The PDV Technique
(photonic Doppler velocimetry)

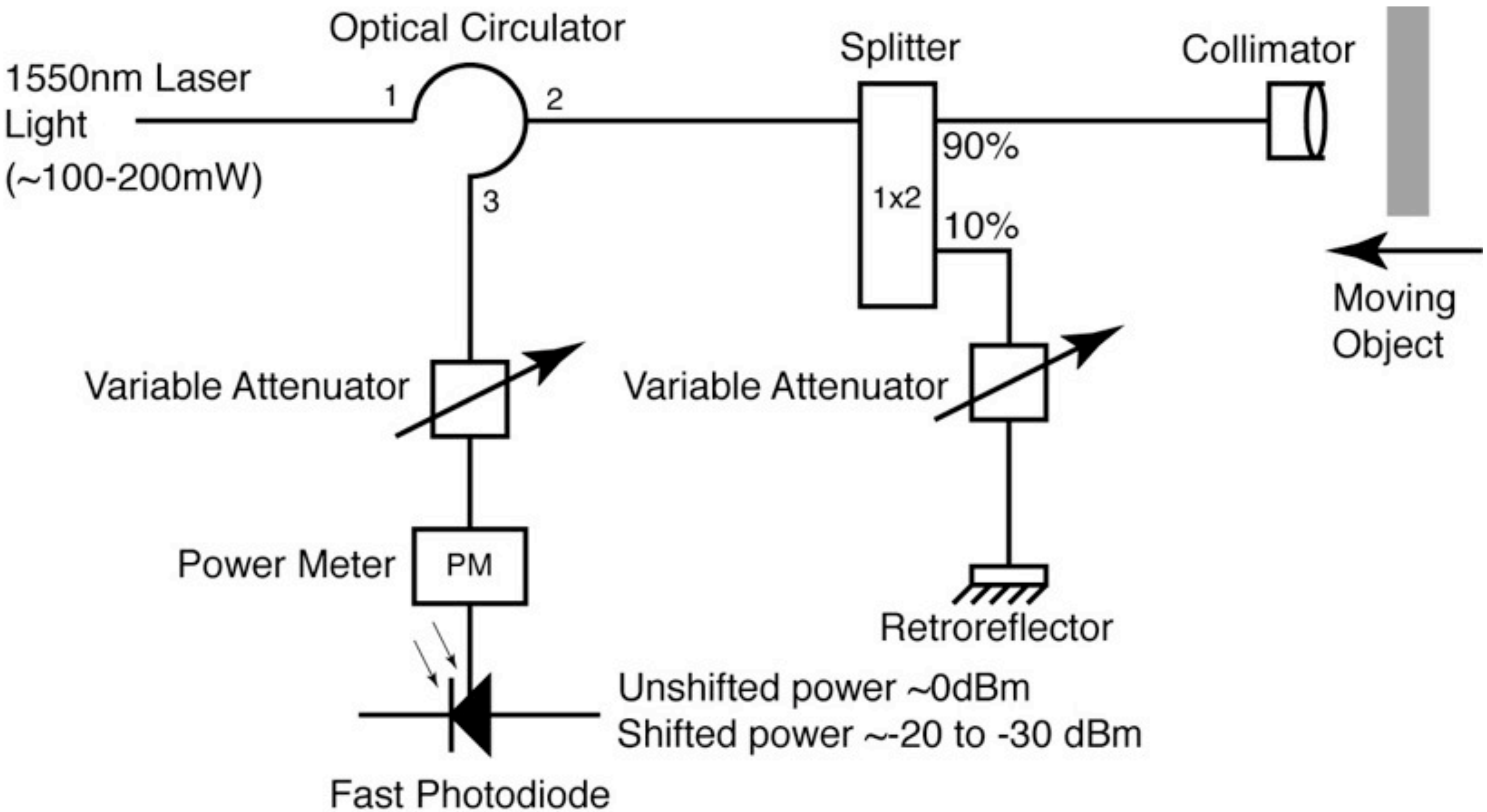
Philip Rae, Carl Trujillo, David Holtkamp and Rick Gustavsen

LANL

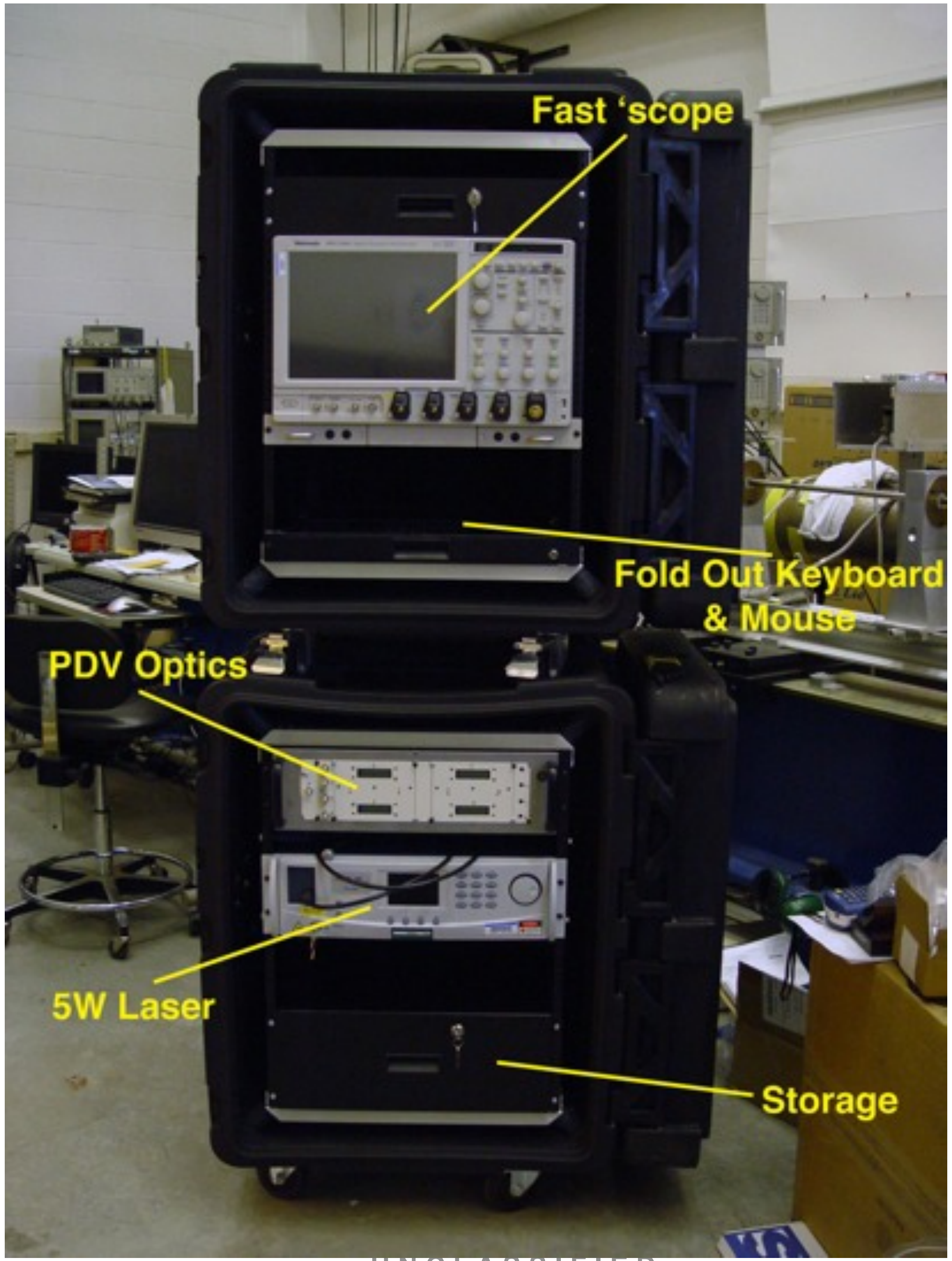
Analysis package (yes another one)

- sFFT analysis in IGOR
- Fixed Bruce Marshall's .wfm loader to use the latest 'scopes
- Also has Wigner transform
- Still somewhat in the development but will be released under a GNU general public license to anyone who wants it.

Typical PDV implementation



My PDV system



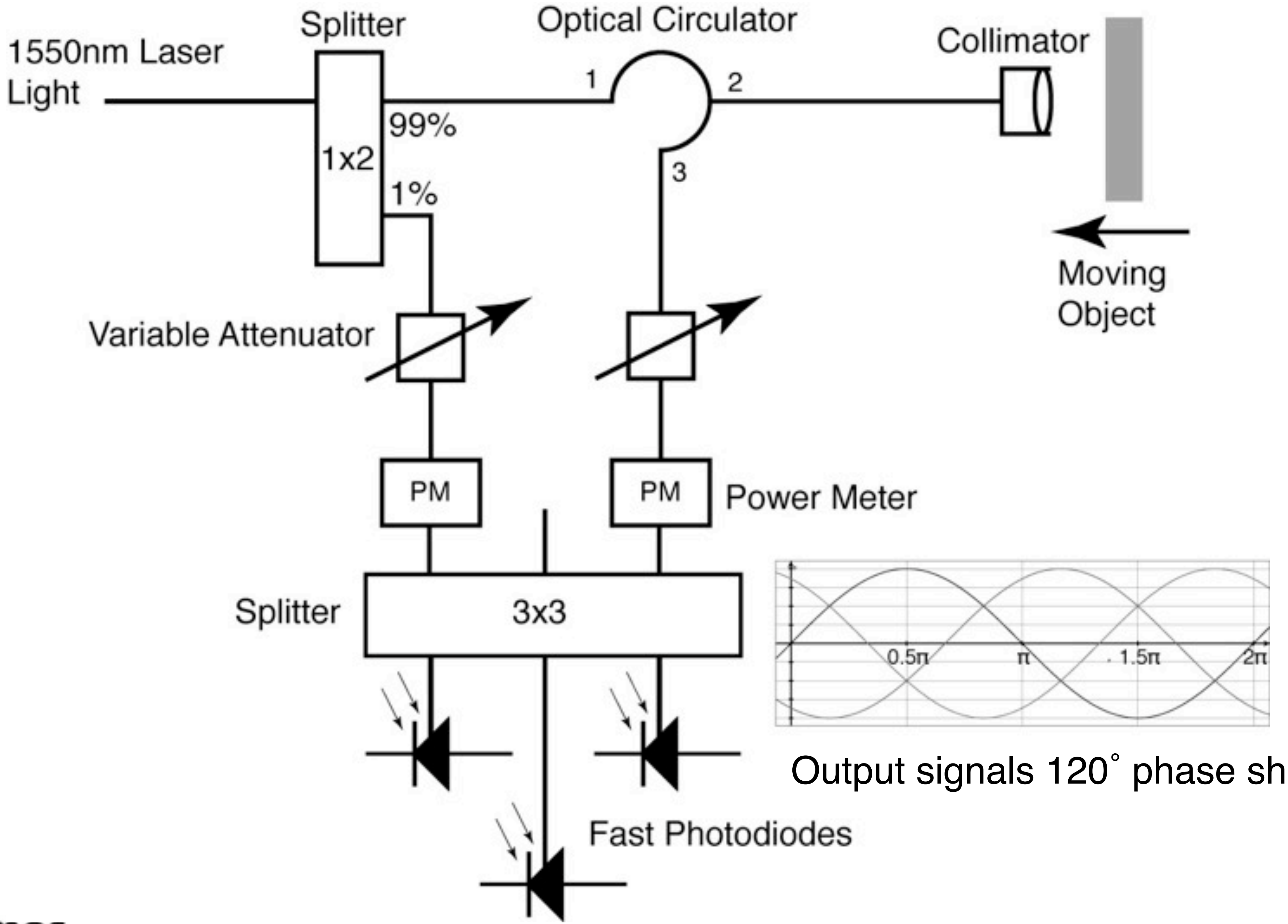
Lasers

- I bought a 5W IPG laser
- Can now order them with a built in 4 way splitter and four FC/APC output connectors. Definitely the way to go.
- Q photonics sell a 40mW 1550nm diode with 1MHz line width. The controller and the diode <$3500. Works well.

Window corrections

- My ‘day job’ is studying polymers
- I would like to measure the window correction parameters for PMMA and PC at 1550nm.
- I will see what we can do......

Triature PDV

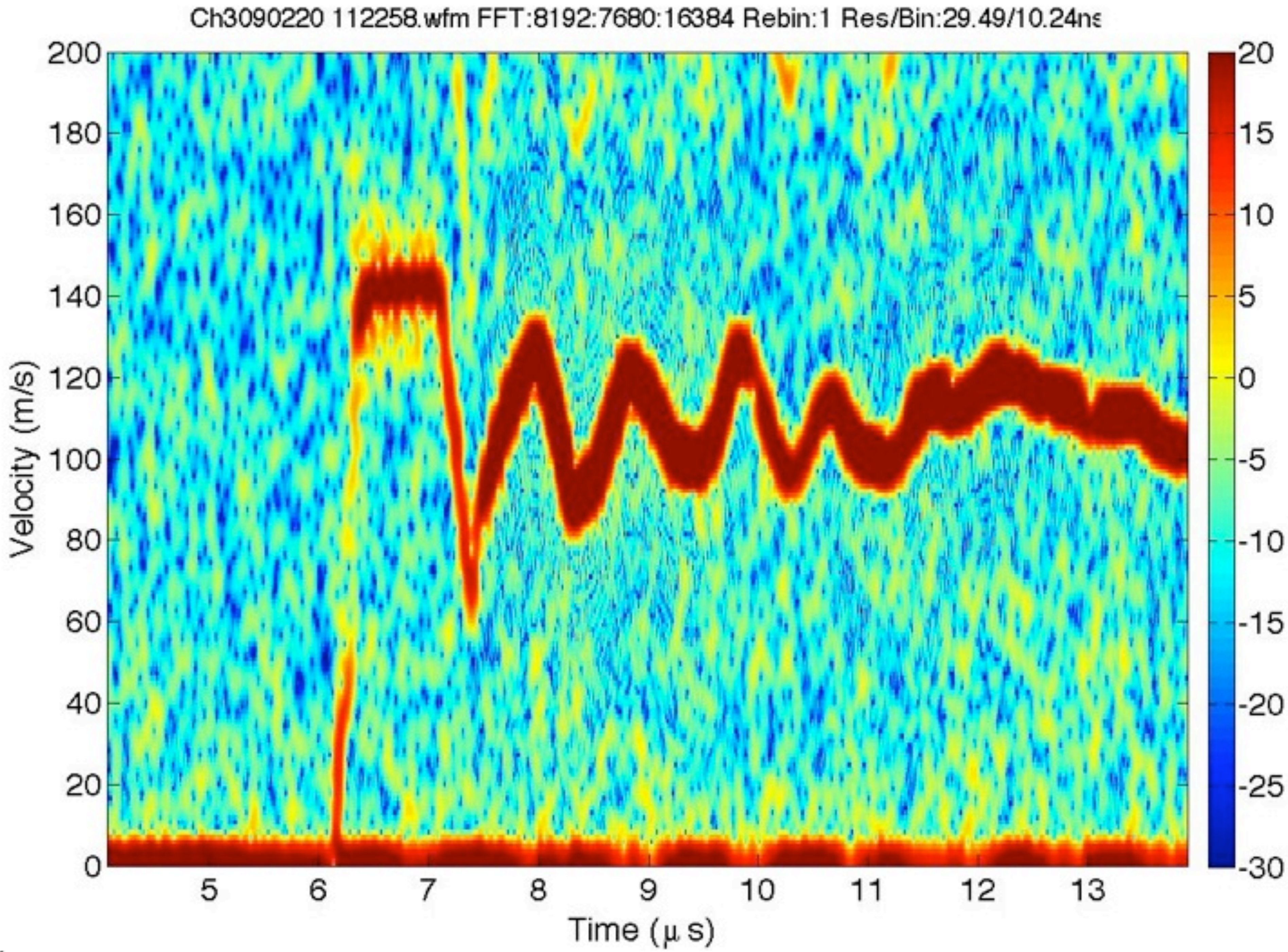


Output signals 120˚ phase shifted

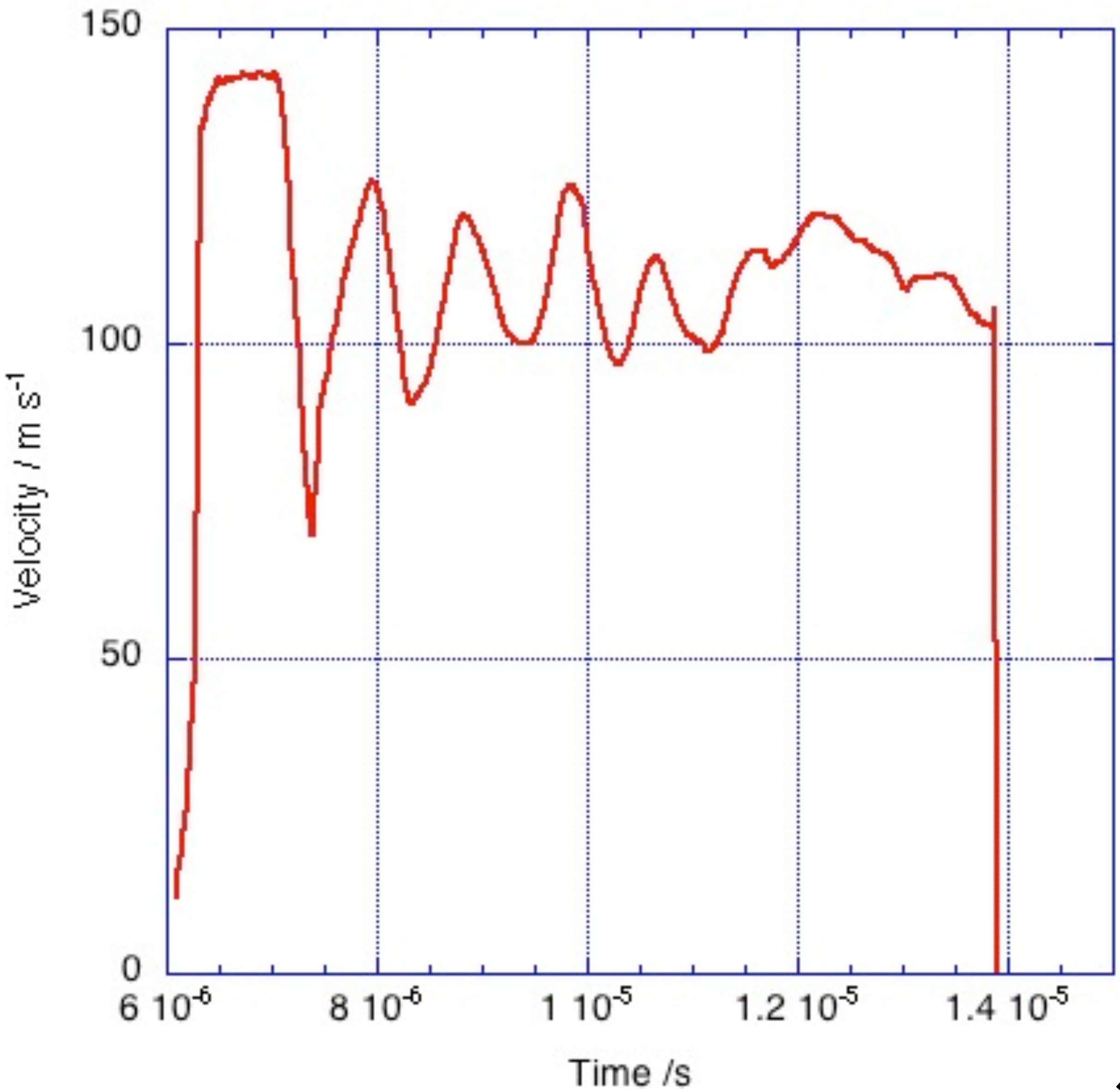
Thursday, November 5, 2009

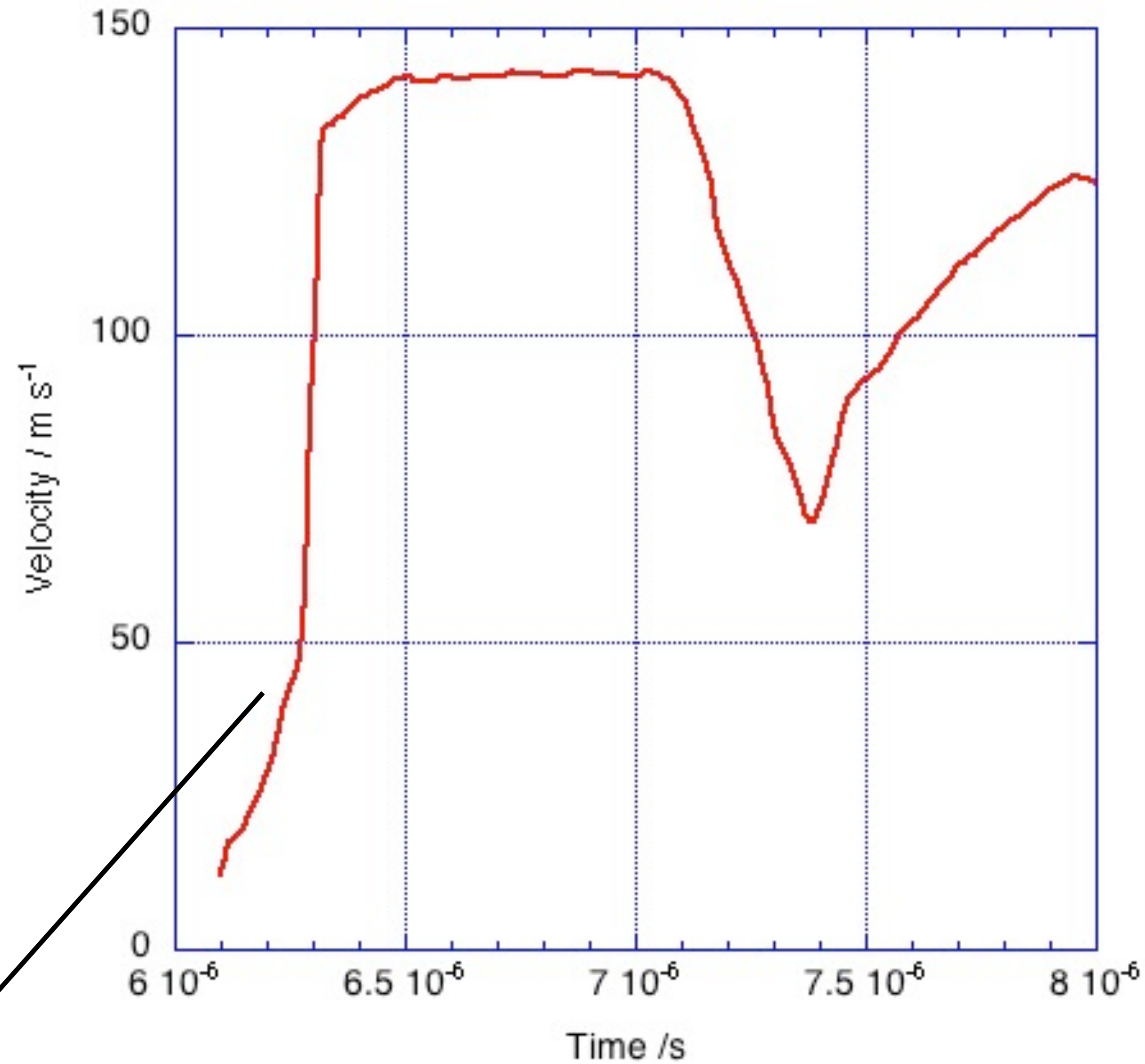
Cu incipient spall (annealed Cu, pre-shocked at 5GPa)

- **Projectile velocity 142m s^{-1}**



Reduced data, free surface velocity





HEL, 41.7 m s-1

Other analysis methods

- The FFT has excellent frequency (velocity) resolution and is quick to perform. It has poor temporal resolution owing to the windowing process.
- Another analysis method is wavelet transforms. These methods are relatively new, some of the key math advances were made in the 1980's, and unfortunately they were developed by pure mathematicians and so layman comprehension is difficult.
- VERY briefly, a wavelet transform takes a mother wave with special properties and scales it in frequency and time to form many wavelets that are fit to an input waveform.
- One of many properties of a suitable mother wave is that the wavelets can be tuned to give high temporal resolution at high frequencies (fast changing signals) but greater frequency resolution at low frequencies.

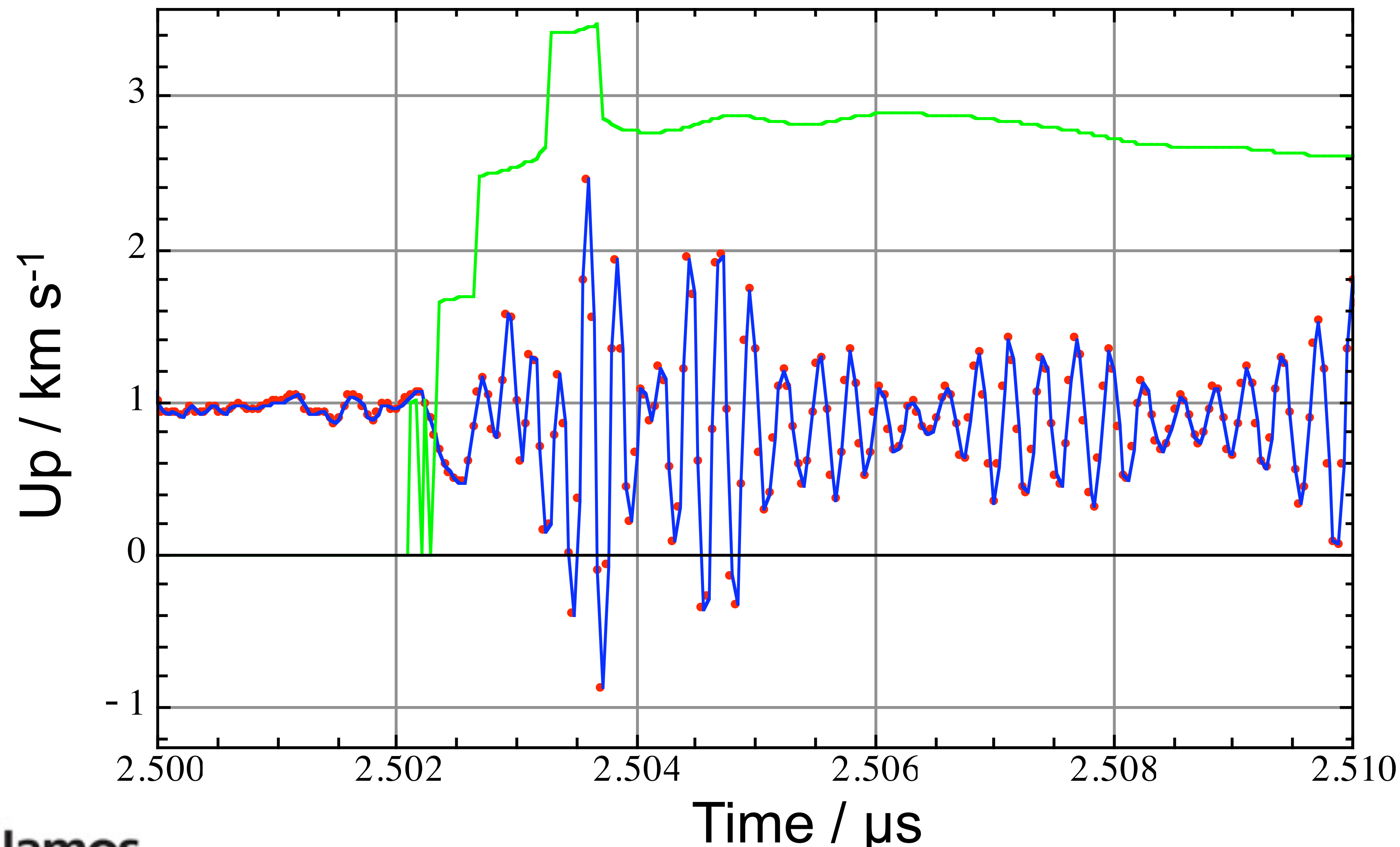
Wavelet transforms

- **By analogy to the Heisenberg uncertainty principle, it may be shown that in an arbitrary waveform there is a limit to how accurately one may know the frequency of the wave at a time instant and vice versa.**
- **At LANL we have been using a particular transform (mother wavelet) by Harrop (Robinson College, Cambridge, 2004) which he has shown will approach this theoretical limit.**
- **At LANL this PDV analysis approach has been spearheaded by Rick Gustavsen and David Holtkamp. Rick, in particular, has been trying to measure the reaction zone length in non-ideal explosives by looking at the shock breakout into window materials. The whole experiment is effectively over in 100ns.**
- **The wavelet analysis is proving useful when FFT's are all but useless at the required temporal resolution.**

Pushing the limits

HMX based explosive breakout into a LiF window

Rick used wavelet analysis to generate this



Other ideas

- The FFT method is excellent for stable velocities (i.e. Hugoniot measurements and the like).
- Shock breakout is tricky owing to very fast rise times implying high frequency components.
- Other methods under development for breakout problems:
- Hilbert transforms
- Harmonic inversion
- Wigner transform
- Some form of Kronecker delta transform (does this exist?)
- Robust Sin-wave fitting routines on short ‘windows’ of data
- ?????

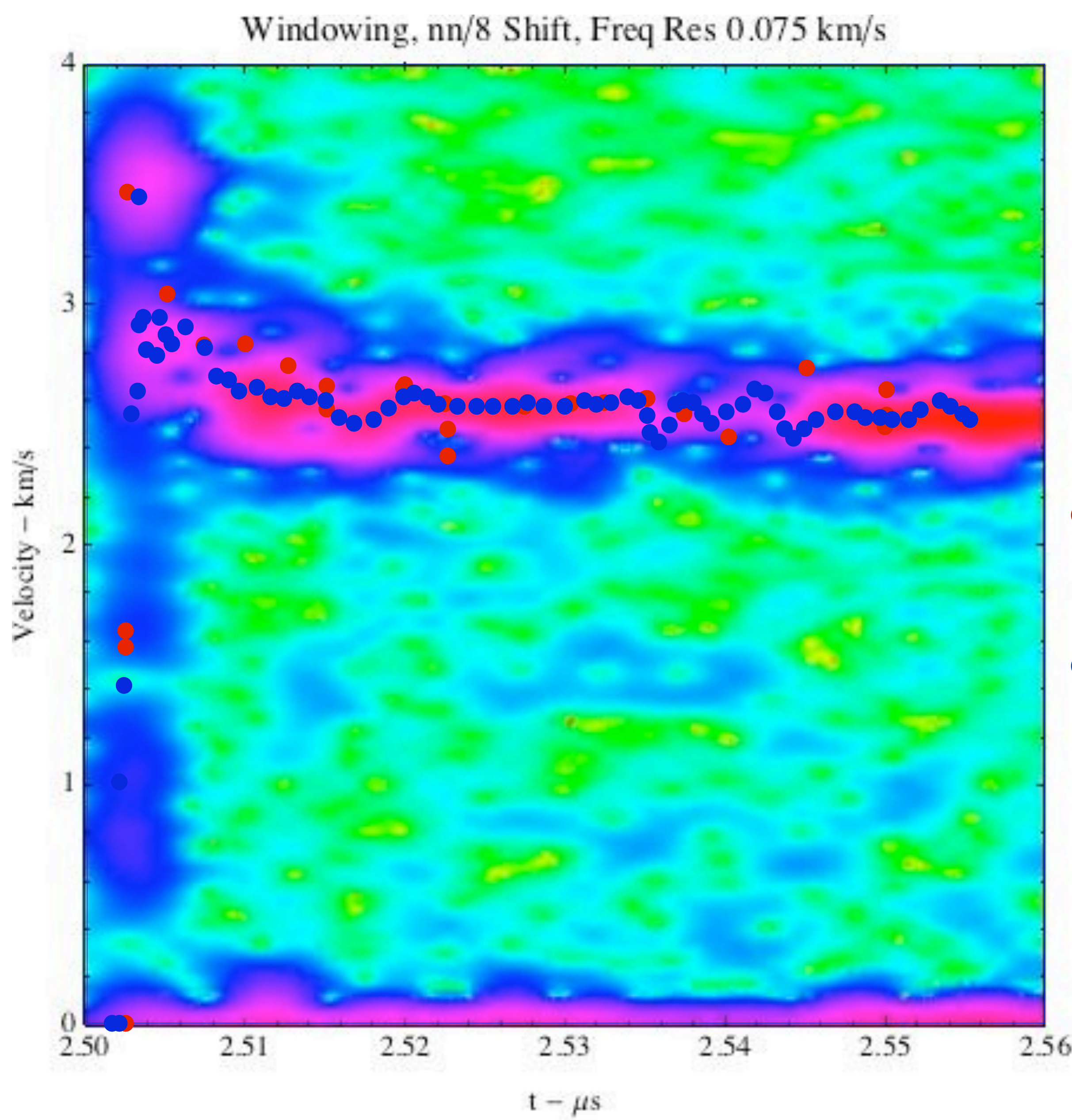
Harmonic inversion

- Uses linear inversion to solve the following expression

$$C\,(t_n) = \sum_{k=1}^{K} d_k \exp(-i t_n \omega_k),\quad n = 1, 2 \ldots, N$$

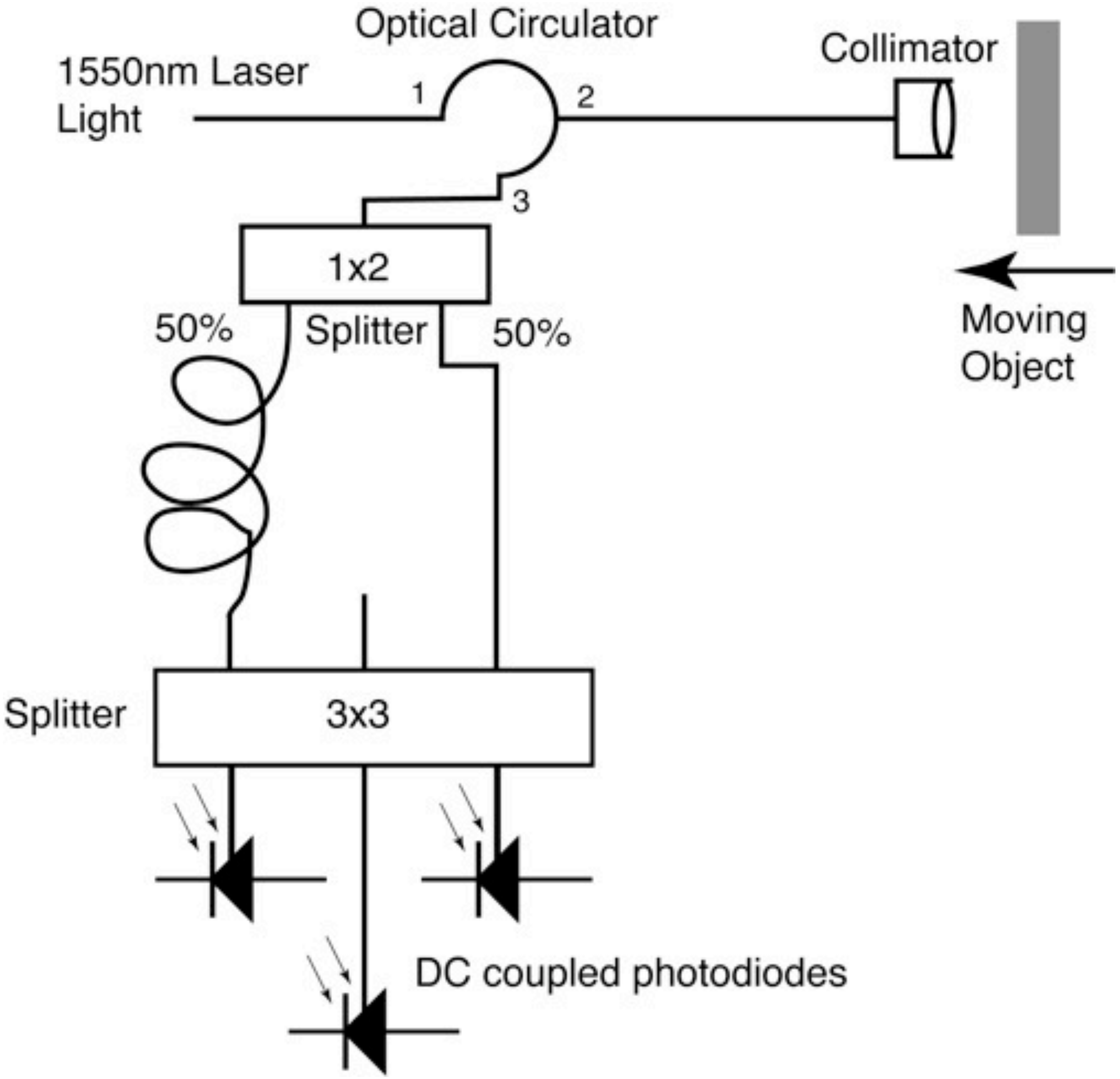
- Because the form of the waveform is assumed, the FFT uncertainty problem does not occur
- I have been playing with an implementation of this written in C, but called from within Mathematica
- I have compared a FFT, Wavelet transform and Harmonic inversion approach to Rick's data

Method comparison



- Harmonic inversion
- Wavelet transform

An all fiber 1550nm triature VISAR?



- An idea I am currently exploring.
- Previous fiber based ideas have been published but they all involve some odd complications or open beam optics at some stage.
- Simultaneous PDV and VISAR channels in one experiment?
- Genuine triature phase analysis using the Sandia THRIVE program
- A little light starved

Questions