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Measurement of dynamic strength at high pressures using magnetically applied pressure-shear (MAPS) on the Sandia Z accelerator

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Sandia National Laboratories

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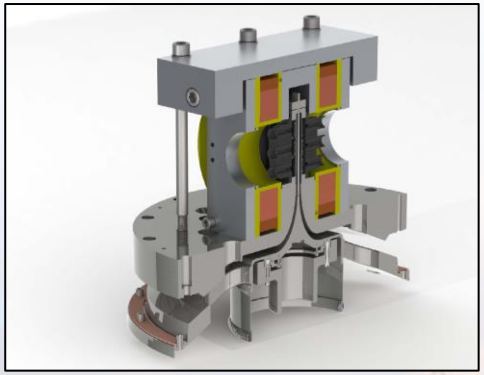

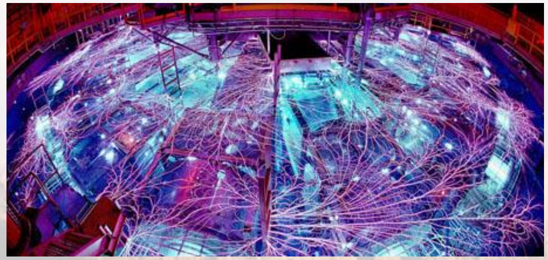

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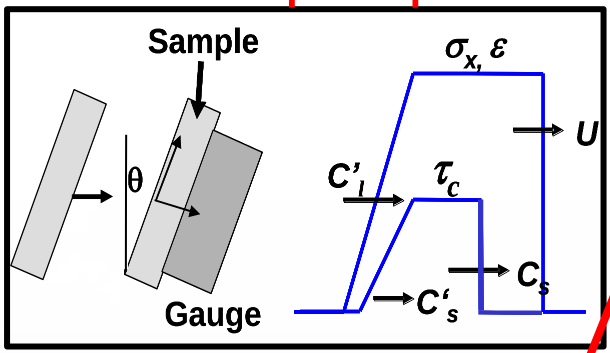
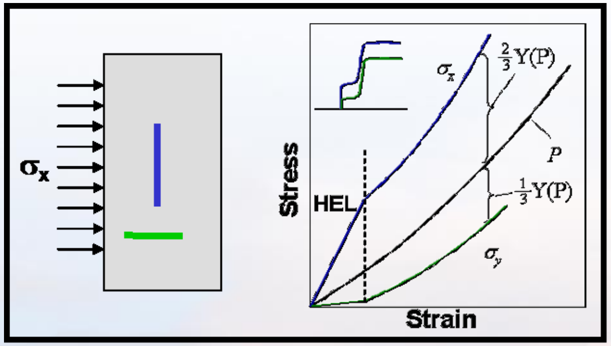
Existing strength measurement techniques have limitations at high pressure

Oblique impact



Lateral gauges



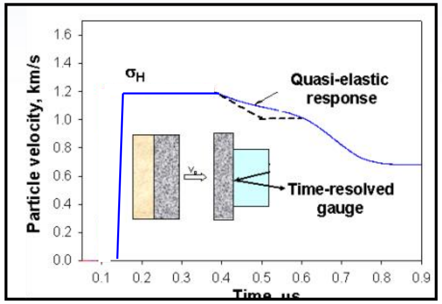
Limited to low P (<200 kbar or 20 GPa)

Requires assumptions

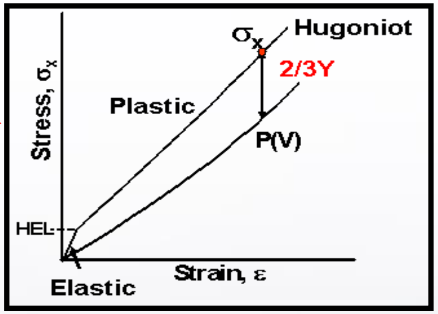
Large uncertainties

Requires accurate models which are unknown

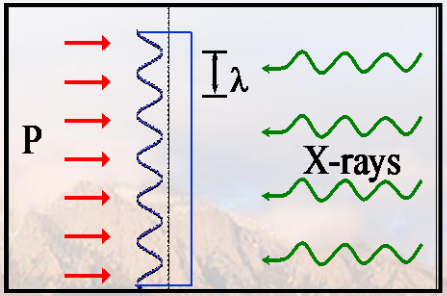
Wave Profile



Stress Difference



Rayleigh-Taylor



There is a need for improved strength measurement capability at high pressures

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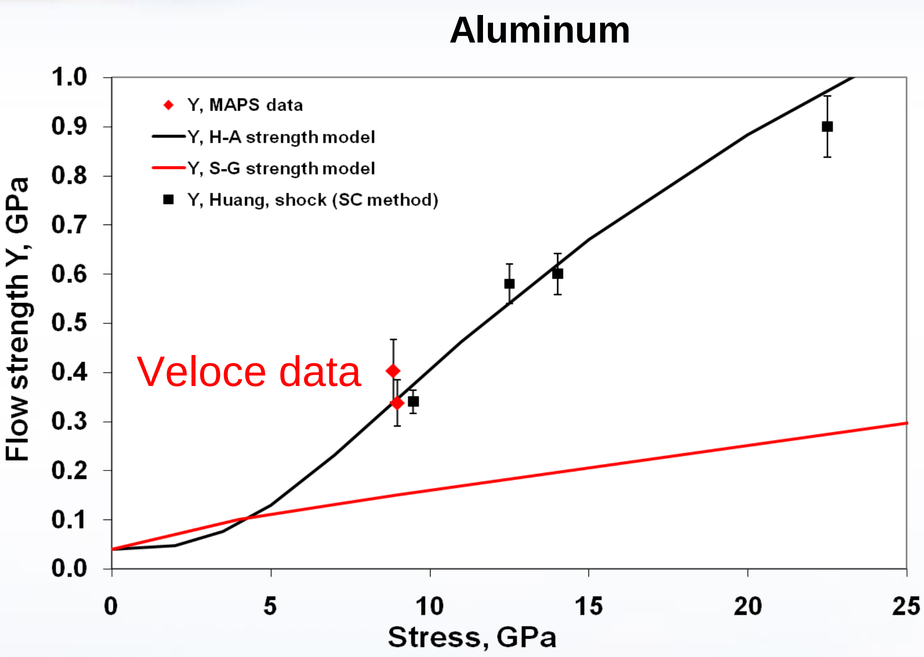
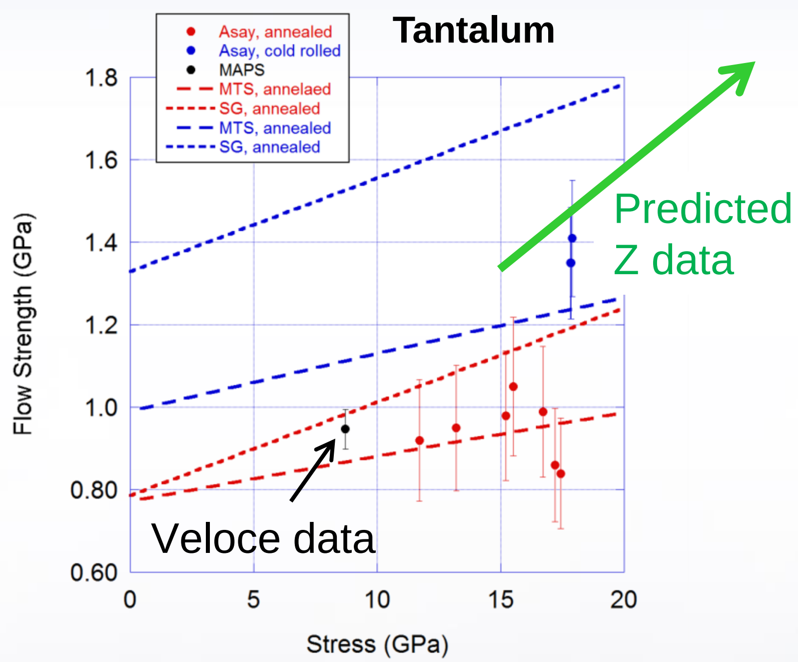
MAPS directly measures strength at high pressures

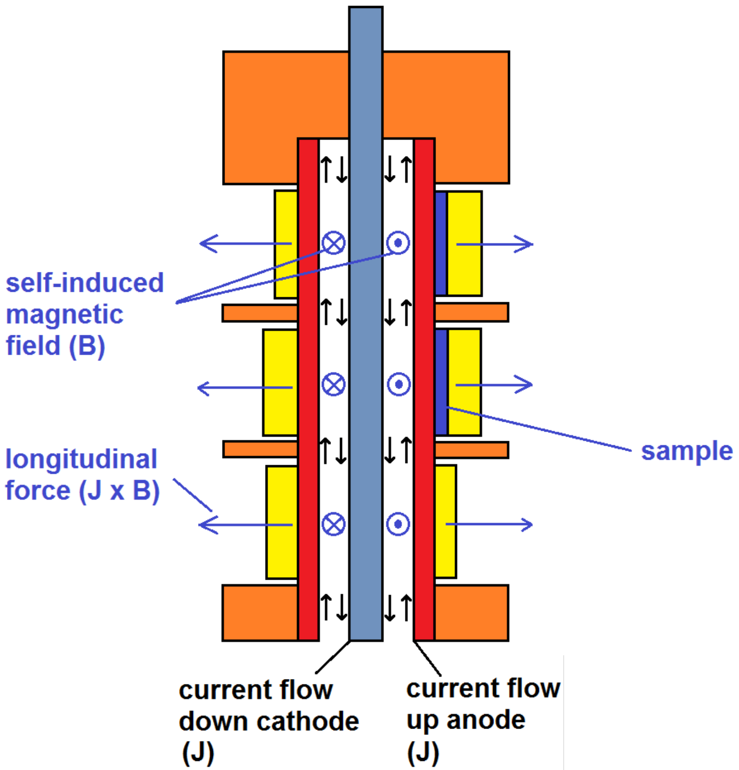


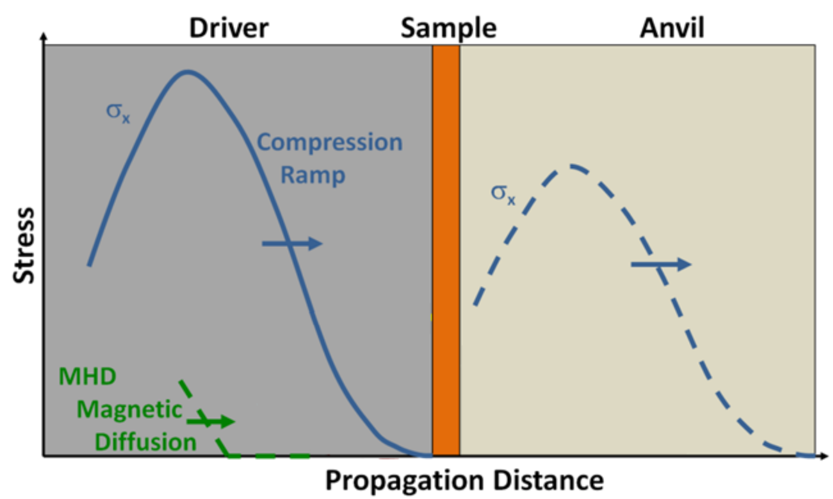


- Technique easily discriminates between strength models
- Z experiments are planned on Ta at 30 GPa and 50 GPa

1. C.S. Alexander, J. R. Asay and T. A. Haill, *J. Appl. Phys.* 108, 126101 (2010)
2. H. Huang and J.R. Asay, *J. Appl. Phys.* 98, 033524 (2005)
3. D.J. Steinberg, S.G. Cochran, and M.W. Guinan, *J. Appl. Phys.* 51, 1498 (1980)
4. J.R. Asay et al., *J. Appl. Phys.* 106, 073515 (2009)

Pulsed power drives generate pressure ramps with electric current flowing on parallel plates





- Standard coax loads have no applied magnetic fields
- Load current generates a magnetic field in the gap between the anode and cathode
- Lorentz forces result in longitudinal stresses that drive the anode plates outward

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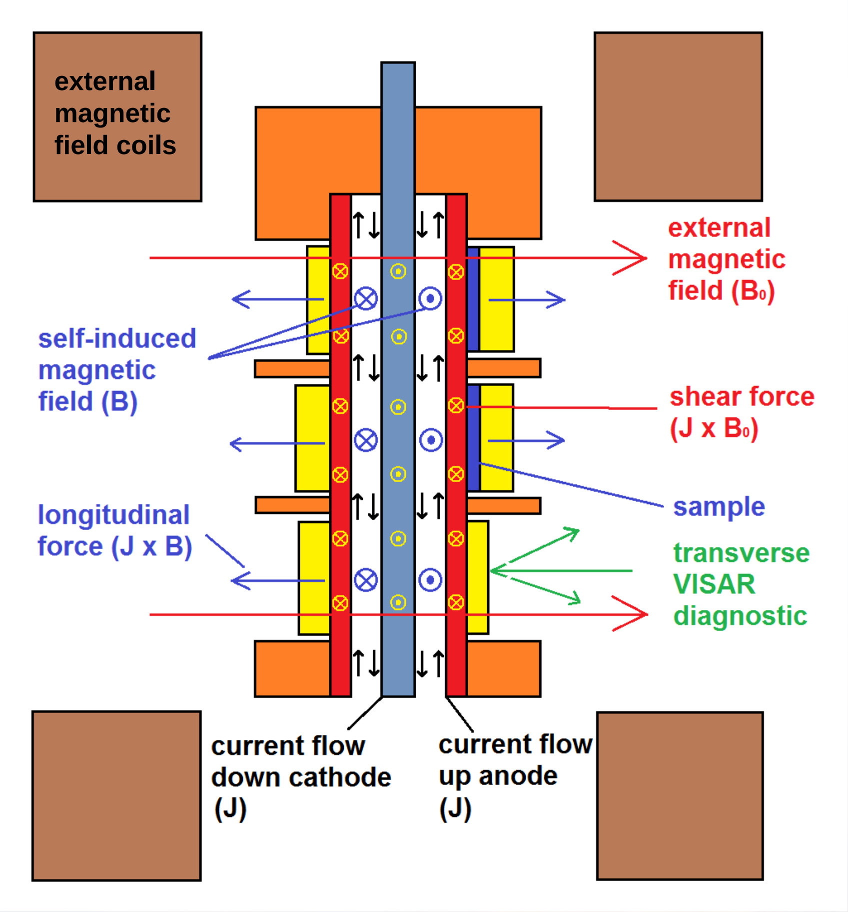
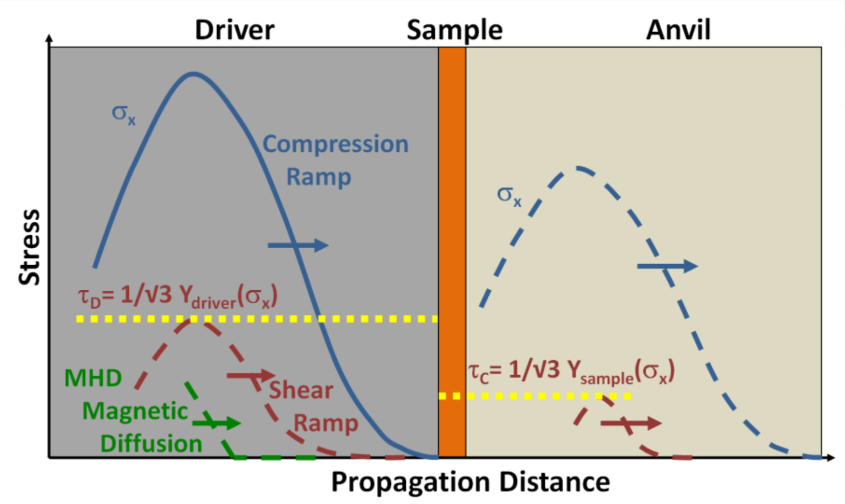
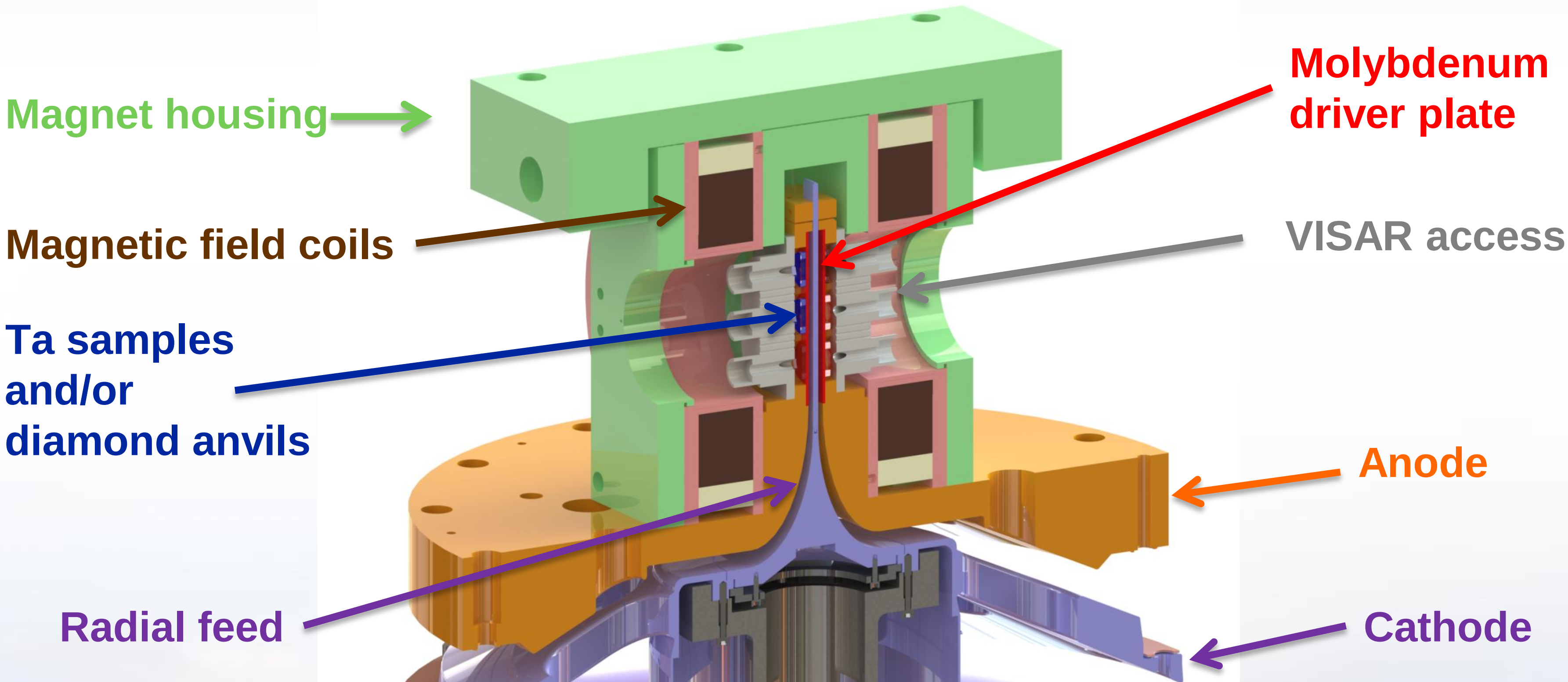
MAPS adds an applied longitudinal magnetic field to generate a shear wave

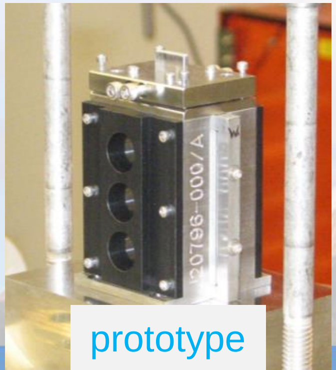




- MAPS applies an external magnetic field (B_0) that results in a shear wave
- Shear wave is truncated by sample based on material strength
- Elastic anvil material allows for coexistence of longitudinal and shear waves without coupling

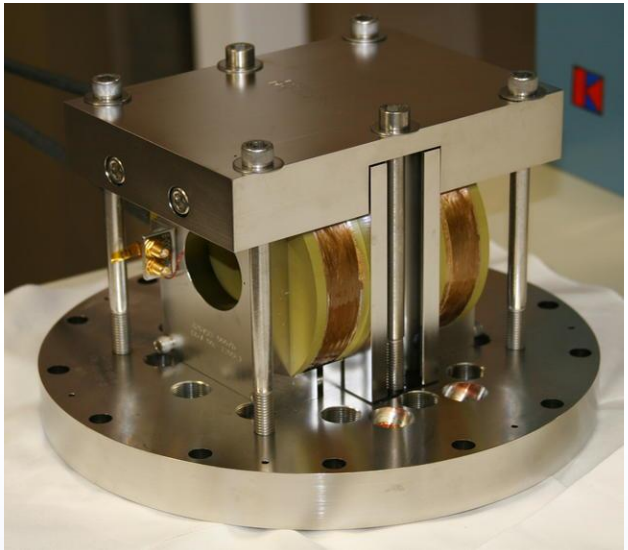
Implementation on Z requires modification of a standard coaxial load

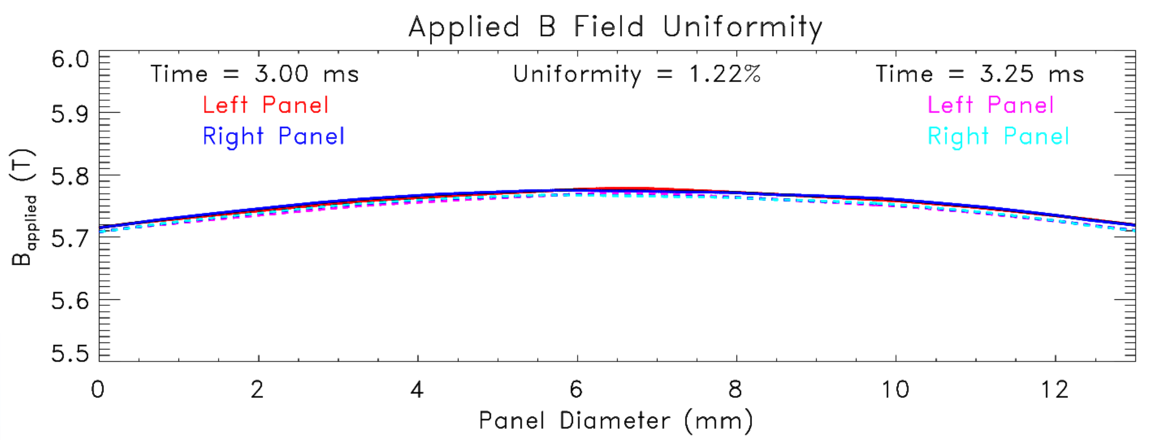



prototype


final design

Long-pulse coils produce a uniform longitudinal magnetic field

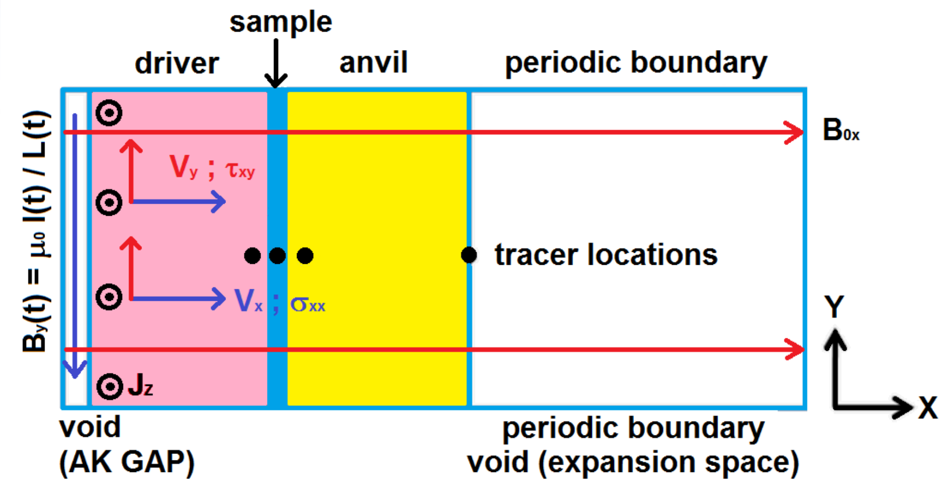




- **Applied B_o coils are developed and tested at the Sandia Systems Integration Test Facility (SITF)**
- **Long-pulse ~4.75-ms FWHM currents drive the applied B field coils**
- **B field magnitude is uniform to ~1.2% across 12 mm diameter sample**
- **B field magnitude is uniform to <0.5% during a 250 ns time interval**

ALEGRA 2D modeling is used to optimize the design of MAPS experiments

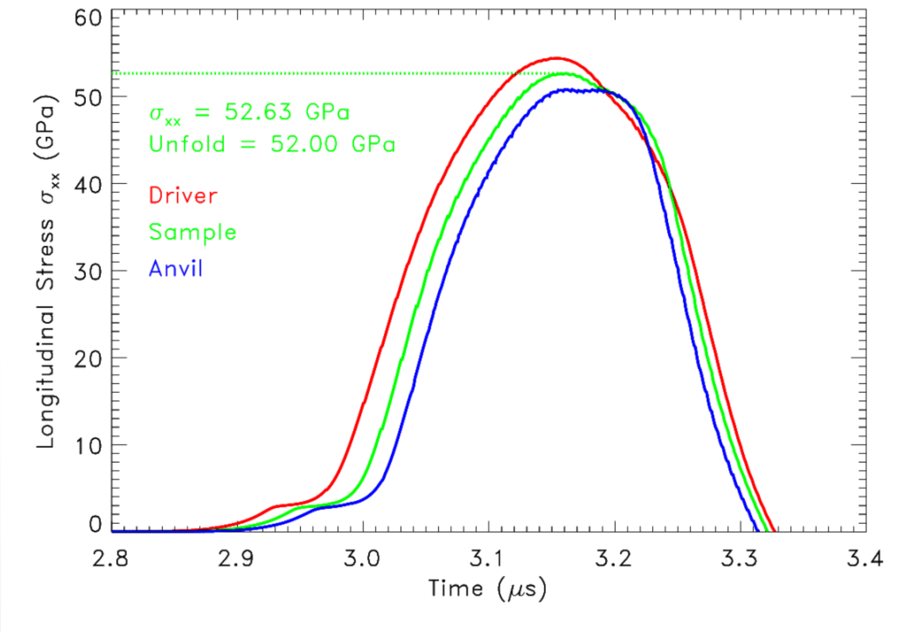
- Assume uniformity near center of sample
- 2D Cartesian Eulerian mesh
    - 5 - 10 μm cell size
- Periodic mesh in transverse or shear direction (Y)
- Uniform, static B_0 magnetic field in longitudinal direction (X)
- Current driven tangent magnetic field applied at AK gap



MAPS Materials and Material Model Parameters

Panel Layer Material	Equation of State	Strength Model	Conductivity Model	Density (g/cm^3)	Longitudinal Wave Speed (km/s)	Shear Wave Speed (km/s)	Yield Strength (GPa)
Driver Molybdenum	LANL Sesame 2984	CTH Elastic-Plastic Steinberg-Guinan-Lund	Lee-More-Desjarlais (LMD)	10.22	6.45-6.45	3.47-3.48	0.9
Sample Tantalum	LANL Sesame 3720	CTH Elastic-Plastic Steinberg-Guinan-Lund	Lee-More-Desjarlais (LMD)	16.654	3.35-4.16	2.07-2.09	0.375
Anvil Diamond	LANL Sesame 7834	CTH Elastic Perfectly Plastic	Insulator	3.5126	18.328	11.659-12.0	50-90

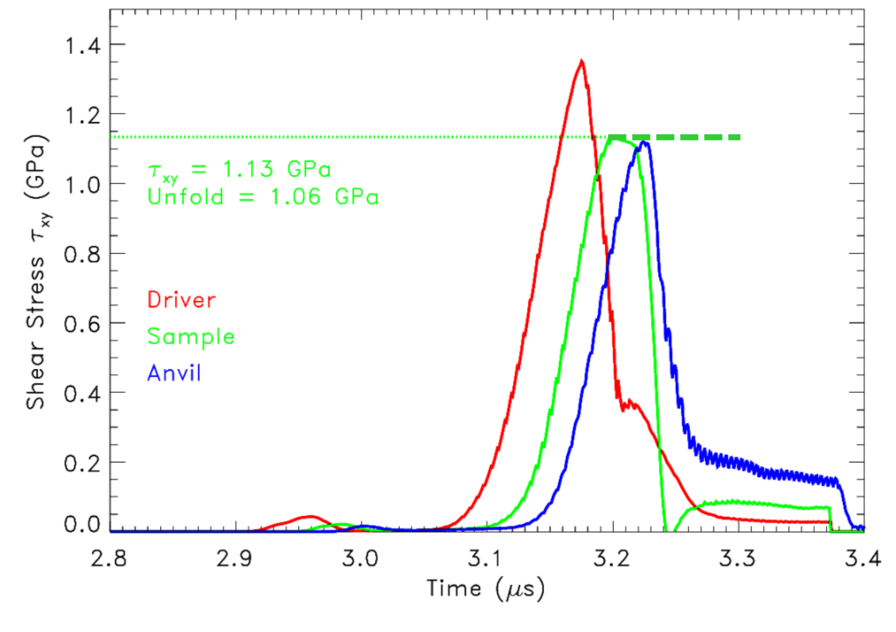
Simulated stress profiles illustrate shear wave truncation based on sample strength



Simulated Longitudinal Stress

$$\sigma_{xx} = \rho\, C_L\, U_{PL} = ½\, \rho\, C_L\, V_L$$

$$\sigma_{xx} = 52.00 \text{ GPa}$$



Simulated Shear Stress

$$\tau_{xy} = \rho\, C_S\, U_{PS} = ½\, \rho\, C_S\, V_T$$

$$\tau_{xy} = 1.06 \text{ GPa}$$

$Y = \sqrt{3}\, \tau_{xy} = 1.83$ GPa
$Y_{SGL} = 1.93$ GPa

Self-consistent

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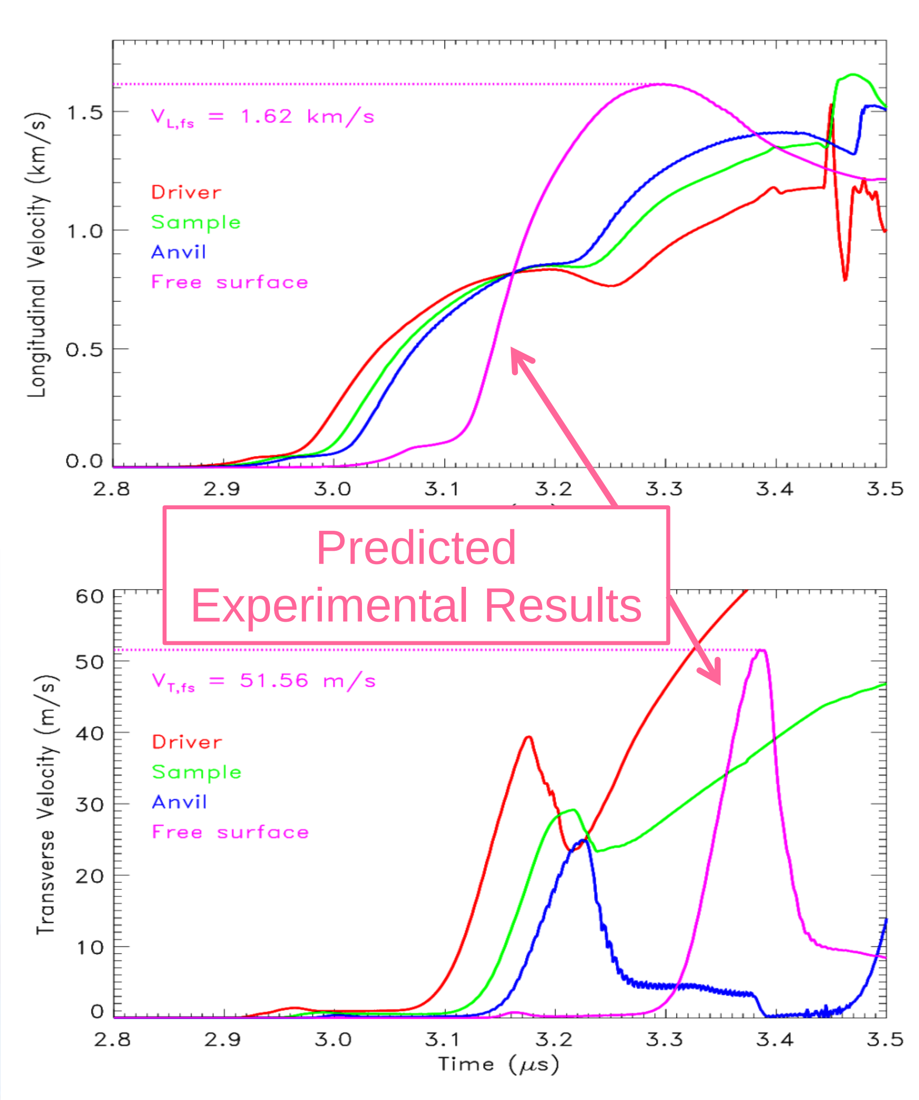
Simulations predict experimental profiles and provide in-situ response



Simulated Longitudinal Stress

$\sigma_{xx} = \rho\, C_L\, U_{PL} = ½\, \rho\, C_L\, V_L$

σ_{xx} = ½ (3.5126 g/cm³)(18.328 km/s)(1.62 km/s)

σ_{xx} = **52.1** GPa

Simulated Shear Stress

$\tau_{xy} = \rho\, C_S\, U_{PS} = ½\, \rho\, C_S\, V_T$

τ_{xy} = ½ (3.5126 g/cm³)(11.659 km/s)(0.052 km/s)

τ_{xy} = **1.06** GPa

Y = √3 τ_{xy} = 1.83 GPa
Y_{SGL} = 1.93 GPa

MAPS experiments on Z will provide a new approach to direct strength measurement

- Direct strength measurement utilizes shear wave truncation to measure dynamic strength
- Proven technique at lower pressures
- Hardware design suitable for use on Z is complete
- Applied B on Z capability will produce uniform external field to generate a stable shear wave and allow multiple samples per shot
- First experiments to be fielded soon