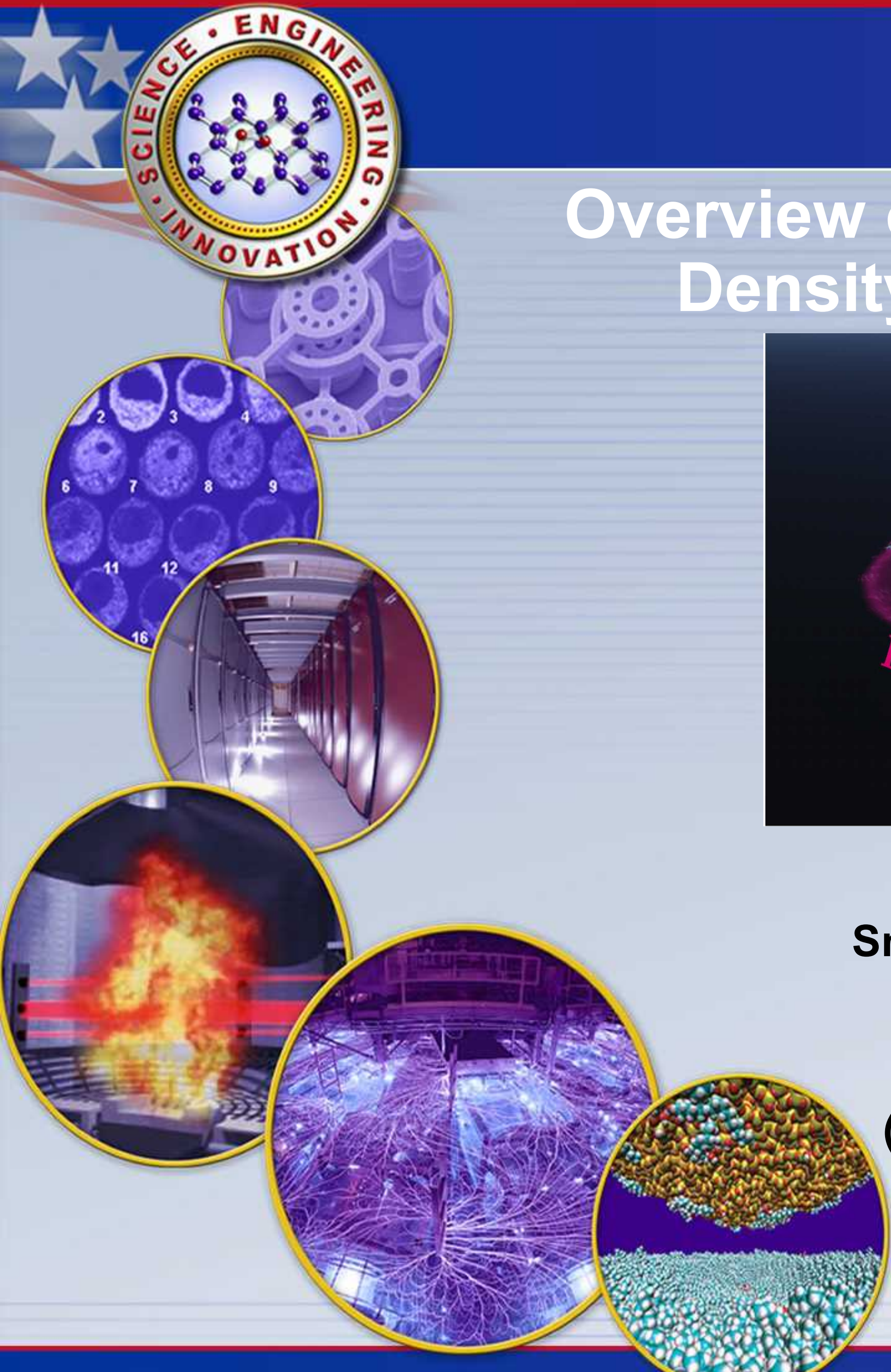
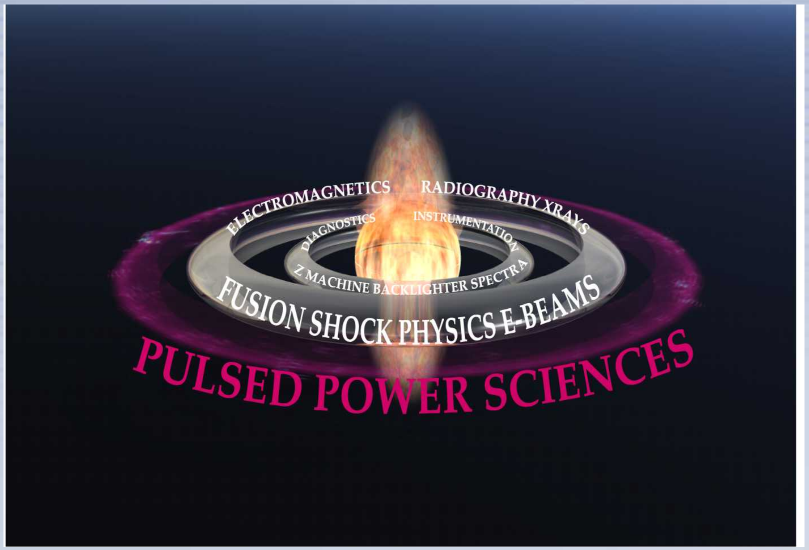
SAND2008-0447C



Overview of Sandia High Energy Density Physics Program



Zababakhin Scientific Talks

Snezhinsk, Chelyabinsk Region, Russia

10-14 September, 2007

Tom Mehlhorn

(505) 845-7266; tamehlh@sandia.gov

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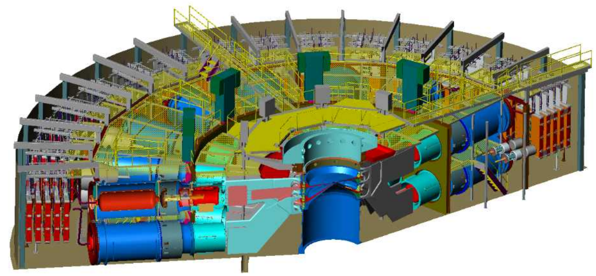
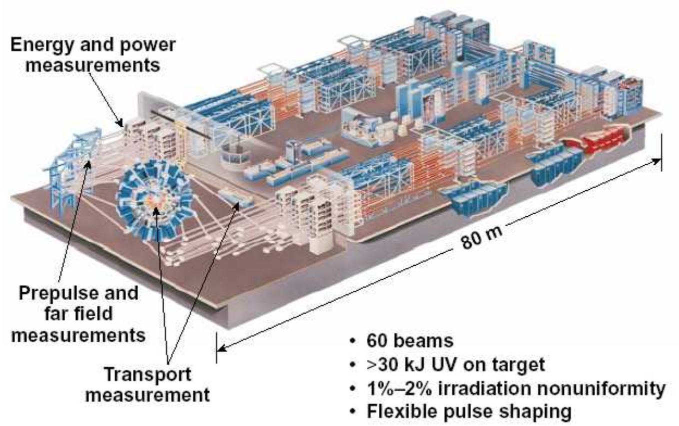
The US HEDP Program has three major facilities for HED science experiments

ZR (2007)



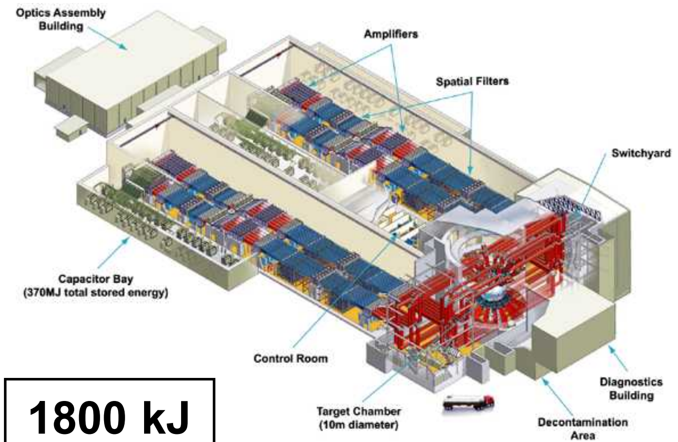
2700 kJ

Omega



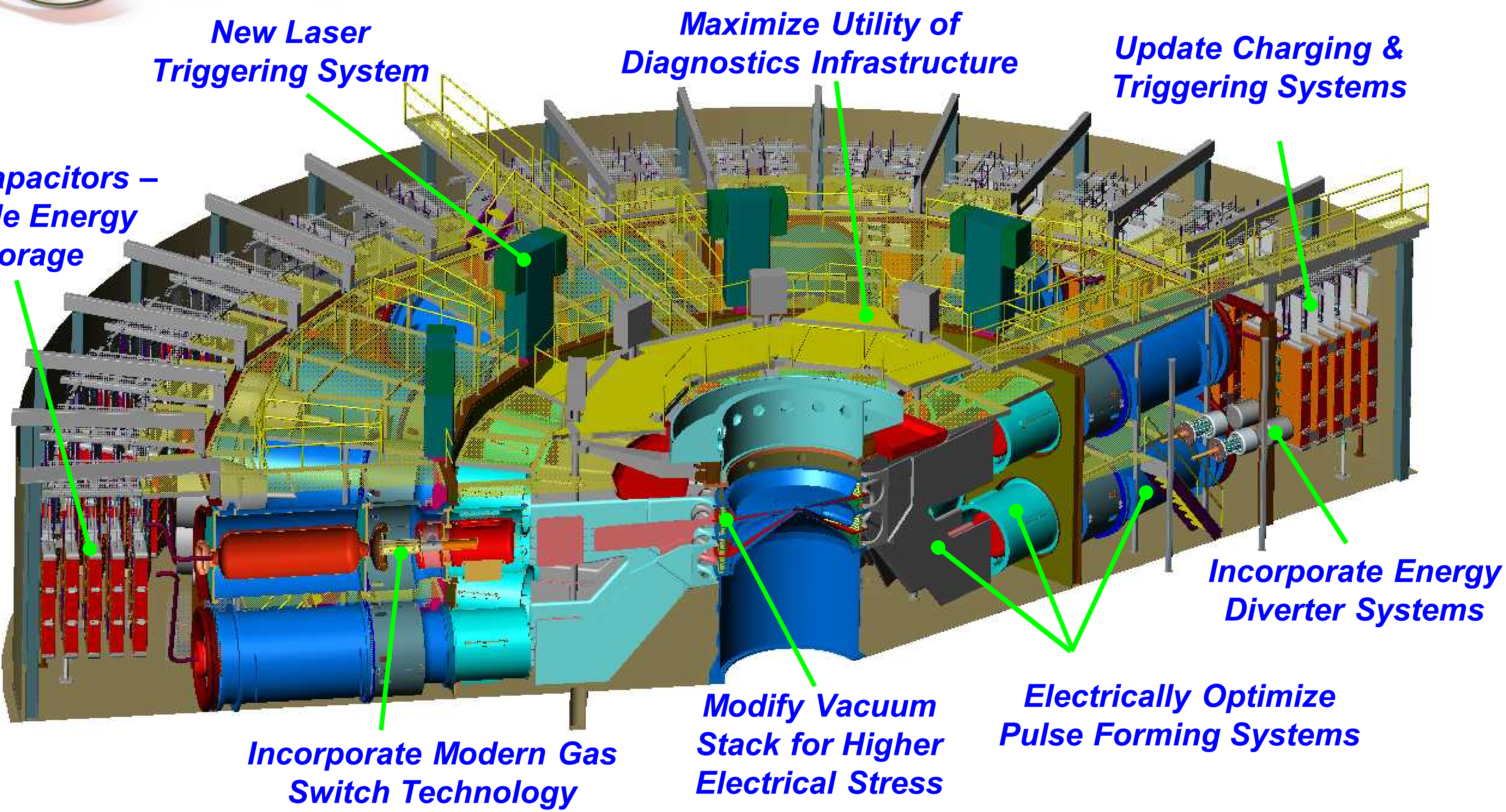
30 kJ

NIF (2010)



1800 kJ

ZR: Refurbishment of the Z Pulsed Power Generator



Cost of the refurbishment of the Z facility will total $90.4M – $61.7M for engineering, design and hardware, and $28.7M for R&D, installation and testing.

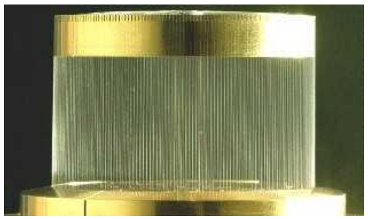
The Z facility gives us several methods of achieving high energy density conditions

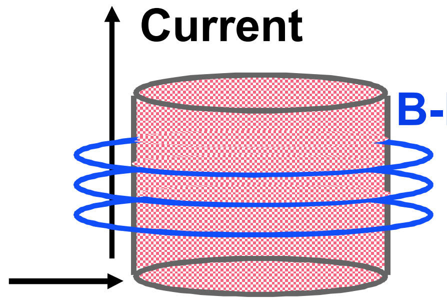
High Current

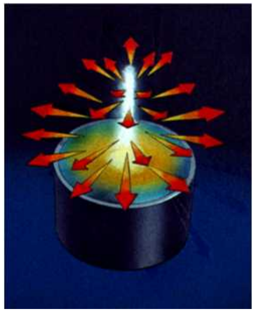
Z-pinch x-ray source

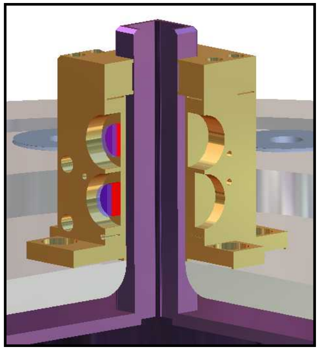
Magnetic pressure

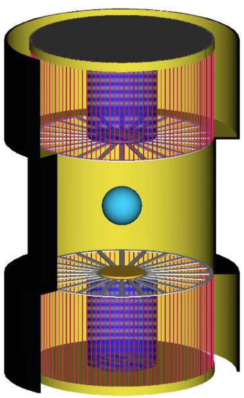
Wire array



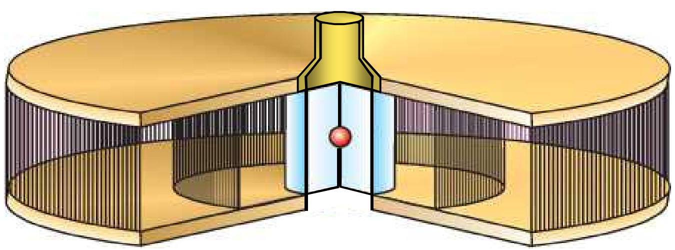




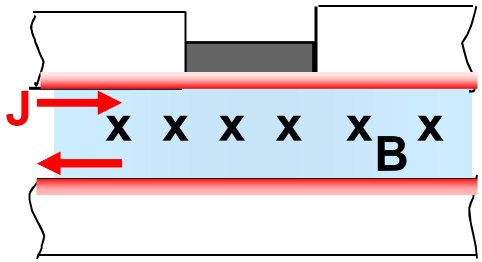




Fusion



Radiation Science



Material Properties

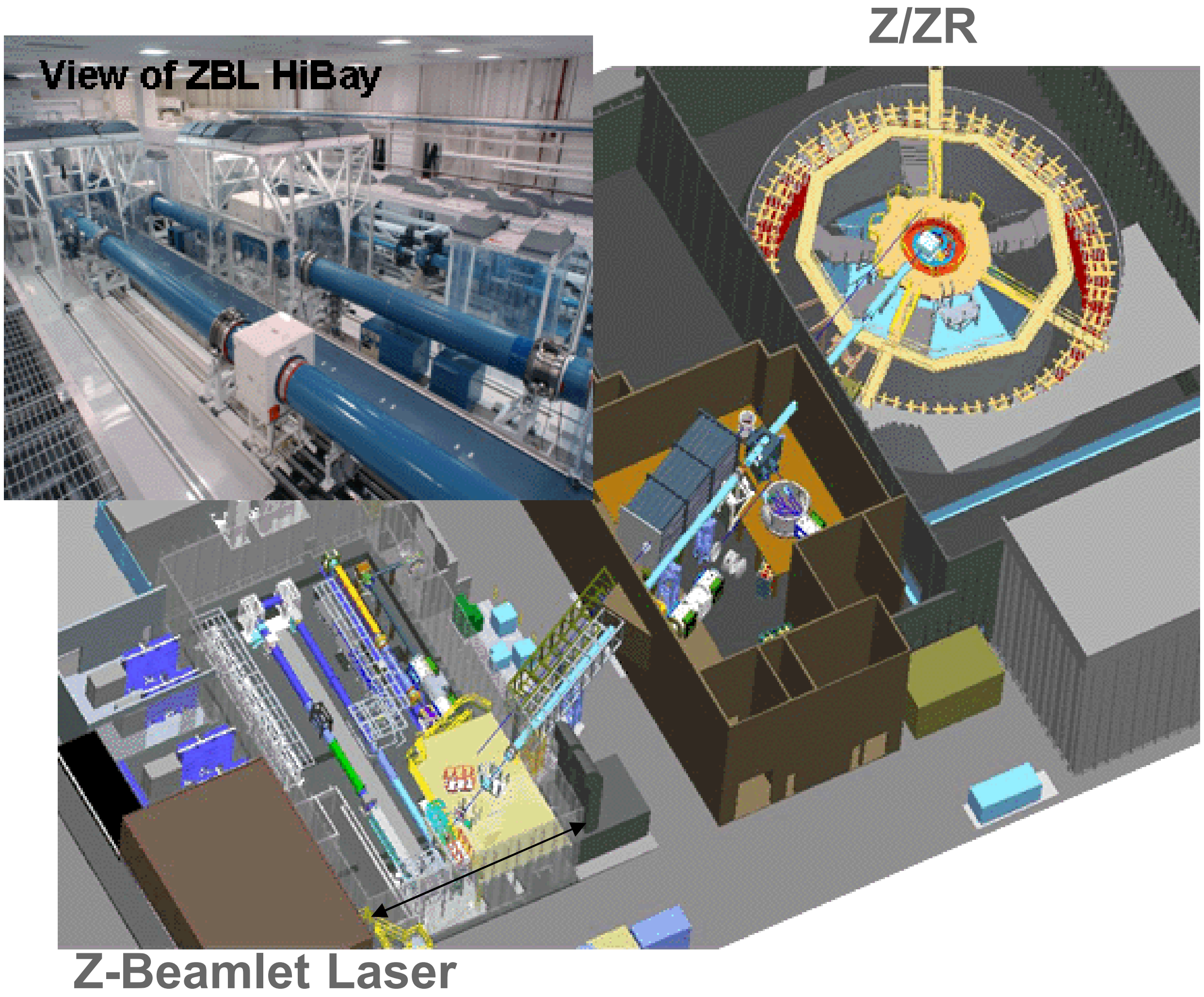
Increased current on refurbished Z will increase capability for multiple applications

Capability	Z Today	After Refurbishment*
Power Radiated (Nested Arrays)	230 TW	350 TW
Energy Radiated (Single Array)	1.6 MJ	2.7 MJ
T_r for Radiation Physics VH / DH	140 / 215 eV	165 / 260 eV
T_r for ICF VH / DH	70 / 215 eV	85 / 260 eV
P_{pk} for ICE (Cu)	3.25 Mbar	10 Mbar
Flyer Plate Velocity	34 km/s	> 40 km/s
In band energy 1 keV / 5 keV / 8 keV	450 / 100 / 18 kJ	900 / 300 / 72 kJ

VH = Vacuum Hohlraum DH = Dynamic Hohlraum ICE = Isentropic Compression Experiments

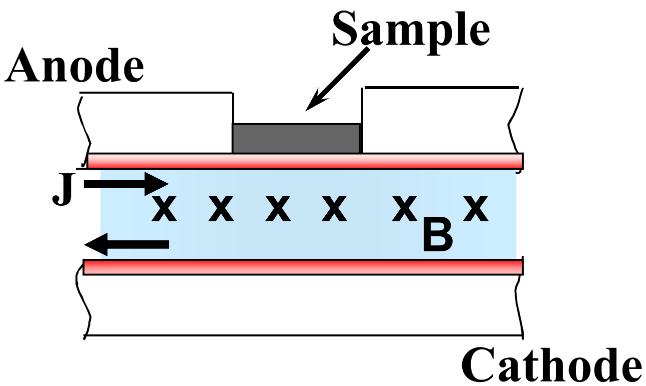
*The ZR project will deliver 26 MA into baseline z-pinch load with pulse shaping capability for ICE and flyers. ZR full capability will be achieved by the program.

The Z-Petawatt Laser System will provide new capability for radiography and fast ignition research



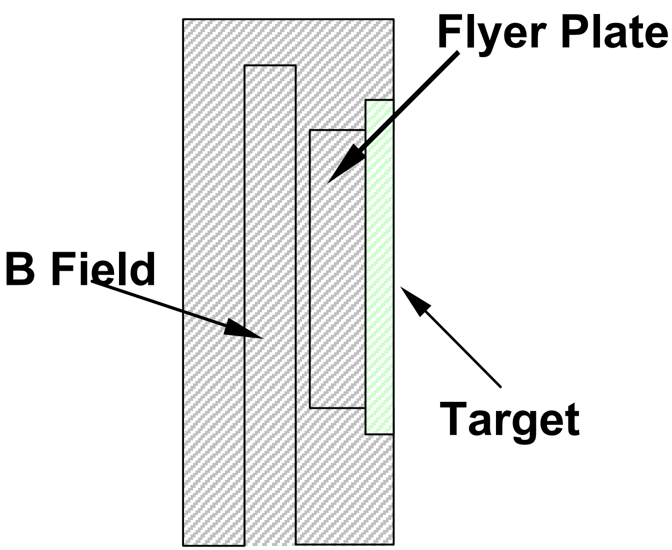
- Currently, the terawatt-class Z-Beamlet Laser (ZBL) creates a backlighting x-ray source in the 1-10 keV range on Z
- A petawatt-class enhancement, referred to as the Z-Petawatt (ZPW), is being constructed for:
  - New radiography options (X-ray radiography in the 10-100 keV range; Proton radiography)
  - Fast Ignitor fusion research on Z/ZR
- The 2 kJ/1 ps system will begin operation in 2007

Techniques have been developed on Z for accurate EOS studies—both major advances



Isentropic Compression Experiments (ICE)

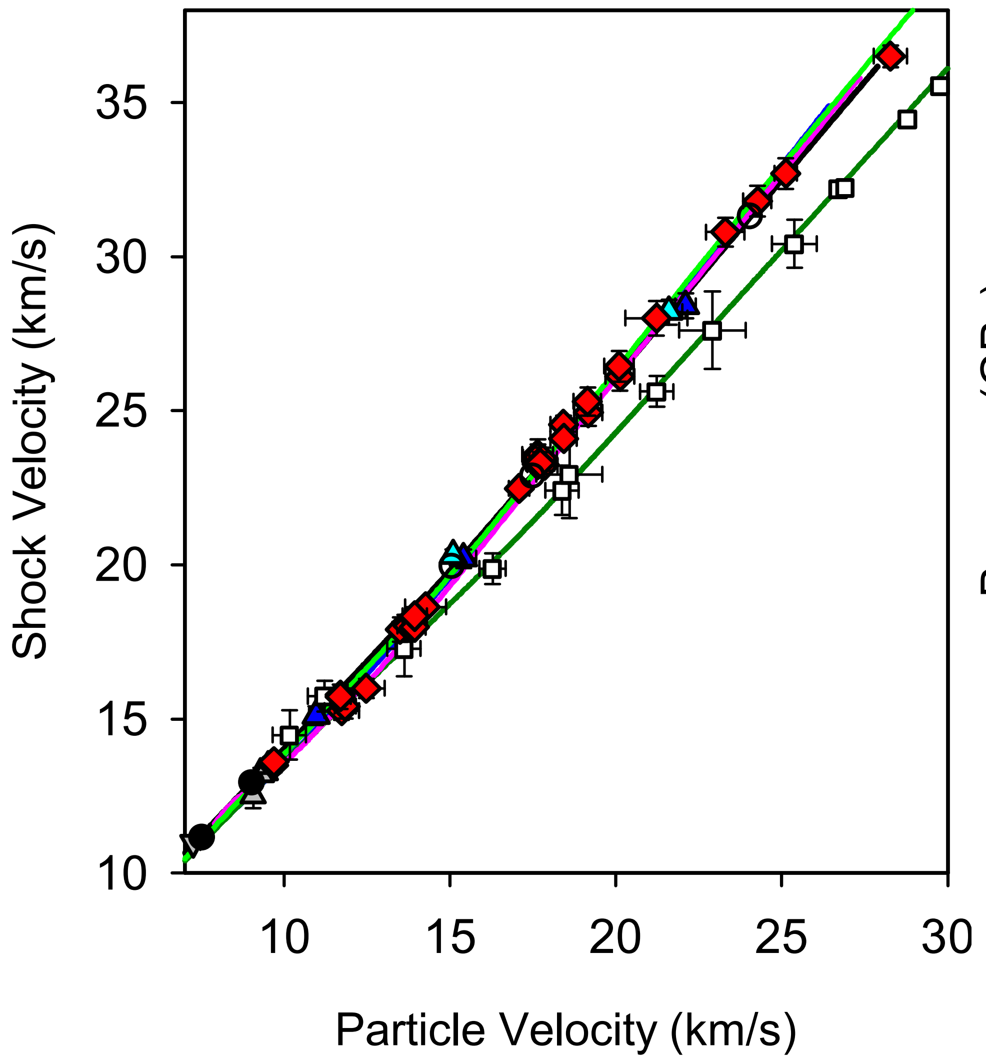
Magnetically produced Isentropic Compression Experiments (ICE) to provide measurement of continuous compression curves to ~3 Mbar
- previously unavailable at Mbar pressures

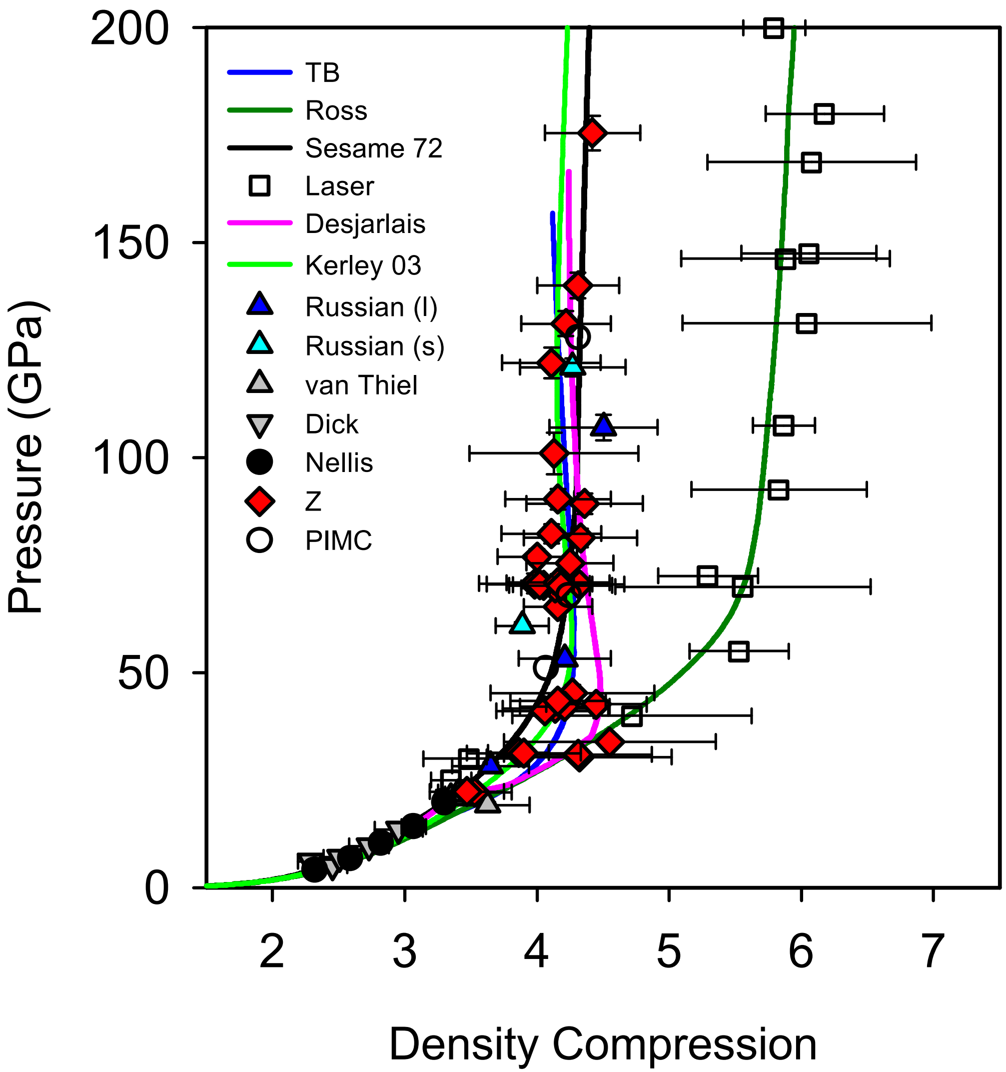


Magnetically launched flyer plates

Magnetically driven flyer plates for shock Hugoniot experiments at velocities to ~ 34 km/s
- exceeds gas gun velocities by ~ 4X and pressures by ~ 7-8X with comparable accuracy

Data to 1.8 Mbar has been obtained on liquid D_2 to help resolve discrepancy in high-pressure response





M.D. Knudson, et al., Phys. Rev. Lett. **87**, 225501 (2001); Phys. Rev. B **69**, 144209 (2004)

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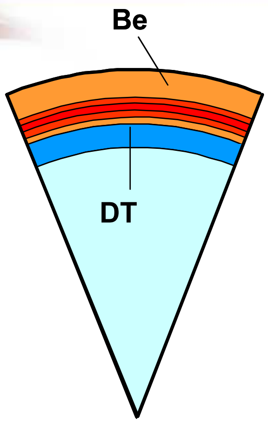
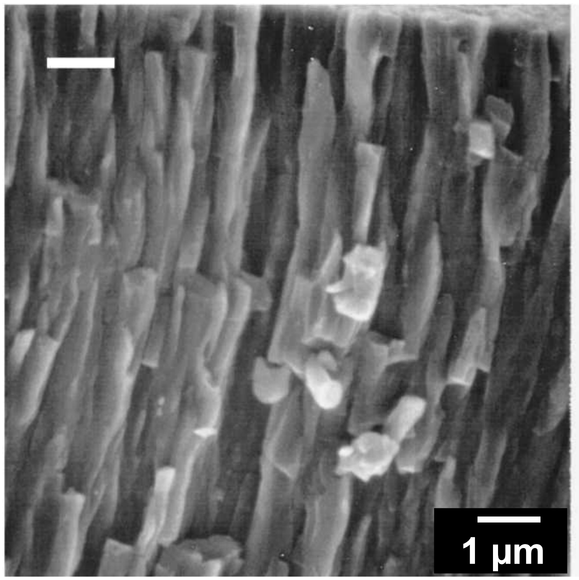
Sandia was asked to quantify Be & diamond melt for the National Ignition Campaign (NIC)

300 eV graded-doped Be design:



- **Risk reduction strategy**
  - **Ensure Be capsules melt**
  - **Measure melt properties of Be on the Hugoniot**
  - **Compare measurements with QMD modelling**

Sputtered Be has Grains

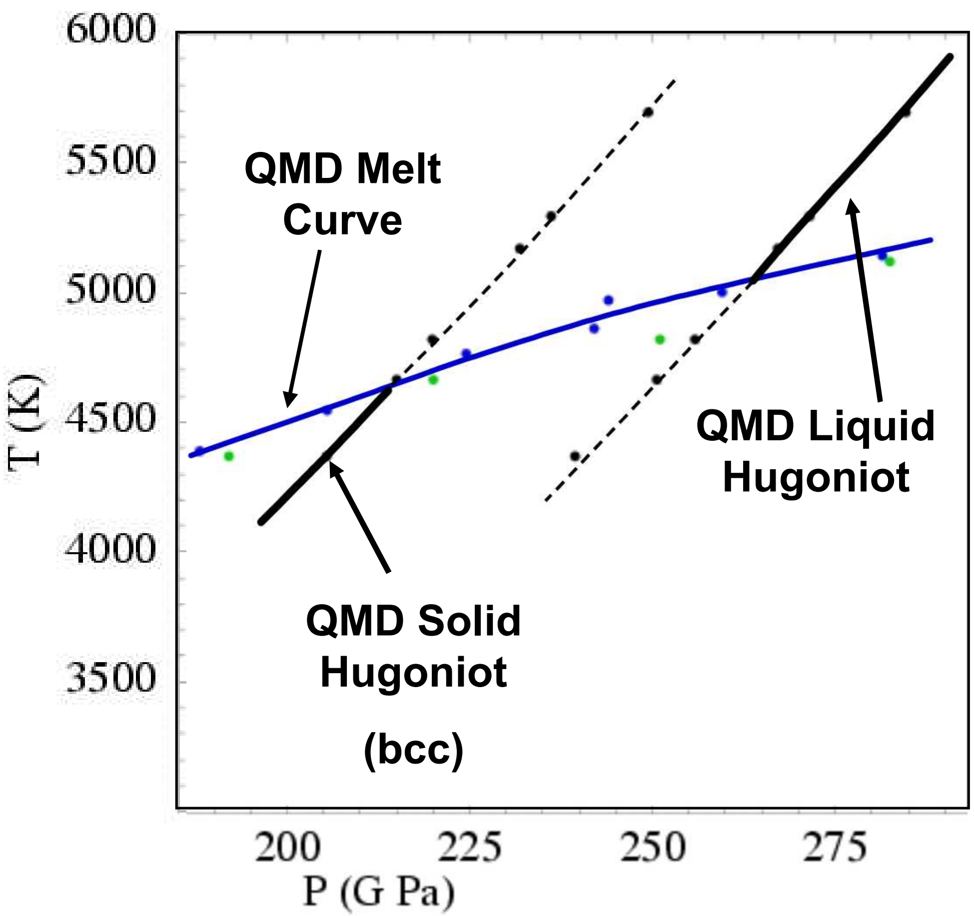


This is predicted to be of no consequence when the Be melts

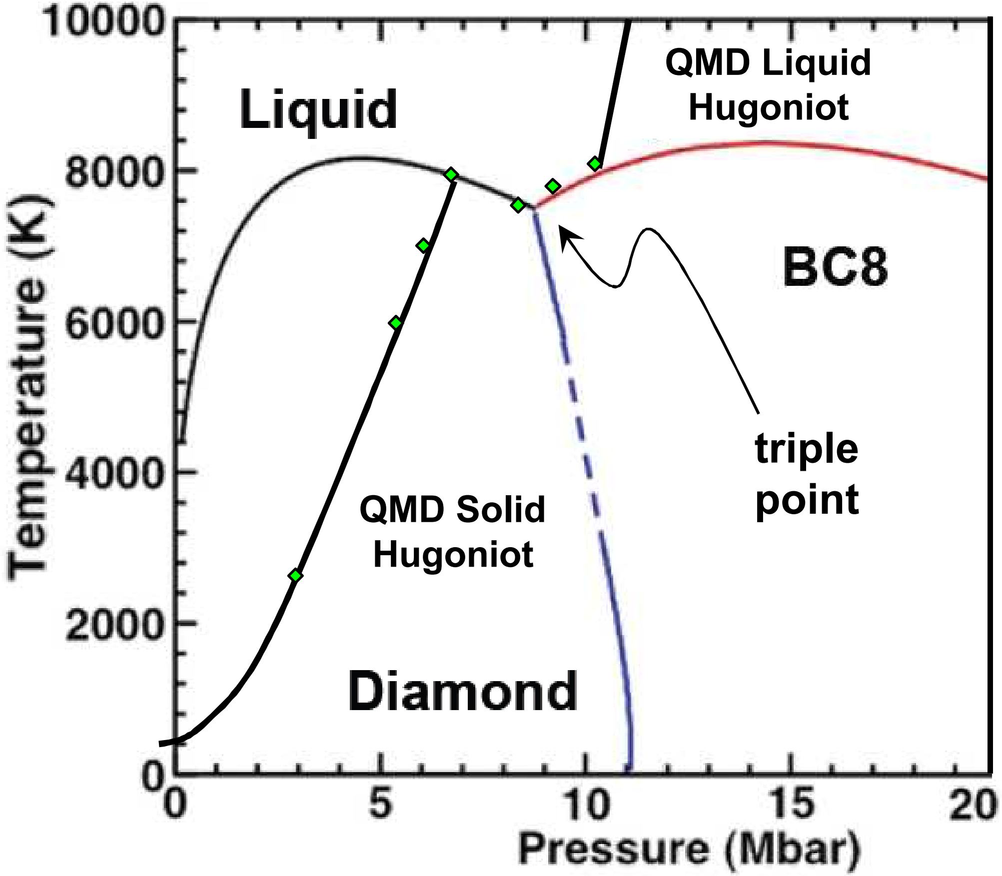
- Determine melt properties of pure, polycrystalline Be samples from Brush-Wellman
- Success of the beryllium experiments led to experiments to investigate the melt properties of diamond
  - CVD grown, polycrystalline diamond samples supplied through LLNL (both microcrystalline and nanocrystalline)
- Diamond studies resulted in a delay in the shutdown of Z for the upgrade

QMD calculations were critical in providing estimates of the stress regime of interest

Be Phase Diagram



Diamond Phase Diagram



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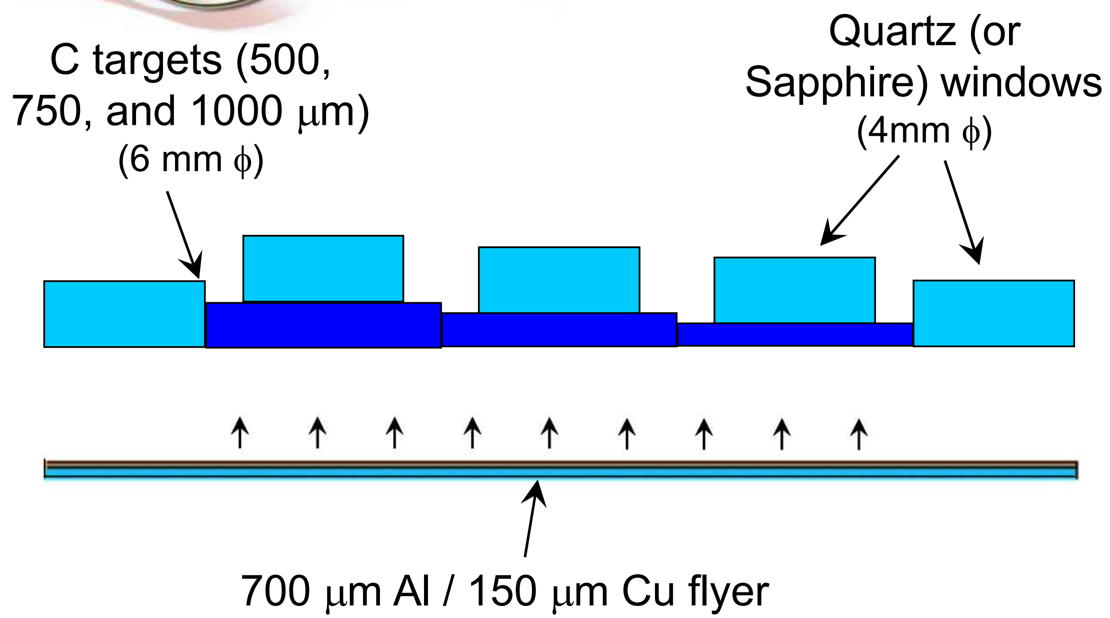
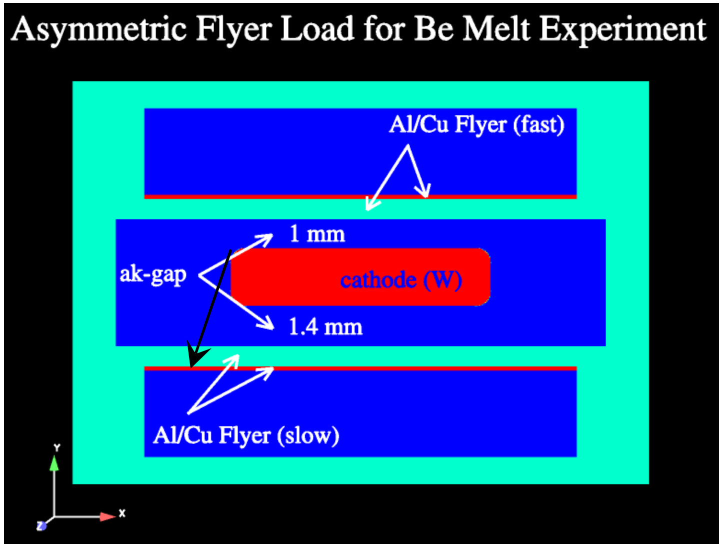
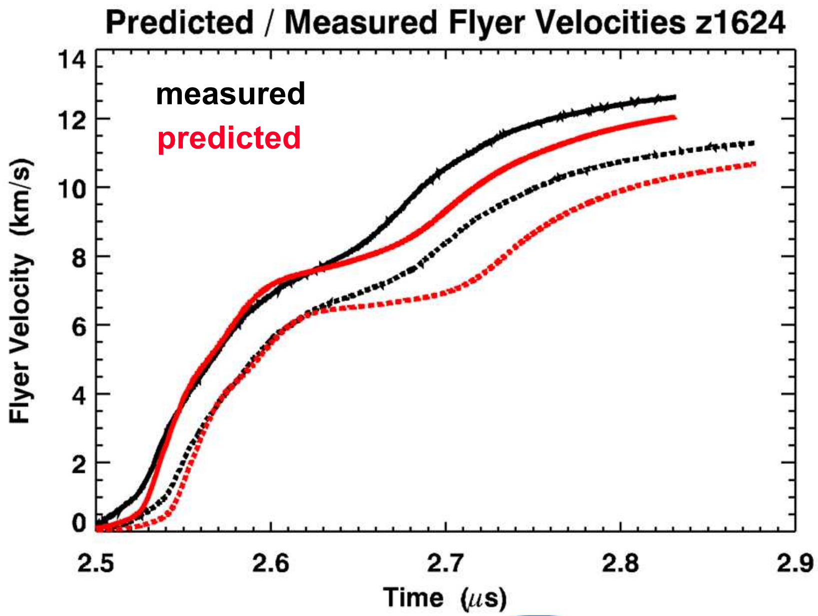
Correa, et al., PNAS **103**, 1204 (2006)

MHD simulations were critical in providing load geometries to achieve desired flyer velocities



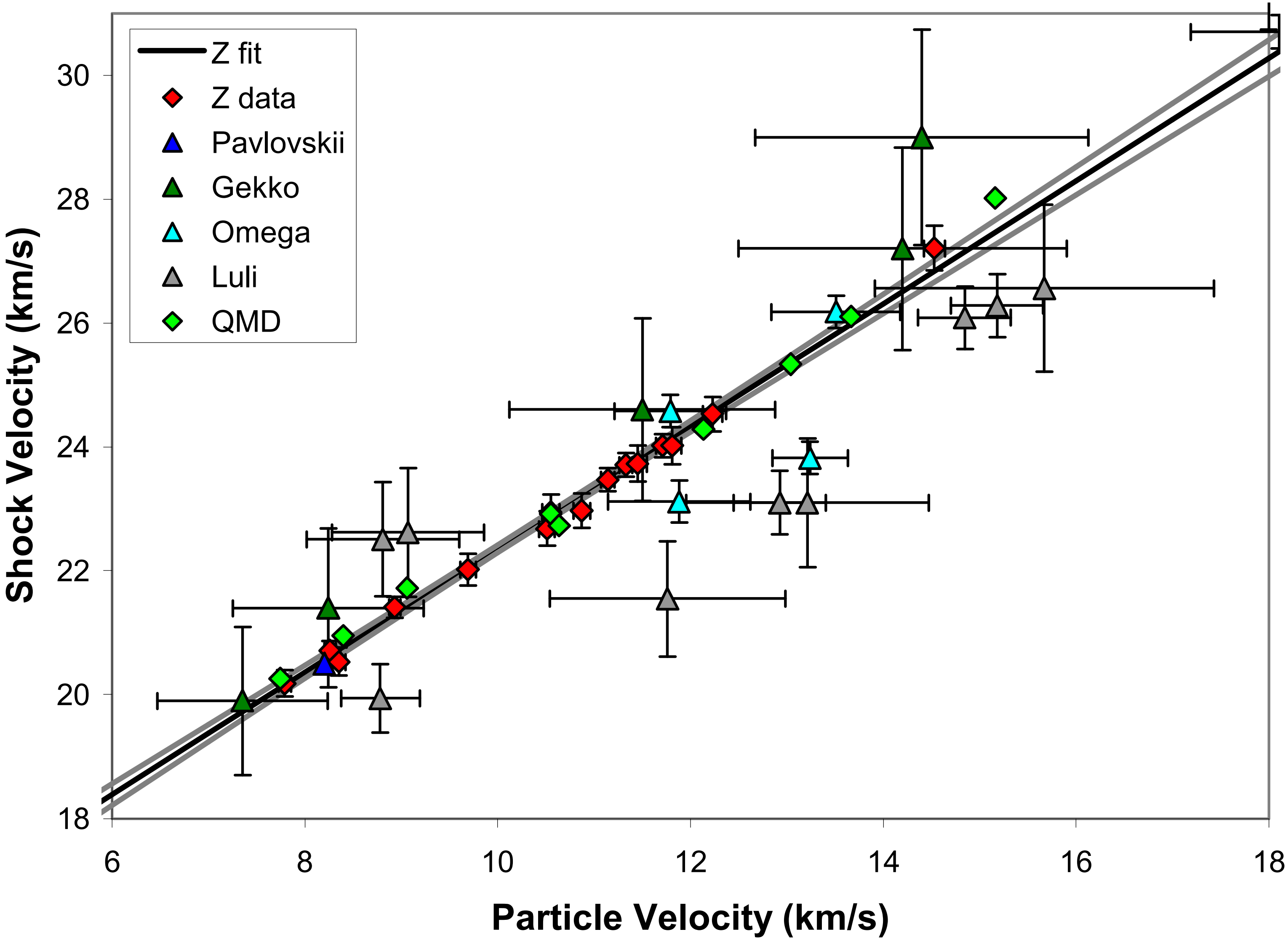




- Experiments required an Al/Cu flyer with peak velocities in the range of 7-24 km/s
- Four asymmetric loads were designed to produce 2 flyers per shot with ~10% difference in peak velocity
- ALEGRA 2D MHD was used to set flight distances and to set charge voltages on Z

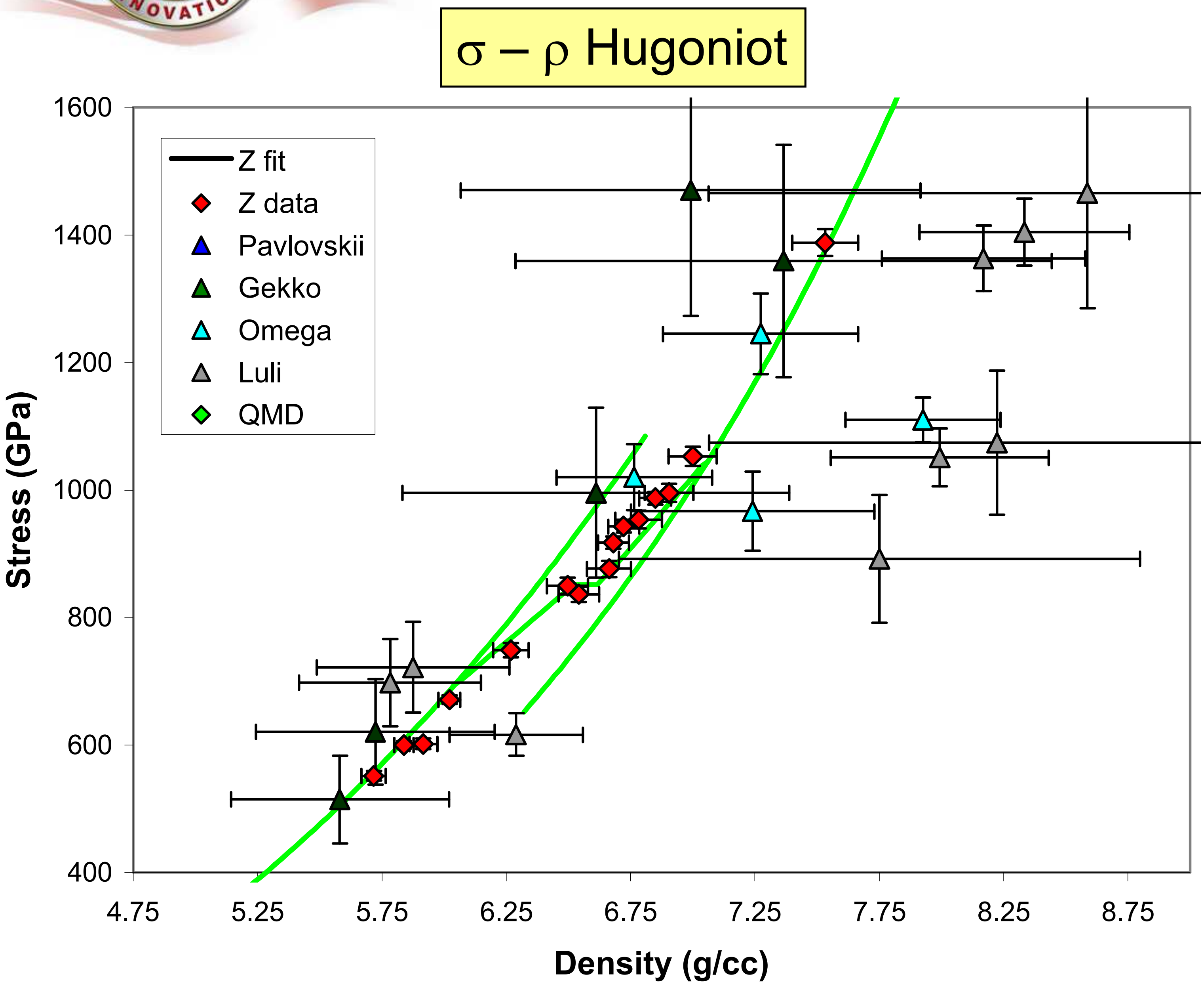
Experimental geometry enabled very precise Hugoniot measurements at multi-Mbar stresses

$U_s - u_p$ Hugoniot



- Sub-percent measurement of U_s and u_p
- Each point is a weighted average of 2 or 3 individual measurements (3 samples per panel)
- Significant benefit in being able to measure flyer plate velocity for impedance match

Experimental geometry enabled very precise Hugoniot measurements at multi-Mbar stresses



- Density precision of ~1% on average, as low as 0.67%
- High precision allows for quantitative comparison with theory
- These are by far the most accurate Hugoniot measurements of diamond in the multi-Mbar stress regime

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Summary of Results

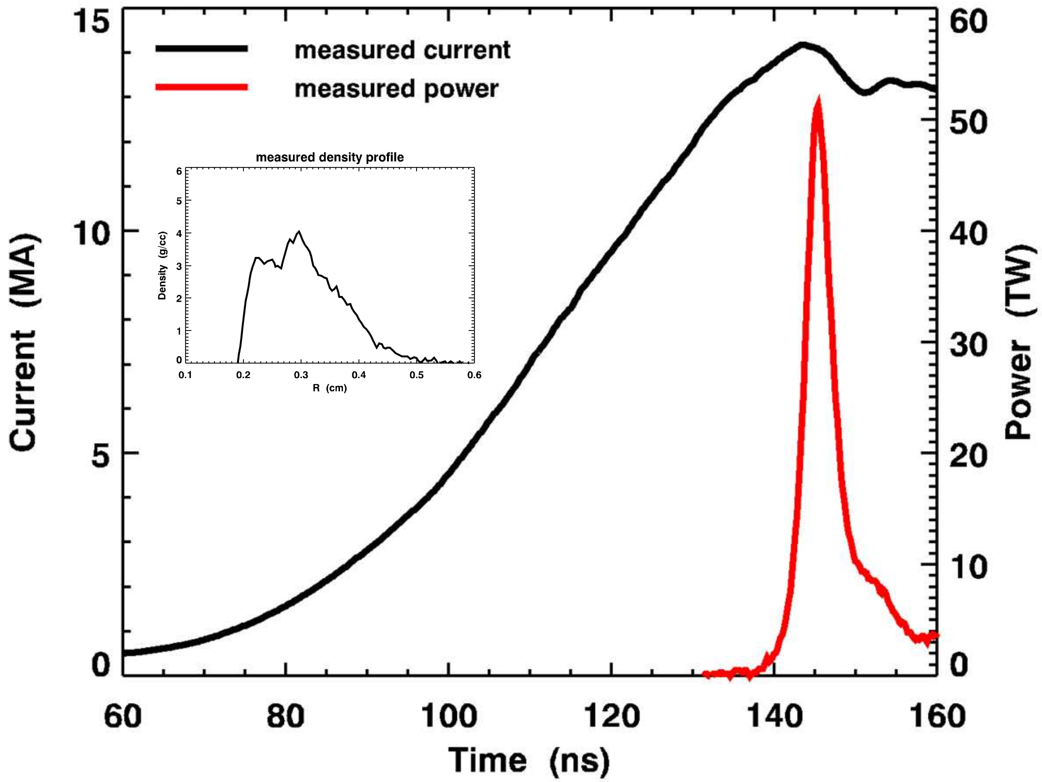
Beryllium Conclusions

- Be melts on the Hugoniot at ~210 GPa
- Be coexistence ~50 GPa
- Be melts directly from hcp (not bcc)
  - Caused us to revisit the phase diagram
- Be exhibits significant yield strength near melt, ~3.5 GPa

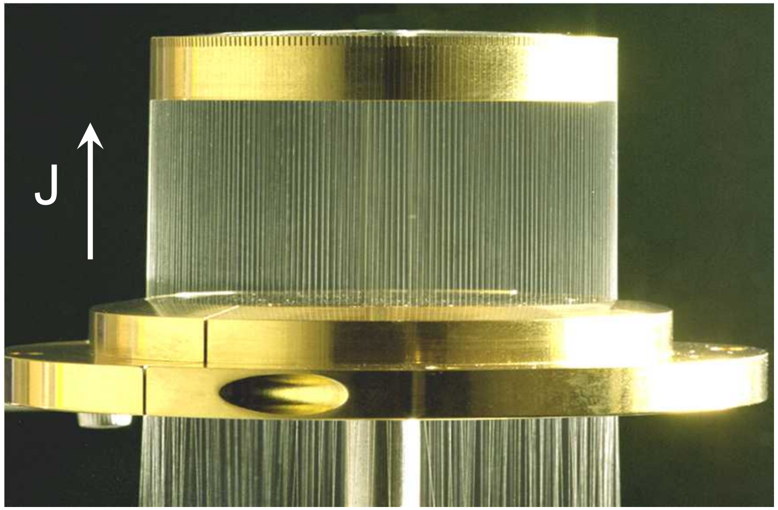
Diamond Conclusions

- Extremely precise Hugoniot measurements obtained for diamond at multi-Mbar pressures
- Diamond melts on the Hugoniot at ~650 GPa
- Diamond coexistence is large, ~400 GPa
- There appears to be a diamond-liquid-bc8 triple point along the coexistence curve at ~850 GPa
- Diamond exhibits an extremely large yield strength near melt, ~50-80 GPa
  - It appears there is negligible shear stress in the shocked state
- Nano- and Micro-crystalline samples appear to behave similarly

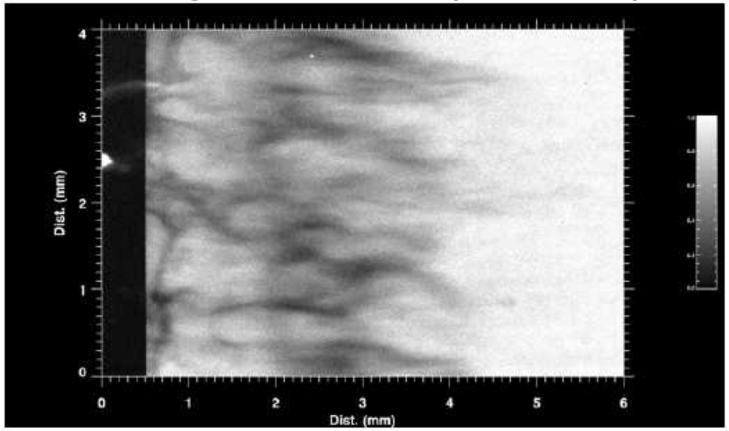
Understanding the dynamics of wire array z-pinches is critical for optimizing radiation sources



Wire Array Z-Pinch

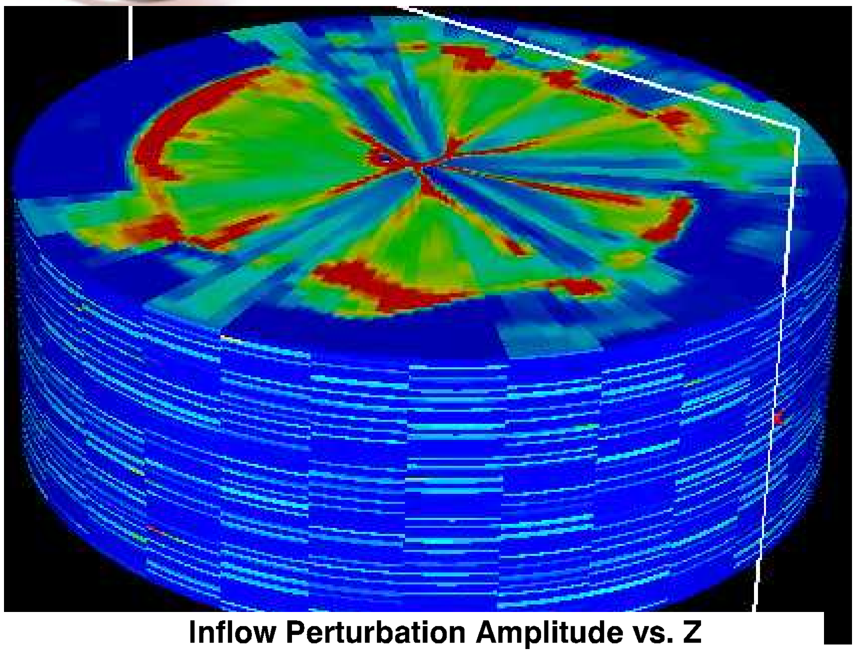


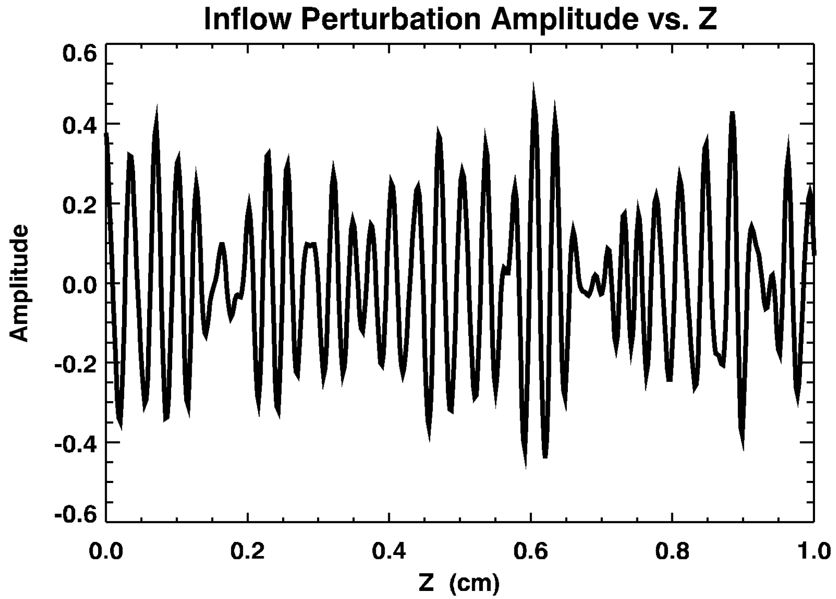
Radiograph t=-5 ns (D. Sinars)



Goal: Validate an ablation model for simulating wire array z-pinches using Z data; design & predict shots on ZR

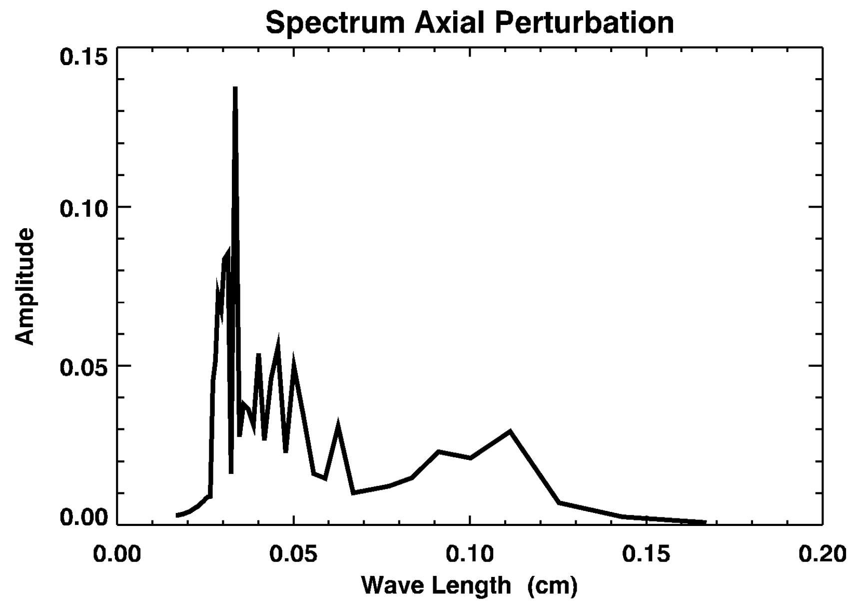
We are studying 3-D wire array z-pinch implosions using a mass ablation model



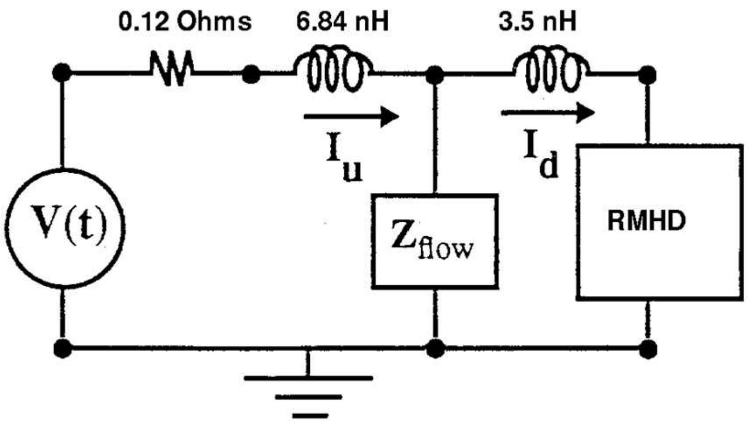


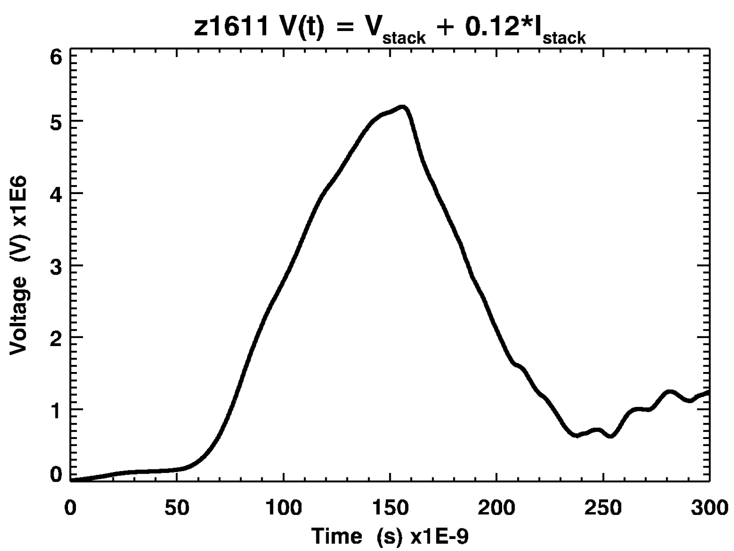
$$\dot{m} = \dot{m}_0 I^{1.4}$$

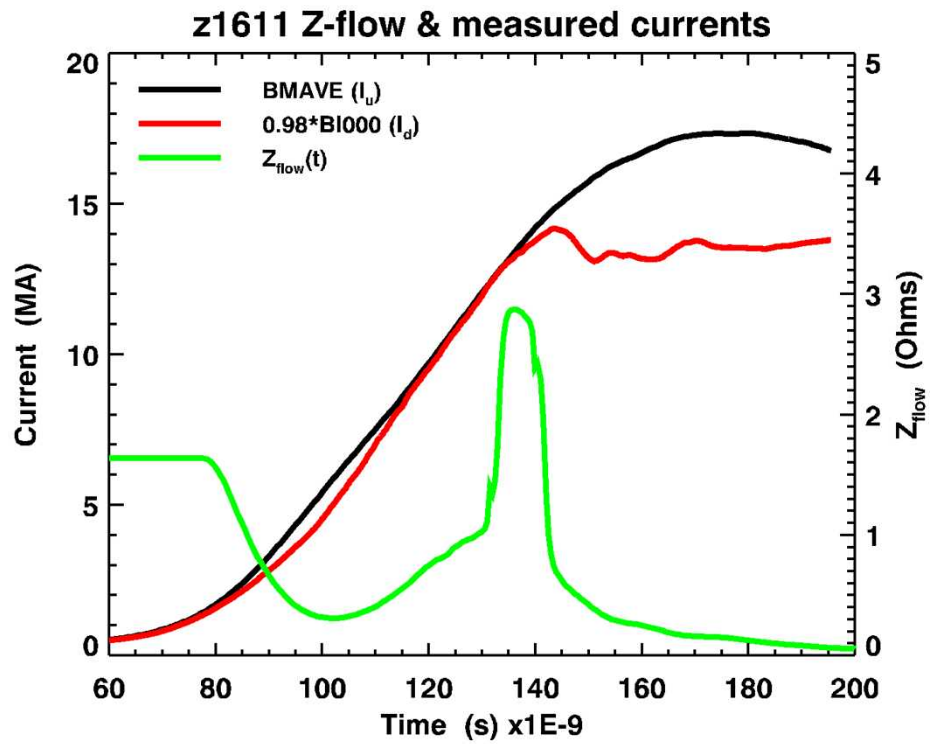
E.P. Yu, B.V. Oliver, P.V. Sasorov, et. al., Phys. Plasmas 14, 022705 (2007)



Z1611 stack voltage & current, mitl & load B-dots used to obtain $V(t)$ & $Z_{flow}(t)$ for simulation







$$Z_{flow}(t) = \Delta V / \sqrt{I_u^2 - I_d^2}$$

See Z circuit analysis in E. M. Waisman, et al., Physics of Plasmas 11(5), 2009-2013 (2004), in which the 4 MITL levels are accounted for.

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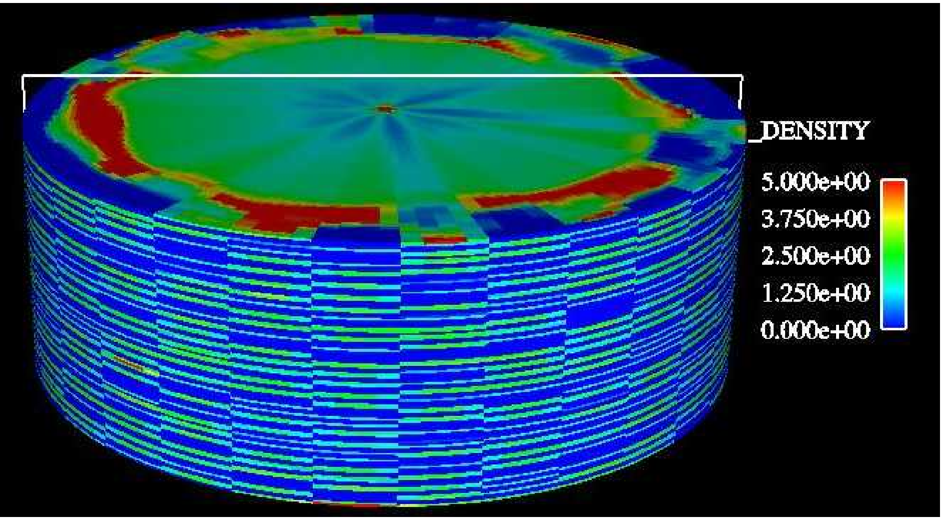
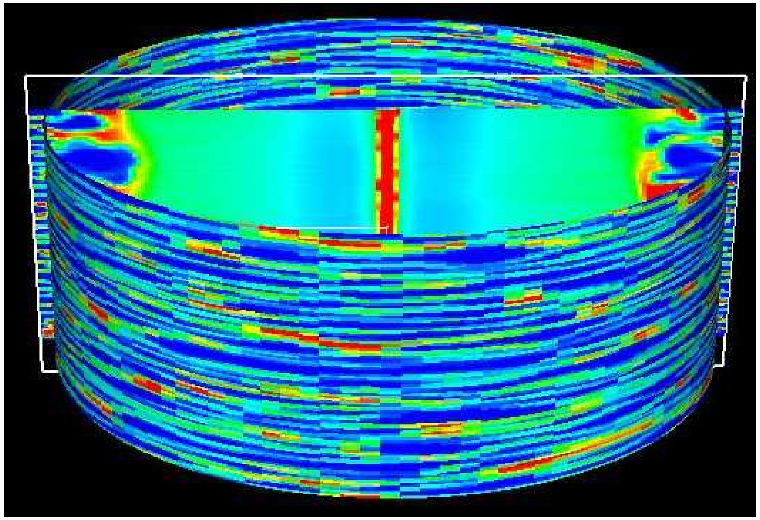
3-D simulations show azimuthal correlation of plasma structure grows with time & depth

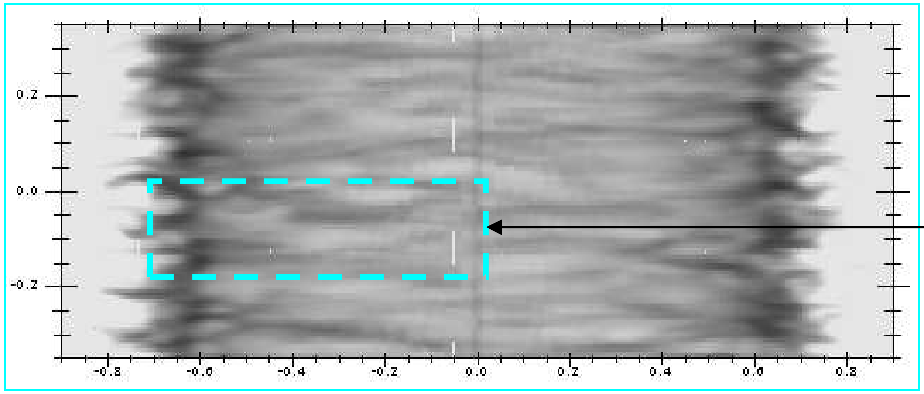
R=10 mm surface (entire pinch)

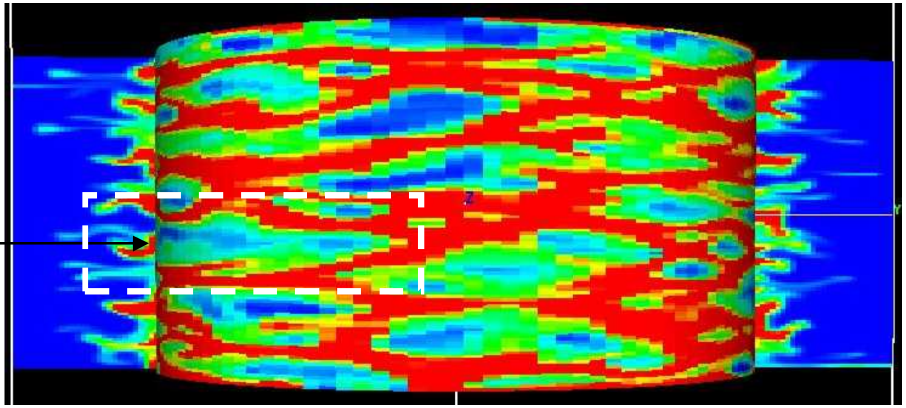


R=9.5 mm surface



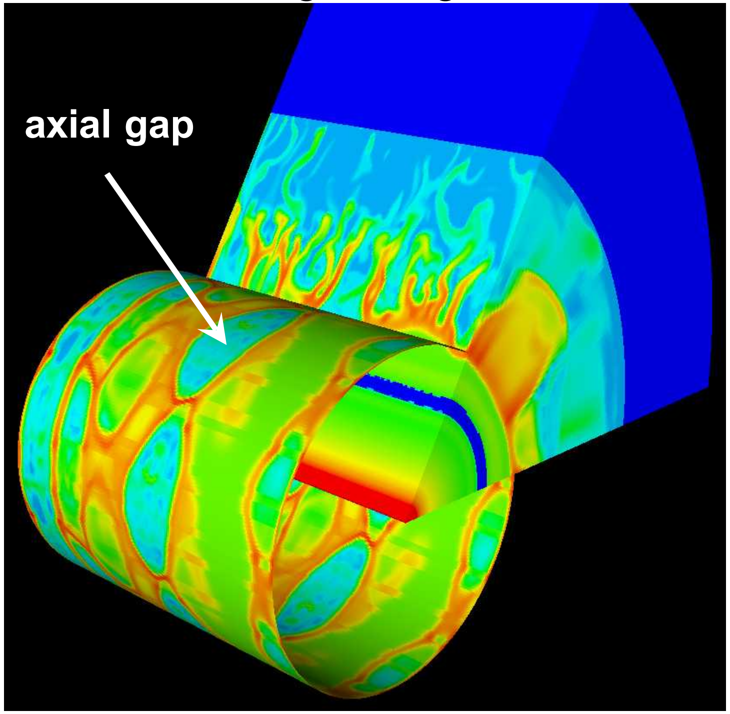
R=8 mm surface



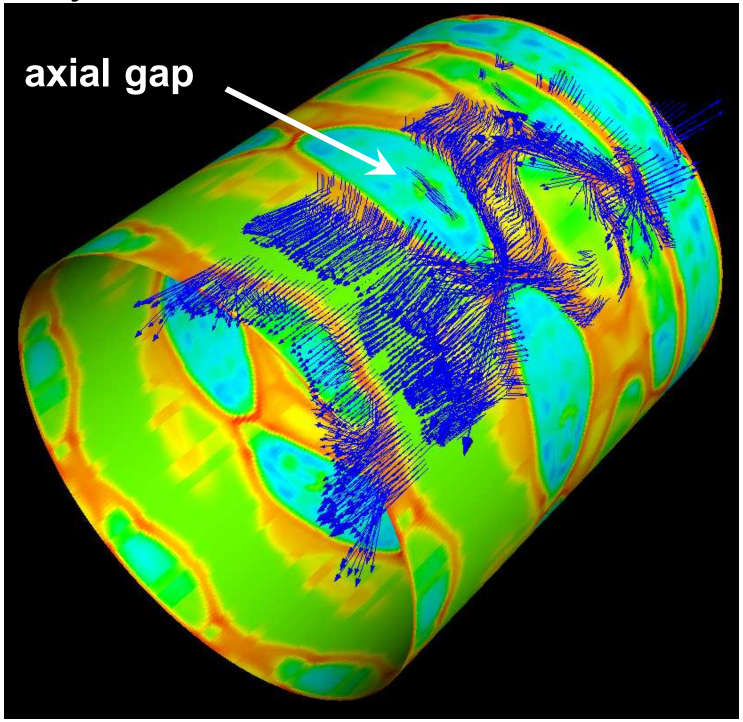


Z-pinch dynamics are 3-dimensional: current can flow around axial gaps in the plasma

60 Degree Periodic Wedge with Cylindrical Cut Surface through Tungsten Plasma



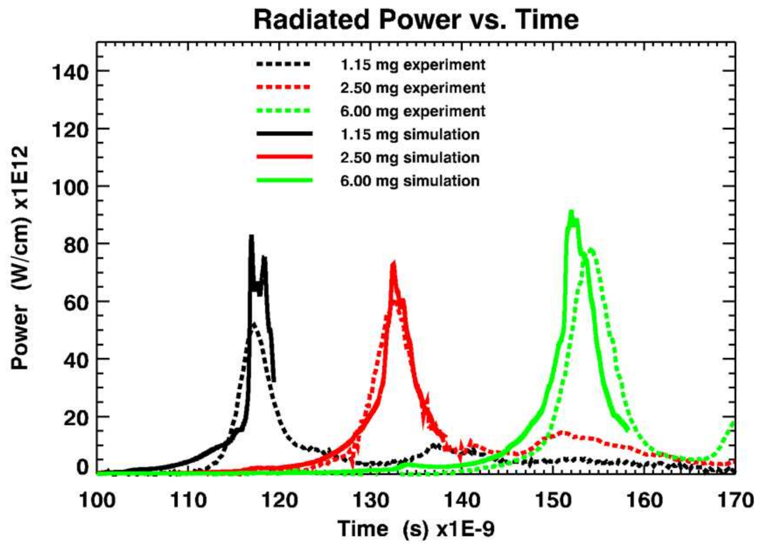
Current Density Vectors Superimposed on Cylindrical Cut Surface

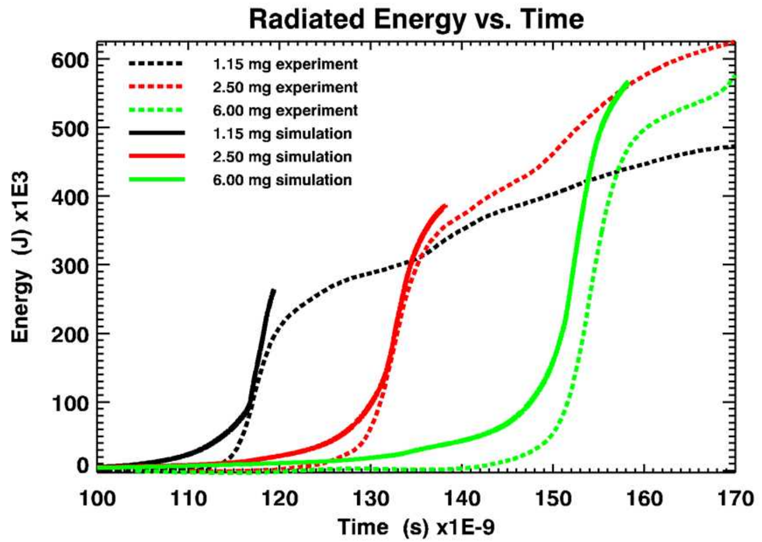


Radial & azimuthal currents create jXB forces that modify plasma structure

We are using this ablation model to guide the design for initial wire array shots on ZR

- Perturbation is fixed from experimental data, but we believe we will understand this theoretically soon.
- Mass ablation rate is constrained by the implosion time.
- Energies and powers then agree well with experiments, and partially validate ablation model.
- We are designing ZR shots to validate our understanding of how the model parameters scale.





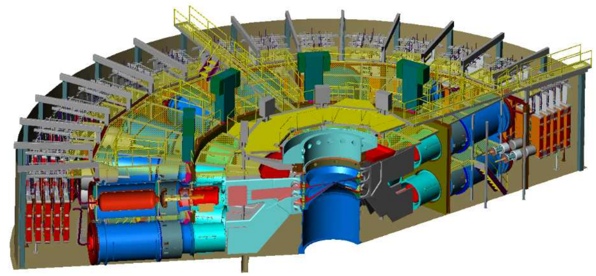
Data: D. B. Sinars et al, Phys. Plasmas 13, 042704 (2006).

For more details see

- ***Z-Pinch Physics Through Resistive Radiation Magnetohydrodynamics, Heath Hanshaw, Ray Lemke, Edmund Yu, Mike Desjarlais, and Tom Mehlhorn***

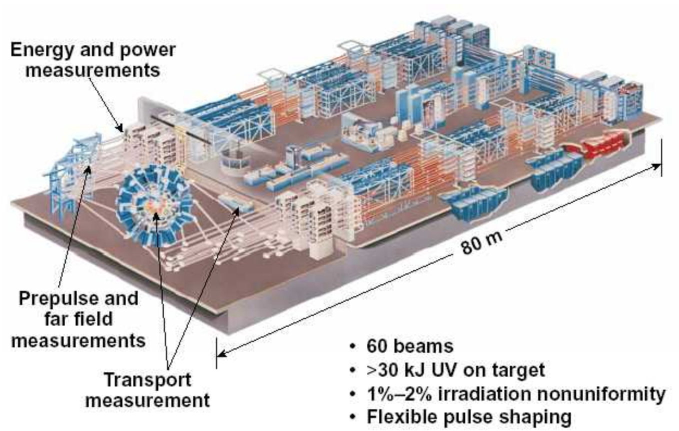
ZR + simulation tools makes Sandia the pulsed power center for HEDP research

ZR (2007)



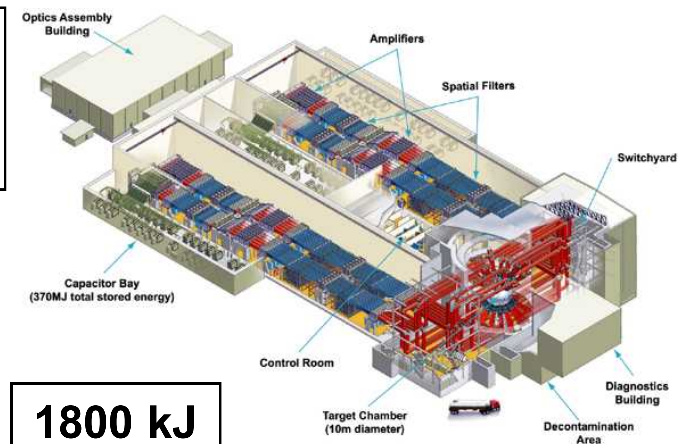
2700 kJ
>40 km/s
10 Mbar ICE (Cu)

Omega



30 kJ

NIF (2010)



1800 kJ