PDV development at the LANL Proton Radiography Facility: smaller, cheaper, lower bandwidth

The Los Alamos Proton Radiography Facility (pRad) employs a high-energy proton beam to image the properties and behavior of materials driven by high explosives. We will discuss features of pRad and describe some recent experiments, highlighting optical diagnostics for surface velocity measurements.

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LANSCE:
Los Alamos Neutron Science Center

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Proton Radiography
National security research
Dynamic Materials science
Hydrodynamics

WNR
National security research
Nuclear Physics
Neutron Irradiation

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

Isotope Production Facility
Medical radioisotopes

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Pass through the sample

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A magnetic lens re-images the sample

The most highly-scattered protons are removed
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Protons form a real image
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A visible image is recorded

protons → protons

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Detector

Object

Magnetic Lens

Simple “shadow” image – results are substantially blurred.

Magnetic imaging of the protons preserves high resolution. (Los Alamos 1995)
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Proton pulse timing sequences can be specified by the experimenter

High-speed radiographic movies!
21.4 microsec

Experiment Principal Investigator: Billy Buttler
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Experiment Principal Investigator: Russ Olson
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**PDV:** Photon Doppler Velocimetry

1550nm laser system with control electronics

PDV photonics

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New hardware implementations towards several goals:

1. Miniaturize PDV hardware
2. Reduce total cost per channel
3. Reduce digitizer bandwidth requirements
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(1) Miniaturize PDV hardware

Replace rack-mounted EDFA lasers with single frequency laser diodes and tapered amplifiers.

Goal: “Small as a deck of cards”
(2) Reduce total cost per channel

Add a 1310nm-based PDV; overlay signal with 1550nm PDV
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Demonstration that dual-wavelengths and tapered amplifier technologies work for PDV application
(3) Reduce digitizer bandwidth requirements. For 1550 nm, PDV signal is 1.3 GHz per km/s speed. Electrical heterodyning produces signal at $f_{\text{LO}} \pm f_{\text{sig}}$. 

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(3) Reduce digitizer bandwidth requirements: Electrical heterodyning produces signal at $f_{LO} \pm f_{sig}$
(3) Reduce digitizer bandwidth requirements:
Electrical heterodyning produces signal at $f_{LO} \pm f_{sig}$
(3) Reduce digitizer bandwidth requirements:

Electrical heterodyning requires recording multiple bands of frequency offset.

Alternative approach: reduce constant for velocity/GHz
(3) Reduce digitizer bandwidth requirements:
Reduce signal frequency per given speed

\[ \Delta f_{1550} \approx 1.3 \text{ GHz/km/s} \]

\[ \Delta f_{1310} \approx 1.5 \text{ GHz/km/s} \]

\[ (\Delta f_{1310} - \Delta f_{1550}) \approx 237 \text{ MHz/km/s} \]
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(3) Reduce digitizer bandwidth requirements:
Reduce signal frequency per given speed

$$\Delta f_{1310} - \Delta f_{1550} \approx 237 \text{ MHz/km/s}$$
(3) Reduce digitizer bandwidth requirements:
Decode digitizer “alias” with two laser frequencies

Undersampling a periodic function produces aliasing

![Graph showing True Signal and Aliased Measurement](image)
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(3) Reduce digitizer bandwidth requirements: Decode digitizer “alias” with two laser frequencies

Sampled at 312 MS/s

Sampled at 100 MS/s
Multiple spectra can result in a single measured spectrum

\[ f_{\text{signal}} = Nf_s \pm f_M \]

\[ N = ??? \]

\( f_M \) = Measured spectrum
\( f_S \) = Scope bandwidth
\( f_N \) = Nyquist frequency

\[ f_{\text{signal}} = f_M \]
\[ f_{\text{signal}} = f_s - f_M \]
\[ f_{\text{signal}} = f_s + f_M \]
\[ f_{\text{signal}} = 2f_s - f_M \]
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(3) Reduce digitizer bandwidth requirements:
Decode digitizer “alias” with two laser frequencies

![Graph showing 1310 and 1550 signals]
(3) Reduce digitizer bandwidth requirements:
Decode digitizer “alias” with two laser frequencies

**Figure**: Graph showing signal aliasing with two laser frequencies.
(3) Reduce digitizer bandwidth requirements: Decode digitizer “alias” with two laser frequencies
(3) Reduce digitizer bandwidth requirements: Decode digitizer “alias” with two laser frequencies

1310 nm signal reflects six times, therefore using 7*BW
1550 nm signal reflects five times, using 6*BW
(3) Reduce digitizer bandwidth requirements:
Decode digitizer “alias” with two laser frequencies

Knowing that both signals represent the same velocity yields one unique solution for any given time
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OZ Optics MEMS-based voltage controlled attenuators

Single-channel

Eight-channel
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OZ Optics MEMS-based voltage controlled attenuators

- Low voltage, 0-6V
- Low power electrical power consumption (<10 mW)
- High optical power handling, up to 500 mW
- Repeatable (negligible hysteresis)
- Available with built in power monitoring
- No new optical noise
Conclusions:

There is ongoing development on PDV at the LANL Proton Radiography facility to make the diagnostic:

1. Smaller
2. Lower cost, for opto/electronics
3. Available at digitizer bandwidths attainable on a university budget
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Proton Radiography team:

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