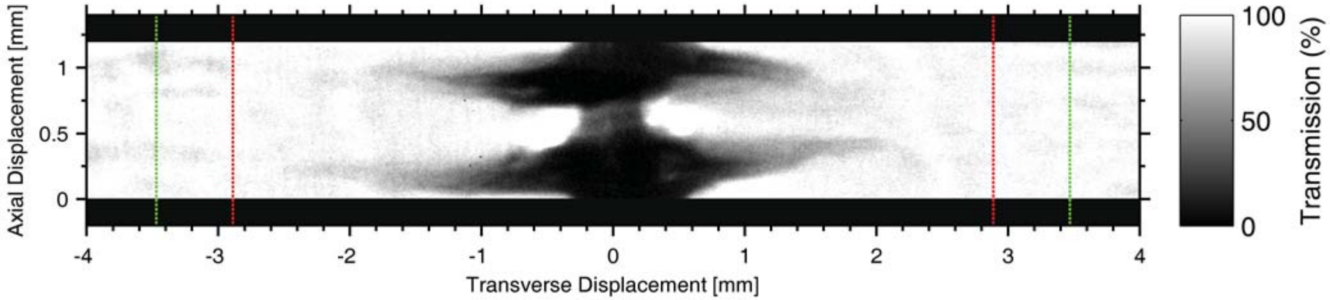
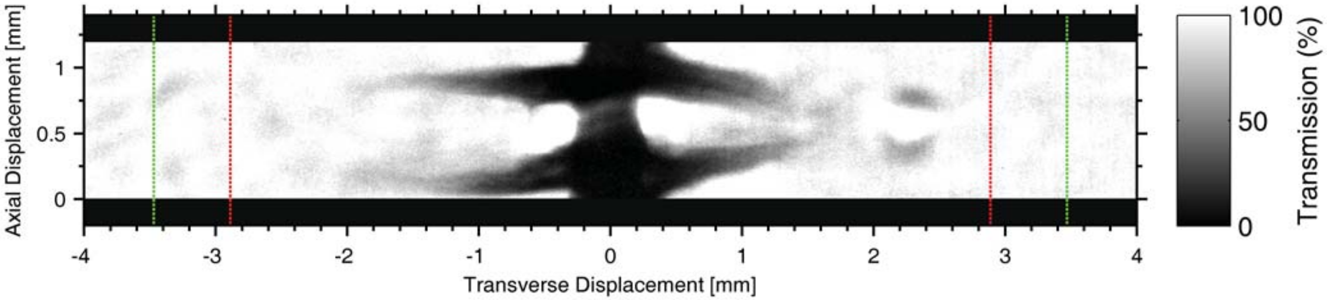
$r_{inner,0}$ = 2.89 mm



AR=6:

$r_{outer,0}$ = 3.47 mm

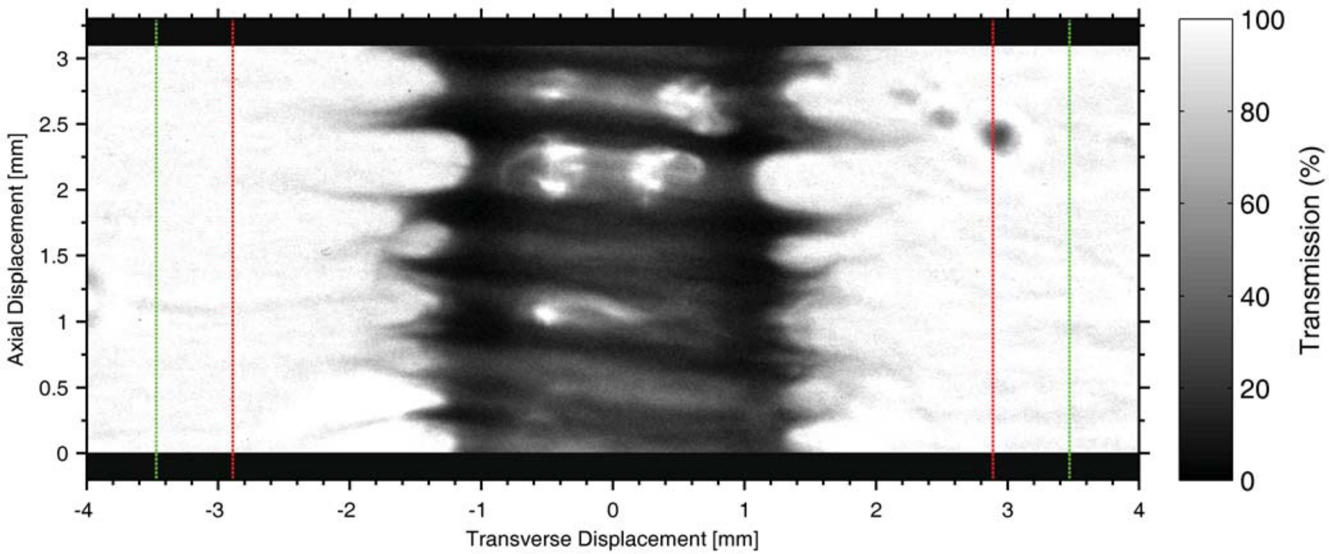
$r_{inner,0}$ = 2.89 mm



AR=6:

$r_{outer,0}$ = 3.47 mm

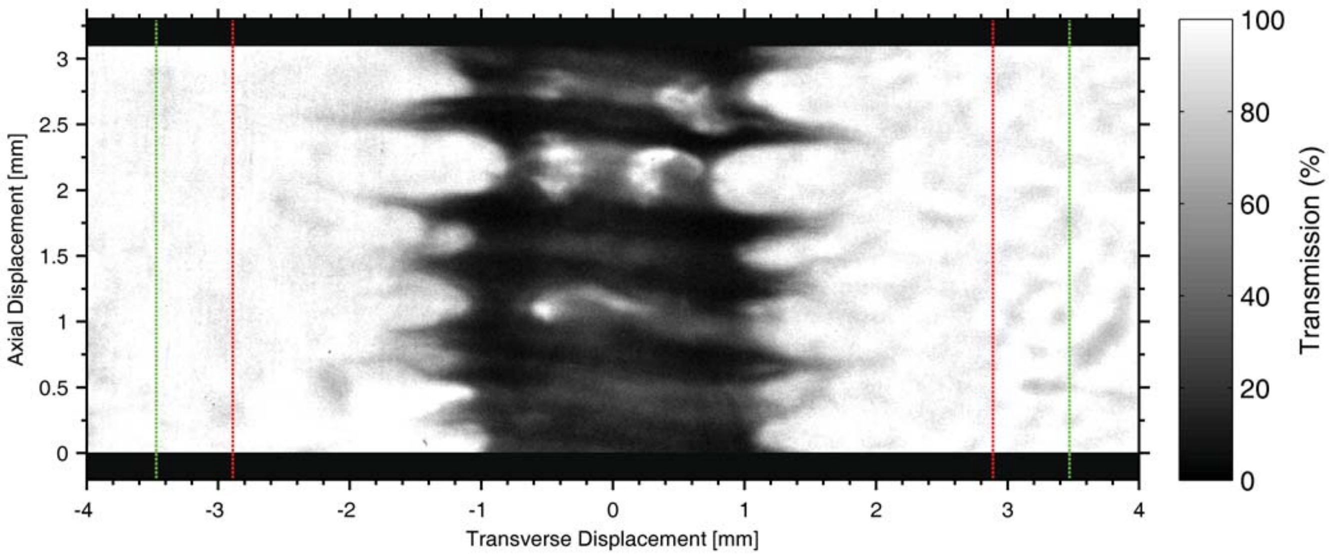
$r_{inner,0}$ = 2.89 mm



AR=6:

$r_{outer,0}$ = 3.47 mm

$r_{inner,0}$ = 2.89 mm



AR=6:
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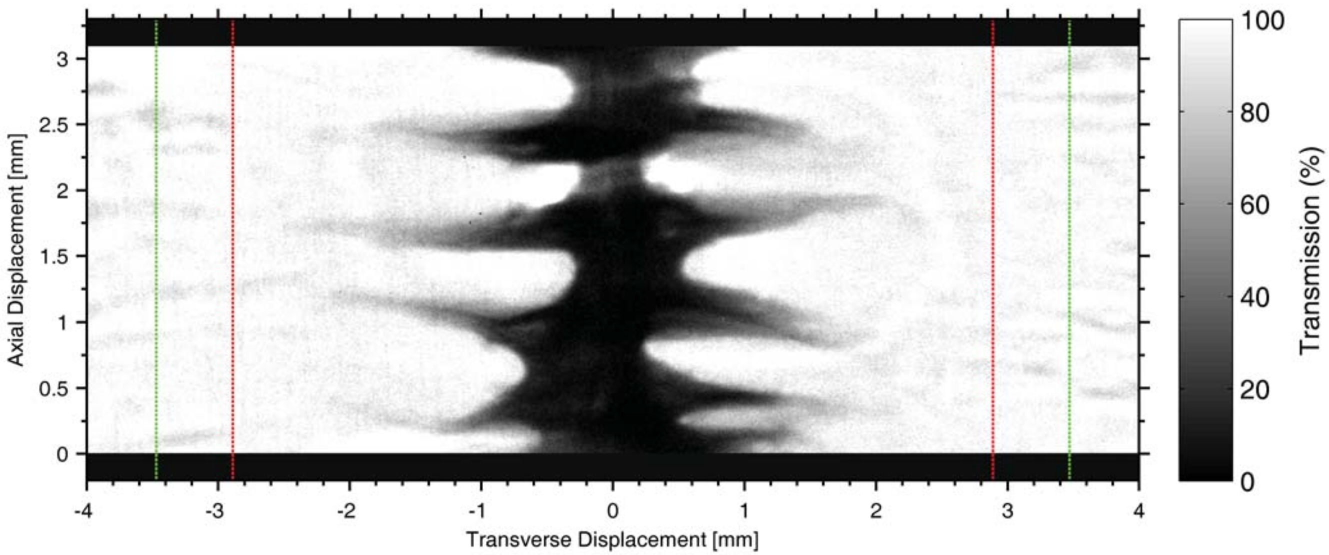
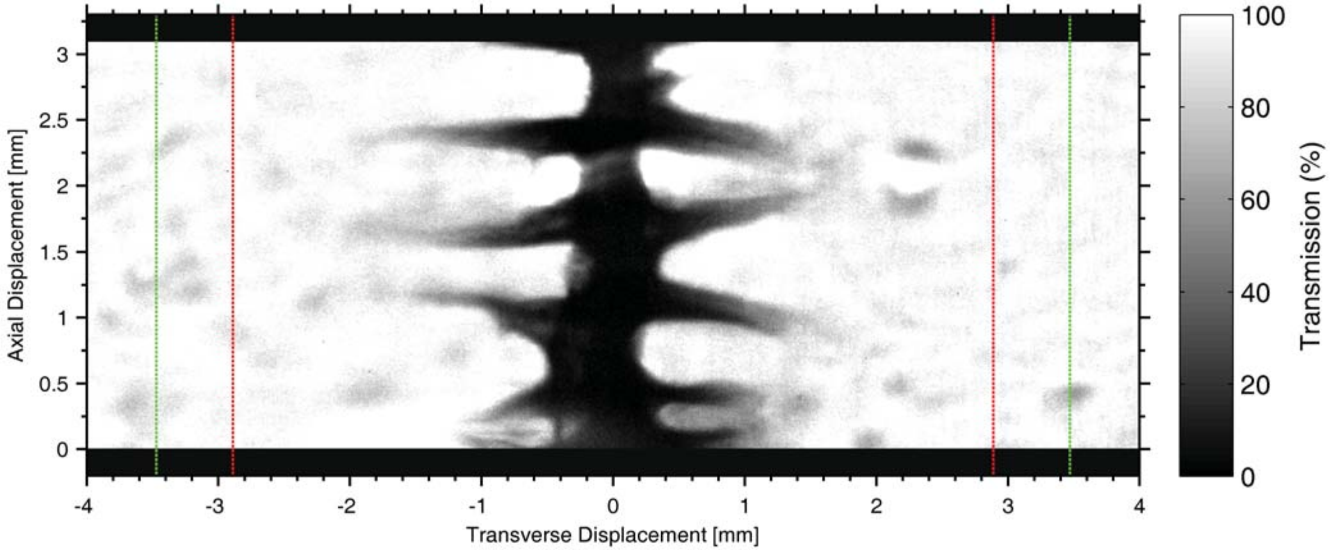
$r_{inner,0}$ = 2.89 mm



AR=6:

$r_{outer,0}$ = 3.47 mm

$r_{inner,0}$ = 2.89 mm

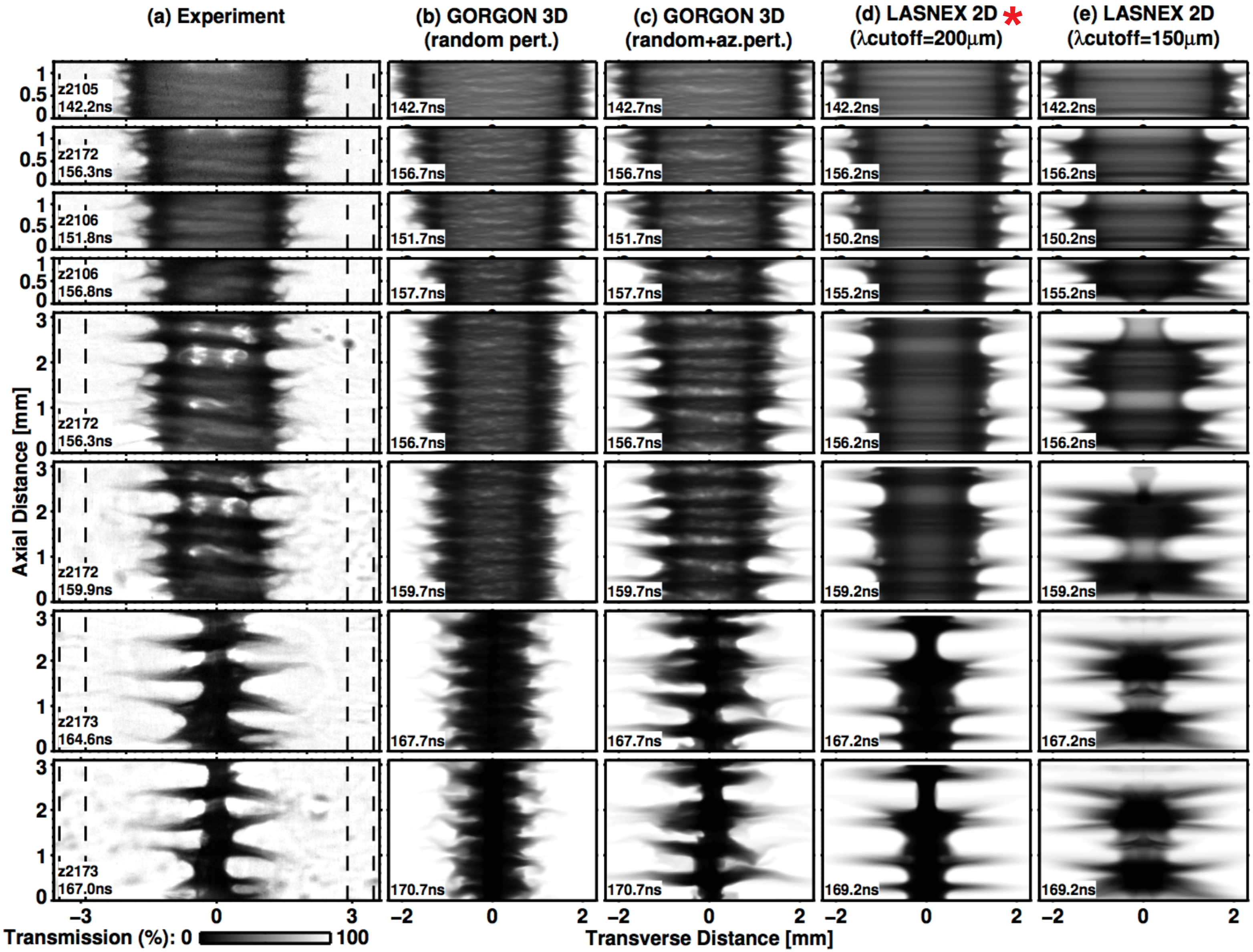


AR=6:

$r_{outer,0}$ = 3.47 mm

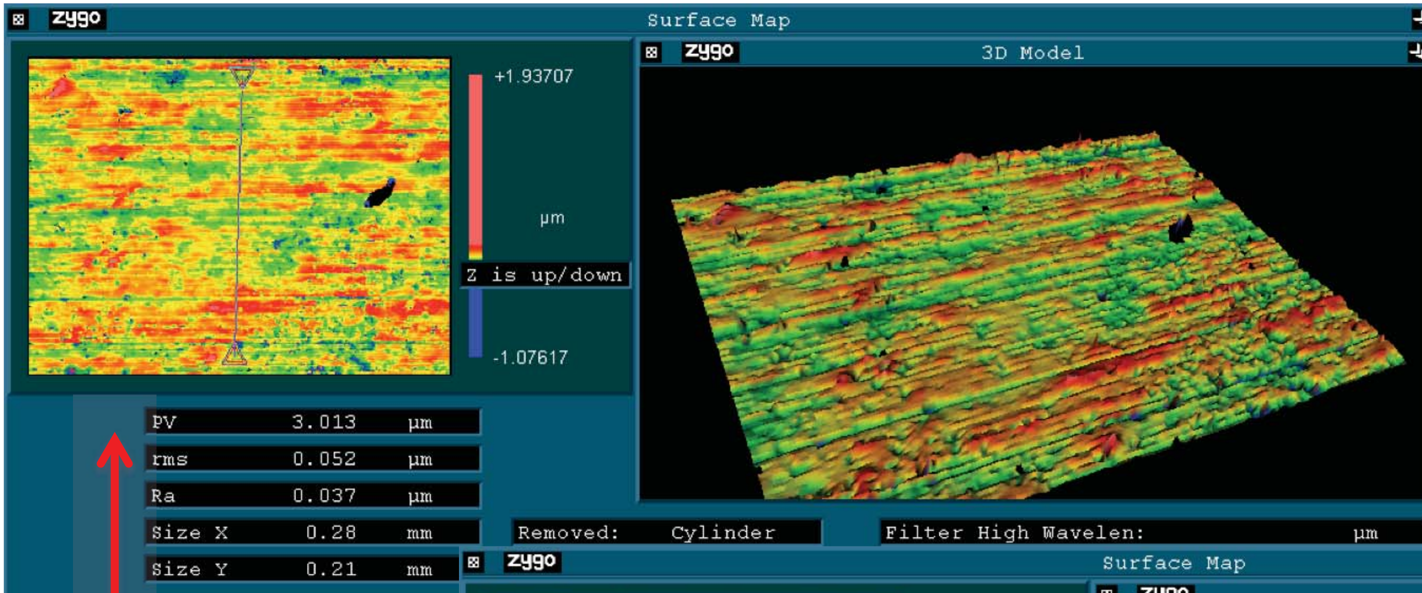
$r_{inner,0}$ = 2.89 mm

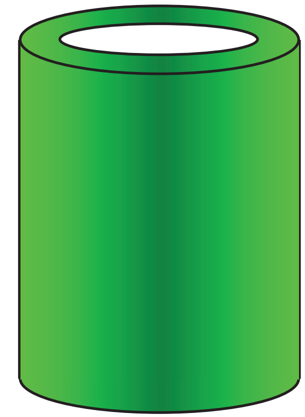
Beryllium experiments show surprisingly correlated instability growth at late times that appears to be related to the initial surface roughness



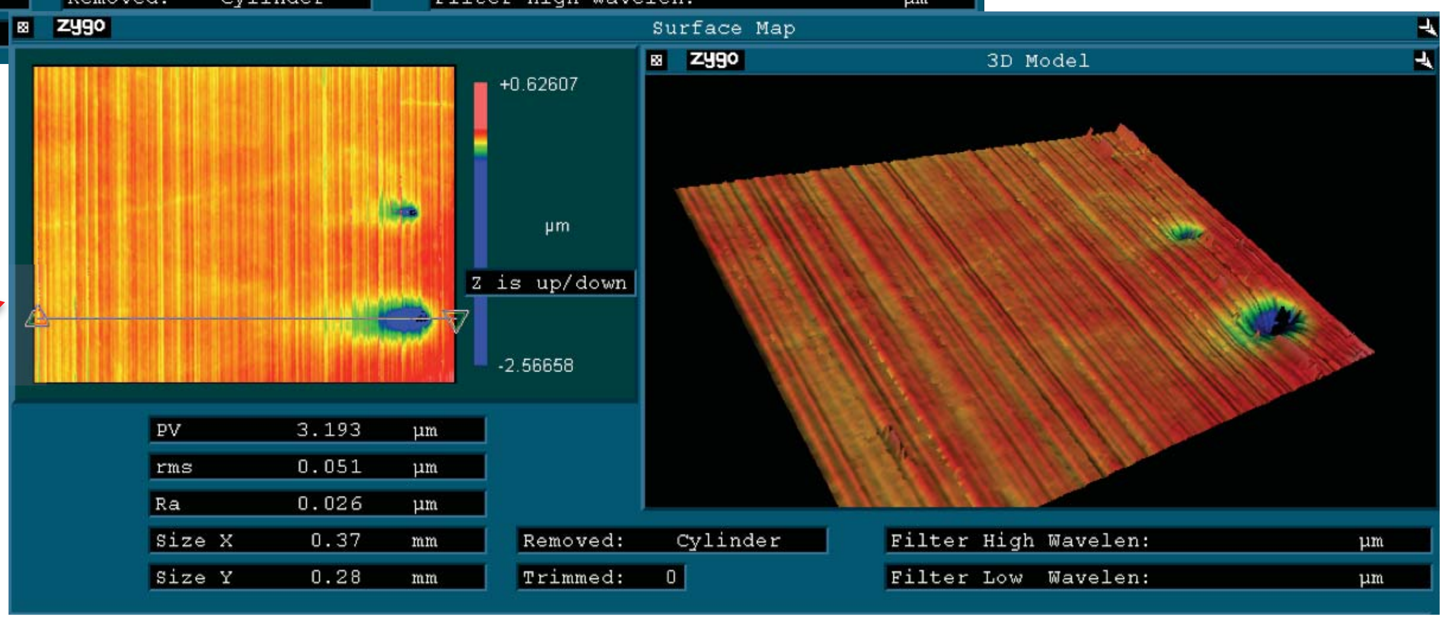
R.D. McBride *et al.*, Phys. Rev. Lett. 109, 135004 (2012).

Our liners are diamond-turned on a lathe to provide smooth surfaces, but this process leaves azimuthally-correlated tool marks





Standard process
(50 nm RMS)



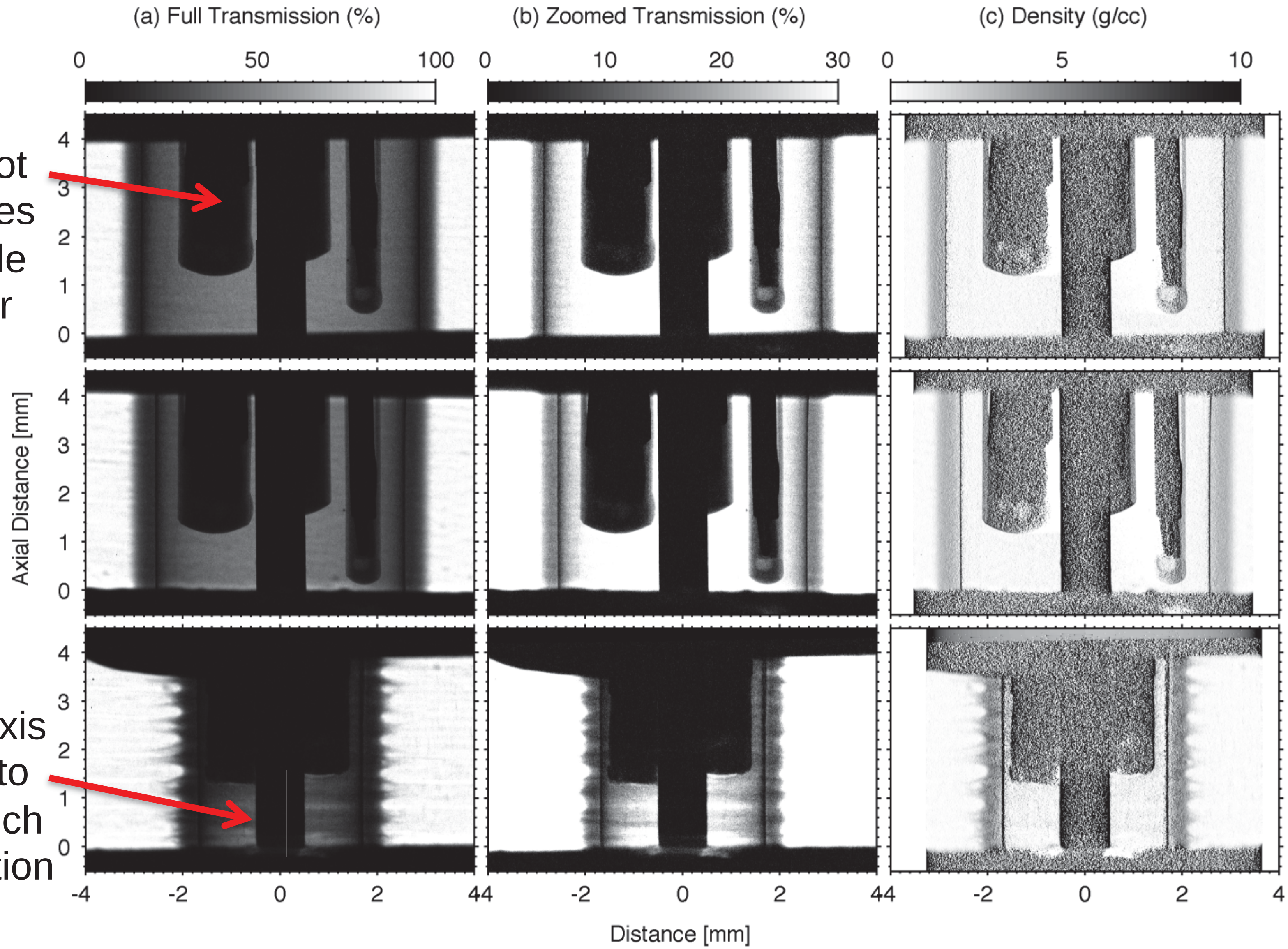
After axial polishing
process applied
(50 nm RMS)

We have just started investigating whether a different surface structure affects the results

Recent experiments used 2 μm Al just inside the Be liner to enhance the contrast of the liner's inner surface*

μBdot probes inside liner

On-axis rod to quench radiation

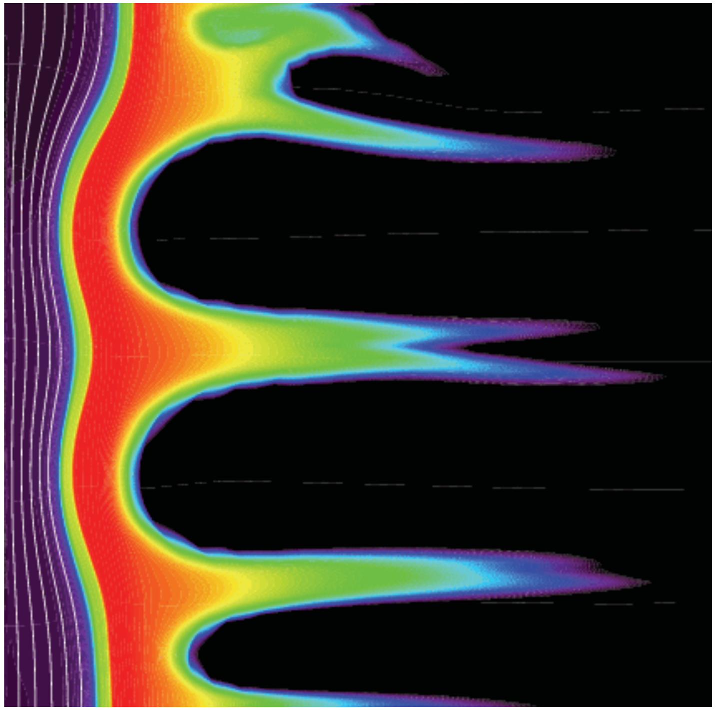


*Thin Al layer to enhance contrast suggested by D.D. Ryutov

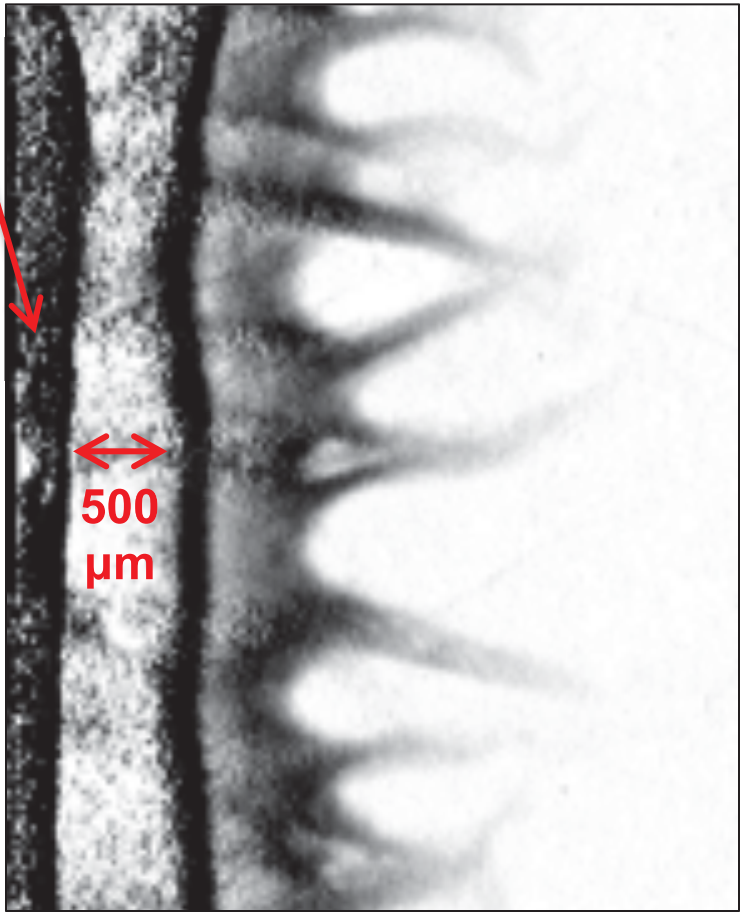
R. D. McBride et al., Phys. Plasmas **20**, 056309 (2013).

Radiographs at a convergence ratio of ~5 show remarkably good stability for inner liner surface

Note: MagLIF requires final compression to on-axis rod

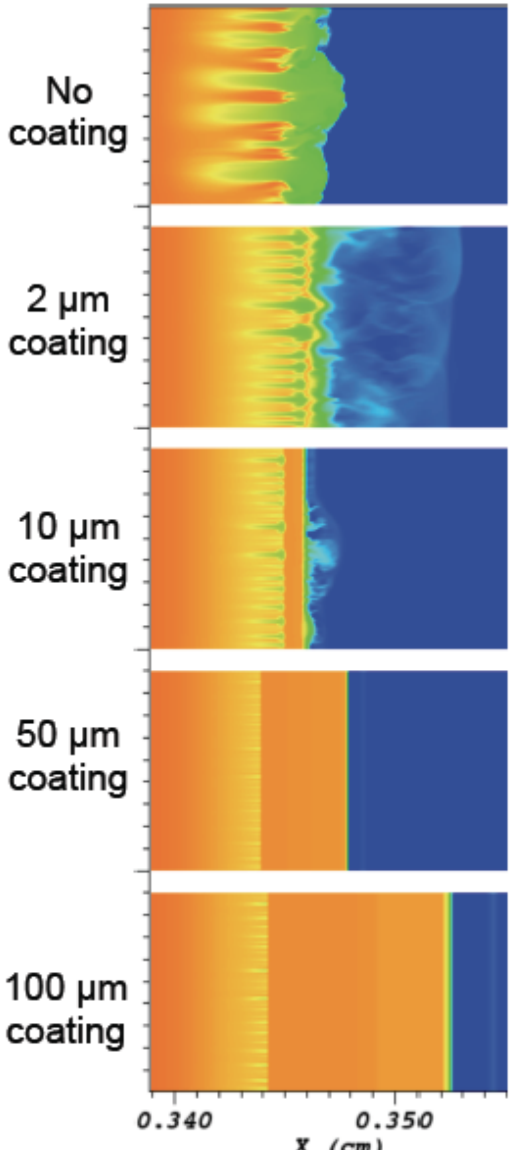


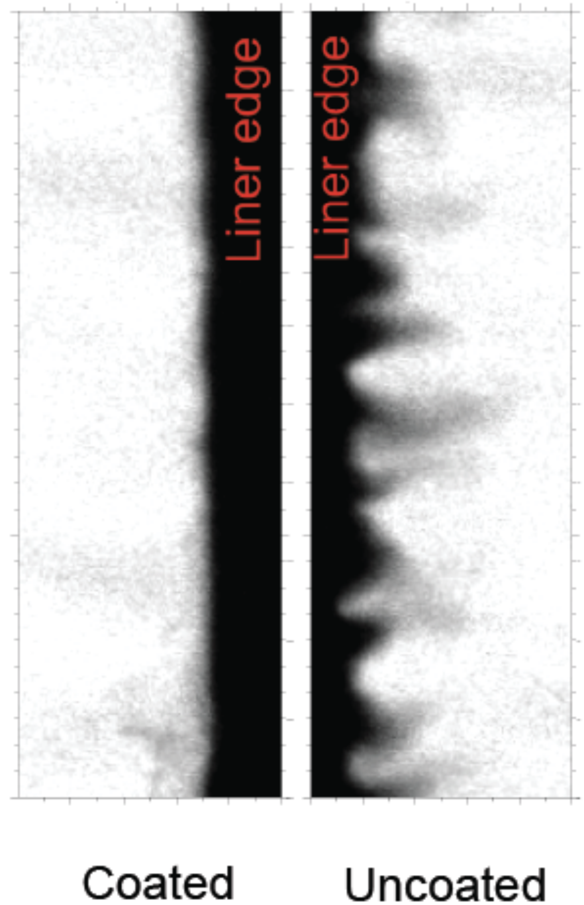
LASNEX 2D from
S. A. Slutz, *et al.*, PoP (2010)



Experiment

Relatively thick insulating coatings suppress liner instabilities that are seeded by the electro-thermal instability*

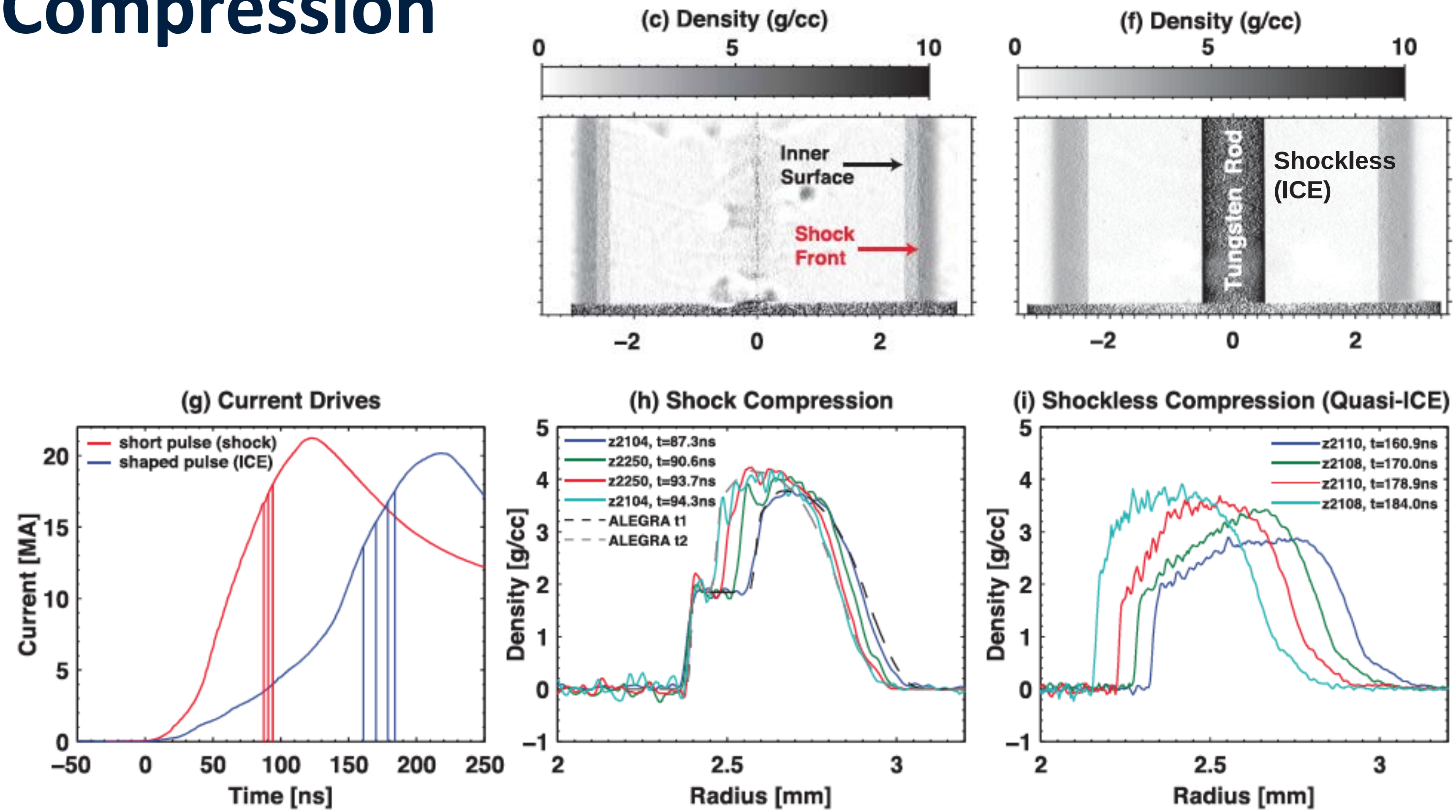




New data from K.J. Peterson *et al.*, manuscript in preparation

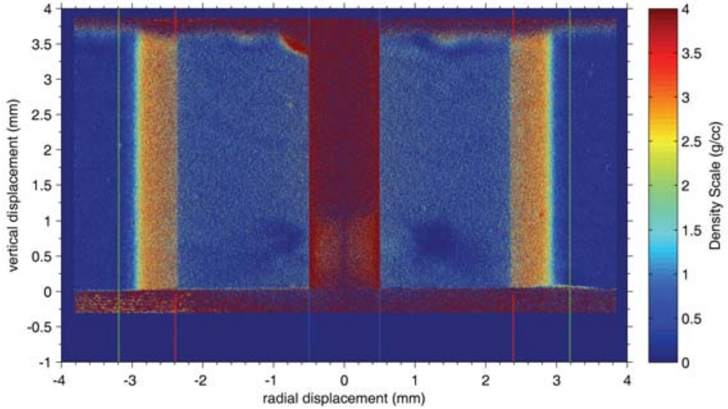
* K.J. Peterson *et al.*, Phys. Plasmas 19, 092701 (2012); K.J. Peterson *et al.*, Phys. Plasmas 20, 056305 (2013).

Shock vs. Shockless (Quasi-Isentropic) Compression



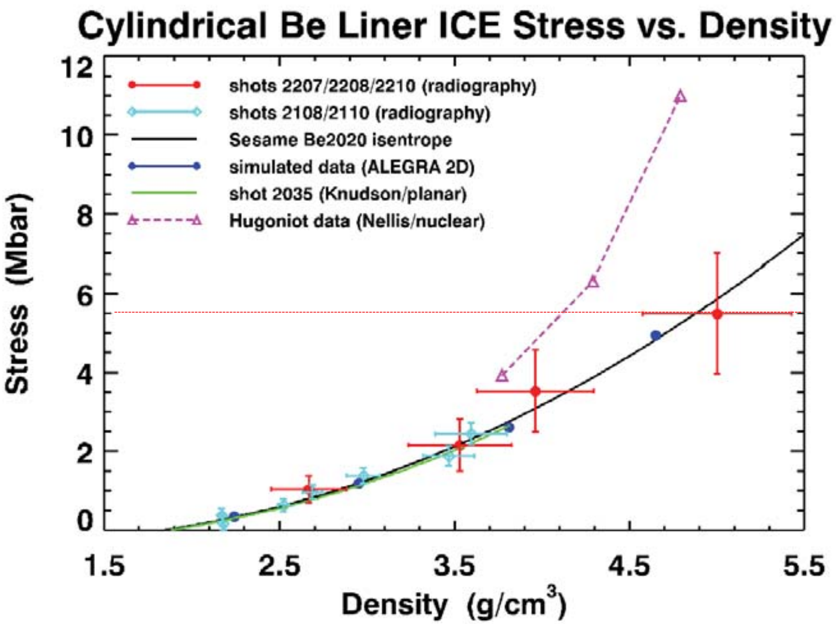
R. D. McBride et al., Phys. Plasmas **20**, 056309 (2013).

Most Recent Be ICE to >5 Mbar



$$\frac{\partial(rv)}{\partial m} = \frac{1}{2\pi}\frac{D}{Dt}\left(\frac{1}{\rho}\right),$$

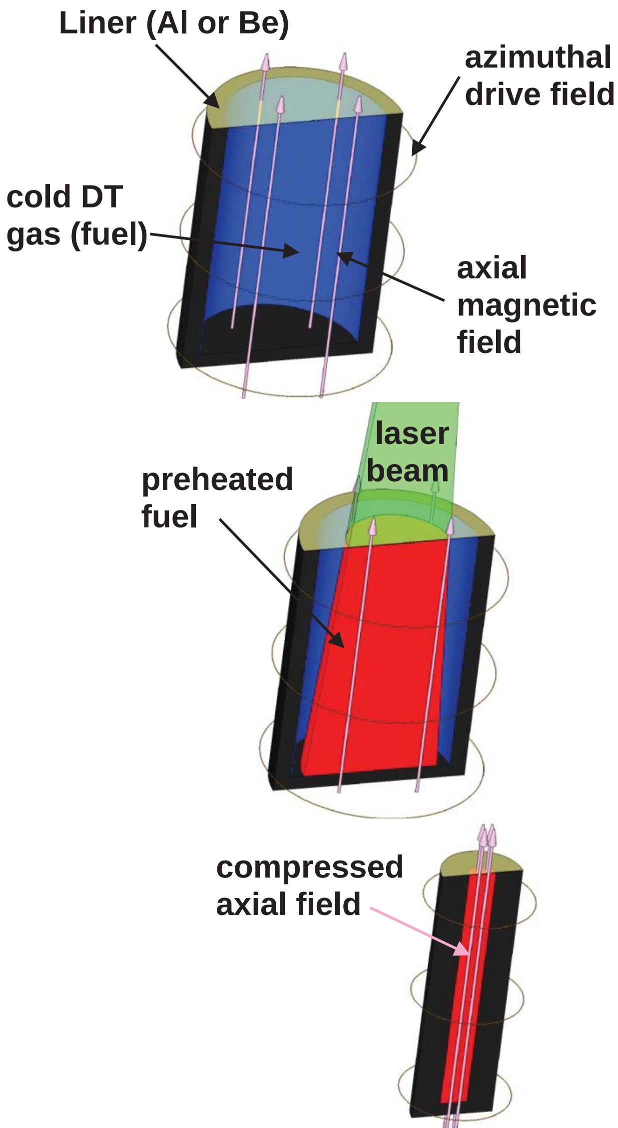
$$\frac{\partial P_T}{\partial m} = -\frac{1}{2\pi r}\frac{Dv}{Dt}.$$



EOS unfolds by
M. R. Martin

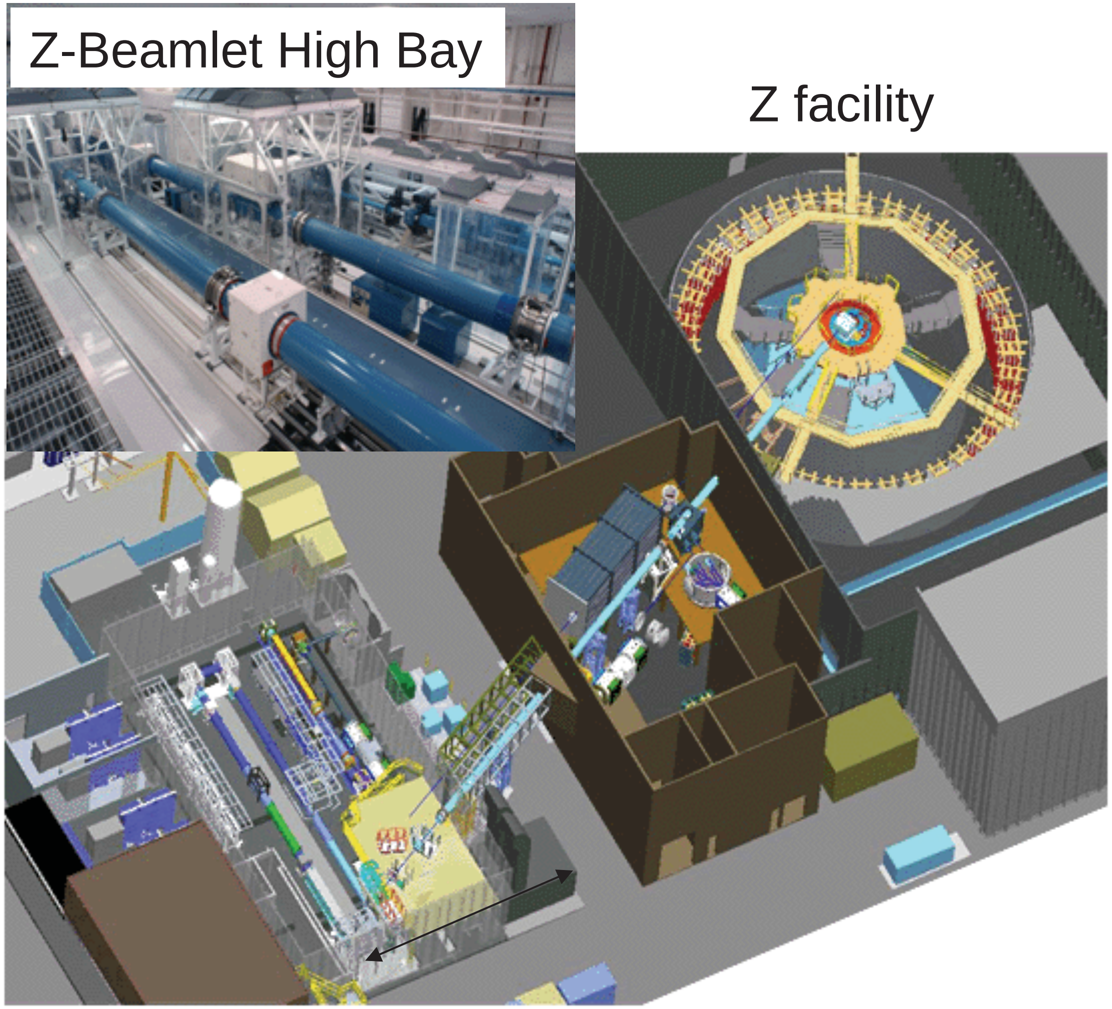
M. R. Martin, R. W. Lemke, R. D. McBride *et al.*, Phys. Plasmas **19**, 056310 (2012).

Sandia plans to address key science and engineering research questions related to MagLIF in the next 3-5 years



- Liner implosion dynamics
- Fuel preheating
- Impact of fuel magnetization
- Fuel assembly & stagnation

The Z-Beamlet laser at Sandia* can be used to radiograph liner targets and heat fusion fuel



Z-Beamlet and Z-Petawatt lasers

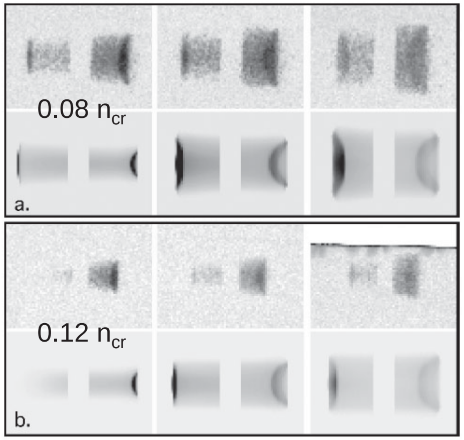
Z-Beamlet (ZBL) is routinely used to deliver ~ 2.4 kJ of 2ω light in 2 pulses for backlighting experiments on Z

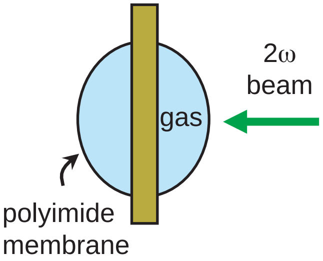
Filling out the booster amps would enable longer pulses (5-7 ns) which would extract up to 6 kJ of 1ω, for 4.2 kJ of 2ω. This energy could be used to heat fusion fuel to a few hundred eV.

This capability would be useful for both MagLIF and x-ray Thomson scattering (being developed for dynamic materials experiments)

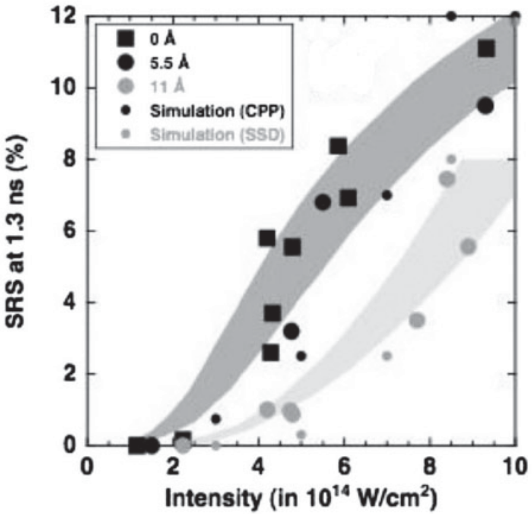
* P. K. Rambo *et al.*, Applied Optics 44, 2421 (2005).

Preheating plasmas using 2ω light seems feasible, and experimental testing on Z has begun

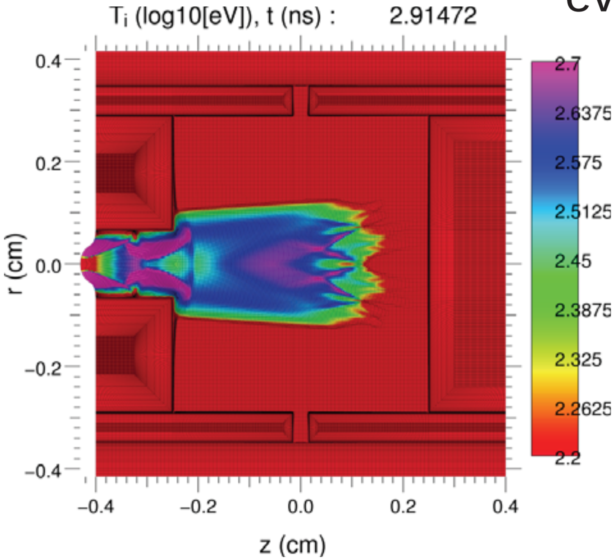




Prior work* found agreement between experiments and Hydra simulations assuming classical absorption of 2ω for n_e/n_{cr} ~ 0.05 to 0.15 gasbag targets on the HELEN Laser



Other work** showed efficient coupling of 2ω to $0.13n_{cr}$ gasbag plasmas at intensities $<3\text{x}10^{14}$ W/cm^2, even without beam smoothing

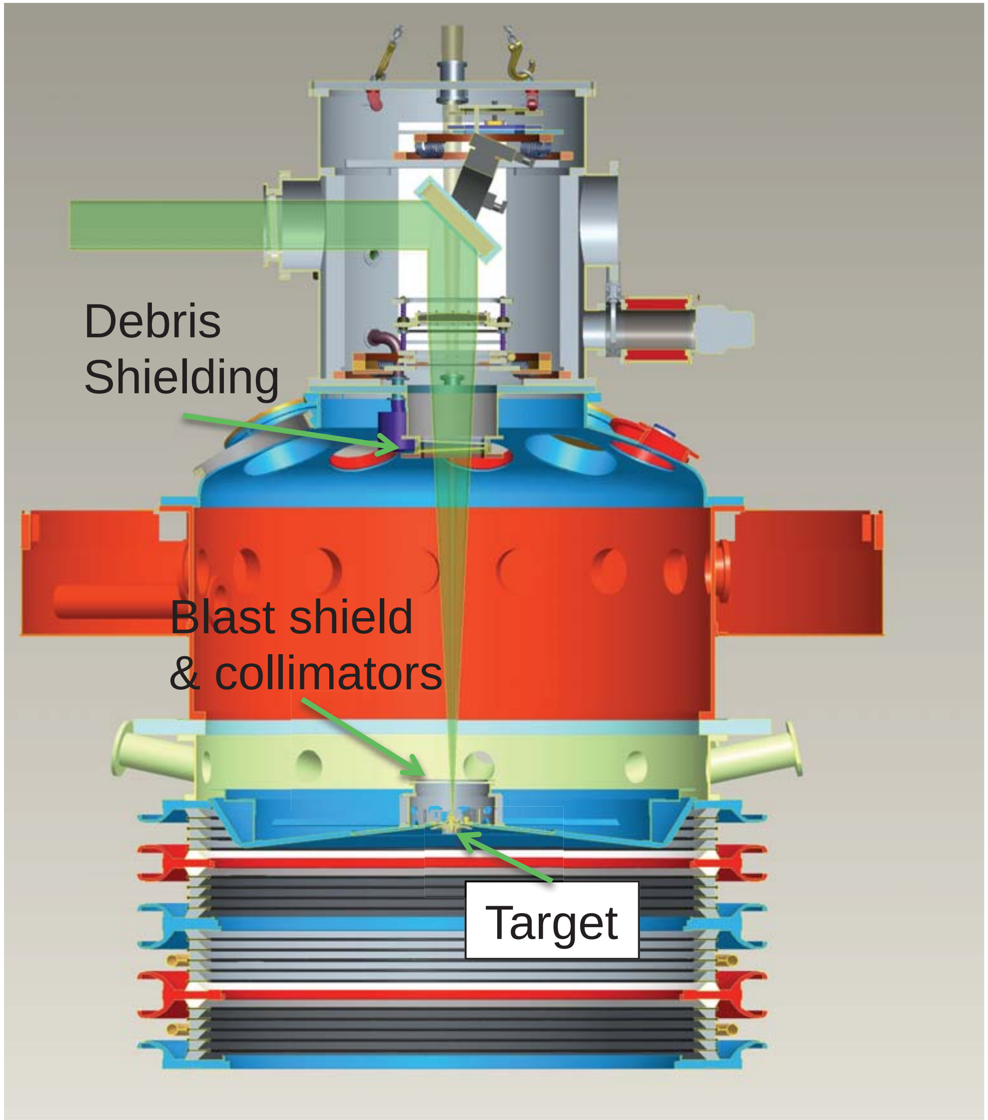


Standalone preheat experiments on Z using a 2-kJ ZBL beam have begun to test our HYDRA predictions; we are also looking at the possibility of OMEGA experiments to study heated plasma lifetimes in the presence of a magnetic field

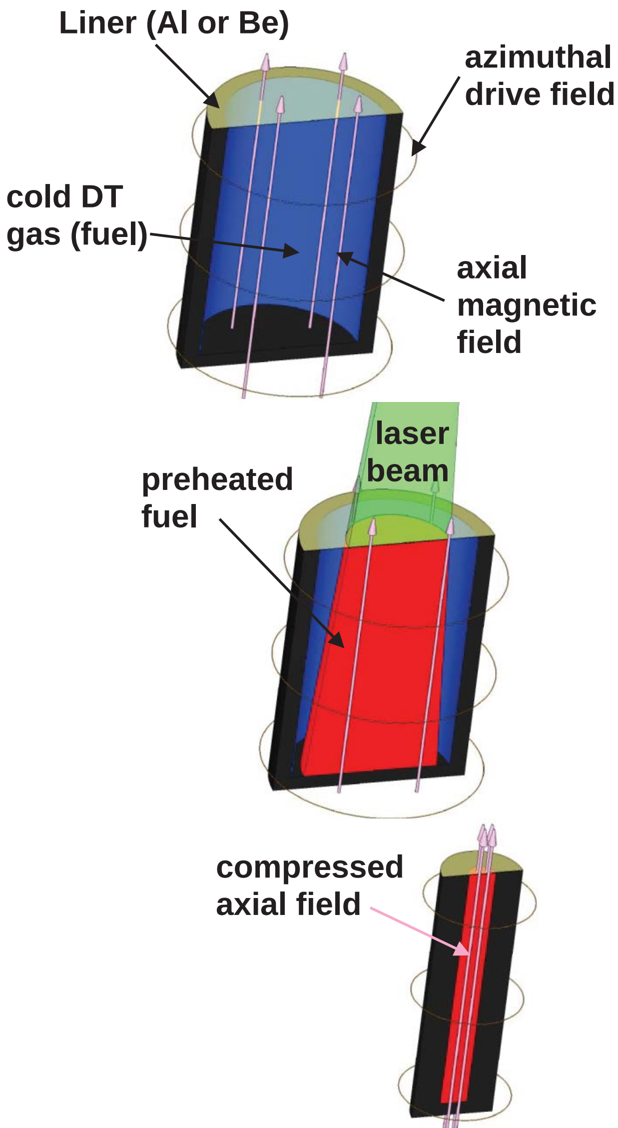
* N.B. Meezan *et al.*, Phys. Plasmas (2004); ** J.D. Moody *et al.*, Phys. Plasmas (2009).

We will begin integrating laser preheating into Z experiments in July 2013 and will continue to assess the relevant physics

- MagLIF requires laser light to be delivered on or very close to the axis
- Concern about damaging final laser optics
- We will begin testing engineering solutions to the debris concerns next month (July, 2013)

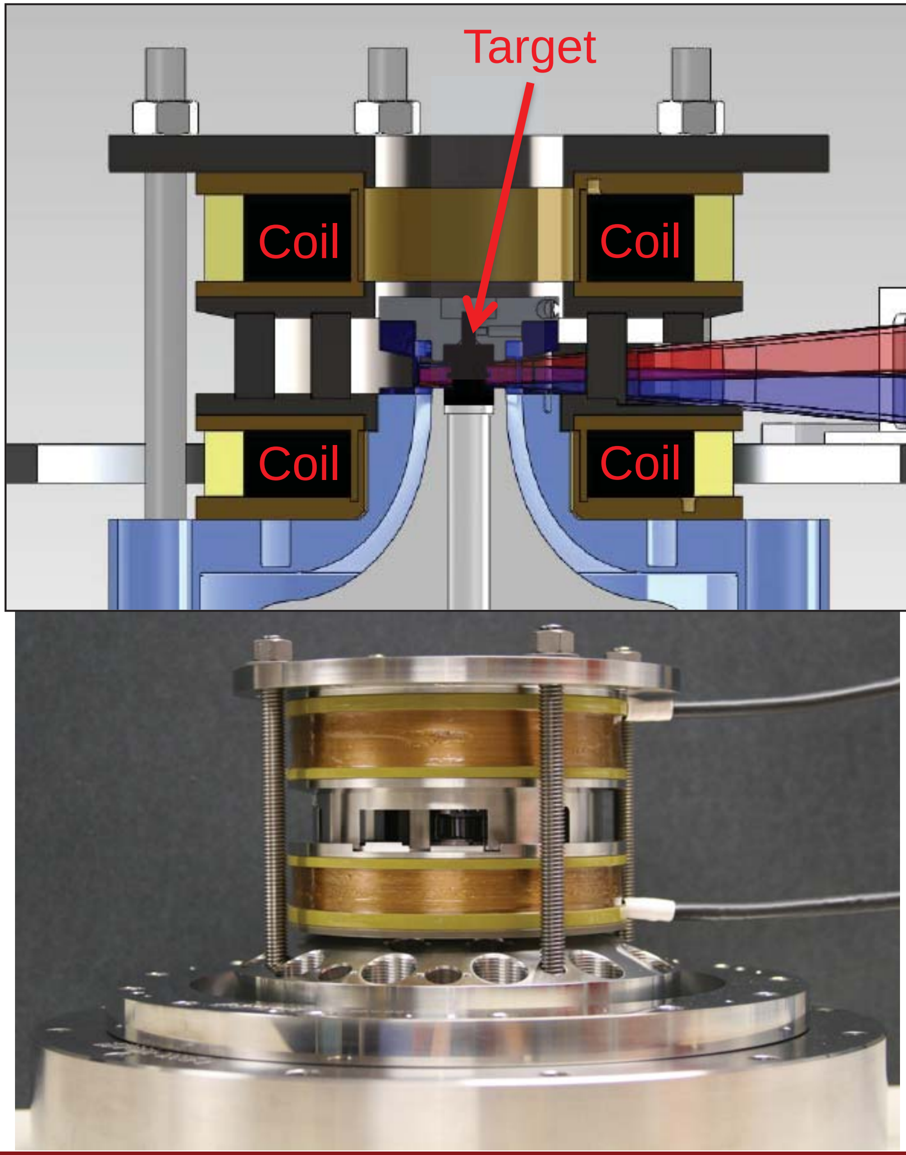


Sandia plans to address key science and engineering research questions related to MagLIF in the next 3-5 years

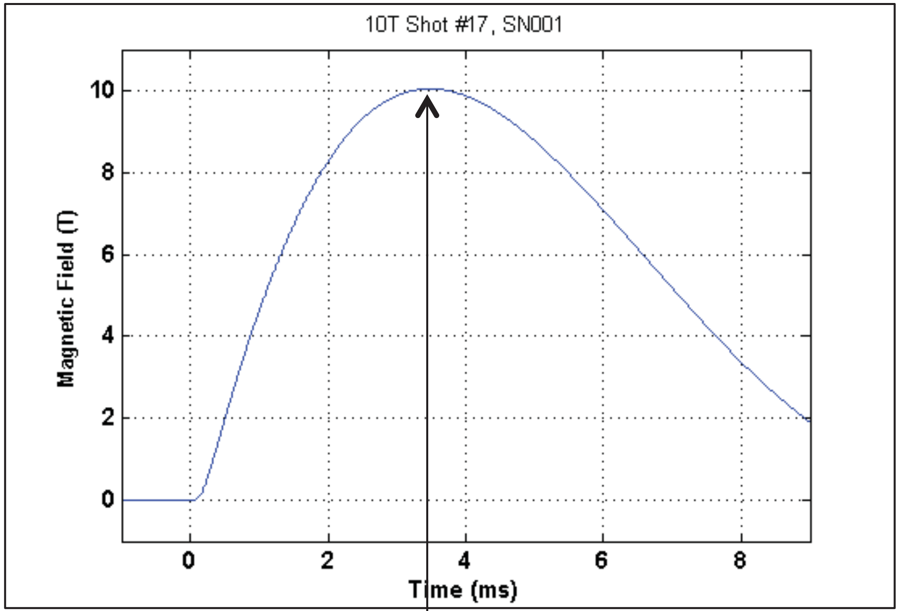


- Liner implosion dynamics
- Fuel preheating
- Impact of fuel magnetization
- Fuel assembly & stagnation

Prototype coils have been demonstrated that generate 10 T axial fields over a several cm^3 volume for MagLIF with full diagnostic access



10 Tesla point design



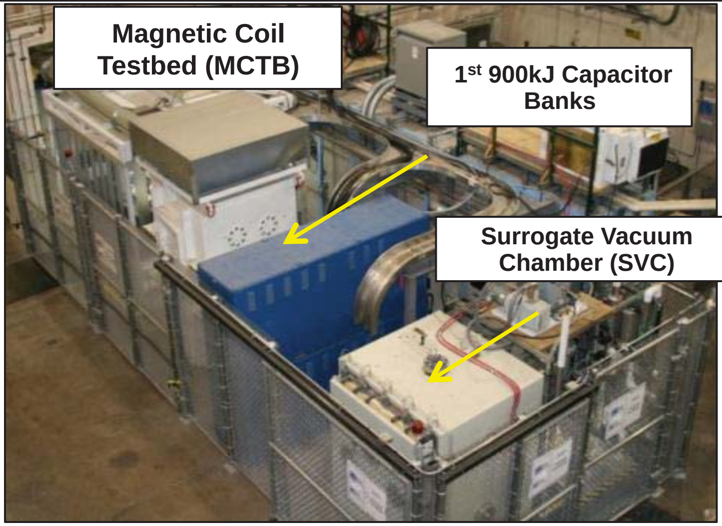
Time to peak field = 3.49 ms

Long time scale needed to allow field to diffuse through the liner without deformation

An 8 mF, 15 kV, 900 kJ capacitor bank has been installed on Z to drive the coils

- Two identical units (repurposed from ion beam facilities) allows for high-fidelity surrogacy testing in separate test facility
- We believe 900 kJ is enough to meet our short and long term goals (30 T)

The SITF Testbed in Bldg. 970

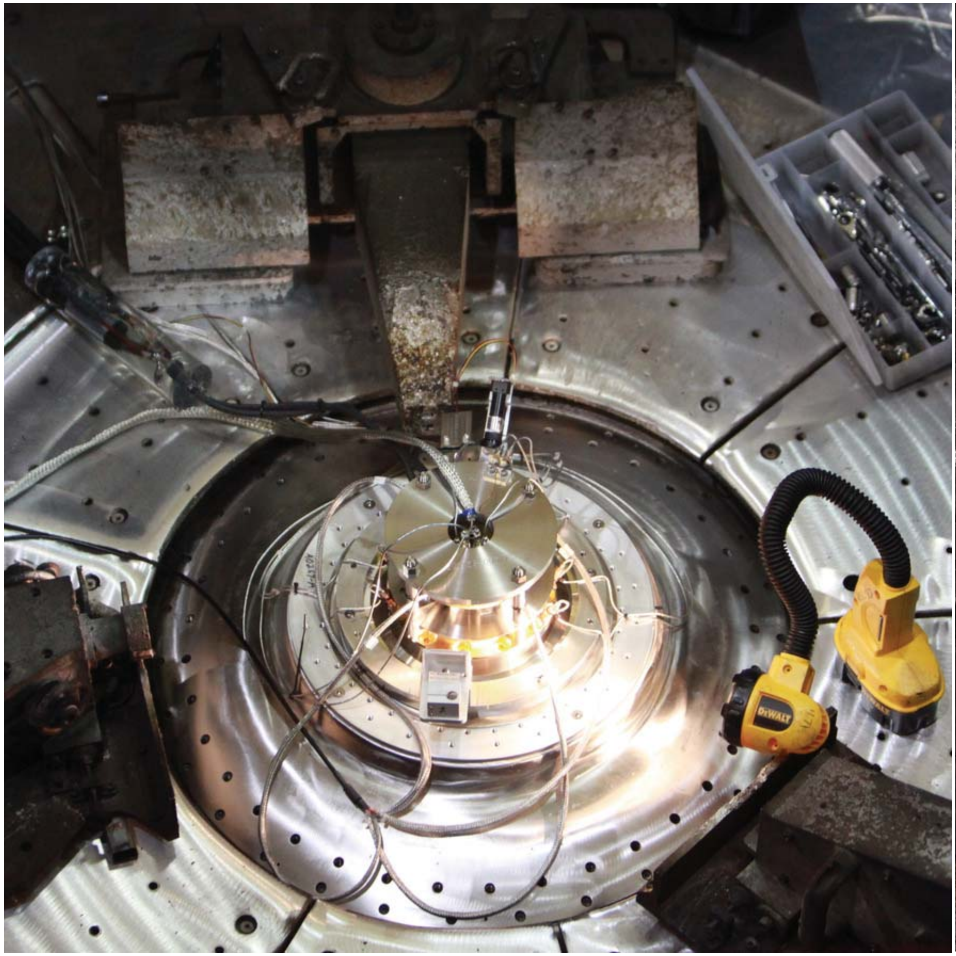


Commissioning of coils in the Z chamber completed in Feb. 2013

Photo of capacitor bank w/o covers; with covers

D.C. Rovang *et al.*, see http://www.sandia.gov/pulsedpower/maglifpres/Agenda.html

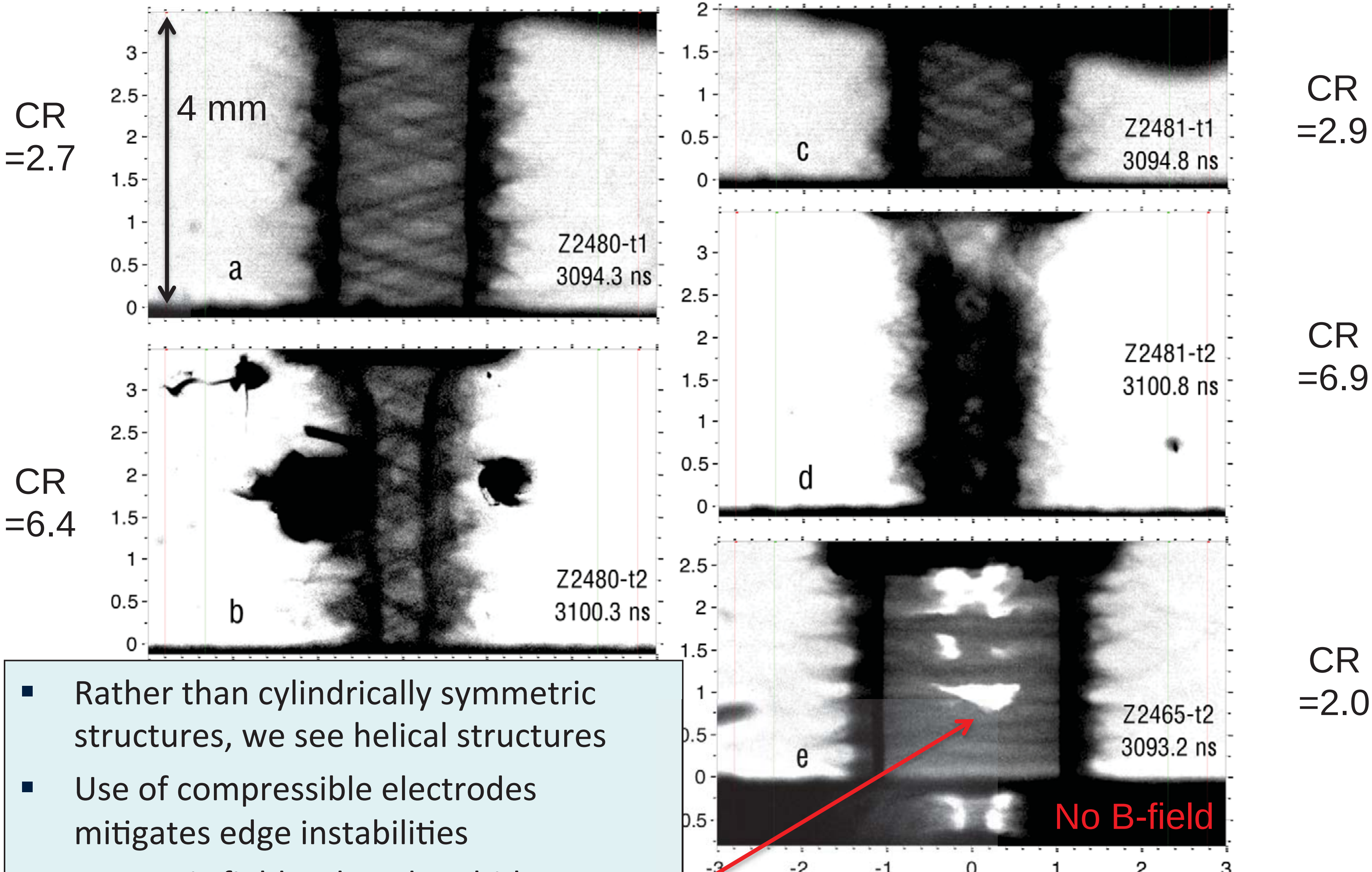
Debris from MagLIF experiments must be carefully managed (several MJ energy release equivalent to few sticks of dynamite)



Pre-shot photo of coils & target hardware

Post-shot photo

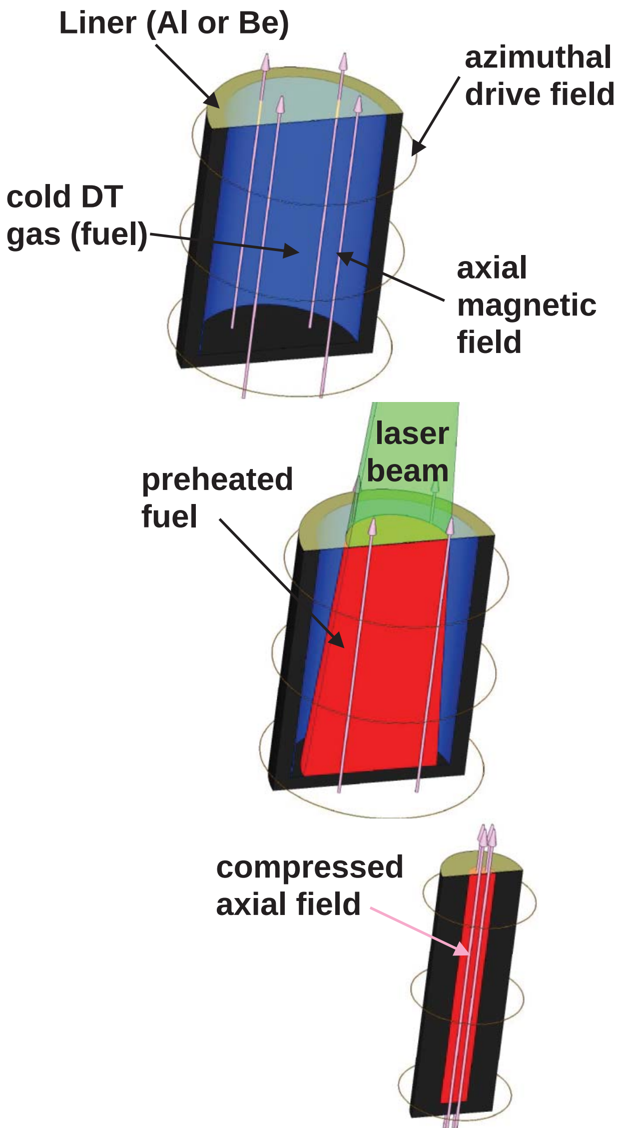
The addition of a 7-10 T axial magnetic field produces a dramatic change in the structure of the liner instabilities



- Rather than cylindrically symmetric structures, we see helical structures
- Use of compressible electrodes mitigates edge instabilities
- Magnetic field reduced multi-keV x rays associated with late-time instabilities

T. J. Awe *et al.*, manuscript in preparation (2013).

Sandia plans to address key science and engineering research questions related to MagLIF in the next 3-5 years



- Liner implosion dynamics
- Fuel preheating
- Impact of fuel magnetization
- Fuel assembly & stagnation

We plan to apply the extensive suite of neutron and spectroscopy diagnostics on Z to measure the stagnation conditions created by MagLIF targets

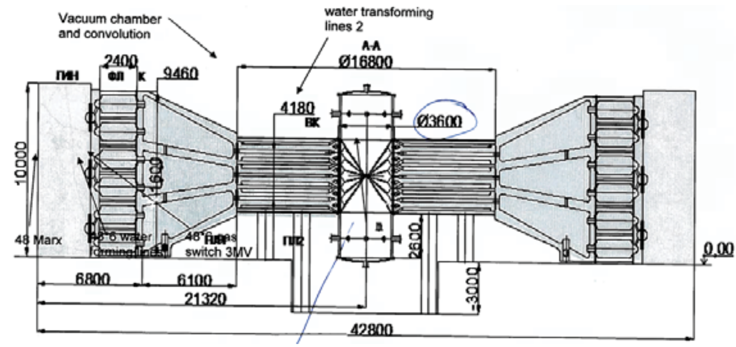
- MagLIF is predicted to produce significant yield on Z at pressures of only ~5 Gbar—want to diagnose the plasma conditions and not just measure a neutron yield
  - Numerous x-ray spectroscopy diagnostics developed for ICF and Science campaigns can help assess electron temperature and density
  - ICF program already has extensive experience with neutron yield, nTOF, and imaging diagnostics
  - Nonetheless, diagnosing some conditions at stagnation (e.g., magnetic field strength) would require new capabilities due to the small spatial and time scales
- We have made substantial progress in these areas on Z as part of other work, and we are also benefiting from the experiences and diagnostics developed on NIF

We should be able to evaluate the promise of magnetized liner inertial fusion in the next 3 years

Sandia National Laboratories

- Magnetic field coil capability was commissioned in February 2013
- Laser preheating capability to be commissioned in July 2013
- First integrated MagLIF experiments planned for August 2013 using existing capabilities (10 T, 2 kJ preheat, 16-18 MA, D2 fuel)
- Already working on improvements to reach conditions needed for MagLIF (e.g., 30 T, 6 kJ preheat, ~25 MA)
- Magnetic fields are ubiquitous in nature and HEDP experiments, and are of increasing interest worldwide

Baikal (Russia) 50 MA, 150 ns



Primary Test Stand (China)
7.2 MJ, 8-10 MA, 90 ns rise

U. Rochester LLE