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PDV measurements on the Sandia Z machine

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Sandia National Laboratories

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Overview

- **Making PDV work at Z**
  - System capabilities
  - Frequency-shifted measurements
- **Single- and multi-point measurements of cylindrical implosion**
  - Liner studies
  - Liquid-filled liners
- **Planar impact experiments**
  - High speed flyers
  - Shock front measurements

Making PDV work at Z

System capabilities

- **Electrical bandwidth**
  – Eight 20 GHz receivers recorded with 25 GHz digitizers at 80 GS/s
    - Covers up to 19.4 km/s
- **Lasers**
  – One amplified laser (space limited)
    - Tunable seed + EDFA or 2 W system at fixed wavelength
  – Several adjustable reference lasers (25-50 mW output)
    - Fast tuning over 1550-1551 nm
  – Leapfrog is temporarily disabled in favor of multi-point measurements
- **Other**
  – Wavelength monitoring to ~0.1 pm
  – Timing characterization
    - <<100 ps uncertainty between PDV channels
    - ~200 ps uncertainty to machine time

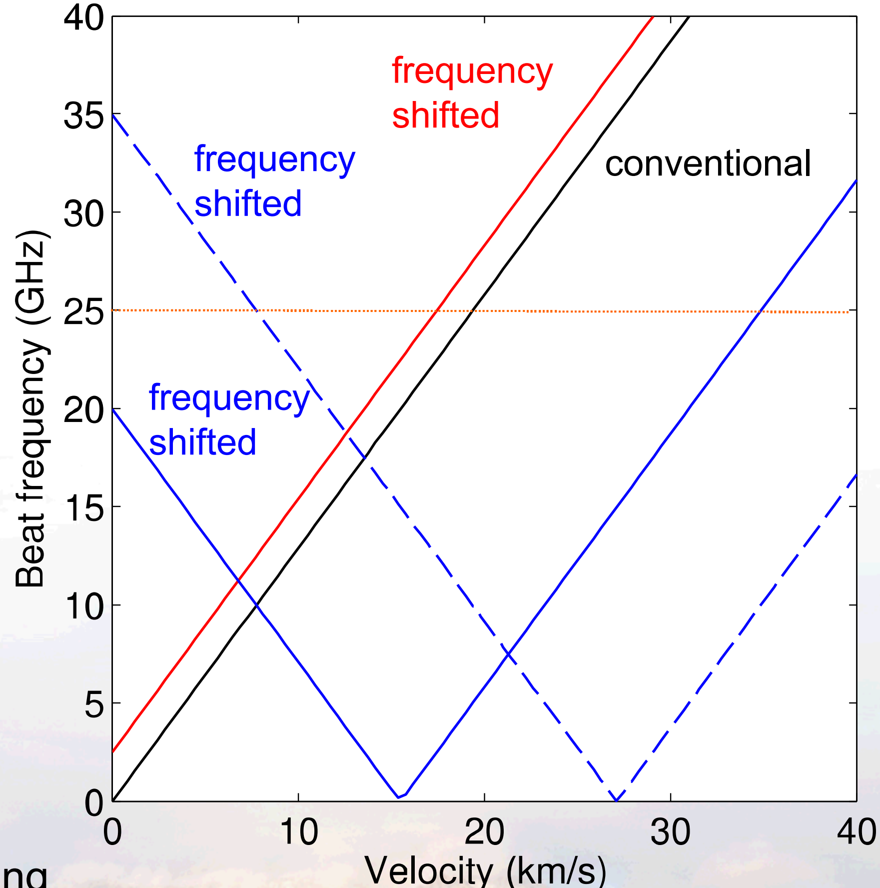
Velocity-frequency mapping

- **Conventional** $$B = \frac{2v}{\lambda_T}$$
  - No motion, no beating
  - Not currently used at Z

- **Frequency shifting**

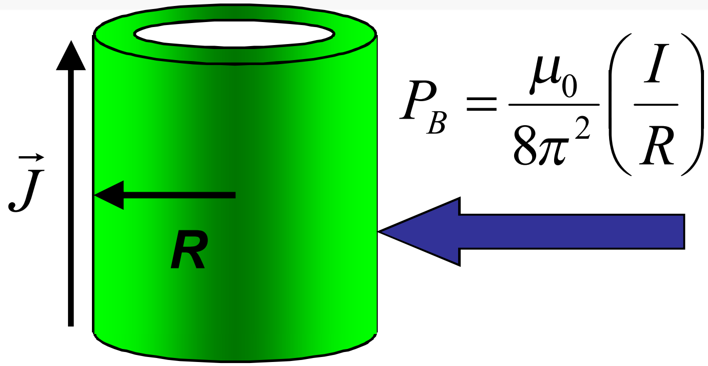
$$B = \left| \frac{2v}{\lambda_T} + c_0 \left(\frac{1}{\lambda_T} - \frac{1}{\lambda_R} \right) \right|$$

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



Cylindrical implosion

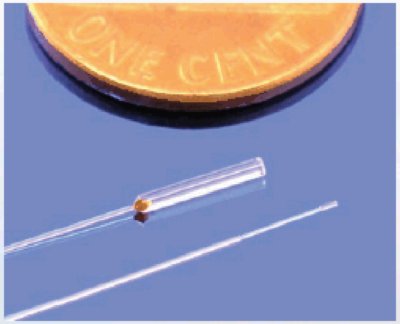
Cylindrical implosion reaches extreme pressure states

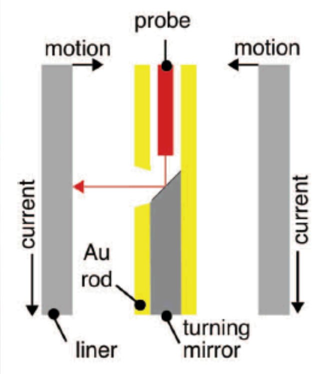


$$P_B = \frac{\mu_0}{8\pi^2}\left(\frac{I}{R}\right)^2$$

I=20 MA
R=0.1 cm
$P_B \approx 64$ Mbar

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

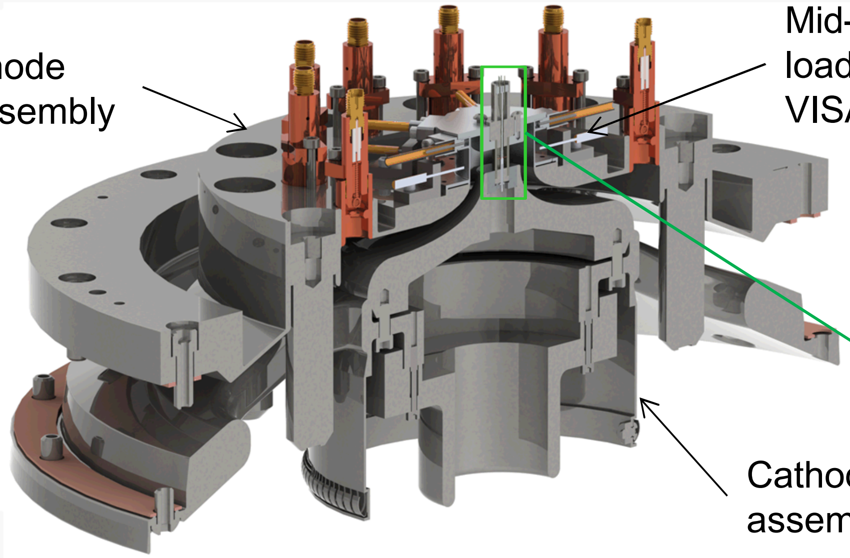


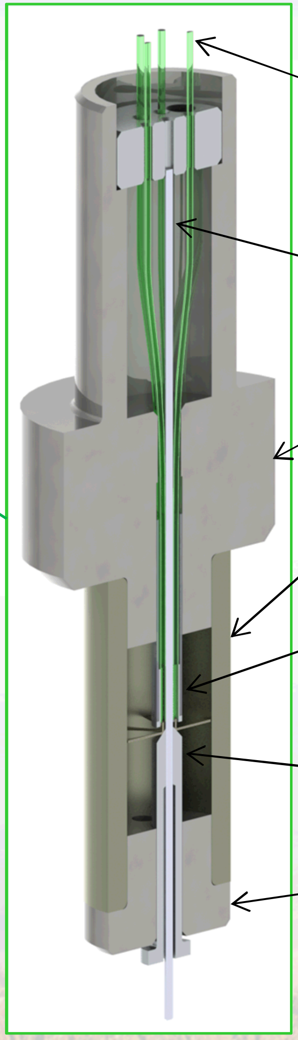


Diagnostics are challenging

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

Multi-point design evaluates symmetry

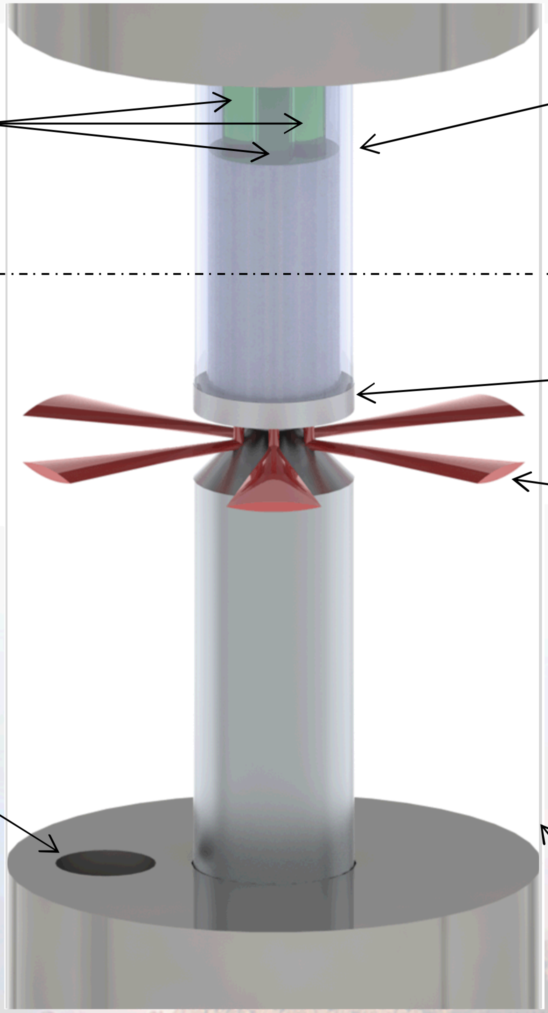


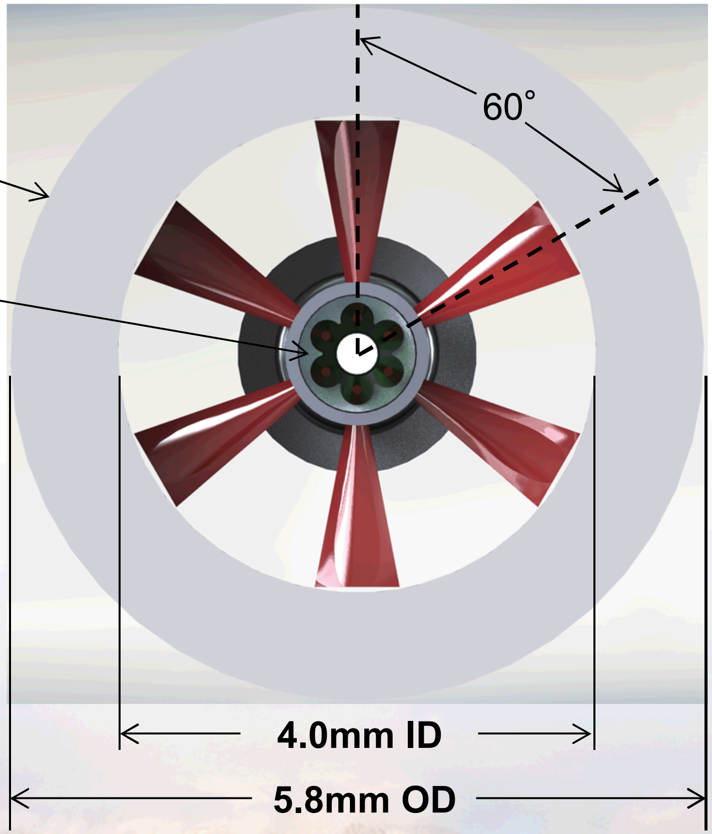


- ≈18.6 MA Load Current
- 10-20 km/s velocity (heavier liners)

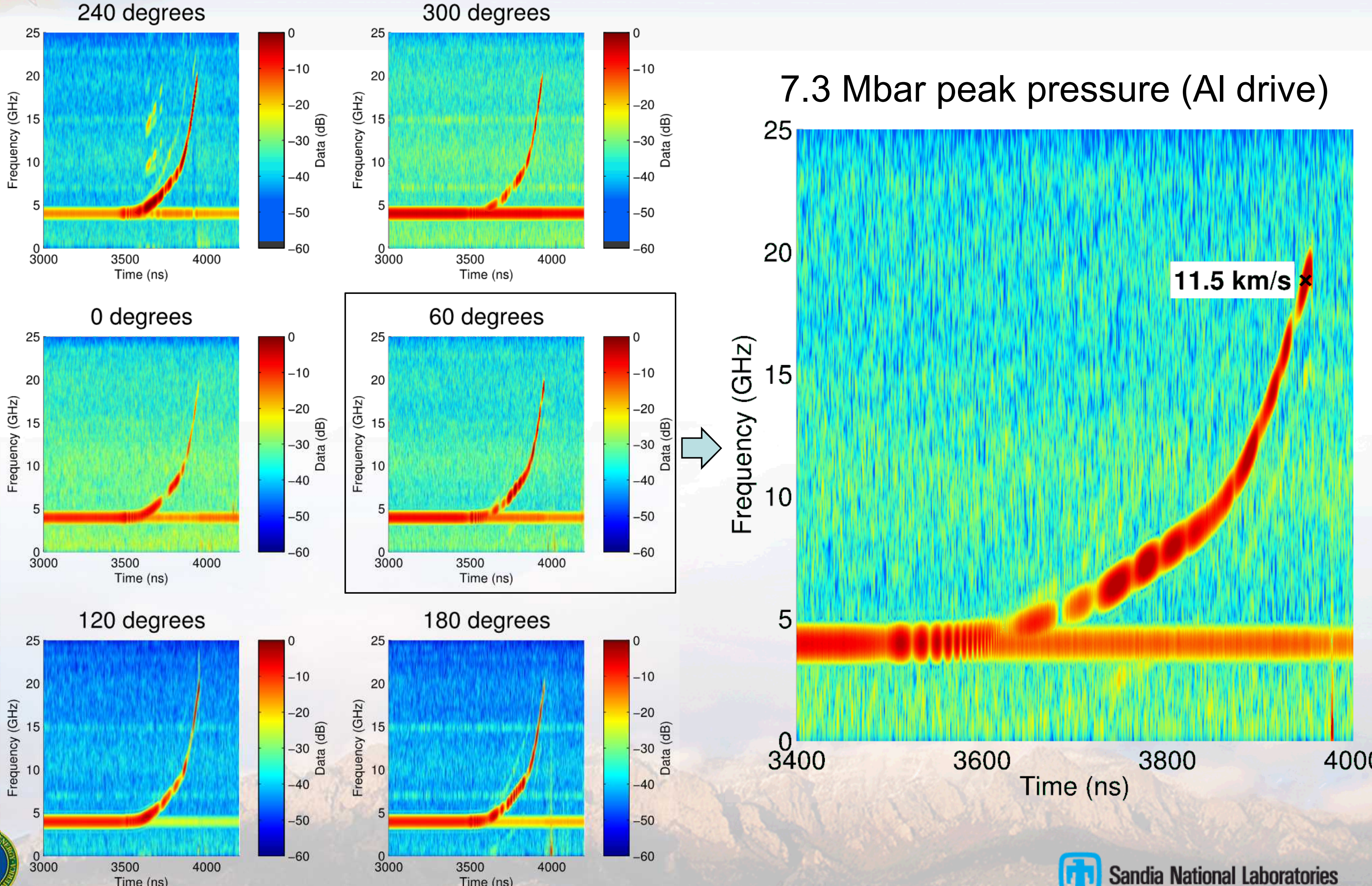
Conical mirror design

Measurements every 60 degrees





Symmetric results for Ta



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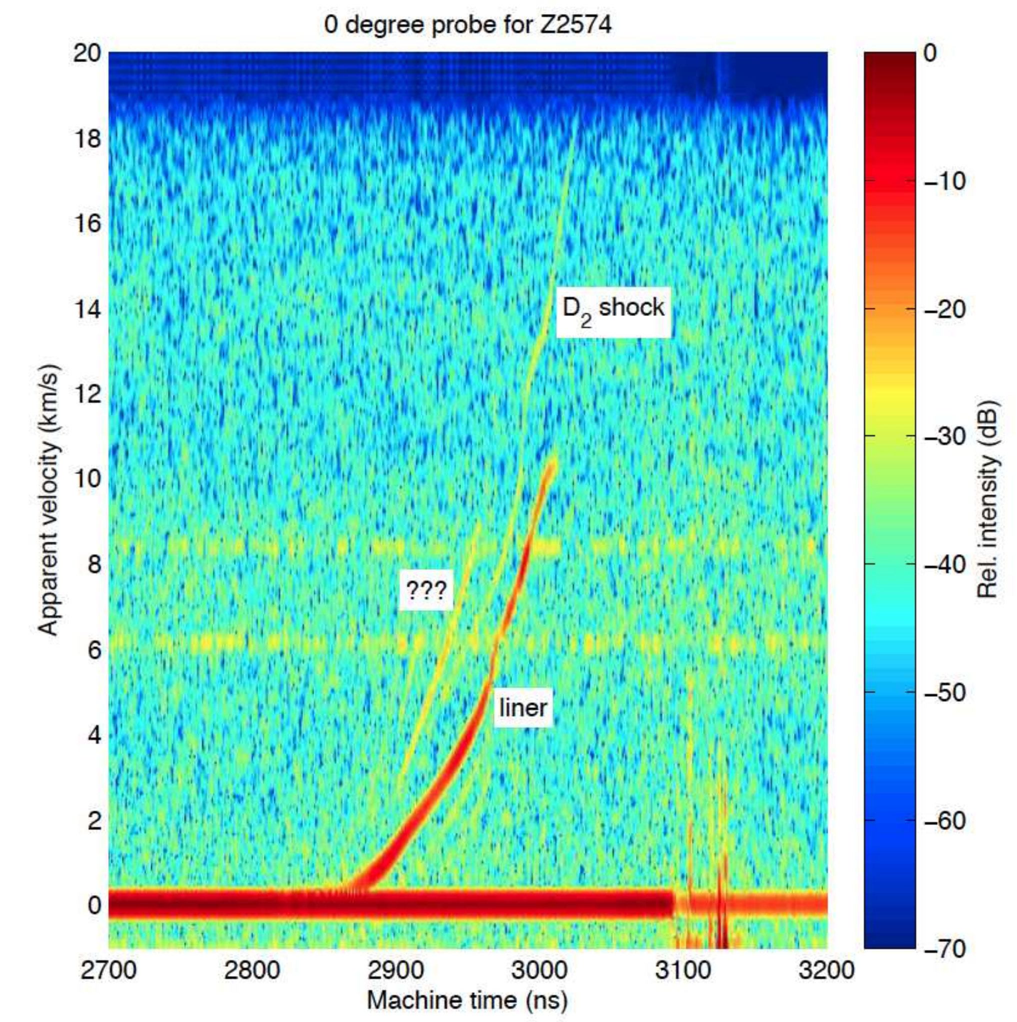
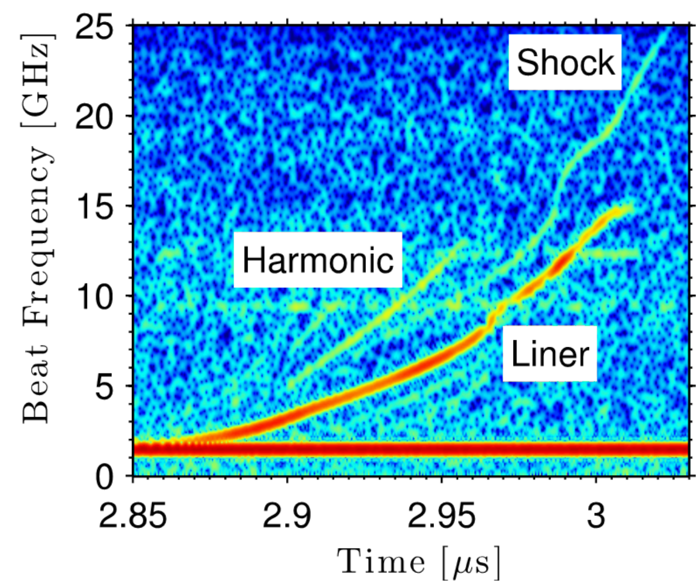
Hollow liner can be filled with a liquid

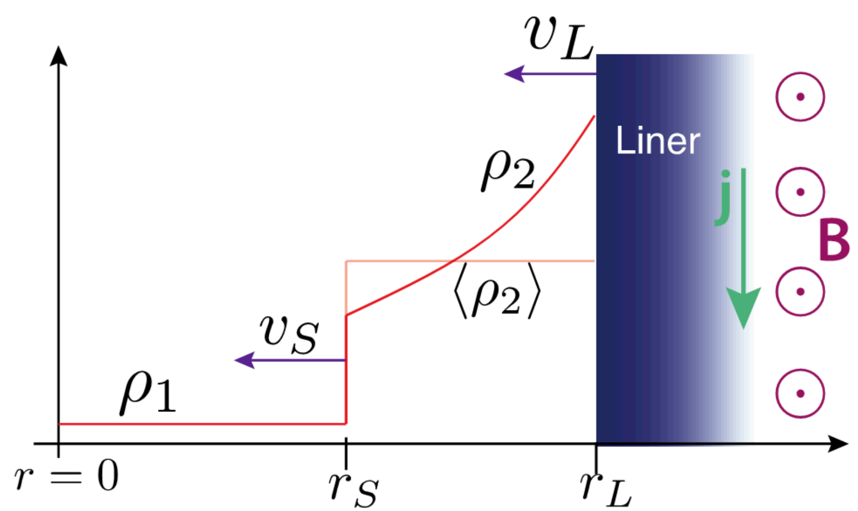
- **Eddy series:**
  - Beryllium liner filled with liquid deuterium (4 K)
  - Probe immersed in liquid
    - Survives condensation
    - Some fibers damaged during freeze/melt cycle
  - "Chandelier" design
    - Conical mirror incorporated into the probe bundle
    - X-ray radiography performed underneath 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
  - Shock shock (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

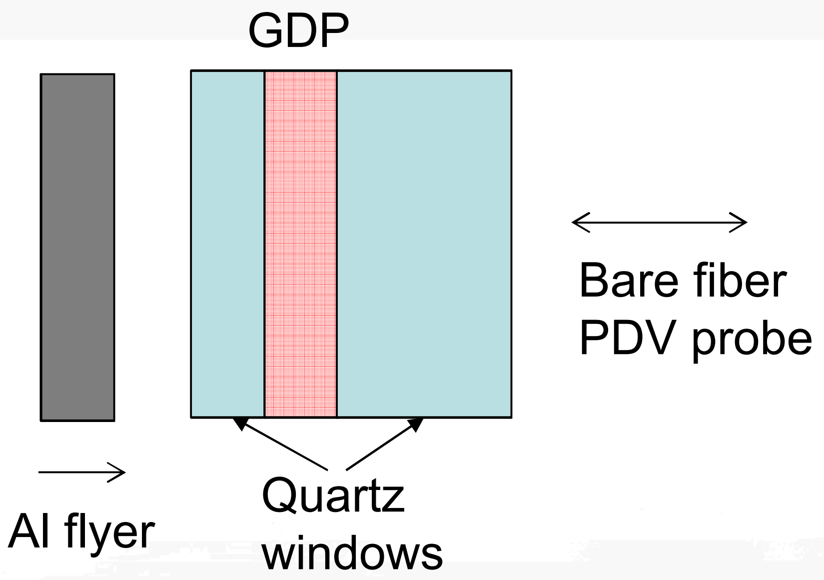




Planar impact

Planar impact measurement

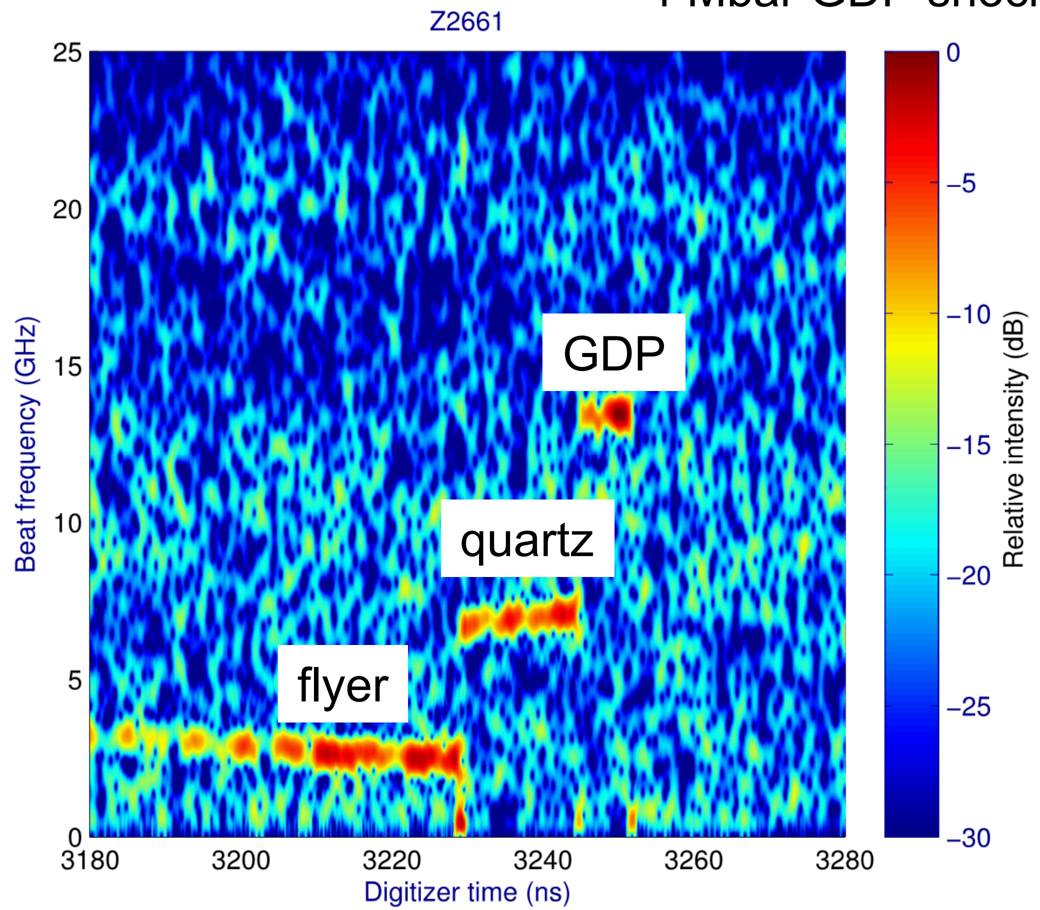
- **Glow Discharge Polymer (GDP)**
  - NIF ablator material
  - Very little Hugoniot data
- **Ideal experiment**
  - Measure flyer velocity
  - Measure GDP shock velocity
  - Impedance match GDP to the flyer
- **Real experiment**
  - Sample sealed between quartz windows to prevent oxygen absorption
  - 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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Future work

- **Probe development**
  - Specular reflections are common (DT surfaces, shock fronts)
  - Very little orientation control, almost no optimization possible
  - Must be very small (ideally <1 mm diameter)
  - <1 mm to 10-20 mm working distances
  - Desired return losses: 30-50 dB
- **Multi-channel leapfrog support**
  - Eight channels with four-way leapfrog coming online later this year
  - Support velocities up to 81 km/s using only two digitizers (8 detectors)
- **Improved analysis capabilities**
  - Extended baseline management
  - Multiple peak capabilities

Special Thanks

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