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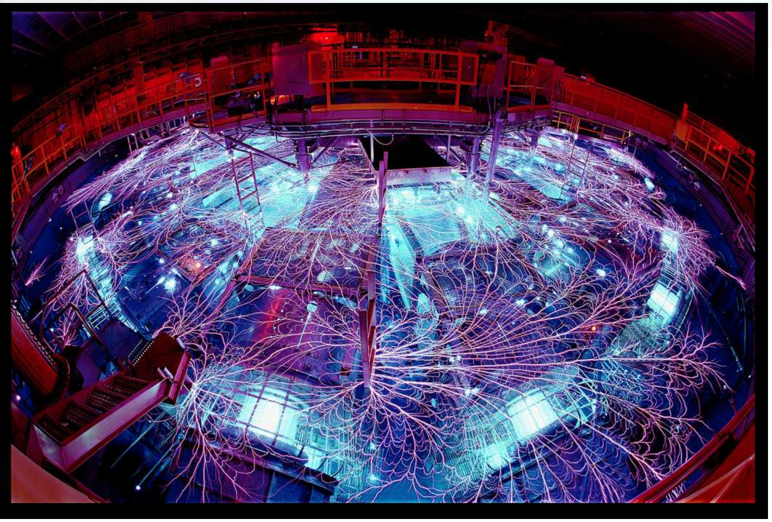

PDV measurements on the Sandia Z machine

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Sandia National Laboratories

Diagnostics Workshop
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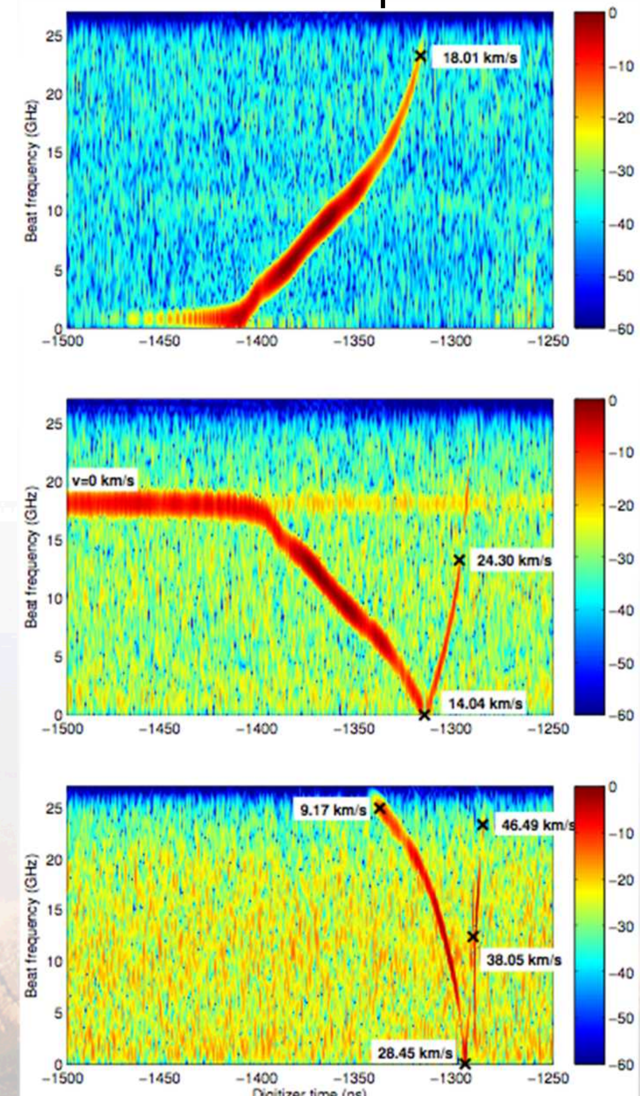
Photonic Doppler Velocimetry overview

- **Frequency-shifted PDV**
  - What is PDV and how is it different from VISAR?
  - How can be PDV be used to measure extreme velocities?
    - Dealing with finite electrical bandwidth

- **Examples**
  - Cylindrical implosion
    - Hollow and liquid-filled liners
  - Plate impact experiments

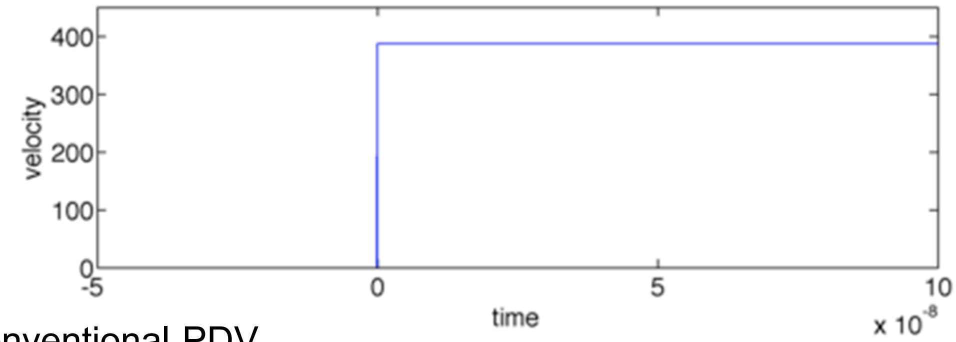
Be liner implosion



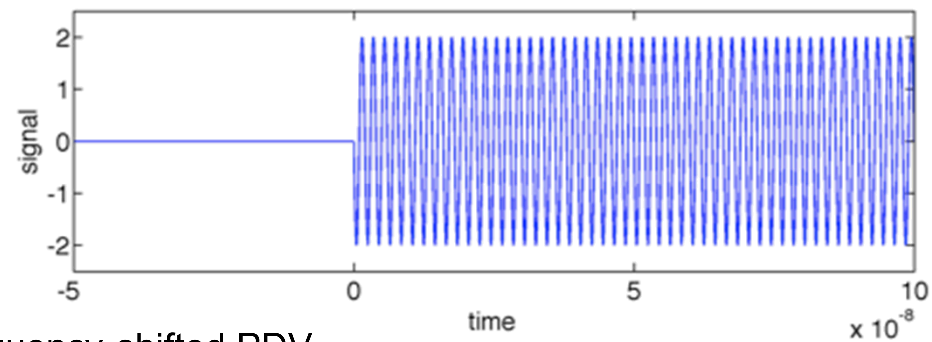
Differences between VISAR and PDV

- **VISAR mixes Doppler shifted light with a time-delayed version of itself**
  - Velocity changes correspond to fringe shifts
  - Typically visible light (532 nm)
- **PDV mixes Doppler shifted light with a reference source**
  - Conventional: single laser
  - Frequency-shifted: multiple lasers
  - Velocity changes correspond to frequency shifts
  - Infrared light (1550 nm)

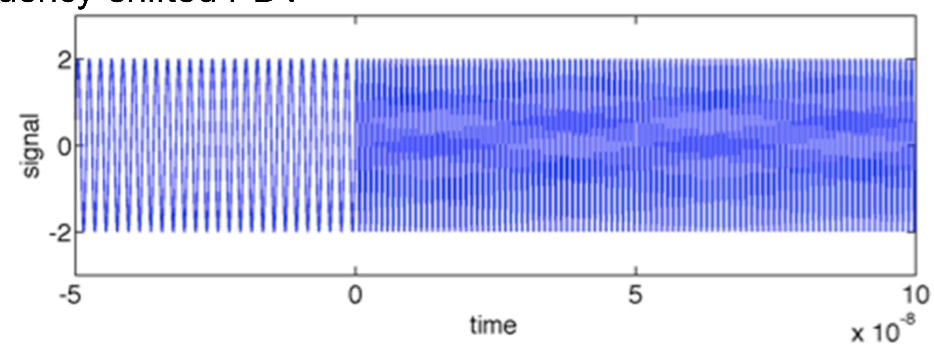
Velocity step



Conventional PDV

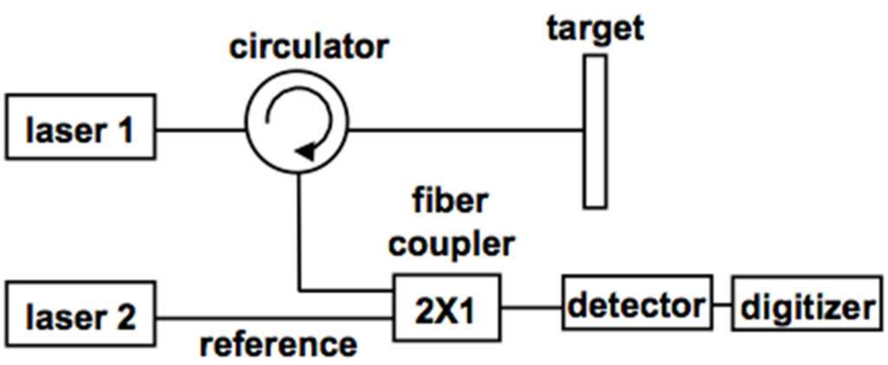


Frequency shifted PDV



Why bother with PDV?

- **Very simple to field**
  - Fiber-based, commercial components
- **Extremely compact**
- **Relatively low power requirements**
  - ~100 mW target power
  - ~1 mW reference power
  - Mostly class I hazard
- **Very robust to light variation**
  - >50 dB return variations are acceptable
- **No hardware time scale (etalon)**
  - Time resolution defined in the analysis
  - Can be optimized for different purposes (arrival time, etc.)
- **Tolerates multiple velocities (where VISAR loses contrast)**



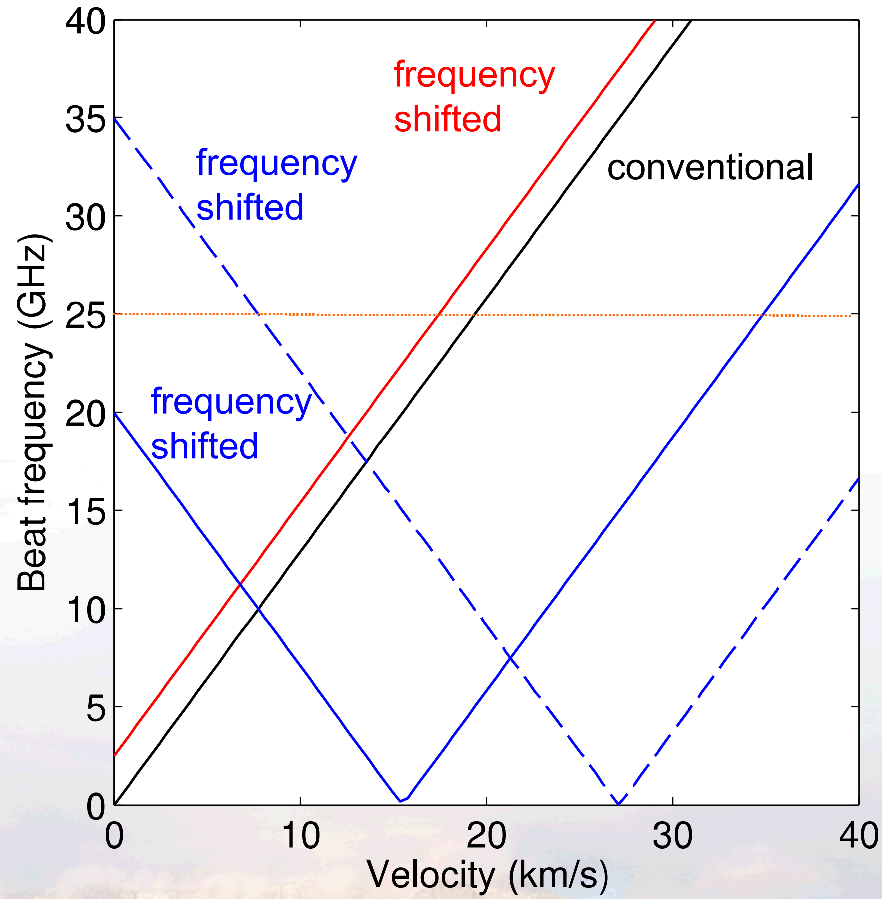
Velocity-frequency mapping

- **Conventional** $$B = \frac{2v}{\lambda_T}$$
  - 1.3 GHz per 1 km/s
  - No motion, no beating
  - Not currently used at Z

- **Frequency shifting**

$$B = \left| \frac{2v}{\lambda_T} + c_0 \left(\frac{1}{\lambda_T} - \frac{1}{\lambda_R} \right) \right|$$

  - Red reference
    - Unambiguous mapping
    - Preferred configuration
  - Blue reference
    - Greater coverage
    - Issues near f=0
    - May require precise wavelength monitoring



System capabilities at Z

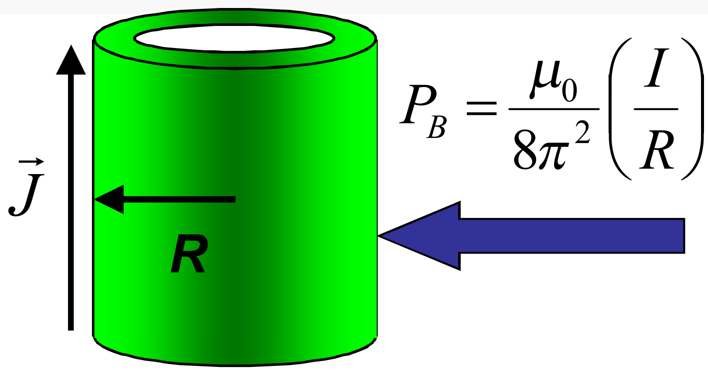
- **Electrical bandwidth**
  - Eight 20 GHz receivers recorded with 25 GHz digitizers at 80 GS/s
    - Covers up to 19.4 km/s in conventional mode

- **Tunable reference lasers allow red/blue reference configurations**
  - Can span a 50 GHz (39 km/s range) with a “bounce” in the middle
  - Coverage can be tuned to any velocity range: 0-39 km/s, 100-139 km/s, …
  - “Leapfrog” configuration provides even greater coverage
    - 8-channel, 4-reference system coming online in October will span 80+ km/s

- **Other**
  - Laser wavelength monitoring to ~0.1 pm
  - Timing characterization
    - <<100 ps uncertainty between PDV channels
    - ~200 ps uncertainty to machine time

Cylindrical implosion

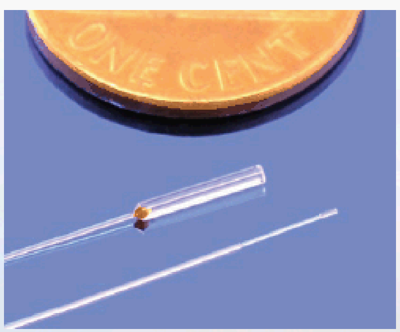
Cylindrical implosion reaches extreme pressure states

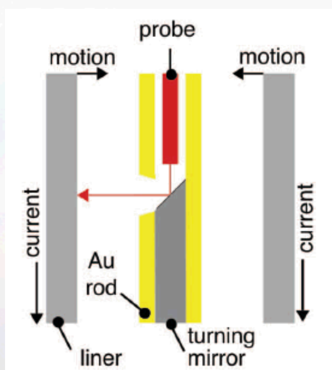


$$P_B = \frac{\mu_0}{8\pi^2}\left(\frac{I}{R}\right)^2$$

I=20 MA
R=0.1 cm
P_B≈64 Mbar

- **Current pulse shaping creates ramp-wave compression**
  - Quasi-isentropic compression to 20 Mbar

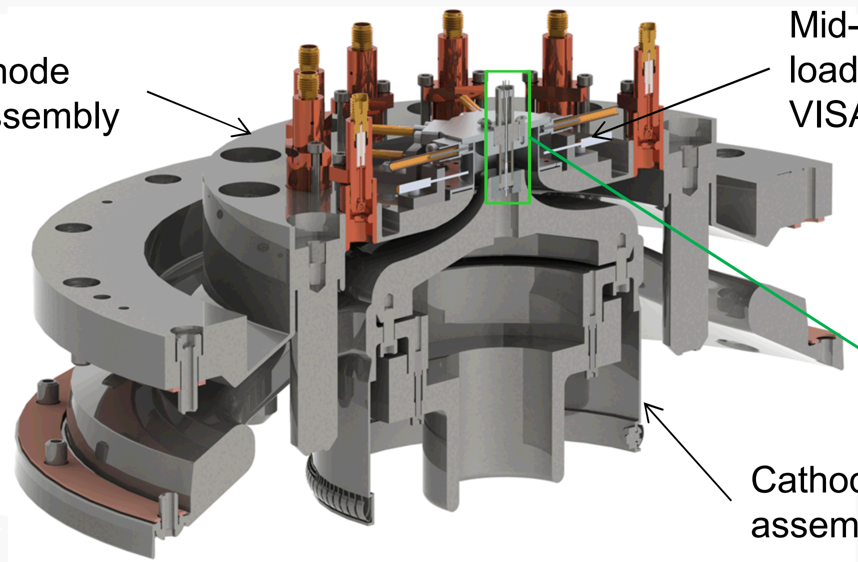


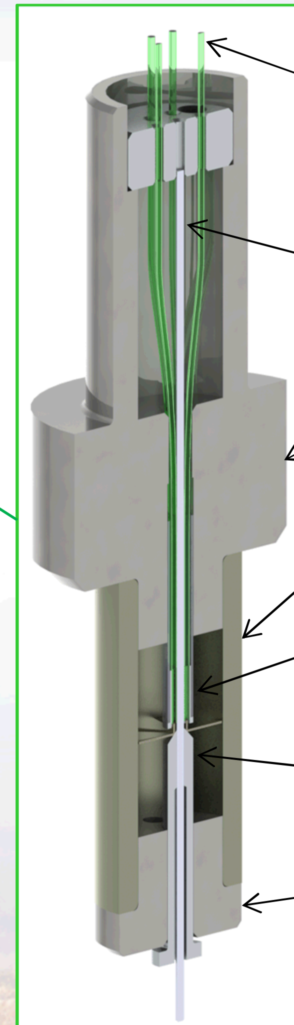


Diagnostics are challenging

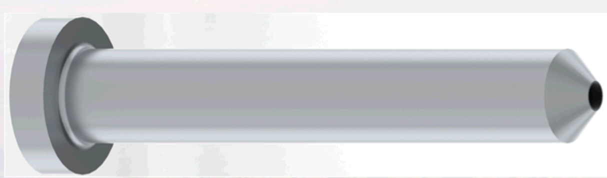
- **Limited space**
  - Miniature PDV probes
- **Velocities well beyond 10 km/s**

Multi-point design evaluates symmetry



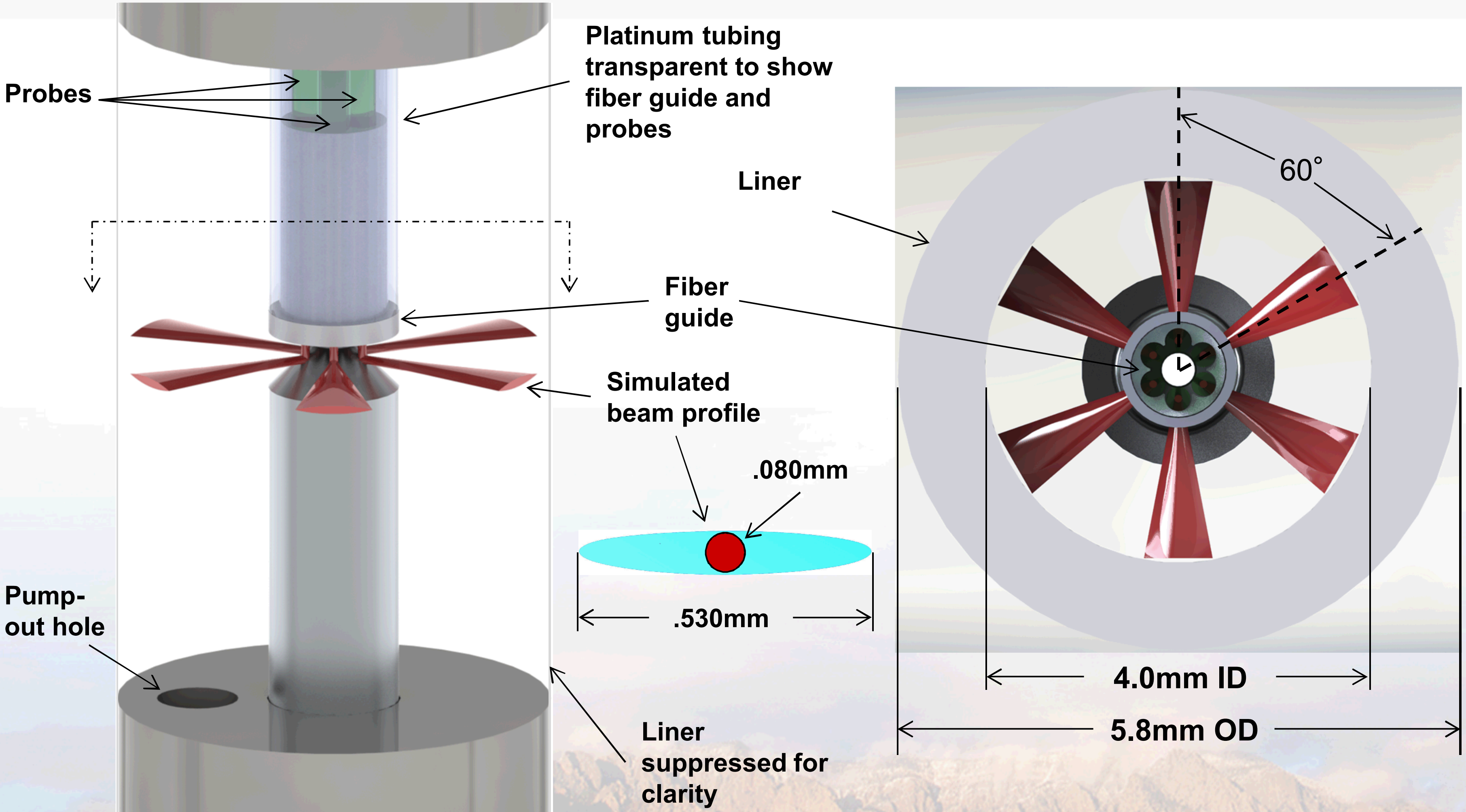


- ≈18.6 MA Load Current
- 10-20 km/s velocity (heavier liners)

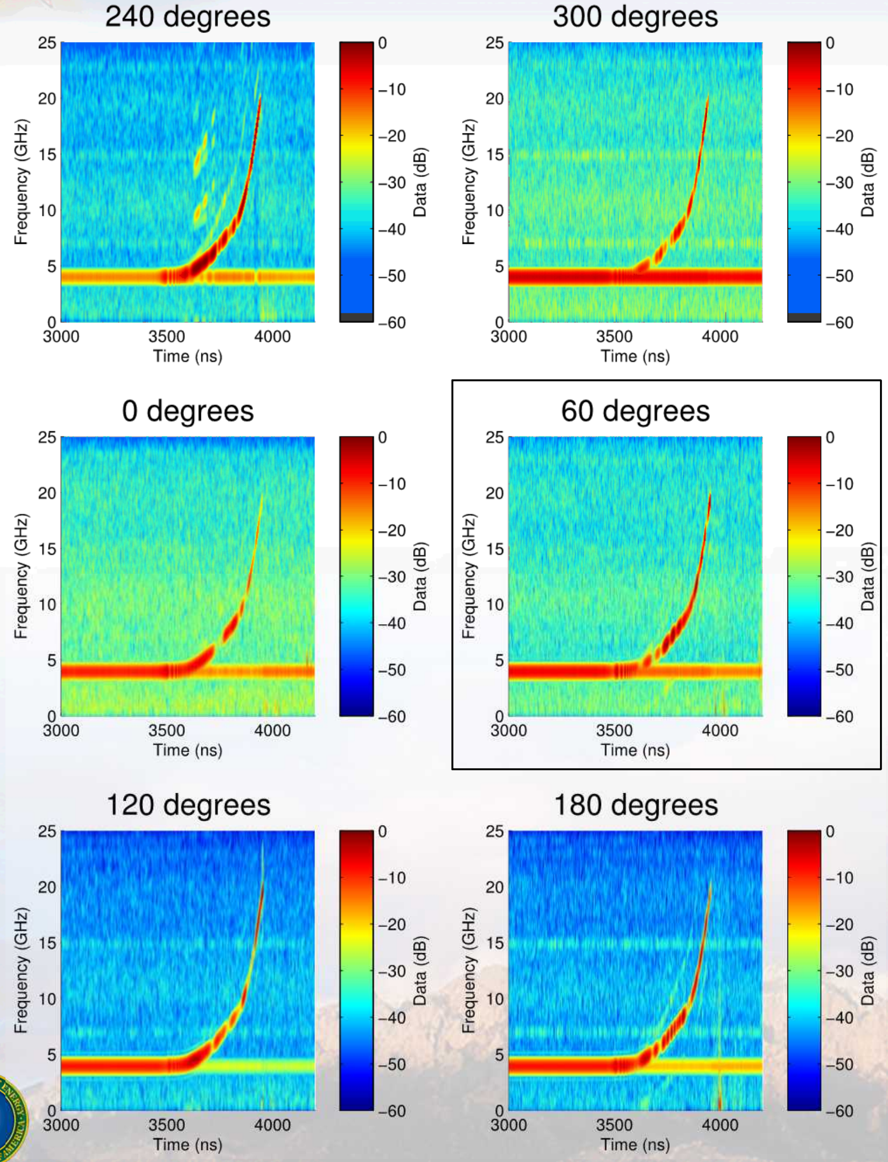


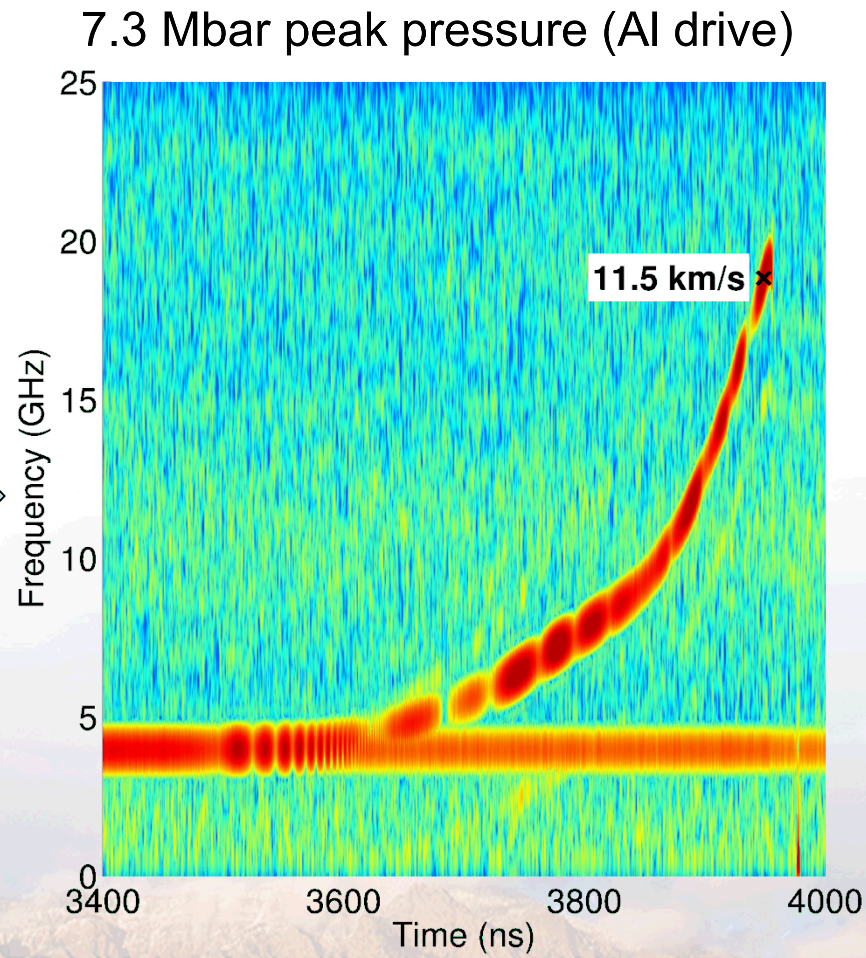
Conical mirror design

Measurements every 60 degrees



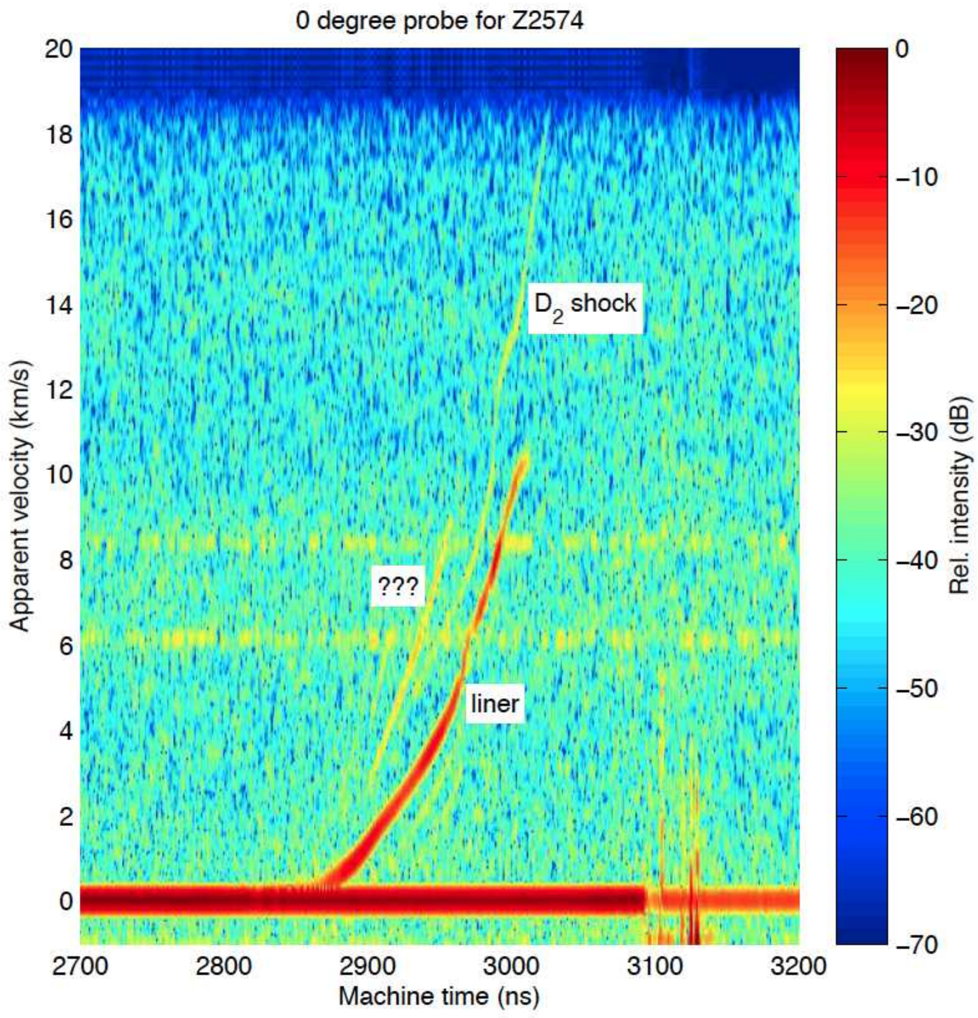
Symmetric results for Ta





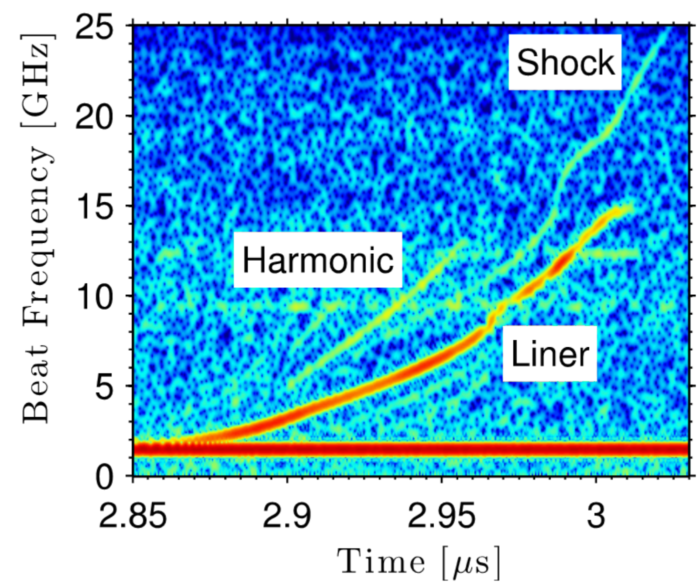
Hollow liner can be filled with a liquid

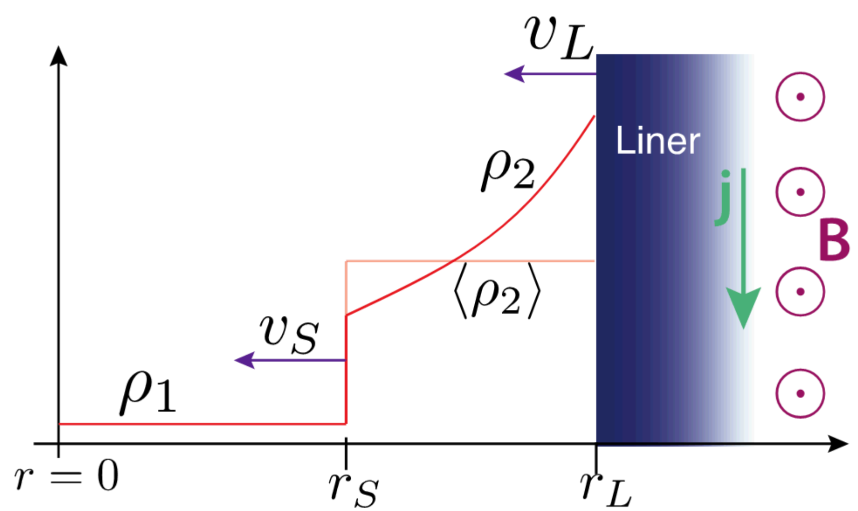
- **Eddy series:**
  - Beryllium liner filled with liquid deuterium (20 K)
  - Probe immersed in liquid
    - Survives condensation
    - Some fibers damaged during freeze/melt cycle
  - "Chandelier" design
    - Conical mirror incorporated into the probe bundle
    - X-ray radiography performed underneath the PDV measurement



Eddy interpretation

- **Magnetic drive launches a ramp wave in the liner**
- **Ramp wave quickly becomes a shock wave in the liquid**
  - Liner reflection
  - D2 shock front (initially weak)
- **As the shock grows stronger, its reflectance increases**
  - Eventually light cannot reach the liner
- **Window corrections are complicated**
  - Ambient index unknown
  - No steady state

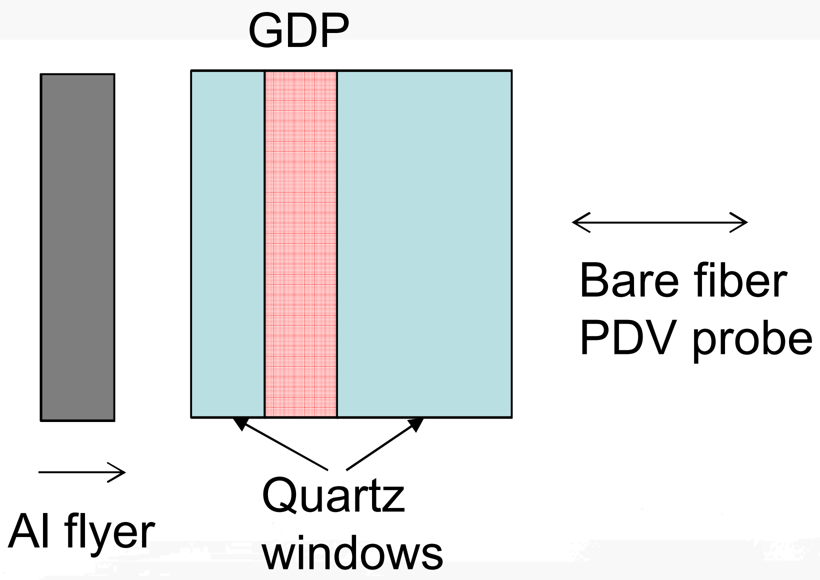




Planar impact

Planar impact measurement

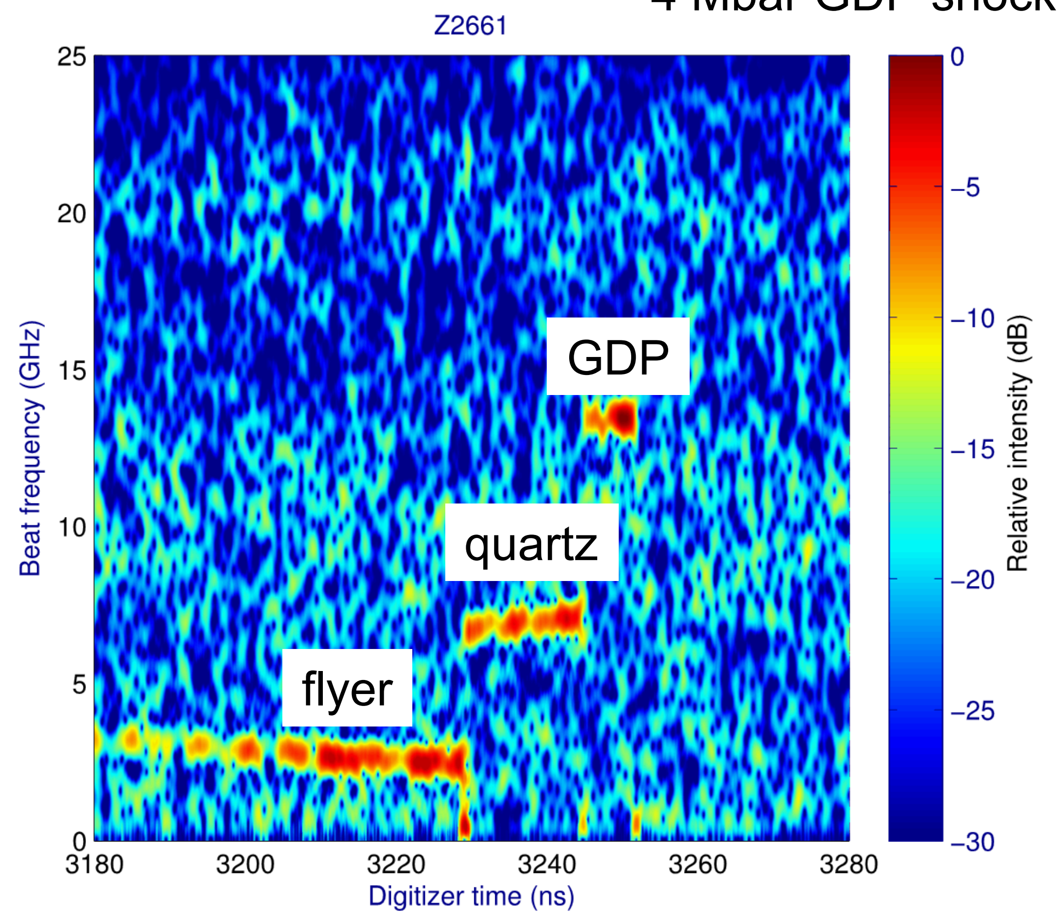
- **Glow Discharge Polymer (GDP)**
  – NIF ablator material
  – Very little Hugoniot data
- **Ideal experiment**
  – Measure flyer velocity
  – Measure GDP shock velocity
  – Impedance match GDP to the flyer
- **Real experiment**
  – Sample sealed between quartz windows to prevent oxygen absorption
  – Impedance match to the front quartz window
- **Characteristic velocities**
  – Flyer: 25 km/s
  – Shock: 20-30 km/s (apparent velocity ~50% higher)



GDP results

- **Offset frequency**
  - 35.148 ± 0.006 GHz
  - 27.257 ± 0.005 km/s
- **Flyer measurement**
  - 2.44 GHz beat
  - ~25.4 km/s (before bounce)
- **Quartz measurement**
  - 6.7-7.2 GHz beat
  - 32.5-32.9 km/s apparent velocity (after bounce)
- **GDP measurement**
  - 13.4 GHz beat
  - 37.6 km/s apparent velocity (after bounce)

~4 Mbar GDP shock



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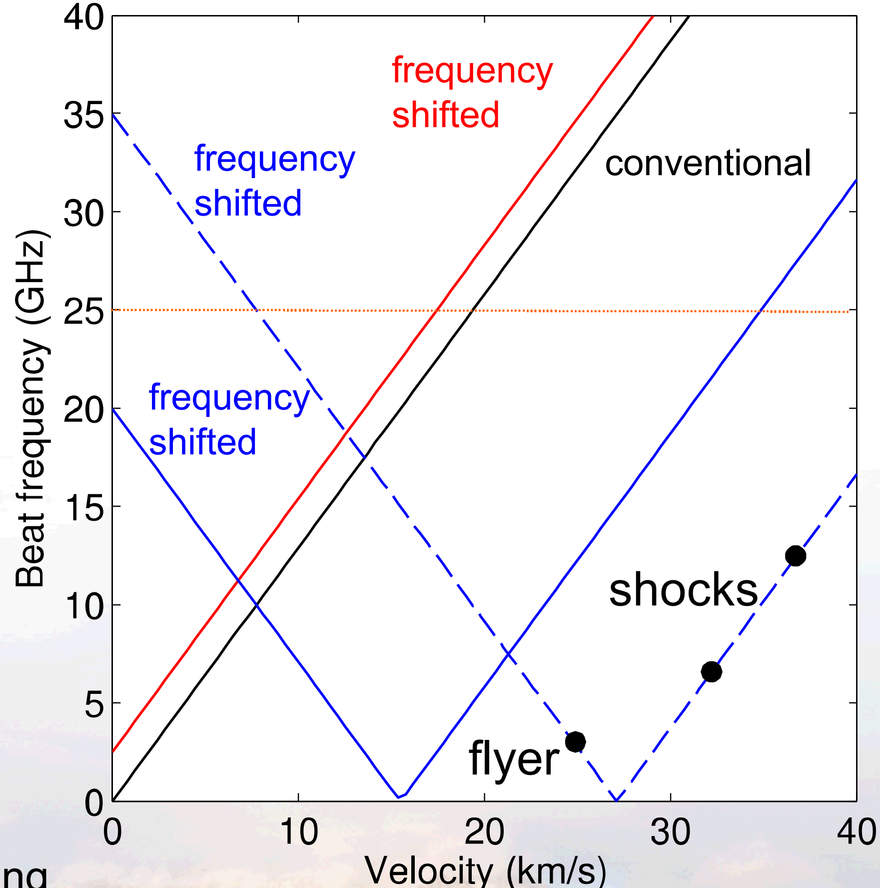

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