Determining time of arrival using windowed PDV and experimental verification

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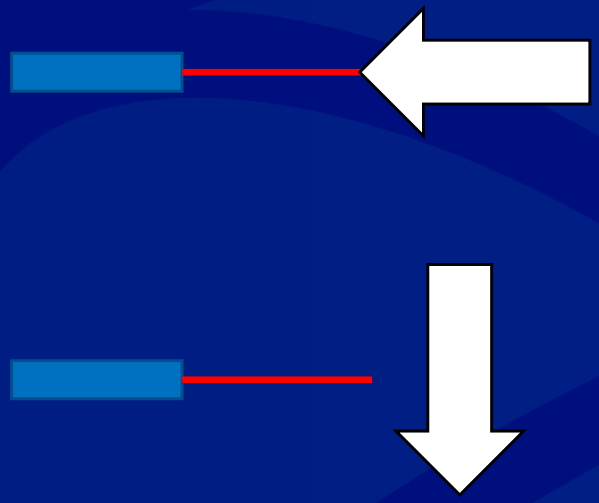
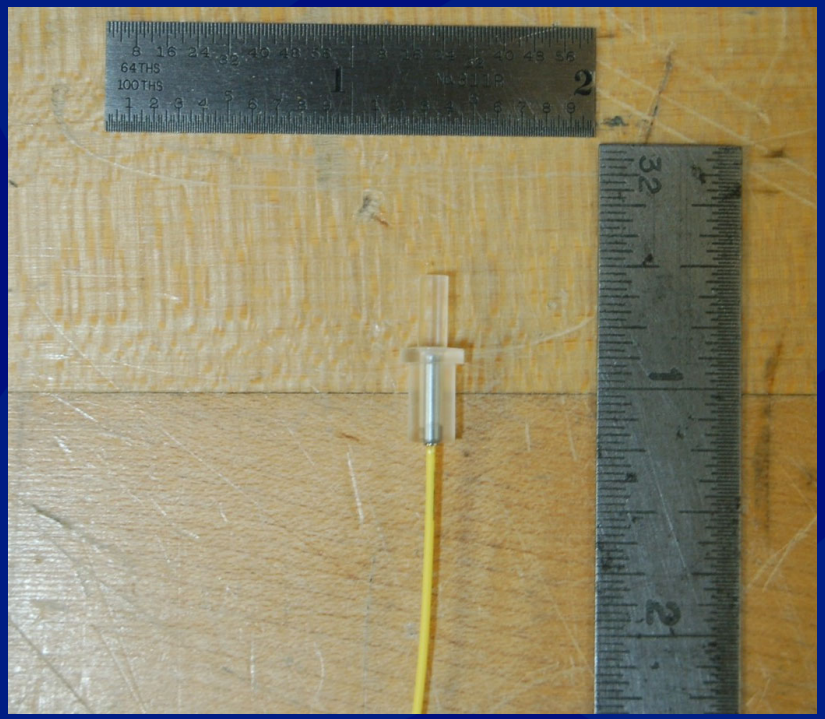
Introduction

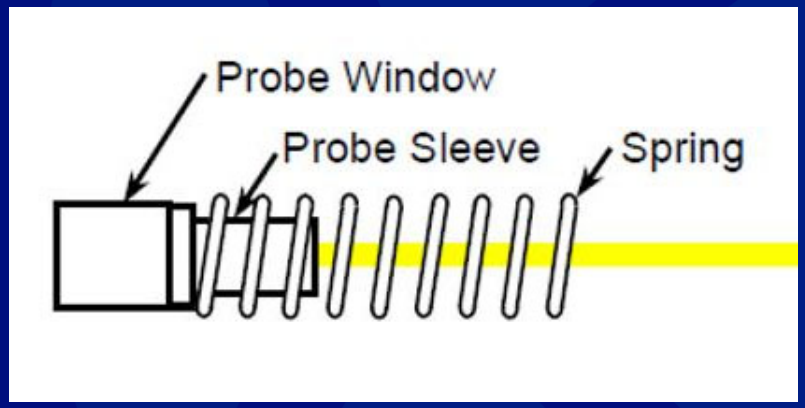
- Windowed PDV probes have been proven in a normal incidence case to determine time of arrival as well as sweeping wave.
- Built and tested smaller diameter windowed probe for more minimally invasive sweeping wave time of arrival measurements.
- Experimental proof and verification with piezo pins of windowed probes in sweeping wave with small diameter.
- Time of arrival determined by IQ analysis.





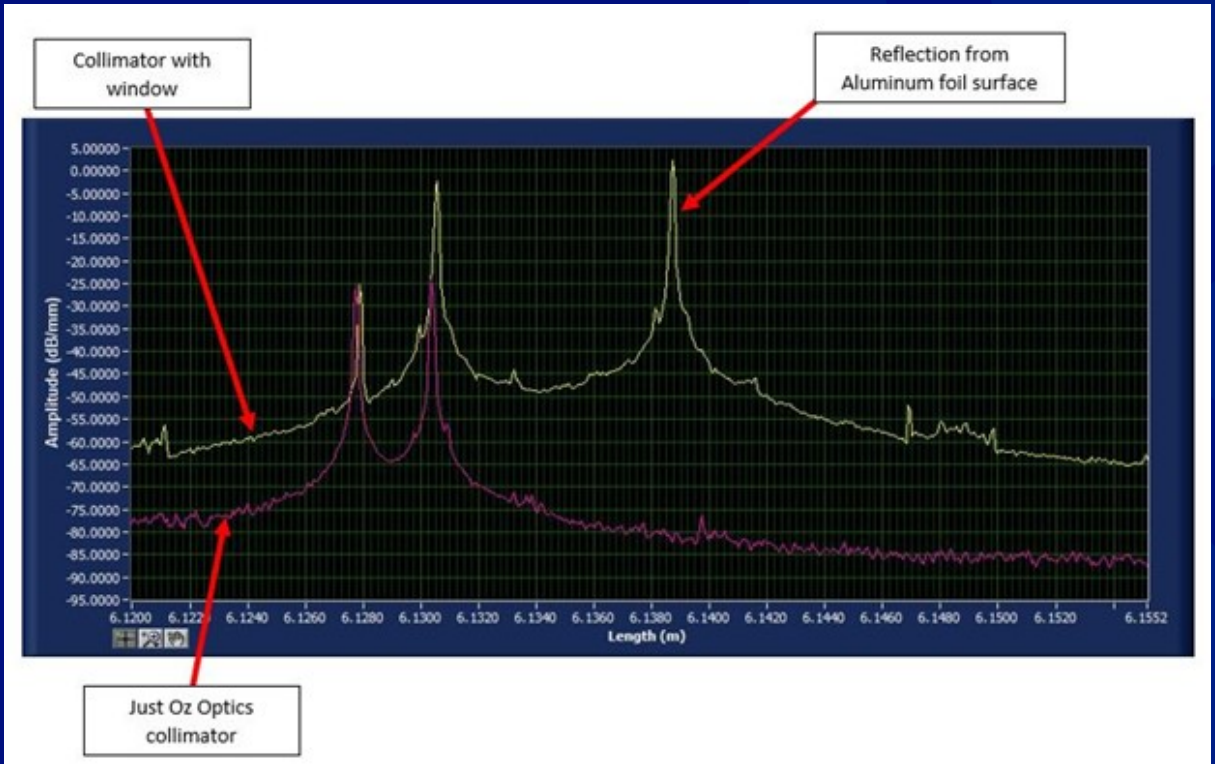
Smaller Diameter window PDV probe Proof of concept

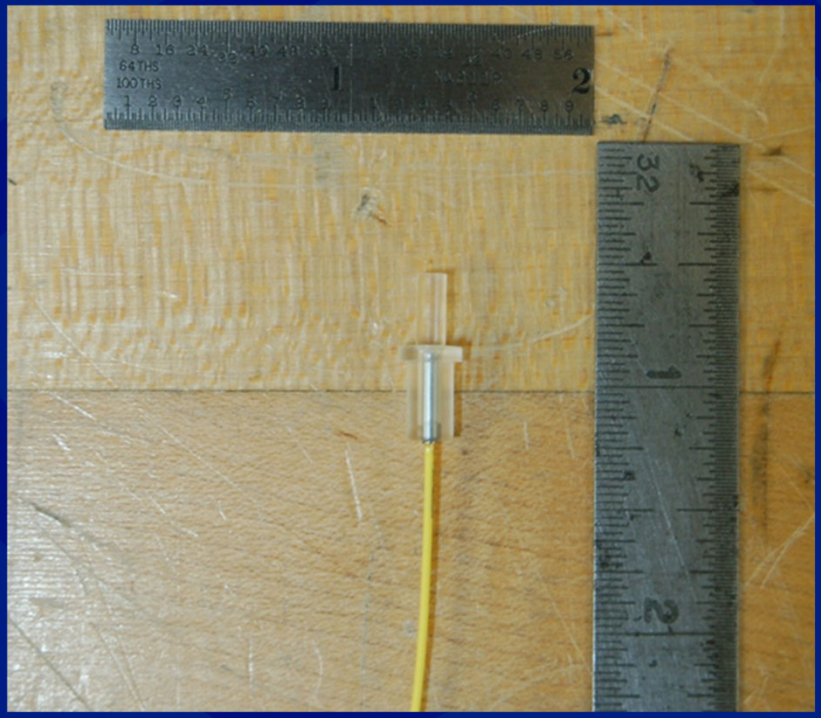
- Made with conventional Oz Optics GRIN lens fiber collimator in a PMMA Sleeve portion that couples into window.
- Original windowed portion was 6.75 mm in diameter
- Reduced to 3 mm with same features and tolerances as in the original probe



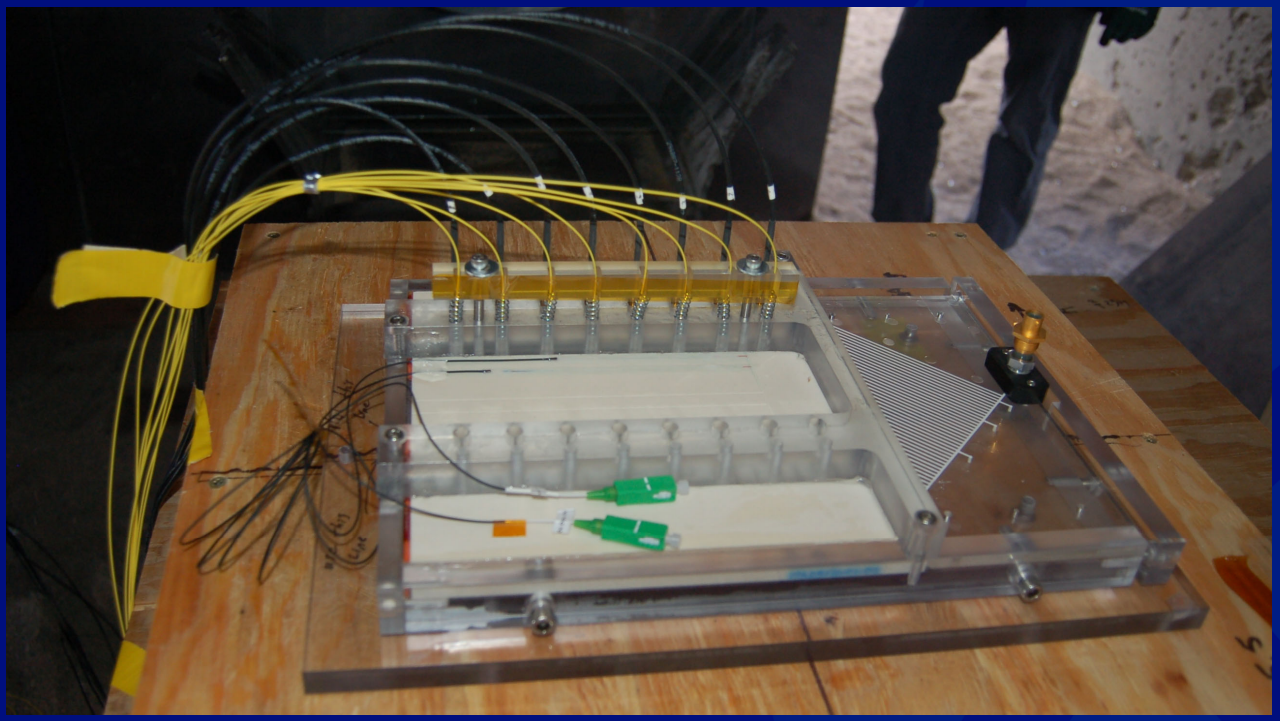
Proof of concept assembly

- Windowed portion was adhered to sleeve and then GRIN lens was placed in the sleeve ensuring contact with the window.
- Window portion has ~25 micron thick Aluminum adhered to the windows end surface for strong reflection.
- Collimator and final assembled probe was measured and verified with swept wavelength interferometer (Luna)





Experimental verification Slab shot



- Rectangular ½ in thick slab of PBX9501 detonated at one end using a line wave generator.
- Piezo pins and the prototype small windowed probes are placed side by side with a total of 8 each.
- Diagnostic positions are measured prior to experiment for as built positions.

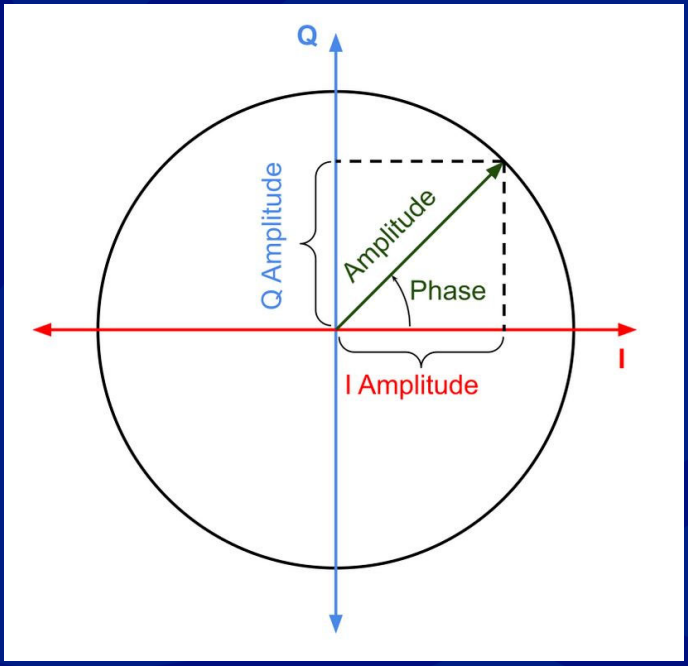
IQ Analysis

- Analysis technique for more easily representing jump off
- Takes PDV trace and separates into in-phase and in-quadrature components.

1. Fit heterodyne baseline frequency to 10^{-8} precision
2. Multiply Raw PDV trace by In-phase (cosine) and in-quadrature (sine) components of fitted baseline frequency
3. Bandpass filter around fitted baseline frequency

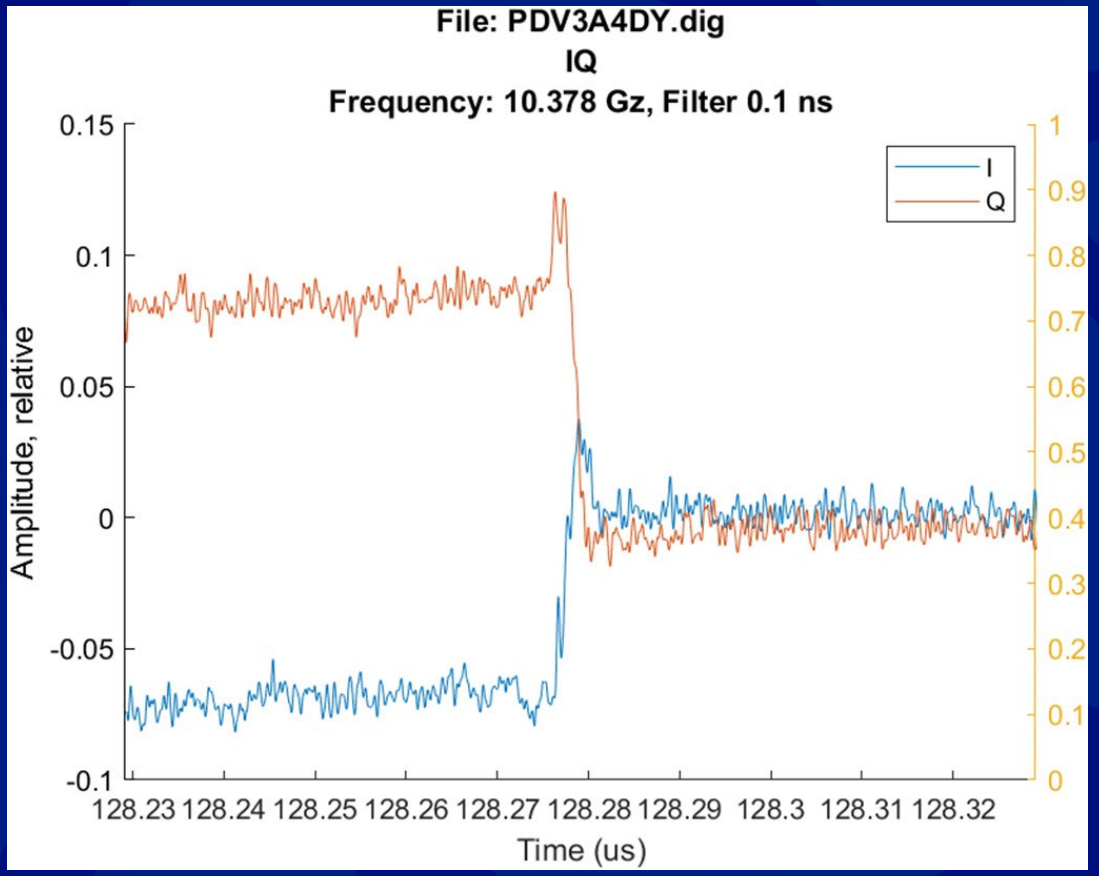
$$I(t) = bandpass\{v(t) * \cos(2\pi f t + \varphi)\}$$

$$Q(t) = bandpass\{v(t) * \cos(2\pi f t + \varphi)\}$$

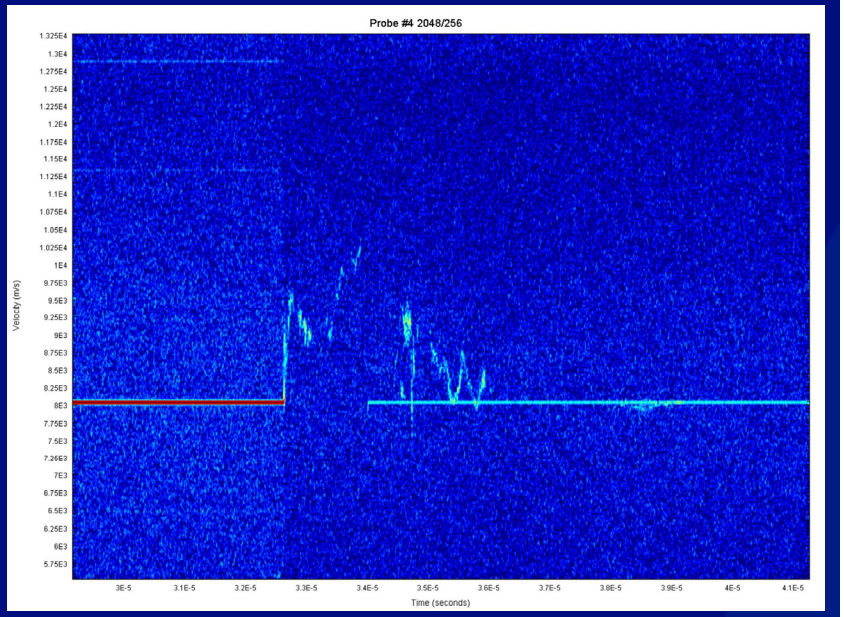


IQ Analysis on sweeping wave TOA data

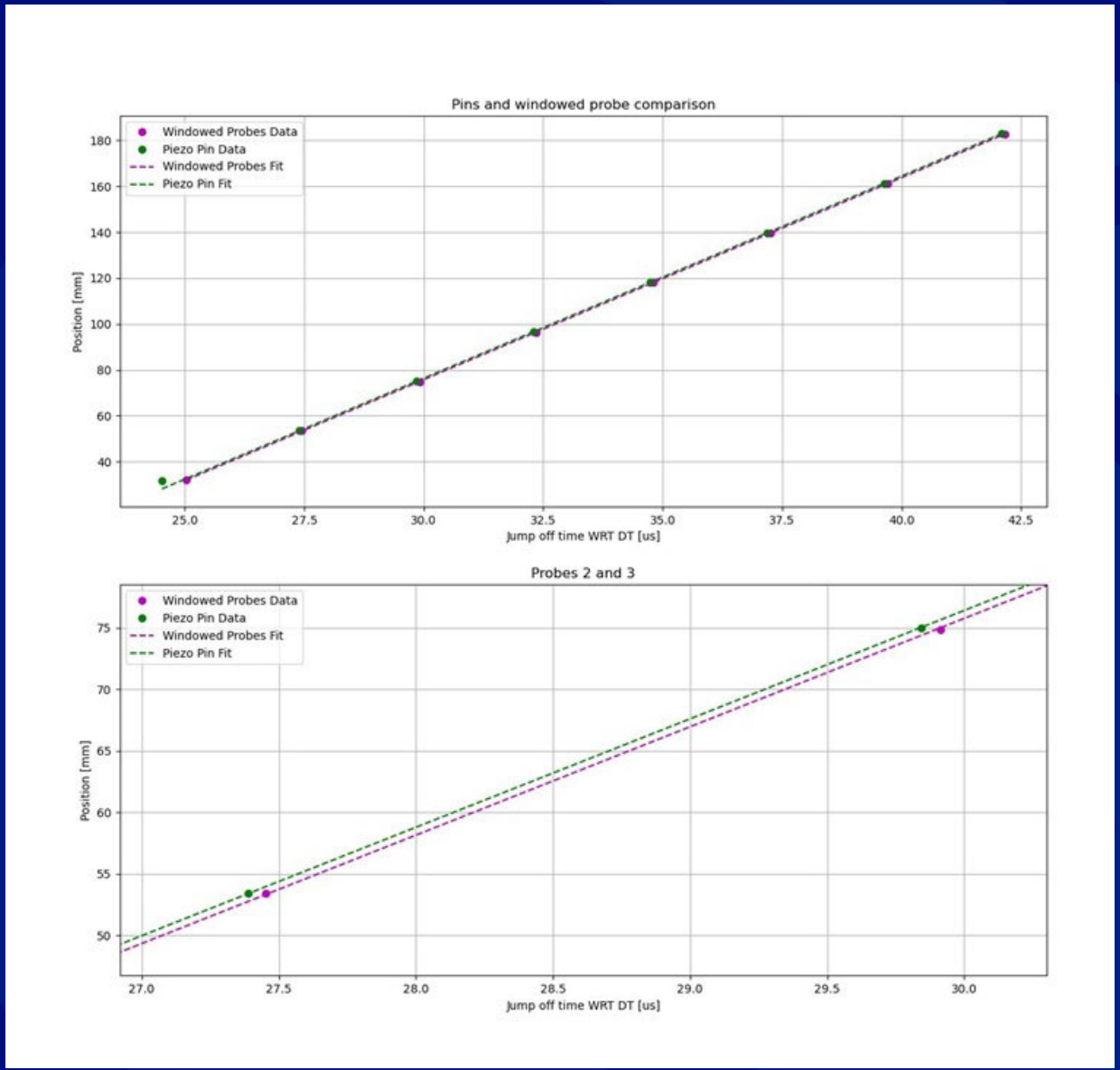
- With I and Q calculated and plotted the bandpass filter edge forms a step function during jump off.
- A step function is fit to either I or Q and 50% is selected as the jump off time.
- This was the technique we used for the experimental verification of the small windowed experiment



Results from experimental verification



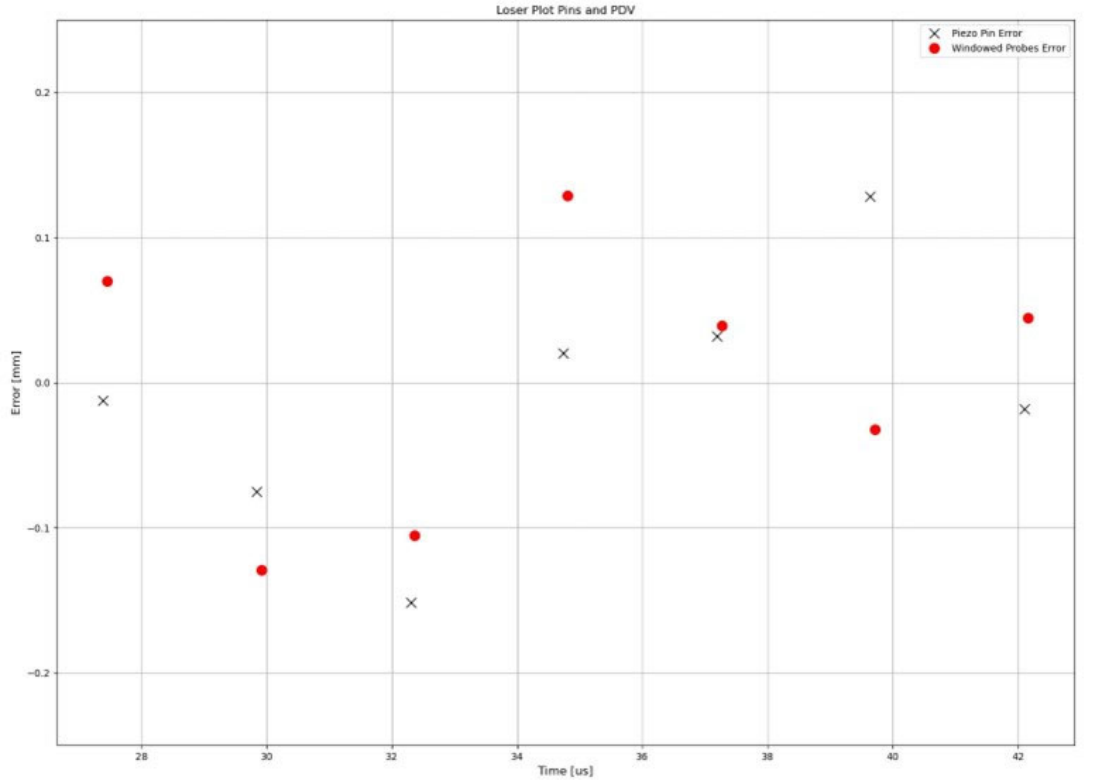
- Linear fit of position VS jump off time showed agreement
- First pin and probe not interpreted because of their proximity to the LWG



Results from experimental verification

TABLE I. Summary of Detonation Velocity error

Diagnostic	Detonation Velocity from Fit [mm/μs]	Percent Error
Piezo Pins	8.8083	.09%
Windowed PDV	8.8037	.04 %



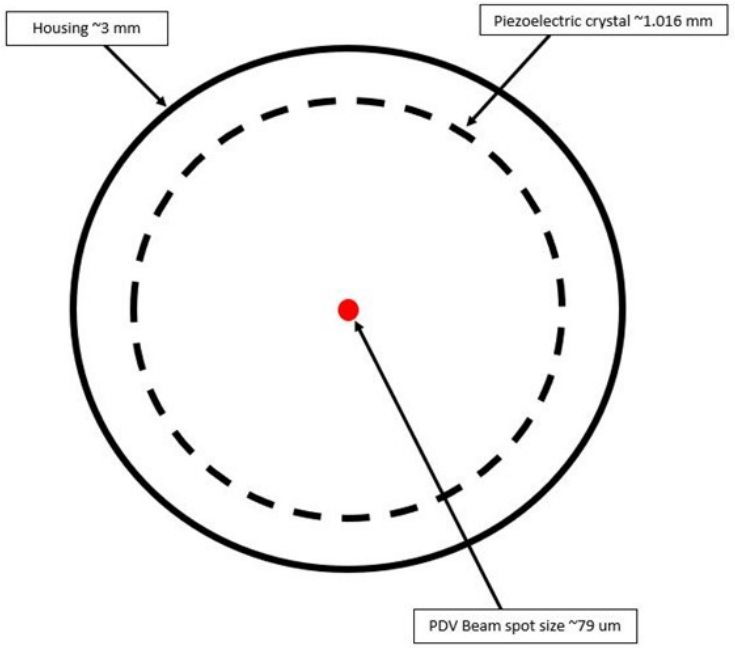
- Both the piezo pin and small windowed probes show strong agreement with the accepted detonation velocity for PBX 9501 (8.8 mm/us)
- Loser plot also shows no bias in either pins or windowed probes measurement.

Discussion on results

TABLE II. Offset in jump off times (JOT) between pins and PDV

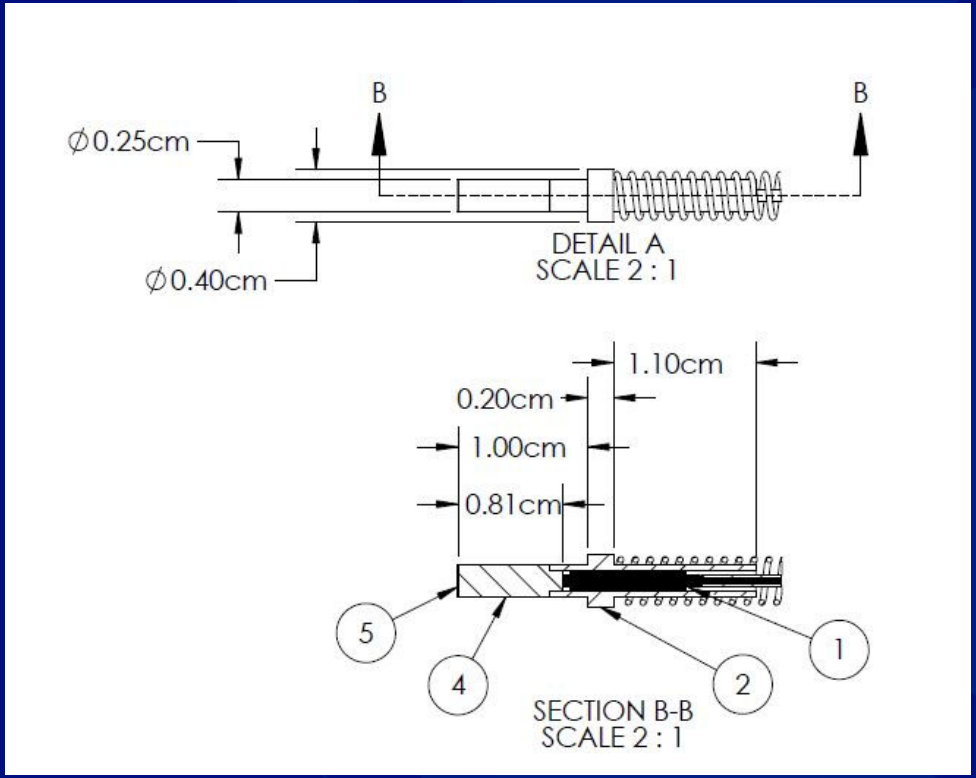
Position	Pin JOT [μs]	Predicted PDV JOT [μs]	Offset [μs]
2	27.3877	27.4668	-.07910
3	29.8425	29.9133	-.07088
4	32.3017	32.3628	-.0611
5	34.737	34.8166	-.0796
6	37.192	37.2718	-.0798
7	39.633	39.7227	-.0897
8	42.1002	42.1722	-.0720

- Noticing an offset between the pins and windowed PDV.
- This can be accounted for in the positional error associated with the piezo crystal (Shock arriving at edge VS. center).
- Windowed PDV error only limited by the spot size of the beam



Manufactured small windowed probe

- With convincing evidence that the window does not play a role in the jump off measurement for windowed PDV probes we pursued a manufacturer for the smaller diameter probe.
- Timbercon has begun producing windowed probes with 3 mm diameter with a design that is easily scalable with window length.



Conclusion

- Build prototype 3 mm diameter windowed PDV probes
- Utilizing IQ Analysis to determine windowed probe jump off in a slab shot experiment, we verified that these probes show strong agreement side by side with piezo pins.
- From this data we are starting to where windowed PDV is potentially a more accurate measurement than piezo pins.
- Data has resulted in third party manufacturer producing a smaller window design.