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Broadband laser ranging for explosive experiments

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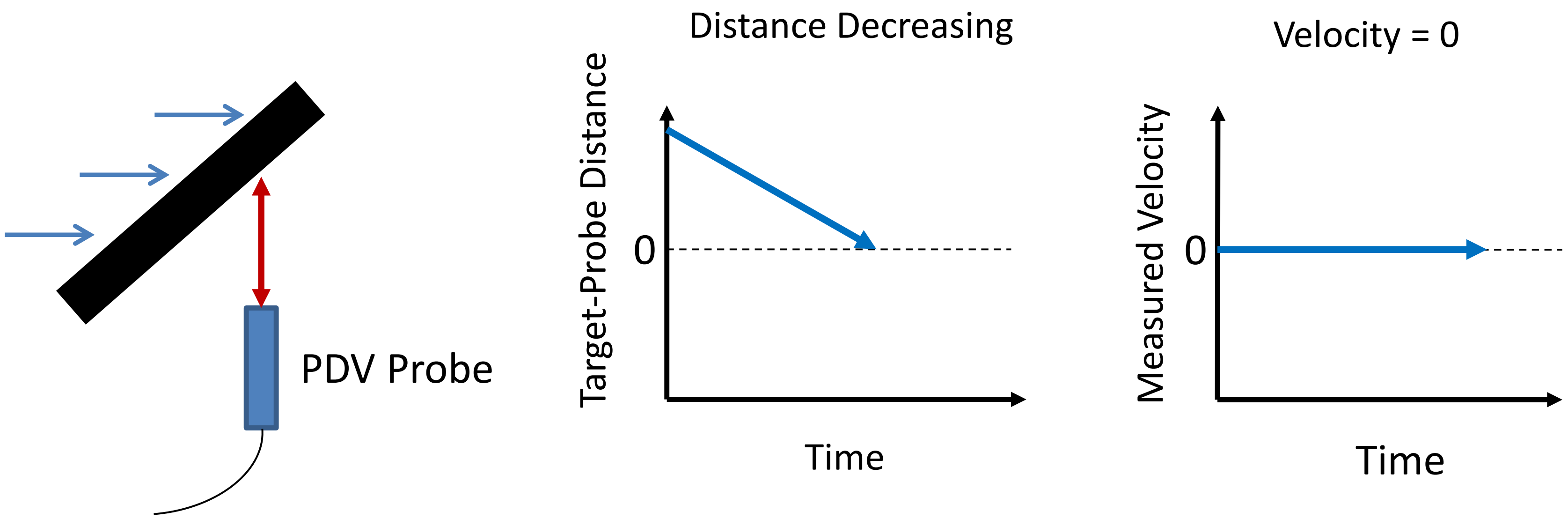
The time integral of the PDV velocity does not always give material position, independent position measurements are needed

Extreme Case: motion perpendicular to probe axis * (Briggs et al.)



Off-normal motion may be important, VISAR and PDV can not detect it.

* Briggs et al, J. Phys.: Conf. Ser. **500**, 142005 (2014)

Examples of PDV experiments in the literature with potential off-normal motion

Expanding cylinder tests

Imploding cylindrical liners on Z

Explosively driven frangible joints

Shaped charge liners

Time history of positions useful for comparing to PDV as well as to x-ray images and impact pins.

Position measurement needs for dynamic experiments are unique and are not met by traditional time-of-flight range finders

Goals of ranging system

- Accuracy and resolution < 100 μm and sampling rates > 1 MHz
- Full range from mm to many cm depending on experiment
- Independent of target velocity (immune to Doppler shift)
- High dynamic range for returning signal from time varying surface
- Compatible with existing PDV probes
- Capable of simultaneous detection of multiple targets (fragments or particle clouds)

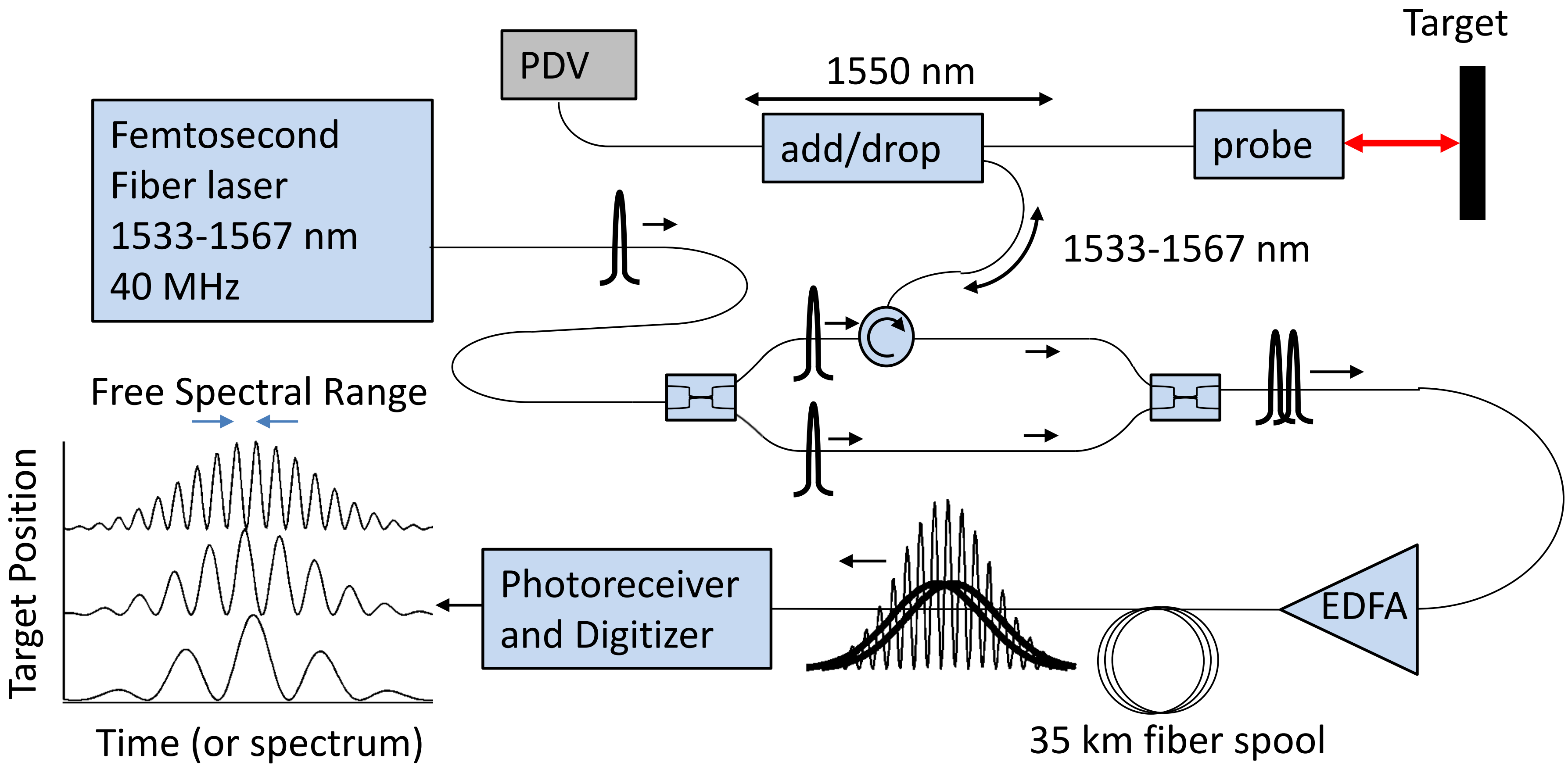
We discovered a potential solution to the ranging problem while searching the literature

In April of 2014 we found a journal article describing a technique for optical ranging that is immune to the Doppler shift*

- They tracked small position fluctuations of a vibrating speaker cone and had a total range of about 10 mm
- We had all equipment and local expertise to try a quick bench test
- The technique looked promising for use on explosive experiments with some minor modifications

* Dynamic ranging idea from: H. Xia and C. Zhang, Optics Express, **18**, 4118 (2010)

Our first system for Broadband Laser Ranging (BLR) and PDV



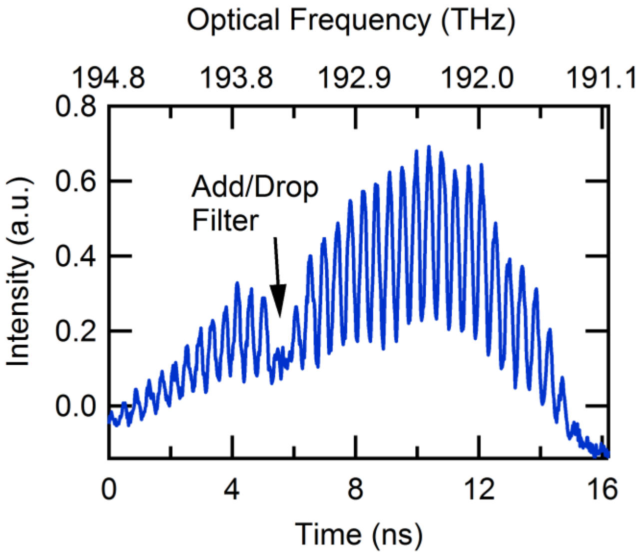
Essentially a fiber broad spectrum interferometer where the interfered spectrum is converted to the time domain using a short pulsed laser and fiber dispersion

Our innovation was to modify the diagnostic for use on explosive experiments by adding PDV and extending the full range

In June of 2014 we built a prototype system and began fielded it on small-scale experiments

Prototype System

Single Pulse Signal

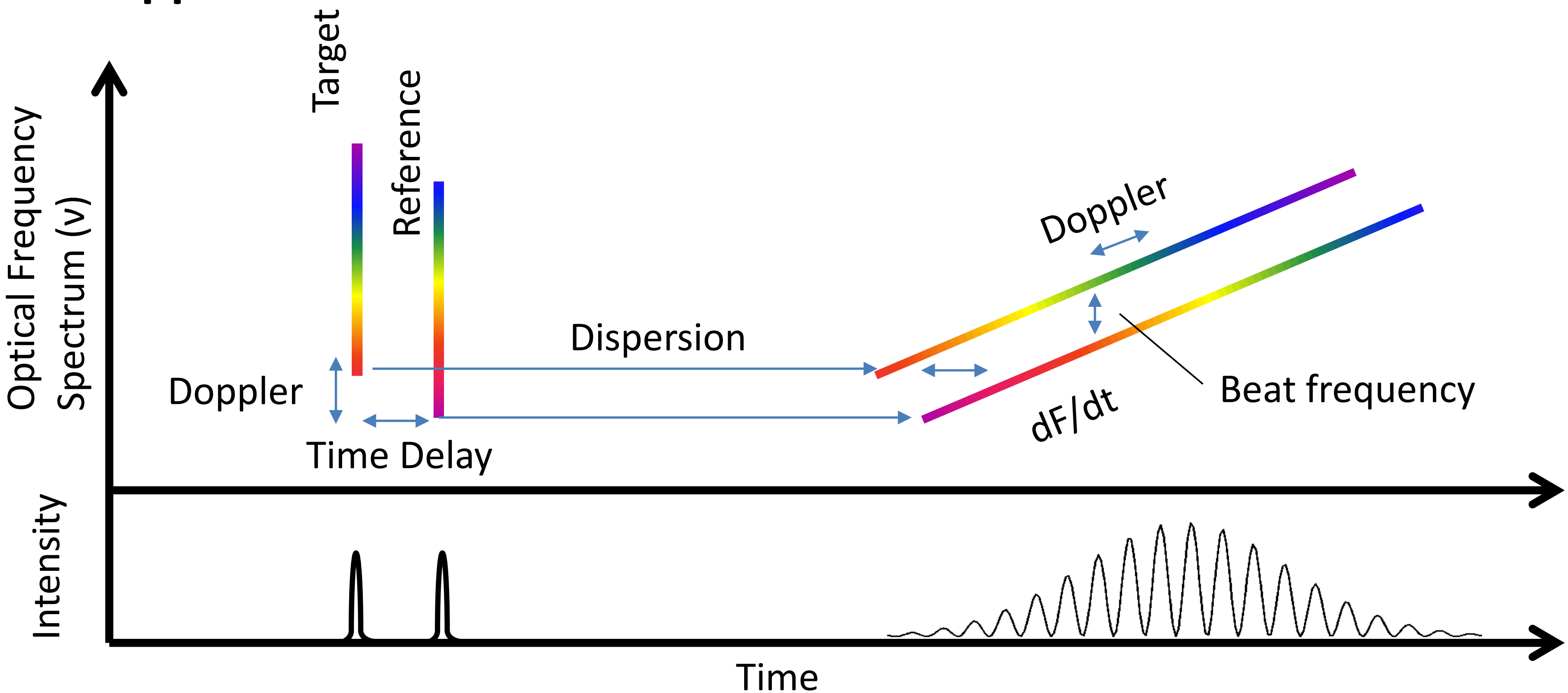


Pulse rep rate at 40 MHz

FFT analysis is used to extract the beat frequency/position information

Single position per peak in the FFT

Frequency domain description demonstrates the insensitivity to the Doppler shift

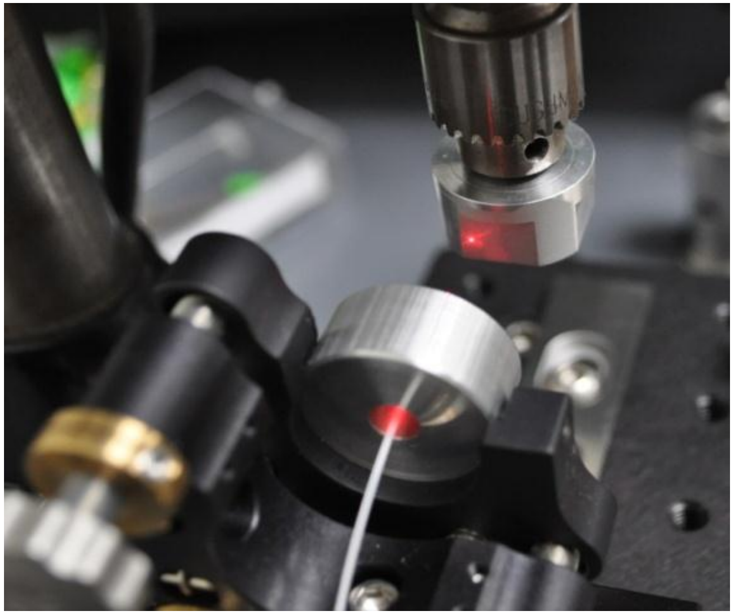


Dispersion preserves the delay between pulses at each optical frequency. <u>Doppler doesn't change the delay (or beat frequency) if there is zero dispersion when the pulse is on target</u>

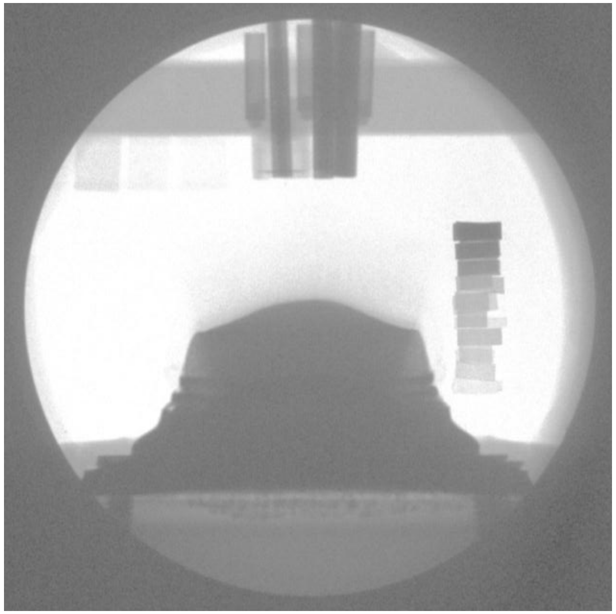
Time Delay = Beat frequency/(dF/dt), independent of the Doppler shift
Position = c*Time Delay/2

Experiments

Spinning Square



Explosive Experiments

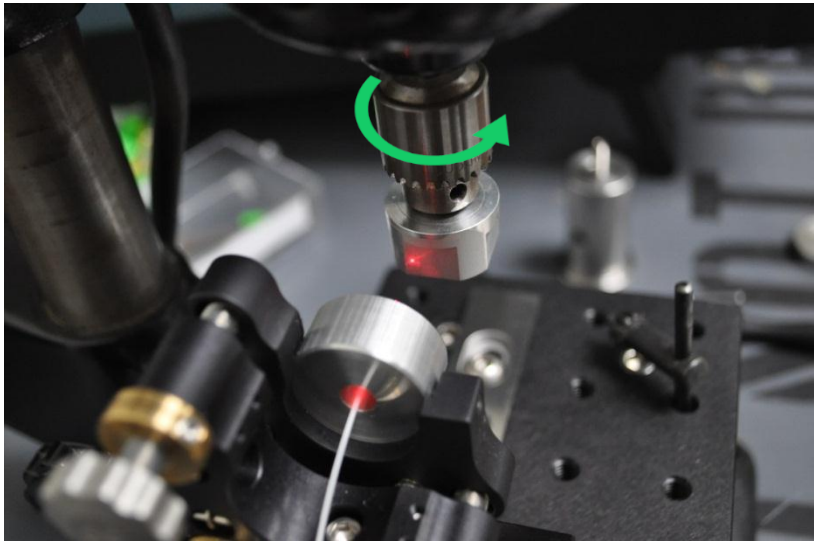


Why do we need to measure both velocity and position?
Example: Spinning object

Calculating the time integral of PDV velocity to be obtain distance can be misleading

A spinning square emphasizes this difference (similar to Dan Dolan's "spinning cam" demonstration)

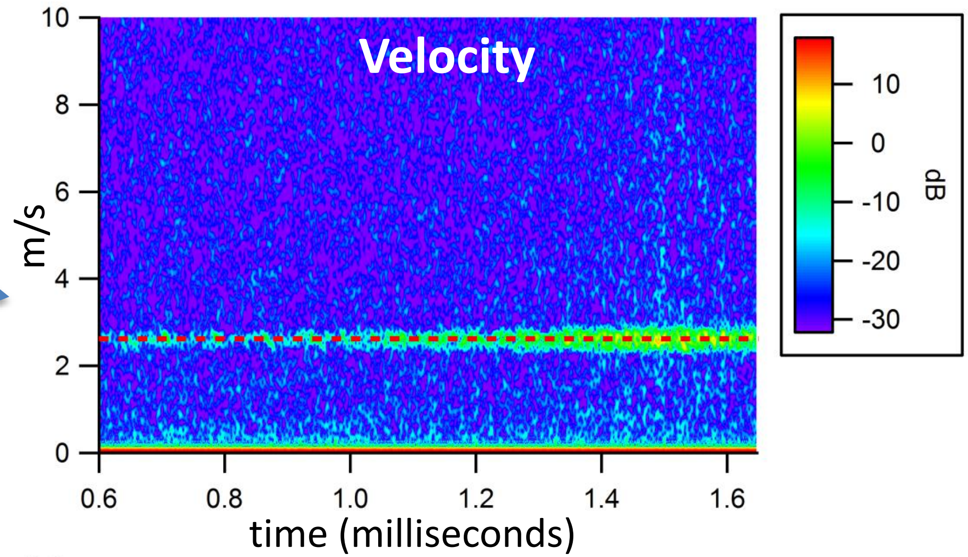
We performed simultaneous velocity and ranging data on a spinning square target

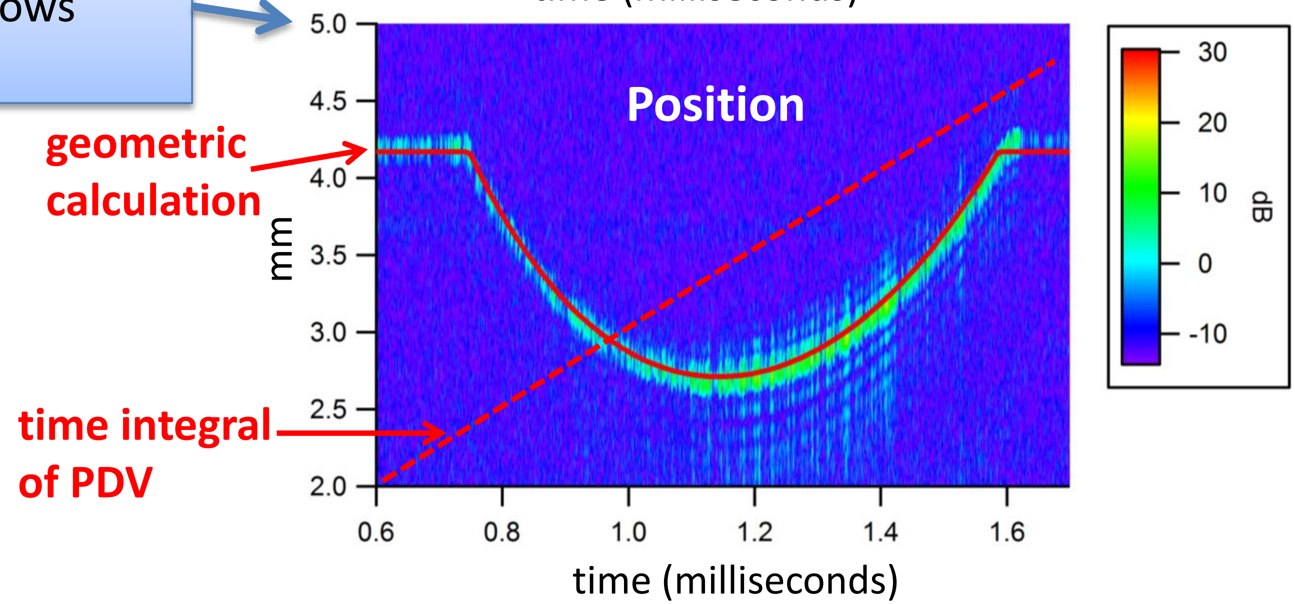


Distance to the surface of a spinning square by range measurement is correct; time integral of PDV is not

PDV spectrogram from spinning square shows constant speed

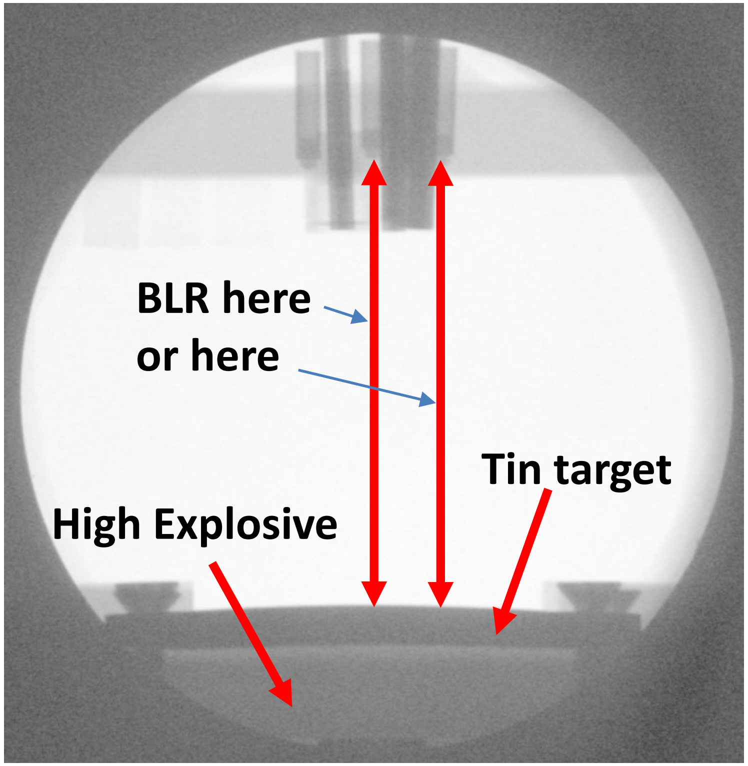
Range spectrogram from spinning square shows changing distance



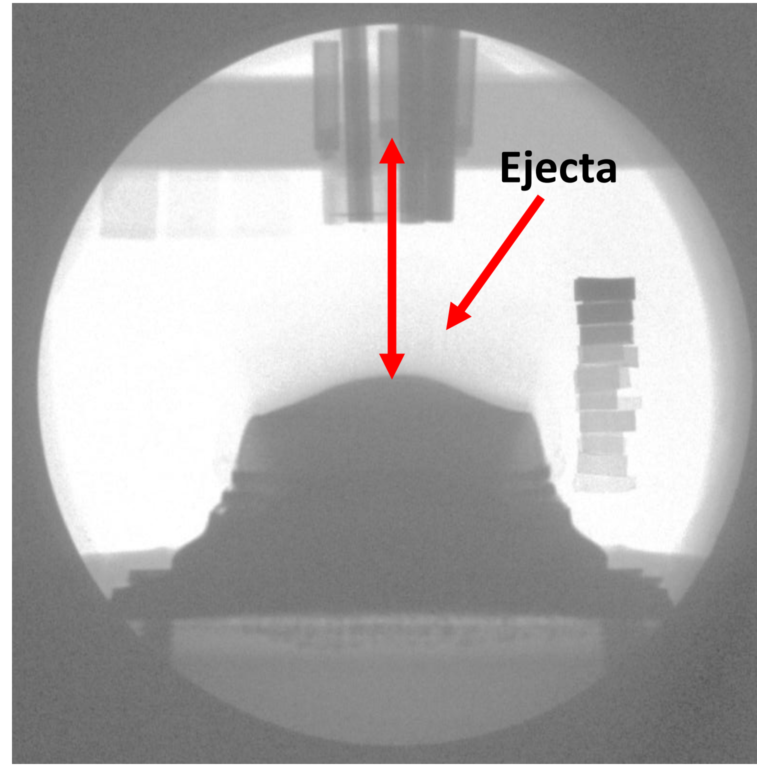


Recent explosive tests at Santa Barbara Boombox

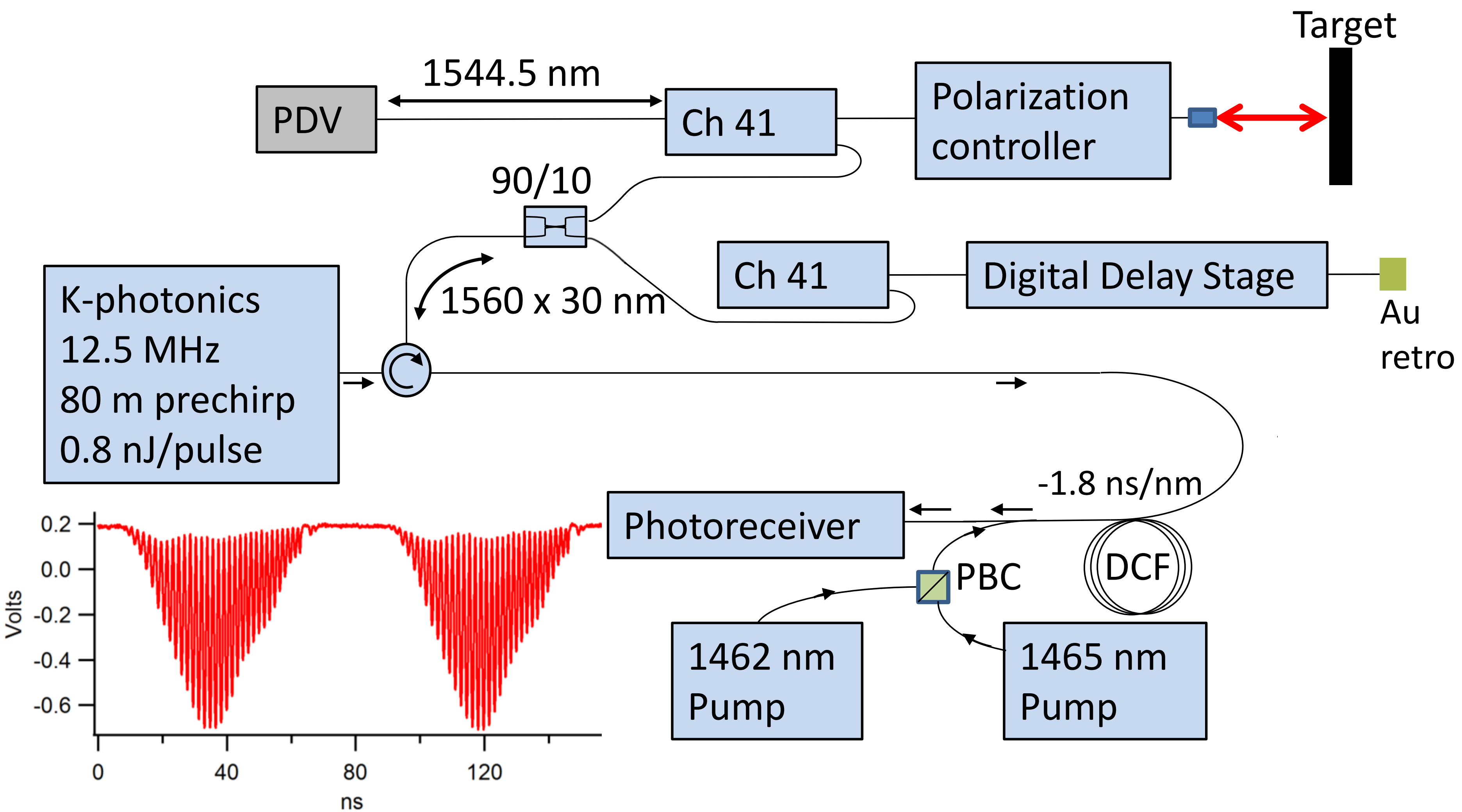
Preshot X-ray image



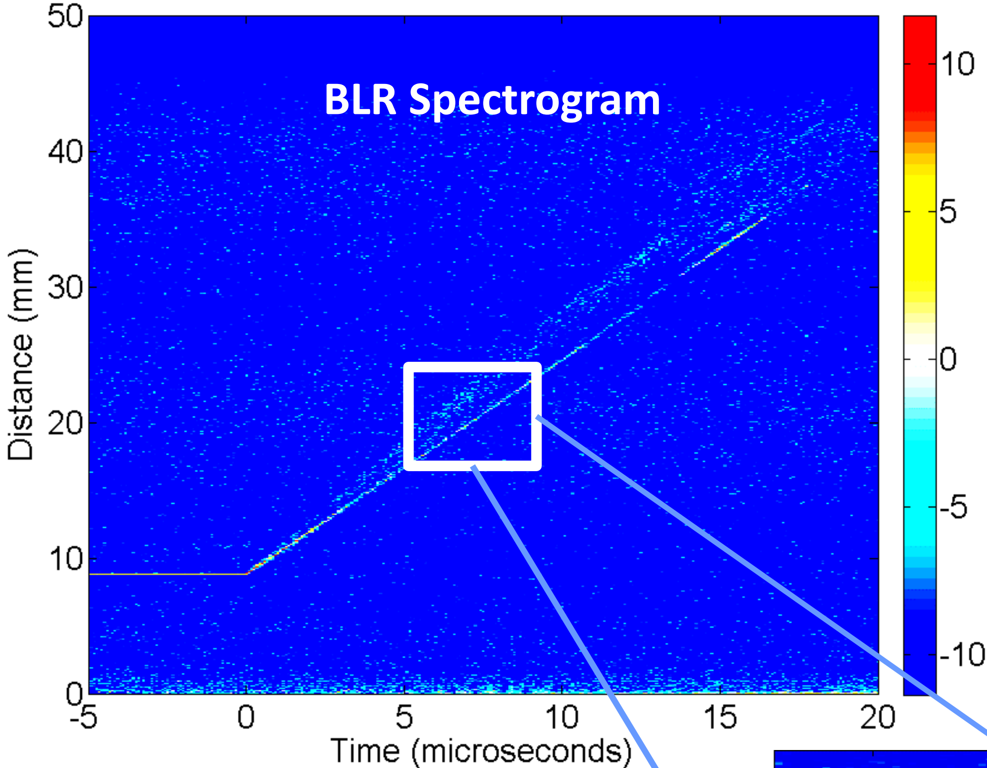
Dynamic X-ray image

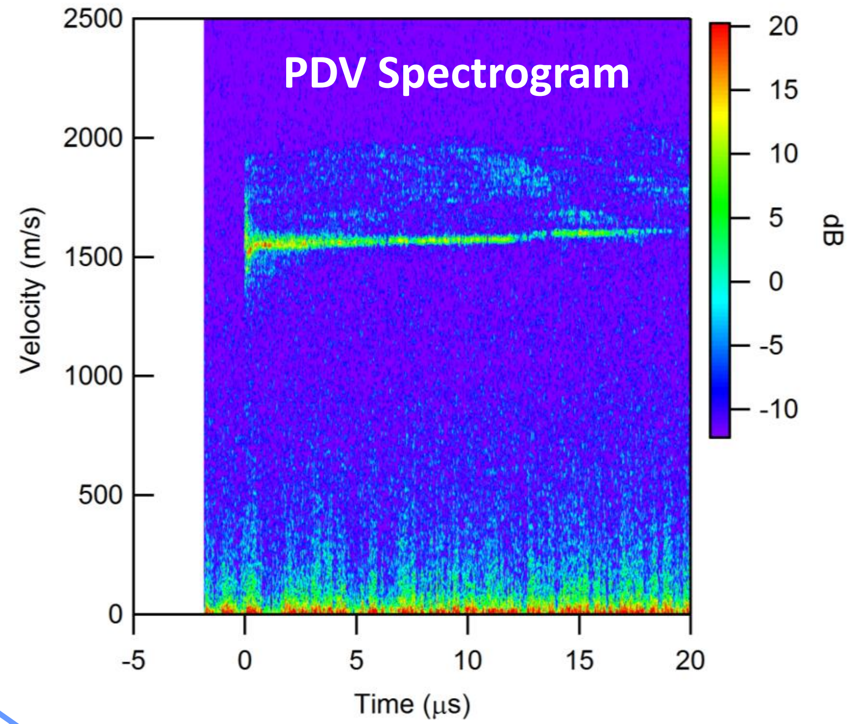


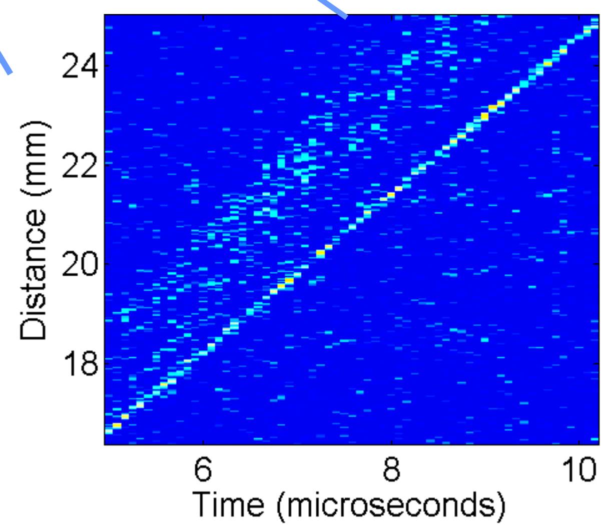
Updated system used on recent HE driven experiments



Recent explosive tests at Santa Barbara Boombox

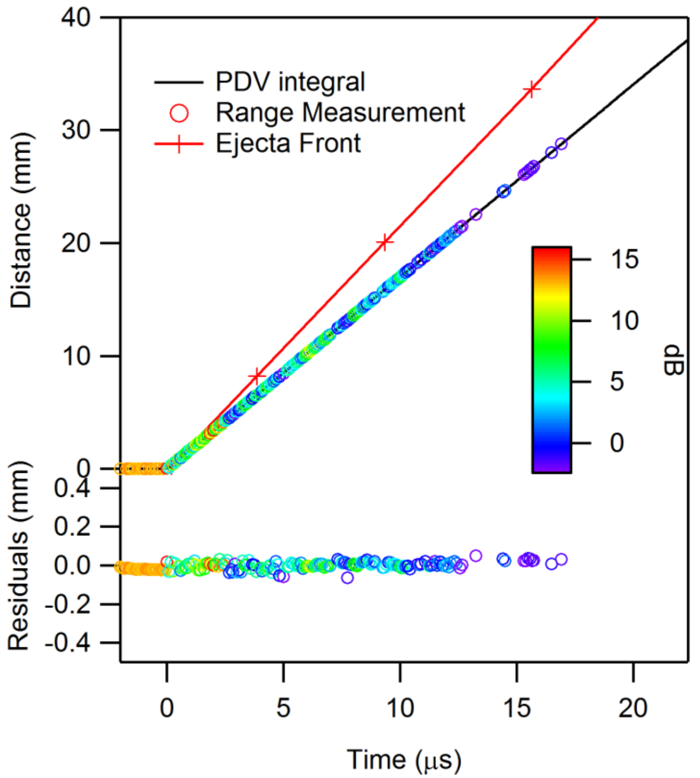






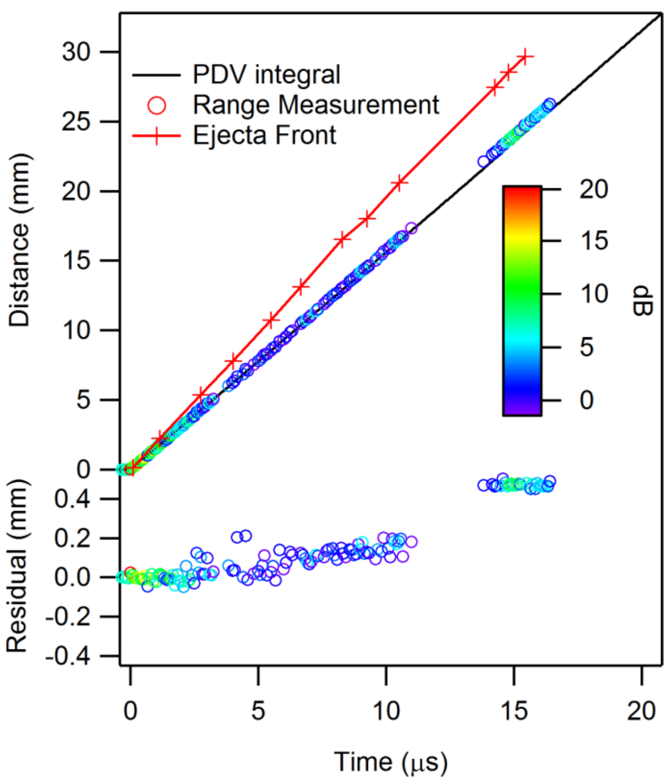
Comparison of BLR range and PDV integral for recent Boombox experiments

Probe on center axis of HE drive



Average deviation between BLR distance and PDV integral = 15 µm, max = 60 µm, **Good Match!**

Probe 5.6 mm off-center axis of HE drive



Average deviation between BLR distance and PDV integral = 150 µm, max = 560 µm, **Measureable Difference!**

Conclusions (the good parts)

Doppler free ranging in the frequency domain demonstrated on dynamic experiments (believed to be a first) *

Multiplexing with PDV is simple

Position is determined every 10 to 40 ns with <30 μm accuracy?, 2-surface resolution < 100 μm

Maximum range tested was about 150 mm – no real upper limits to this value

Heterodyne gain enables measurements with low signal return (–50 to –60 dB return loss), similar to PDV

Multiple positions can be resolved simultaneously, including fragments and clouds of ejecta

* La Lone et al, Rev. Sci. Instrum. **86** 023112 (2015)

Complications that make this system more difficult to field than PDV

Higher order dispersion in the DCF causes nonlinear mapping of the optical frequency to the time domain. Result is a chirped signal. We correct for this in the analysis but it leads to systematic errors (See Natalie Kostinski's and Ted Strand's talks)

Fiber interferometer dispersion must be balanced to < 6 fs/nm (about as much dispersion as 0.3 meters of fiber). (See LaLone's talk)

Nonlinear optical effects, such as self-phase modulation, limit laser energy (in present experiments to ~ 0.8 nJ/pulse). (See Patrick Younk's talk)

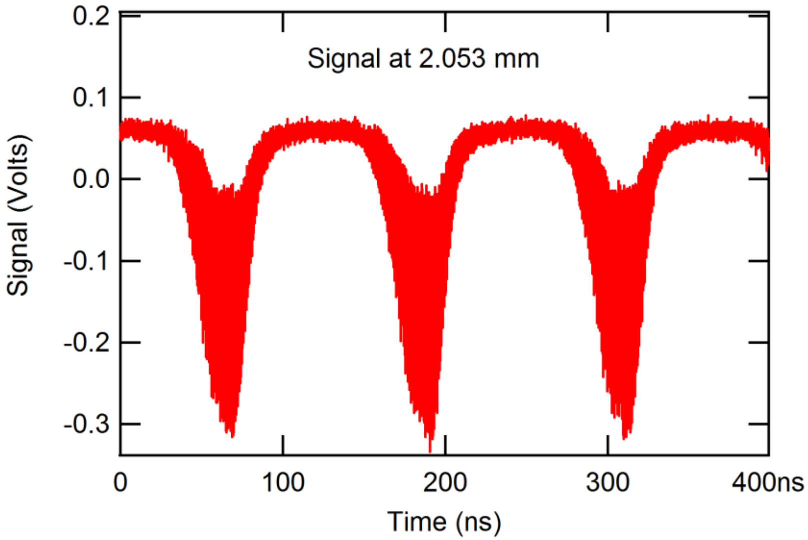
If pulses are not transform limited on target, there may be some sensitivity to the Doppler shift. (See Patrick Younk's talk)

Calibration is not as simple as PDV.

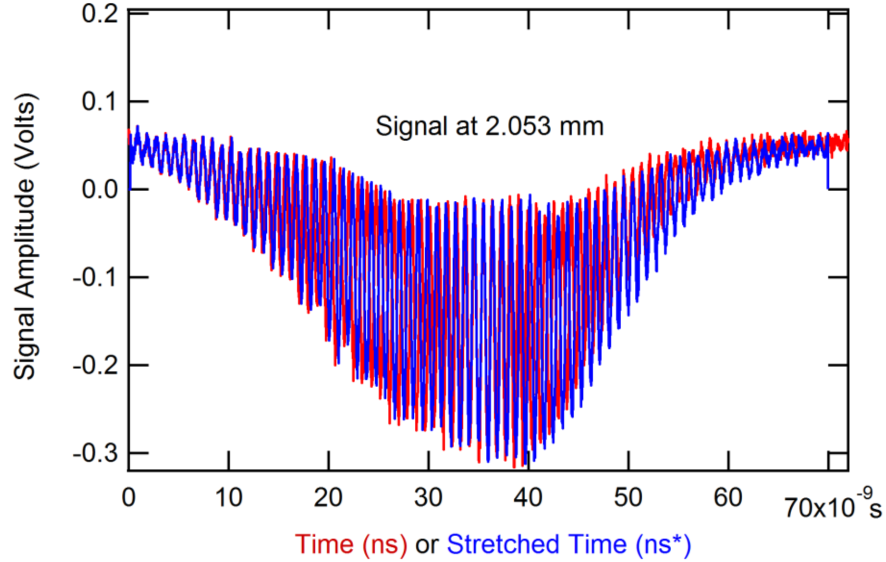
Extra Slides

Higher order dispersion results in chirped signals

Pulses from target arrive every 121.8 ns



Nonlinear time stretch corrects for the 2nd order dispersion in fiber, red is original, blue is corrected



Correcting for 2nd order dispersion narrows FFT peak and increases amplitude. Also shifts to lowest frequency. FWHM ~ 0.02 GHz