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Title: Velocimetry Overview for visitors from the DOD

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Intended for: Follow-up information requested by DOD visitors to U1-A.

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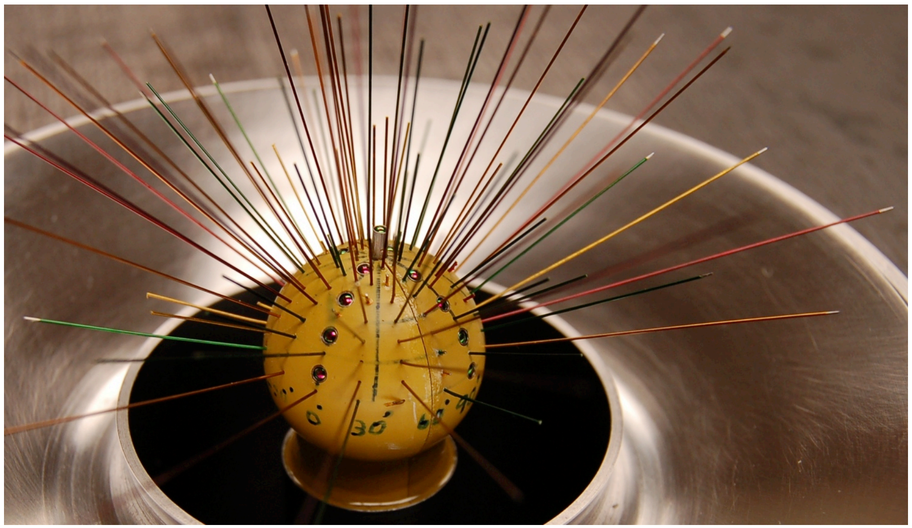

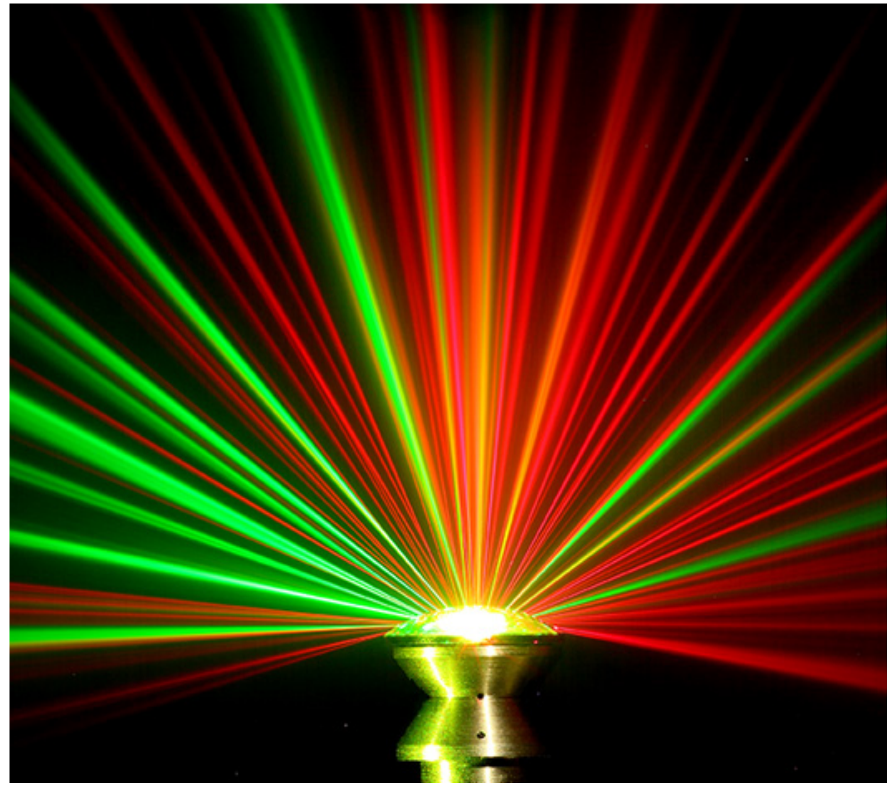

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August 19, 2016

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Velocimetry in the weapons complex

We are in the midst of a transformative period in which technological advances are making fundamental changes in the measurement techniques that form the backbone of nuclear weapon certification. Optical velocimetry has replaced electrical shorting pins in "Hydrotests," which measure the dynamic implosion process. This advance has revolutionized nuclear weapons certification during the last 5 years. We can now measure the implosion process that drives a nuclear detonation with many orders of magnitude more resolution in both space and time than was possible just 10 years ago. It has been compared to going from Morse Code to HDTV, resulting in a dozen or more improvements in models of these weapons.

These Hydrotests are carried out at LANL, LLNL and the NNSS,* with the later holding the important role of allowing us to test with nuclear materials, in sub-critical configurations (i.e., no yield.) Each of these institutions has largely replaced pins with hundreds of channels of optical velocimetry. Velocimetry is non-contact and is used simultaneously with the X-ray capability of these facilities. The U1-a facility at NNSS pioneered this approach in the Gemini series in 2012, and continues to lead, both in channel count and technological advances. Close cooperation among LANL, LLNL and NSTec in these advances serves the complex by leveraging capabilities across sites and accelerating the pace of technical improvements.

* Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Nevada National Security Site, administered by National Security Technologies, LLC (NSTec)

What we do:

Congress has directed the Weapons Labs (Los Alamos, Lawrence Livermore and Sandia) to report annually to the President of the United States through the Secretaries of Energy and Defense on the state and health of the U.S. nuclear stockpile, through work done under the science-based Stockpile Stewardship Program.

How we do it:

Computational models are guided by and constrained to match *experimental results* which include surrogate, sub-critical experiments and legacy underground nuclear tests. These models are then applied to assure us that our stockpile is safe, reliable, and secure.

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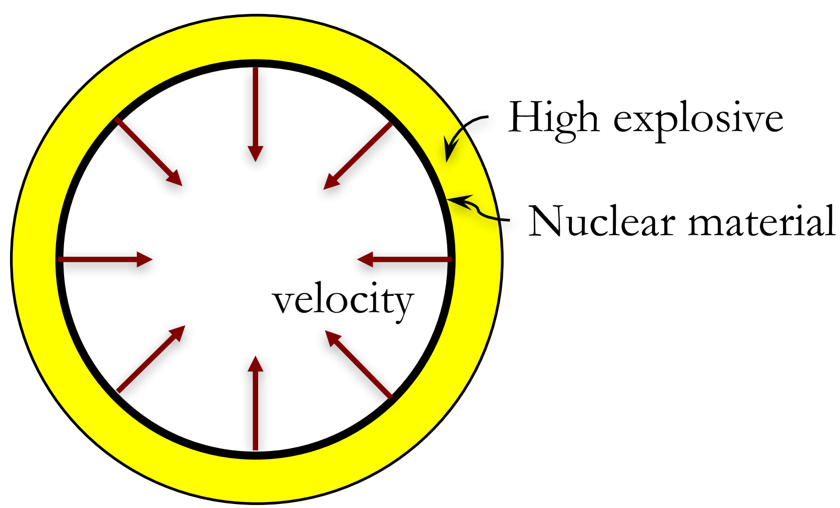
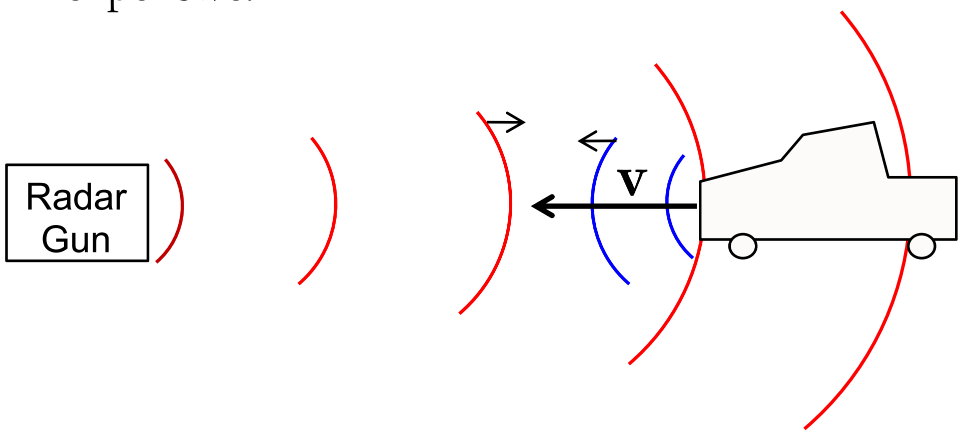
Velocity is a fundamental quantity in nuclear implosions

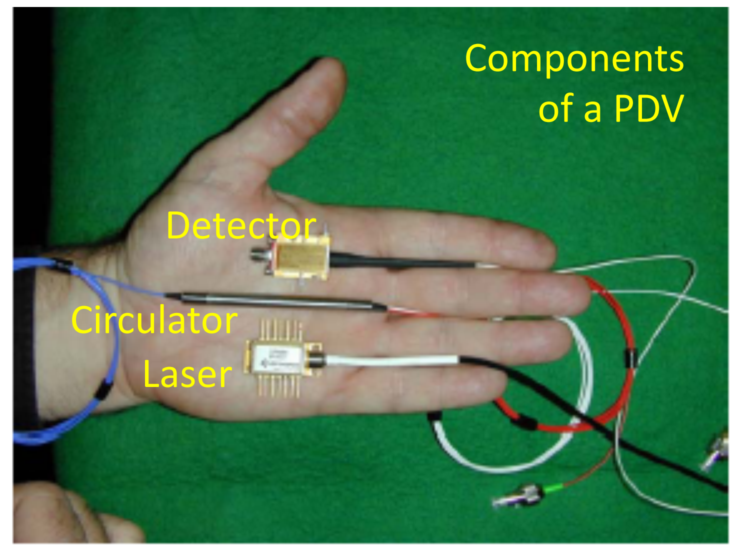
Explosives drive nuclear material from an initially safe configuration into a critical mass. Our ability to predict weapon performance therefore rests in part on our ability to calculate the material configuration at all times during the implosion. What is calculated is the acceleration and resulting velocity that gives rise to the material configuration. At the moment, there is no non-contact way to measure acceleration directly, and so velocity is the next highest resolution measurement technique available.

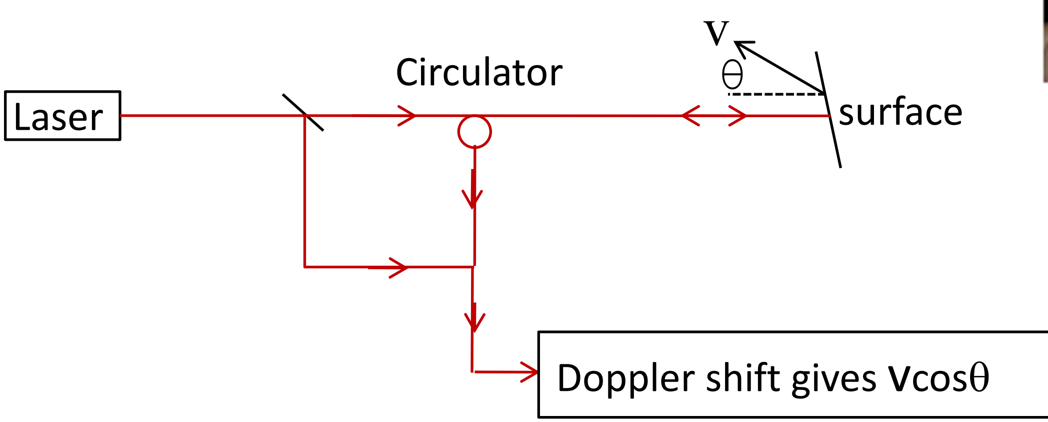


Photonic Doppler Velocimetry (PDV)

- Police use a radar, we use an optical laser beam.
- The velocity of the target shifts the frequency of the reflected beam, and we use optical heterodyne velocimetry to measure that frequency shift, and therefore velocity (v).
- The components are small, inexpensive and fiber-coupled; recording channels are expensive.







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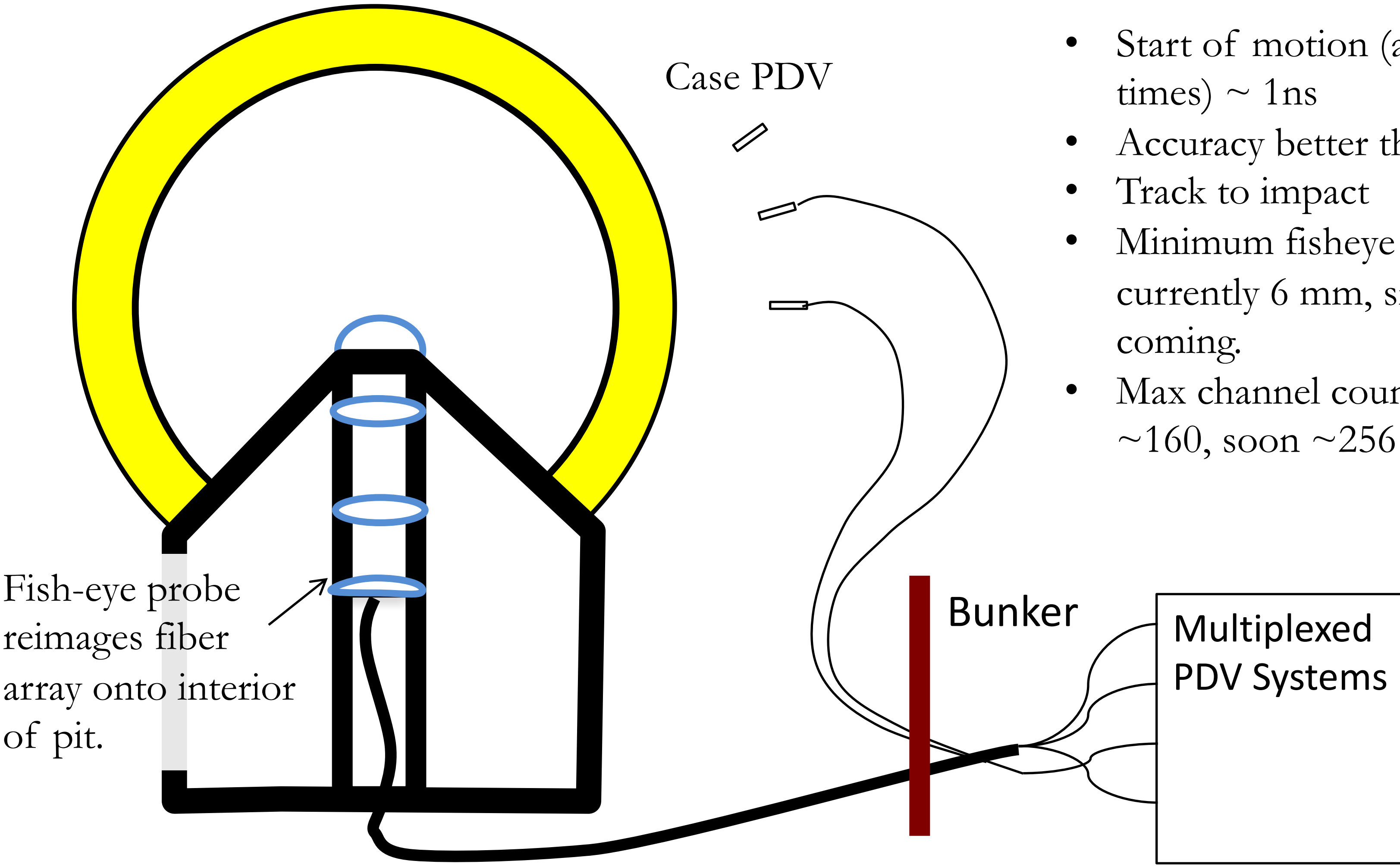
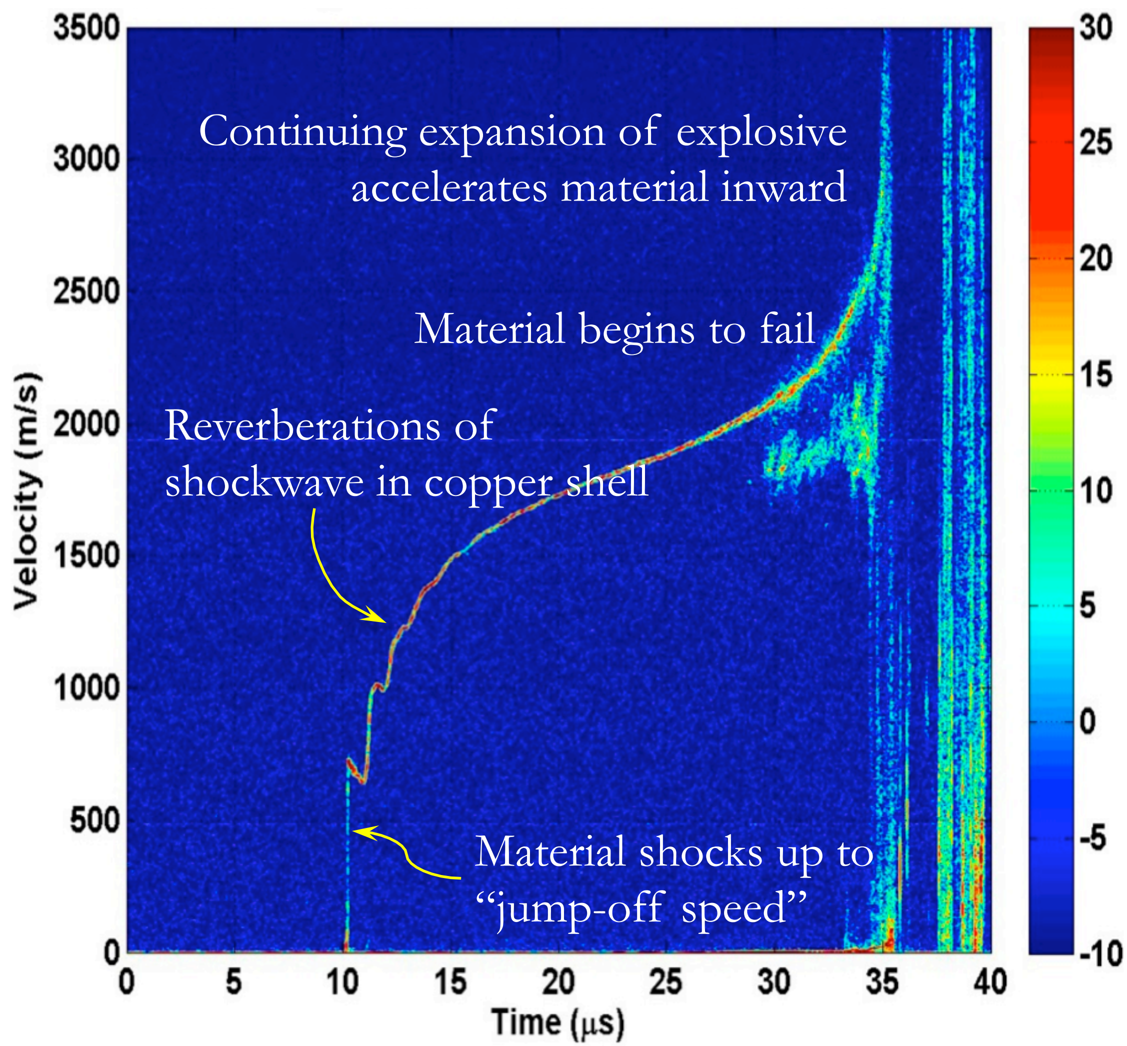
Typical Optical Hydrotest



- Start of motion (arrival times) ~ 1ns
- Accuracy better than 1%
- Track to impact
- Minimum fisheye radius currently 6 mm, smaller coming.
- Max channel count now ~160, soon ~256

Velocimetry: continuous measurement of material flow with a resolution of a few ns.

Velocimetry spectrum from an unclassified copper hemisphere experiment



Measurement attributes of optical heterodyne velocimetry

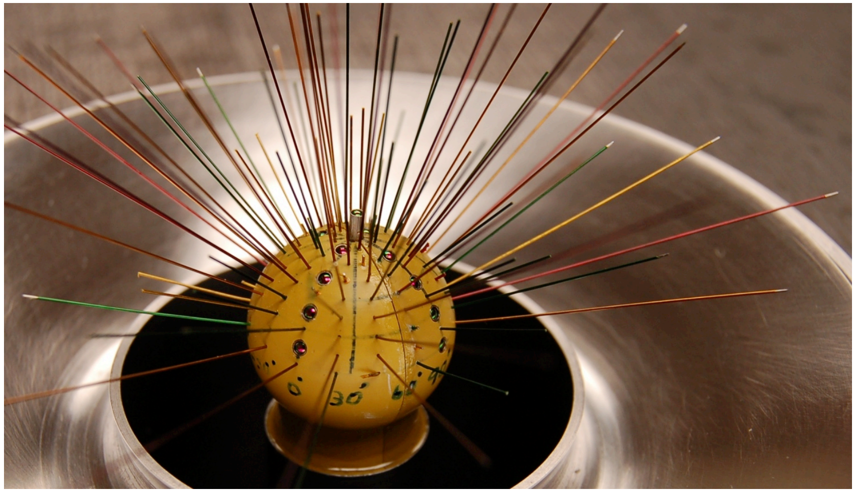
1. Large number of measurement points can fit in a small confined geometry.
2. Non-contact.
3. Unambiguous interpretation: measures the component of scatterer velocity along the beam, $v_{scatterer}$* $\cos(\theta)$.
4. High accuracy velocity measurements with a time resolution of a few ns.
5. Robust extraction of signal from noise using analysis techniques in the frequency domain.
6. Can measure multiple velocities simultaneously.
7. Can measure the bulk velocity of a cloud of particles – in principle, no solid surface required.

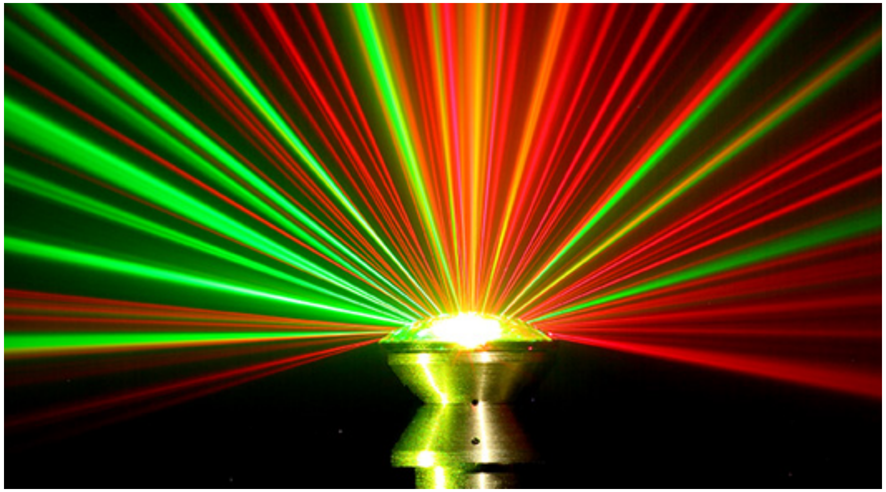
Single-point to multipoint

To provide the volume of velocimetry data required to constrain weapons models, the single-point measurement optics and recording had to be re-invented to allow miniaturization of the probe while increasing the number of beams, and multiplexing many signals onto a single recording channel. Similarly, analysis tools had to become much more stream-lined.

This was done in a heroic fashion during the Gemini series, from 2011-2012. LANL and NSTec partnered under the subcritical experiment program to create MPDV, "multiplexed PDV," and its corresponding analysis program "QuickView," and fielded it at U1a. The benefits became obvious to the complex as the analysis was completed and the results shared, and the technique has now become standard across the complex in just the ensuing few years since 2012.

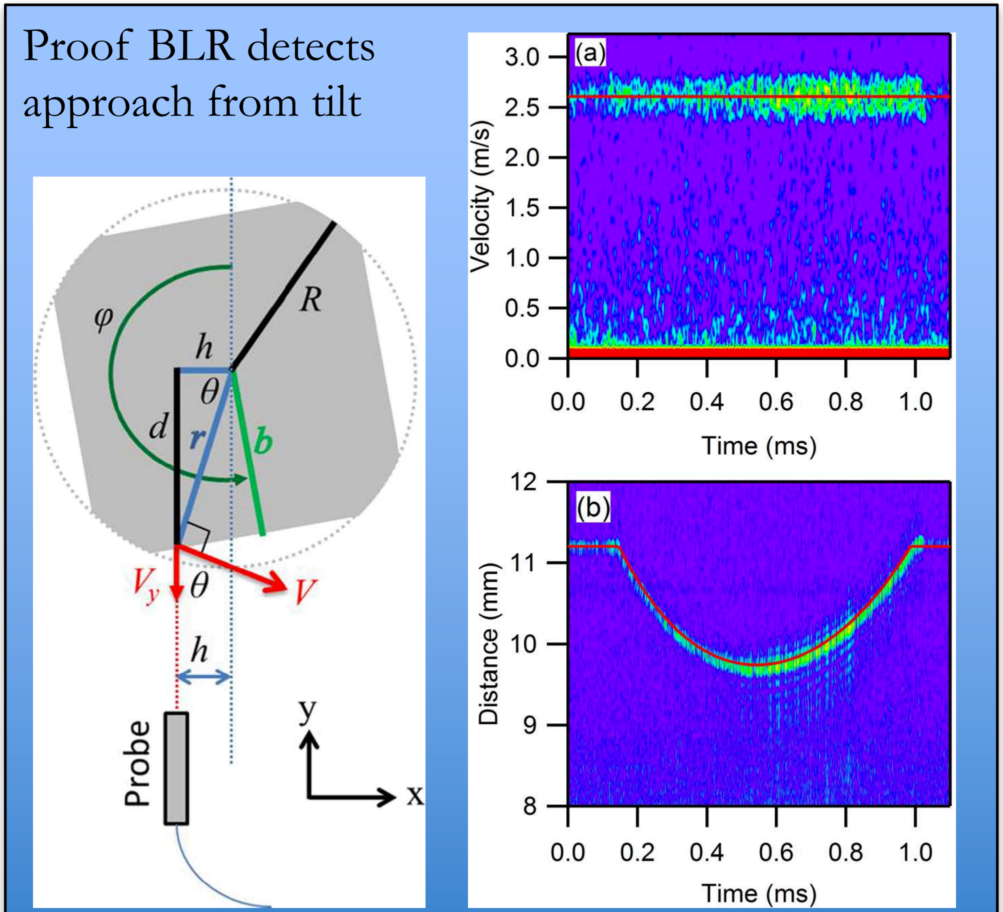
Left: old technology (pins) alongside new (optical probes) in a large pin-dome; PDV systems and recording channels for 17 optical points fills bunker. Right: advanced probe and systems now provide 128 points in same footprint, same number recording channels

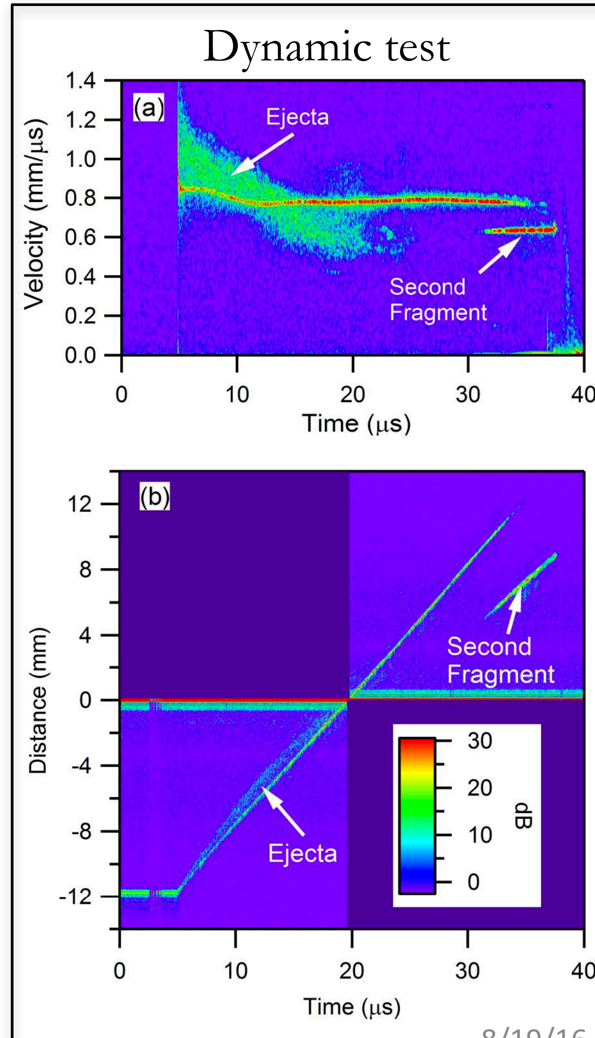




The innovations continue

One of velocimetry's assets, its unambiguous interpretation as vcosθ, means it cannot report position directly. A complimentary diagnostic has now been invented and is in the process of its first deployment down hole: BLR, broadband laser ranging.





Summary

- Because velocity is one of the fundamental quantities in the physical description of shock physics, and because it can now be measured with nanosecond time resolution, <1% velocity accuracy, for 100s of channels in a small confined space, optical velocimetry is growing dramatically in applications to shock physics and the weapons community.
- Velocimetry now plays a critical part in the weapons labs mission to certify our nations stockpile, having largely replaced electrical shorting pins for Hydrotesting.
- Because fiber-optic, laser and high-bandwidth electronics continue to advance quickly, we are continuing to improve the dynamic range of MPDV, the analysis of the data, and develop additional measurement techniques to supplement MPDV. These continuing advances will allow us to establish new baseline data sets on all our weapons systems that will provide a whole new level of fidelity in our understanding and predictive capability.
- The velocimetry community has set an important precedent in leveraging resources across laboratories to maximize our technical progress and minimize redundancy.