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Embedded Fiber Optic Probes to Measure Detonation Velocities Using the PDV

WCI WEAPONS AND COMPLEX INTEGRATION

D.E. Hare, R.G. Garza,

O.T. Strand, T.L. Whitworth, LLNL

D.B. Holtkamp, LANL

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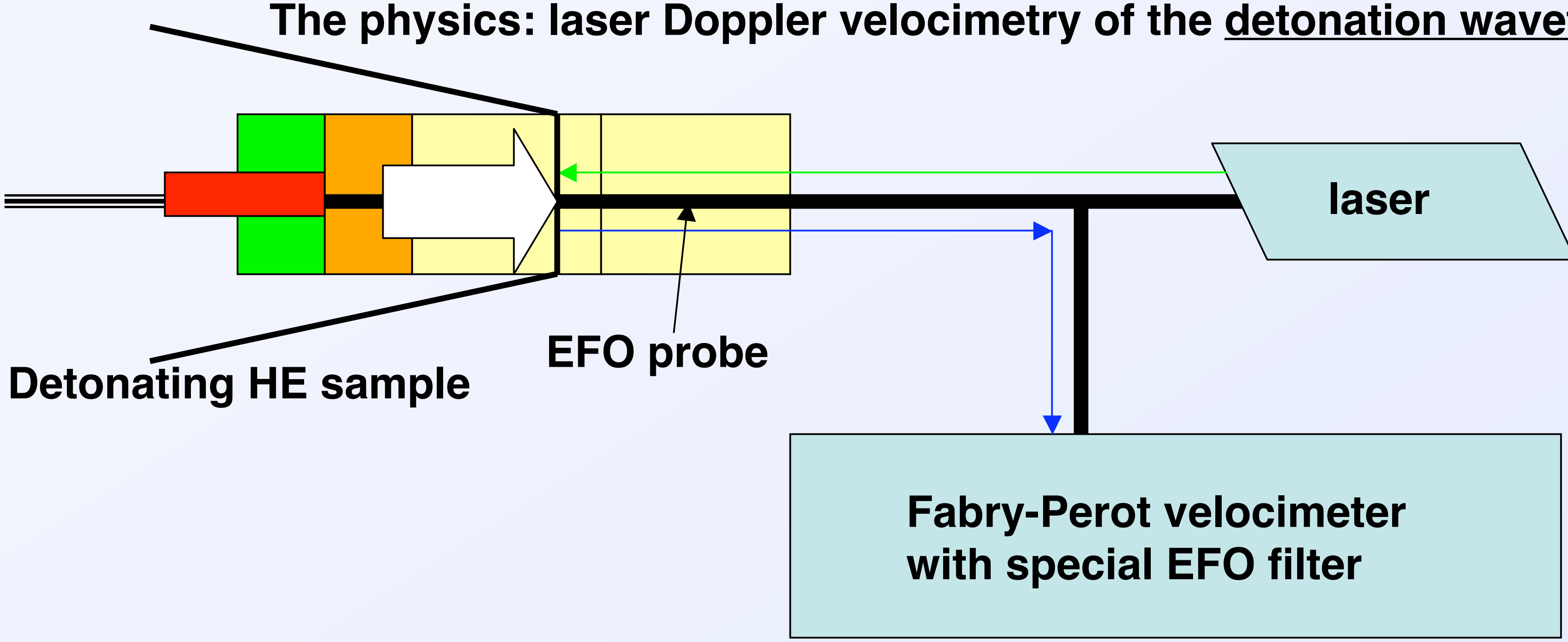
Lawrence Livermore National Laboratory

Outline

- Previous work with the Fabry-Perot Velocimeter
- Description of the Embedded Fiber Optic (EFO) probe
- Background of the PDV
- Experimental Setup for EFO Measurements
- Examples of the data
- Issues
- Conclusions

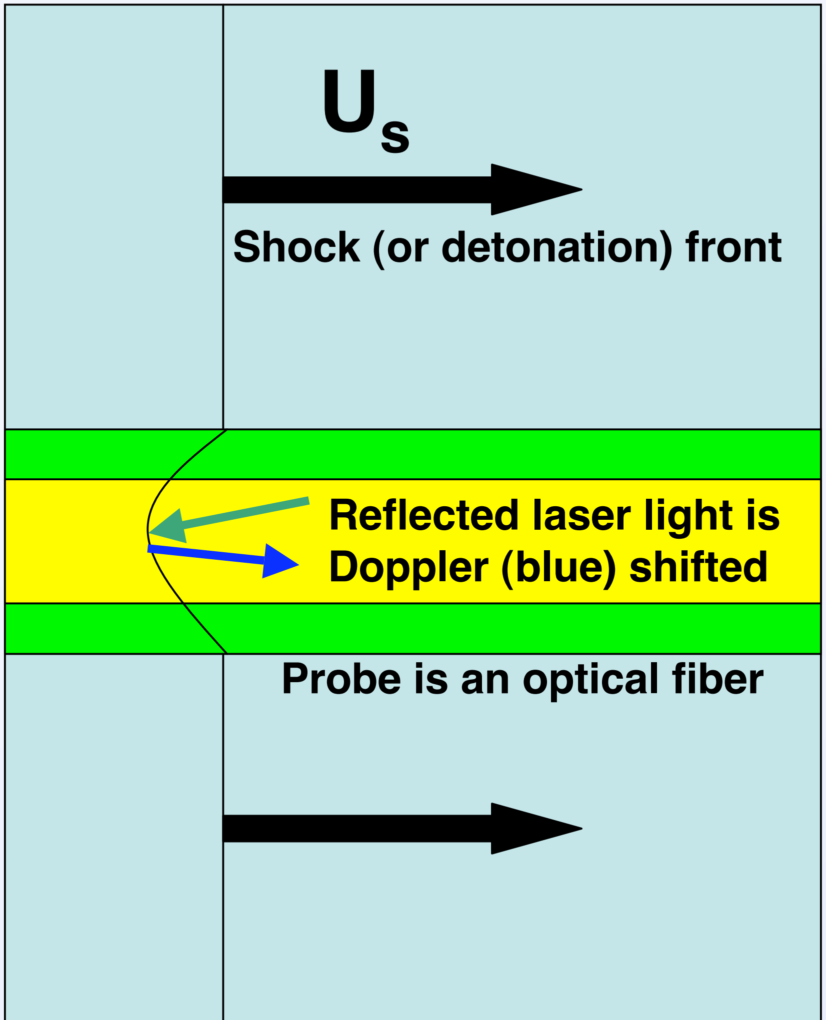
Previous work with Fabry-Perot Velocimeter

The physics: laser Doppler velocimetry of the detonation wavefront



(This work was presented at the 13th International Detonation Symposium, Norfolk, VA, July 23-28, 2006.)

Previous work with Fabry-Perot Velocimeter



- Shock wave creates / maintains a refractive index discontinuity in probe core
- Index discontinuity:
  - Reflects laser light
  - Imparts a Doppler shift because it is moving
- In the case of steady flow:
  - The Doppler shift should be exactly the same as the steady shock or steady detonation speed

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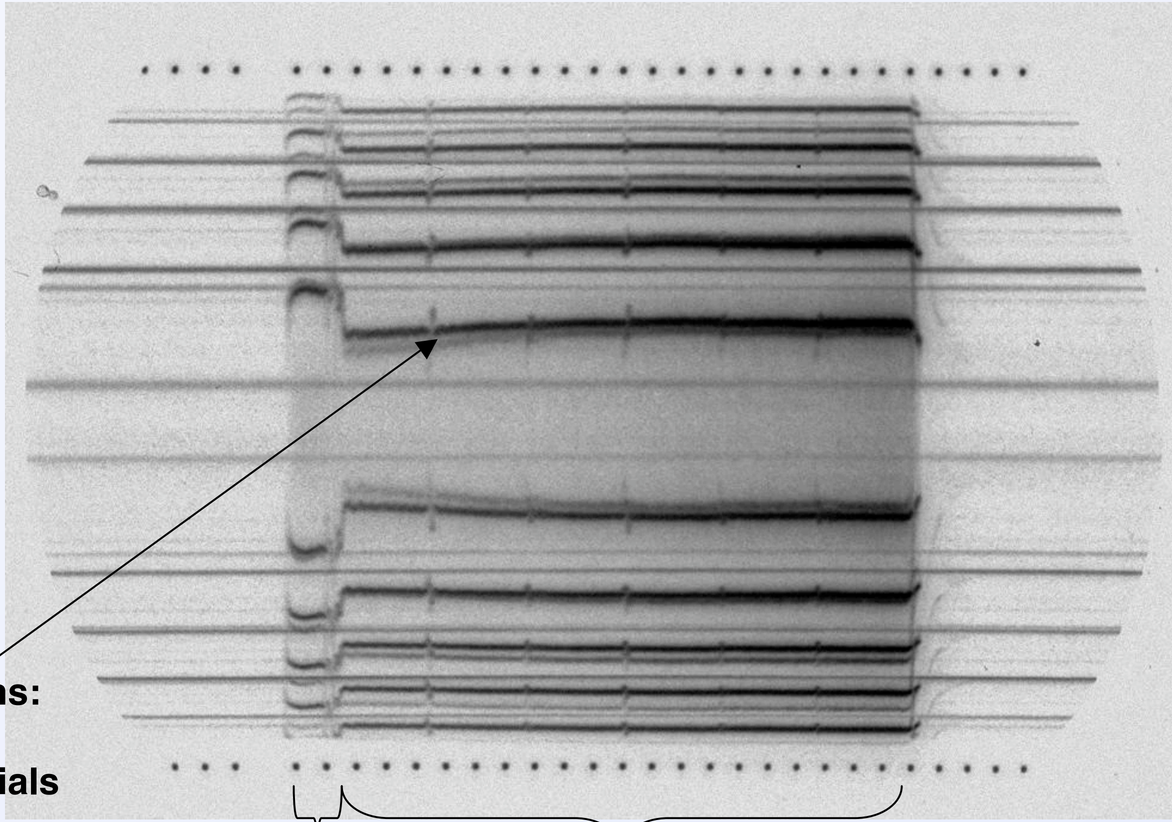
Previous work with Fabry-Perot Velocimeter



Pellet junctions: Make good position fiducials

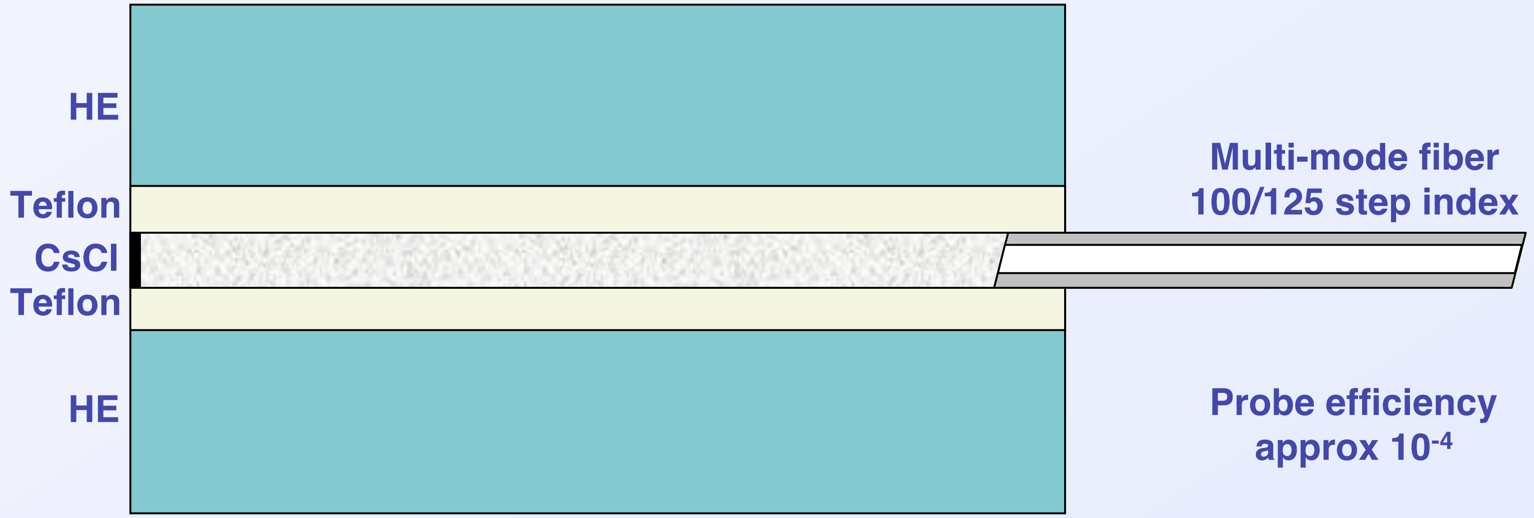
booster LX-17 or 9502 column

(This work was presented at the 13th International Detonation Symposium, Norfolk, VA, July 23-28, 2006.)

EFO probe used with the Fabry-Perot Velocimeter has an aqueous solution of CsCl as its core

EFO-FP probe

- Used with FP velocimeter at 532 nm
- PTFE (Teflon) cladding (1.6 mm OD, 127 μm ID)
- Aqueous CsCl solution core (127 μm OD)
- Will measure wave speeds > 1.9 km/s



Probe efficiency approx 10^{-4}

Note the angle polish on the end of the fiber inside the EFO probe

EFO probe used with PDV has a single mode fiber inserted into the Teflon tube

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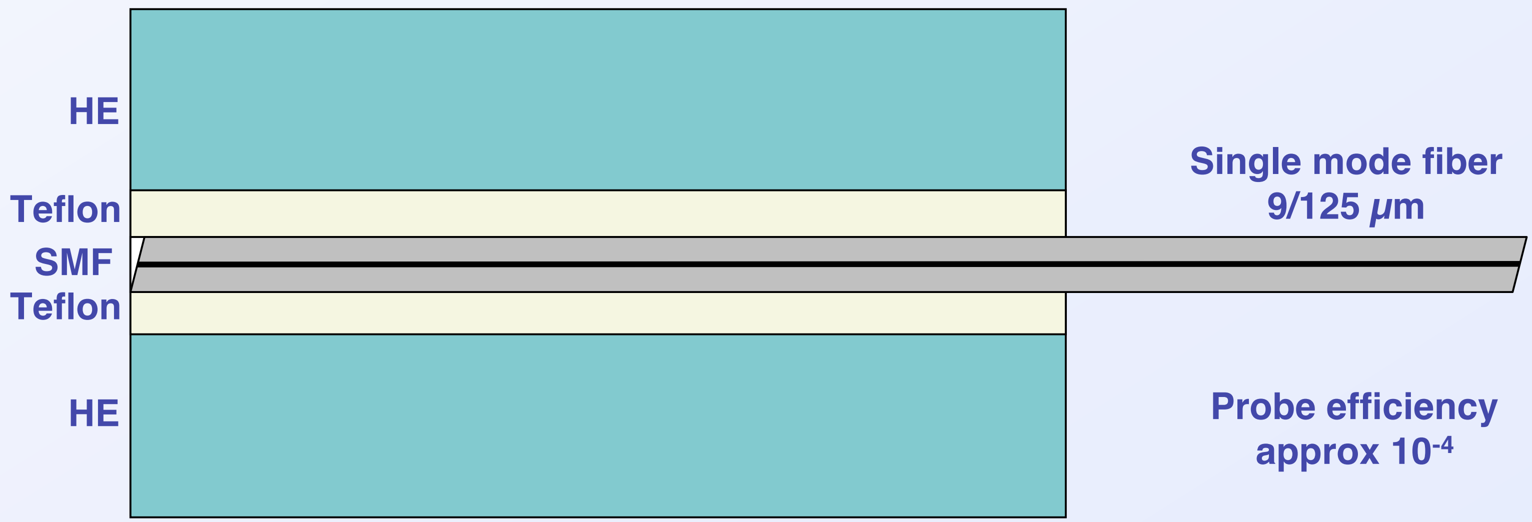
EFO-PDV probe

- Used with PDV at 1550 nm
- PTFE (Teflon) cladding (1.6 mm OD, 127 μm ID)
- Single mode fiber (125 μm OD, 9 μm core)
- Will measure wave speeds > 5 km/s



Note the angle polish on the end of the fiber inside the EFO probe

The index discontinuity of the shock front inside the core reflects the laser light back to the PDV

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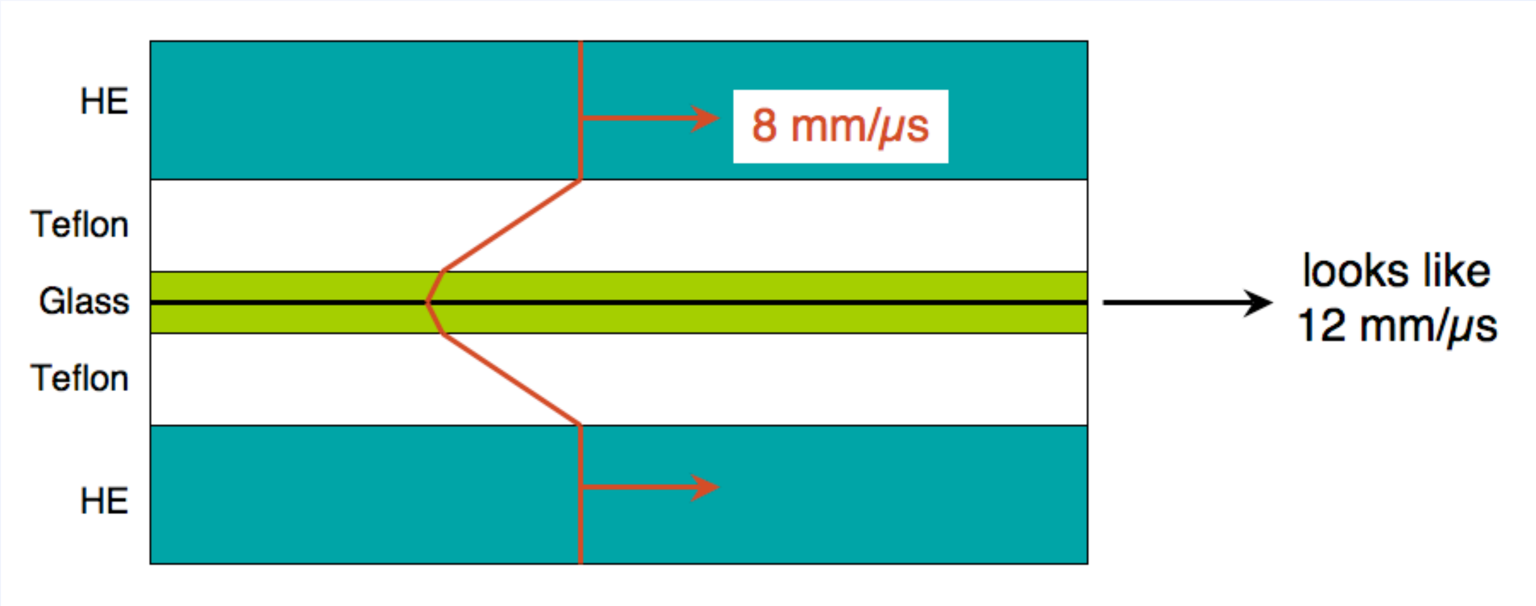
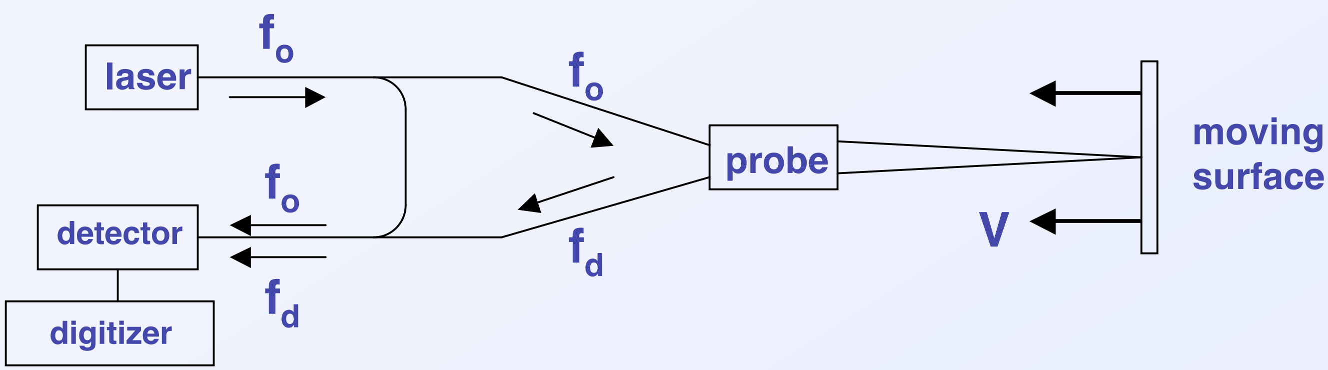
Approximately 1 x 10^{-4} efficiency



The measured velocity is the time rate of change in the optical path length, which is the actual distance x the index of refraction.

The PDV operates by generating a beat frequency proportional to the velocity

Develop velocimetry by mixing undoppler-shifted light with Doppler-shifted light and measuring the beat frequency



Beat frequency = $f_b = f_d - f_o = 2(v/c)f_o$

Example: at 1550 nm and 1000 m/s:

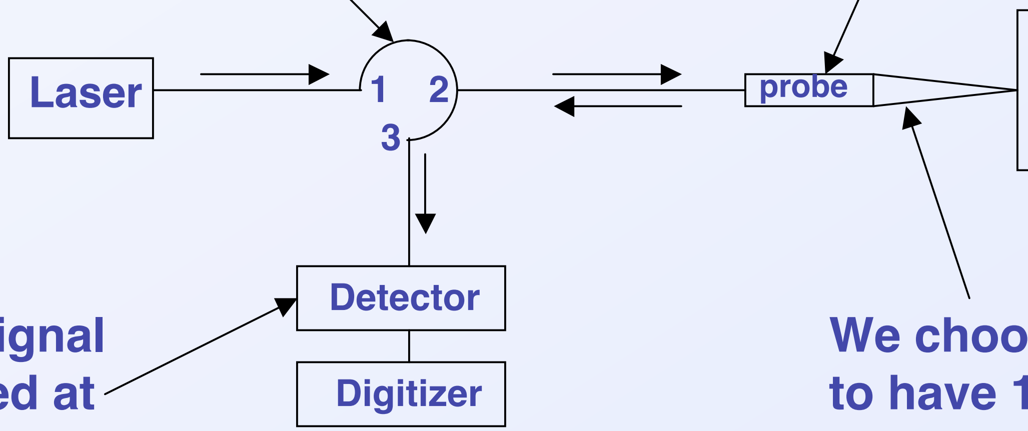
f_o = 193414.49 GHz
f_d = 193415.78 GHz → f_b = 1.29 GHz

We use a 3-port optical circulator as the heart of the PDV

The circulator directs the light into the desired directions

We order the probes to have -40 dB return of the input light

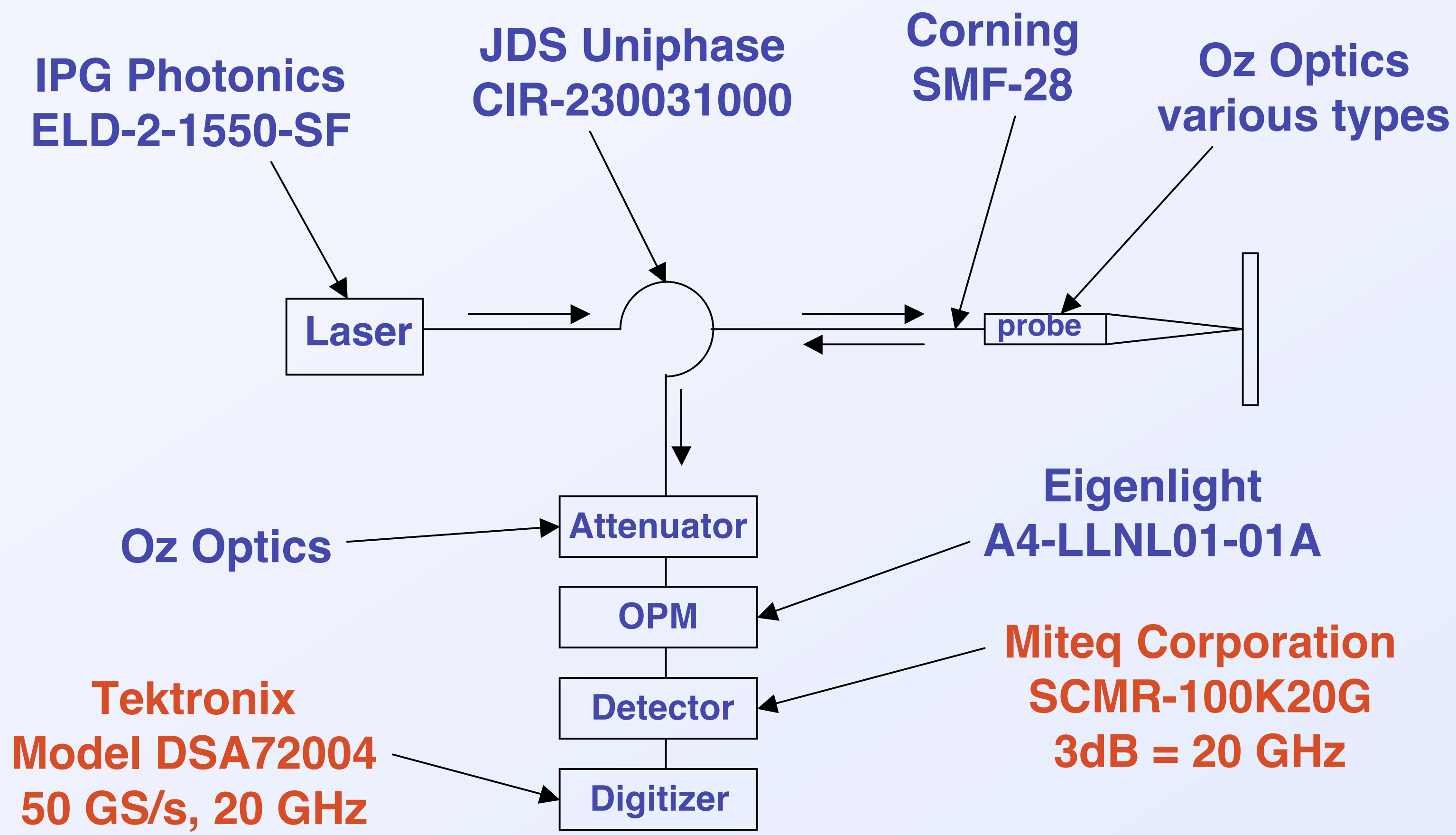
The fiber laser is easy to use



The beat signal is generated at the detector

We choose probes to have 1 x 10^{-4} efficiency

High bandwidth electronics allow the PDV to measure velocities over 12 km/s



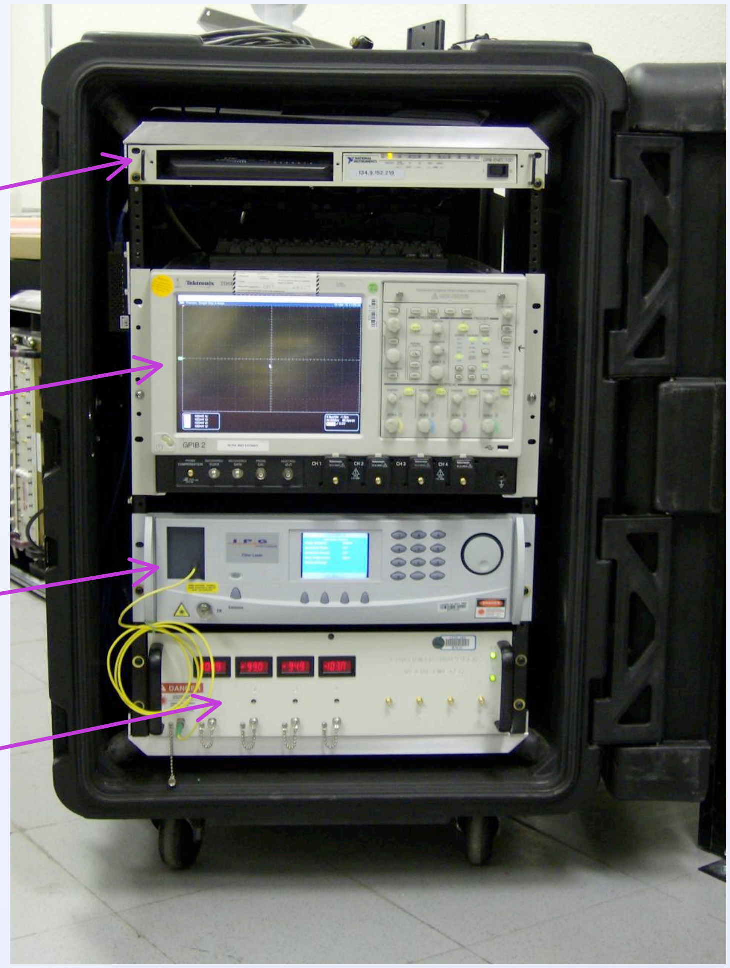
We package each 4-channel PDV system in a roll-around rack

Ethernet

High bandwidth digitizer

2W fiber laser

Custom-built fiber/detector chassis



LANL has a modular format for the PDV chassis and can package 8 channels per rack

We use a variable reflector to provide the reference signal

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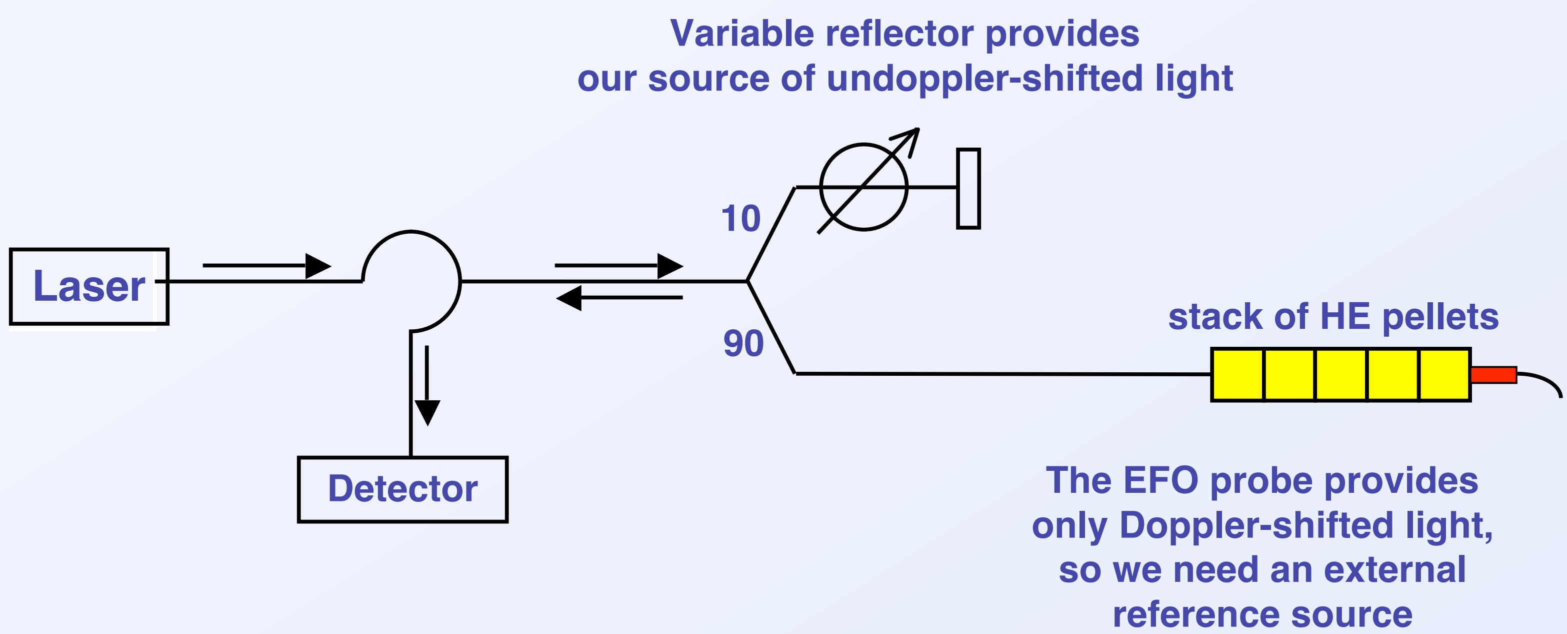
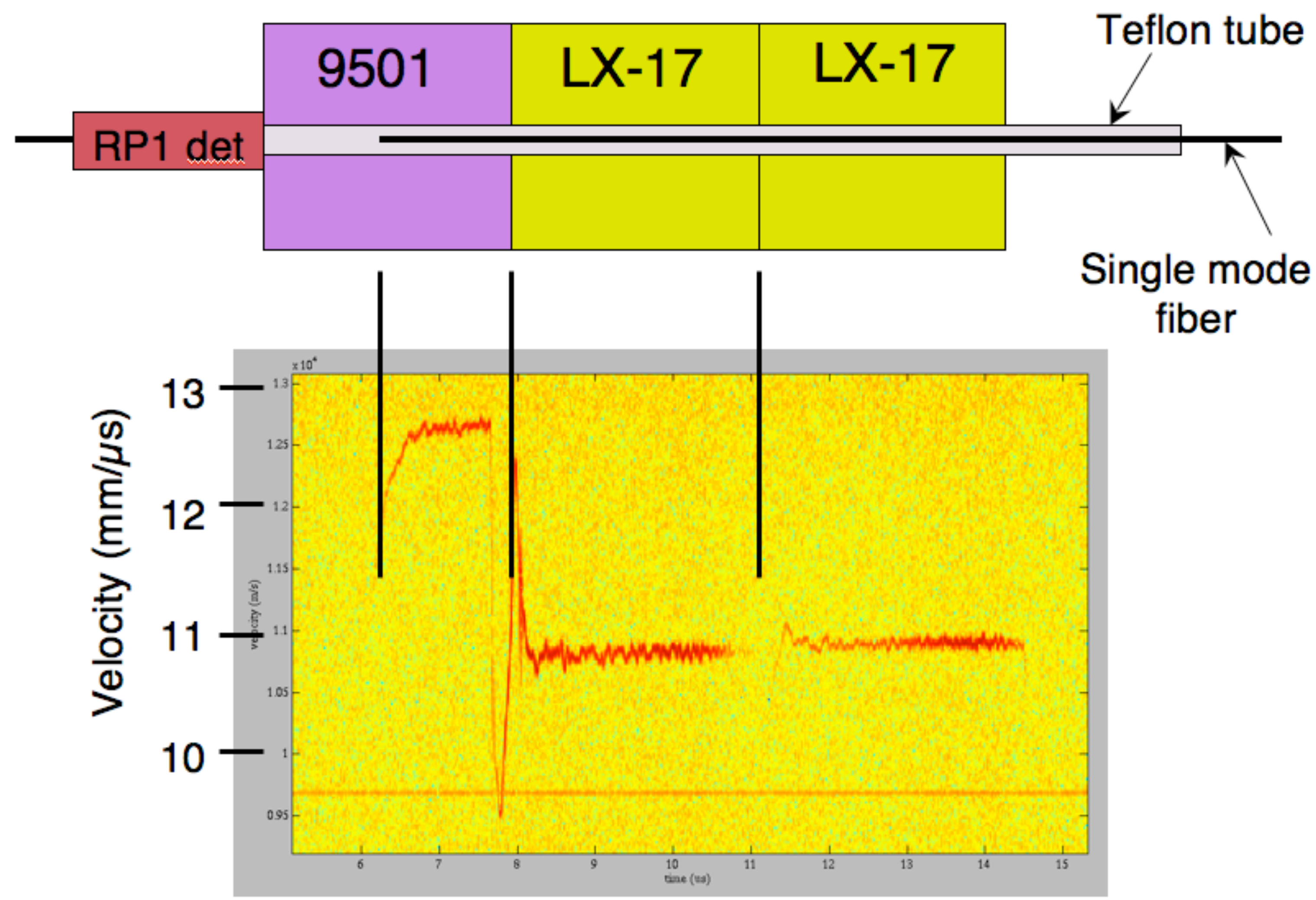
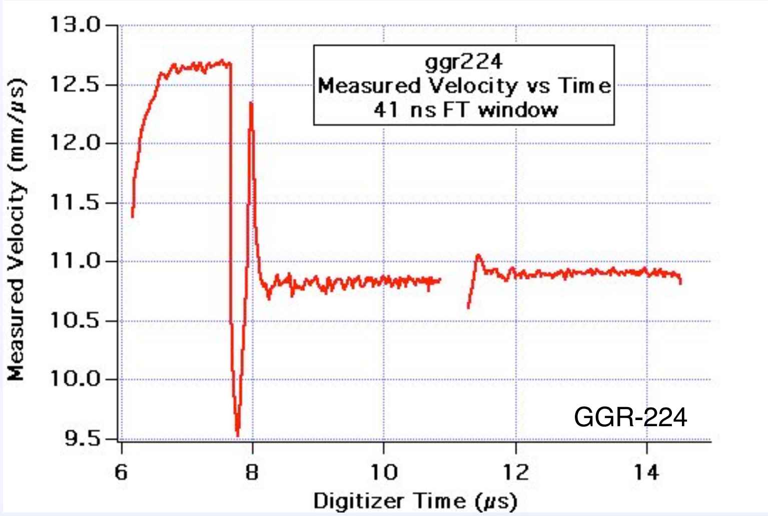
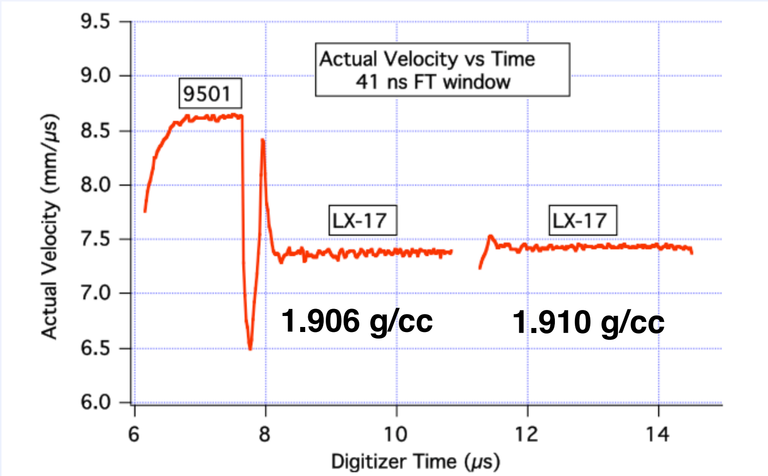


Over-driven LX-17 with on-axis detonator



Divide the measured velocity by the refractive index (1.4682) to obtain the actual velocity





Many thanks to Jim Crain of LANL for loaning us his TDS-6154 for this 1st set of shots.

Under-driven PBX-9501 with off-axis detonator

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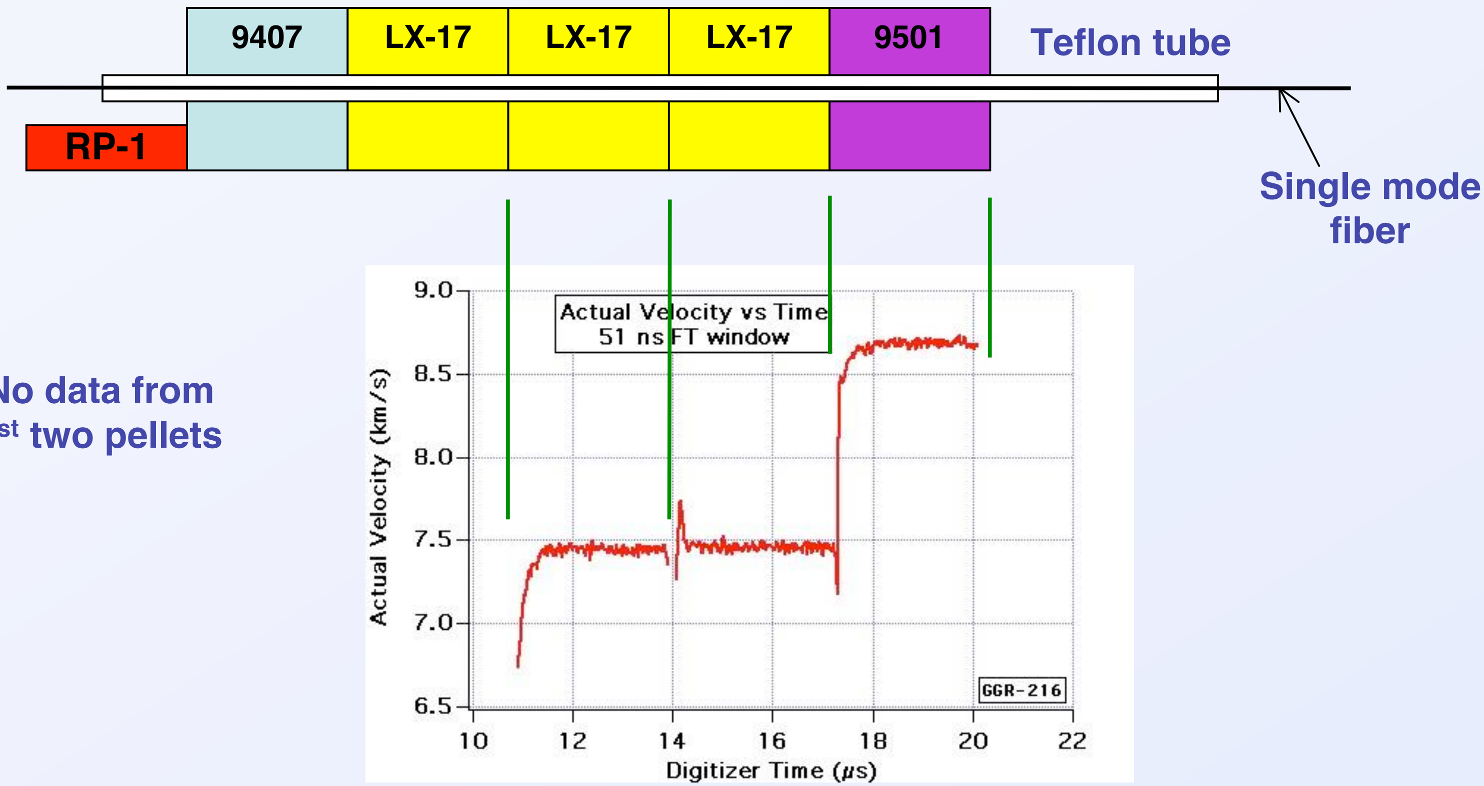

No data from 1st two pellets

We believe the oscillations are caused by the granularity of the HE

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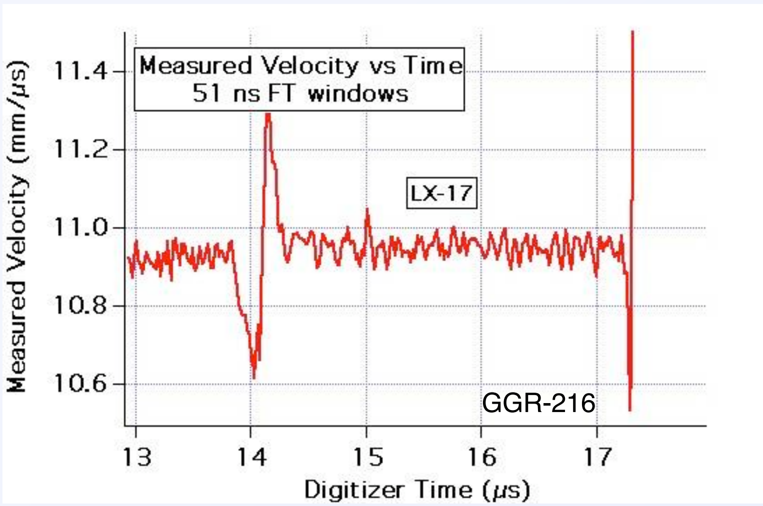
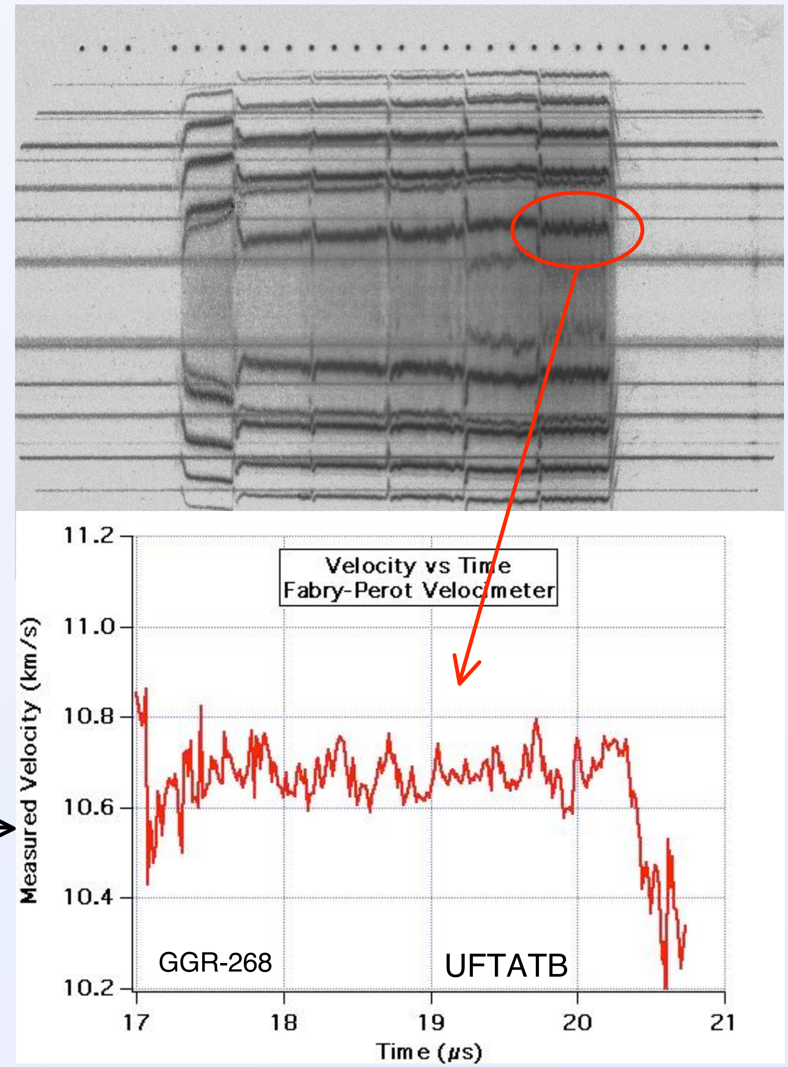
This data is from the PDV EFO probe.

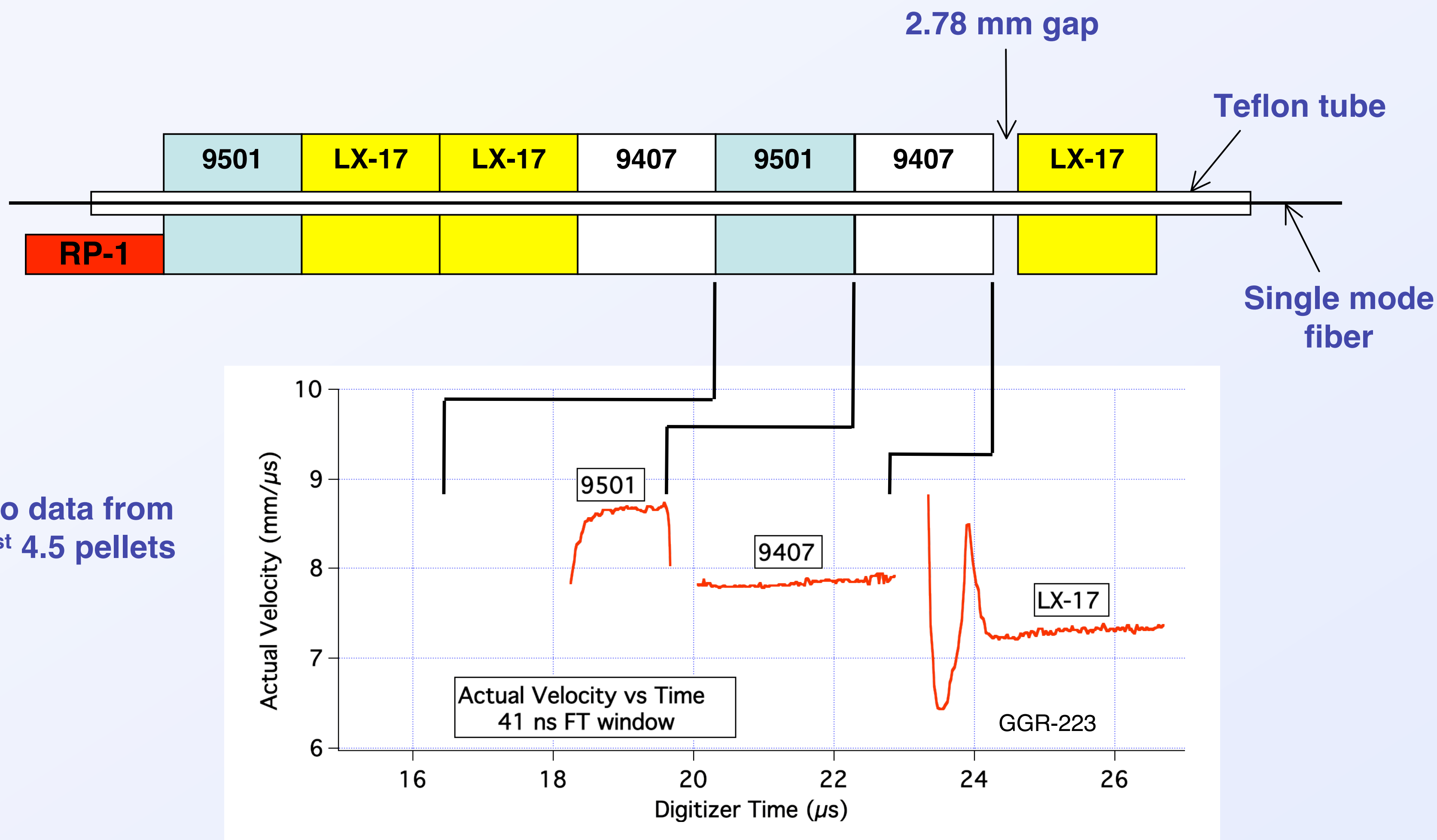




We see the same type of oscillations with the Fabry-Perot EFO probe, also.

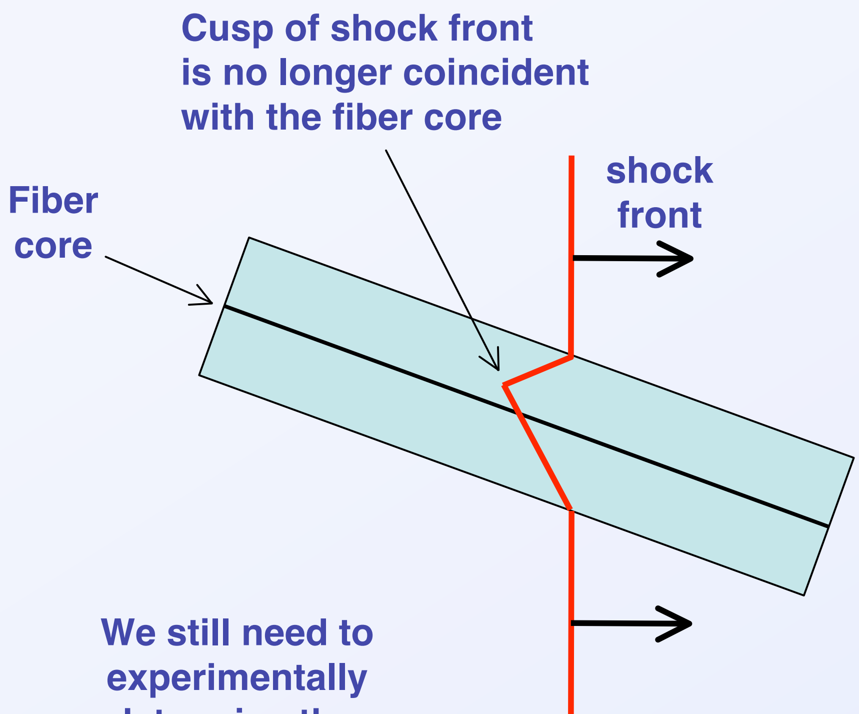
Note: This level of detail is not possible using electrical pins for detonation velocity.

We observe that LX-17 detonates after a 2.78-mm gap

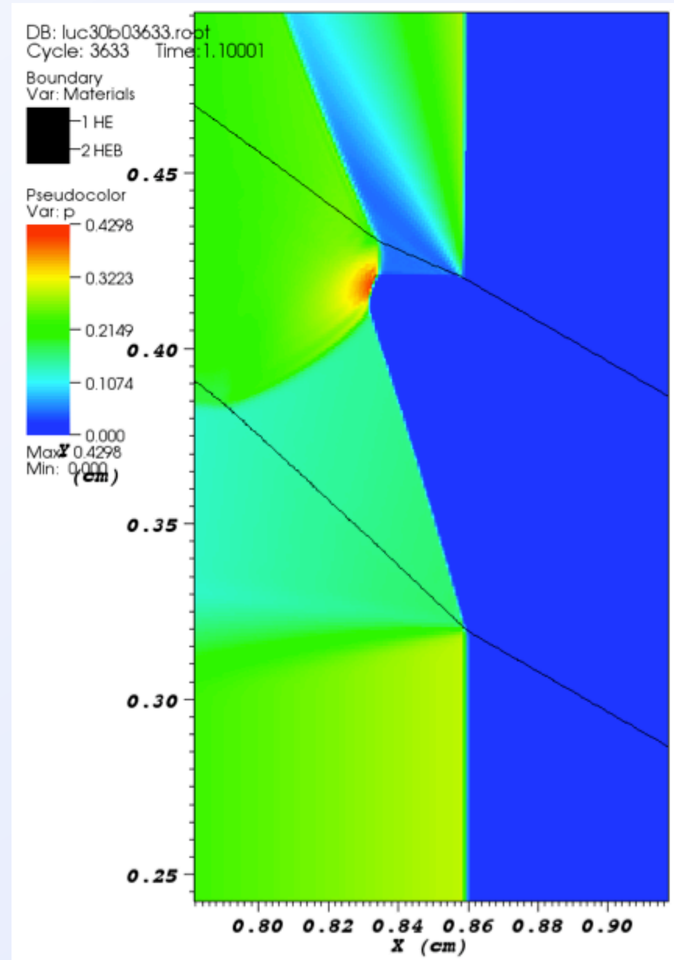


No data from 1st 4.5 pellets

Issue #1:
Detonation front must be nearly normal to the probe axis

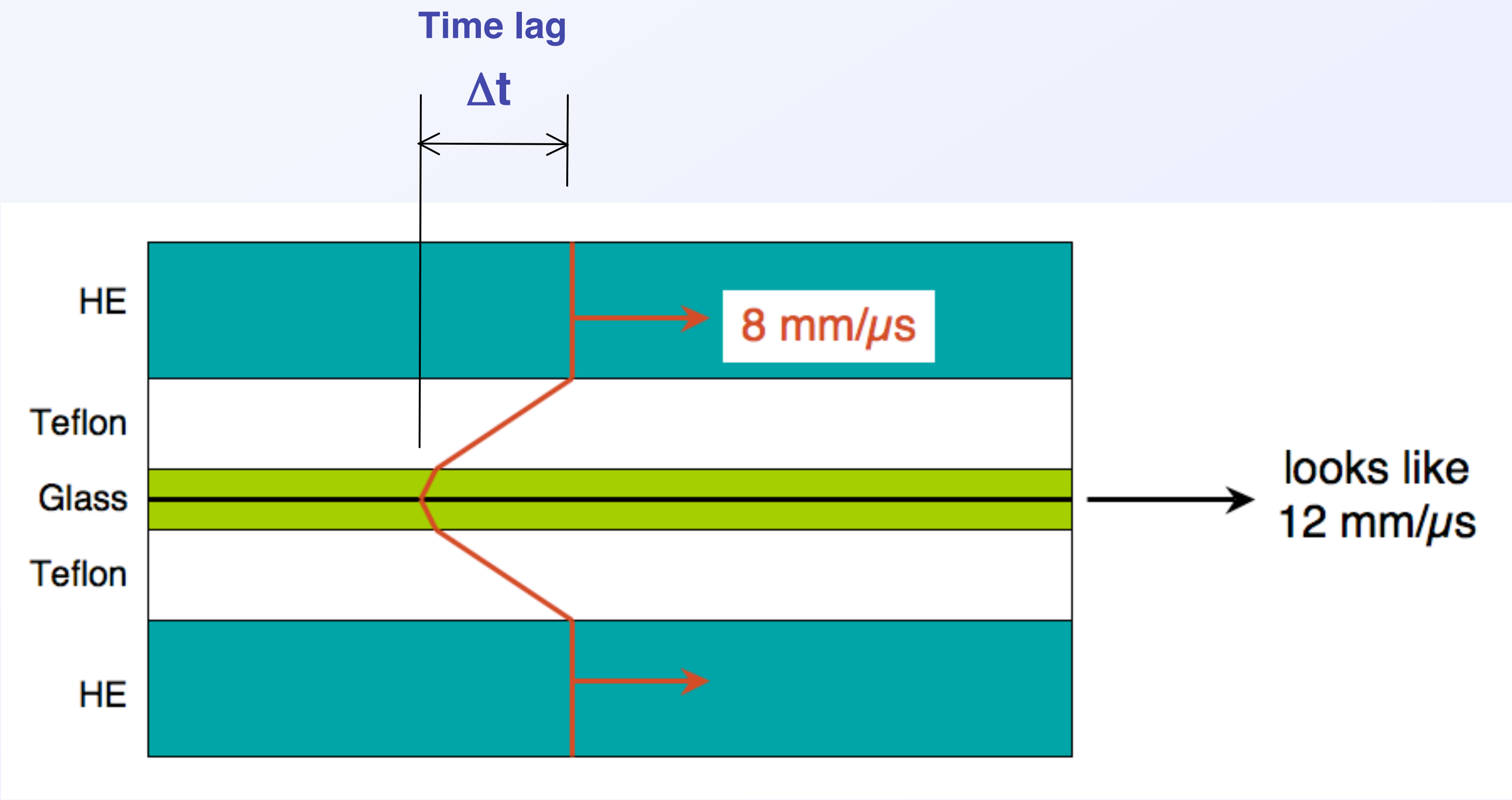


We still need to experimentally determine the maximum angle that returns data.



Computation by Ray Tolar, LLNL

Issue #2:
What are the time response and time lag of the PDV EFO?



Conclusions

- We have developed an embedded fiber optic (EFO) probe for use with the Photonic Doppler Velocimeter.
- We have successfully obtained data with the PDV on several different HE stack-ups.
- The EFO-PDV probe has a Vmin of 5 km/s. We are investigating the use of plastic fibers with lower sound speeds.
- We still need to determine such parameters as time response, time lag, maximum angle with shock front.
- We wonder whether the normal index of refraction is the proper correction factor to use.