SAND2009-5181C

High accuracy Hugoniot measurements at multi-megabar pressure utilizing the Sandia Z accelerator

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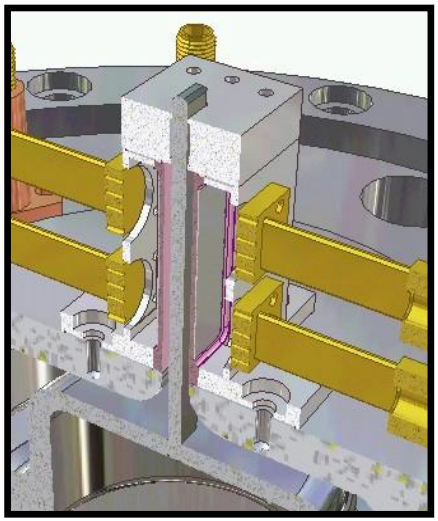
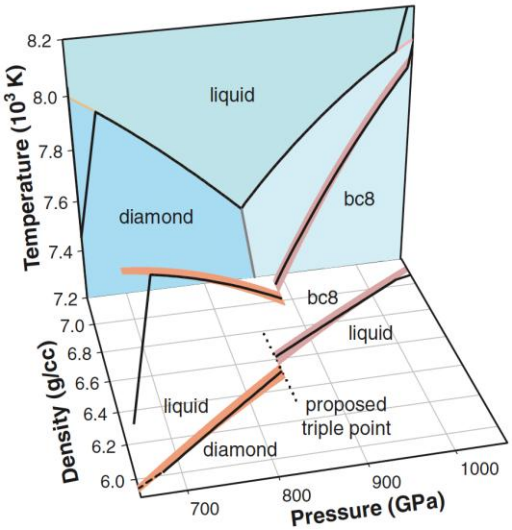


International Conference on High Pressure Science and Technology

Odaiba, Tokyo, Japan

July 26 – 31, 2009



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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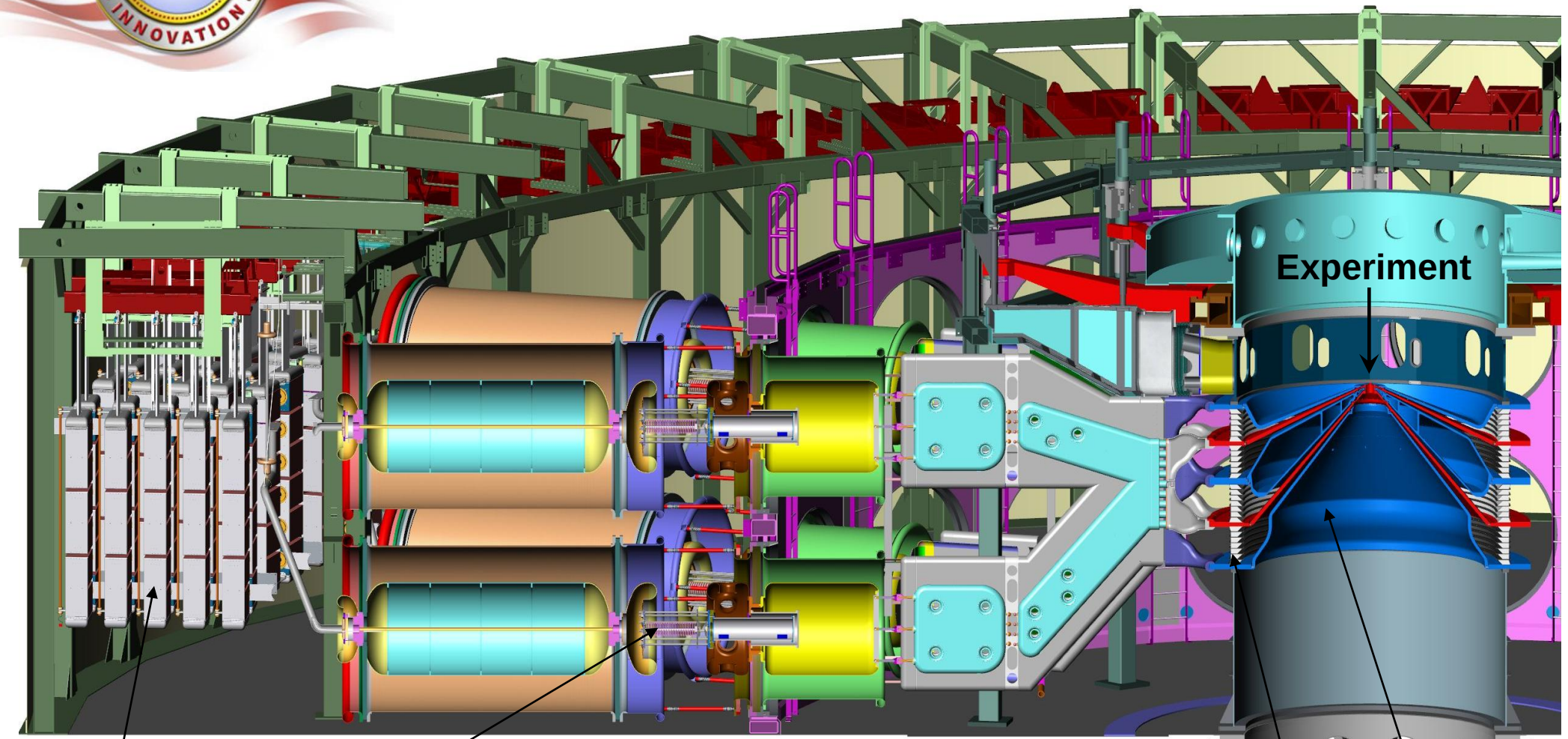
The Sandia Z Machine



Marx generator

laser-triggered gas switch

insulator stack

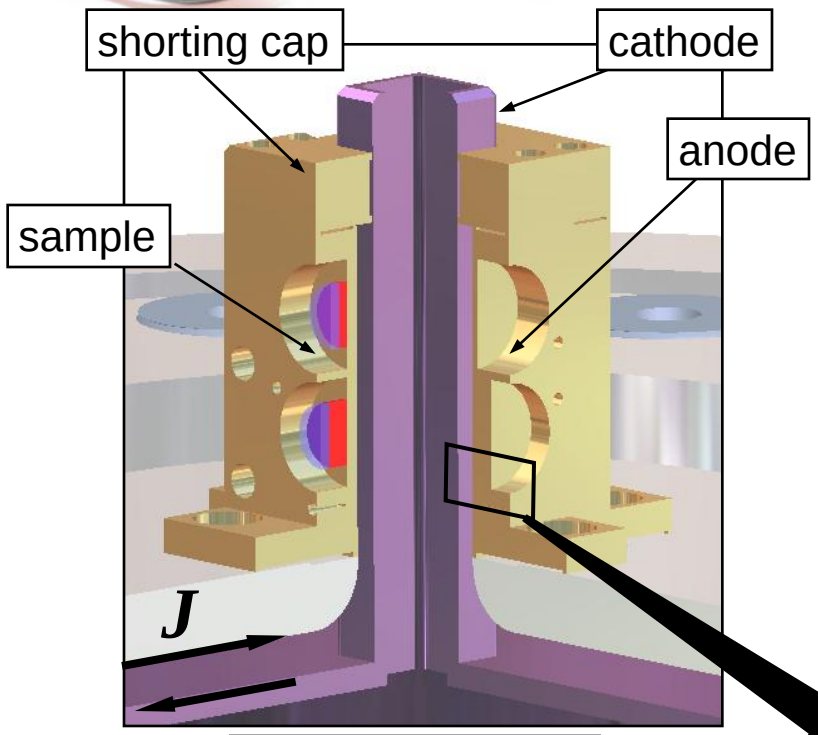
magnetically insulated transmission lines

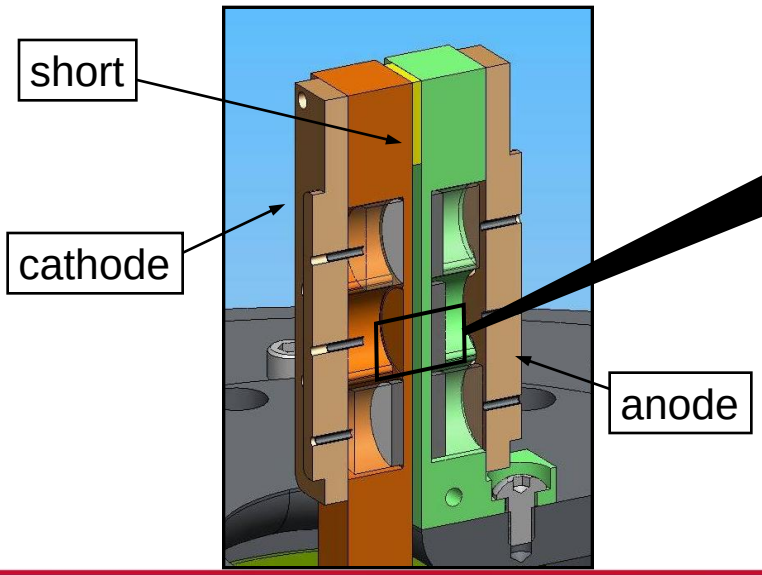
22 MJ stored energy

~25 MA peak current

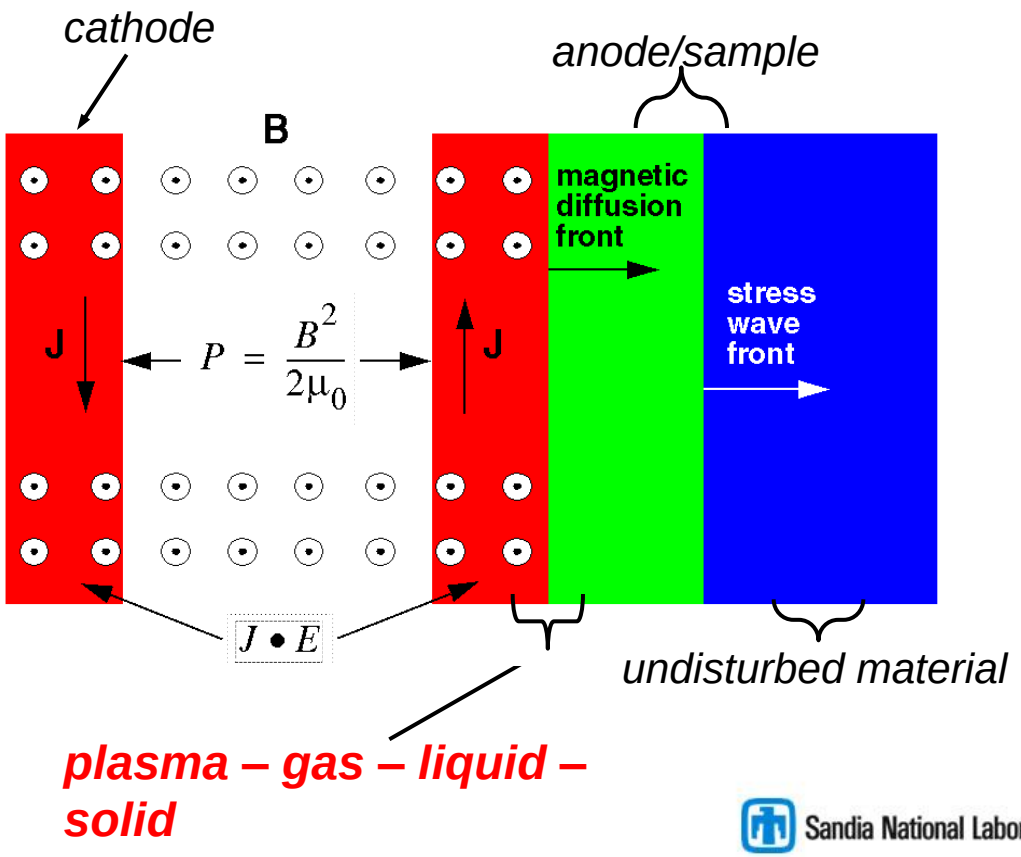
~200-600 ns rise time

Magnetic compression on Z produces smooth ramp loading to ultra-high pressures





- pulse of electric current through electrodes (coaxial or strip line) induces magnetic field
- ***J***x***B*** Lorentz force provides pressure ramp



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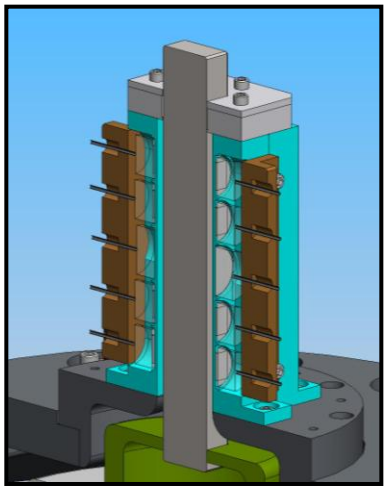
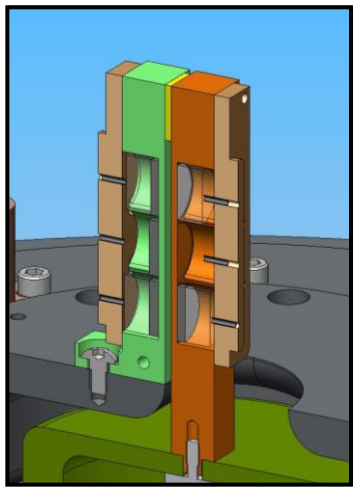
Two platforms have been developed for accurate equation of state studies – both major advances



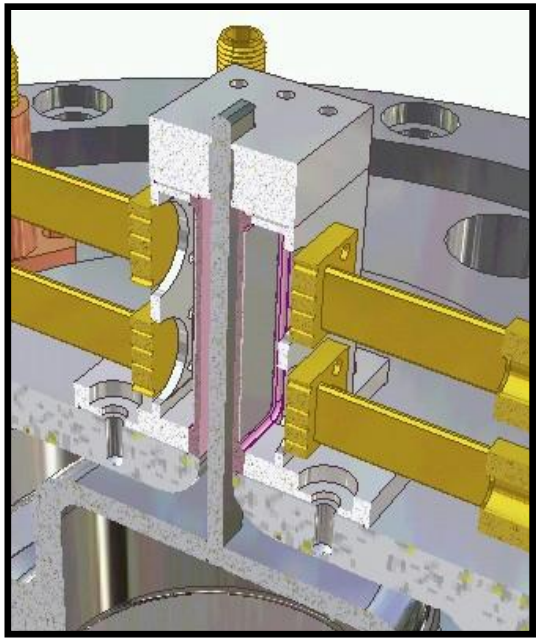


Isentropic Compression Experiments (ICE)*

Magnetically driven Isentropic Compression Experiments (ICE) to provide measurement of continuous compression curves to ~4 Mbar

- previously unavailable at Mbar pressures

* Developed with LLNL



Magnetically launched flyer plates

Magnetically driven flyer plates for shock Hugoniot experiments at velocities to > 40 km/s

- exceeds gas gun velocities by > 5X and

pressures by > 7-8X with comparable accuracy

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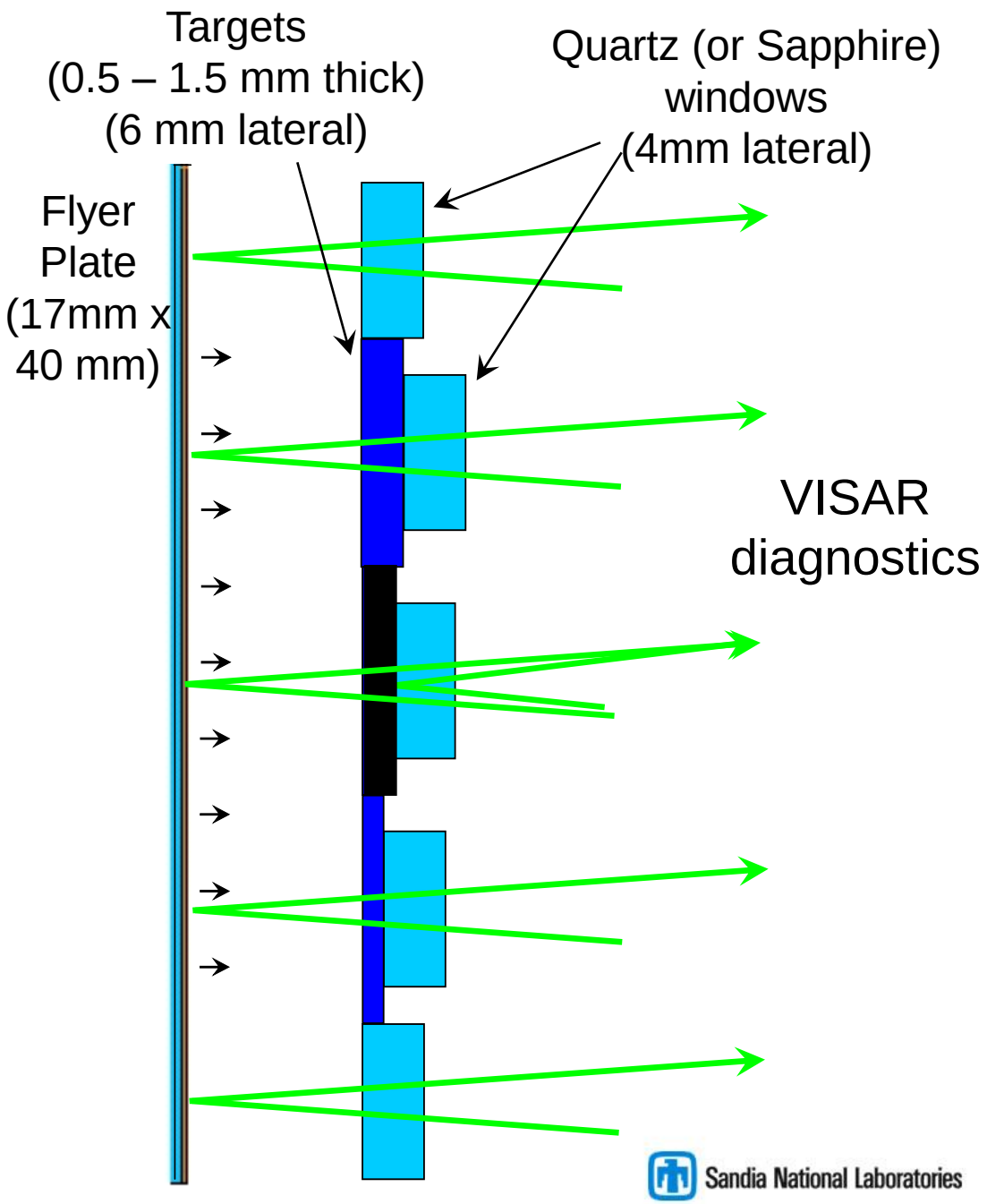
Lateral dimensions of the flyer plate enabled multiple large samples to be fielded

Experimental configuration



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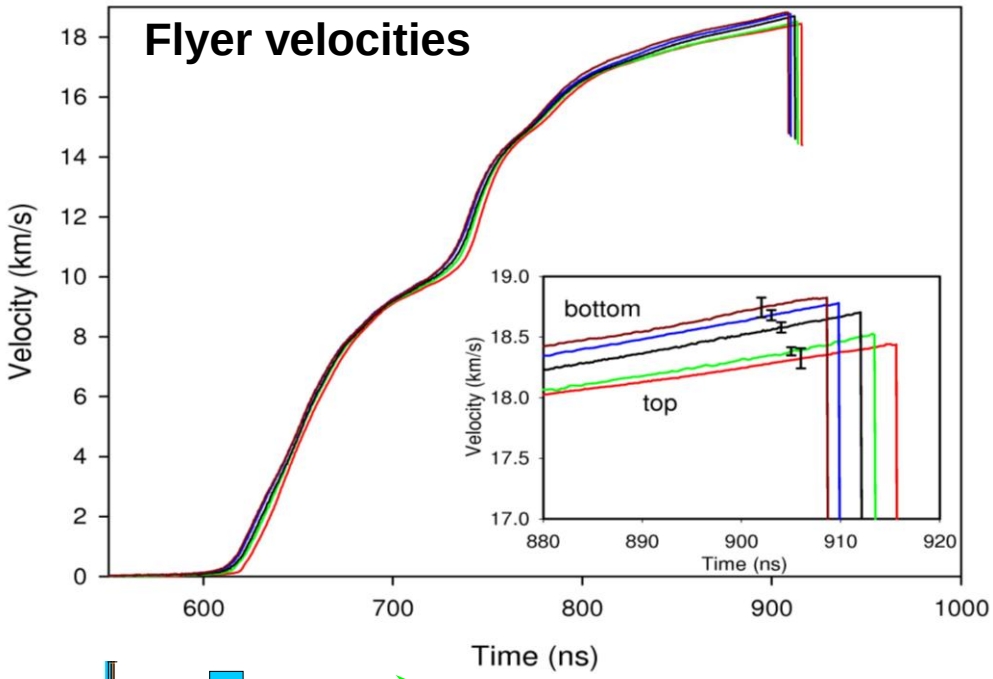
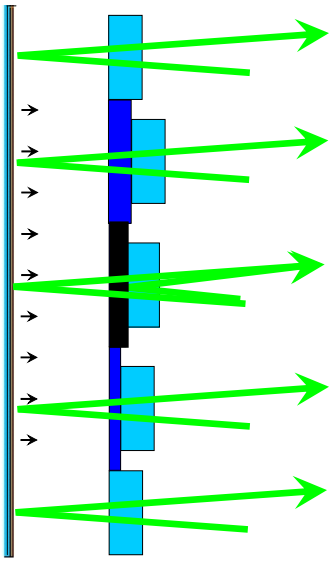
Flyer velocities are measured to within 0.5% uncertainty





- Multiple samples and diagnostics allow for redundant measurements providing increased accuracy
- Transparent samples allow for in-line measurement of impact velocity
- Opaque samples analyzed by interpolating data from adjacent windows

- Uncertainty determined by VISAR
  - Typical vpf : 500 m/s/fr
  - Conservative fringe resolution: 0.1 fr
  - 50 m/s absolute uncertainty
  - 0.1-0.4% of typical flyer velocity

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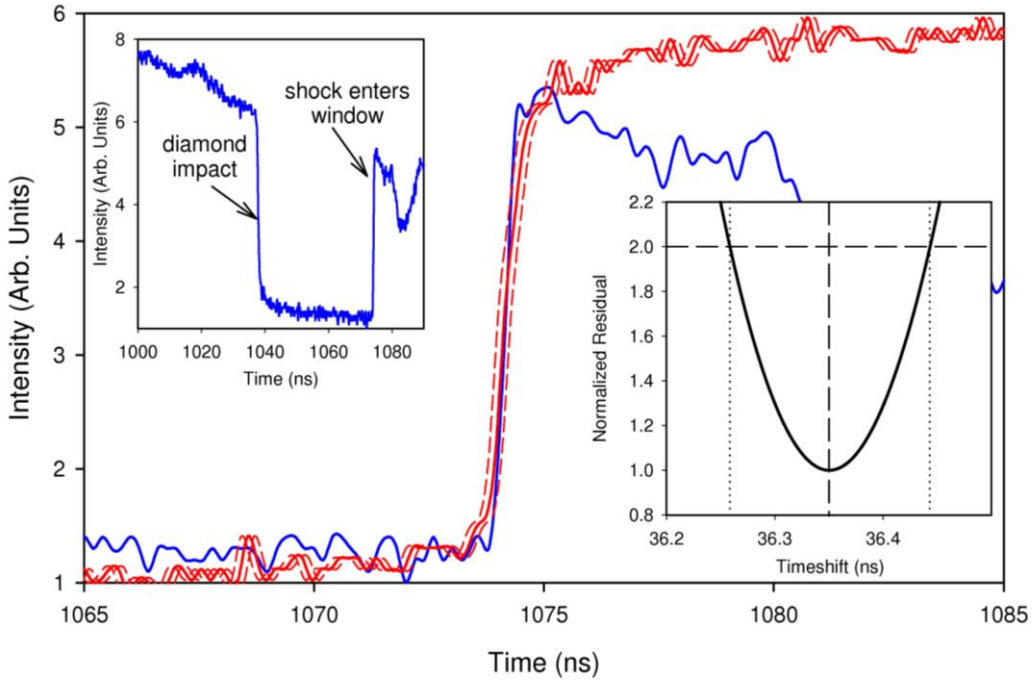
Diamond data from Knudson, Desjarlais, and Dolan, Science **322**, 1822 (2008)

Wave speeds are measured to within 1-2% uncertainty (2-4% for opaque samples)



- Multiple samples and diagnostics allow for redundant measurements for increased accuracy
- Transparent samples allow for in-line measurement of shock transit time
- Opaque samples use an interpolated impact time combined with the measured shock arrival at the window
- $U_s = h/\Delta t$
  - Thickness (h) typically 500 – 1500 μm
  - Measurement resolution 1-2 μm (~0.4%)
  - Time (Δt) typically ~30ns
  - Measurement resolution 100-200 ps
    - Assume 400 ps (1.3 %)
  - Combined uncertainty in U_s 1-2%
    - 2-4 % for opaque samples

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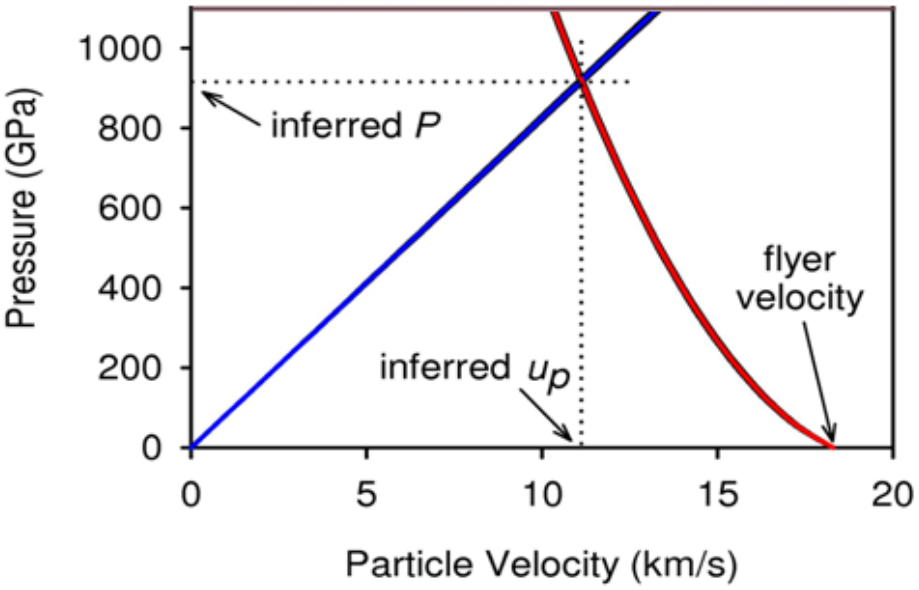
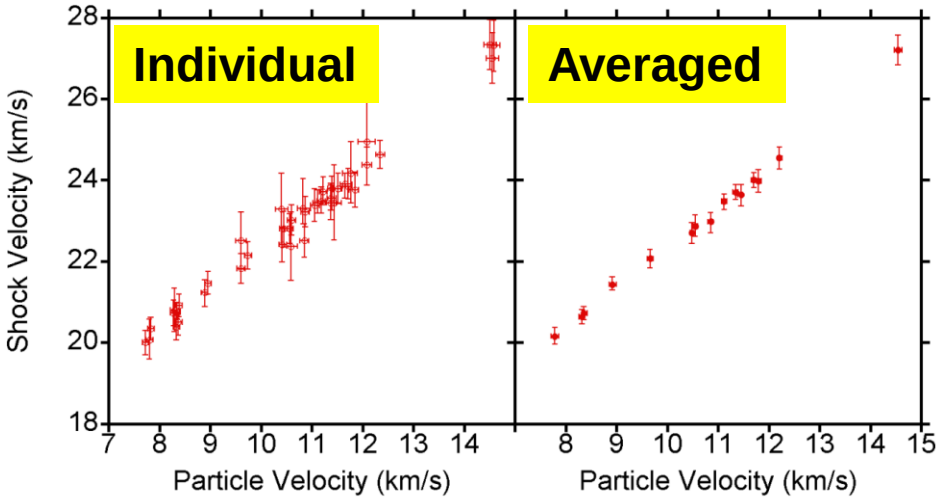
Diamond data from Knudson, Desjarlais, and Dolan, Science **322**, 1822 (2008)

The Hugoniot state pressure and particle velocity are inferred from the measured impact and shock velocities





- Flyer velocity and the impactor Hugoniot (red) are impedance matched with a Rayleigh line determined from the measured target density and shock velocity (blue)
- Impact velocity and shock speed measurement provides tight constraint on the inferred particle velocity and density
- Uncertainties:
  - Density: 0.01%
  - Us: 1-2%
  - Flyer Velocity: 0.5%
  - Impactor Hugoniot: 0.05%
  - Inferred state: 1% (single measurement)
  - Averaging multiple measurements improves uncertainty

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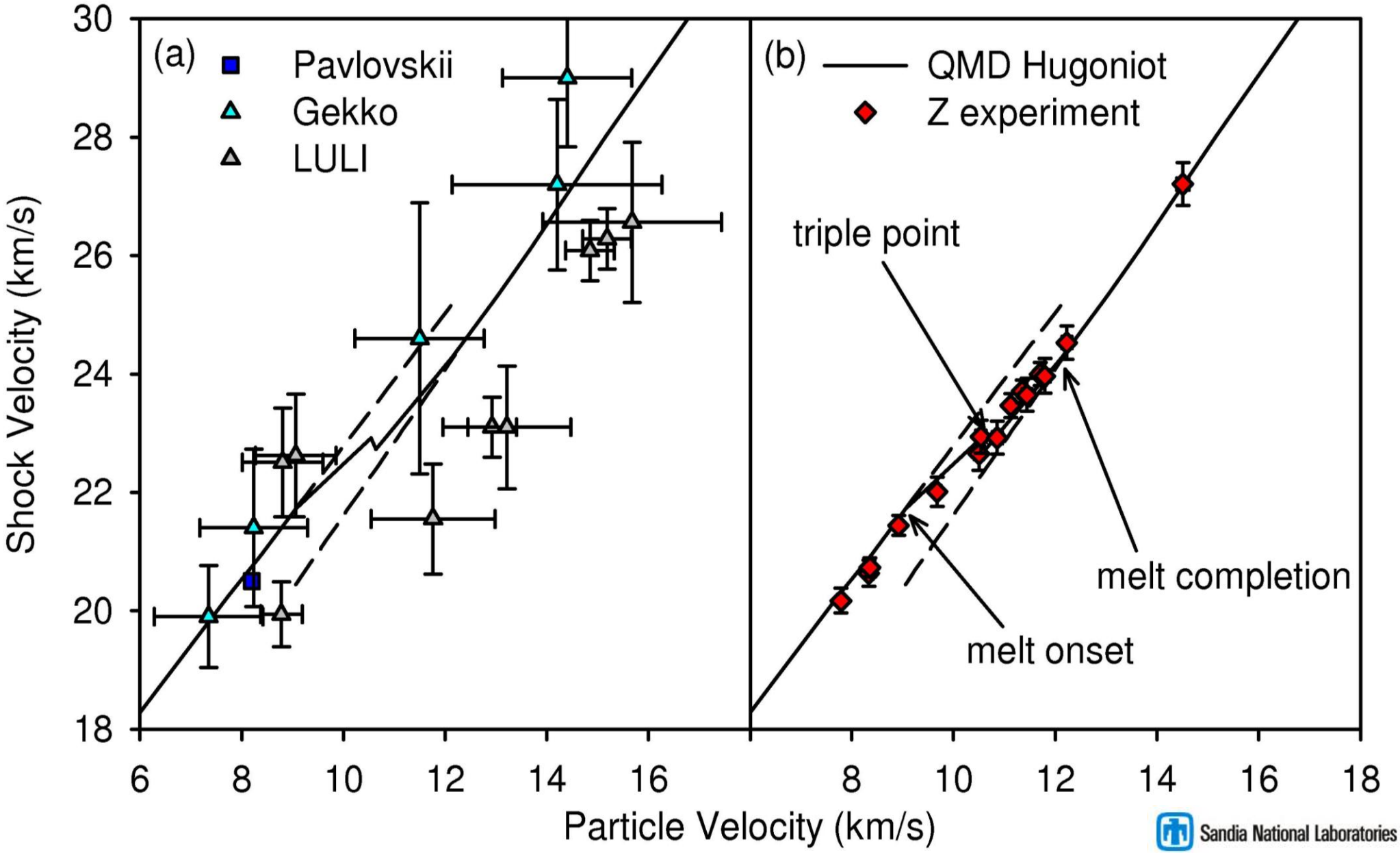
Diamond data from Knudson, Desjarlais, and Dolan, Science **322**, 1822 (2008)

High accuracy allowed for quantitative comparison with QMD predictions and evidence of the triple point in diamond



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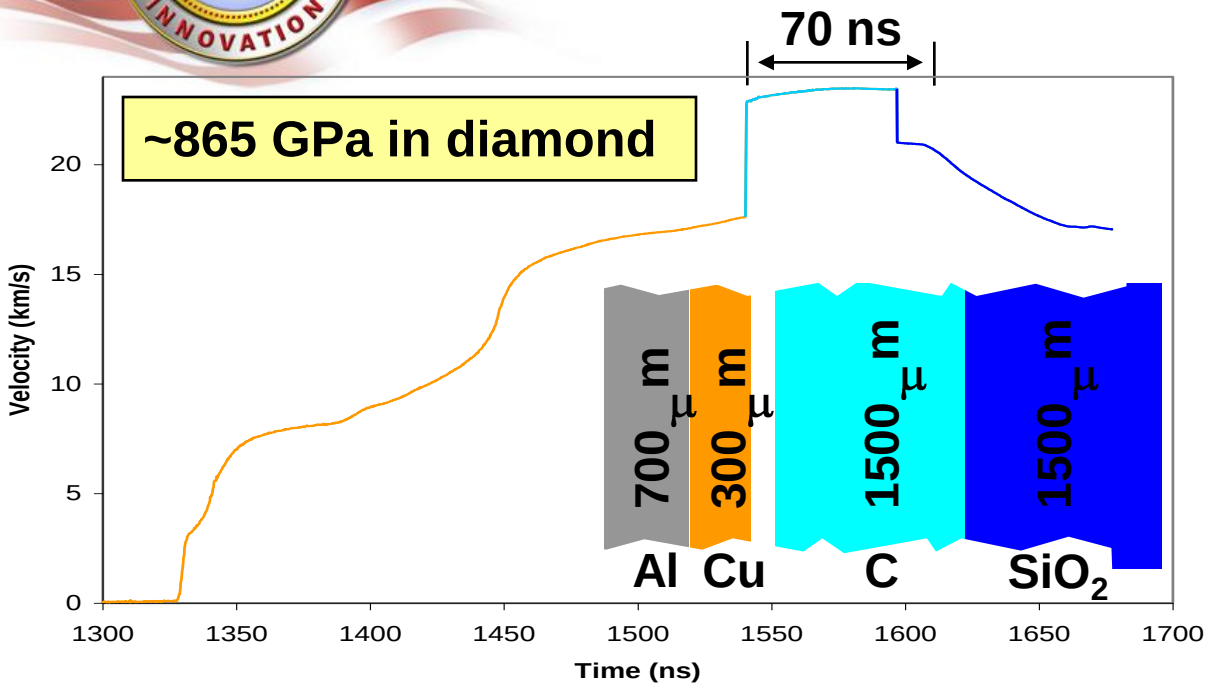
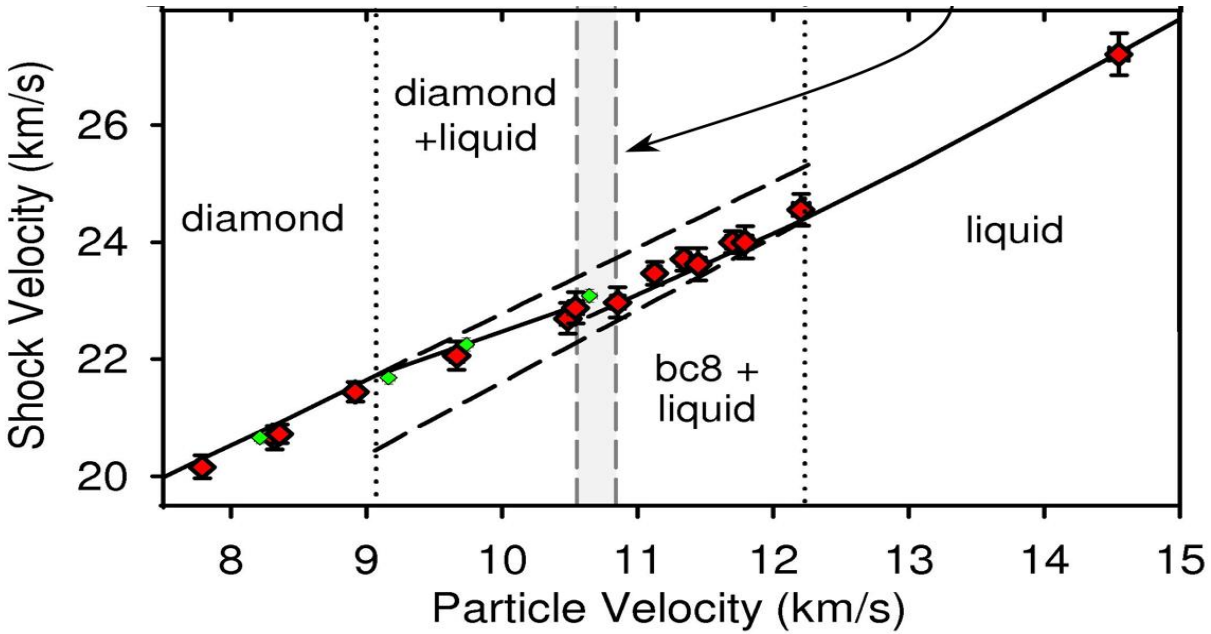
Recent experiments provide unprecedented timescales at extreme pressure and density





- Thicker samples allow unprecedented measurement time scales
- Further reduction in uncertainty to ~0.1% (green data points)

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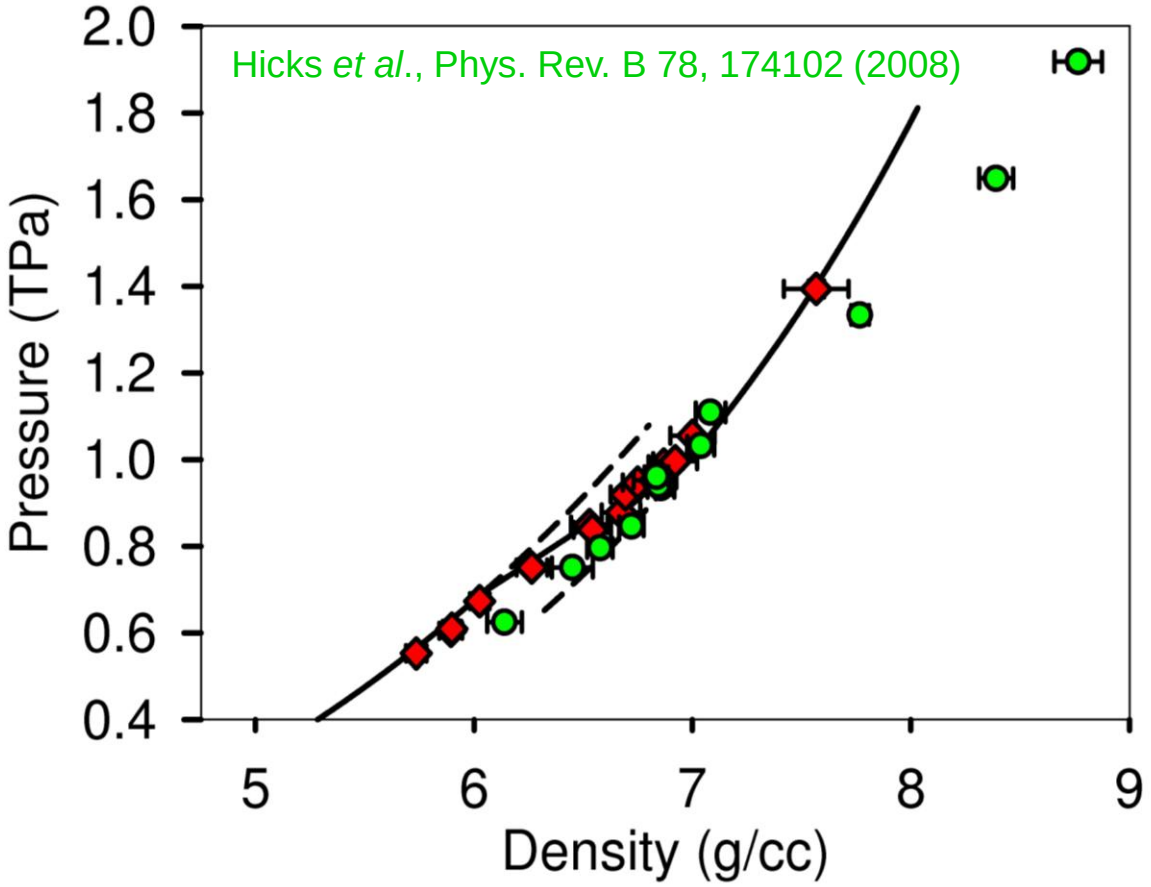
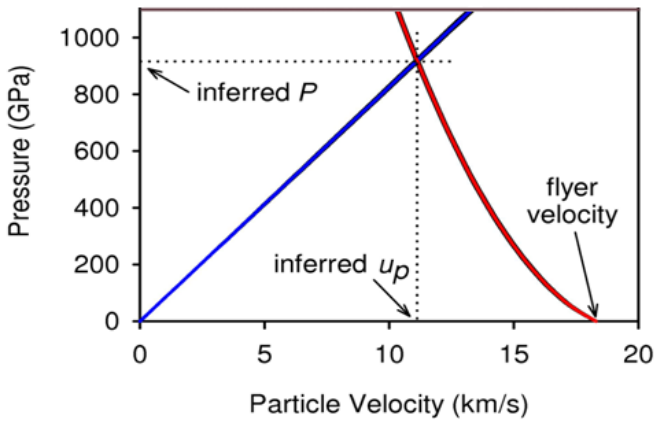
More recent data from Omega is in better agreement with the Z data and improves over the earlier laser data

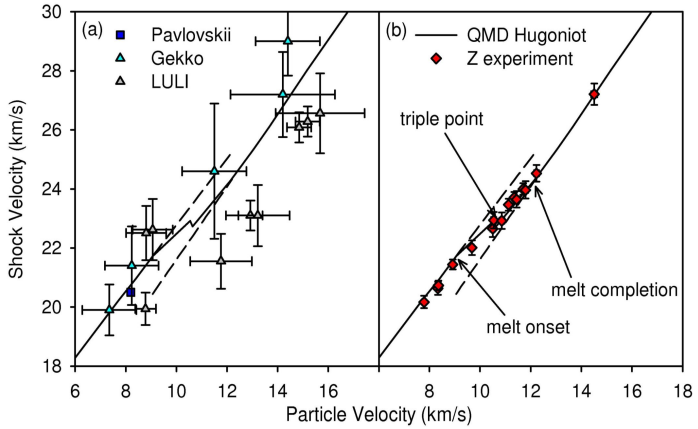


The Omega data will need to be re-analyzed using a revised quartz Hugoniot recently reported by Knudson and Desjarlais at the 2009 Shock Compression of Condensed Matter conference.

Summary

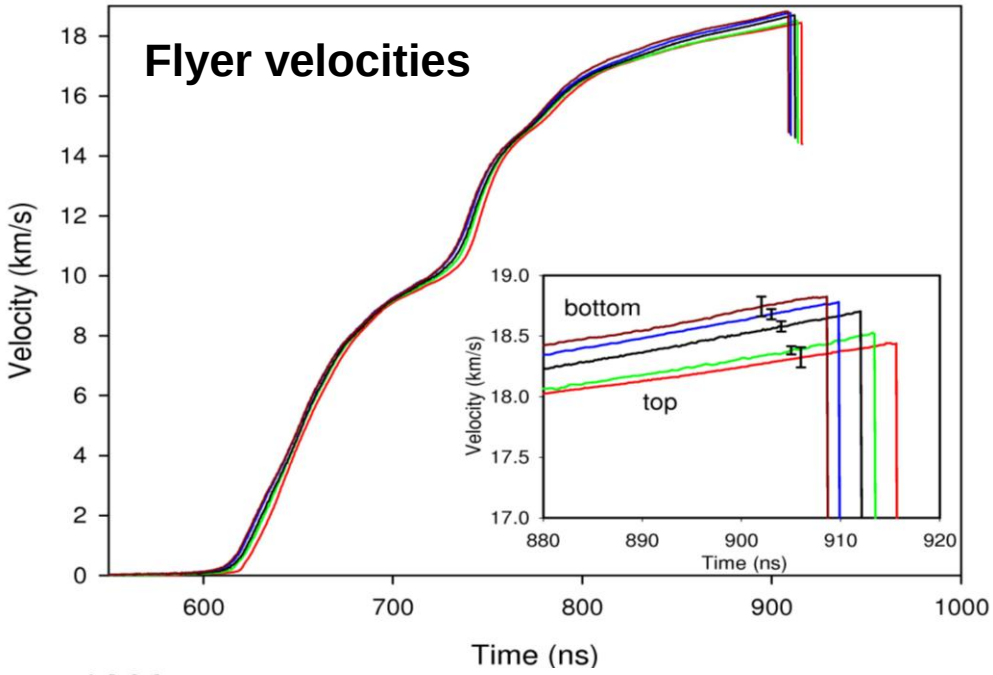
- **Hugoniot response has been measured to better than 1% accuracy using the Sandia Z accelerator**
- **Larger samples allow greater accuracy (to ~0.1%)**
- **Capability has allowed for the observation of material response that was previously unobservable due to data scatter**

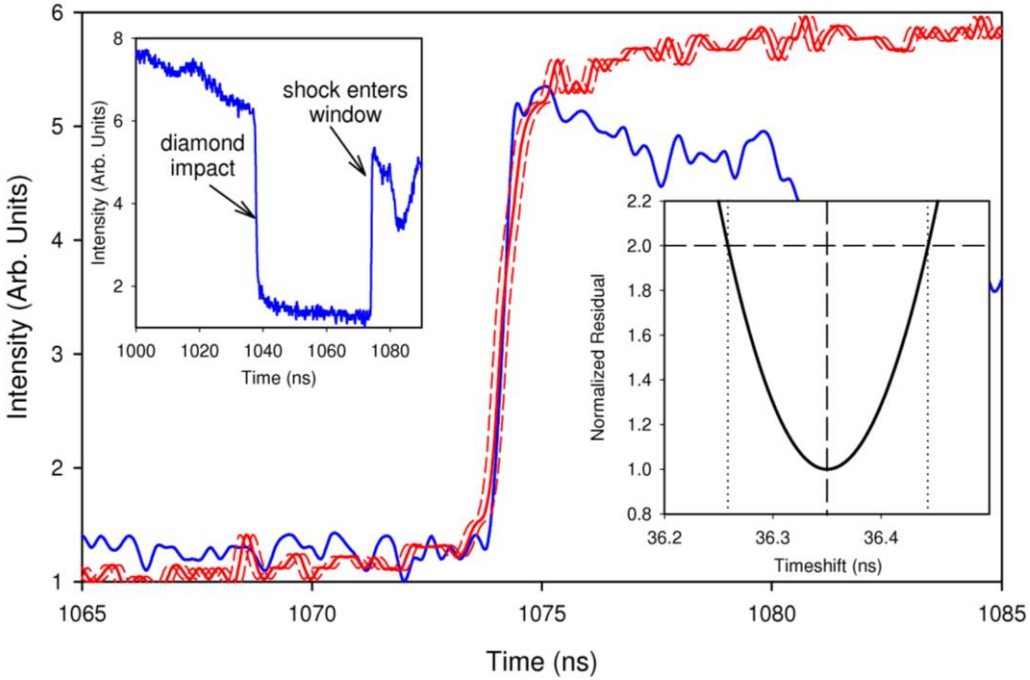


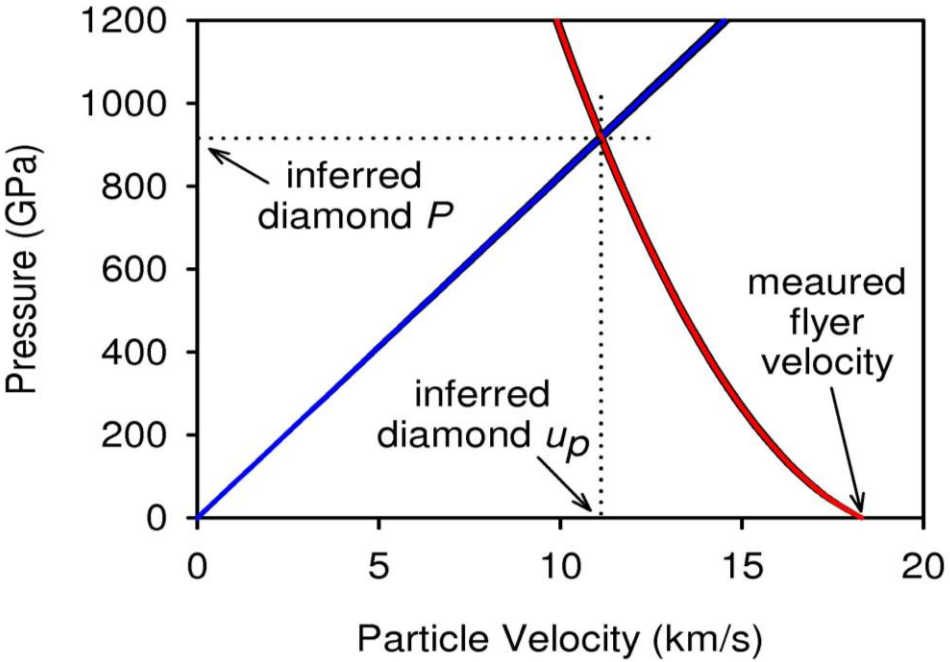


- **Back up slides**

The Z platform provides extremely accurate Hugoniot measurements







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