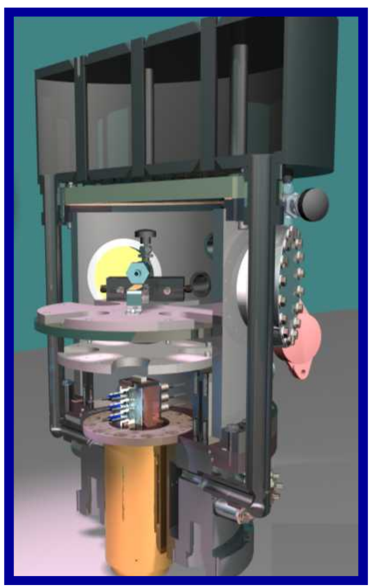
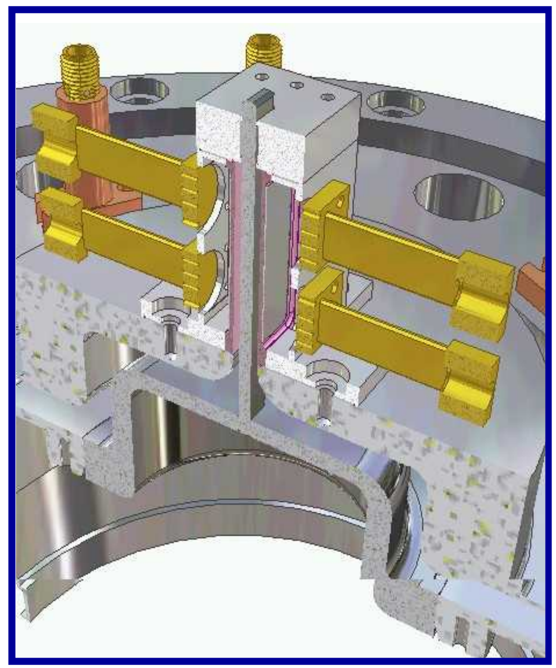
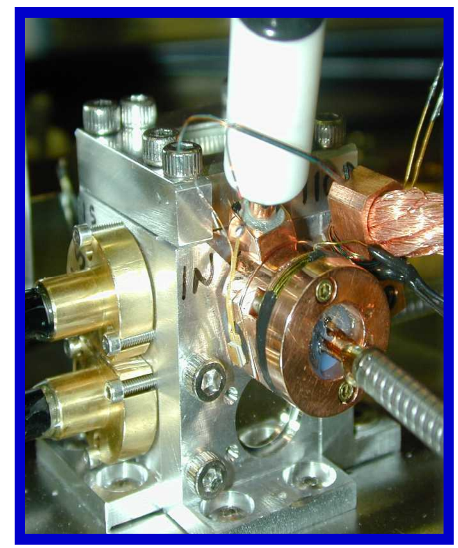
SAND2007-0701C

Materials Dynamics Under Extreme Conditions: Overview of activities at Sandia National Labs

2007 Stewardship Science Academic Alliances Symposium
Washington, DC February 5-7, 2007







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- Jerry Kerley, Dennis Hayes, Jim Asay (Consultants)

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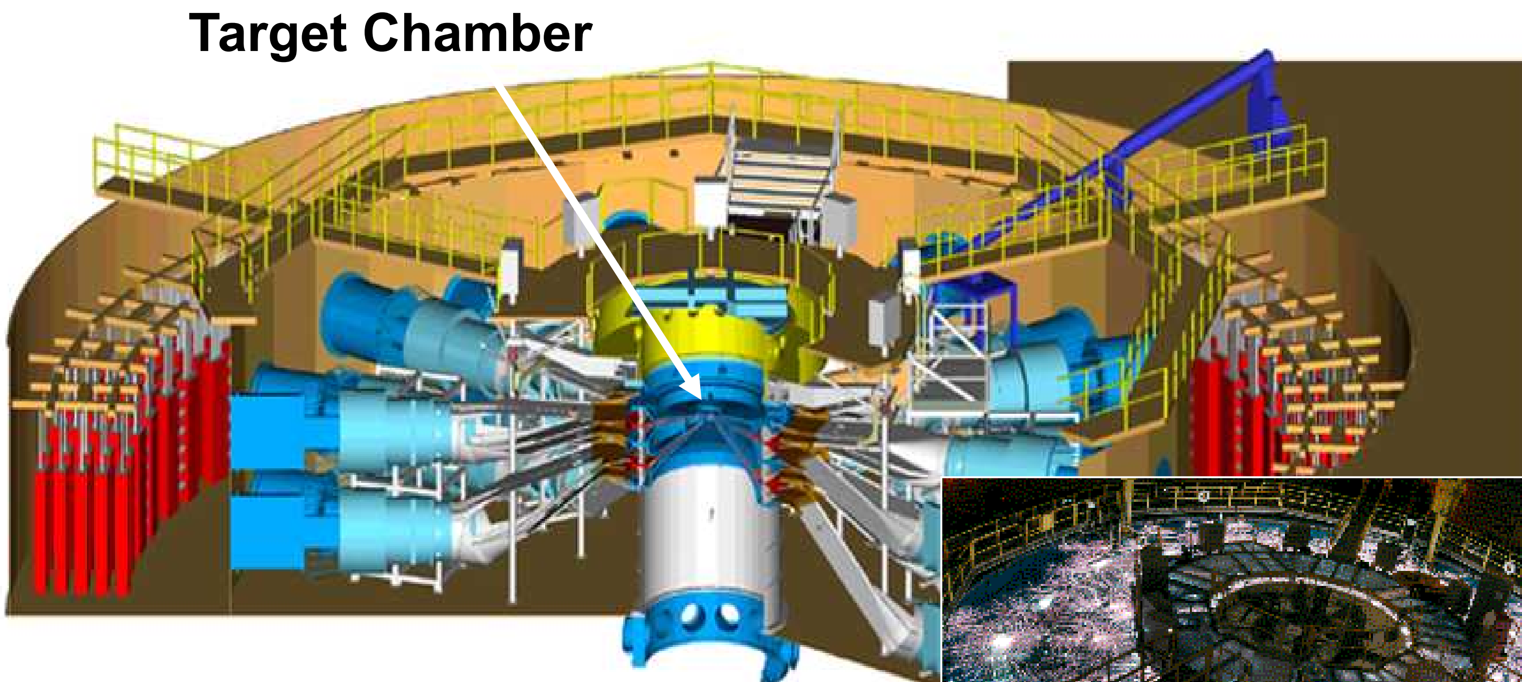
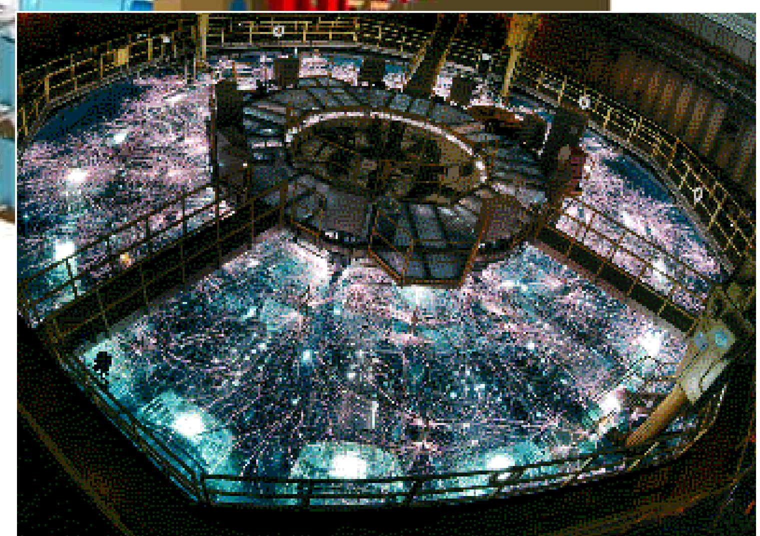
The Sandia Z Accelerator



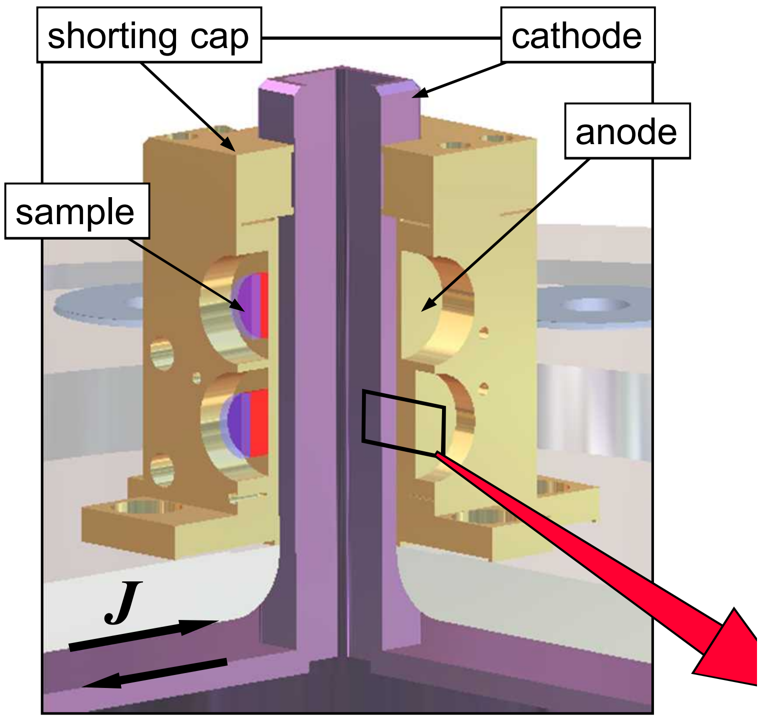


11.5 MJ stored energy

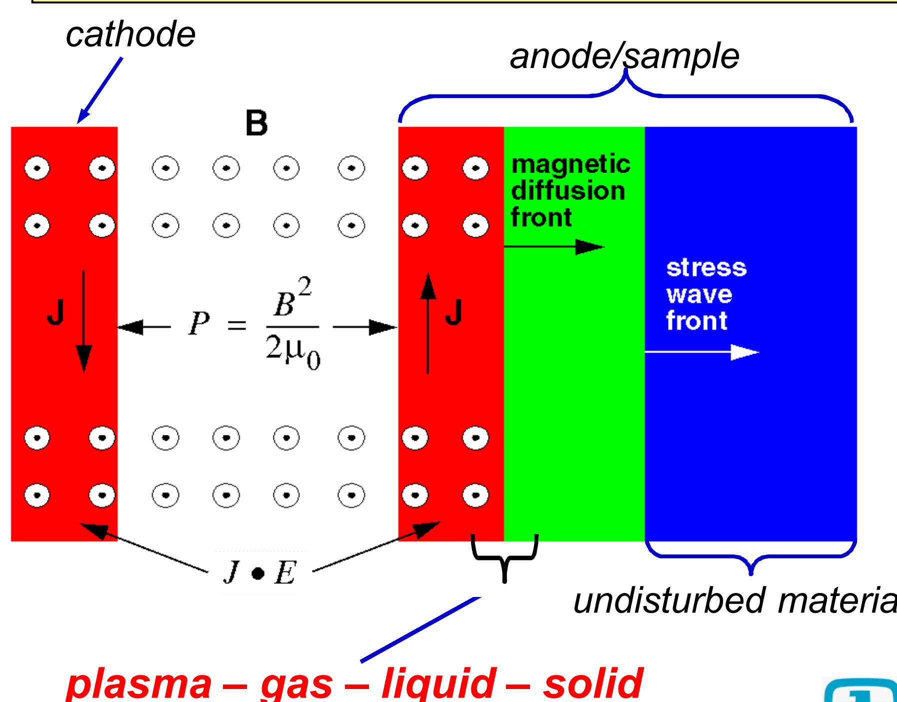
~20 MA peak current

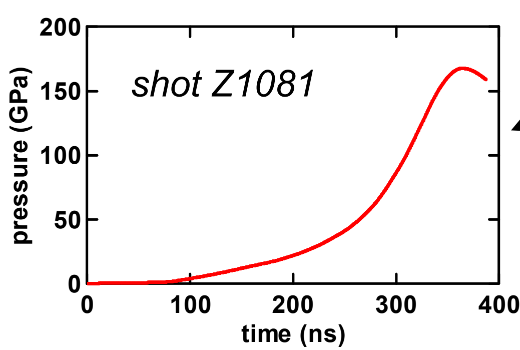
~200-300 ns rise time

Magnetic drive on the Z accelerator can produce smooth ramp loading to very high pressures



- pulse of electric current through rectangular coaxial electrodes (shorted at one end) induces magnetic field
- $J \times B$ magnetic force transferred to electrode material





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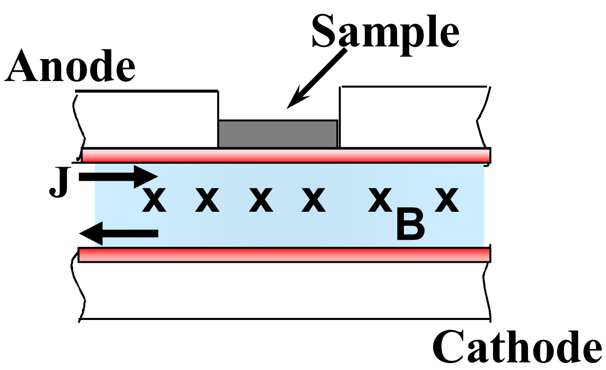
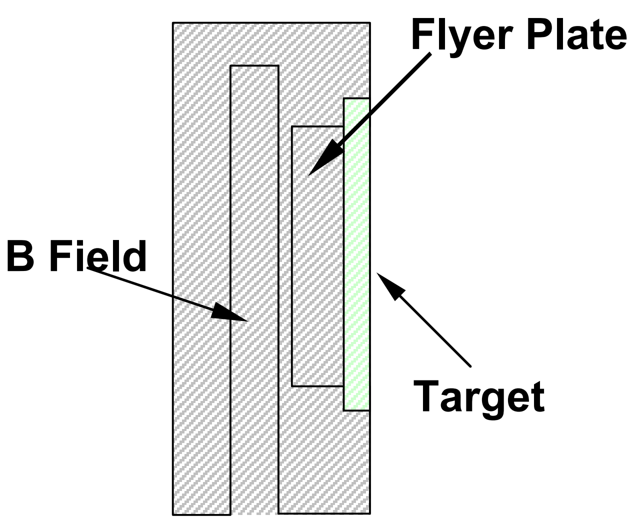
Techniques have been developed on Z for accurate EOS studies—both major advances



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

* Developed with LLNL



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

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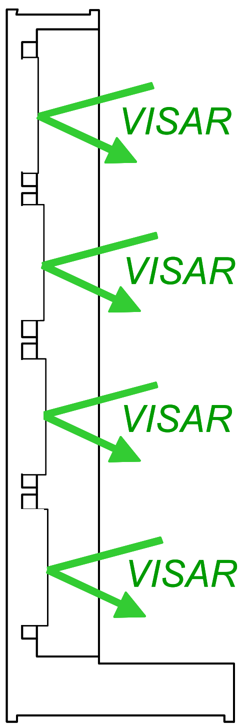
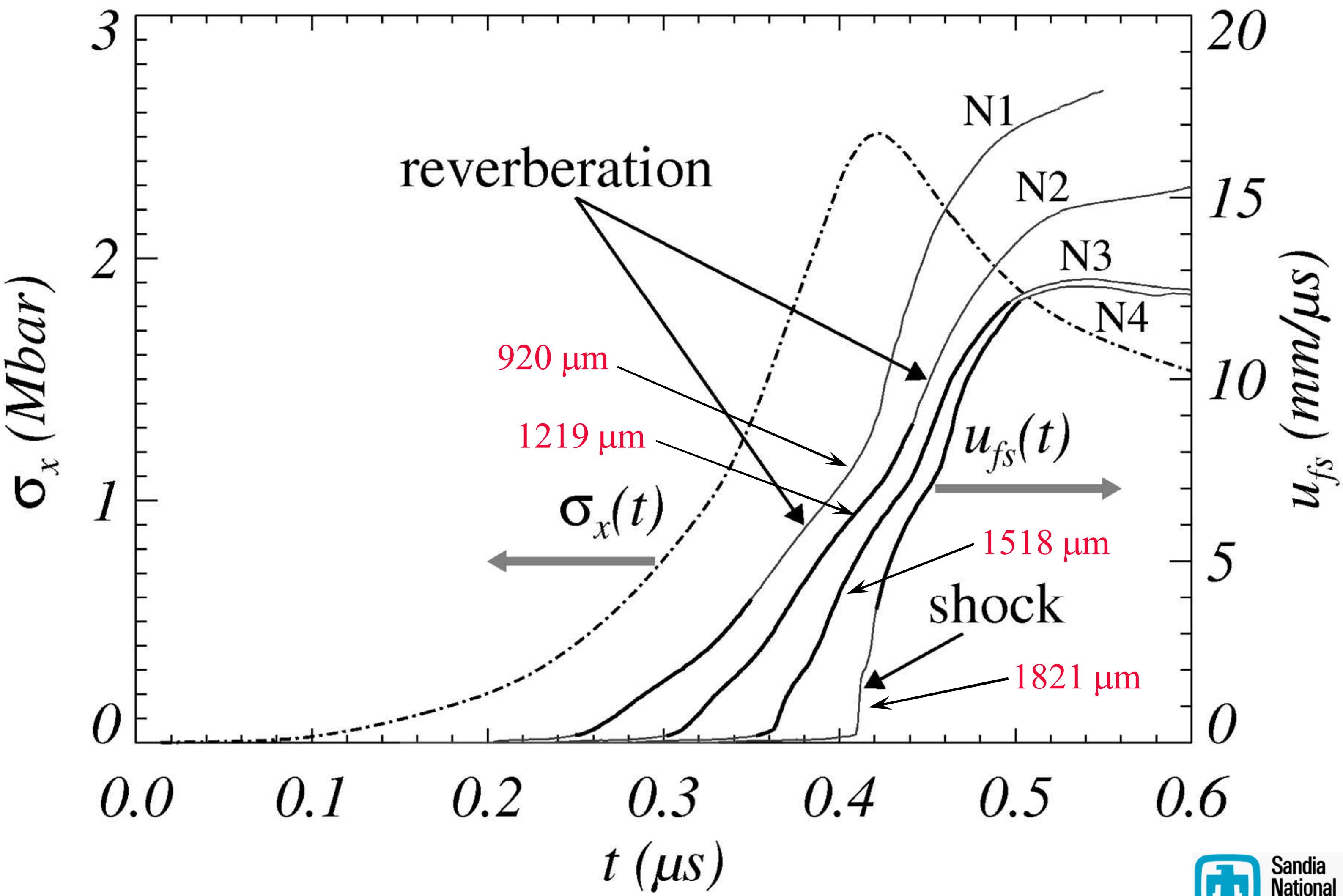
Outline

- (Quasi) Isentropic compression experiments
  - High pressure Isentropic compression
  - Phase transformations
  - Strength
- Hugoniot experiments
  - Ultra-high pressure material response
  - Sound speed measurements to identify melt
- Summary

Pulse shaping and MHD modeling has enabled loading of aluminum to ~250 GPa at > 1.5 mm





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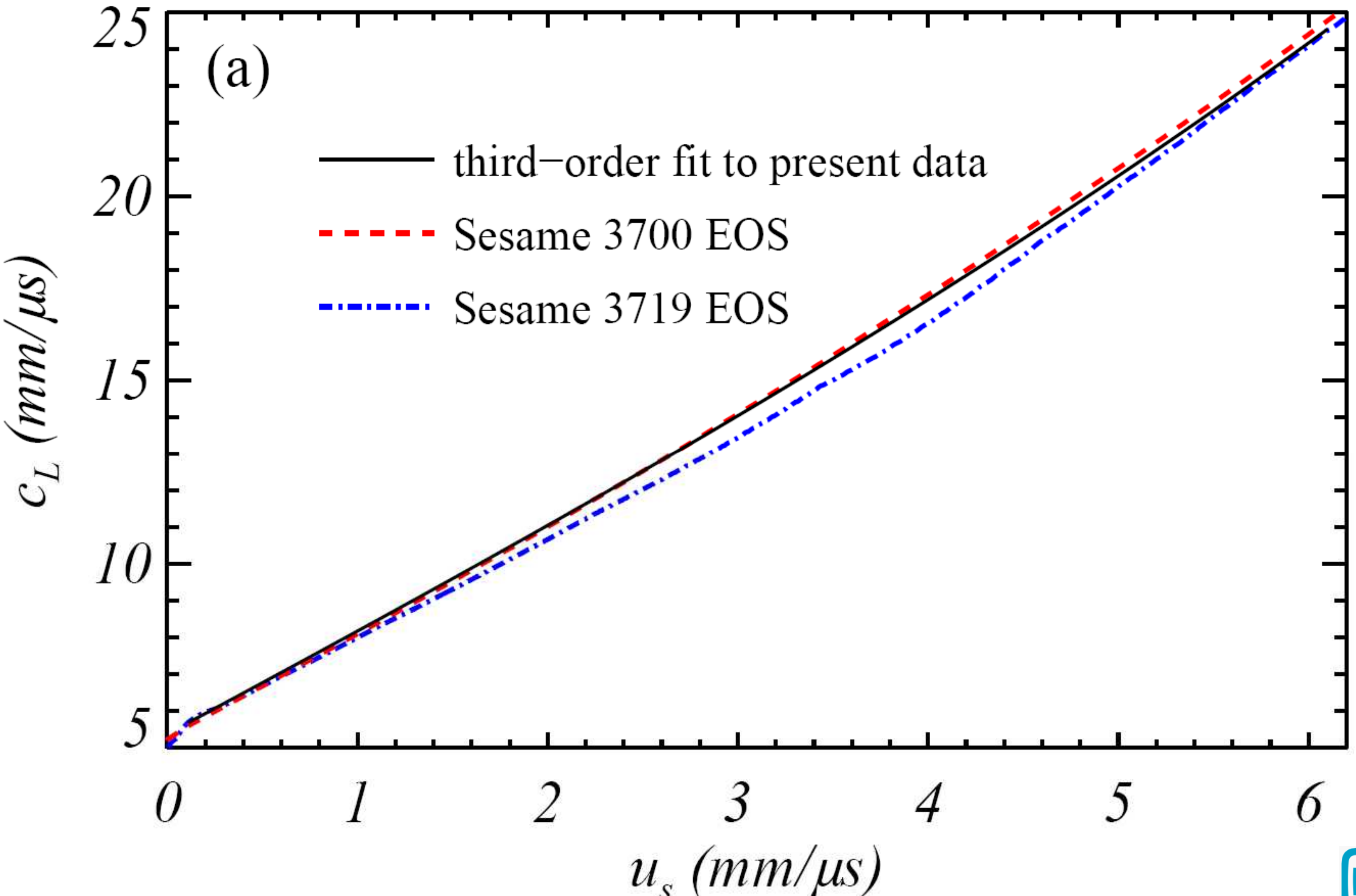
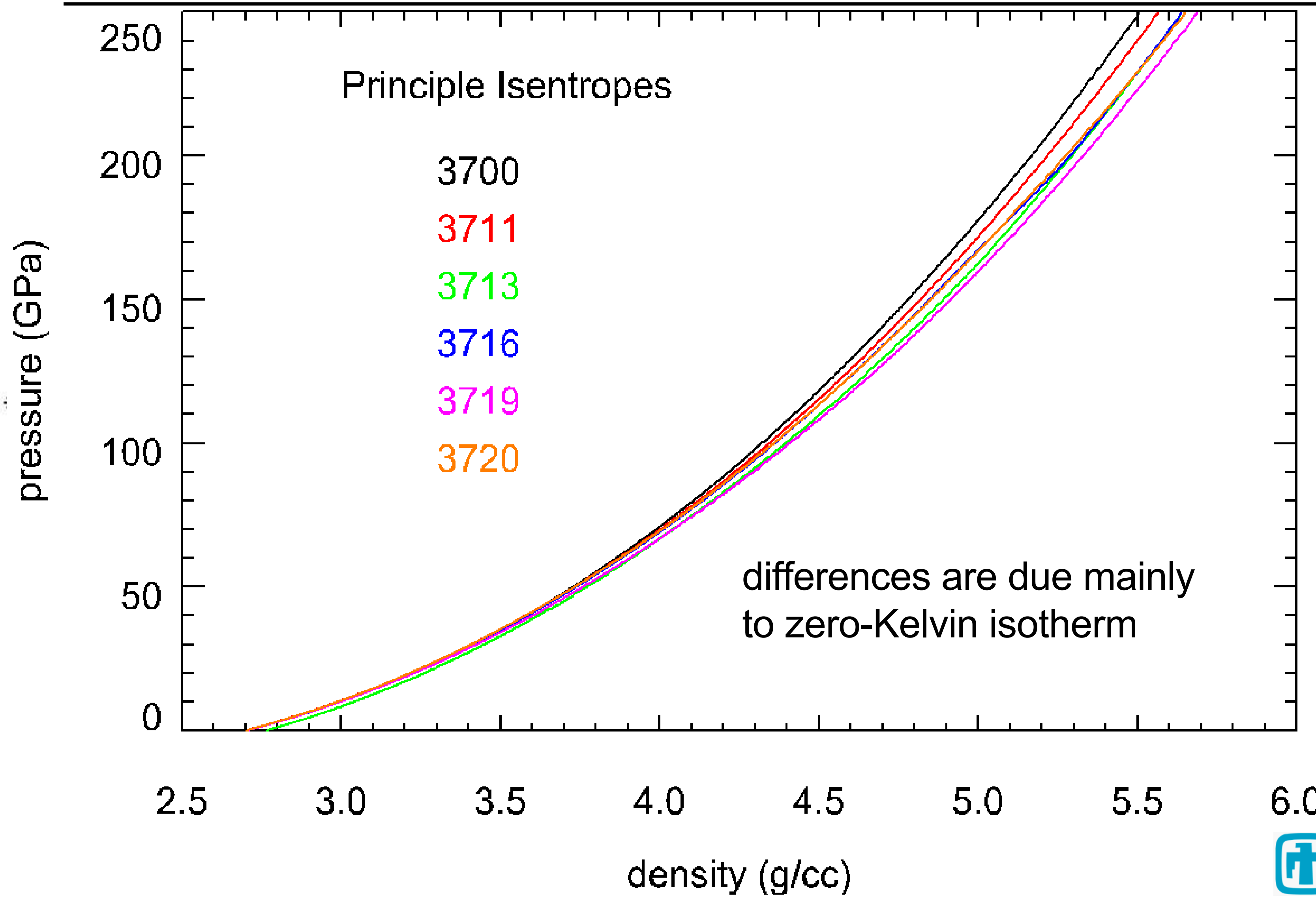
Backward analysis of profile pairs determines sound speed $c_L(u_s)$: third order fit to data

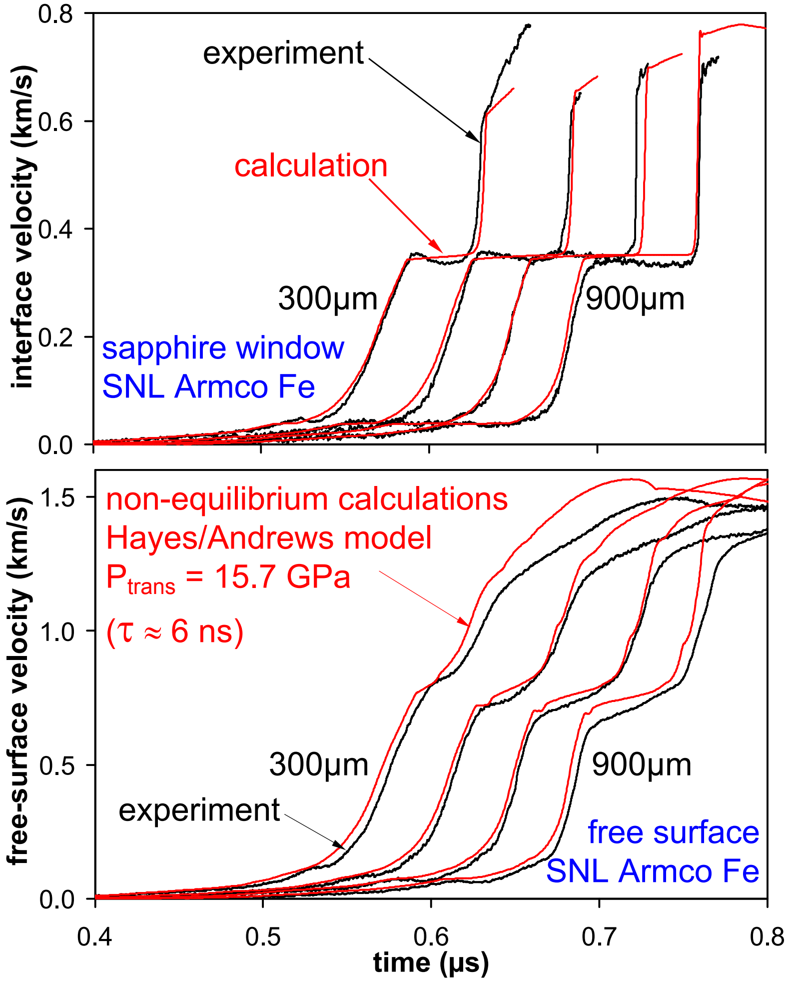


Inferred stress-strain response distinguishes between commonly used models for aluminum



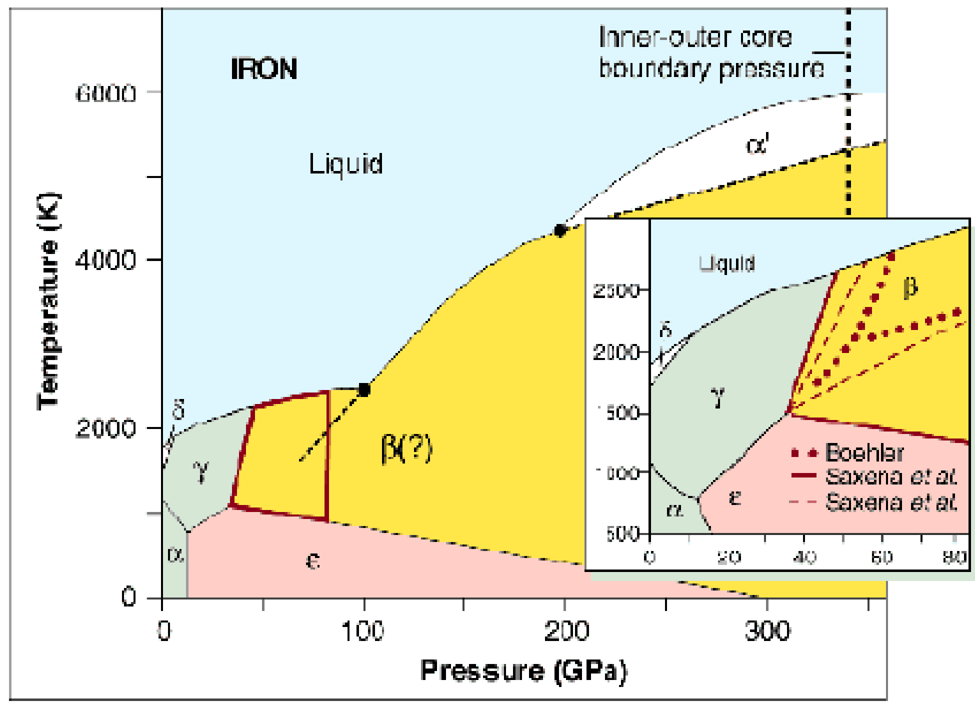
ICE technique is very well suited for study of solid-solid polymorphic phase transitions

α-ε Transition in Fe

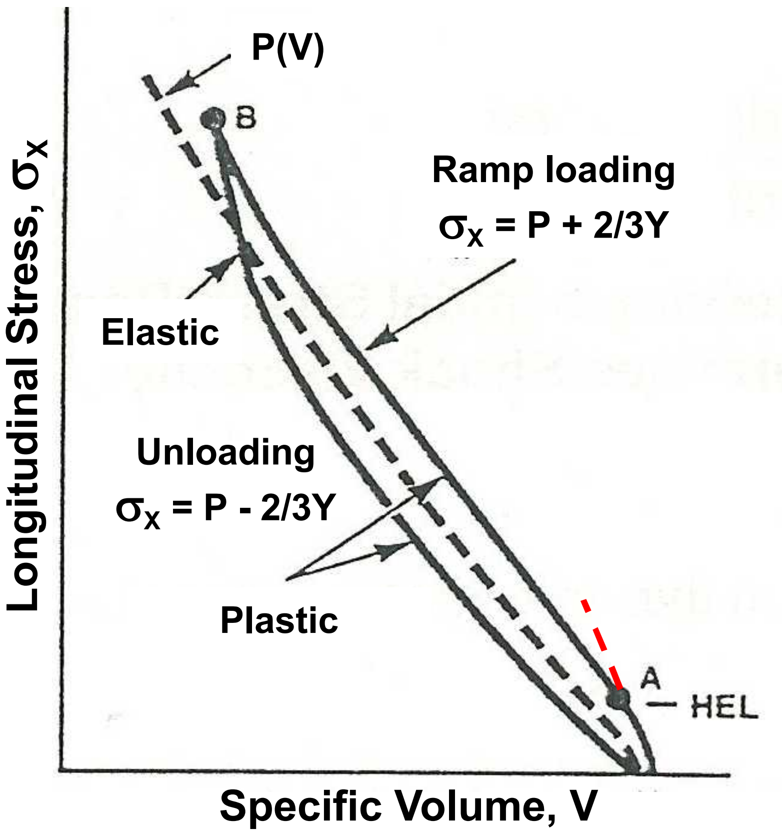


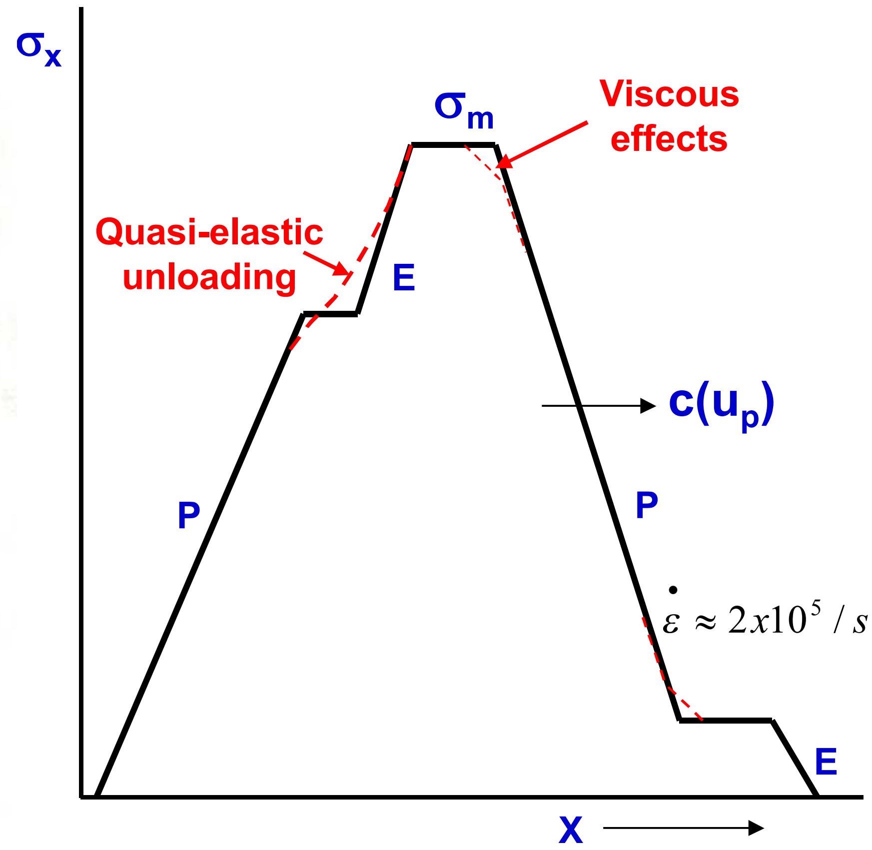
Detection of phase boundaries

Determination of kinetics



Time-resolved measurements of loading and unloading profiles allows estimates of strength





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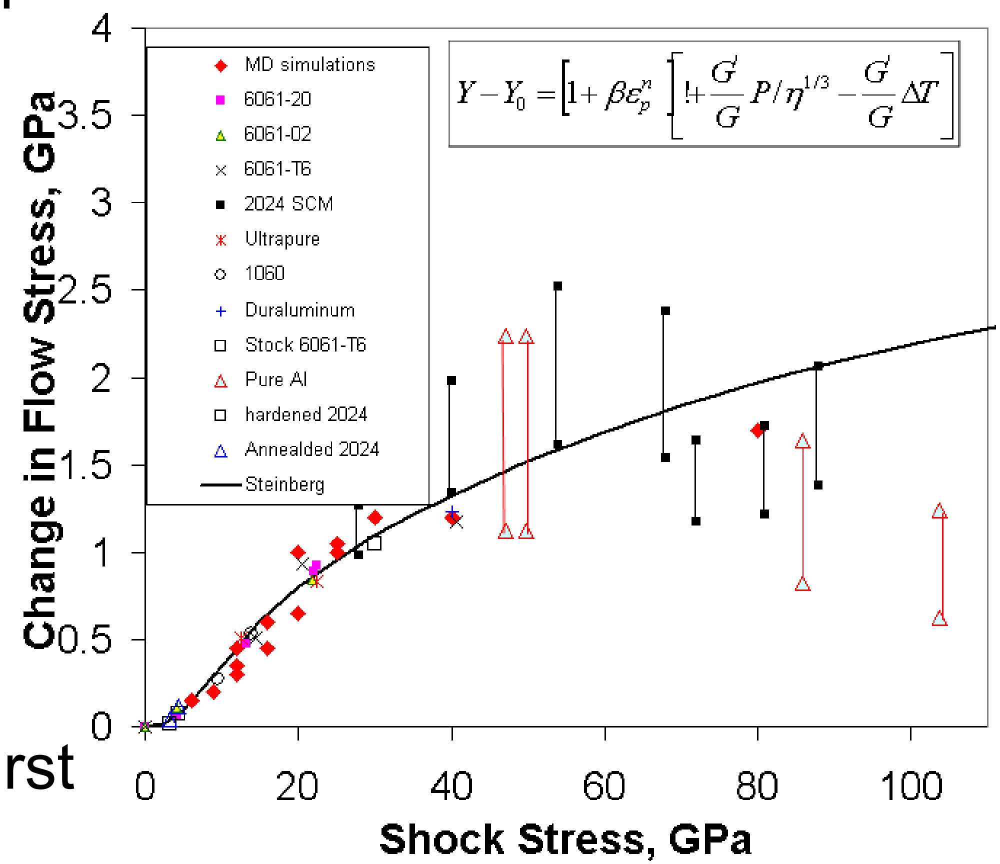
Sandia program in high pressure strength measurements

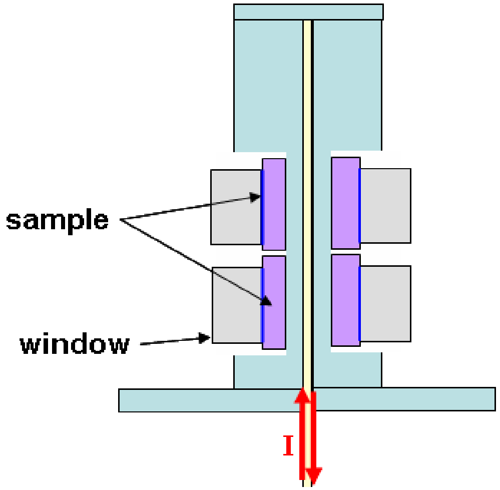
- Provide accurate strength data for shock & quasi-isentropic loading
- Provide database of strength properties for model development
- Evaluate effects of:
  - Initial material properties
  - Stress history
  - Phase transitions
  - Loading rate
- Validate continuum and first principles models of strength

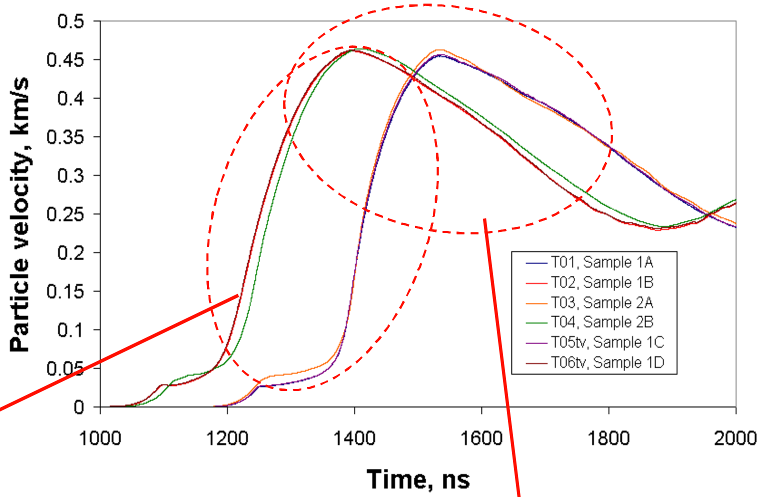
Aluminum, shock loading



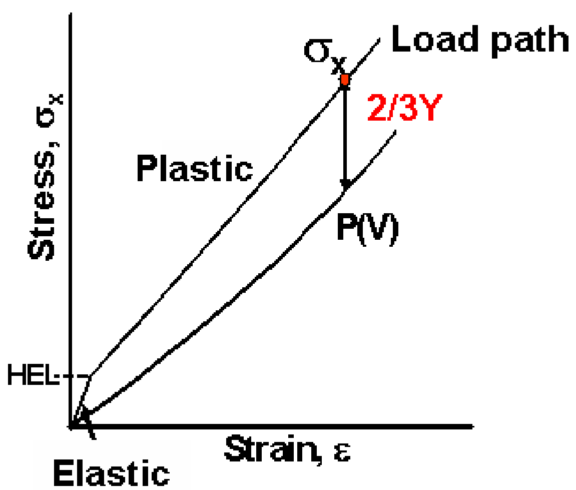
Huang and Asay, 2005

Experimental techniques are being developed for estimating shear strength in ICE experiments

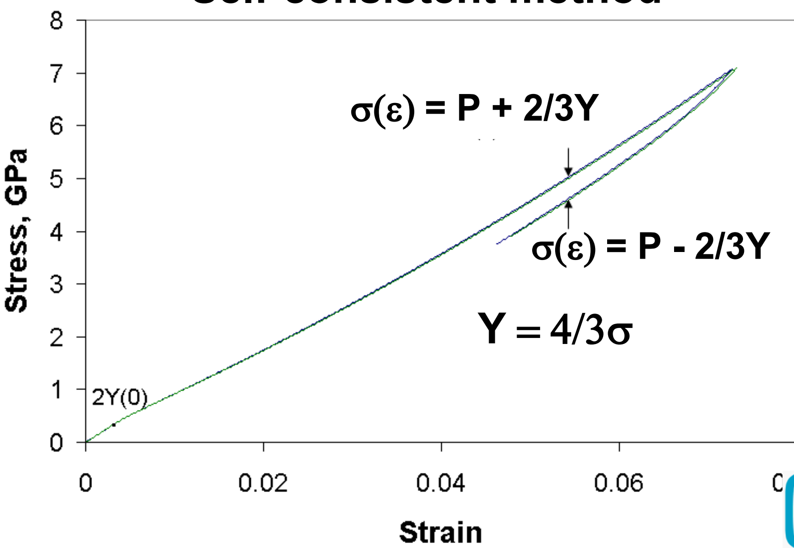




Difference method



Self-consistent method



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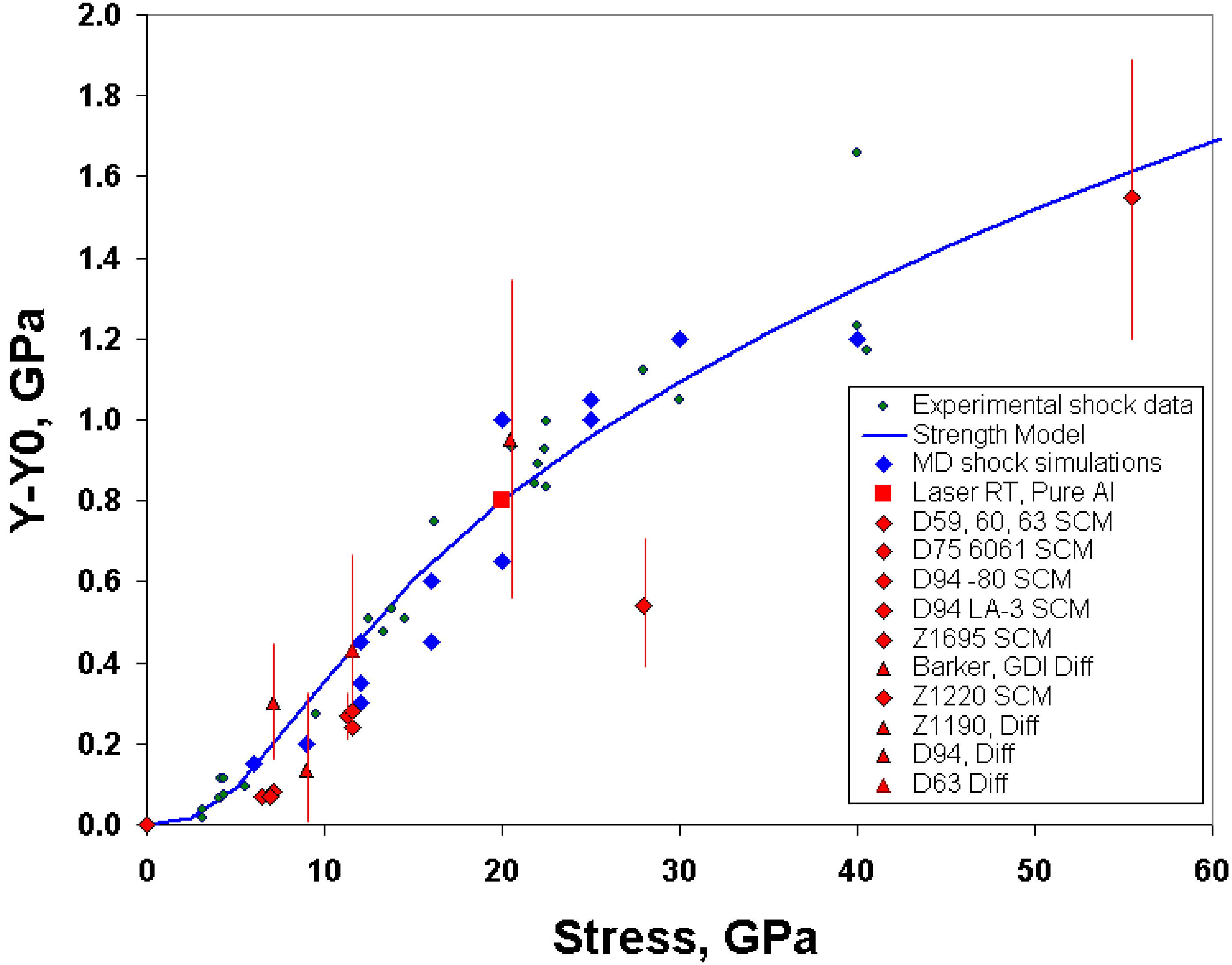
Preliminary strength data in aluminum for quasi-isentropic loading



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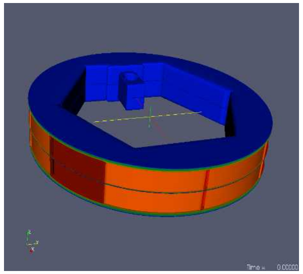
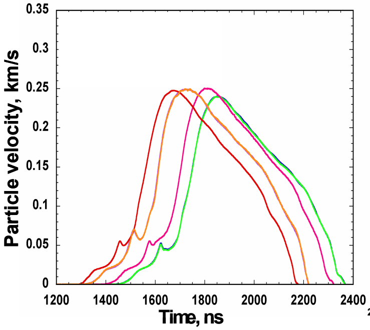
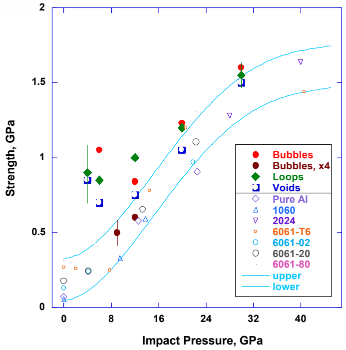
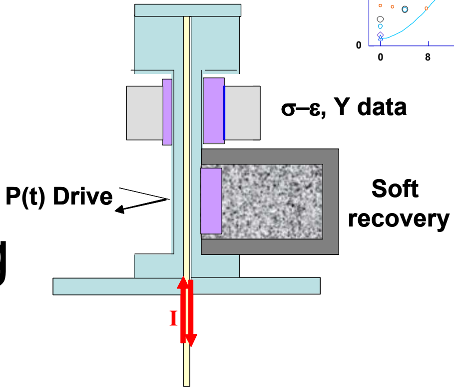
Future directions in strength research

- MHD simulations to improve VELOCE strip line drives
- Characterization of LiF/other windows
- Analysis of rate-dependent elastic yielding
- Effects of strain-rate on compressive strength
- Verification of first principles strength models
- Simultaneous strength and post-loading microstructure analyses









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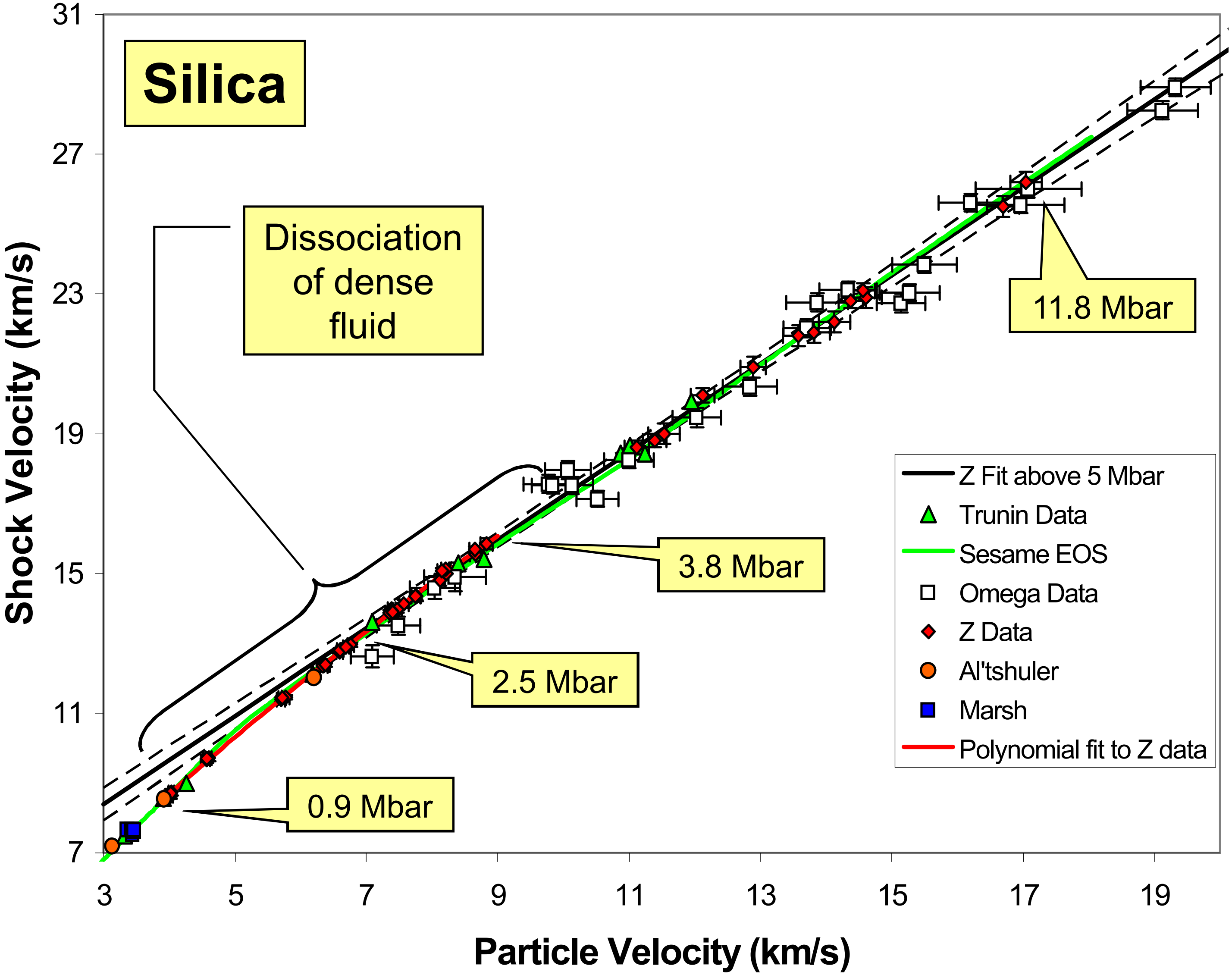
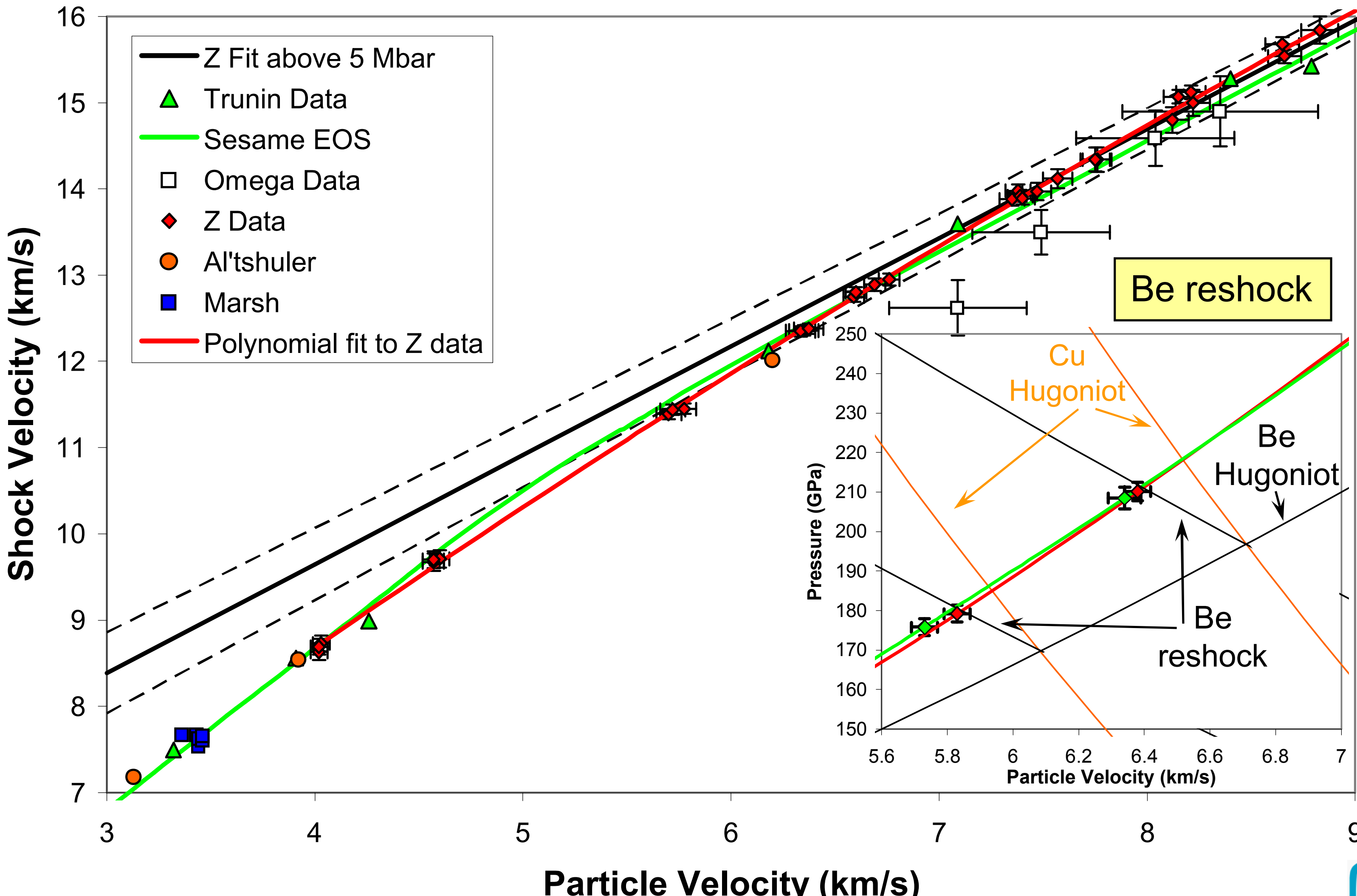
Hugoniot data for silica illustrates the accuracy and precision achievable on Z



High pressure response of Silica is of fundamental importance to geophysics

Quartz is becoming the standard of choice for high pressure laser Hugoniot measurements

Flyer plate configuration and multiple samples allow for consistency checks and greater insight



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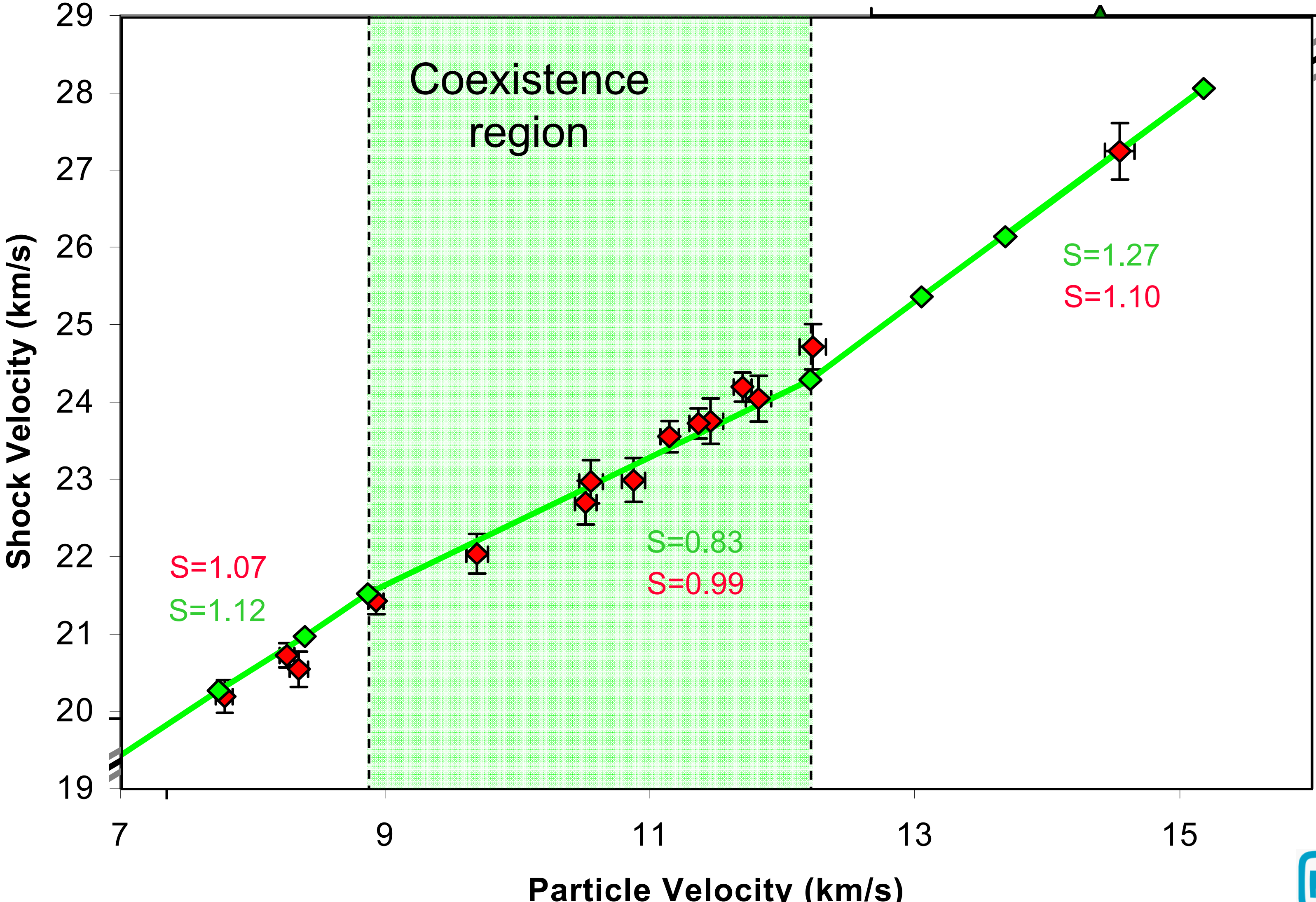
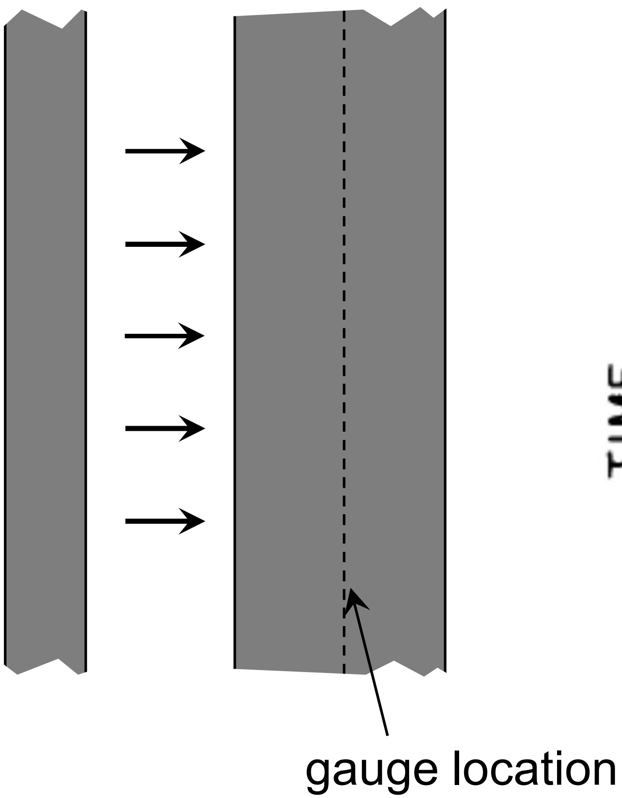
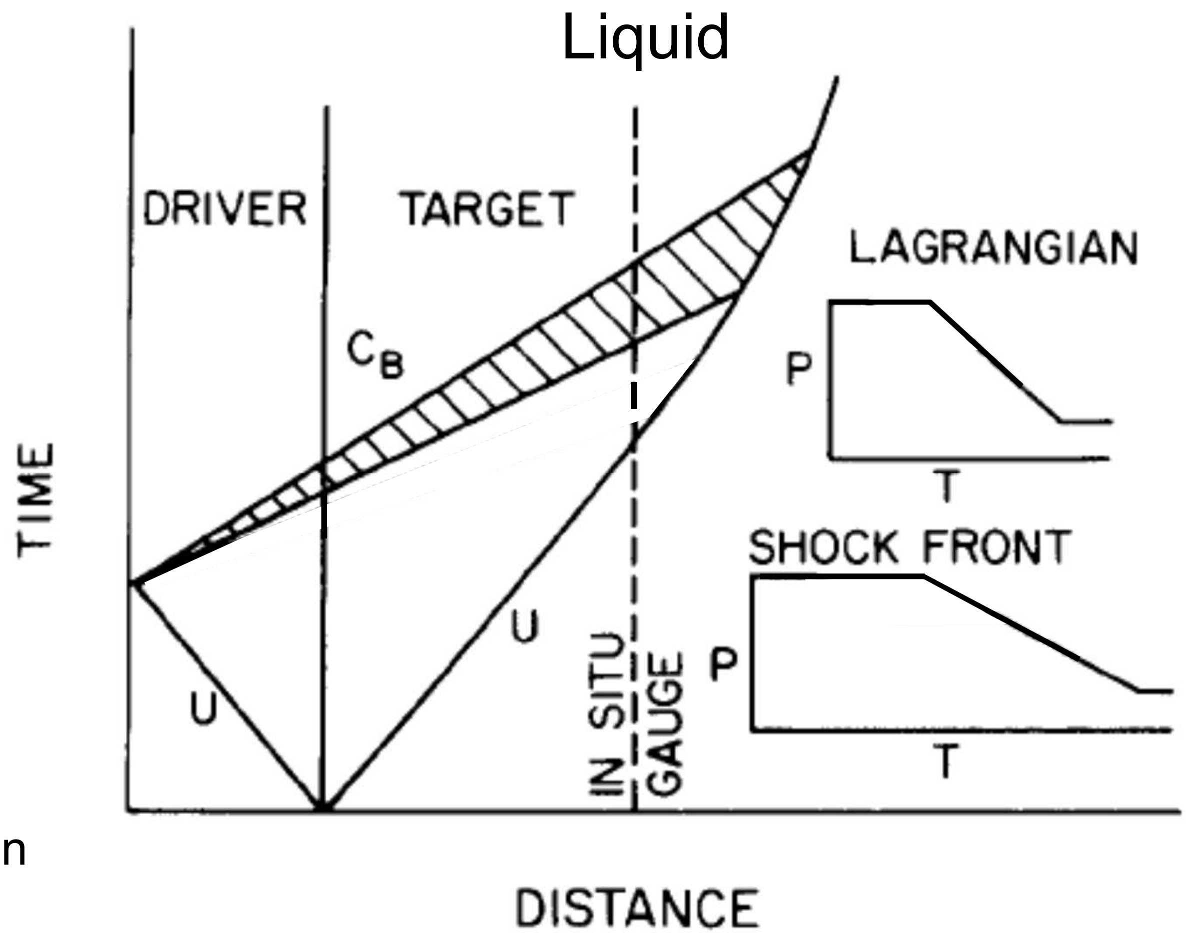
The C melt experimental configuration provides for very accurate Hugoniot measurements



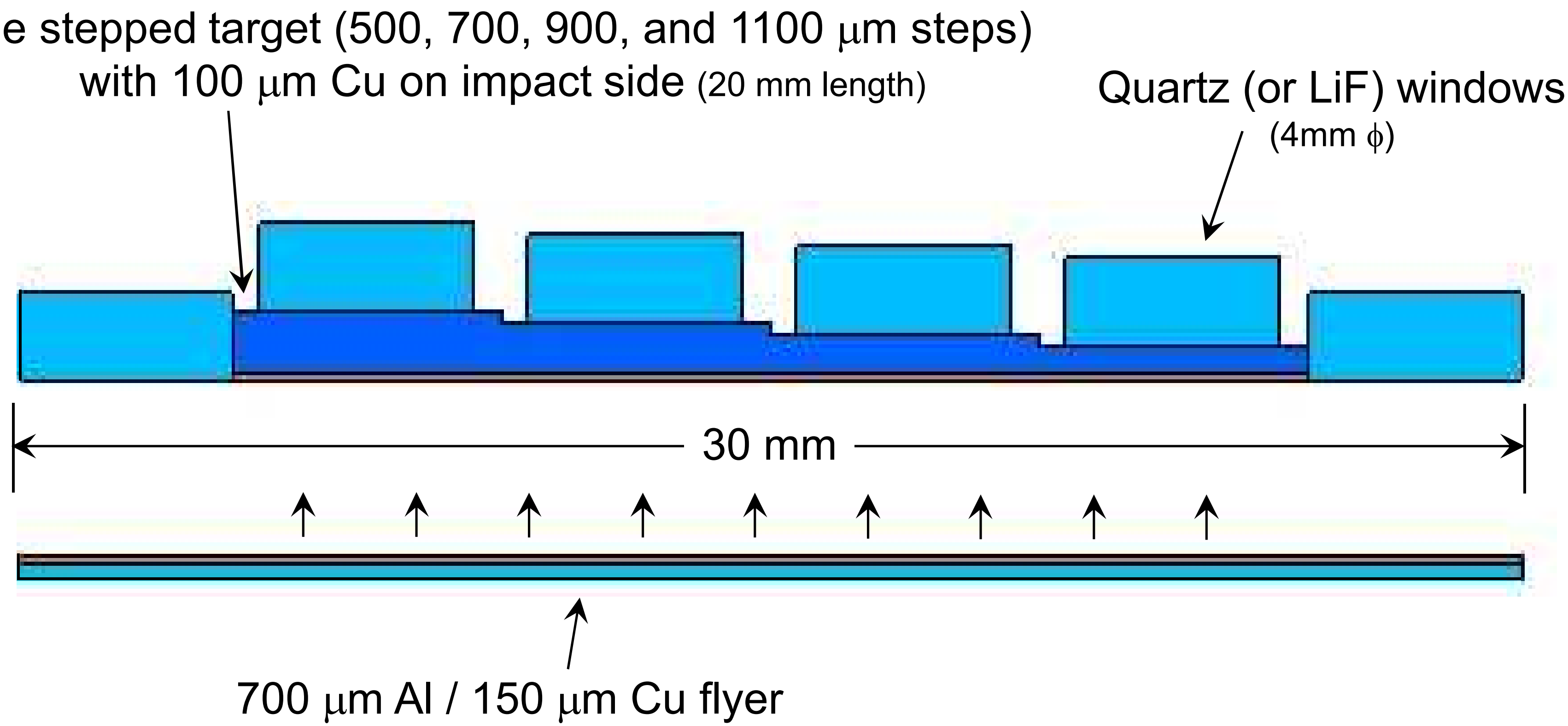
Melt on the Hugoniot is determined by measuring sound speed using wave overtake technique





McQueen, et al., Rev. Sci. Instrum. **53**, 245 (1982)

Target design for the Be melt experiments on the Z accelerator



v_f 7 km/s
Cu_H 2.9 Mbar
Be_H 1.25 Mbar

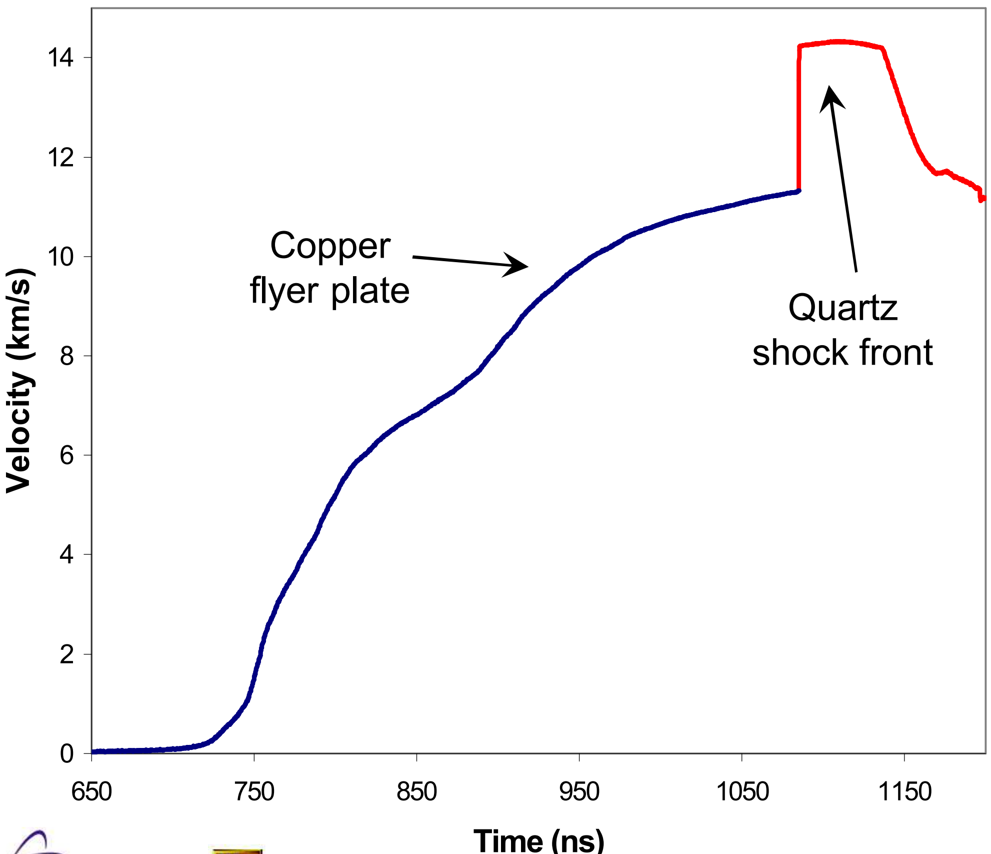
to

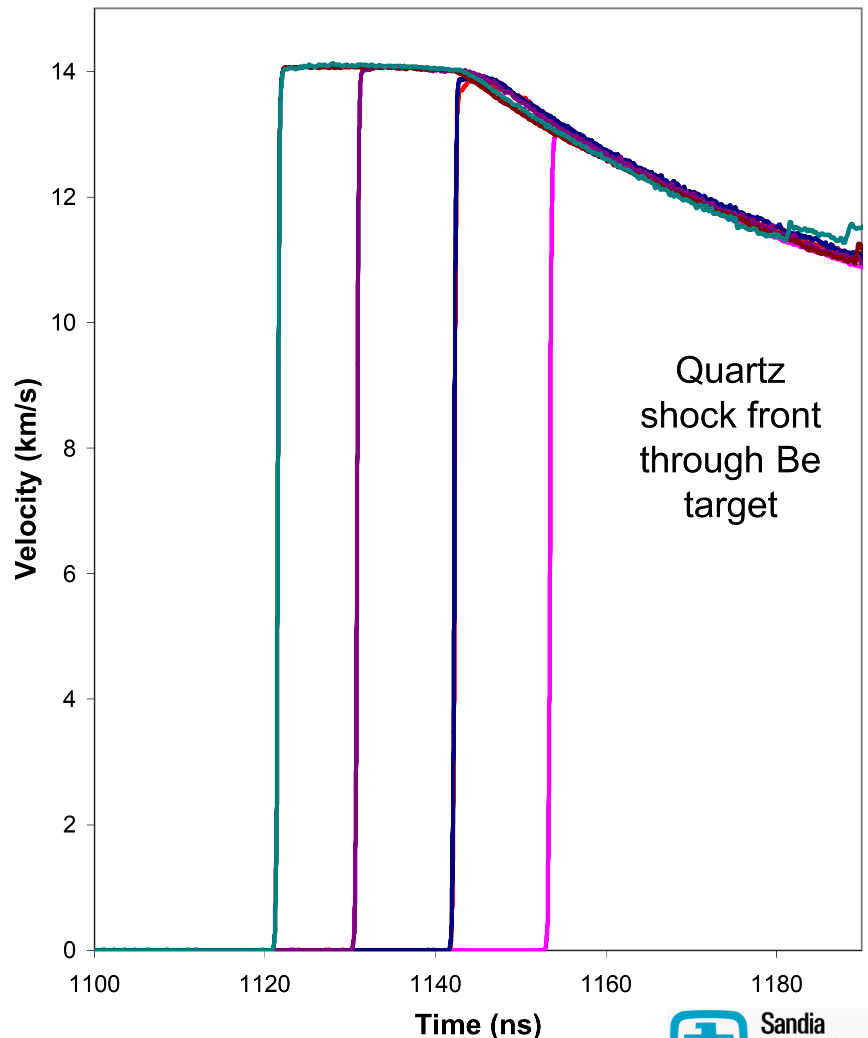
v_f 14 km/s
Cu_H 8.9 Mbar
Be_H 3.5 Mbar

These velocities are easily achievable on Z

High quality data is being obtained from the Be melt experiments

Sample data at ~250 GPa in Be





Los Alamos

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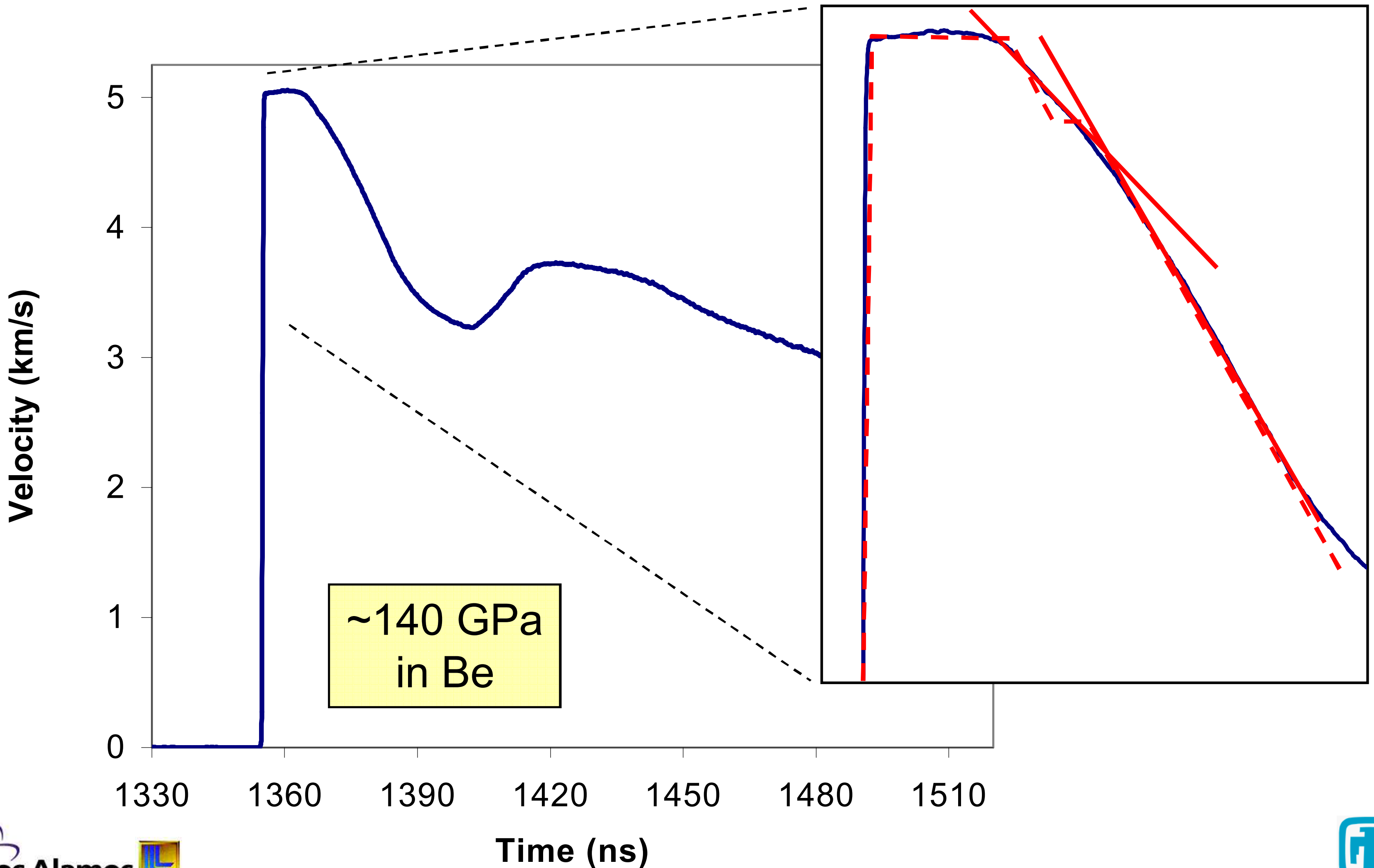
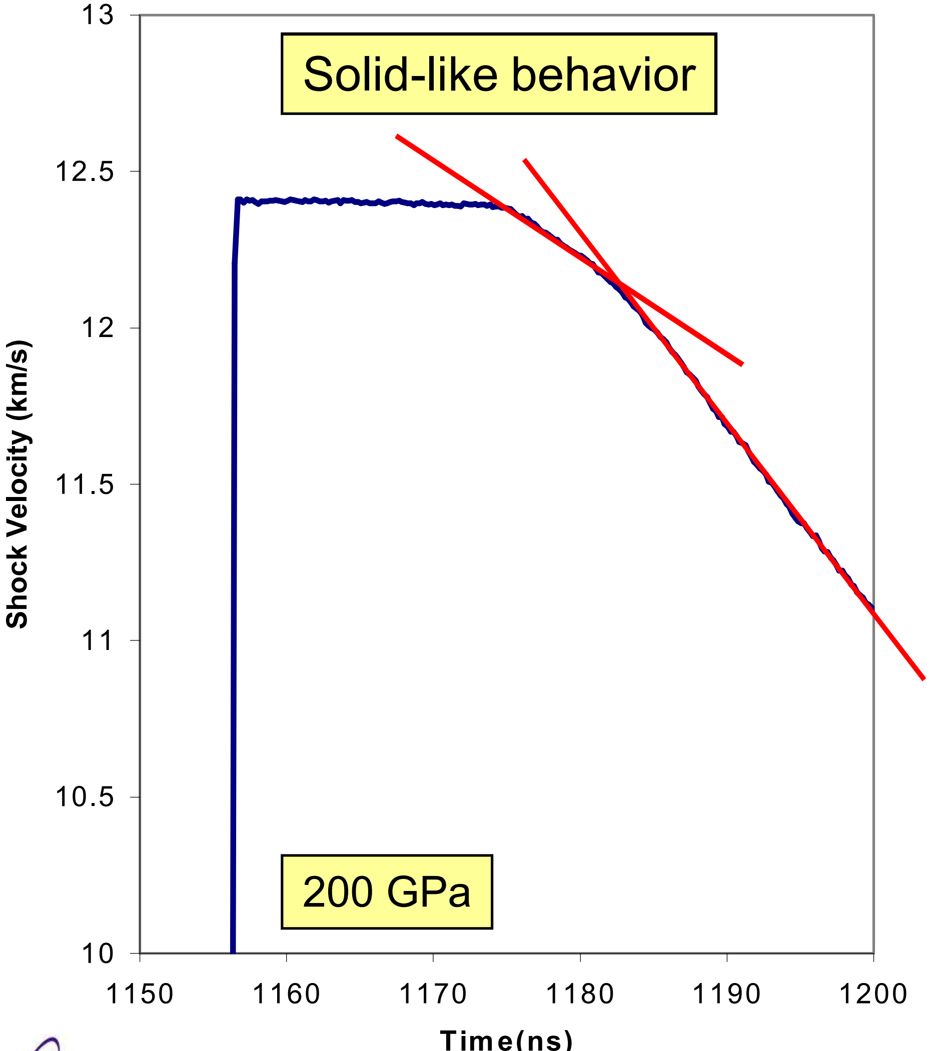
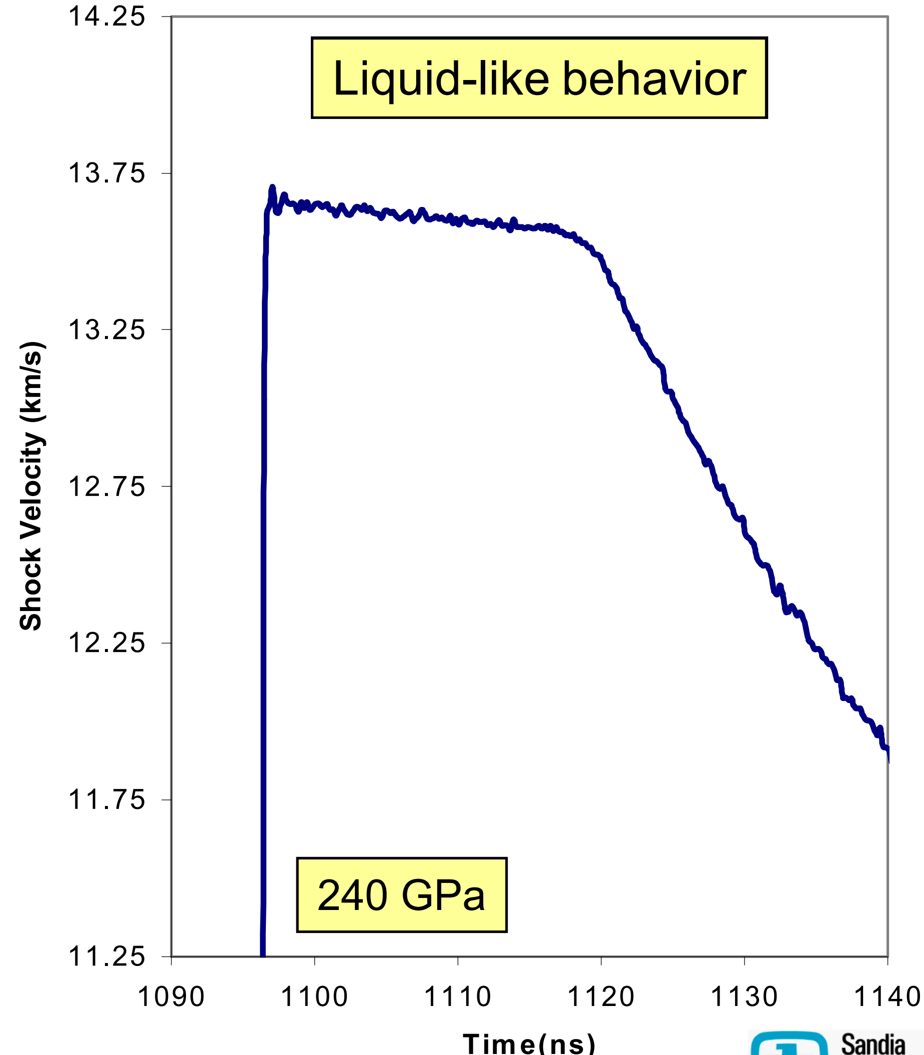
Classic elastic/plastic release observed at lower stresses with LiF window



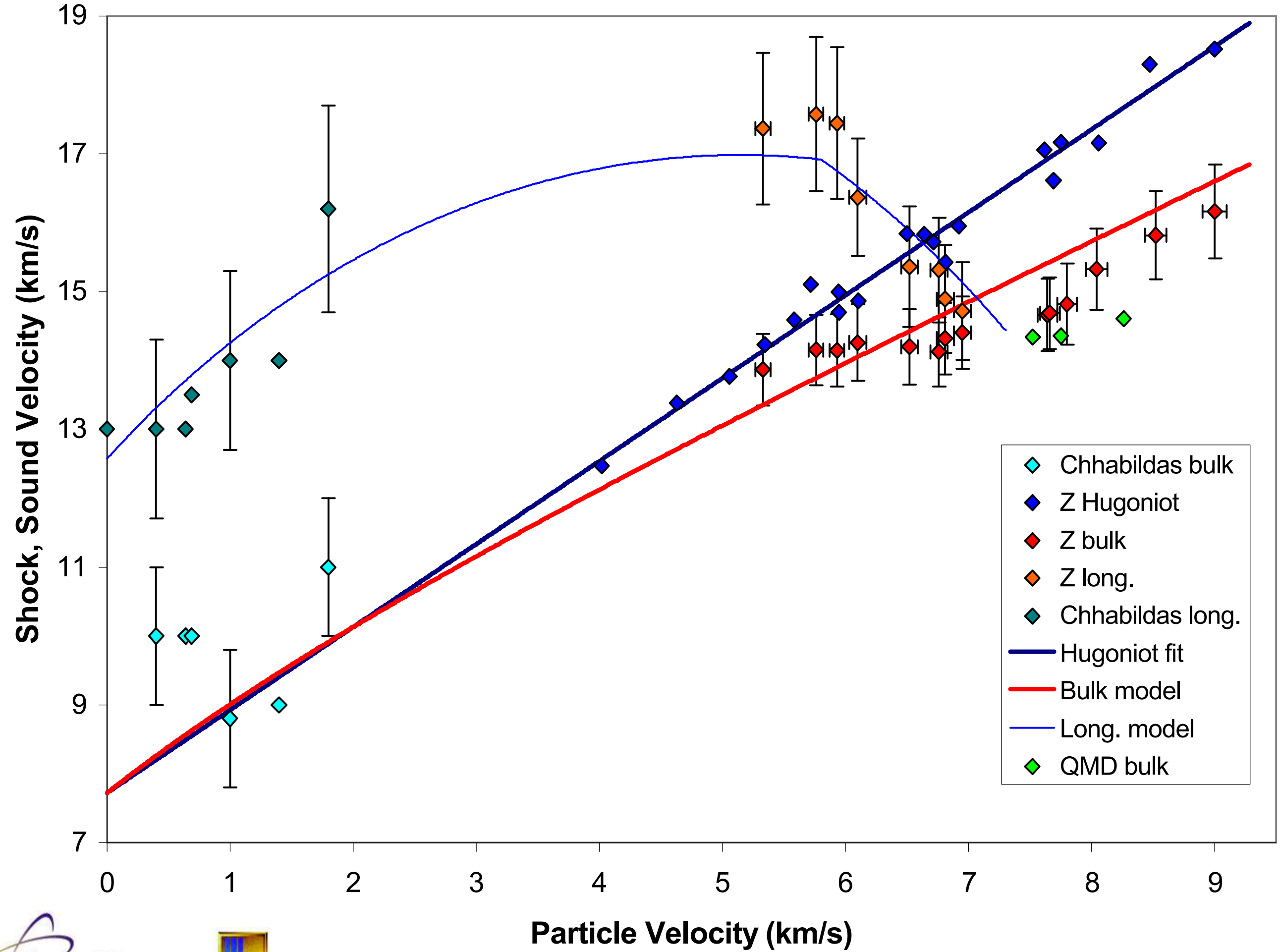
Release profile at ~200 GPa suggests initial longitudinal release and thus Be is solid





Preliminary results suggest the melt transition begins ~210 GPa

Preliminary sound speed measurements for Be

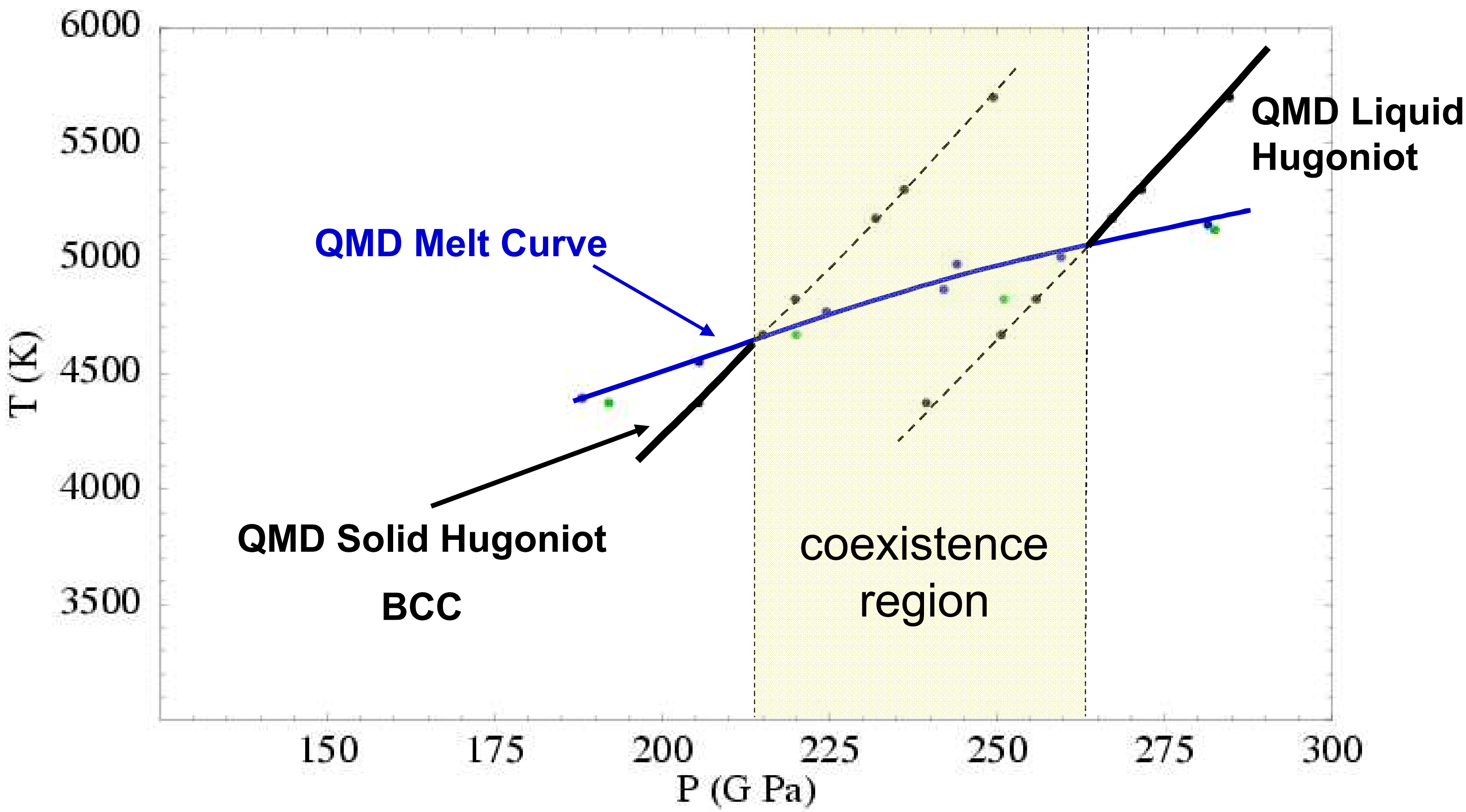


Ratio of longitudinal and bulk sound speed gives a measure of the Poisson's ratio

Extrapolation of the Poisson's ratio to 0.5 provides estimate of the onset of melt

Preliminary results suggest Be melts at ~210 GPa on the Hugoniot

QMD calculations predict that shock melting of Be begins ~213 GPa consistent with experiment



The Hugoniot exits the coexistence region around 263 GPa

Summary

- ICE developments
  - Continuing to develop experimental techniques and data analysis methods to address ultra-high pressure ICE experiments on Z
  - Experimental techniques to infer strength being investigated on VELOCE
  - Very successful first set of SNM experiments on Z
- Hugoniot experiments
  - Significant real estate for experiments on Z enable high fidelity, self-consistent shock wave experiments at very high pressures