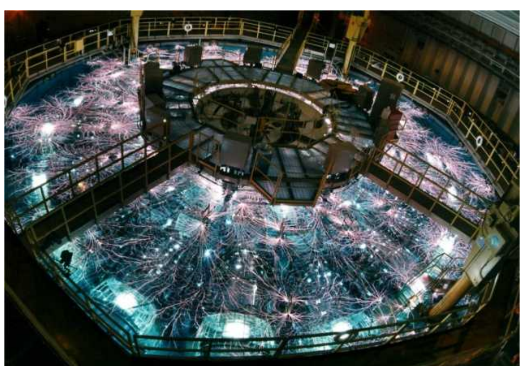
SAND2014-15941PE

Experimental Capabilities and Challenges for Dynamic Material Properties on the Z Machine

Chris Seagle

Fundamental Science on Z Workshop

July 23, 2014



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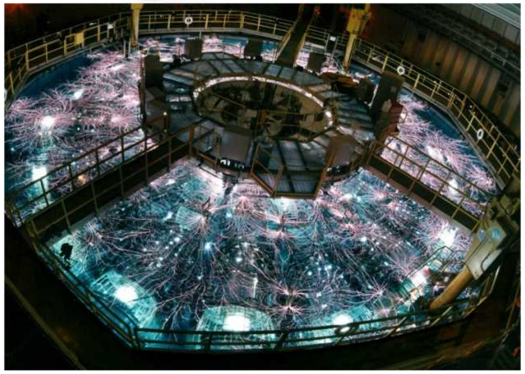
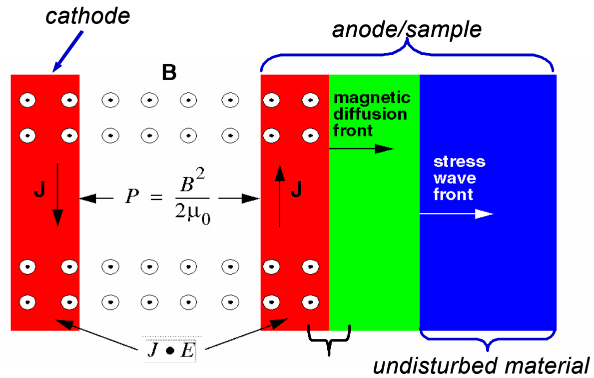
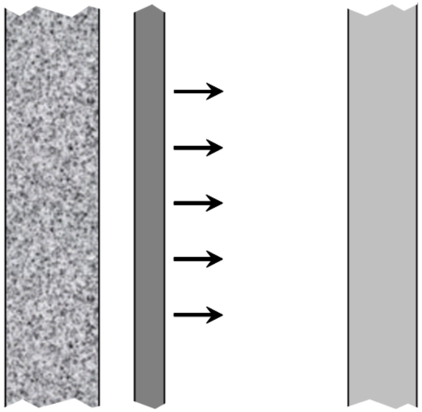
Outline





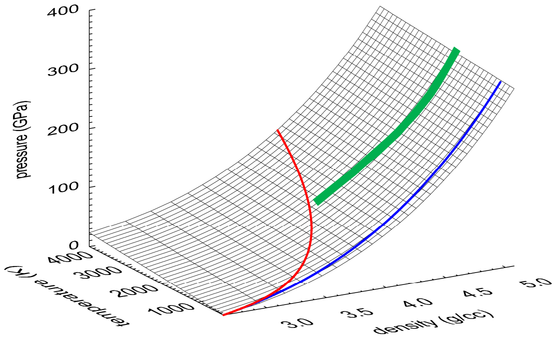
Z Machine Overview

Shock Compression



Ramp Compression

Shock-Ramp Compression



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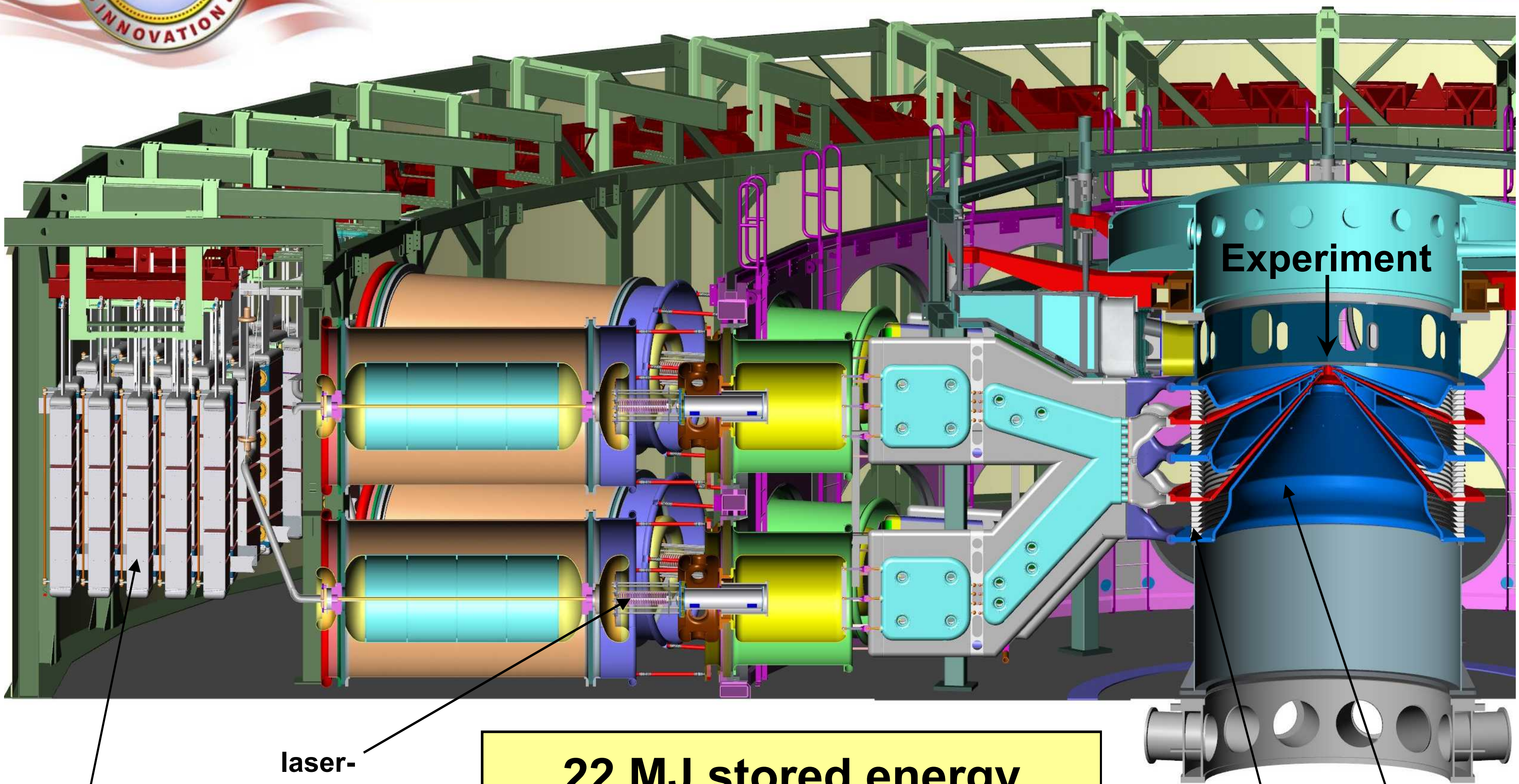
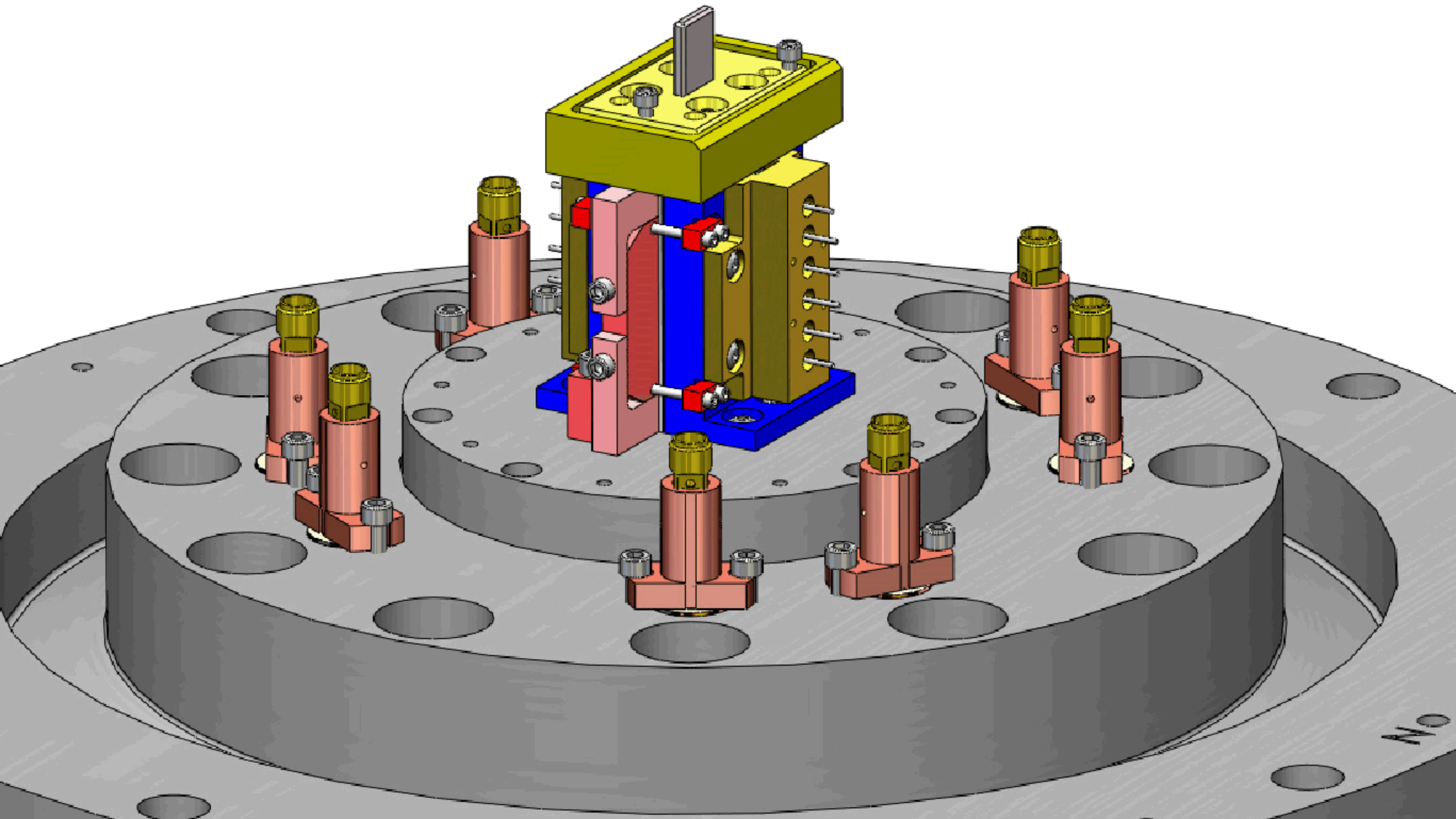
The Sandia Z Machine

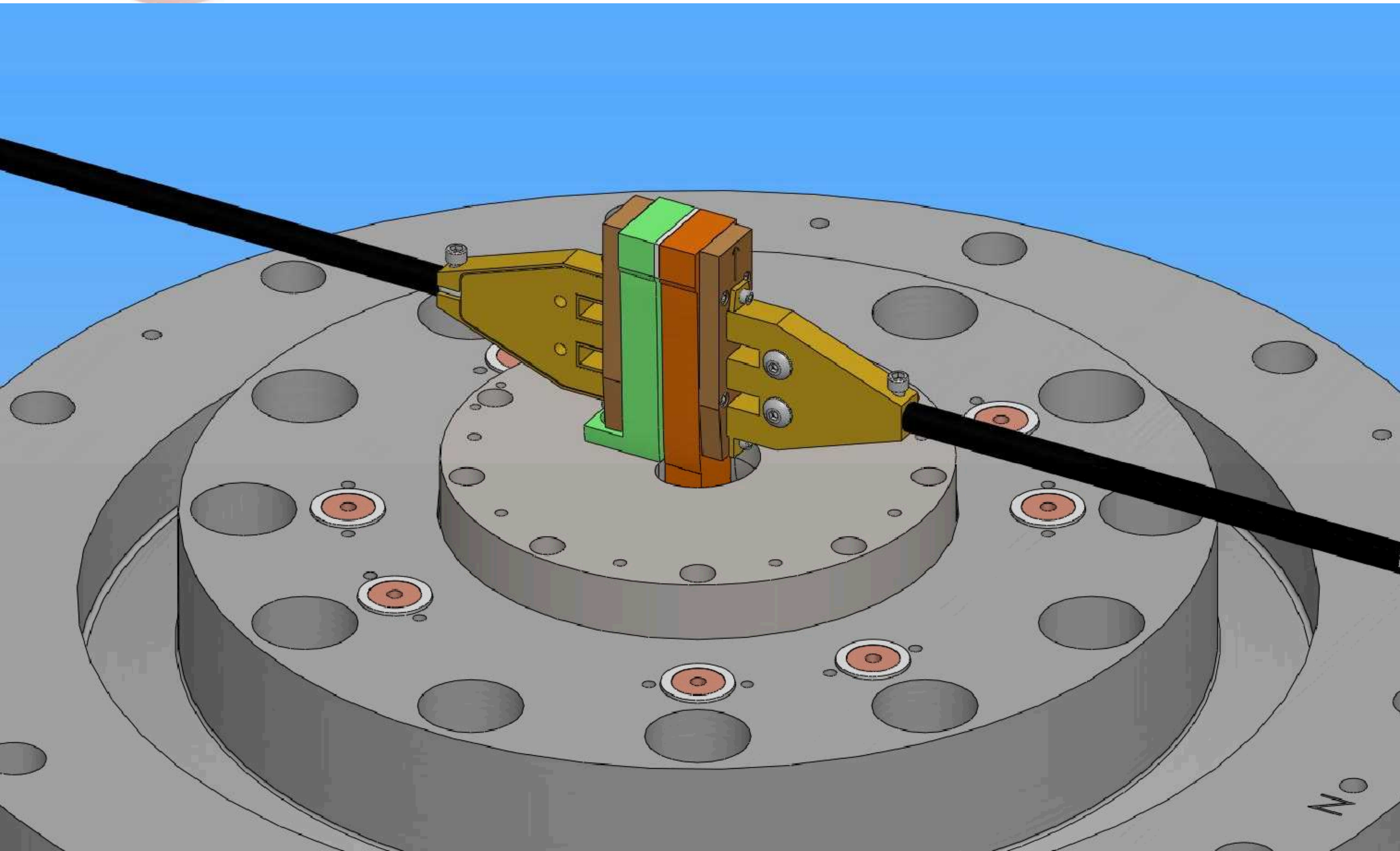


22 MJ stored energy
~25 MA peak current
~200-600 ns rise time

Typical coaxial load for multi-Mbar shock compression experiments on Z

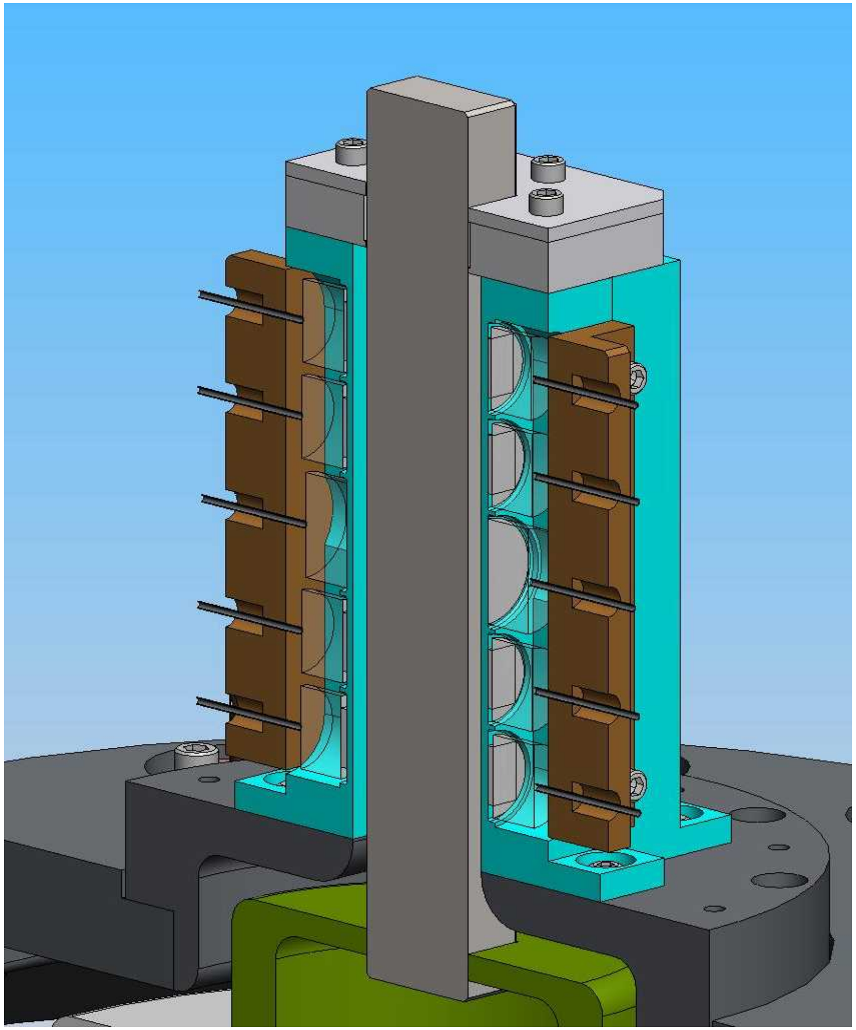


Typical stripline load for multi-Mbar ramp compression experiments on Z

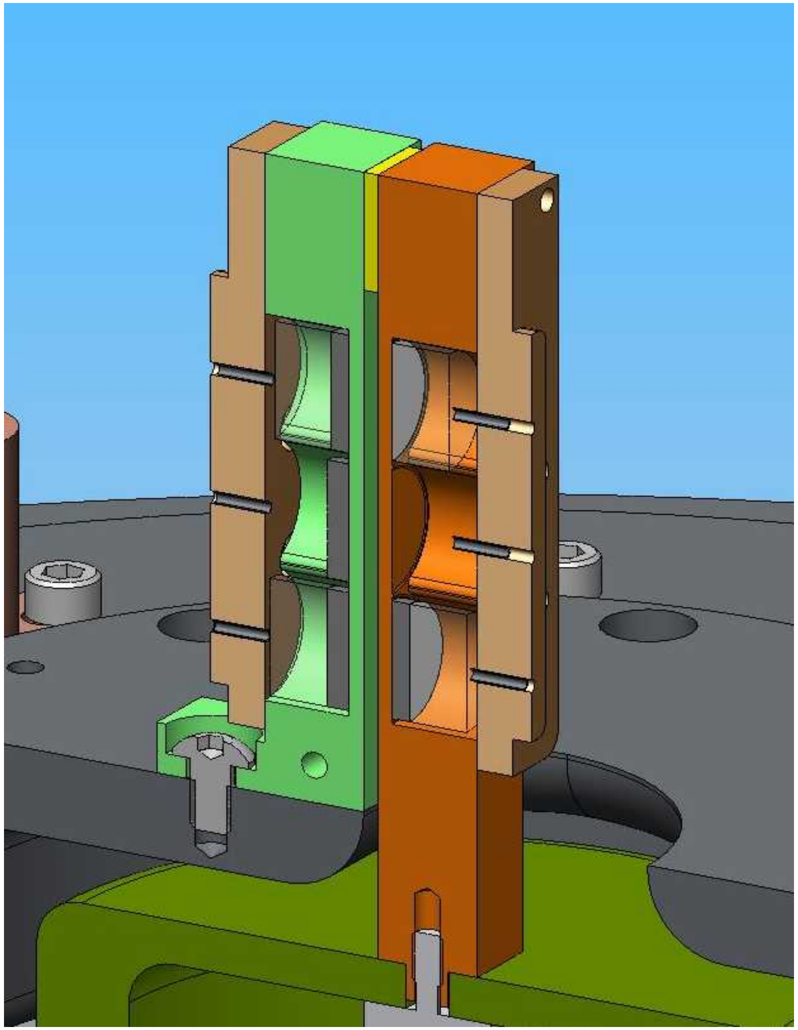


Two different load designs have been used for material dynamics experiments on Z

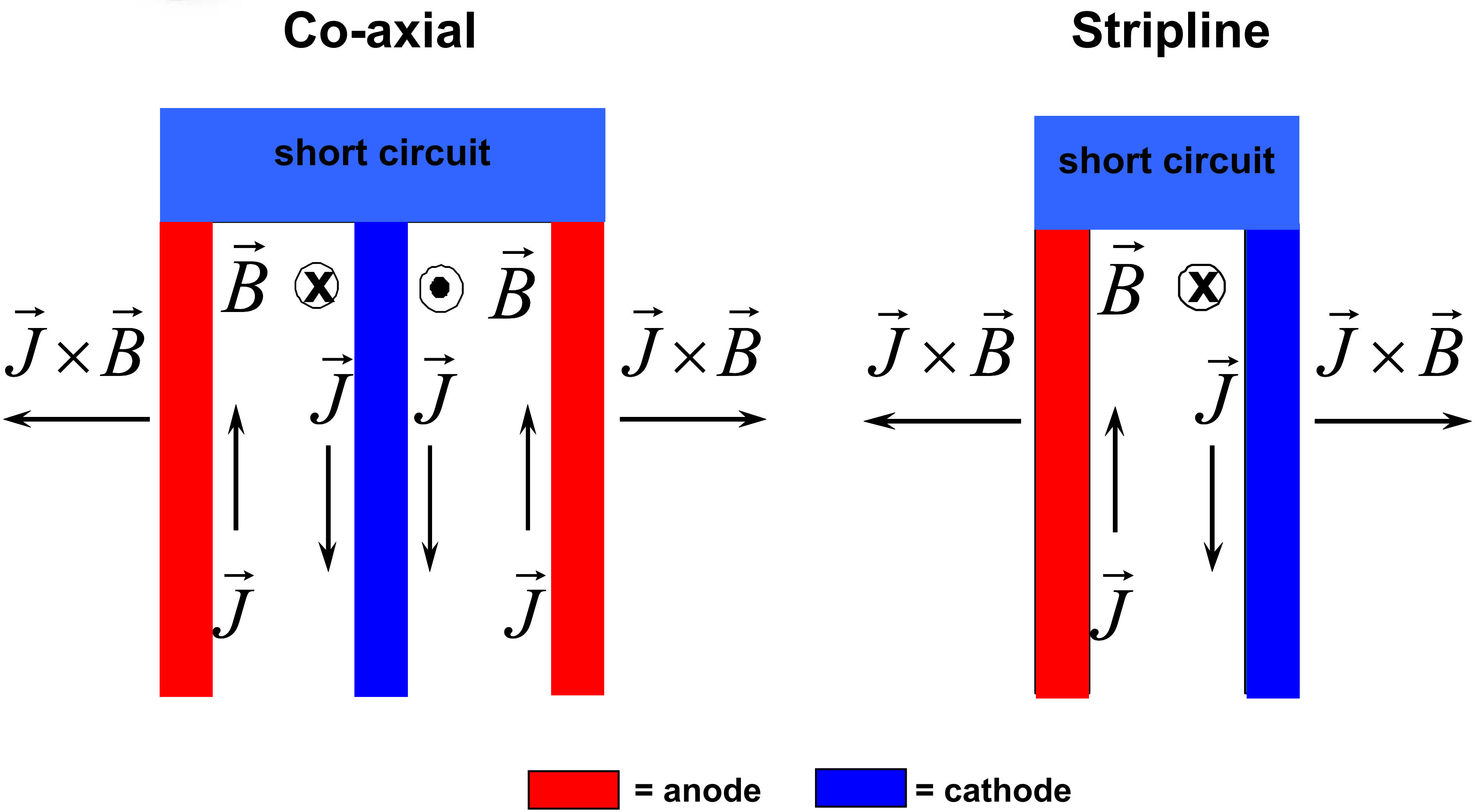
Co-axial



Stripline



Stripline enables two samples to experience identical B-field, ensuring identical pressure histories



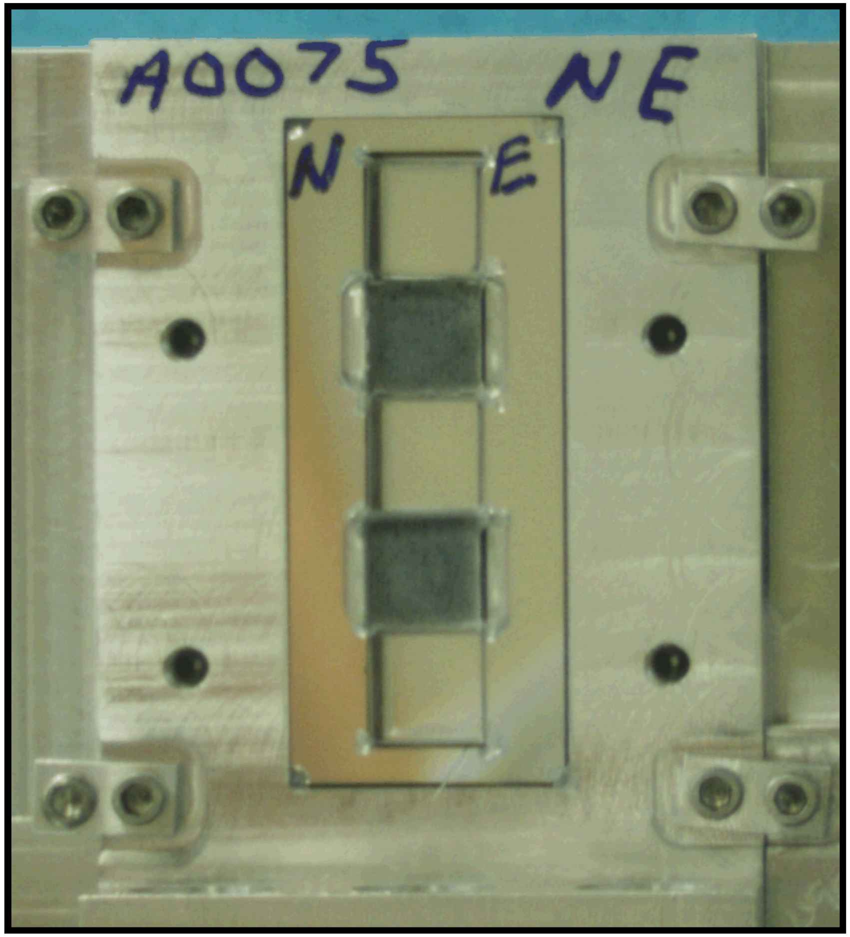
Shock Compression

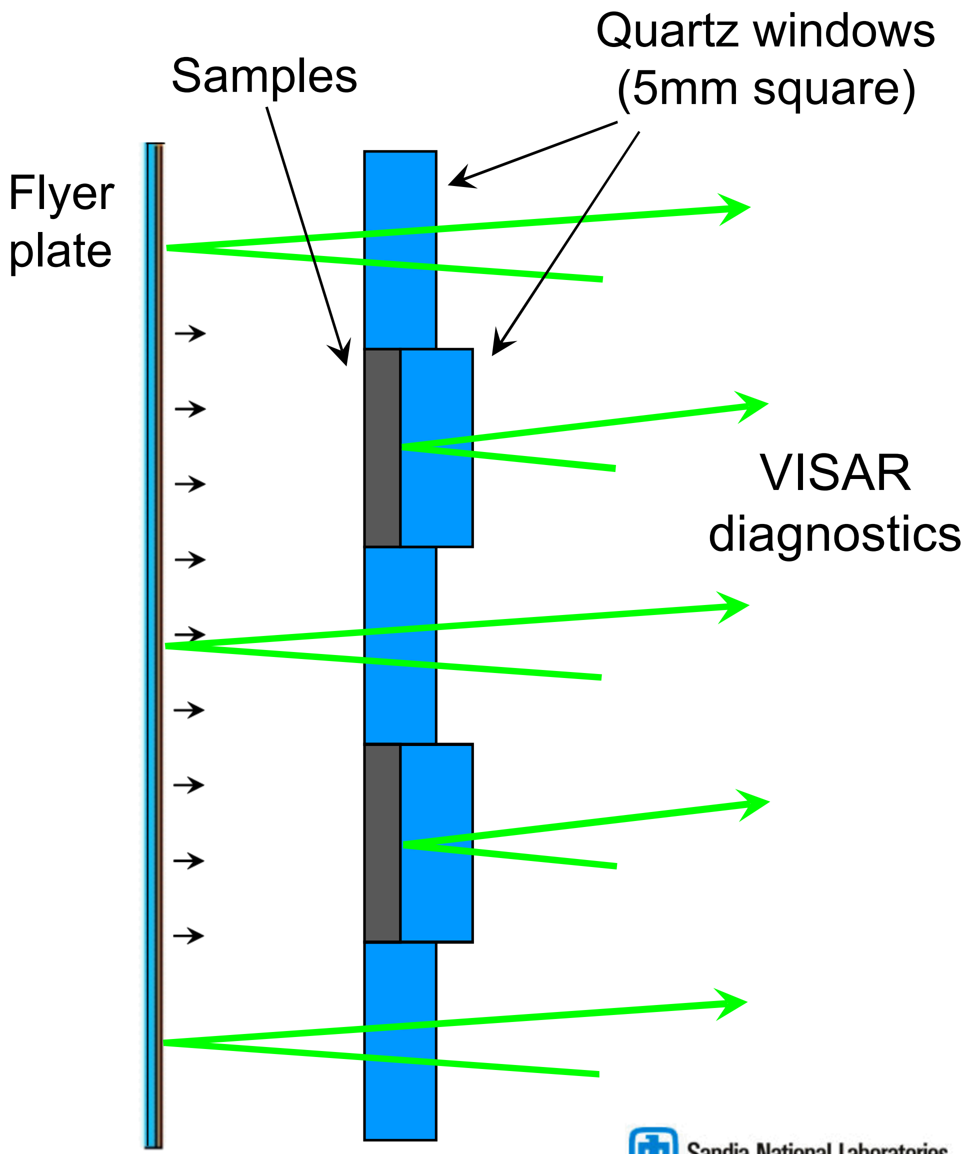
“Typical” Capabilities

- 1.5 – 35 km/s flyers
- Aluminum or Copper flyers (~100 micron thick at solid density)
- Absolute Hugoniot or quartz impedance standard
- Coaxial or stripline geometry
- 5-7 sample positions per panel (10-14/shot)
- Asymmetric coax for two flyer velocities (one per panel, velocities coupled)
- Samples ~100’s microns thick, 5-8 mm diameter or square
- Cryogenic targets (gas fill @ 10’s psig)

Quartz has been used as a transparent window enabling multiple flyer velocity measurements

Typical configuration

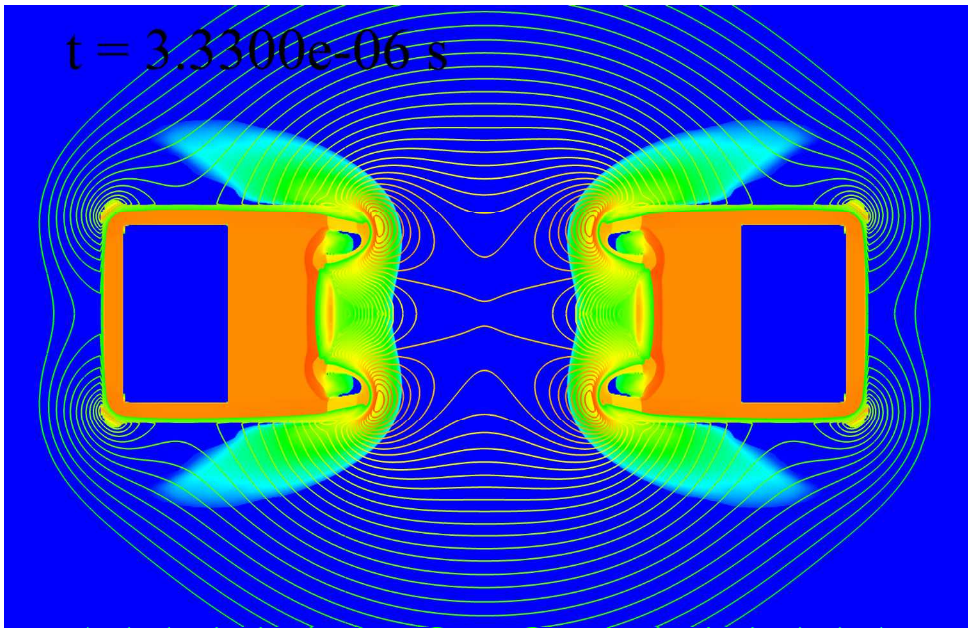


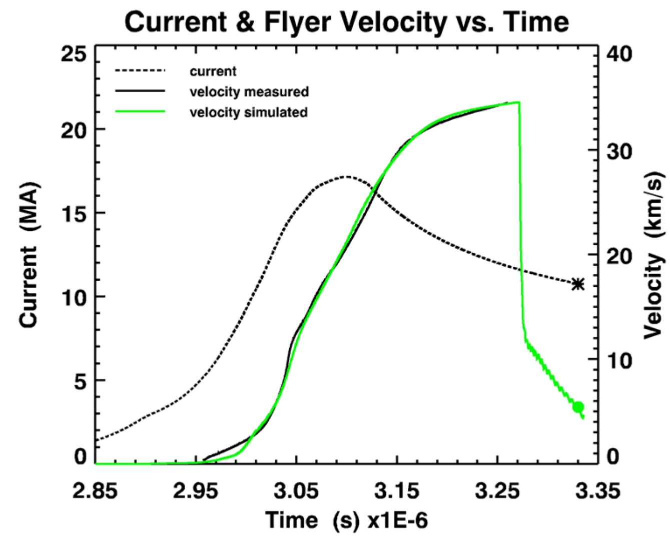


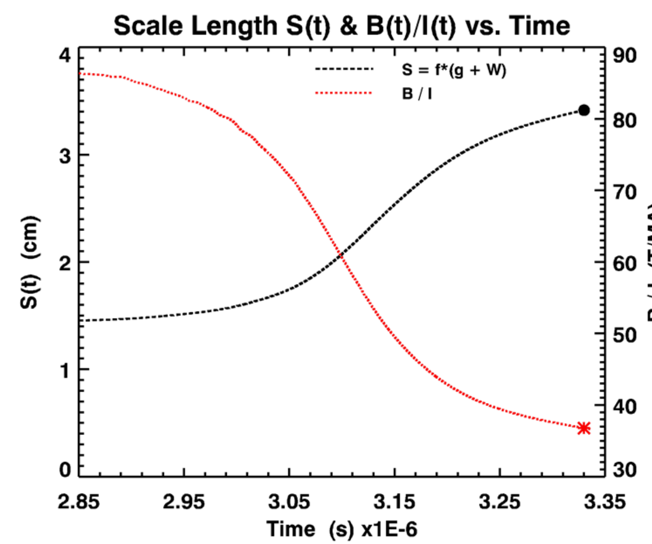

shot2611

A truly predictive MHD modeling capability has been developed over the last several years

Simulation 2-sided, 11 mm strip-line, 900 µm Al flyers, density & magnetic field

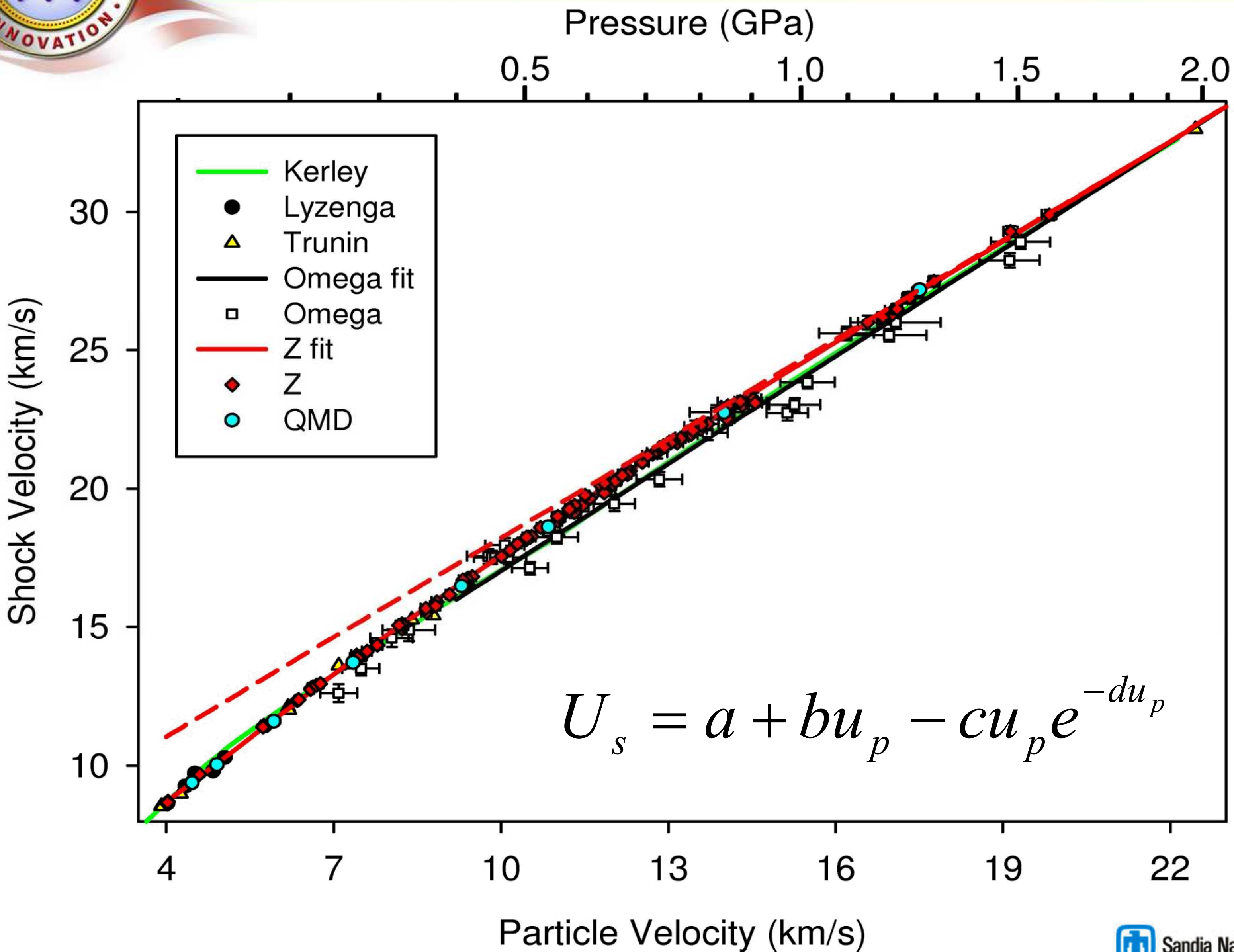






Agreement between simulation and experiment at the ~1% level can be achieved

U_s-u_p Hugoniot for α-Quartz – over 200 points



$$U_s = a + bu_p - cu_p e^{-du_p}$$

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Knudson and Desjarlais, PRL 103, 225501 (2009)

Shock Platform Challenges

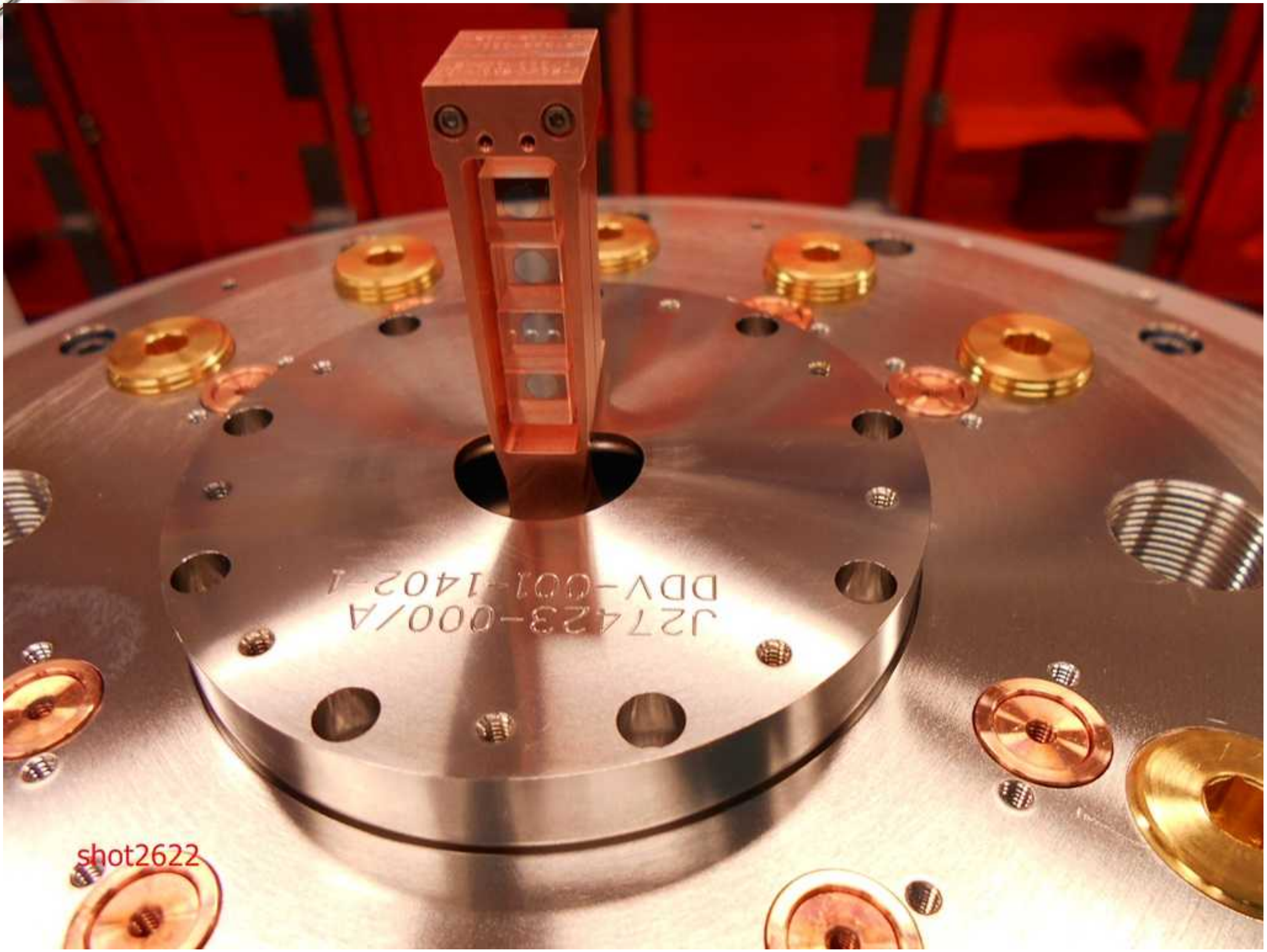
- Challenges are largely diagnostic/physics/sample based
  - Shock and/or particle velocities measured with high accuracy (principal Hugoniot is easiest/most accurate)
  - Database of design pulseshapes for many flyer velocities
- Sample procurement/quality
- Data interpretation for samples exhibiting complex phenomena (phase transitions, rate dependent phenomena, etc.)

Shockless (Ramp) Compression

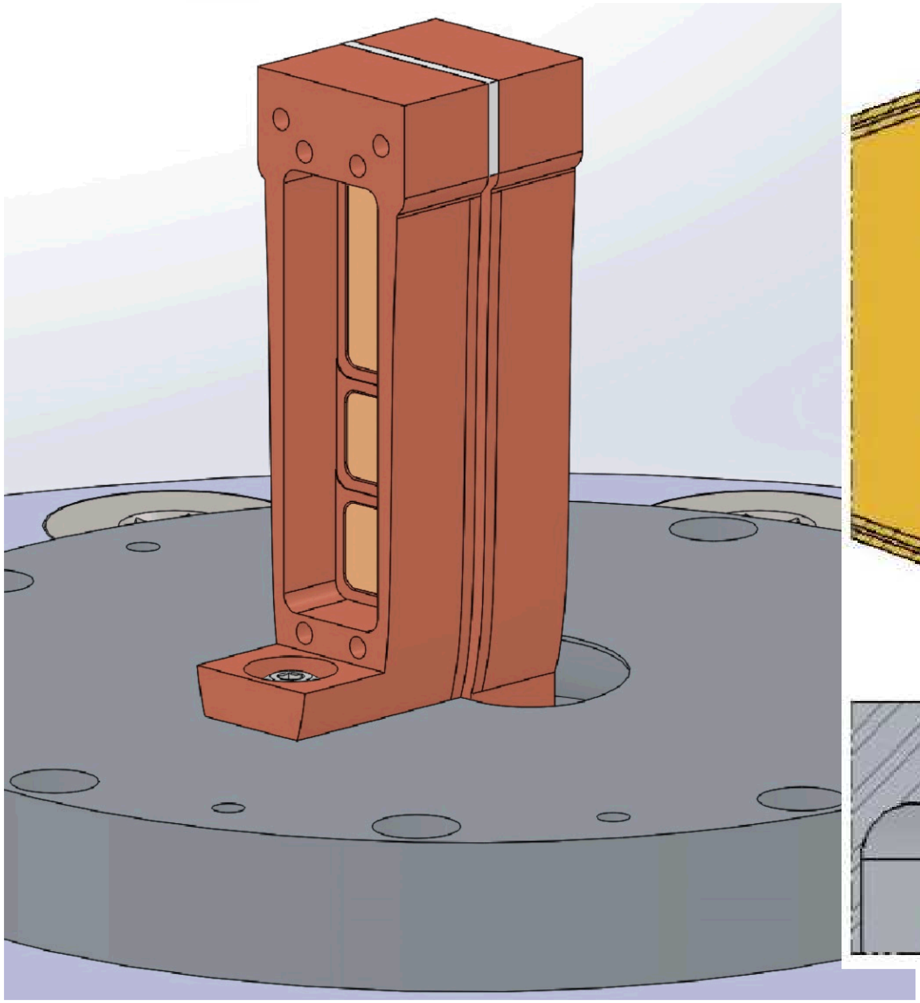
"Typical" Capabilities

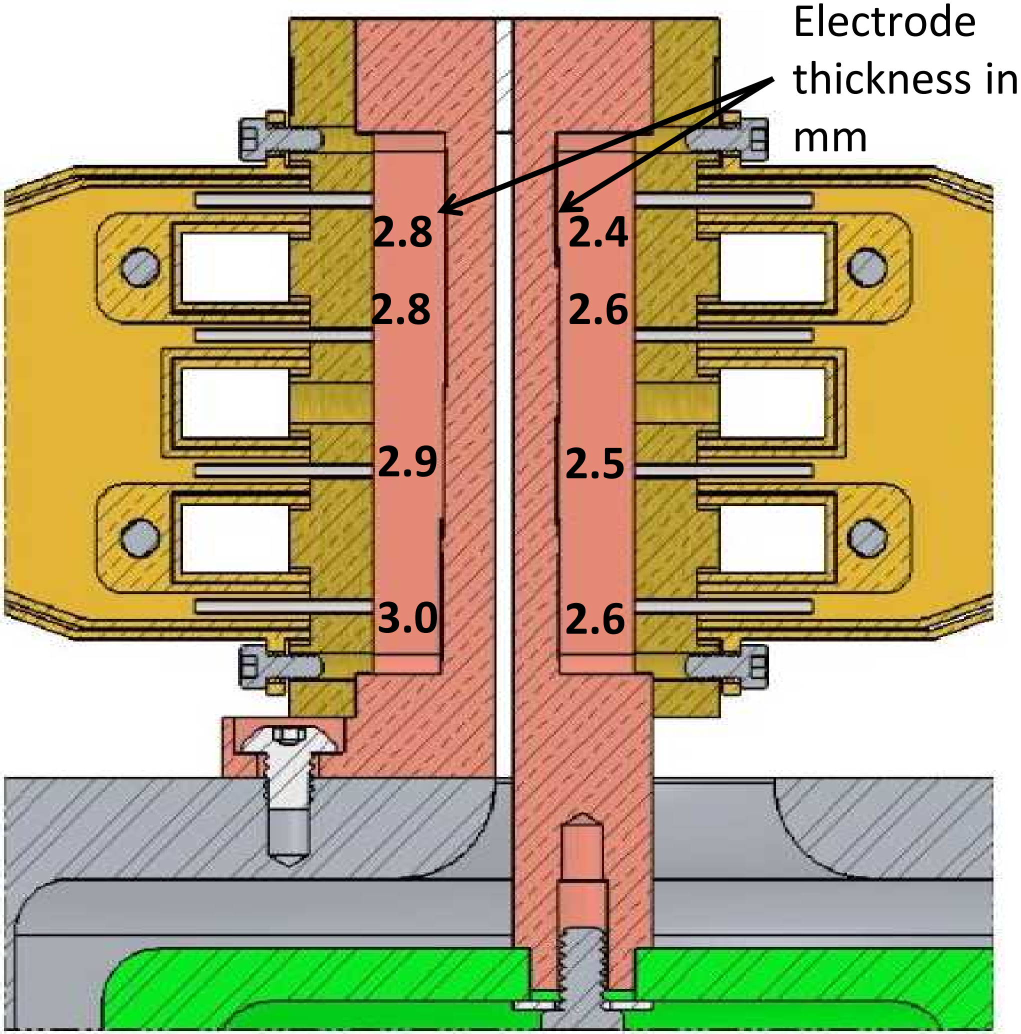
- 500 – 1200 ns pulse length
- Aluminum or Copper electrodes
- Free surface or windowed samples
- Stripline geometry preferred (coax possible)
- 2-5 sample positions per panel (4-10/shot)
- Samples ~100's microns to few mm thick, 5-8 mm diameter or square
- Peak stresses highly dependent on sample material (~4 Mbar for high impedance, ~1-2 for low impedance)
- Experiments designed for EoS and/or Strength

Recent Stripline panels for Shockless Compression EoS

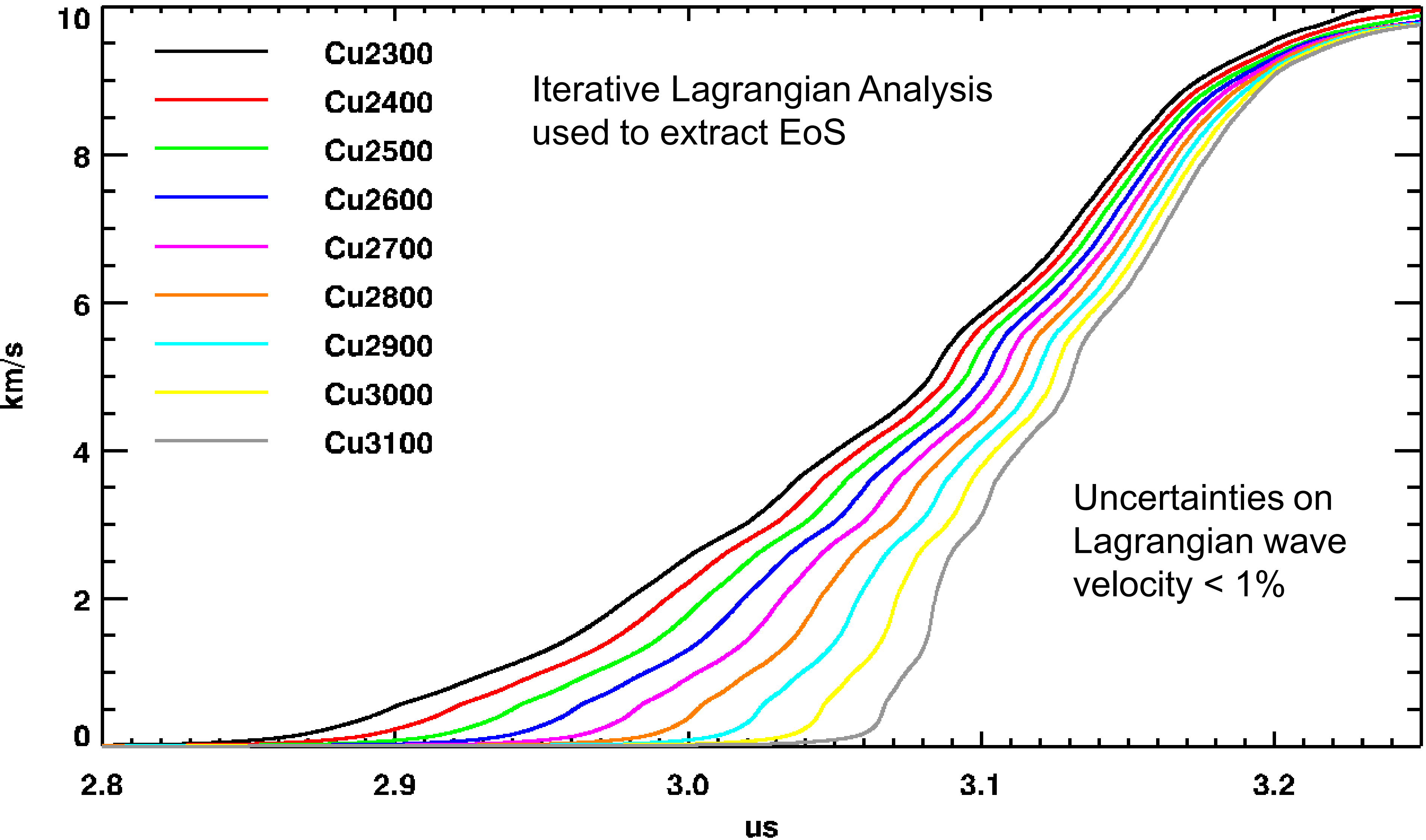


Recent Hardware for Copper Ramp to ~4 Mbar

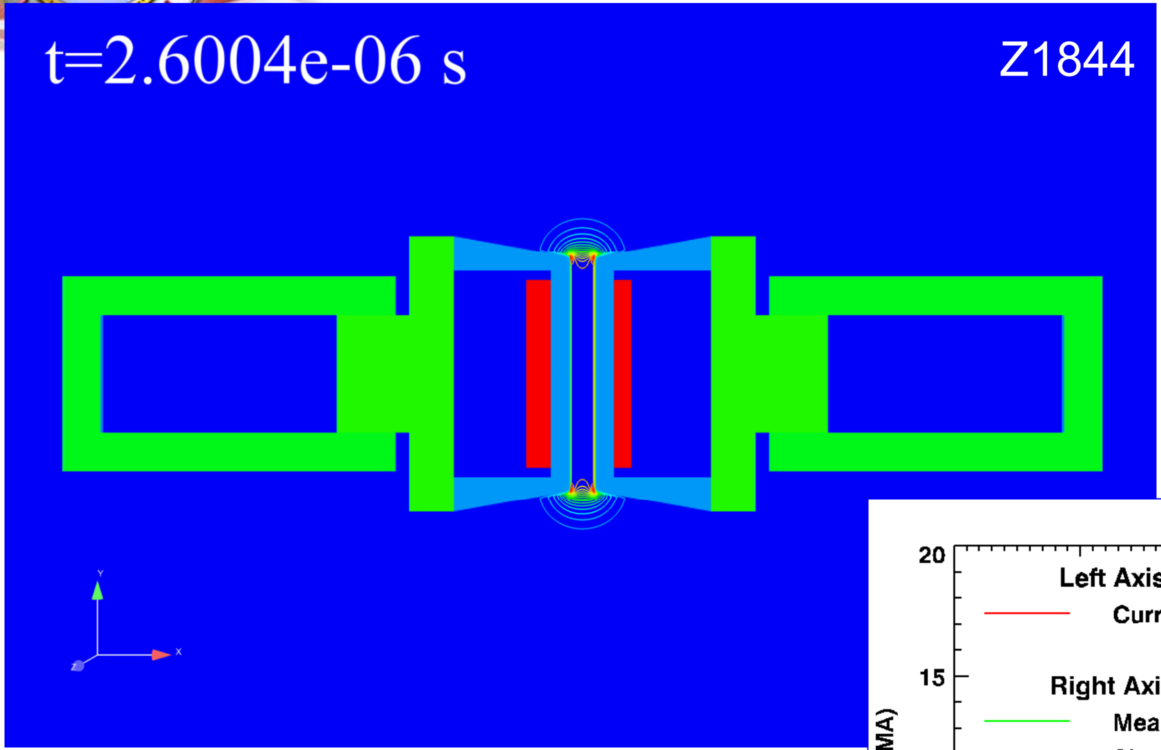




Predicted Free Surface Velocities

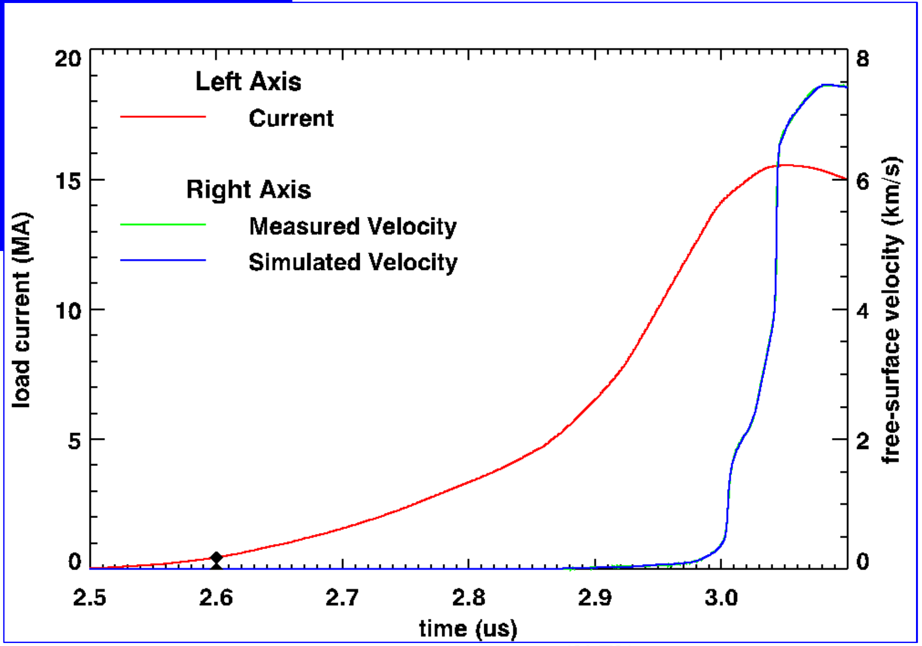


Simulations predict highly uniform B-field in the lateral and normal directions over most of the gap

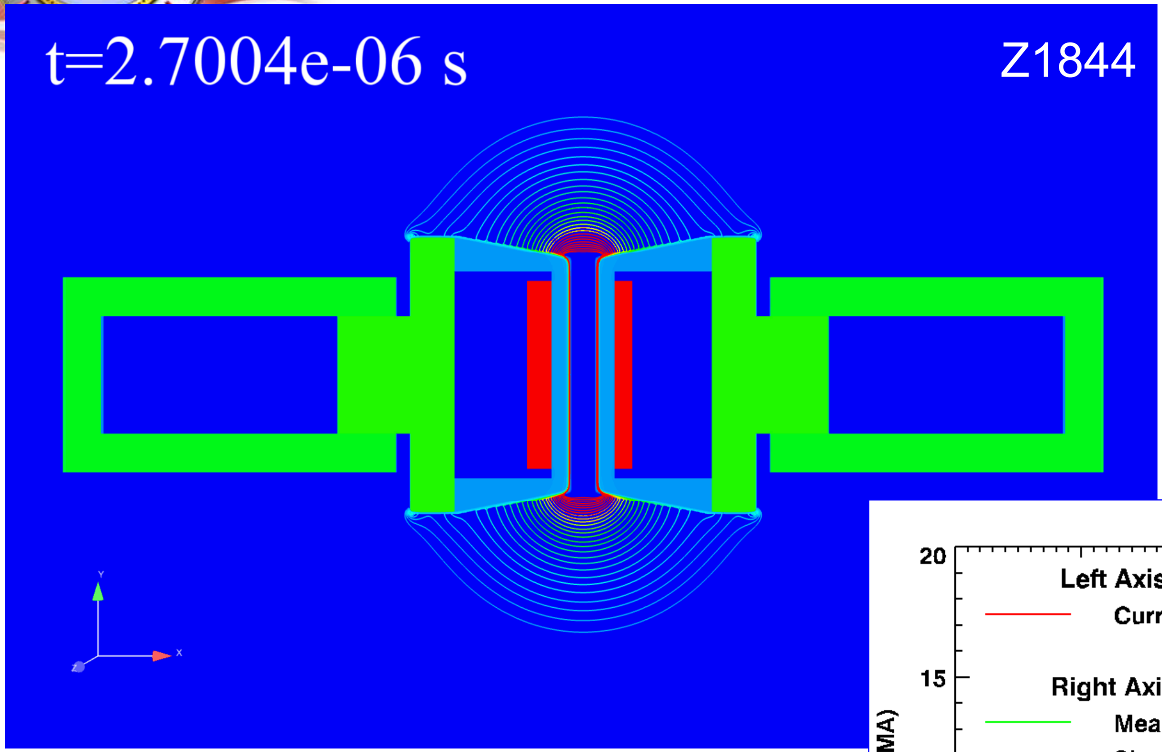


Magnetic Field (line contours)
Density (filled contours)

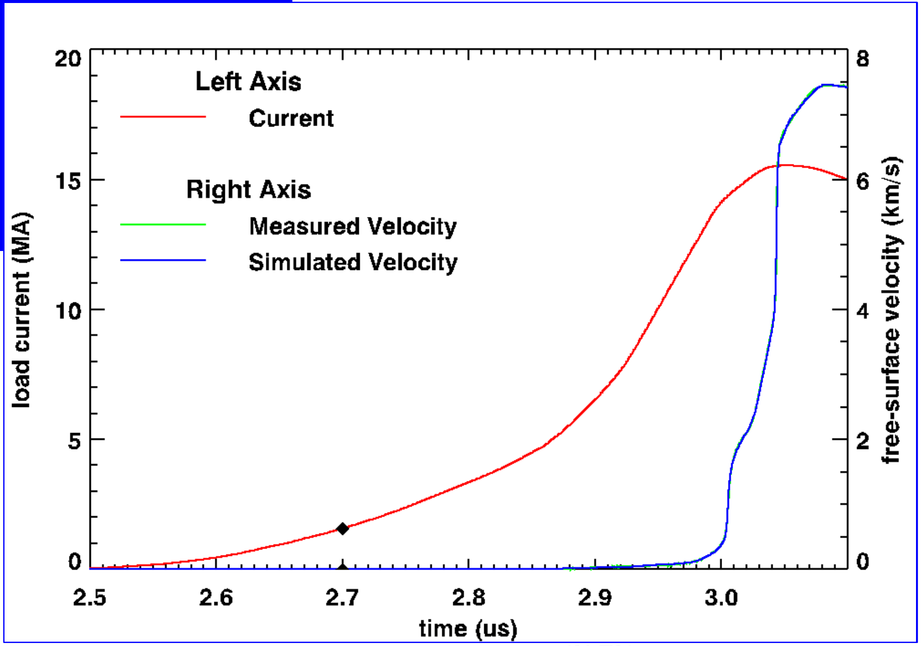
2-D Alegra-MHD:
- Resistive MHD
- QMD/LMD conductivity
- Sesame EOS
- Circuit model



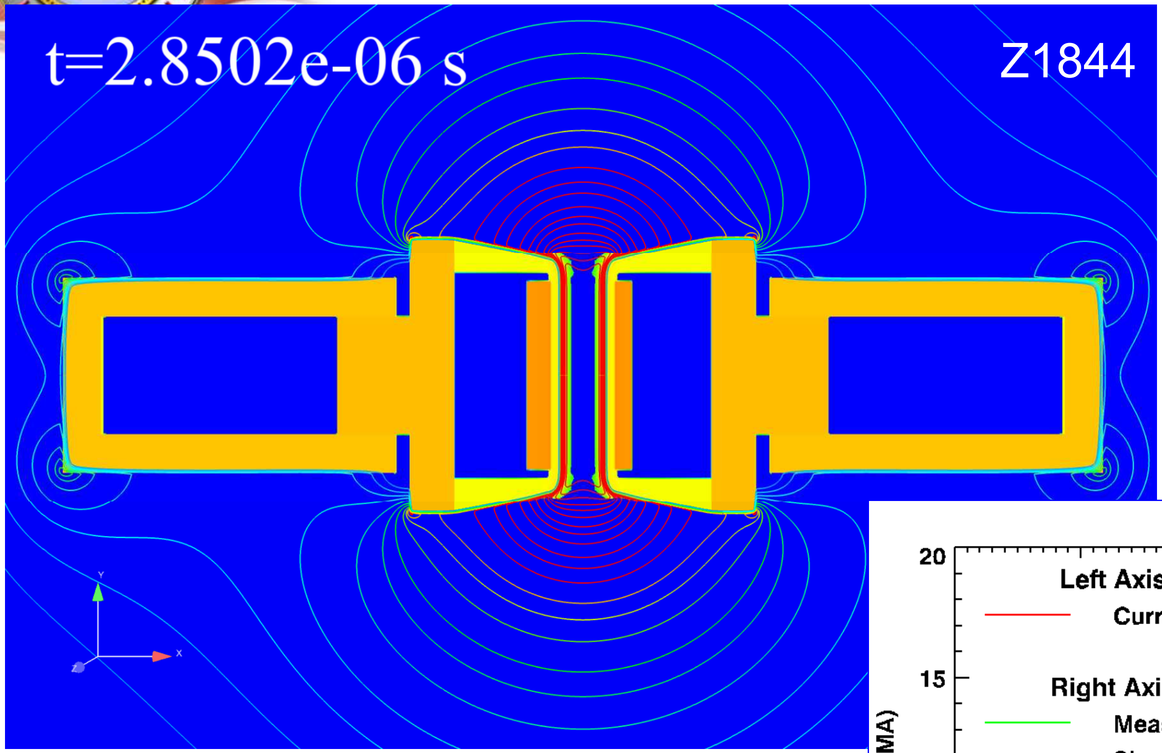
Simulations predict highly uniform B-field in the lateral and normal directions over most of the gap



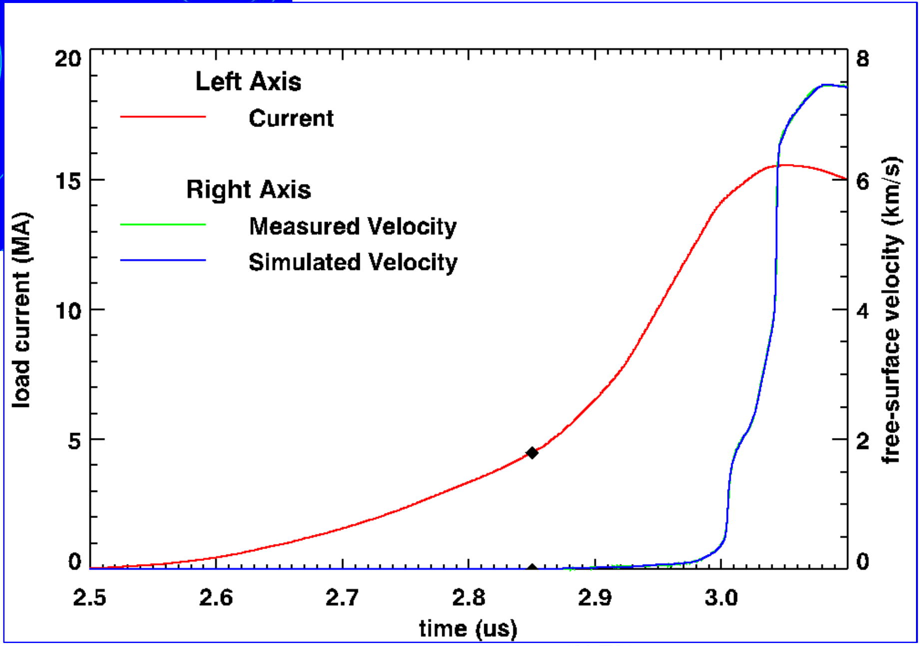
Magnetic Field (line contours)
Density (filled contours)



Simulations predict highly uniform B-field in the lateral and normal directions over most of the gap



Magnetic Field (line contours)
Density (filled contours)



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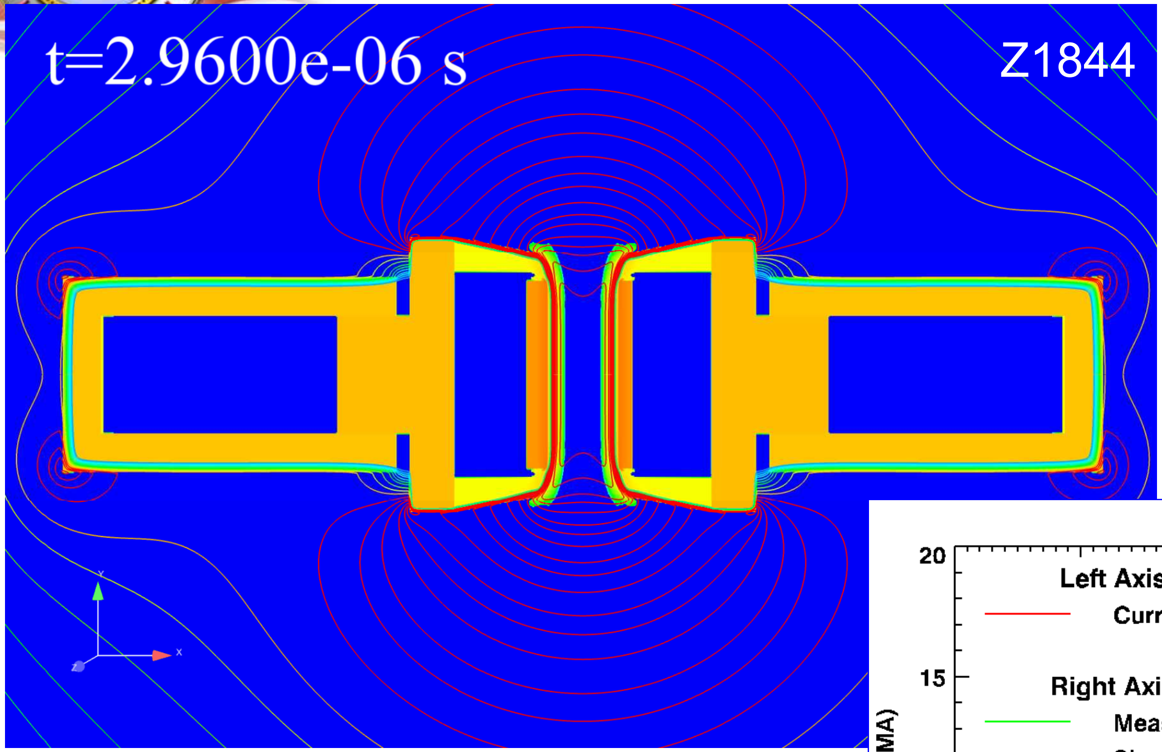
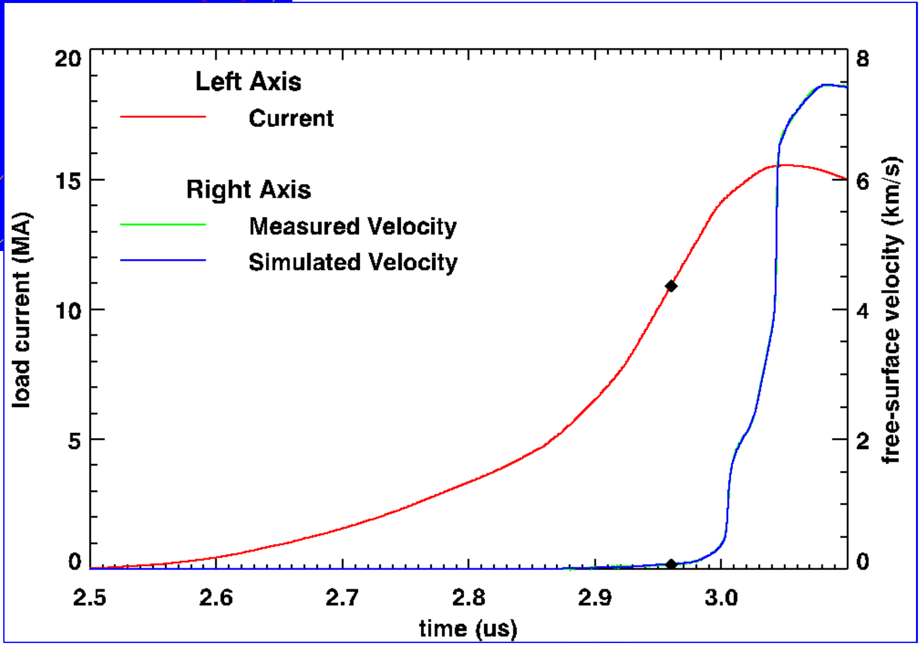


Magnetic Field (line contours)
Density (filled contours)



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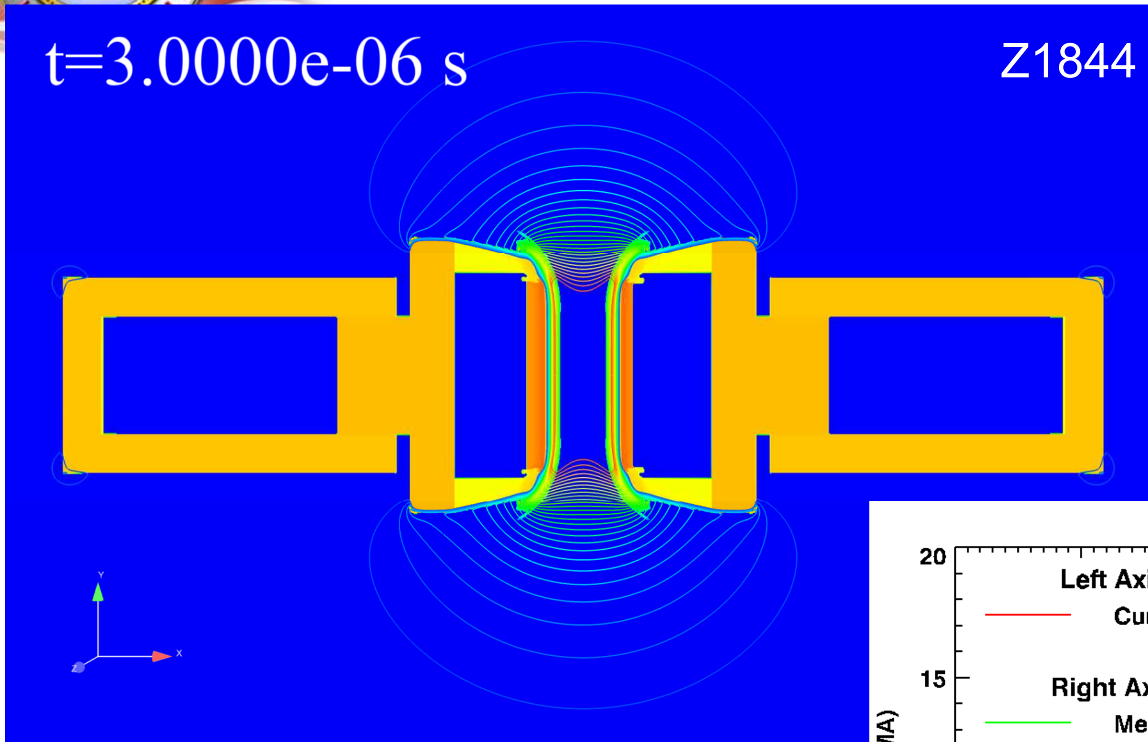

Magnetic Field (line contours)
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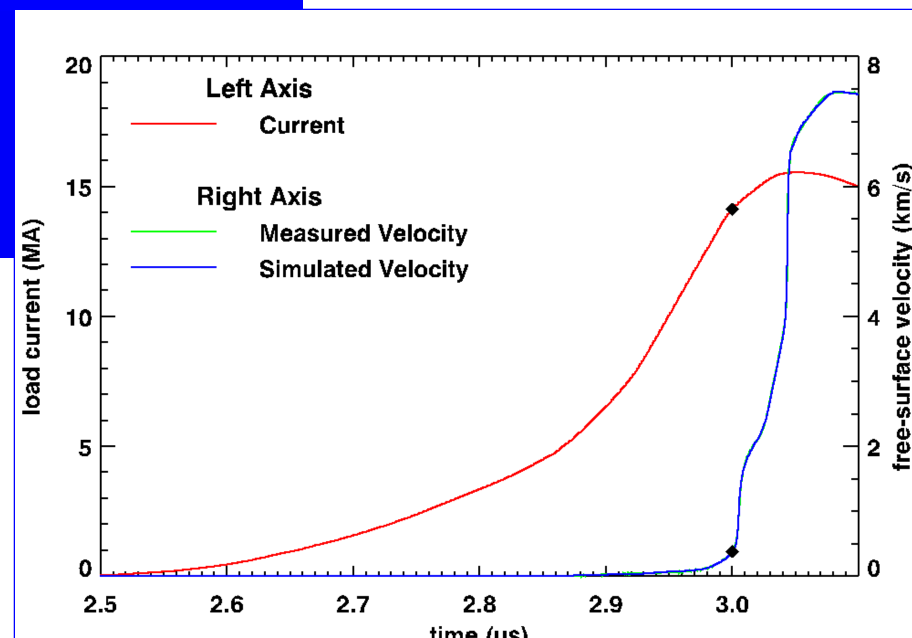

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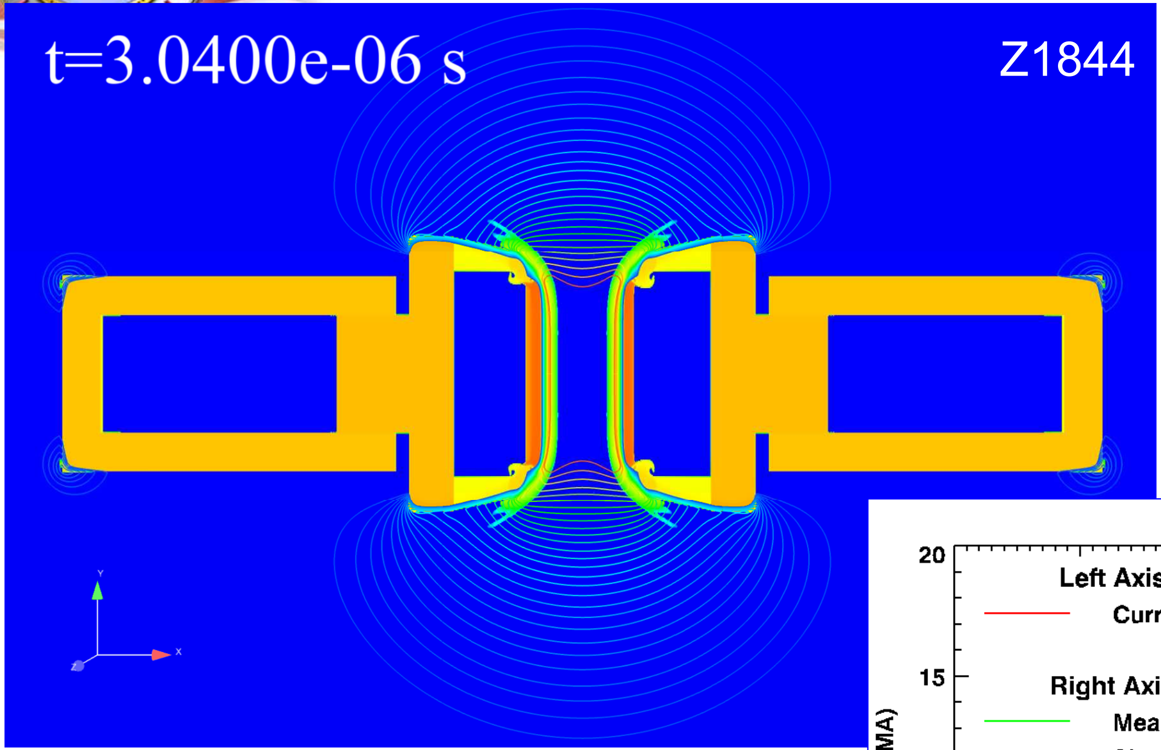
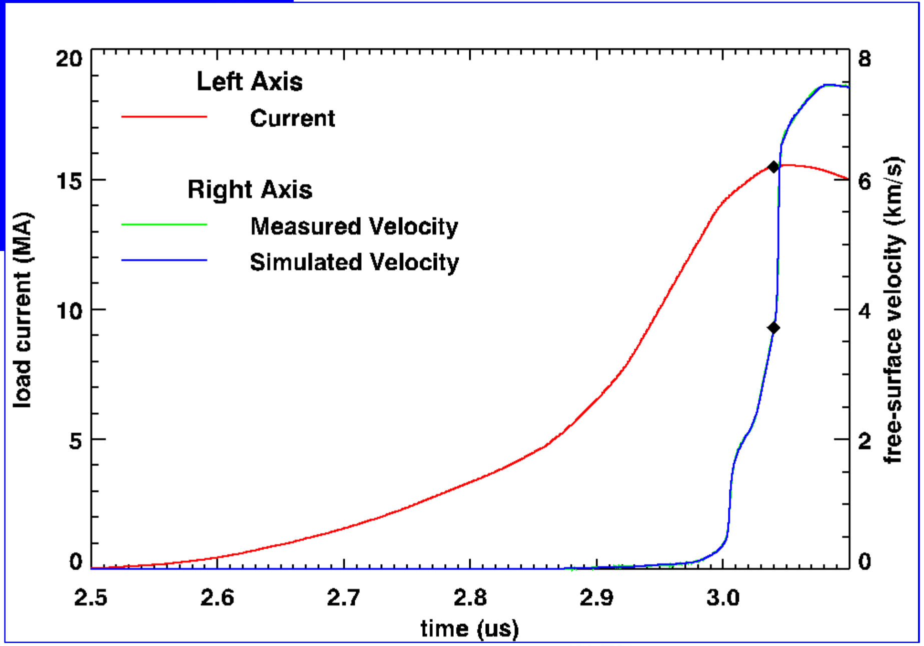


Magnetic Field (line contours)
Density (filled contours)



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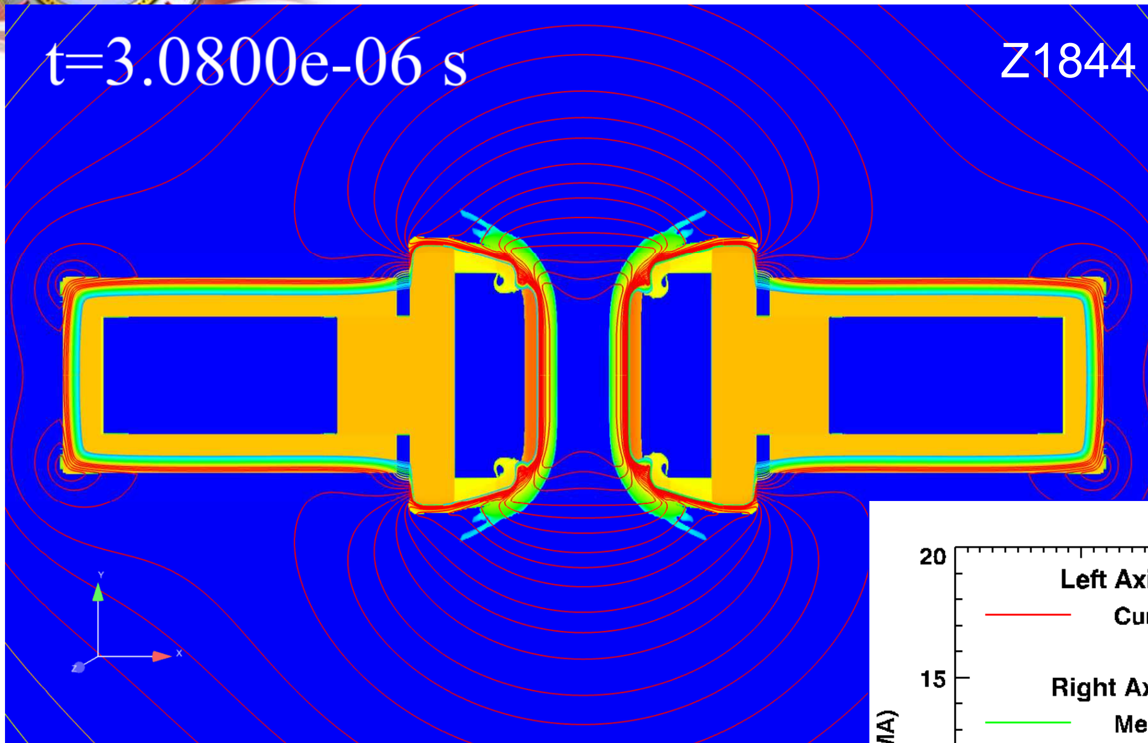
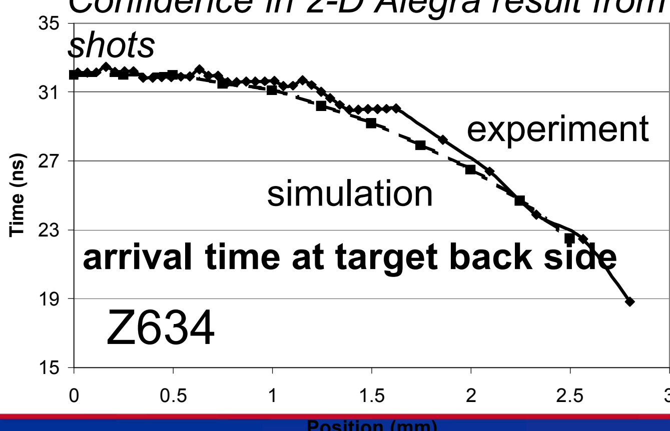
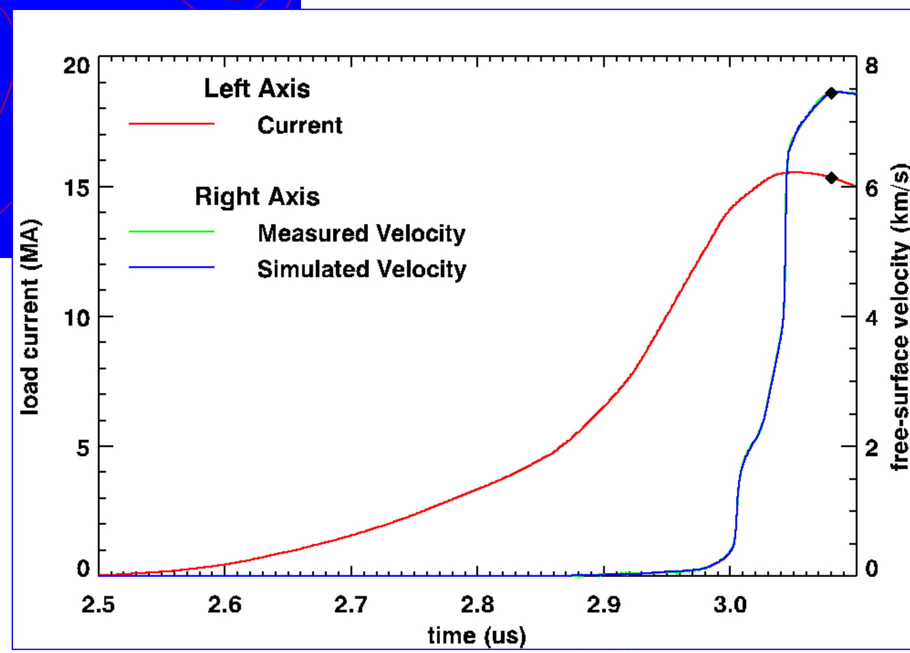
Simulations predict highly uniform B-field in the lateral and normal directions over most of the gap

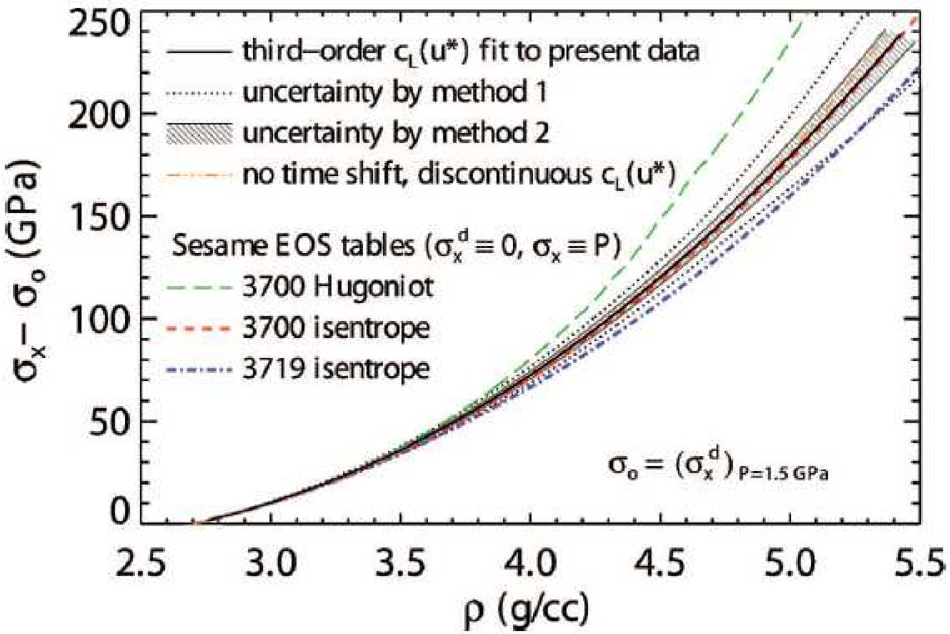


Confidence in 2-D Alegra result from pre-ZR coax shots



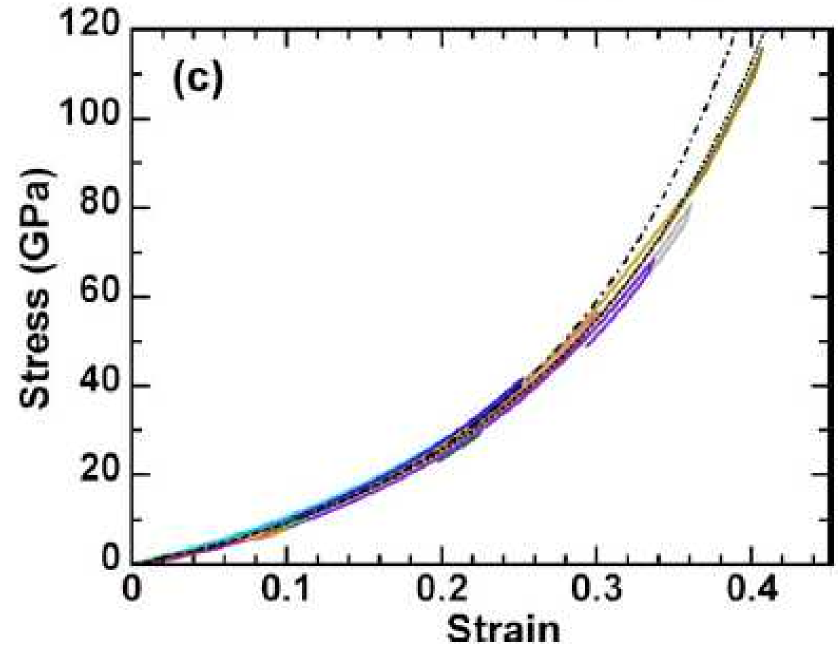


High precision data may be used to discriminate models



Aluminum, Davis, JAP, 2006

LiF, Ao et al., JAP, 2009



Shockless Compression Challenges

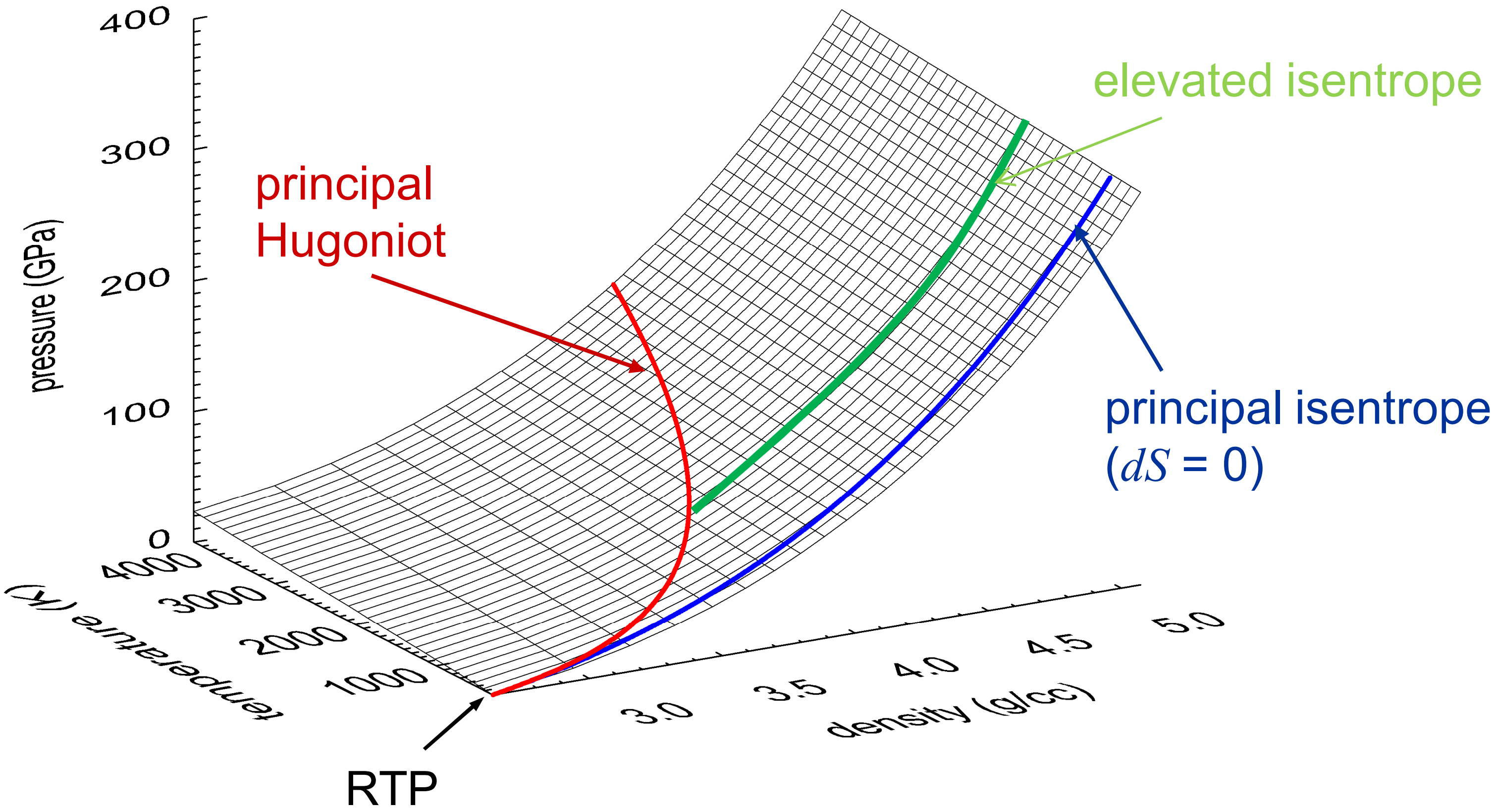
- Almost every experiment requires a new pulseshape
- Experiment design requires a guess of the sample EoS
- Preventing shock-up vs delaying reverberation in sample
  - Assumptions in analysis techniques breakdown at time of reverberation
- Highest pressure data requires very accurate relative timing (currently <100 ps accuracy)
- Sample Quality
- Strength/EoS often coupled

Shock-Ramp

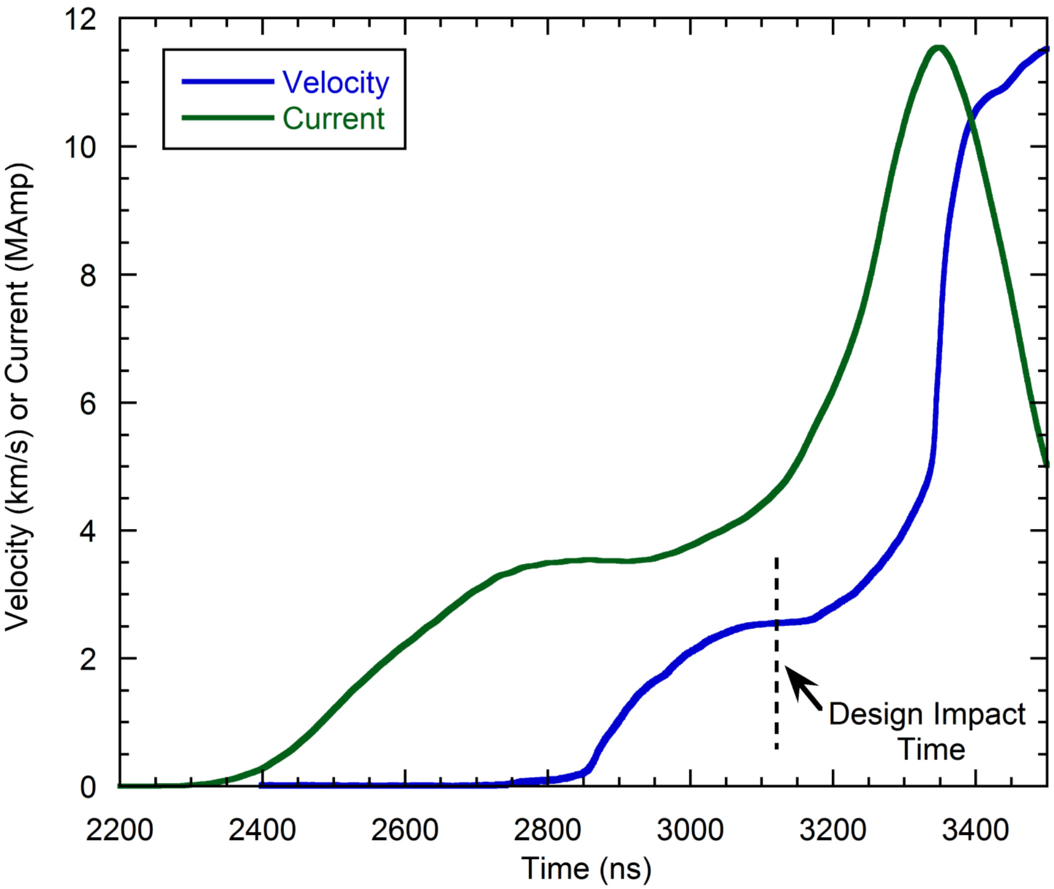
“Typical” Capabilities

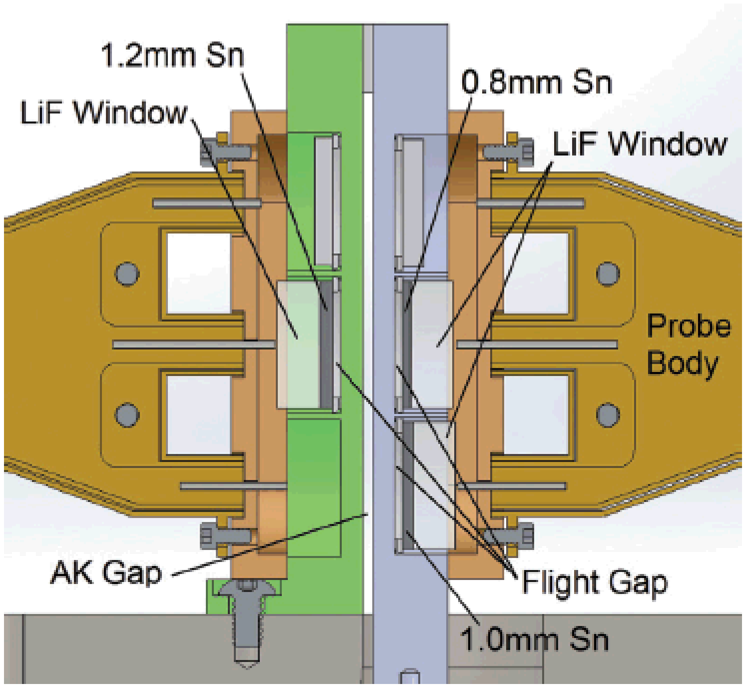
- 800 – 1200 ns pulse length (double-ramp)
- Aluminum or Copper electrodes
- Flyer velocity ~1.5 – 4.5 km/s
- Free surface or windowed samples
- Stripline geometry preferred (coax possible)
- 2-5 sample positions per panel (4-10/shot)
- Samples ~mm thick, 5-8 mm diameter or square
- Experiments designed for EoS

- **Shock to a point on the Hugoniot – then ramp compress from this density/pressure**
- **Flyer accelerated to constant velocity – impact, then push harder**

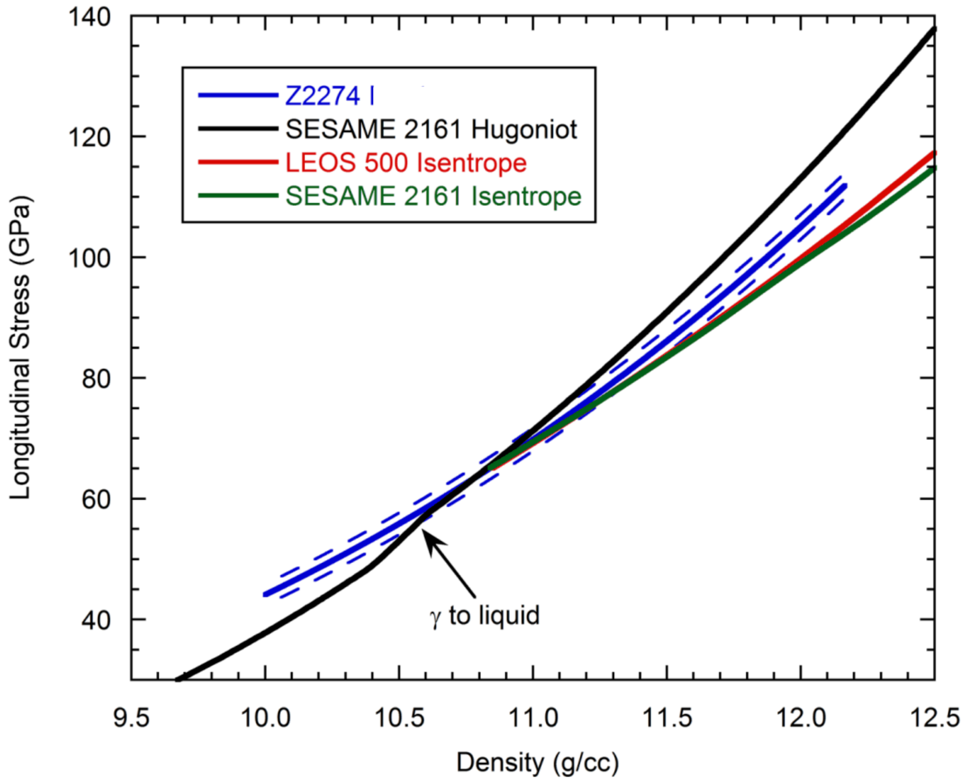


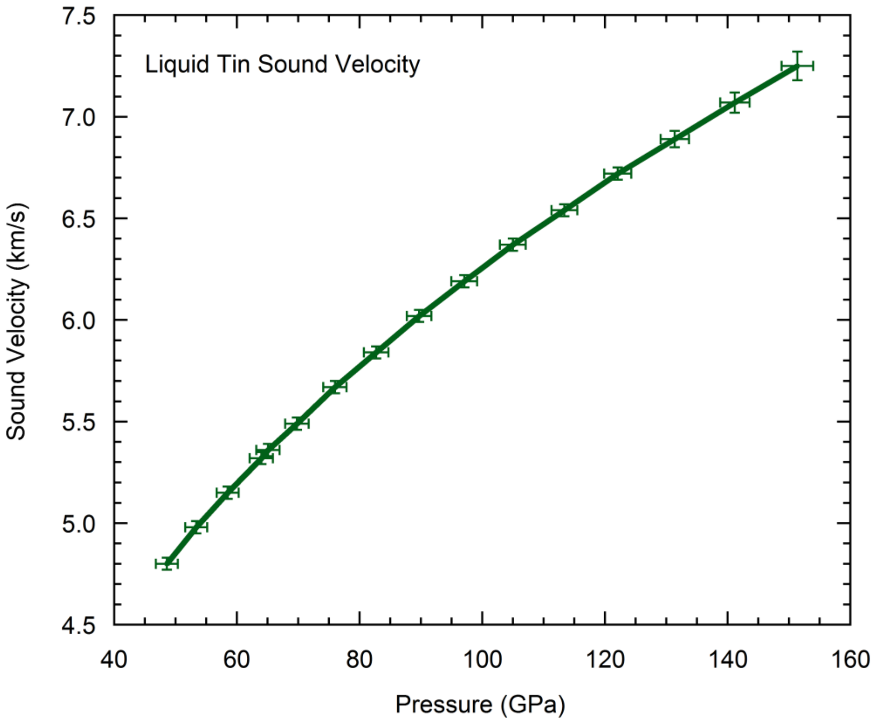
Double-ramp pulseshape "holds" a Hugoniot state in the sample before ramping





High accuracy EoS at elevated temperatures





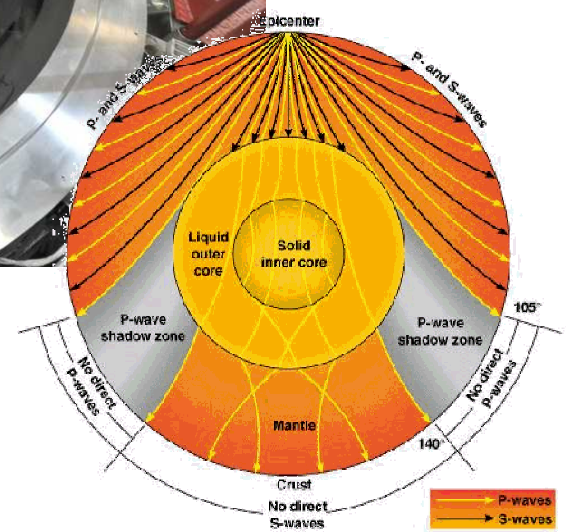
Tin, Seagle et al., APL, 2013

Shock-Ramp Challenges

- Every experiment requires a new pulseshape
- EoS of sample must be guessed to design experiment
- Strong trade-off between peak stress, shocking up during ramp, and reverberation
- Significant machine energy used to accelerate the flyer – peak stress typically limited below shockless compression platform

Z Provides Unique Opportunities for Planetary Science

High Stress – High Entropy States



High Accuracy Sound Velocities of Solid and Shock-Melted Materials

Slide Credits: Chris Seagle, Marcus Knudson, Jean-Paul Davis, Ray Lemke

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