Physics Division

Photon Doppler Velocimetry

A Year (or Two) in the Life of Photon Doppler Velocimetry

David B. Holtkamp
Hydrodynamic & X-Ray Physics

This is not going to be a "Physics" talk…
At least not much…
Mostly gadgets, examples, and stuff…

Acknowledgements

- Ted Strand (LLNL) – it is a tribute to the quality of his advice that our first generation PDV worked the first time we turned it on
- LANL – Pat Rodriguez, Benjie Stone, Lenny Tabaka, Brian Hollander (P-22), Matt Briggs, Will Hemsing (HX-3)
- NSTech – Doug DeVore, Araceli Diaz, Adam Iverson, Greg Lare, Vince Romero, Don Rosenberry, Mike Rutkowski, Jason Young, and many other valued collaborators
- STL (Santa Barbara) – Bruce Marshall
- And many others at LANL, NSTech, & STL who collaborated on experiments shown here

Our "First" PDV…

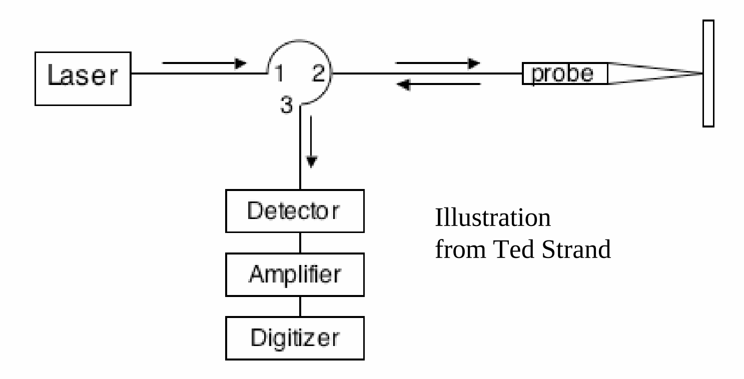
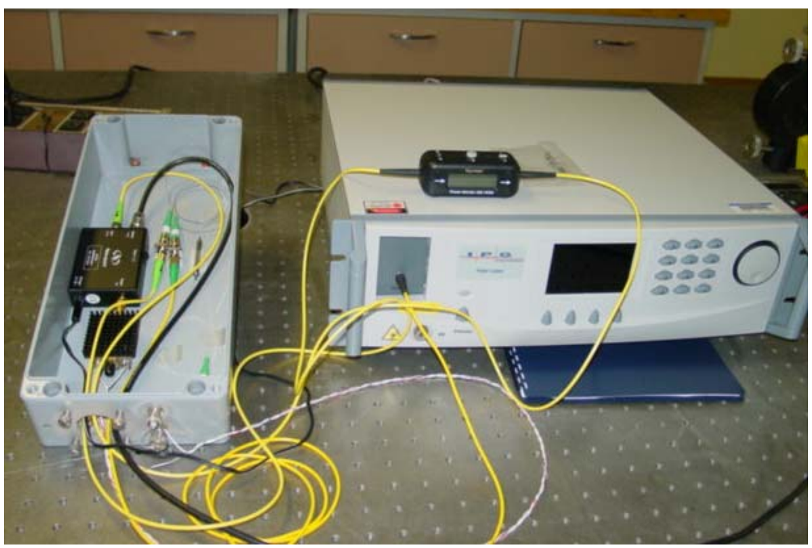


Illustration
from Ted Strand



P-22 Single Point PDV

Beat frequency = $f_b = f_d - f_0 = 2\,(v/c)f_0$

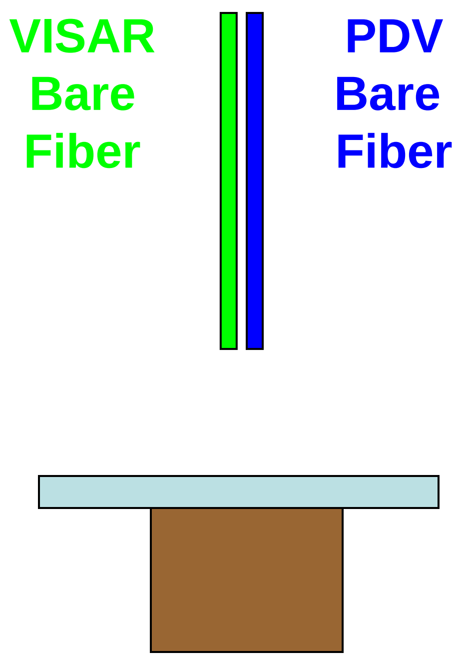
@ 1550 nm and v = 1 mm/μs

f_0 = 193414.49 GHz
f_d = 193415.78 GHz
f_b = 1.29 GHz

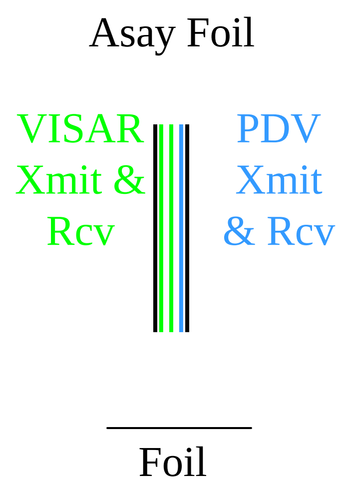
$V = \lambda/2 \times F$
V(mm/μs) = 0.775 x F (GHz)

- Single channel shown (2 watt laser can support ~4 pts)

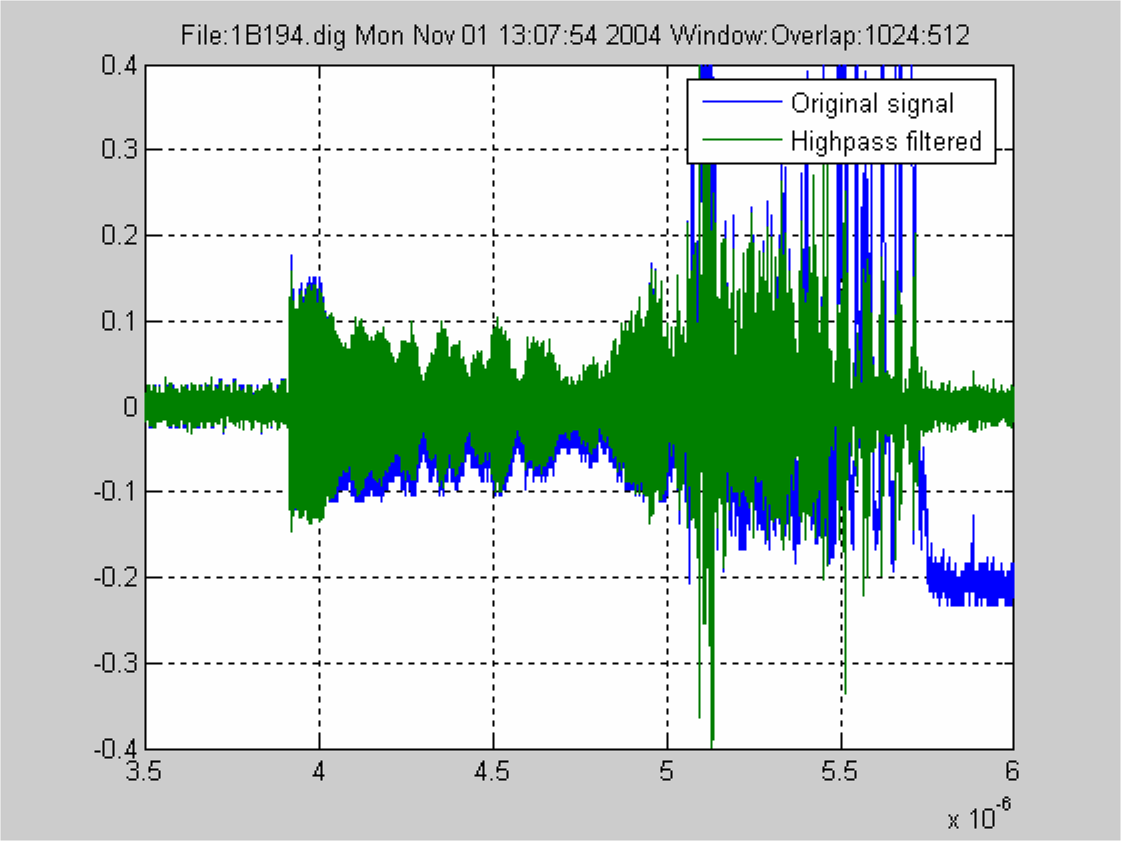
First Data at Santa Barbara (2004)



- 3 shots with bare fiber in tube + bare fiber VISAR alongside
- 2 mm standoff from polished or ball rolled surface

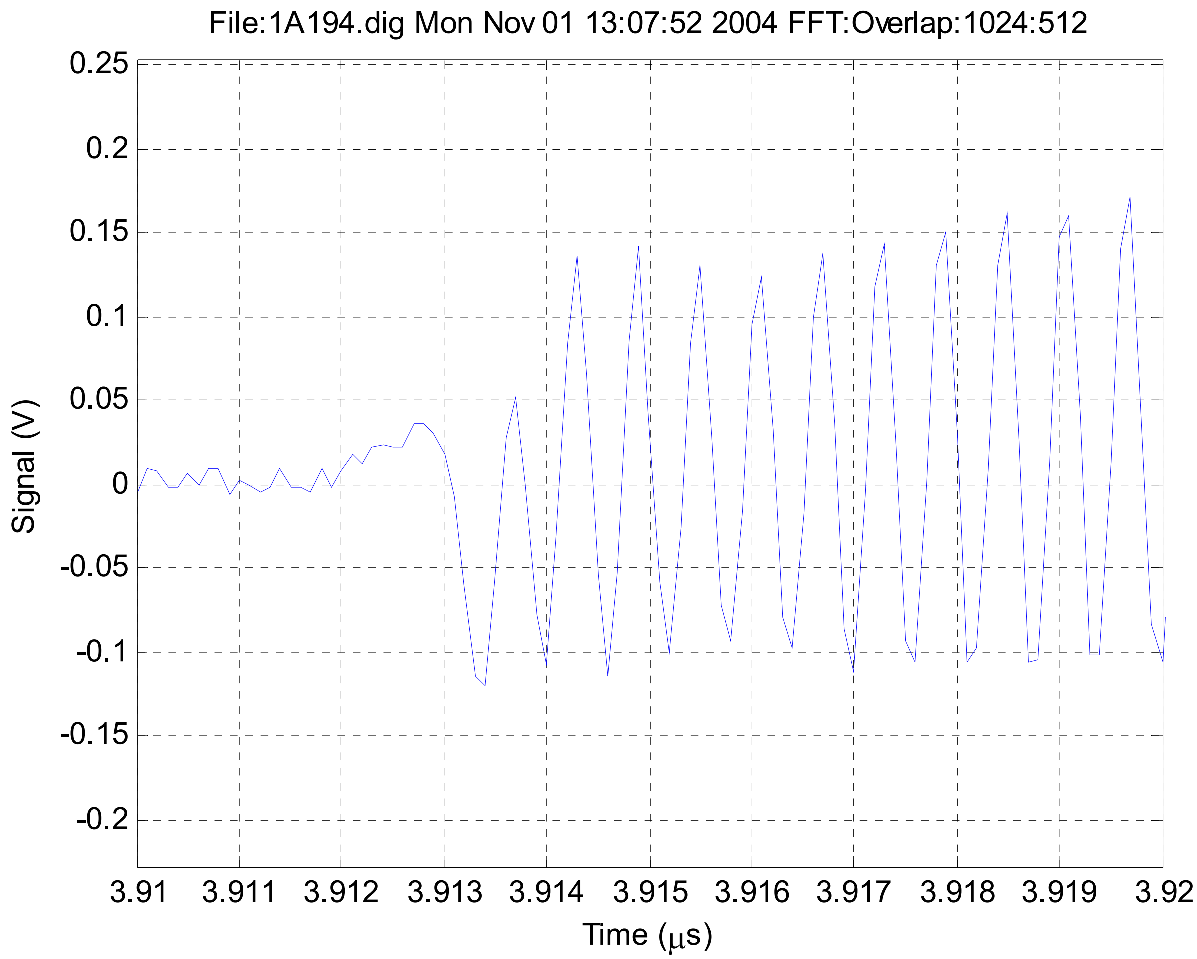


Ball Rolled Surface (2004)



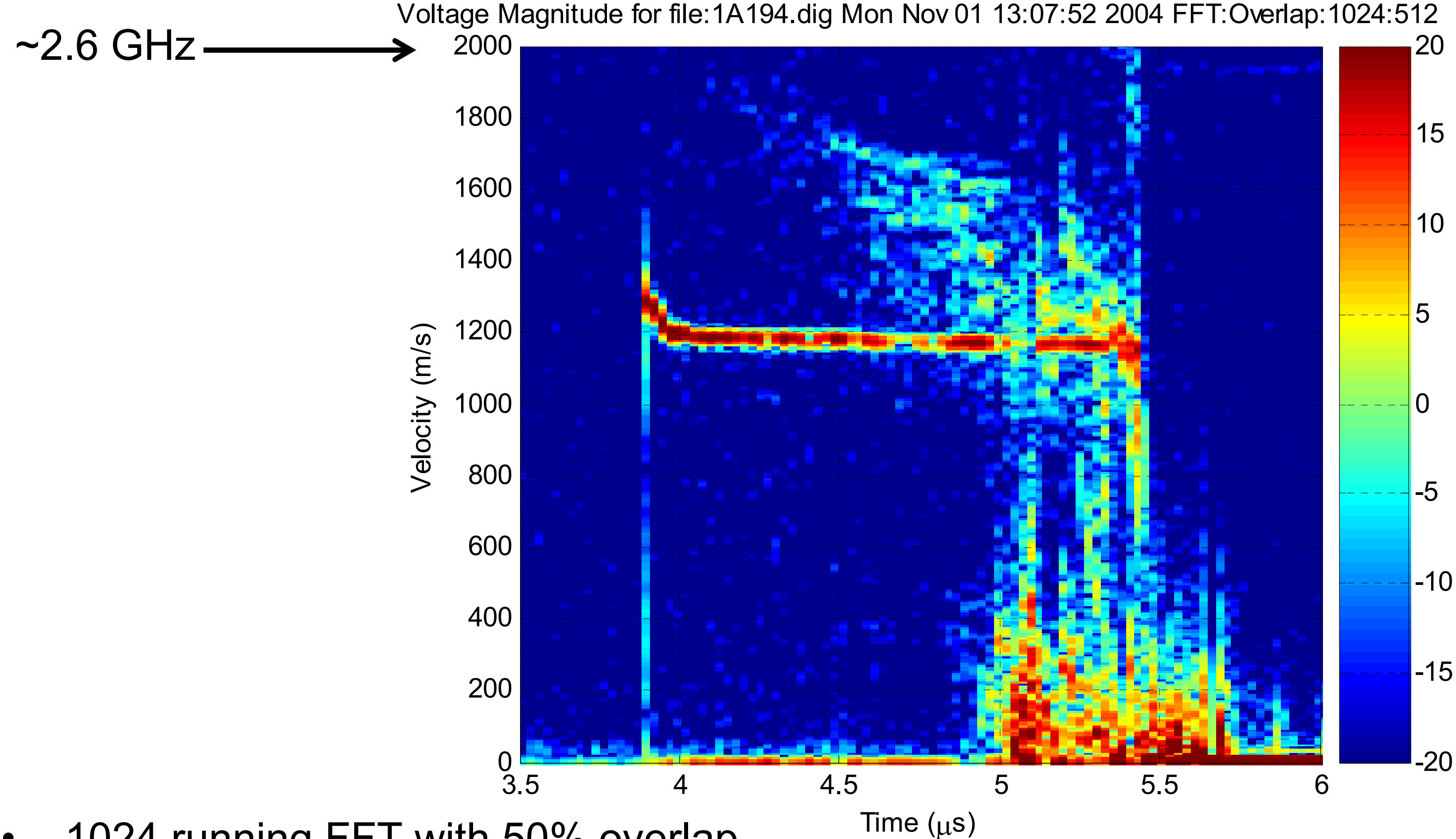
- Blue is raw signal, green is high passed digitally
- Note that raw signal is > ± ~100 mV

Raw PDV Signal (2004)



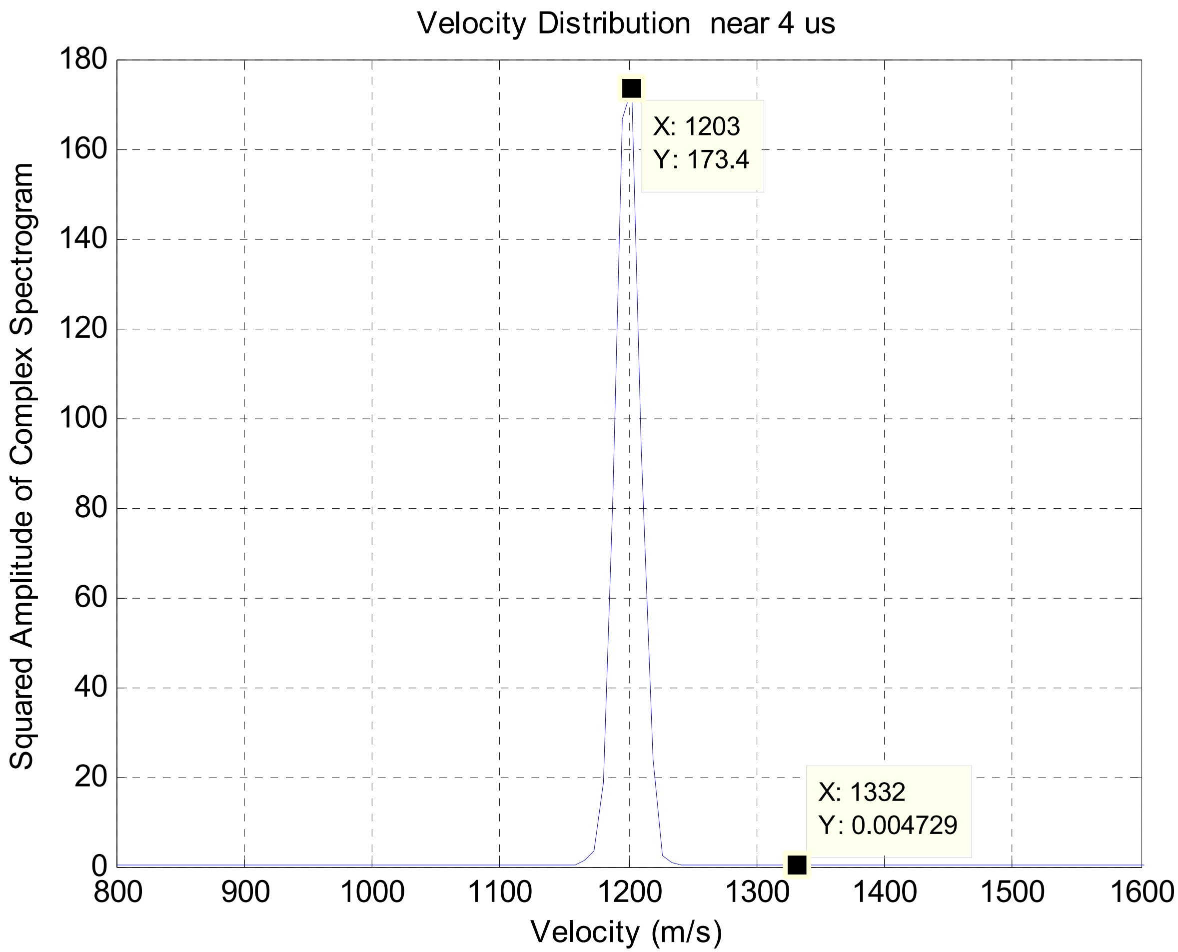
- Shock break out to << 1 ns
- Elastic precursor evident
- Can use various methods to estimate velocity "fast" when SNR is good

Bare Fiber + Ball Rolled Surface



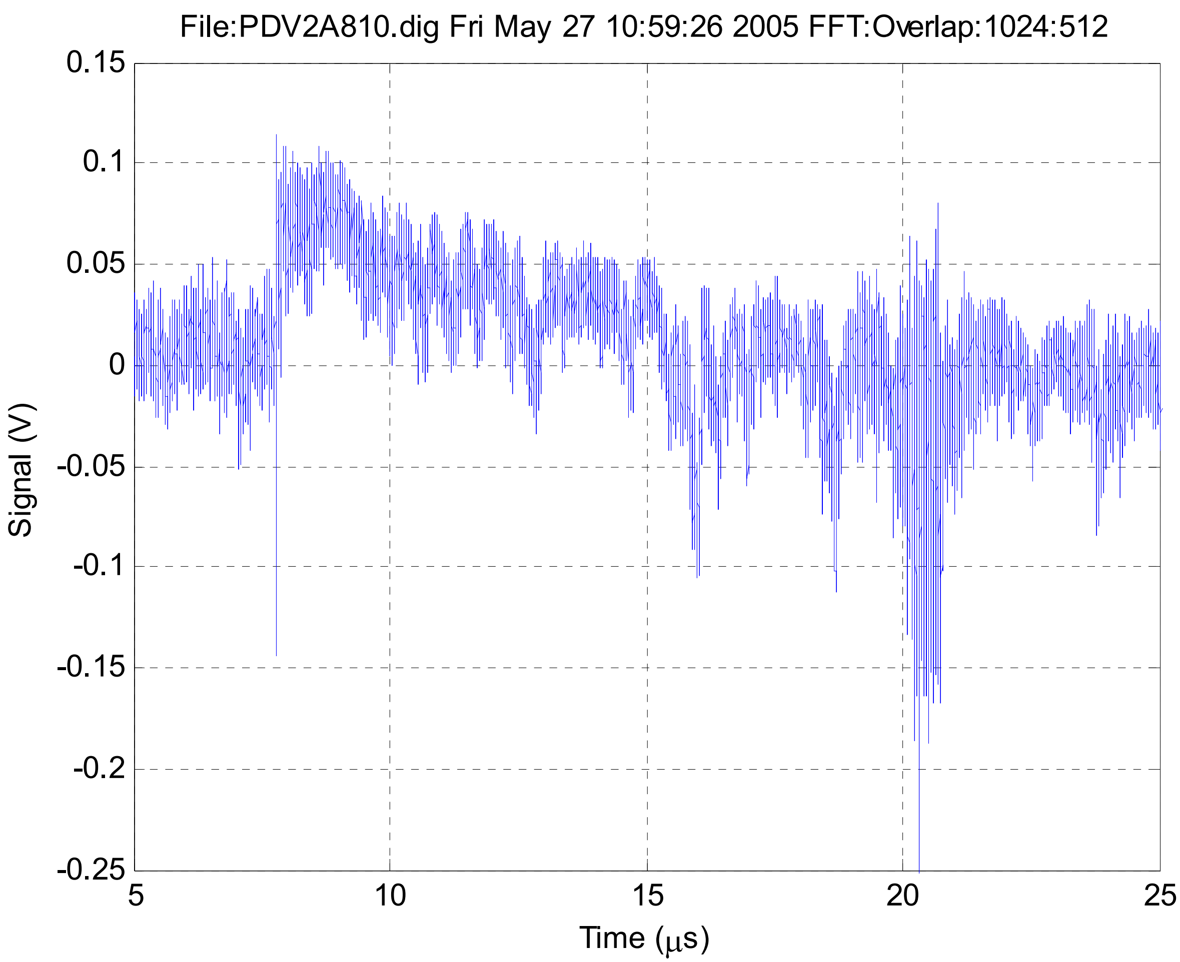
- 1024 running FFT with 50% overlap
- Note SNR is ~40dB in places (less elsewhere)
- VISAR also shows impact of debris on bare fibers between 5 and 5.5 μs

SNR @ 1 Time



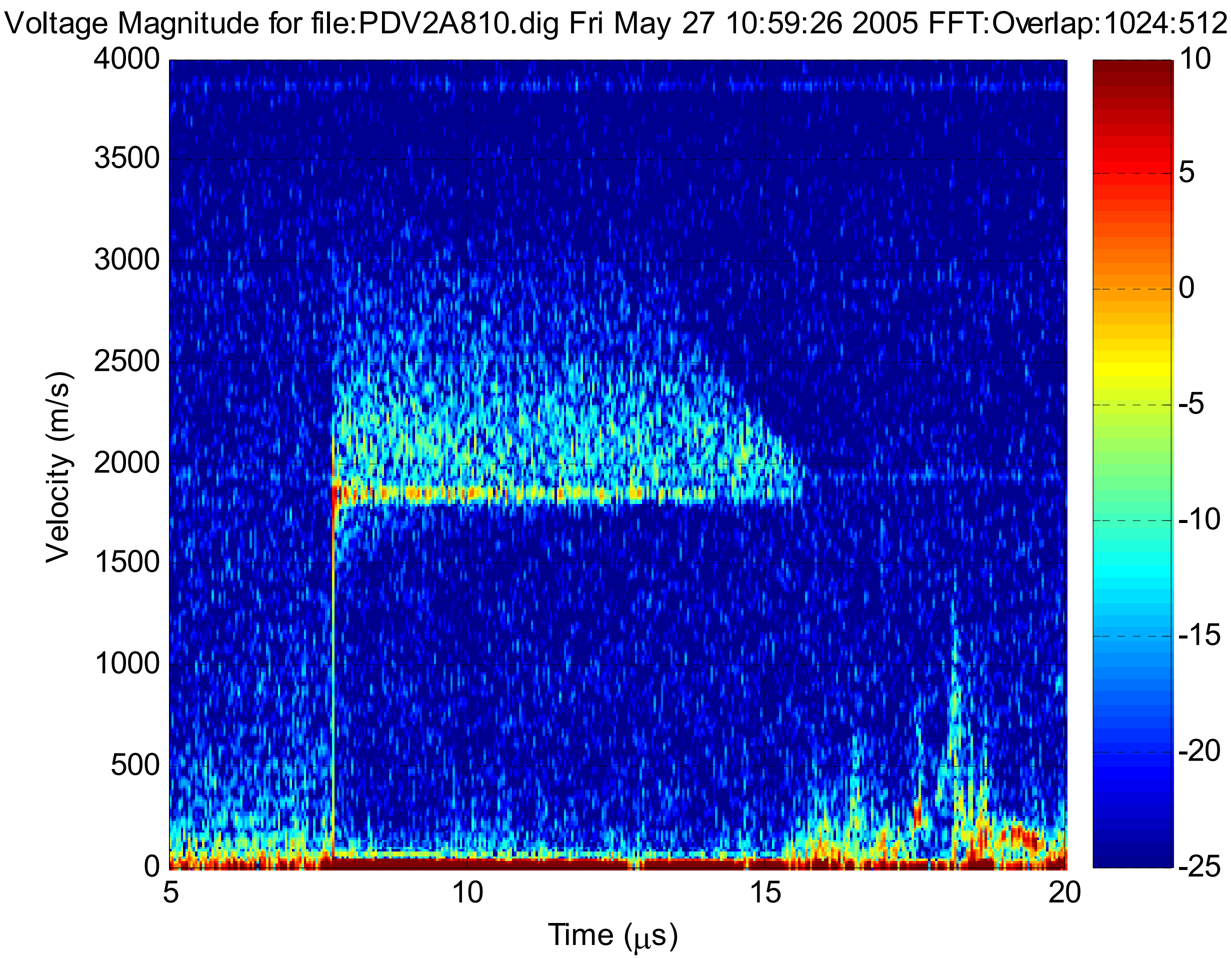
- Picked a point near 4 μs
- SNR ≈ 10^4:1 in frequency/ velocity domain

Later Data (2005) – Tin Ejecta



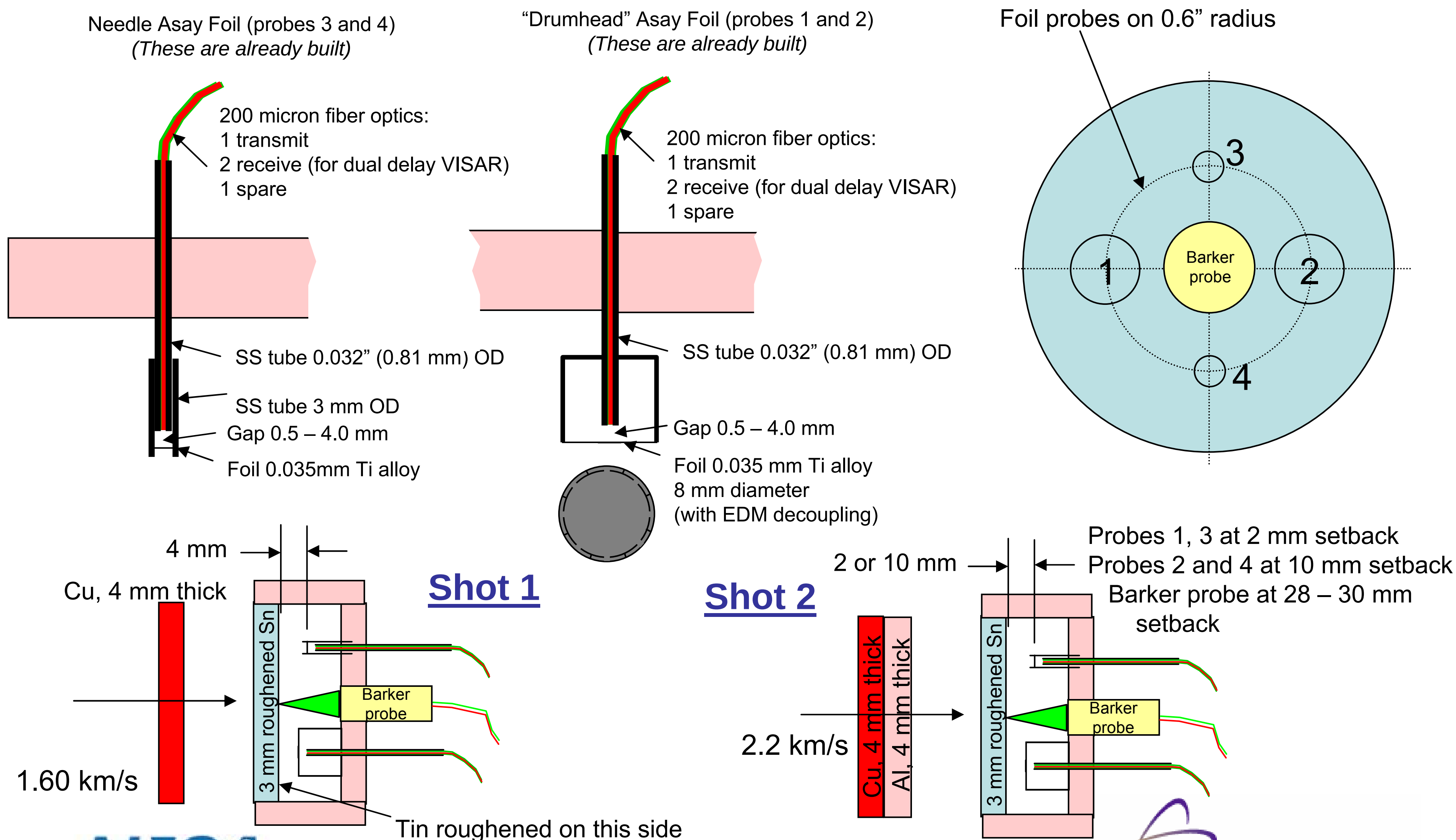
- Raw data can really look pretty bad at times…

Later Data (2005) – Tin Ejecta

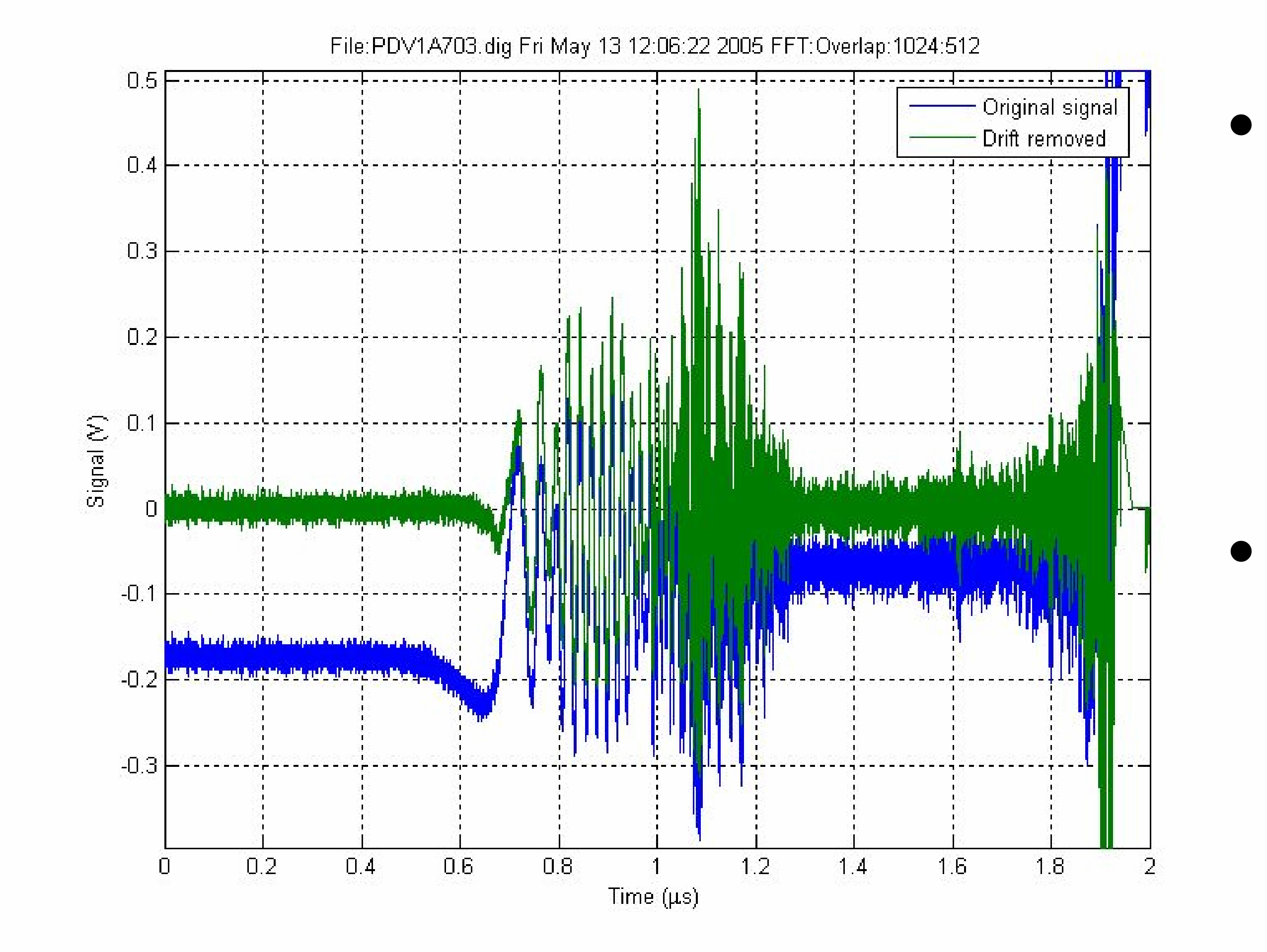


- When multiple velocities present (i.e. ejecta or melt), can resolve intact surface (if cloud is not too opaque)
- V_{fs} = 1.848 ± 0.030 km/s
- P = 26.2 ± 0.4 GPa
- Ejecta impact signature on window

Asay foil probe shots (Sandia)



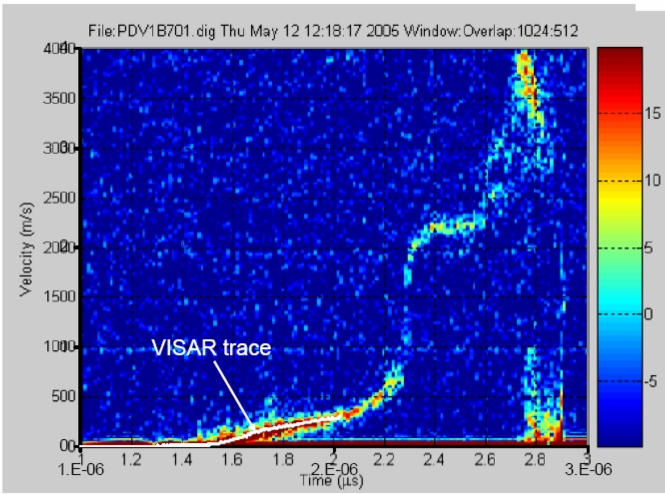
Asay Foil PDV data



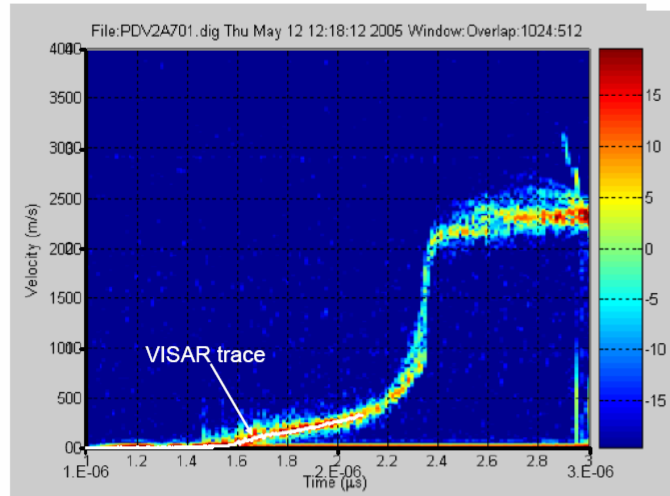
- Raw (blue) & baseline corrected (green)
- Foil (and fringe rate) accelerates with time

Asay foil probe shots (w/ Mike Furnish @ Sandia)

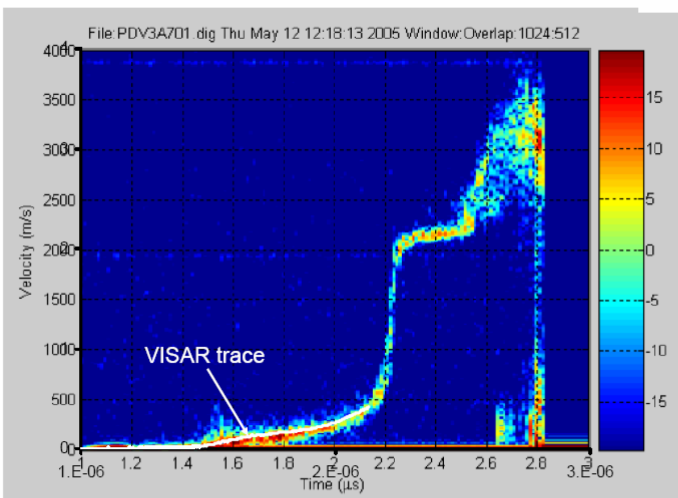
Shot 1 Probe H1 (Needle)



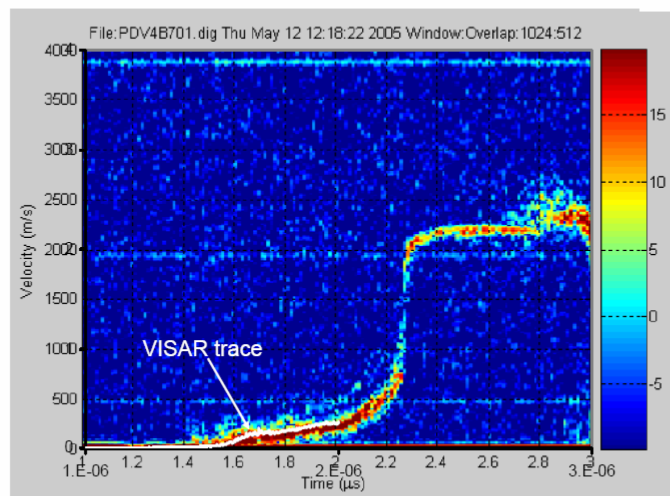
Shot 1 Probe F1 (Drumhead)



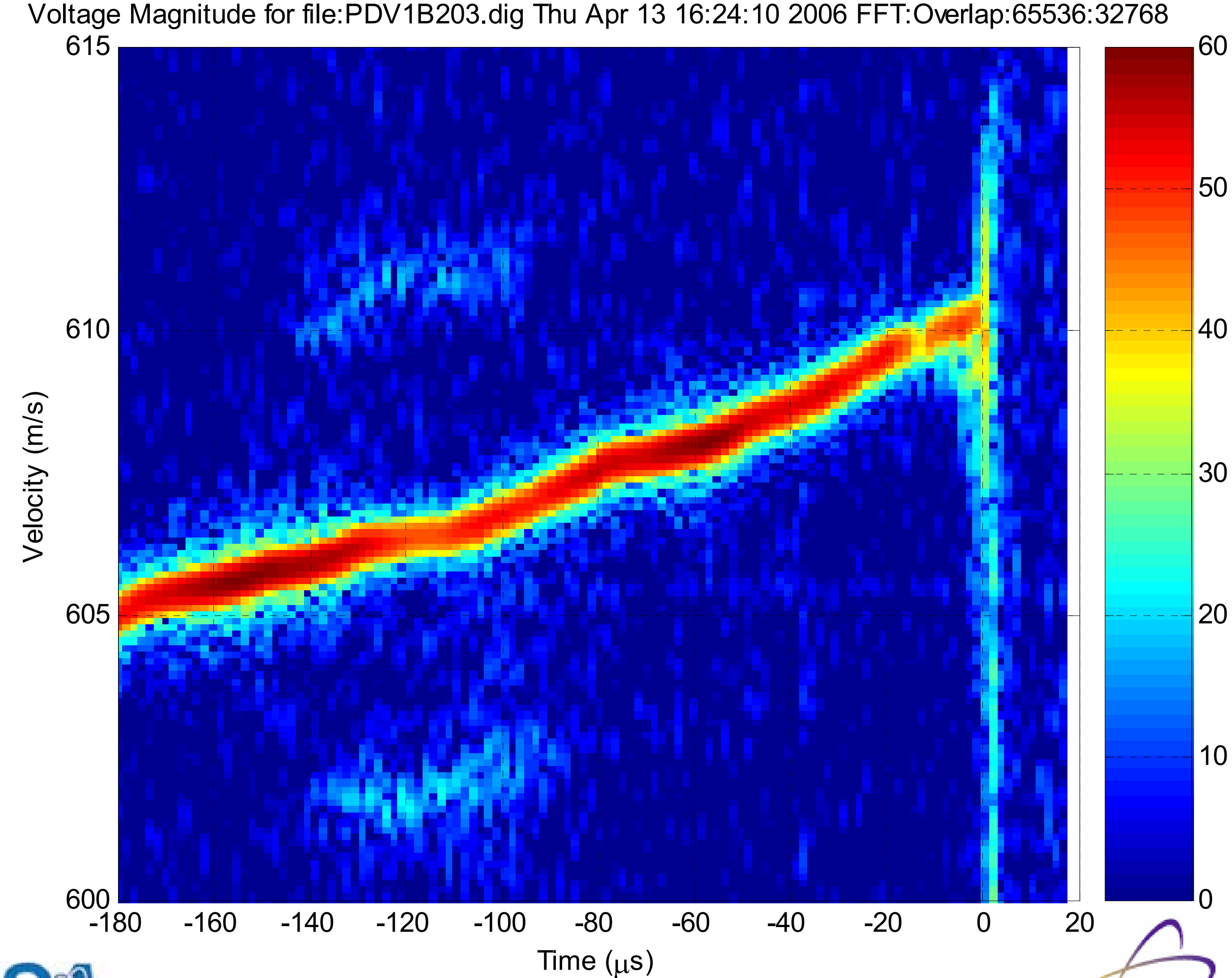
Shot 1 Probe D1 (Needle)



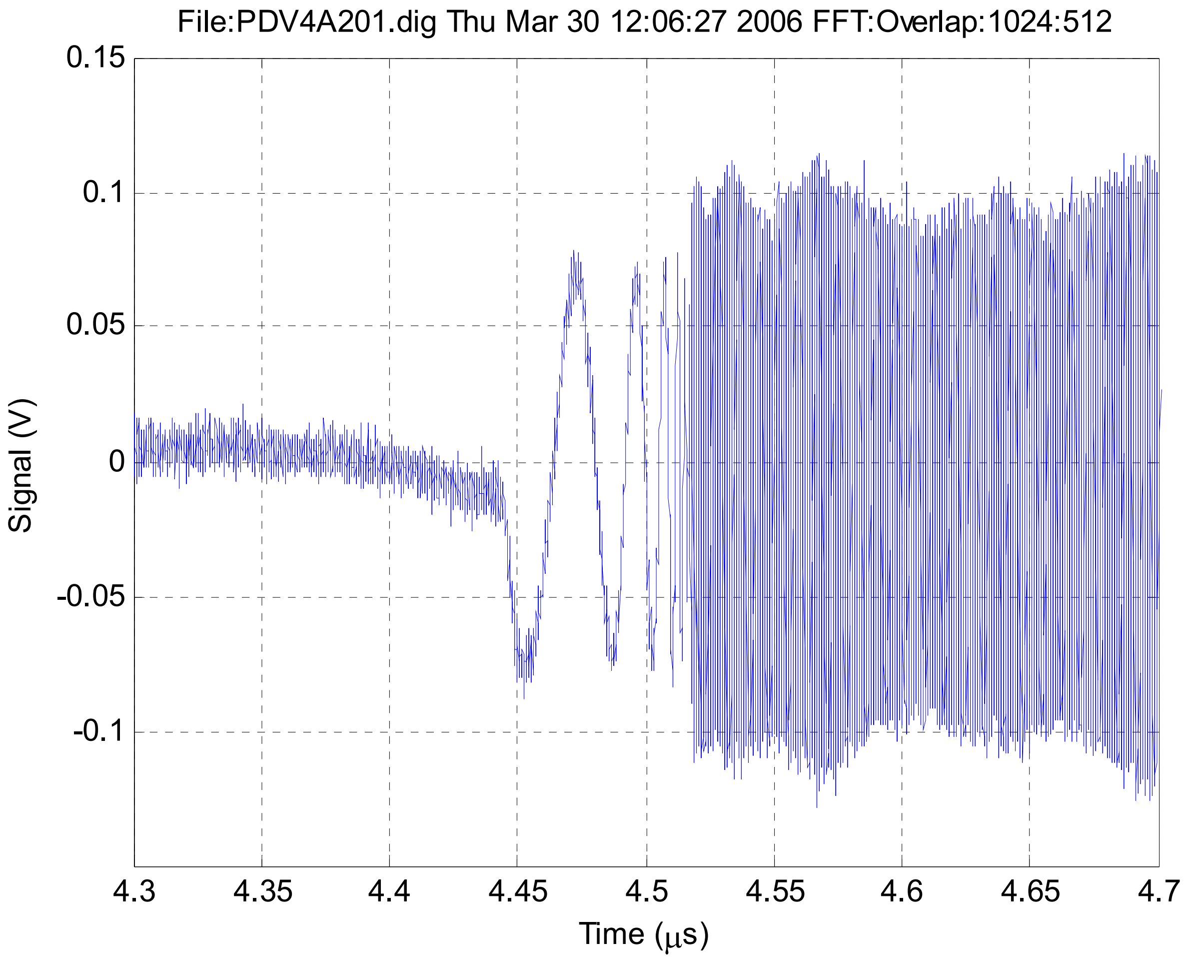
Shot 1 Probe H2 (Drumhead)



Sabot Velocity (LiF-LiF Shot)

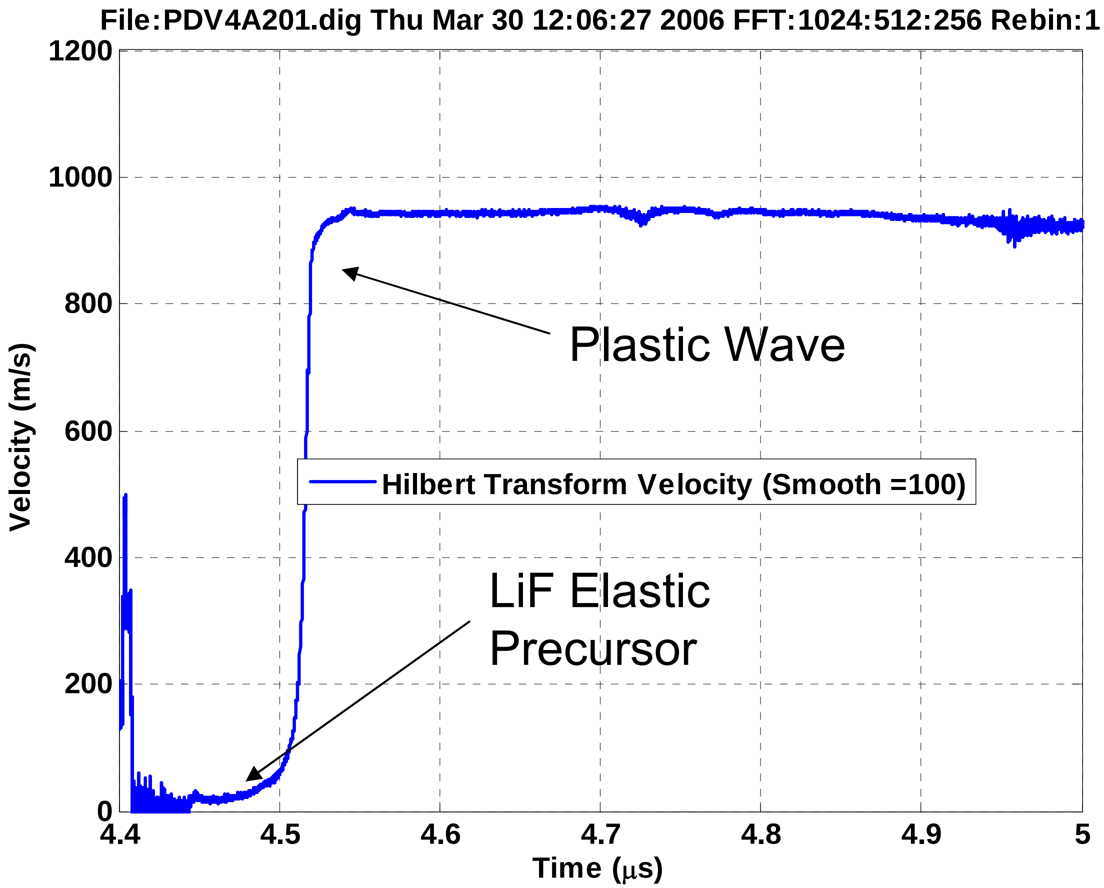


LiF-LiF Impact (March 2006)



- LiF-LiF gun shot (3/2006)
- Good fringe contrast
- Single velocity at surface

LiF LiF Impact (March 2006)



- With good fringe contrast can measure velocity with good time resolution
- Elastic precursor and plastic wave resolved + ringing in metal coating at LiF LiF interface

Compare Pins to PDV (May 2006)

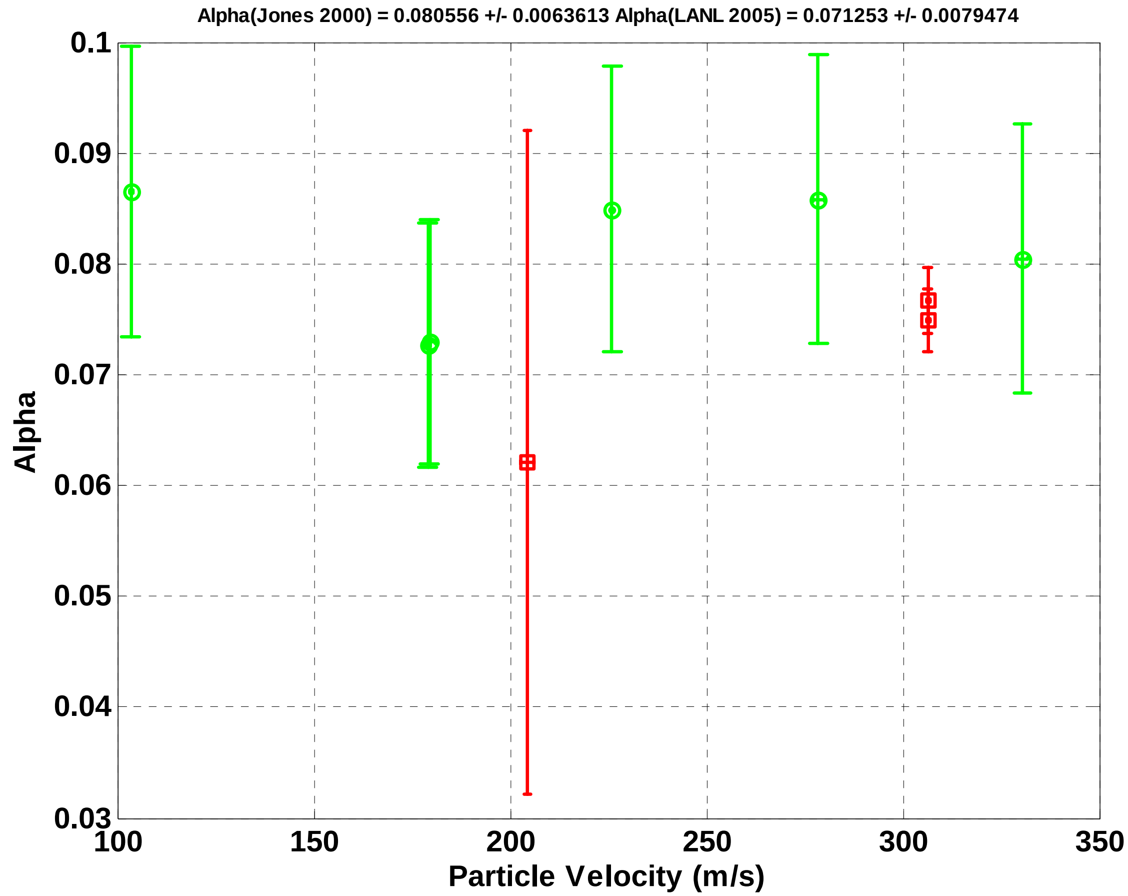
Shot	Pin Velocity (m/s)	PDV (#1)	PDV (#2)	PDV Average
56-06-17	268.7 ± 0.4 m/s	268.3706 ± 0.0067 m/s (fit error only)	268.5900 ± 0.0067 m/s (fit error only)	268.48 ± 0.16 m/s 268.62 ± 0.16 m/s (corrected)
56-06-18	742.9 ± 0.5 m/s	742.555 ± 0.012 m/s (fit error only)	742.934 ± 0.017 m/s (fit error only)	742.74 ± 0.27 m/s 743.14 ± 0.27 m/s (corrected)

- 10 pin block on muzzle mounted target (Brian Jensen)
- Corrected PDV data (× 1.00053761) for 1.88° steering (from 4° angle polish on fiber tip)
- Absolute PDV values agree with Pins (to within errors)

Quartz-Quartz Impact (July 2005)

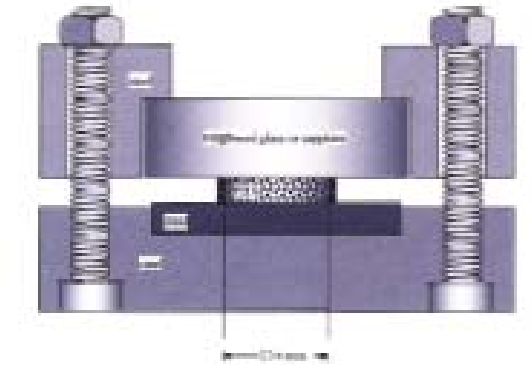
Green @ 532 nm (Jones 2000)
Red @ 1550 nm (Jensen et al 2006)

$\alpha=(U_m-U_p)/U_p$

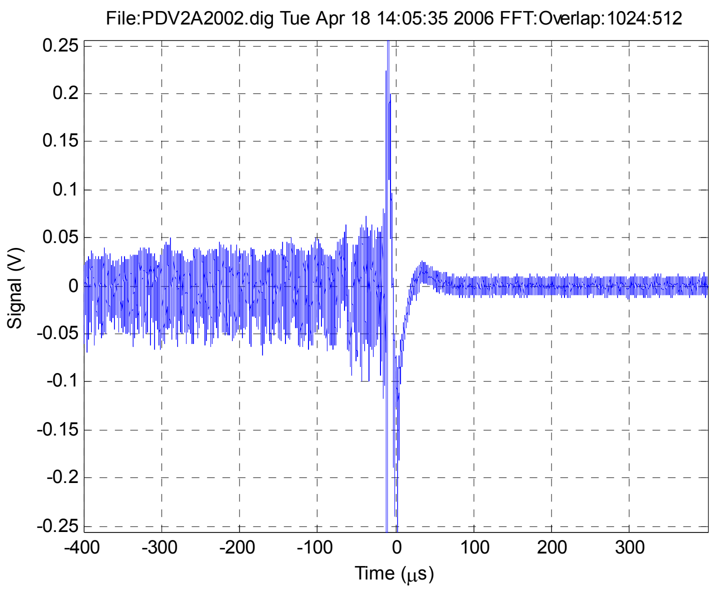


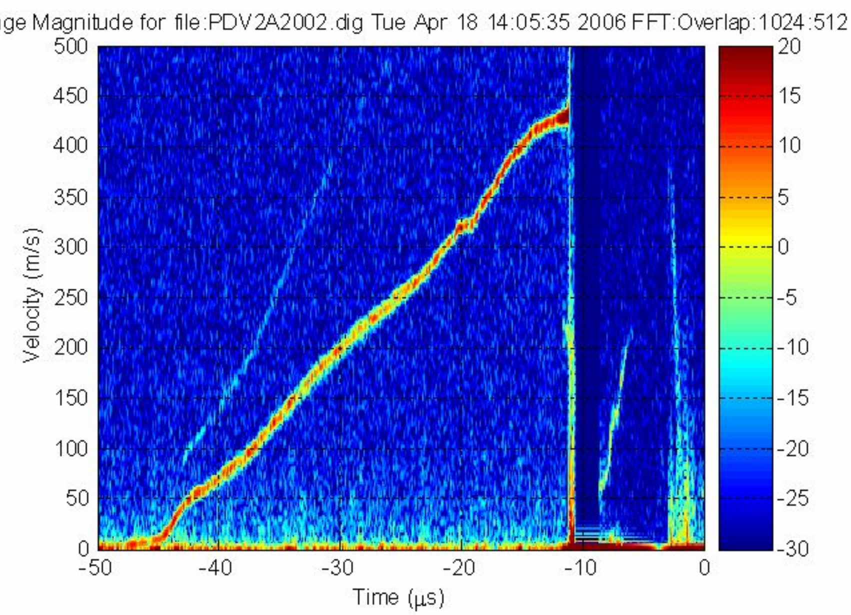
- Compare window correction to earlier VISAR data

Thermal Cookoff of HE

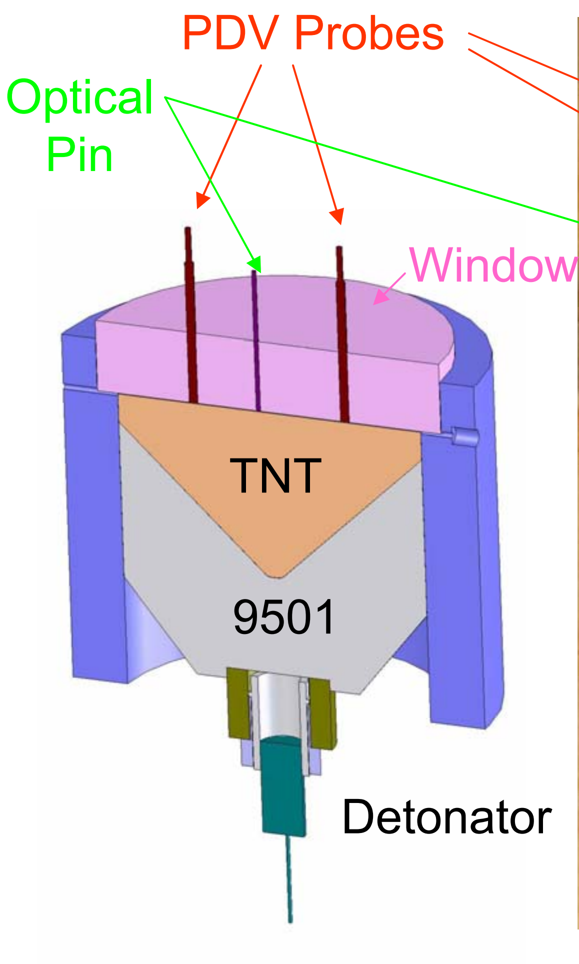


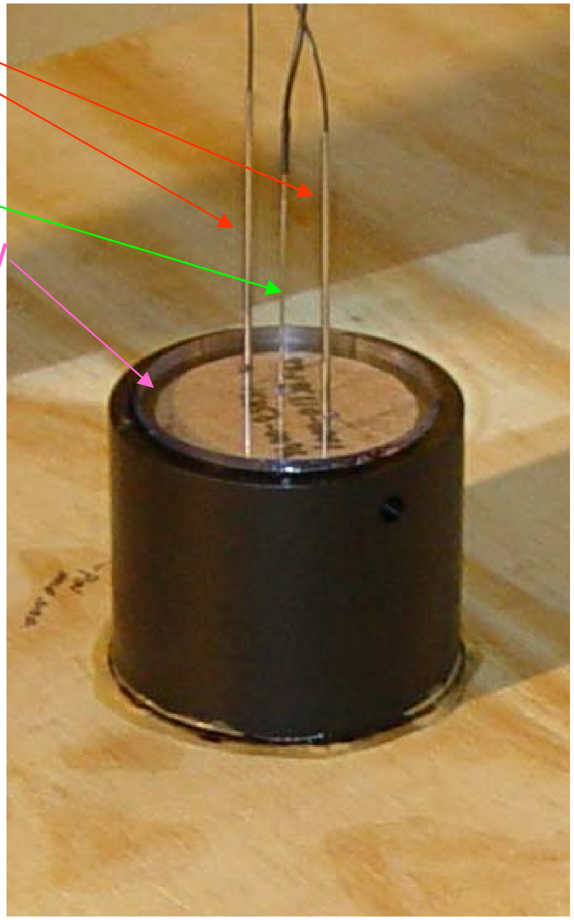
- L. Smilowitz, et al (C & HX Divisions) investigate thermal runaway of HMX explosives in heated, confined HE assemblies (figure is for a windowed configuration)
- Large raw PDV signal (lower left) allows possibility of self-triggering data acquisition (lasers on for minutes at a time)



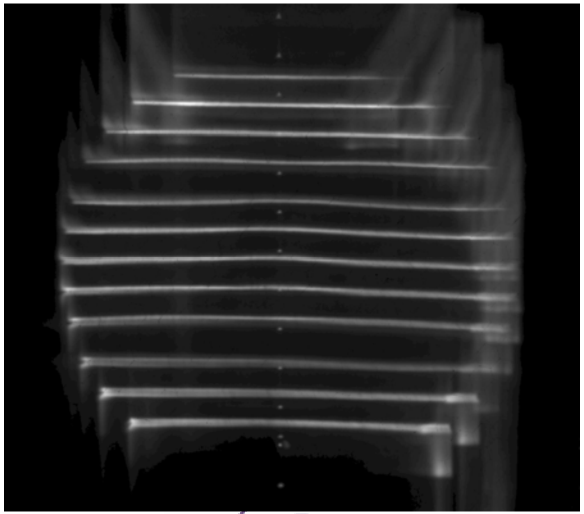


Bare HE Shots





- Characterization of plane wave HE lens systems
- Streak + slits looking at shock light for planarity
- Blind optical pin for SBO
- PDV on bare HE for SBO & velocities (?)
- Better scopes (6804 & 6154) & better detectors

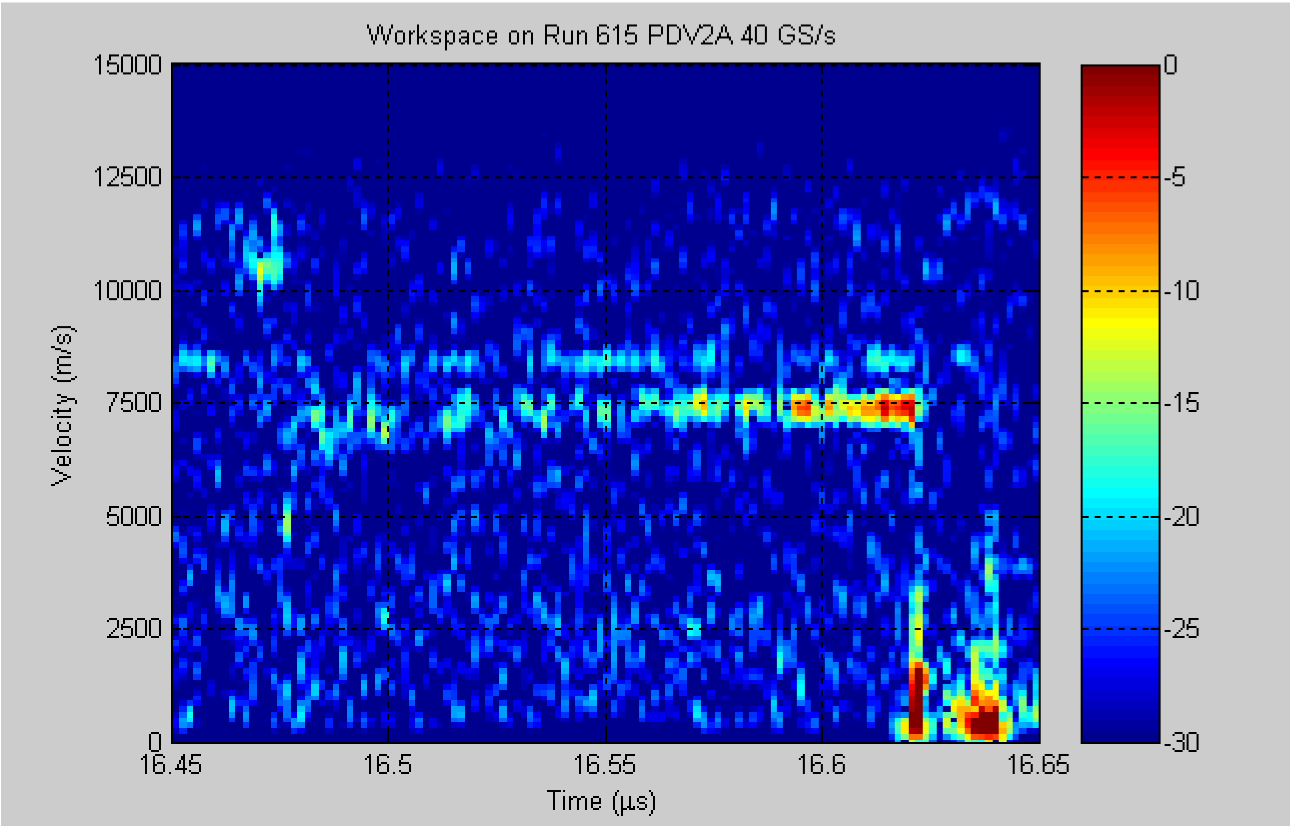


1st Shot

Shock Breakout (Zoomed)

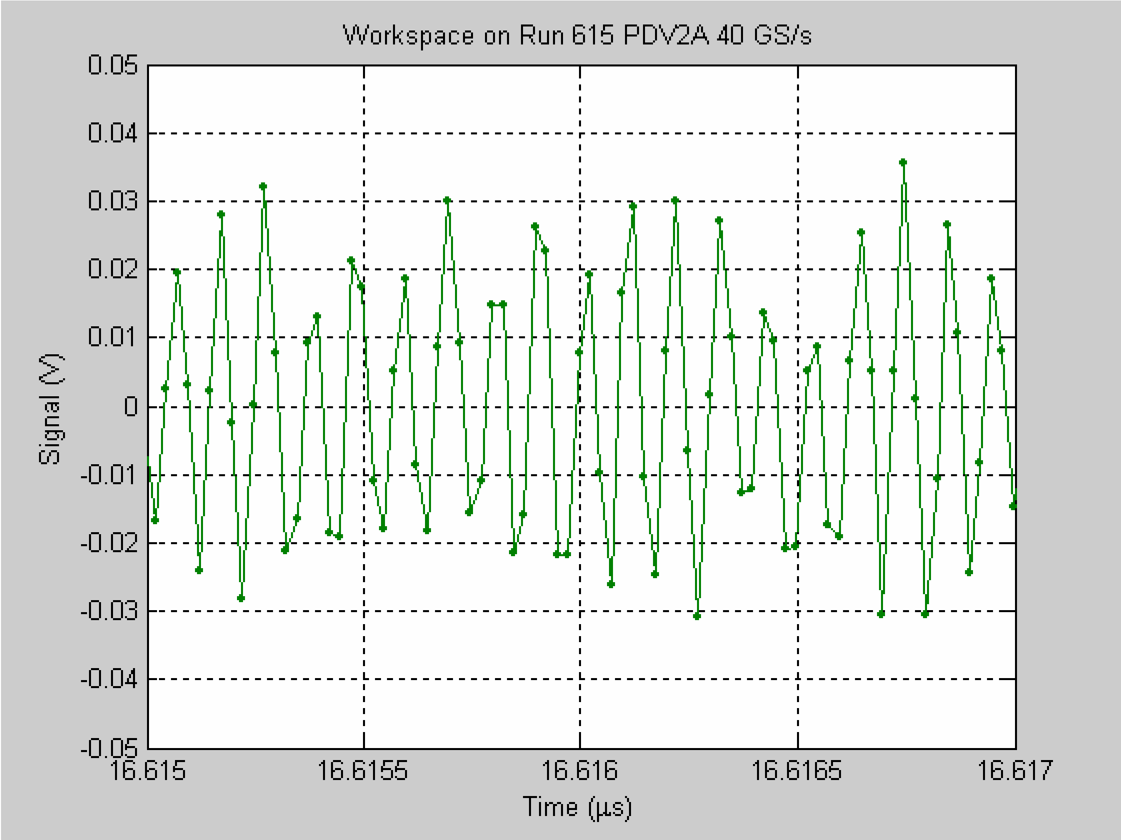
- Zoom in on shock breakout feature
- ~300 ps (FWHM)
- SBO to < 100 ps

PDV Data (Zoomed)



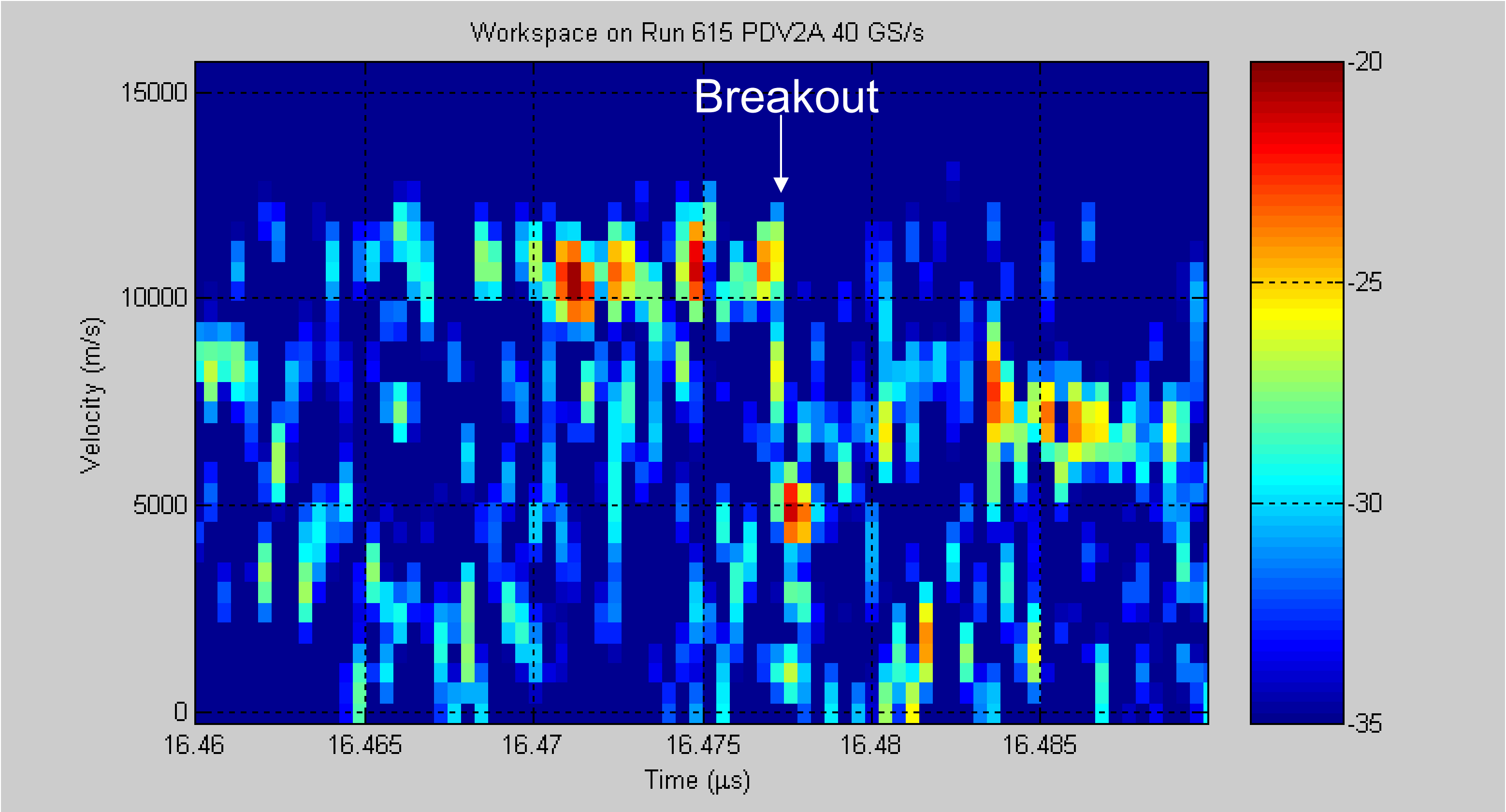
- 256 pt FFT (256 x 25 ps x 50% overlap = 3.2 ns/bin)
- Breakout @ 16.4782 µs
- Probe hit @ ~16.621 µs
- Air shock @ ~7.4 km/s
- Scope artifact @ ~8.4 km/s

Air Shock (Zoomed)



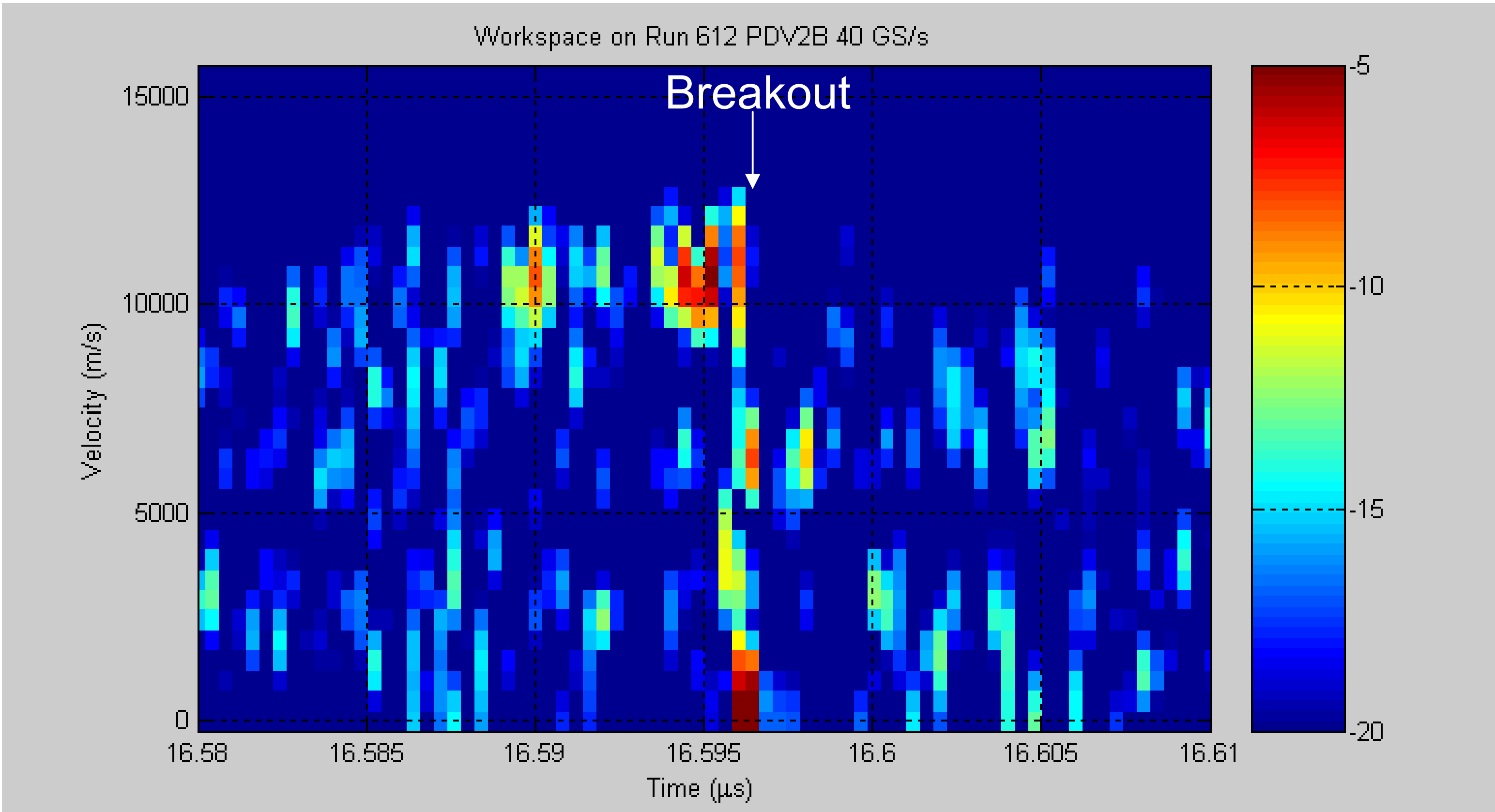
- Air shock region before probe impact
- 25 ps per point
- F = 9.53 GHz (± 0.05 GHz)

Zoom Near Breakout



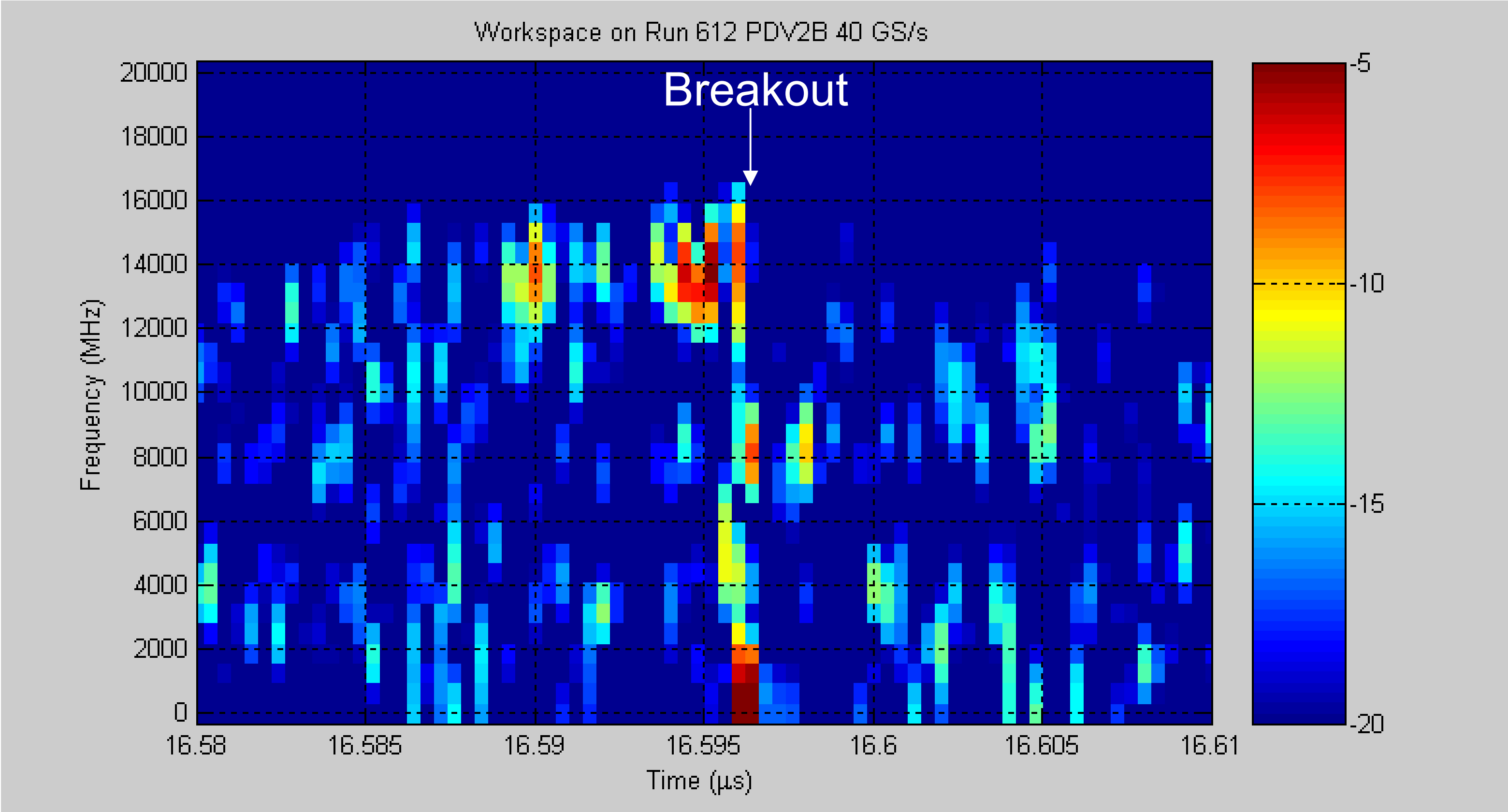
- 64 pt FFT → 64 x 25 ps/pt x 50% overlap = 0.8 ns/bin
- ~6-7 ns before breakout @ 6.95 μm/ns ≈ 45 μm into TNT (?)

Other Shots (#612)



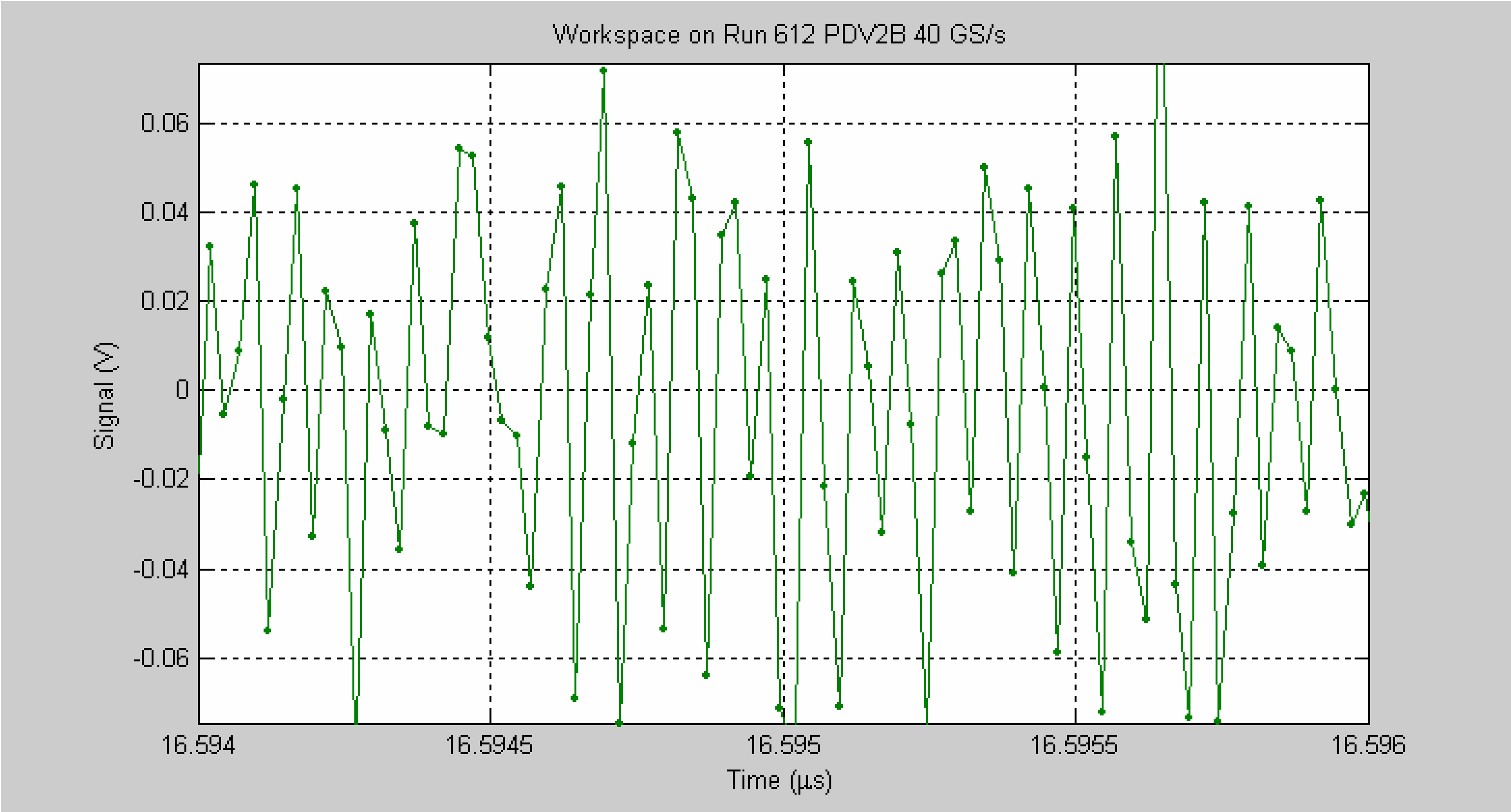
- 64 pt FFT → 64 x 25 ps/pt x 50% overlap = 0.8 ns/bin
- ~6-7 ns before breakout @ 6.95 μm/ns ≈ 45 μm into TNT (?)

#612 in Frequency Domain



- F = 13.75 GHz @ 16.595 μs

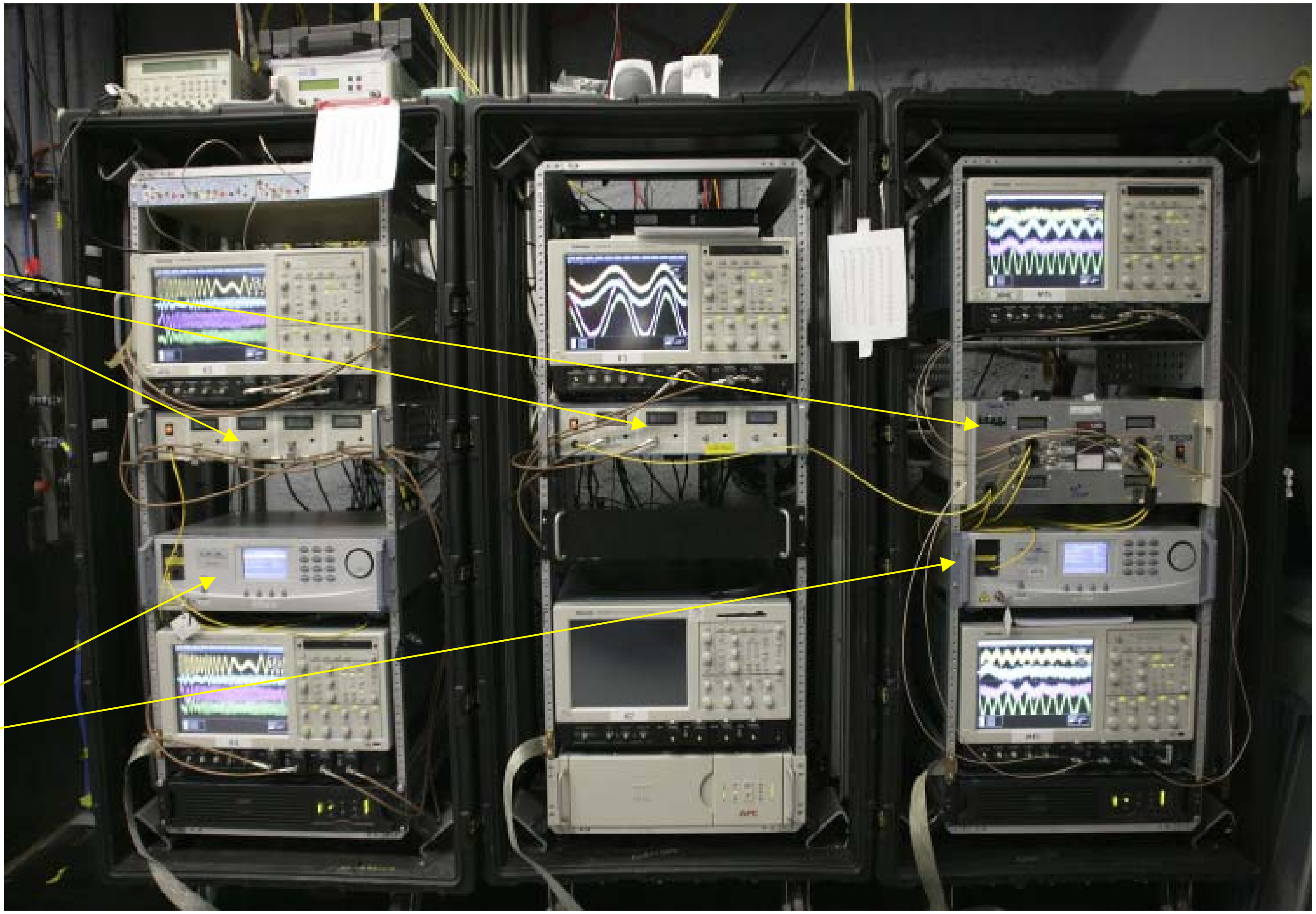
#612 in Time Domain



- 25 ps/pt sampling rate; ~15 GHz scope analog bandwidth

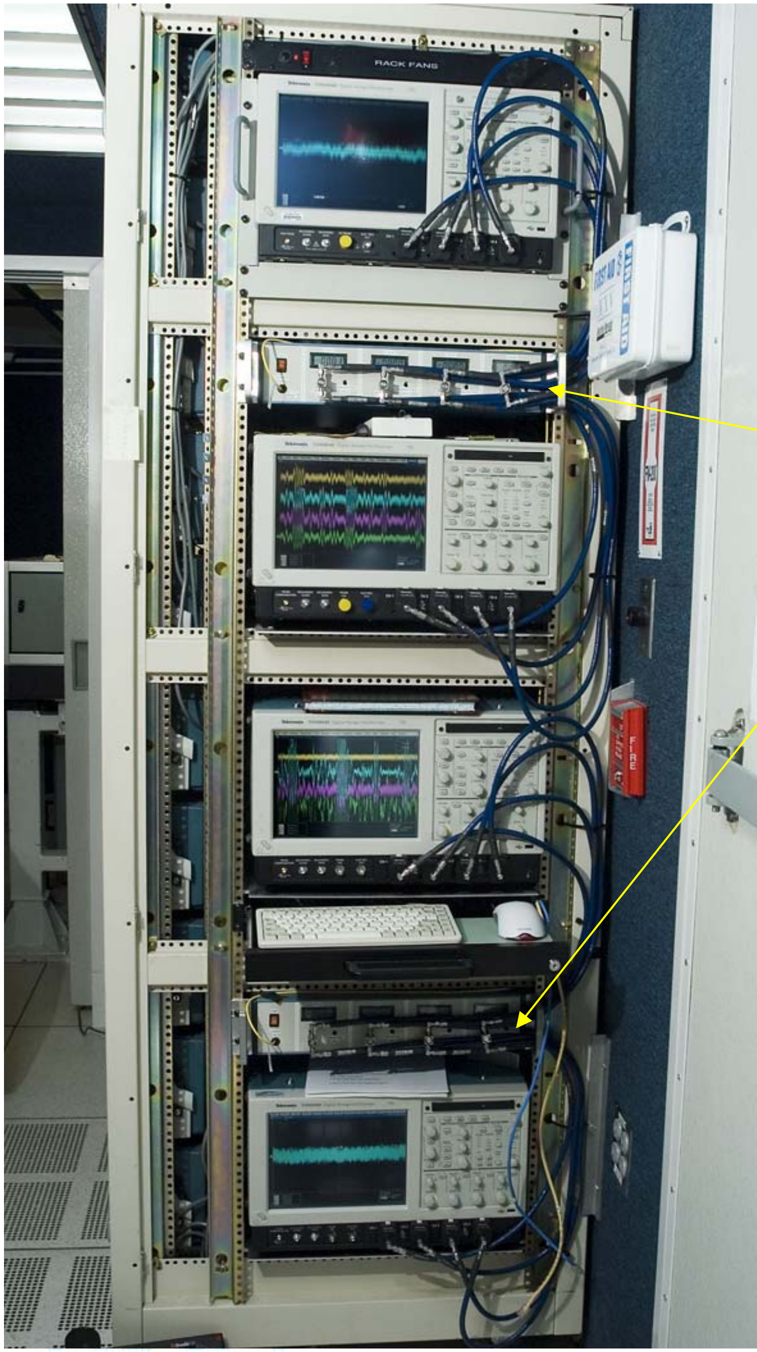
Krakatau Installation

4 Channel Optic & Detector Boxes



5 W Lasers

- 12 point system (10 used) with two 5 W lasers & recording

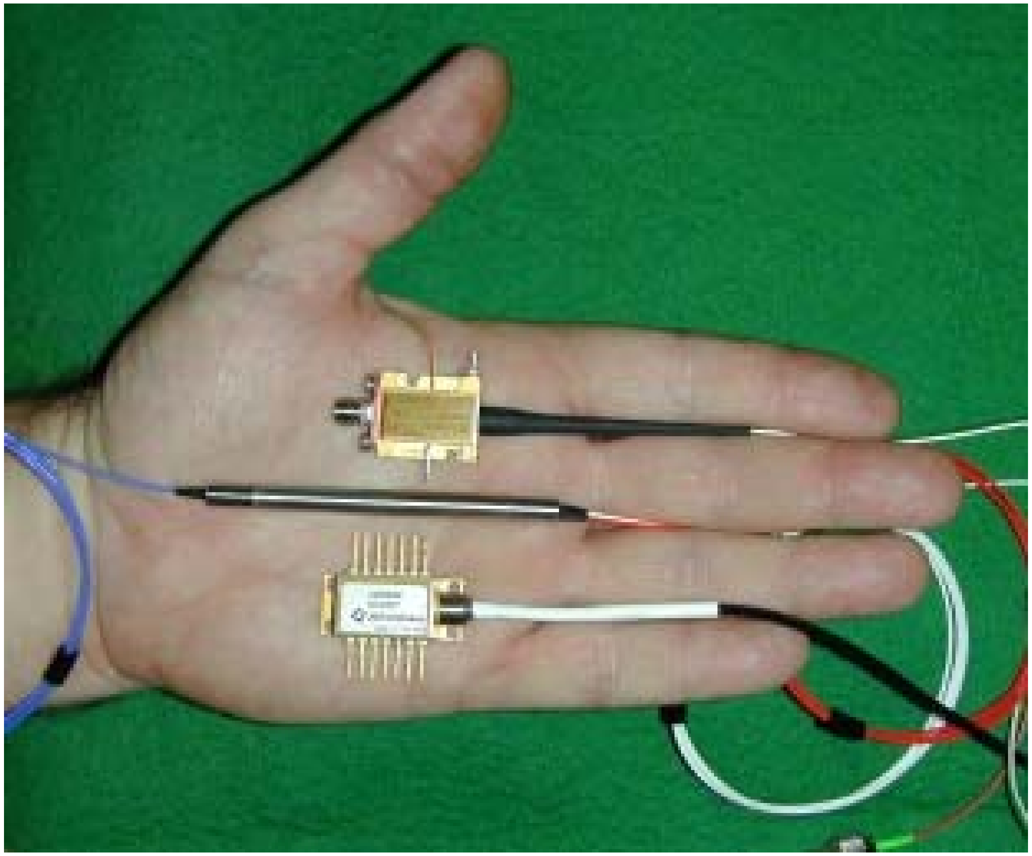


Unicorn Installation

- 8 channels (2 x 4 point systems)
- 2 lasers (not shown)
- 4 scopes (2 voltage coverages per channel)

Los Alamos

“Handheld” PDV

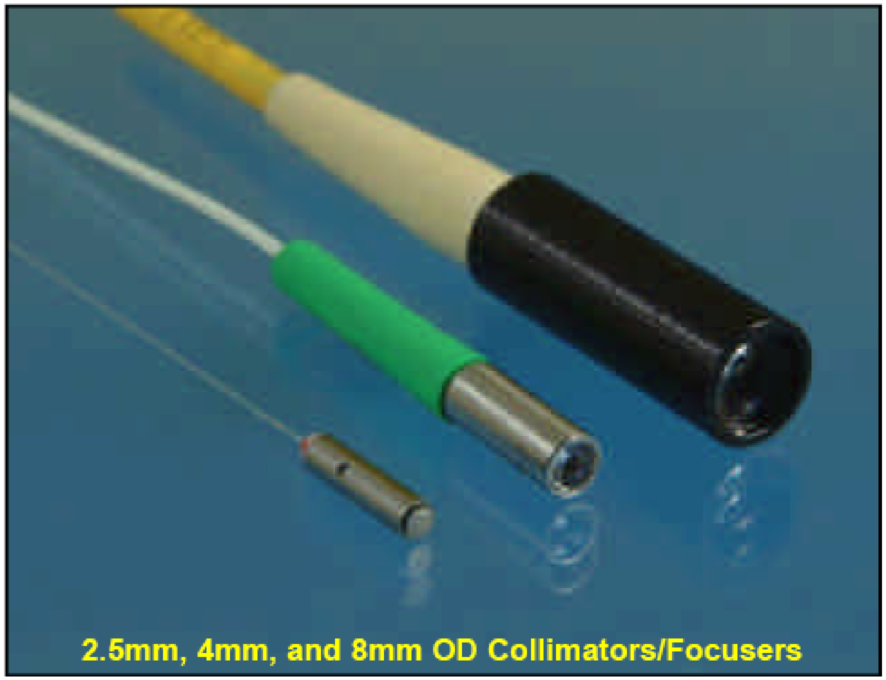


- Miniature PDV
  - Developed for DOE flight applications
  - 12 V @ < 1 A
  - Ready < 100 ms after power on
  - Multimode fiber
  - Up to 5 km/s
  - Analog downlink for recording on ground
  - Patent pending

Probe Assortment & Applications

- Bare fiber probes – angle polished (2° – 4°) to make ~ -20 to -30 dB return loss for unshifted
  - Useable from ~1 mm to > 10 mm standoff (perhaps longer?)
  - Inexpensive, small, easy to use, alignment forgiving, but not very efficient at large distance from most surfaces
- Commercial probes (3 to 6 mm diameter) – e.g. Oz Optics
  - Collimated & focused probes
  - Useable from ~1 mm to > 100 mm; efficient light return!
  - Cost a bit higher ($100 - $200)
  - Alignment can be tricky from mirror surfaces
- Miniature collimated probes – e.g. Lightpath
  - ~ 1.25 mm (D) x 3 mm (L)
  - Flexible to implement, but relatively inefficient (diffuse surface only)
  - Cost (now) ~$150 ea (used to be ~$30 ea…)

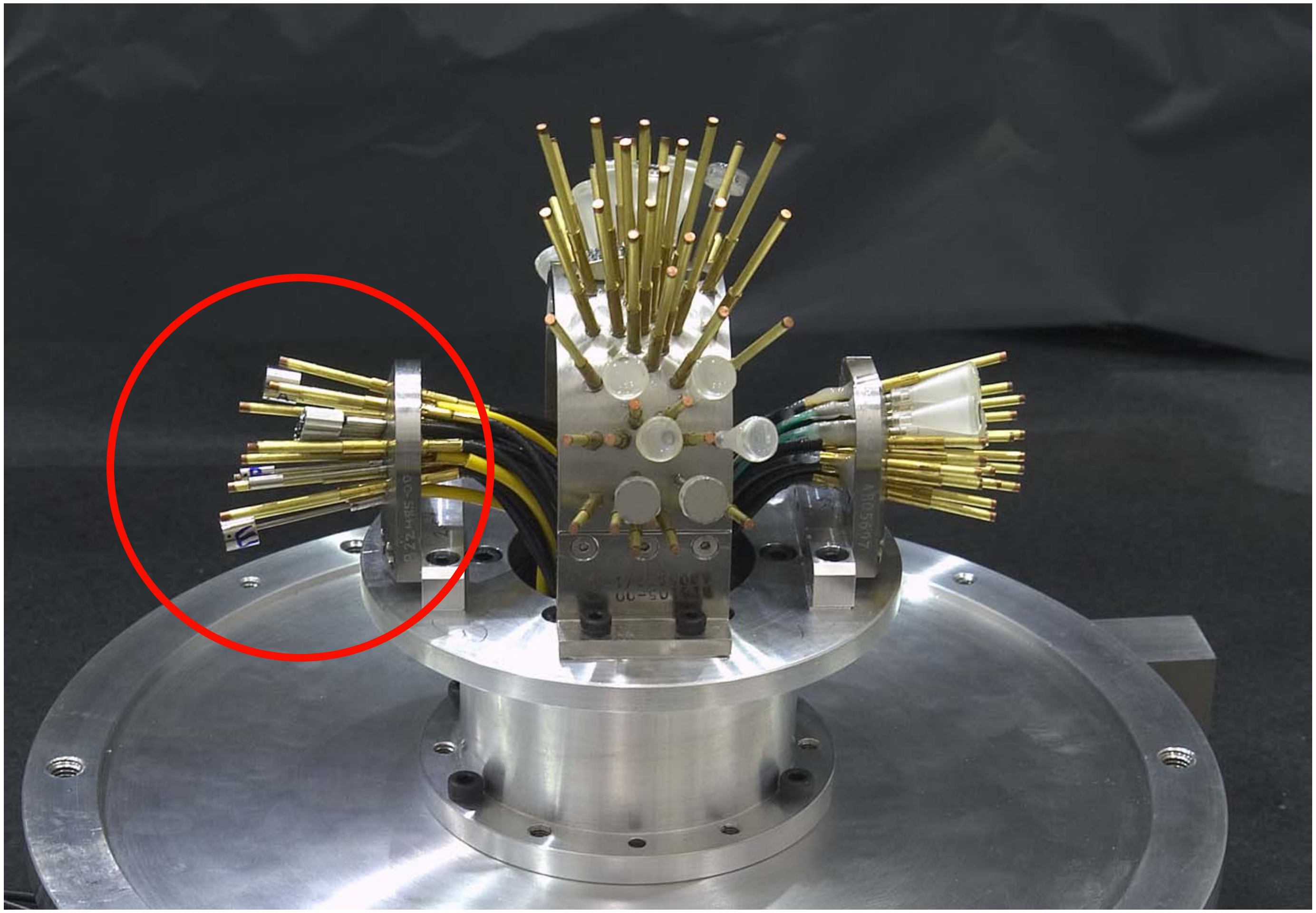
Oz & Lightpath Probes



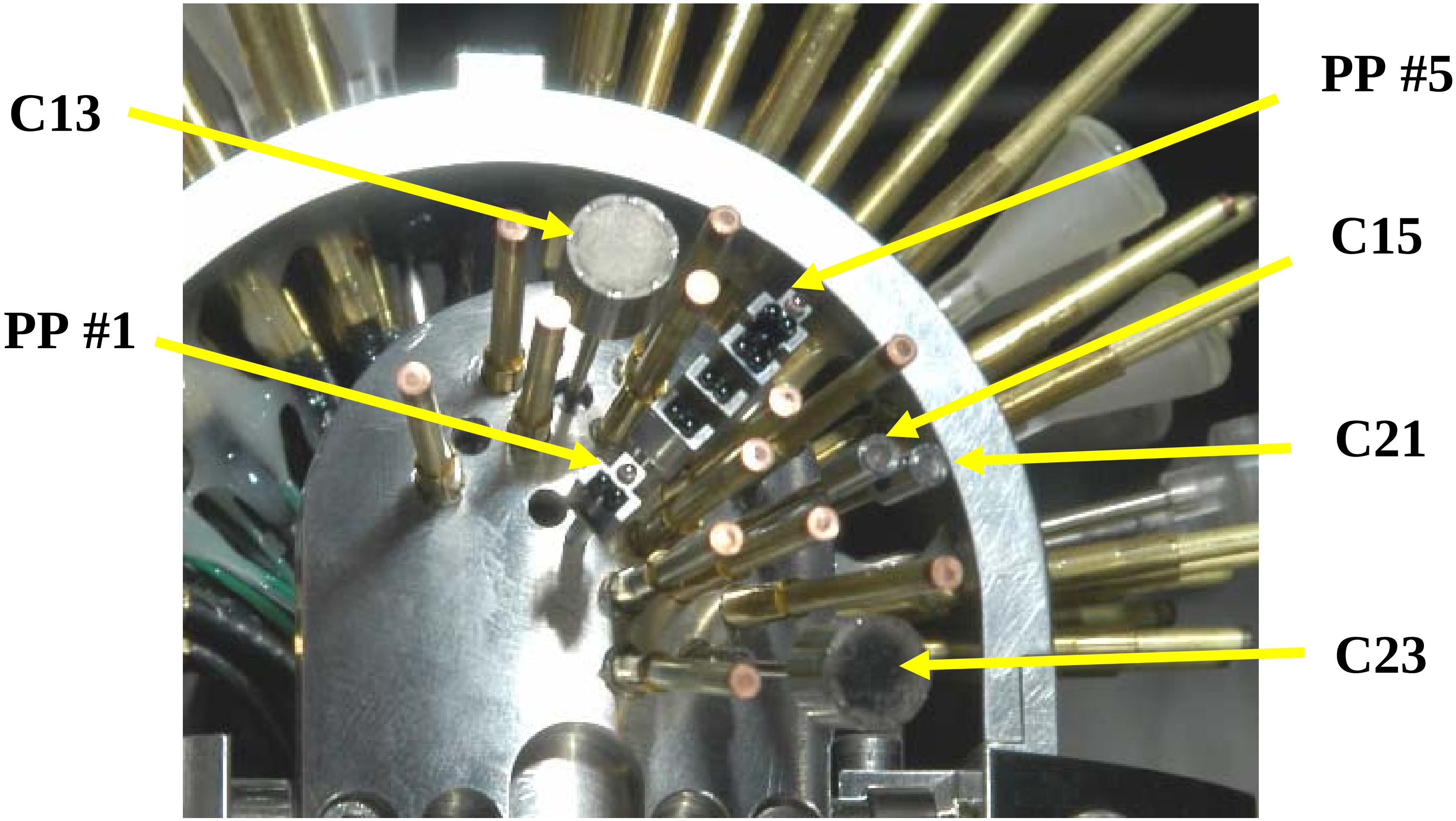
Oz Optics Probes

- Trying to standardize on bare fiber (& Lightpath) probe tube diameters, length, etc for multiple users

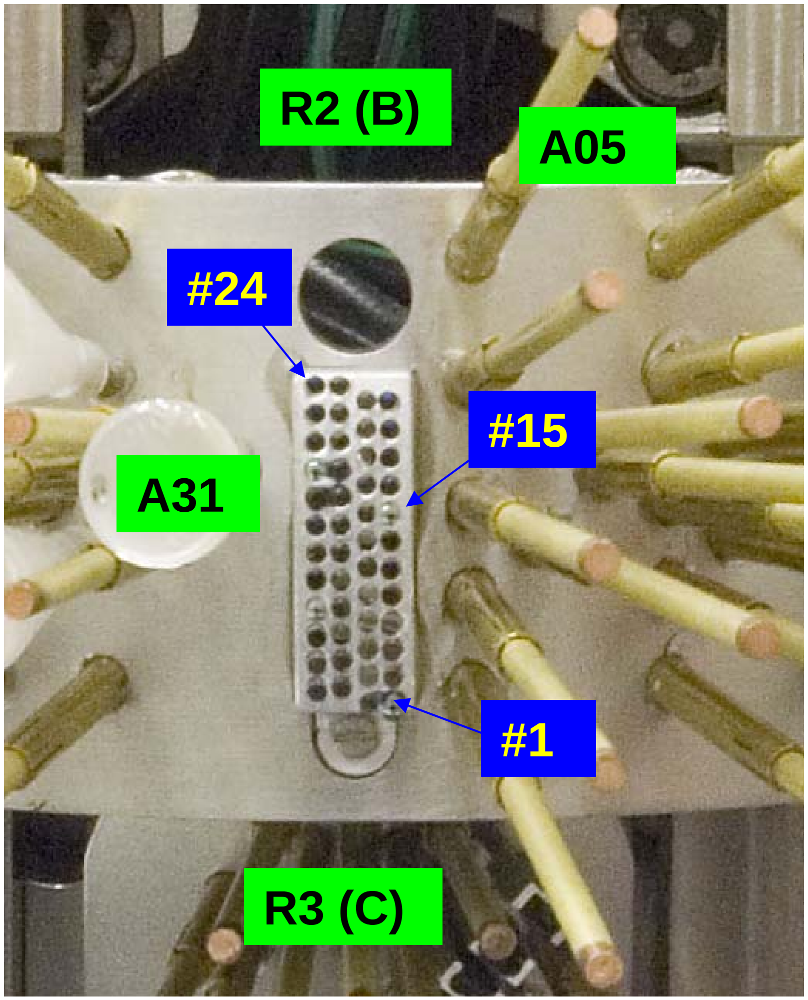
Probes on Kerinei & Krakatau



Probes on Kerinei & Krakatau



Probes on Kerinei & Krakatau

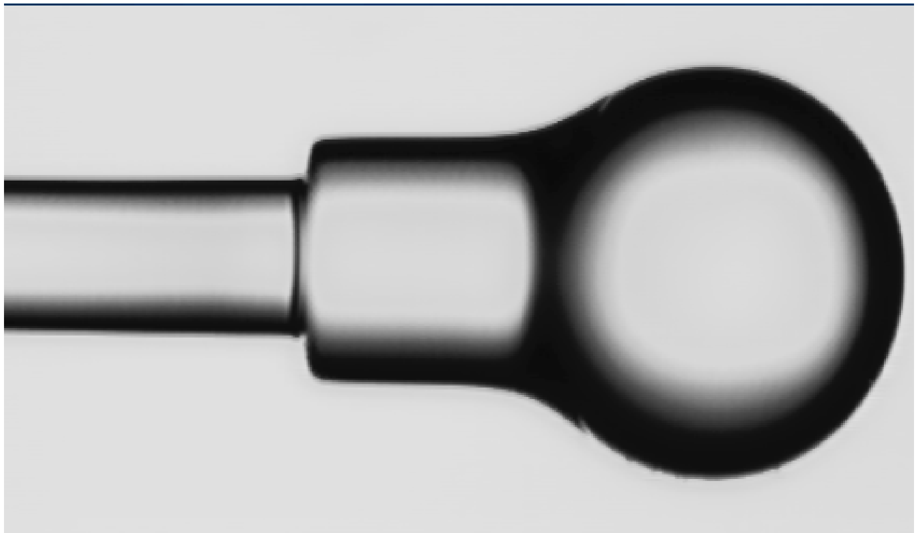


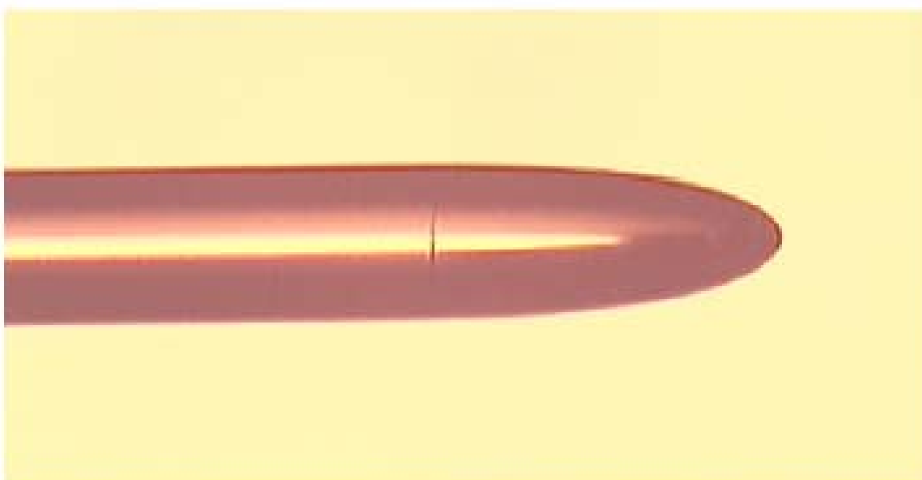
R2 (B)

22	16	10	0	10	16	22	28	
A06				A05			A04	70.0
								78.0
A17				A16			A15	80.0
								83.5
	A26				A25			84.5
A32		A31	18			A30		87.5
								88.5
			15	A39			A38	90.0
	A50				A49			87.0
A52								86.0
								85.0
			8	A57			A56	82.5
								81.5
A67			1	A66			A65	75.0

R3 (C)

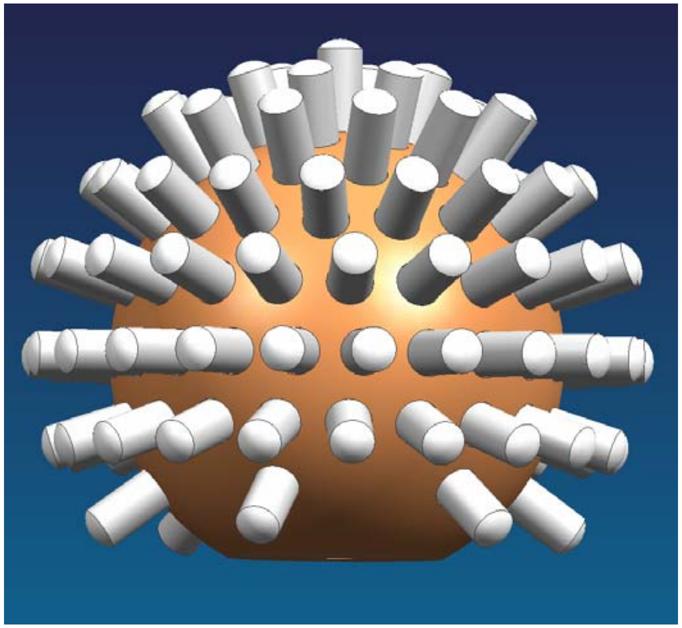
Ultra-Miniature Probes

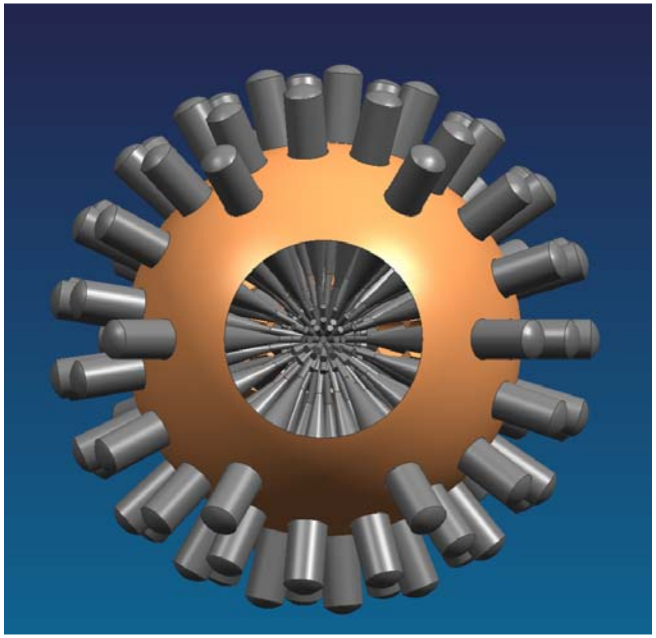




- Corning “Optifocus”
- Monolithic collimator
  - Fusion spliced
  - No epoxy
  - Single AR coated surface
- Low cost ($40-50 ea)
- Concerns
  - Efficiency
  - Alignment accuracy to probe assembly

Future Work (We Hope!)





- Memo coauthored with Vince Romero (Bechtel Nevada)
- Complimentary to current multipoint VISAR approaches
- 0.7” (< 18 mm) tip-to-tip probe diameter (above is ½” ball; really likely to be 5/8” for practical reasons)
- Interferometric OTDR to locate probe tip and target surface to few microns

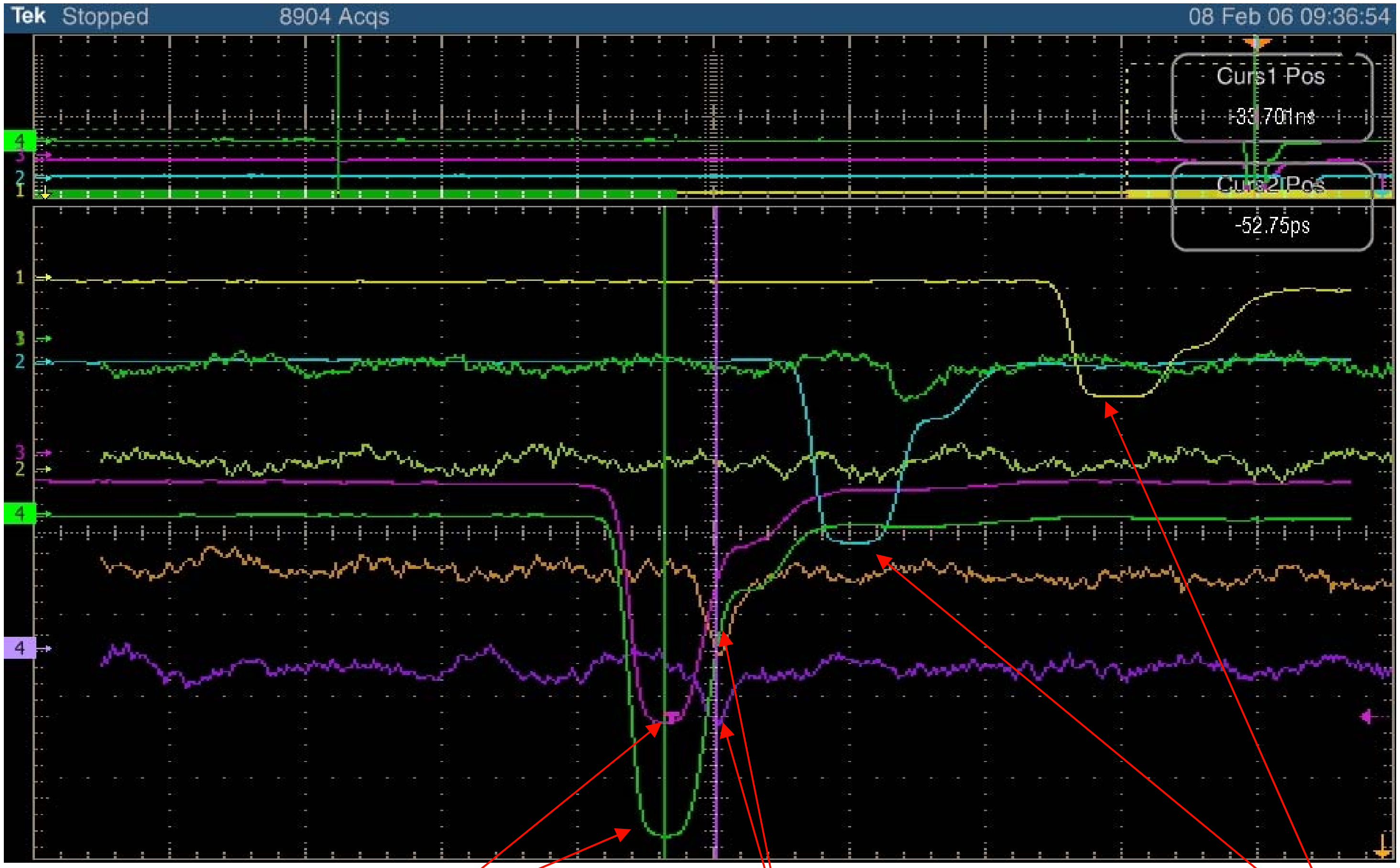
Future Probes

- Specialty Probes for Hydros & Subcrits
  - Optical Pin Domes (e.g. Vince Romero's concept)
  - High temperature pin domes (e.g. Pat Rodriguez)
  - Novel concepts (e.g. Bruce Marshall, Vince Romero & others)
- Ultra-miniature probes
  - Z capsule "pin" shots
- Ultra-long Standoff Probe
  - Use Nikon lens and retro tape – fringes at > 30 m (!)
- Combined Multifunction Probes
  - VISAR + PDV
  - PDV + Pyrometry
  - Reflectometry? Ellipsometry? Others?

Rise Time of Detector + Recording

- Used pulsed laser (instead of CW shot laser for OTDR)
- 10-90% rise time ~125 ps
- Scope ≈ 8 GHz Detectors ≈ 15 GHz

OTDR in (Near) Shot Configuration



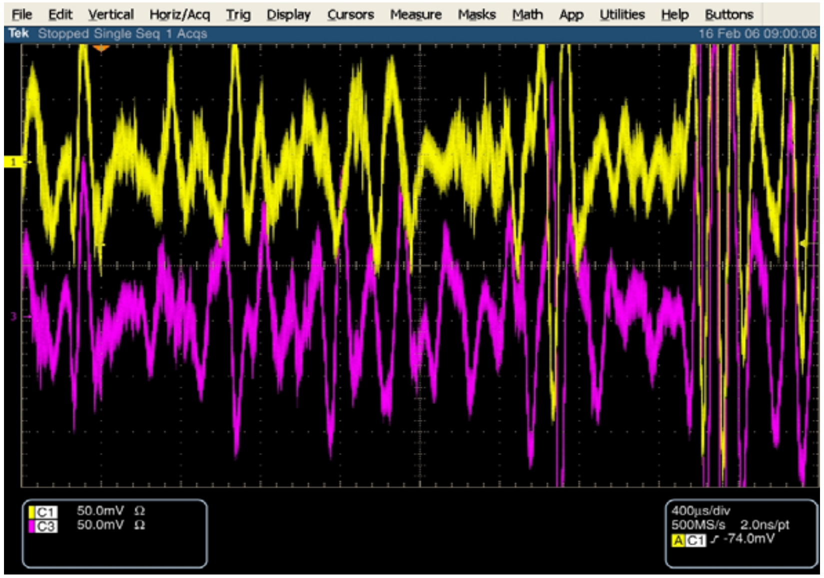
Because connectors & probes are < -50 dB return loss, used variable retro reflector at J box

Retros in Detector Box

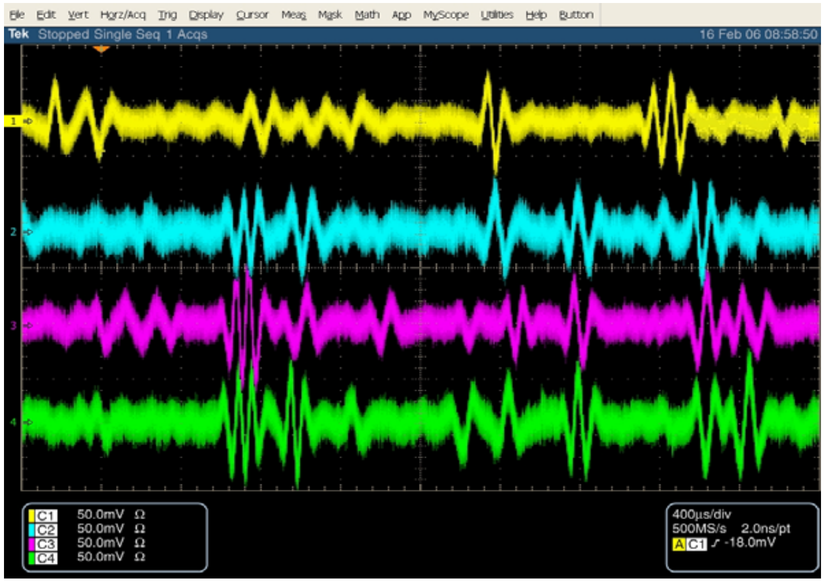
Circulator Bleedthrough at PDV System

Retros in J-Box

Post-Insertion



Free surface probes (2)

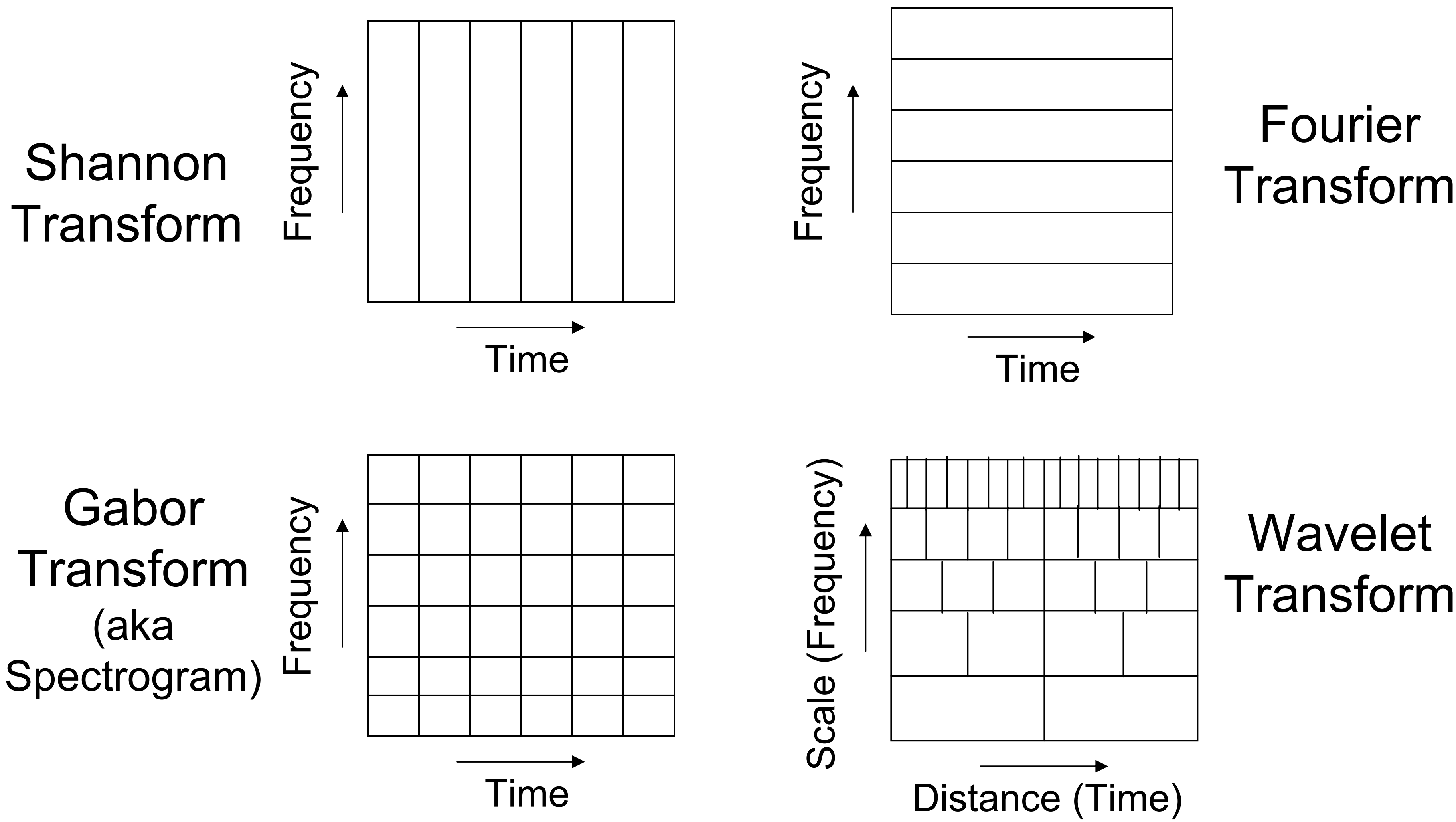


4 MP PDV Probes (3 of 4 good?)

- Non-Destructive Acoustic Testing Technique*

* Also known as “thumping the ESA plate”

Data Analysis Approaches



Data Analysis Approaches

- FFT based spectrogram (Gabor) always reliable
  - Good place to start; compromise between time and velocity resolution; best with weak fringes and low SNR in frequency domain, but may not be optimal for temporal resolution
- When fringe contrast high –
  - Hilbert transforms are attractive but unforgiving of baseline shifts and detector/digitizer harmonics; some care needed
  - Hilbert-Huang transforms for multiple discrete frequencies (?)
- For most cases where fringe contrast is moderate
  - Some optimal balance exists between velocity and time resolution for particular data sets – not global optimum for all
  - Wavelet or Wigner-Ville transform optimal? Needs more work with knowledgeable DSP folks…

Doug's 4 Big Questions

- PDV vs. VISAR Accuracy
  - Demonstrated ~0.1% absolute accuracy, better perhaps in progress
- PDV Rise Time
  - < 100 ps in signal; currently few ns in velocity (depends on velocity (frequency) and SNR in frequency domain)
- PDV Performance on Sweeping Wave
  - VISAR has problems also; PDV would show increasing contrast in frequency domain as surface across spot accelerates (small spot size with single mode fiber would be easier than with larger VISAR fibers)
- Performance on Poor Surface (e.g. goes black on shock breakout)
  - Demonstrated robust performance with large variations in SNR in frequency domain, of course if reflectivity is == 0, then of course nothing is seen (or can be), but PDV can be robust to large changes in surface reflectivity and recover velocity (frequency) when SNR improves

PDV vs. VISAR

- PDV is well suited to:
  - Long tracking distance on ill-conditioned surfaces
  - Ejecta, rubble, multiple velocities
  - More compact, easier installation & operation
- VISAR is well suited to:
  - Measuring a small velocity or velocity changes *quickly*

Summary

- PDV does ***not*** replace VISAR – both are useful diagnostics that should be chosen (or used together) as the physics requirements dictate
- Fielded > 100 shots at LANL, Sandia, NTS, other locations; multiple systems fielded simultaneously in some cases
- Continuing to develop/refine for specific applications – probe geometries tailored to experimental requirements
- Progress needed in data analysis approaches and with new probe requirements tailored to experimental requirements