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Photonic Doppler Velocimetry for Dynamic Experiments

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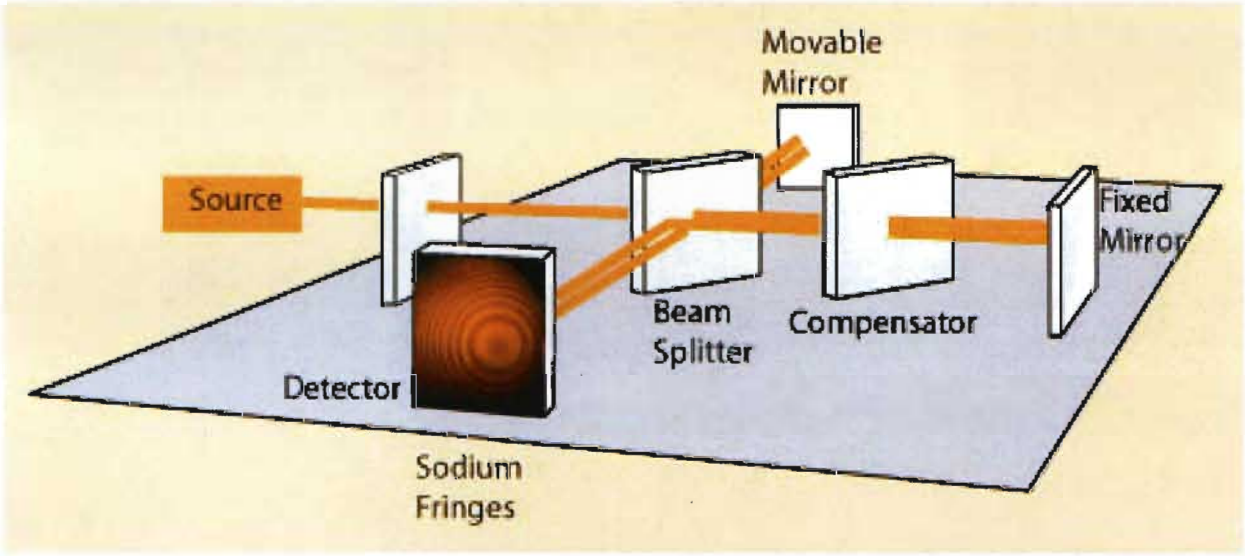
Acknowledgements

- We gratefully acknowledge our friends and collaborators at RFNC-VNIIEF (Sarov), Lawrence Livermore National Laboratory, National Security Technologies, and Los Alamos National Laboratory without whose help and hard work these experiments would not have been possible.
- We especially thank Ted Strand (LLNL)* for his generous sharing of his creativity and friendship with us and many others around the world.

* O. T. Strand, et al, "Compact system for high-speed velocimetry using heterodyne techniques," Rev. Sci. Instr. **77** (2006) 083108-1.

What is Photonic Doppler Velocimetry (PDV)?

- **Direct detection of the interference between unshifted and Doppler shifted light**
  - PDV is Ted's original name; he also suggested Heterodyne Velocimeter ("Het-V")* but it was not as catchy…



Michelson Interferometer

* Original PDV is actually a "homodyne" velocimeter since local oscillator of transmitter & reference are the same; "heterodyne" implies different local oscillators.

What is Photonic Doppler Velocimetry (PDV)?

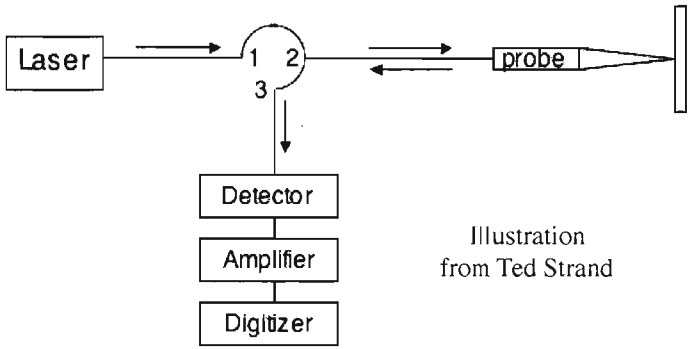
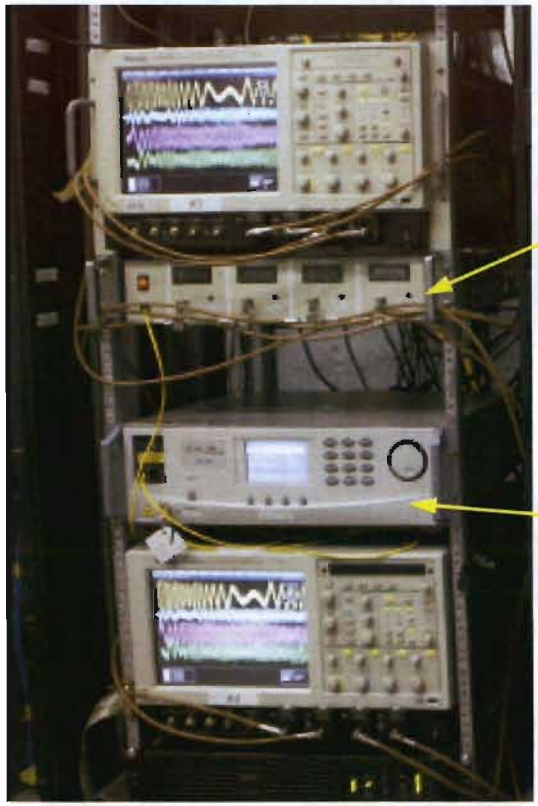


Illustration
from Ted Strand

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

@ 1550 nm and v = 1 km/s

f_b = 1.29 GHz
V = λ/2 x F
V(km/s) = 0.775 x F (GHz)



4 Channel Optics & Detector Boxes

5 W Fiber Laser

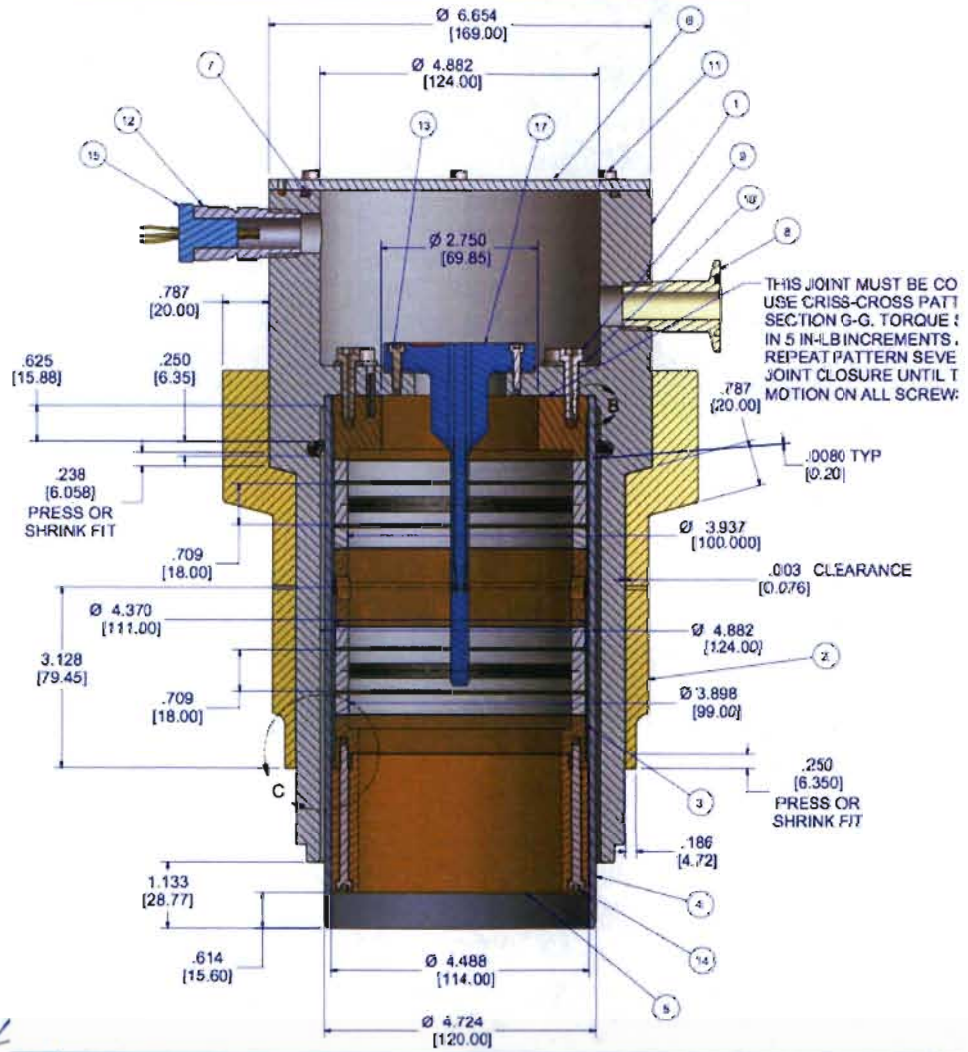
Circa 2005

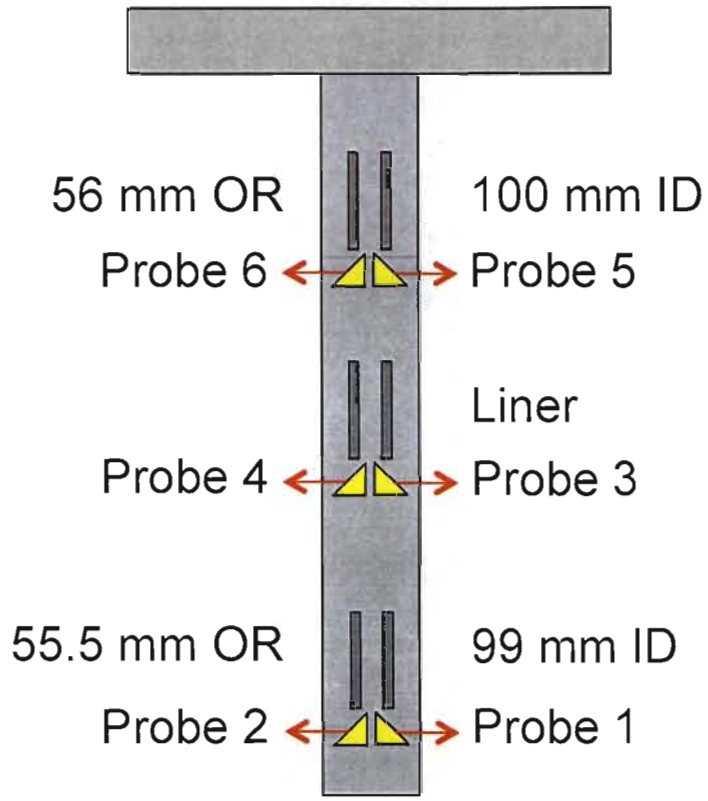
R-Damage Series of Experiments

Photo from RD 6 & 7 – April 2009

- Goal was to spall, recollect, and stop in a converging geometry
- Soft recovery of Al samples for metallographic analysis
- Used a helical EMG & two targets per shot
- Completed at VNIIEF (Sarov) in August 2011 (RD 8 & 9)

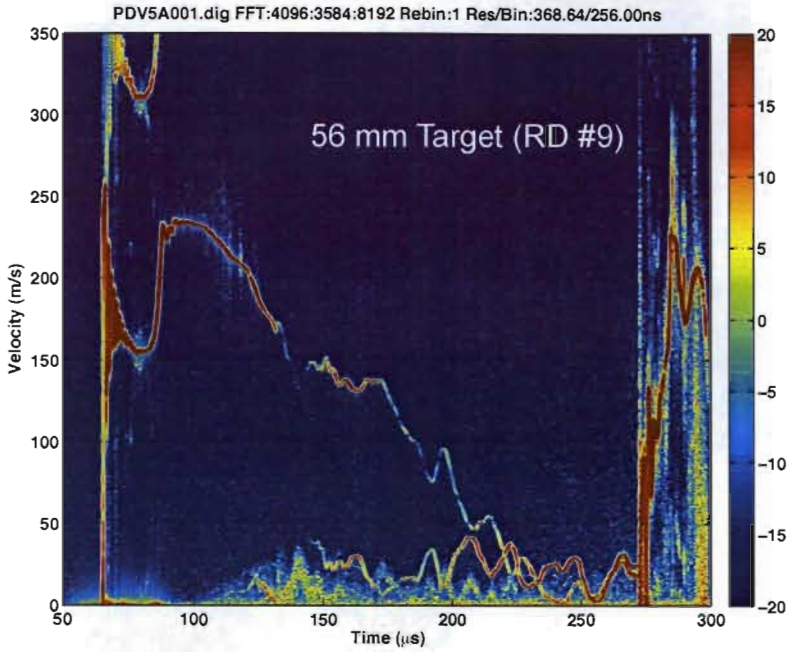
R-Damage Package & PDV Probes

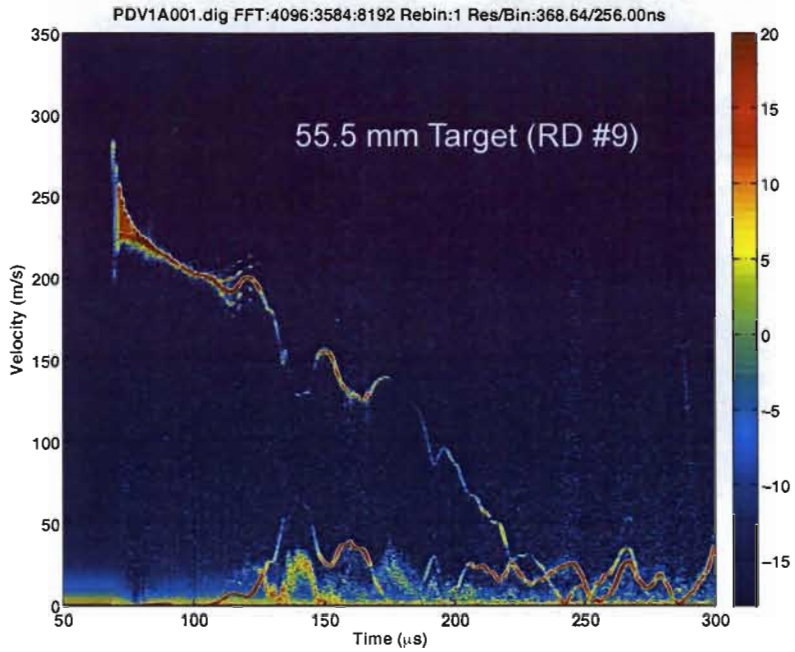




Used 1.6 mm GRIN probes
& 2x2 mm μ-prisms

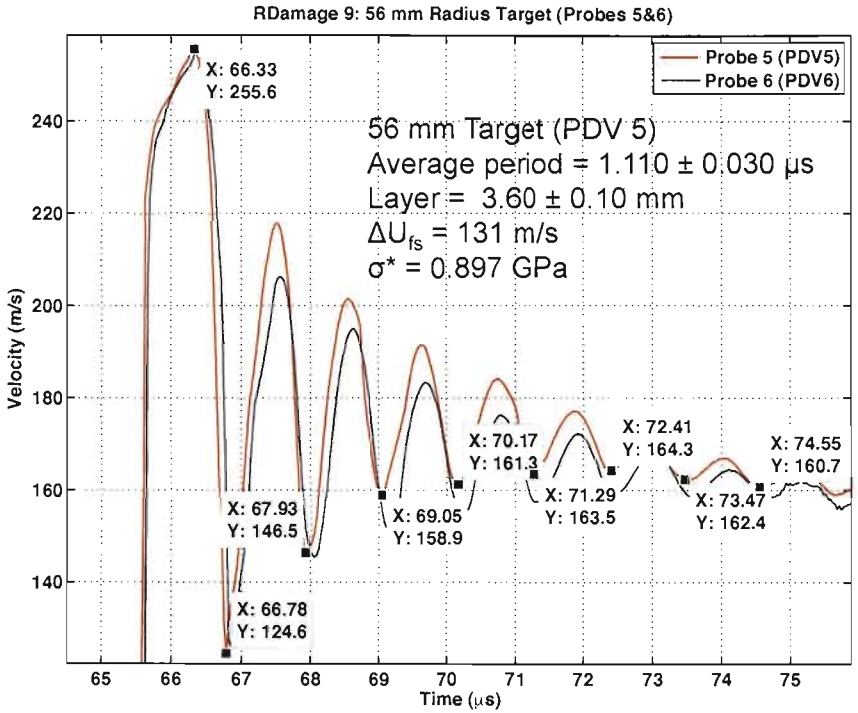
Examples of PDV Data from R-Damage 9

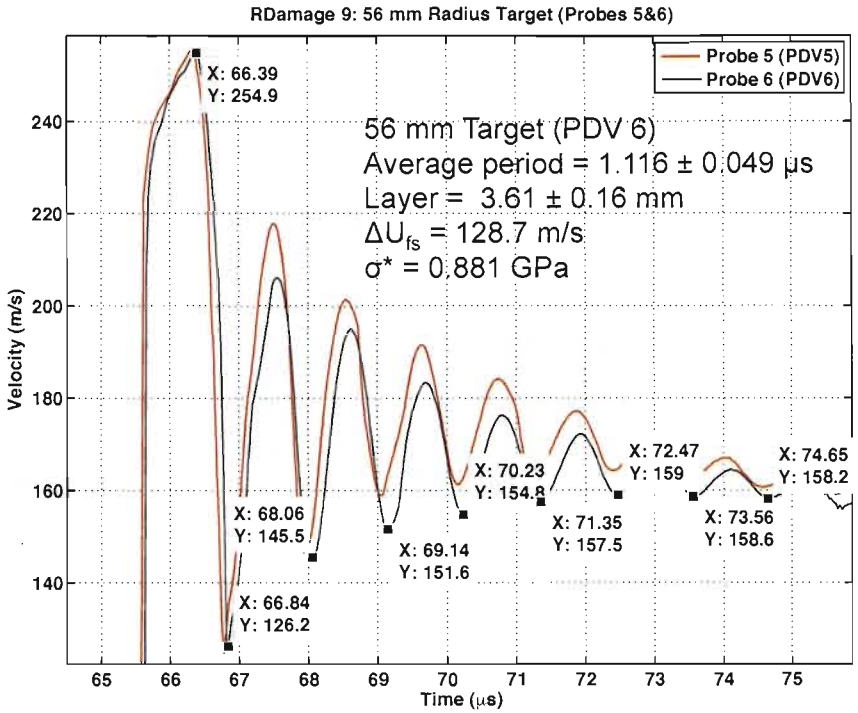




- On RD #8, both targets (55.5 & 56 mm) fully spalled, recollected, and stopped before probe impact. Samples soft recovered intact.
- On RD #9, 56 mm target also fully spalled, layer was recollected and stopped before probe impact – similar to RD8; samples also recovered intact; 55.5 mm target spalled but was not recollected (only experienced a light "tap") *and* stopped.
- These two shots span a useful range of damage/recollection space w/sample recovery

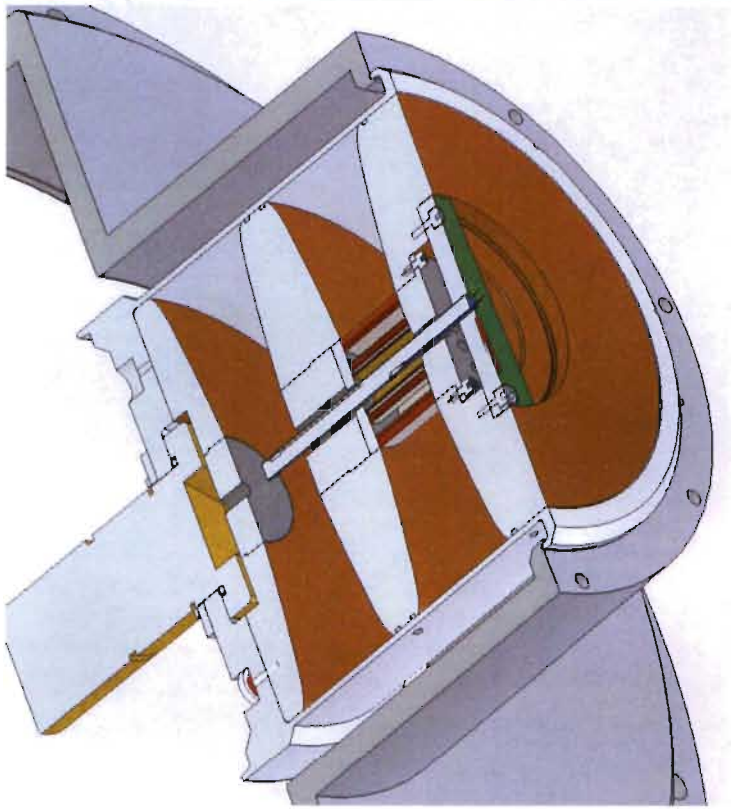
PDV Data Show Reproducible, Precision Results





- PDV data illustrate the practicality of precision, reproducible implosion experiments using pulsed power
- For further details, please refer to Olga Tyupanova's (VNIIEF) talk elsewhere in this meeting

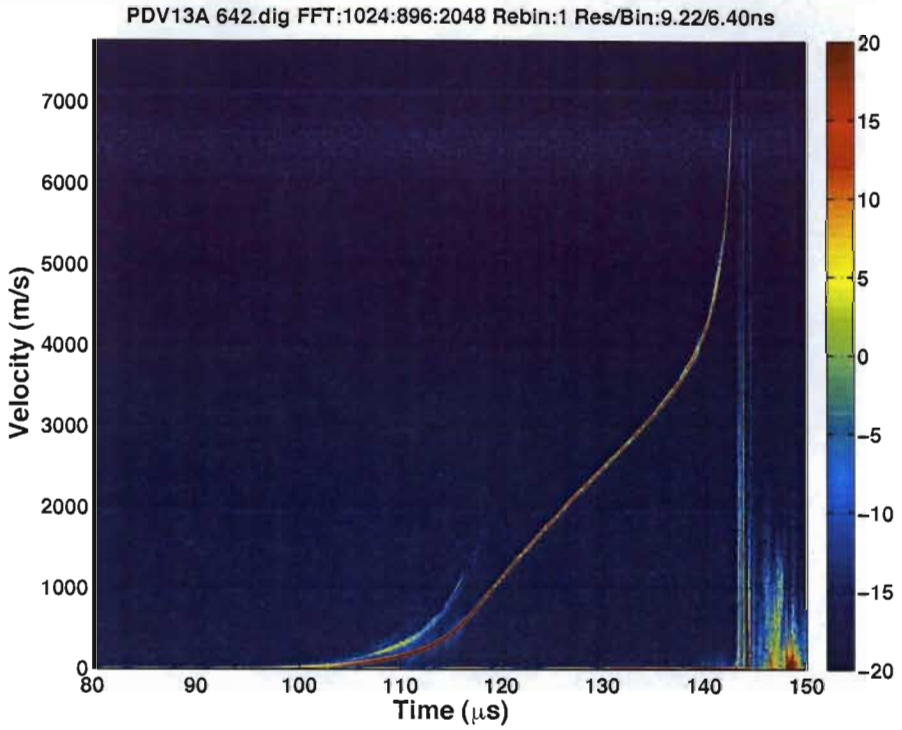
High Speed Liners for Velocity Multiplication

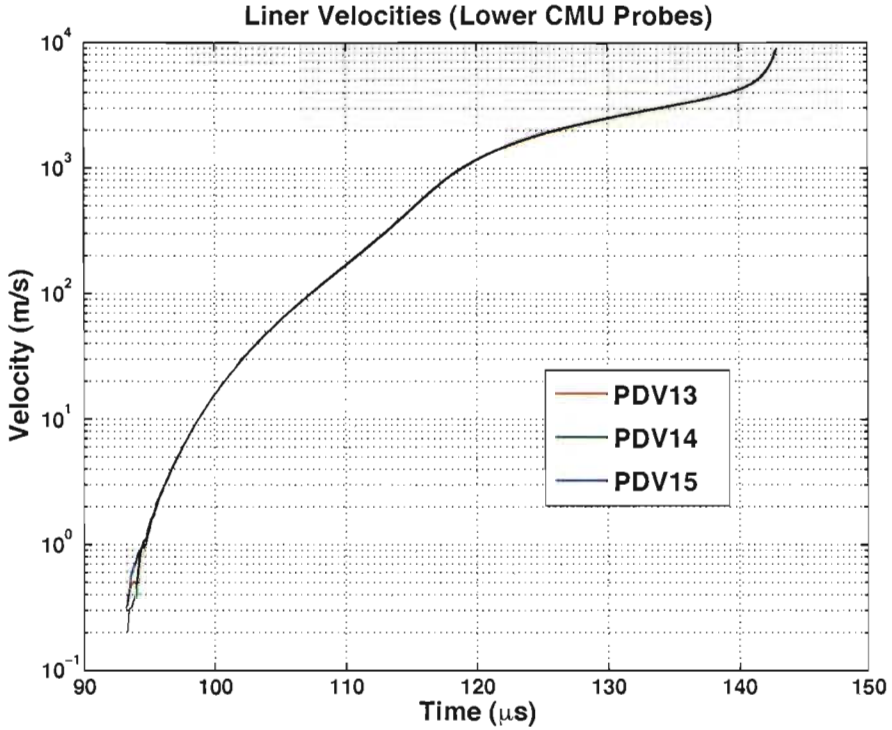


Robert G. Watt, et al, "Preshot report, MS-2: Development of a magnetically driven target for thermo-nuclear burn studies," Los Alamos National Laboratory Report LA-UR-10-01305 (2010); Robert G. Watt, et al, "MS-2 post-shot report," Los Alamos National Laboratory Report LA-UR-10-01981 (2010).

- Laboratory Directed Research & Development project to explore feasibility of using a high-speed liner impacting a series of concentric shells to achieve very high pressures & temperatures using velocity multiplication
- Miniature PDV probe (3.6 mm diameter) measured both liner acceleration & velocity multiplication at several points

Dynamic Range of PDV





- Large dynamic range of PDV data (> 30dB) allows extraction beyond -3dB bandwidth limit of recording
- All 3 probes track the velocity over a range of ~5 decades*

* Limited by 8 GHz/20 GS/s recording

Improvements to PDV are in Progress

- Limits to a conventional PDV are the bandwidth of amplified detectors (20 GHz ⇔ ~15.5 km/s) and recording oscilloscopes (20-33 GHz ⇔ ~15.5-25.6 km/s)
- Practical limit to the number of points fielded is often the cost of high speed recording, although depending on the velocity range of interest, slower scopes do well
- Gen I PDV systems (usually) use the transmit laser as reference light source: avoids trouble with laser linewidth & stability
- Gen II systems with many points employ tuneable lasers to multiplex in frequency (and time) domain

Multiplexed PDV Development Underway

- MPDV developed by Ed Daykin under NSTec SDRD program
- "Proof of concept" 28 pt. demonstration unit tested (4/11)
- Accelerated development: prototype version (32 point system shown) & tested (8/11) in HE drive experiments
- @ 8 points per detector, 4 channel scope records 32 probes

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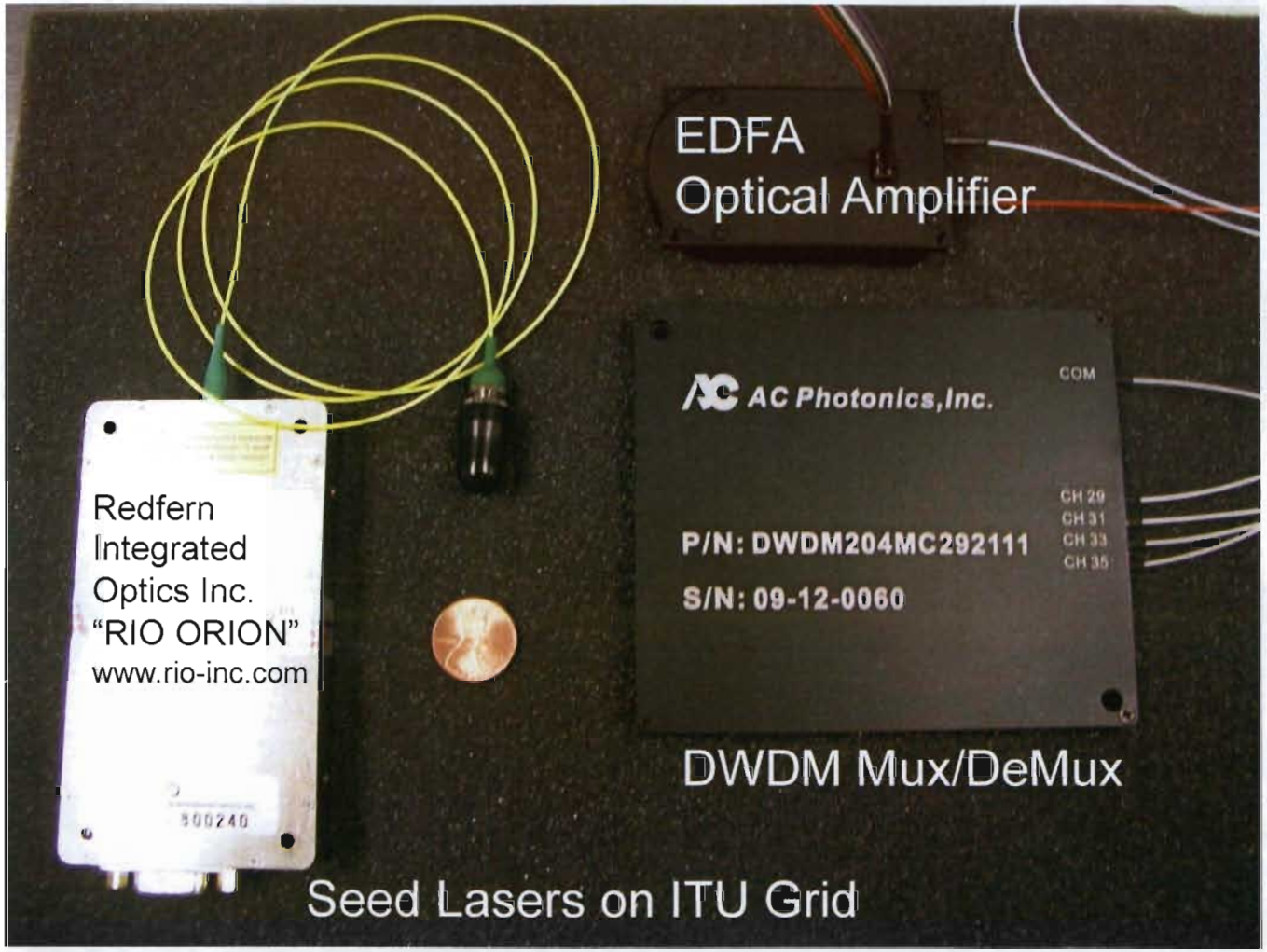
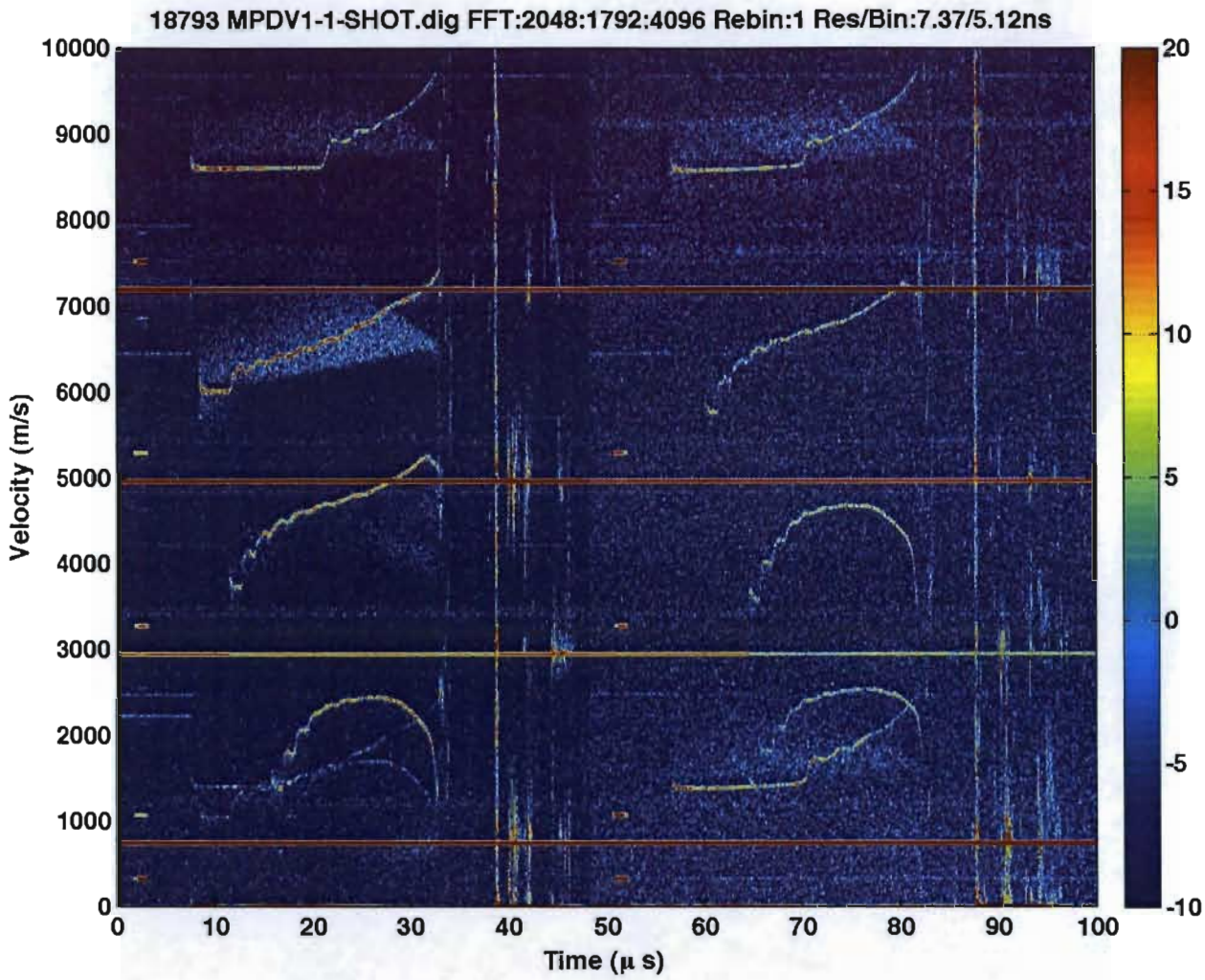
Site Directed R&D SDRD

MPDV uses Telecom Technologies



MPDV Data from HE Driven Tests

- Multiplexed x4 in the frequency domain (ΔF: 1.0, 3.8, 6.7, & 9.5 GHz on ITU channels 29, 31, 33, & 35)
- Also multiplexed x2 in the time domain (with a 50 μs fiber delay)
- HE driven copper hemisphere with a multipoint PDV probe near origin



Summary

- PDV is the future of velocimetry measurements in a wide variety of experimental situations
- Both PDV & MPDV can measure shock breakout time to < 1 ns (± 30 ps demonstrated & can be improved) – already used at LANL & LANL on gun experiments
- Multiplexed PDV may be a better choice when the number of points exceeds some value (~20?)
  - MPDV now uses "up-conversion" for multiplexing
  - Greater than 100 km/s possible with "down-conversion" & MPDV (over limited ΔV intervals)