Broadband Laser Ranging: Optimizing the Design for Different Experiments

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Outline

- Why BLR
- Design Equations
- Calibration considerations
- LANL Prototype System: A wide pulse, Multiplexed Architecture
- Summary

Some Reasons to Field BLR

1. **Indication of 1-D:** When you want an indication that your experiment is 1-D or nearly 1-D throughout the motion.
2. **Transverse Motion:** When there may be transverse (or complex) motion, but you can only field probes along a single direction due to other constraints.
3. **Interested in Displacement:** When you are interested in position more than velocity, and/or when there may be drop-outs in the signal so that integrating the PDV signal is unreliable.
4. **Interested in Thickness:** When you want to measure the thickness of a cloud of ejecta particles (or any other semi-transparent medium).

May be other reasons…..

Some Reasons to Field OR, cont.

- We do **<u>not</u>** believe that ranging will have inherently better temporal or spatial resolution or sensitivity than a Doppler-based measurement. (Comparable but not better).
- Nor is ranging easier to field.
- **<u>Ranging is Complementary to PDV.</u>**

Design Equations….

λ: center wavelength (nm)
w_p: Pulse BW (nm)
F: Recording BW (GHz)
D: Total Dispersion (ns/nm)
D_0: Dispersion on target (ns/nm)
L: Length of Fiber to Target (m)

- Usable Range: $x = \lambda^2 FD$
- Displacement Resolution*: $\Delta x = \lambda^2/(4w_p)$
- Time Resolution*: $\Delta t = w_p D/\sqrt{12}$
- Doppler Sensitivity: $b_x = (D_0\lambda)v$
- Max Pulse Energy: $E_{pulse} = (400\ W/m)\ (D_0 w_p/L)$

* Resolution is the ability to differentiate two surfaces. Note that displacement precision is ~10x the displacement resolution for strong signals.

Design Equations for BLR….

λ: center wavelength (nm)
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D: Total Dispersion (ns/nm)
D_0: Dispersion on target (ns/nm)
L: Length of Fiber to Target (m)

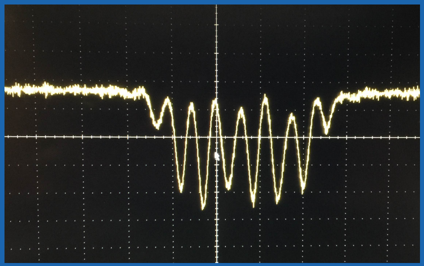
- Typical Design:
  - D = 2 ns/nm (120 km of fiber),
  - w_p = 20 nm, λ = 1560 nm
  - L = 30m, D_0 = 0.017 ns/nm
- Performance:
  - x = 12 cm,
  - Δx = 30 μm,
  - Δt = 12 ns.
  - B_x = 26 μm / (km/s)
  - E_{pulse} = 4.5 nJ (~90 mW CW)
- The optimum values will be different for each experiment.

* Resolution is the ability to differentiate two surfaces. Note that position precision (i.e., repeatability) is ~10x the resolution for strong signals.

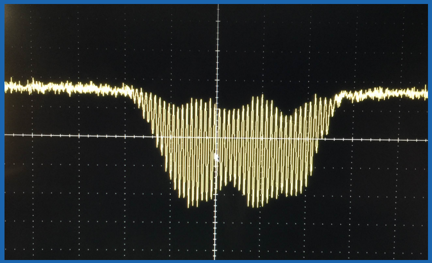
Calibration

- The mapping of a time waveform to a distance.

- Two Categories of Methods:
  - In Situ: Calibration at shot time.
  - Ex Situ: Calibration before/after shot.



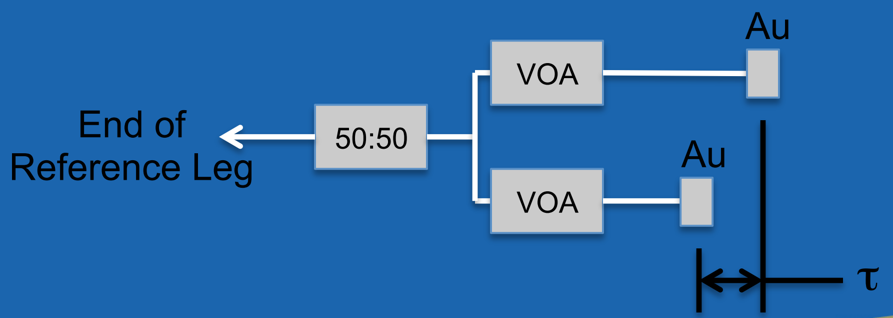
5 cm



10 cm

In Situ Calibration

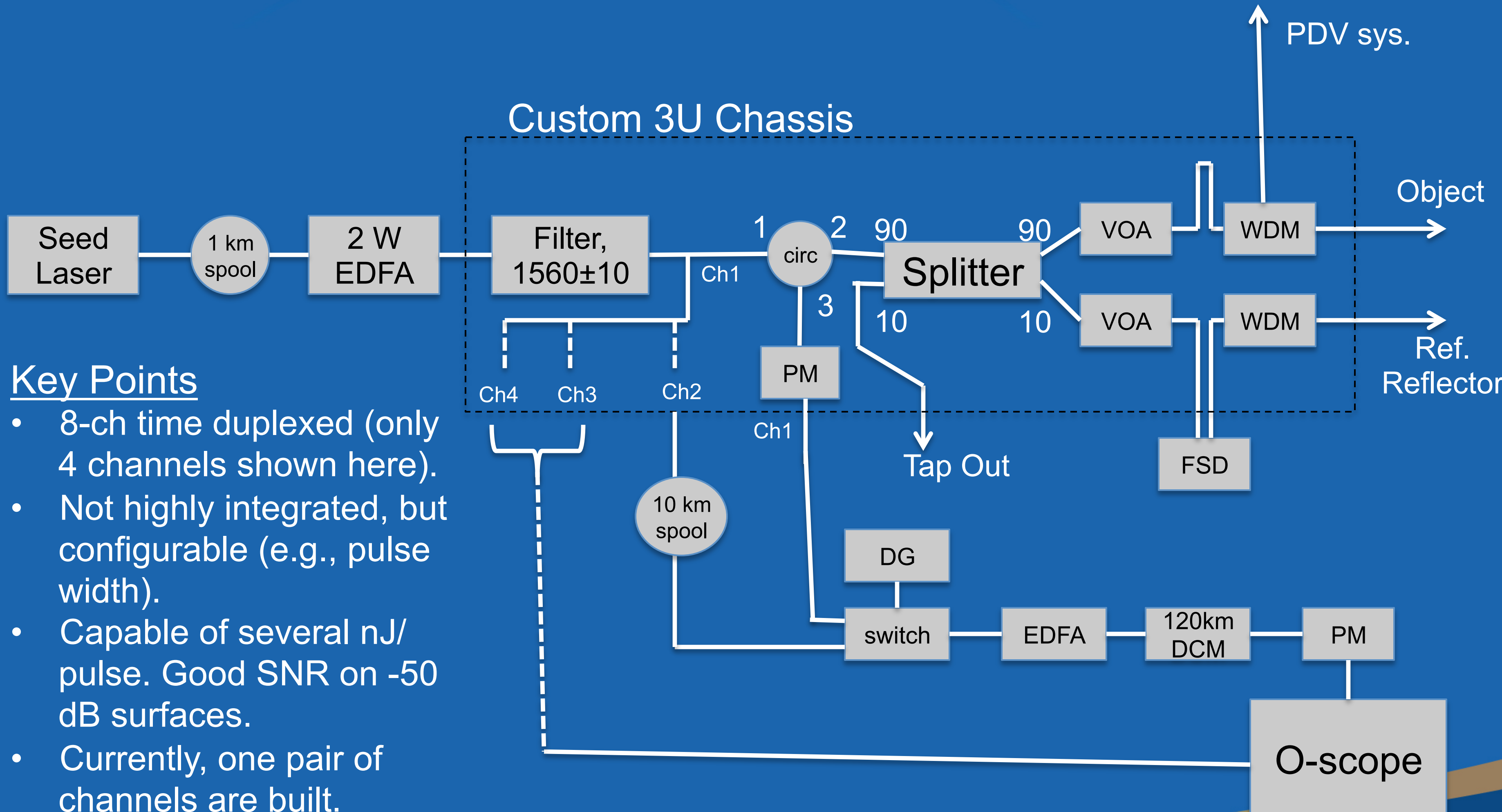
- For example: Extra Reflection(s) in the reference leg of the interferometer at known distances.
- Benefits:
  - Fairly straightforward to field.
  - Confidence of calibration at shot-time.
- Concerns:
  - Works well if the legs of the interferometer are well-matched in dispersion.
    - If not, a more complicated calibration function may be required that cannot be constrained with this method.



Ex Situ Calibration

- For example: Accurately moving the Reference Reflection to different known positions and recording the waveforms before the shot.
- Benefits:
  - Gain confidence in the repeatability of the system before the shot.
  - The entire interferometer is calibrated.
  - Can do many Calibration Points without much trouble -> A Complex Calibration Function could be used.
- Concerns:
  - The placement of the pulse in the analysis window has to be consistent between all cal records and the shot record.
    - This can be done with a spectral feature or recording the heart beat of the laser.
  - How much time will the Ex Situ Calibration take, and how far ahead of the shot should I do the calibration?

LANL Prototype System with Front-End and Back-End Multiplexing

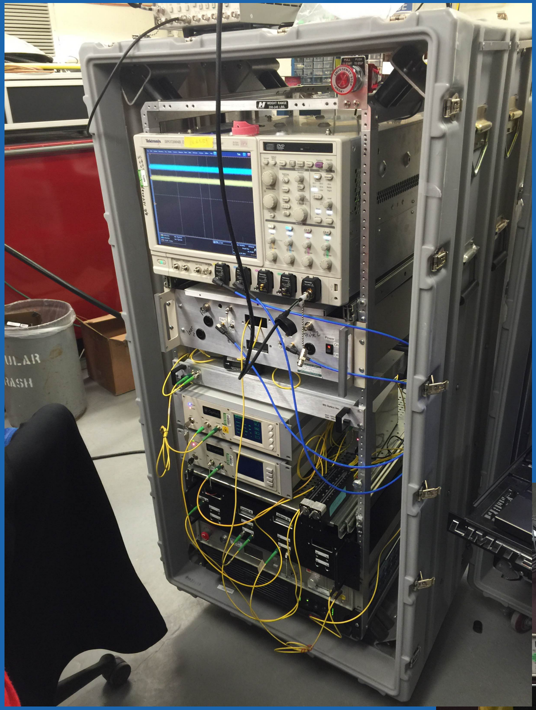


Key Points

- 8-ch time duplexed (only 4 channels shown here).
- Not highly integrated, but configurable (e.g., pulse width).
- Capable of several nJ/ pulse. Good SNR on -50 dB surfaces.
- Currently, one pair of channels are built.

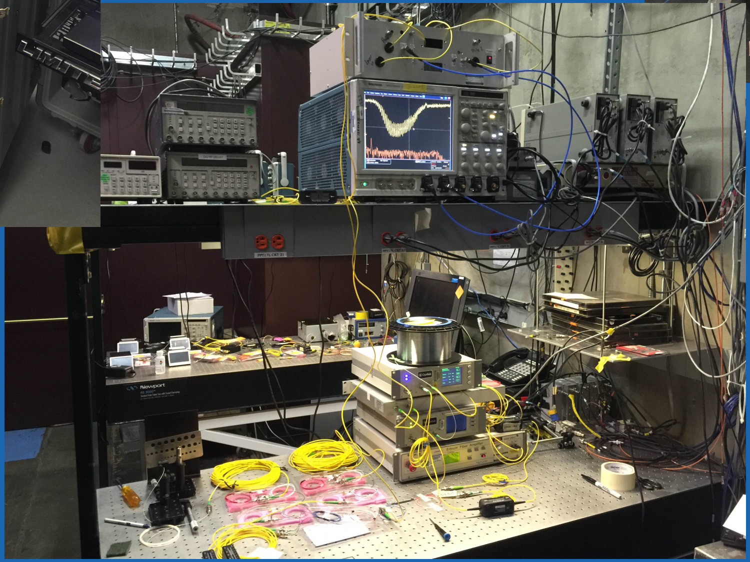
LANL Prototype System

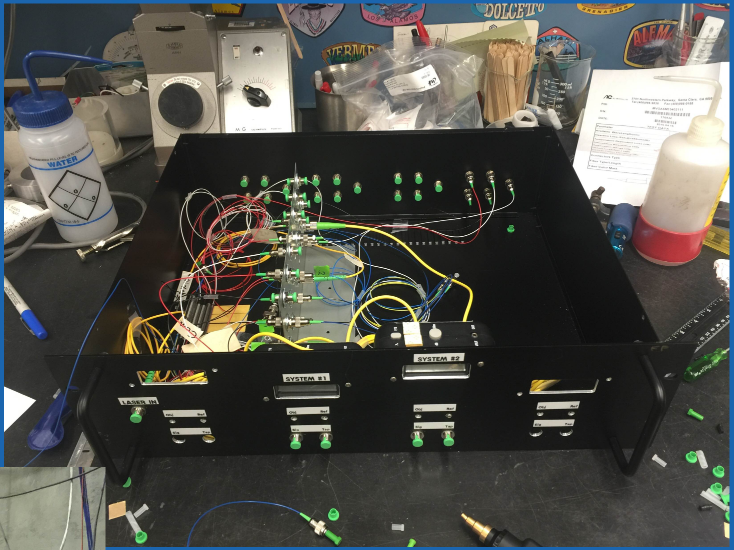
Los Alamos
NATIONAL LABORATORY
EST. 1943



System in a
Hardigg Rack

R&D in Lab

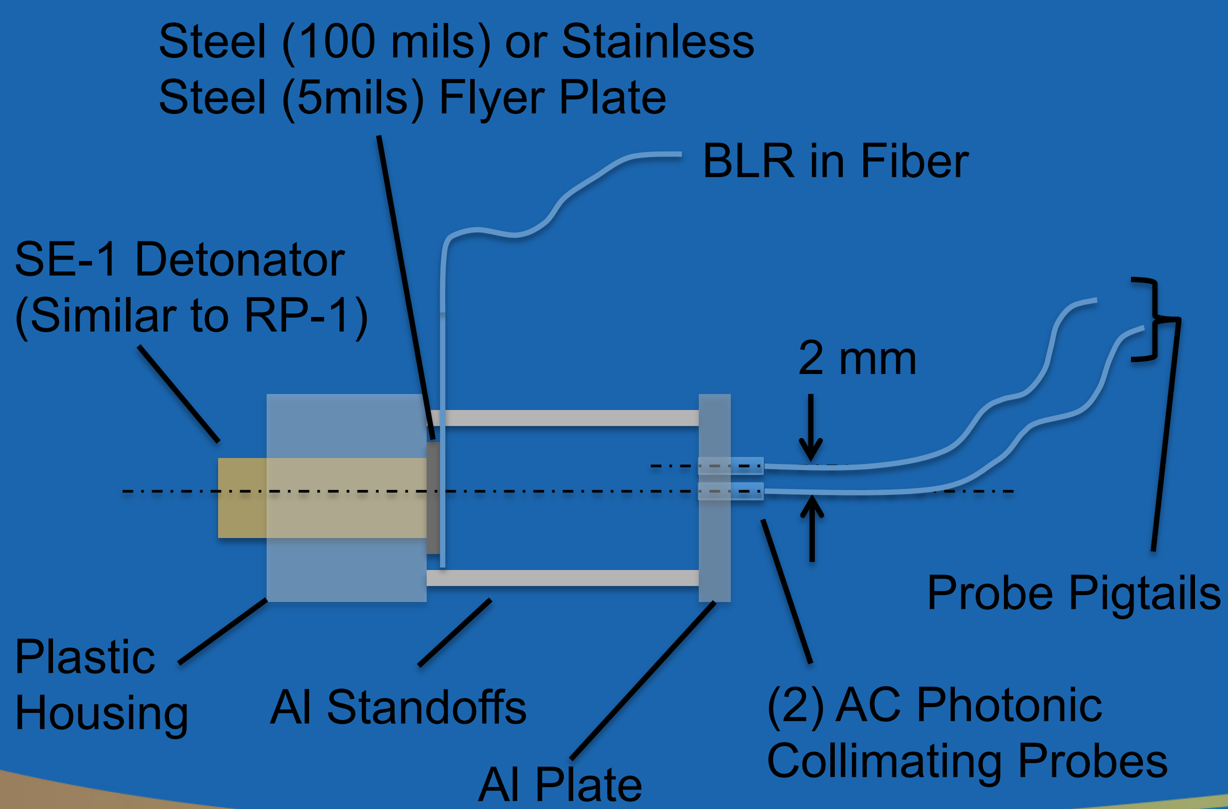


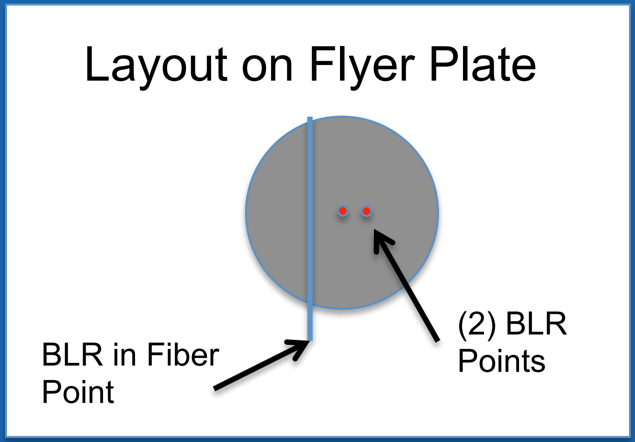


Custom Chassis
Thank you Lenny Tabaka
and Ruben Manzanares

Latest Dynamic Tests at LANL, Week of May 23

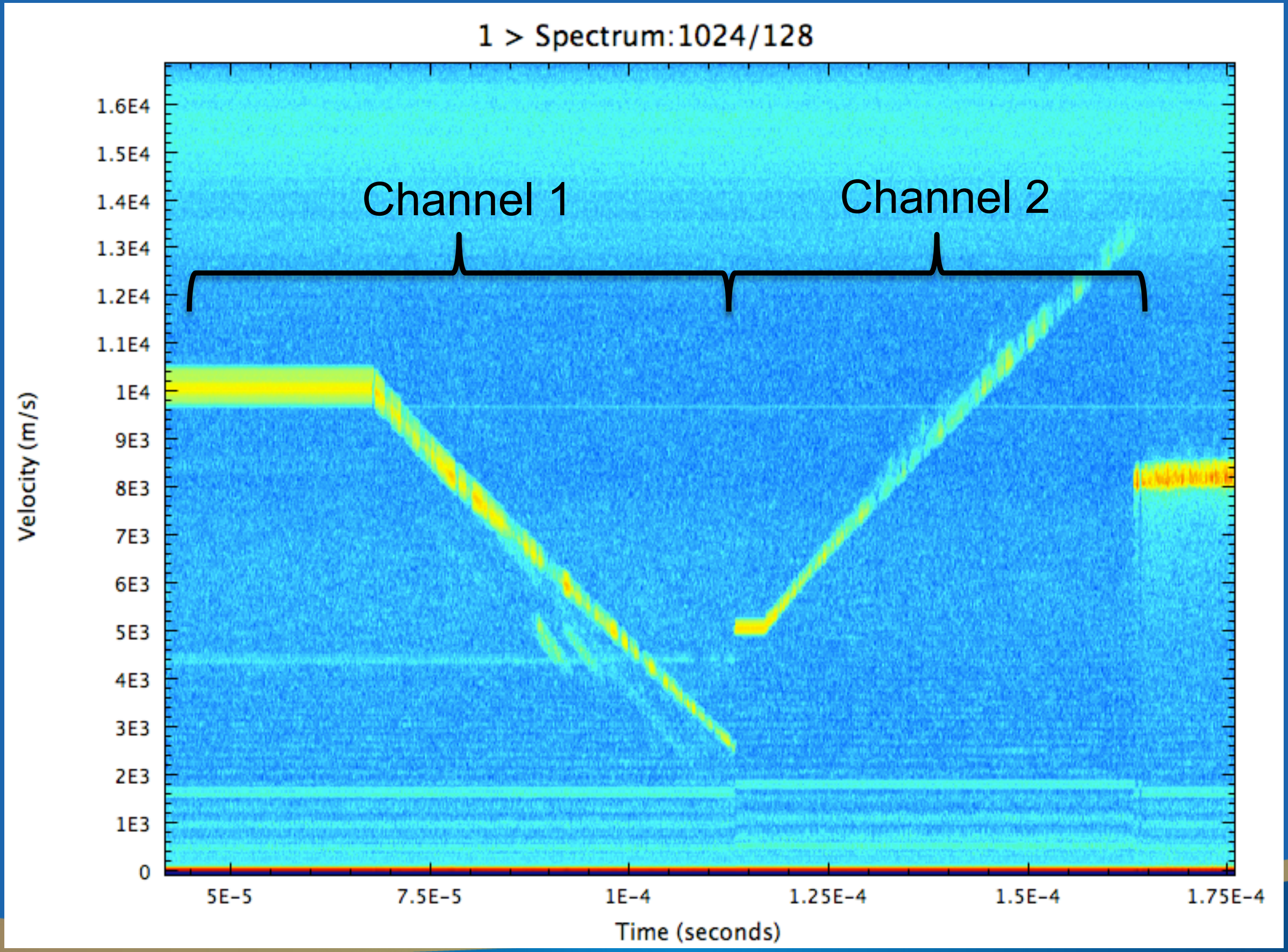
- Two BLR Points. BLR and PDV on same line-of-sight.
- One BLR in Fiber Point (Steve Gilbertson, J-4, and George Rodriguez, MPA-CINT)





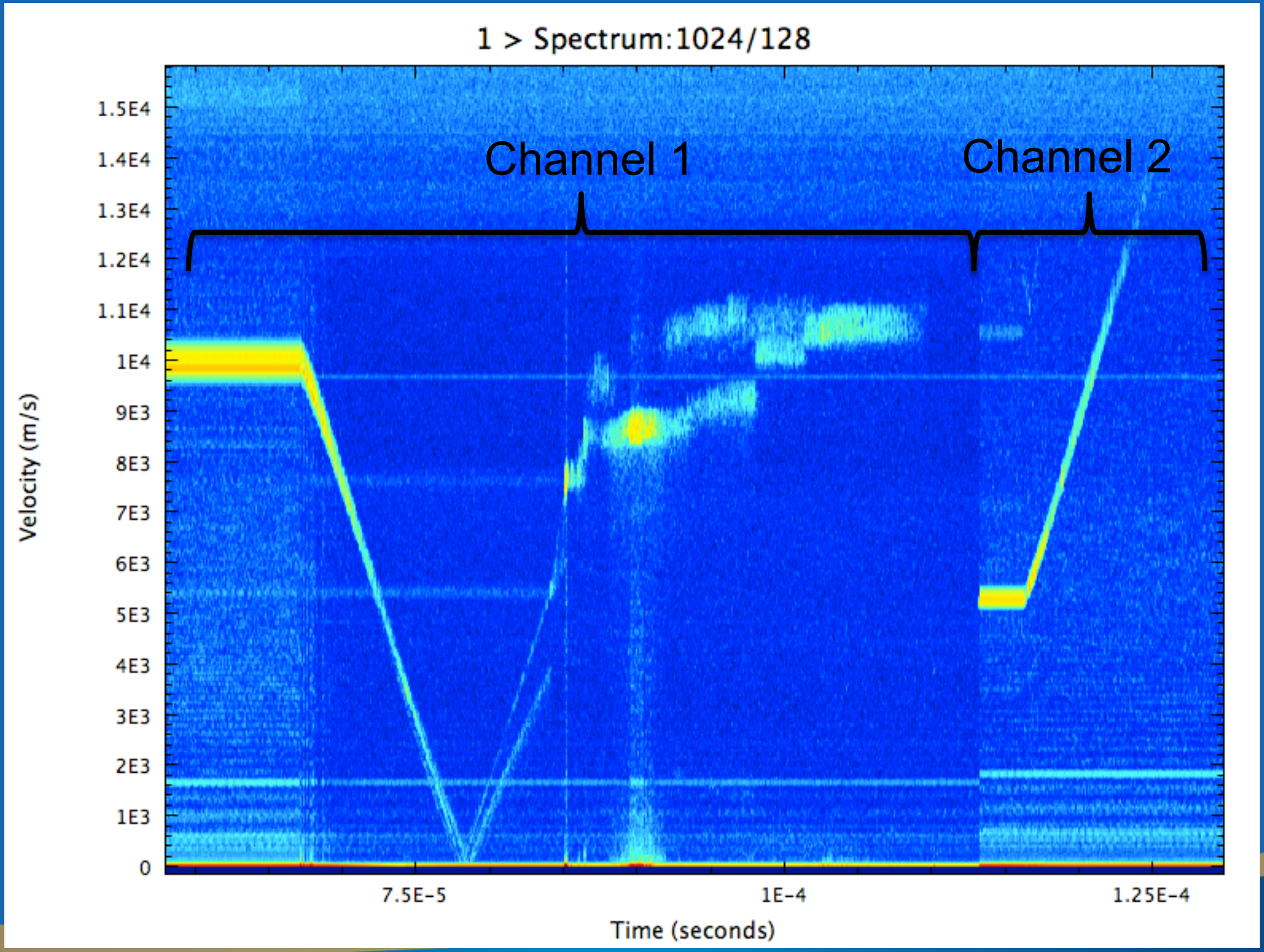
Results: BLR Det Run #1

Simple Spectrogram of Data Record (time duplexed)



Results: BLR Det Run #2

Simple Spectrogram of Data Record (time duplexed)

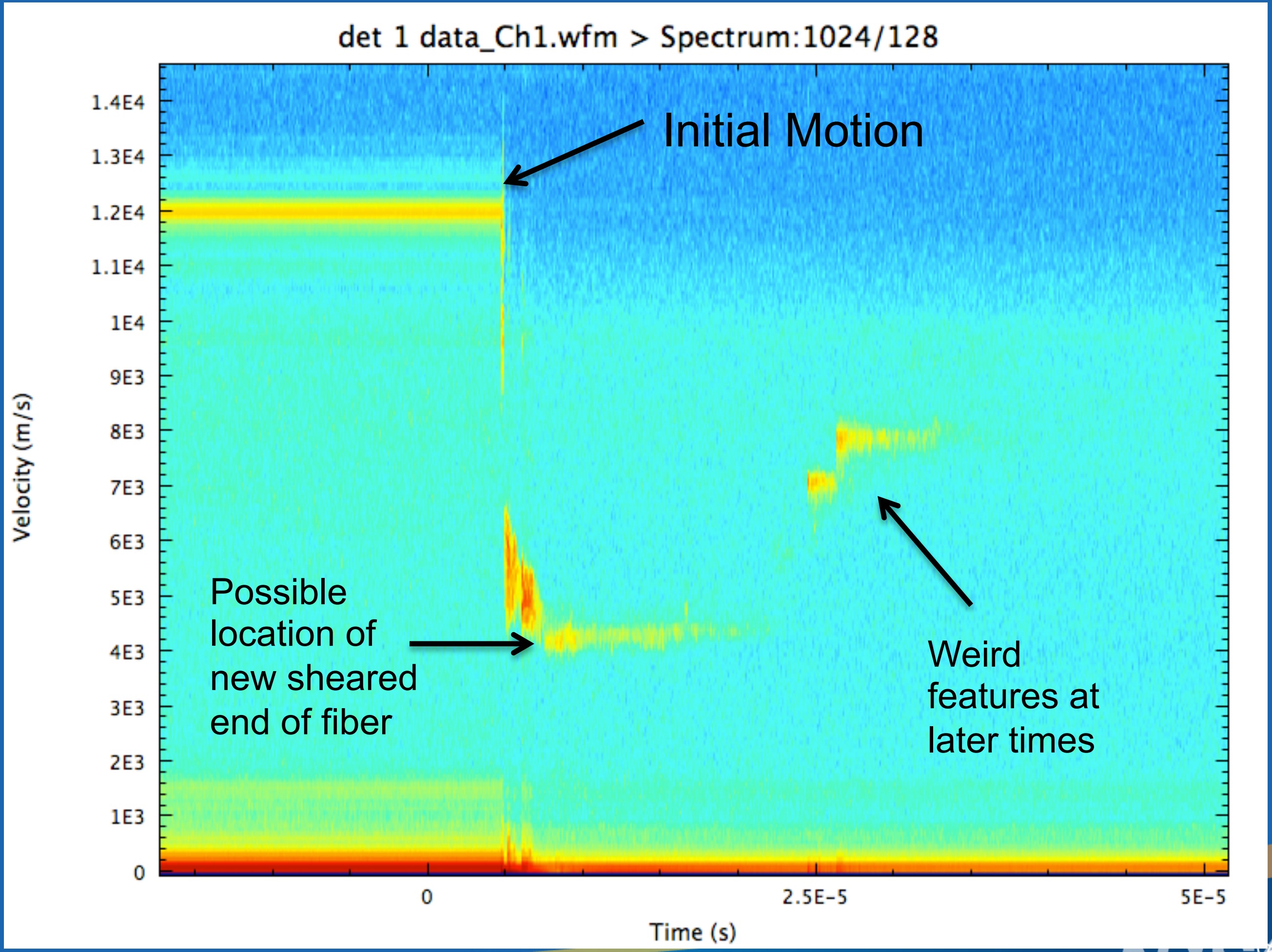


BLR in Fiber: Det Run #1

This is an intriguing new diagnostic. More work has to be performed to understand its limitations, etc.

Thank you, George and Steve for sharing this brand new data set!

Simple Spectrogram of Data Record



Summary

- The BLR Design Equations:
  - You can build a BLR system that works for your experiment.
  - But you probably can't build one system for all experiments.
- There are different ways to do calibration. The PI must decide which one is best or possible both.
- LANL has a prototype system with both front-end multiplexing and back-end multiplex architectures.
- Our first dynamic BLR and BLR In-Fiber shots were performed two weeks ago.
- We have several more shots planned this summer.
- The inter-Lab working group has and will continue to help the BLR effort.