Measurement of wave-front curvature in a detonating explosive using PDV

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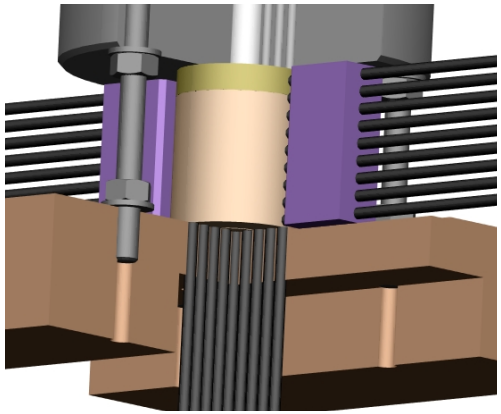
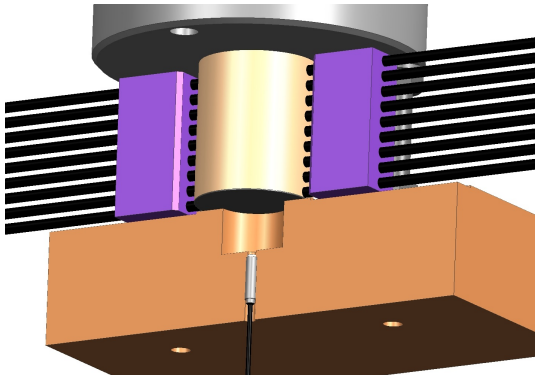
Current Experiments

ITraC – Initiation Train Characterisation



Wave-curvature Measurement

- Measure detonation wave time-of-arrival (TOA) to obtain wave curvature D(κ) for Detonation Shock Dynamics models (DSD).
- 2 mm fibre diameter.



Detonation Pressure Measurement

- Use PDV to measure material interfacial velocity to infer P_{CJ} in HE.
- LiF window in contact with HE.
- 220 μm spot on target.

- Multiple tests are time consuming and expensive.
- Limited confidence in data read-accross due to potentially large random uncertainties in HE.
- Can we make these measurements using just one diagnostic?

Solution?

Measure curvature $D(\kappa)$ and interfacial velocity (u_{CJ}) with PDV?

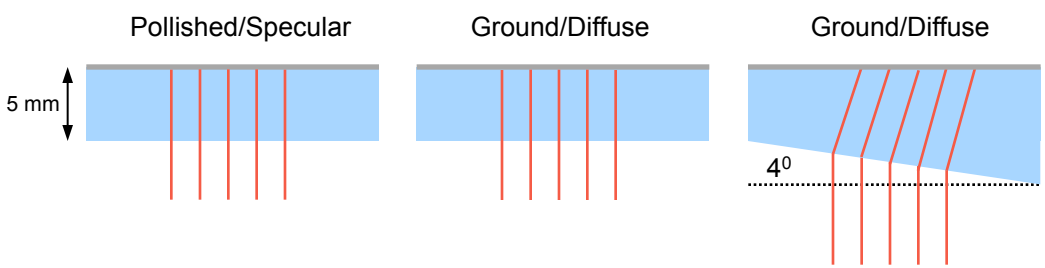
Advantages:

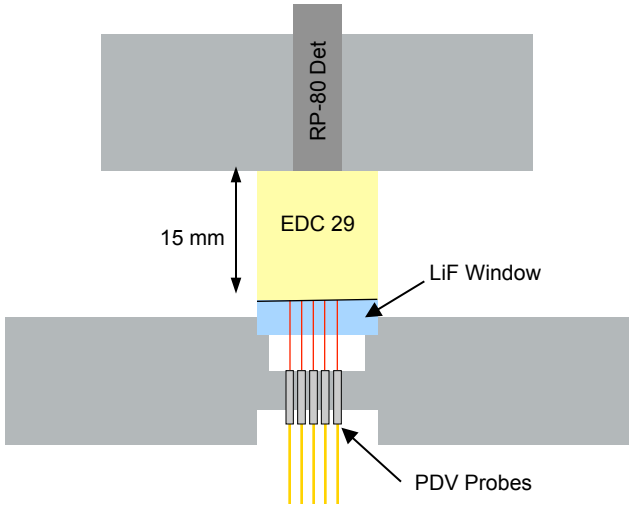
- Half the number of experiments.
- Improved correlation between P_{CJ} and $D(\kappa)$ measurements.
- Reduced spatial averaging on measurement position (PDV ≈ 1% of PMMA fibre area).
- Improved accuracy on z measurement location and therefore breakout time.

Disadvantages:

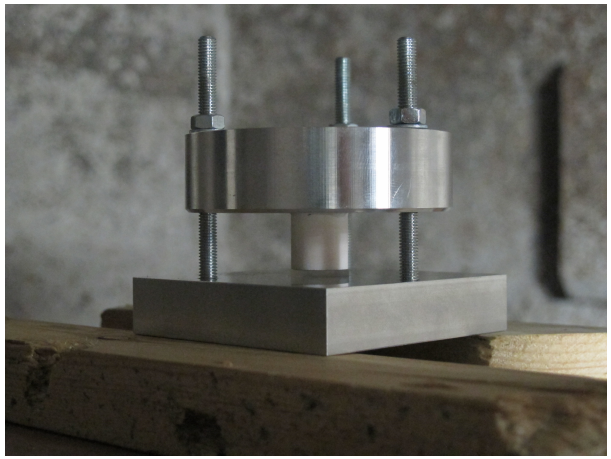
- Expensive (more PDV probes per experiment n*£50/$75).
- Complicated setup compared to PMMA fibres.
- Potential for reduced temporal accuracy.

Experiments

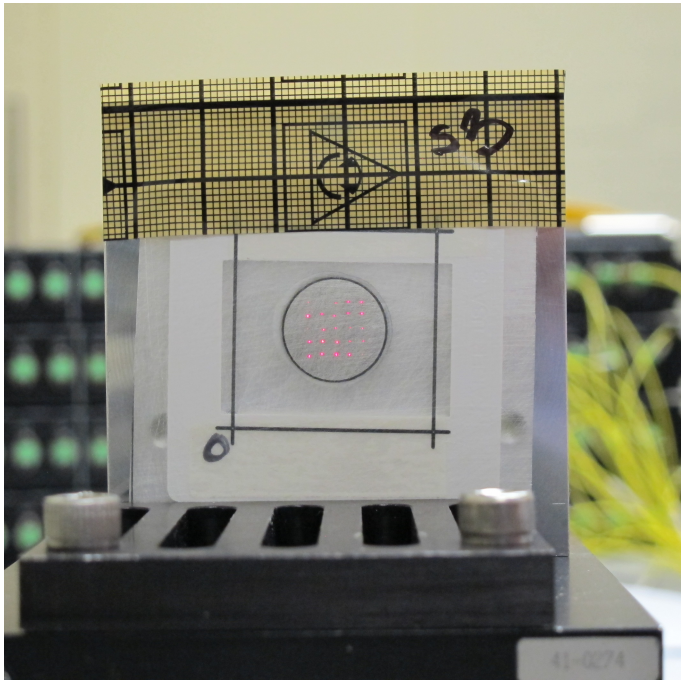


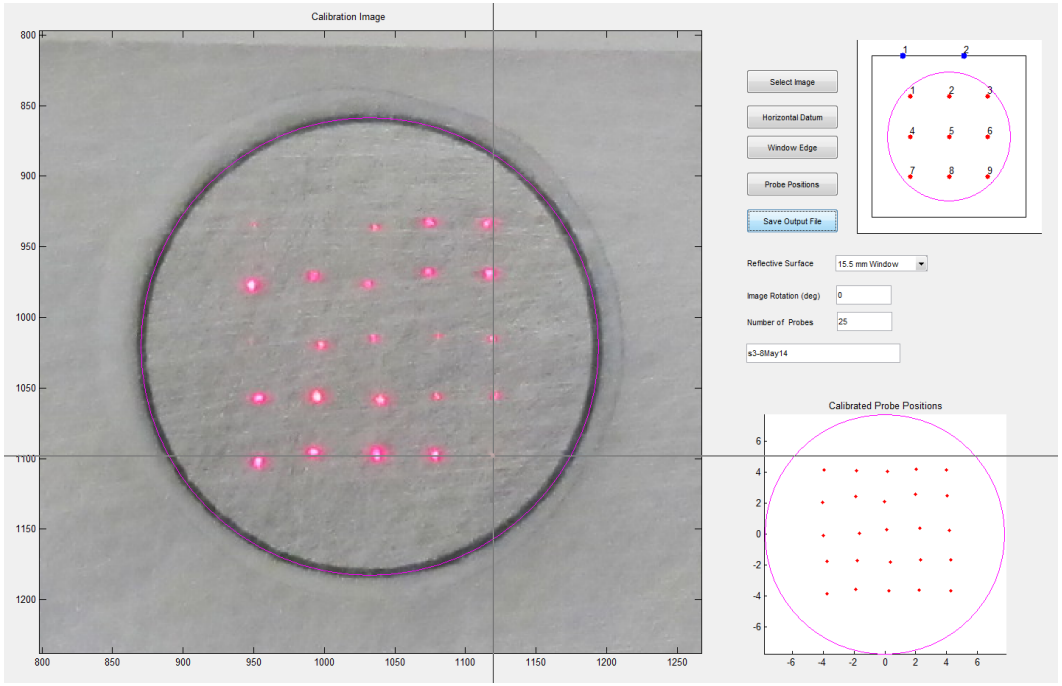


- Anecdotal evidence of preferable window reflectance – *"The reflectivity of mirrored window surfaces change significantly during shock-wave transit when in contact with HE. The consistency in return-signal power is better with diffuse reflectors compared to specular ones."*
- Three window configurations tested (50 nm Aluminium):
  - Parallel LiF with mirrored upstream surface
  - Parallel LiF with diffuse upstream surface
  - Wedged LiF with diffuse upstream surface
- 25 PDV collimating PDV probes in square grid pattern:
  - 220 µm spot size
  - 5 mm from rear surface of window
  - 1.6 mm outer diameter
  - Inter-probe spacing dictated by acceptance angle of probe to avoid mixing of return signals
- Downstream surface on window AR coated to minimise back reflections
- Window surface in contact with HE. Intimate contact aided by silicon grease.



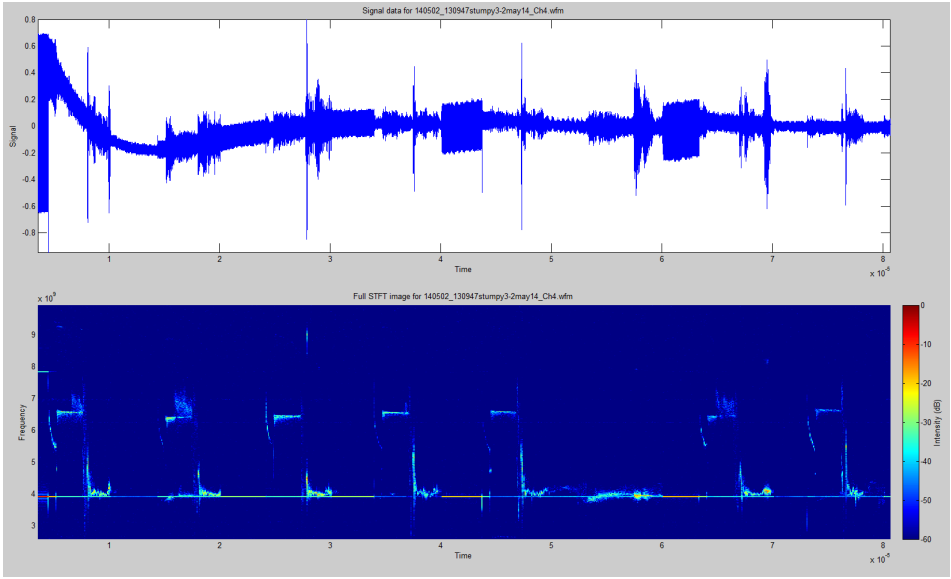
Improving the spatial accuracy





- Build up of tolerances cause laser spots to deviate from probe axes leading to x-y positional uncertainty:
  - Hole machining
  - Probe construction
  - Refraction of window (wedged prism)
- Visible laser used to measure probe locations on surface of window.
- x-y accuracy controlled by pixel size.
- Position measured to ± 50 μm

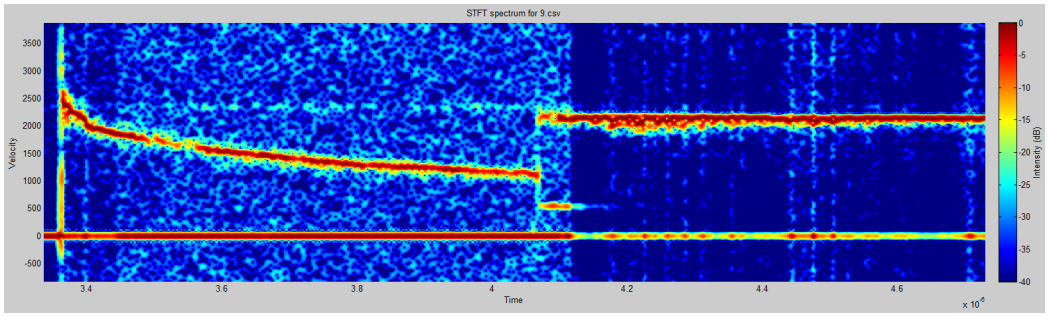
MEDUSA – *Multipoint Experimental Diagnostic for Ultrafast Shock Applications*



- 32 Channels frequency upshifted PDV
- Time-Multiplexing gives 8 x 10 μs recording windows per detector/oscilloscope channel

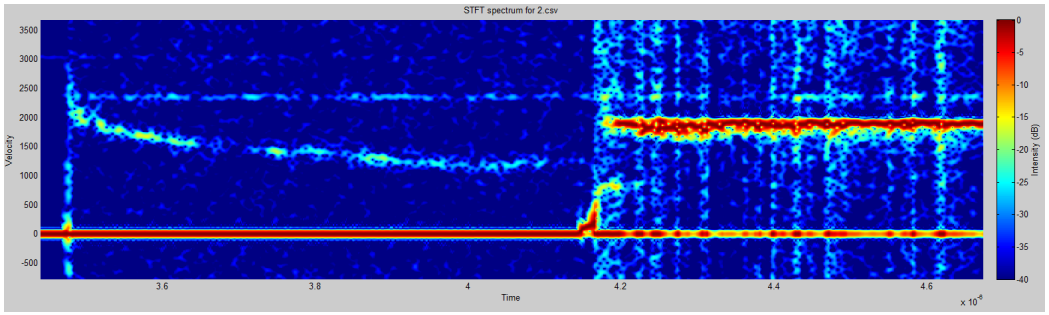
Mike Bowden will discuss this later in the week!

PDV Data



Good Data

- Strong signal throughout
- Good resolution of shock rise



Bad Data

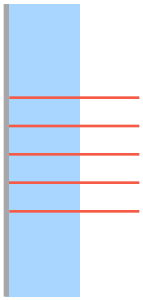
- Signal drops in and out during release wave
- Poor data in shock front

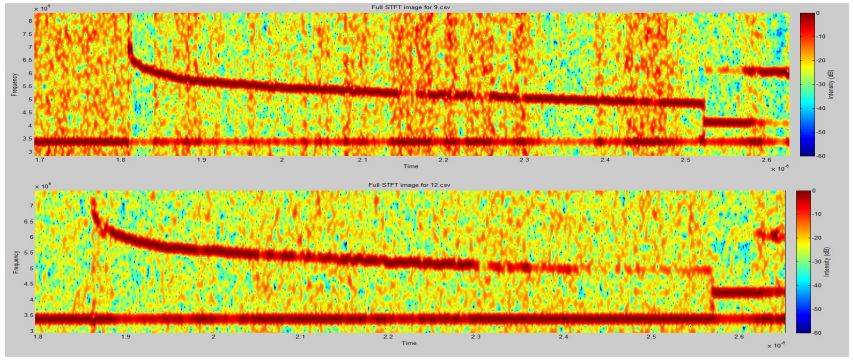
- Difficult to accurately measure shock TOA due to frequency upshifting.
- Poorly resolved Von-Neuman spike due to low frequency offset
- Reduces uncertainty in TOA to size of analysis window (5-10 ns)

Window Comparison

Diffuse-Planar

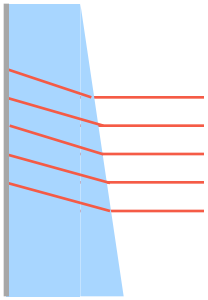
- High signal-to-noise before and during surface motion
- Few signal-dropouts

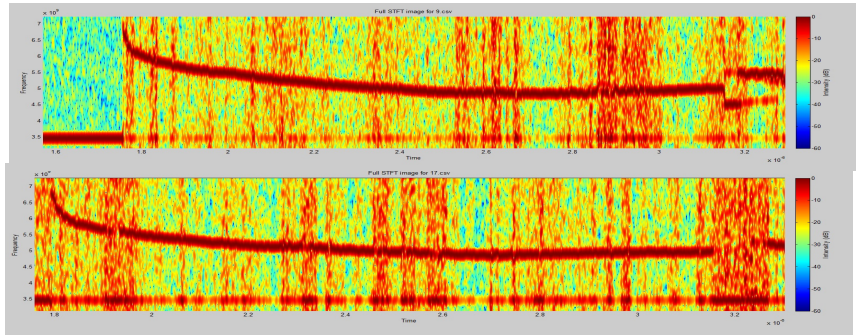




Diffuse-Wedged

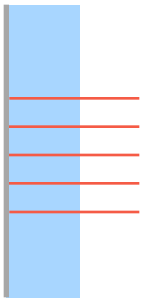
- Signal-to-noise of similar quality to diffuse-planar.
- Wedge seems to have little effect.

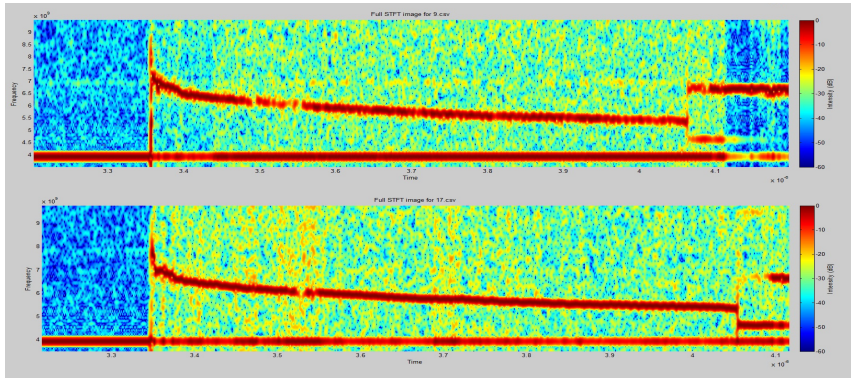




Specular-Planar

- Signal consistency good enough but some loss throughout shock transmission
- Much better signal-to-noise ratio.
- Strong harmonics present in 50% of traces.
- Wedge may eliminate harmonics



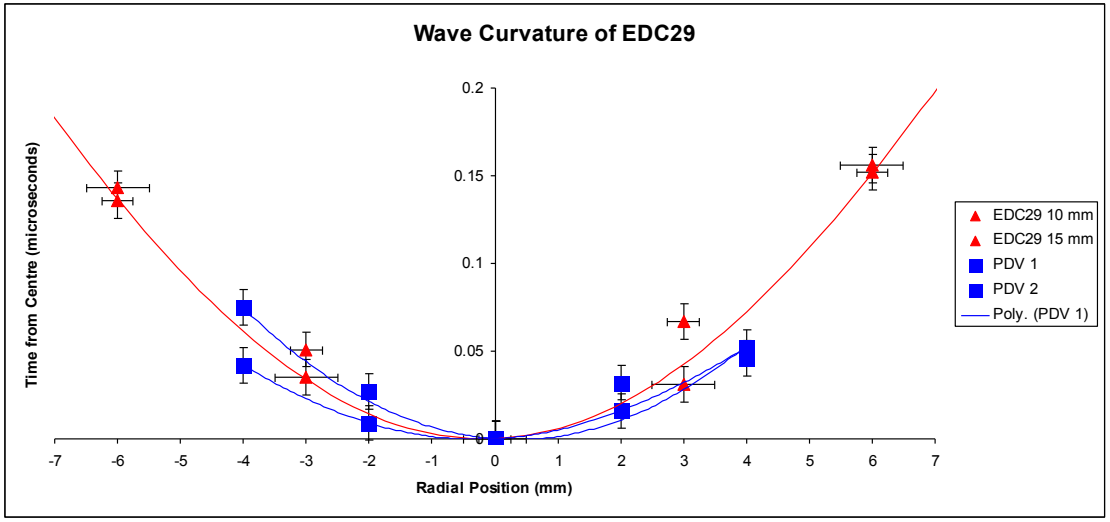


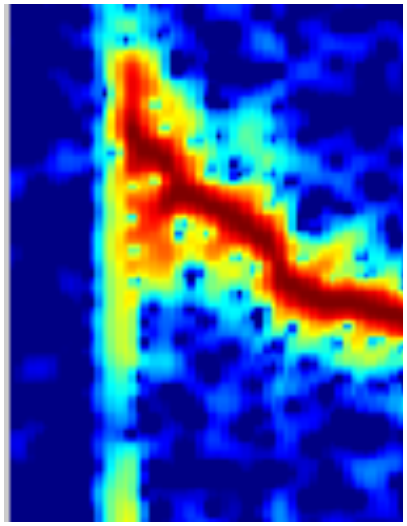
**All signals analysed using identical FFT parameters*

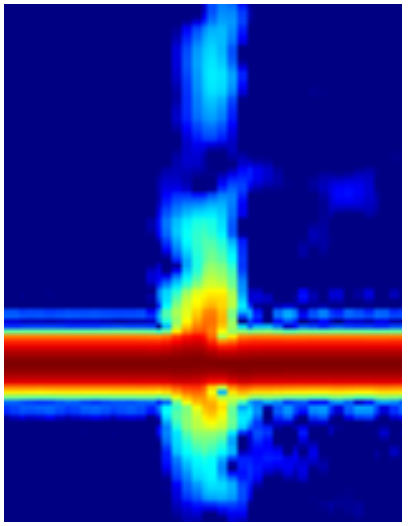
Curvature Measurements

Wave Time of Arrival Data

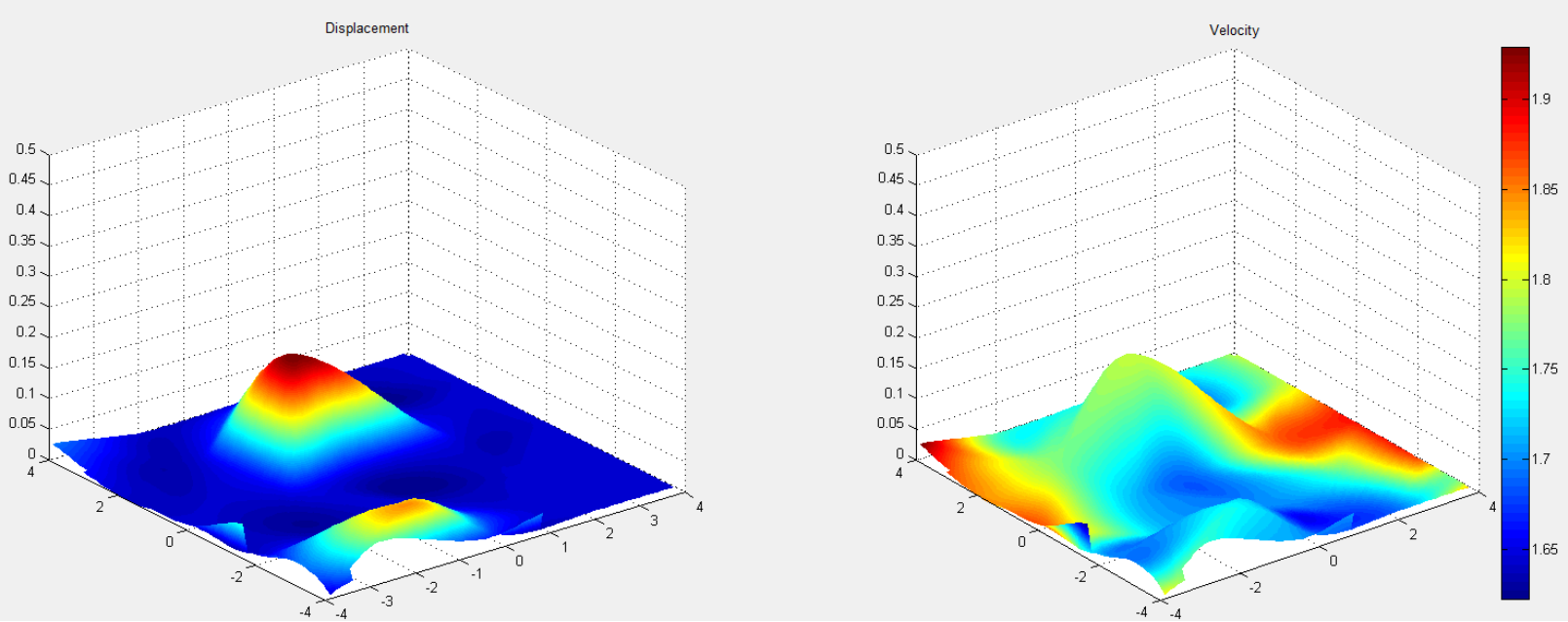
- Data shows good agreement with previous PMMA fibre data.
- Uncertainty in time due to frequency-upshifting but we need upshifting to resolve reaction zone (Von-Neuman Spike)
  - Perhaps a mixture of shifted and non-shifted channels in probe array?
  - Digital Down Conversion techniques may help improve V-t jump-off resolution?
- Frequency shift was not optimised for either measurement in these experiments as we got poor reaction zone and jump-off resolution.







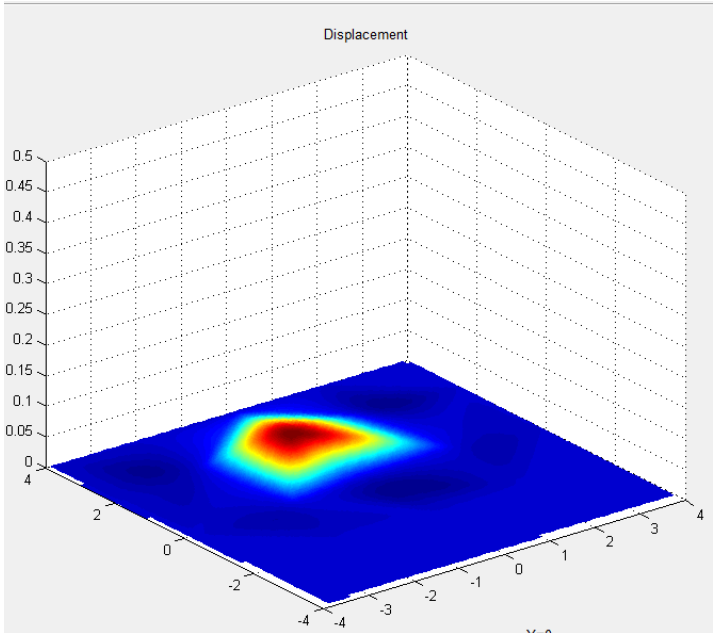
Surface Motion Tracking

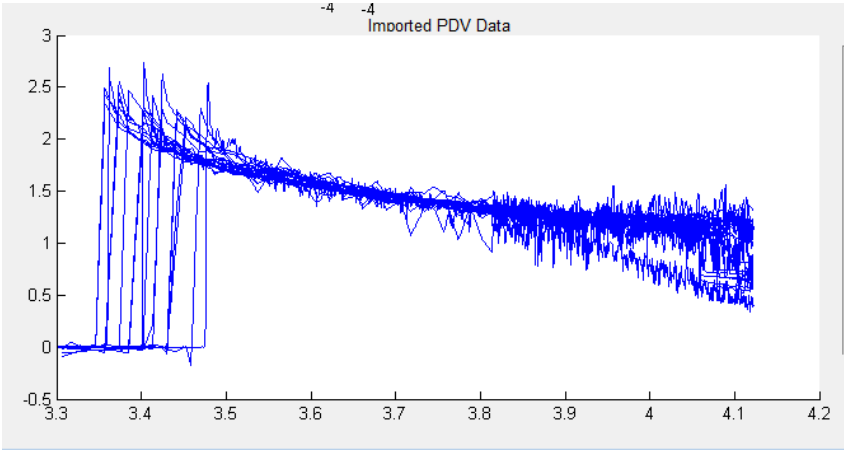


- Data imported into Matlab code:
  - Laser spot positions.
  - PDV data.
- Calculated:
  - Interpolated velocity across window surface.
  - Displacement calculated over fixed time intervals.

Discussion

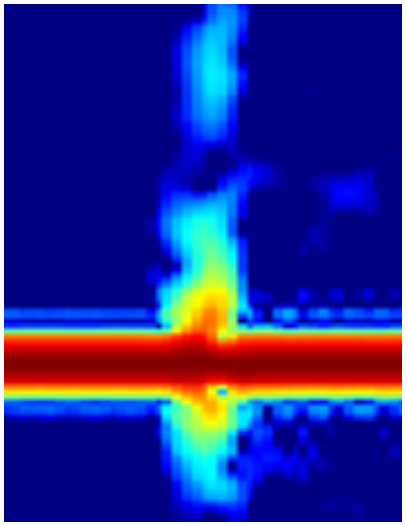
- Variations in zero-velocity noise, between channels, cause artificial movement before shock wave reaches surface.
- Strength of PDV signal very important to accurate displacement in later stage movement.
- Challenges:
  - Increase resolution of shock rise time
  - Interpolated PDV data noise reduction
  - Move towards 3D, spherically diverging geometries
  - Reduce analysis time
  - Increase consistency in analysis method with regards to FFT and breakout timing.
  - Improve PDV signal power-consistency of reflective surface. Thicker depositions or flying plates?



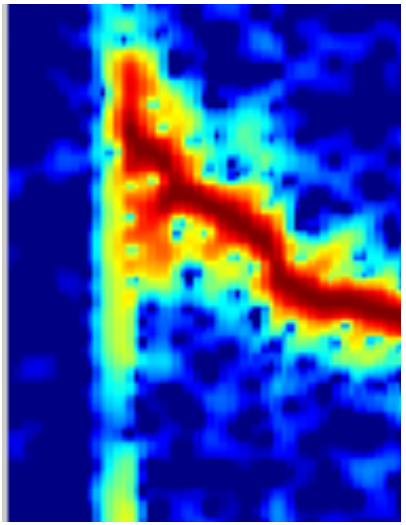


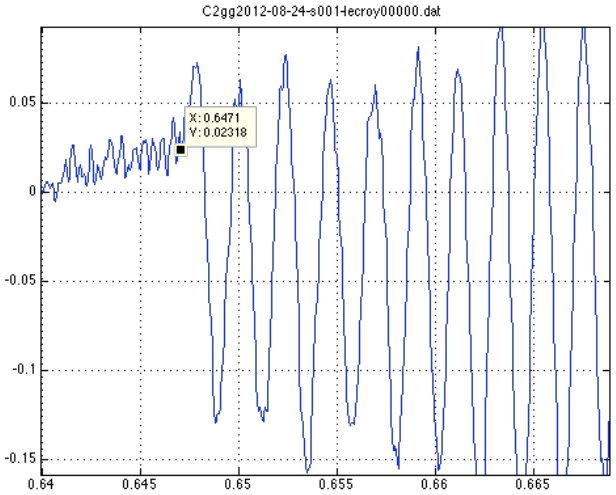
Discussion

- Difficult to determine detonation wave time of arrival due to frequency upshift.
- Difficult to resolve wave rise features due to limited beat periods during time of event.



- But, upshifting is needed to resolve the Von Neuman spike and therefore the Chapman-Jouguet Position.
- Perhaps a mixture of shifted and non-shifted channels in probe array?
- Frequency shift was not optimised for either measurement.





Conclusions

- PDV has good potential to accurately measure wave front curvature.
- Currently limited by:
  - Resolution of detonation wave time-of-arrival
  - Late-time signal power of PDV data
  - These could both be improved with better analysis methods

- Possible Solutions to measuring wave time-of arrival:
  - Variety of frequency upshifted and non-upshifted PDV channels in array
  - Techniques to analyse velocity jump off such as digital down conversion

Questions?