Potential Velocimetry Extensions of the Spectrally Encoded Imaging Diagnostic

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Campaign 8
Enhanced Surveillance

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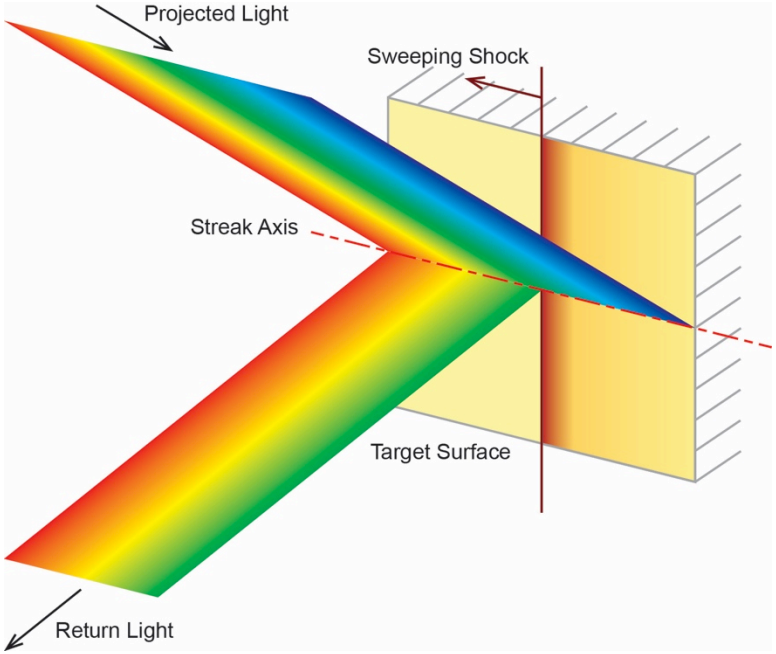
Technique

Spectrally Encoded Imaging (SEI)

- Image target surface through one single optical fiber.
  - Spectrally encode light with spatial target information.
  - Measure return spectra as a function of time.
  - Spectral dropouts correlate to target surface perturbations.



Technique
SEI versus PDV

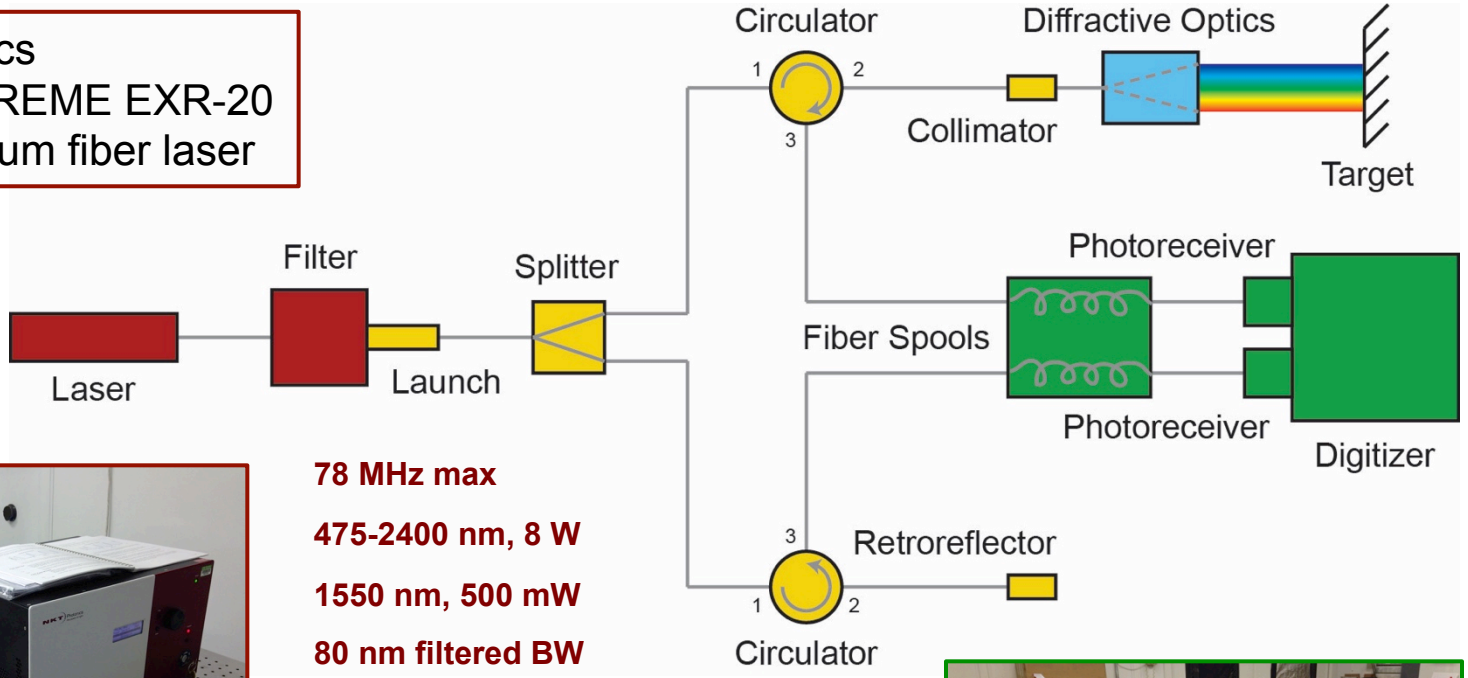
- Measured quantities.
  - PDV measures breakout at single point with velocimetry.
  - SEI measures breakout across surface without velocimetry.
- Both are fiber-based systems.
  - Open beam at target only.
  - Capable of accessing enclosed targets lacking optical access.
- Both systems share major components.
  - Telecommunications band fiber optics and equipment.
  - High speed digitizers.
- Technique convergence may be possible.
  - Desire velocimetry across entire surface.

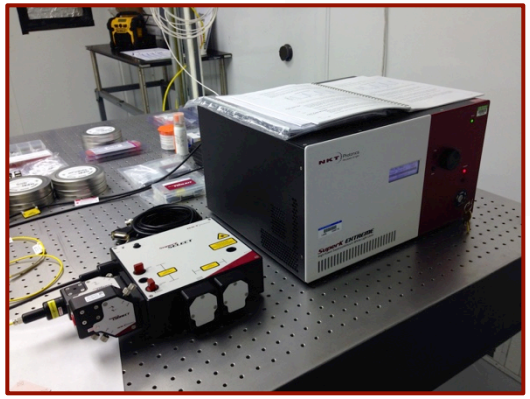
Technique

Reference: K. Goda et al. Dispersive Fourier transformation for fast continuous single-shot measurements. *Nature Photonics*, Vol 7(2), pp 102–112, 2013.

Diagnostic System Schematic

NKT Photonics
SuperK EXTREME EXR-20
supercontinuum fiber laser





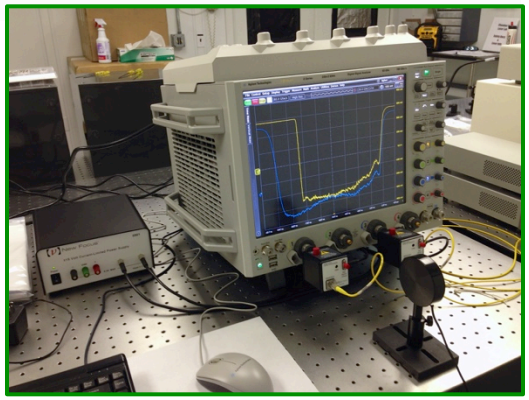
78 MHz max

475-2400 nm, 8 W

1550 nm, 500 mW

80 nm filtered BW

63 GHz, 160 GS/s

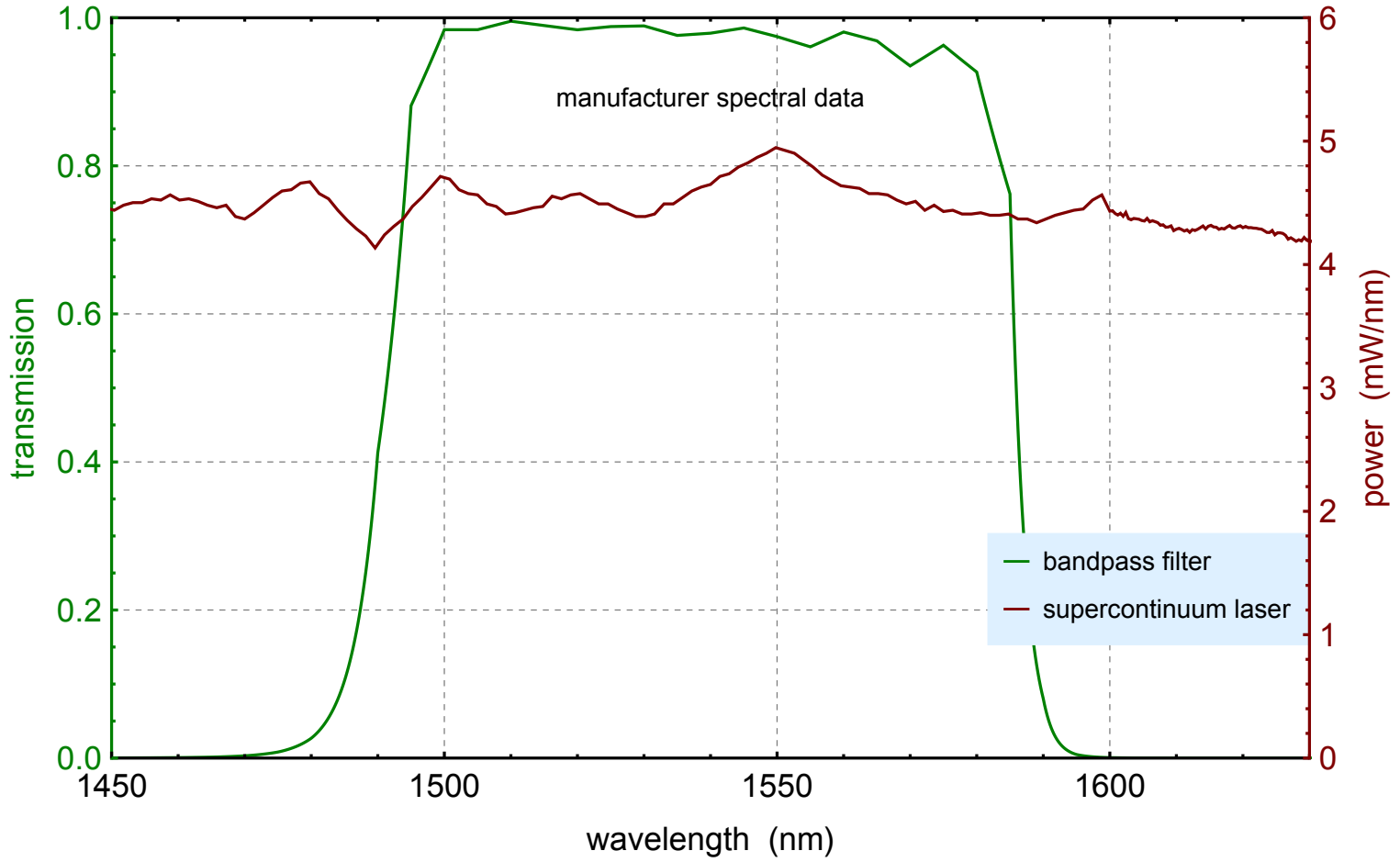


Agilent
DSAZ634A
high speed digitizer

Technique

bandpass filter covers C-band from 1530-1565 nm

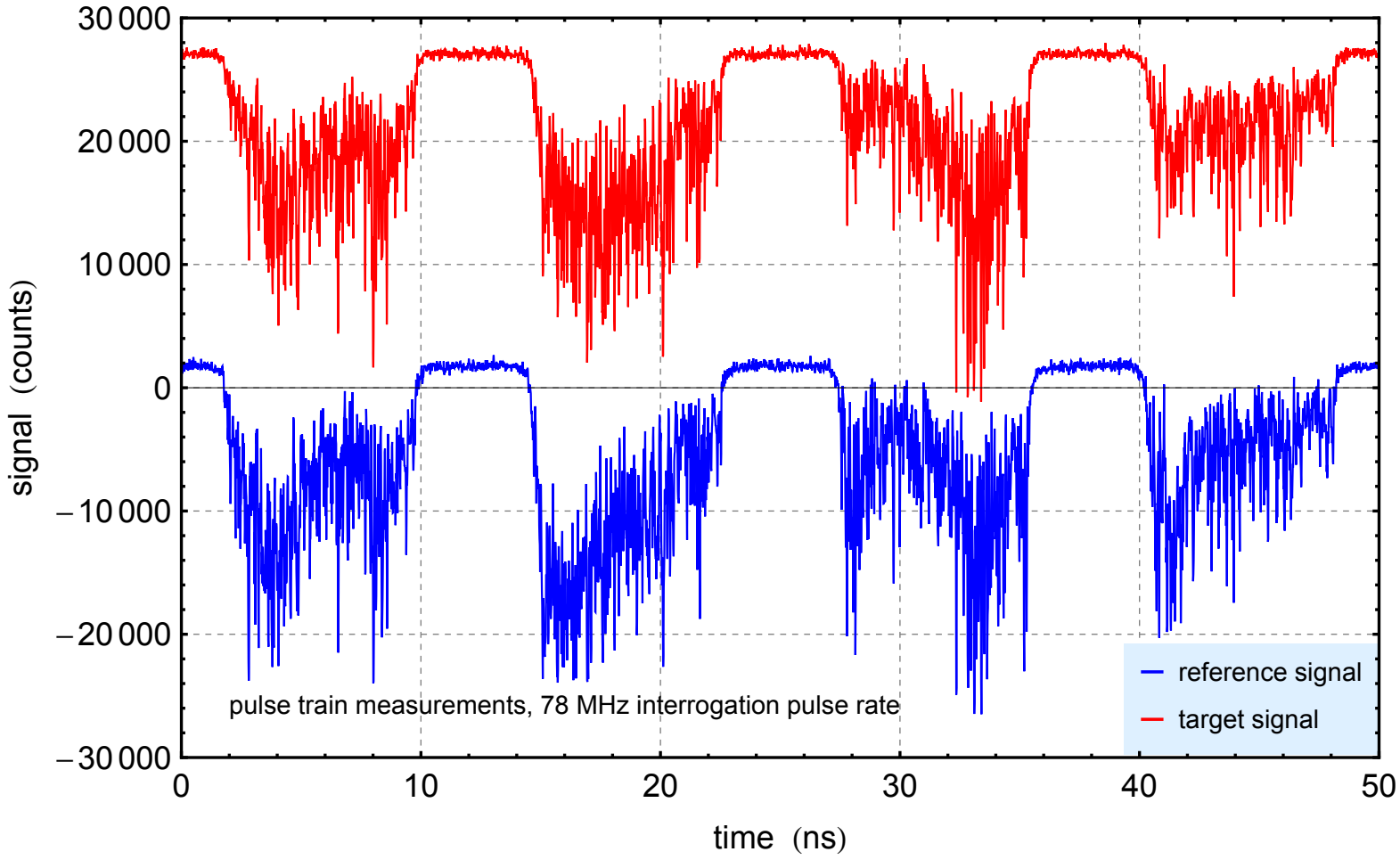
Spectral Output Characteristics



Technique
Pulse Train Characteristics

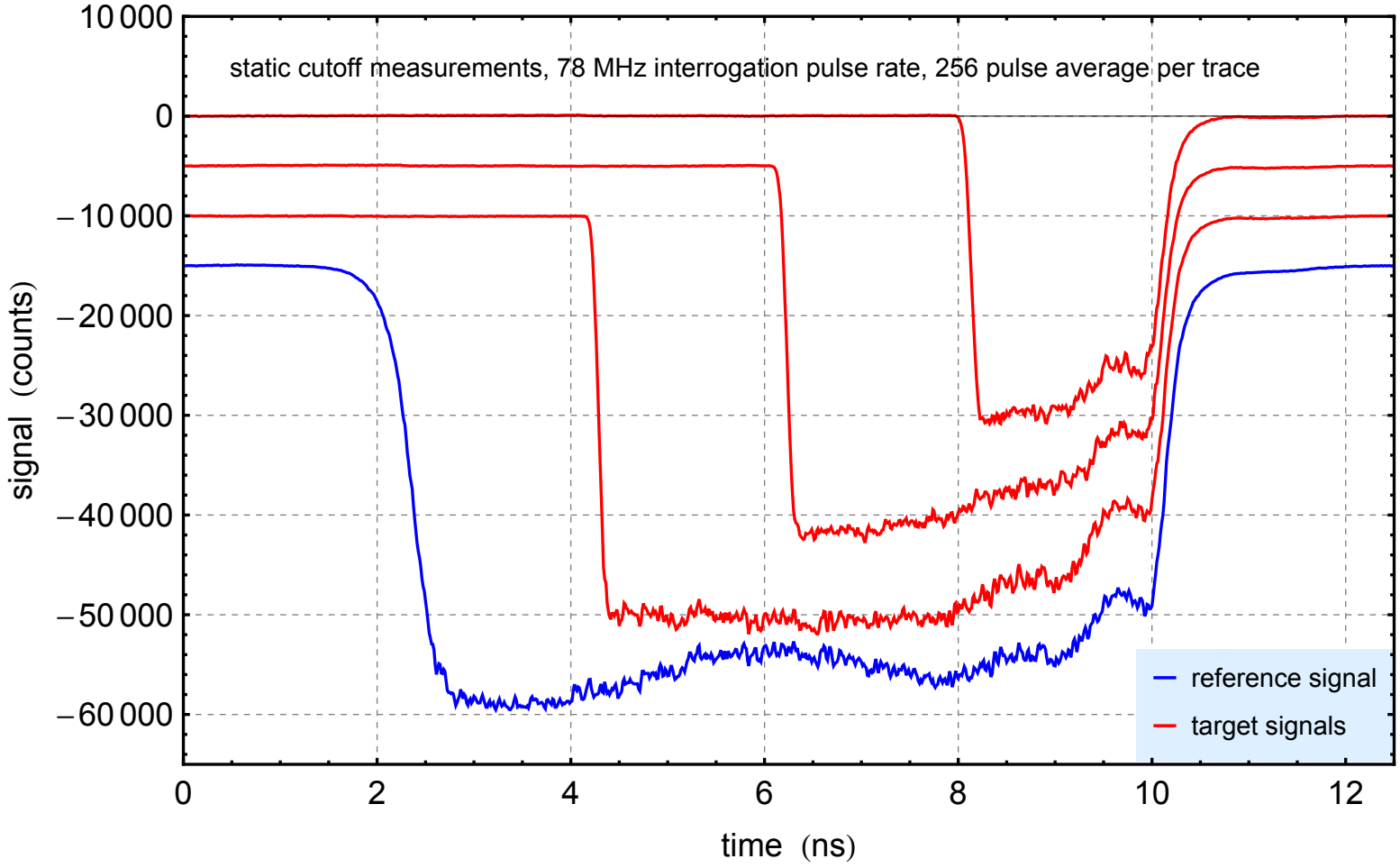
SMF-28 dispersion = 17.4 ps nm^{-1} km^{-1}

5 km of SMF-28 yields ~8 ns stretch



Experiment

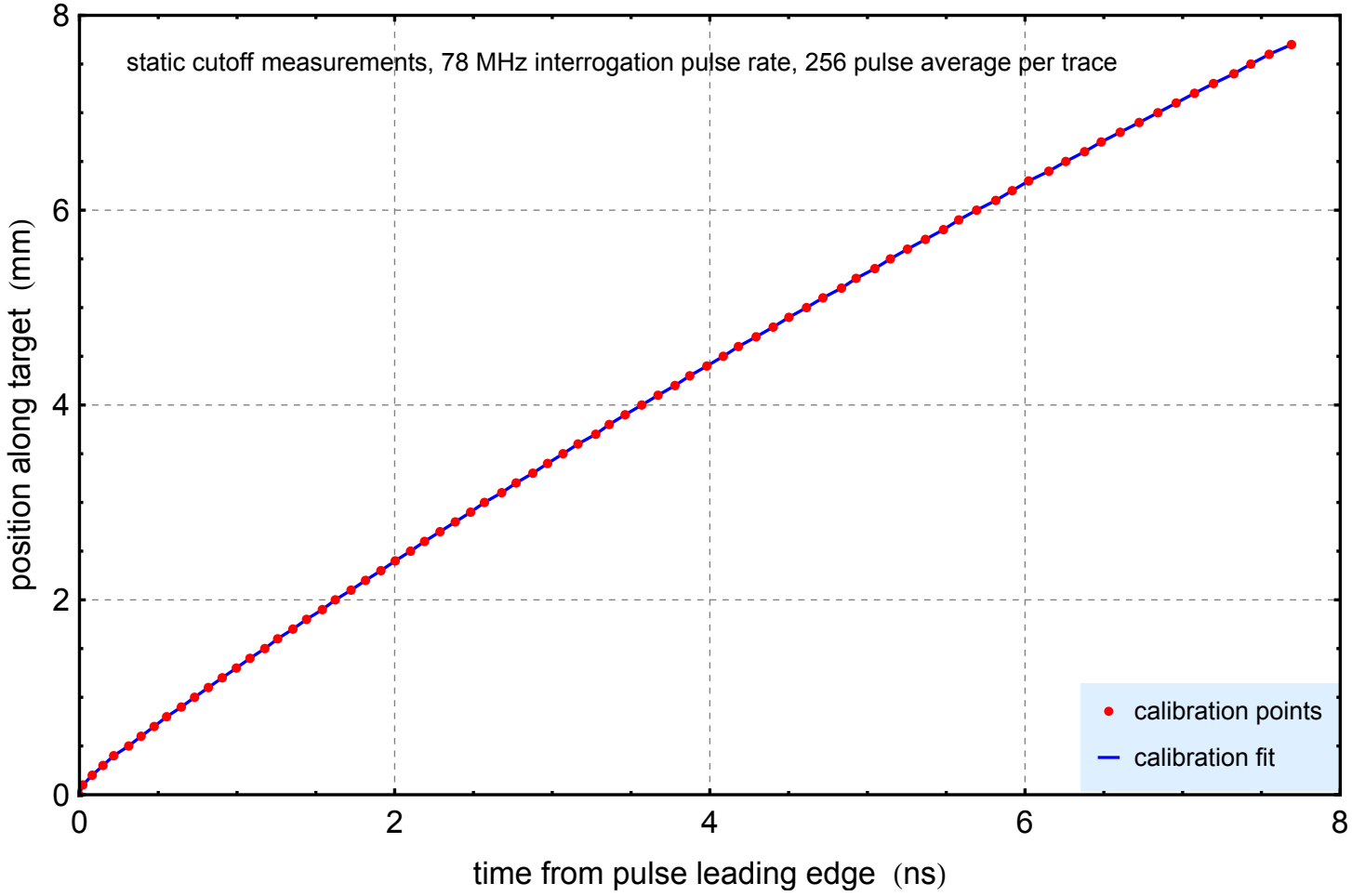
Static Cutoff Measurements – Sweep



Experiment

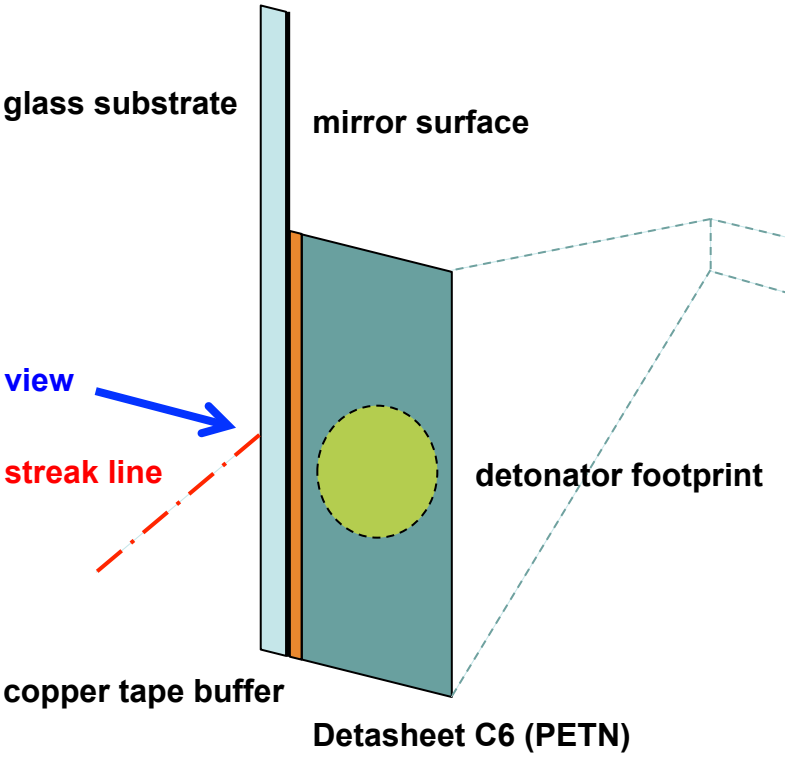
semi-automated process with motorized traverse assembly

Static Cutoff Measurements – Spatial Mapping



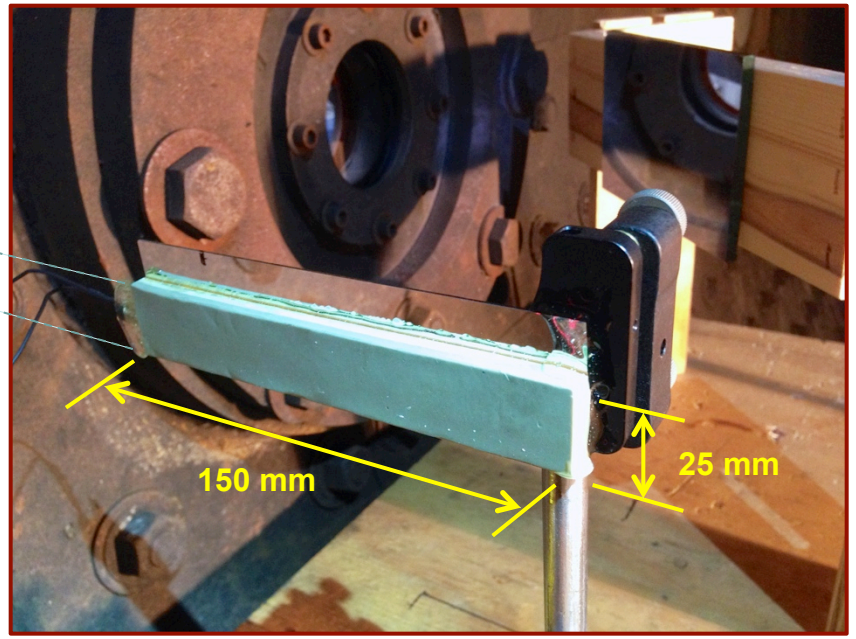
Experiment

Dynamic Measurements – Assembly Geometry



Shot Cross-Section

(not-to-scale)

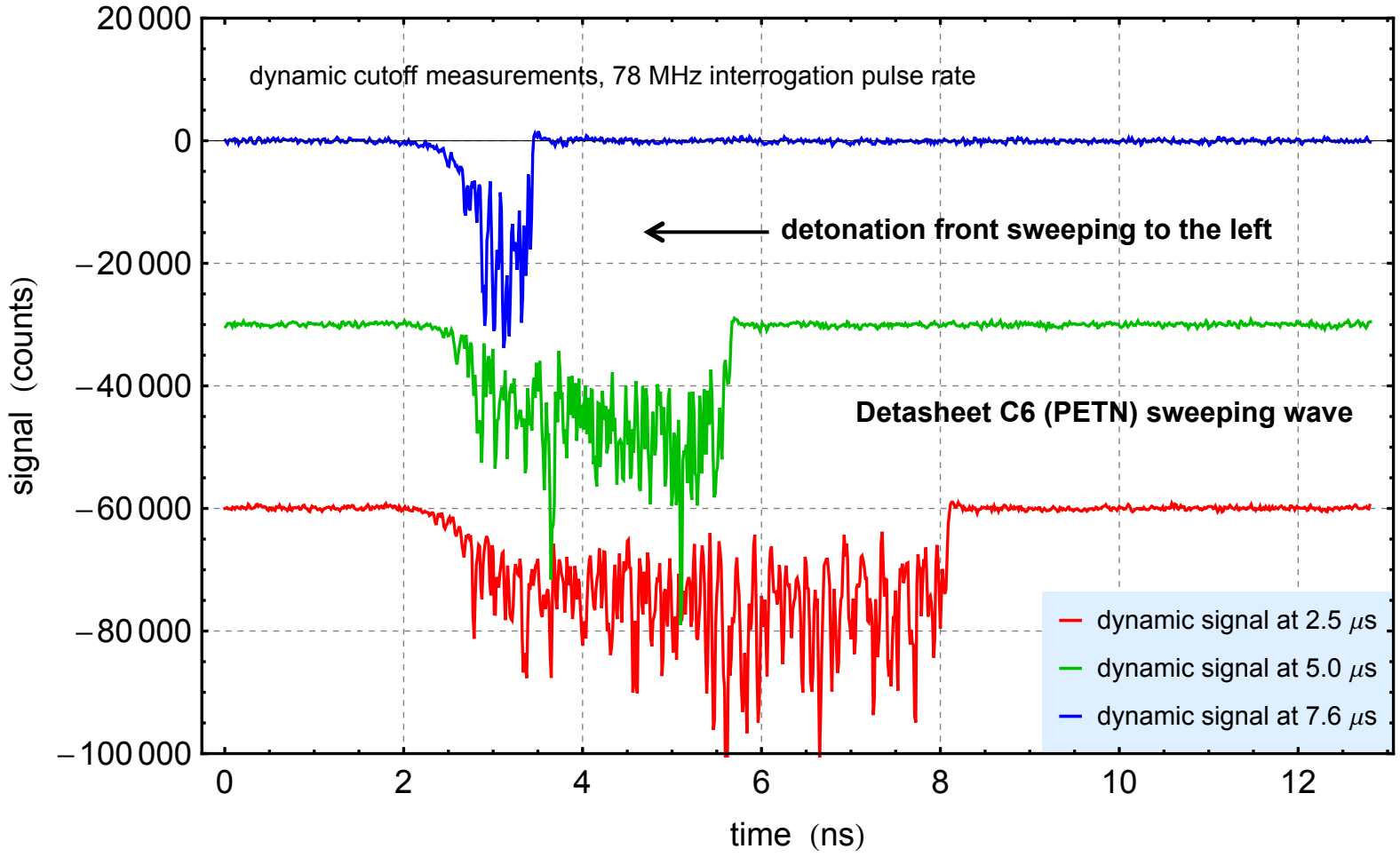


Shot Parameters:

- 800 mm shot standoff from probe relay lens
- ~60 mm streak length (beam spread along target)
- ~40 mm streak start offset from detonator output
- ~0.1 mm focused beam in transverse direction

Experiment

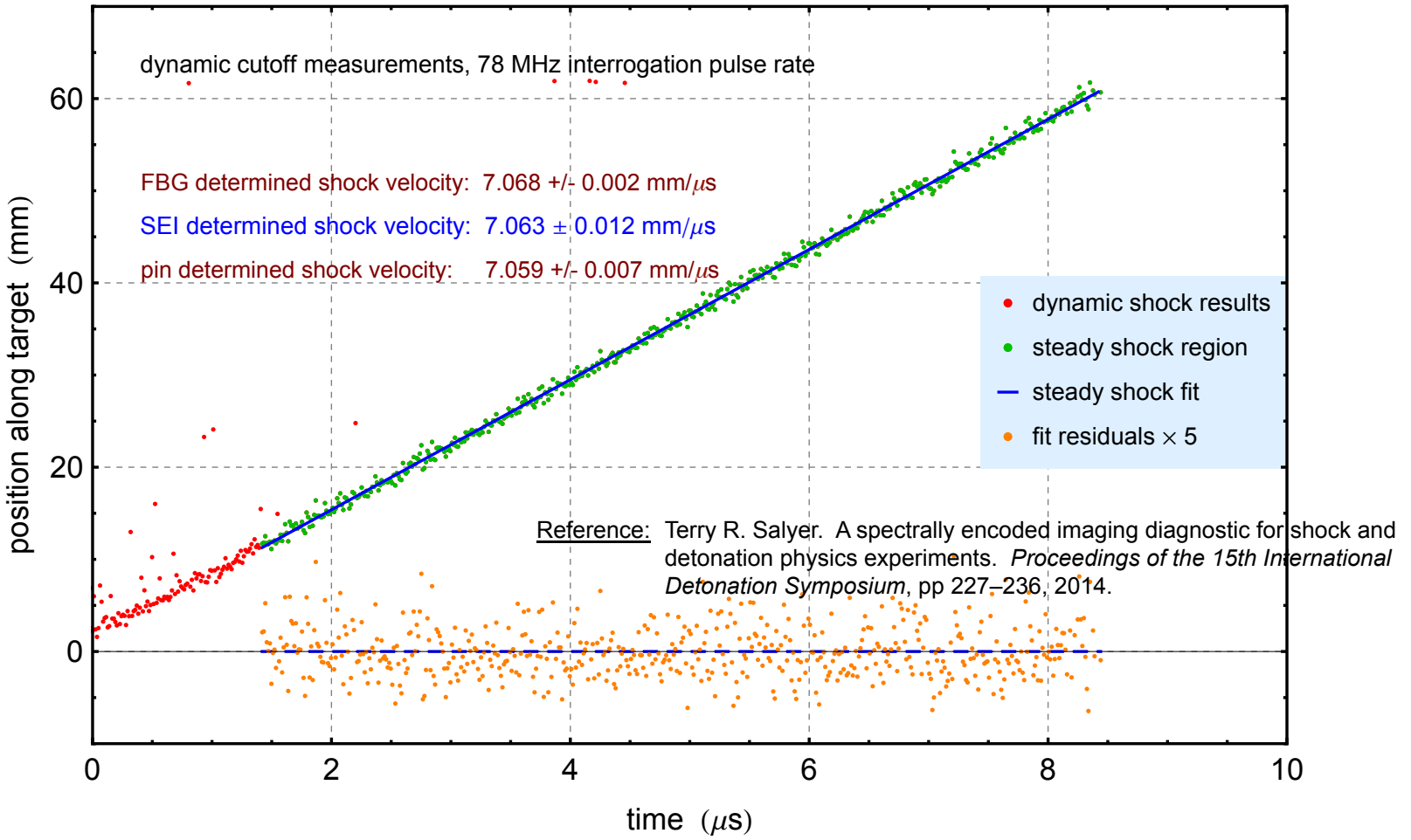
Dynamic Measurements – Pulse Evolution



Experiment

Reference: G. Rodriguez et al. Fiber Bragg sensing of high explosive detonation experiments at Los Alamos National Laboratory. *Journal of Physics: Conference Series*, 142030, 2014.

Dynamic Measurements – Detonation Breakout



Enhancement
Potential Velocimetry Capability

- Issues with Doppler shift velocimetry analysis.
  - Target spectral resolution.
  - Small frequency shift.
  - Wavelength mixing.
  - Reflectivity attenuation.
  - Pulse-to-pulse spectral variation.

source wavelength = 1550 nm
initial frequency = 193.414 THz

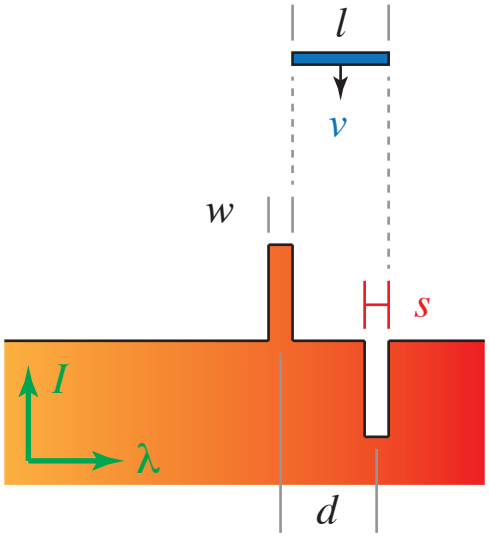
surface velocity = 1000 m/s

frequency shift = 0.000645162 THz
wavelength shift = -0.00517023 nm

- Physical effects and system features to exploit.
  - Combined reverse wavelength gradient beams.
  - Heterodyning to remove attenuation effects while doubling signal.
  - Polarization control to encode interrogation beam.
  - Possible pulse interference effects.

Enhancement

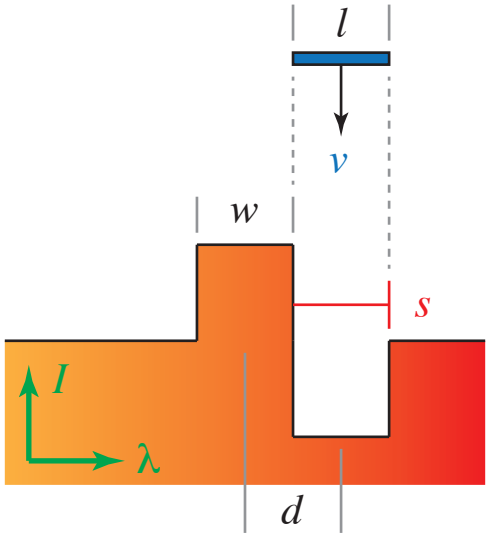
Doppler Shifted Spectral Response



low velocity regime

$s < l$

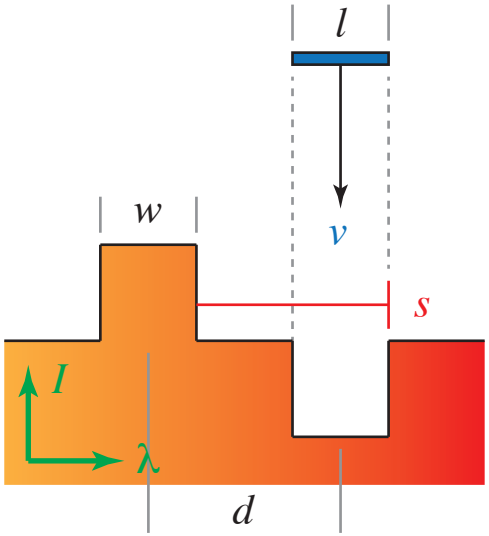
$v \sim (s = w)$



critical velocity regime

$s = l$

$v \sim (s = w = d)$



high velocity regime

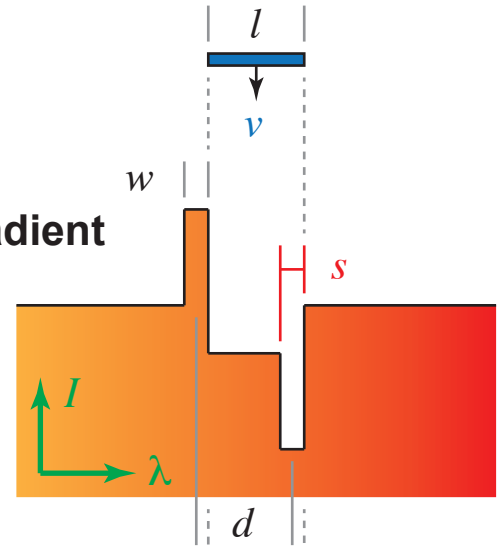
$s > l$

$v \sim (s = d)$

Enhancement
Heterodyned Signal

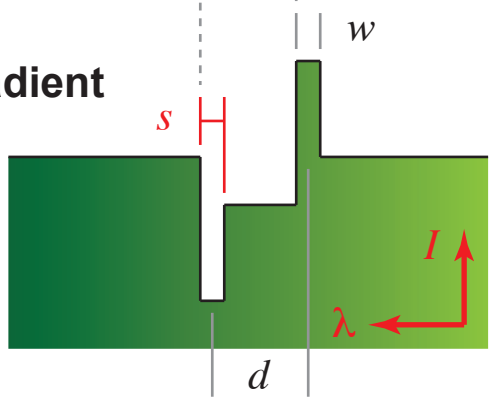
forward wavelength gradient

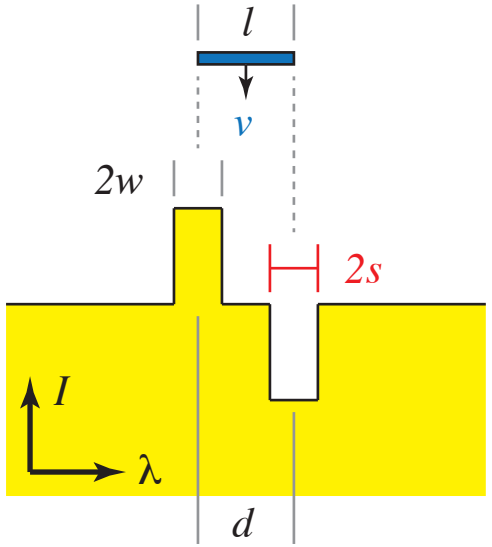
with attenuation



reverse wavelength gradient

with attenuation





heterodyned signal

attenuation effects removed

shift signal doubled

Enhancement
Additional Capability Improvements

- SEI time resolution improvements.
  - Increased pulse repetition rate via pulse split/delay/recombine.
  - Requires tunable optical fiber delay lines.
- SEI spatial resolution improvements.
  - Limited by digitizer bandwidth and sampling rate.
  - Maximize digitizer channel capacity with regard to memory depth.
  - Time multiplexing via fast switches and delay/compensation coils.
- SEI signal-to-noise ratio improvements.
- Add ranging capability to SEI as with PDV.
  - DFT technique integral to pulsed SEI system.
  - PDV BLR capability currently uses DFT technique as well.

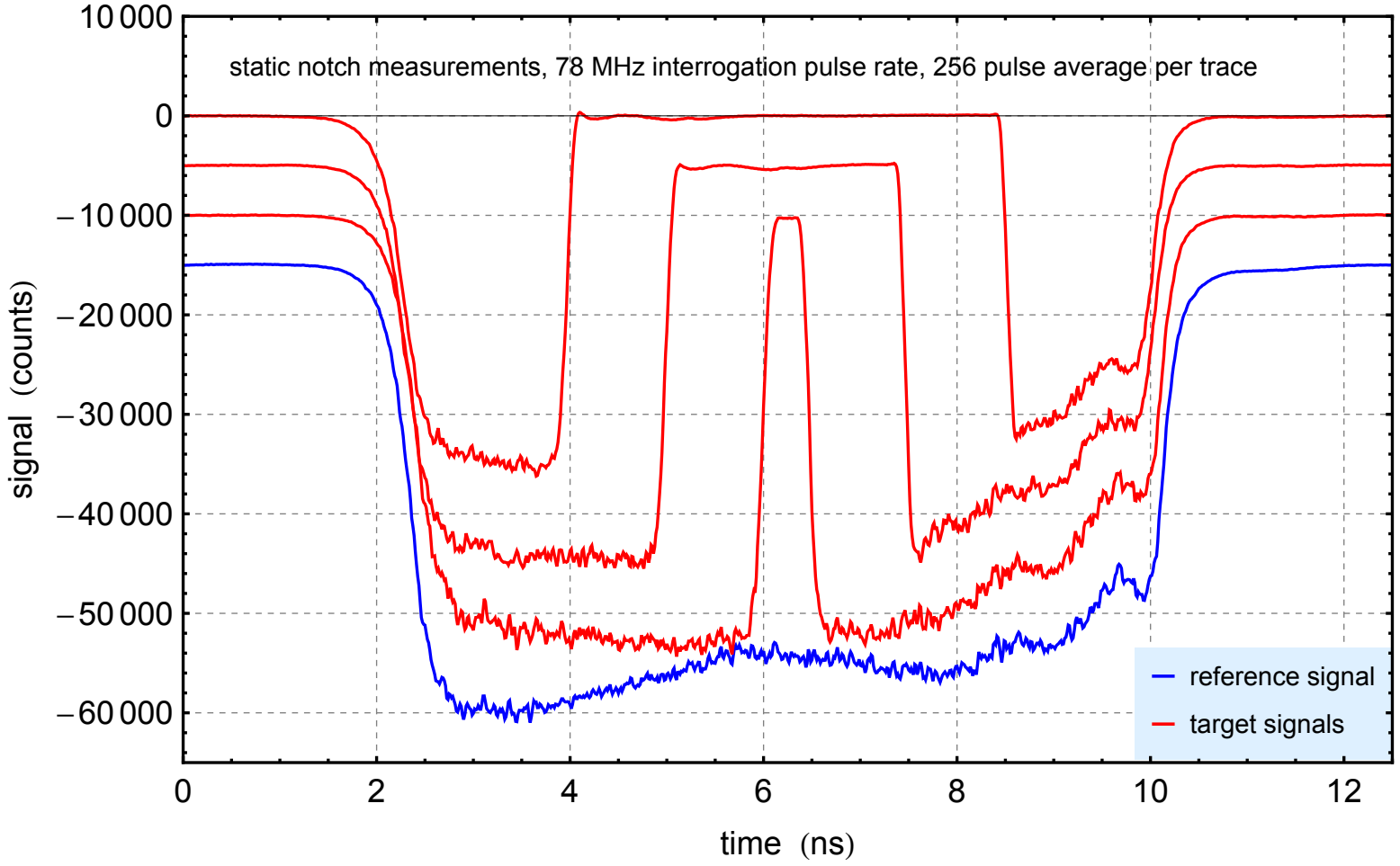
Acknowledgments

- Program
  - Stockpile stewardship (Enhanced Surveillance Campaign)
  - Program management (Tom Zocco, Sheldon Larson)
- Technical Support
  - System development (Israel Owens)
  - Optical sciences (Dave Moore, Shawn McGrane, Peter Goodwin)
  - Detonation physics (Larry Hill, Rick Gustavsen)
  - Site operations (Sam Vincent, Tim Kuiper)

Support Slides

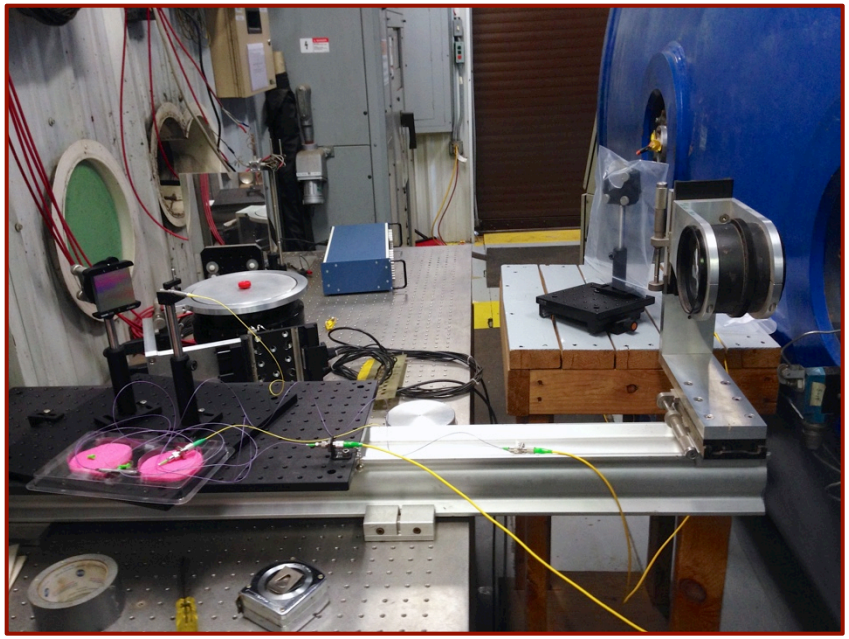
Experiment

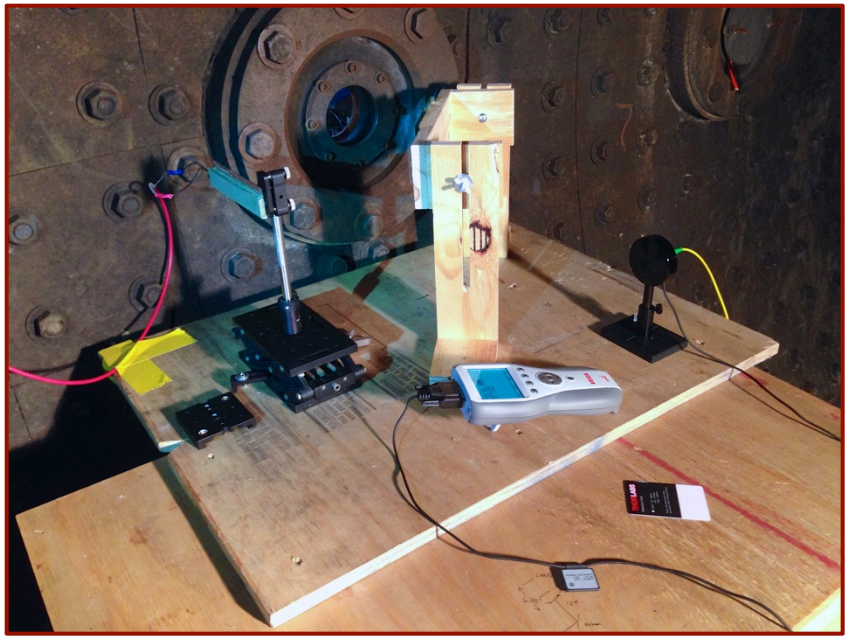
Static Cutoff Measurements – Notch



Experiment

Dynamic Measurements – Shot Layout





Probe System:

- aspheric fiber collimator
- ruled diffraction grating (1.6 micron blaze)
- 800 mm compound relay lens
- turning mirror

Shot Assembly:

- surface mirror
- copper tape buffer
- Detasheet C6 (PETN)
- RP-2 EBW detonator
- optomechanical positioners

Experiment

Dynamic Measurements – Spatial Mapping