Target Production in Support of Z Inertial Fusion Energy

Brent Blue
General Atomics

Target Fabrication Specialists Meeting
May 21st, 2012

This is the work of a large collaboration of exceptional people

B.E. Blue, D. Schroen, E. Giraldez, K. Tomlinson, M. Mauldin, D. Goodin, and A. Nikroo
General Atomics, La Jolla, CA & Albuquerque, NM

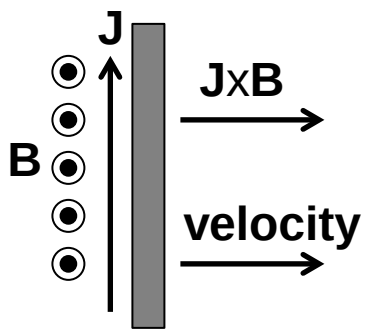
R. Stamm, R. Holt, G. Smith, and J. Taylor
Schafer Corp, Albuquerque, NM

D. Ampleford, B.W. Atherton, J.E. Bailey, V. Bigman, M.E. Cuneo, J.P. Davis,M.P. Desjarlais, A.D. Edens, D.G. Flicker, S.B. Hansen, D.L. Hanson, G.S. Heffelfinger, C.A. Jennings, B.M. Jones, K. Killebrew, M.D. Knudson, G.T. Leifeste, R.W. Lemke, A.J. Lopez, M.R. Lopez, R.J. Magyar, J.H. Carpenter, T.R. Mattsson, M.R. Martin, R.D. McBride, R.G. McKee, C. Nakhleh, K.J. Peterson, J.L. Porter, G.A. Rochau, S. Root, D.C. Rovang, M.E. Savage, A. B. Sefkow, D.B. Sinars, S.A. Slutz, J. Shores, I.C. Smith, W.A. Stygar, M.A. Sweeney, R.A. Vesey, and M.K. Matzen
Sandia National Laboratories, Albuquerque, NM, USA

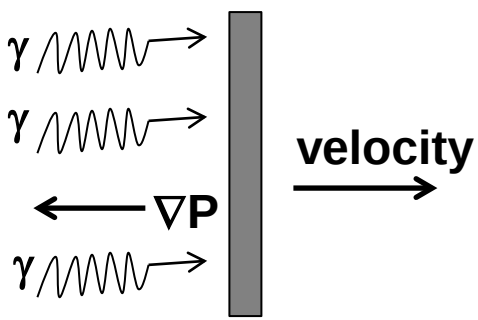
Large currents and the corresponding magnetic fields are used to drive the experiments

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t}+(\mathbf{u}\cdot\nabla)\mathbf{u}\right)=\frac{\mathbf{J}\times\mathbf{B}}{c}-\nabla P$$

Magnetic Drive

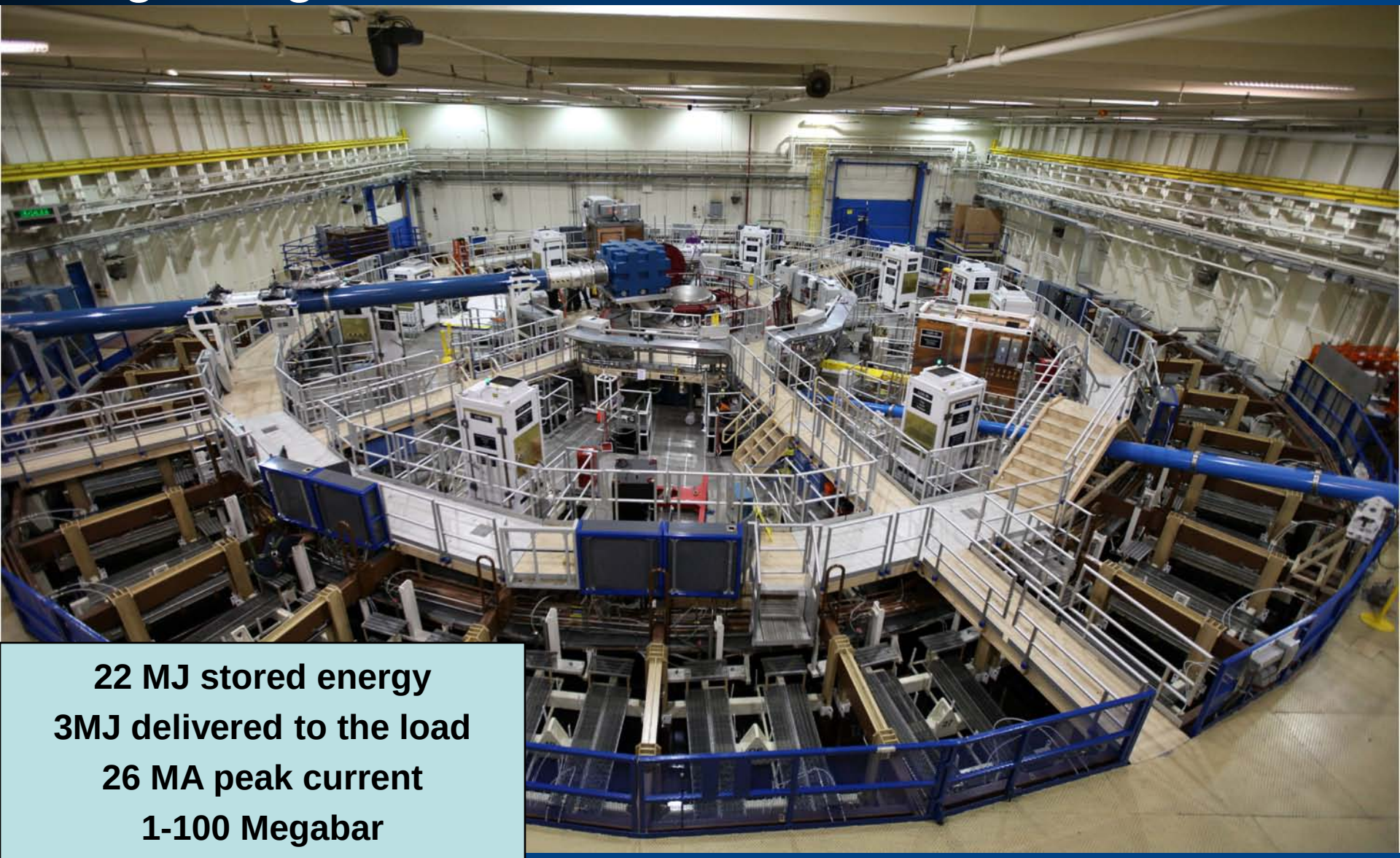


Photon Drive



3 paths to 100 Mbar pressures		
26 MA @ 1mm	$10^{15}\ \frac{W}{cm^2}$	$270\ eV$

We use the Z pulsed power facility to generate large magnetic fields



22 MJ stored energy

3MJ delivered to the load

26 MA peak current

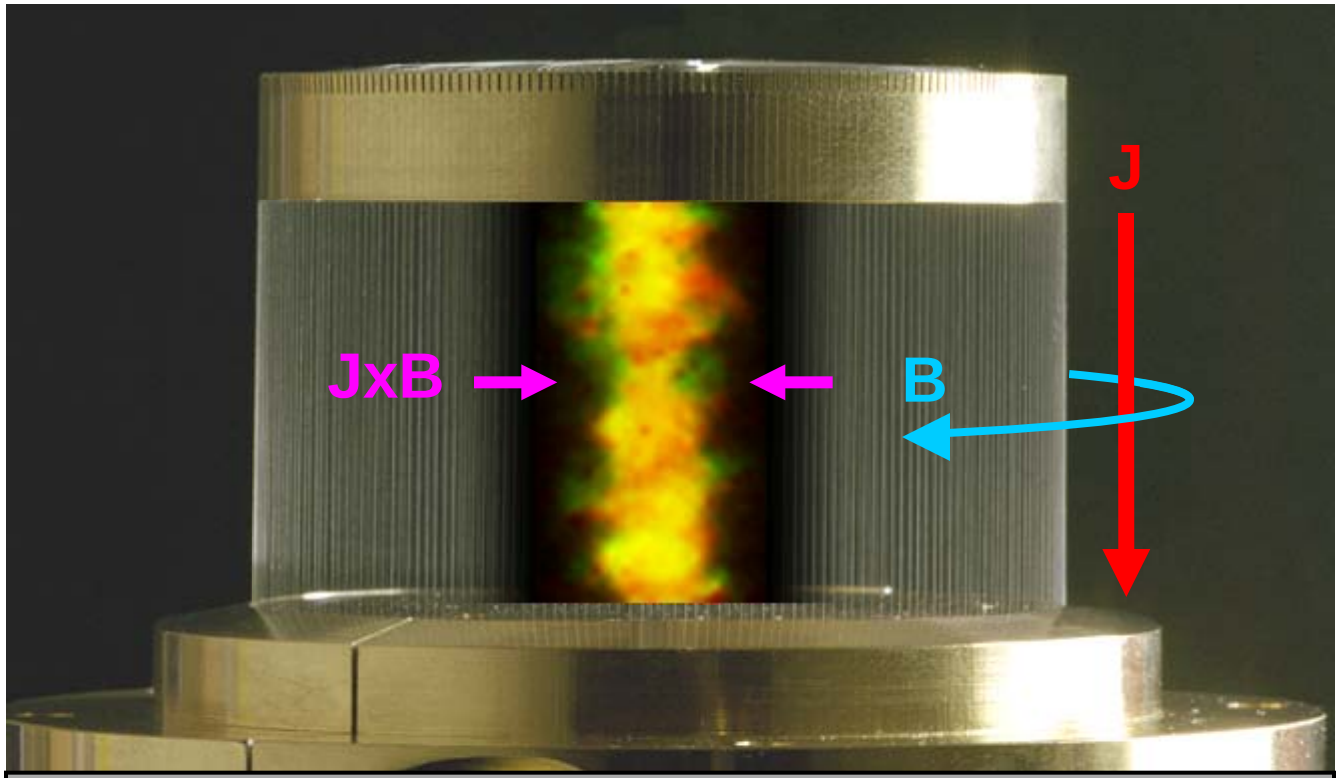
1-100 Megabar

100-600 ns pulse length

Z is an excellent facility for studying HED and ICF science

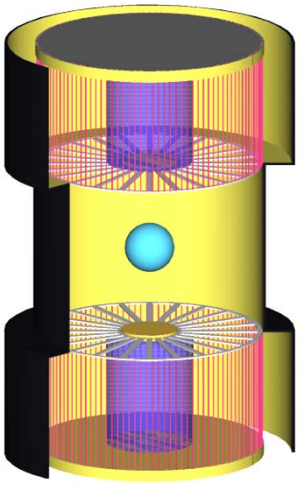
- **Three important classes of Z targets will be discussed**
  - Radiation sources
  - Material equation of state
  - Inertial confinement fusion
- **On Z, radiation sources have been used to study the growth of an engineered defect on NIC capsules**
- **Z generated multi-Megabar pressures have been used to study the equation of state of materials relevant to ICF**
- **A new class of Z ICF targets holds the promise of scientific breakeven (energy from the fuel > energy into the fuel)**
- **General Atomics internal research and development in support of pulsed power ICF**
  - Complex materials
  - High volume production

Wire array Z-pinches efficiently radiate soft x-rays



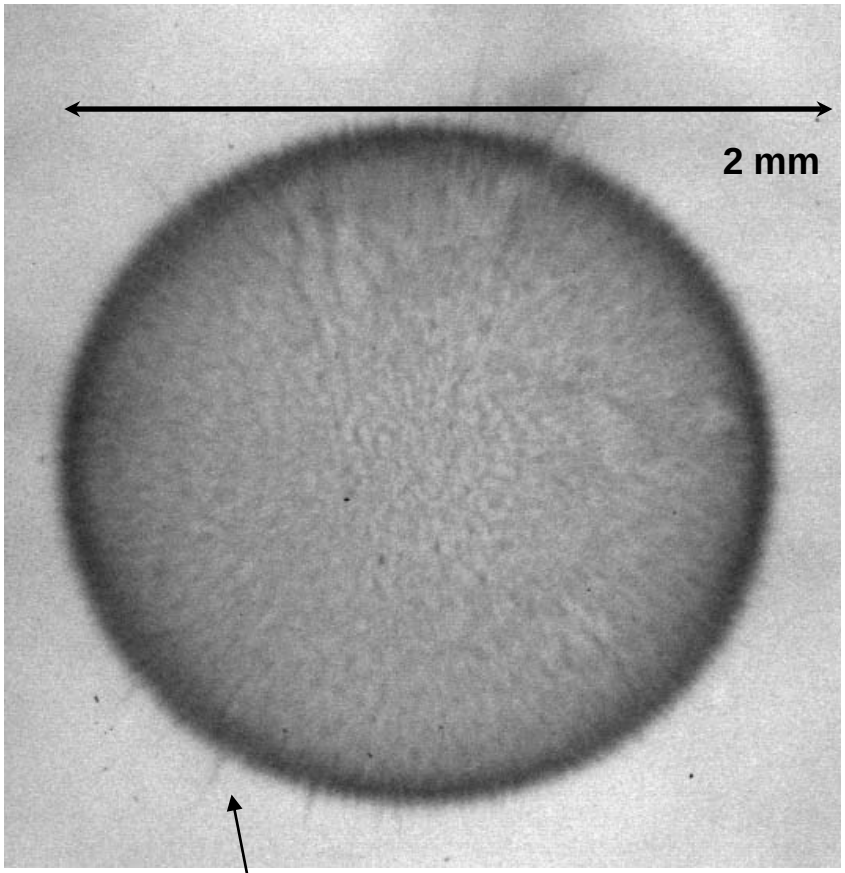
P_{rad} ~ 330 TW, Y_{rad} ~ 2 MJ

> 10% wall plug efficiency



X-rays used to heat hohlraum and implode ICF capsule

Experiments were performed to understand the growth of instabilities in ignition scale capsules



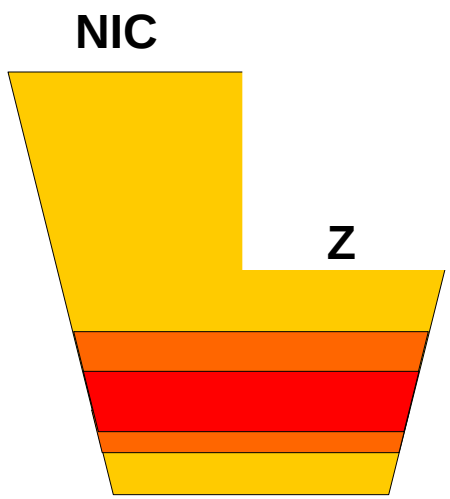
20 µm diameter jet/5 pixels

- 3.2mm capsule with embedded glass layer and hundreds of isolated defects
- Z has a high resolution (~10 um), monochromatic x-ray backlighter
- Convergent RT growth is computationally challenging and depends sensitively on several unmeasured quantities

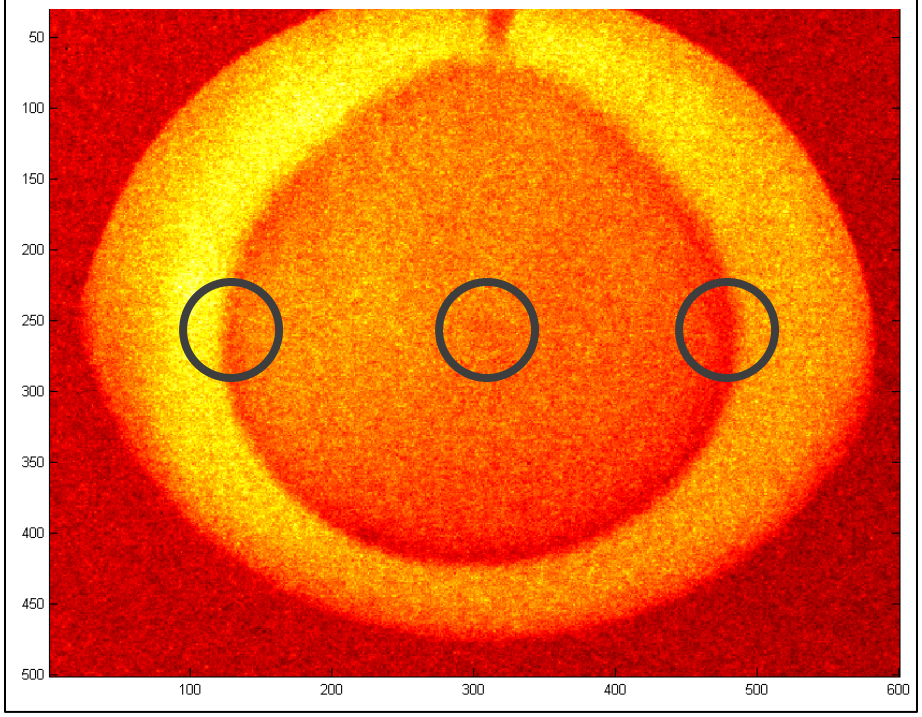
Cuneo, Bennett, Sinars, Vesey et al

Recent experiments successfully captured the evolution of an engineered defect

Z used a NIC capsule with a thinned outer ablator

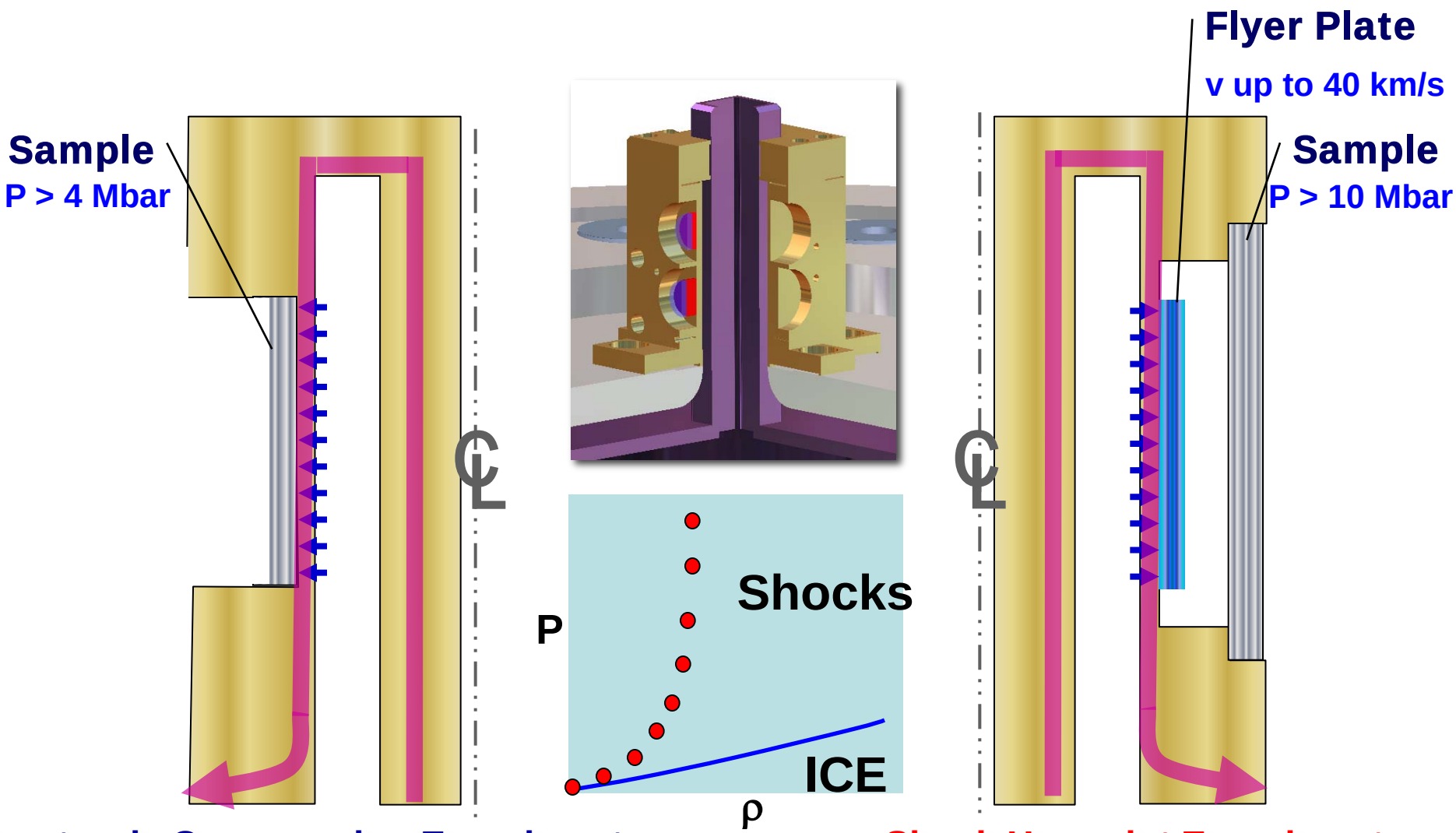


Radiograph showing growth of precisely placed and characterized divots (defects)



Defect visible at later time, but not at the earlier time

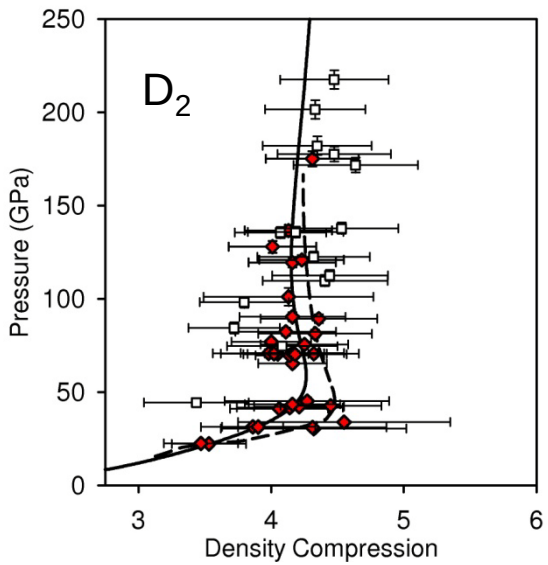
Z can perform both shockless compression and shock wave experiments

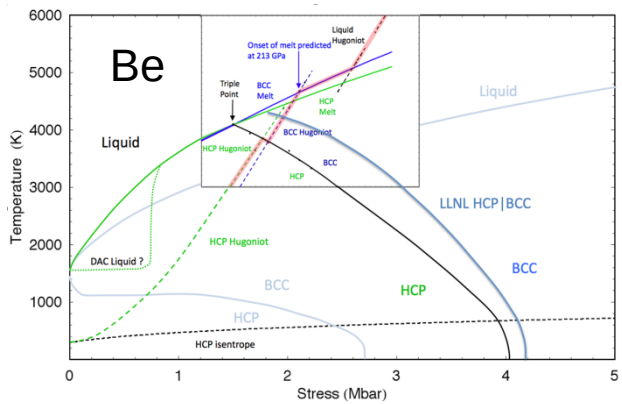


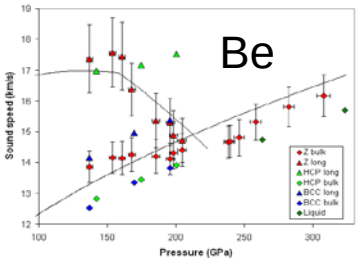
Isentropic Compression Experiments

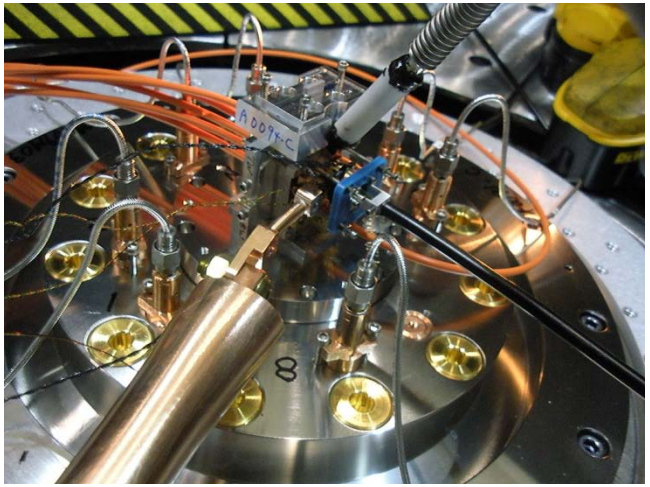
Shock Hugoniot Experiments

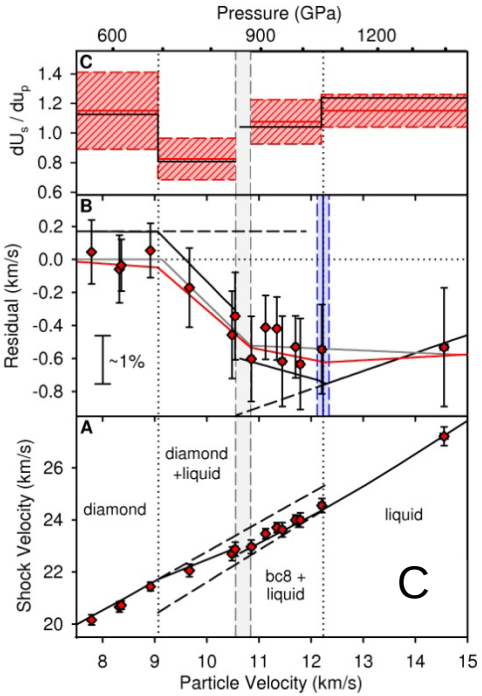
Z has been used to study material properties in the multi-Mbar regime for many ICF materials





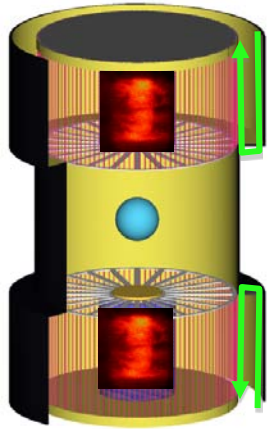






Z ICF Targets have advanced significantly in the last few years

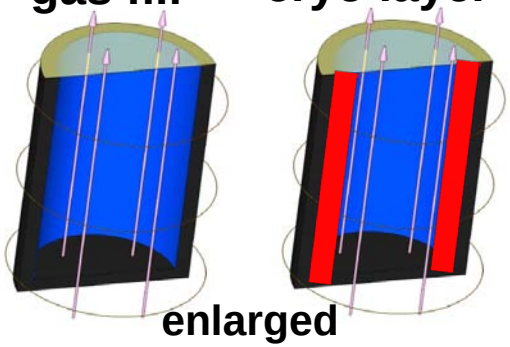
X-ray Indirect-Drive



Current

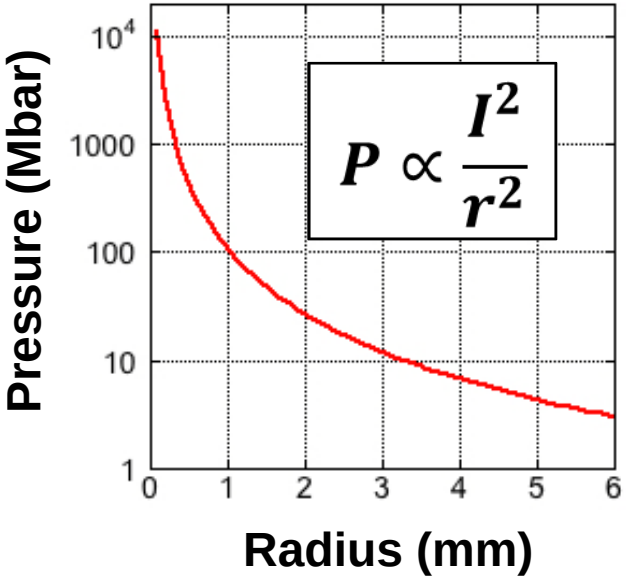
6 mm

Magnetic Field Direct-Drive

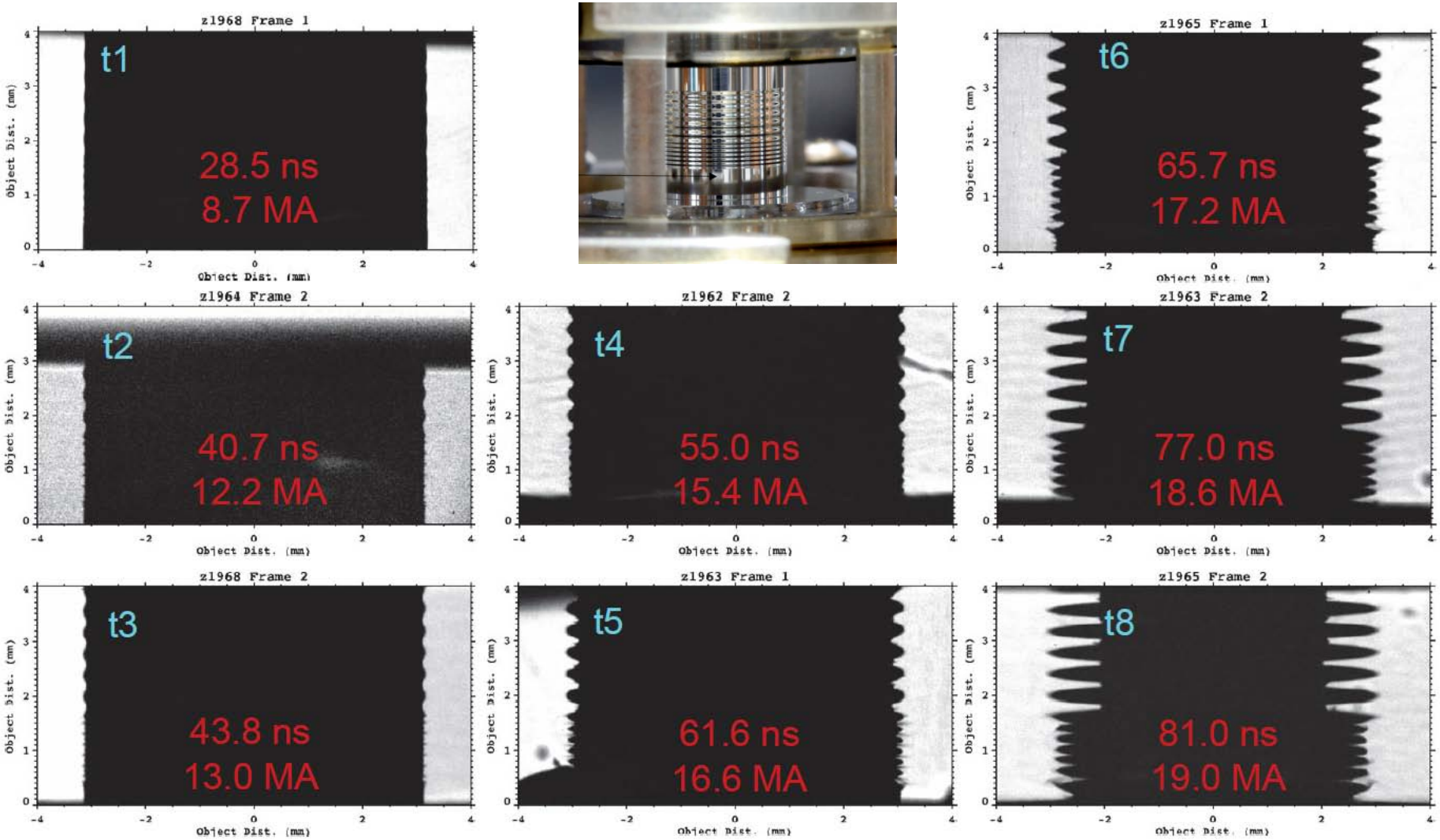


Slutz, Vesey et al

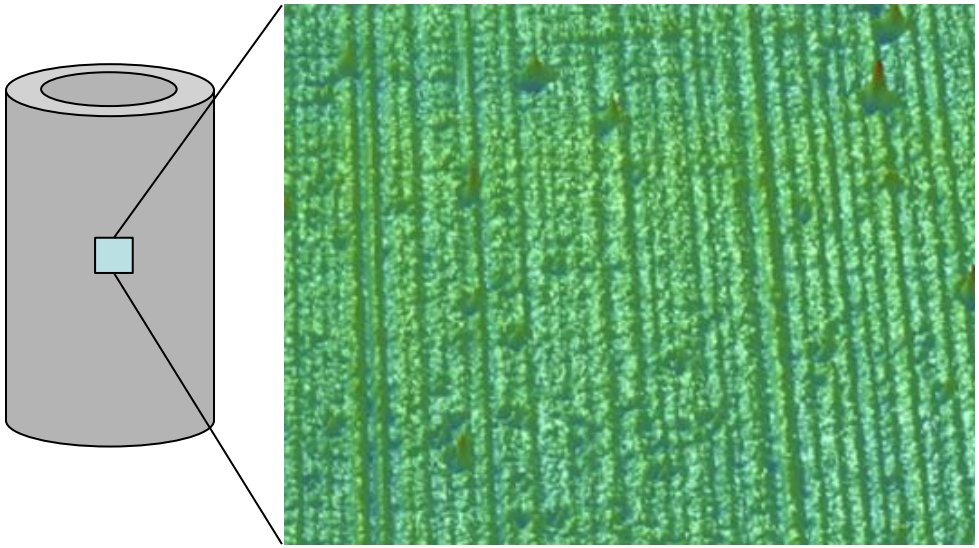
- Compact targets, easier and lower cost to fabricate
- Lower inductance hence higher coupling of current
- Higher coupling efficiency to fuel with direct driver, hence higher energy delivered, higher fusion yields

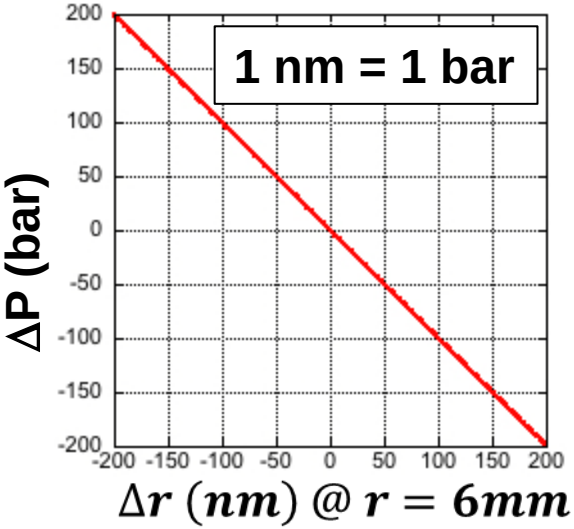


Suppressing the magneto-Rayleigh-Taylor instability is crucial for a stable implosion

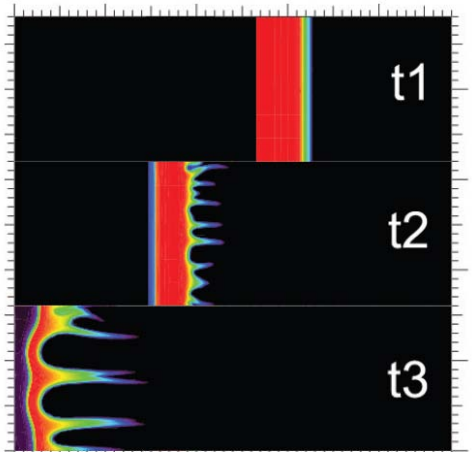


Surface roughness can seed the MRT instability



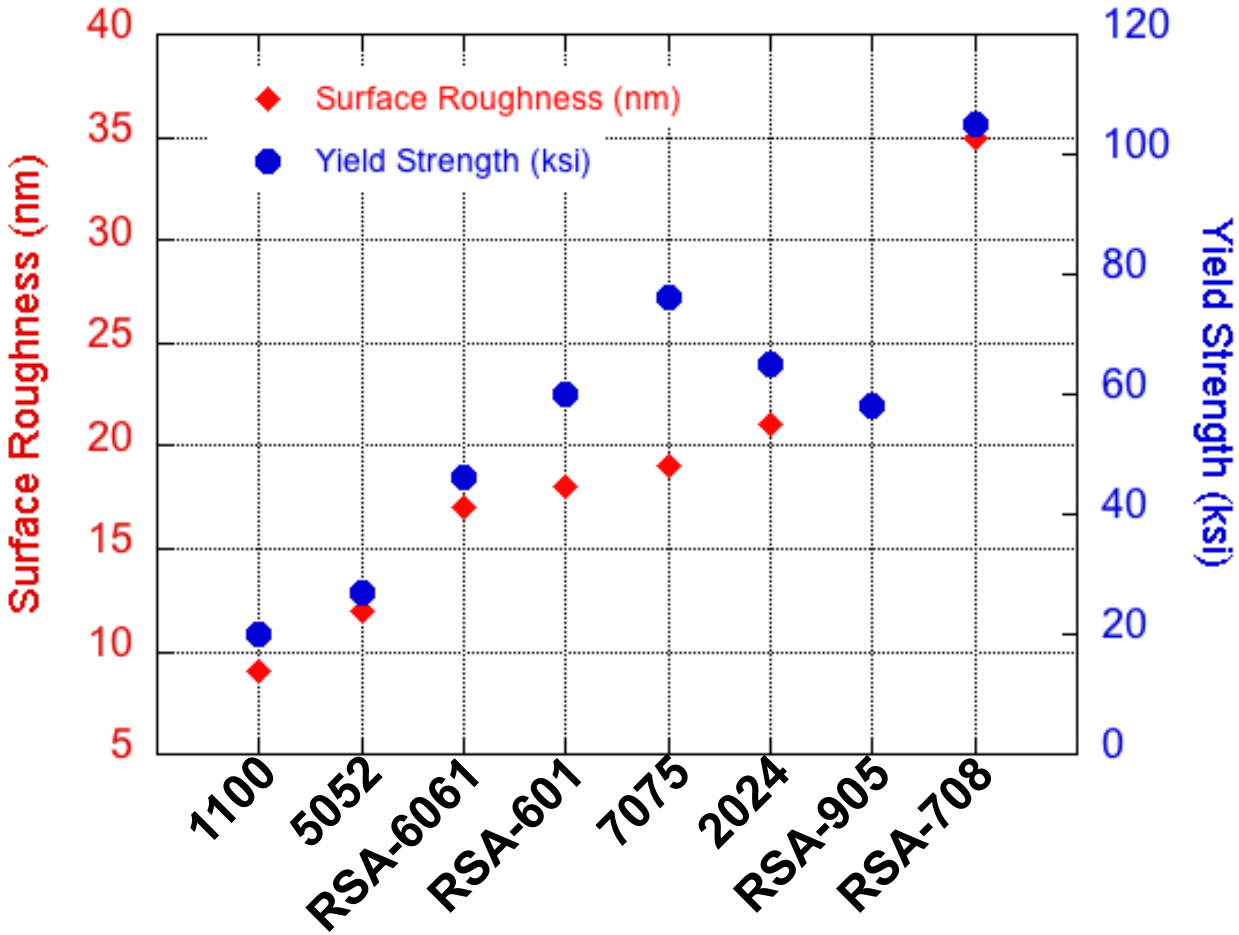


- **All materials have an inherent surface roughness**
- **Function of material and how it was fabricated**

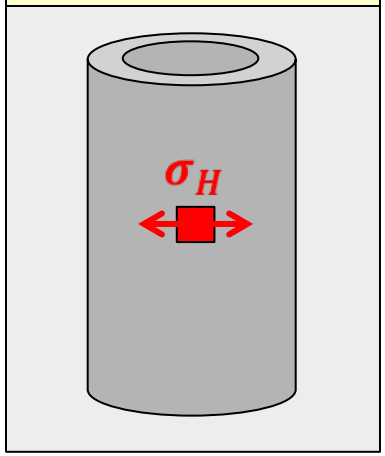


Simulated liner implosion with surface roughness

Aluminum is a candidate material for a ZFE target due to its low cost and ease of machining



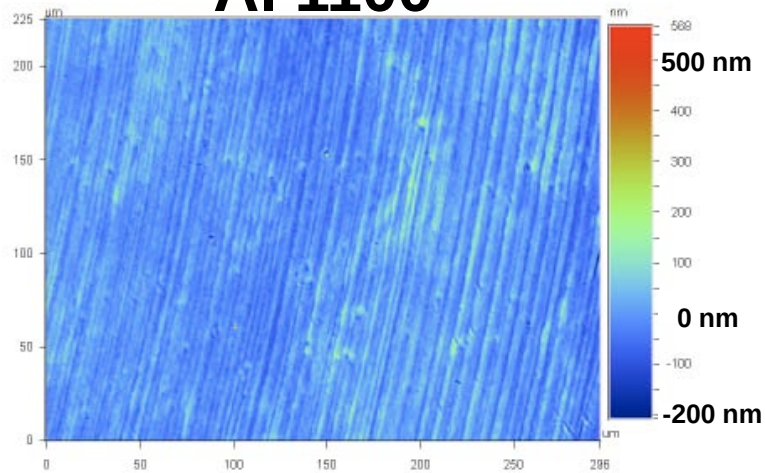
$$\sigma_H = \frac{Pr}{t} < \sigma_{YS}$$



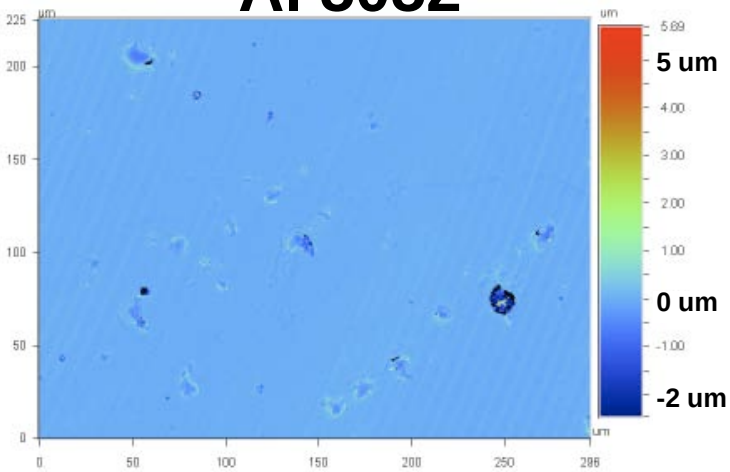
Alloys can also be selected based on elements desired for spectroscopic diagnostics

Localized surface features are not captured by solely looking at the RMS surface roughness

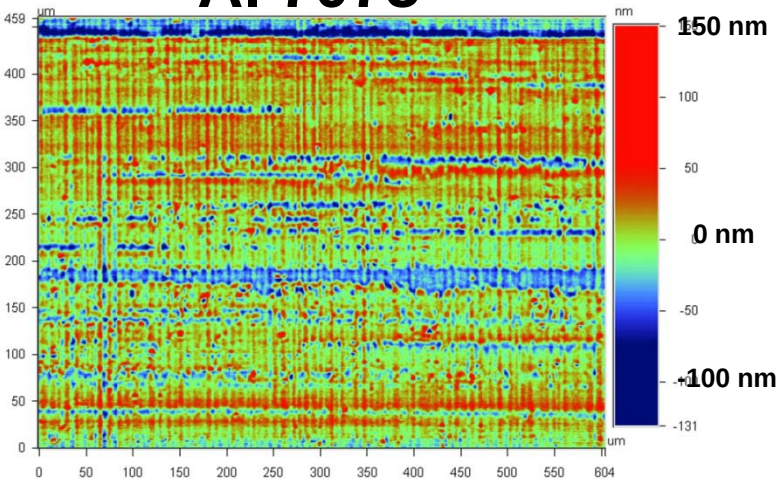
Al 1100



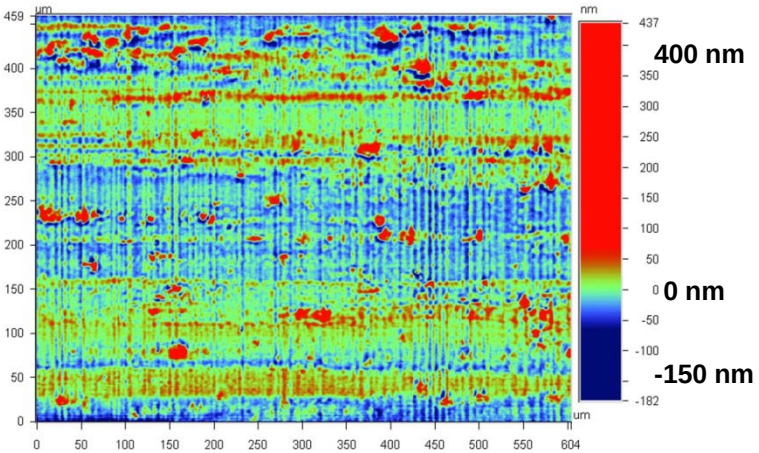
Al 5052



Al 7075

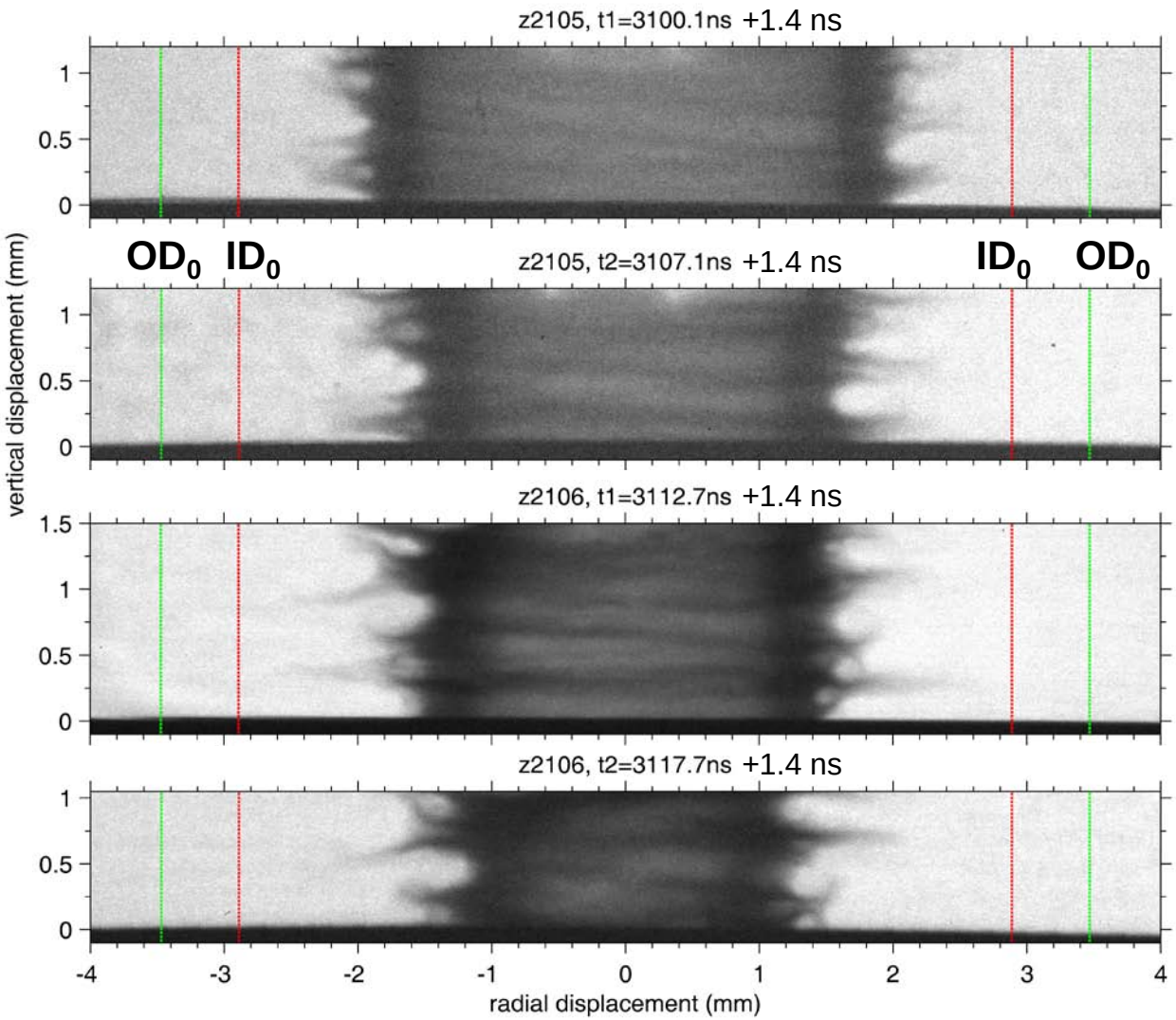


Al 2024



Beryllium is an excellent material for diagnosing the physics of a ZFE target

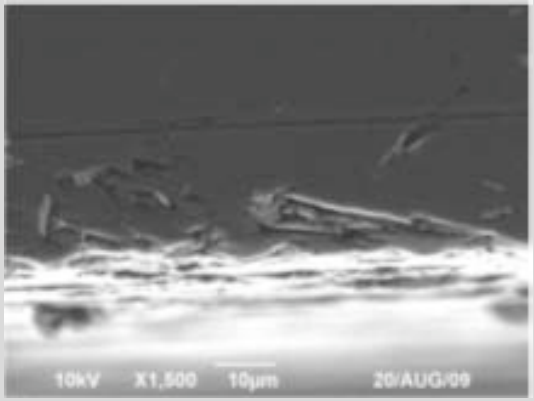
Beryllium Target

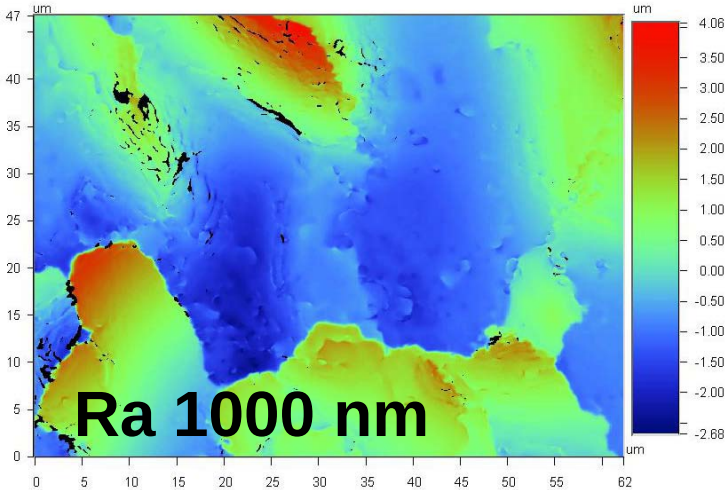


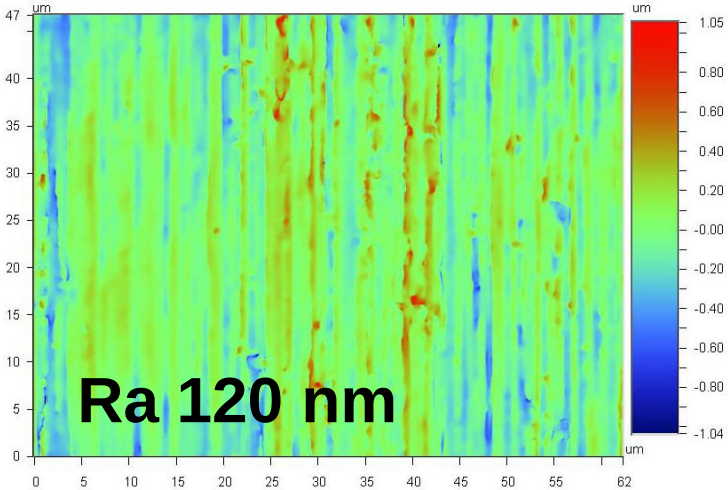
Simultaneous measurements of ID, OD, and density

Beryllium is a hazardous material that is difficult to machine

Surface Defects



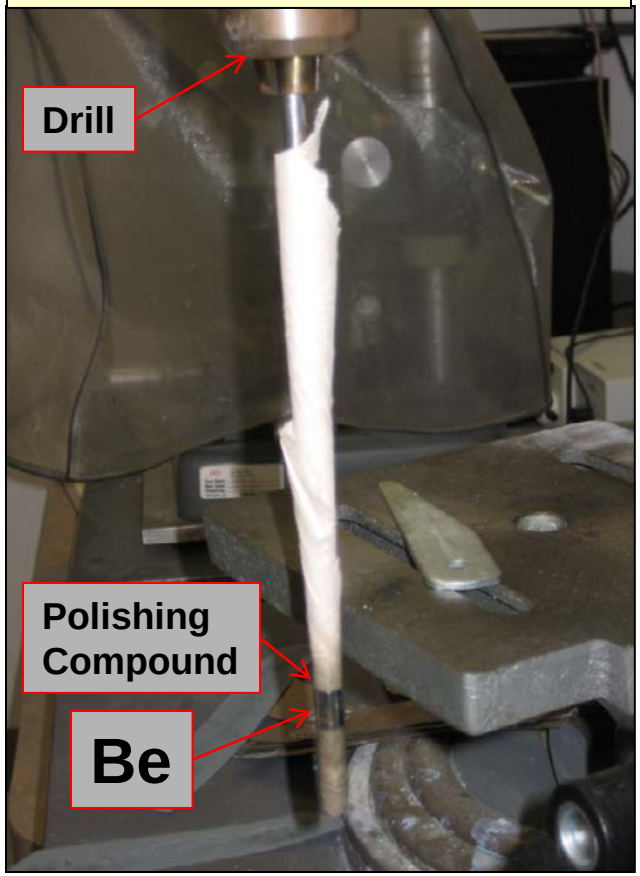




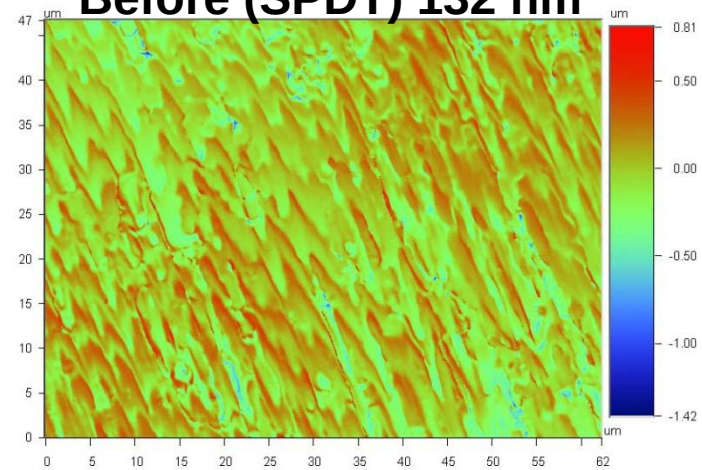
Understanding the mechanisms of subsurface damage is critical to achieving a suitable surface roughness

The surface roughness has been further improved by polishing the ID and OD of Beryllium tubes

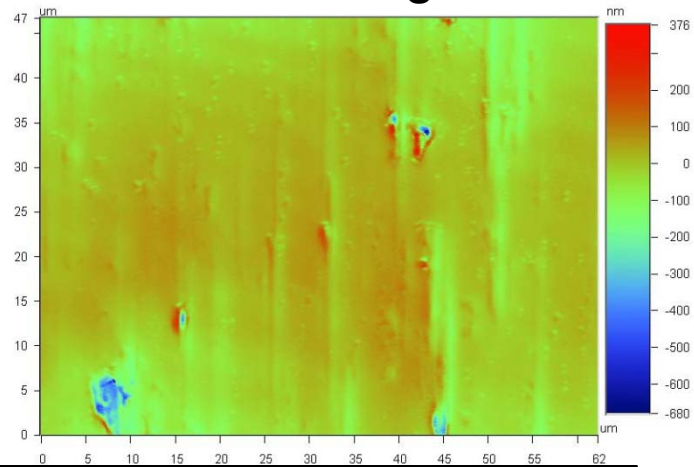
Polishing Setup



Before (SPDT) 132 nm



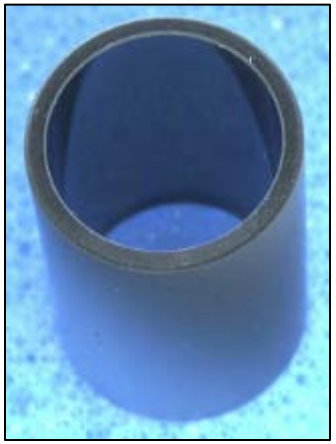
After Polishing 36 nm



Significantly improves the surface roughness after diamond turning while maintaining dimensional tolerances

GA has been investigating new materials and fabrication techniques for liner research

Beryllium on Sapphire



Conductor on insulator

Beryllium w/ 2 µm inner Aluminum shell

Inner shell as a radiographic tracer

Germanium

Test of casting a cylinder from powder

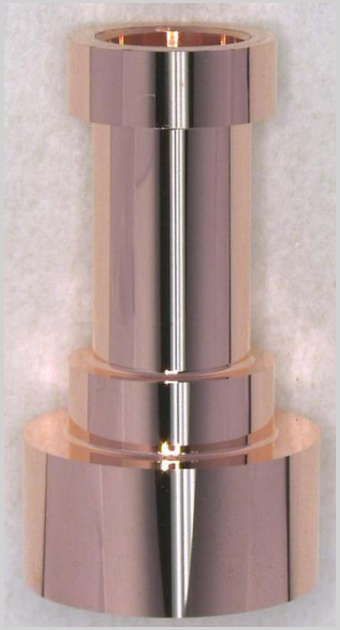
MgB_2 Superconductor

Superconducts @ 39K

We routinely explore their feasibility of various concepts with target designers

New robotic technologies are being used to support higher volume production

Cornell Liner target



These technologies are enabling low-cost delivery of high-quality targets

We increased production rate while maintaining high quality targets

Liner Endcaps

		Dimension (mm)					
		OD1	**OD2**	**ID**	**D1**	**D2**	**D3**
	Spec	12.000	5.705	2.050	2.500	4.000	1.500
	Tolerance	0.005	0.005	0.020	0.010	0.010	0.010
Part Number	**1**	12.004	5.707	2.049	2.499	4.005	1.506
	2	12.002	5.705	2.047	2.499	4.009	1.510
	3	12.001	5.707	2.045	2.499	4.004	1.505
	4	12.003	5.706	2.045	2.500	4.007	1.507
	5	12.001	5.707	2.044	2.500	4.010	1.510
	6	12.004	5.707	2.054	2.499	4.002	1.503
	7	12.000	5.707	2.047	2.499	4.009	1.510
	8	12.002	5.708	2.049	2.499	4.006	1.507
	9	12.002	5.706	2.048	2.500	4.007	1.507
	10	12.002	5.707	2.057	2.498	4.001	1.503
	11	12.001	5.706	2.048	2.498	4.000	1.502
	12	11.999	5.706	2.046	2.499	4.009	1.510
	13	11.998	5.707	2.053	2.499	4.007	1.508
	14	12.001	5.707	2.046	2.499	4.012	1.513
	15	11.999	5.707	2.047	2.499	4.005	1.506
	16	12.001	5.707	2.047	2.500	4.010	1.510
	17	12.004	5.707	2.044	2.499	4.009	1.510
	18	11.998	5.708	2.043	2.500	3.998	1.498
	19	12.000	5.708	2.046	2.499	4.009	1.510
	20	11.999	5.707	2.049	2.499	4.005	1.506

1.9	0.7	3.5	0.6	3.7	3.6
Standard Deviation (um)					

Machining time reduced from 1 month to 2 hours!

Z is an excellent facility for studying HED and ICF science

- **Three important classes of Z targets will be discussed**
  - Radiation sources
  - Material equation of state
  - Inertial confinement fusion
- **On Z, radiation sources have been used to study the growth of an engineered defect on NIC capsules**
- **Z generated multi-Megabar pressures have been used to study the equation of state of materials relevant to ICF**
- **A new class of Z ICF targets holds the promise of scientific breakeven (energy from the fuel > energy into the fuel)**
- **General Atomics internal research and development in support of pulsed power ICF**
  - Complex materials
  - High volume production

Questions?

GENERAL ATOMICS