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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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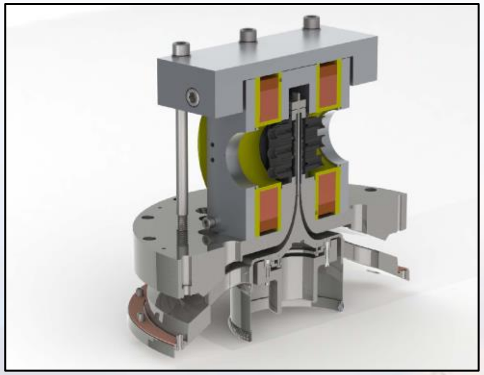
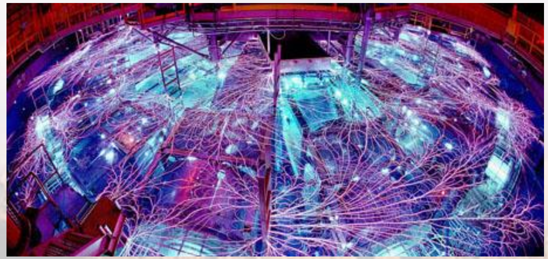


Aeroballistics Range Association
Destin, FL
October 6-11, 2013



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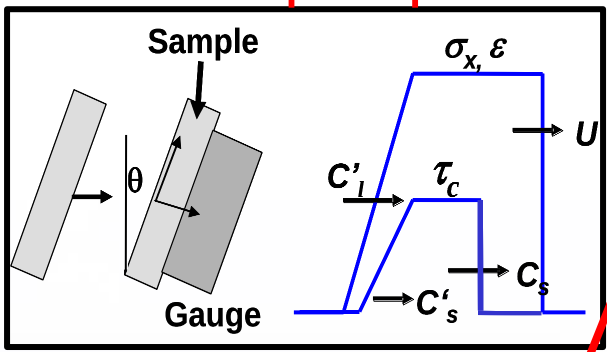
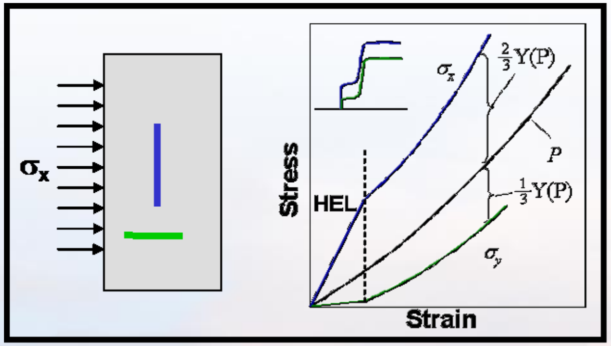
Existing strength measurement techniques have limitations at high pressure

Oblique impact



Lateral gauges



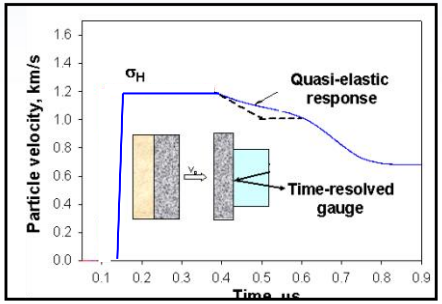
Limited to low P (<200 kbar or 20 GPa)

Requires assumptions

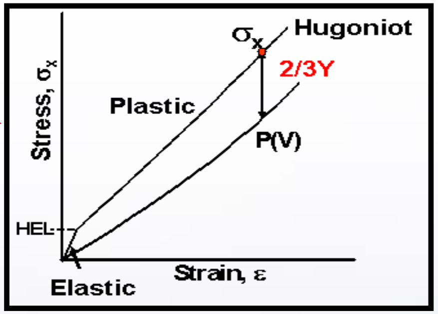
Large uncertainties

Requires accurate models which are unknown

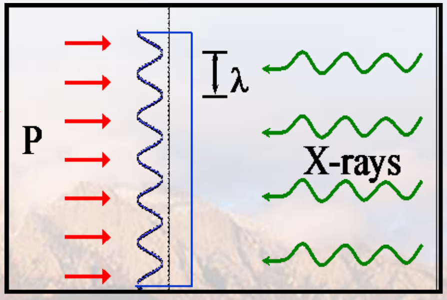
Wave Profile



Stress Difference



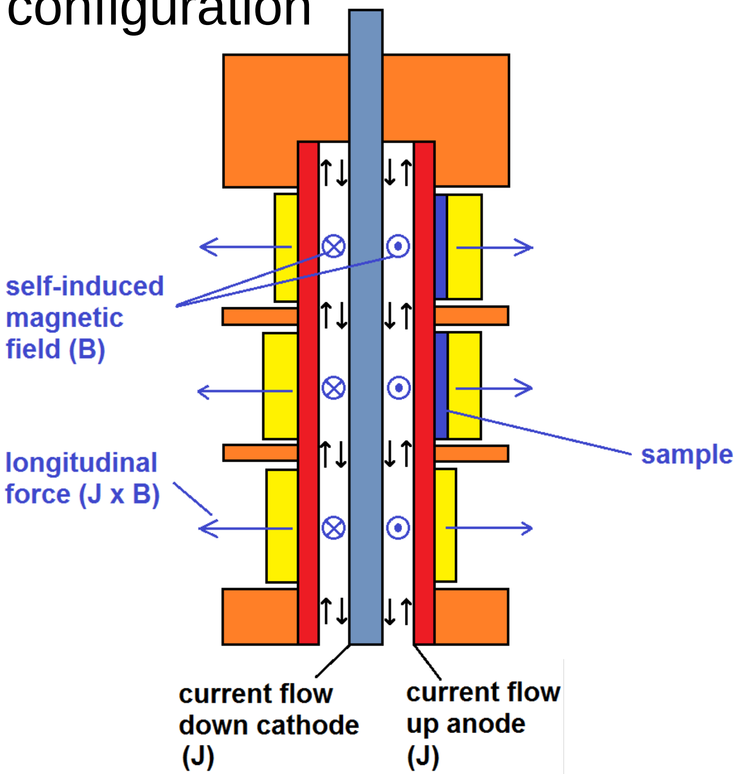
Rayleigh-Taylor

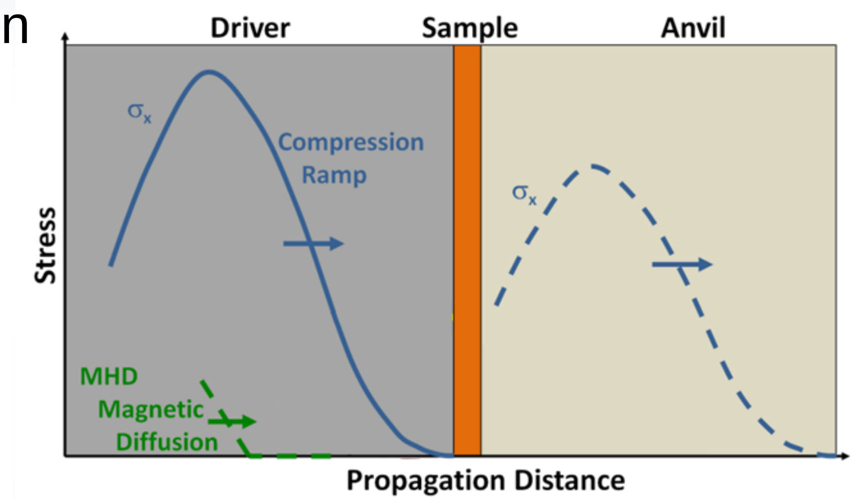


There is a need for improved strength measurement capability at high pressures

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

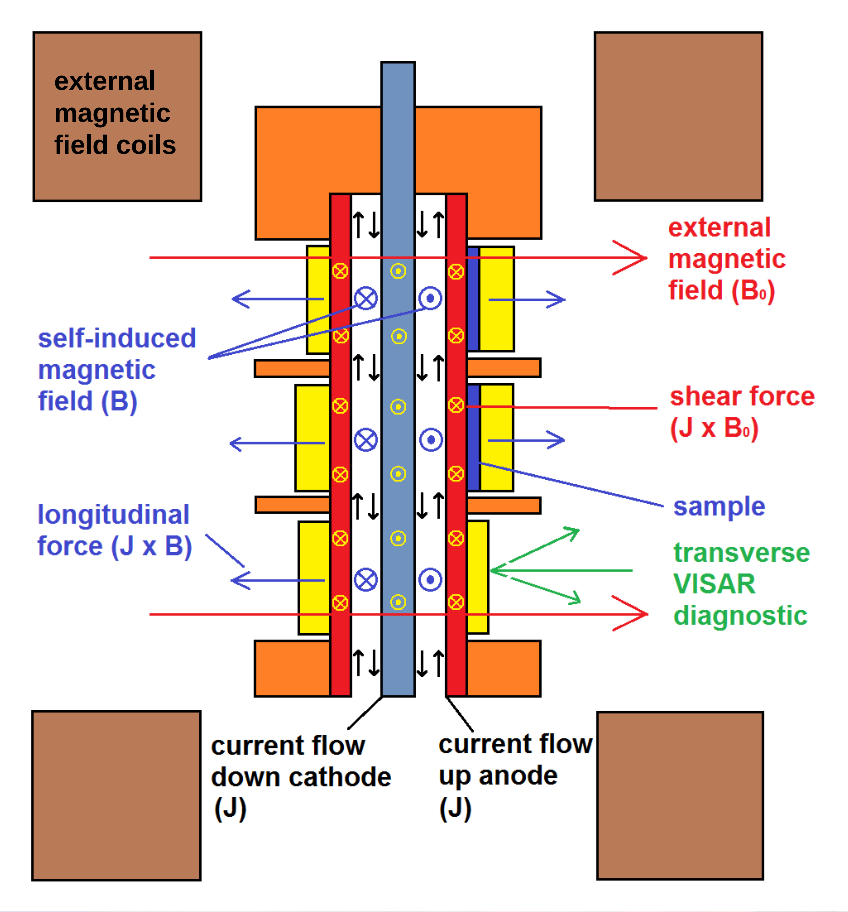
Z can generate up to ~20 MA current in this configuration

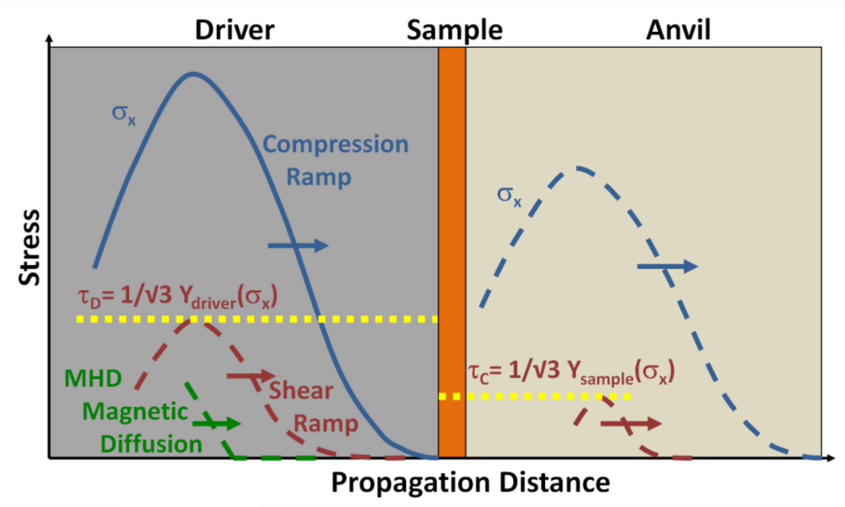




- Standard coax loads have no applied magnetic fields
- Load current generates a magnetic field in the gap between the anode and cathode
- Lorentz forces result in longitudinal stresses that drive the anode plates outward

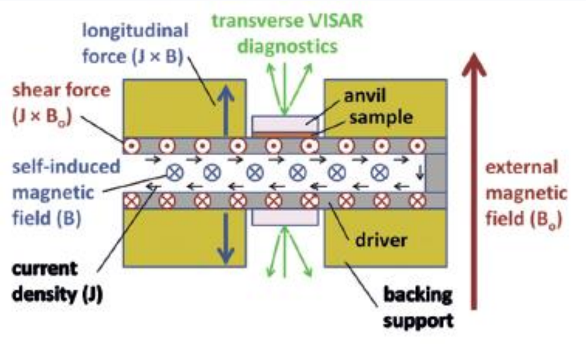
MAPS adds an applied longitudinal magnetic field to generate a shear wave

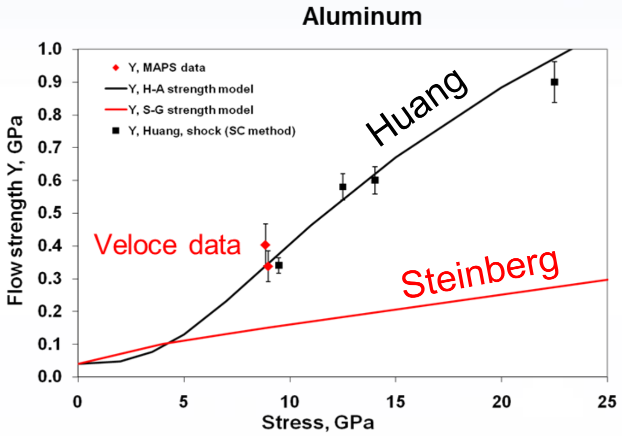


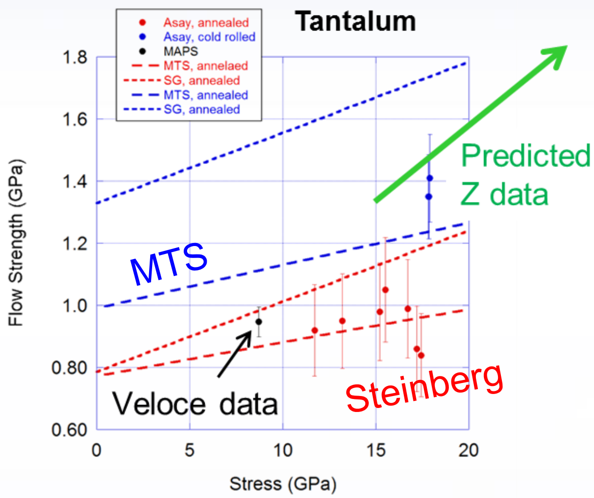


- MAPS applies an external magnetic field (B_0) that results in a shear wave
- Shear wave is truncated by sample based on material strength
- Elastic anvil material allows for coexistence of longitudinal and shear waves without coupling

MAPS technique has been proven at modest pressures up to ~10 GPa on Veloce



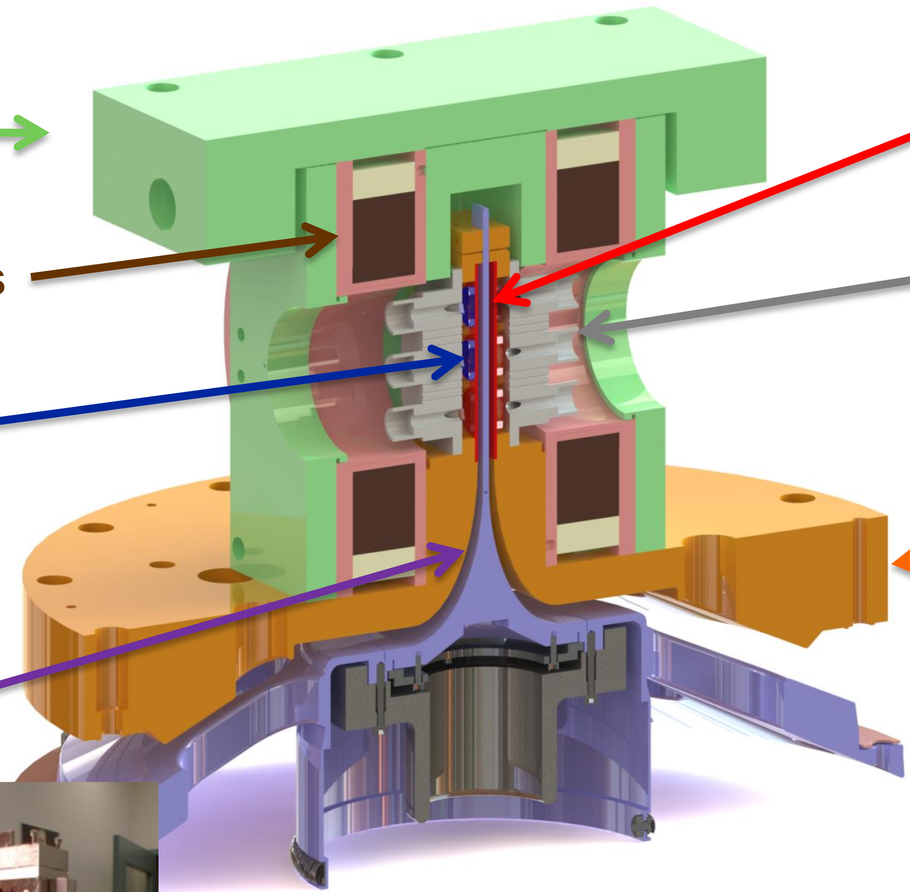


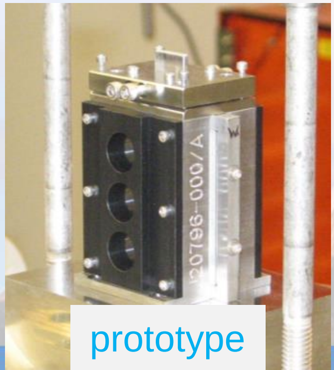


- Previous work on Al and Ta at lower pressures has produced results capable of distinguishing between proposed strength models
- At higher pressures, uncertainty is expected to be reduced due to higher particle velocities and fixed systematic uncertainty

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)

Implementation on Z requires modification of a standard coaxial load



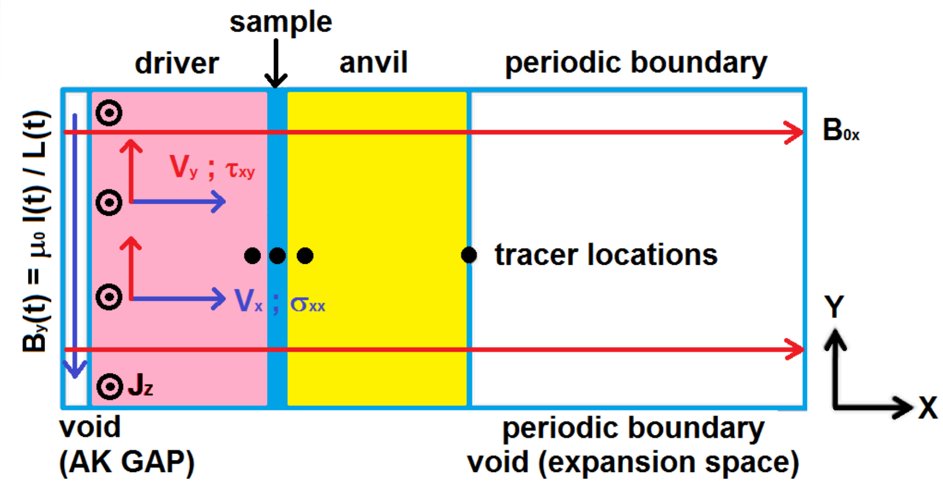

prototype


final design

To achieve required field magnitude and uniformity, coil separation must be reduced

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

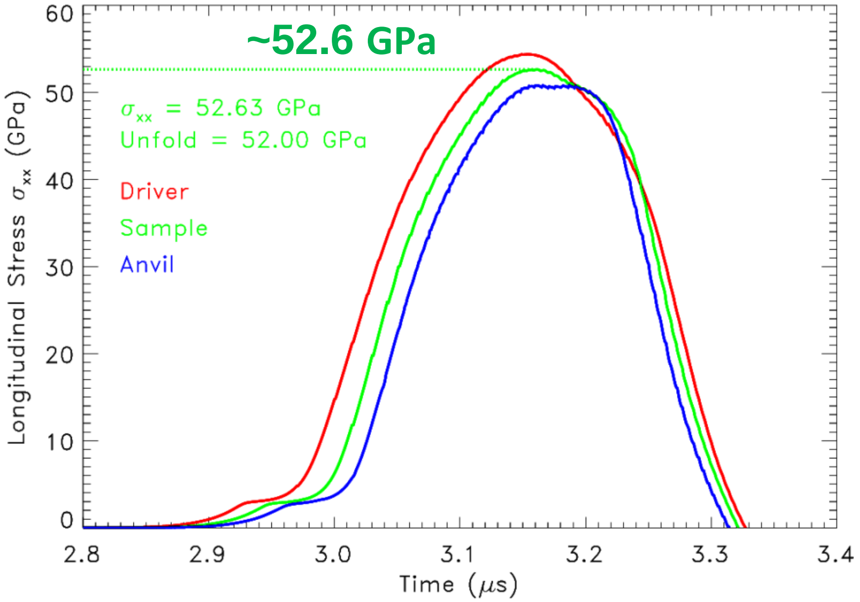


MAPS Materials and Material Model Parameters

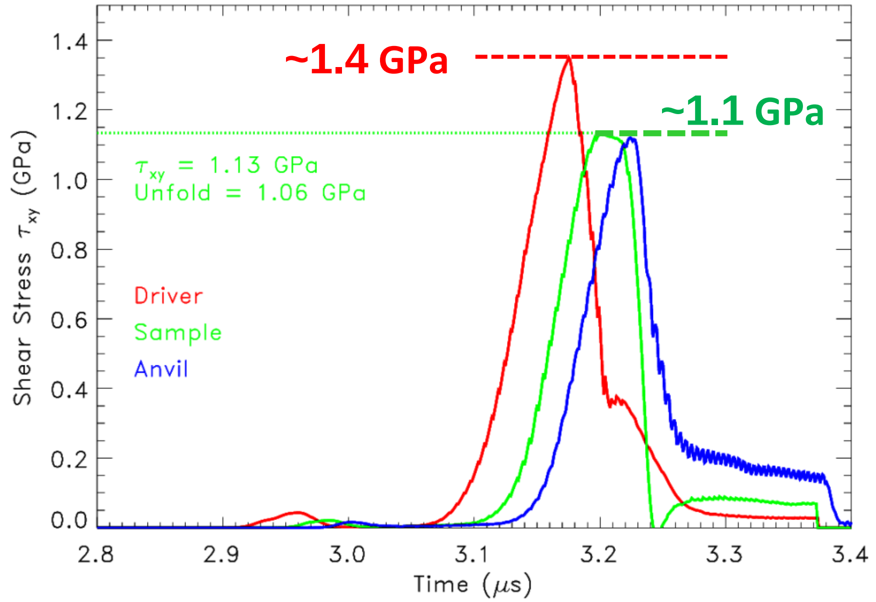
Panel Layer Material	Equation of State	Strength Model	Conductivity Model	Density (g/cm^3)	Longitudinal Wave Speed (km/s)	Shear Wave Speed (km/s)	Yield Strength (GPa)
Driver Molybdenum	LANL Sesame 2984	CTH Elastic-Plastic Steinberg-Guinan-Lund	Lee-More-Desjarlais (LMD)	10.22	6.45-6.45	3.47-3.48	0.9
Sample 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



Simulated Shear Stress



Longitudinal wave response:

- Generate ramp wave in driver
- Compress sample
- Anvil delays release

Shear wave response:

- Generate excess shear in driver
- Truncate shear in sample based on strength
- Transmit truncated shear to anvil

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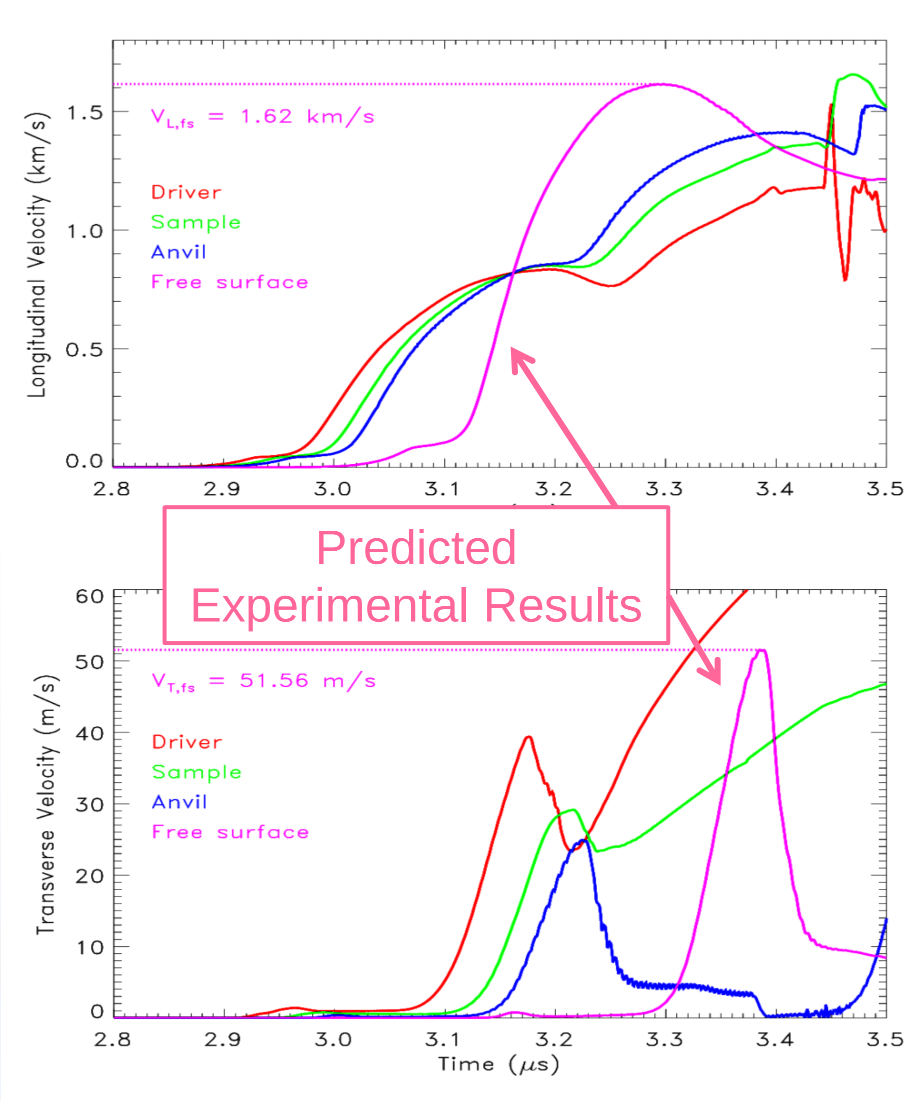
Simulations predict experimental profiles and provide in-situ response



Simulated Longitudinal Stress

$$\sigma_{xx} = \rho C_L U_{PL} = \tfrac{1}{2} \rho C_L V_L$$

$$\sigma_{xx} = \tfrac{1}{2} (3.5126 \text{ g/cm}^3)(18.328 \text{ km/s})(1.62 \text{ km/s})$$

$$\sigma_{xx} = 52.1 \text{ GPa}$$

Simulated Shear Stress

$$\tau_{xy} = \rho C_S U_{PS} = \tfrac{1}{2} \rho C_S V_T$$

$$\tau_{xy} = \tfrac{1}{2} (3.5126 \text{ g/cm}^3)(11.659 \text{ km/s})(0.052 \text{ km/s})$$

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

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

$Y_{SGL} = 1.93$ GPa

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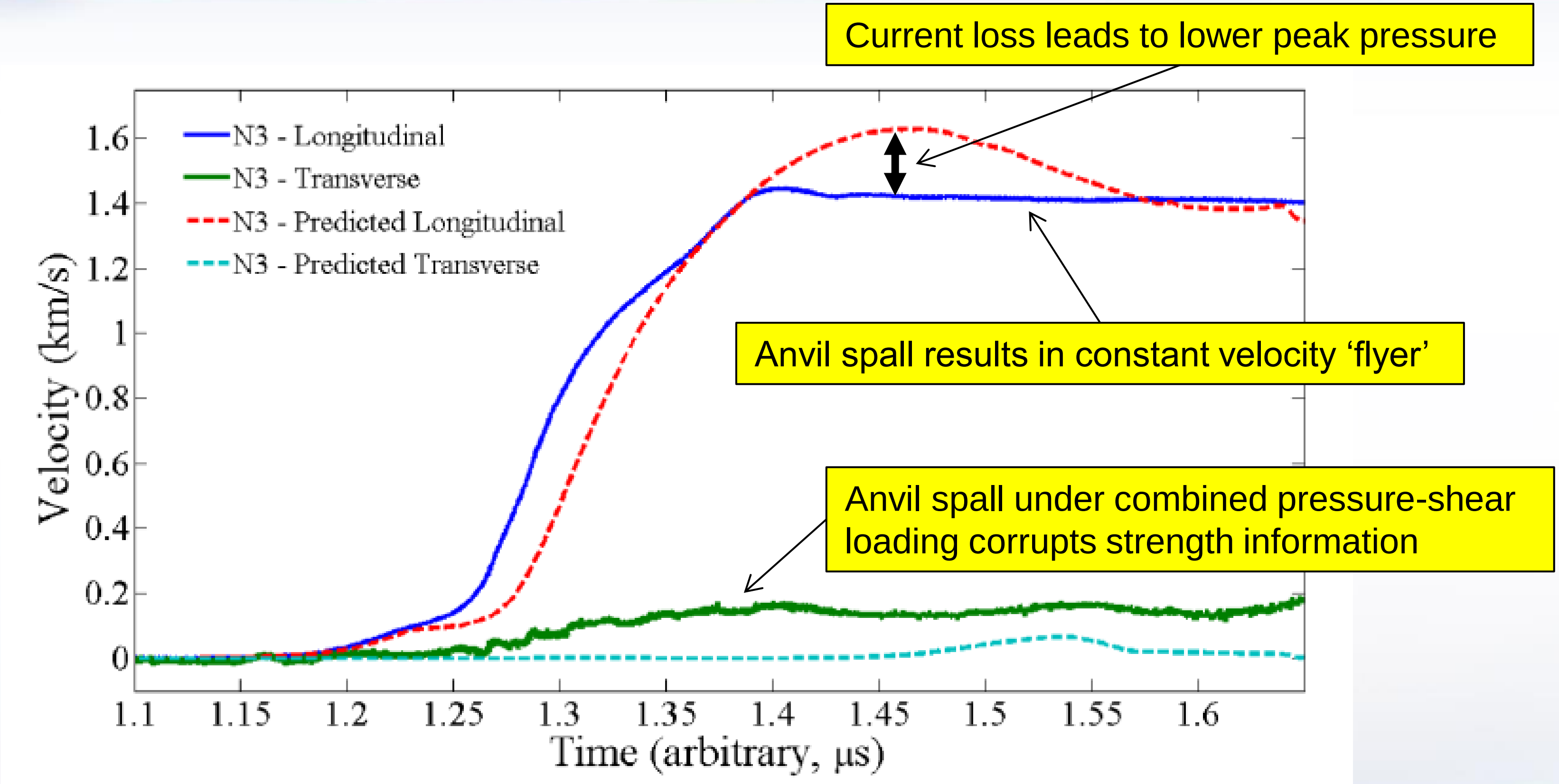
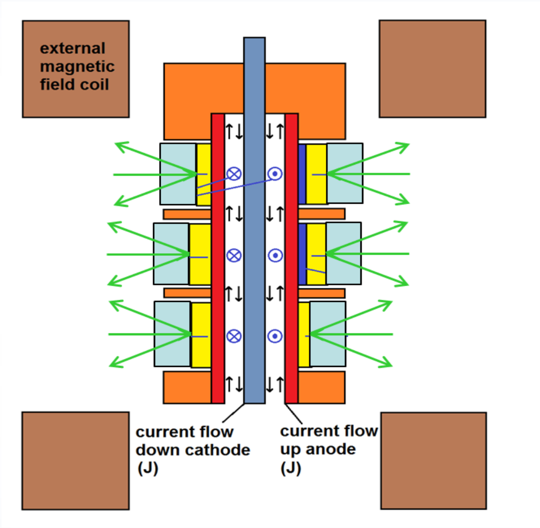
Results of first attempt on Z: PCD anvils perform well under compression, not tension

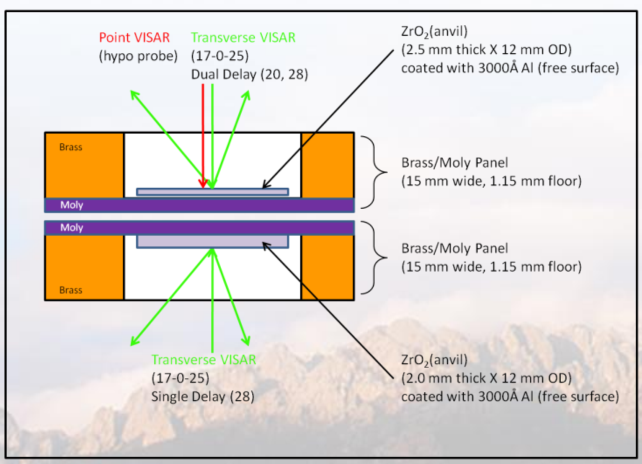


- First attempt at applied B field on a dynamic materials experiment
- First application of transverse capable VISAR on Z

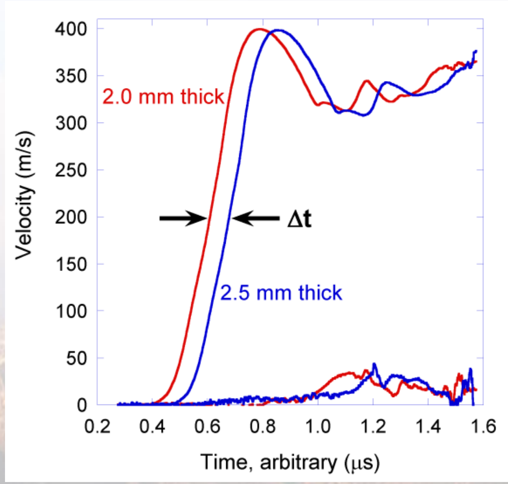
Future work and other applications of MAPS on Z

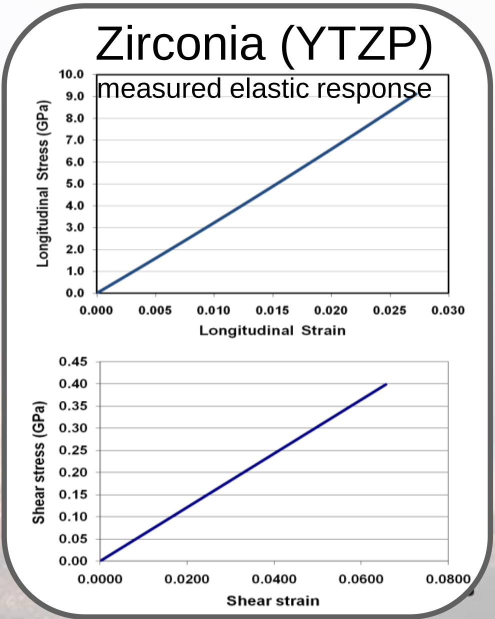


- **Future shots will utilize LiF windows behind PCD anvils to reduce tension**
- **Expand use of MAPS for multi-dimensional model verification**



Lagrangian Analysis in 2D





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

- **MAPS strength measurement utilizes shear wave truncation to directly measure dynamic strength**
- **Proven technique at lower pressures**
- **First experiments indicate PCD anvil spall leading to loss of strength data**
- **Future work will address spall issue and expand use of MAPS for multi-dimensional model validation**