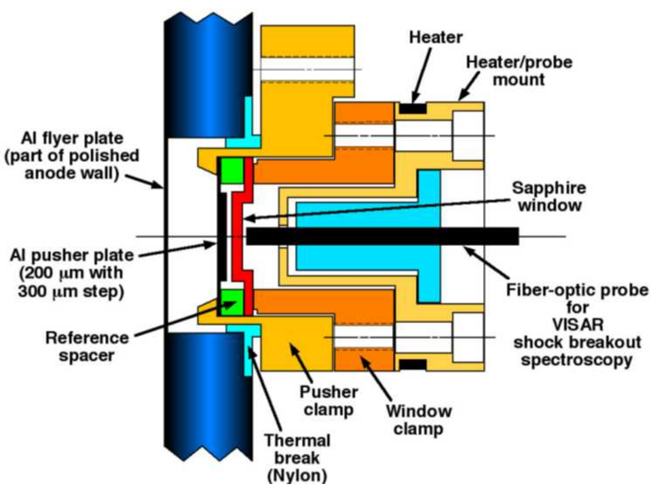
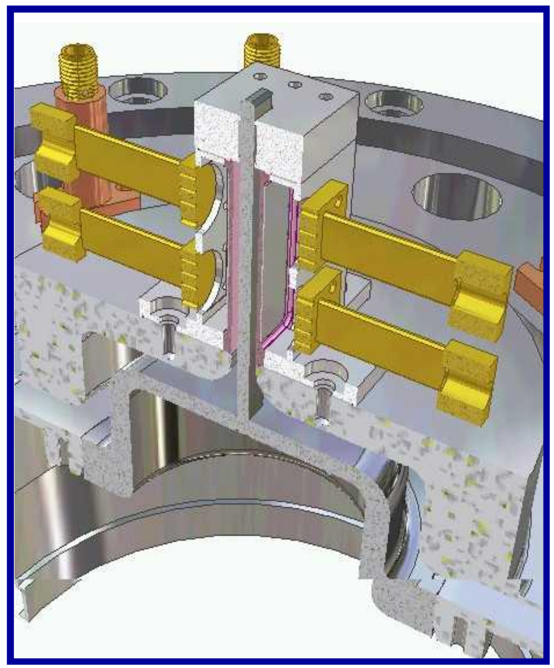
SAND2006-6665C

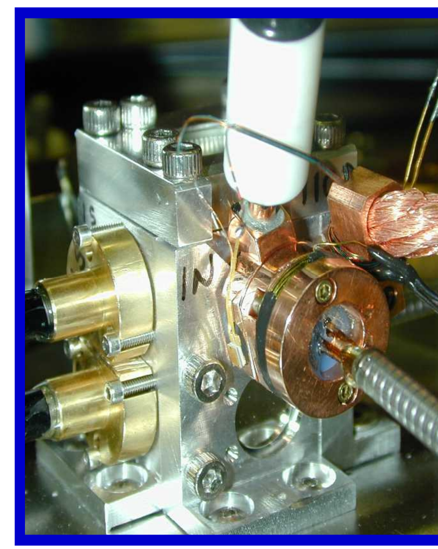
Multi-Mbar Measurements of Shock Hugoniots and Melt in Beryllium and Diamond for ICF Capsule Physics

48th Annual Meeting of the Division of Plasma Physics

October 30 - November 3, 2006   Philadelphia, PA







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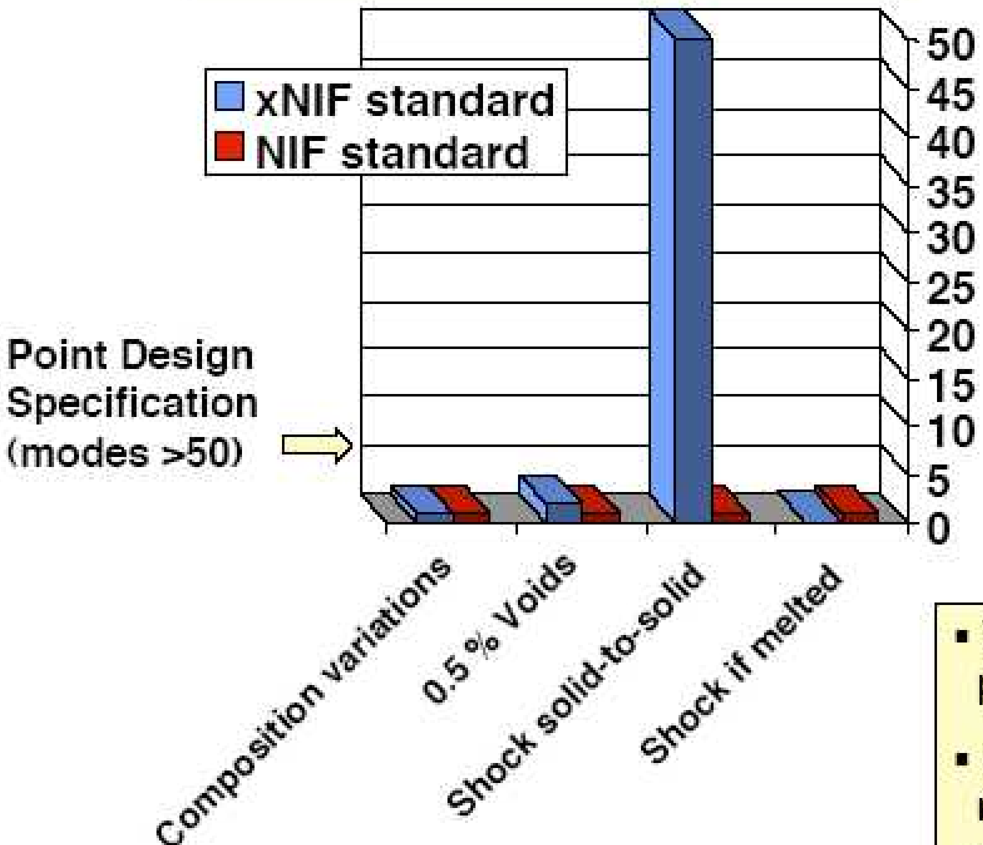
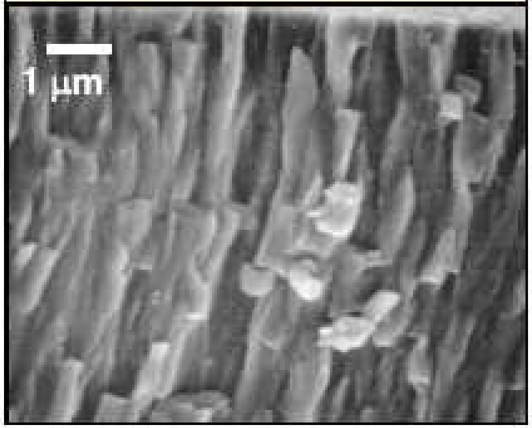
Initial calculations indicate that melting the beryllium is the key to minimizing microstructure effects

(Results from ALE3D calculations and analytic estimates



Sputter deposited Be has submicron grains



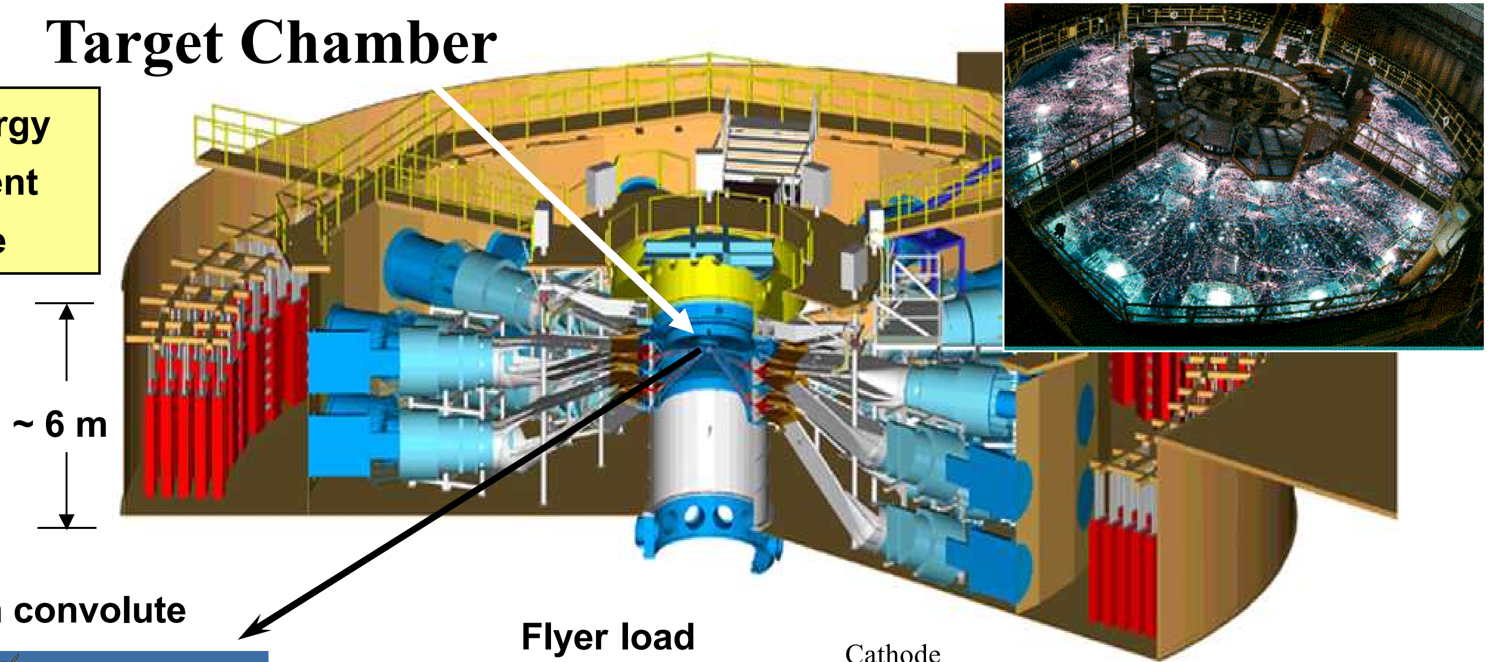
- The first shock in the ignition point design target melts the Be
- We are developing experiments to measure the melt conditions and residual perturbations on Omega and Z experiments

From John Lindl

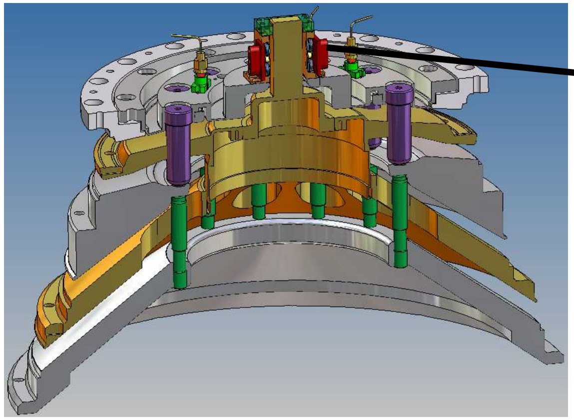
Sandia Z accelerator

11.5 MJ stored energy
~22 MA peak current
~200 ns rise time

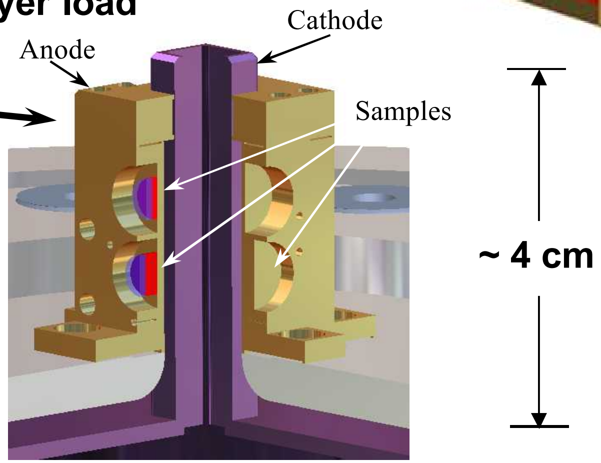
Target Chamber



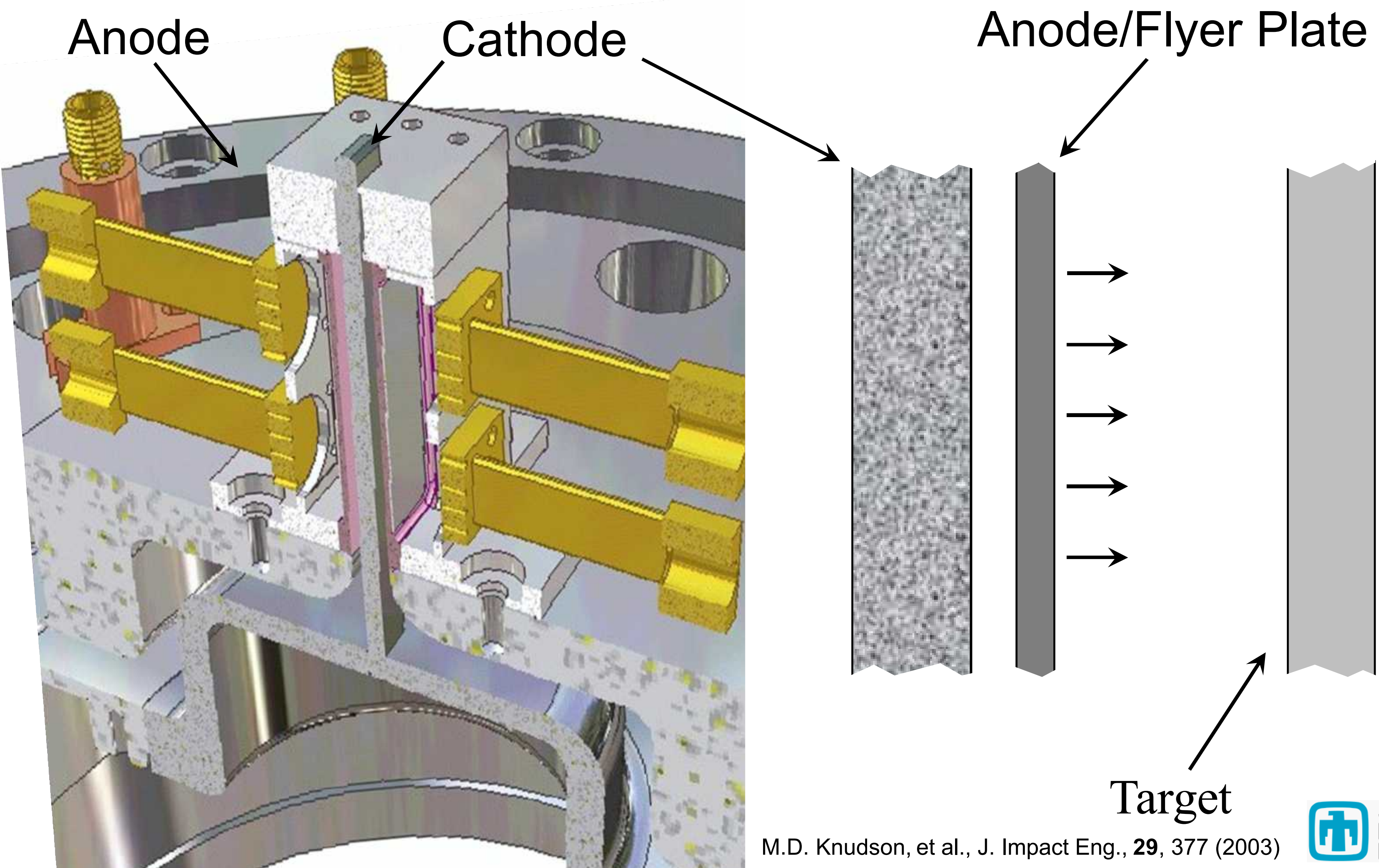
Flyer load on convolute



Flyer load



These experiments utilize the ultra-high velocity flyer plate capability on Z



M.D. Knudson, et al., J. Impact Eng., **29**, 377 (2003)

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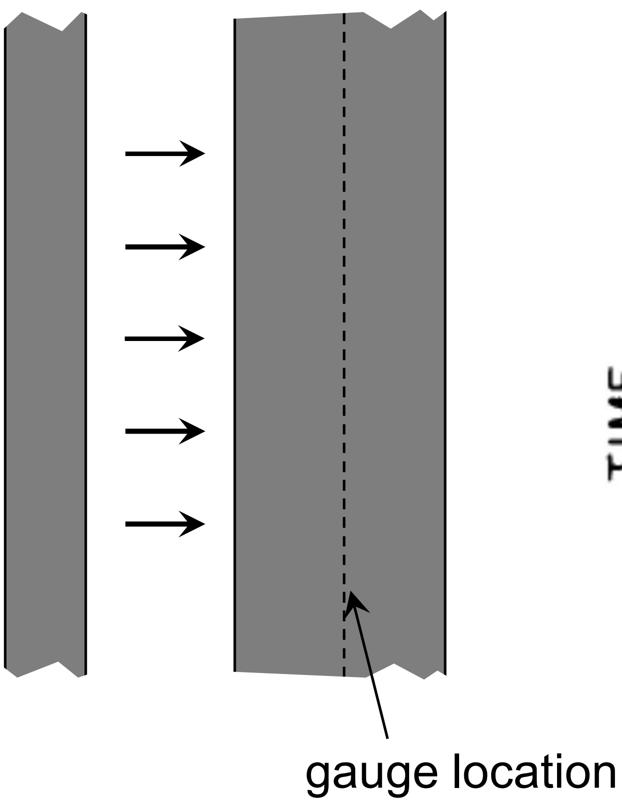
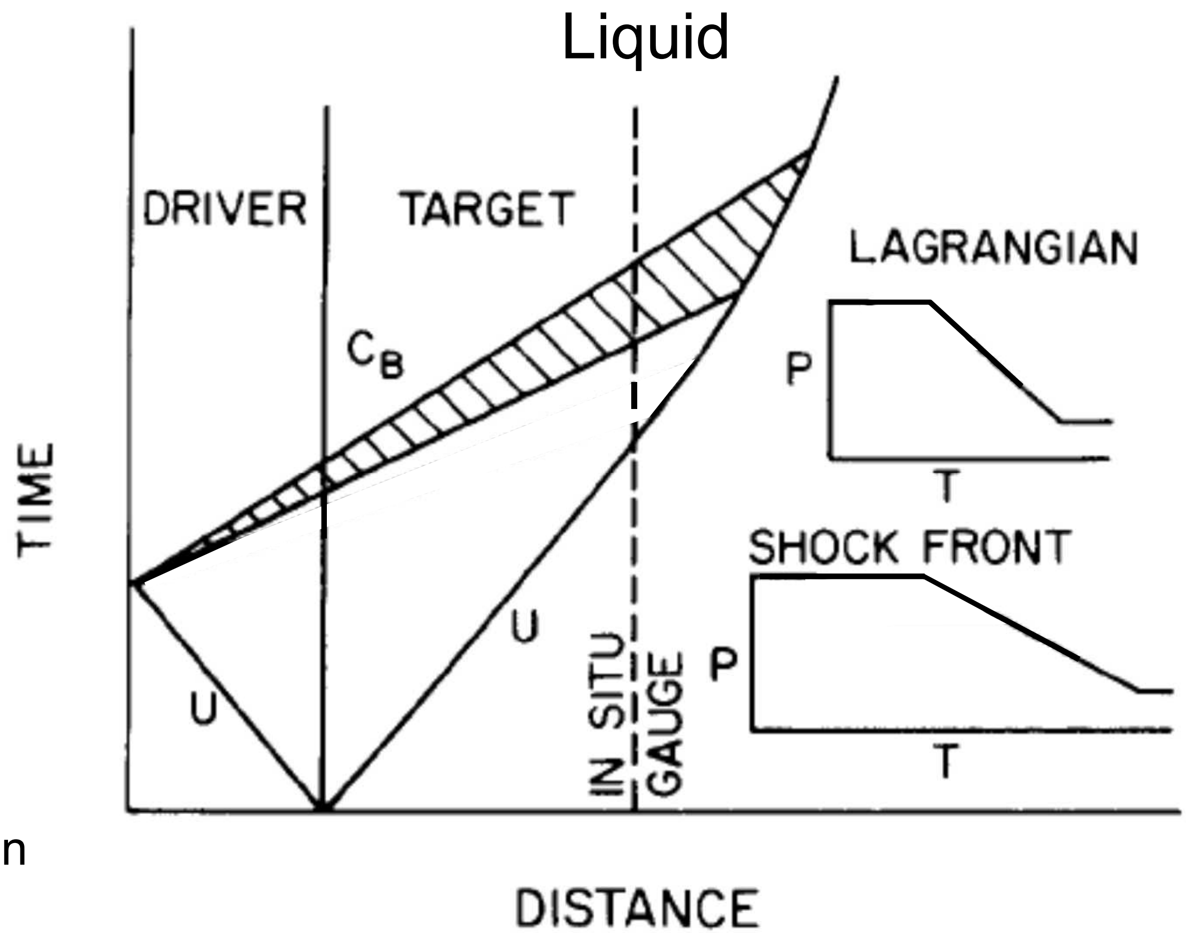
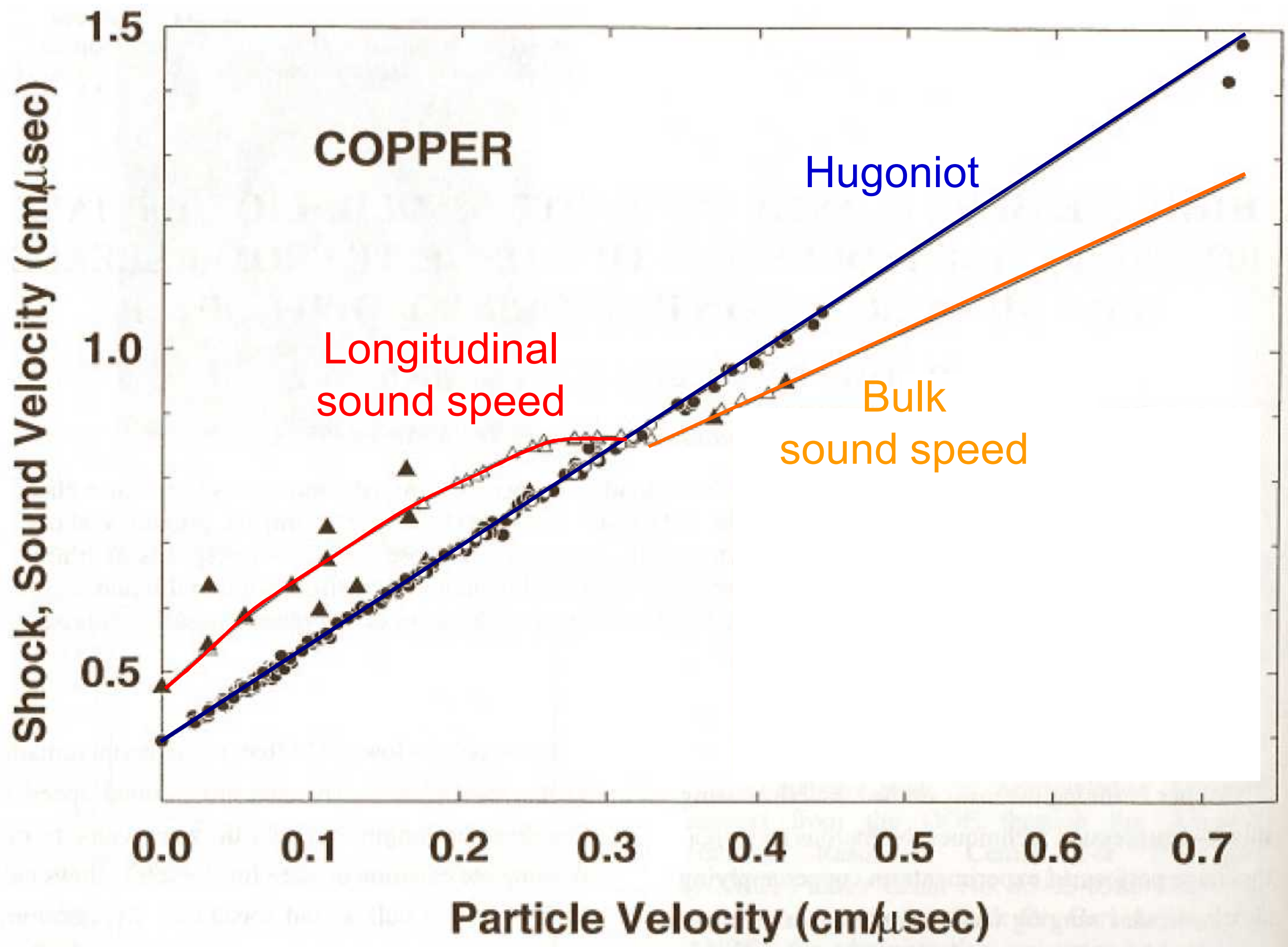
Melt on the Hugoniot is determined by measuring sound speed using wave overtake technique





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

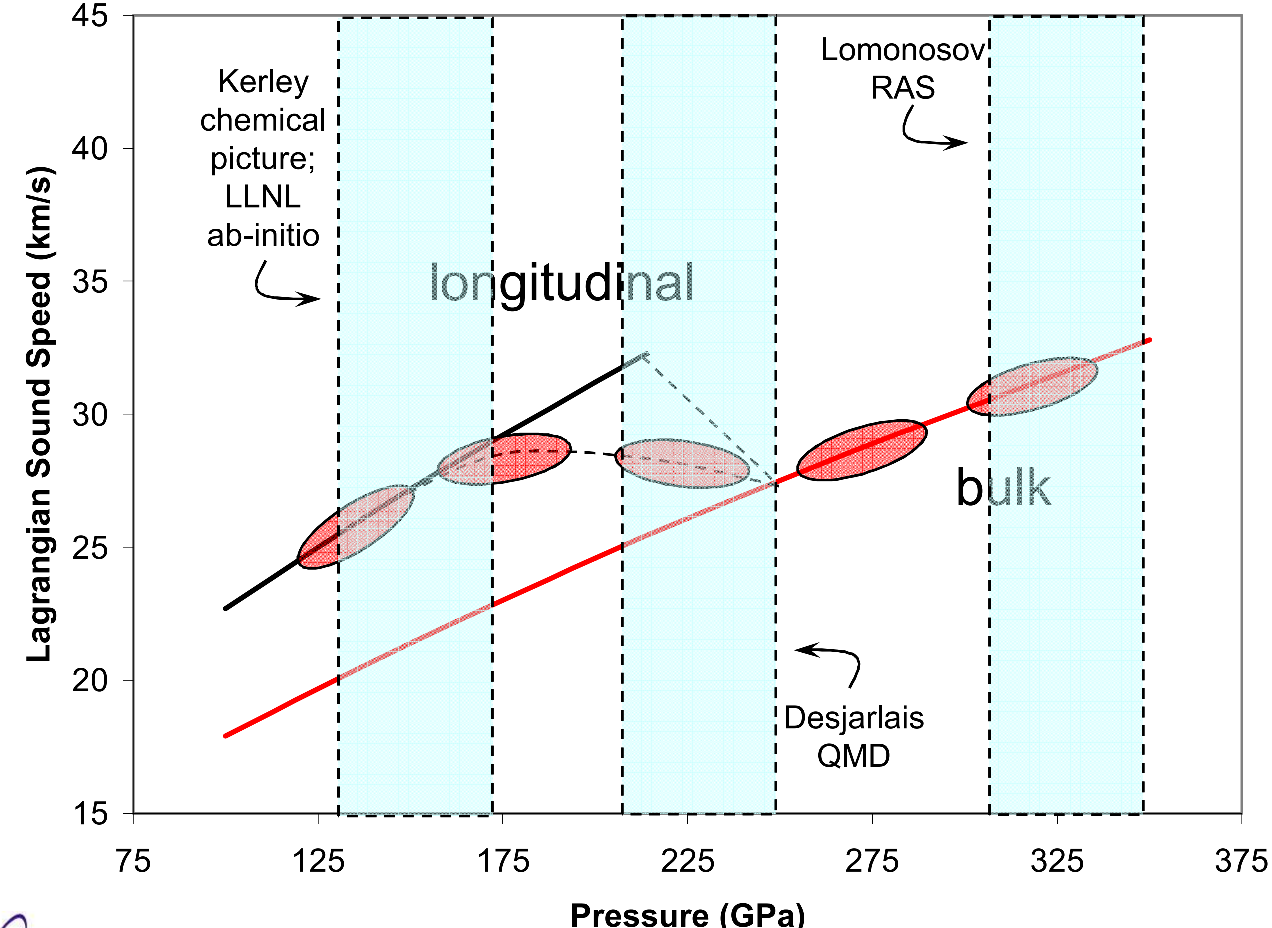
We are using the work of Hayes, et al. on Cu as a model for the Be and C melt study



Hayes, et al., Shock Compression of Condensed Matter – 1999

Experiments spanned the various estimates for the melt pressure on the Hugoniot

Simple estimate of Be sound speed



Simple Mie-Grüneisen EOS

Assuming $\rho\Gamma$ is a constant

Assuming fixed Poisson's ratio of 0.3

Estimates for Be melt range from ~150 to over 300 GPa

Estimates for C melt range from~400 to over 1000 GPa

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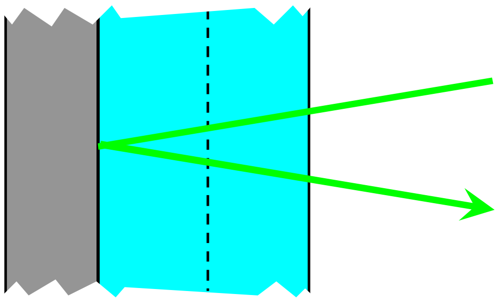
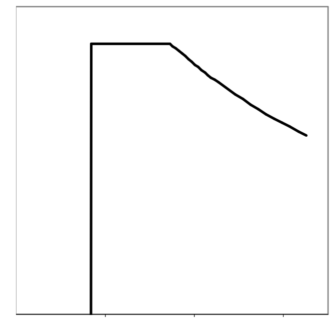
In practice in-situ measurement is not feasible – other options depending on pressure

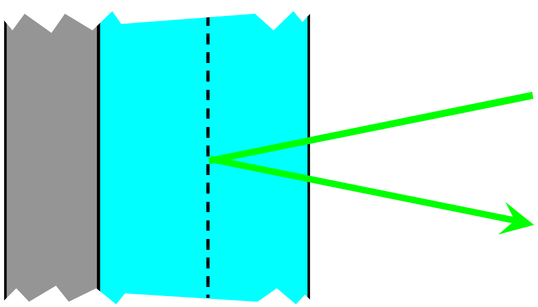


Transparent window
i.e. LiF



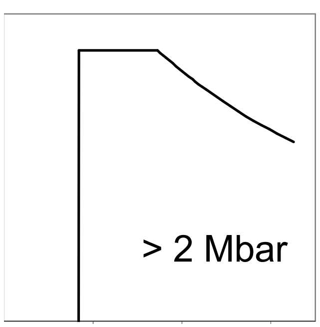
Interface velocity – rarefaction arrival at interface

Technique can be used at stresses below ~2 Mbar



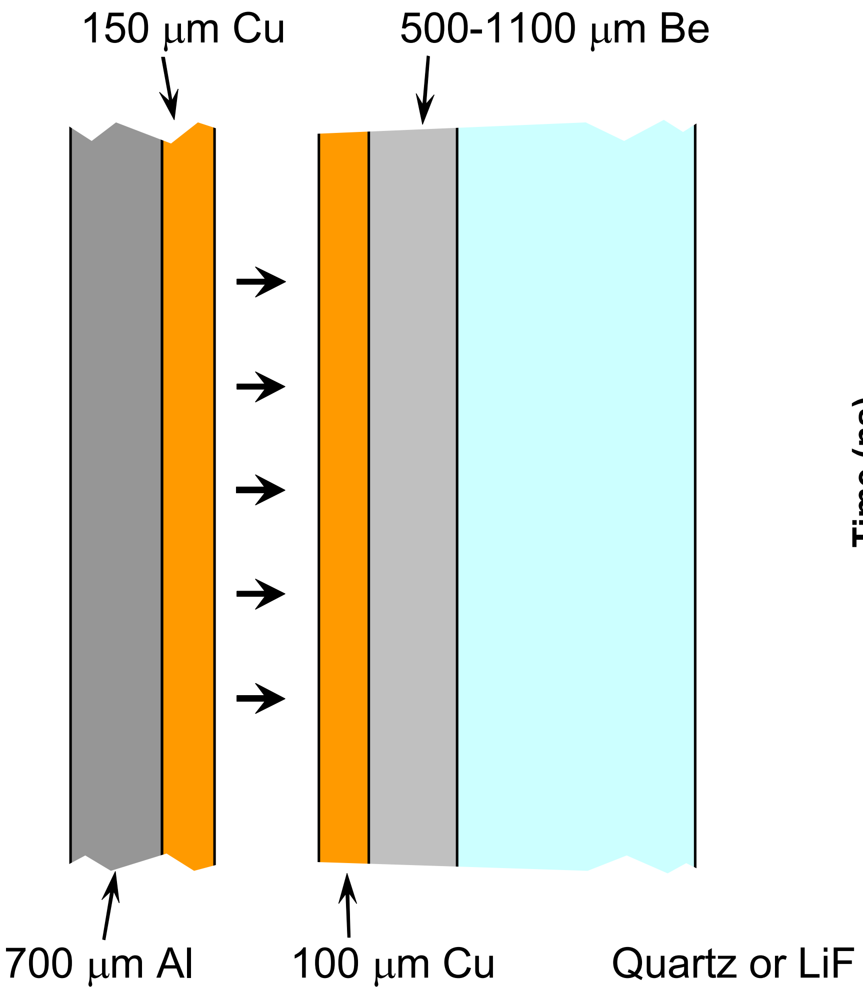
Reflective shock
i.e. Quartz or Sapphire

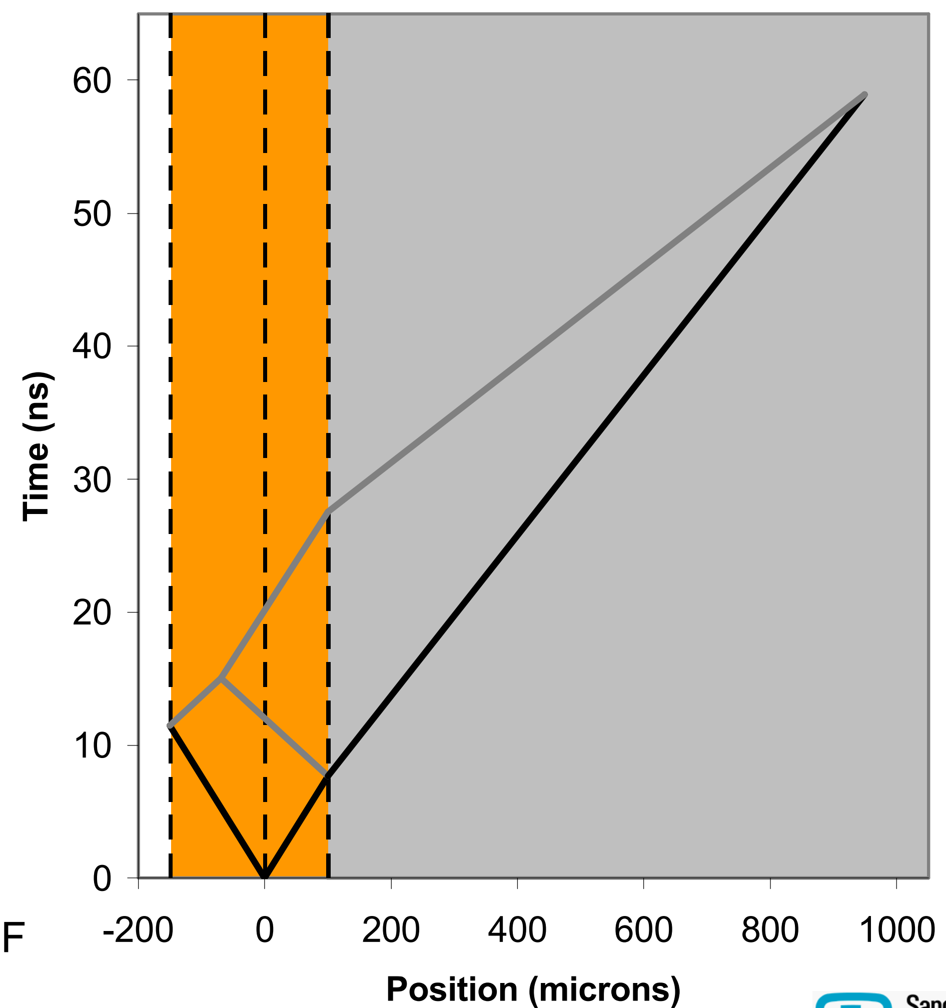
Shock velocity – rarefaction arrival at shock front



Technique can be used at stresses above ~1 Mbar

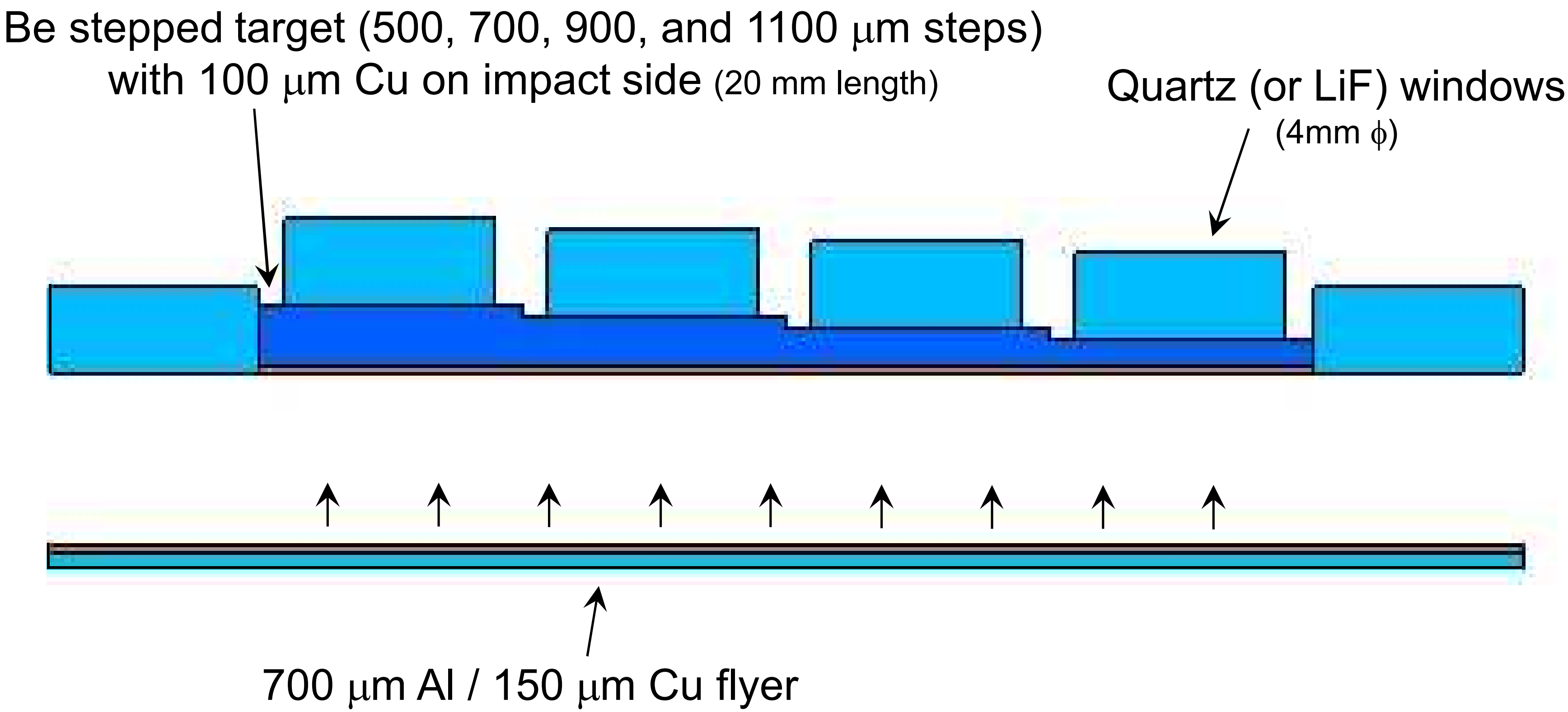
For Be a copper baseplate was used to avoid complication of copper melt near 250 GPa





Design suggested by P. Celliers

Target design for the Be melt experiments on the Z accelerator



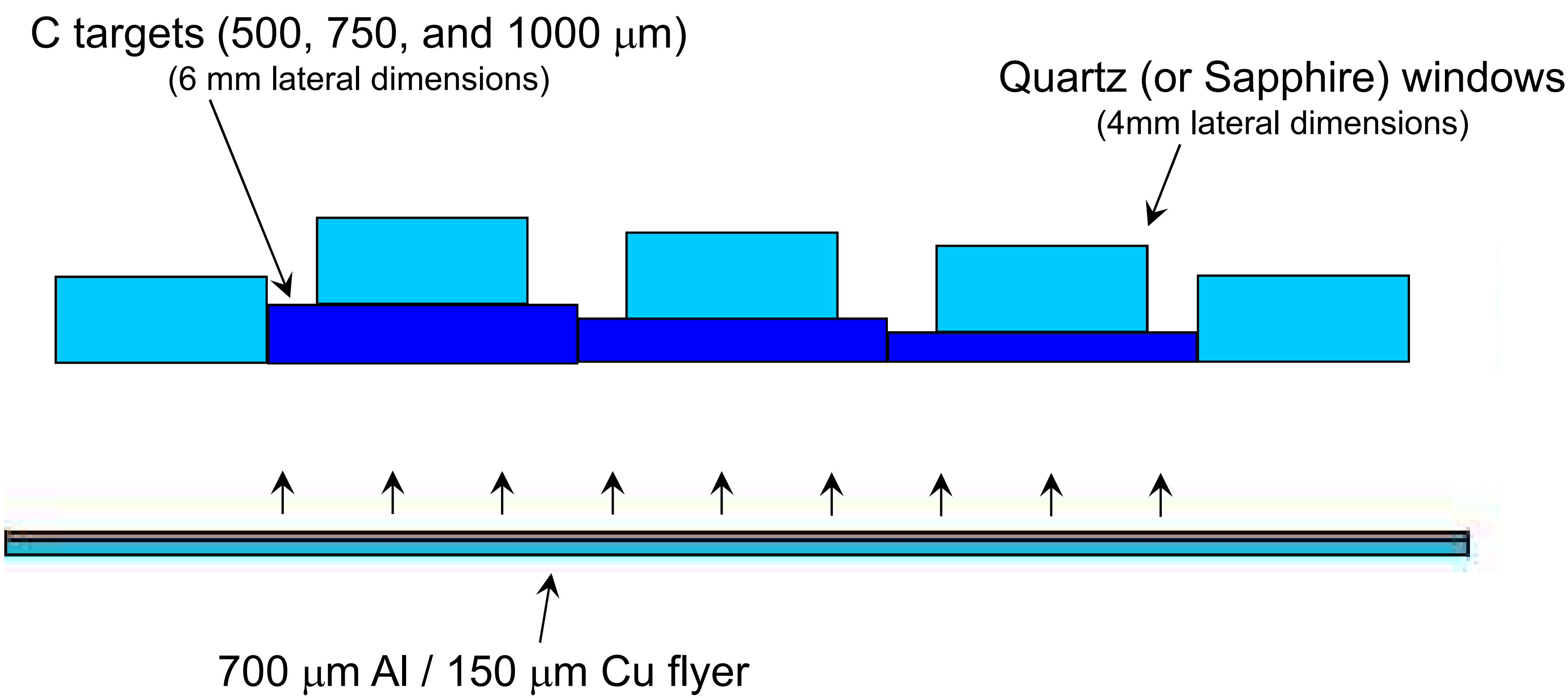
v_f 7 km/s
Cu_H 2.9 Mbar
Be_H 1.25 Mbar

to

v_f 14 km/s
Cu_H 8.9 Mbar
Be_H 3.5 Mbar

These velocities are easily achievable on Z

Target design for the C melt experiments on the Z accelerator



v_f 13 km/s C_H 5.5 Mbar

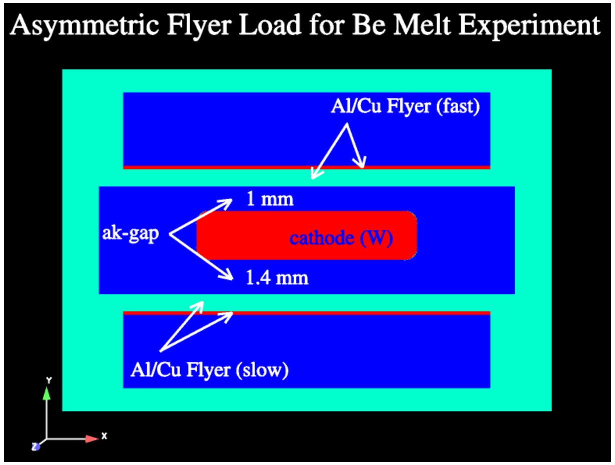
to

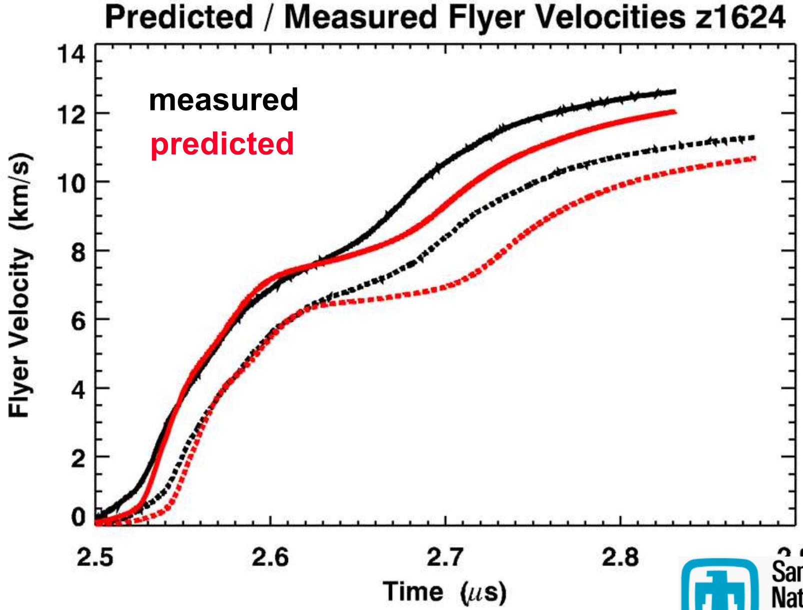
v_f 24 km/s C_H 14 Mbar

These velocities are achievable on Z

ALEGRA MHD simulations used to design flyer loads and set charge voltages

- **Experiments required an Al/Cu flyer with peak velocities in the range 7-24 km/s to produce range of shock pressures in Be (~1-3 Mbar) and C (~5-14 Mbar).**
- **Four asymmetric loads designed to produce 2 flyers / shot with 10% difference in peak velocity that covered desired range.**
- **ALEGRA 2D MHD used to set flight distance, charge voltage on Z, verify flyer state, and predict results.**

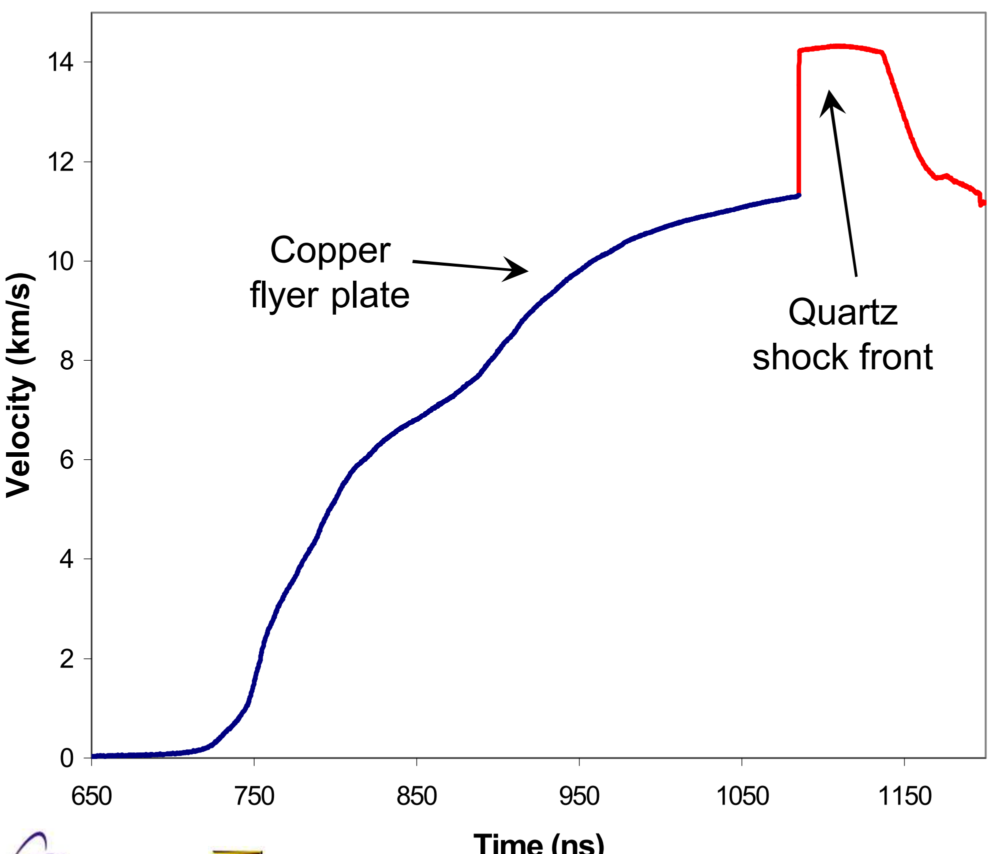


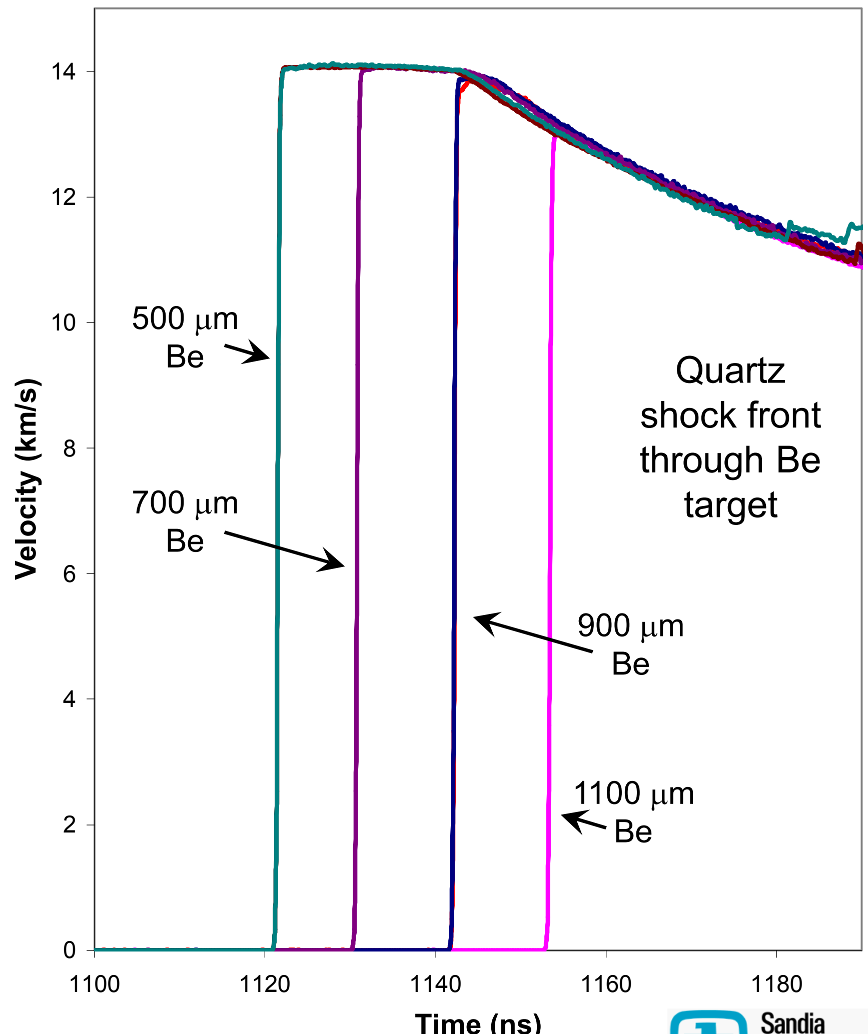


QMD simulations of beryllium melting were used to guide desired pressures

Excellent data quality was achieved in the Be and C melt experiments

Sample data at ~2.5 Mbar in Be





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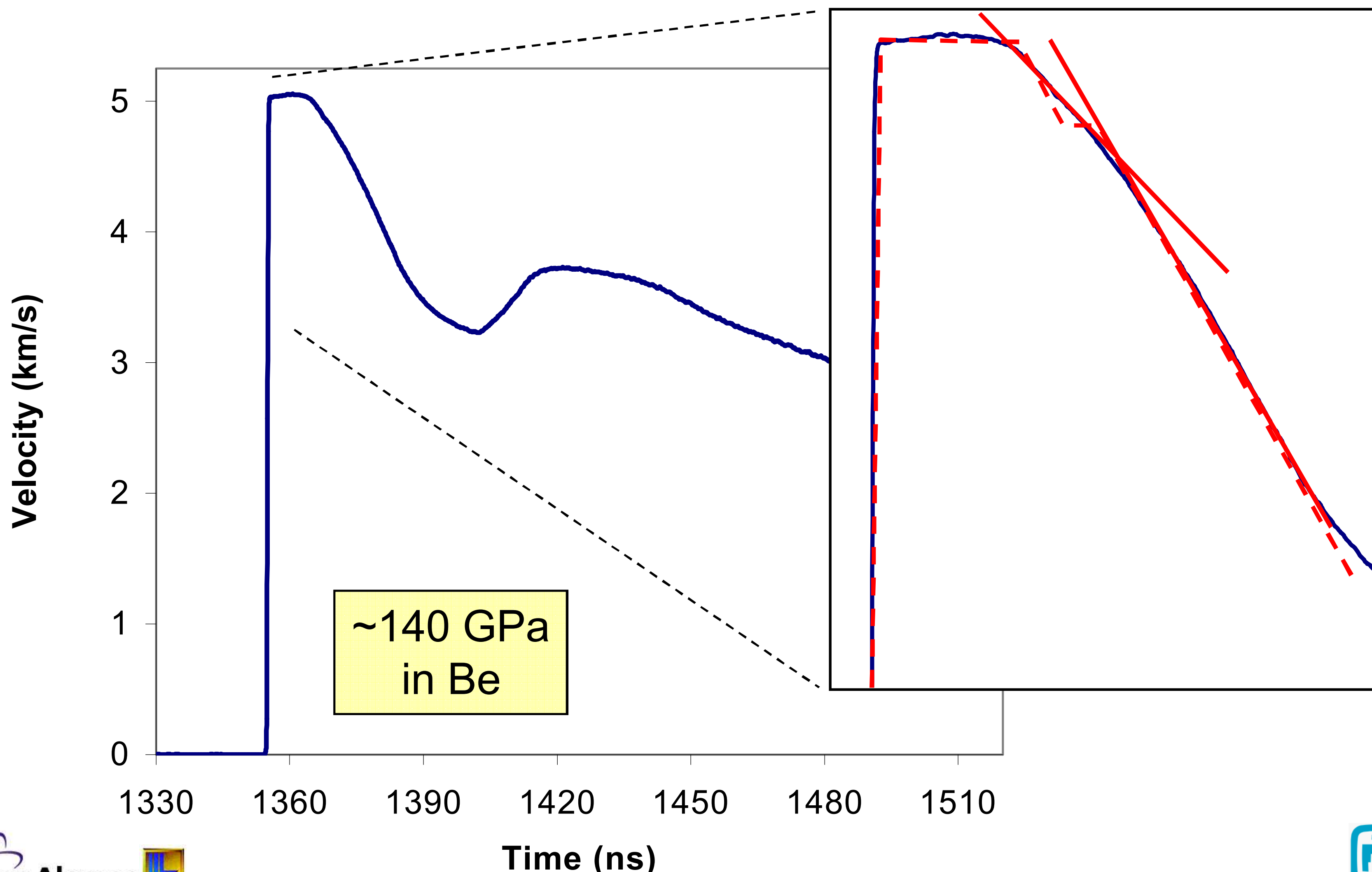
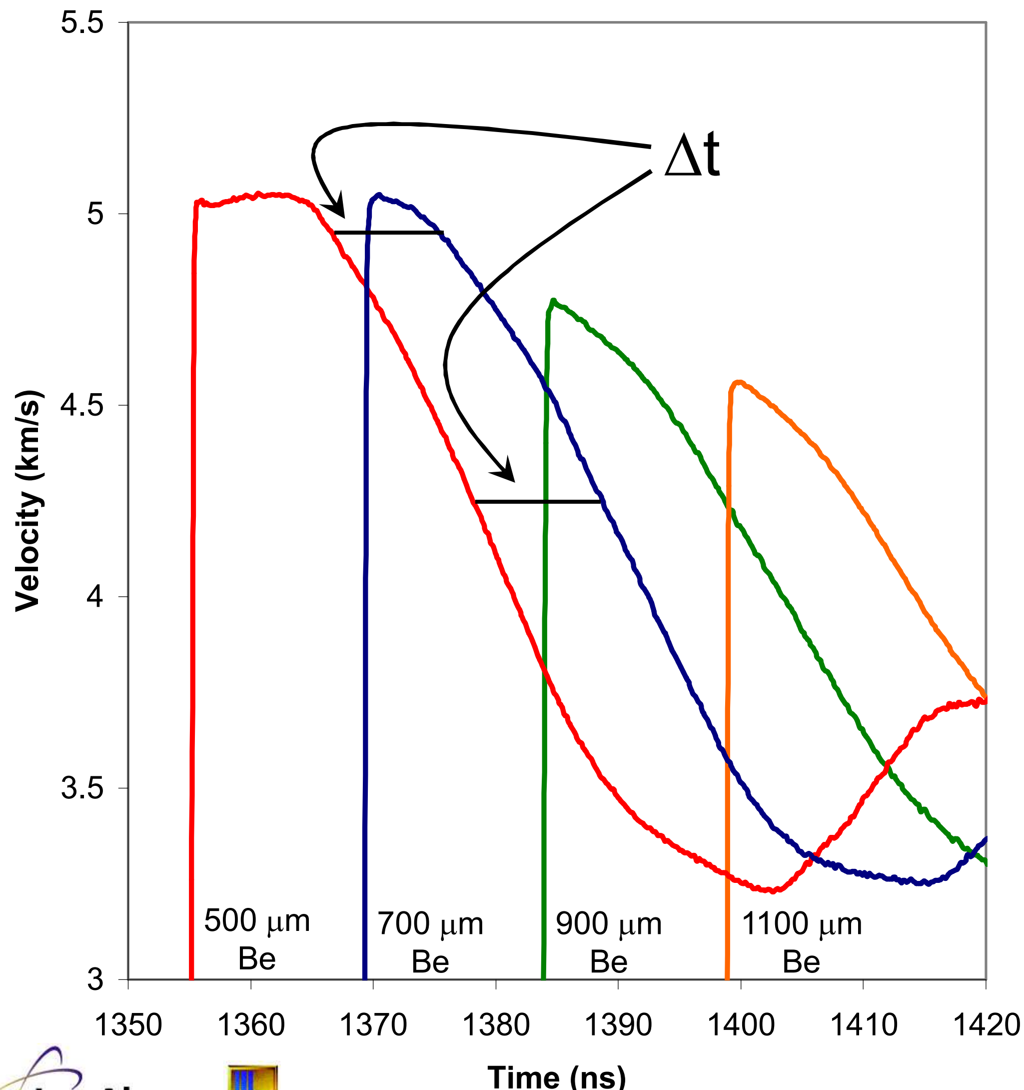
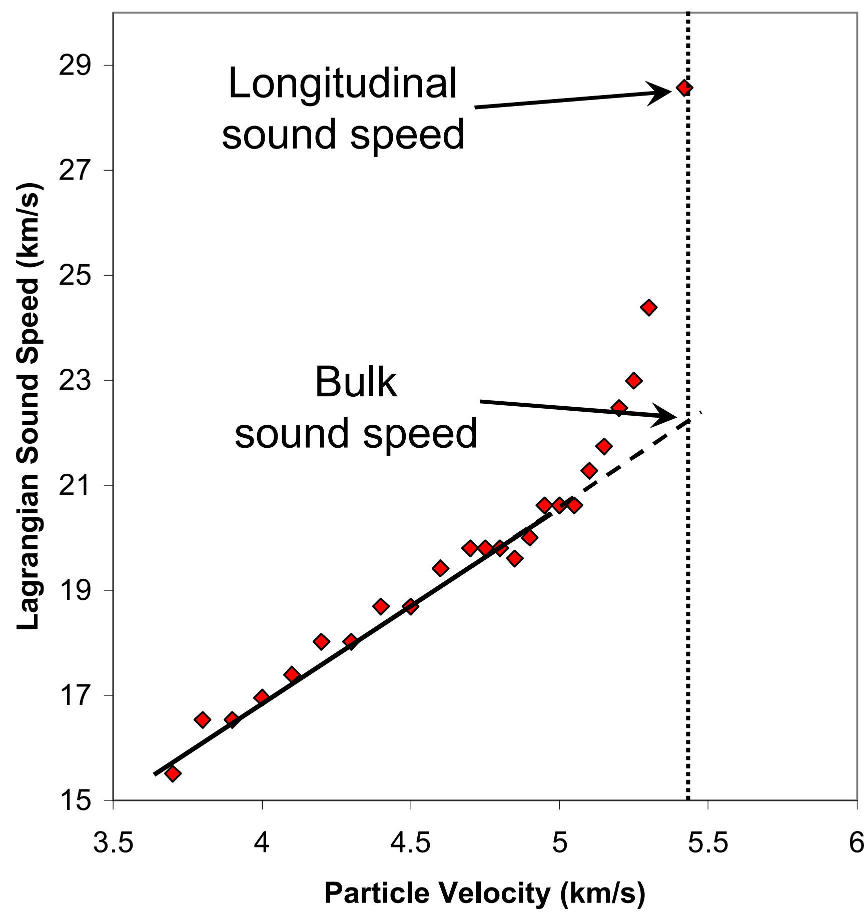
Classic elastic/plastic release observed at lower stresses with LiF window



Longitudinal and bulk sound speeds can be determined via Lagrangian analysis





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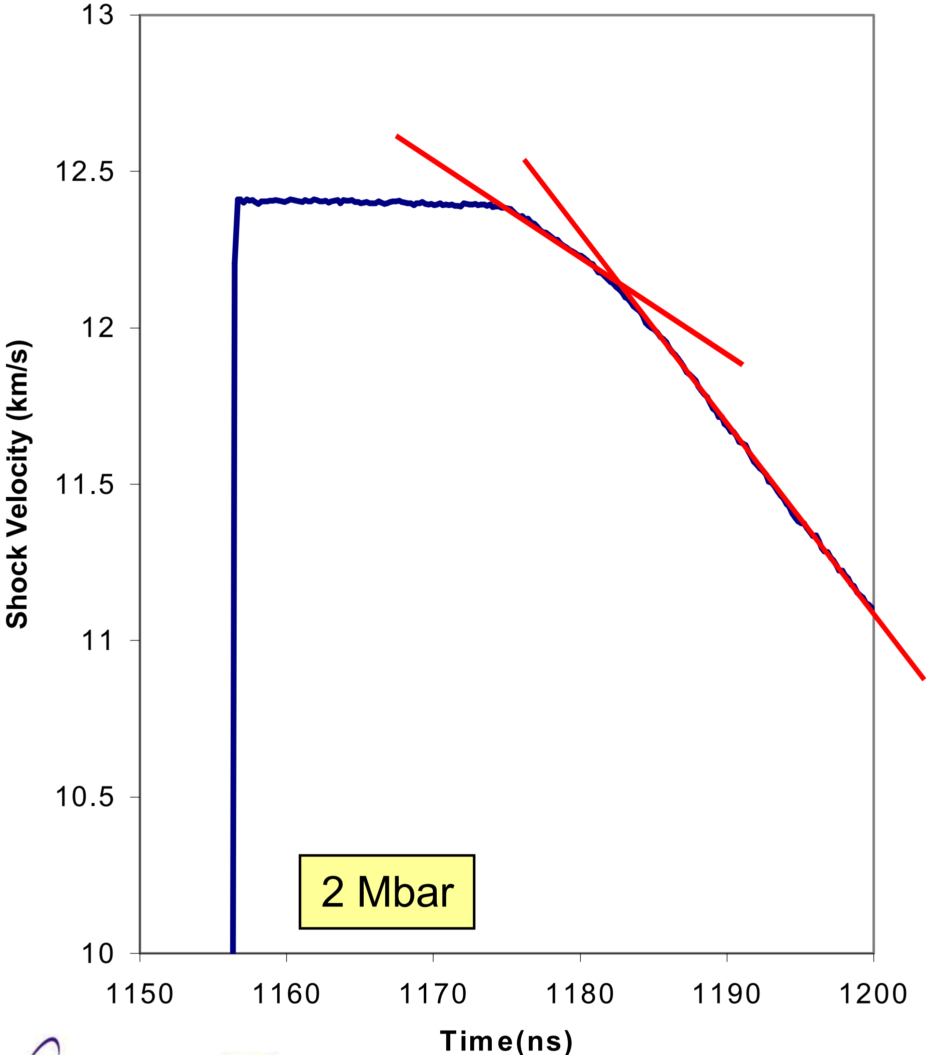
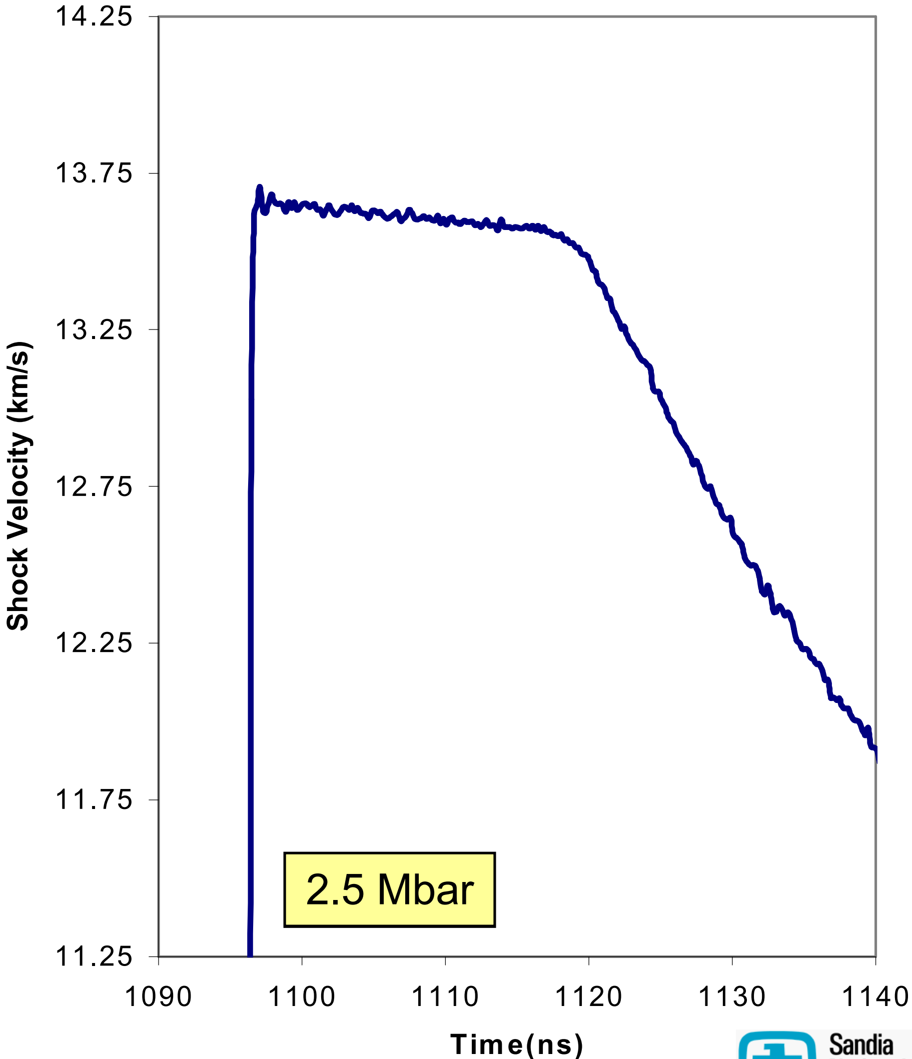
Release profile at ~200 GPa suggests initial longitudinal release and thus Be is solid





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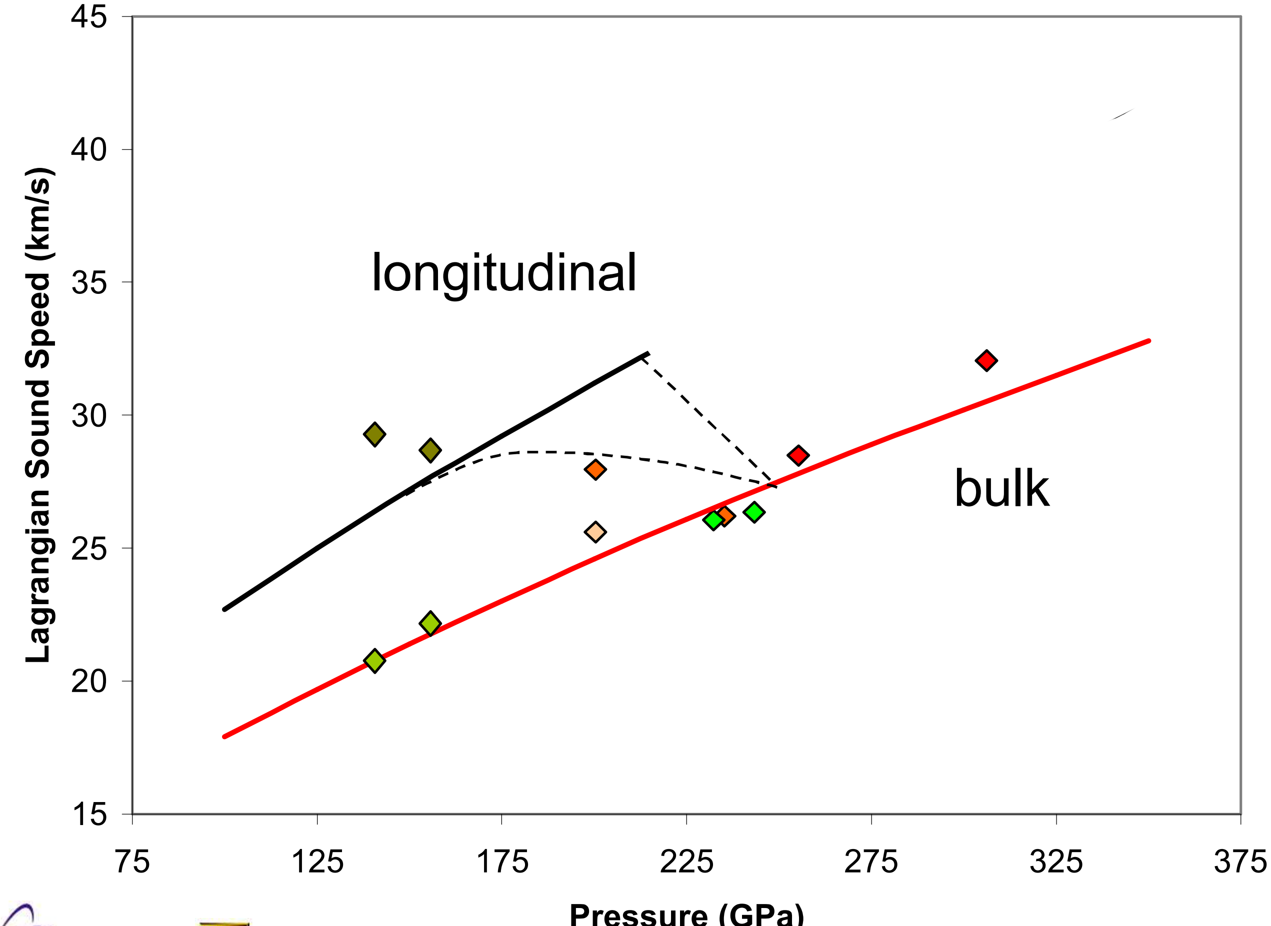
Preliminary results suggest the melt transition begins ~220 GPa

Preliminary sound speed measurements for Be

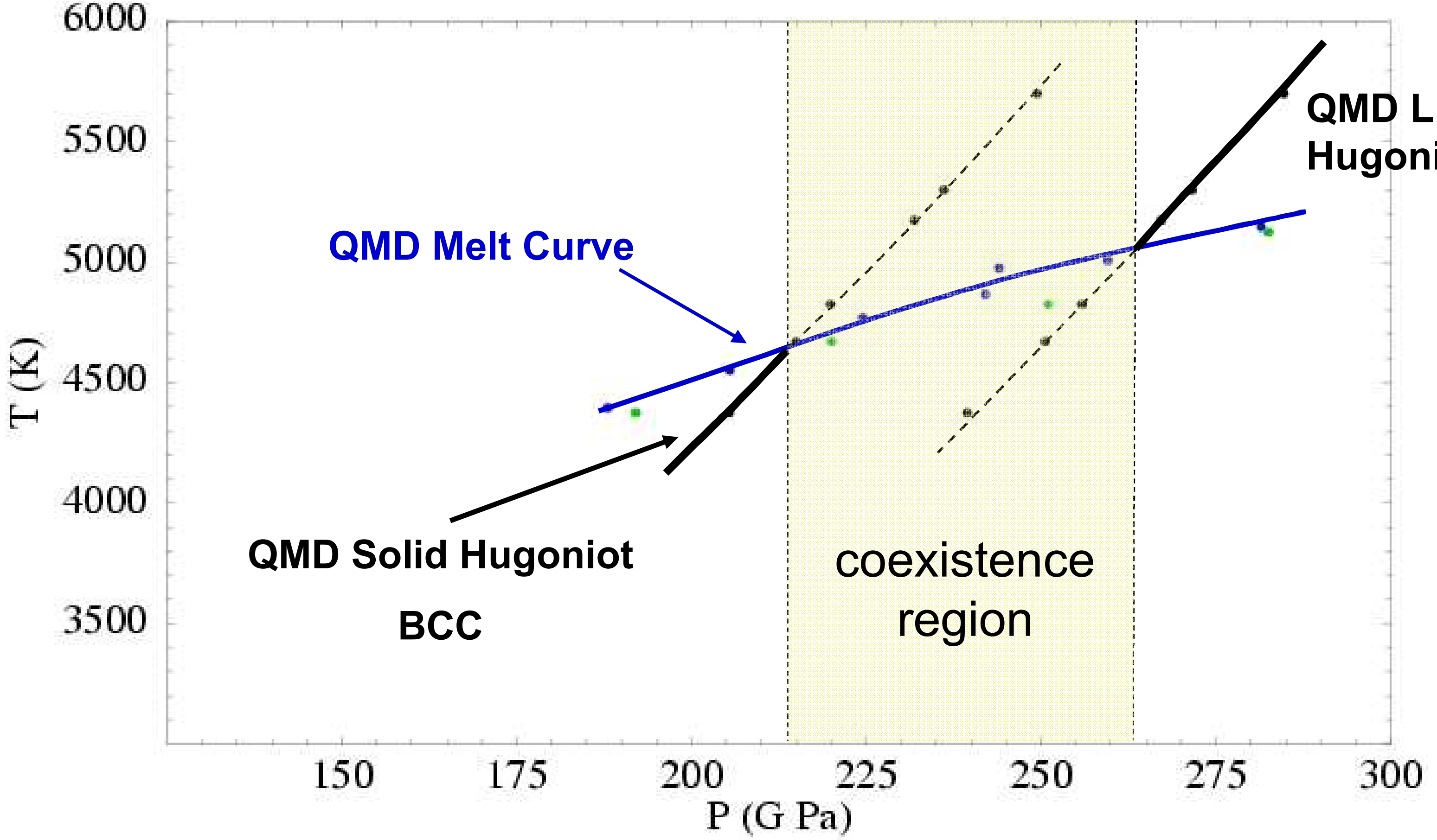


Ratio of longitudinal and bulk sound speed gives a measure of the Poisson's ratio

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

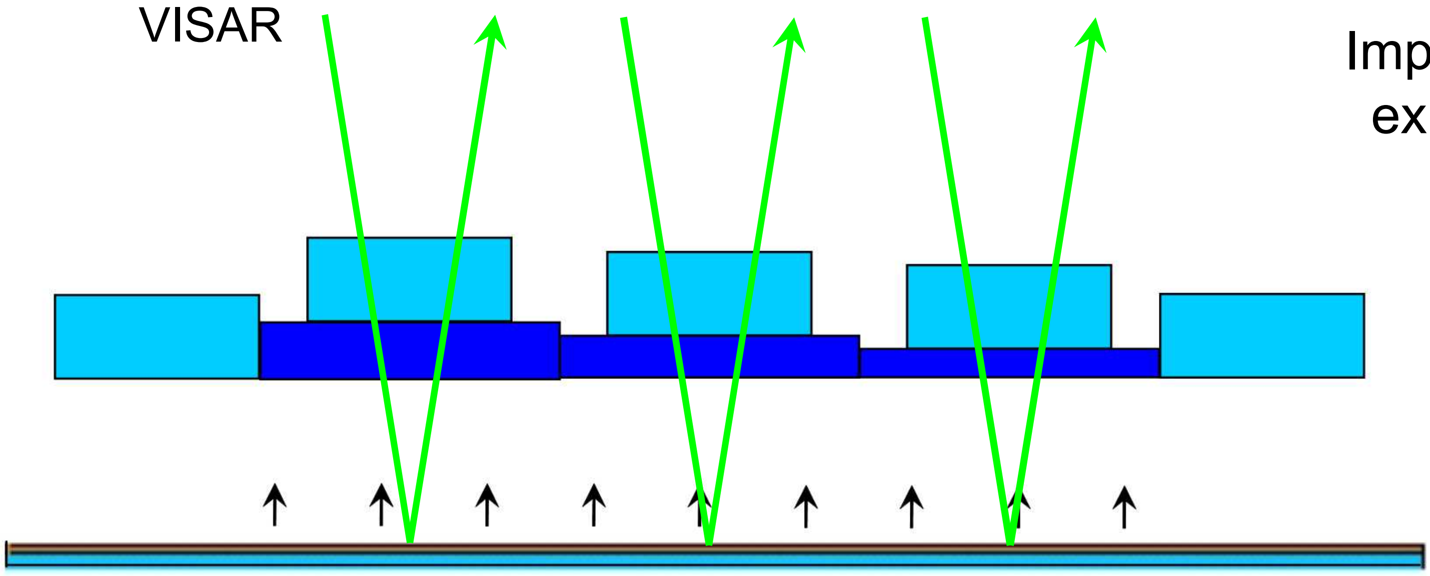
Preliminary results suggest Be melts at ~220 GPa on the Hugoniot

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



The Hugoniot exits the coexistence region around 263 GPa

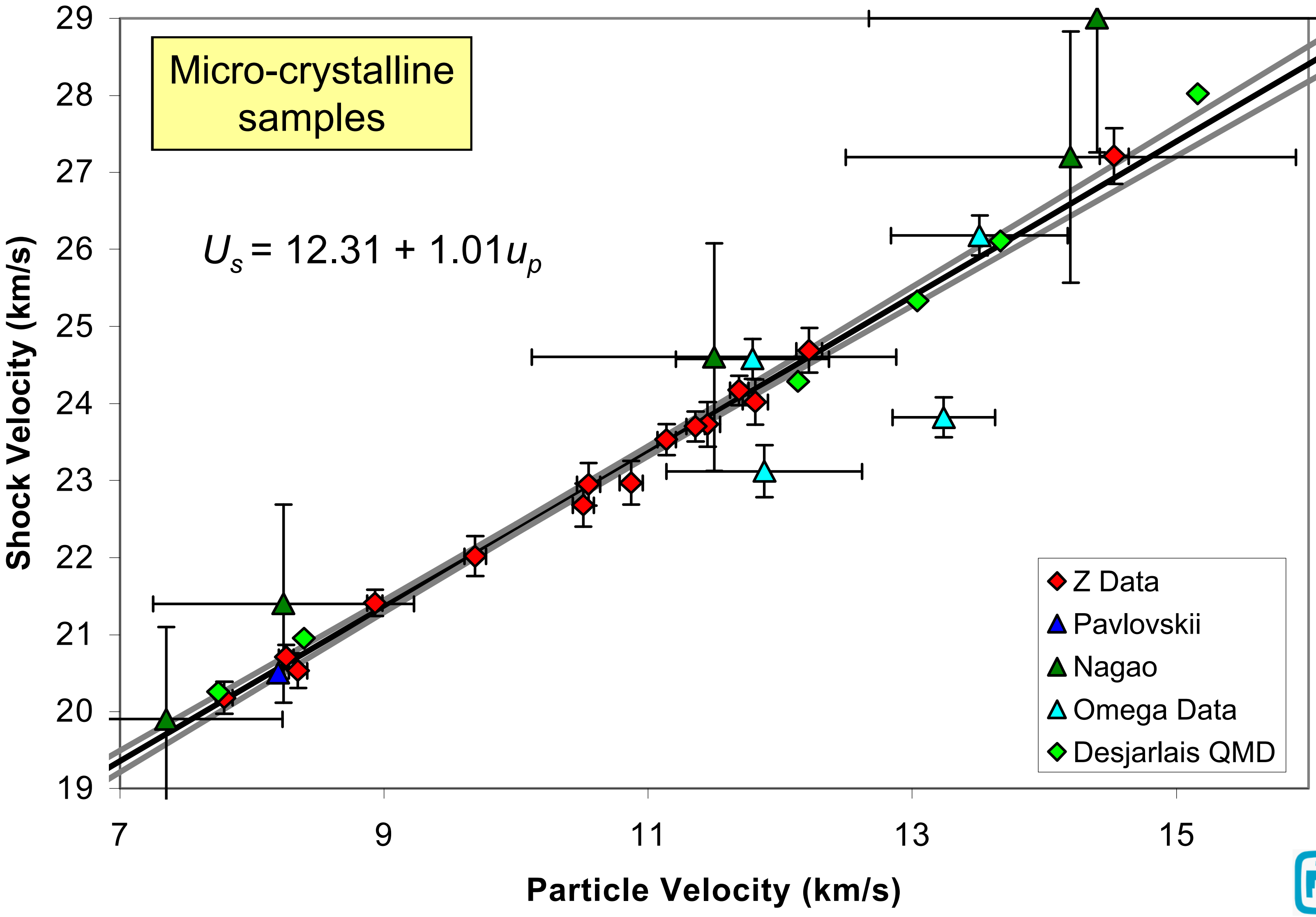
Target design for the C melt lends to very accurate Hugoniot measurements



Impedance match experiment with Cu flyer

- •Transparent samples allow for in-line measurement of flyer velocity
- •Very clear fiducial indicating flyer impact and shock breakout into window
- •Each experiment had 2 to 3 samples per panel
- •Weighted average of data from each panel enabled measurements with ~1% uncertainty in U_s and <1% in u_p

The C melt experimental configuration provides for very accurate Hugoniot measurements



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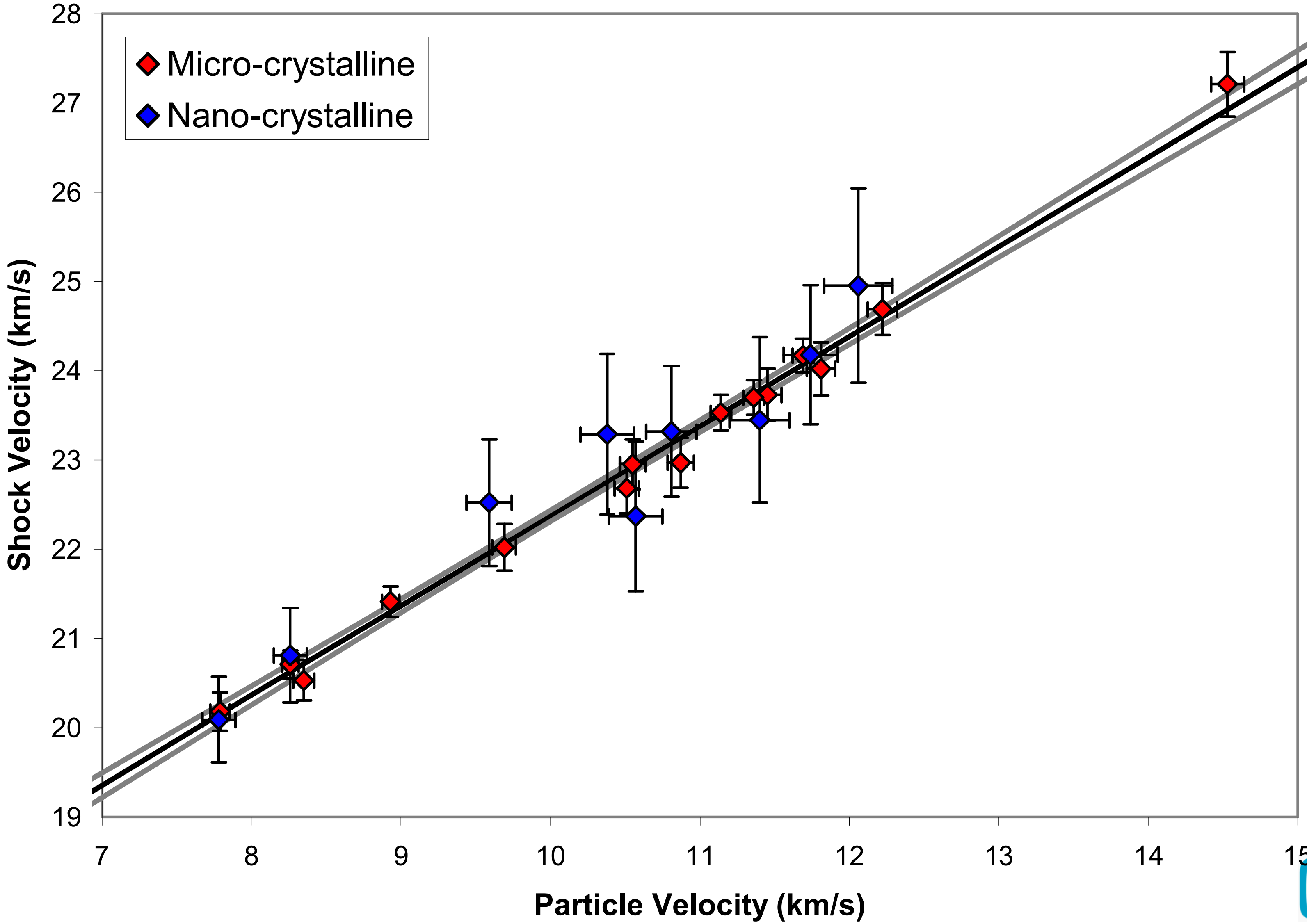
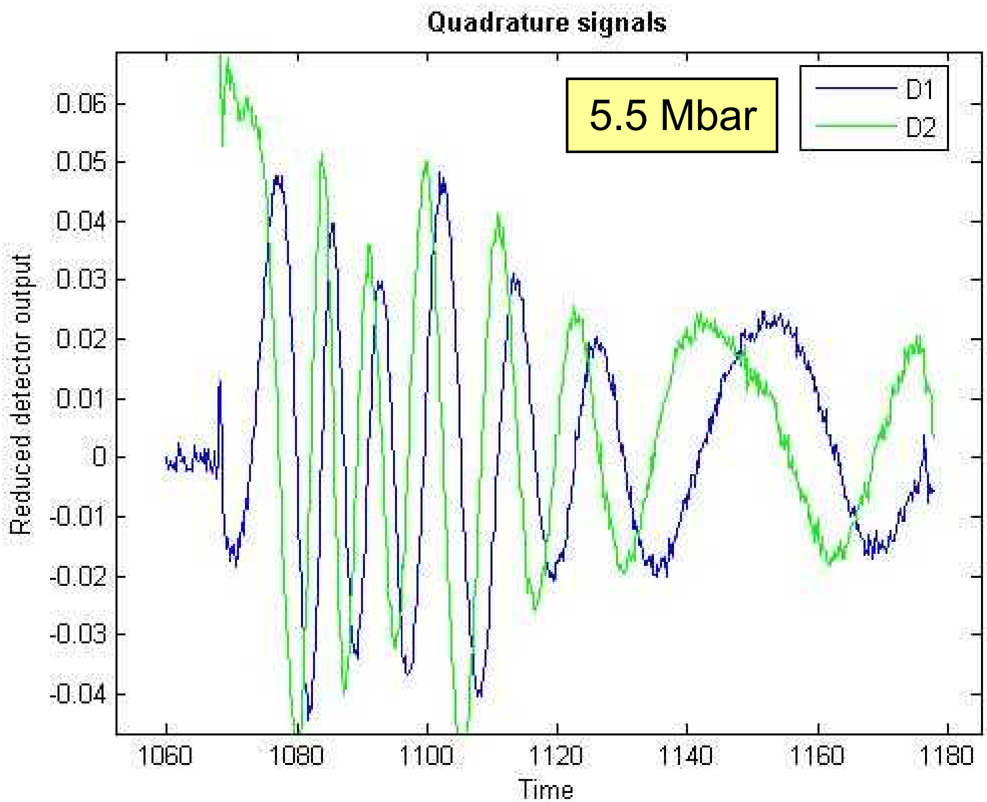
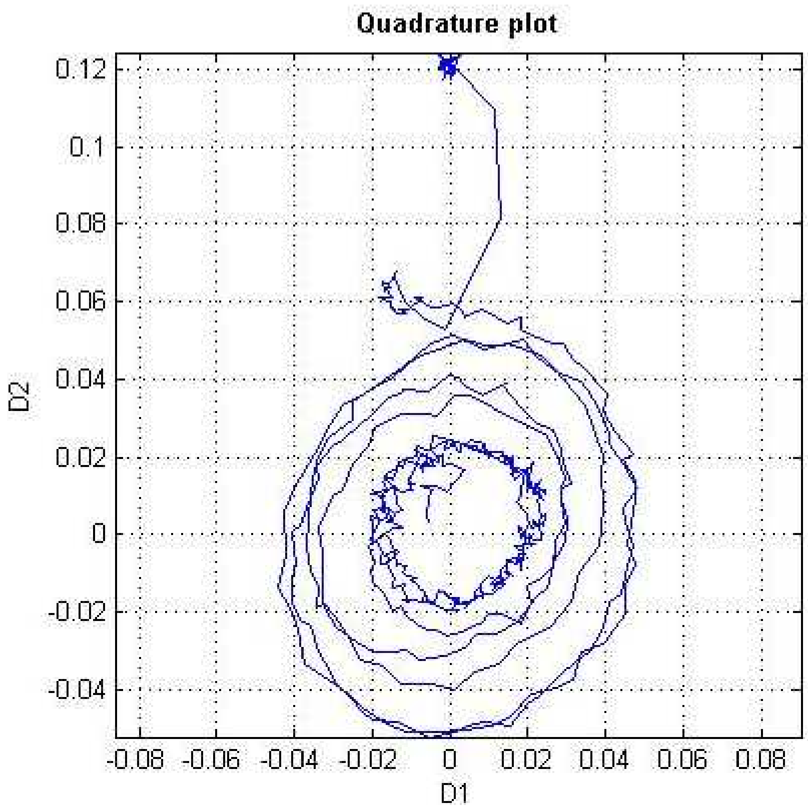
Nano-crystalline samples show no statistical difference in Hugoniot response



Release data from C melt experiments are proving to be a bit more challenging to analyze





Low pressure (below ~6-7 Mbar) data exhibit expected behavior upon release – well behaved fringing

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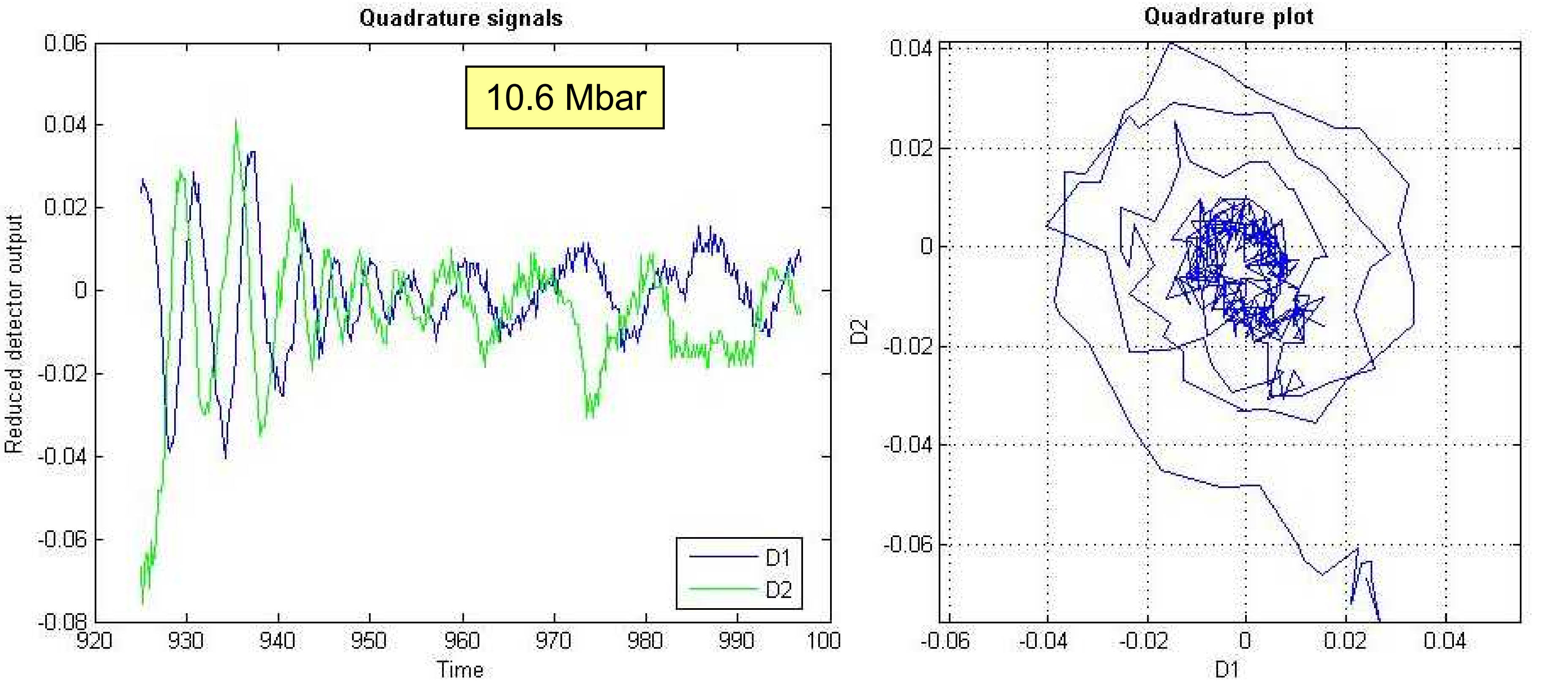
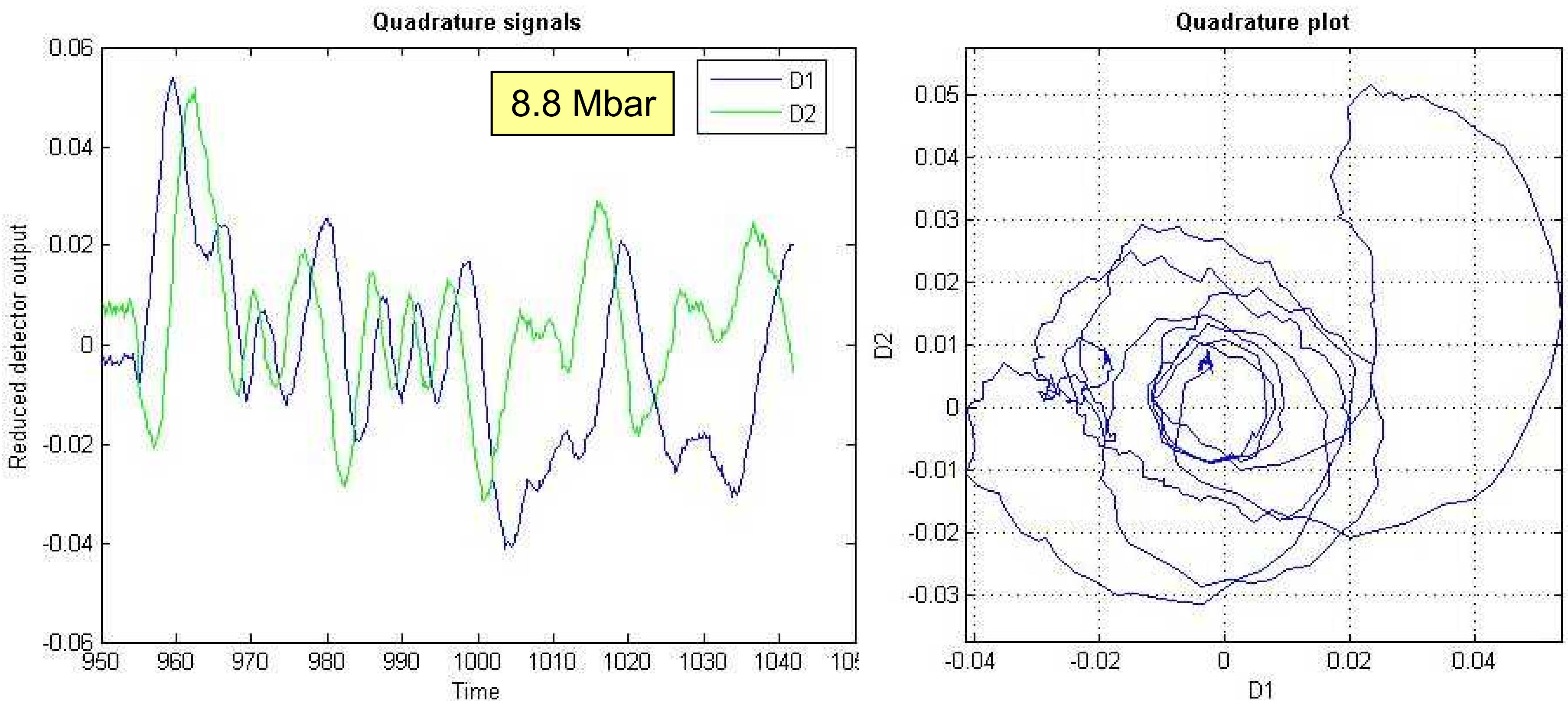
Release data from C melt experiments are proving to be a bit more challenging to analyze



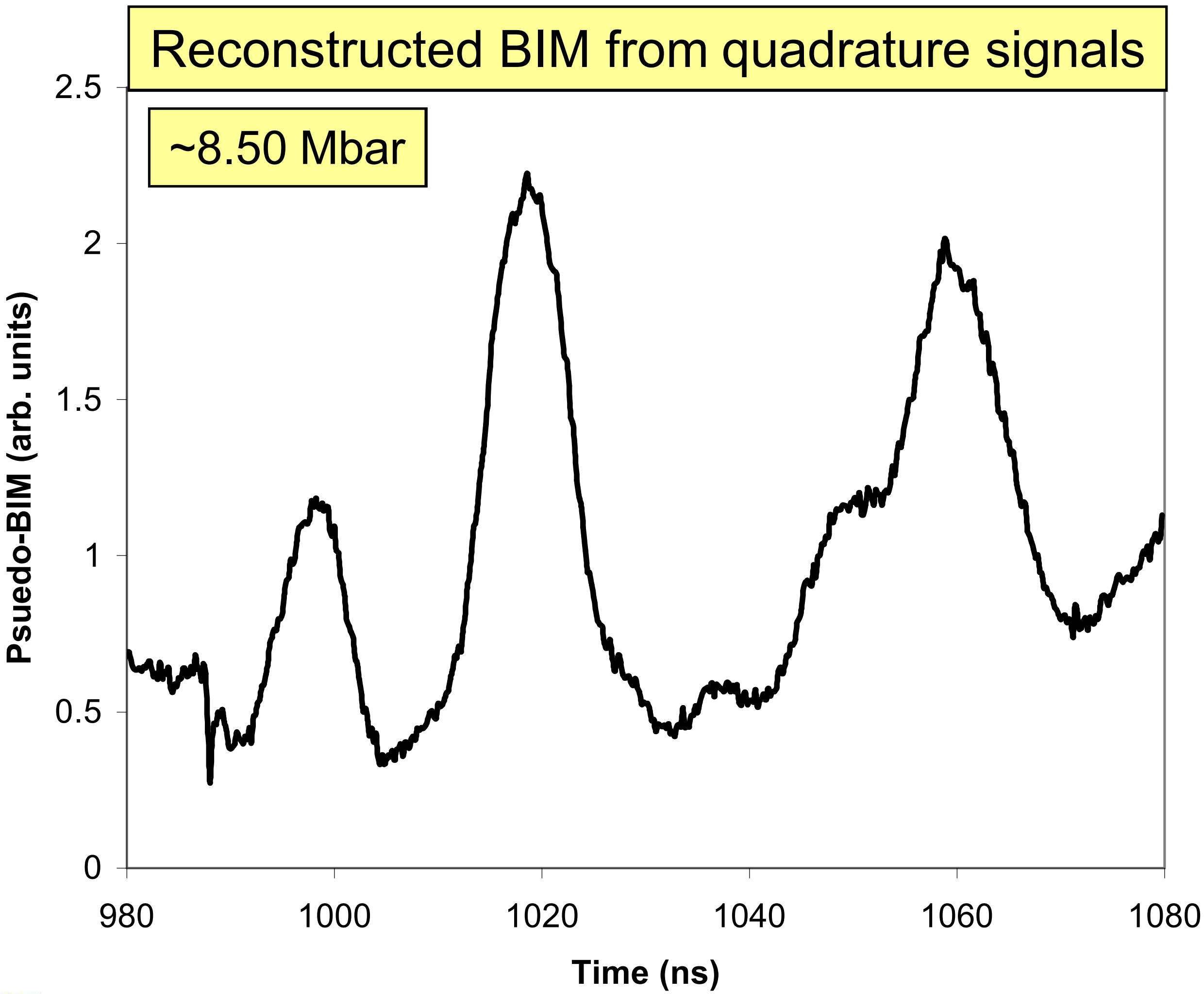
High pressure (above ~9-10 Mbar) data exhibit expected behavior upon release – well behaved fringing

Release data from C melt experiments are proving to be a bit more challenging to analyze



Intermediate pressure (between ~6-9 Mbar) data exhibit unexpected behavior upon release – complicated fringing

Reconstructed beam intensity from quadrature signals suggests a velocity distribution

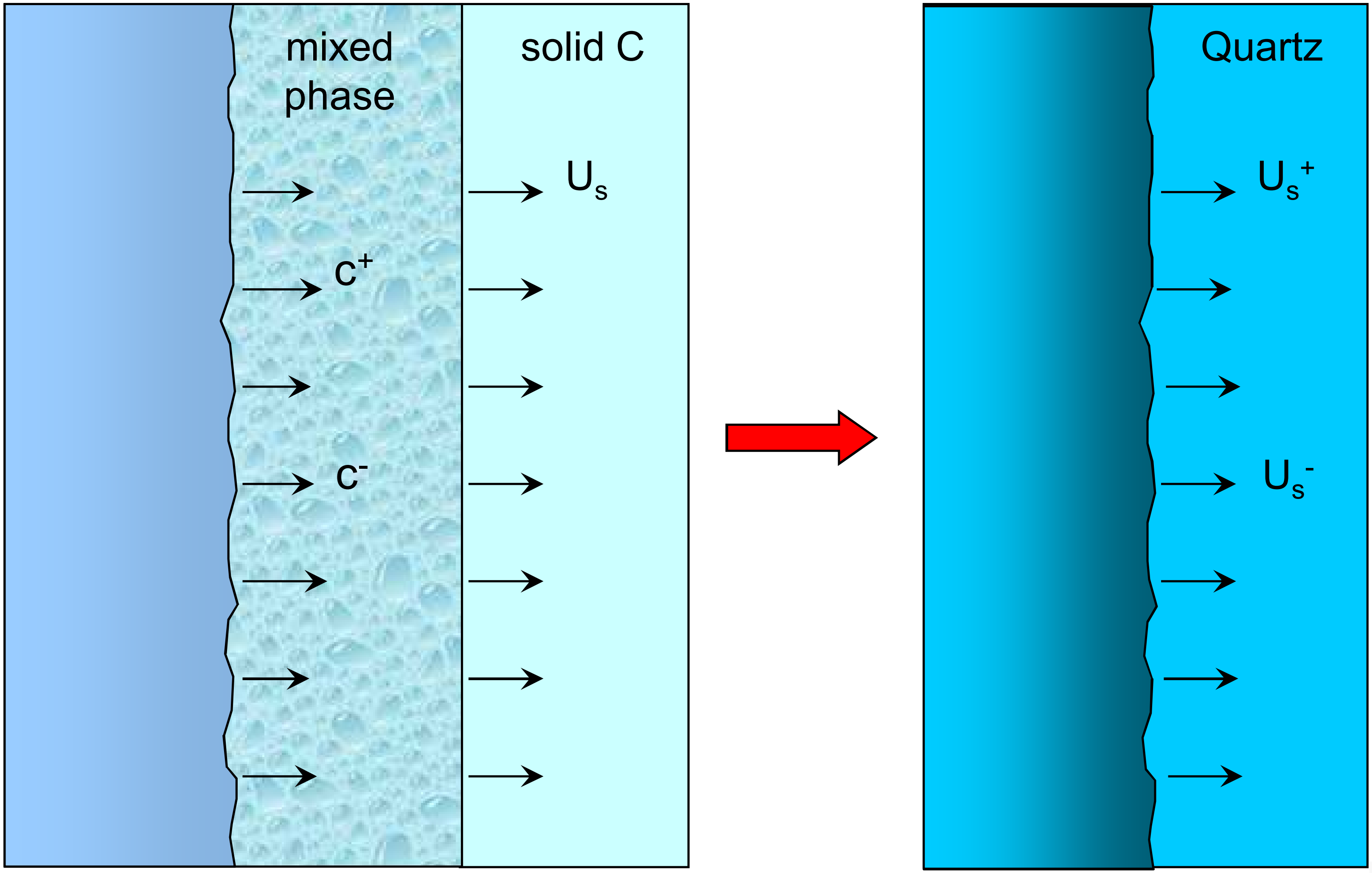


Significant variation in light intensity through the VISAR system

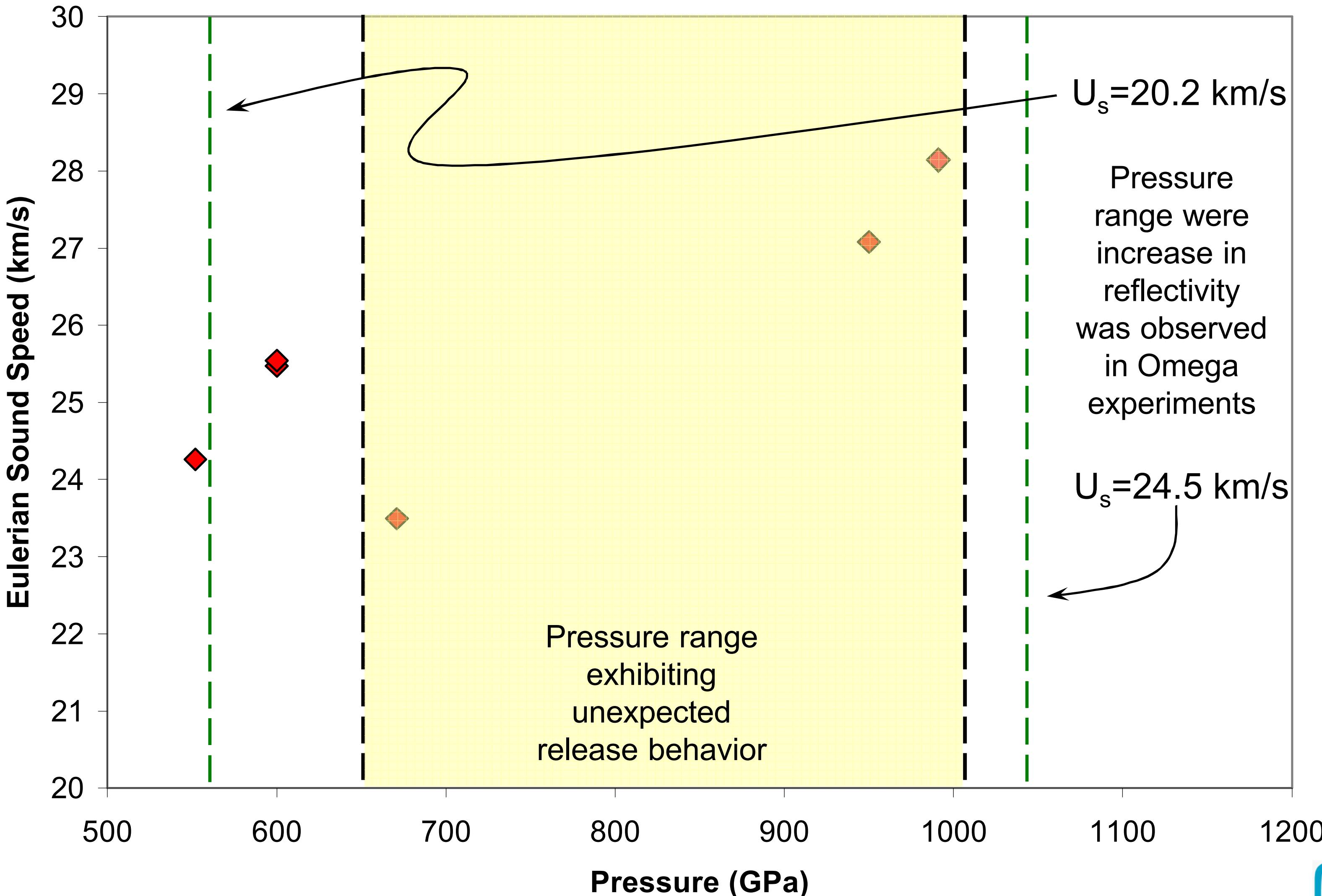
One plausible explanation may be a velocity distribution resulting in a complex interference pattern

Further analysis is underway

The VISAR signal may be sensitive to the co-existence region on the Hugoniot



Very preliminary sound speeds for C seem to indicate that melt begins at ~6-7 Mbar



Conclusions

- Performed a study of shock melting in Be and C over the pressure ranges of ~1-3 and ~5-14 Mbar, respectively
- Be data set is quite rich
  - Will be able to extract onset of melt, the magnitude of the coexistence regime, as well as the strength of solid Be near the melt line
- Preliminary results for Be melt agree quite well with QMD modeling of Desjarlais with the onset ~220 GPa
- Very accurate Hugoniot data obtained for C
  - U_s and u_p precision of ~1 and ~0.7%, respectively
- C melt data proving to be more difficult to interpret, but preliminary results consistent with the QMD modeling of Desjarlais and recent experiments at Omega
- Analyses are ongoing

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