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Experimental and Computational Investigation of the Shock Melting Properties of Diamond

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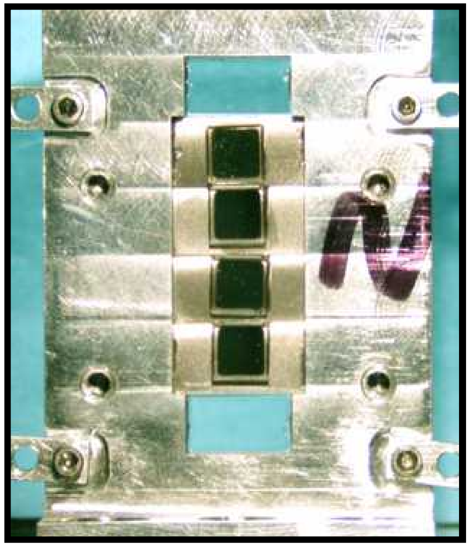

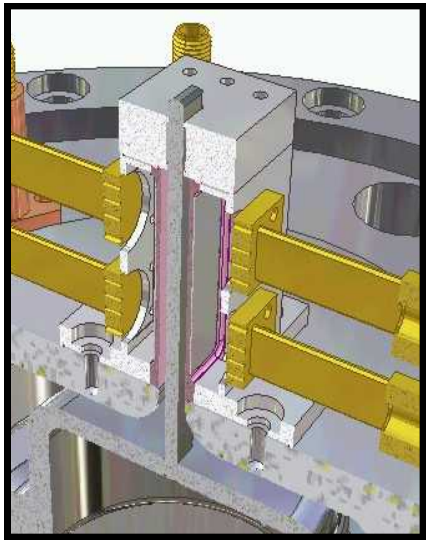

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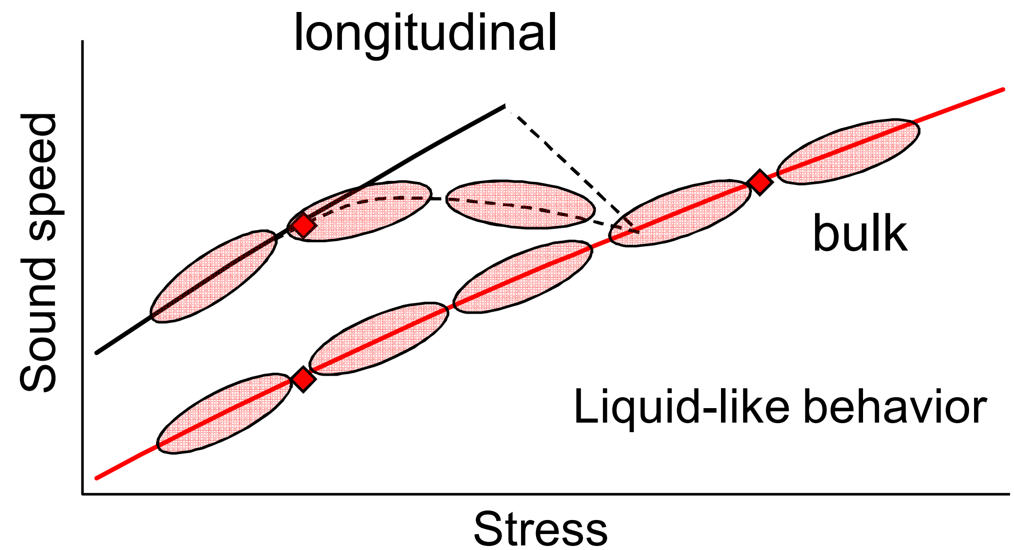
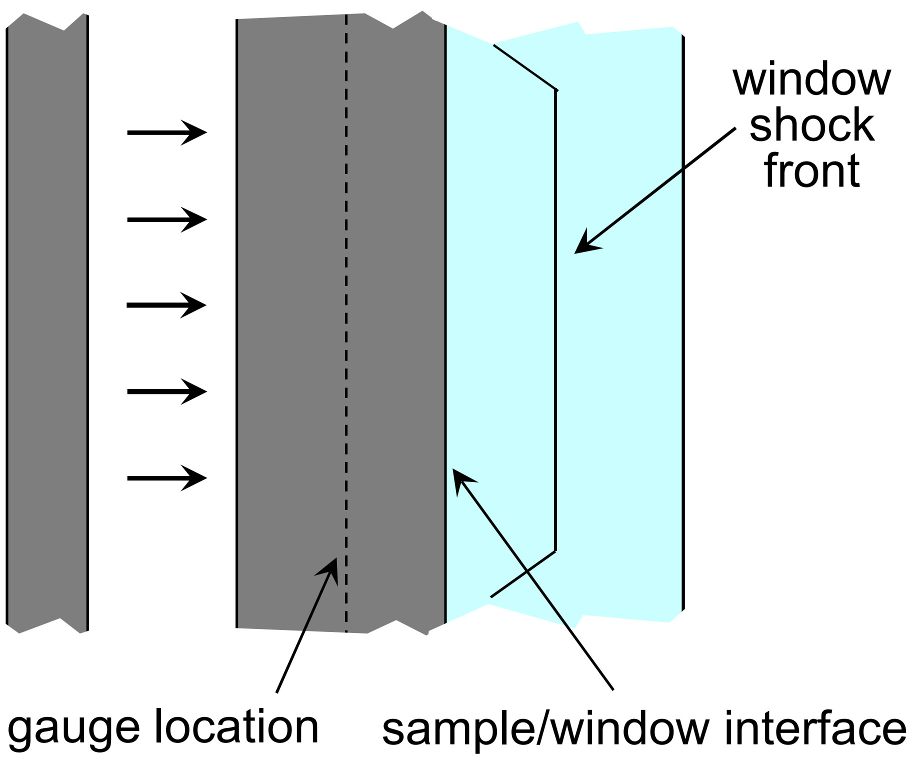
• Ray Lemke	MHD simulations
• Jim Asay	Strength discussions
• LLNL NIC IET	Be experimental configuration
• LANL NIC IET	Be experimental configuration

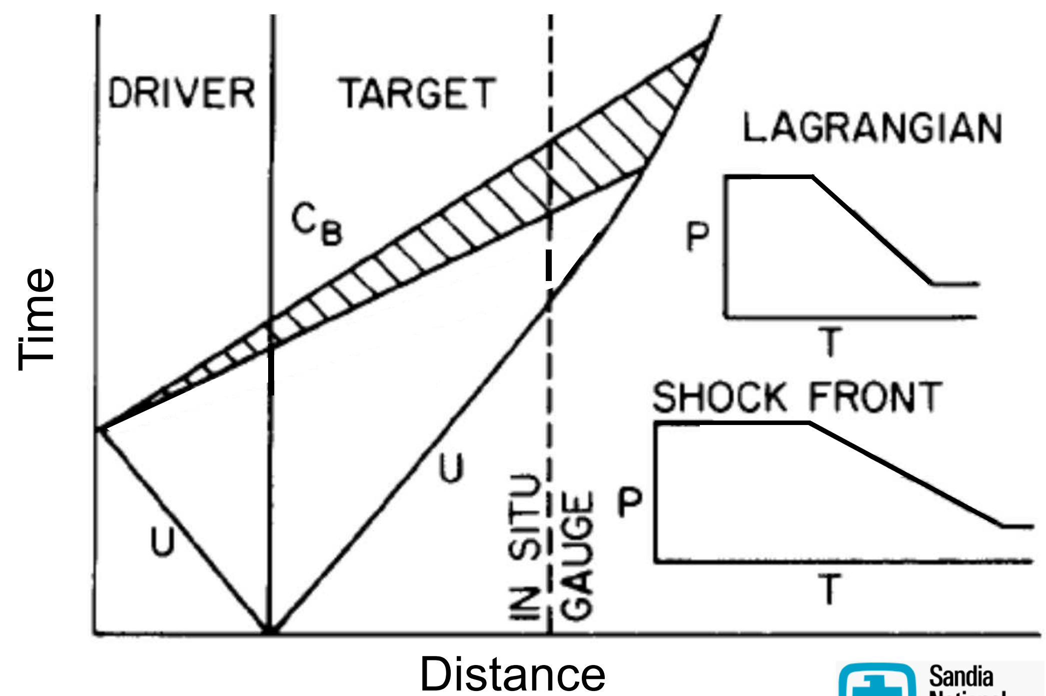
- Z Operations crew

Sound speed measurements were performed to identify the onset of melt

- Well accepted method to identify melt on the Hugoniot
- Requires multiple experiments over a broad stress range
- Can also provide information regarding the yield strength on the Hugoniot







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

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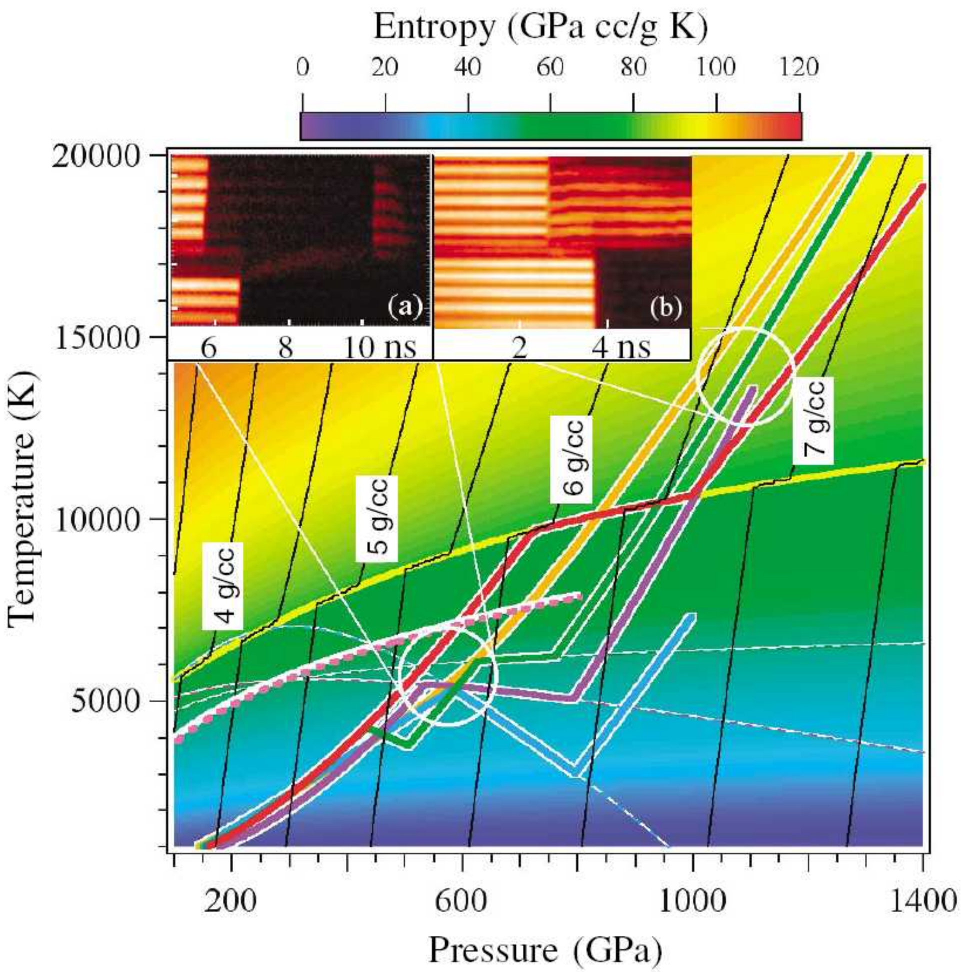
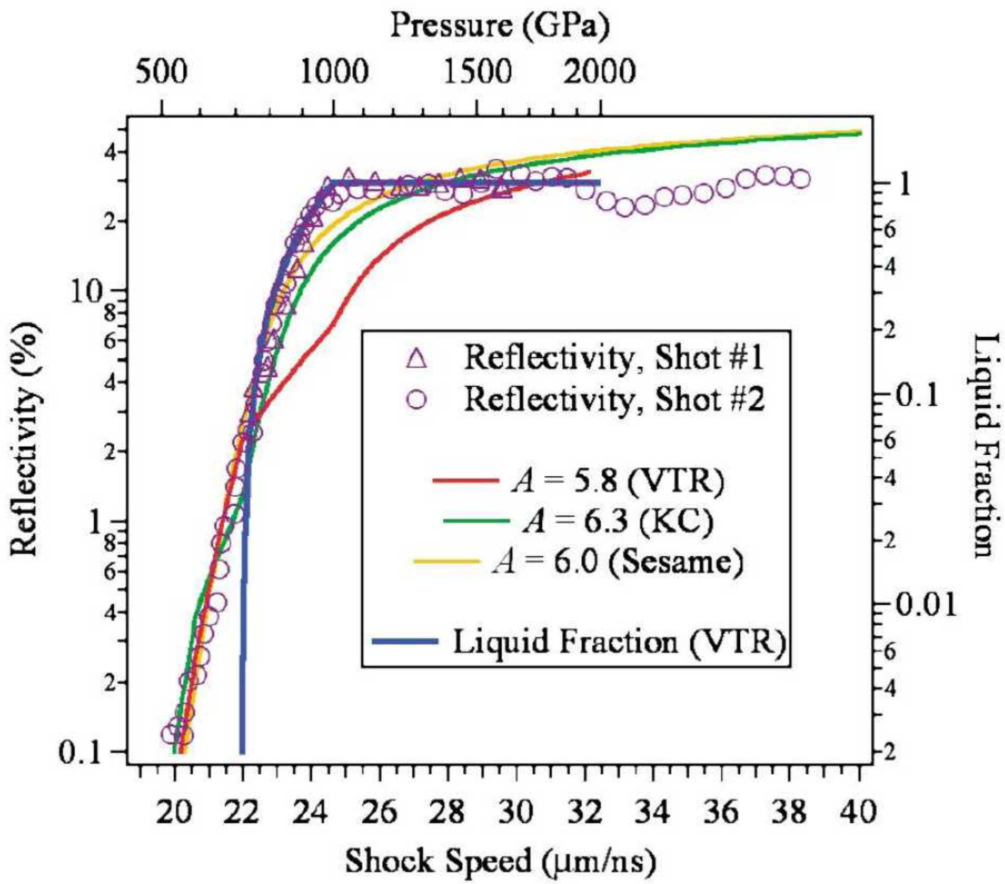
Previous estimates of diamond melt stress indicates that the melt properties are poorly understood

Several chemical picture models for diamond



Reflectivity study on Omega suggests complete melt near 1100 GPa



Bradley, et al., Phys. Rev. Lett. **93**, 195506-1 (2004)

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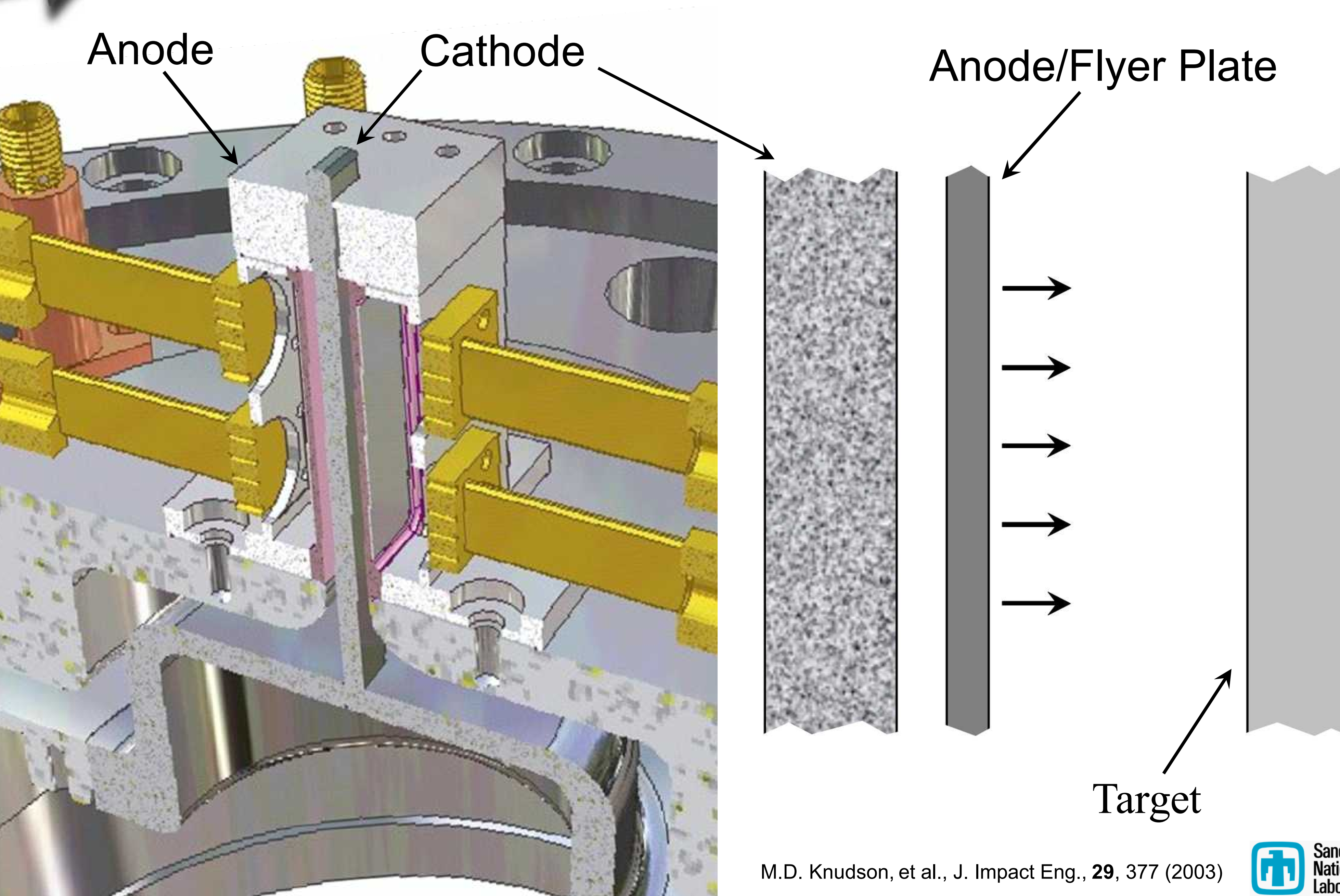
These experiments utilize the ultra-high velocity flyer plate capability on Z



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

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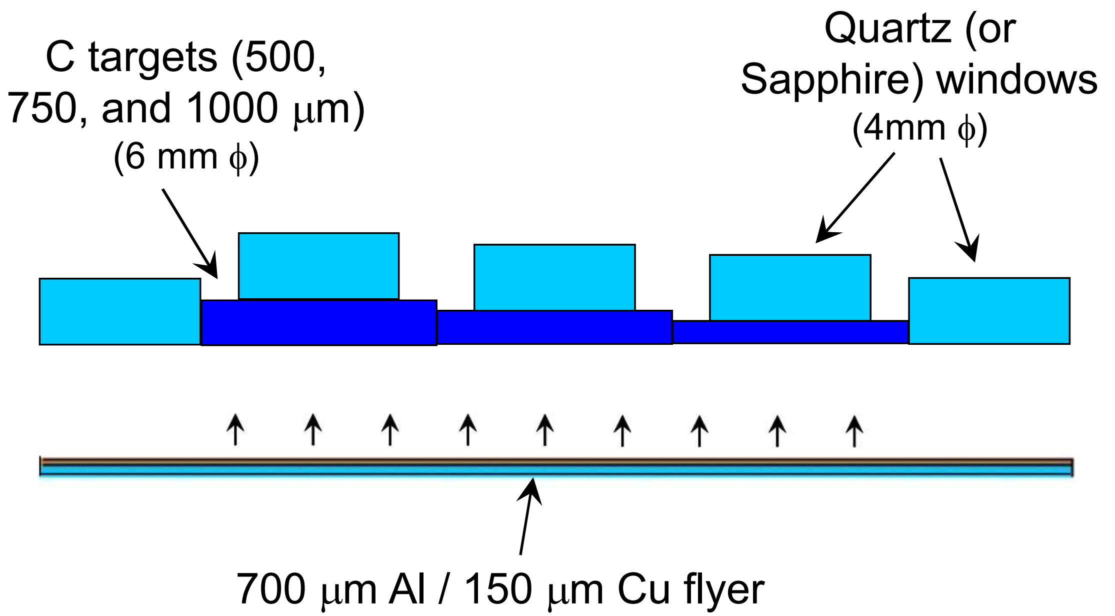
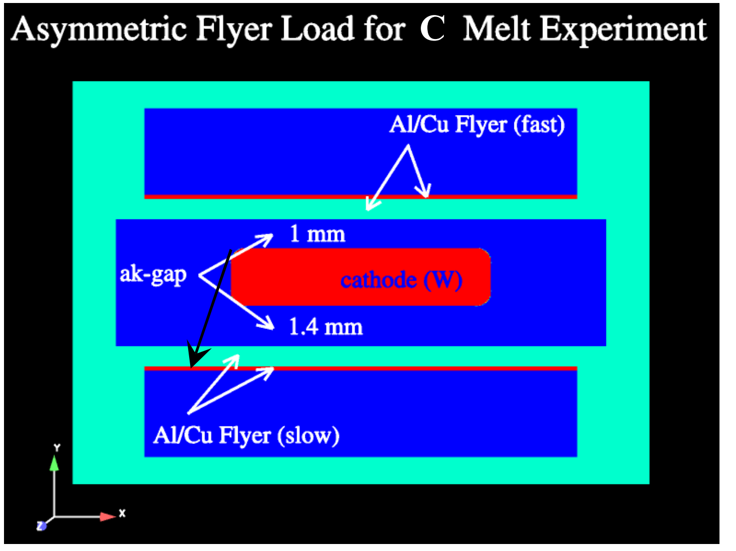
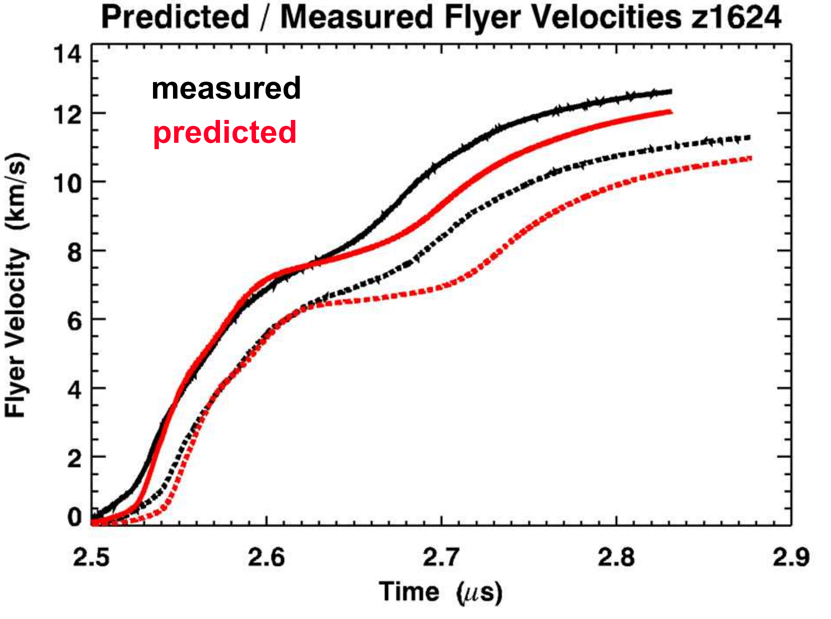
MHD simulations were critical in providing load geometries to achieve desired flyer velocities

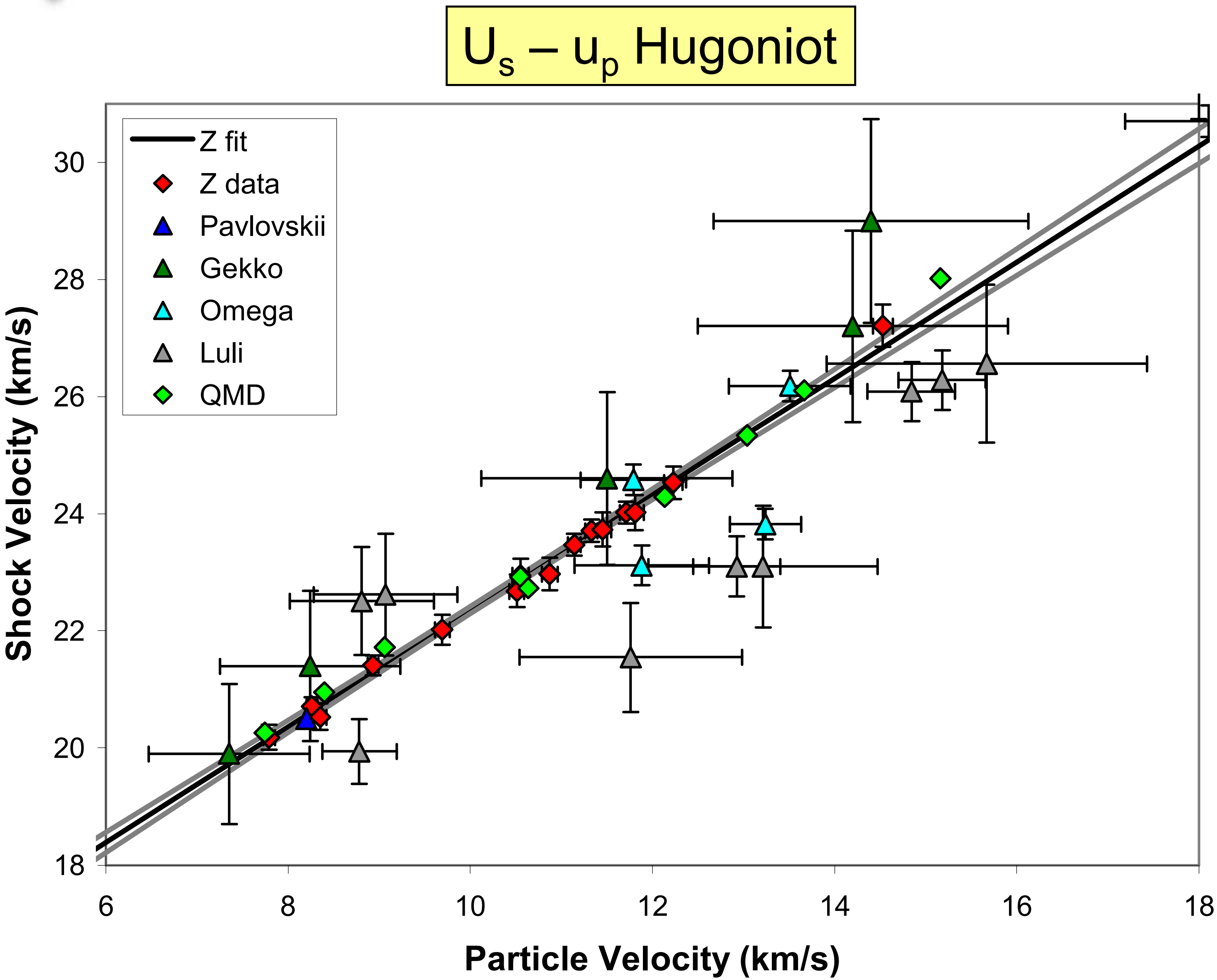






- Experiments required an Al/Cu flyer with peak velocities in the range of 13-24 km/s
- Three asymmetric loads were designed to produce 2 flyers per shot with ~10% difference in peak velocity
- ALEGRA 2D MHD was used to set flight distances and to set charge voltages on Z

Experimental geometry enabled very precise Hugoniot measurements at multi-Mbar stresses



- Sub-percent measurement of U_s and u_p
- Each point is a weighted average of 2 or 3 individual measurements (3 samples per panel)
- Significant benefit in being able to measure flyer plate velocity for impedance match

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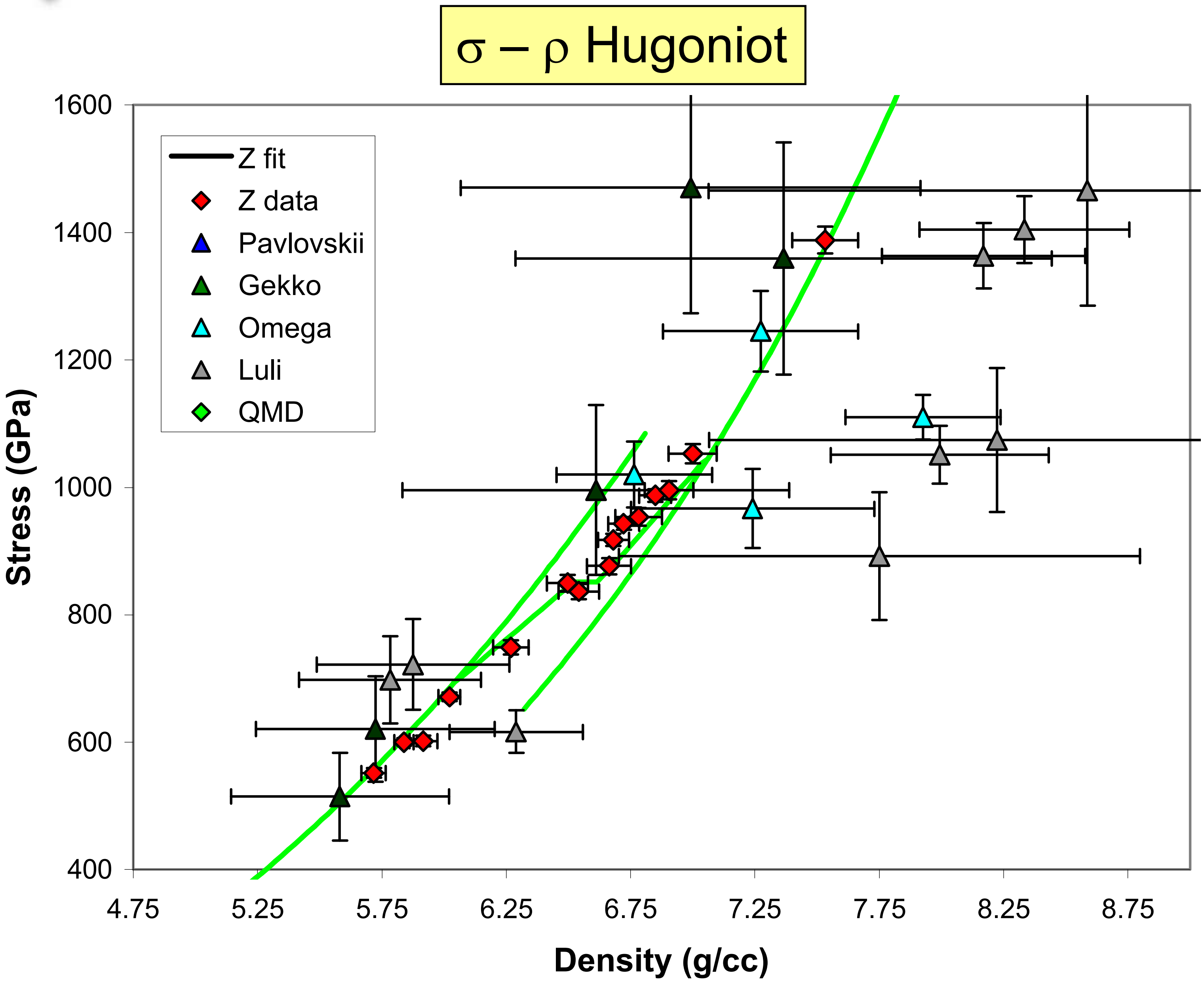
Experimental geometry enabled very precise Hugoniot measurements at multi-Mbar stresses



- Density precision of ~1% on average, as low as 0.67%
- High precision allows for quantitative comparison with theory
- These are by far the most accurate Hugoniot measurements of diamond in the multi-Mbar stress regime

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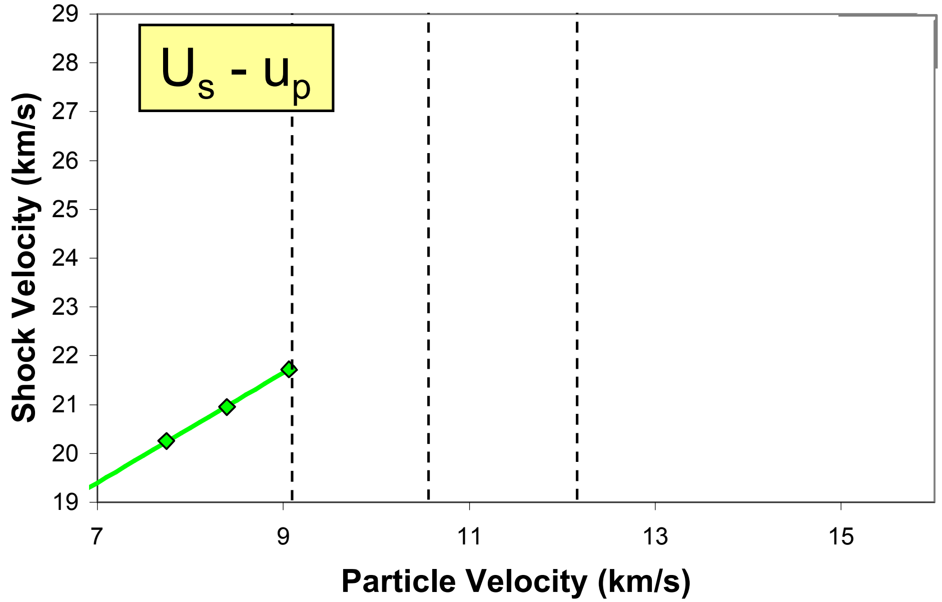
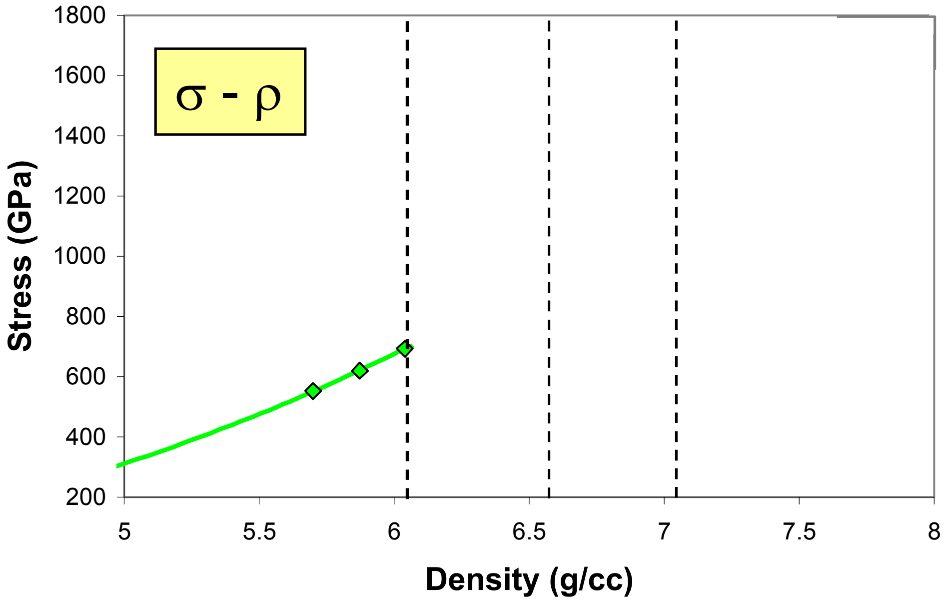
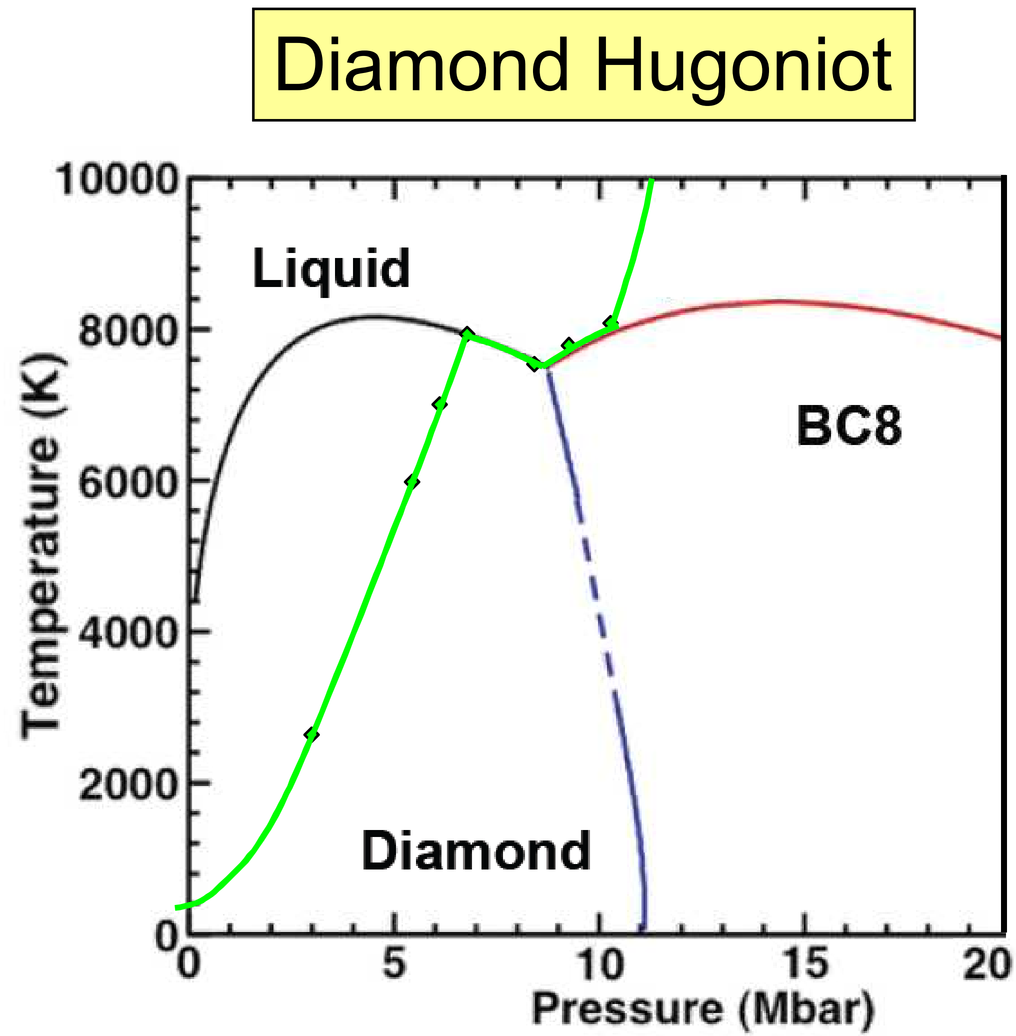
QMD calculations predict a diamond/liquid/bc8 triple point within the coexistence region

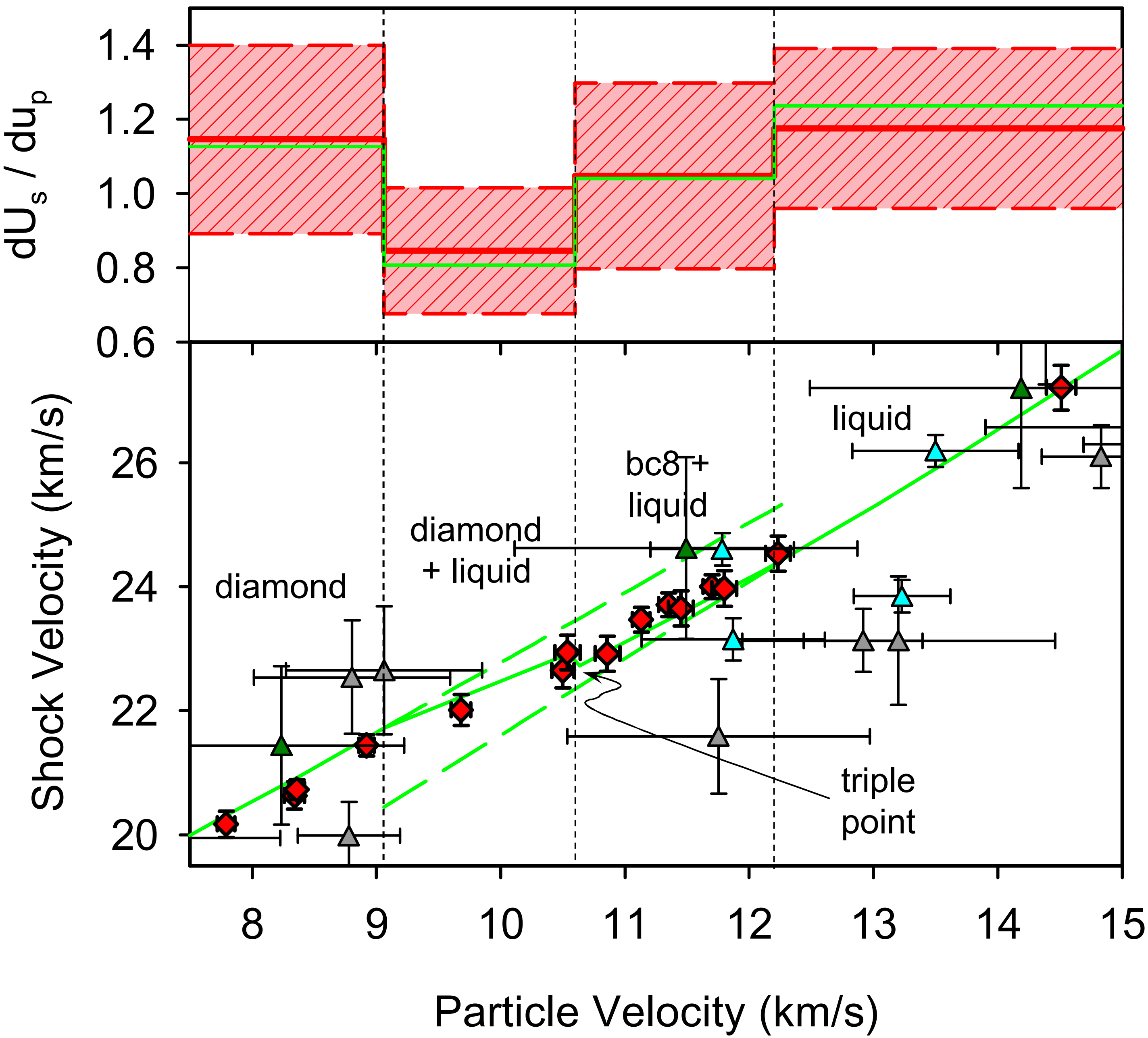






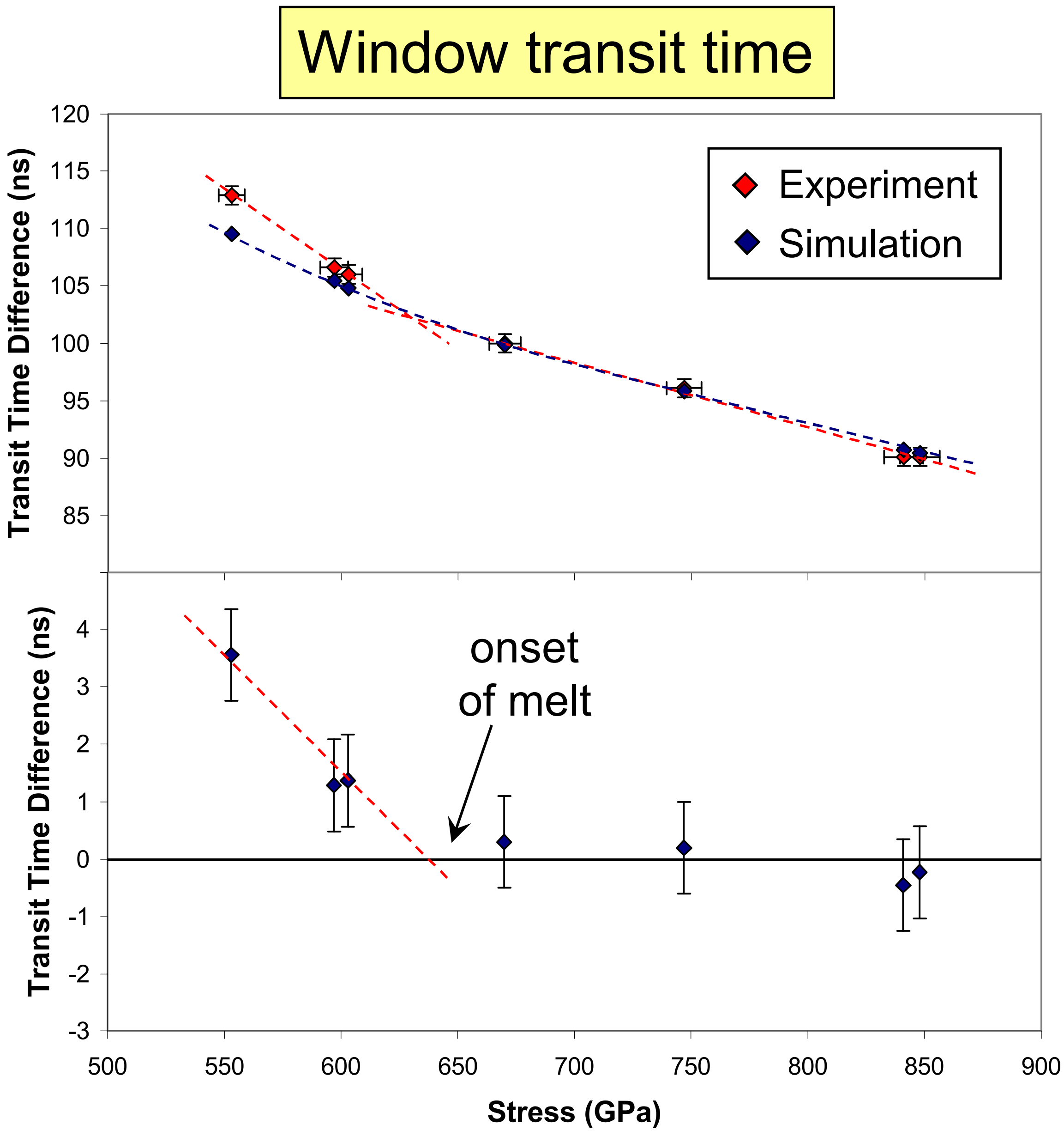
Correa, et al., PNAS **103**, 1204 (2006)

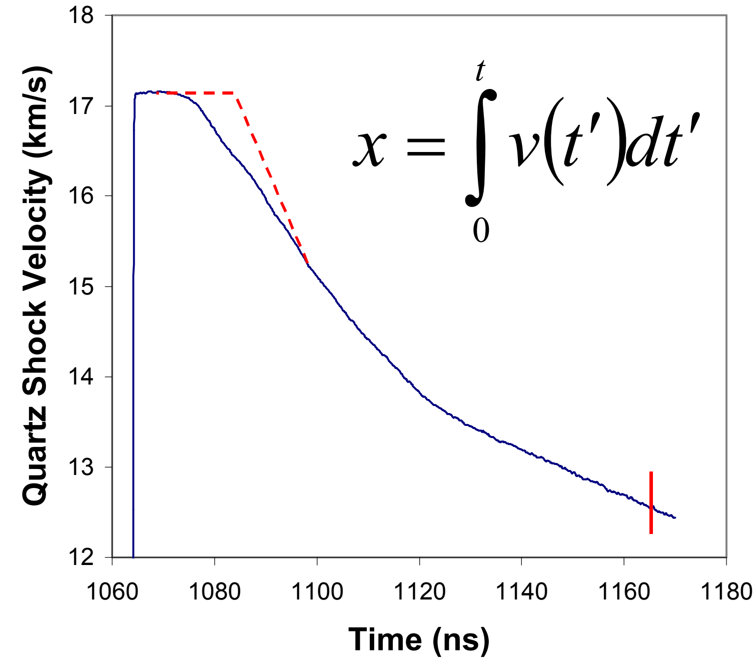
Z Hugoniot data is consistent with the trend in slopes predicted from the QMD calculations



- Piecewise weighted least squares linear fits to the Z data
- Linear segments determined from QMD predictions for onset of melt, triple point, and completion of melt
- Same trends in the magnitude of slope changes observed in experiment
- Experimental results consistent with QMD predictions regarding diamond-liquid-bc8 triple point

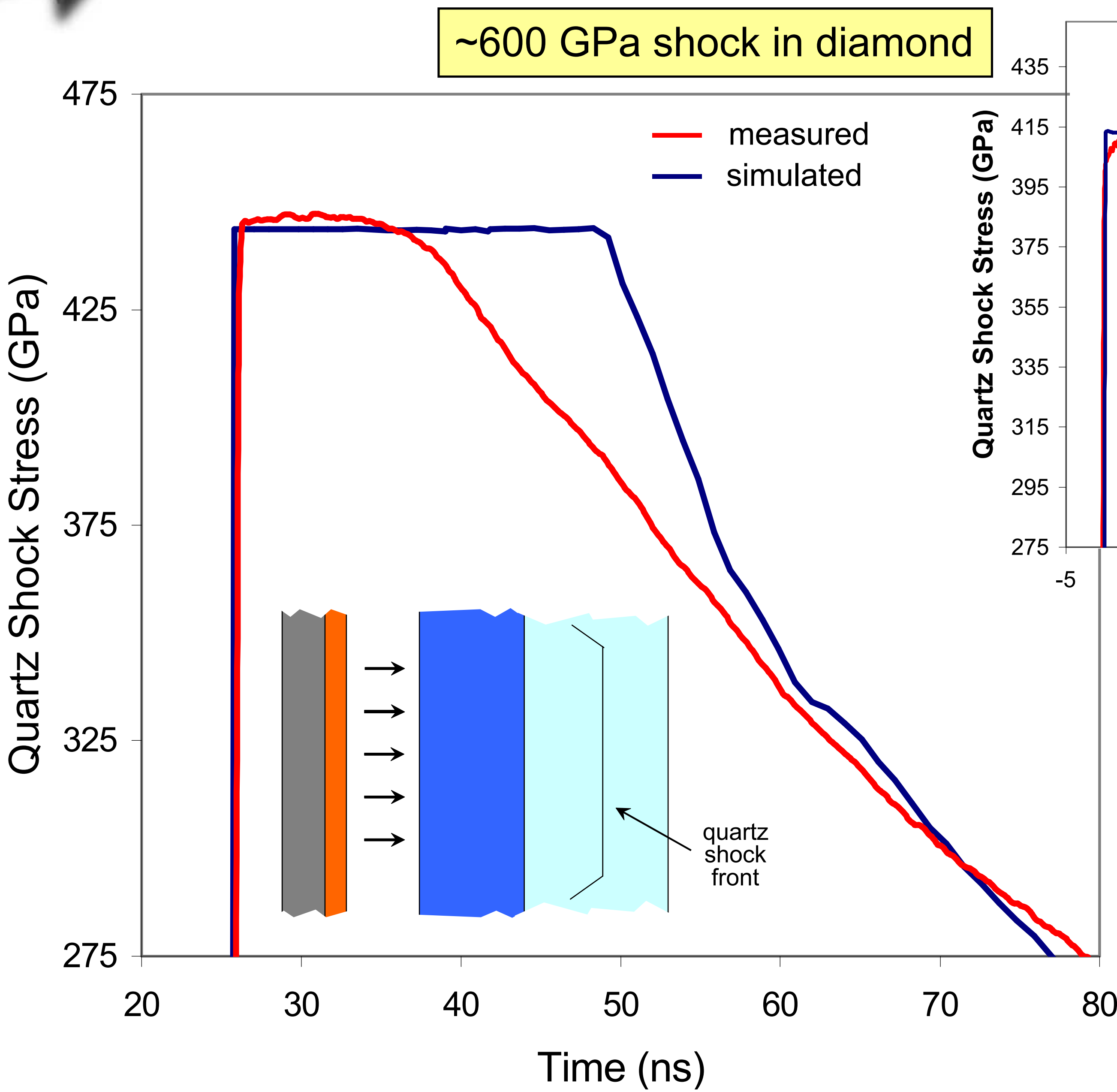
Trends in the data do show a clear indication of melt near 650 GPa

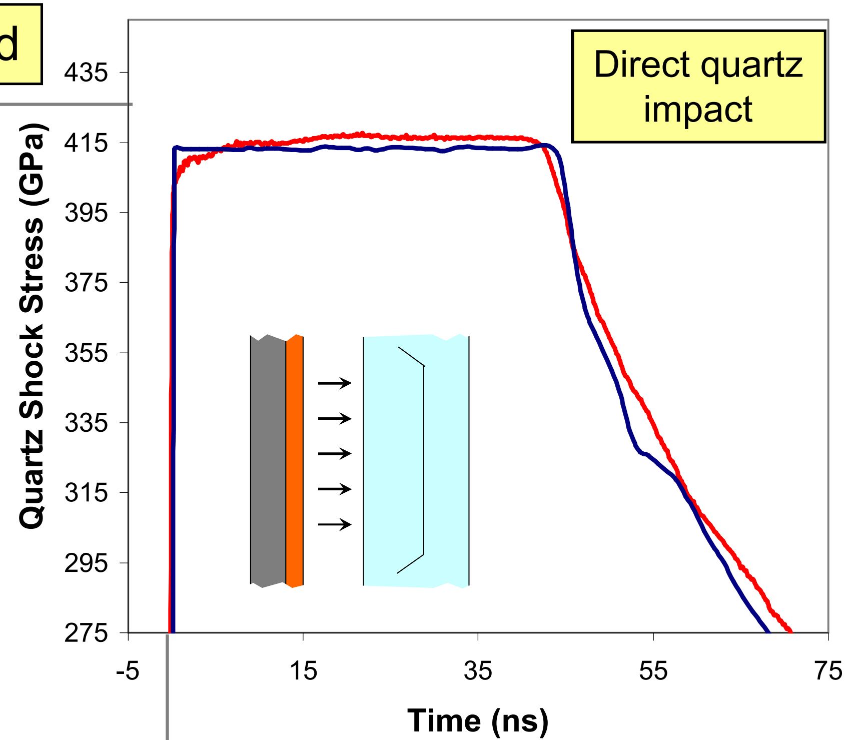




- Window transit time is a measure of the average velocity through the window
- At low stress there is a statistically significant difference between experiment and simulation
- This difference is being attributed to a yield strength effect

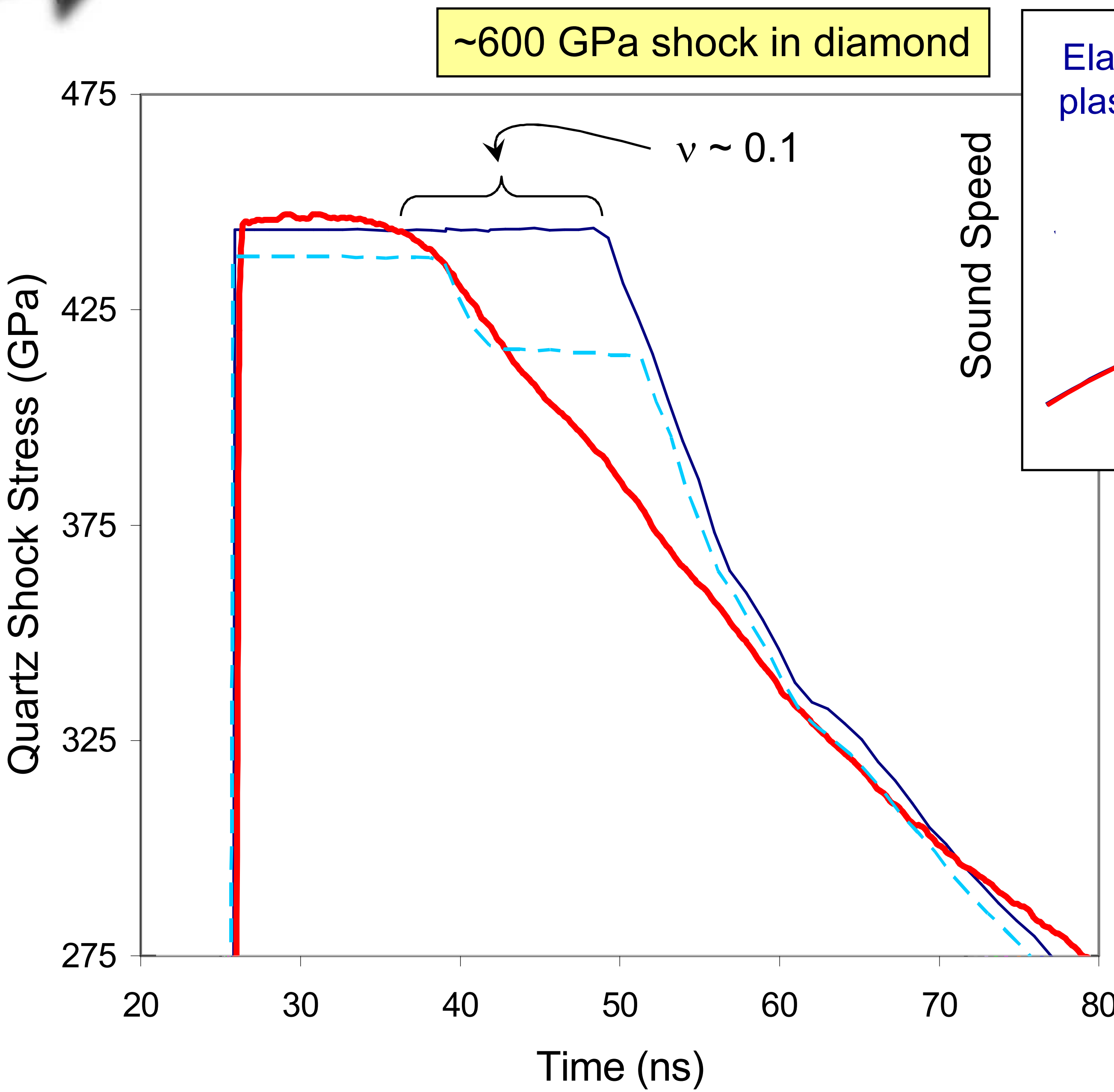
Release wave profiles below melt indicate significant yield strength in the Hugoniot state

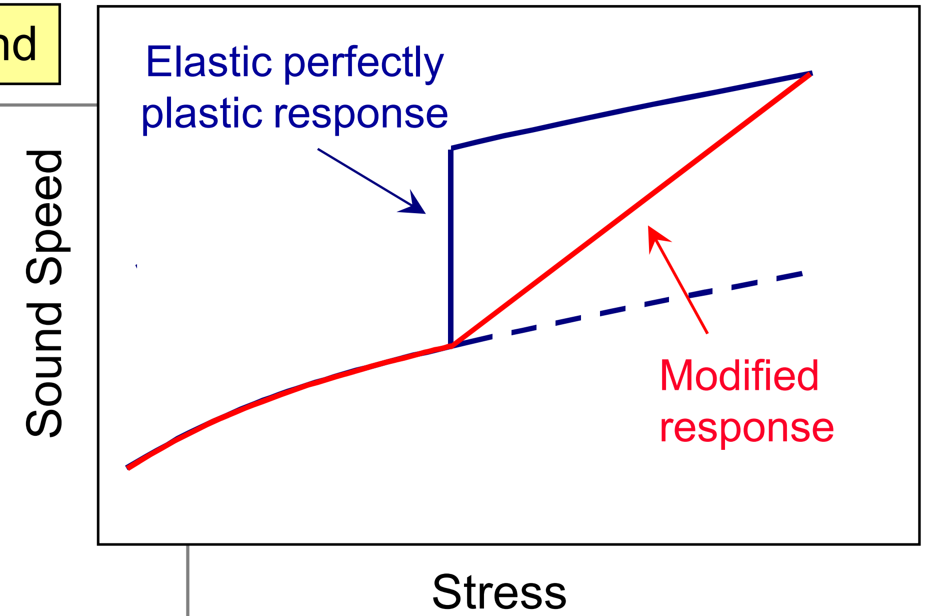




- Reasonable agreement for direct impact into quartz window
- Significant difference between measured and simulated profiles with inclusion of diamond

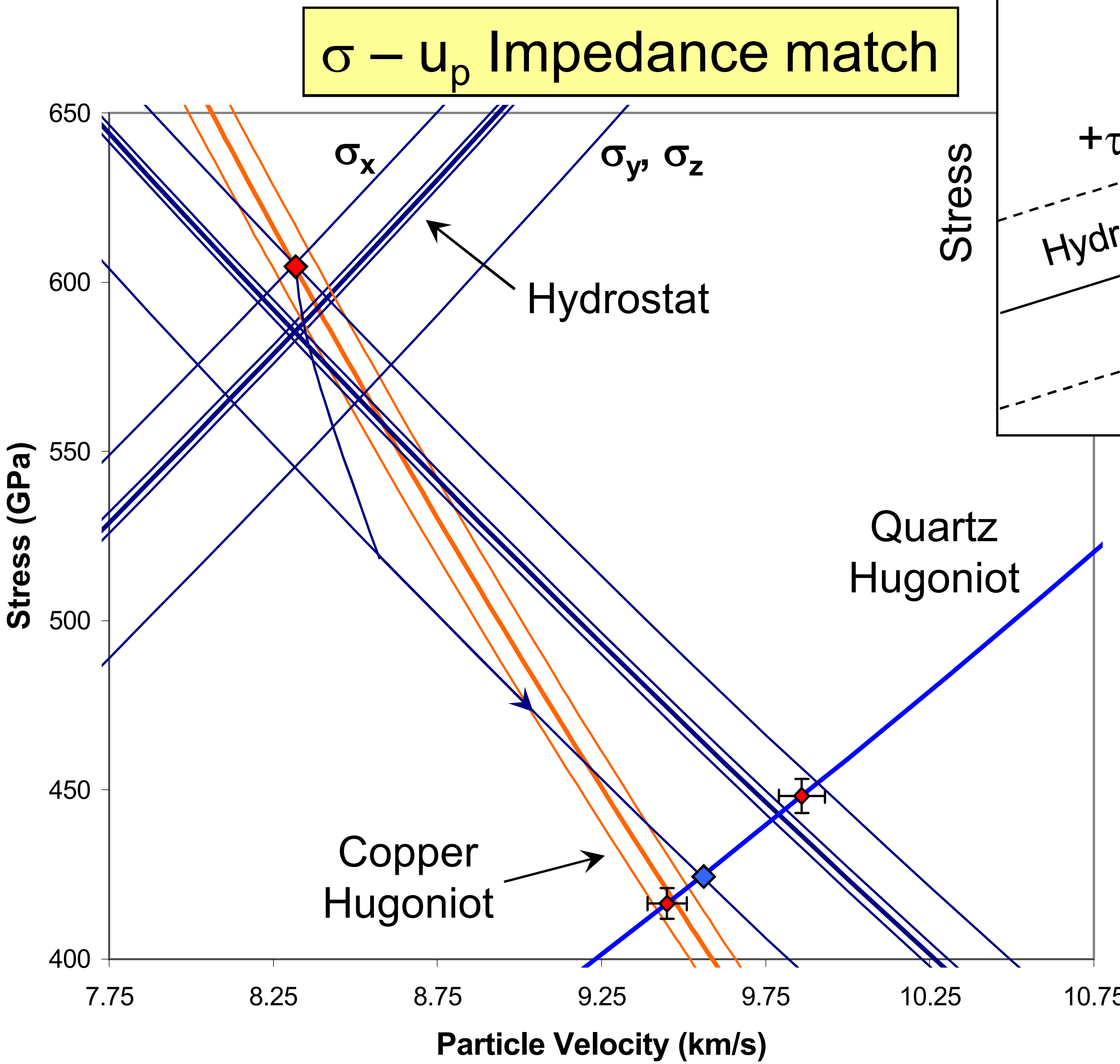
Preliminary inference of yield strength suggest values in the range of ~50-80 GPa

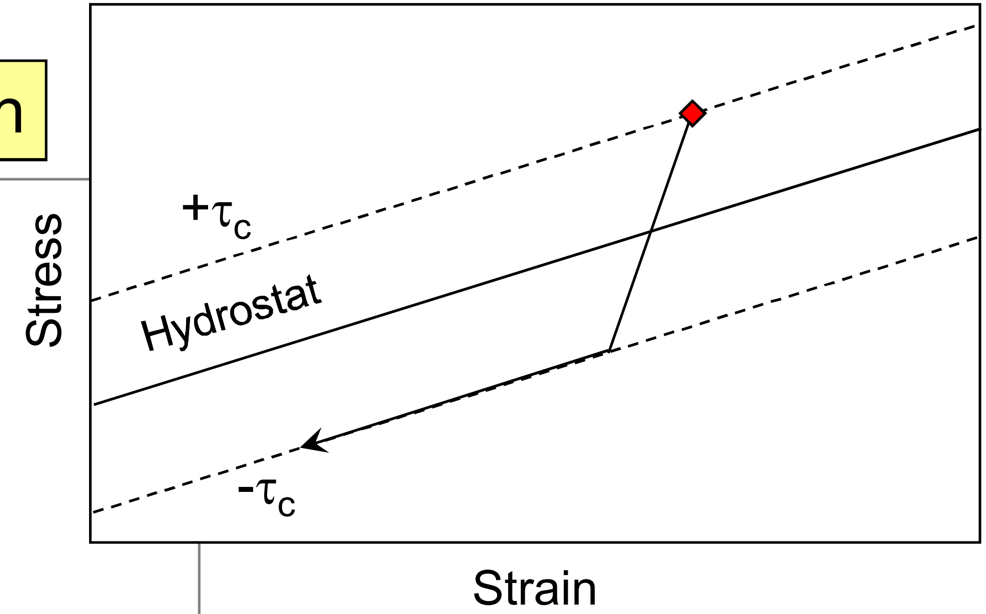




- Hydrocode simulations provide insight into the yield strength
- Poisson's ratio is quite low, of order $\nu = 0.1$
- Reasonable agreement with measured profiles suggests ~50-80 GPa yield strength

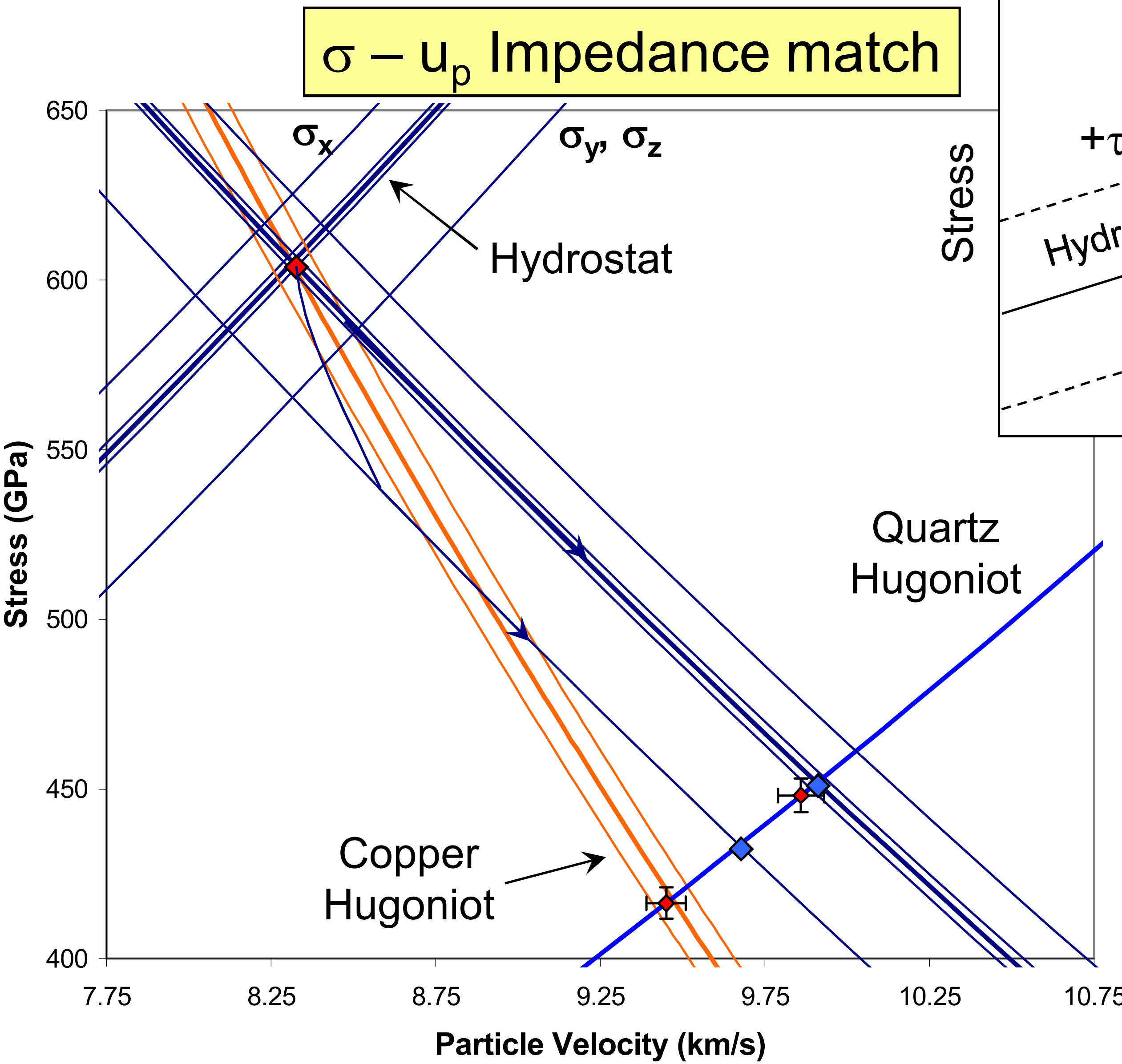
Impedance matching however suggests negligible shear stress in the Hugoniot state

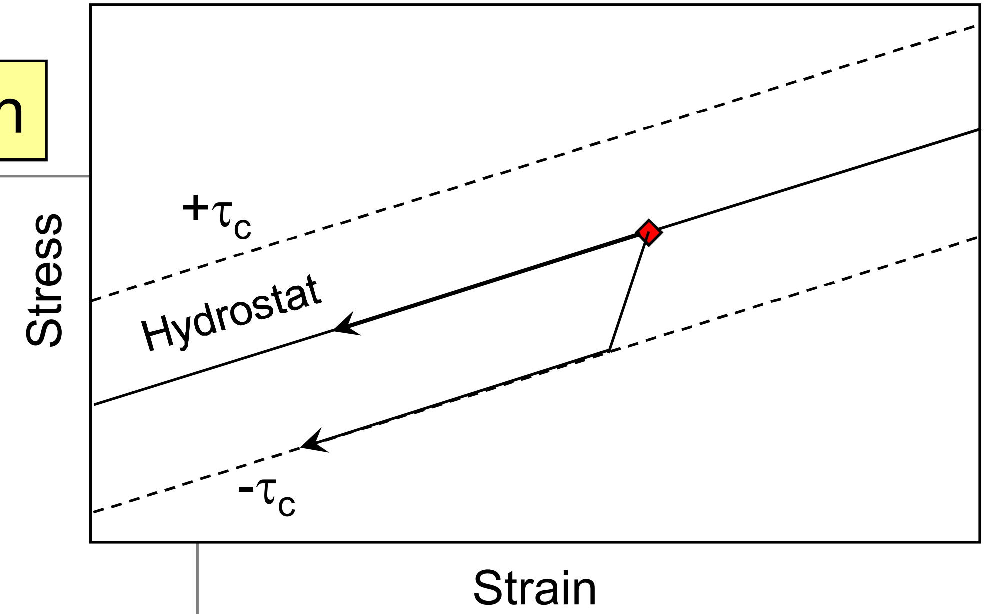




- Difference in impedance match state in Quartz is statistically significant, ~2.7% in U_s
- Uncertainty in the measured Quartz shock velocity is <1%
- Incompatible with the release data

Impedance matching however suggests negligible shear stress in the Hugoniot state





- Better agreement between impedance match and experimental measurement
- Strong case for negligible shear stress in Hugoniot state
- Difference in impedance match state in Quartz may be statistically significant, ~1.7% in U_s

Conclusions

- Very precise Hugoniot data obtained for diamond between 550 and 1400 GPa
  - Consistent with QMD calculations which predict the onset of melt at ~690 GPa, a diamond-liquid-bc8 triple point at ~850 GPa, and completion of melt at ~1040 GPa
- Release data suggests significant yield strength in the shocked state below melt (~50-80 GPa)
  - Enabled trends in window transit time to determine onset of melt at ~650 GPa, in good agreement with QMD
- Impedance matching makes strong case for negligible shear stress in the shocked state, somewhat weaker case for initial release being hydrostatic
  - This issue could be addressed through reshock experiments on ZR