PDV operations and development at Proton Radiography

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on behalf of the pRad Team

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Important people

Proton Radiography team:

J. Allison, M. Freeman, J.J. Goett III, J. D. Lopez, F.G. Mariam, M.J. Martinez, J.J. Medina, P.V. Medina, F.E. Merrill, C.L. Morris, L.P. Neukirch, A.H. Pacheco, A. Sanchez, M. Sandstrom, A. Saunders, T. Schurman, A. Tainter, Z. Tang, F. Trouw, D. Tupa, J. Tybo, C. Wilde, W.V. McNeil, P.D. Scott, S.W. Vincent

Velocimetry contributions:

Dale Tupa, Amy Tainter, Alisha Vira (summer student), Levi Neukirch, Philip Rae, David Holtkamp, Brian Glover, Jake Gunderson

LANSCE – 800 MeV Proton Linac at TA-53

~ 1 km

Lujan Center
- National security research
- Materials, bio-science, and nuclear physics
- National user facility

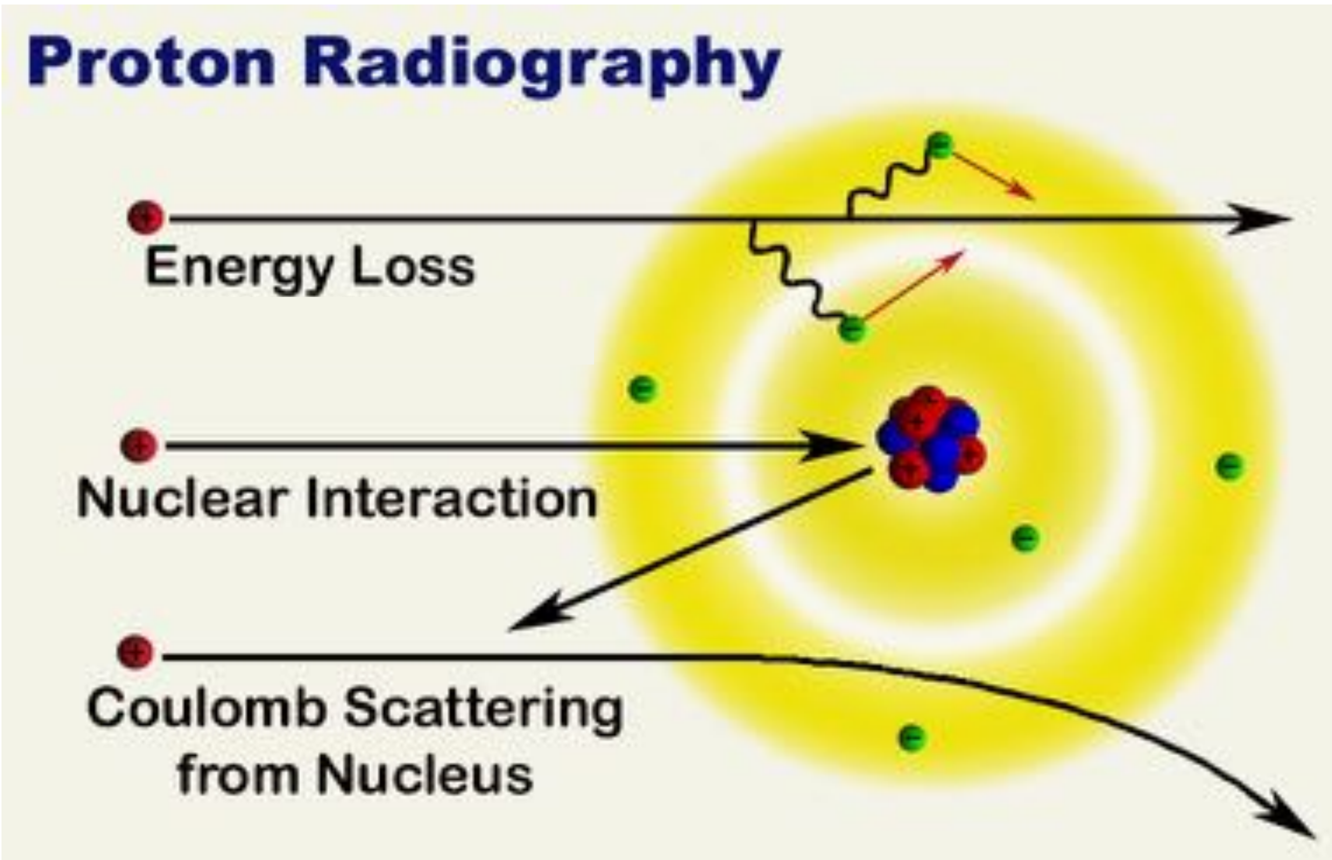
Weapons Neutron Research
- National security research
- Nuclear physics
- Neutron irradiation

Ultra-cold Neutrons
- Neutron EDM search
- Neutron lifetime measurement

Proton Radiography
- National security research
- Dynamic materials science
- Hydrodynamics

Isotope Production Facility
- Medical radioisotope production

How pRad works – Proton interactions w/ matter

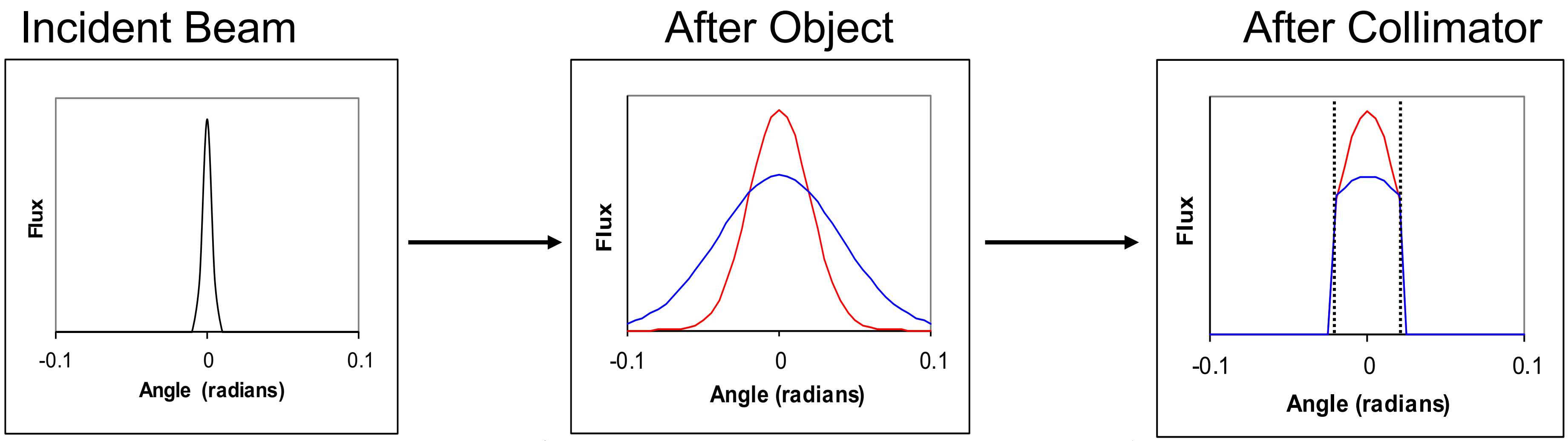


Energy loss results in chromatic blur and is therefore usually a nuisance (usable for ToF radiography)

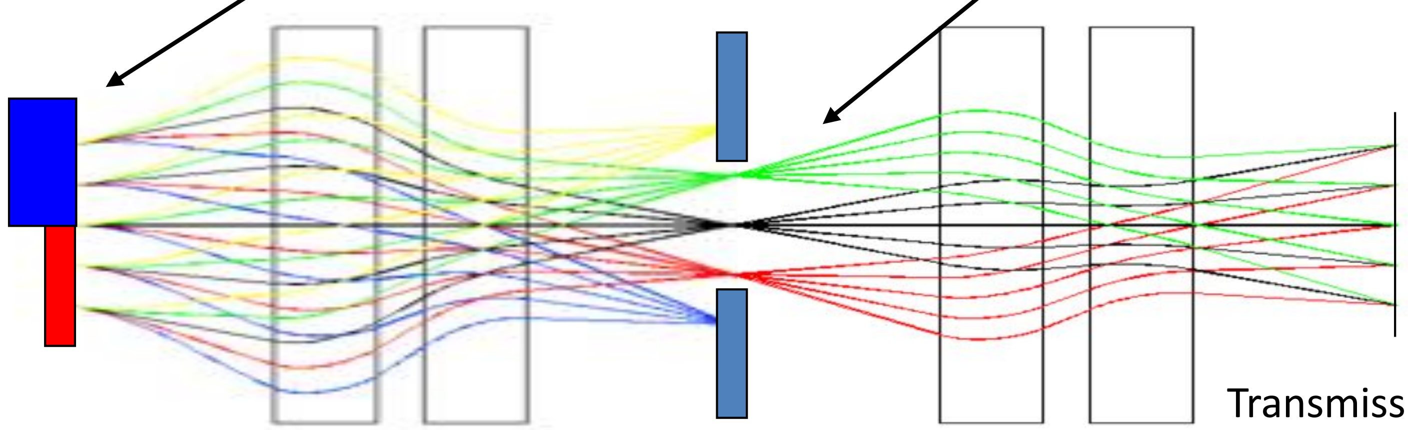
Nuclear collisions are rare(ish). Not so great for radiography.

Coulomb scattering increases with target areal density (ρl)

How pRad works – Contrast from collimators



Input beam has very small emittance

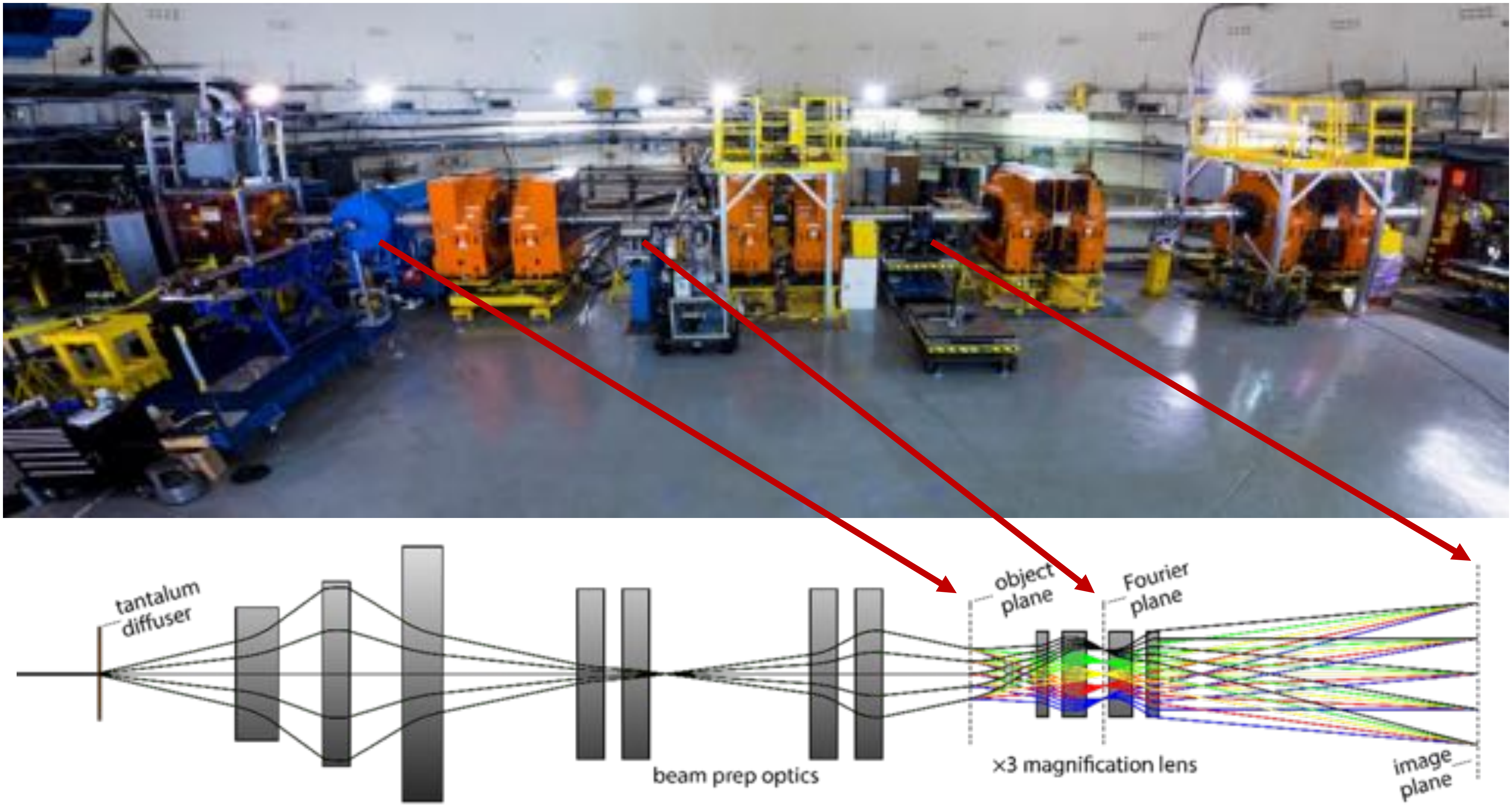


Collimator

Transmission measured at the image plane provides areal density information

The pRad beamline

Protons move left to right

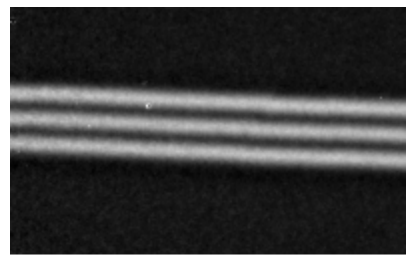


Magnifiers

Identity Lens (x1)

- 12 inch aperture
- <u>Resolution: 180 μm</u>
- 120 mm field of view

x3 Magnifier

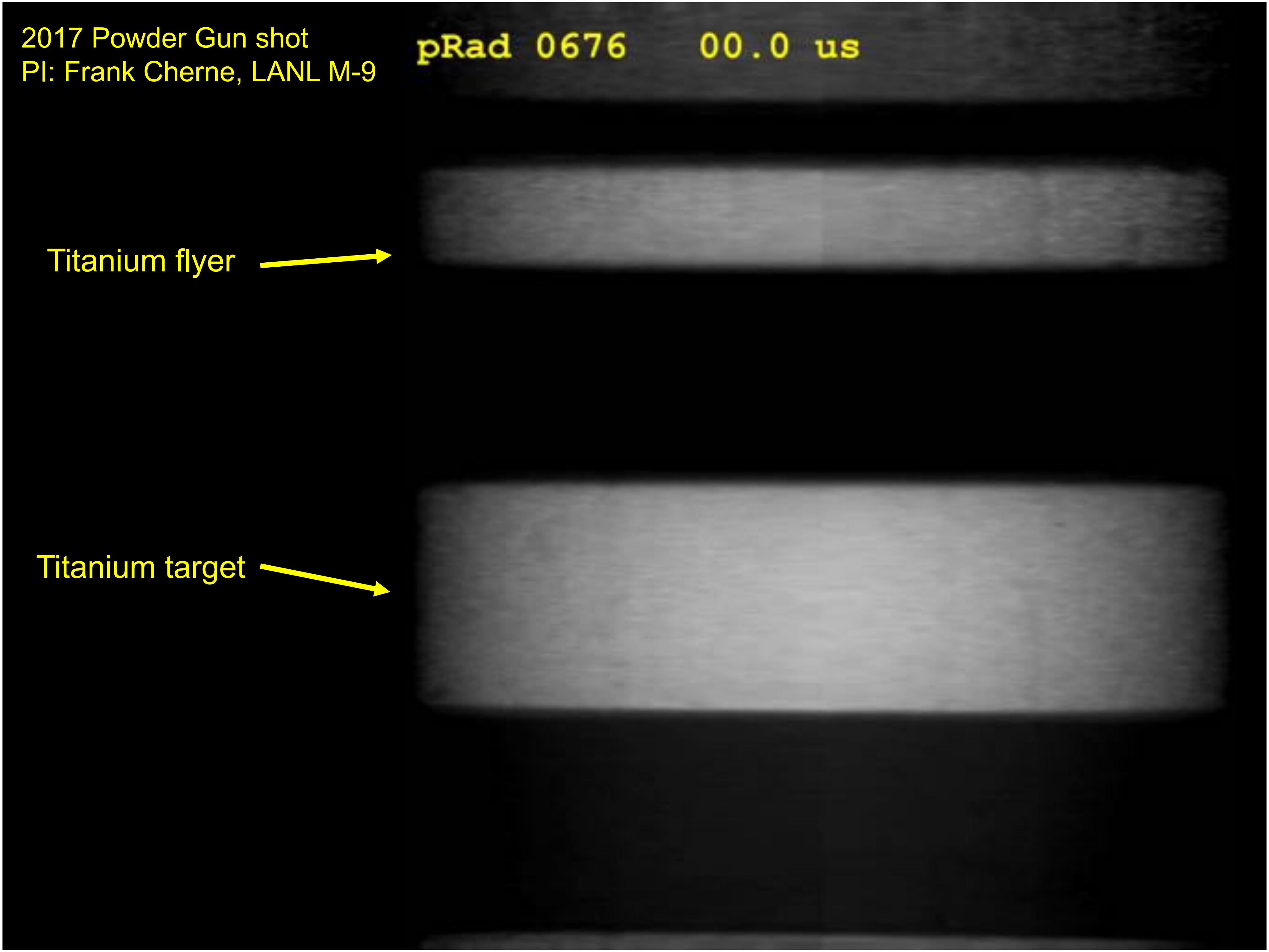


2.5 lp/mm

- 4 inch aperture
- <u>Resolution: 50 μm</u>
- 44 mm field of view

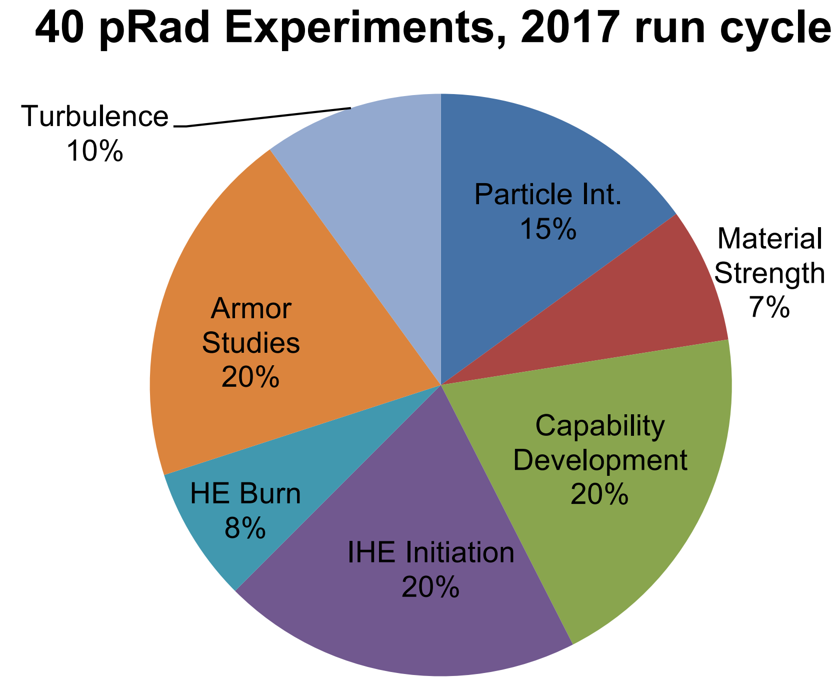
x7 Magnifier

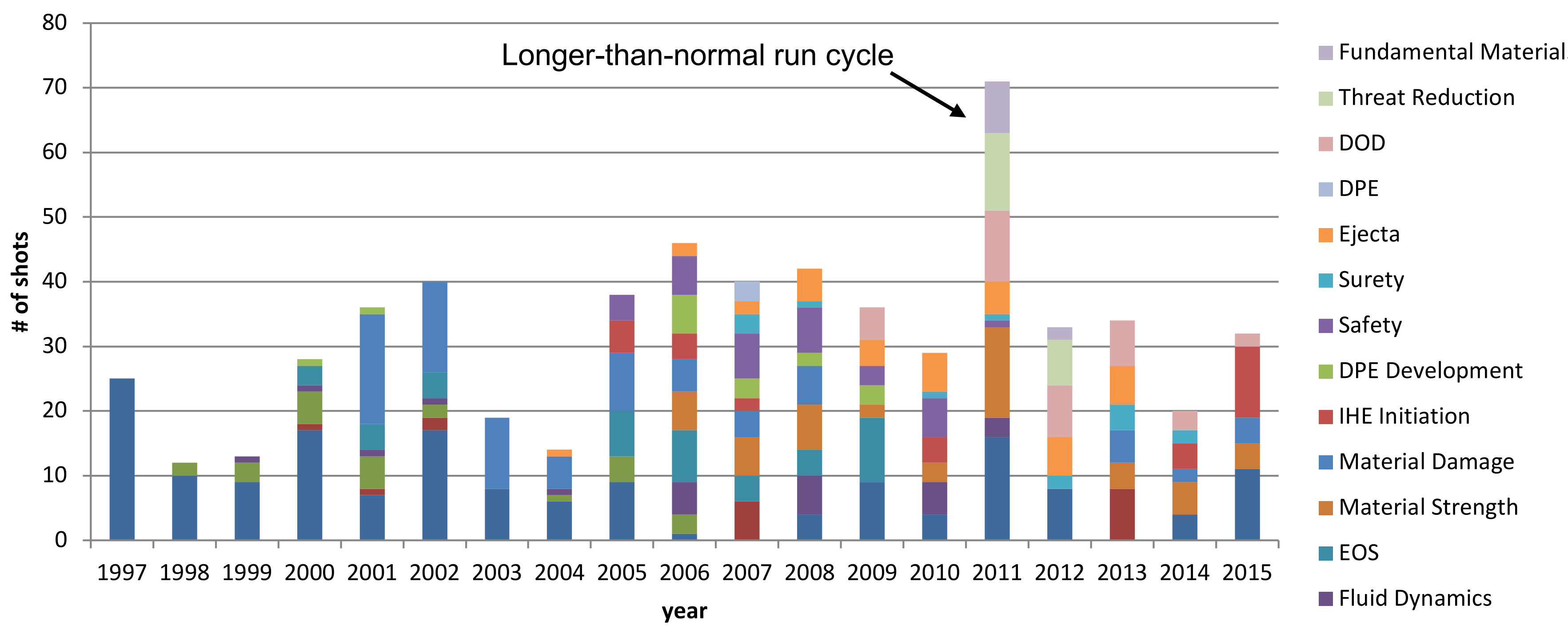
- Permanent quads
- 1 inch aperture
- <u>Resolution: 30 μm</u>
- 17 mm field of view


2017 Powder Gun shot
PI: Frank Cherne, LANL M-9
pRad 0676 00.0 us
Titanium flyer
Titanium target

pRad User Program

- Static or Dynamically Driven experiments
- Classified or Unclassified (~50%/50%)
- Yearly call for experiment proposals
- Beam time allocated by a Program Advisory Committee





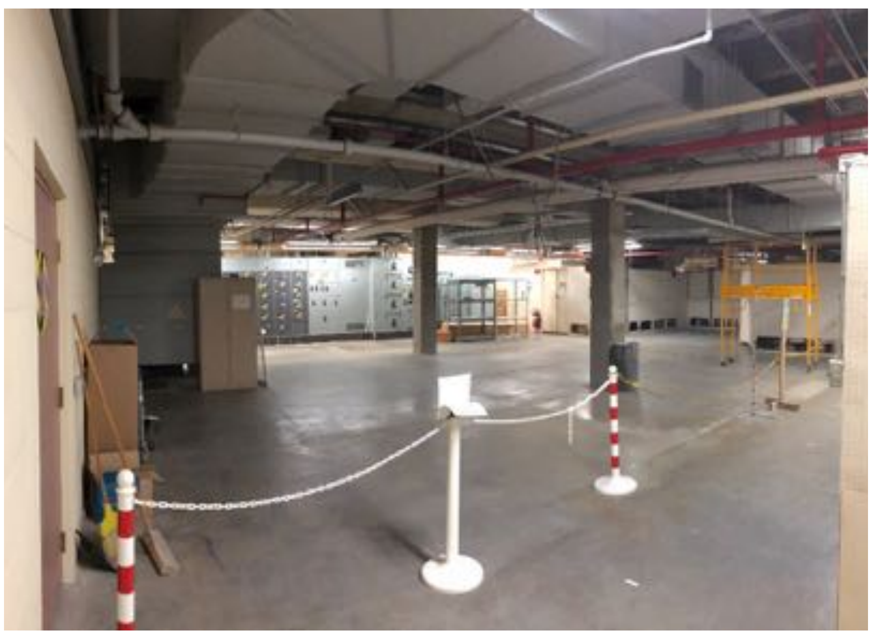
pRad's diagnostic capabilities

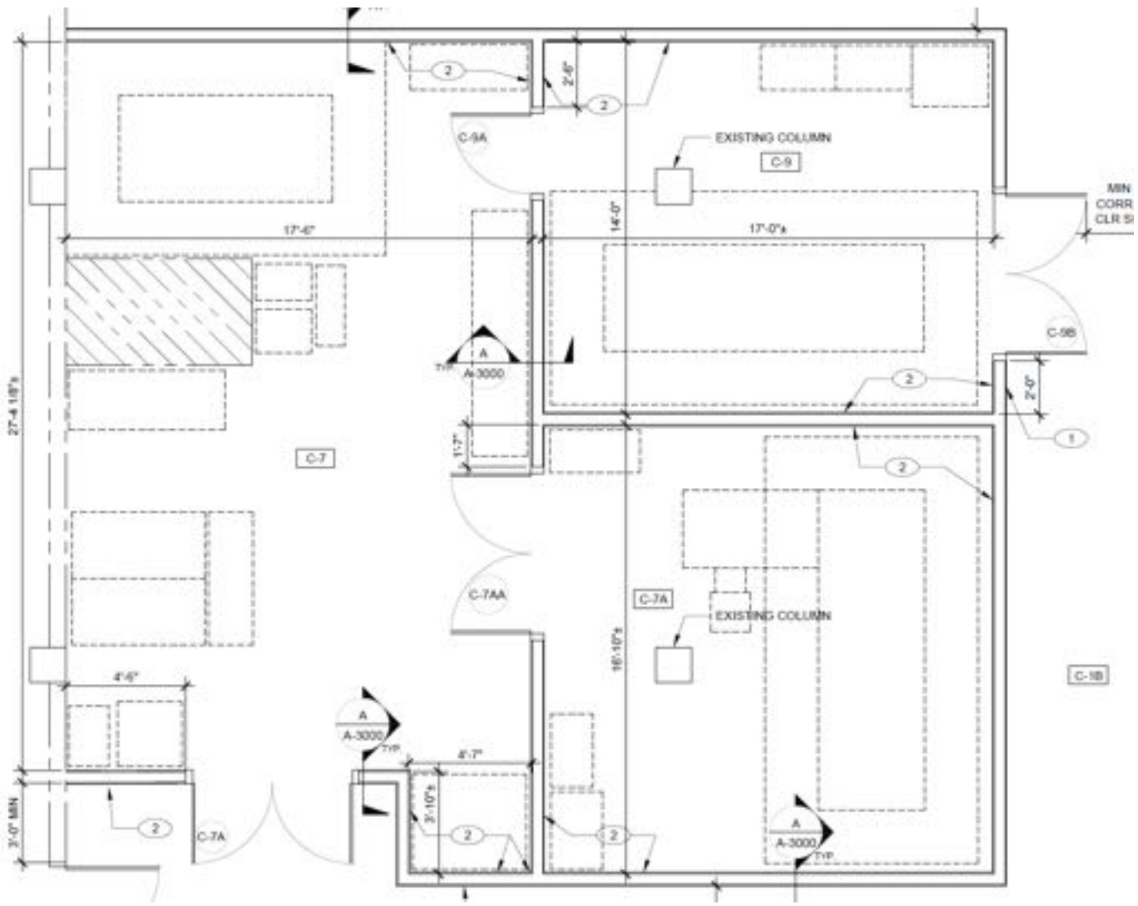
Routinely field up to 20 points of PDV

Have fielded multipoint VISAR, optical spectroscopy, visible-light imaging, and soft flash x-rays

Upgraded fiber plant this Spring – Now have 220 single-mode transport fibers to/from experimental area!

New 3-lab space being built in the basement of TA-53 Bldg. 1





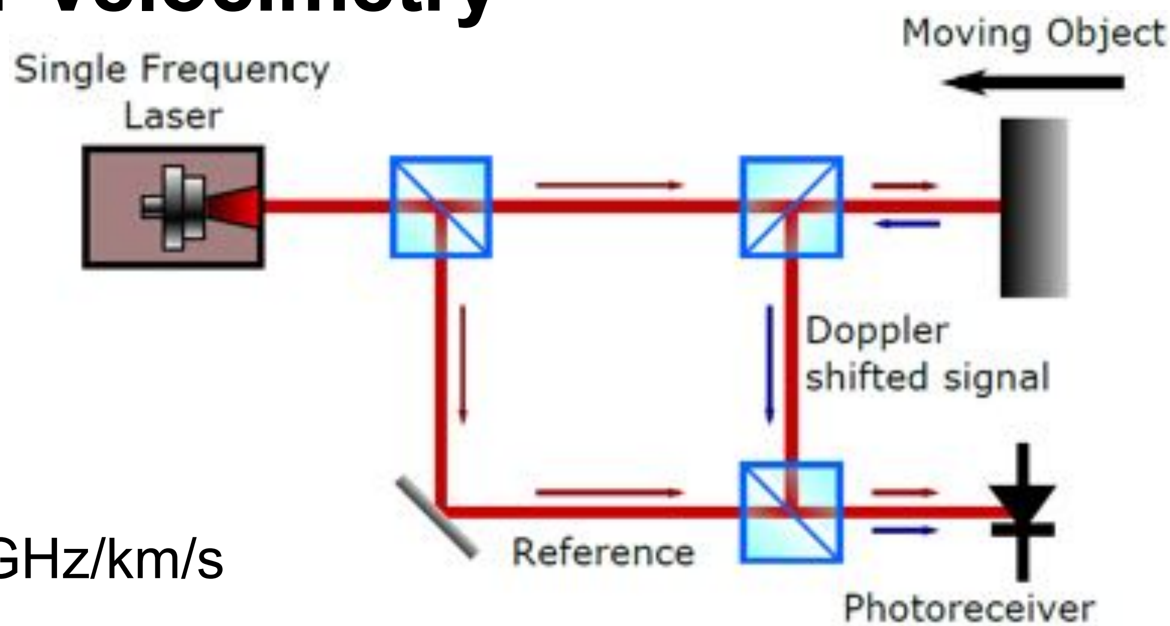
Photonic Doppler Velocimetry

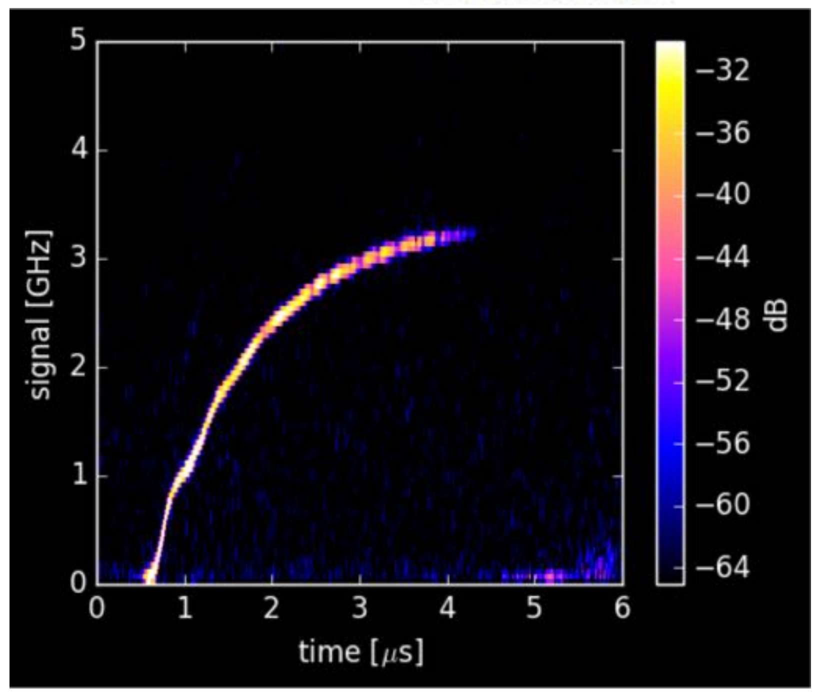
$$\Delta f_{Dop} = \frac{2v}{\lambda}$$

For $\lambda = 1.55\ \mu\text{m}$

$\Delta f_{Dop} = 1.290$ GHz/km/s

PDV generates a temporally continuous record of velocities at discrete points. Its complements spatially continuous, but temporally discrete radiography





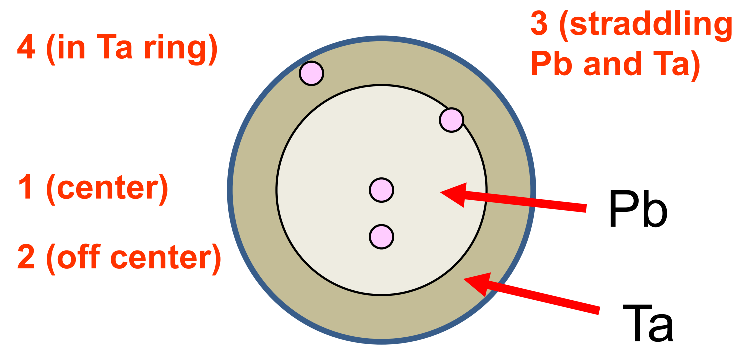
Example of a PDV signal from a pRad shot

PDV data is very rich

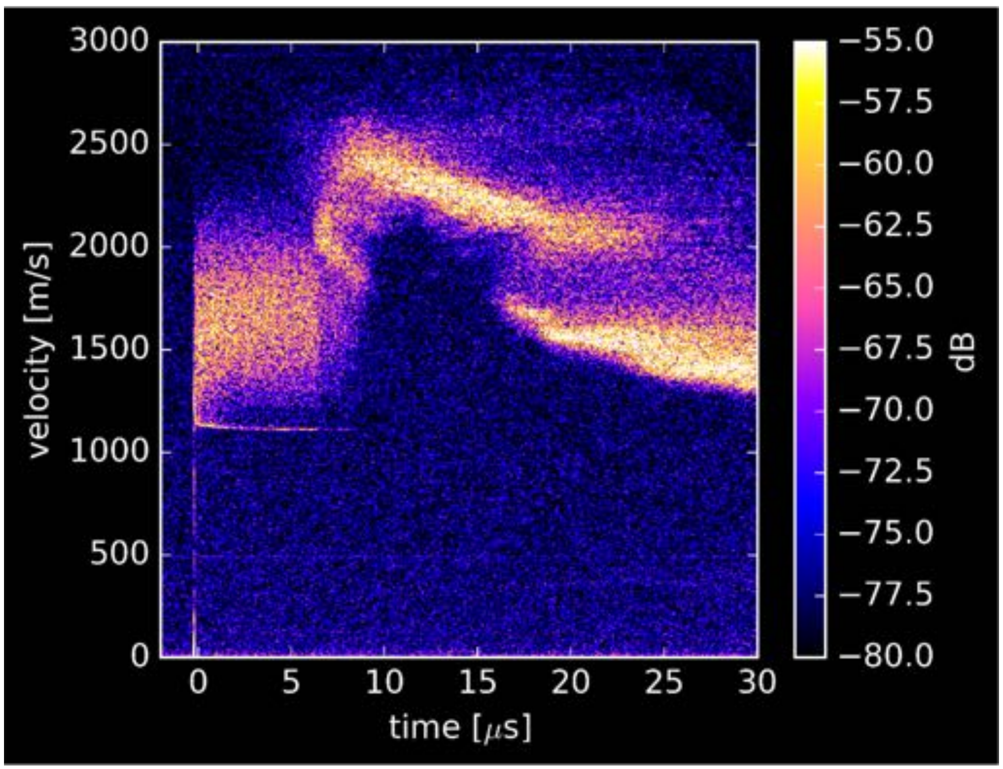
Multiple points on a target are monitored simultaneously.

Spectra provide information about velocity distributions for partially-reflecting materials

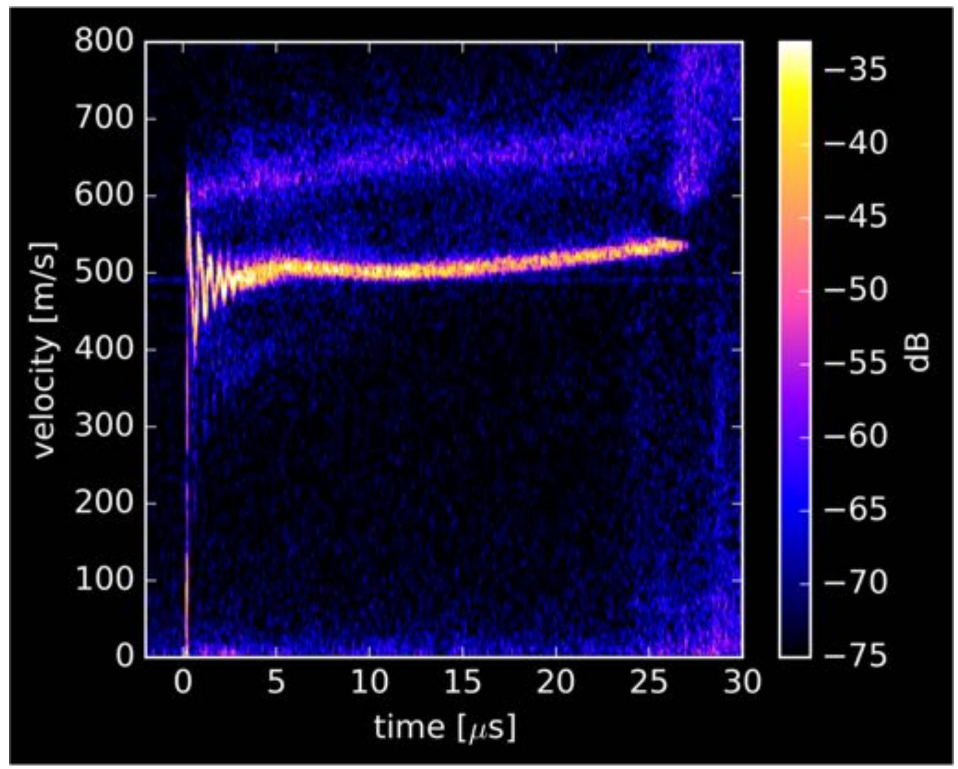
Probe locations



Sample explosively shocked from beneath



Probe 2 (looking at Pb)



Probe 4 (looking at Ta)

Standard PDV hardware

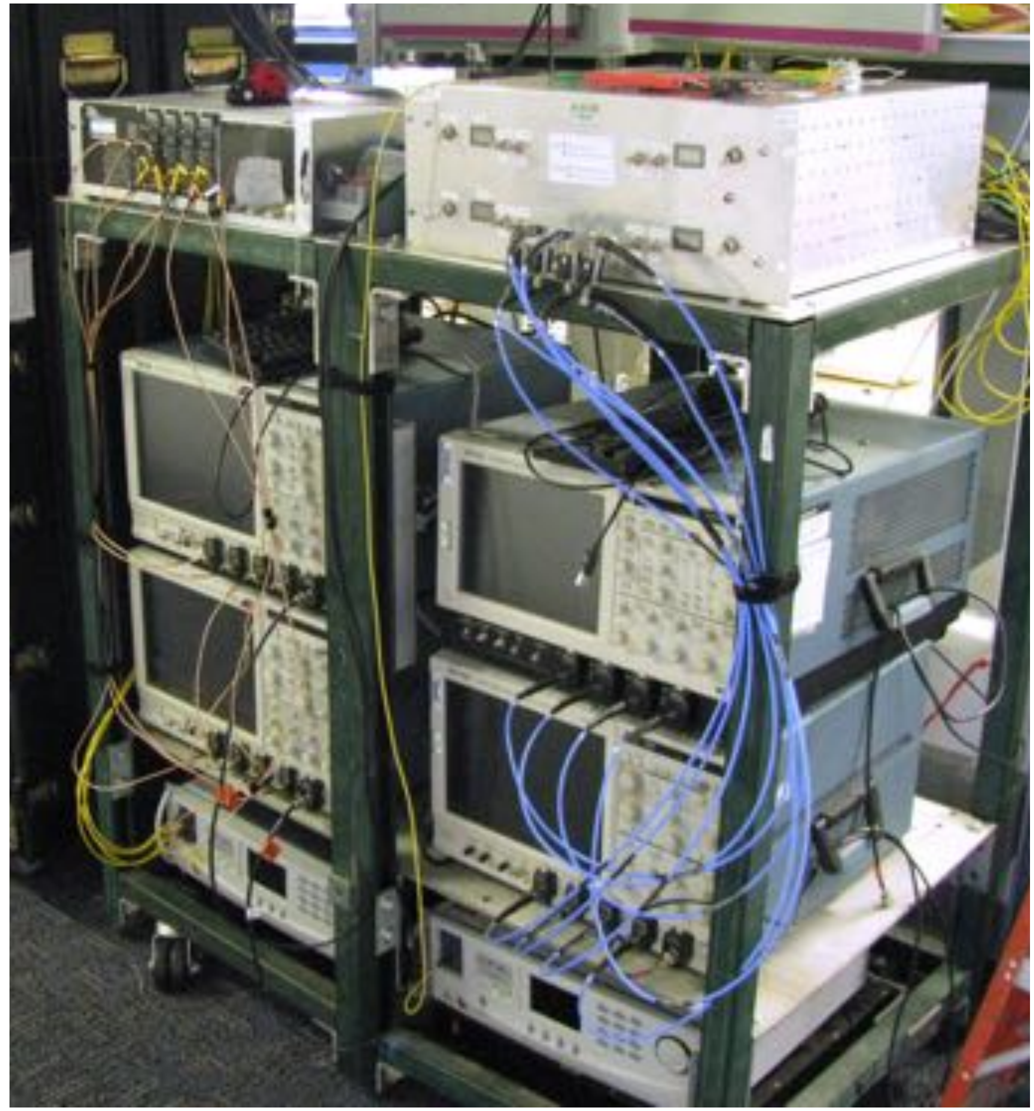
PDV typically requires >10 GHz oscilloscopes to measure Doppler shifts of >1 GHz per km/s of target velocity.

Goals of this work:

(1) Reduce total cost per channel (possibly substantially)

(2) Miniaturize PDV hardware, make it more portable

(3) Reduce digitizer bandwidth requirements through frequency mixing



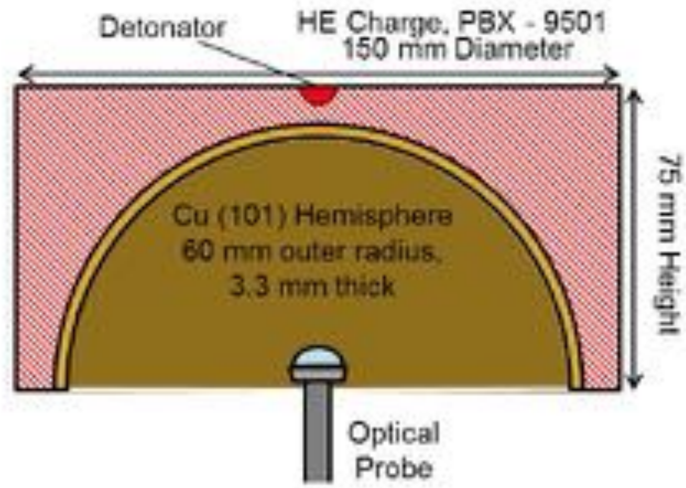
$500k in PDV equipment. Good for 8 simultaneous measurements.

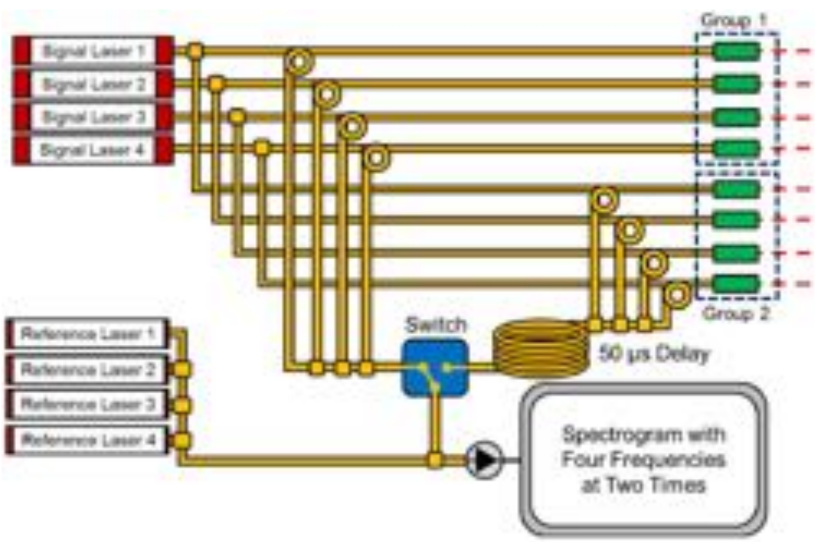
MPDV – Frequency-mixed PDV on steroids

Optical frequency mixing is not new to PDV

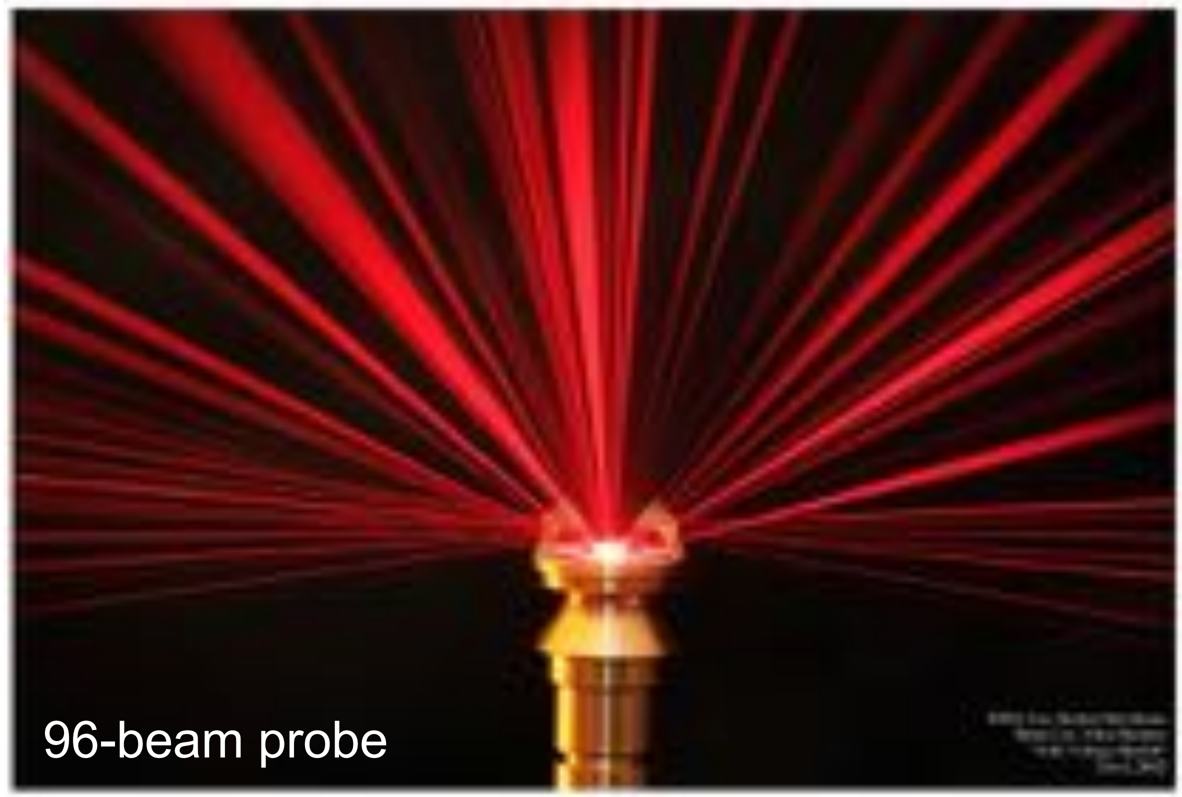
“Multiplexed PDV” (MPDV) uses independent reference lasers to ***upshift*** signals into bandwidth overhead, allowing multiple signals to be combined on a single digitizer channel.

Not done to make PDV cheaper or more accessible!





Danielson et. al, *J. Phys.: Conference Series* **500**, 142008 (2014).

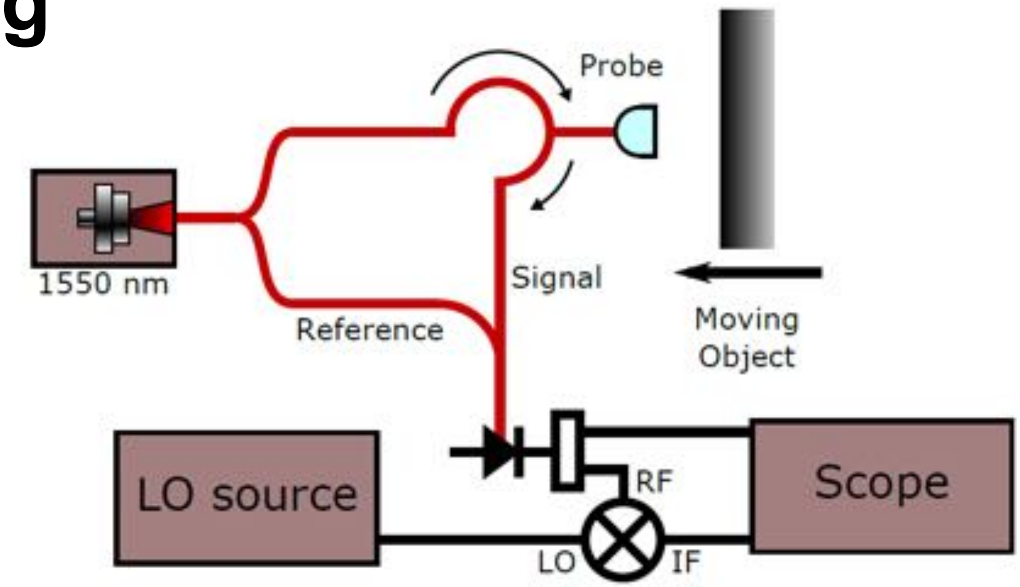


Electrical down-mixing

Electrical heterodyning produces signals at $f_{LO} \pm f_{sig}$

Pros: Cheap, straightforward, extensible, each mixer adds $2BW$

Cons: Signal splitting reduces S/N, multiple channels for a single PDV point, need clean LOs



Compact LO

100 mW diode laser

Electrical down-mixing

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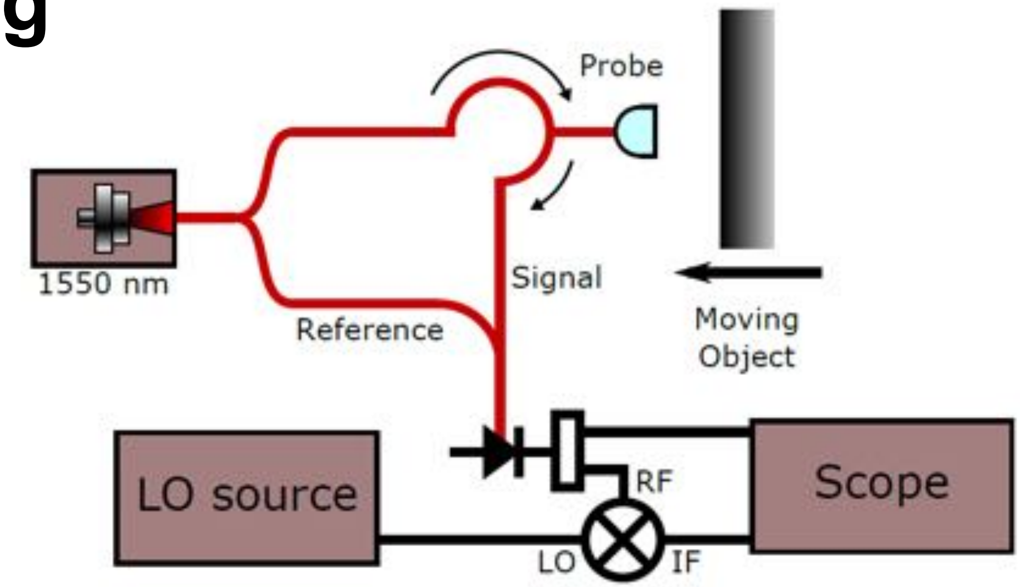
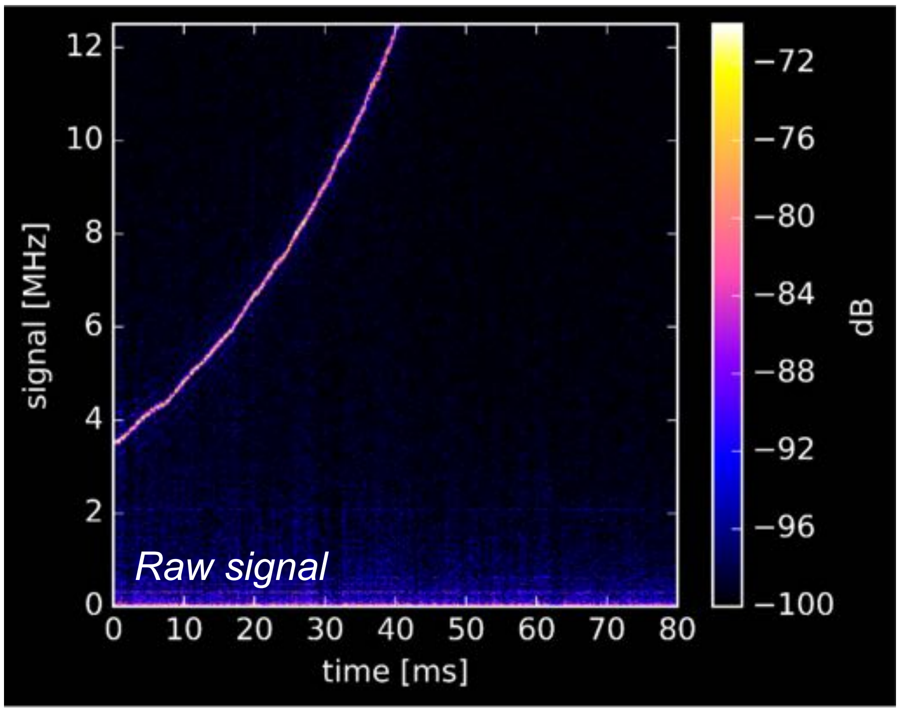
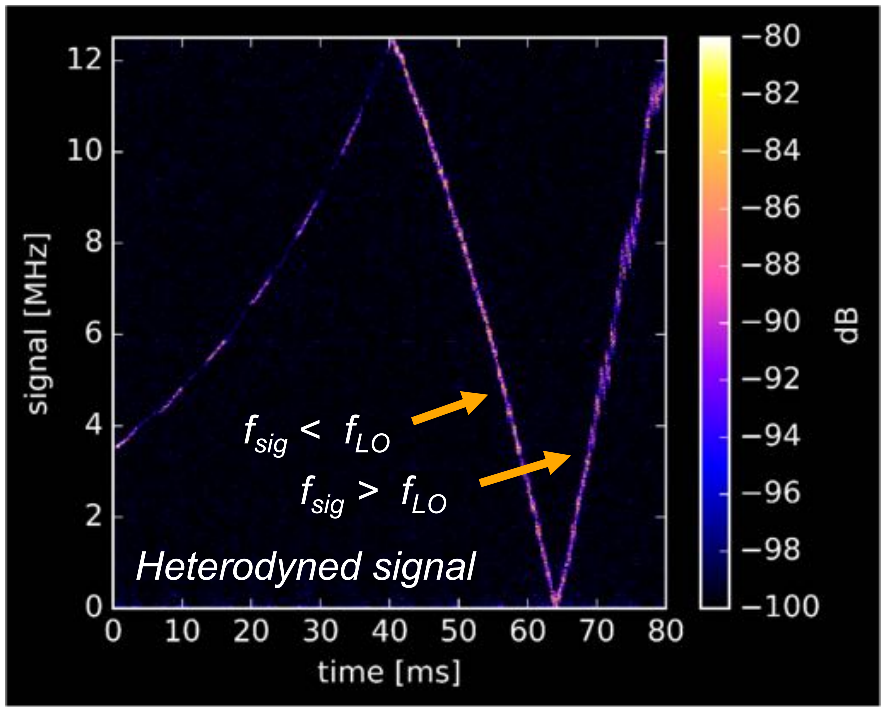


Normal PDV on Ch. 1



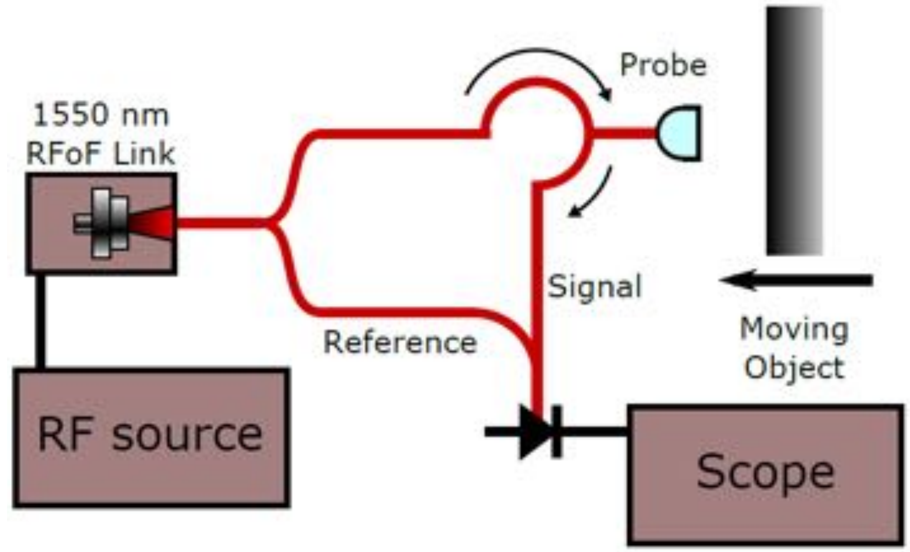
Down-mixed PDV on Ch. 2

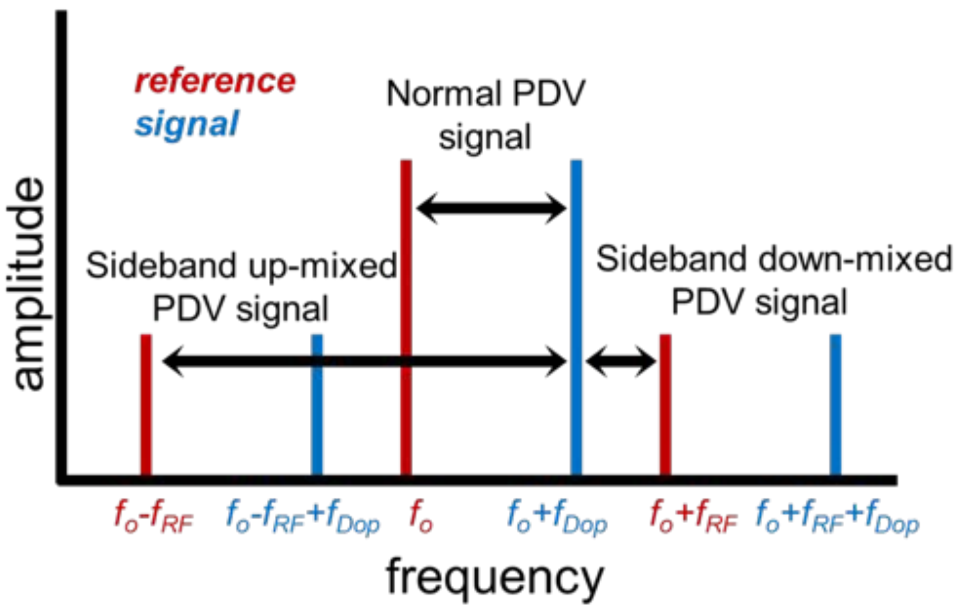


Sideband mixed PDV (work done by 2017 summer student Alisha Vira)

Modulating the laser intensity produces frequency sidebands which also acquire Doppler shifts.

Mixing between the different lines results in multiple signal frequencies from a single velocity.





See Chen et al., *IEEE Phot. Tech. Lett.* **28**(3), (2016)

Optical Zonu OZ516 RFoF source (0-6 GHz)

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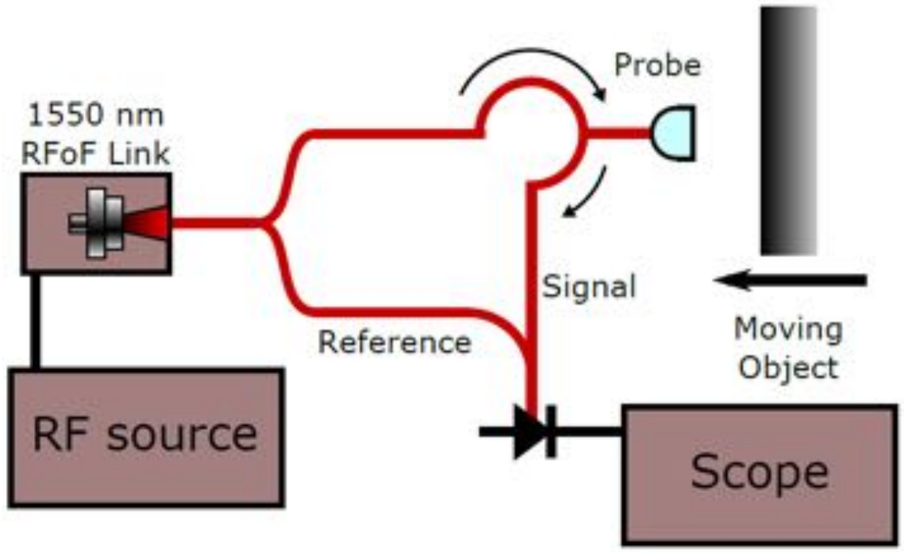

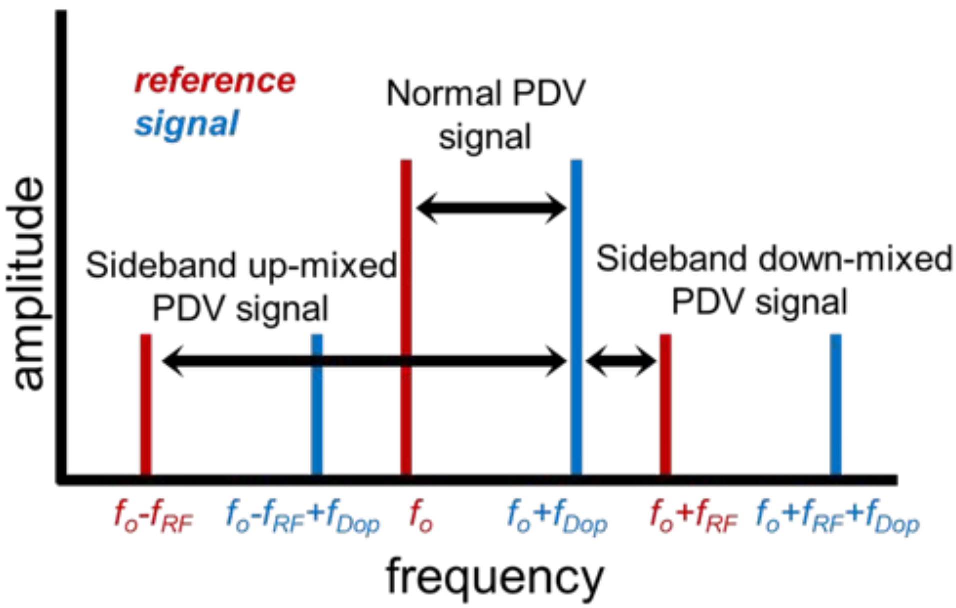

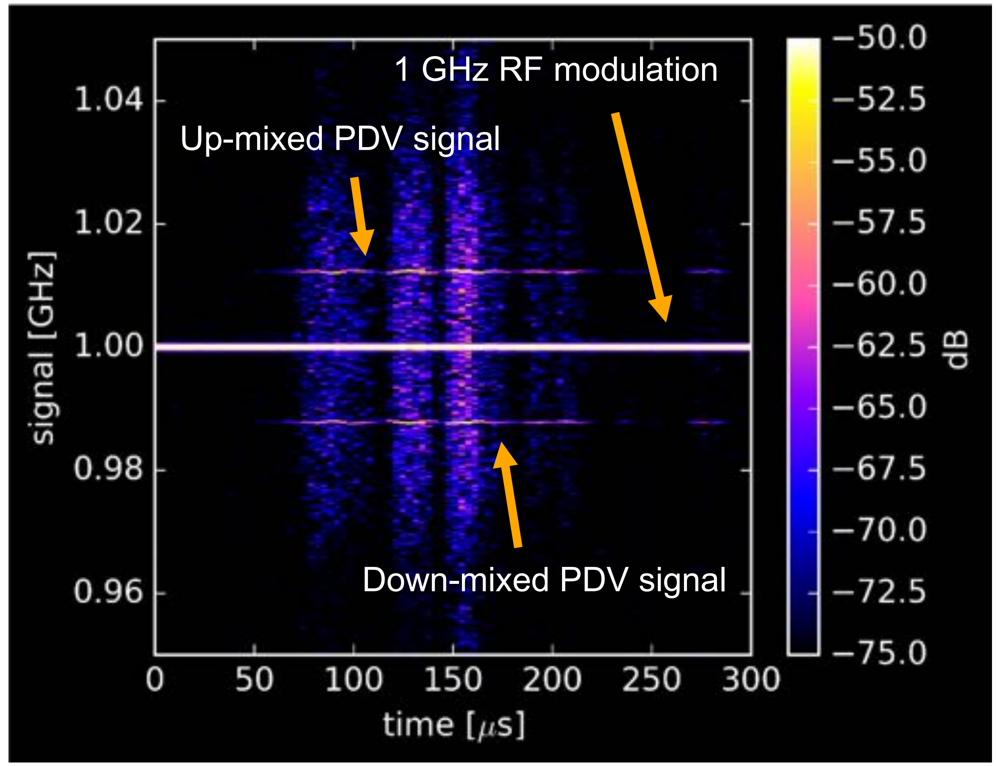

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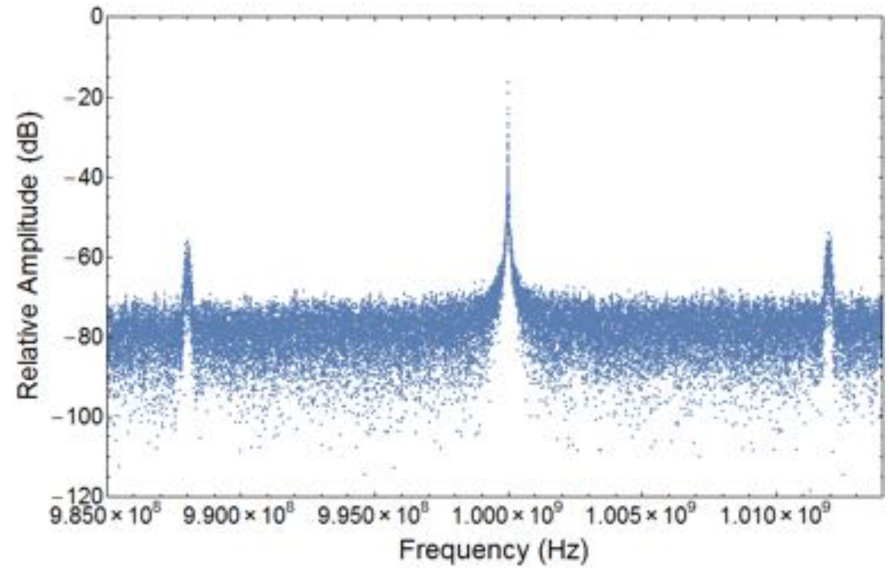
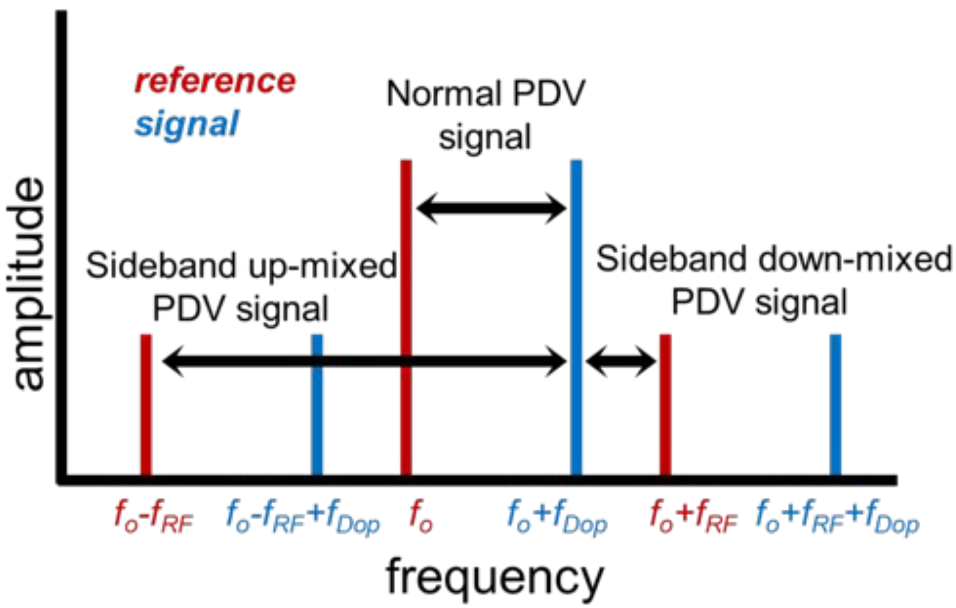
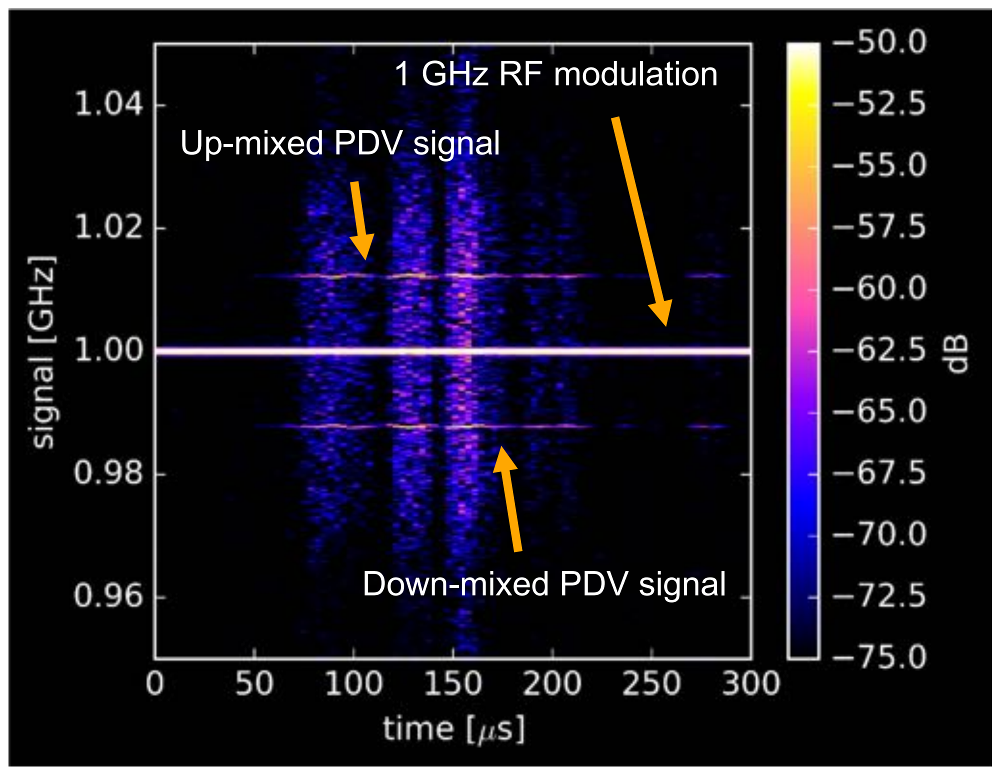


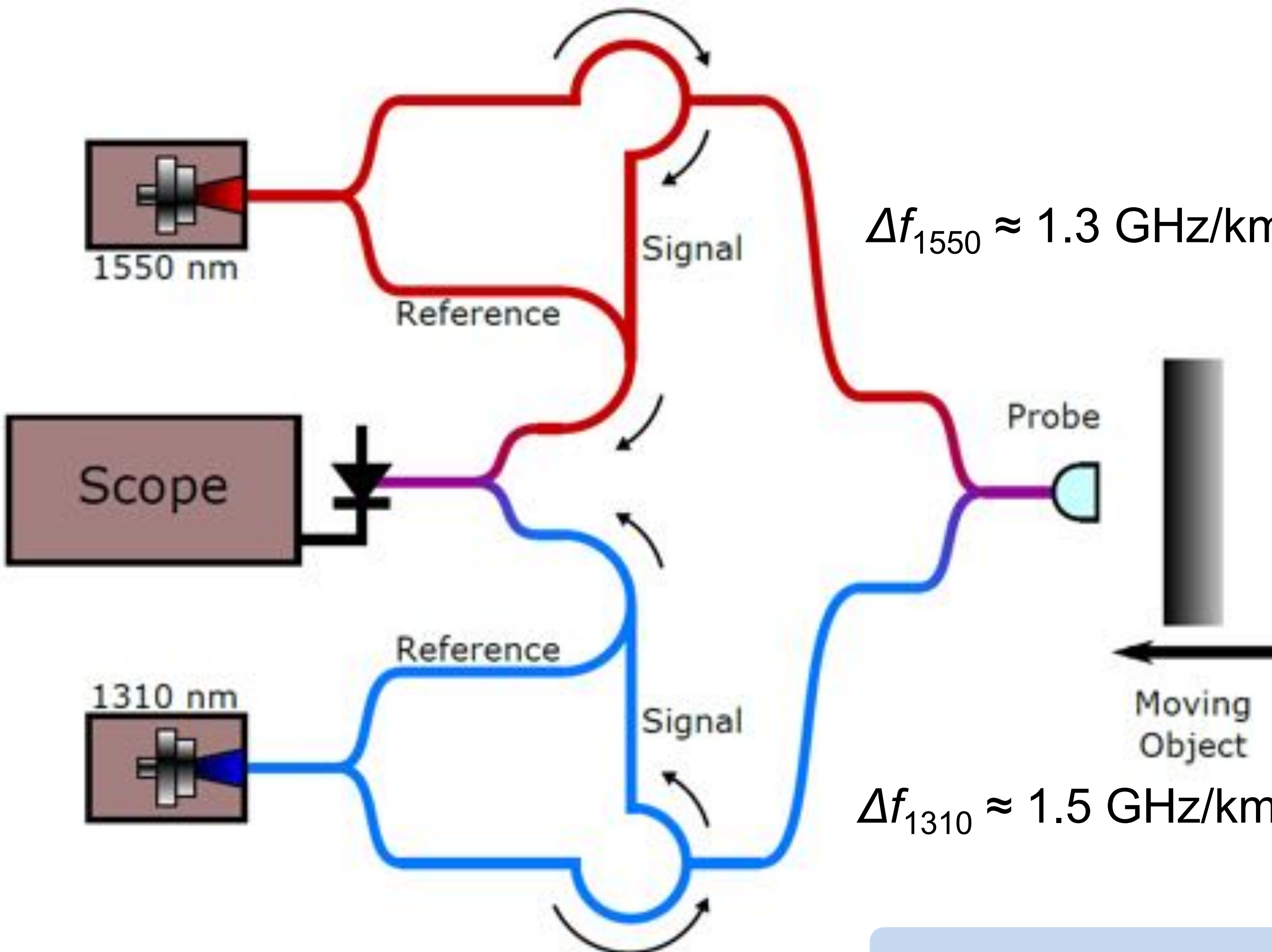




See Chen et al., *IEEE Phot. Tech. Lett.* **28**(3), (2016)

Two-color optically mixed PDV

Using two different color lasers results in signal frequencies whose difference scales with the target velocity!



$\Delta f_{1550} \approx 1.3$ GHz/km/s

$\Delta f_{1310} \approx 1.5$ GHz/km/s

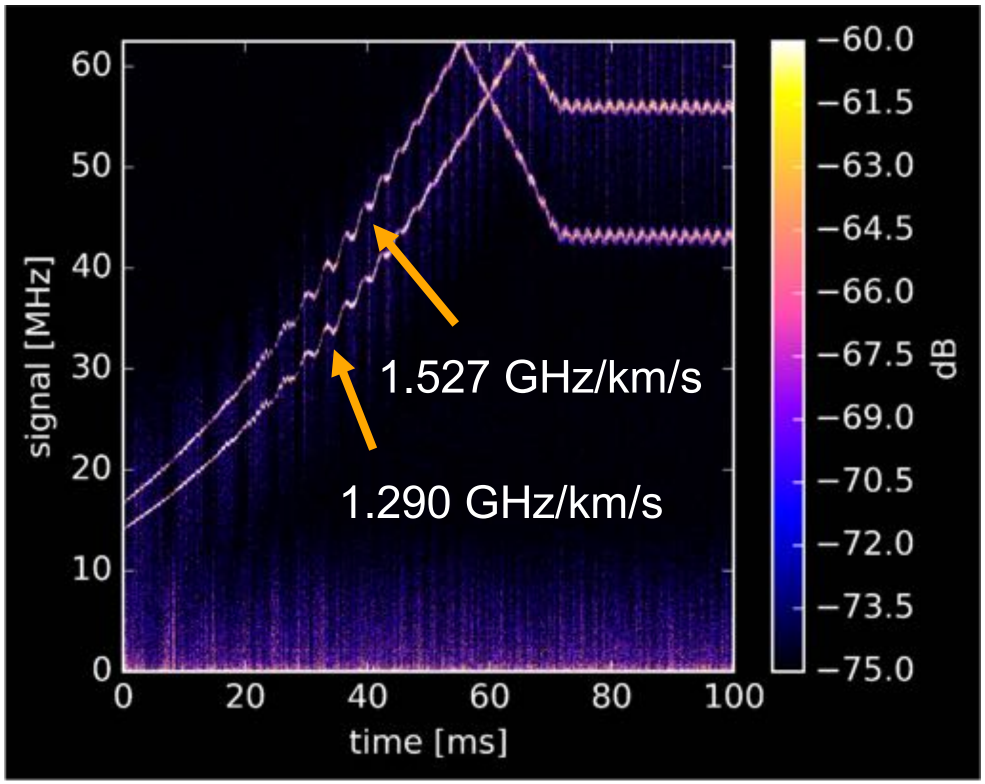
$(\Delta f_{1310} - \Delta f_{1550}) \approx$ 237 MHz/km/s

Based on idea from Philip Rae (M-6, LANL)

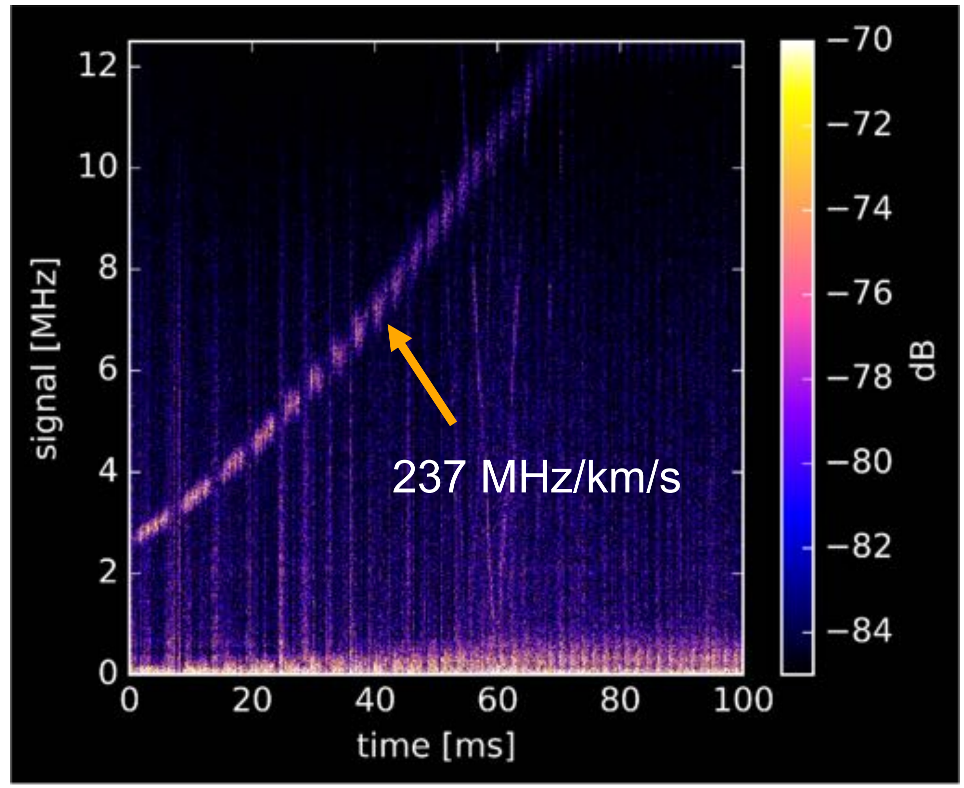
Two-color optically mixed PDV

Using two different color lasers results in signal frequencies whose difference scales with the target velocity!

Raw two-laser signal



Rectified two-laser signal



To be useful, this requires a nonlinear mixing of the two signals. Could be provided electrically (fast diode rectification), or optically.

All-optical down-conversion using XGM

Semiconductor optical amplifiers exhibit nonlinearities which can be leveraged for mixing applications. Cross-gain modulation (XGM) and cross-phase modulation have been explored for communications applications.

2402 JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 29, NO. 16, AUGUST 15, 2011

Performances of a Photonic Microwave Mixer Based on Cross-Gain Modulation in a Semiconductor Optical Amplifier

Christian Bohémond, Thierry Rampone, and Ammar Sharaiha

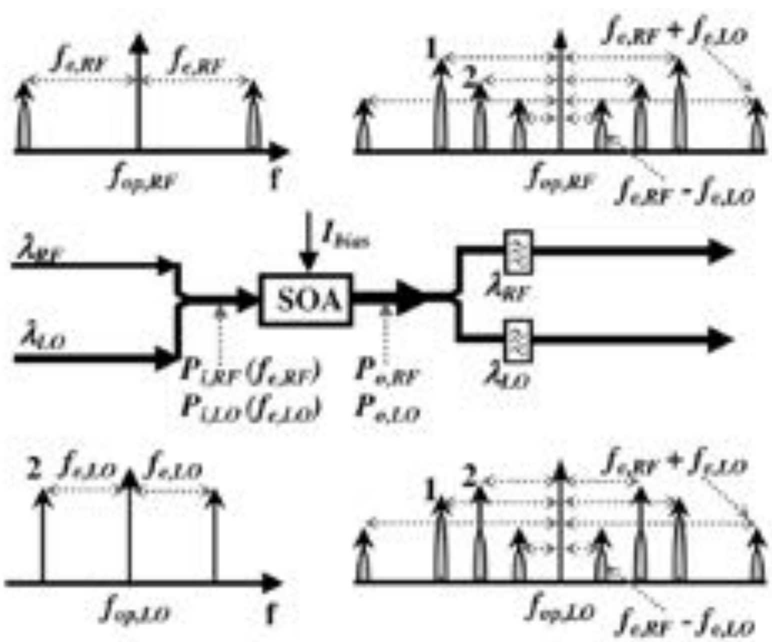
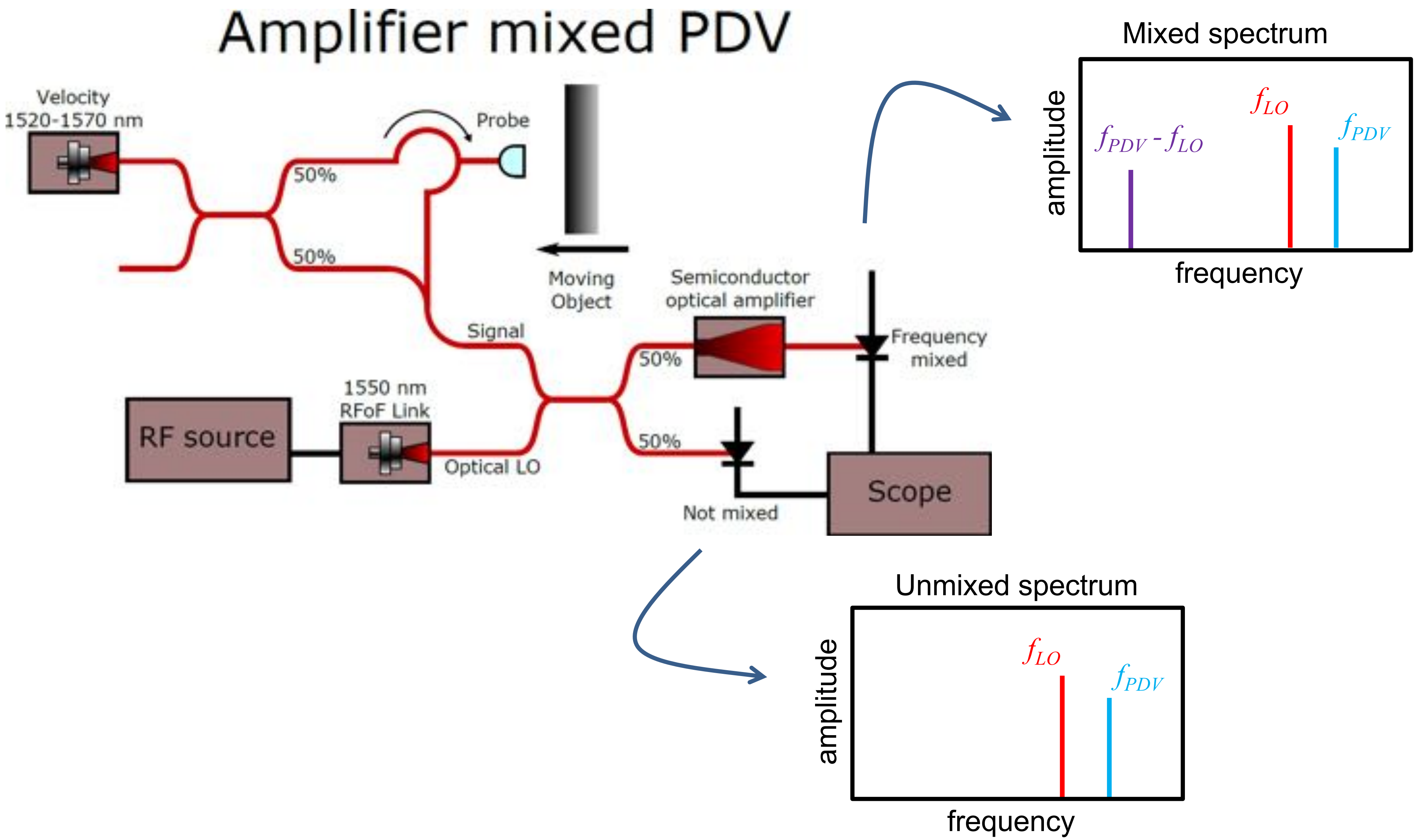


Fig. 1. Photonic microwave mixer based on XGM in an SOA. $f_{op,(RF,LO)}$ is an optical frequency related to the optical wavelength by : $f_{op,(RF,LO)} = c/\lambda_{(RF,LO)}$. (1) and (2), respectively, stand for the electrical signal modulation frequency $f_{e,RF}$ and the electrical local oscillator frequency $f_{e,LO}$. I_{bias} is the bias current applied to the SOA.

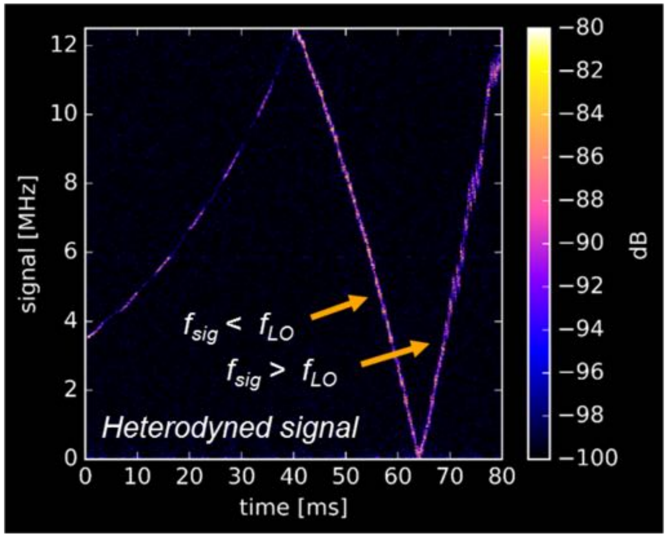
All-optical down-conversion using XGM

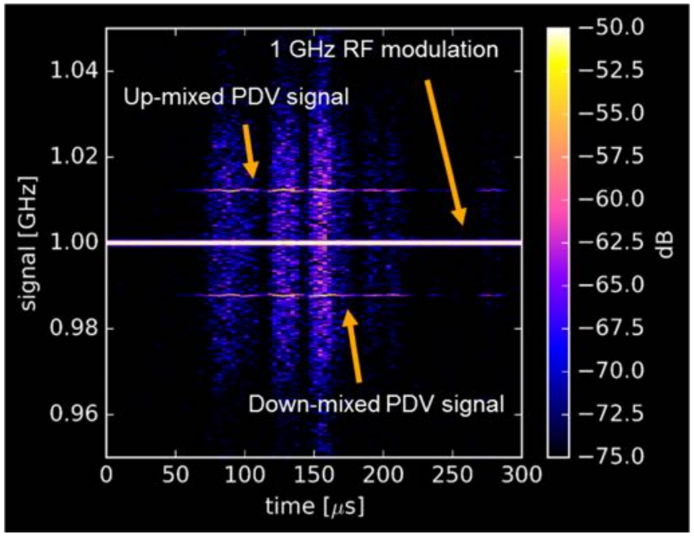
Proposed scheme for XGM-based frequency conversion, experiments to be performed

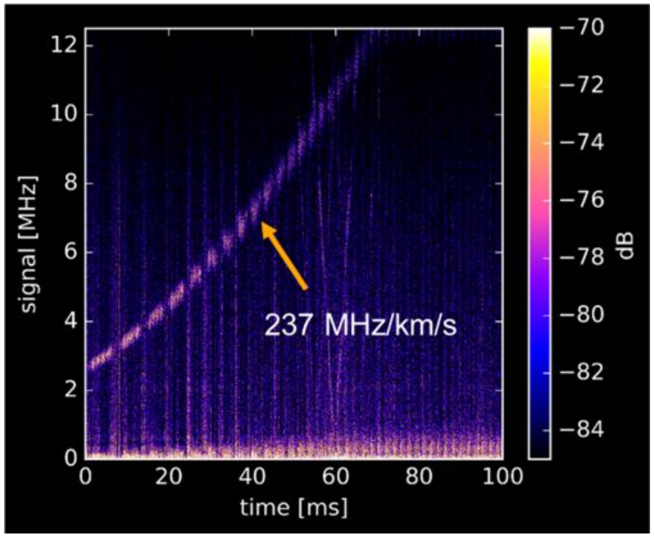


Frequency-mixed PDV status

- Different methods of frequency mixing have been demonstrated to measure low velocities (10-50 m/s)
- Work must be done to quantify performance (S/N, effective BW, etc), and identify regimes/experiment conditions where one technique might be better suited than the others.
- Must be fielded at meaningful velocities (> 1 km/s) under real experimental conditions.







2-color beat signal can be extracted at lower S/N