SAND2012-3893 C

SAND2012-3893C

Sandia National Laboratories

30 January 2011

Pulsed Power Fusion Targets

Mark C. Herrmann, Mike Cuneo

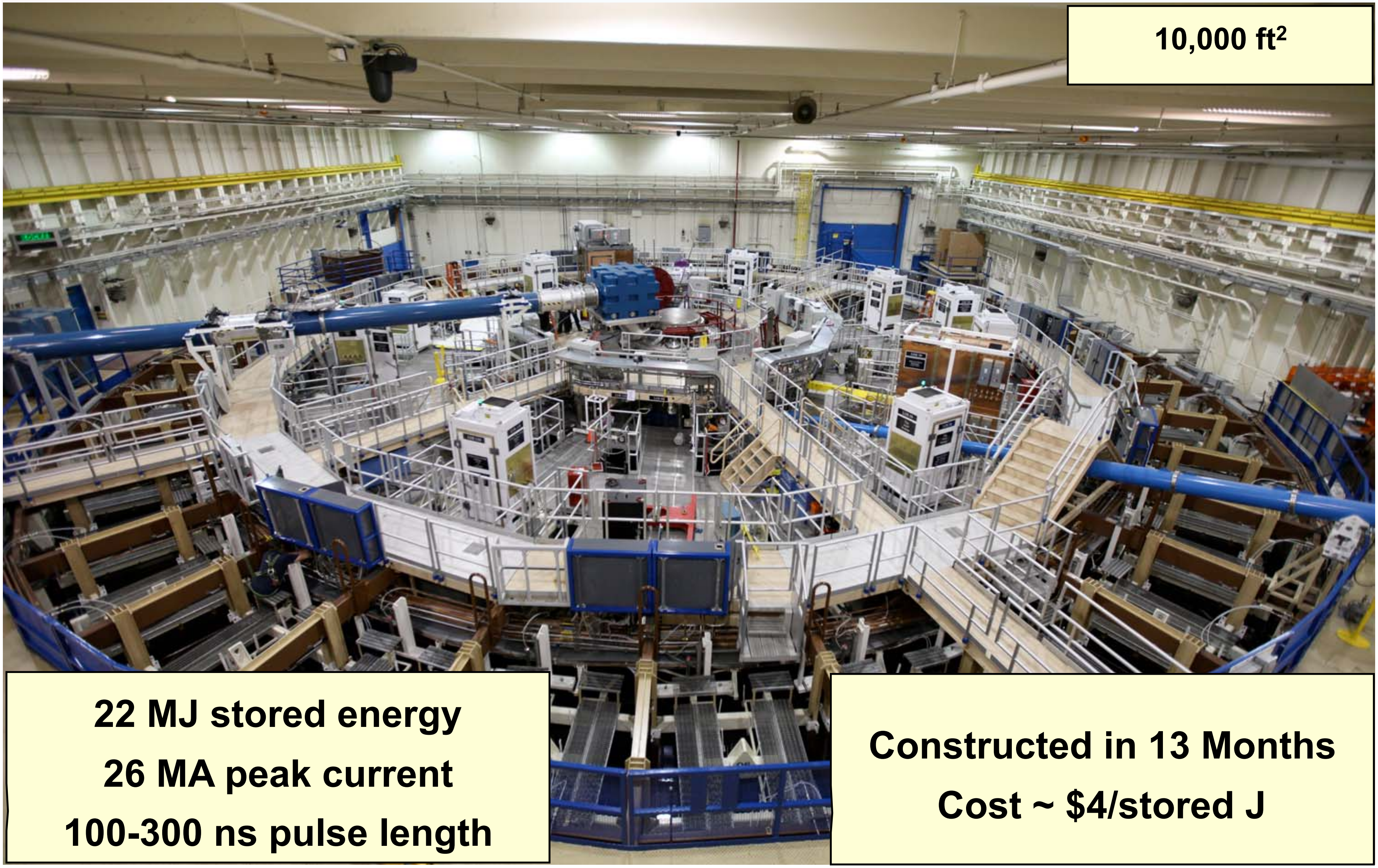
Pulsed Power Sciences Center, Sandia National Laboratories

in collaboration with our colleagues at Sandia National Laboratories

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.

Sandia National Laboratories

The Z pulsed power generator provides a compact MJ-class target physics platform



10,000 ft^2

22 MJ stored energy
26 MA peak current
100-300 ns pulse length

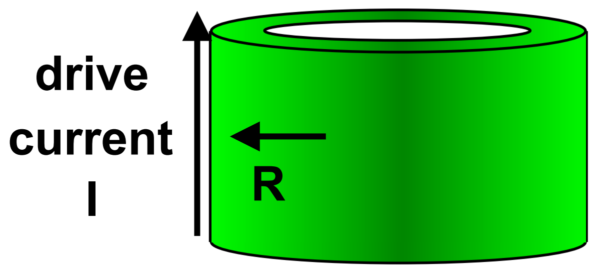
Constructed in 13 Months
Cost ~ $4/stored J

Large currents and the corresponding magnetic fields can efficiently create high energy density matter

Magnetic fields and currents can push conductors around:

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u}\right) = \frac{\mathbf{J}\times\mathbf{B}}{c} - \nabla P = \frac{1}{4\pi}\mathbf{B}\bullet\nabla\mathbf{B} - \nabla\left(P + \frac{B^2}{8\pi}\right)$$

Magnetically-Driven Implosion



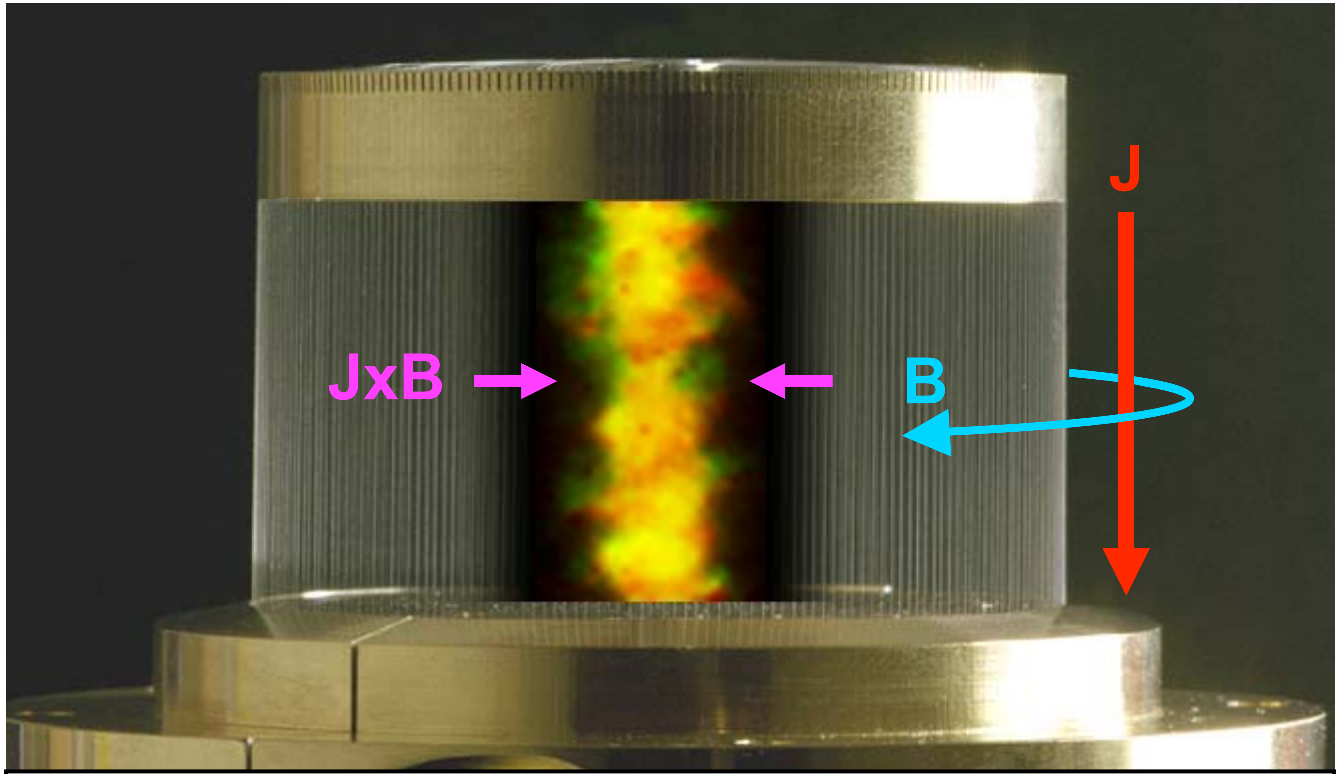
$$B \sim \frac{I}{R} \qquad P \sim B^2 \sim \left(\frac{I}{R}\right)^2$$

100 MBar at 26 MA and 1 mm

- **Magnetic drive can reach very high drive pressures if current reaches small radius**
- **Magnetic drive is very efficient at coupling energy (no energy wasted on ablation)**

Sandia National Laboratories

Wire array Z-pinches efficiently radiate soft x-rays



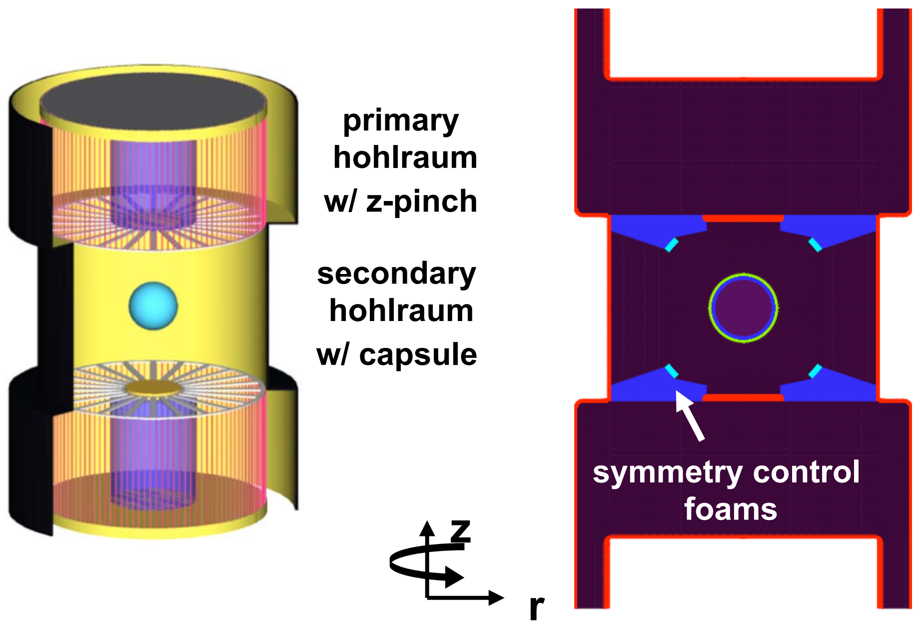
P_{rad} ~ 330 TW, Y_{rad} ~ 2 MJ

> 10% wall plug efficiency

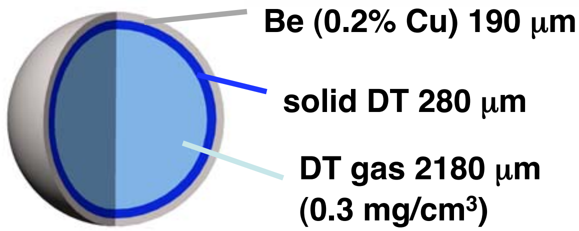
Integrated LASNEX simulations demonstrate 400+ MJ fusion yield in a pulsed-power z-pinch driven hohlraum

Double z-pinch hohlraum fusion concept

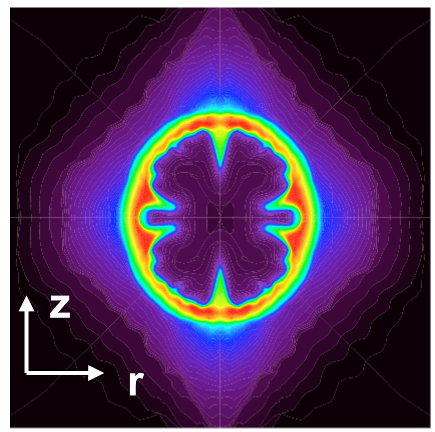
R. A. Vesey, M. C. Herrmann, R. W. Lemke *et al.*,
Phys. Plasmas (2007)



High yield capsule design



Fuel density at ignition

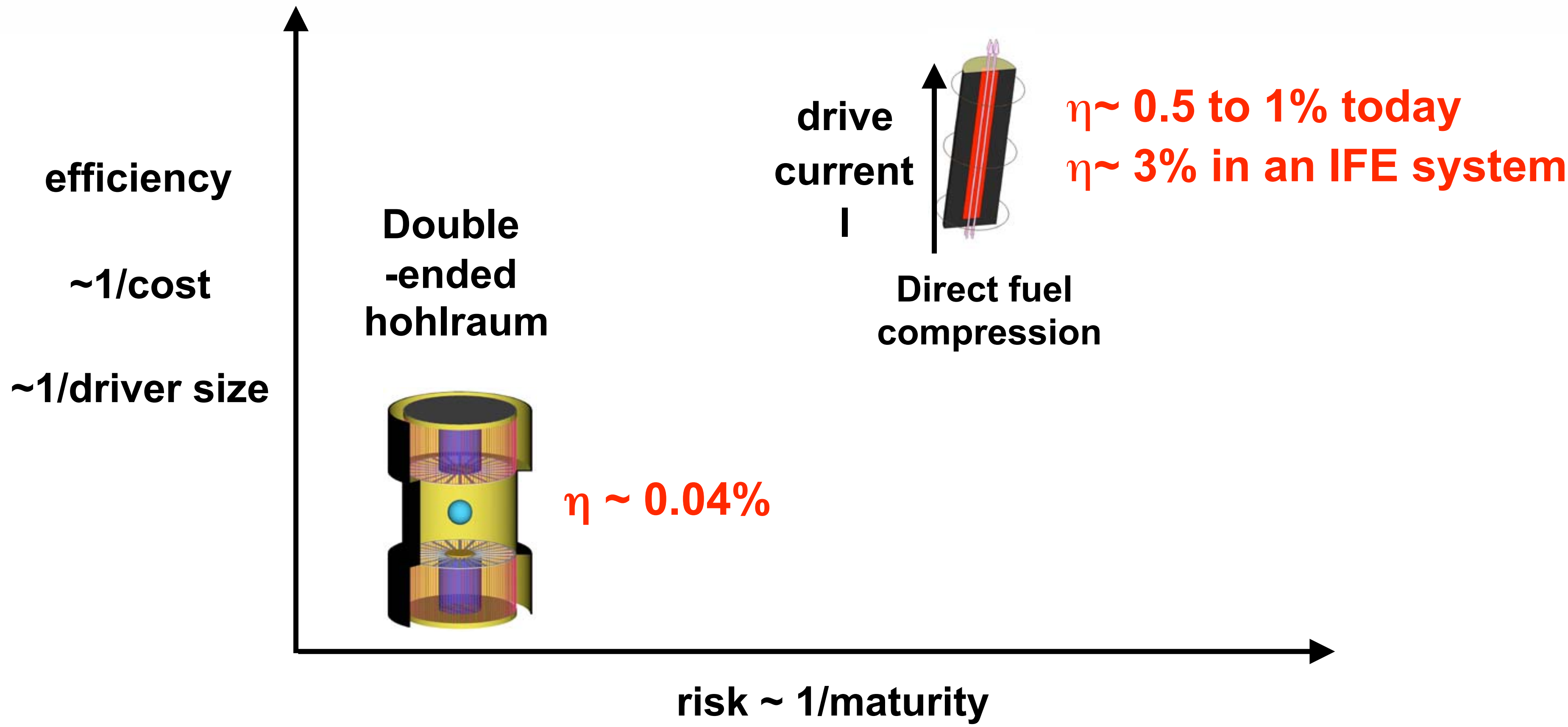


1D capsule yield 520 MJ
2D integrated yield 470 MJ

Inefficiencies lead to only 0.04% of the driver wall plug energy in the fusion fuel

Sandia National Laboratories

Direct fuel compression and heating with the magnetic field could be 25X more efficient than indirect-drive

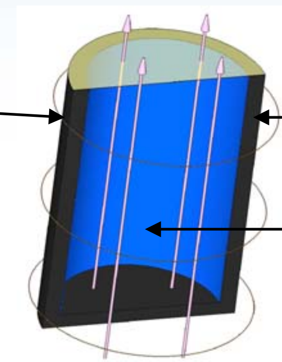


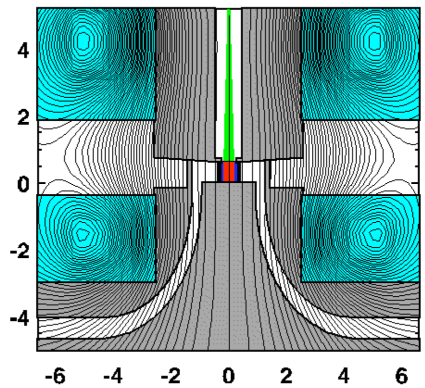
- A near term directly driven concept we can test is Magnetized Liner Inertial Fusion
- Other High Yield/ High Gain concepts are also being explored

The Z facility provides a unique opportunity to test the Magnetized Liner Inertial Fusion (MagLIF) concept

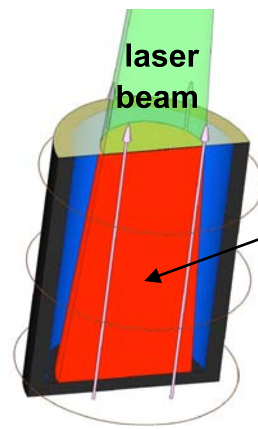
1. A 10-30T axial magnetic field

is applied to inhibit thermal conduction and enhance alpha particle deposition before the implosion begins

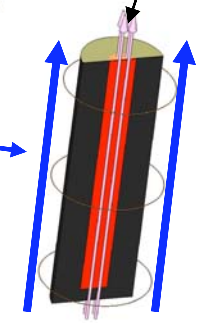




2. Z Beamlet can preheat the fuel to ~100 - 1000 eV to reduce the require compression needed



3. The Z accelerator can provide the drive current which generates an azimuthal drive field (pressure) to efficiently implode the liner (Z pinch) at 50-100 km /sec and compress the axial field by factors of 1000



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

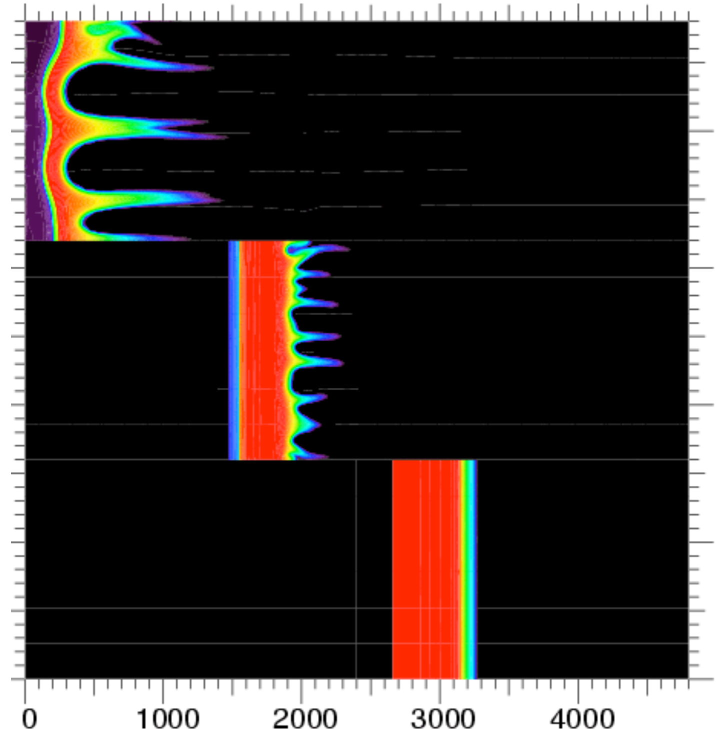
Sandia National Laboratories

Simulations indicate scientific breakeven (fusion energy out = energy deposited in fusion fuel) may be possible on Z

INITIAL CONDITIONS	
Peak Current:	27 MA
Be Liner R0:	2.7 mm
Liner height:	5 mm
Aspect ratio (R0/ΔR):	6
Initial gas fuel density:	3 mg/cc
Initial B-field:	30 T

FINAL CONDITIONS	
Energy in Fusion Fuel	~200 kJ
Target Yield:	500 kJ
Convergence ratio (R0/Rf):	23
Final on-axis fuel density:	0.5 g/cc
Peak avg. ion temperature:	8 keV
Final peak B-field:	13500 T
Peak pressure:	3 Gbar

60 nm surface roughness,
80 (μm) waves are resolved



2D yield for a DT target ~ 350 kJ (70% of 1D)

The magneto-Rayleigh Taylor instability is the biggest concern for this concept

Sandia National Laboratories

The physics issues for direct magnetic-drive targets are similar to those for other inertial fusion concepts

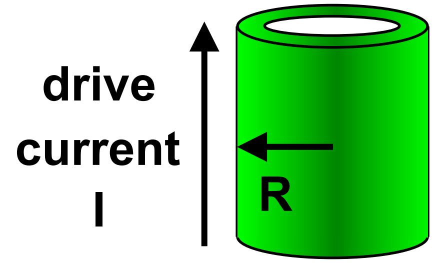
Stabilization techniques

Instability growth

Fuel Preheat

Convergence ratio

Fuel Premagnetization



Implosion time and velocity

Driver coupling

Pusher adiabat

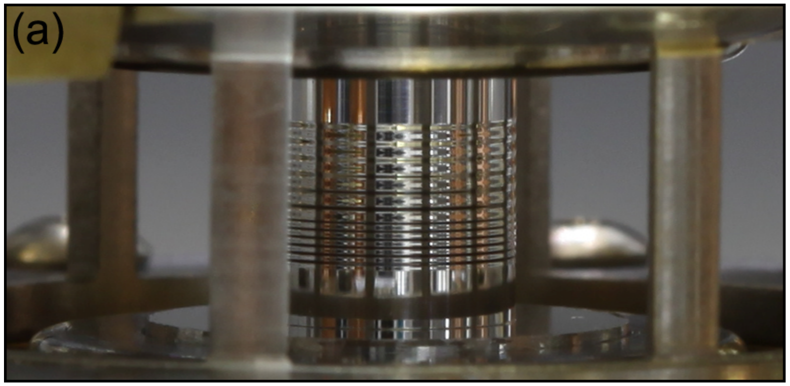
Pusher-fuel mix

r-θ symmetry

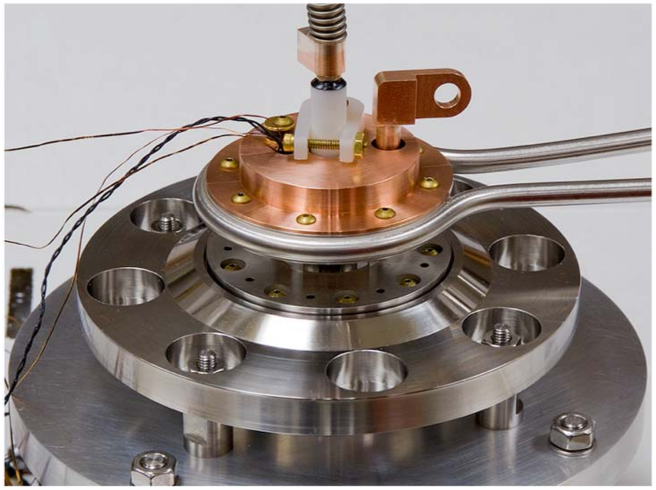
- We are conducting a vigorous research program to validate the general class of magnetically-driven targets on the Z facility at the MJ target scale

Sandia National Laboratories

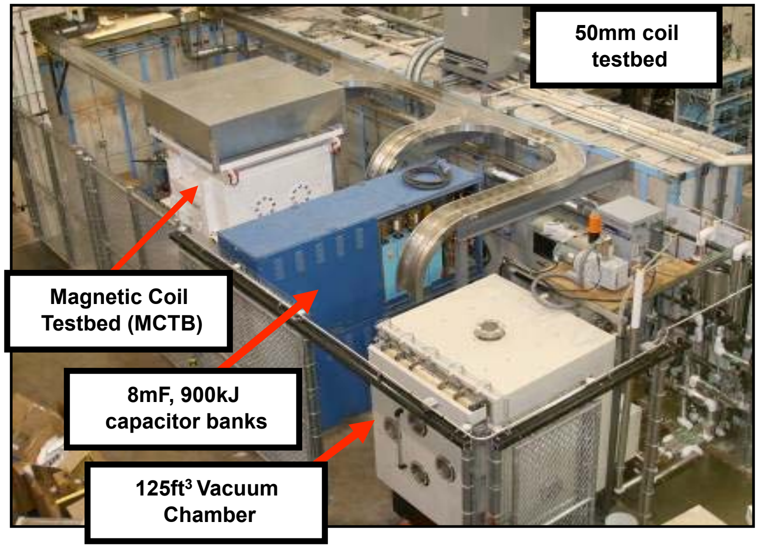
We have already developed most of the capabilities required to test MagLIF on the Z facility, rest are imminent



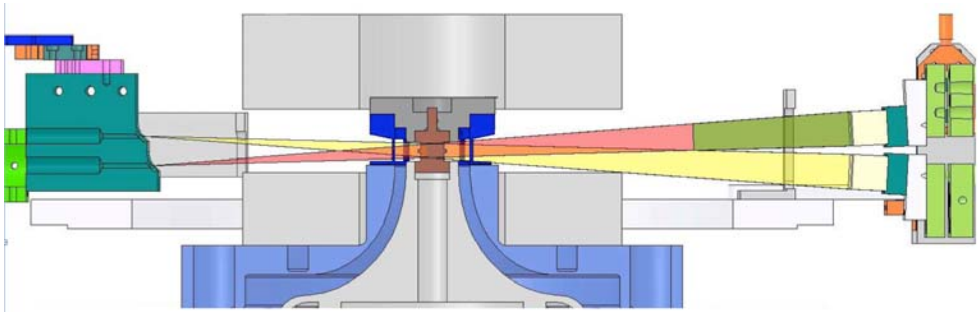
High-quality target fabrication on site



Cryogenic cooling of liner targets has been demonstrated (liquid D2)



Test facility for coil development on site

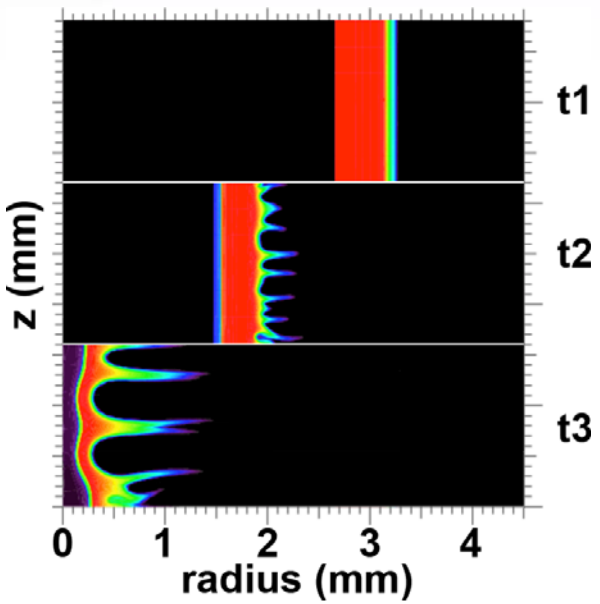


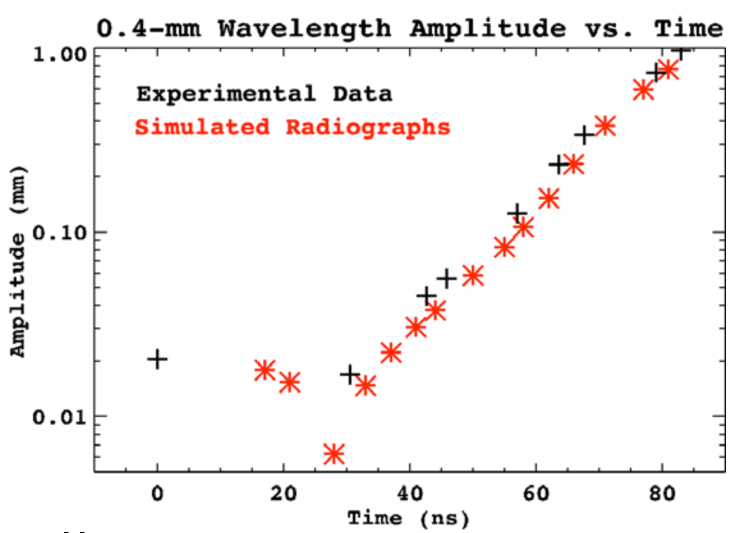
10 T coil designs allowing diagnostic access on Z will be tested

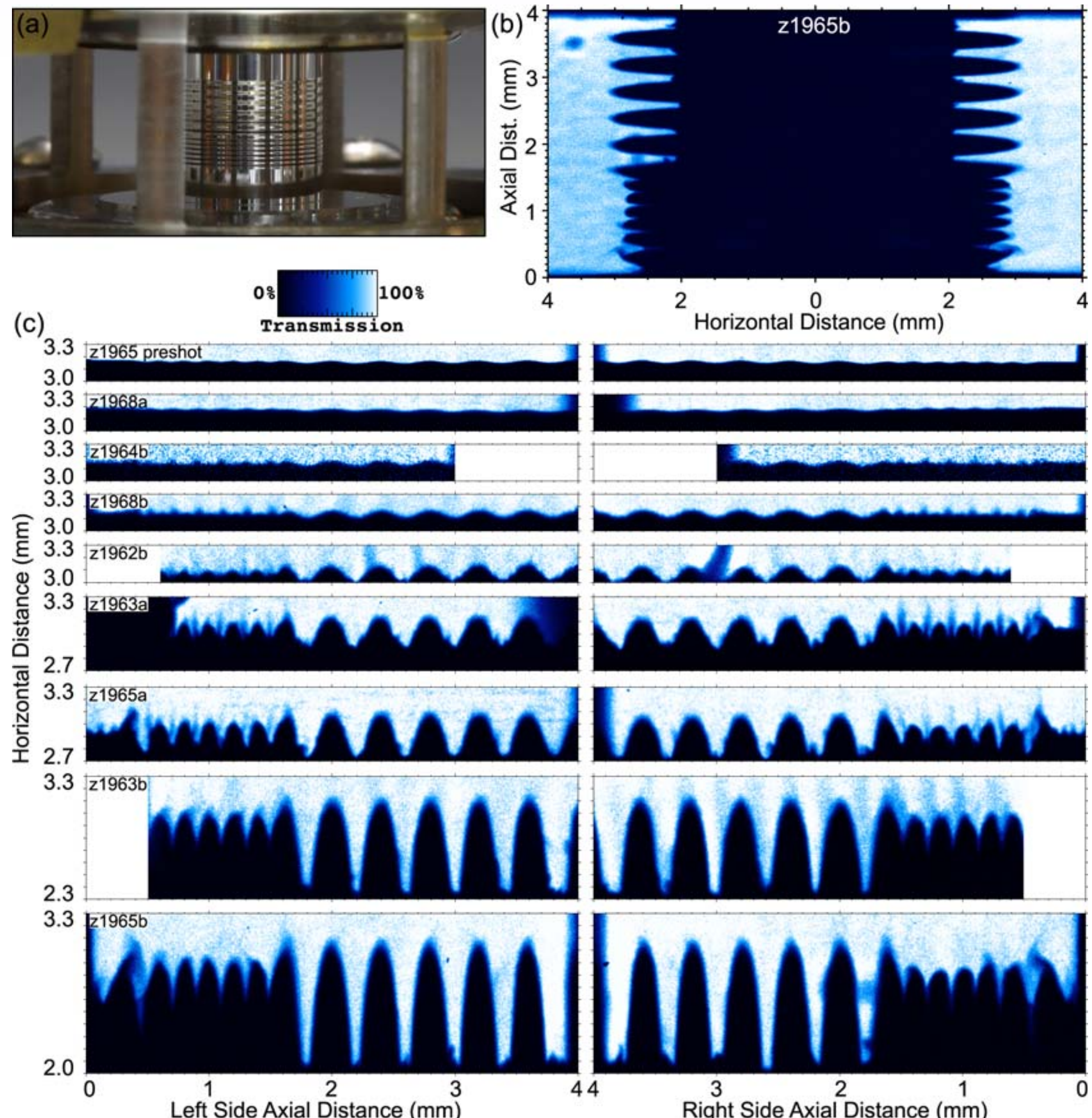
Sandia National Laboratories

D. Sinars, S. Slutz *et al.*, Phys. Rev. Lett. (2010)

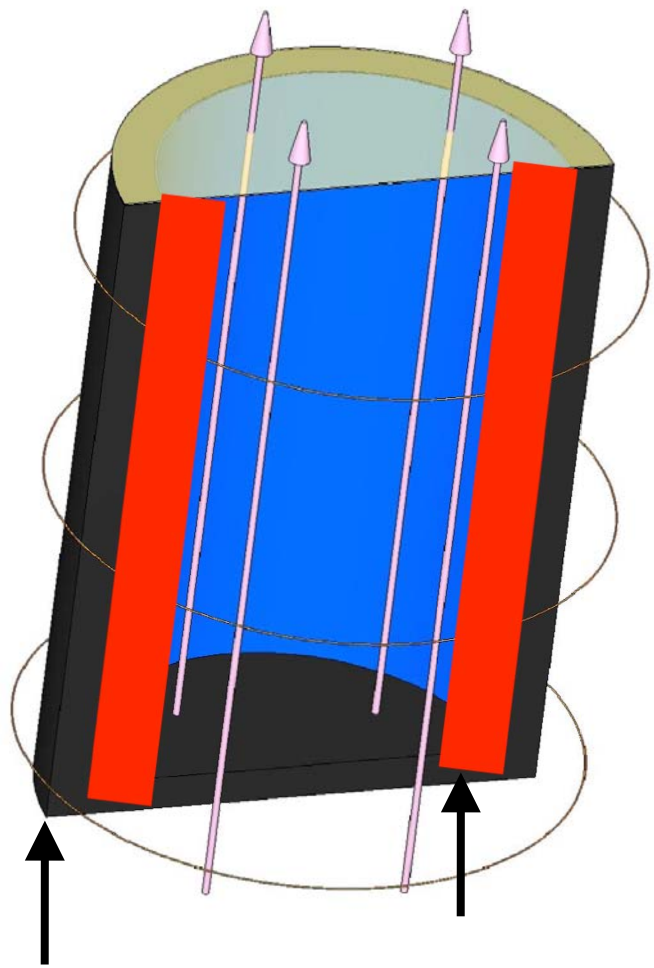
We observe excellent agreement between theory and experiment for single-mode MRT growth experiments







A levitated shell version of MagLIF could give high yield and high gain on a larger facility



INITIAL CONDITIONS	
Peak Current:	61 MA
Al Liner R0:	4.4 mm
Liner height:	10 mm
Aspect ratio (R0/ΔR):	6
Initial gas fuel density:	10 mg/cc
Initial B-field:	10 T
FINAL CONDITIONS	
Target Yield:	4.8 GJ
Target Gain:	700
Convergence ratio (R0/Rf):	22
Final on-axis fuel density:	9.3 g/cc
Final peak B-field:	12500 T

Sandia National Laboratories

Summary

Pulsed power is an efficient, inexpensive way to create matter at high energy densities

Magnetically driven implosions offer a path to coupling much higher fractions of the driver stored energy to fusion fuel

Magnetized Liner Inertial Fusion (MagLIF) offers a near term chance for testing our understanding of magnetically driven implosions. If successful, would lead to breakeven with DT.

Experimental data on the Magneto-Rayleigh Taylor instability is promising, we hope to do an integrated MagLIF test in 2012.

A high-yield (GJs), high-gain (>500) MagLIF design is under development. Much of the relevant physics can be tested on Z.

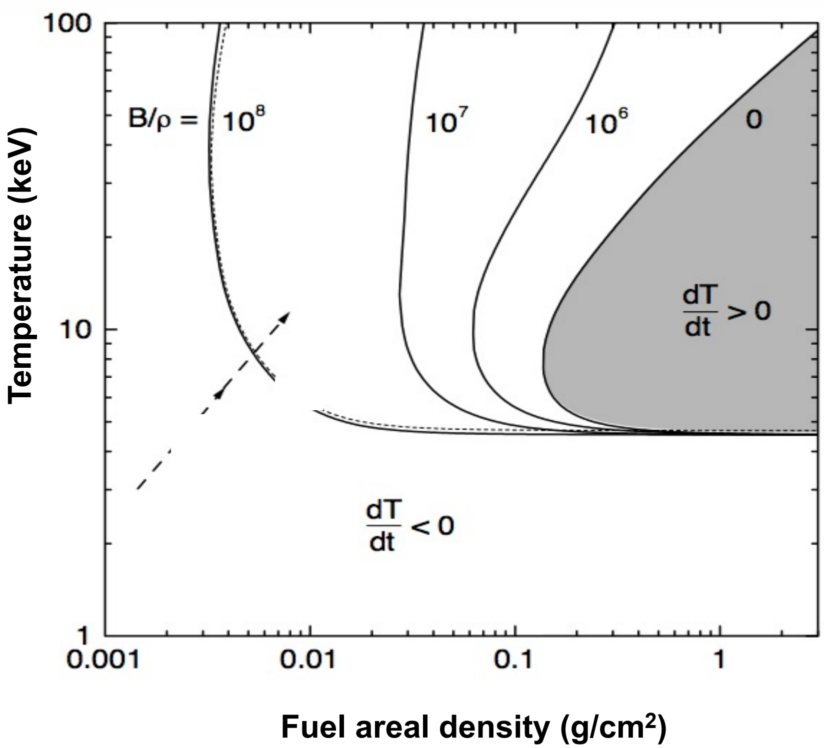
Sandia National Laboratories

Backup

Sandia National Laboratories

A large, embedded magnetic field significantly expands the space for fusion self heating

*Basko et al. *Nuc. Fusion* **40**, 59 (2000)



The ρr needed for ignition can be significantly reduced by the presence of a strong magnetic field

- **•inhibits electron conduction**
- **•enhances confinement of alpha particles**

Lower ρr means low densities are needed (~1 g/cc << 100g/cc)

Pressure required for ignition can be significantly reduced to ~5 Gbar (<< 500 Gbar for hotspot ignition)

Large values of B/ρ are needed and therefore large values of B are needed.

B~ 50-150 Megagauss >> B_0 -> flux compression is needed

Sandia National Laboratories