PDV Usage for Initiation Train Applications

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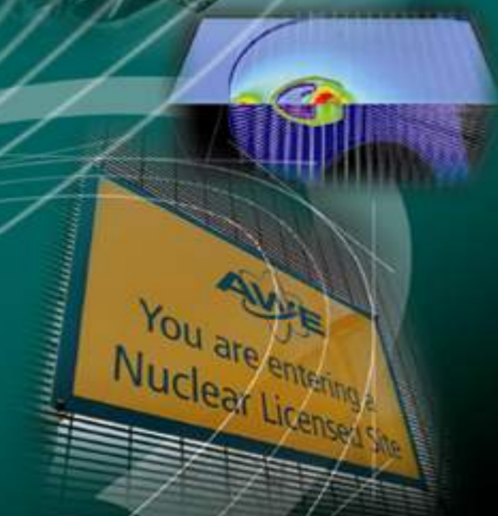


PDV Conference, 4-5th September 2008
Sandia National Laboratories

Outline of Presentation

- Introduction
- Current capability
- Results and Discussions
- Planned capability
- Future work
- Conclusions

Introduction

- Explosive Initiation Science (XIS) Group at AWE responsible for initiation train design
- Need velocimetry as core capability
  - But no customer driver for “blue-sky” development
- Historically, VISAR (Sandia ~1991)
- VISAR capability lost (both equipment and expertise)
- PDV capability development began 2006
  - Mike Bowden – Technical Lead, Optical Diagnostics
  - Matthew Maisey – Technical Lead, Modelling and Software Development

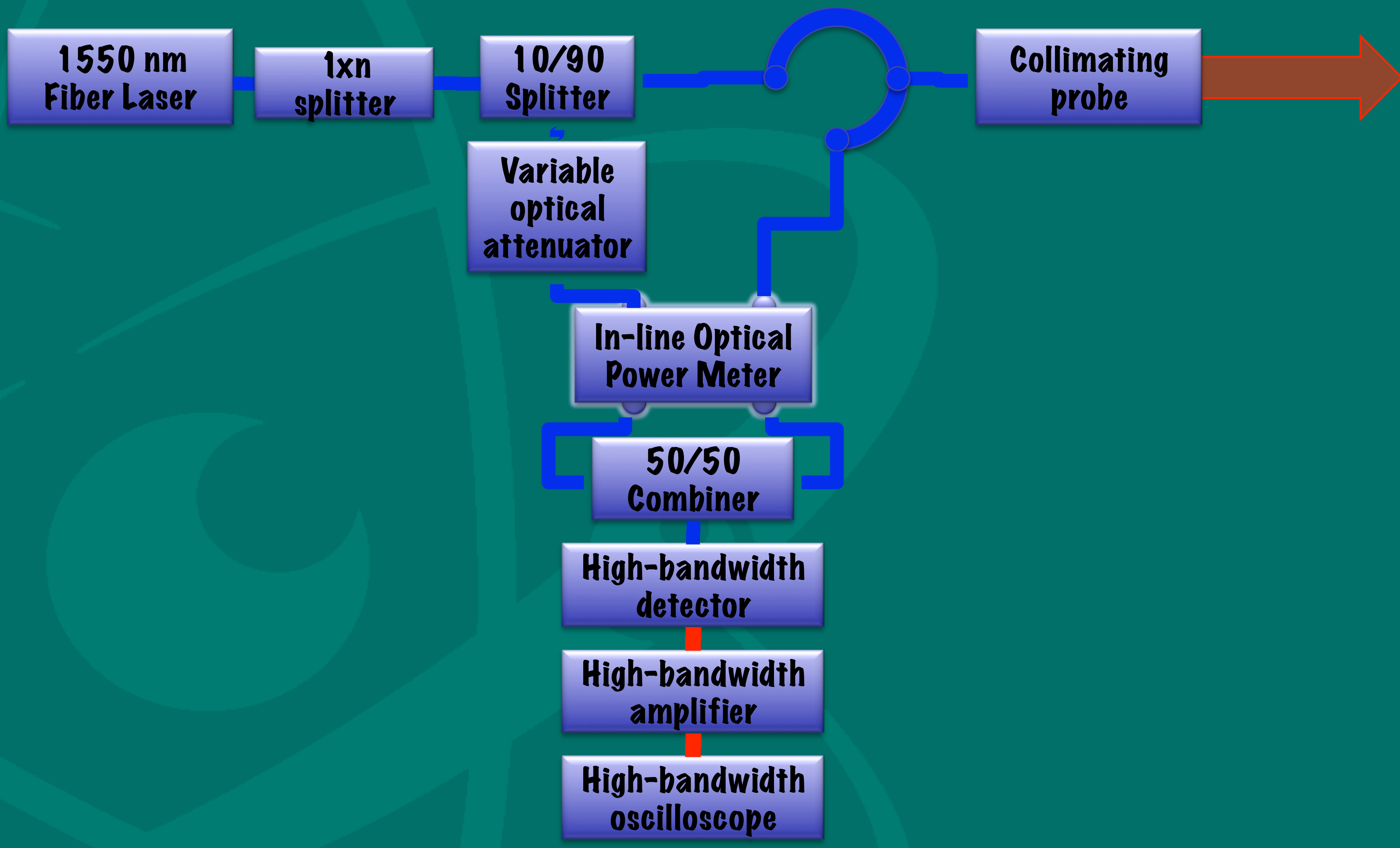
Requirement and Solution

- We need to measure velocities of detonator flyers and bridges
- Velocities to 10 km/s, timescales <100 ns
- Very demanding time/velocity regime
- Heterodyne Velocimetry
  - Cost-effective (<$40K per channel)
  - Portable
  - Possible to scale velocity resolution to meet requirement
  - No published results on high velocity, short timescale experiments

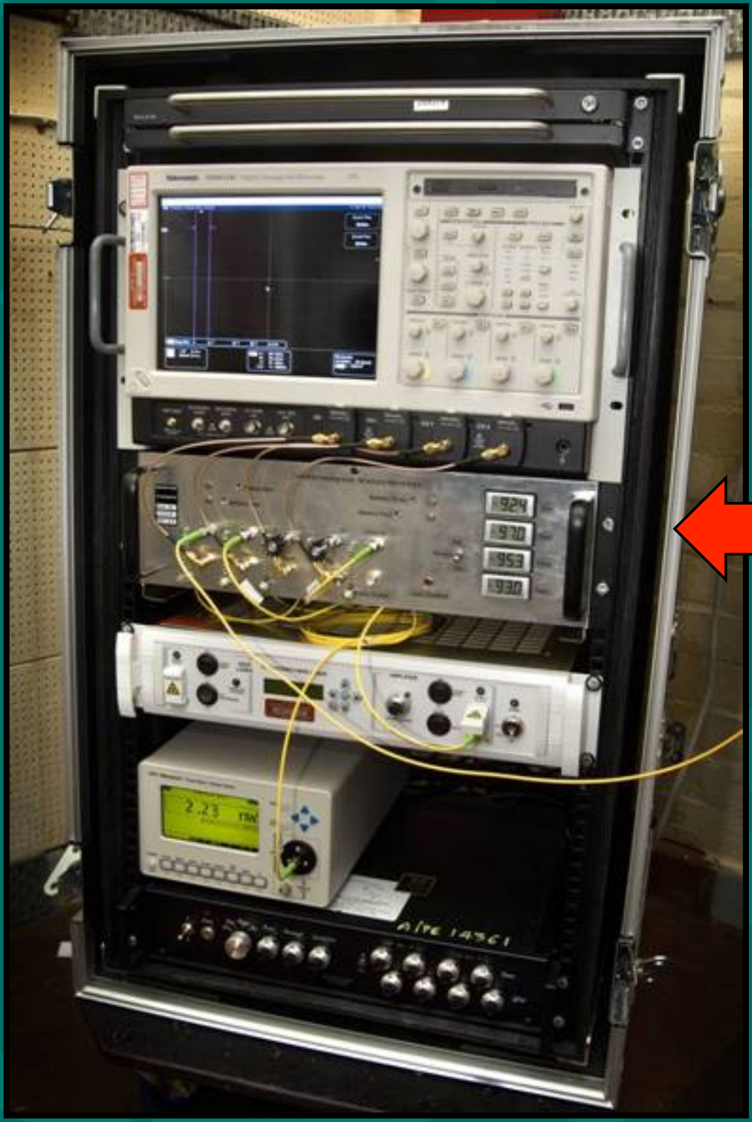
Current Capability

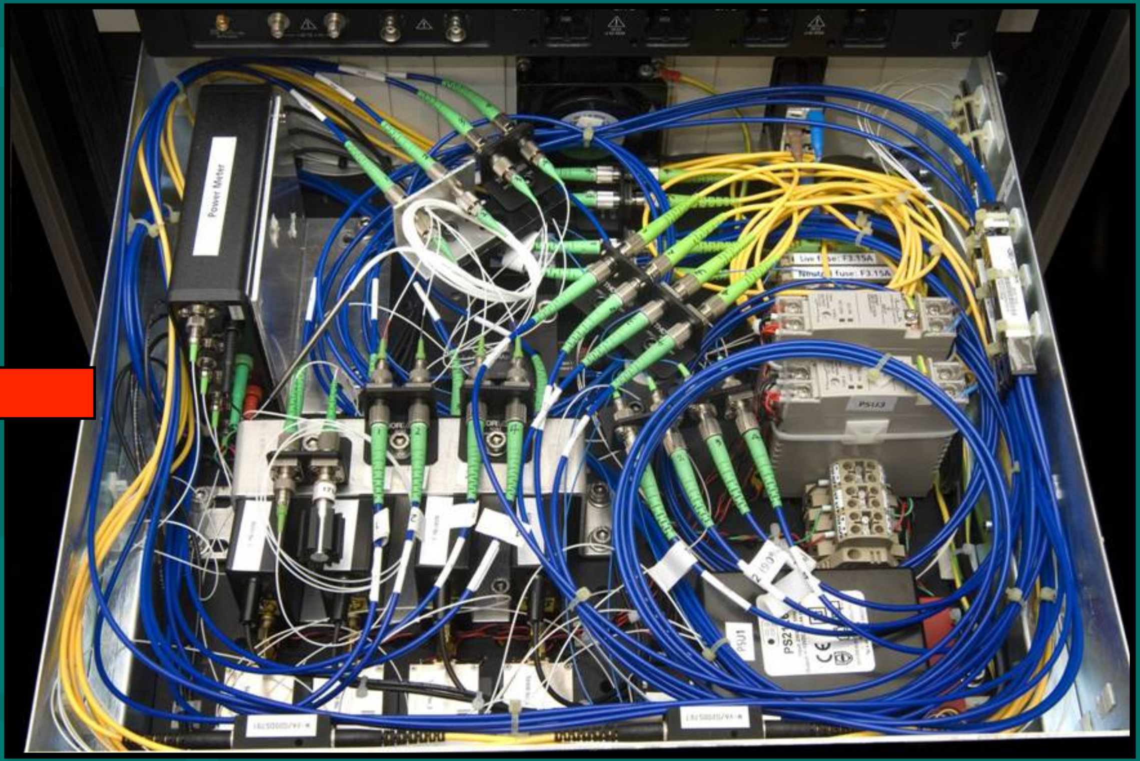
- 4 channel PDV system
  - 2W NP Photonics laser
  - 12 GHz, 40 GS/s Tektronix scope
  - System bandwidth ~10 GHz
  - Newport detectors AD-40APDIR-FC
  - Picosecond Pulse Labs amplifiers
  - Balanced system
    - Can monitor both return and reference (though only 4 channels of measurement)
  - Software based in Matlab
    - Both wavelets and SFFT
    - Usable by experimentalists

Current System Design

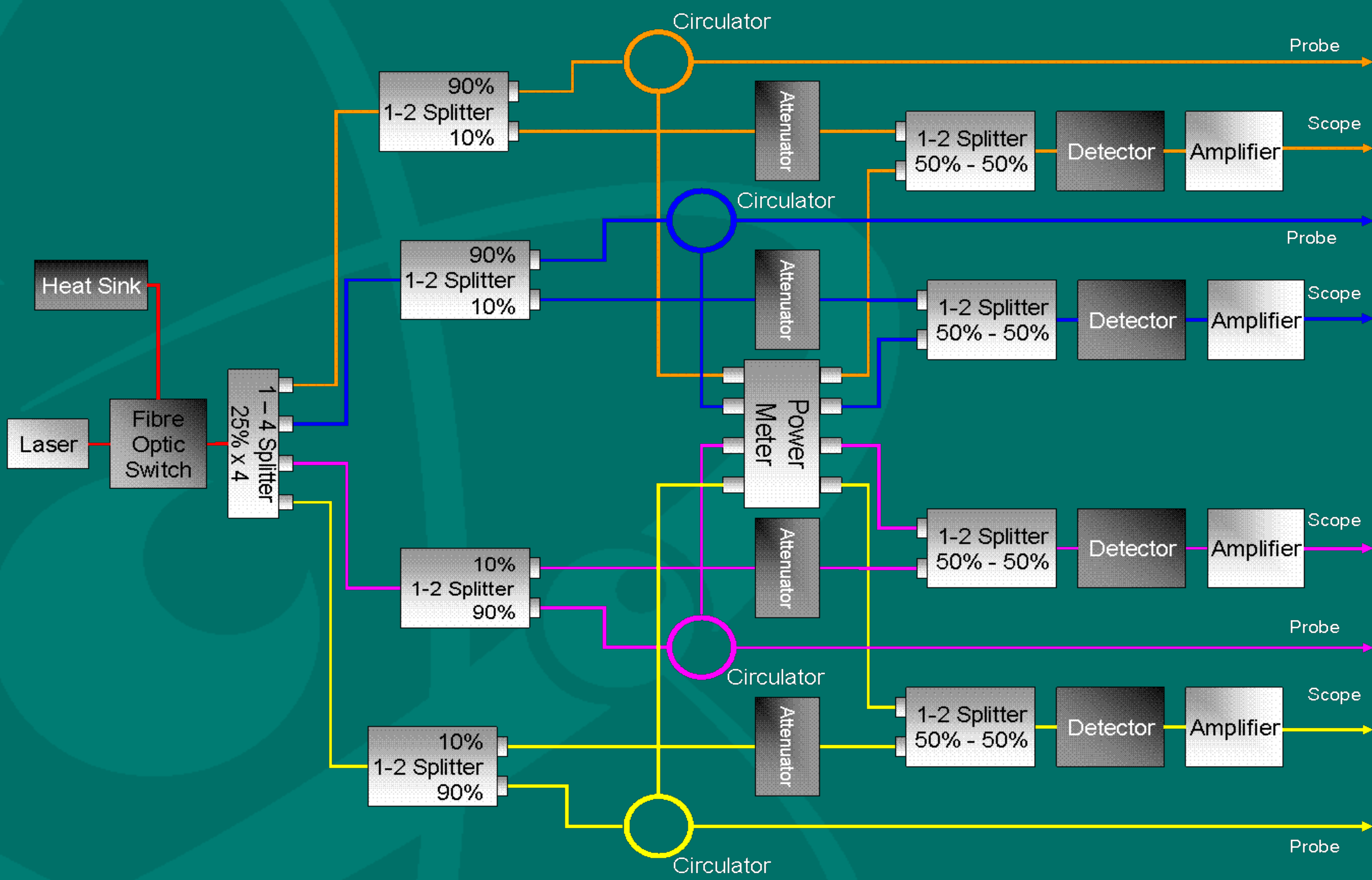


Some Pictures



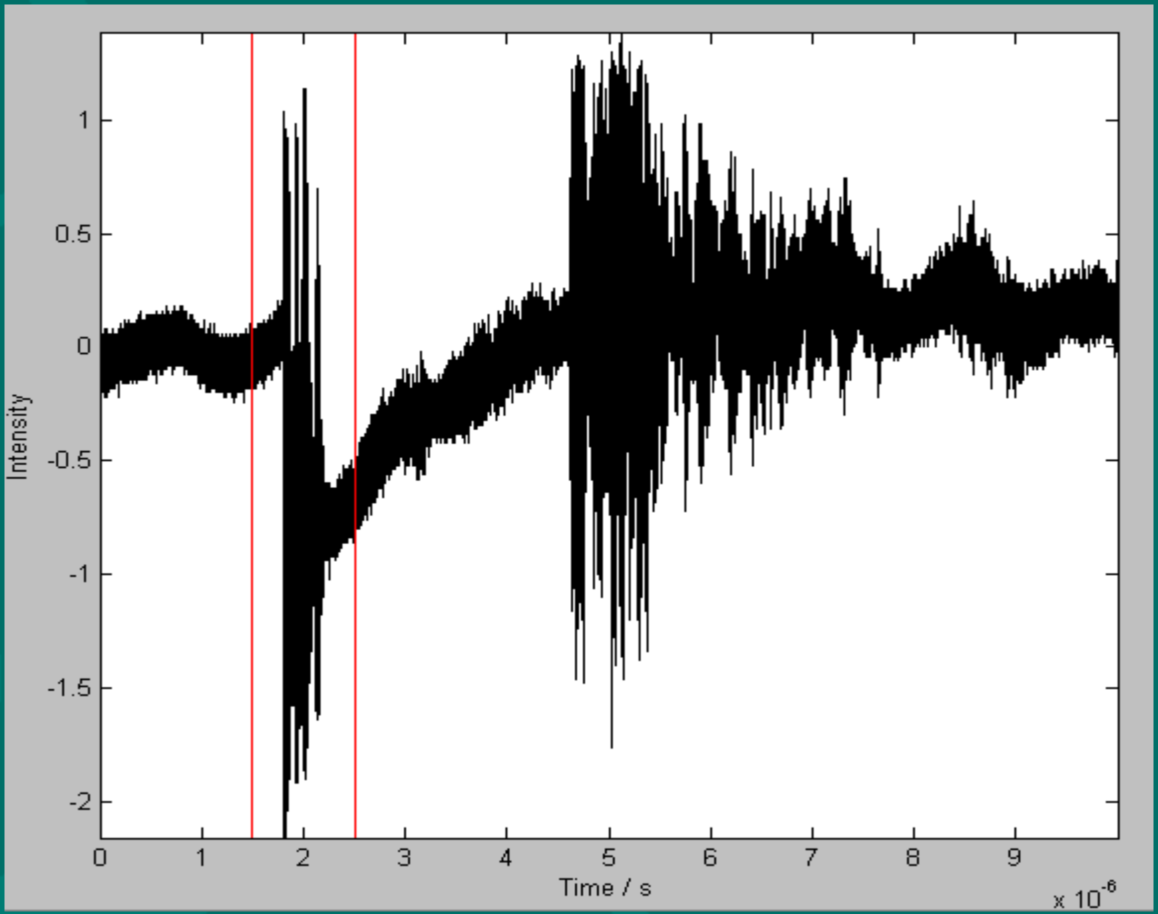


System Schematic



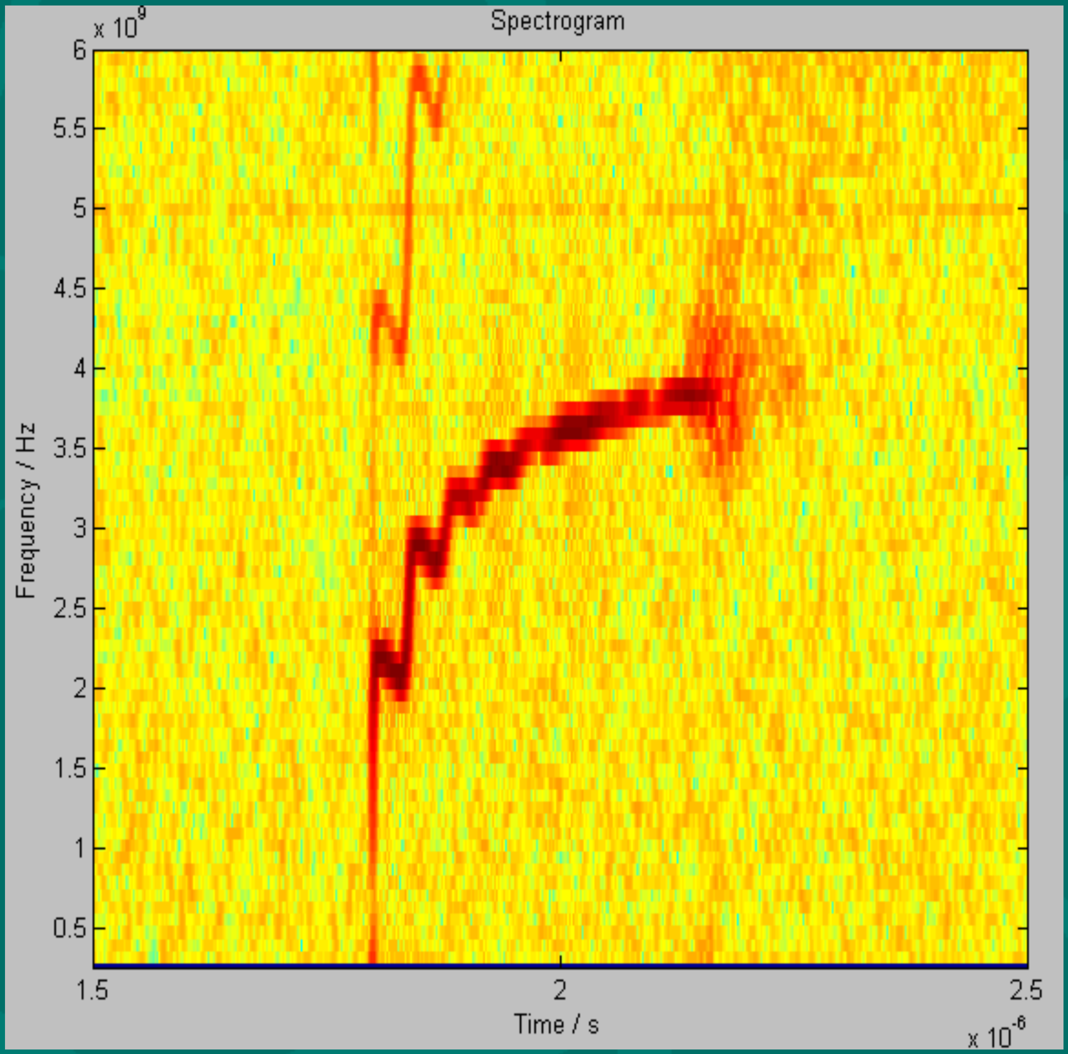
Photonic Doppler Velocimetry

- This is what we record:



- So what do we do with it?

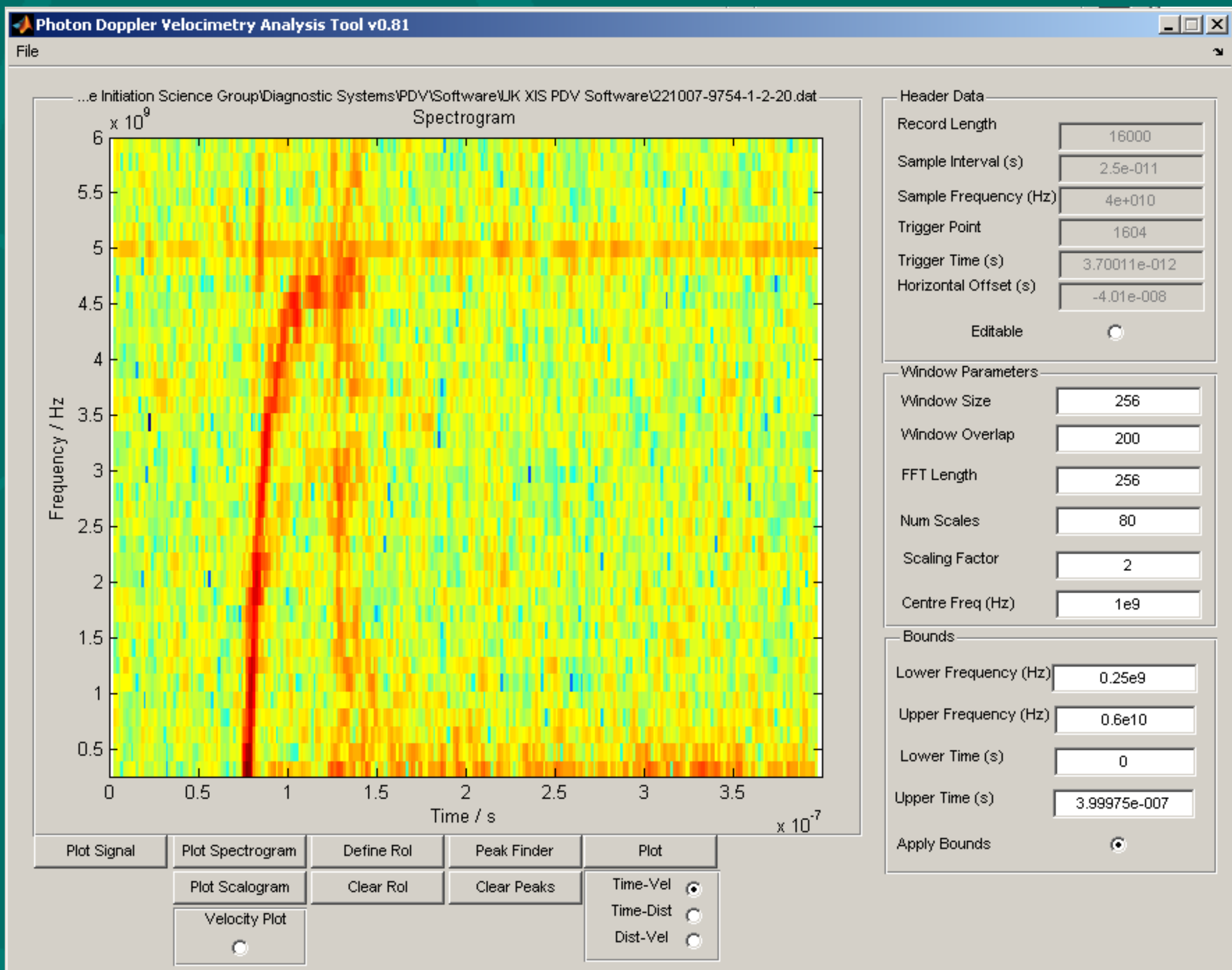
Photonic Doppler Velocimetry



- Convert time-Amplitude data into time-frequency data
- Currently preferred techniques are Spectrograms and Scalograms
- Spectrograms give superior results for this application…
  - Related to signal-noise ratio
- Frequency converted to velocity

Analysis Method

XIS PDV Tool



- Written in Matlab
- Reasonably user friendly
- Outputs include
  - Distance – Time
  - Distance – Velocity
  - Velocity – Time
- Standard Analysis Techniques used
  - SFFT/Spectrogram
  - Wavelet Analysis
    - (originally Matlab, now Colin Landon's)

The Spectrogram

- A sliding fast Fourier transform seems to give us the best results
  - Followed by Wavelet decomposition
  - Other Time Frequency Representations suffer heavily from cross-terms, i.e. Wigner-Ville, Choi-Williams
- Investigated a range of effects including
  - Window Size
    - 256 Point Window selected
  - Window Overlap
    - 200 Point Window selected
  - Assorted Filters
    - Raw data seems to give the best results

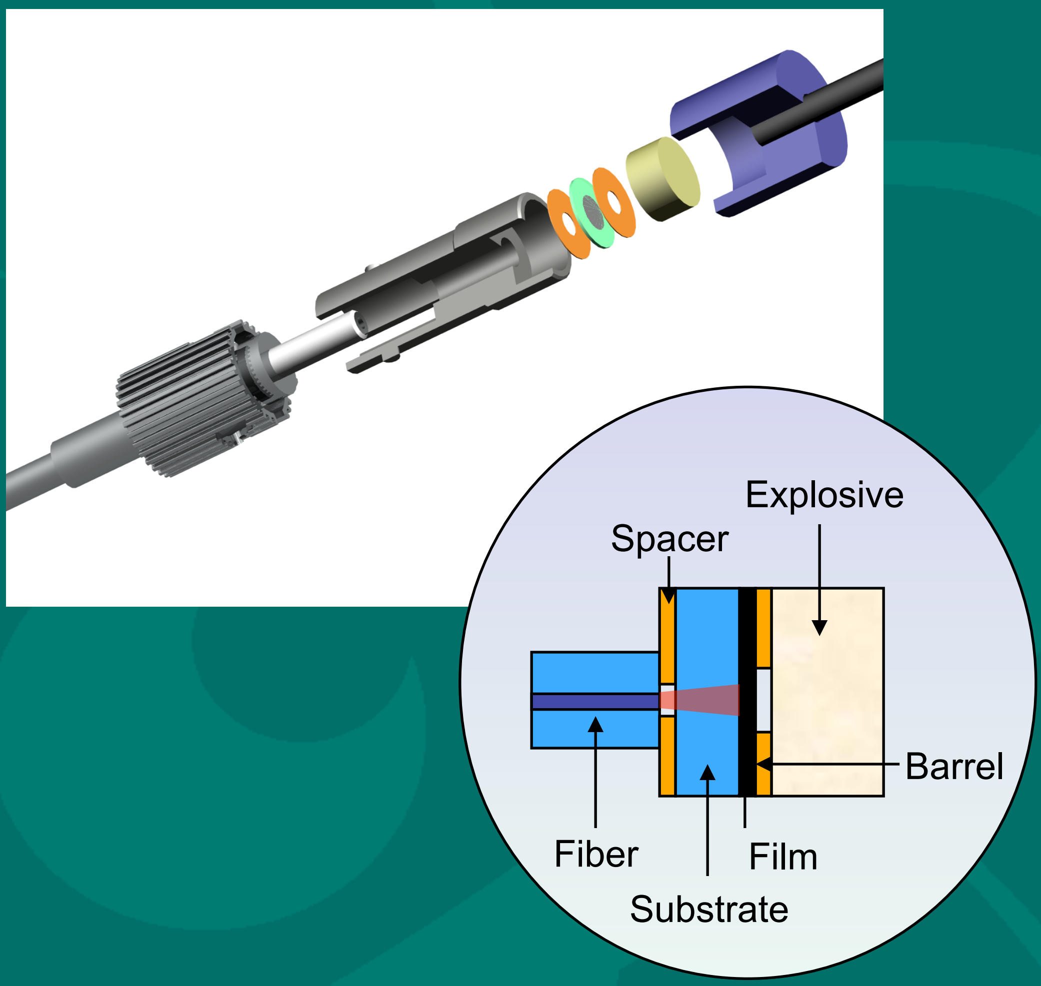
Results

Detonator Outputs

Detonators

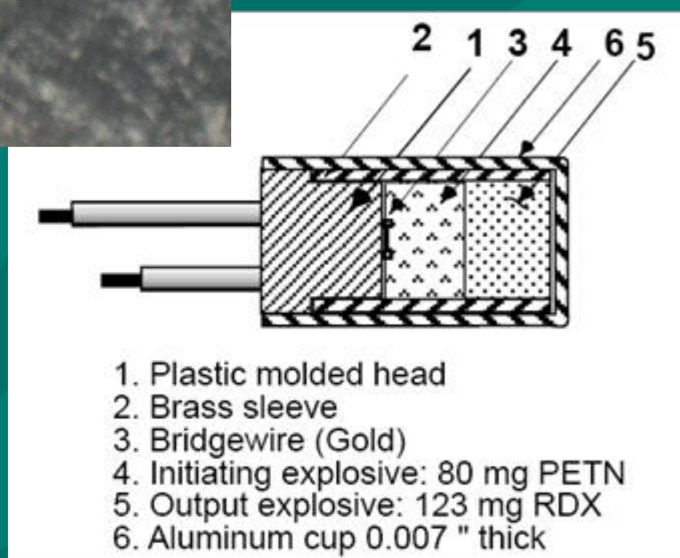
- Detonators convert non-explosive (optical, electrical) energy to explosive energy
- Used to initiate further explosive charges
- We need to understand their output
  - Output pressure, timing
- Typically use PVDF, Manganin gauges
  - Susceptible to electromagnetic interference
  - Require calibration for each gauge
- Desirable to have non-contact, optical measurement of pressure, timing

AWE DOI Detonator



- Q-Switched laser pulse irradiates the interface between a transparent substrate and a metal coating
- A high density plasma forms
- Drives flyer plate across an air gap into an explosive pellet
- High density (1.6 $g.cc^{-1}$) Hexanitrostilbene (HNS) explosive pellet undergoes Shock to Detonation Transition

Risi RP-80

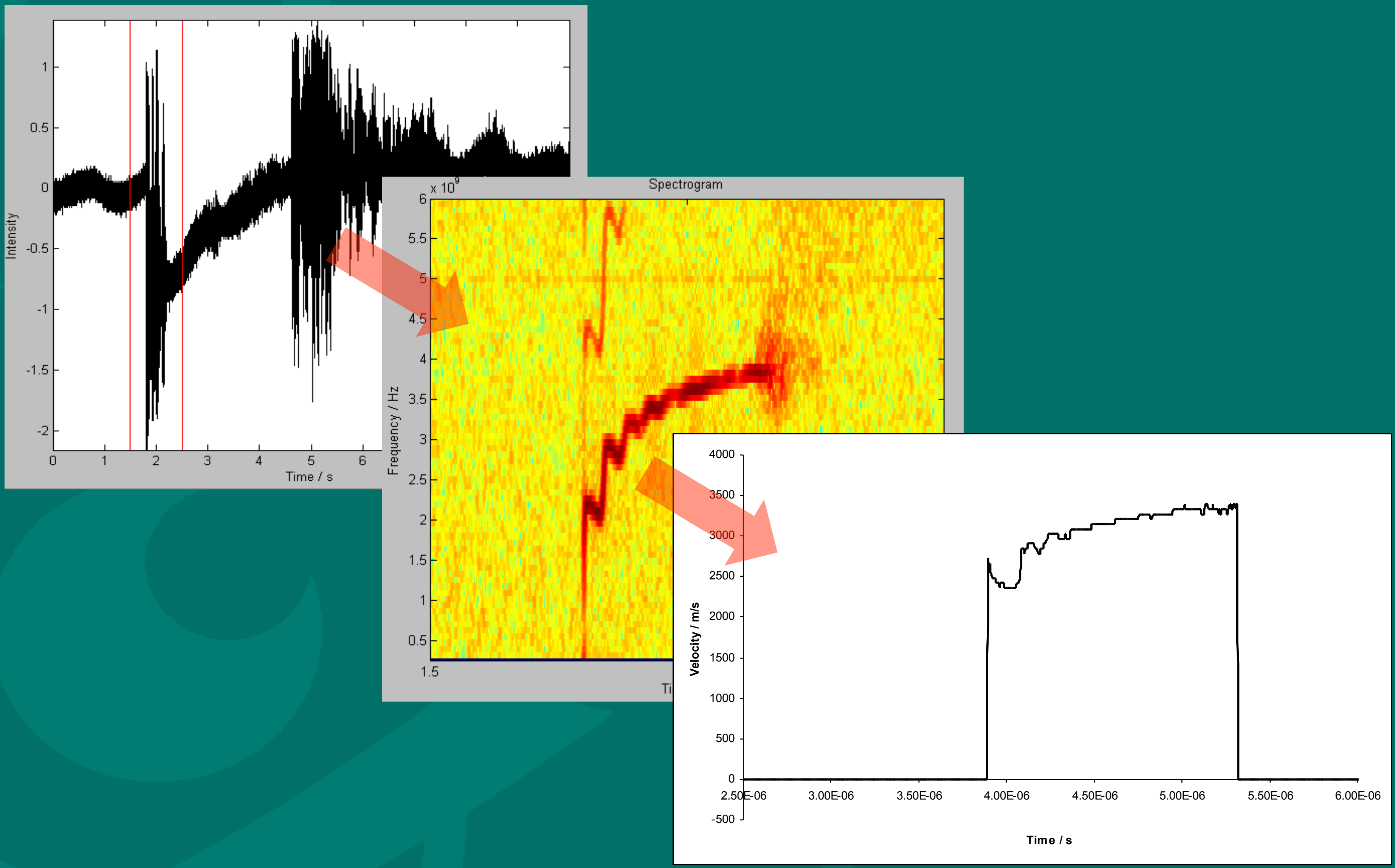


- The Risi RP-80 is an Electric Bridge Wire (EBW) Detonator
- Consists of:
  - A Gold bridgewire
  - a low density PETN fill
  - and a high density RDX based fill (PBX-9407…?)
- Functions by transmitting a High voltage-high current (typically of the order of 1000s of Volts at 1000s of amps) signal through the Bridgewire,
- Bridgewire explodes driving a shock wave into the low density PETN fill,
- Shock to detonation transition (SDT) occurs in the low density fill
- This is then amplified by the high density fill

Experimental Setup

- Detonators mounted in a polycarbonate fixture
- PDV probes held at ~ 3-4 mm standoff from detonator output face
- Collimating probes with 0.5 mm beam diameter
- Probe not precision aligned
  - Primarily due to safety concerns relating to high power laser impingement upon explosives.
  - Experiment data was lost for some shots
- For the AWE DOI detonator a aluminium foil was bonded to the output face

Results 1



Intensity
Time / s
Spectrogram
x 10^9
Frequency / Hz
1.5
Velocity / m/s
Time / s

Results 2

Detonator	Shot Number	Specific Surface Area	Jump-off Velocity	Calculated Pressure
			Km/s	GPa
AWE HNS Based DOI Detonator (HNS @ 1.6 g/cc)	Shot 1	9.9	1.76	21.0
	Shot 2	8.3	1.94	25.0
	Shot 3	8.3	1.88	23.9
	Shot 4	4.5	1.76	21.0
	Shot 5	4.5	1.76	21.0
	Shot 6	10.76	2.00	30.0
	Shot 7	10.76	1.82	23.1
	Shot 8	13.9	1.82	23.1
	Shot 9	13.9	1.93	25.6
	Mean		1.85	23.74
	Std Dev		0.09	2.91

Results 3

Detonator	Shot Number	Specific Surface Area	Jump-off Velocity	Calculated Pressure
			Km/s	GPa
Risi RP-80 EBW Detonator (RDX @ 1.6 g/cc)	Shot 1	Unknown	3.00	28.2
	Shot 2		27.0	27.0
	Shot 3		27.9	27.4
	Shot 4		3.03	28.3
	Shot 5		2.60	26.5
	Shot 6		2.85	27.6
	Shot 7		2.91	27.9
	Shot 8		2.63	26.7
	Shot 9		2.66	26.8
	Shot 10		2.79	27.4
	Mean		2.79	27.4
	Std Dev		0.15	0.63

Hydrocode Model

- 1-D hydrocode (CTH) used to model explosive flyer system
- Free surface velocity of aluminium layer in model matched to velocity as measured by PDV for early time behaviour.
  - Matched by variation of pressure generated in explosive pellet
- Equations of state in general taken from CTH library excepting
  - HNS from Goveas et al
- Model run with a range of aluminum and explosive equations of state to investigate sensitivity to material properties

Output Pressure

- Values obtained
  - AWE DOI detonator (HNS): 23.74 ± 2.91 GPa
  - RP-80 detonator (RDX?): 27.6 GPa
- Dobratz gives output pressure of HNS at 1.6 $g.cc^{-1}$ as 21.5 GPa (CJ pressure)
  - With thin flyer plate and high time resolution we may be seeing a contribution from the Neumann spike resulting in a higher pressure
- For RDX, published pressure is 25 GPa
  - However, PBX-9407 (94% RDX, 6% Exon 46 bw) has CJ pressure of 28.7 GPa
  - RP-80 likely has PBX-9407 output pellet, not pure RDX

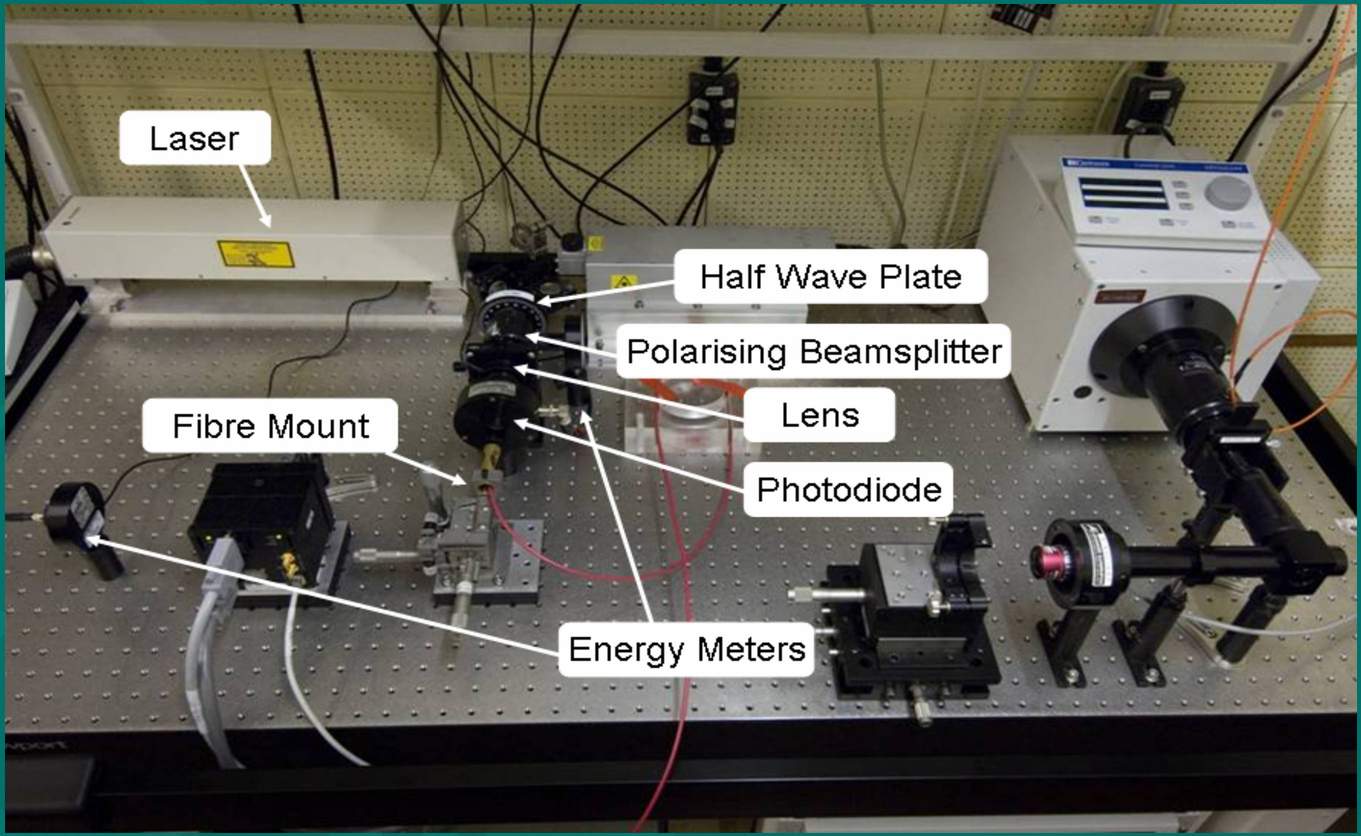
Discussion

- PDV System used to examine the free surface velocity of explosively driven flyers
  - Sensible data recovered
  - Detonation pressures for explosive pellets calculated
- Future Work
  - Proof of principle achieved
  - Compare to results with other detonator systems
  - Examine variation in output pressure when compared to CJ pressures
  - Compare to alternate diagnostics
    - PVDF/Manganin Gauges?
    - VISAR/Fabry Perot?
    - ToA Gauges?

Results

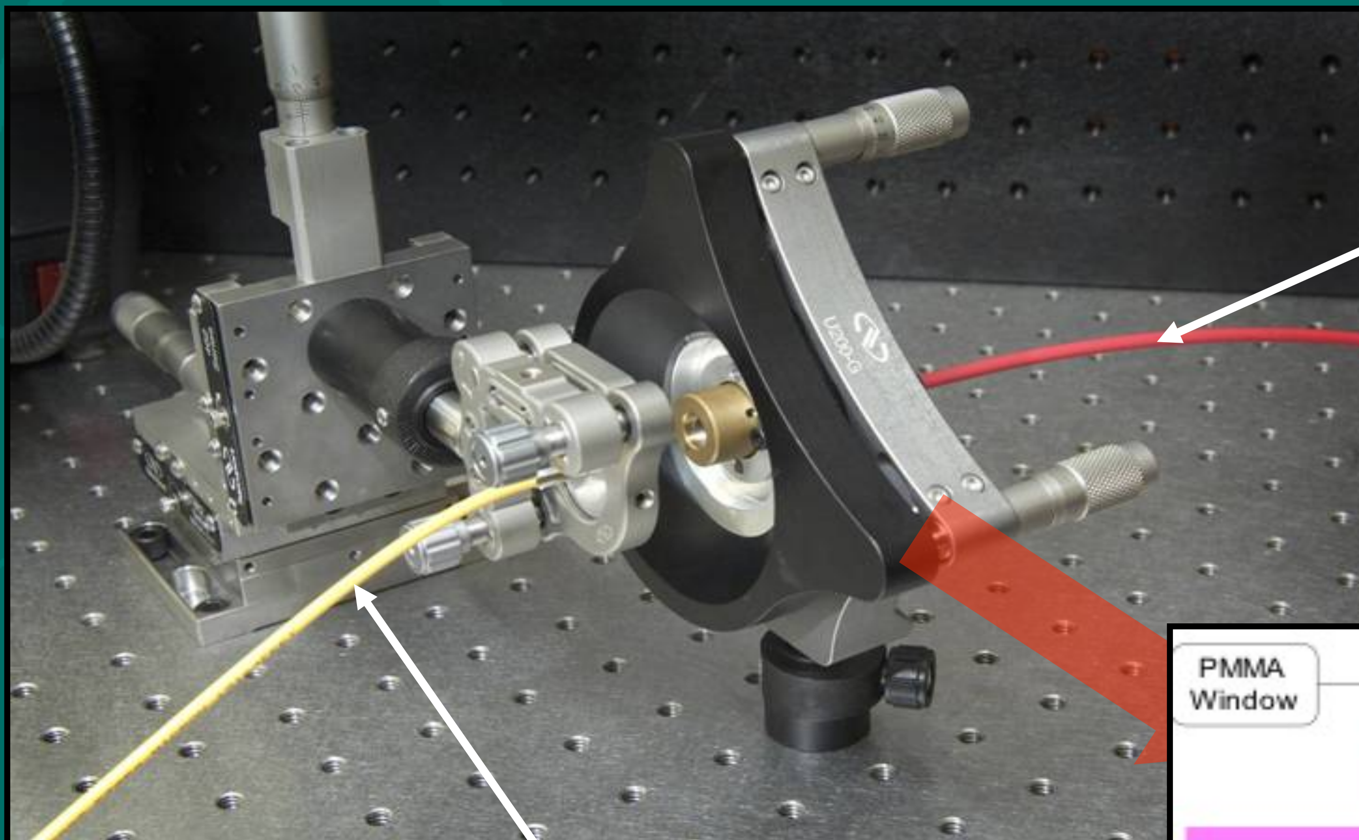
Laser-driven Flyer Plates

Flyer Launch Apparatus



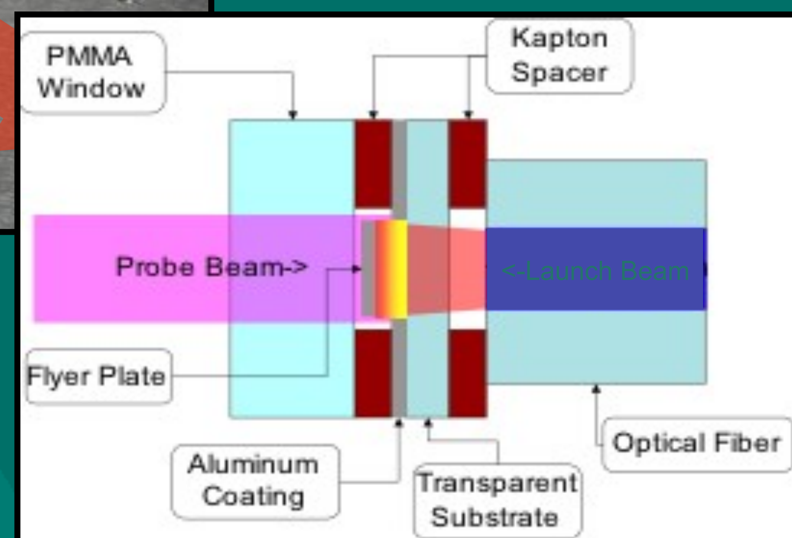
- Nd:YAG laser
  - <100 mJ, 14 ns
- Thin aluminum flyer plates launched

Probe Setup

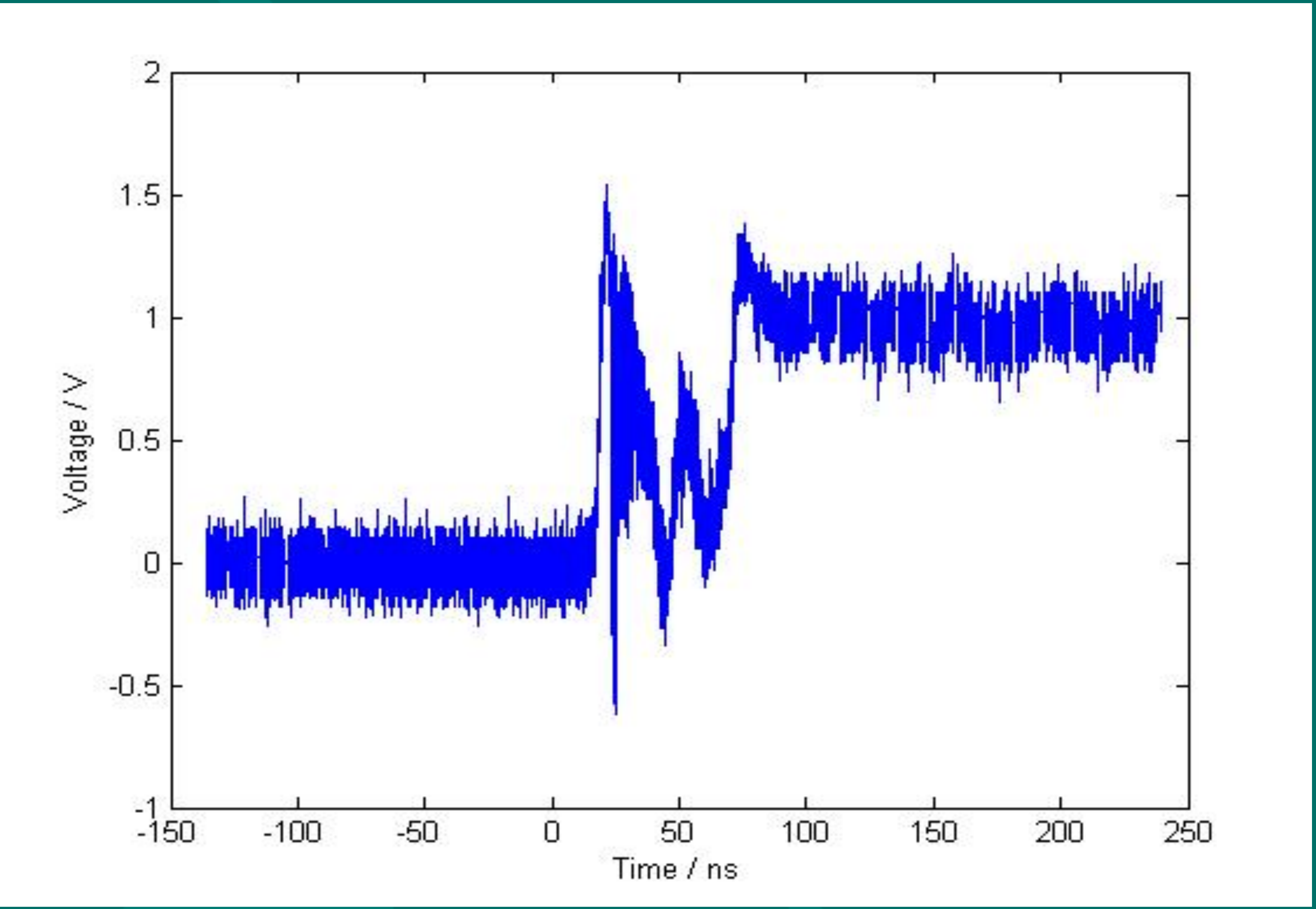


Launch Fibre

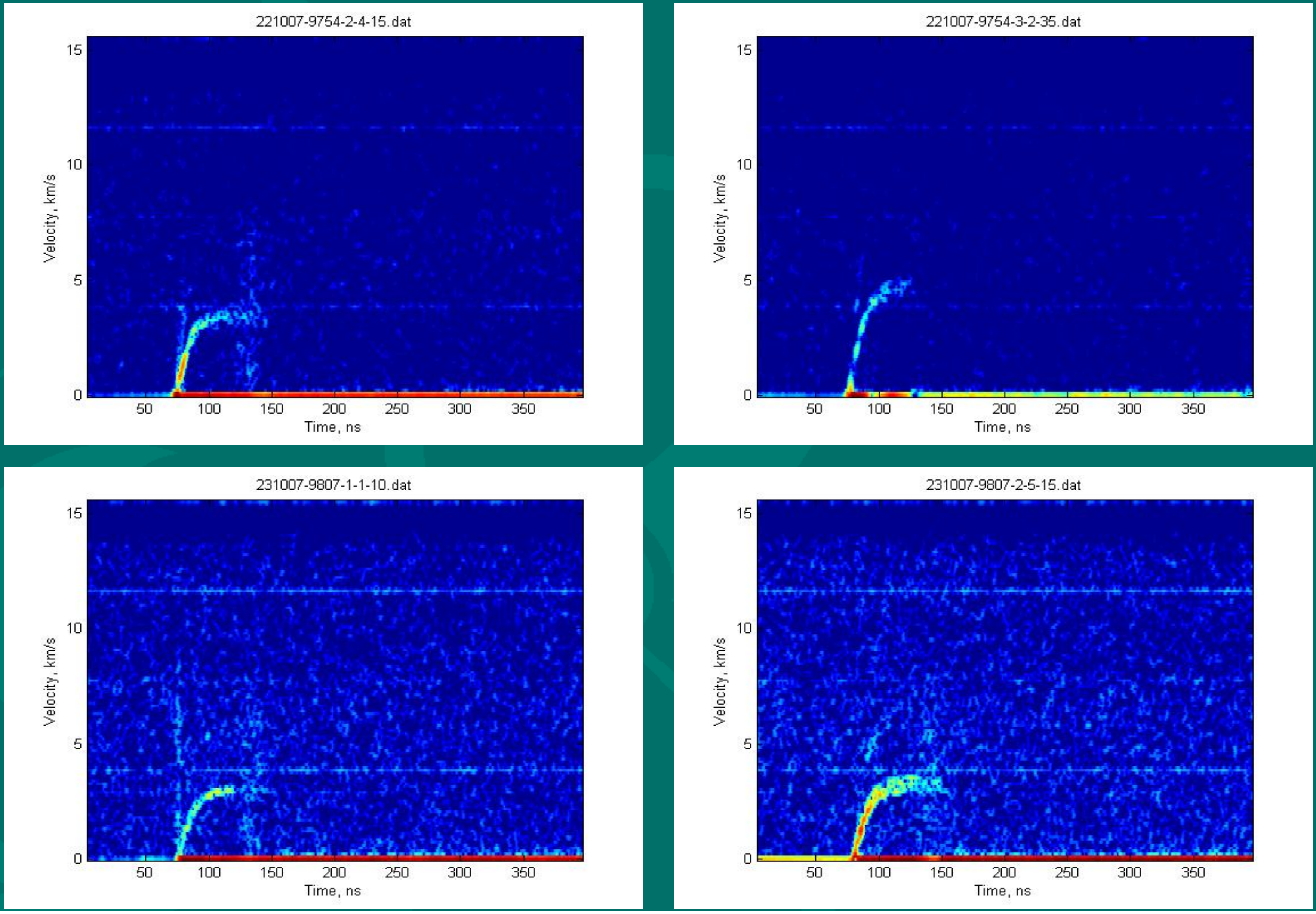
Probe Fibre



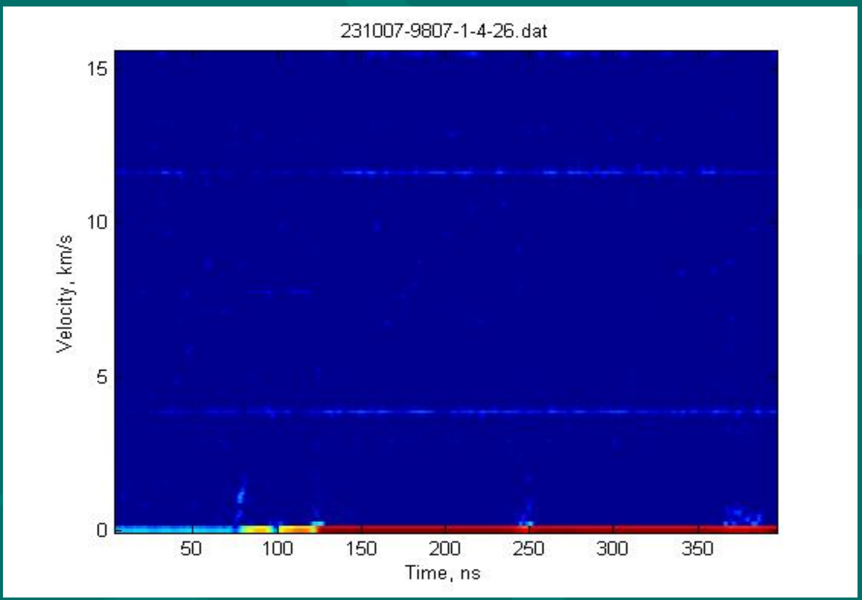
Raw Data

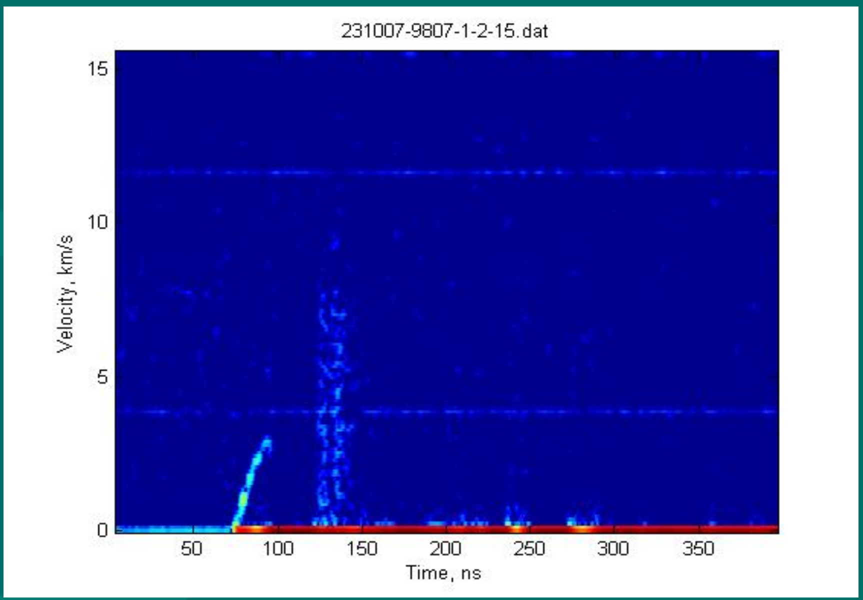


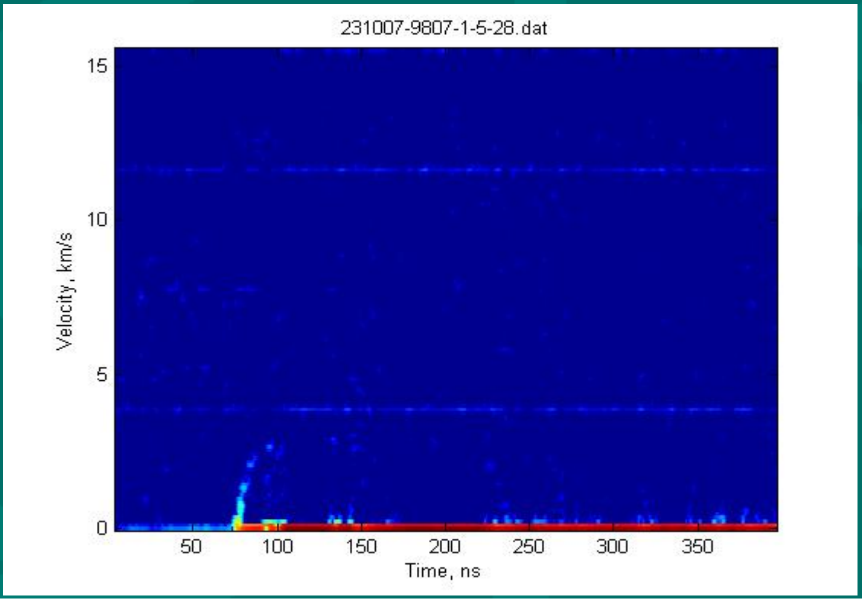
Good Results



Bad Results!

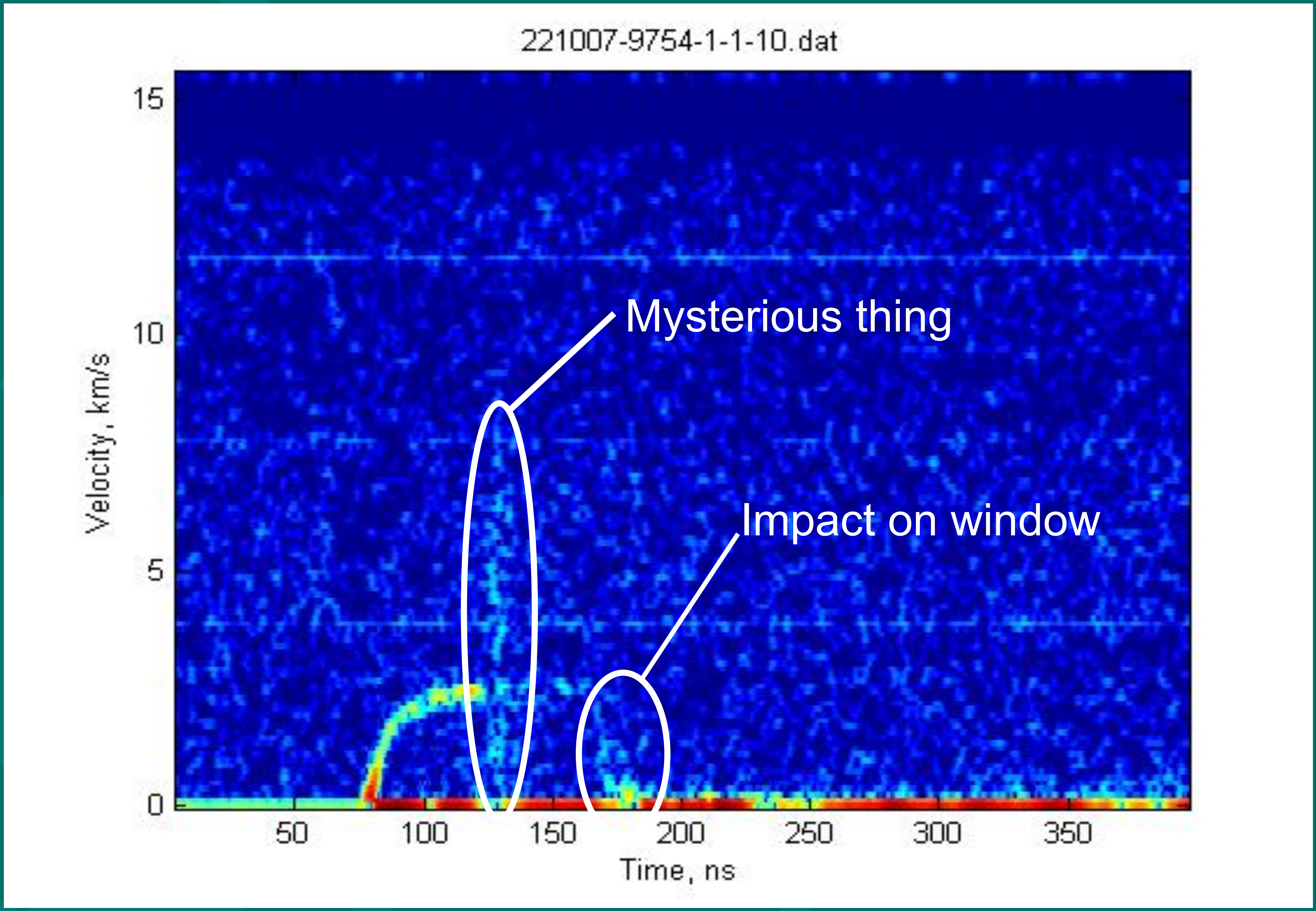




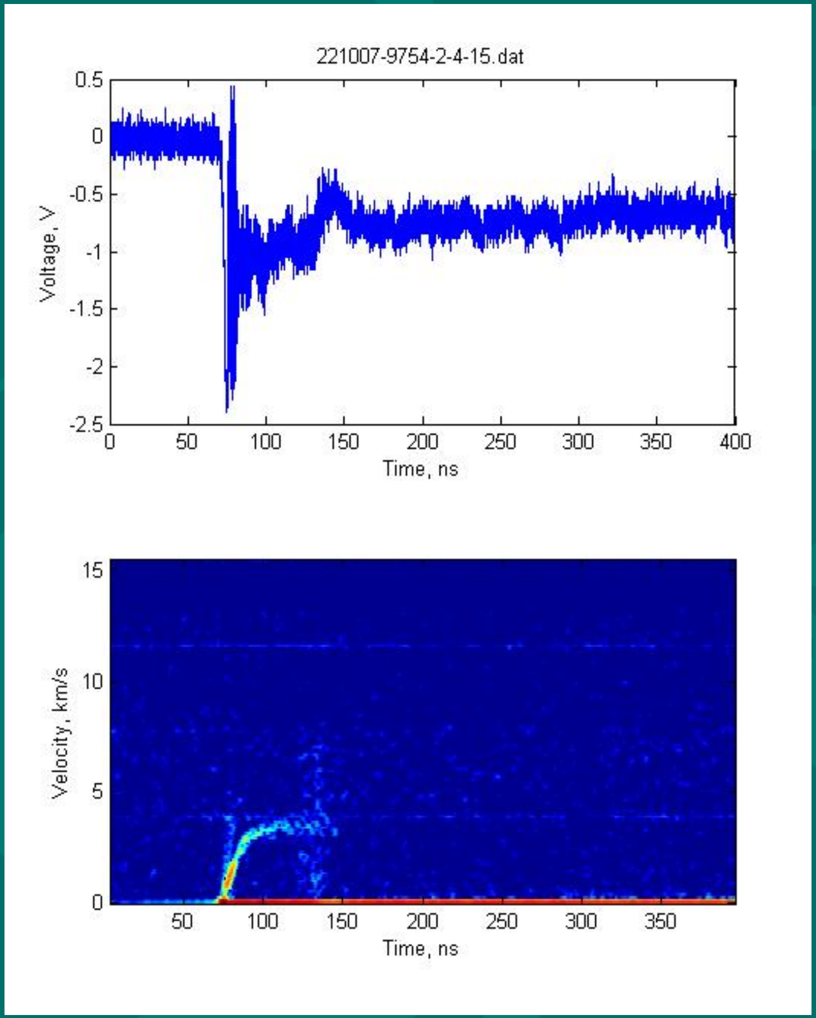


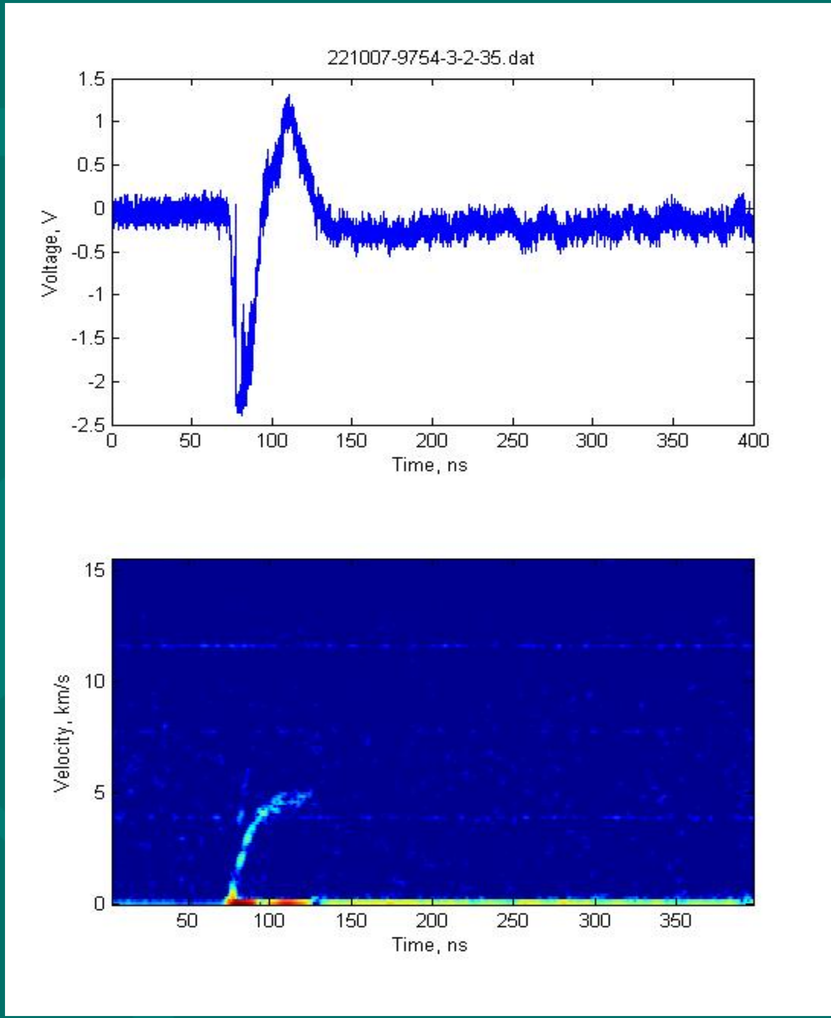
- Not seen often!
- Approaching 80% of shots give good data
- Improving with experience

Interesting Result

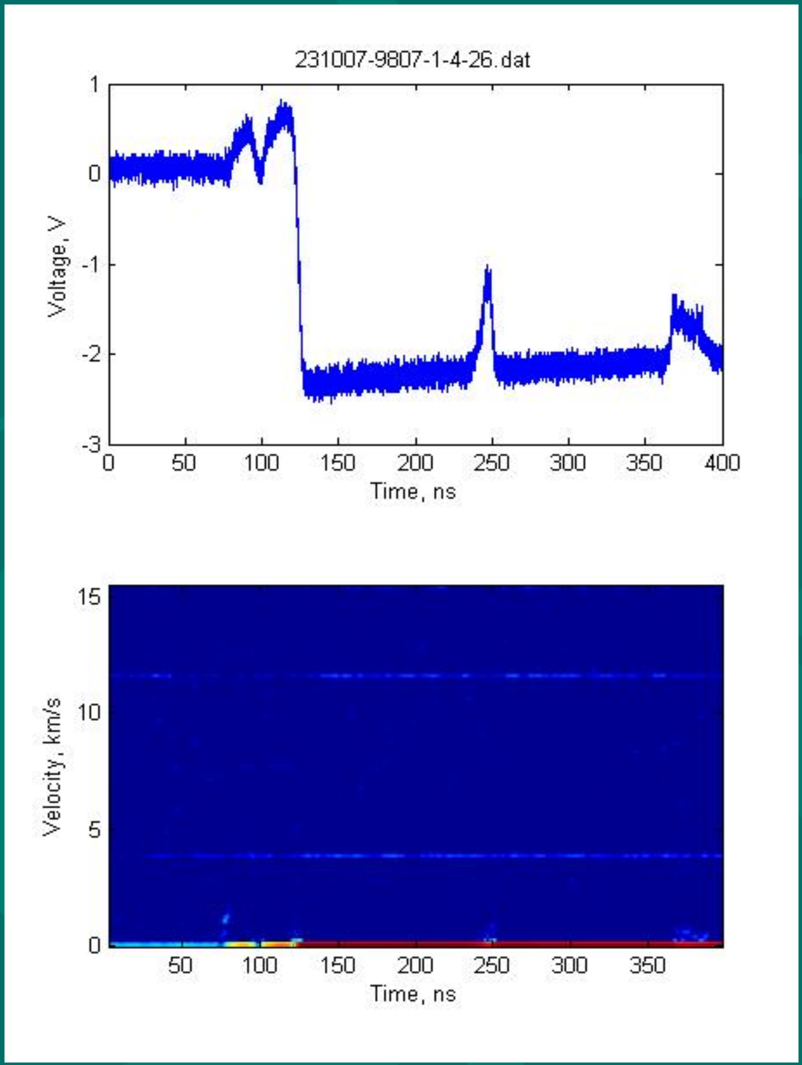


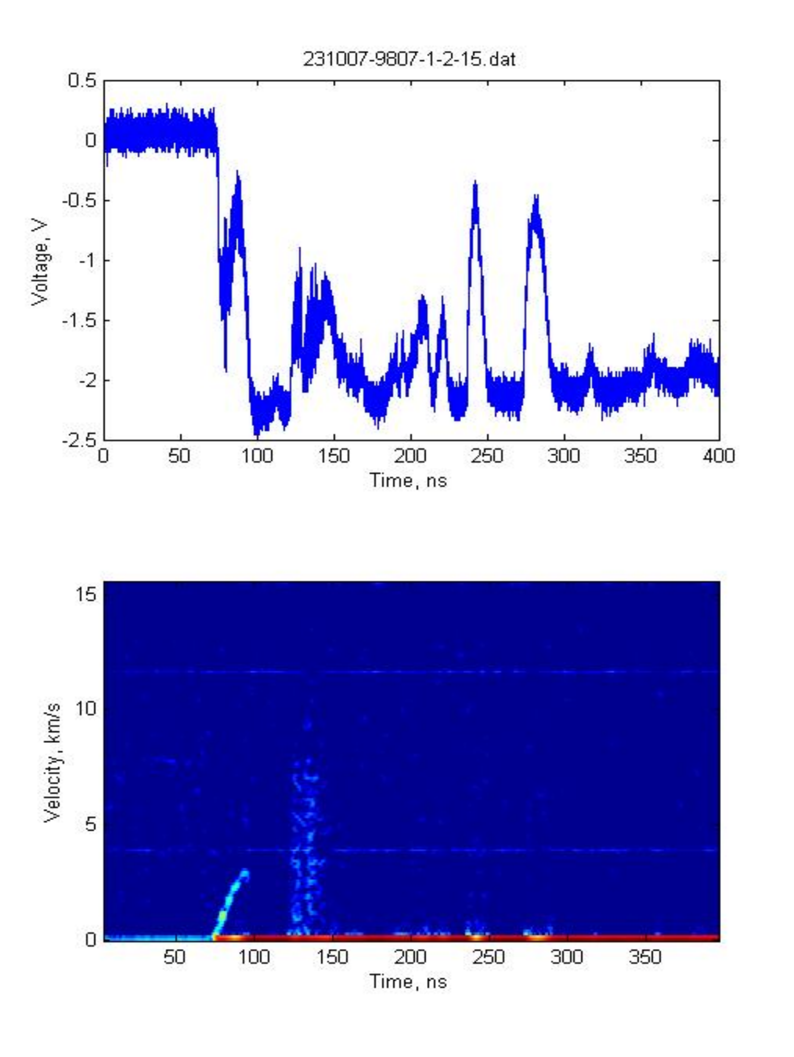
Raw Data and Good Results



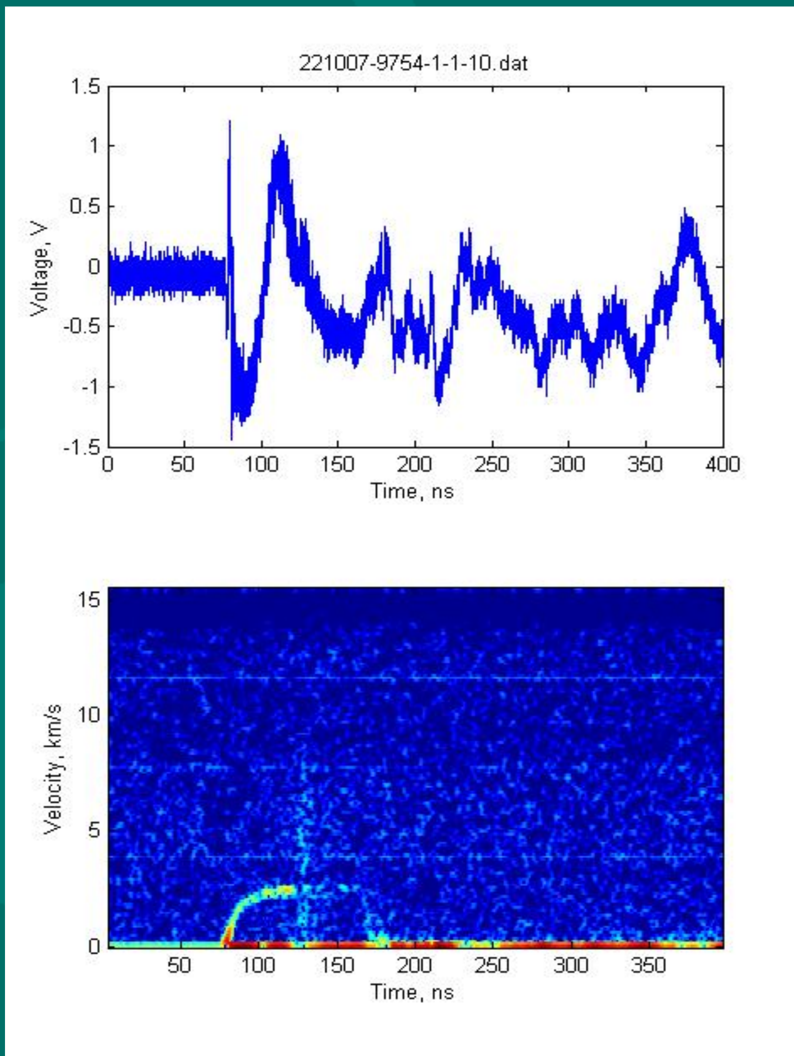


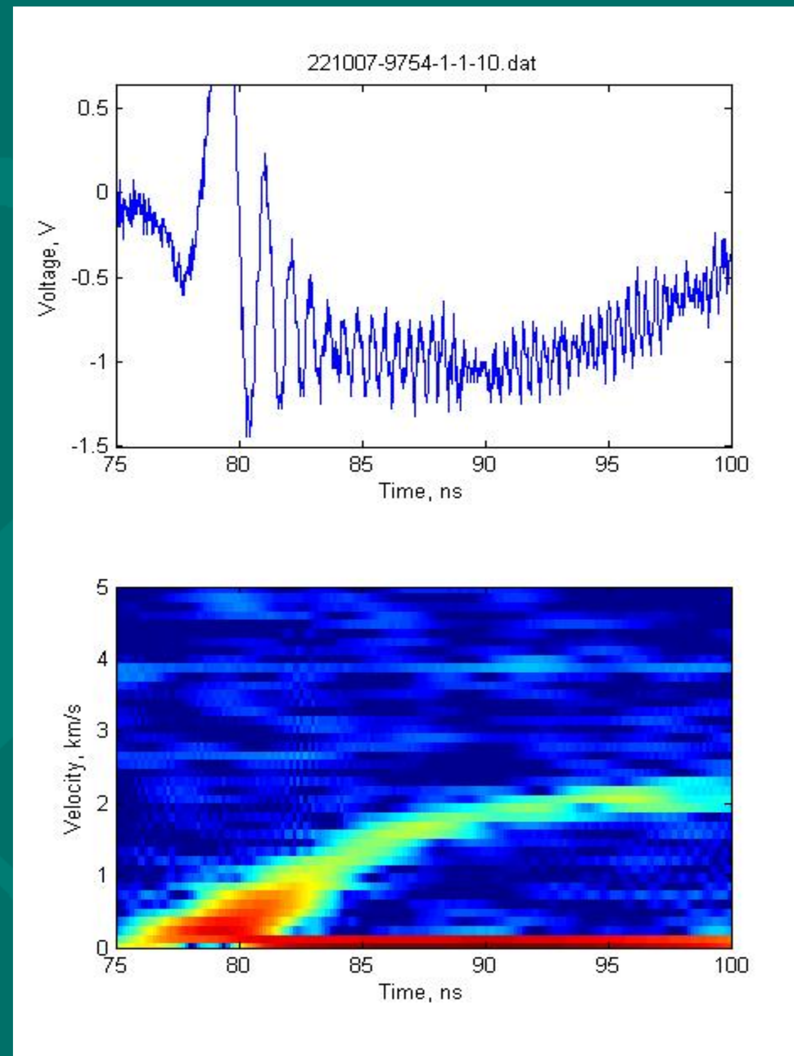
Raw Data and Bad Results





And Now, a Little Closer…

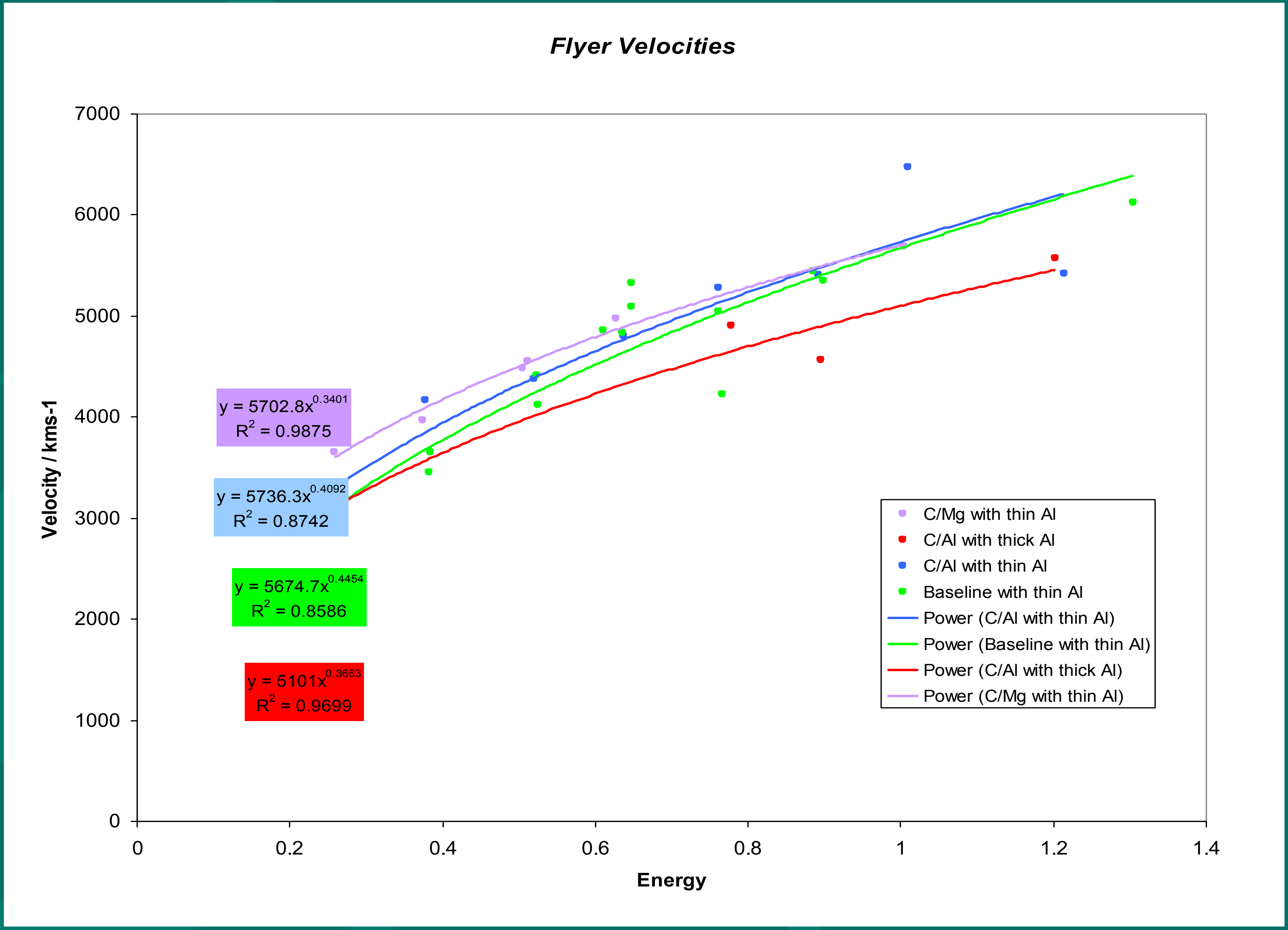




Flyer Optimisation

- We want to maximise our flyer velocity for a given energy
- Baseline flyer
  - $Al/Al_2O_3/Al$ with thin Al impactor
- Enhanced flyers
  - $C/Al/Al_2O_3/Al$ with thin Al impactor
  - $C/Al/Al_2O_3/Al$ with thick Al impactor
  - $C/Mg/Al_2O_3/Al$ with thin Al impactor
  - $C/Mg/Al_2O_3/Al$ with thick Al impactor

Flyer Optimisation



Flyer Optimisation

- Energy required for 5 kms^{-1}
  - $Al/Al_2O_3/Al$ with thin Al impactor – 0.75
  - $C/Al/Al_2O_3/Al$ with thin Al impactor – 0.71
  - $C/Al/Al_2O_3/Al$ with thick Al impactor – 0.94
  - $C/Mg/Al_2O_3/Al$ with thin Al impactor – 0.68
  - $C/Mg/Al_2O_3/Al$ with thick Al impactor – No data
- Carbon absorption layer saves ~6%
- Magnesium ablation layer saves additional ~5%

Learning Points

- In-line power meter *very* useful for alignment, but
- Alignment can be too good!
  - Detectors can saturate
  - Good results from -3 to -12 dB return
- Data lost in one of three ways
  - Too much signal
  - Too little signal
  - Something else…
- Can recognise good trace from raw scope data with practise

System Features

- Total bandwidth ~9 GHz
  - Maximum velocity ~ 4 km/s
  - Bandwidth limited by amplifier
  - Easily upgradeable
- 4 channels powered by 2 watt laser
  - ~500 mW per channel
- Fast switching of laser signal
  - Allows lower average powers
  - Limits issues with temperature rises
- Portable and robust

Conclusions

- PETN has been successfully initiated with laser-driven flyer plates launched from optical fibers
- Firing times, detonation velocities and critical energy calculated
- HNS and PETN thresholds compared
  - PETN thresholds variable with SSA
  - HNS thresholds consistent with SSA (over range tested)

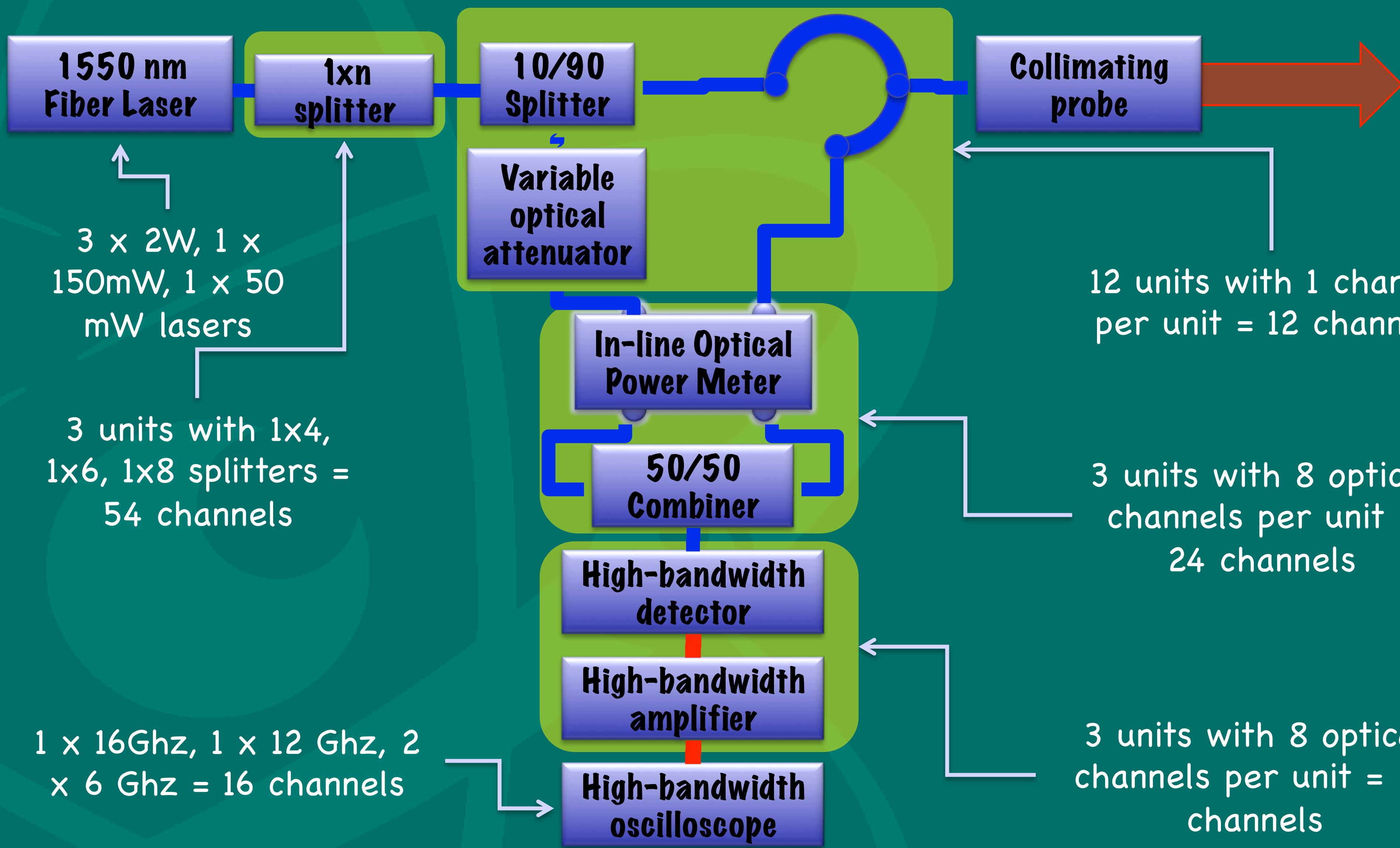
Acknowledgements

- Sarah Knowles, Matthew Cheeseman, Andrew Stoodley
  - Experimental assistance
- Paul Pearson
  - Electronic design and construction
- Andrew Critchley, Ed Price and Martin Philpot
  - Technical discussions and advice
- Steven Clarke and Adrian Akinci (LANL)
  - Technical discussions and advice

Planned Capability

Next 3 months

Modular, Expandable PDV



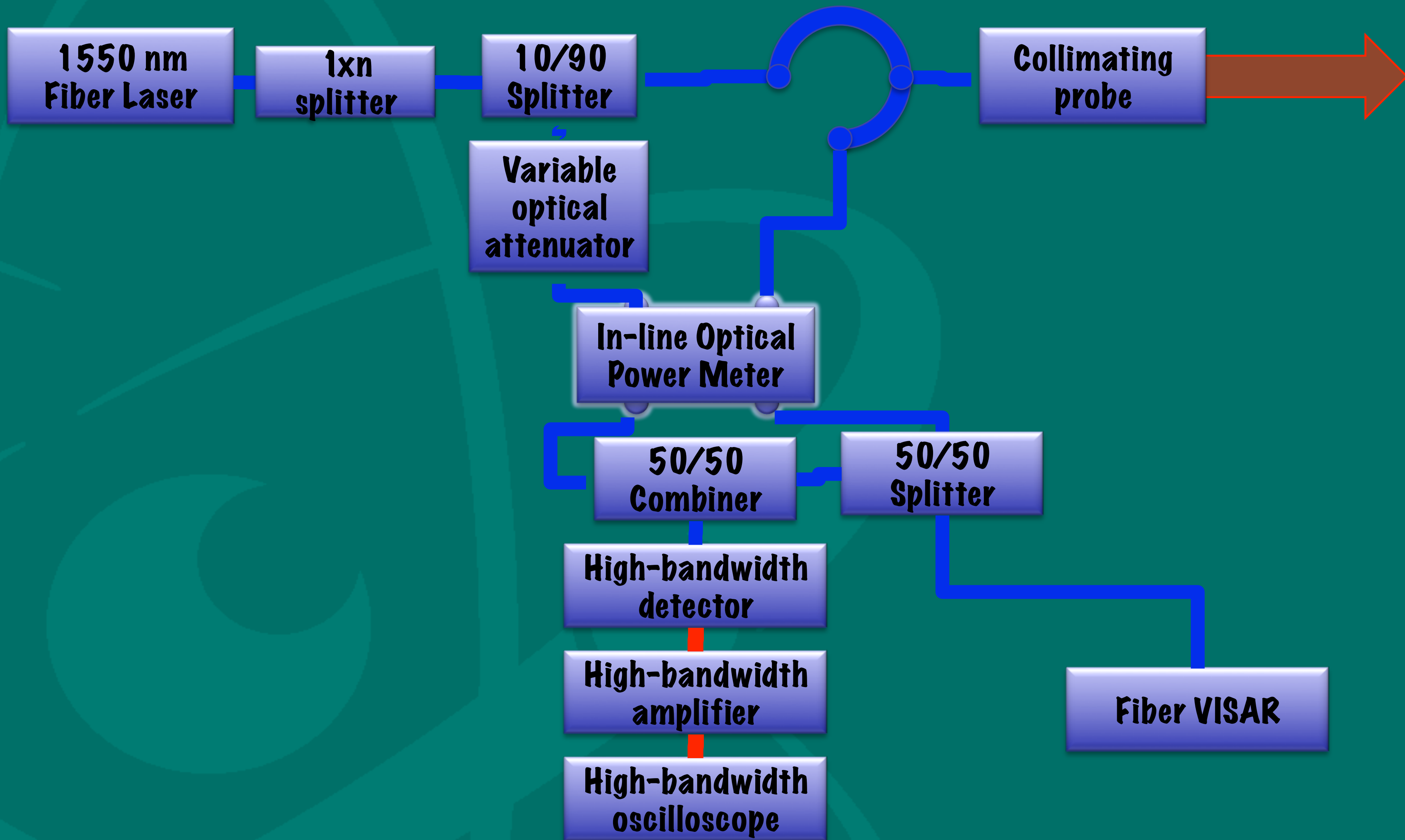
Modular, Expandable PDV

- Discrete rack mount units
  - Approximate cost $5000 per channel not including scope and laser
- Splitter module
  - Contains 1x4, 1x6, 1x8 module
  - ~$1000
- Interferometer module (one optical channel)
  - Contains circulator, splitters, attenuators
  - ~$1000
- Monitor module (8 optical channels)
  - Contains 16 power meters and 1:2 combiners
  - ~$17000 ($2125/channel)
- Detector/amplifier module
  - Contains 10 Miteq DR-125G-A detectors and power supply
  - ~$21000 ($2100/channel)
- Expandable, easily replaceable

PDVISAR

- Simultaneous PDV and VISAR down single fiber
- Use existing MFA Quadrature Fiber VISAR
- Should give enhanced time resolution
- Uses four scope channels for VISAR
- Hence, at least 5 scope channels per measurement point

PDVISAR


1550 nm Fiber Laser
1xn splitter
10/90 Splitter
Variable optical attenuator
Collimating probe
In-line Optical Power Meter
50/50 Combiner
50/50 Splitter
High-bandwidth detector
High-bandwidth amplifier
High-bandwidth oscilloscope
Fiber VISAR

Dual Wavelength PDV

- Uses two PDV systems per laser
  - 1550 nm
  - 1310 nm
- Provides redundant data
- 1310 nm requires slightly higher bandwidth