Solid Liner Implosions on Z SAND2011-8821C
Multi-Megabar, Shockless Compressions

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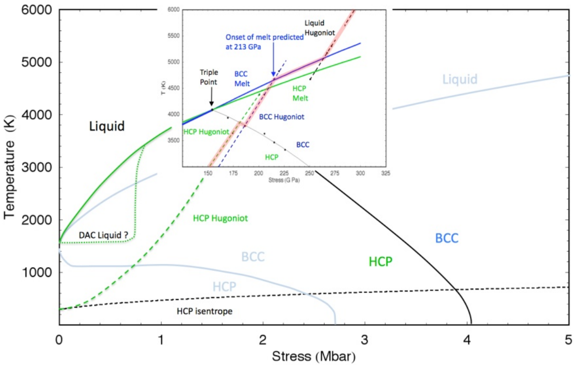
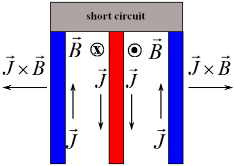
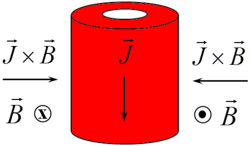
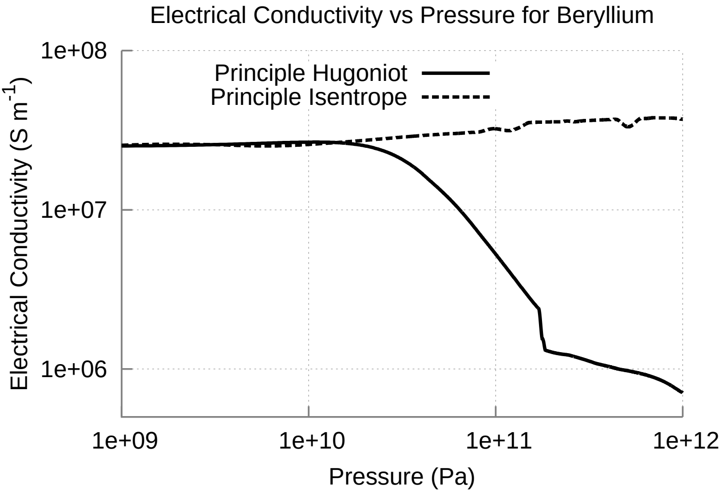
Exploring Extreme States of Matter with Pulsed Power



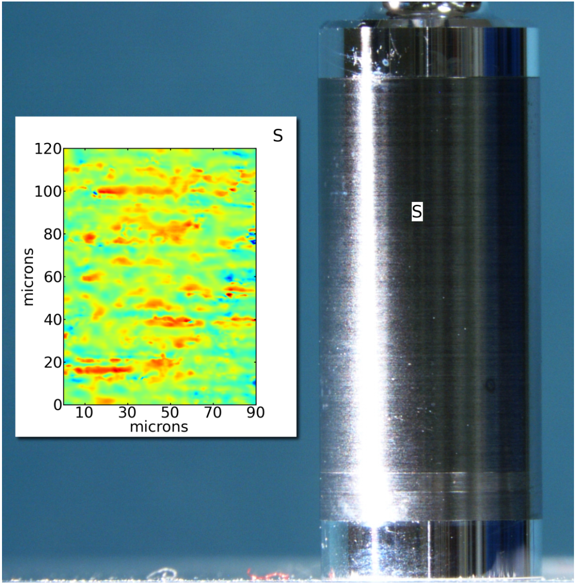




Compression Path Changes the Implosion Dynamics



Diamond Turned Beryllium Liner



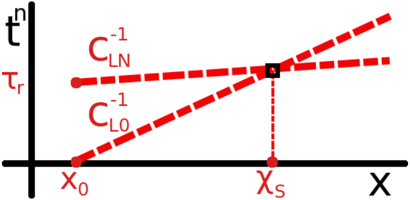
Liner Dimensions

- Liner Height: $1.0cm$
- Outer Radius: $0.29mm$
- Aspect Ratio: 4

Liner Surface

- RMS Height: $\approx 200nm$
- Peak to Valley: $\approx 1\mu m$

Magnetohydrodynamic Drive Pulse Shaping



Given an isentrope $P_n(C_{Ln})$ defined between reference state P_0 and final pressure P_N, the shockup distance, χ_s, is determined from the rise time τ_r and the range of Lagrangian sound speeds C_{Ln}:

$$\chi_s = \tau_r C_{LN} C_{L0} / (C_{LN} - C_{L0})$$

The isentropic pressure drive $P_n(t_n)$ is then determined from:

$$t_n \approx t_r - \chi_s [C_{LN}(P_N) - C_{Ln}(P_n)] / [C_{LN}(P_N) C_{Ln}(P_n)]$$

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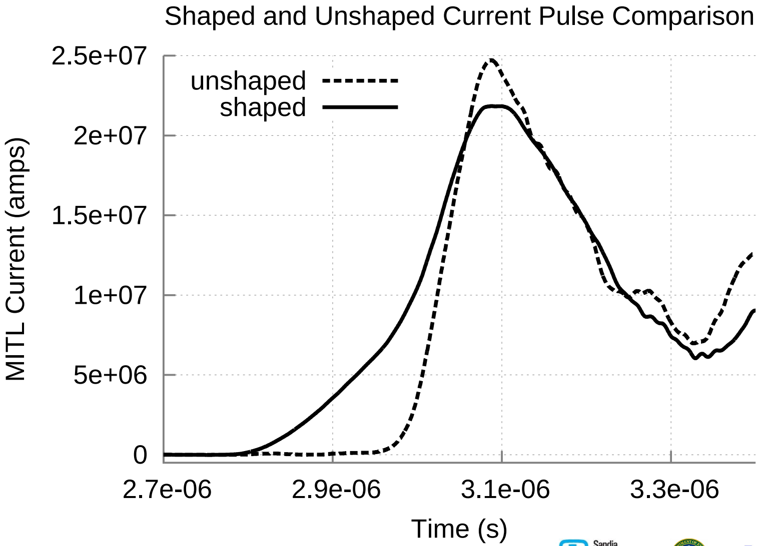
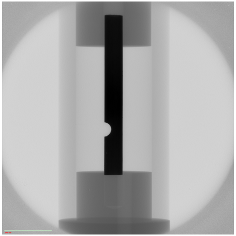
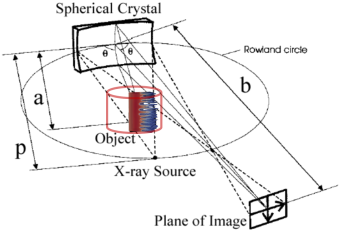
Shaped Current Pulse Determined From Beryllium EOS



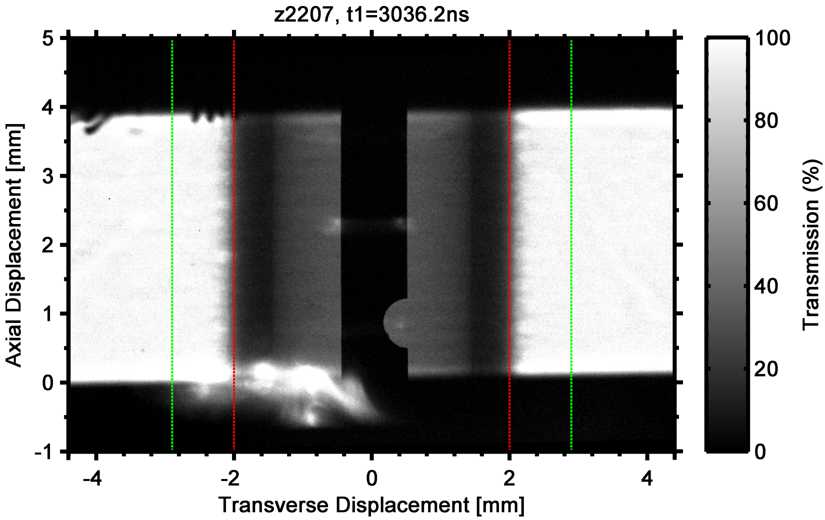
Diagnostic Suite for Solid Liner Experiment

- Radial VISAR diagnostic measures inner surface velocity
- MITL and stack B-dot probe current measurement
- Load current VISAR to detect current loss
- Z-Beamlet backlighter with two-frame 6.151 keV monochromatic imaging
- Fuji BAS-TR2025 image plate detector with $\approx 15\mu m$ spatial resolution after magnification





Liner Experiment Radiographs



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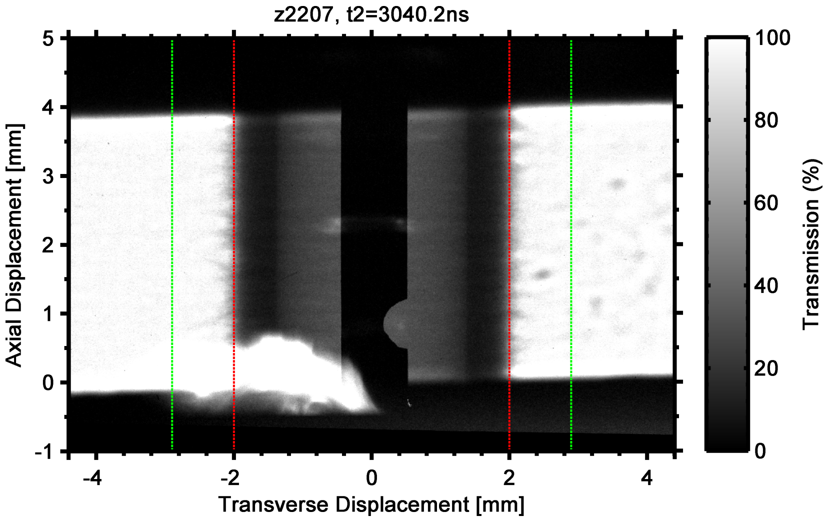

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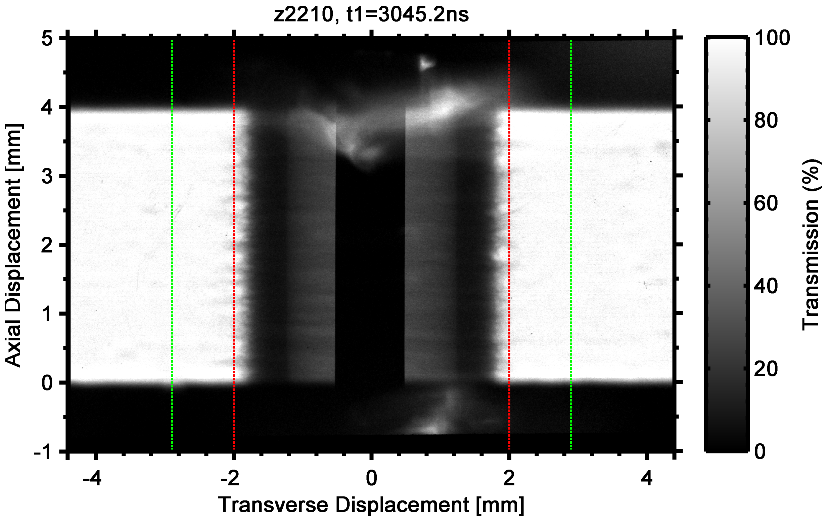

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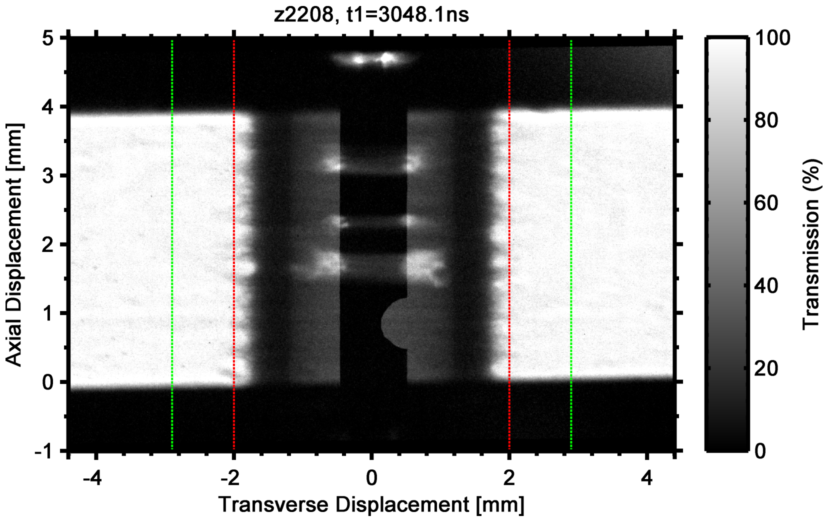
Liner Experiment Radiographs



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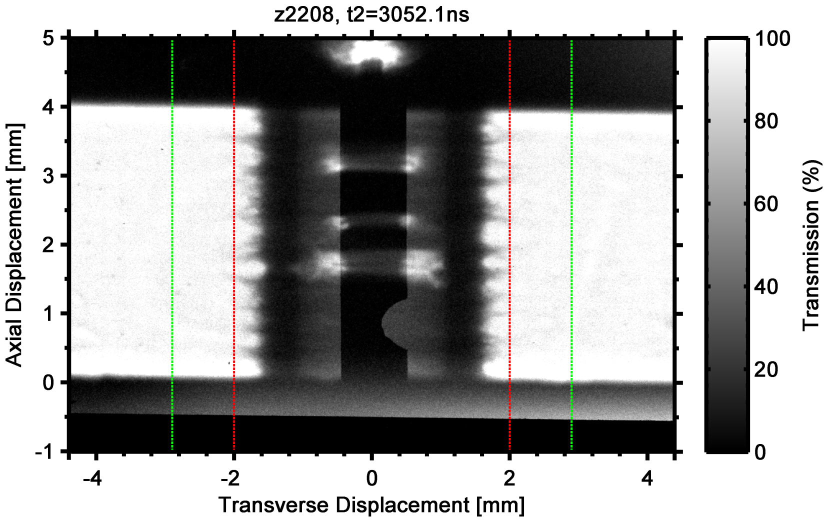

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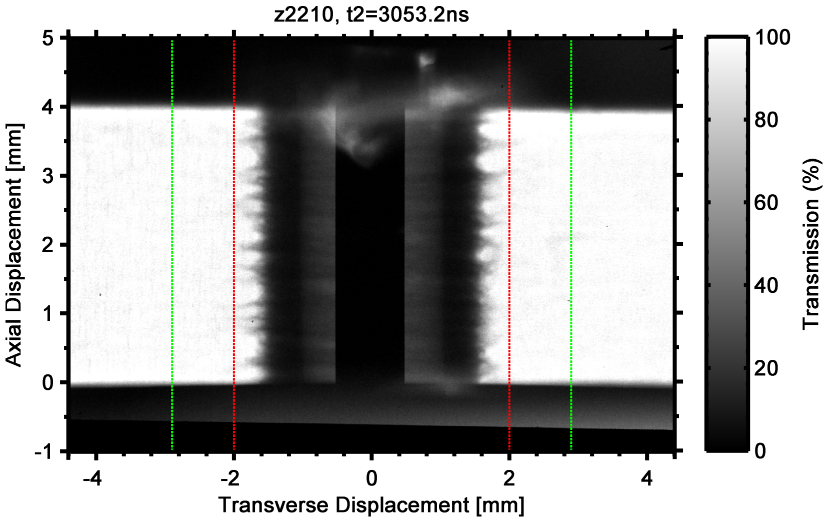
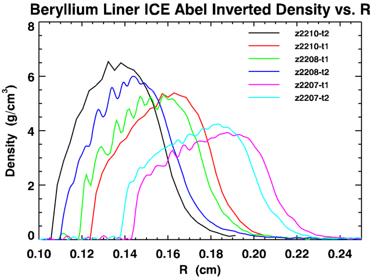
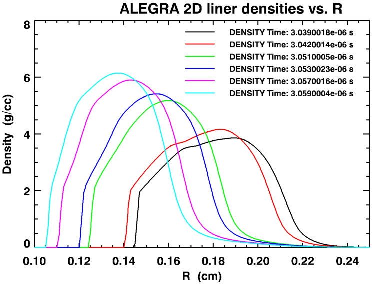


Abel Inverted Density Profiles Validate Simulation





- Density profiles are Abel inverted from axially averaged and normalized intensity profile
- Mean opacity is estimated from known initial line mass of the target and the measured total attenuation
- MHD simulation is driven with VISAR unfolded load current and initialized with measured surface roughness

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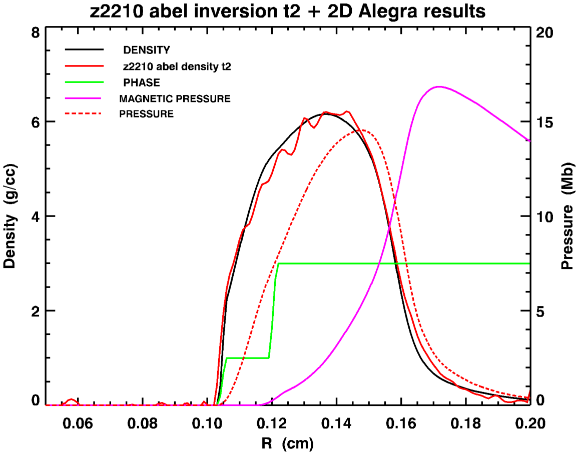
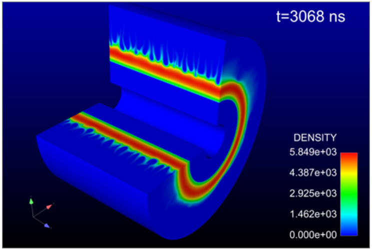
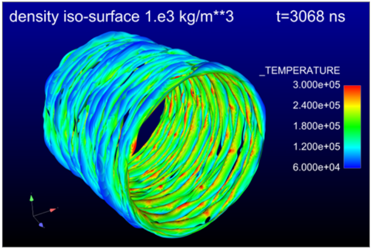
Structure of Imploding Liner at Multi-Megabar Pressures



3D Multiphysics Alegra Simulation of Liner

- 360° Rad-MHD simulation using 30,000 cores on Cielo supercomputer
- Inner surface of liner remains solid and is unperturbed by Magneto-Rayleigh-Taylor instability
- Structure of MRT instability is inherently 3D and couples into field diffusion rate
- For more results on MRT instability in magnetically imploded cylinders, see McBride talk (UO8.00011) in ICF and Magneto-Inertial Fusion session Thursday





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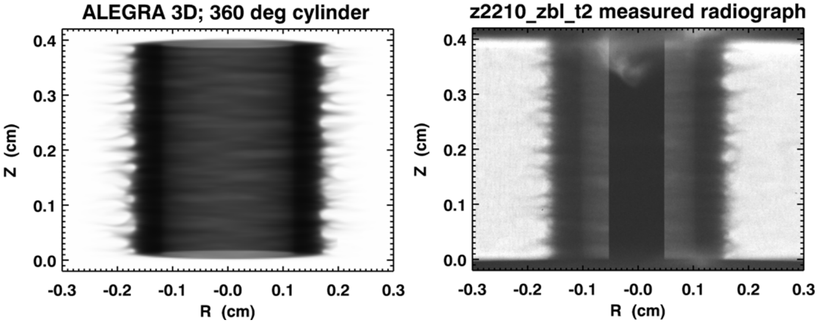
Direct Comparison of Experiment to Synthetic Diagnostics



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Lagrangian Surface Fitting Analysis

Conservation of mass and momentum:

$$\frac{D\rho}{Dt} = -\rho\nabla\cdot\mathbf{u}$$

$$\frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho}\nabla P$$

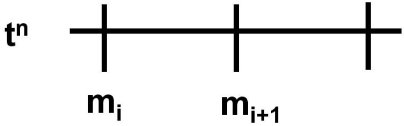
Transform into 1D Lagrangian cylindrical coordinates:

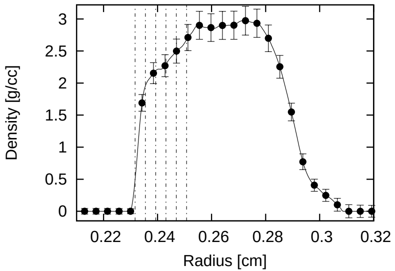
$$dm = 2\pi L_z \rho r dr$$

$$\frac{\partial\nu}{\partial t} = 2\pi L_z \frac{\partial\left(r u_r\right)}{\partial m}$$

$$\frac{\partial u_r}{\partial t} = -2\pi L_z r \frac{\partial P}{\partial m}$$

Lagrangian Surface Fitting Analysis



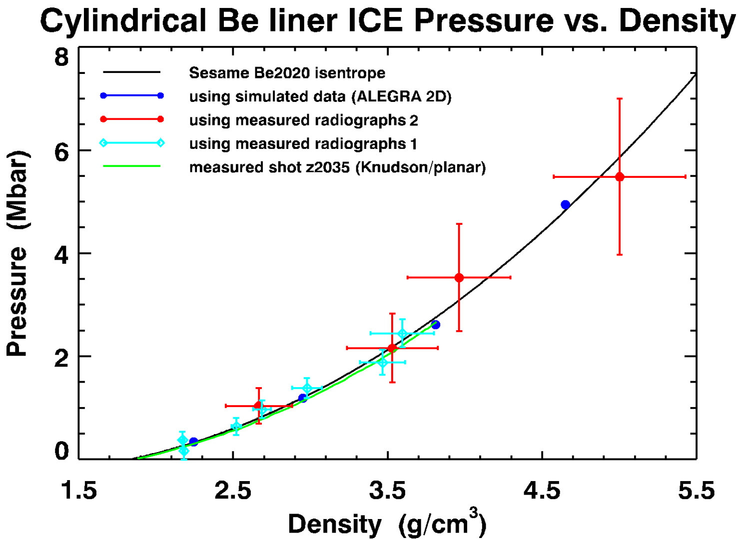


Solve semi-discrete equations on mass grid:

$$u_r^{i+1} = \frac{1}{r^{i+1}} \int_{m^i}^{m^{i+1}} \frac{1}{2\pi L_z} \frac{\partial \nu\,(m,t)}{\partial t} dm + \frac{r^i}{r^{i+1}} u_r^i$$

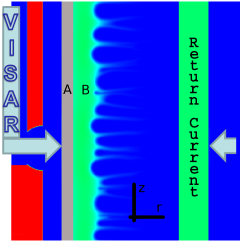
$$P^{i+1} = -\int_{m^i}^{m^{i+1}} \frac{1}{2\pi L_z r\,(m,t)} \frac{\partial u_r\,(m,t)}{\partial t} dm + P^i$$

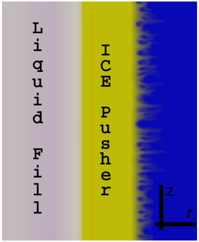
Comparison of Surface Fitting Analysis to Previous Data



Future Applications of Solid Liner Implosions

- Radial velocity diagnostics will greatly reduce uncertainties and remove the opacity constraint of radiographic diagnosis
- Pulse shaping allows for the study of instability growth in previously inaccessible areas of the EOS
- Explore stagnation time mixing of liner interface with a gas or liquid fill





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Conclusions

- Presented a new cylindrical ICE platform that has achieved the highest pressure results to date on the refurbished Z-machine, quasi-isentropically compressing beryllium to $\approx$ 6.0 Mbar
- Demonstrated that surface fitting analysis in conjunction with multi-frame monochromatic radiography and reproducible pulse shaping allows for the inference of the pressure state inside a ramp compressed sample
- Utilized massively parallel 3D multiphysics simulation to understand the structure and dynamics of solid liner implosions
- Future experiments with radial VISAR measurement are possible at pressures greater than 10 Mbar