

Analysis techniques of heterodyne data for EOS and velocity history

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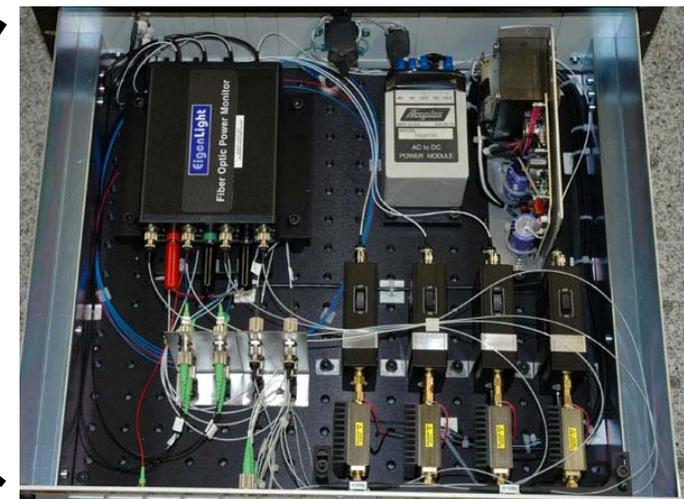
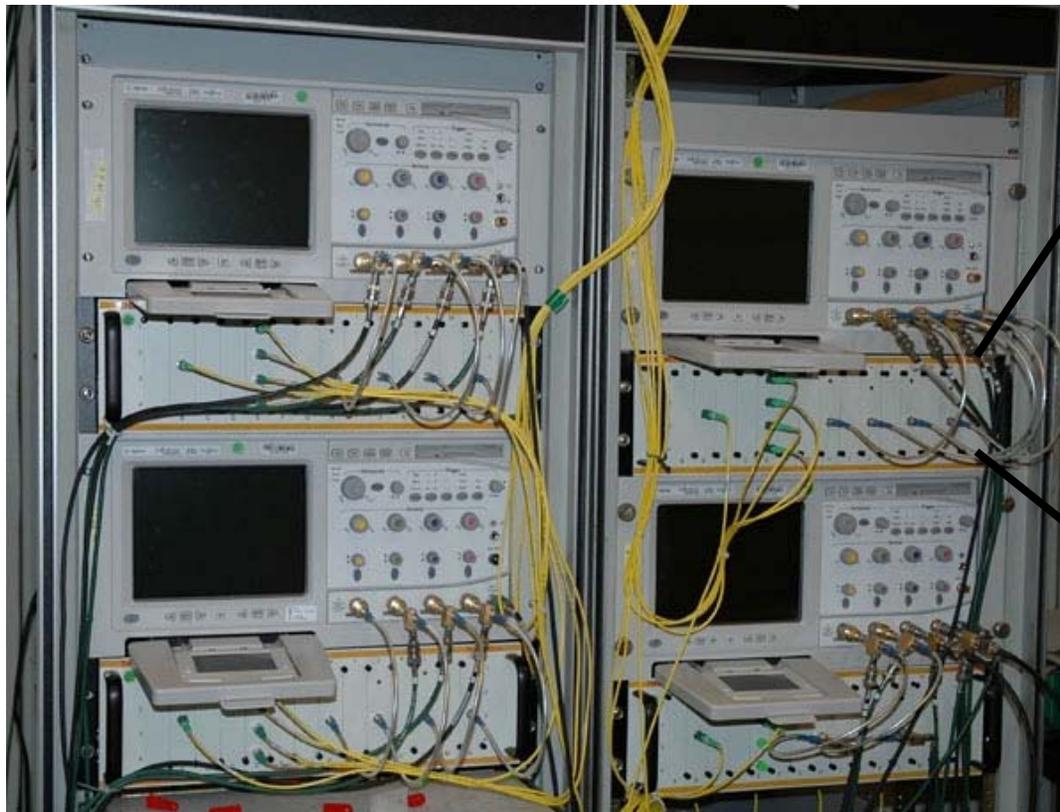
Lawrence Livermore National Laboratory

In collaborations with

**R. Chau, N.C. Holmes, W.P. Ambrose, K. Krauter, T. Strand
M. Kumar, and J. Stolken**

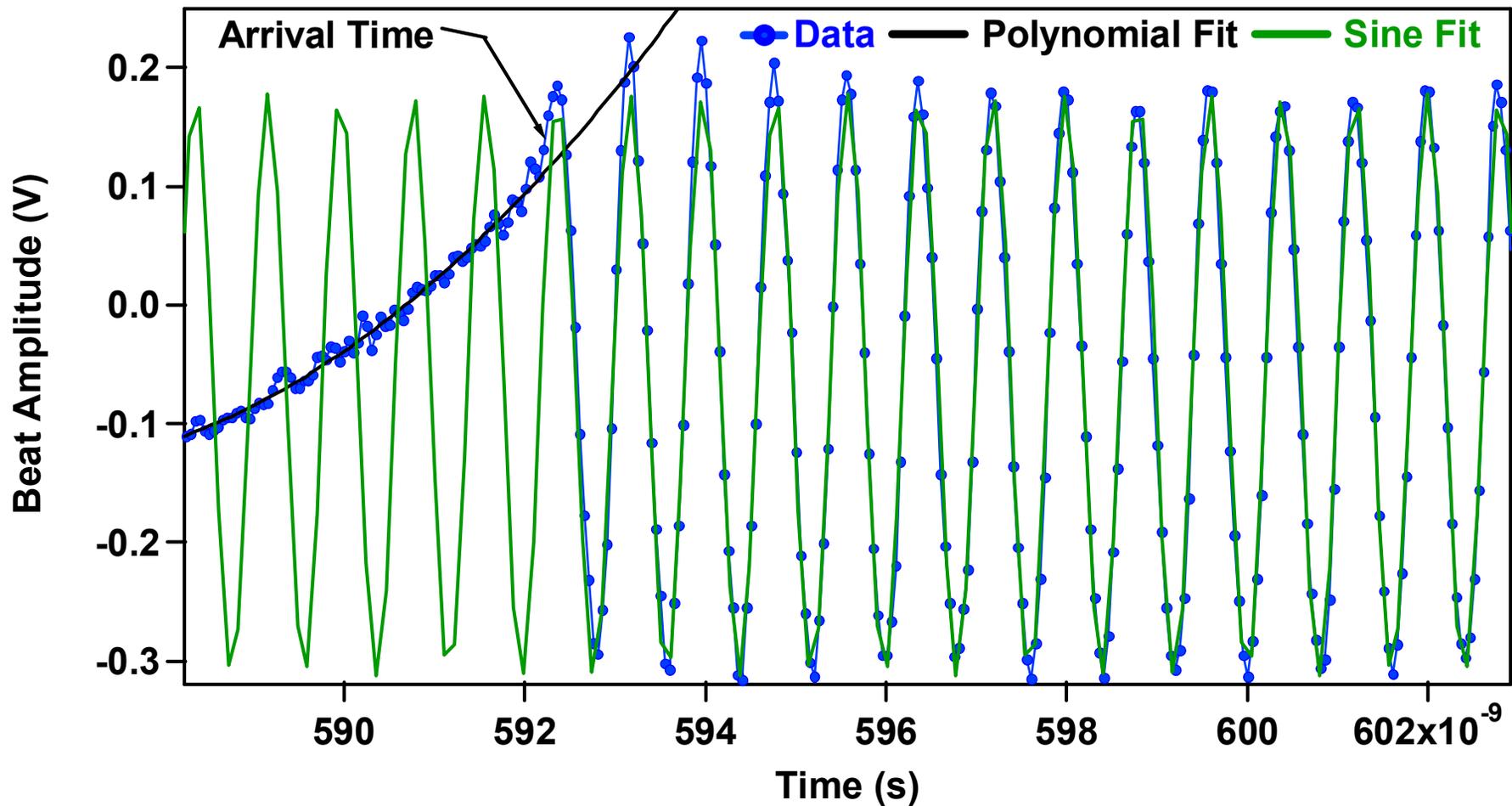
UCRL-PRES-222885

We are using a 13 channel heterodyne system



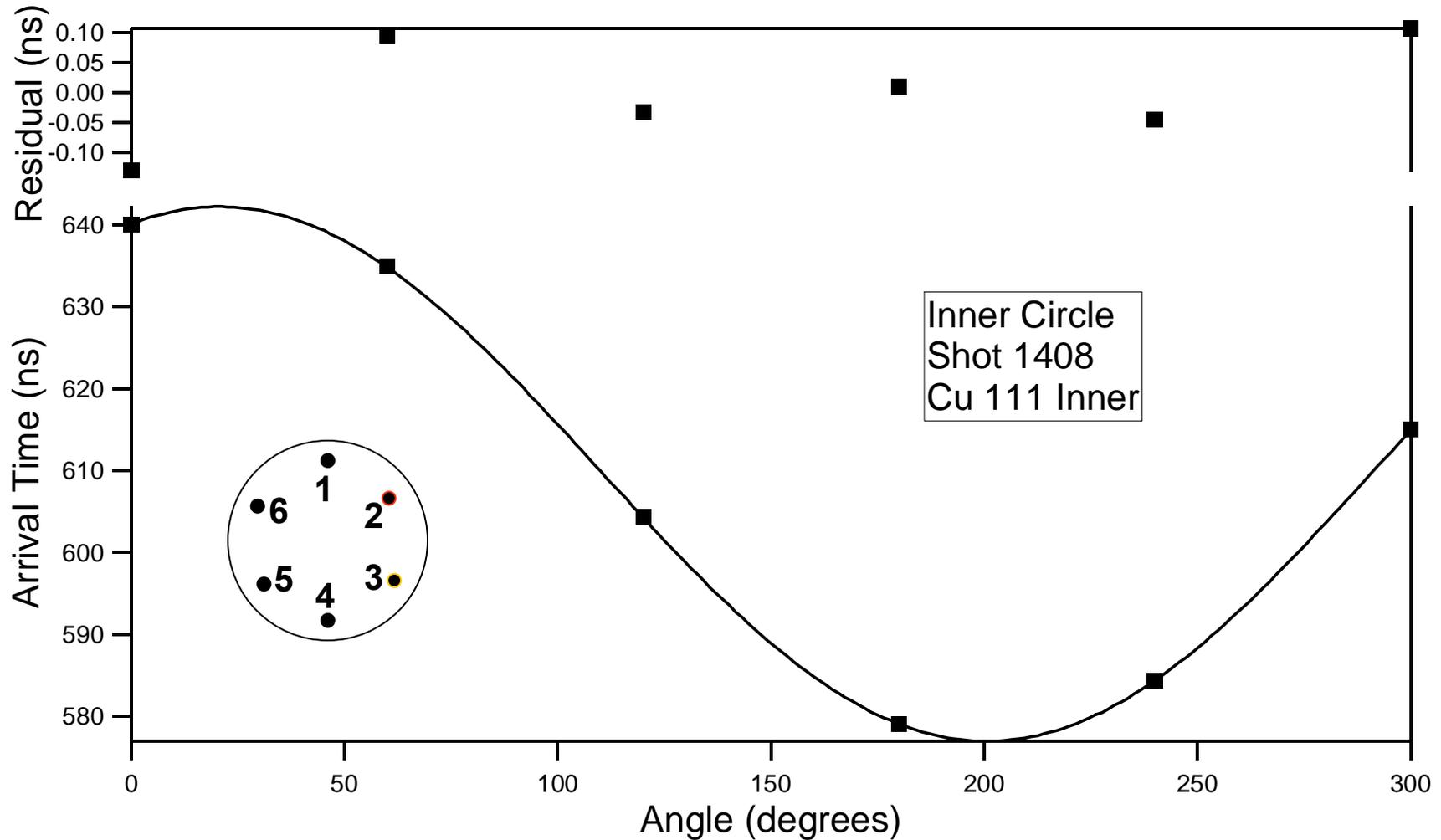
Band Widths { Scope 10 GHz
Photo Detector 6 GHz
Amplifier 8 GHz } → Velocity Limit ~ 4.3 GHz (-3dB) ~ 3.4 km/s

Shock arrival time determined with sine and polynomial fits



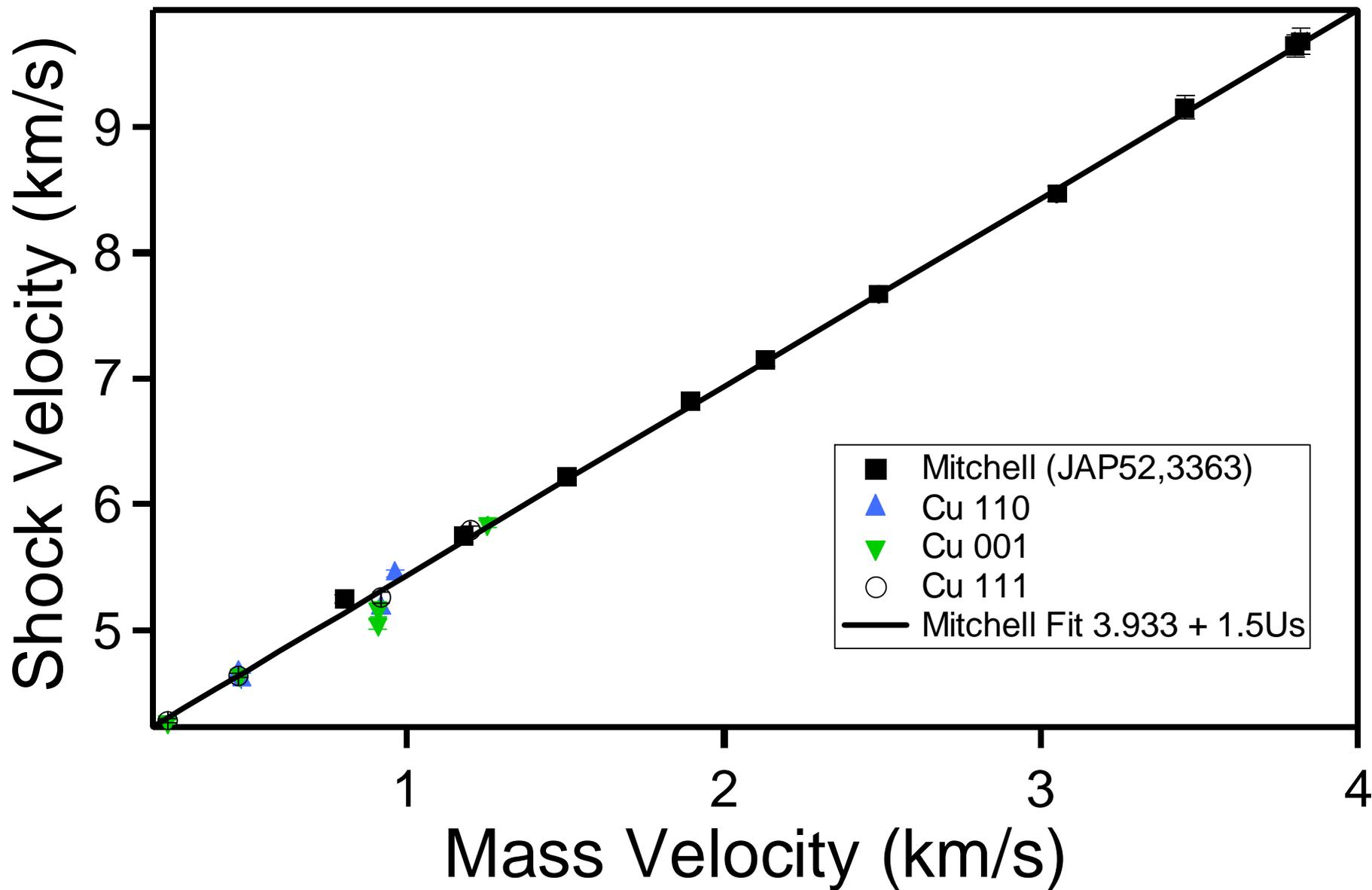
Arrival time derived from the trace to better than 200 ps

Shock arrival times around circular detector arrays follow sine behavior

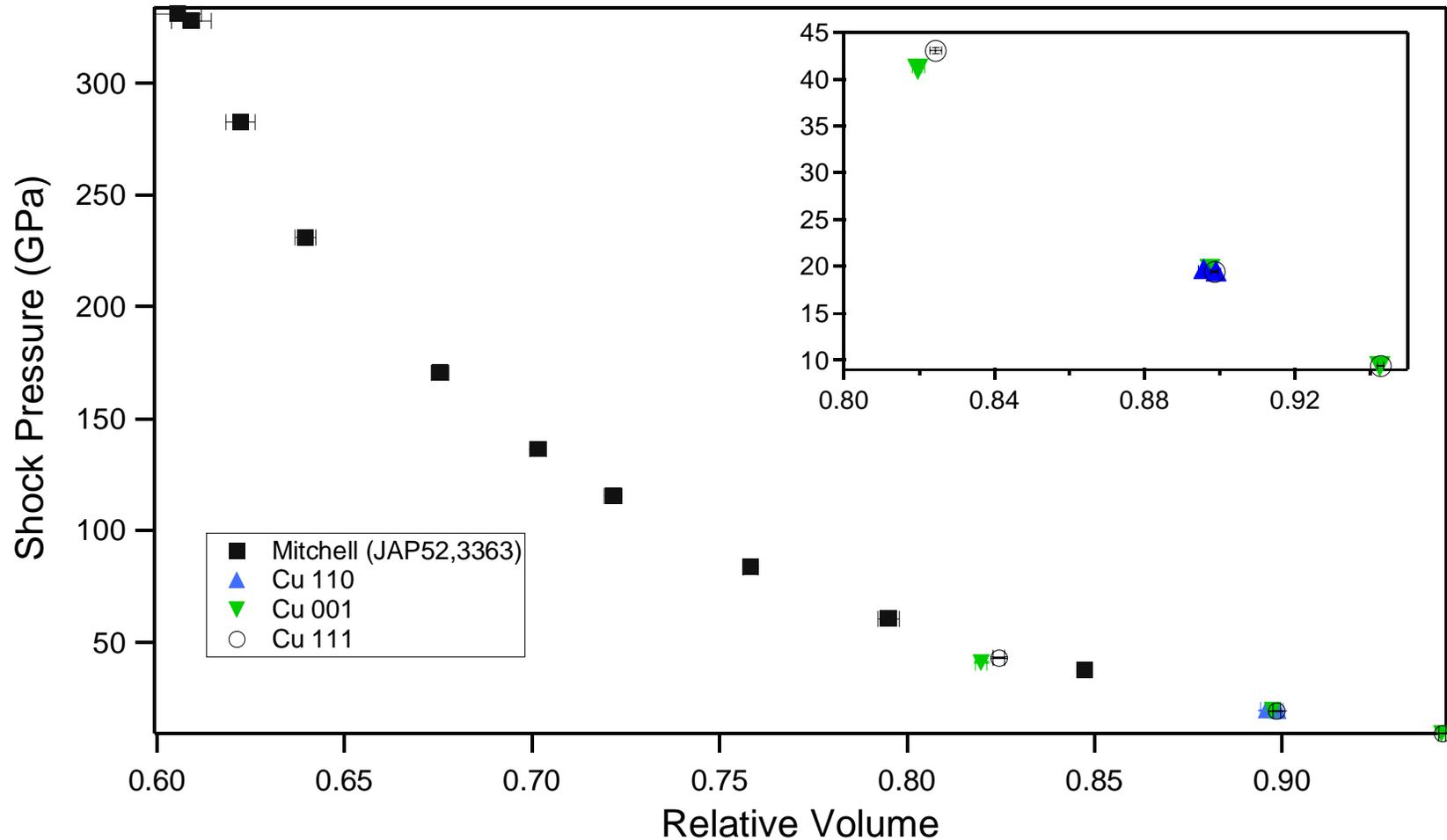


Arrival time detection similar to/better than conventional pin system

Hugoniot Data from Single Crystal Copper

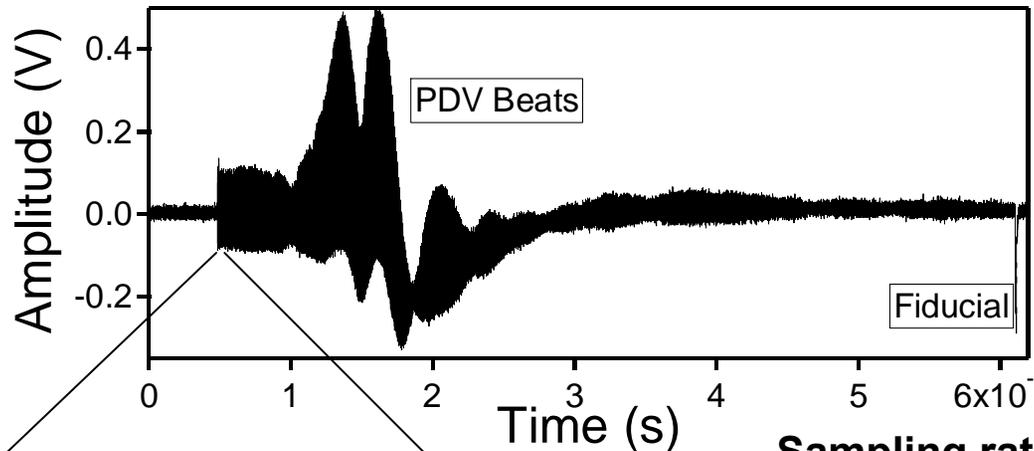


Comparison of single crystal Cu EOS data to previous OFHC Cu data

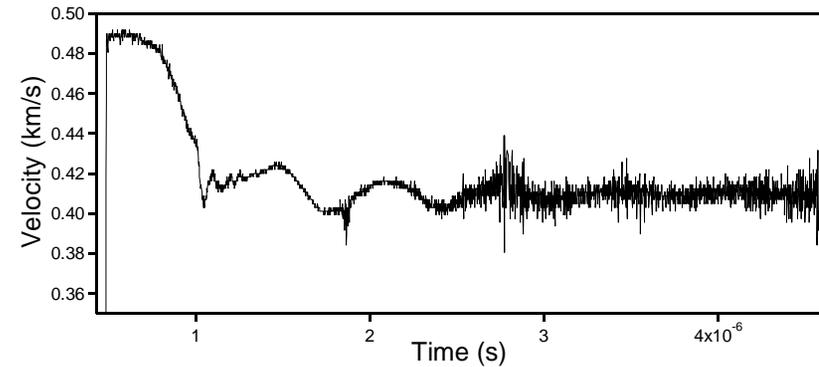
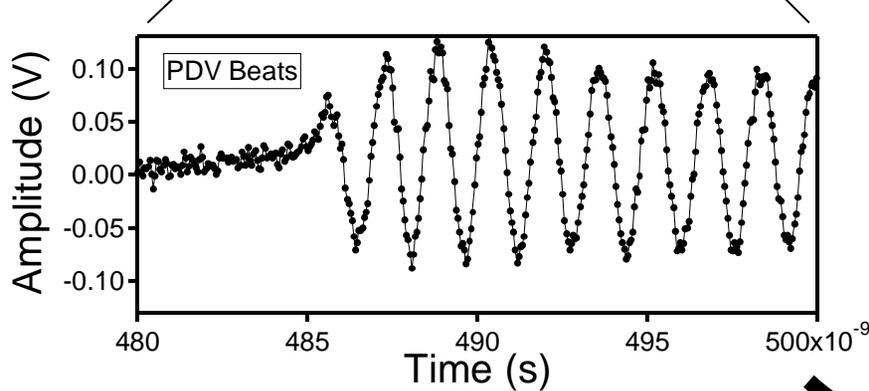


Orientation dependence is not evident in the EOS data

Beat Signal is analyzed to get velocity as a function of time



Sampling rate: 20GS/s → 50 ps/point

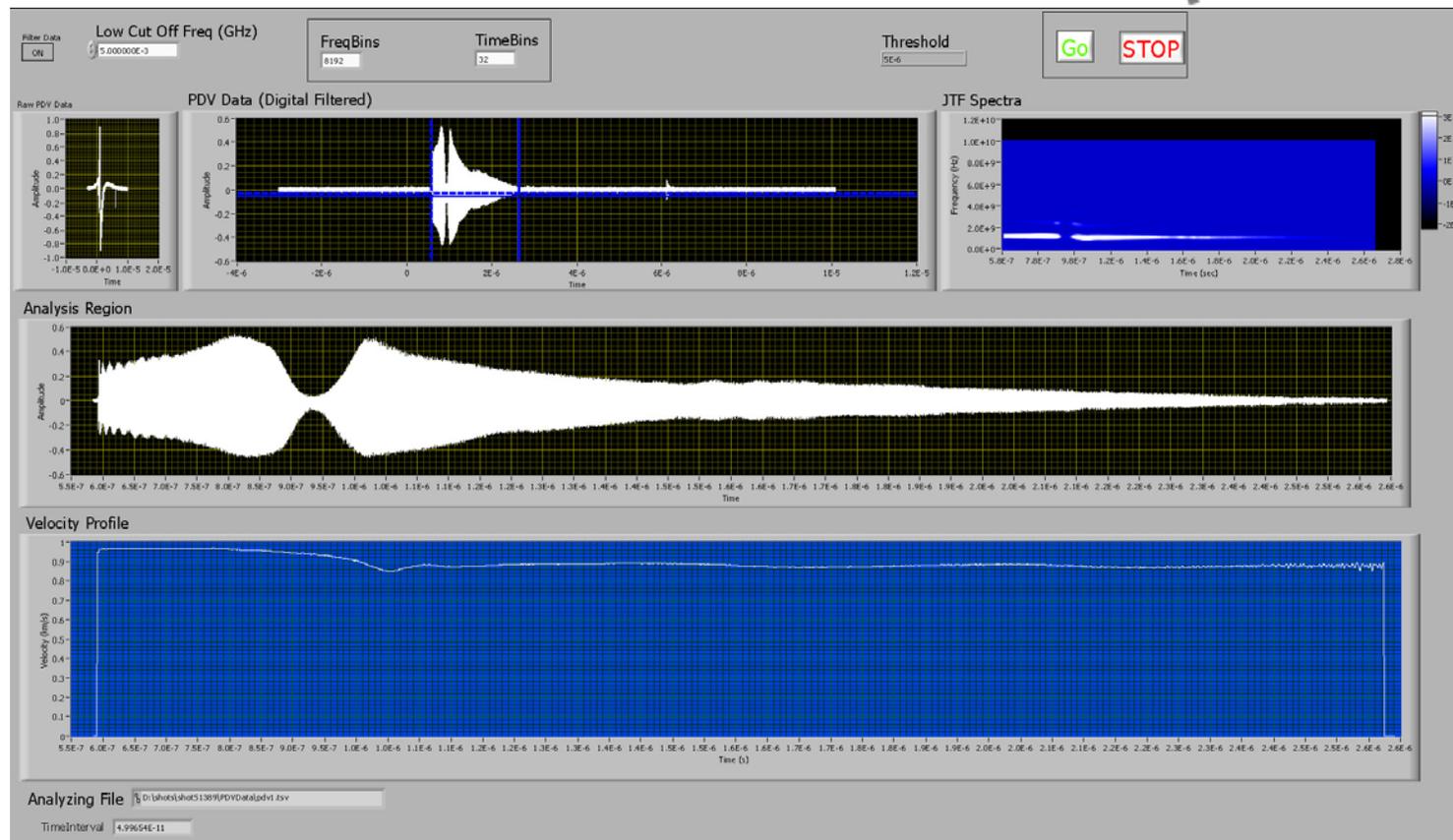


Joint Time-Frequency Analysis

We have developed multiple data reduction tools to analyze data

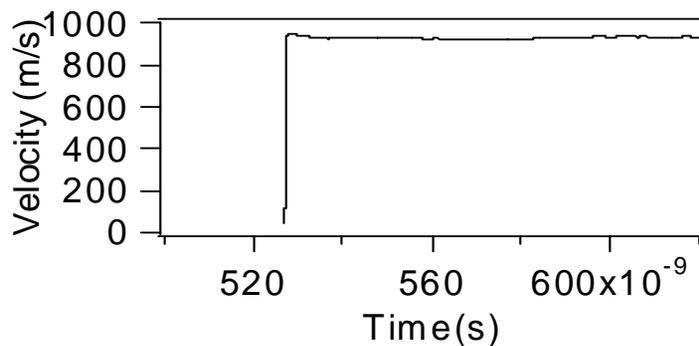
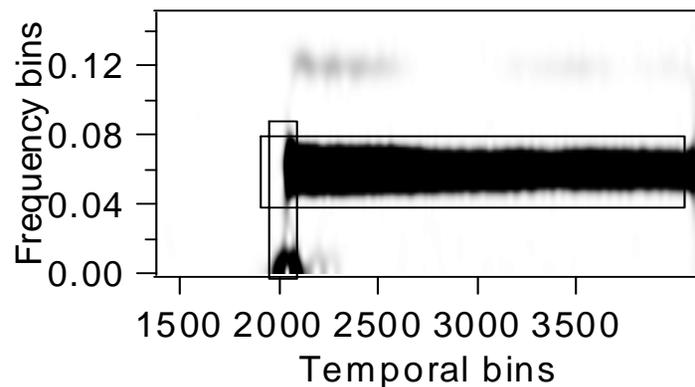
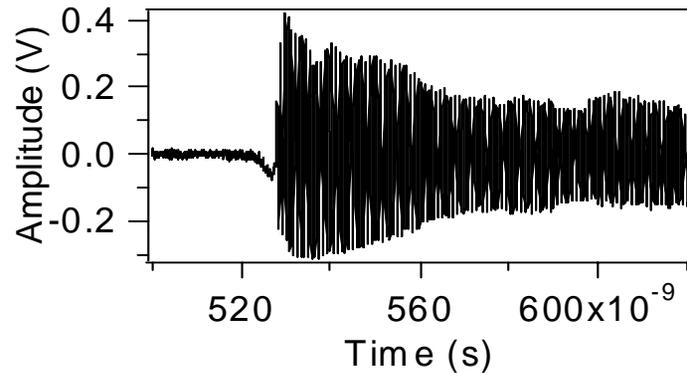


Beat signals that are evolving in time requires frequency analysis that is local in time



Joint time-frequency analysis derives velocity-time history using Gabor Transform or Short Time Fourier Transform

Time history can also be derived using Wigner transform



Wigner Transform maps a time signal $U(t)$ into a 2D time-frequency representation (Fourier transform of the autocorrelation function).

$$W(t, \nu) = \int_{-\infty}^{\infty} U\left(t + \frac{x'}{2}\right) U^*\left(t - \frac{x'}{2}\right) e^{-2\pi i x' \nu} dx'$$

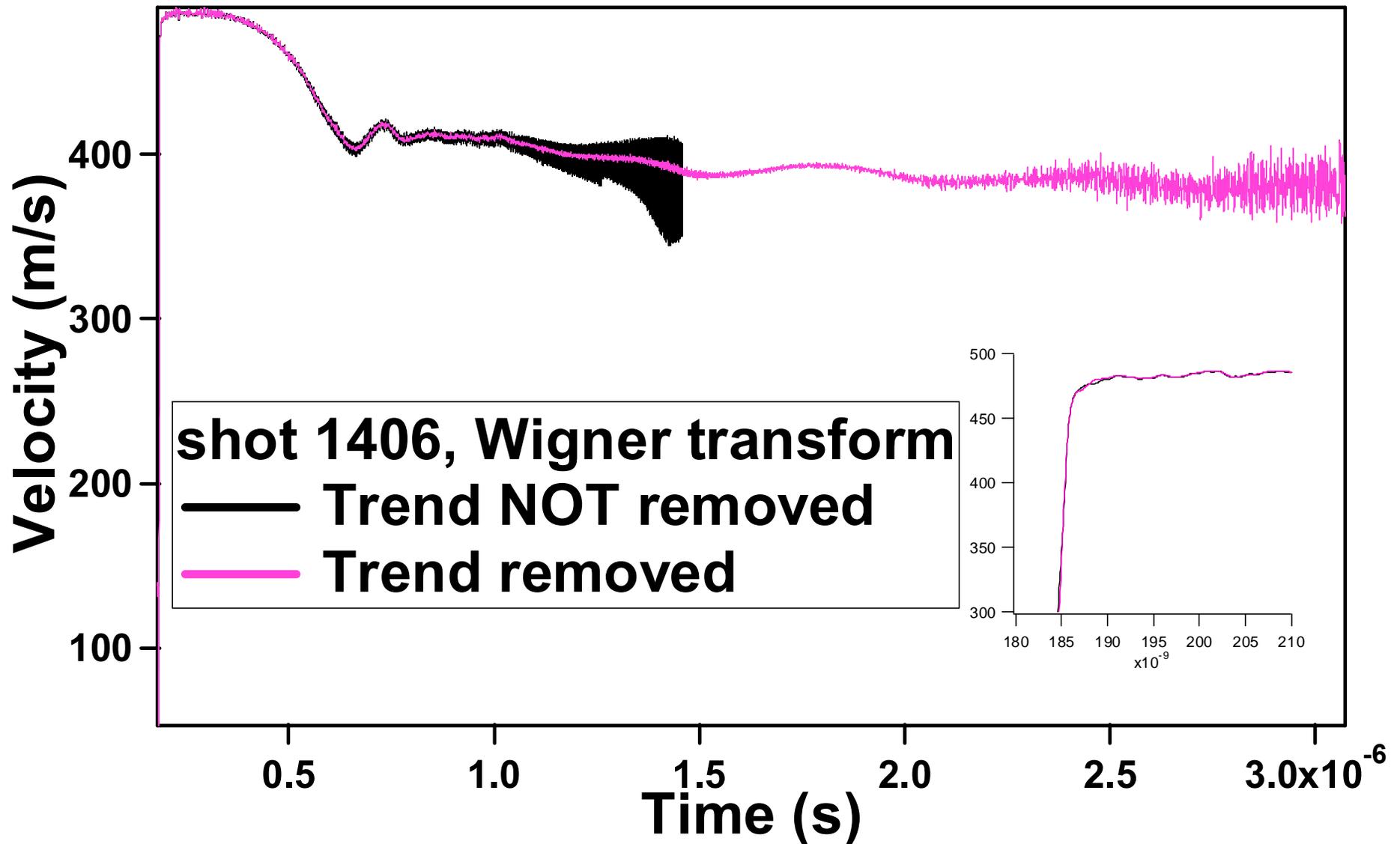
IGOR based Analysis tool for shock arrival time and velocity history



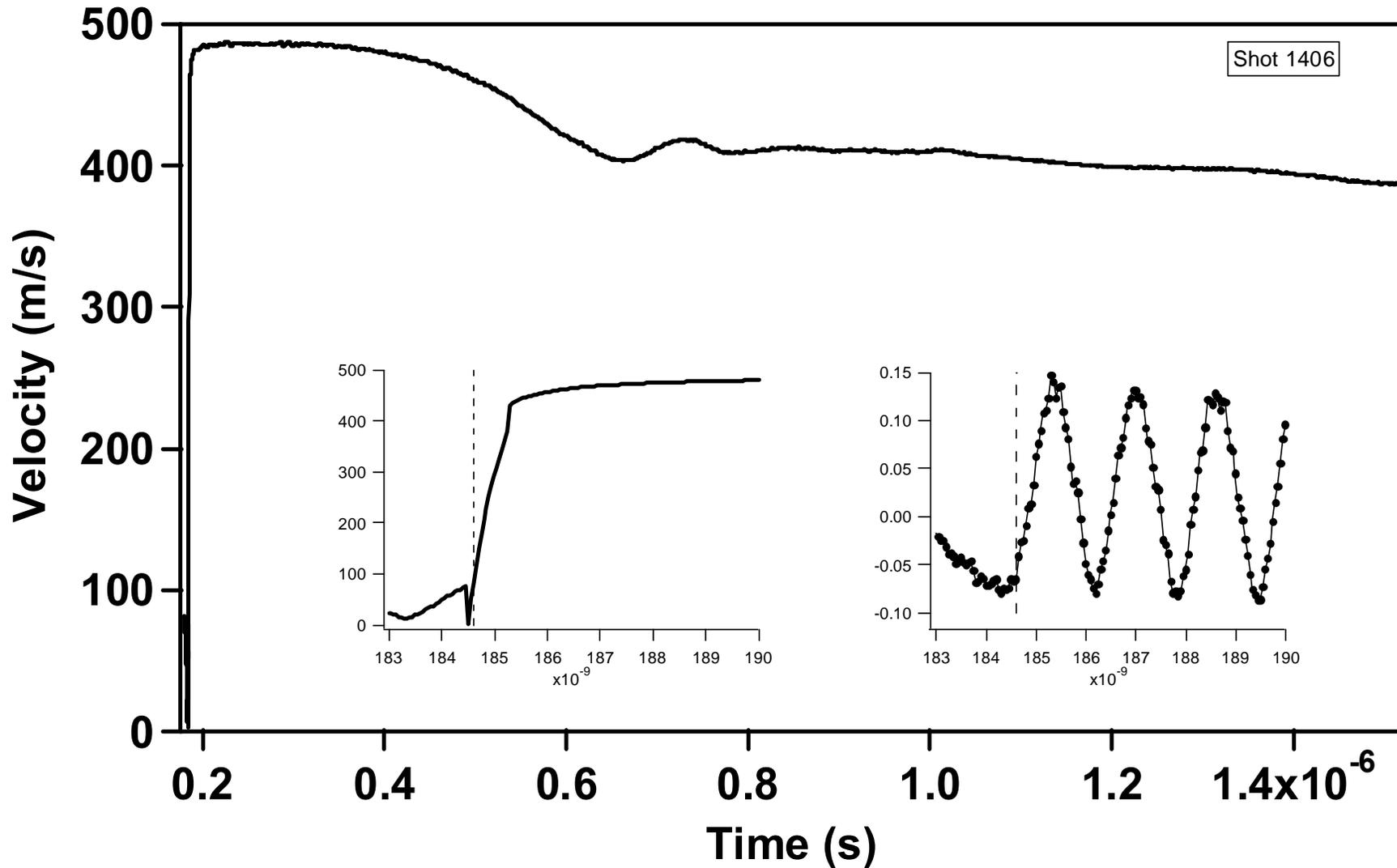
The screenshot displays the Igor Pro 5.04B software interface with several windows open:

- ExtractVelocity - Igor Pro 5.04B**: The main application window with a menu bar (File, Edit, Data, Analysis, Macros, Windows, Graph, Misc, Help, PDVAnalysis).
- grpdvTrace:PDV1 vs PDV0**: A plot showing a signal with a sharp peak and a subsequent dip. A cursor is placed at the beginning of the analysis window. A text box instructs: "Place Cursor A at the beginning of the analysis window. Select Extract Velocity from top Menu".
- Graph0:pdvCut vs tCut**: A plot showing a signal with a sharp peak and a subsequent dip. The x-axis is labeled $\times 10^{-6}$.
- Graph1:pdvWigner**: A Wigner transform plot showing a signal with a sharp peak and a subsequent dip. A text box instructs: "Pick Region of Interest (ROI) using rectangle tool. Multiple overlapping ROIs can be selected. Click Finish ROI when finished".
- Extract Velocity Time History**: A control panel for the analysis tool. It includes fields for "Start Analysis From (s)" (5.18157e-07), "Next Window Starts at Point # (74598)", and "Scope Sampling Rate (GS/s)" (20). Buttons include "Remove Trend", "Reset to Original", "Analyze Next Window", "Start ROI Draw", "Finish ROI", "Erase ROI", "Done", "Change Image Color Scale", "Zoom Out", "Zoom In", "Change Image Y-axis Scale", "Up", and "Down". A text box says "Select Analyze Next Window to Start".
- Notebook0:ExtractVelocityHelpNotes.ifn**: A notebook window containing the title "PDV Velocity History and Shock Arrival Time Analysis" and the author's information: "Author: Palakkal Asoka-Kumar, H-Division, Physics & Advanced Technologies, Lawrence Livermore National Lab, (925) 422 9671, asoka@llnl.gov". It also includes a revision history starting from 4/26/06.
- Graph2:Velocity vs pdvTime**: A plot showing Velocity (m/s) vs Time (s). The x-axis is labeled $\times 10^{-9}$. A text box says "Velocity History Saved in File: PDV1VelocityHistory.dat".
- About Igor Pro**: A dialog box showing the software version (5.04.8) and contact information for WaveMetrics, Inc.

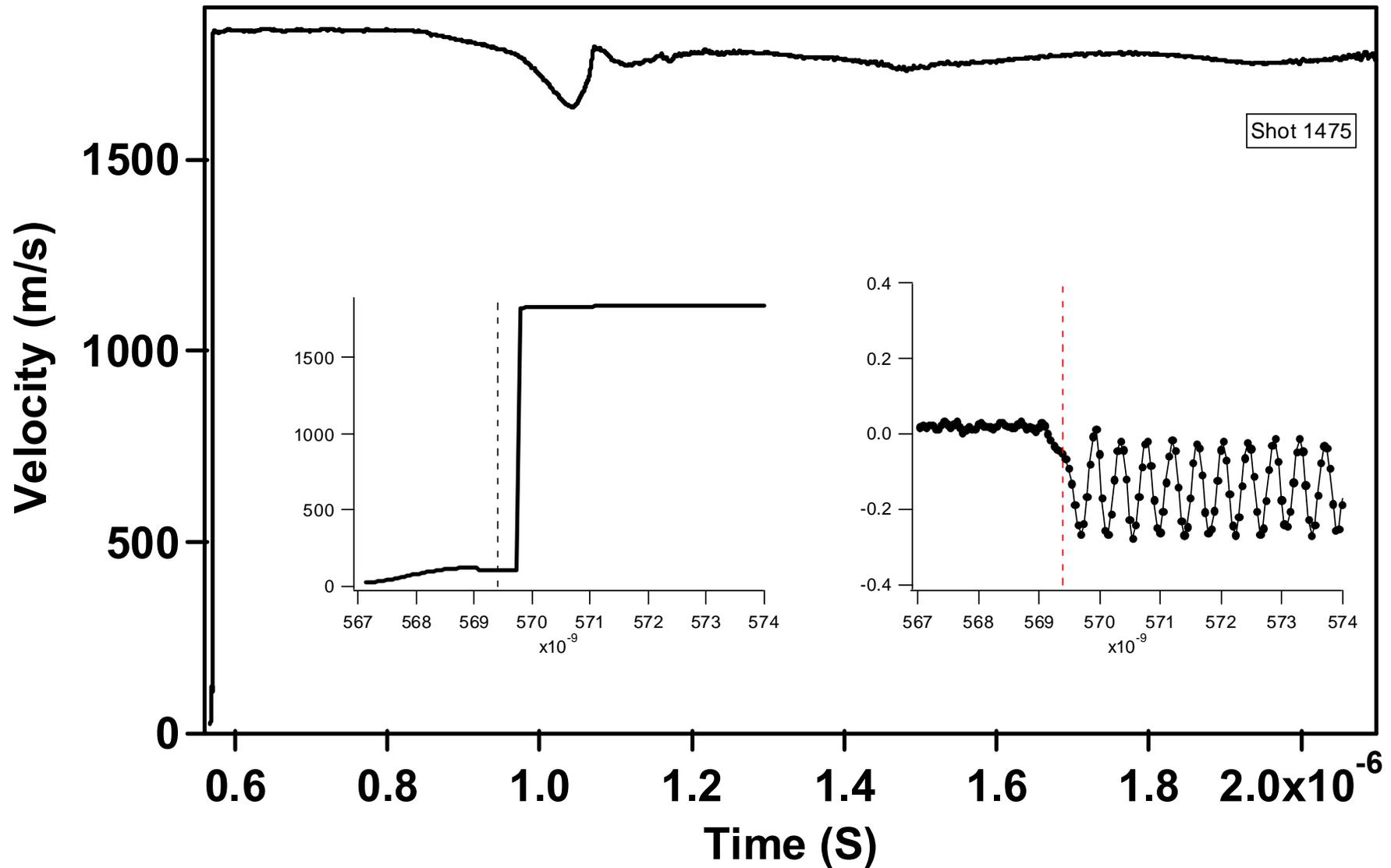
Detrending allows velocity determination to later times



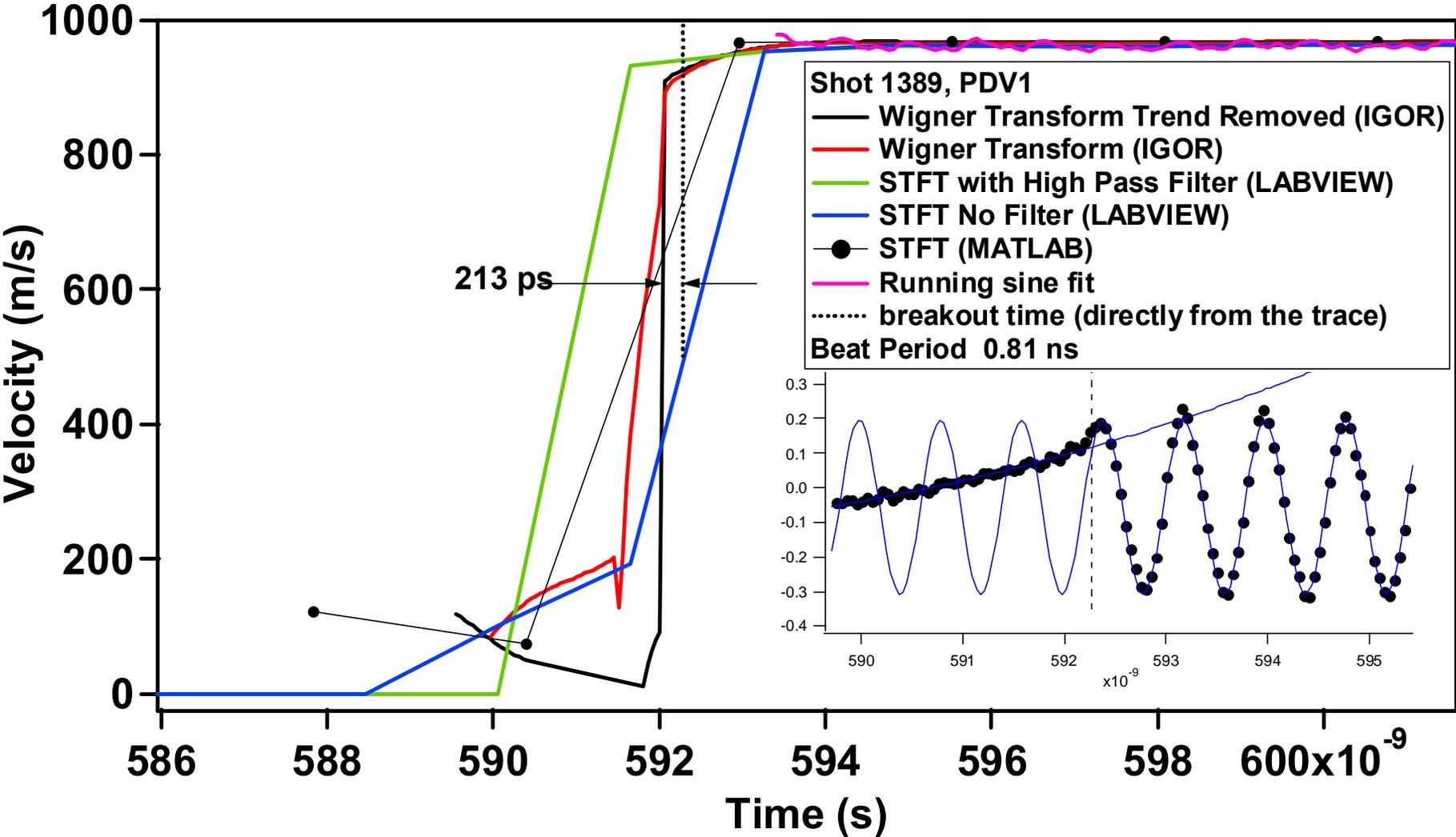
Automated velocity determination near breakout is difficult



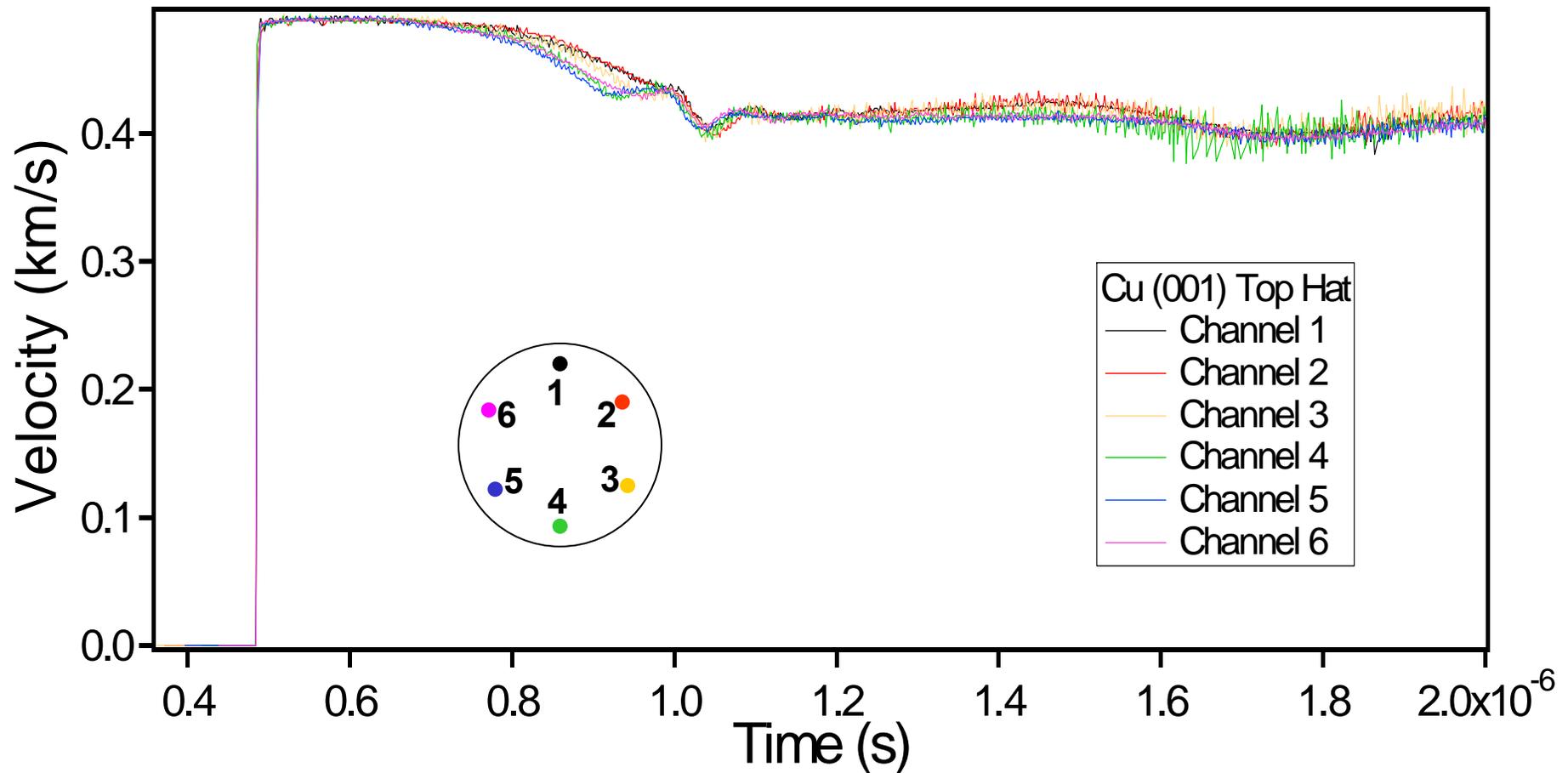
Automated Velocity Determination near breakout is difficult (contd.)



Velocity history near breakout using different analysis

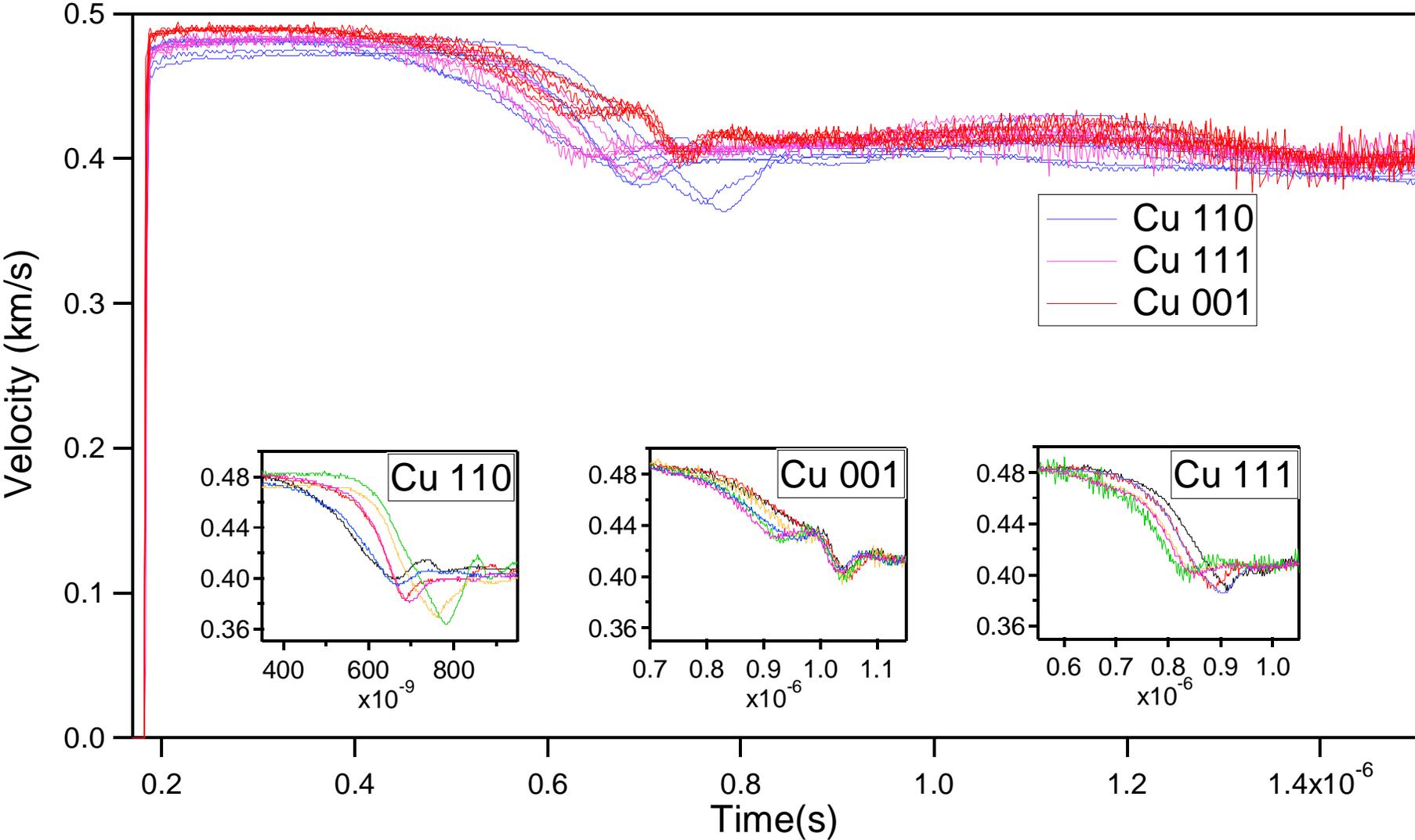


Velocity-time history shows features not easily visible in VISAR traces

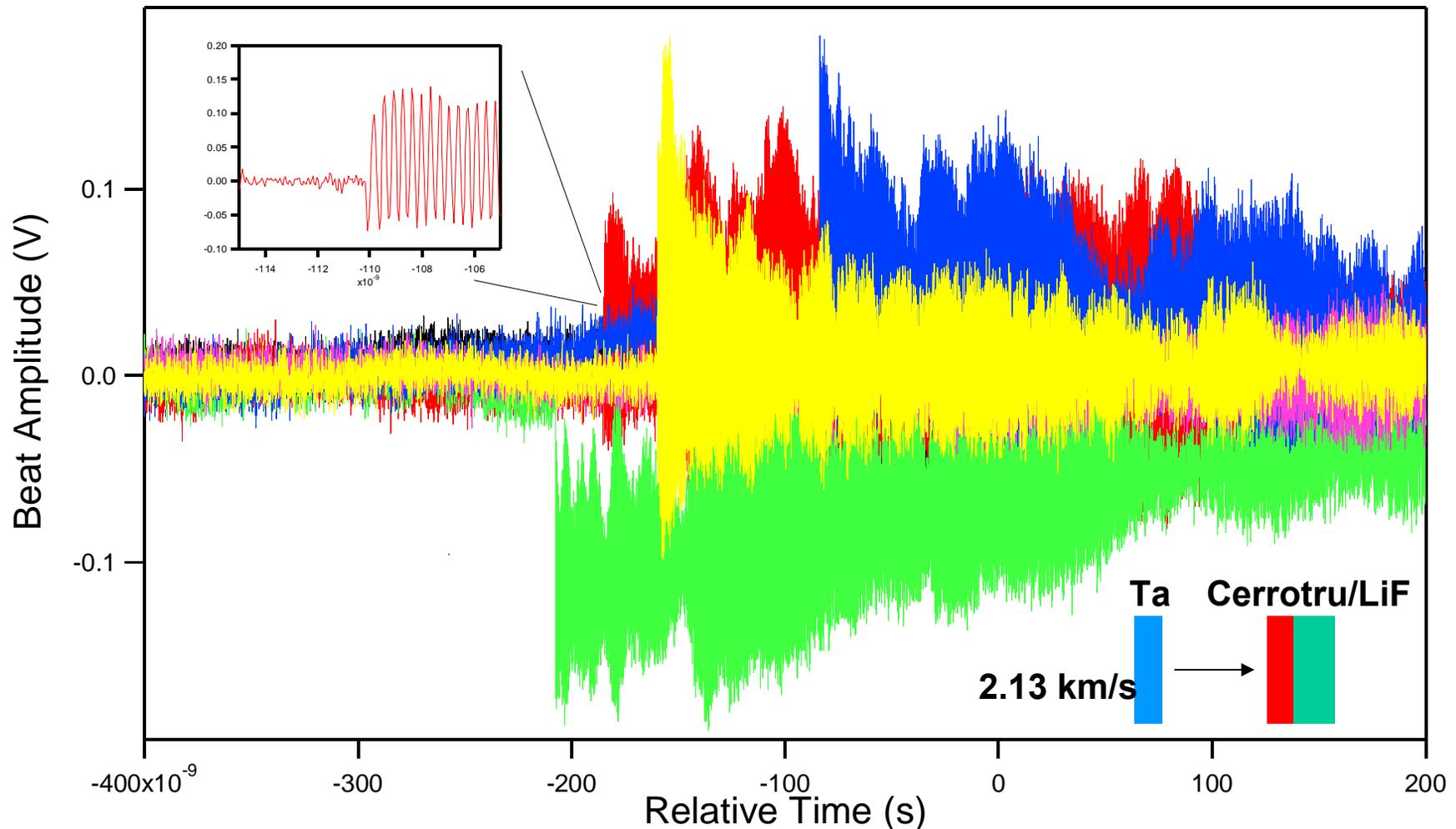


Pull back signals can be used to measure spall strength

Velocity-time history for 3 different crystal orientations



We have performed measurements on targets with LiF windows

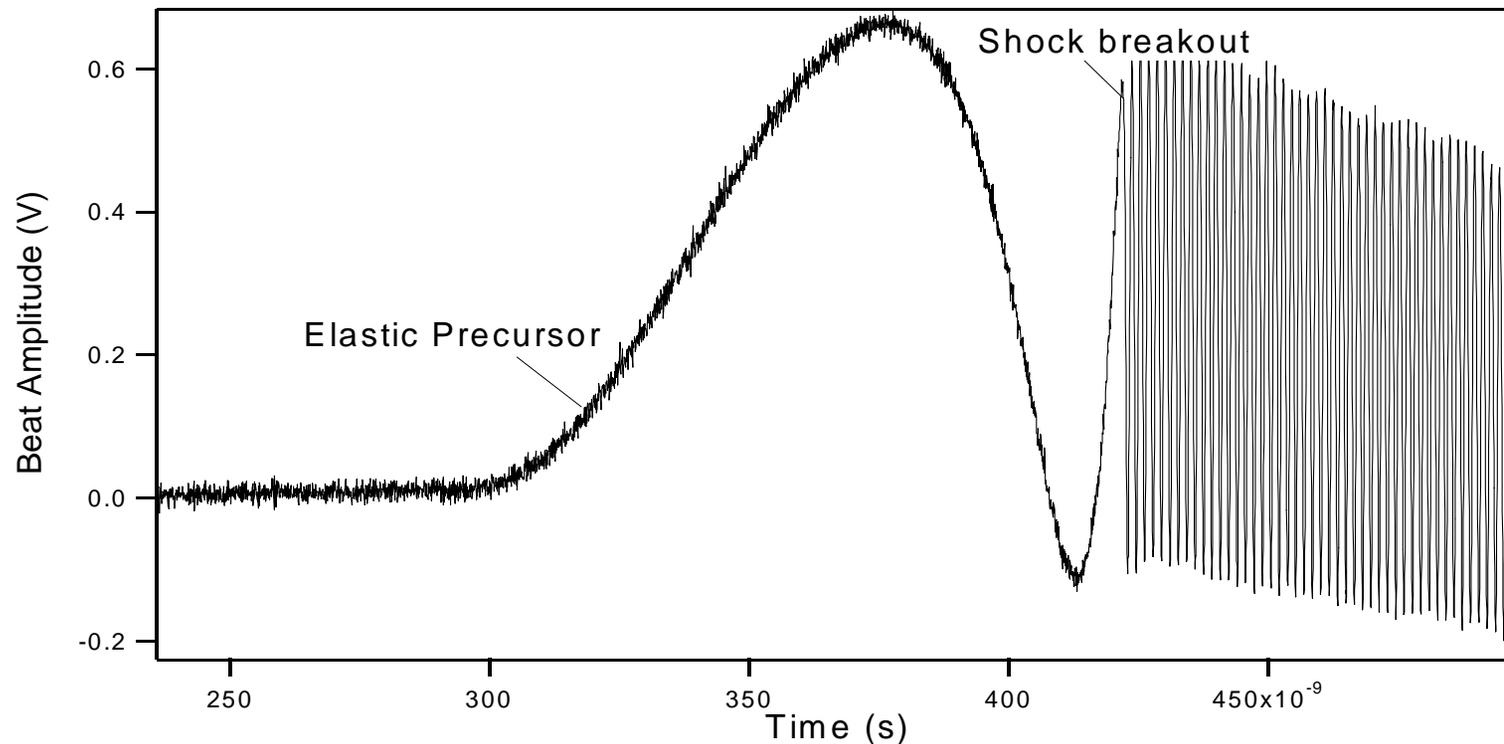


**Velocity measured through shocked LiF is approximately 28% higher.
LiF surface preparation is important to get good fringe contrast.**

Elastic precursor and shock breakout are clearly visible in beat recordings

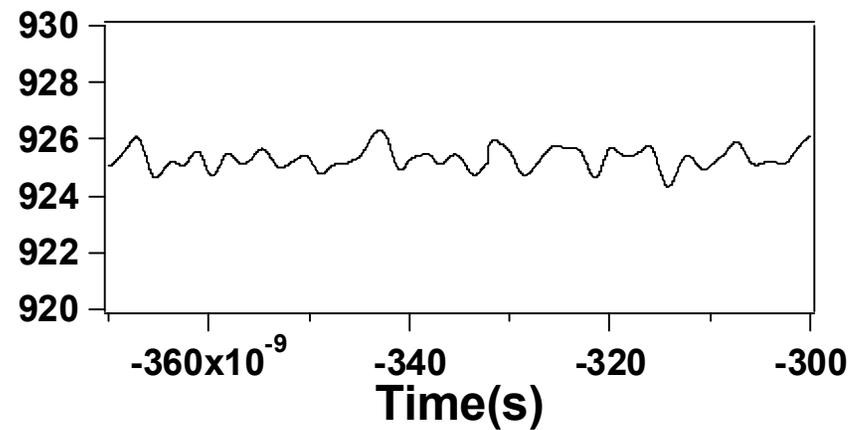
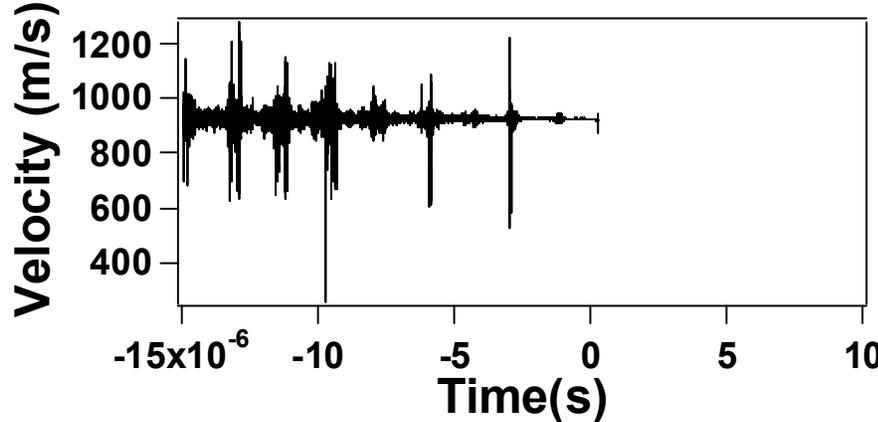
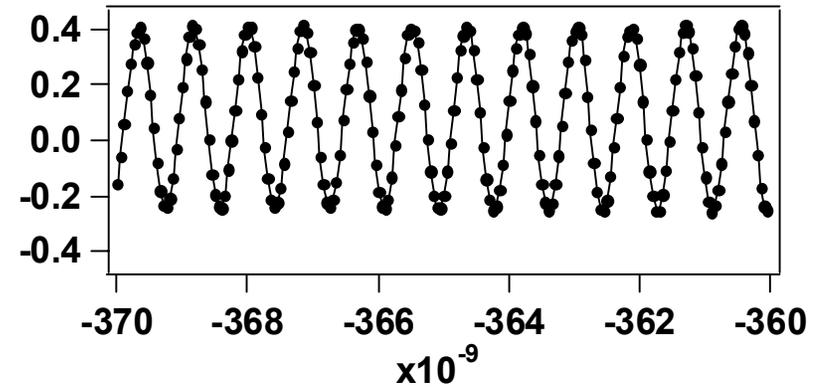
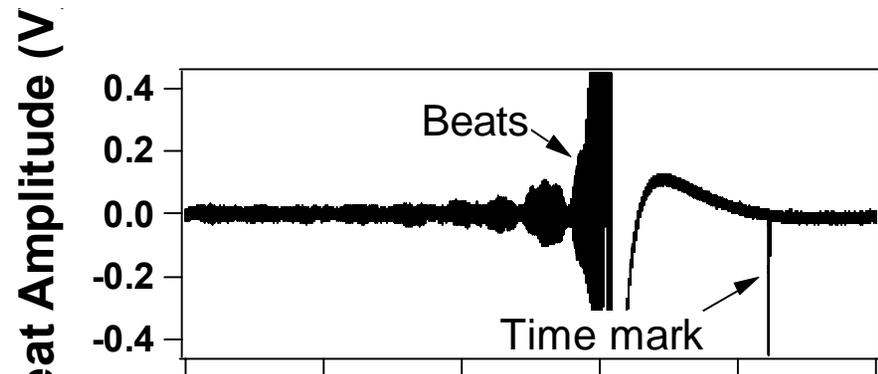


Target & projectile: Cu (111), Projectile velocity 0.49 km/s



	Sound Velocity	
	Beats	Derived from Elastic Stiffness (RT)
Cu 001	4.303 km/s	4.347 km/s
Cu 110	4.907 km/s	4.987 km/s
Cu 111	5.053 km/s	5.183 km/s

Projectile velocity history mapped with a bare fiber probe



Conclusion



- **Velocity-time history shows detailed features that are not easily discernable with other techniques.**
- **Shock arrival time and velocity-time history can be obtained using same channel.**
- **We developed several methods to analyze beat signals.**
- **EOS measurements from single crystal copper show no orientation dependence in the pressure range of 9-45 GPa.**
- **Elastic-plastic release is evident in velocity-time history.**