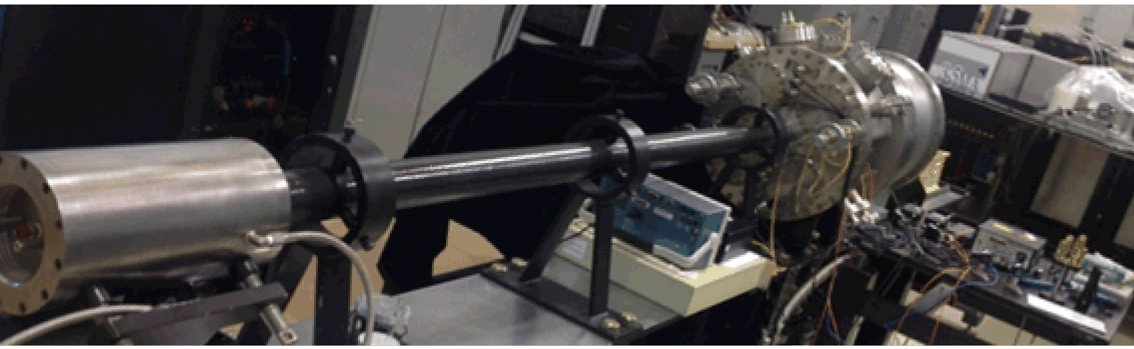
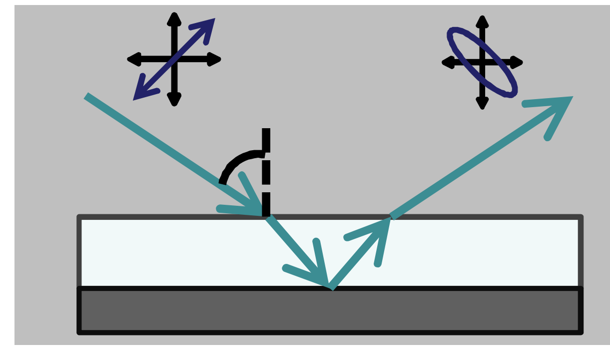
SAND2017-6439PE





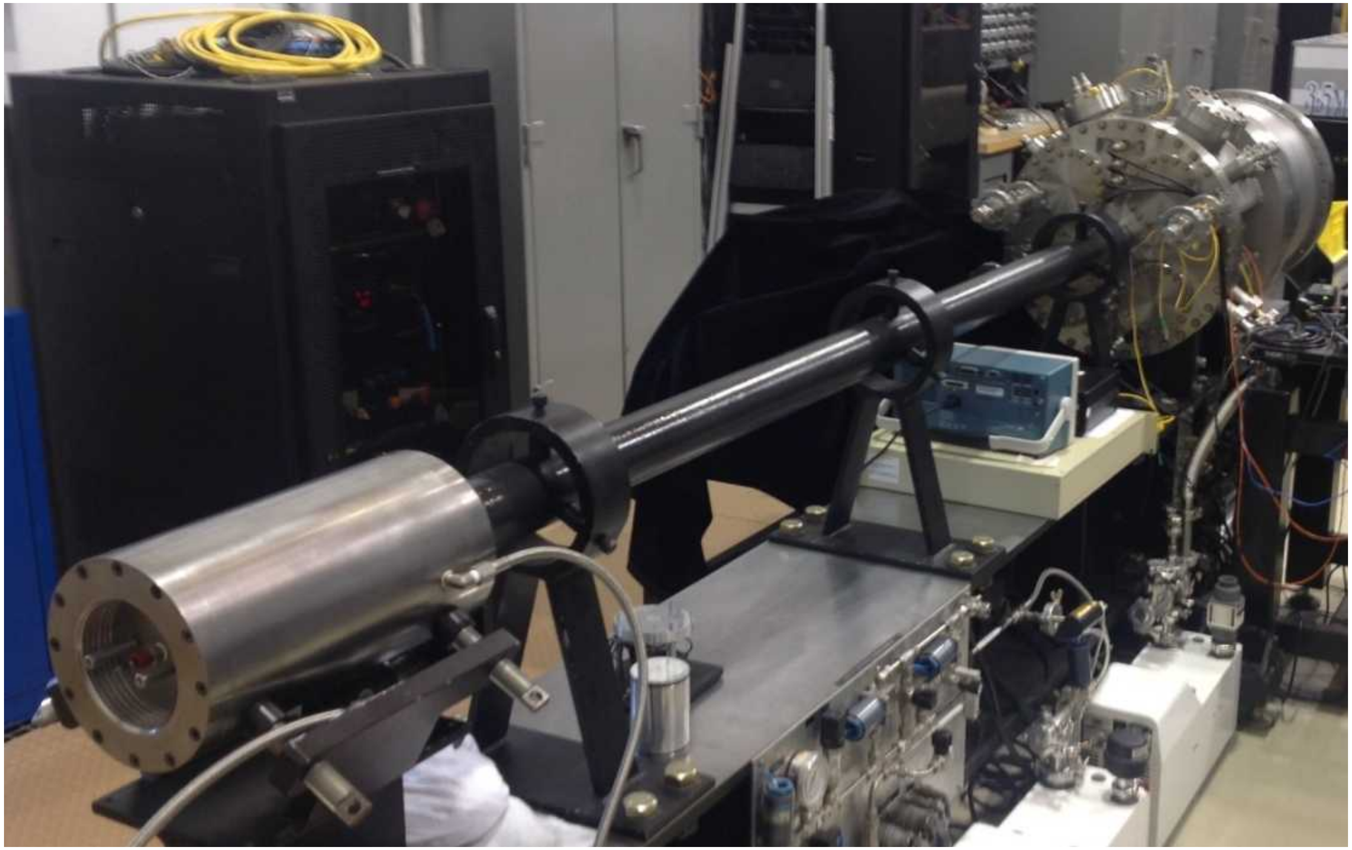
Updates on Single-Shot Ellipsometry

Sean Grant

University of Texas at Austin, Center for High Energy Density Science

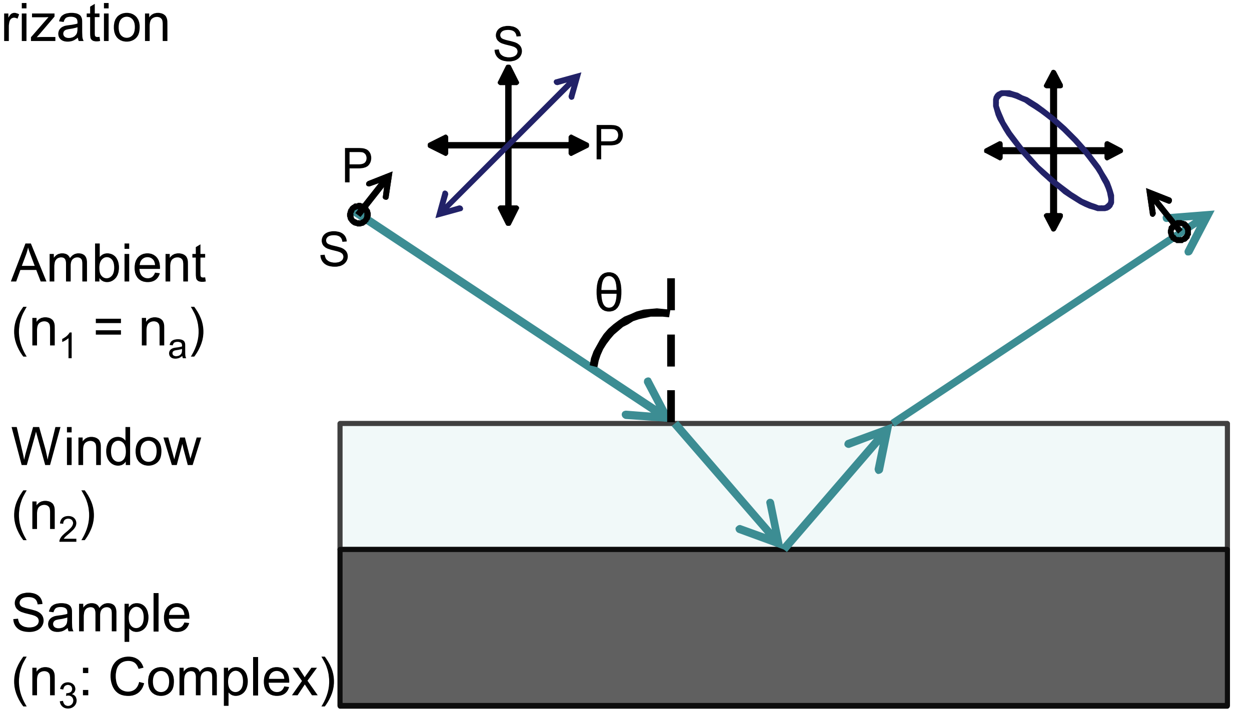
Project Overview

- **Motivation**
  - Enable the time-resolved measurement of a complex dielectric constant on dynamic facilities
    - ➢ Achieved with new ellipsometry diagnostic

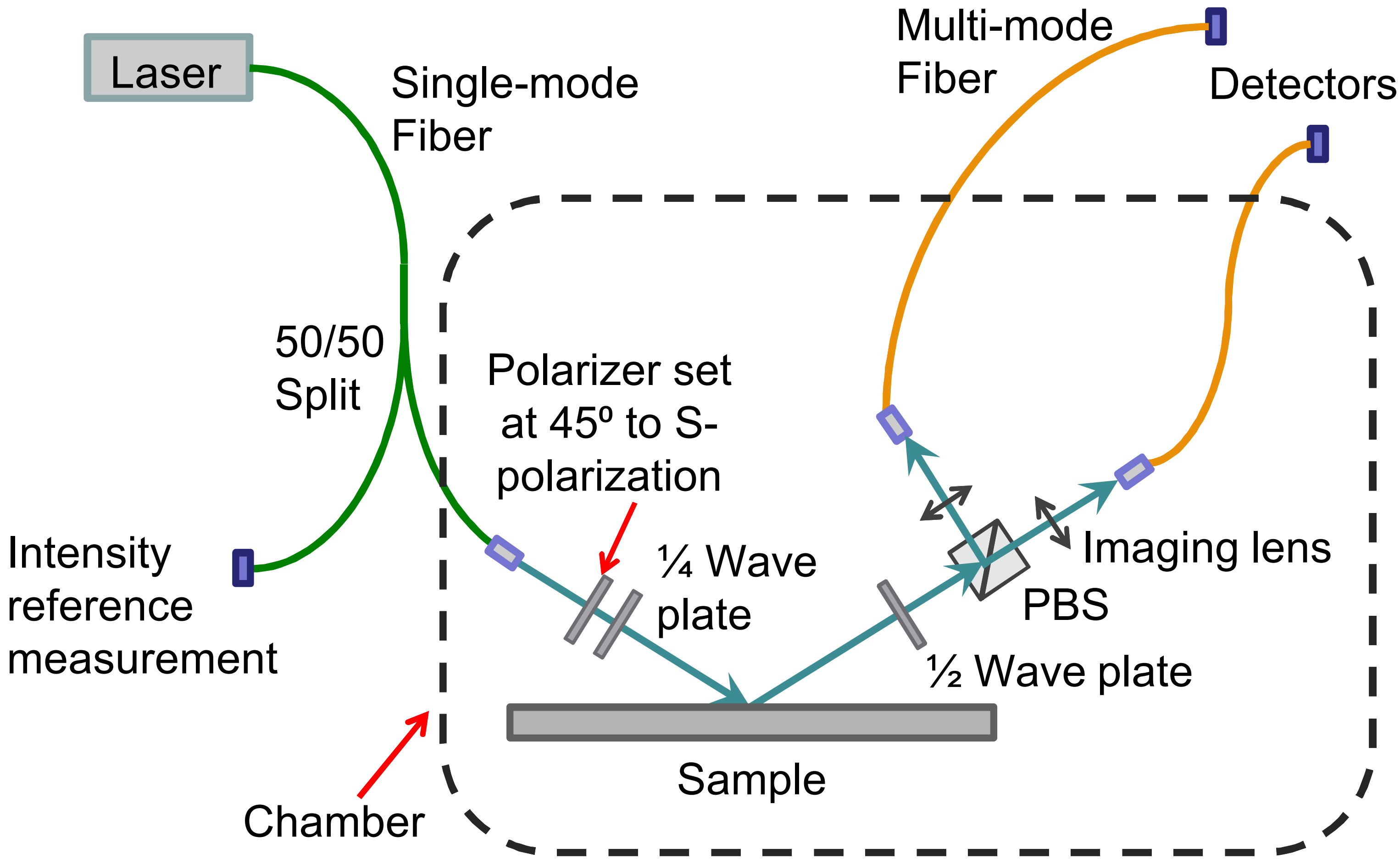


Ellipsometry uses a polarized laser to probe material dielectric properties

- The beam must have a non-zero incidence angle (generally larger is better)
- Input: Linear 45° polarization
- Output: Phase shift and reflection changes lead to an elliptical polarization

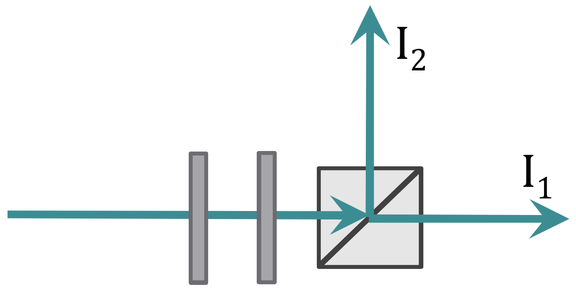


The basic design is a fiber/free-space hybrid



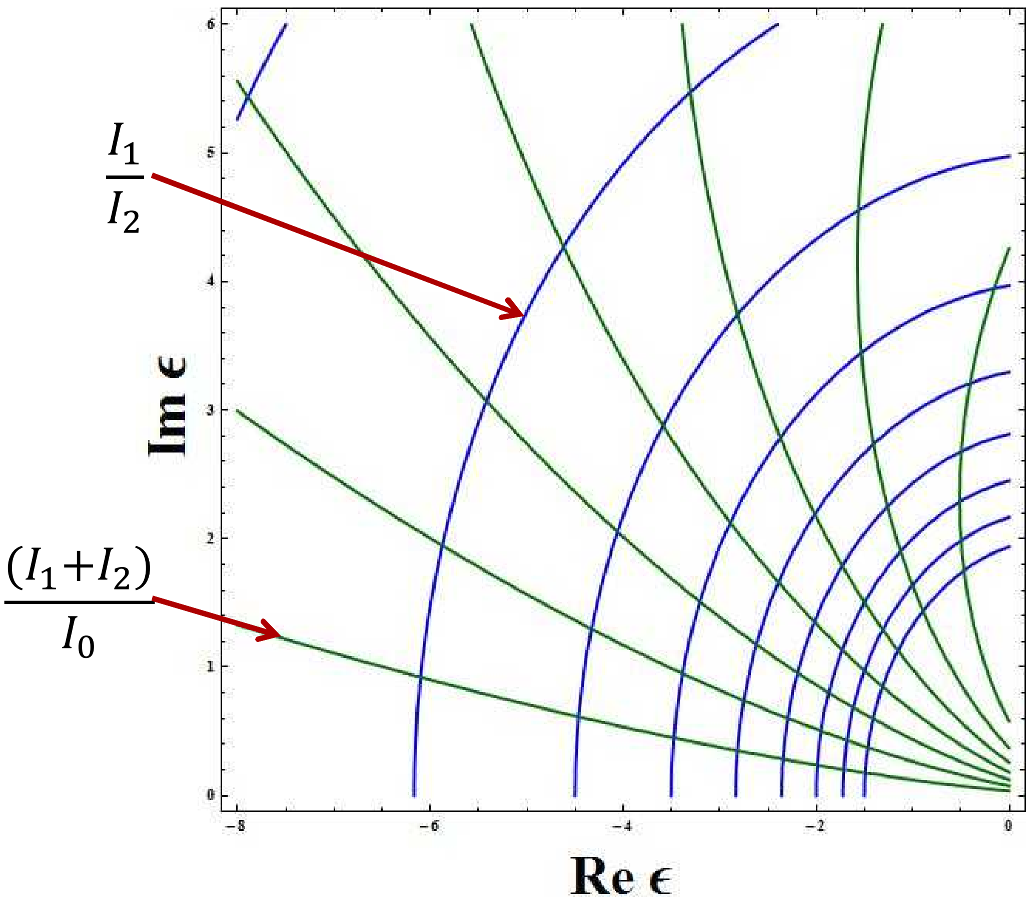
We analyze the polarization state with high signal to noise contrast

- Our Polarization Analysis:

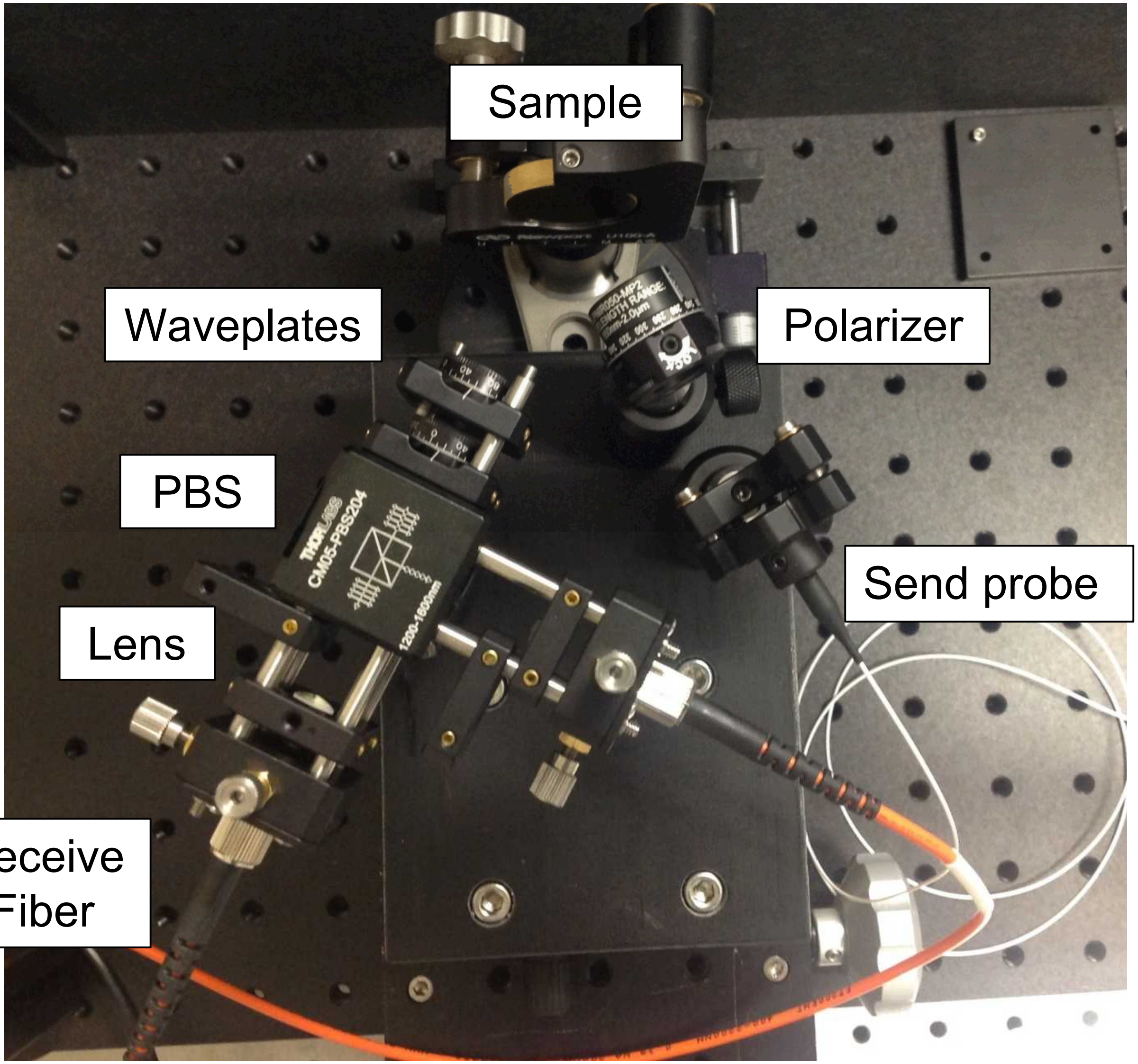


- **1/4 wave plate**: Improves signal to noise ratio by equalizing signal amplitudes
- **1/2 wave plate**: Rotates the polarization to align with the Polarizing Beam Splitter
- **Polarizing Beamsplitter**

Coordinate Space for Dielectric Constant

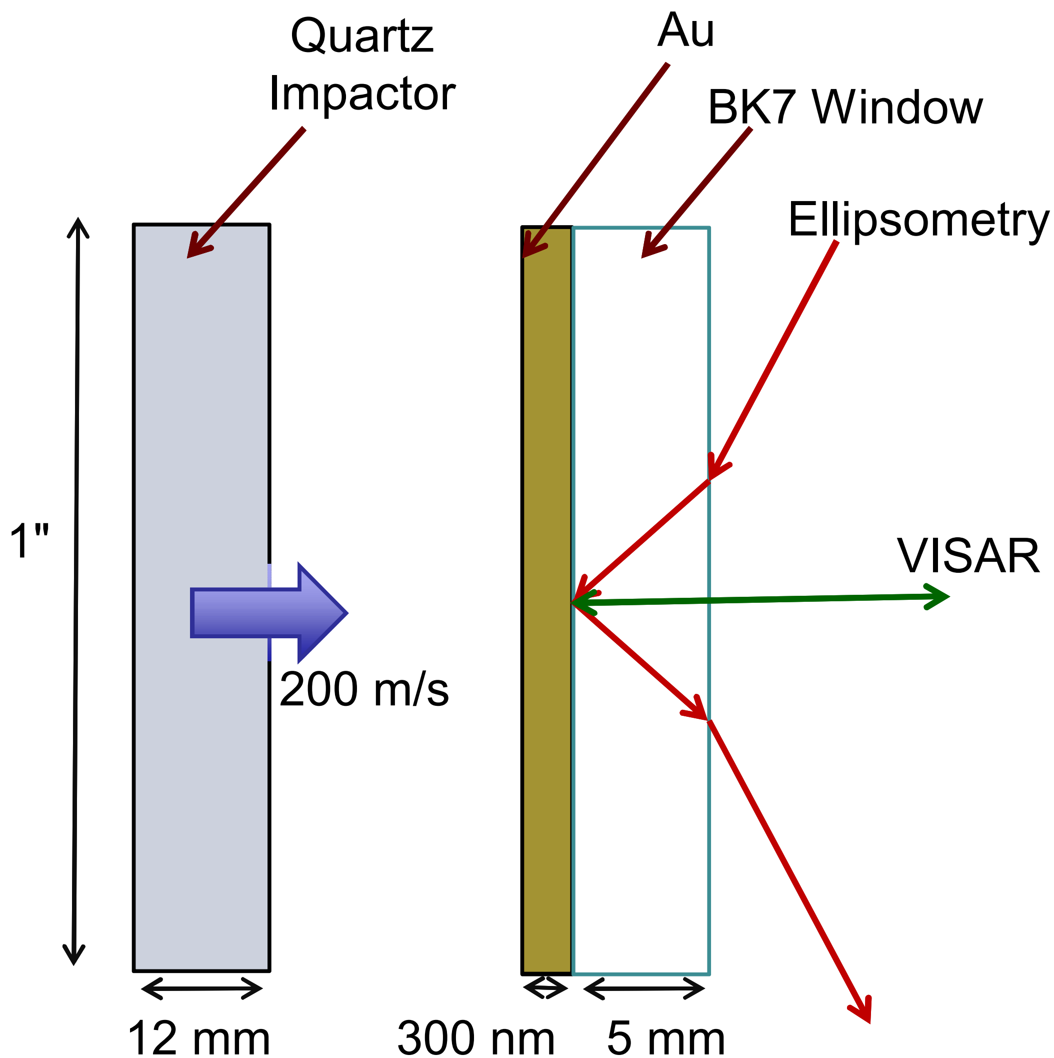


Mock-up of in-chamber setup

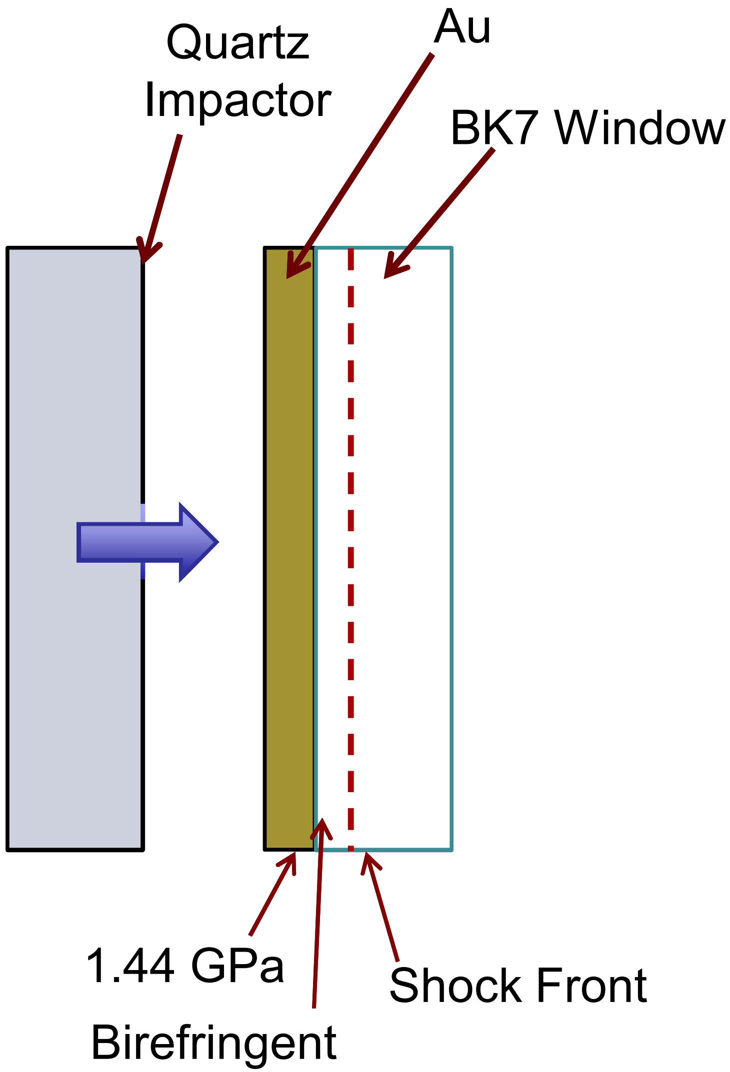


FIRST TESTS
GOLD DEPOSITION ON GLASS

We added ellipsometry to the typical impactor setup with VISAR

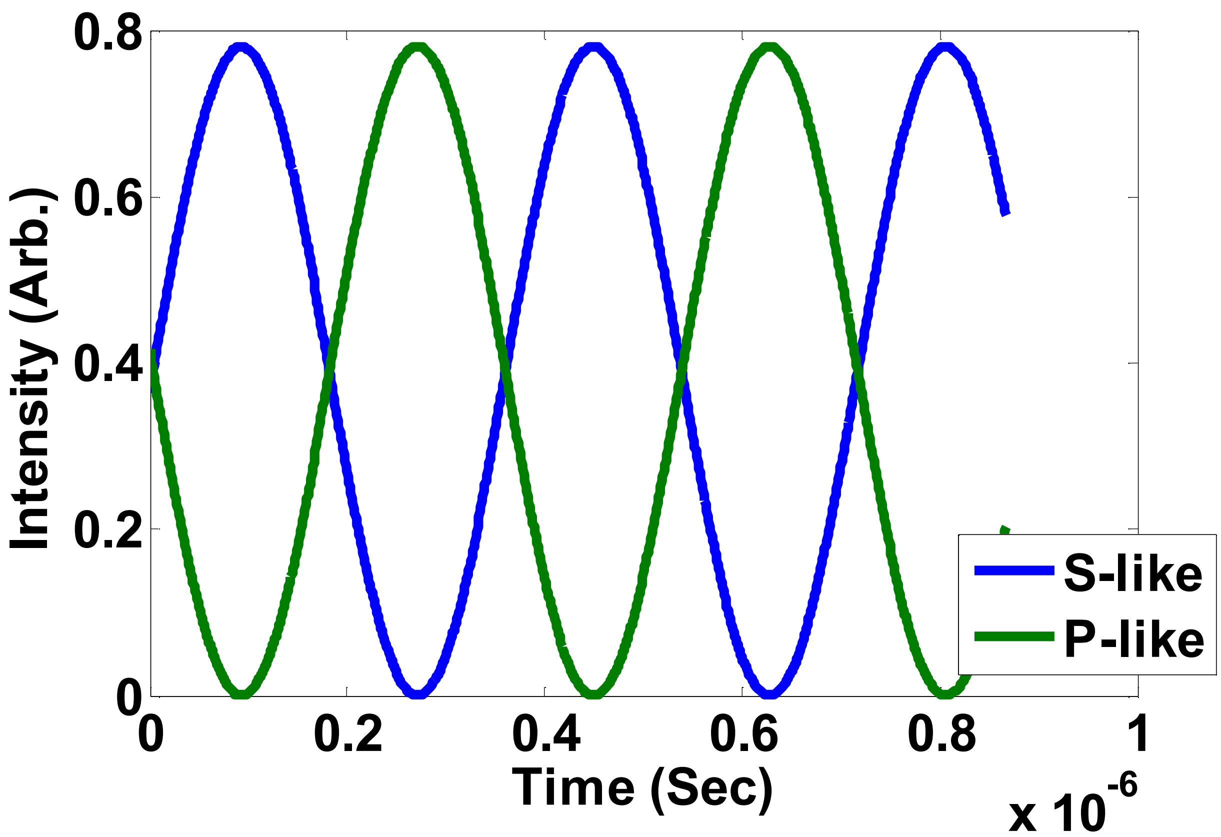


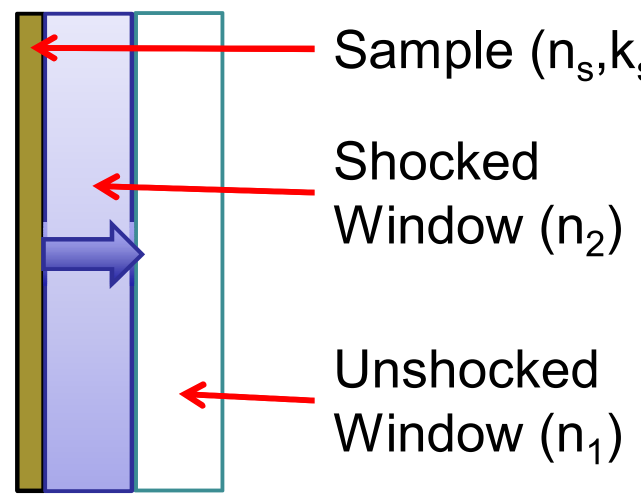
The shock front creates a growing birefringent layer in the window



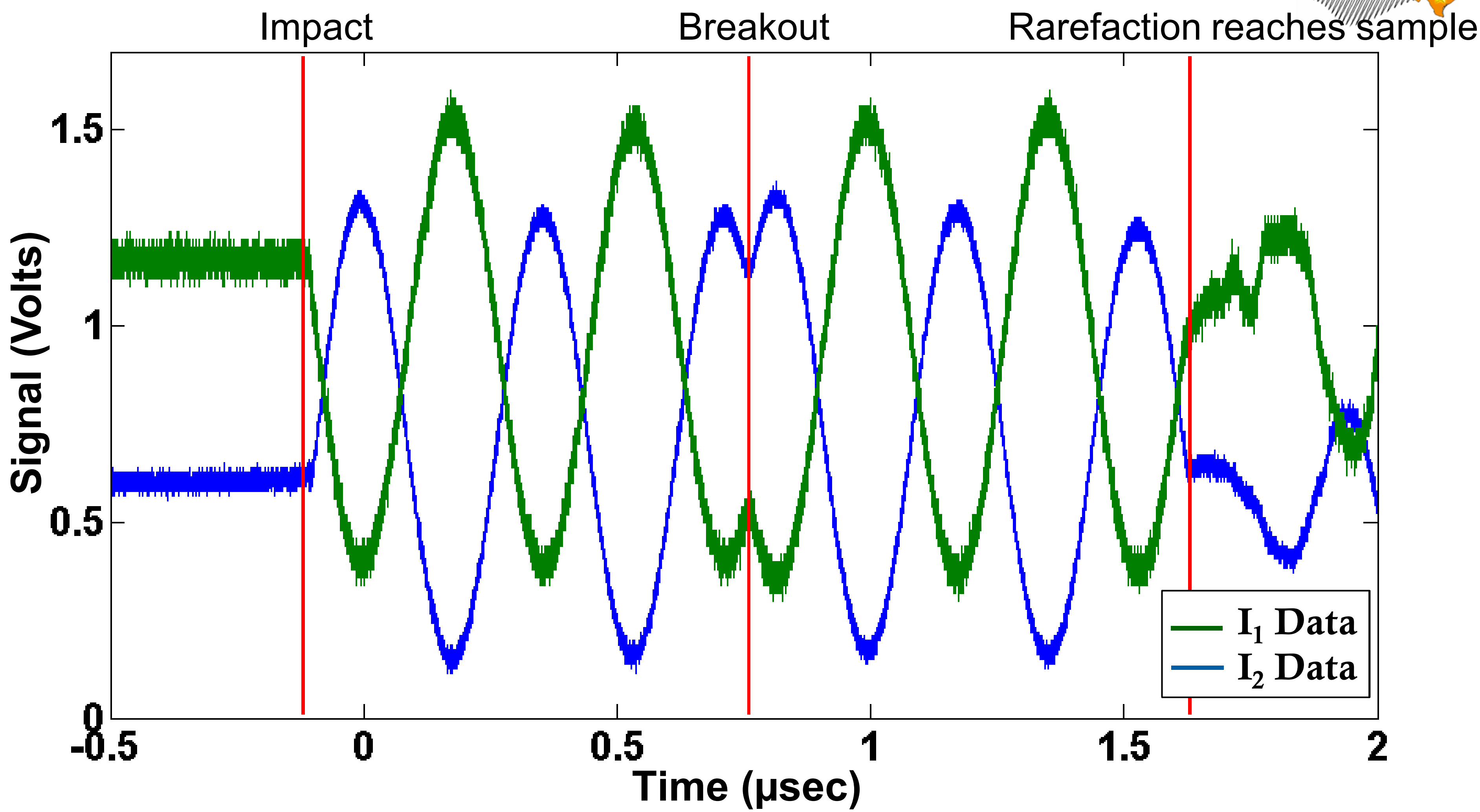
We model signal response to compare to and anticipate experimental results

- Basic model: consistent, steady, planar shock front



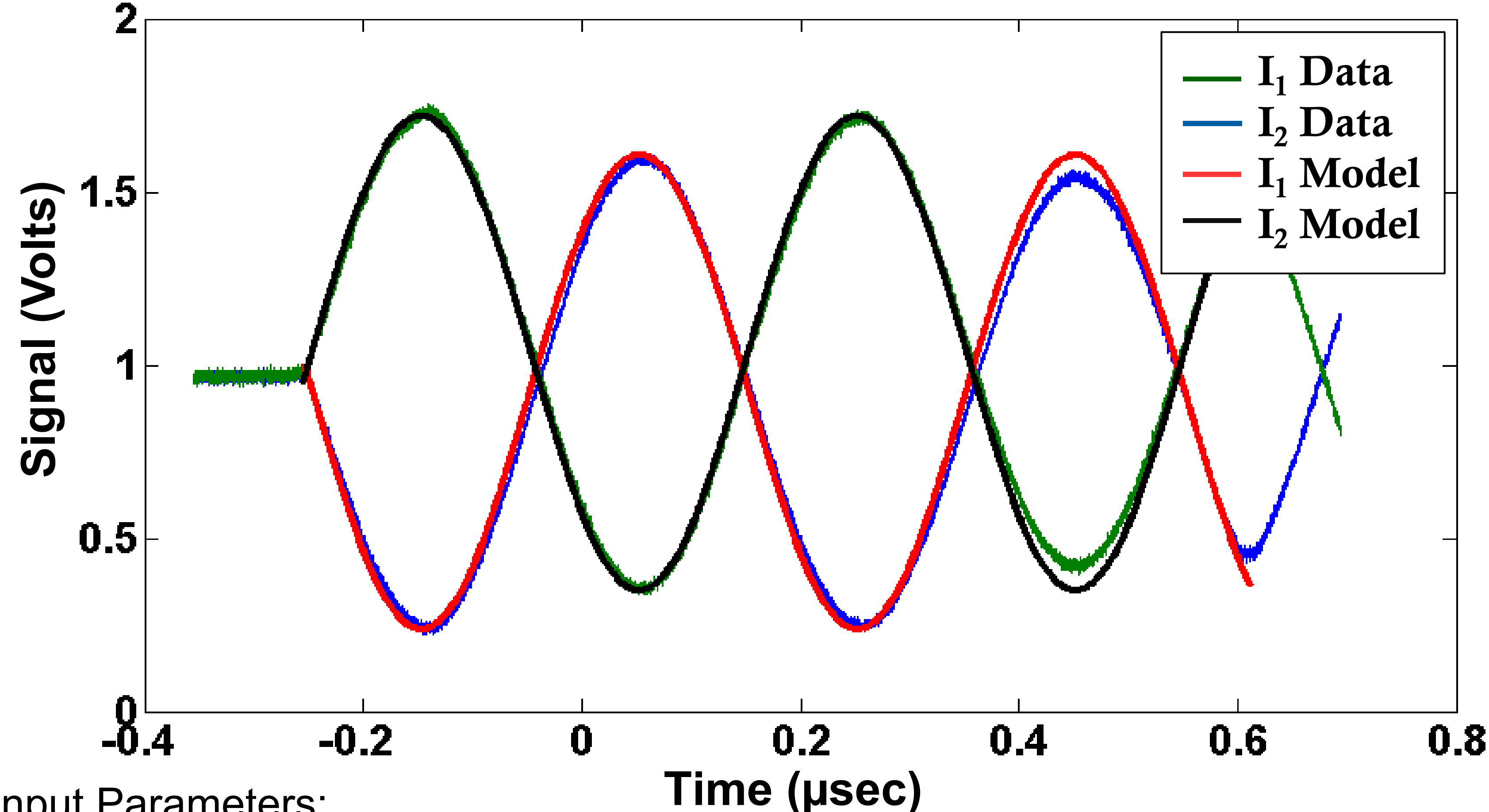


Full-time Shot Data Matches Expectations



- Shock causes uniaxial compression of window, leading to birefringence.
- This leads to the sinusoidal behavior in the output signals.

The model fit yields the strength of the birefringence



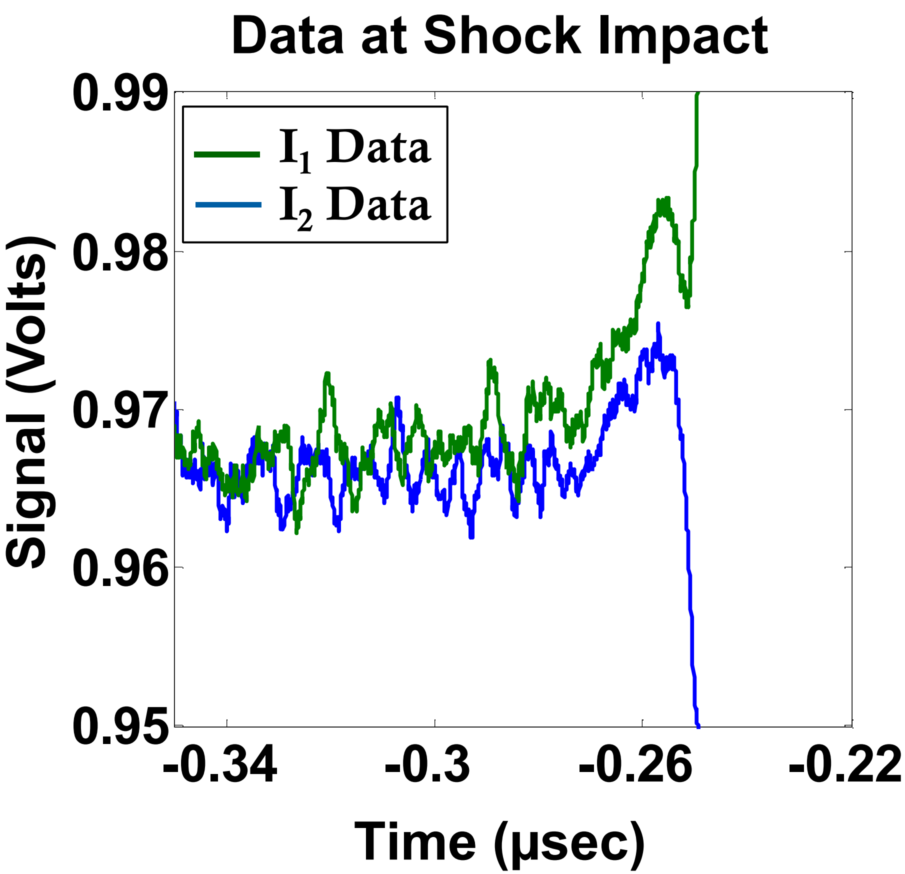
Input Parameters:

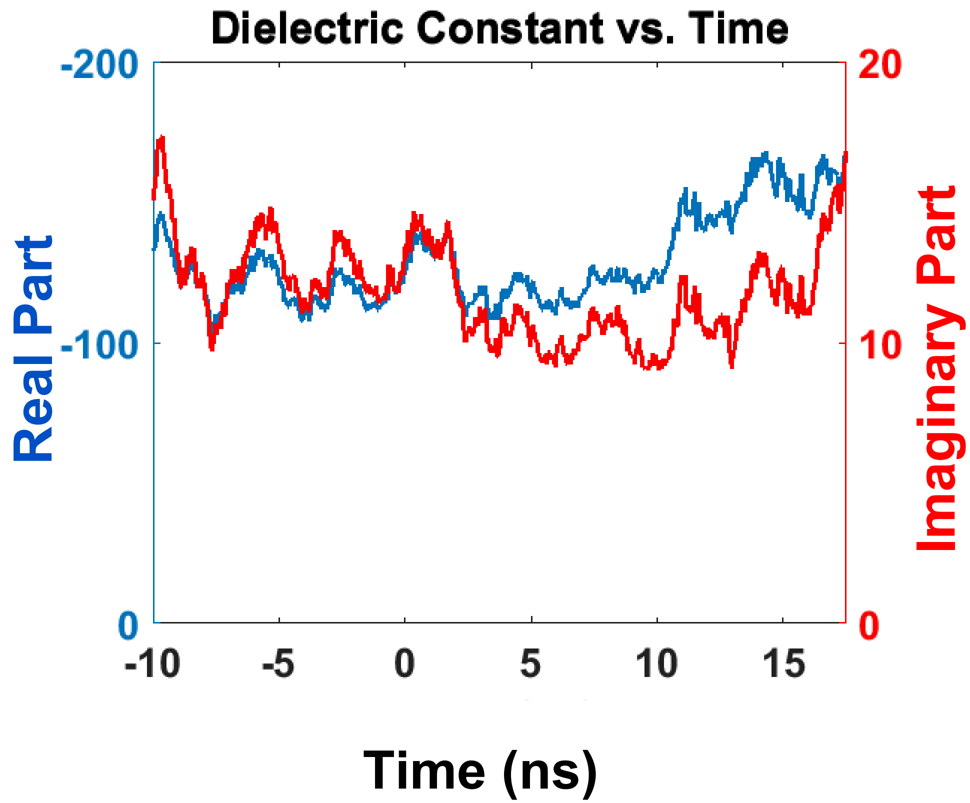
Shock Velocity: 5.88 km/s, Gold Dielectric: -29.4+9.9i, Ambient BK7 index: 1.5007

Fit Parameters:

Shocked (extraordinary) BK7 Index: 1.5039

Evidence of Au signal at initial times



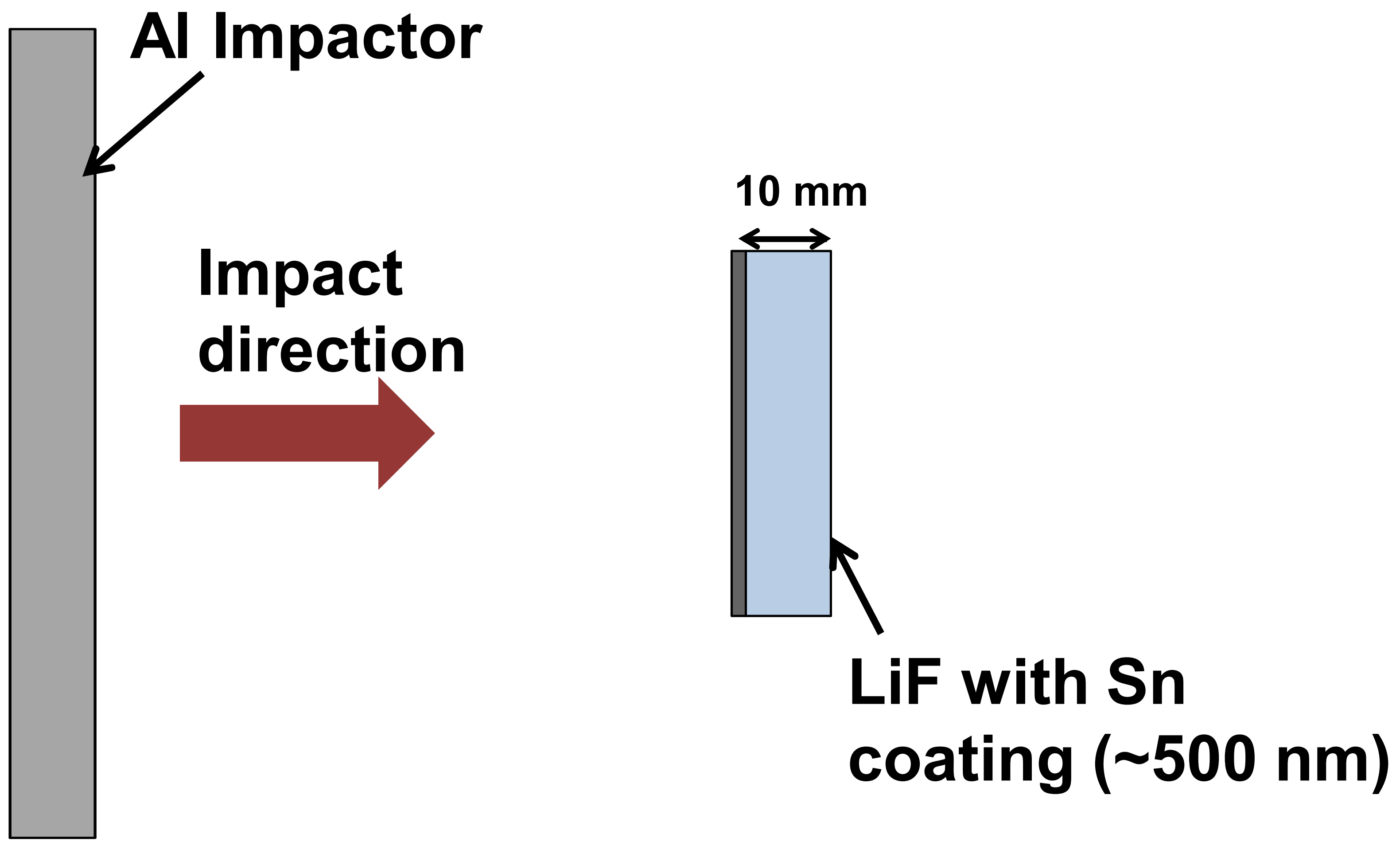


We see a noticeable increase in both signals over a period of about 20 ns before the sinusoidal behavior takes over.

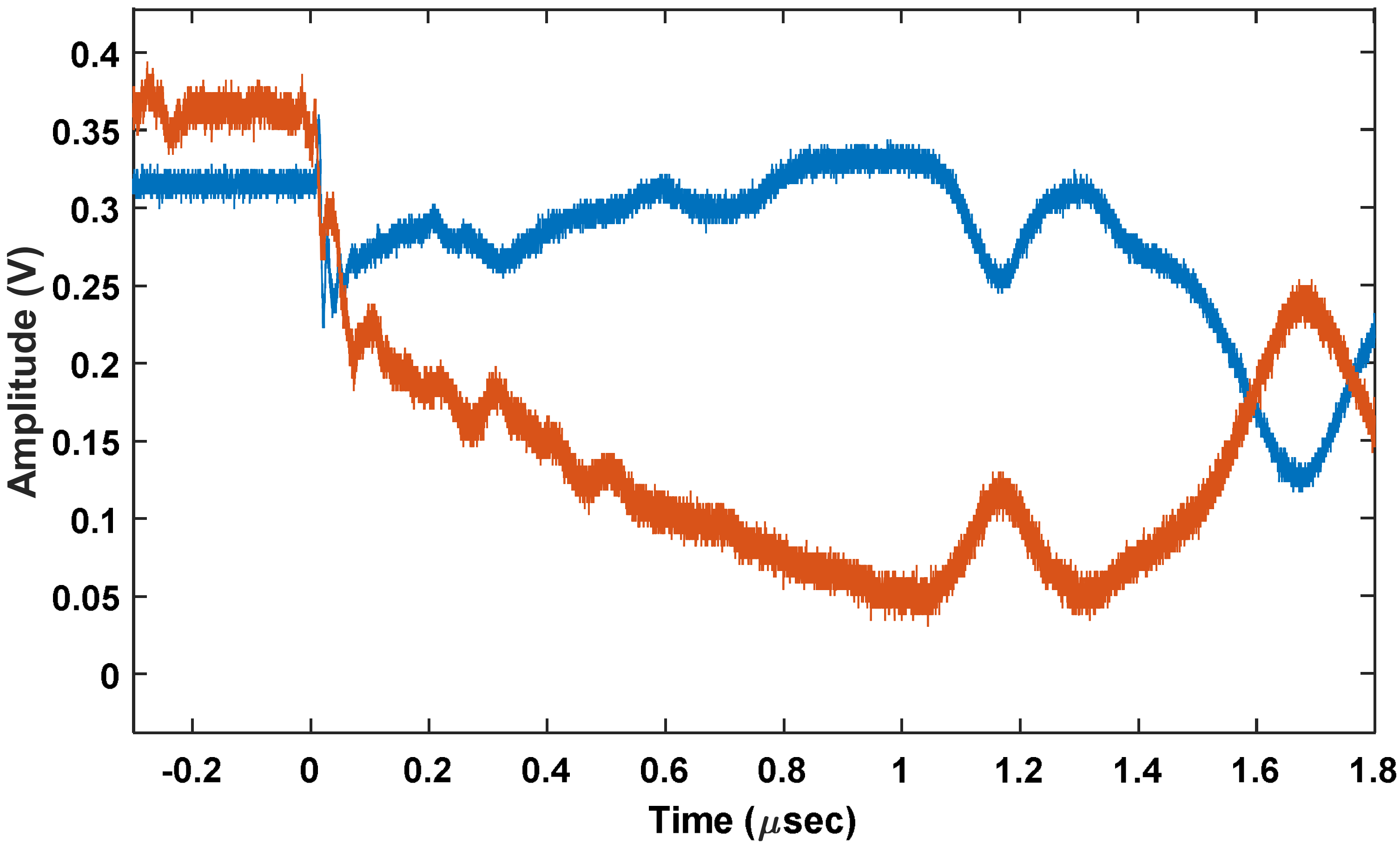
*There is a 2 ns smoothing done to reduce noise

HEATED PROJECTILE:
TIN COATED SAMPLE

Experimental Configuration

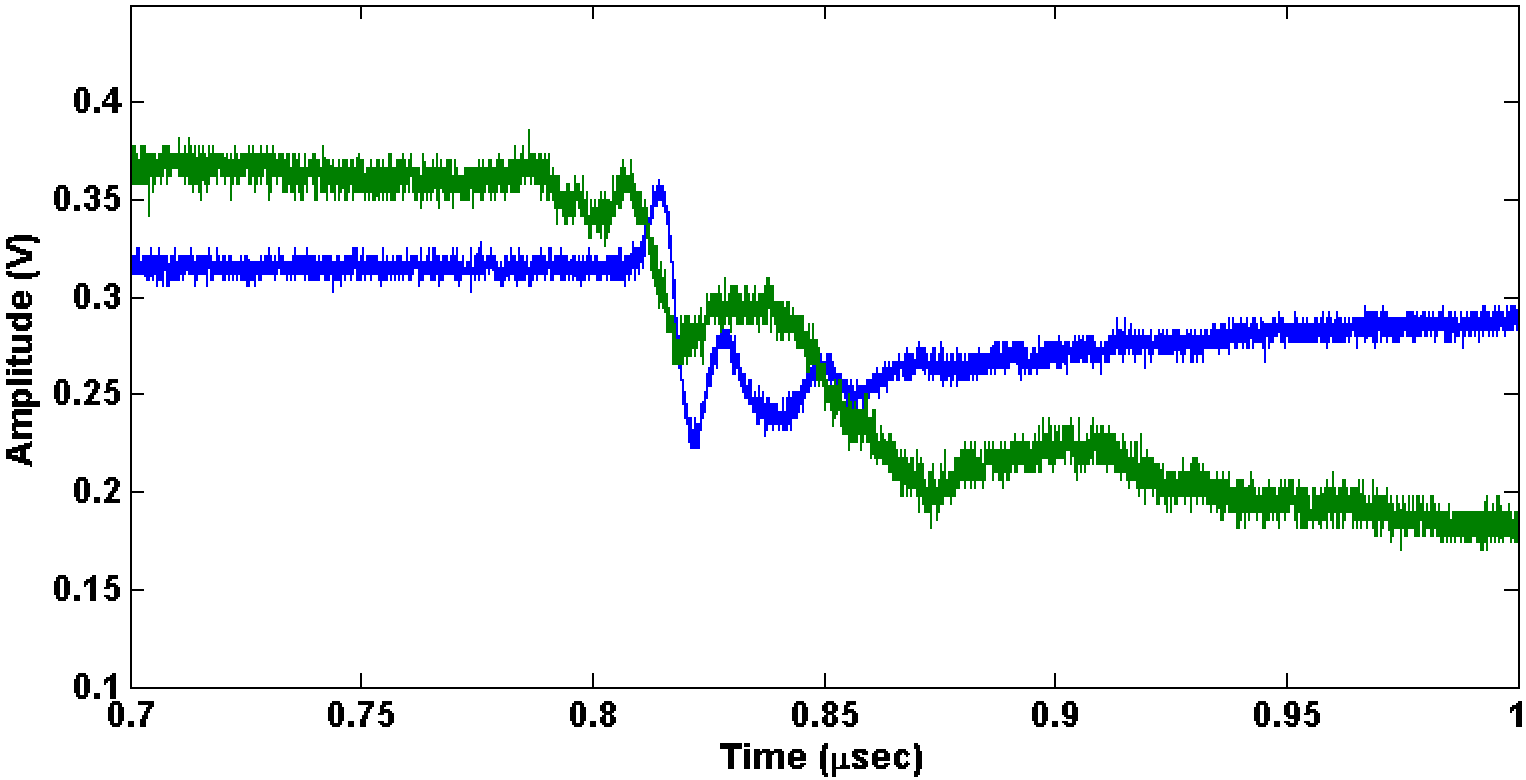


Flyer at room temperature



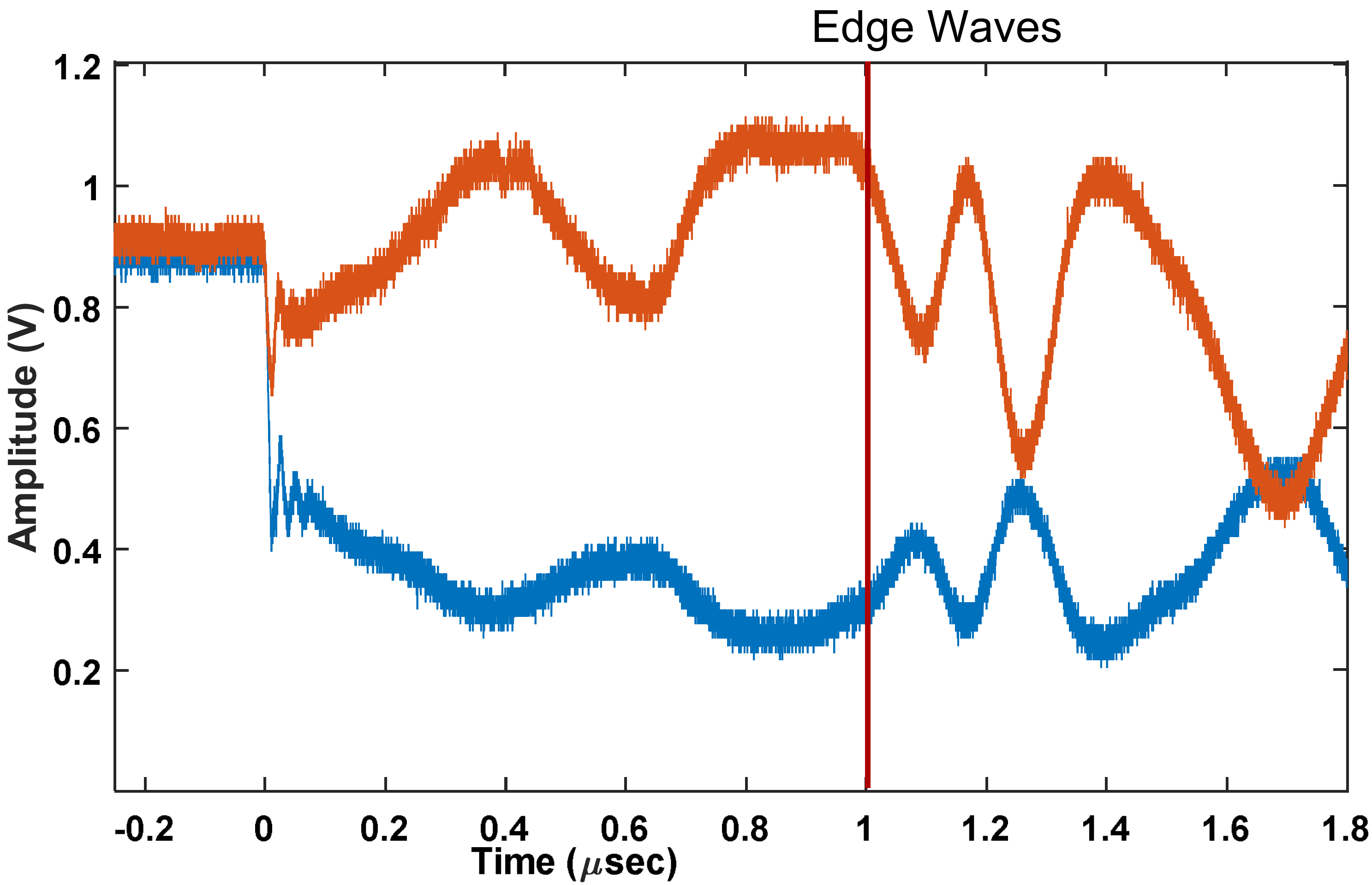
- Long, slow trend with small oscillations
- Rapid oscillations during first 100 ns

Zoom of early time



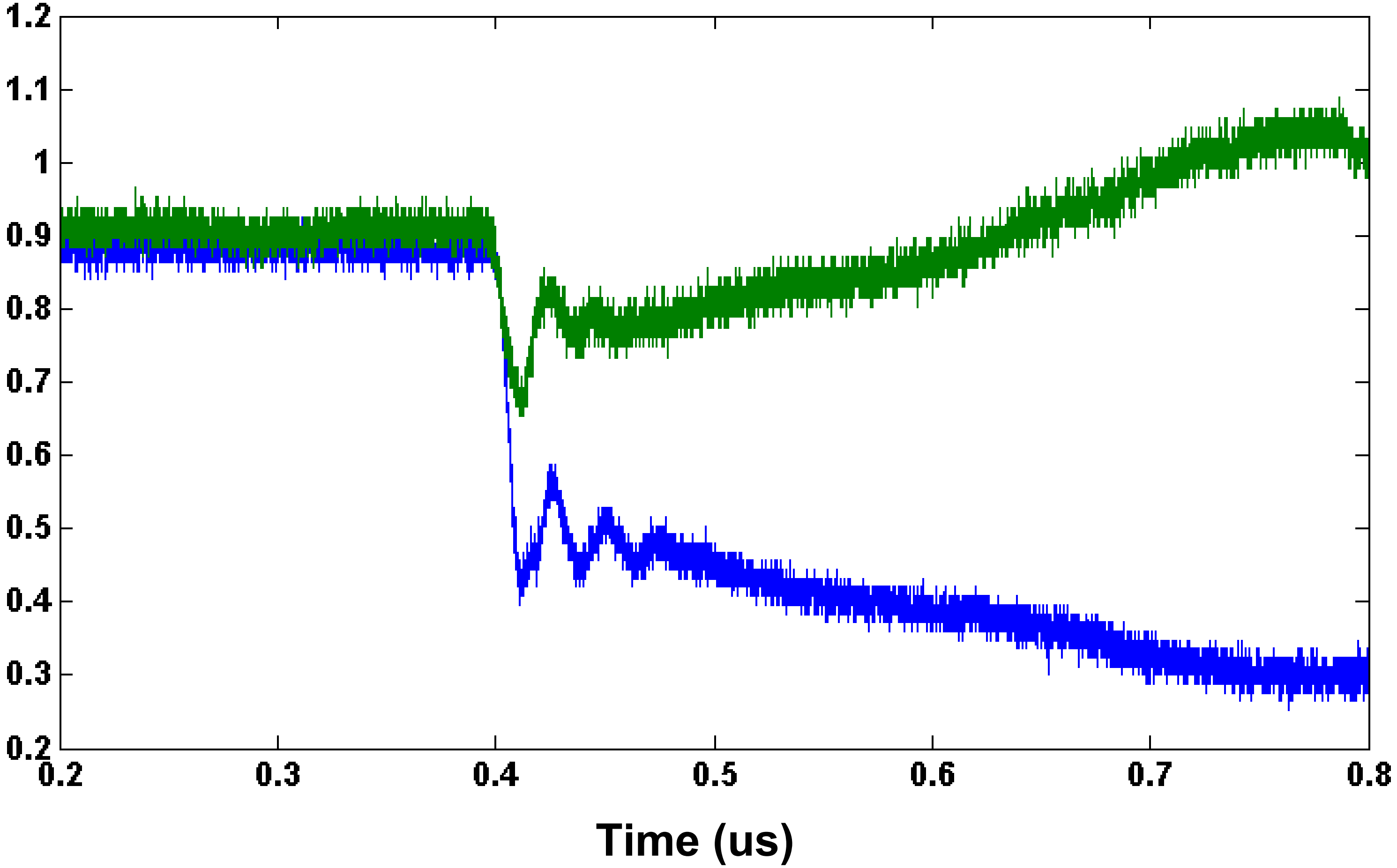
Clear rapid oscillations in one signal

Flyer heated to 250 Celsius



- Some sinusoidal-like behavior, but low amplitude
- Rapid drop in signal, and fast oscillations during first 100 ns

Zoom of early time



It is not clear where this short term, early ringing is coming from. It is not likely to be related to birefringence, because the two signals move in-sync.

Sean Grant

June 2016

STAR EXPERIMENTS FE AND SN ELLIPSOMETRY

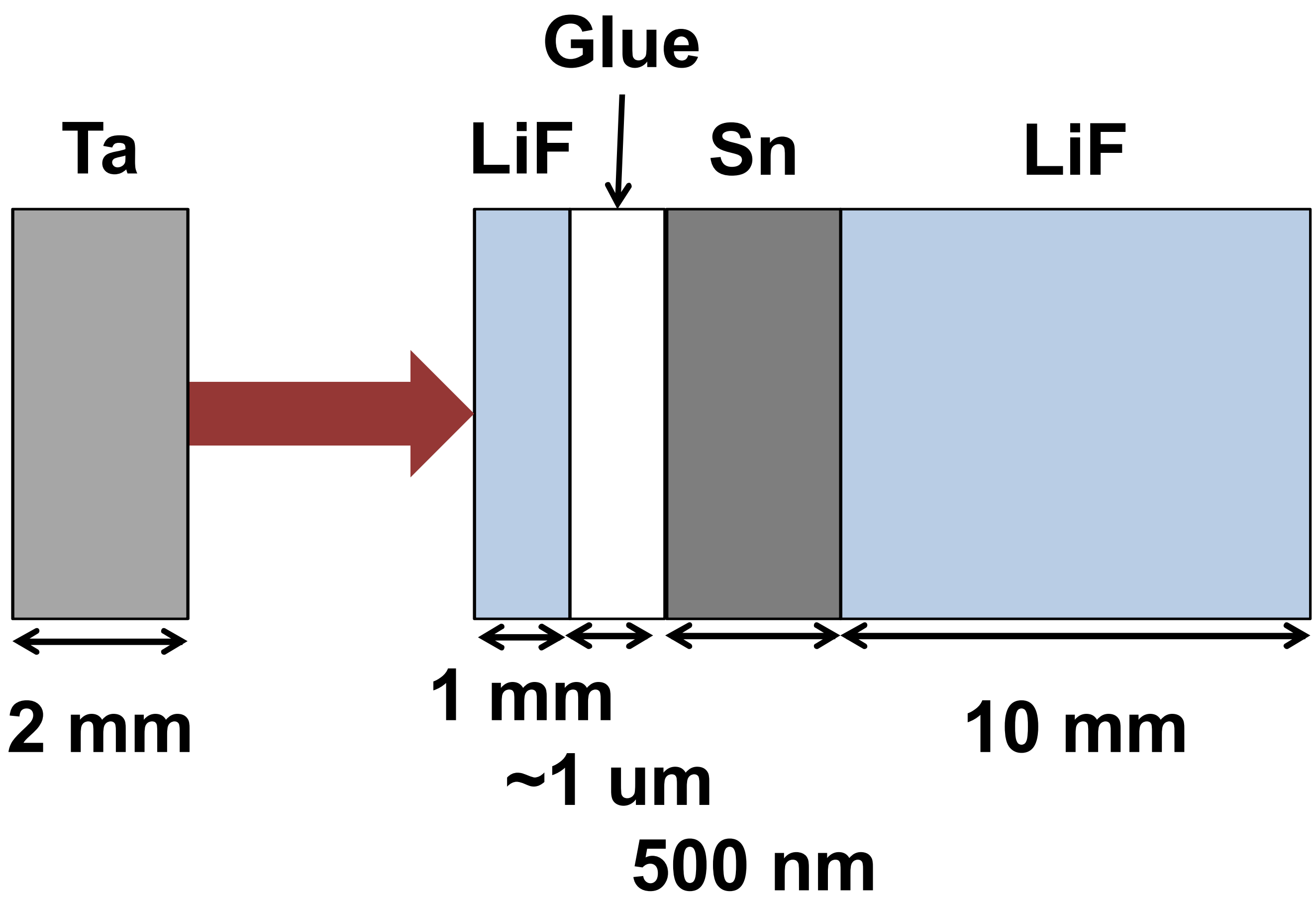
STAR Experiments proposed

We performed the first two shots of our matrix:

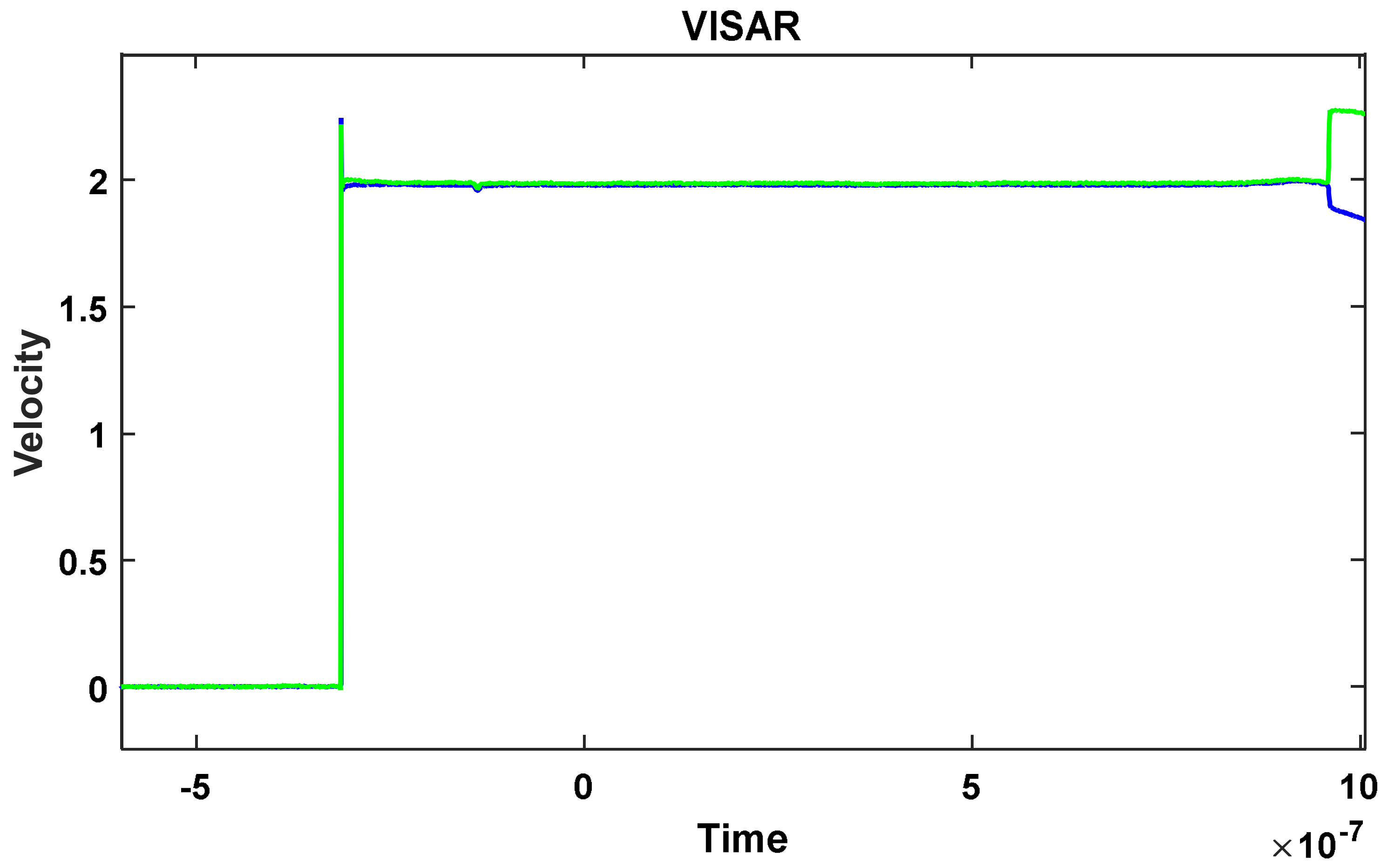
Shot	Gun	Impact Velocity (km/s)	Impactor			Target			Window				Expected	
			Material	thick (mm)	diam (mm)	Material	thick (mm)	diam (mm)	Material	diam (mm)	thick (mm)	Reflector	Stress (Kbar)	up* (window) (km/s)
1	Two-Stage	2.50	Ta	3 (0.118 in.)	25.4 (1.000 in.)	LiF/Tin	1 (0.039 in.)	25.4 (1.000 in.)	**LiF**	25.4 (1.000 in.)	10 (0.394 in.)	**Tin**	390	~2
2	Two-Stage	2.50	Ta	3 (0.118 in.)	25.4 (1.000 in.)	LiF/Iron	1 (0.039 in.)	25.4 (1.000 in.)	**LiF**	25.4 (1.000 in.)	10 (0.394 in.)	**Iron**	390	~2
3	Two-Stage	5.80	Ta	2 (0.079 in.)	19 (0.748 in.)	Iron/Iron	3 (0.118 in.)	25.4 (1.000 in.)	**LiF**	25.4 (1.000 in.)	10 (0.394 in.)	**Iron**	1360	4.6
4	Two-Stage	7.00	Al	4 (0.157 in.)	19 (0.748 in.)	LiF/Iron	1 (0.039 in.)	25.4 (1.000 in.)	**LiF**	25.4 (1.000 in.)	10 (0.394 in.)	**Iron**	933	3.6
5*	Two-Stage	6.80	Ta	2 (0.079 in.)	19 (0.748 in.)	LiF/Iron	1 (0.039 in.)	25.4 (1.000 in.)	**LiF**	25.4 (1.000 in.)	10 (0.394 in.)	**Iron**	1600	5

1. Shock-melt tin
2. a-e transition iron

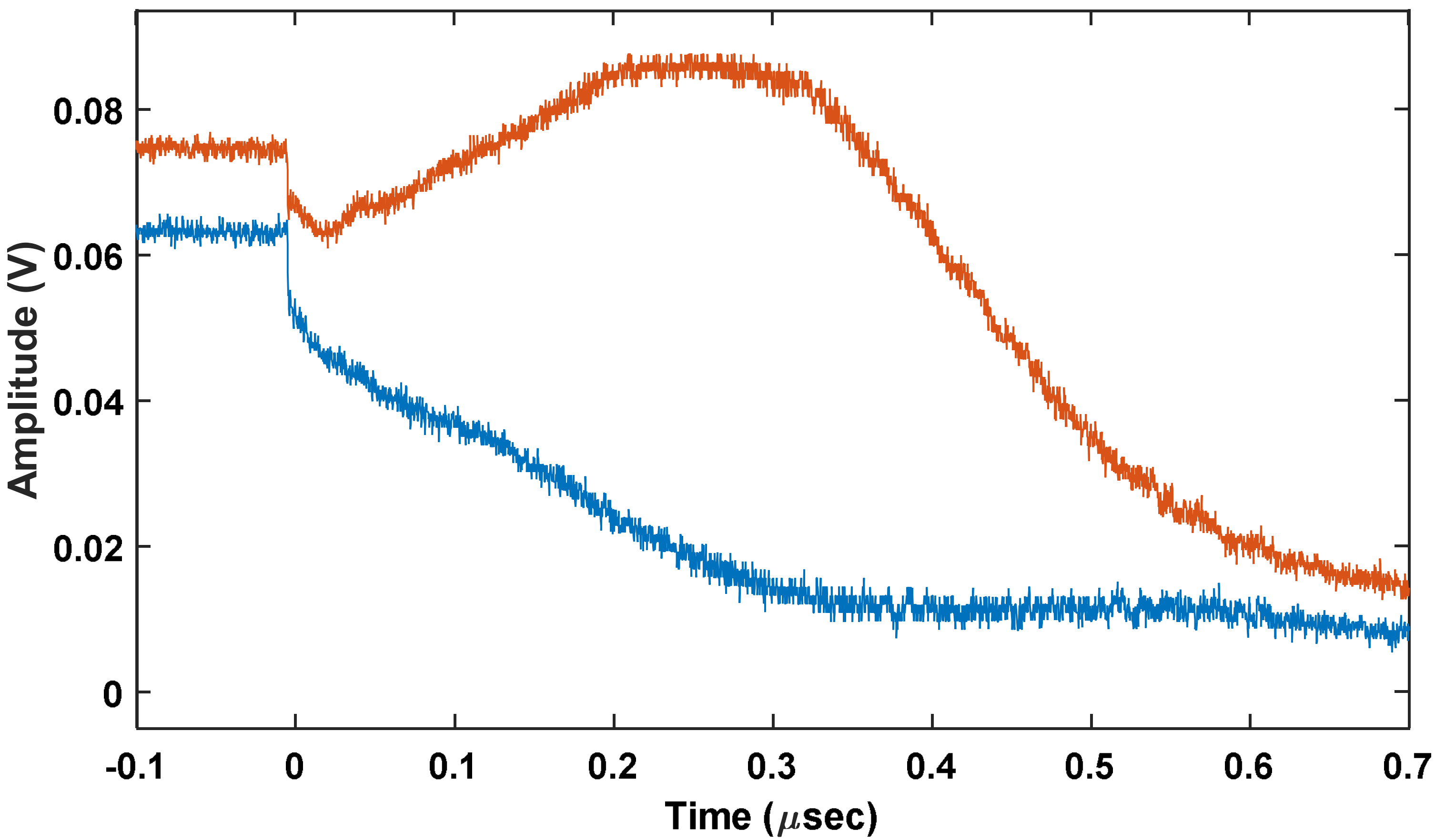
The first experiment was a 2.5 km/s impact onto a tin reflector sample



The VISAR data reveals a clean and consistent shock

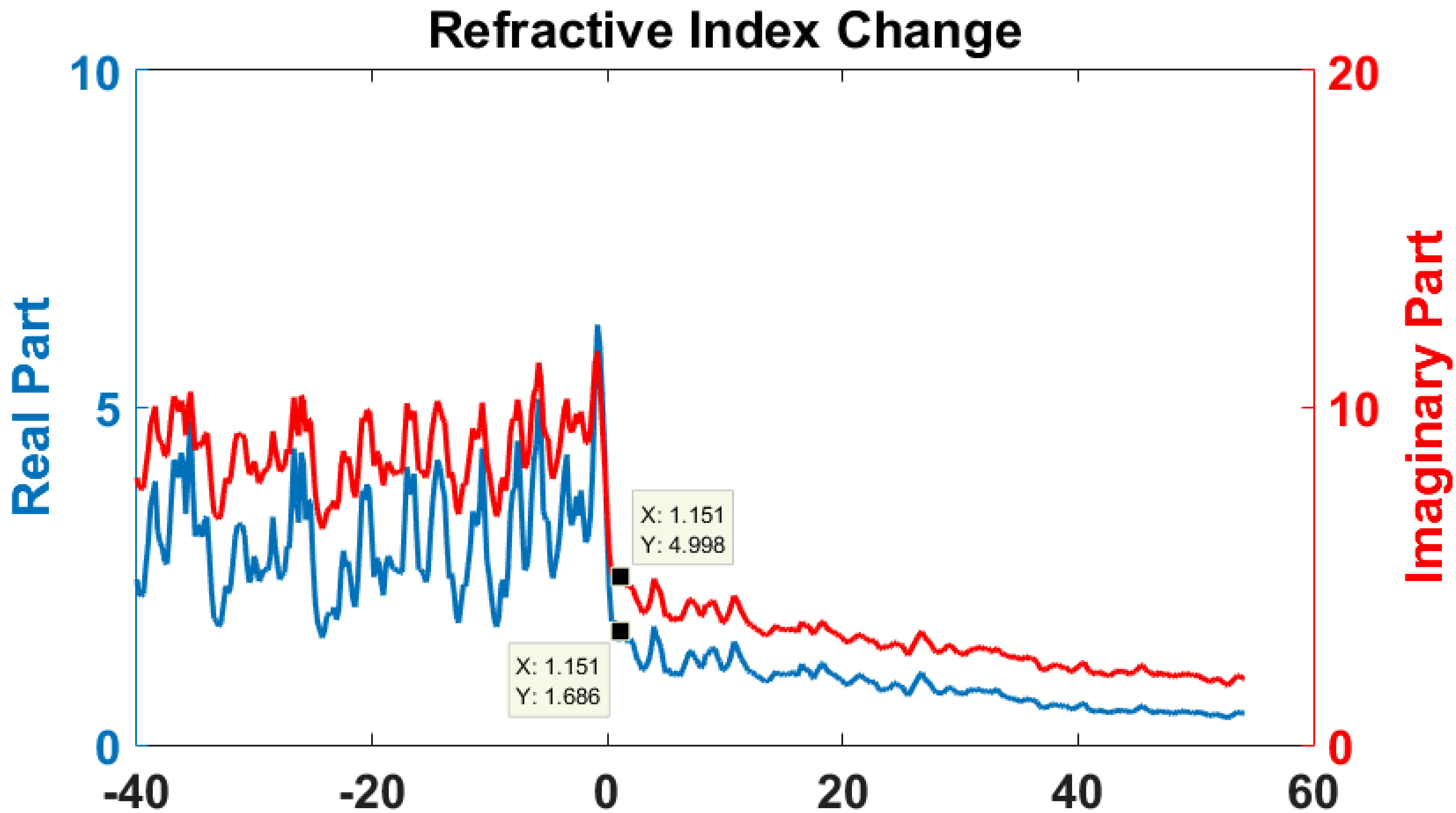


Ellipsometry data output of shock-melted tin

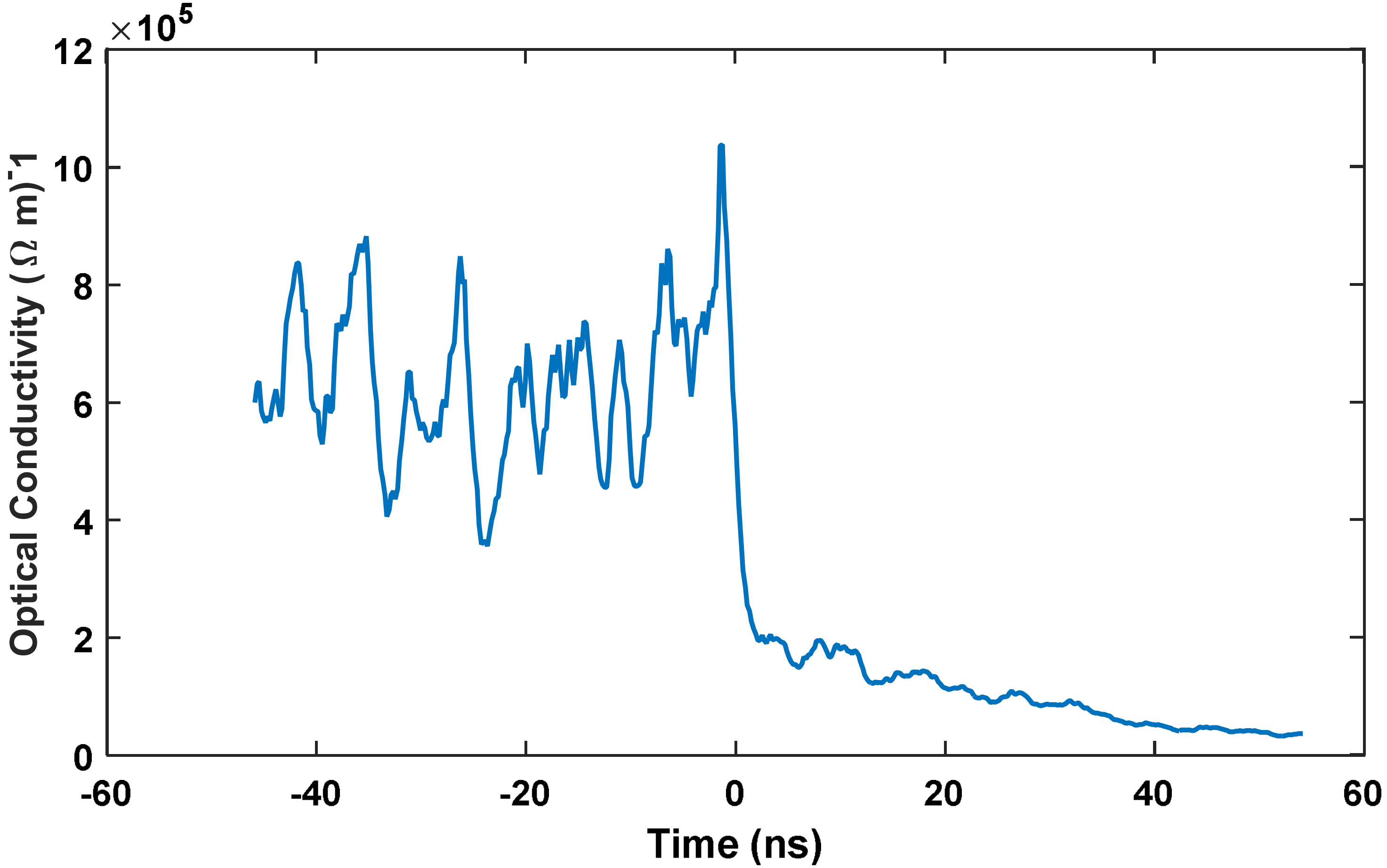


The post-shock behavior indicates that window birefringence may still be present

Converting the signal to refractive index reveals a drop in both n and k upon shock

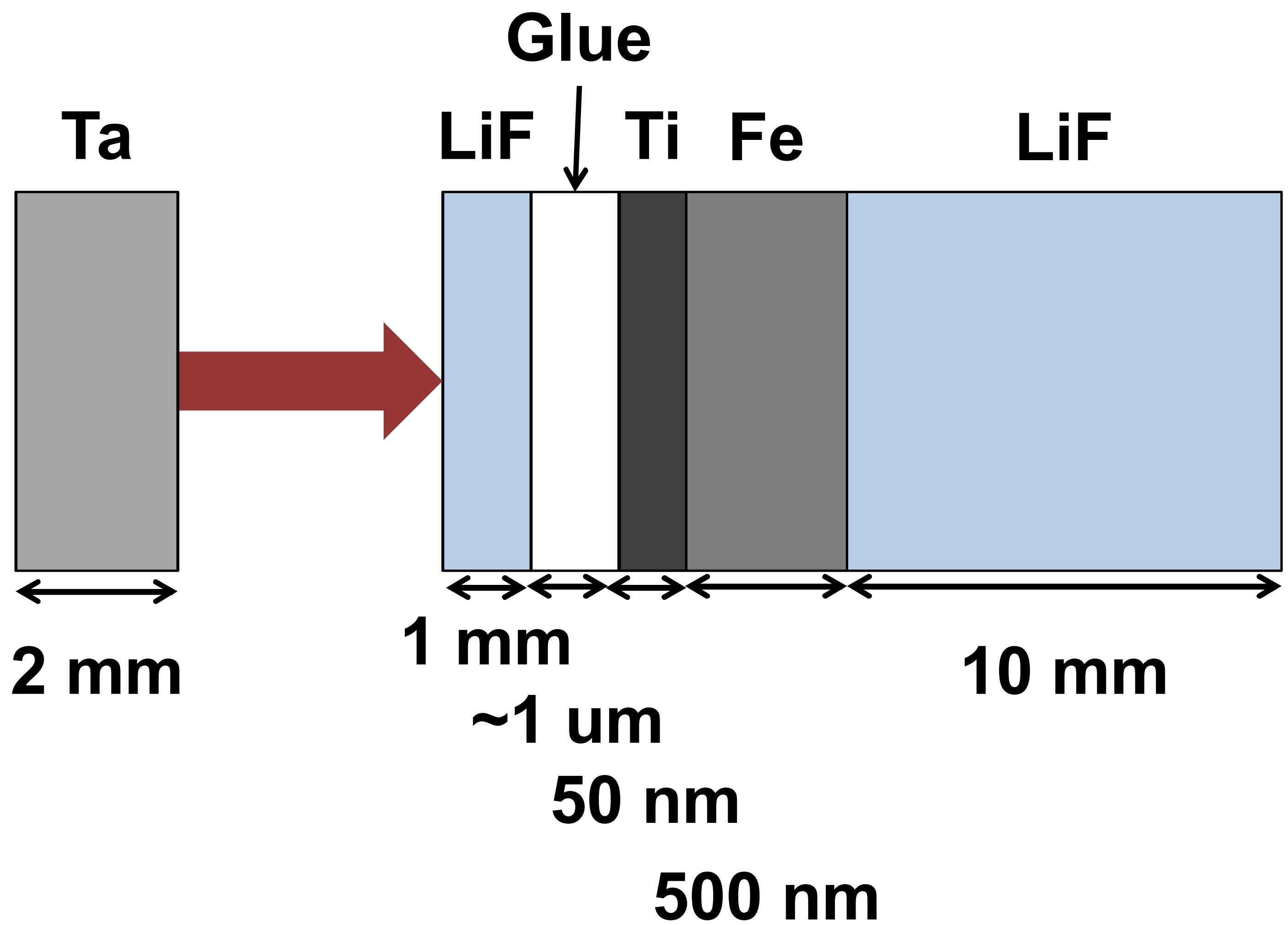


The conductivity shows a significant drop upon shock

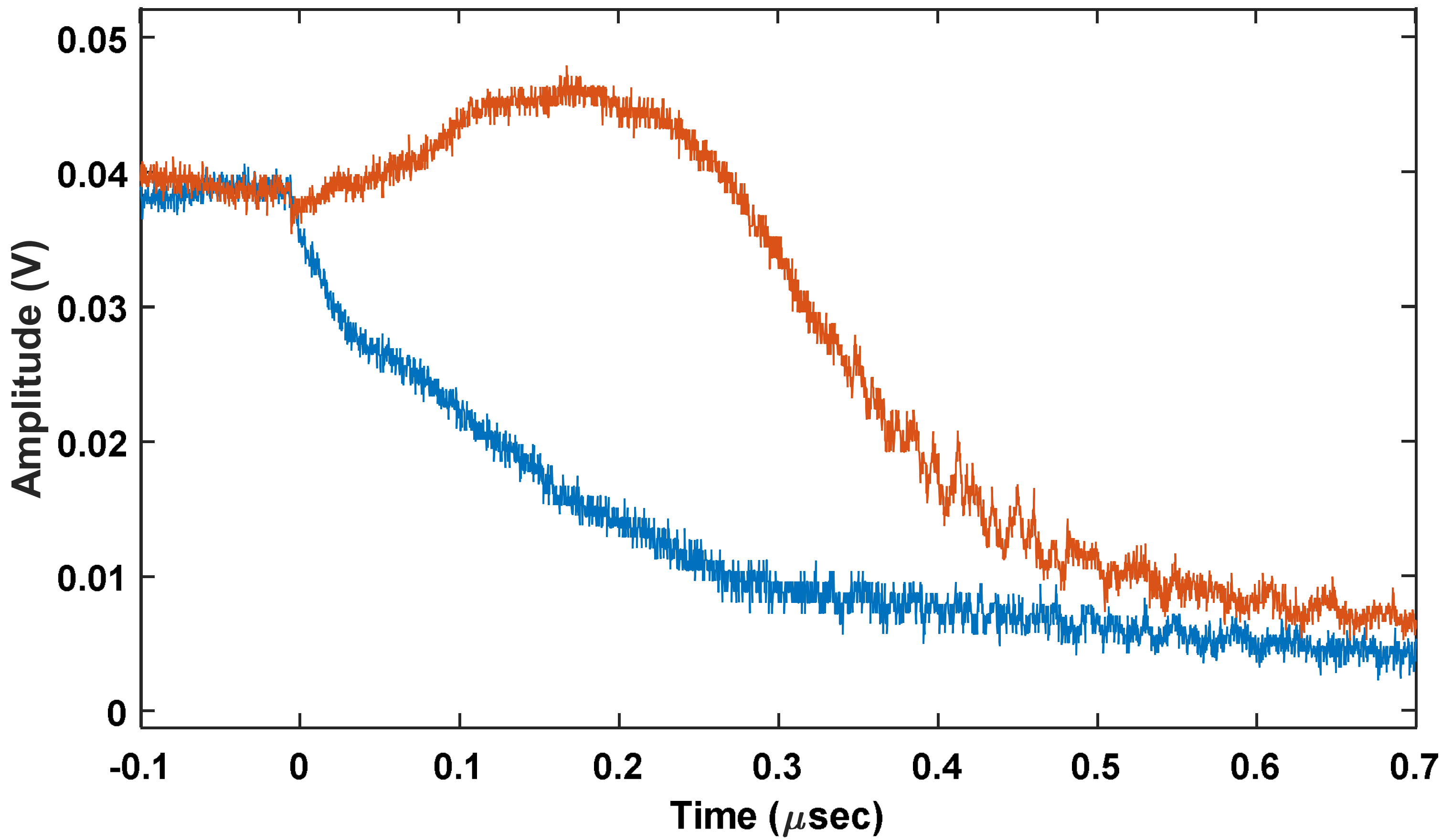


This is from data that has been smoothed with a Savitzky-Golay filter.

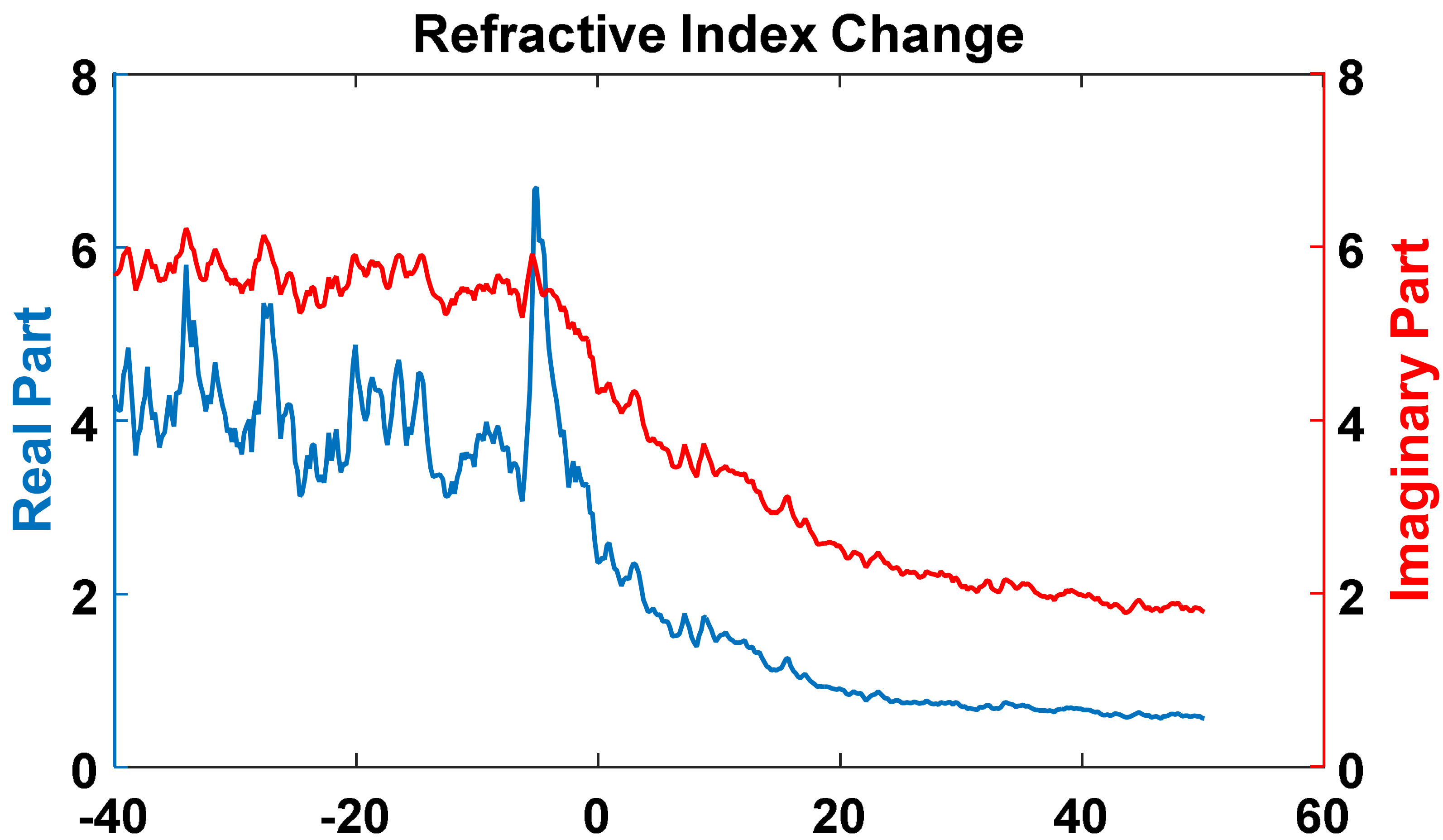
The second shot was at the same conditions as the first, but with an iron reflector instead of tin



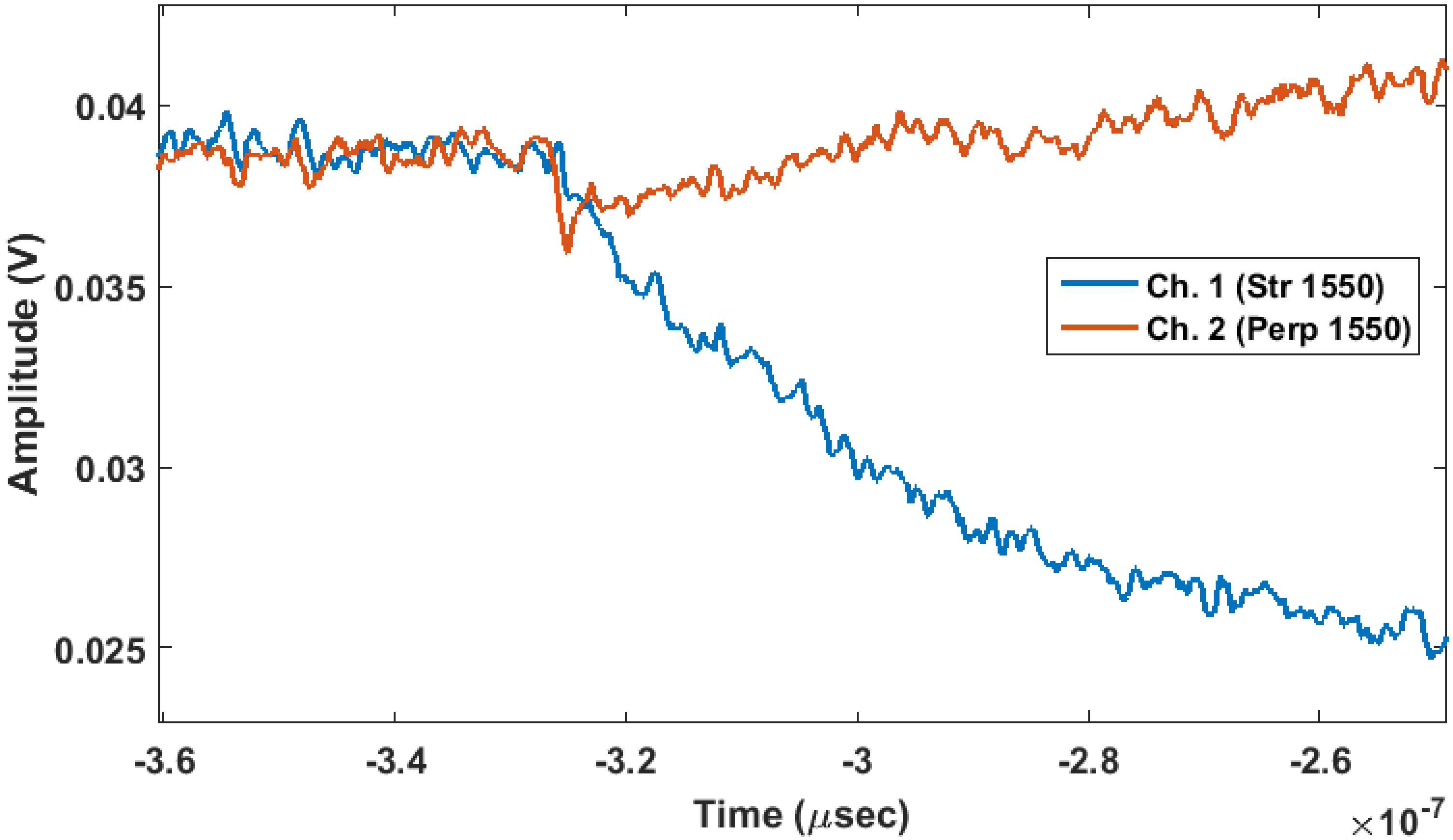
The ellipsometry data output from the iron experiment show qualitatively very similar behavior after initial shock



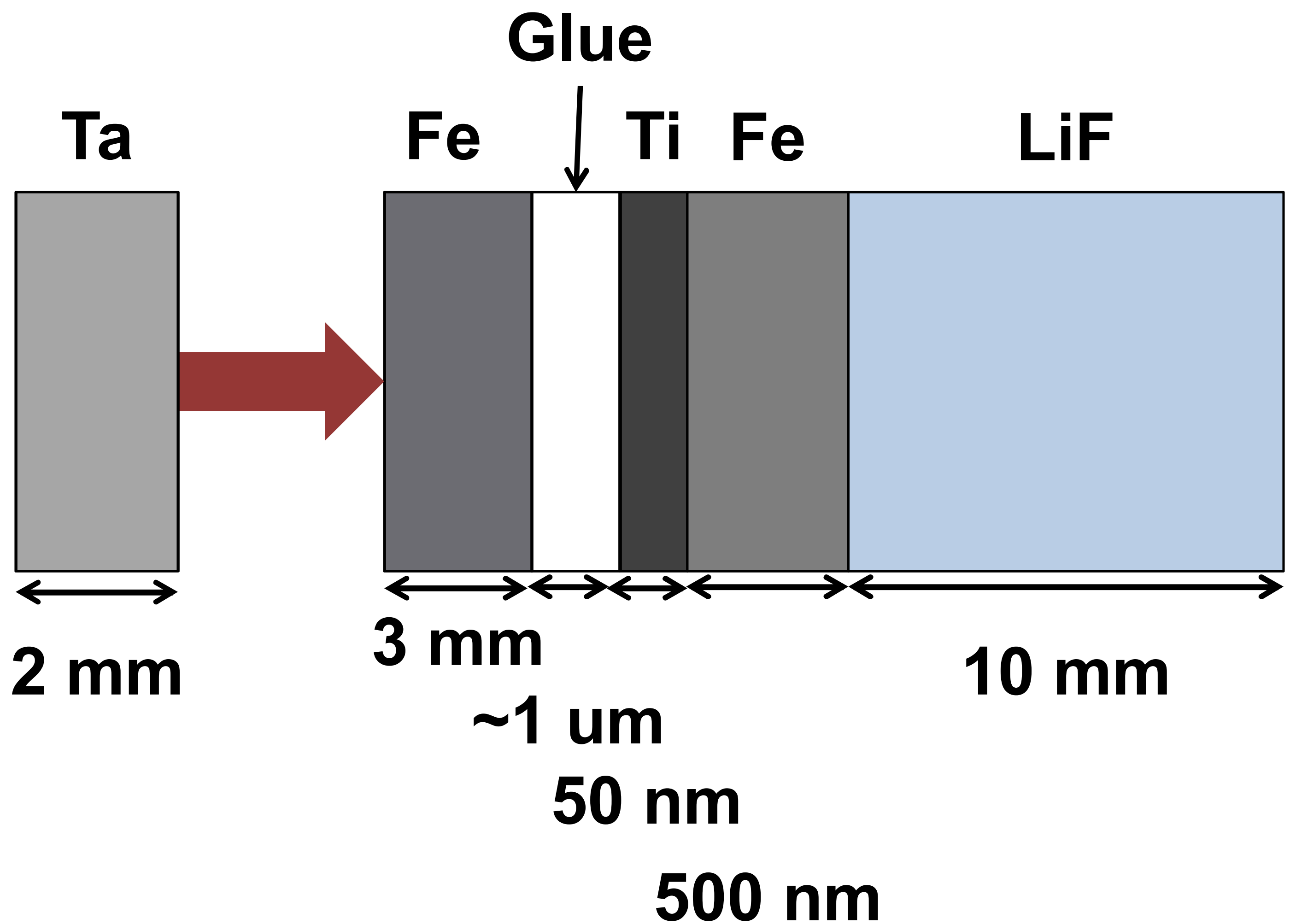
Converting the data to refractive index shows a spike near shock



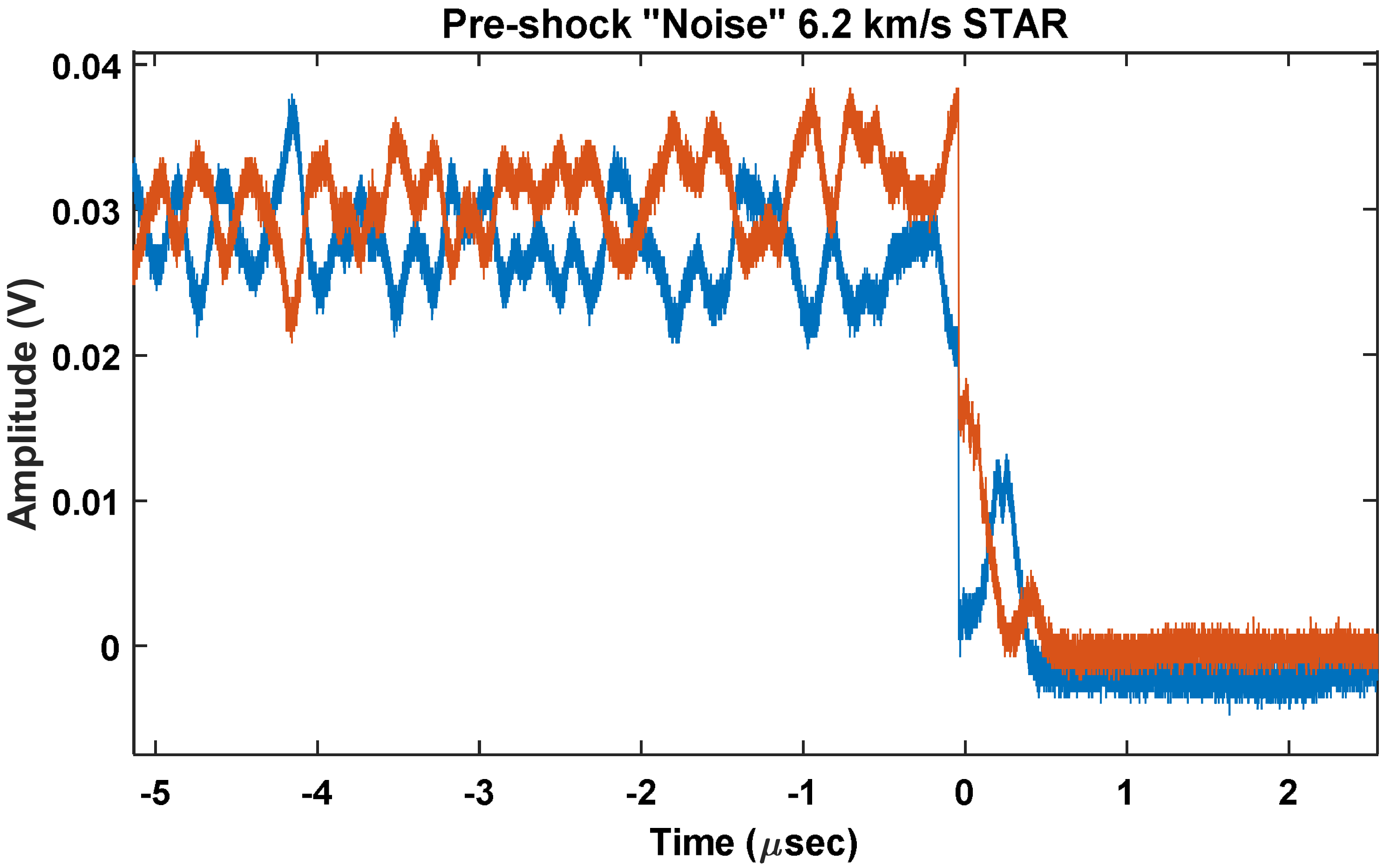
A zoom of the early time reveals that the spike in the material properties can be caused by a relatively minor spike in noise



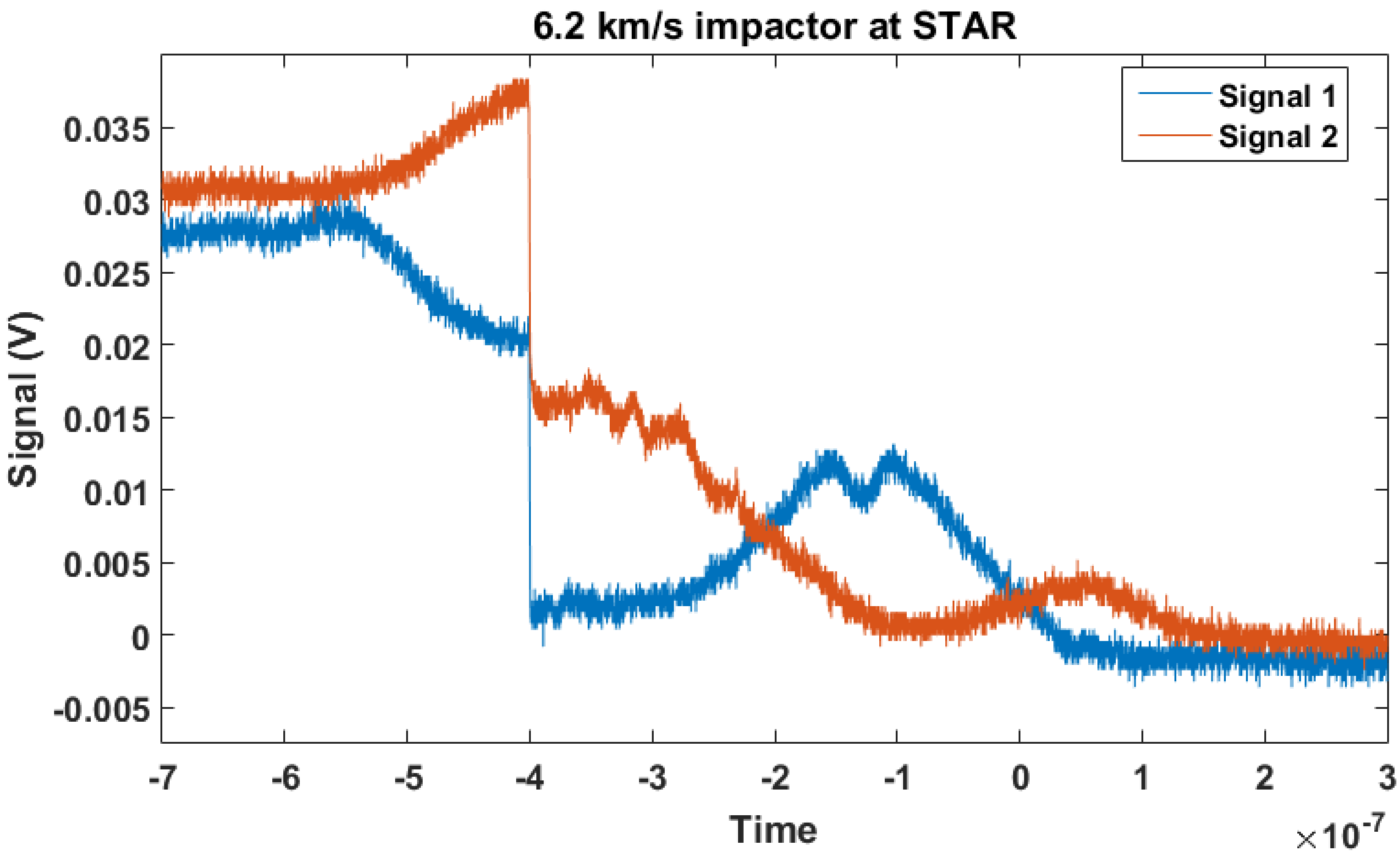
The final shot was a 6.2 km/s impact onto iron – the condition needed for shock-melting



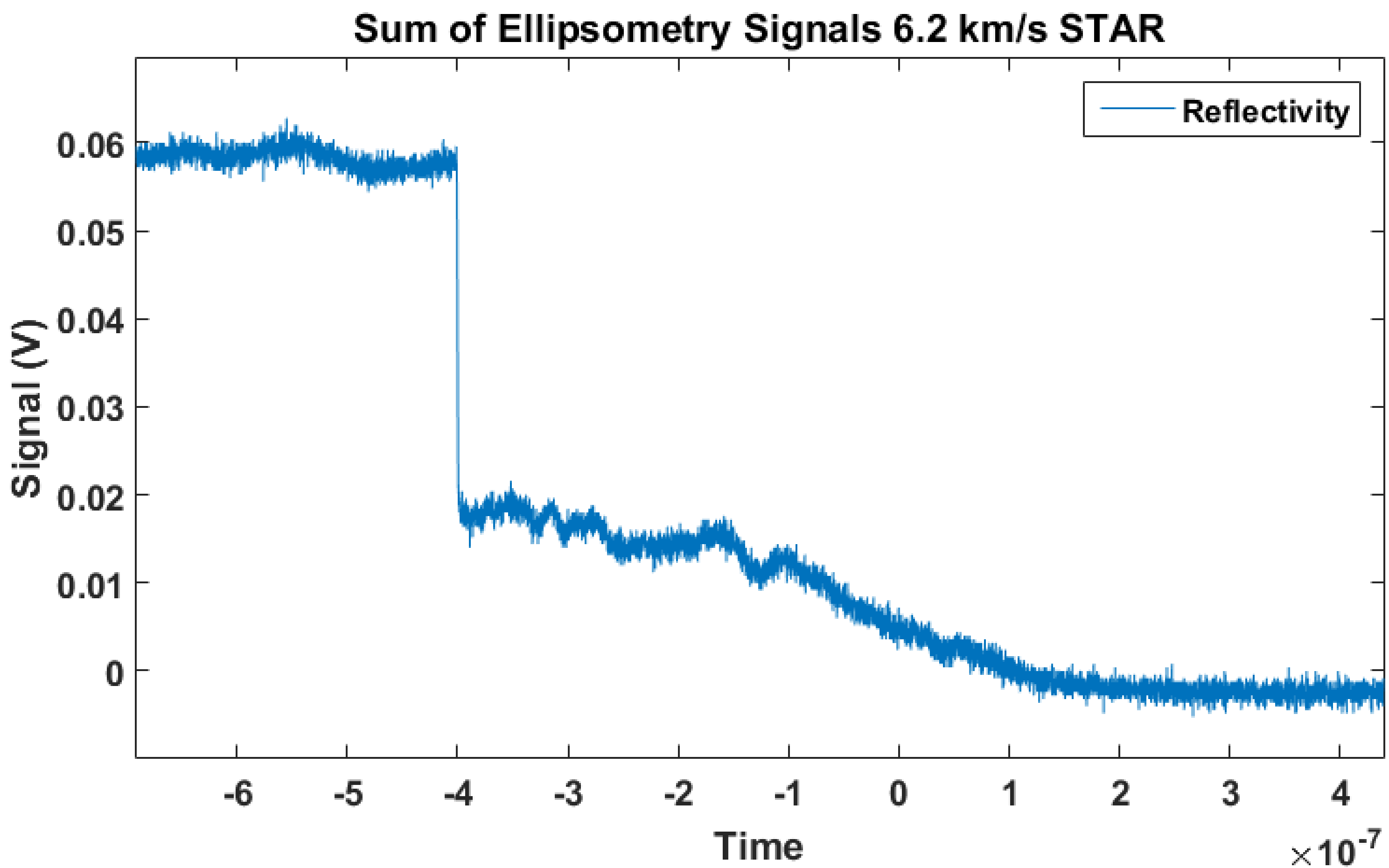
The pre-shock signals of this experiment show correlated oscillations in the data of unknown cause



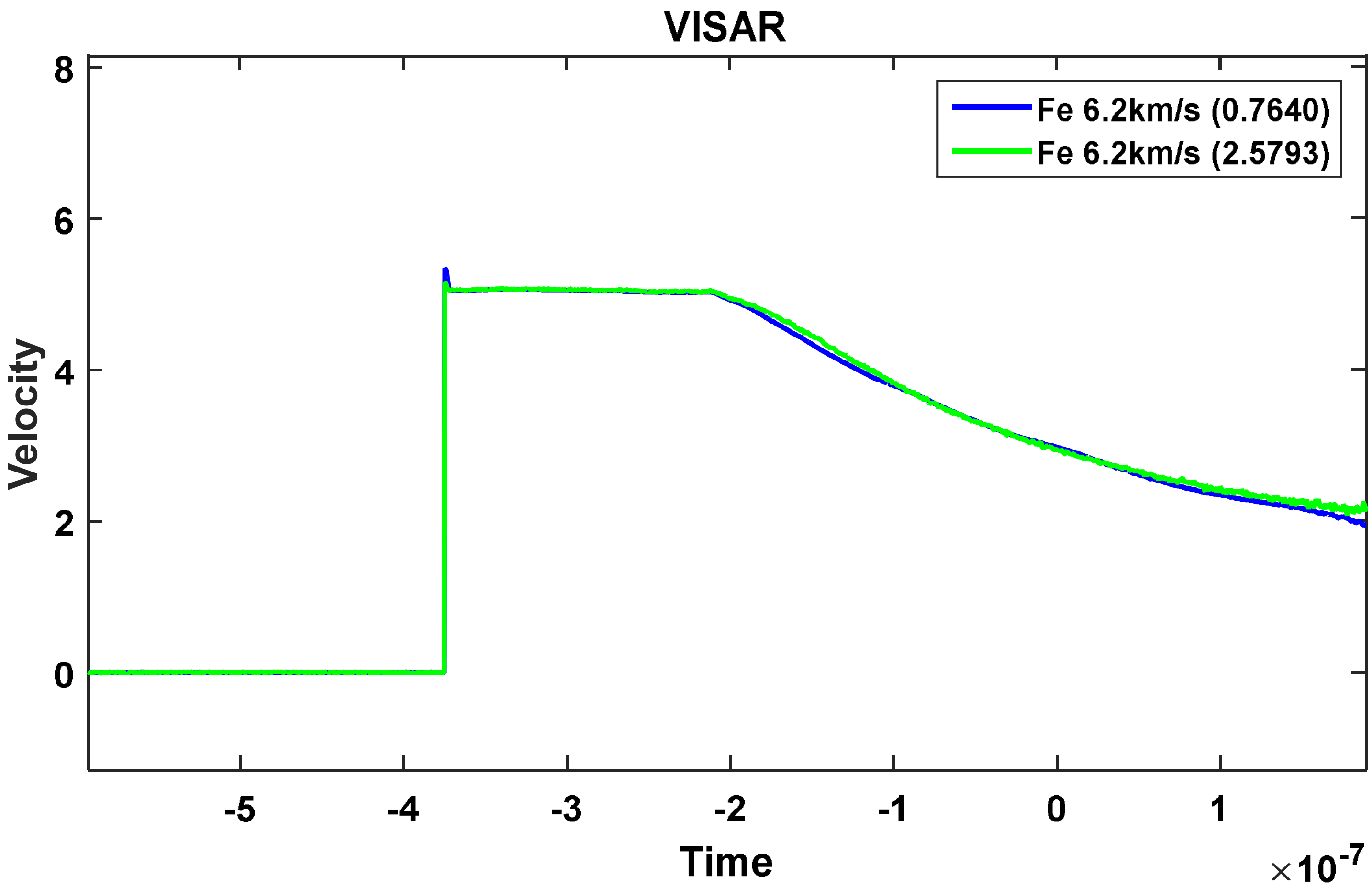
A sharp drop in total reflectivity is seen at impact, however the pre-shock oscillations prevent an appropriate reference for the ellipsometry analysis to be completed



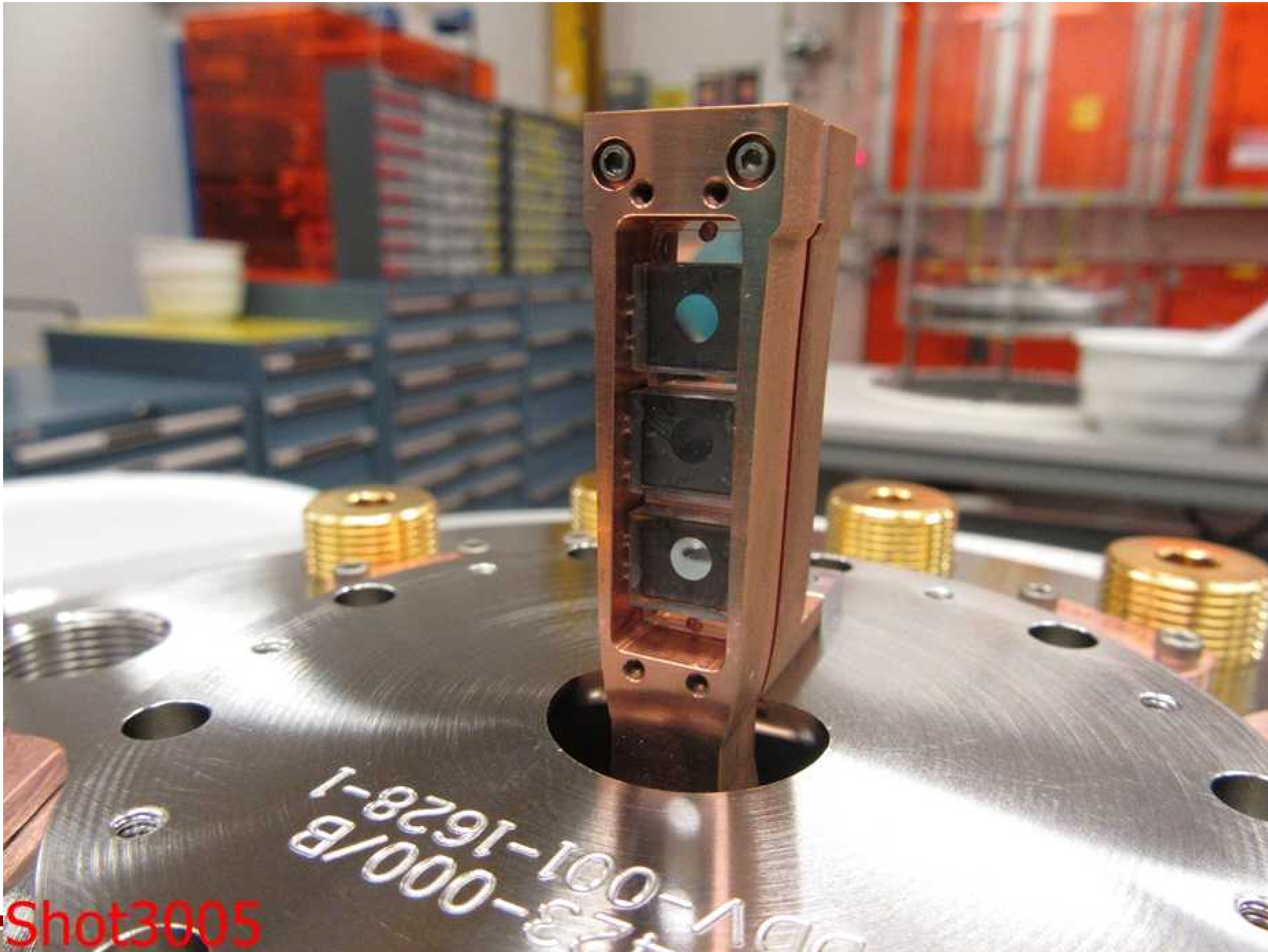
Such a large drop in reflectivity is not expected from the iron conditions achieved

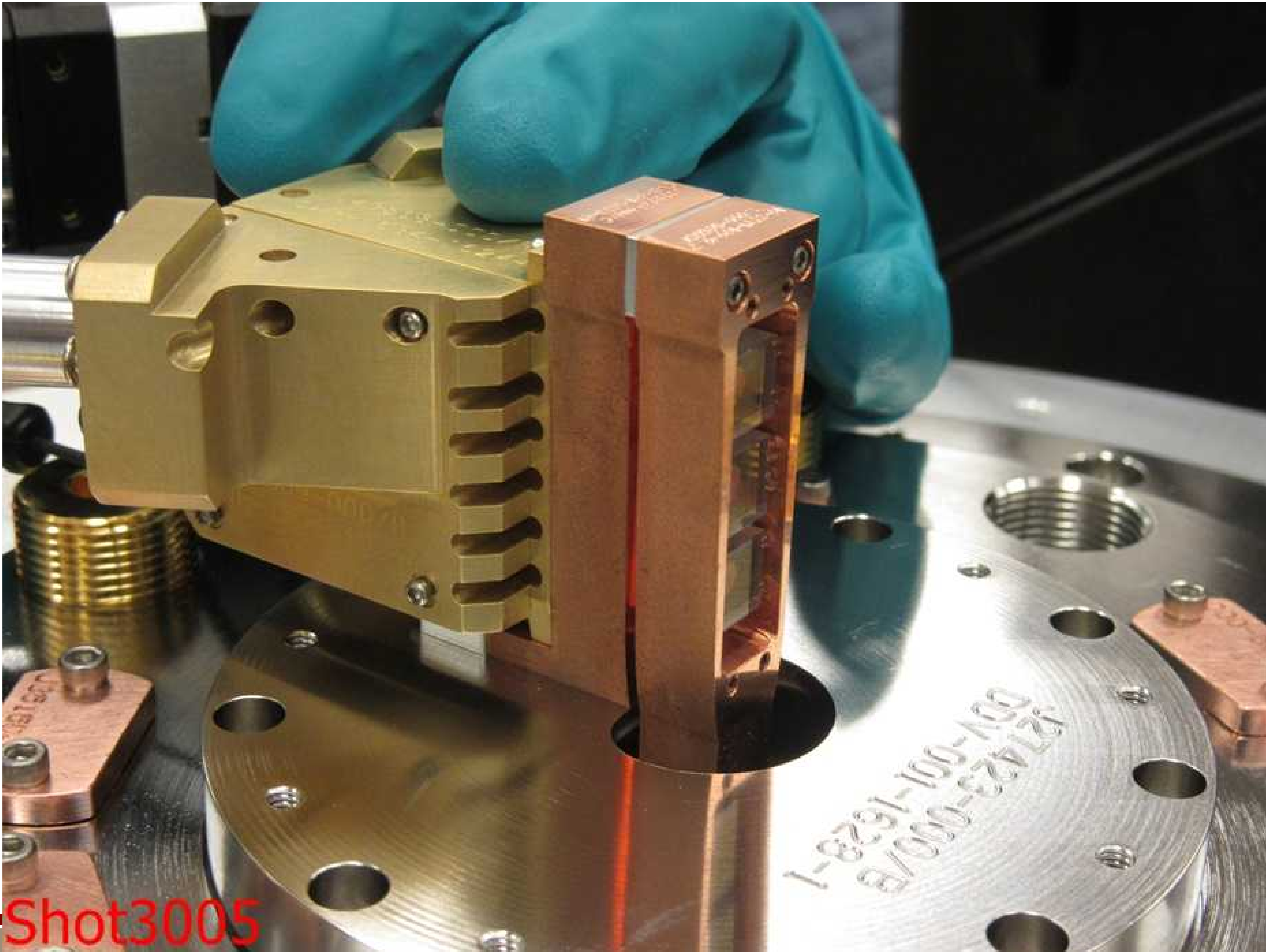


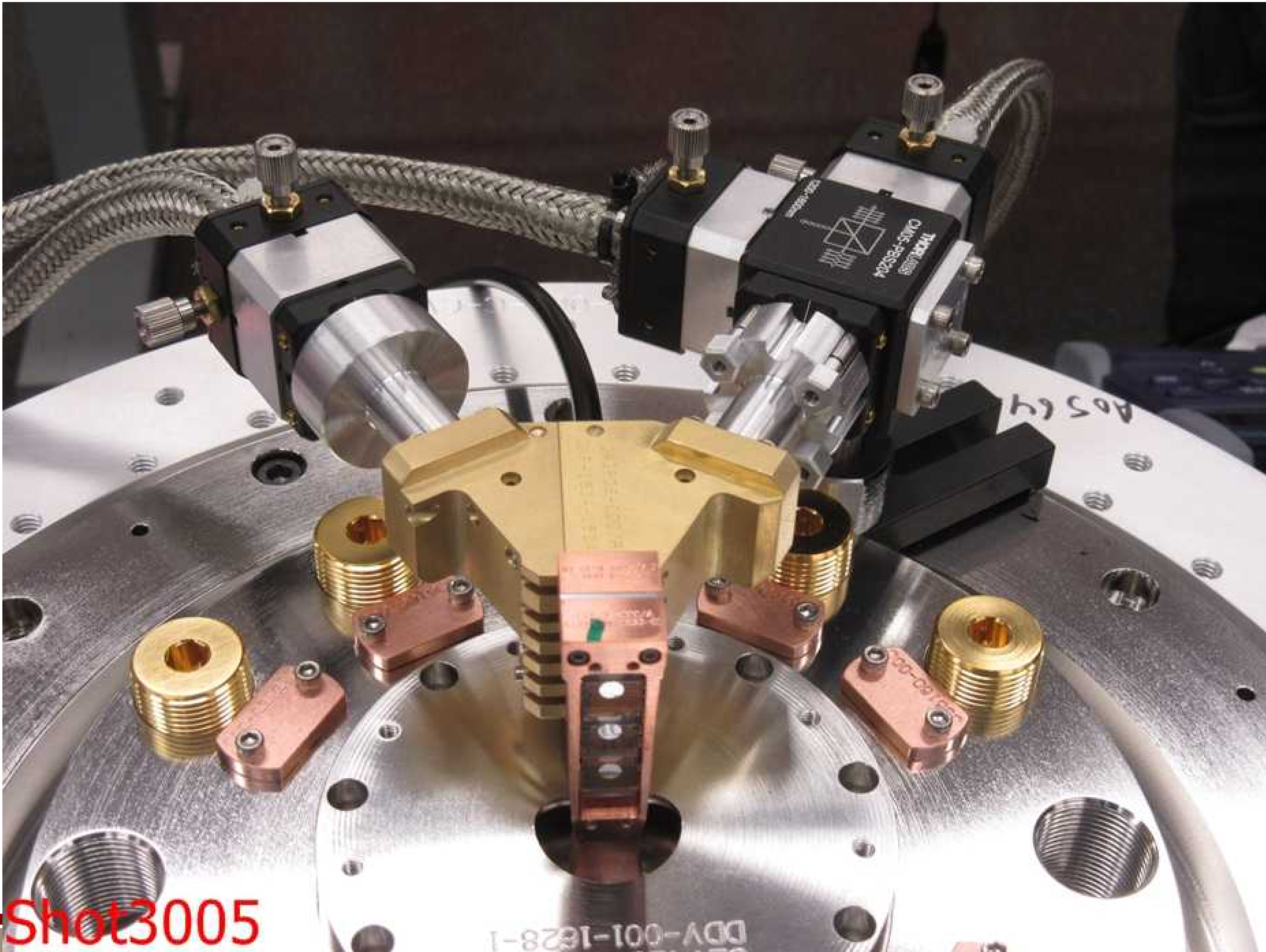
The VISAR data does not reveal any strange behavior

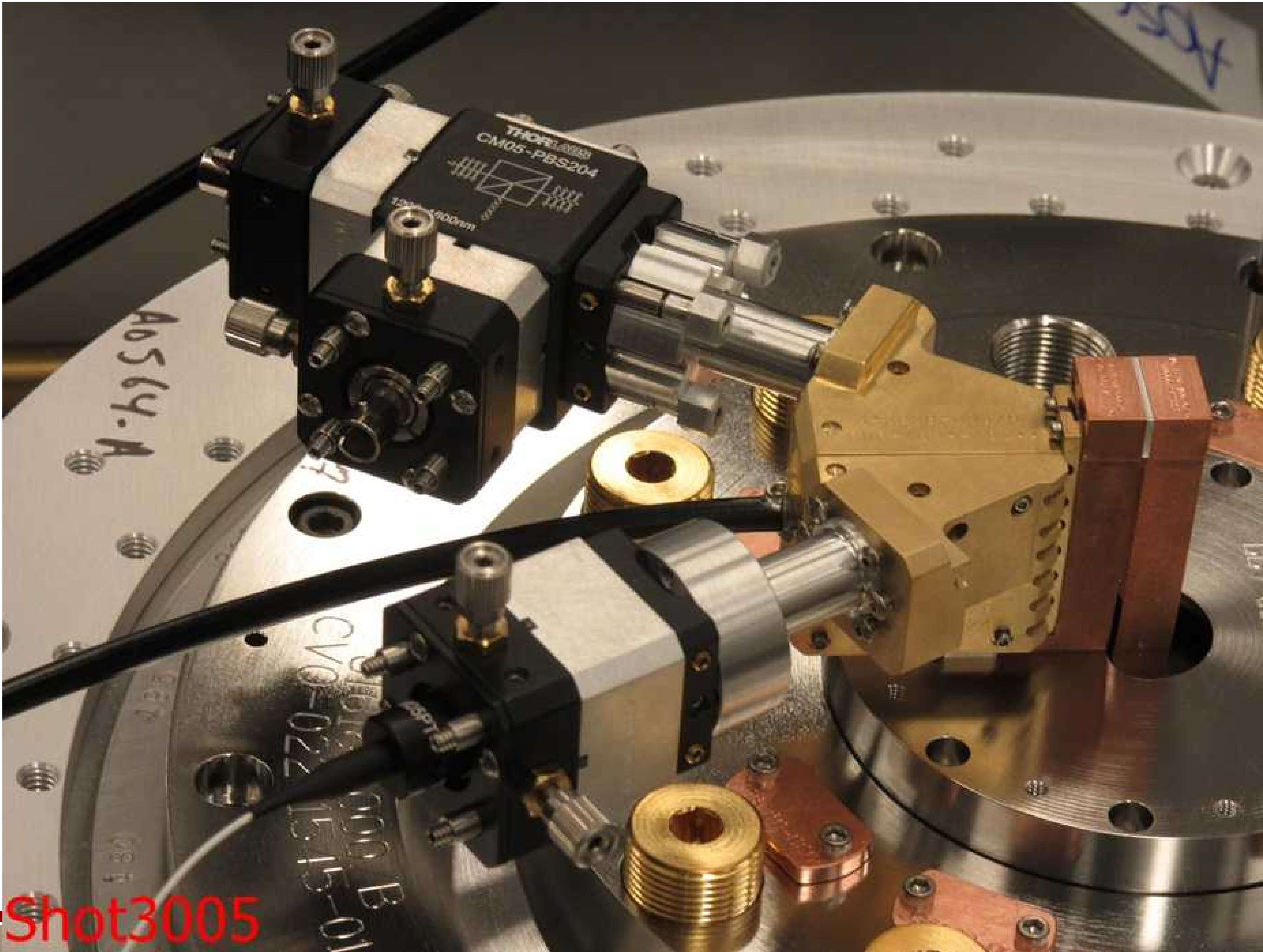


EXPERIMENTS ON THE Z MACHINE

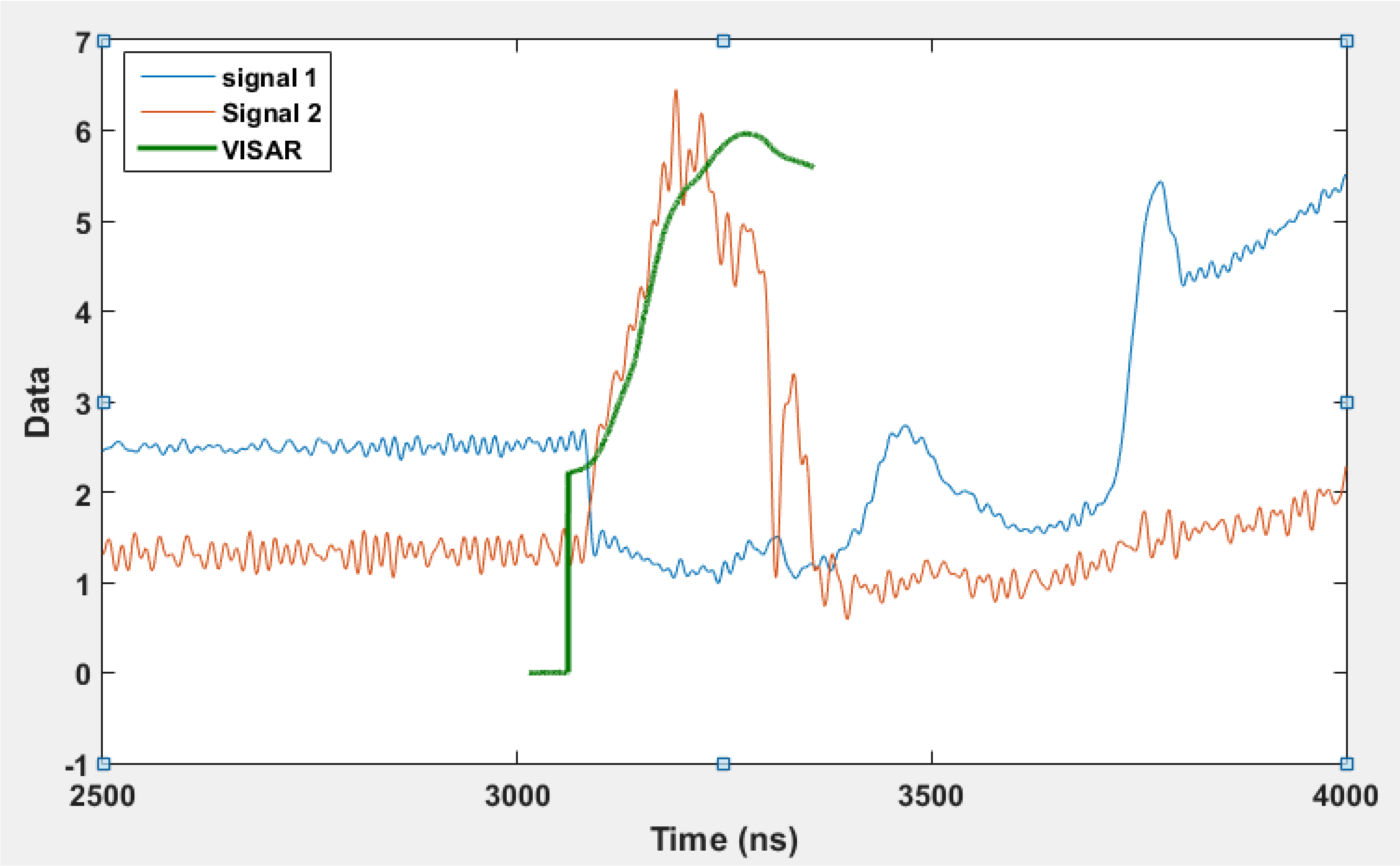

Shot3005


Shot3005


Shot3005

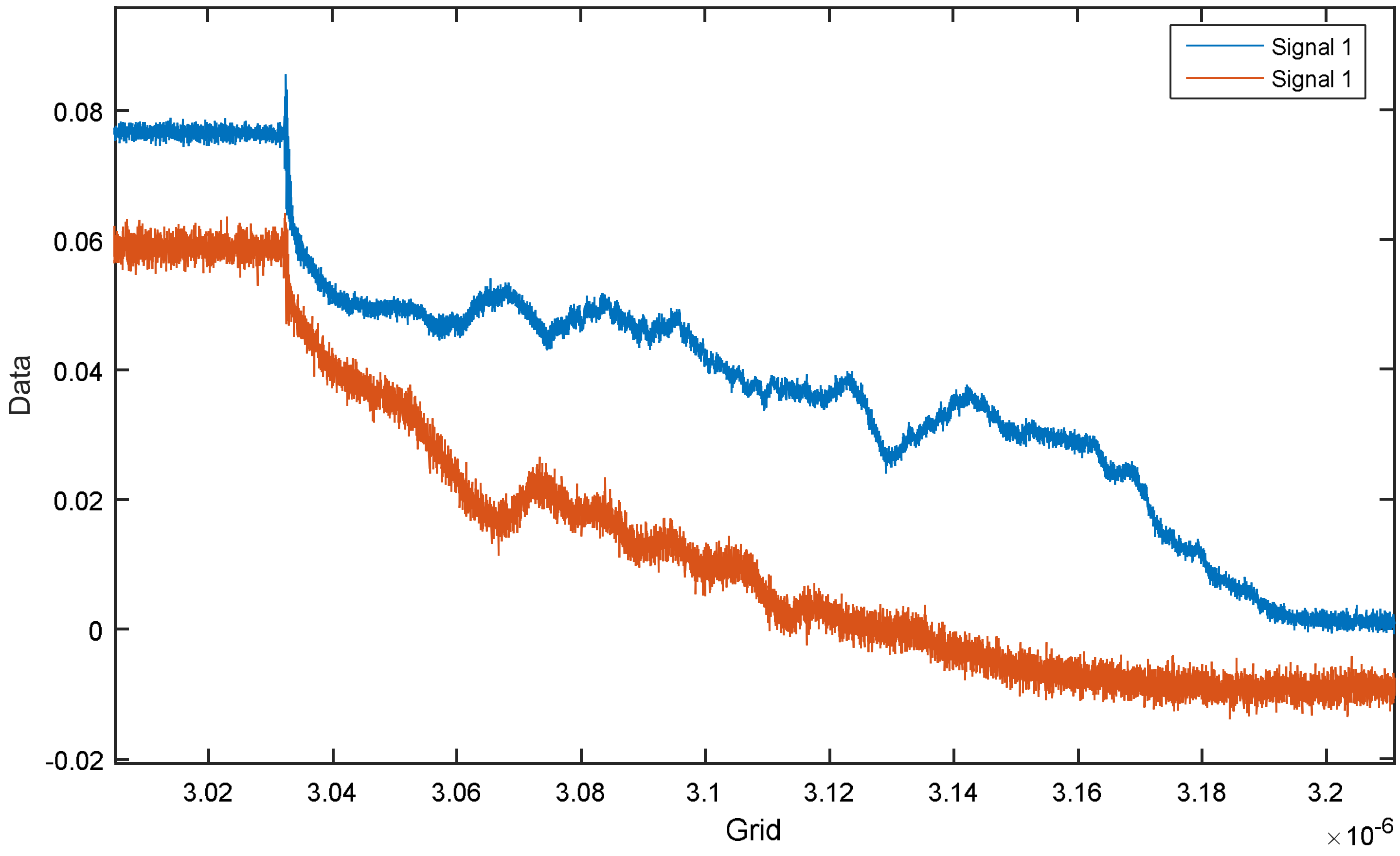

THORLABS
CM05-PBS204
Shot3005

Our initial ride-along experiments revealed the promise of data, as well as several engineering problems

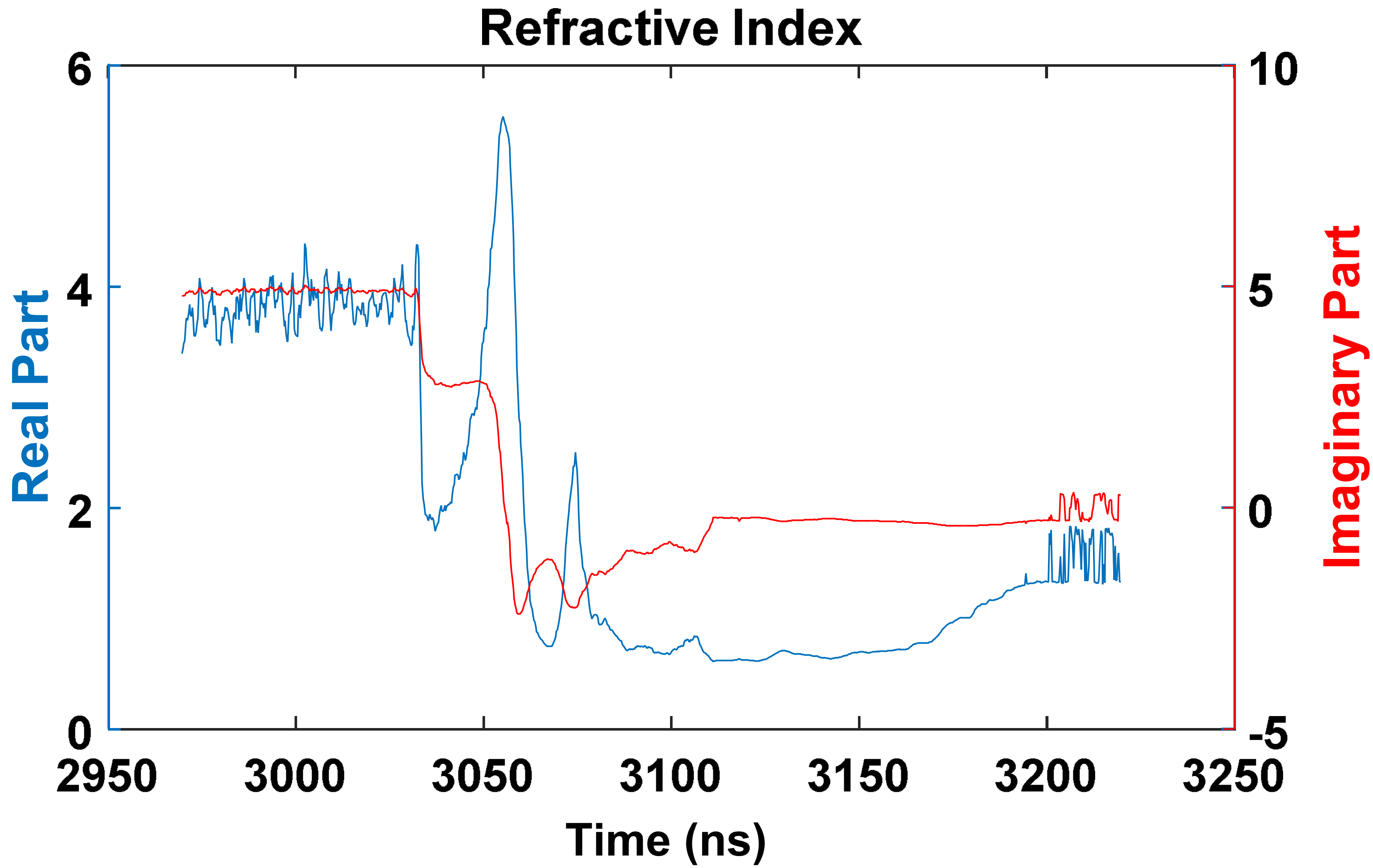


A0652-A
R2
R1
Shot3102

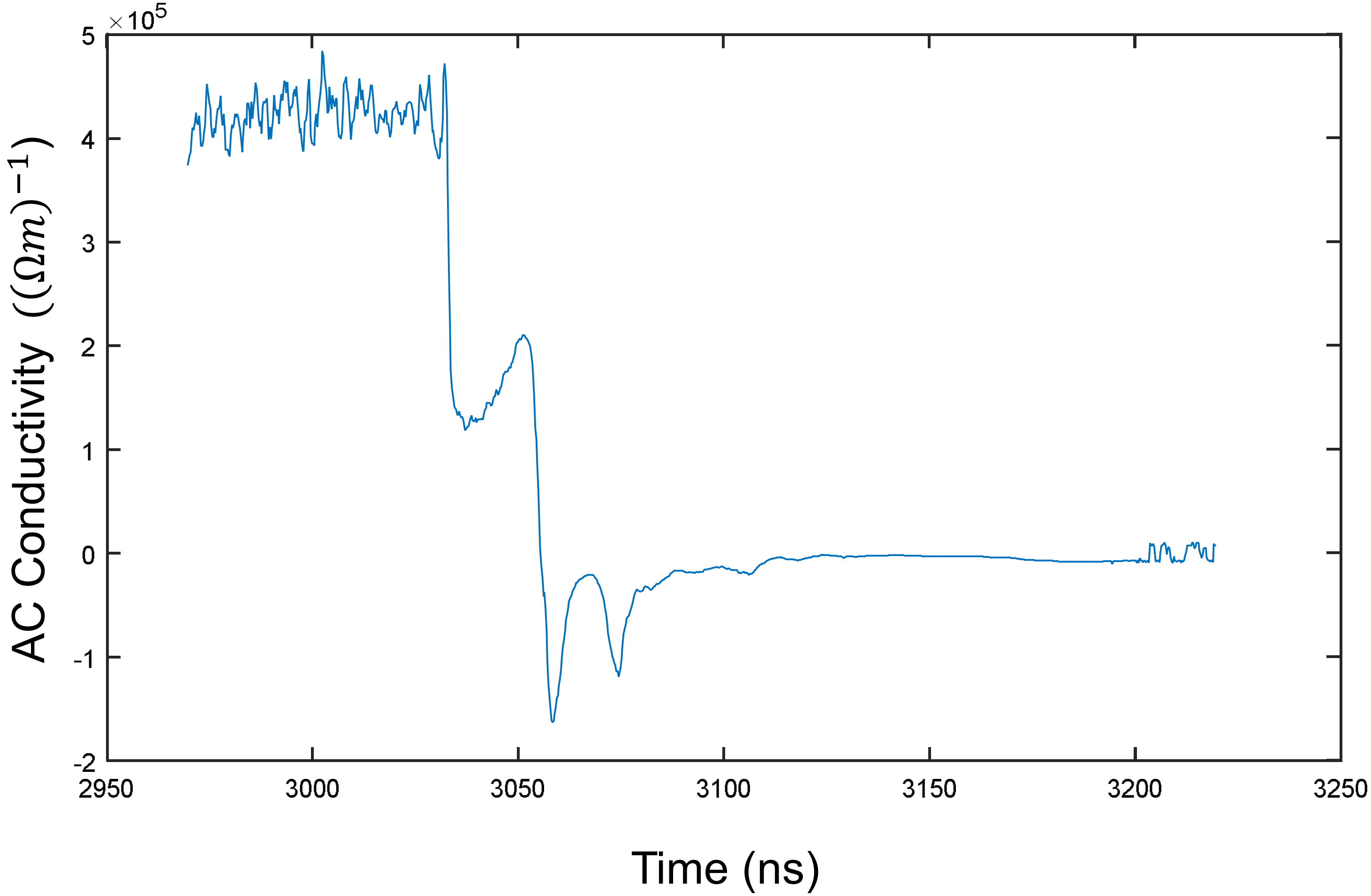
The first results of our dedicated experiment on iron were a significant improvement in initial light alignment



The analysis of the refractive index reveals the properties going unrealistic at very early times (negative k value)



The conductivity shows a drop at shock



Most simulations suggest that our calculated conductivity is significantly too low

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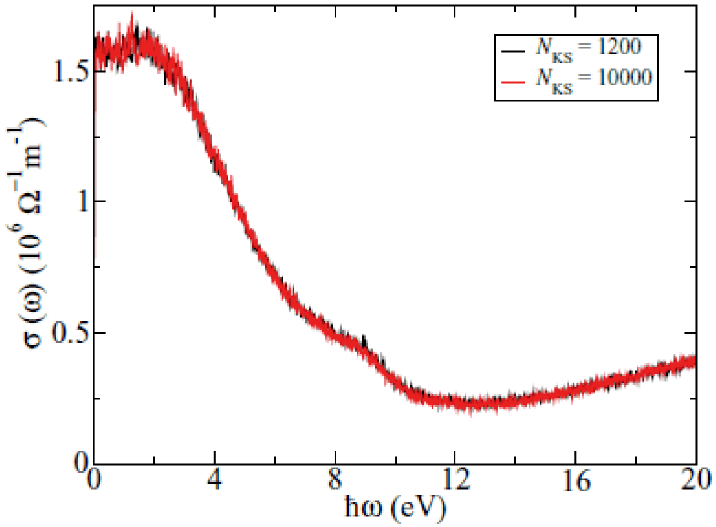


FIG. 1. (Color online) Optical conductivity $\sigma(\omega)$ of liquid iron as a function of energy computed using $N_{KS} = 10\,000$ and $N_{KS} = 1200$ Kohn-Sham states for one configuration extracted from the ensemble at $p = 328$ GPa and $T = 6350$ K.

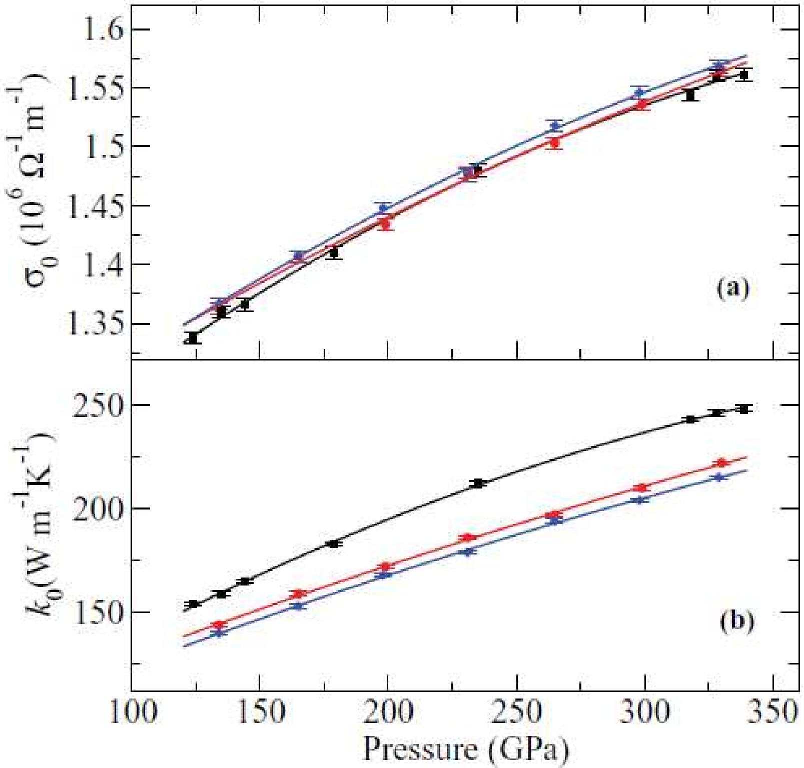
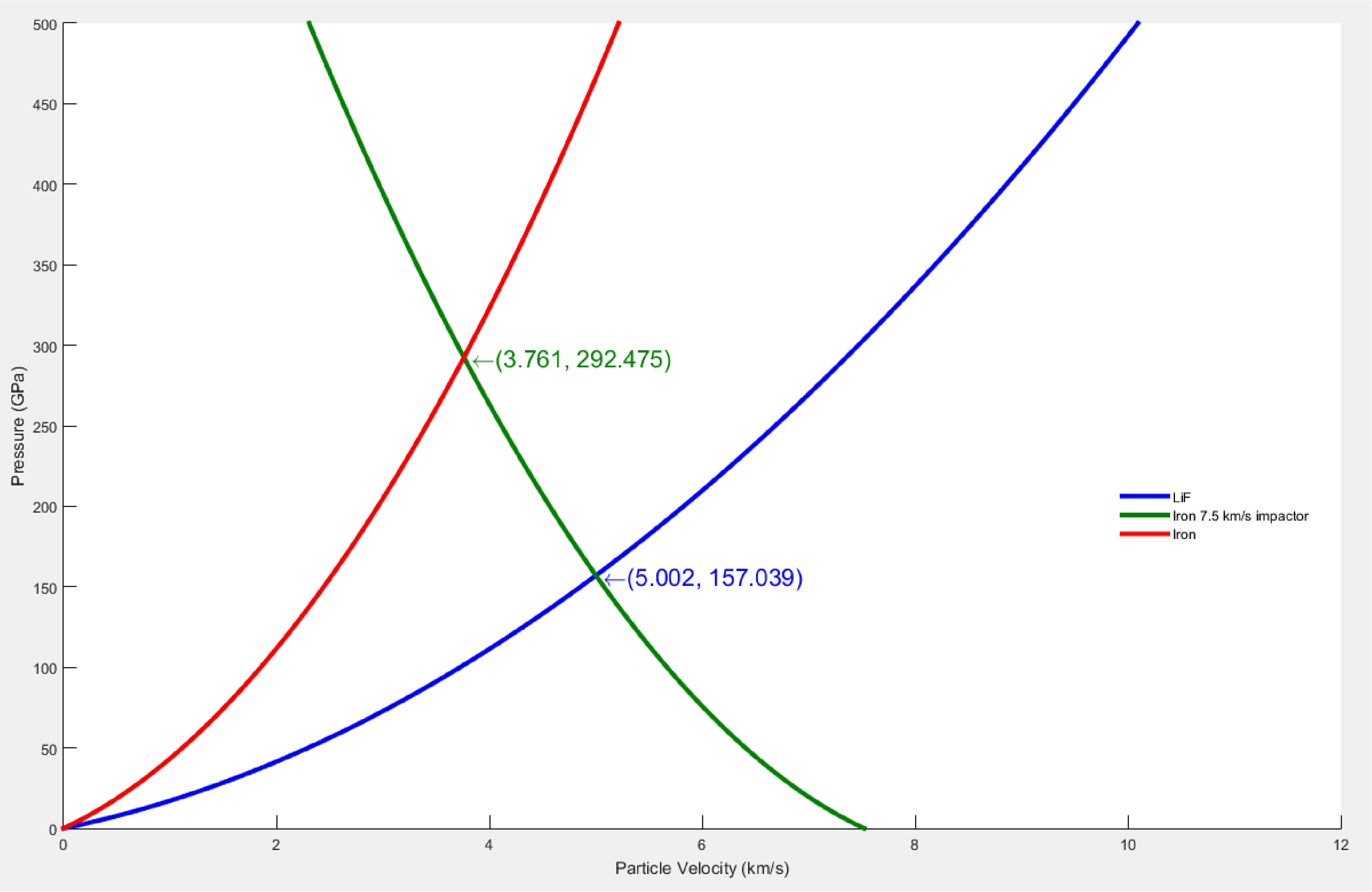


FIG. 11. (Color online) Electrical (a) and thermal (b) conductivity of liquid iron at Earth's core conditions, computed on the FERRO (black), CORE5700 (red), and CORE5500 (blue) adiabats. Lines are quadratic fits to the first-principles raw data (symbols). Error bars (2 s.d.) are estimated from the scattering of the data obtained from 40 statistical independent configurations. Results are obtained with cells including 157 atoms and the single **k** point (1/4,1/4,1/4), which are sufficient to obtain convergence within less than 1%.

Pozzo, Phys Rev B, 2013

Impact Conditions Estimate



UT:

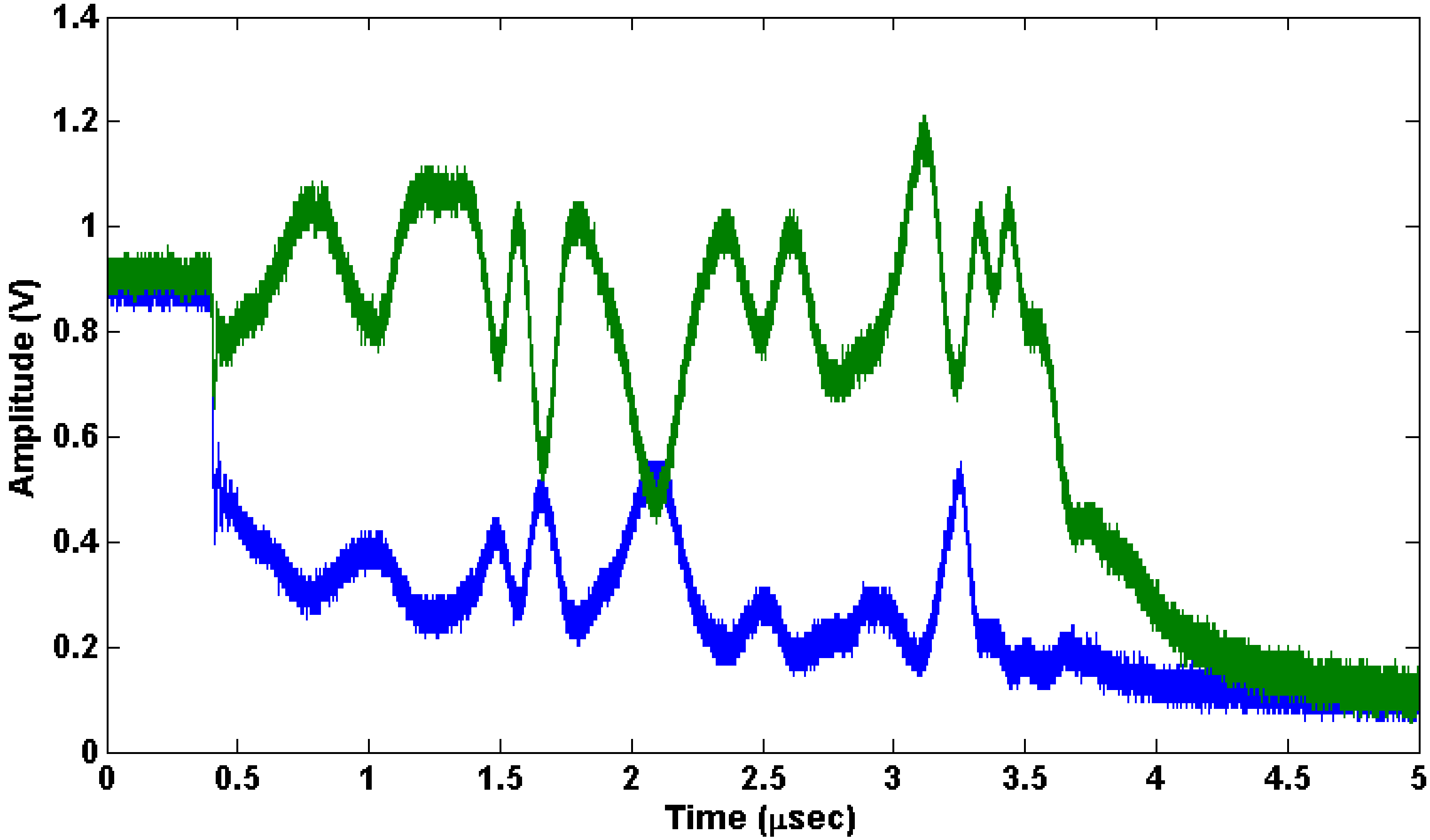
Mentor: Aaron Bernstein
Collaborator: Jung-Fu "Afu" Lin
Advisor: Todd Ditmire

Sandia:

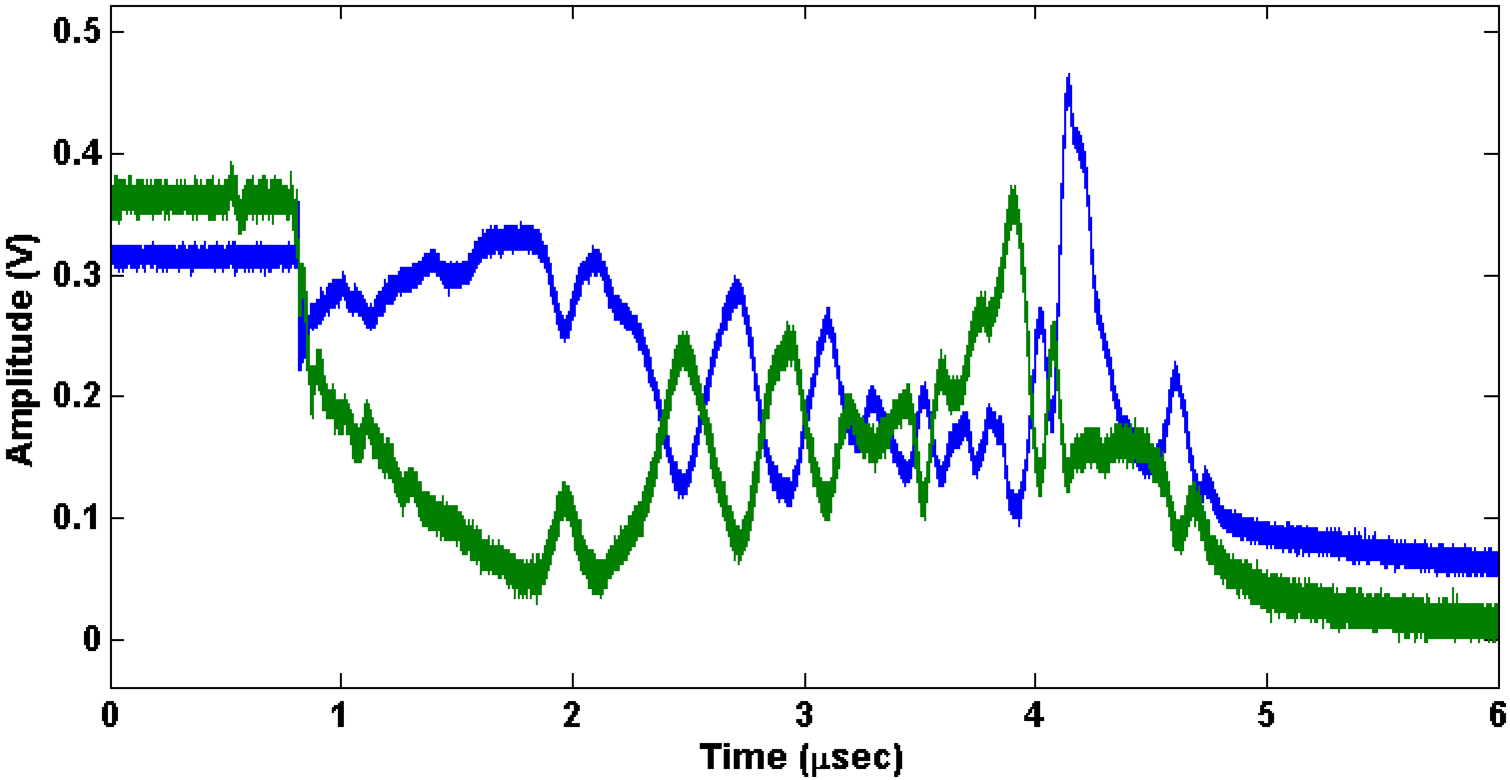
Mentors: Tommy Ao and Dan Dolan
Scientists: Chris Seagle, Jean-Paul Davis, and Andrew Porwitzky
NSTech: Sheri Payne and Richard Hacking
DICE team: Randy Hickman, Nicole Cofer, Keith Hodge, and Josh Usher
Managers: John Benage and Dawn Flicker
SEERI Program: Trish St. John and Kristy Martinez

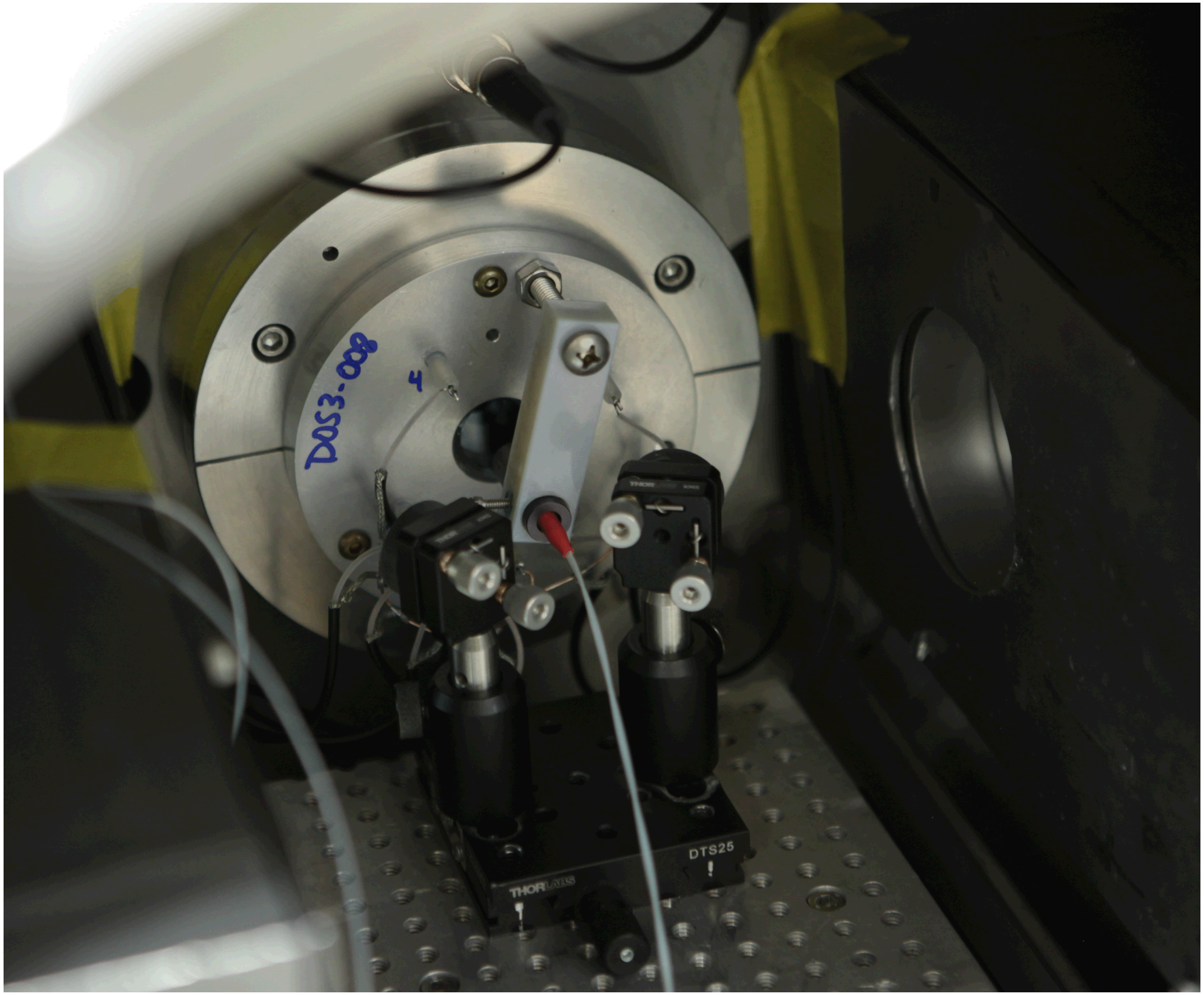
QUESTIONS?

Preheated Flier (full time)



Unheated Flier (Full Time)




DOS3-008
4
DTS25
THORLABS

The thermal DC conductivity is calculated from the dielectric value

$$\varepsilon = (\varepsilon_1 + i\varepsilon_2) = (n + ik)^2$$

$$\sigma(\omega) = \omega\varepsilon_0\varepsilon_2 - i\omega\varepsilon_0\,(\varepsilon_1 - 1)$$

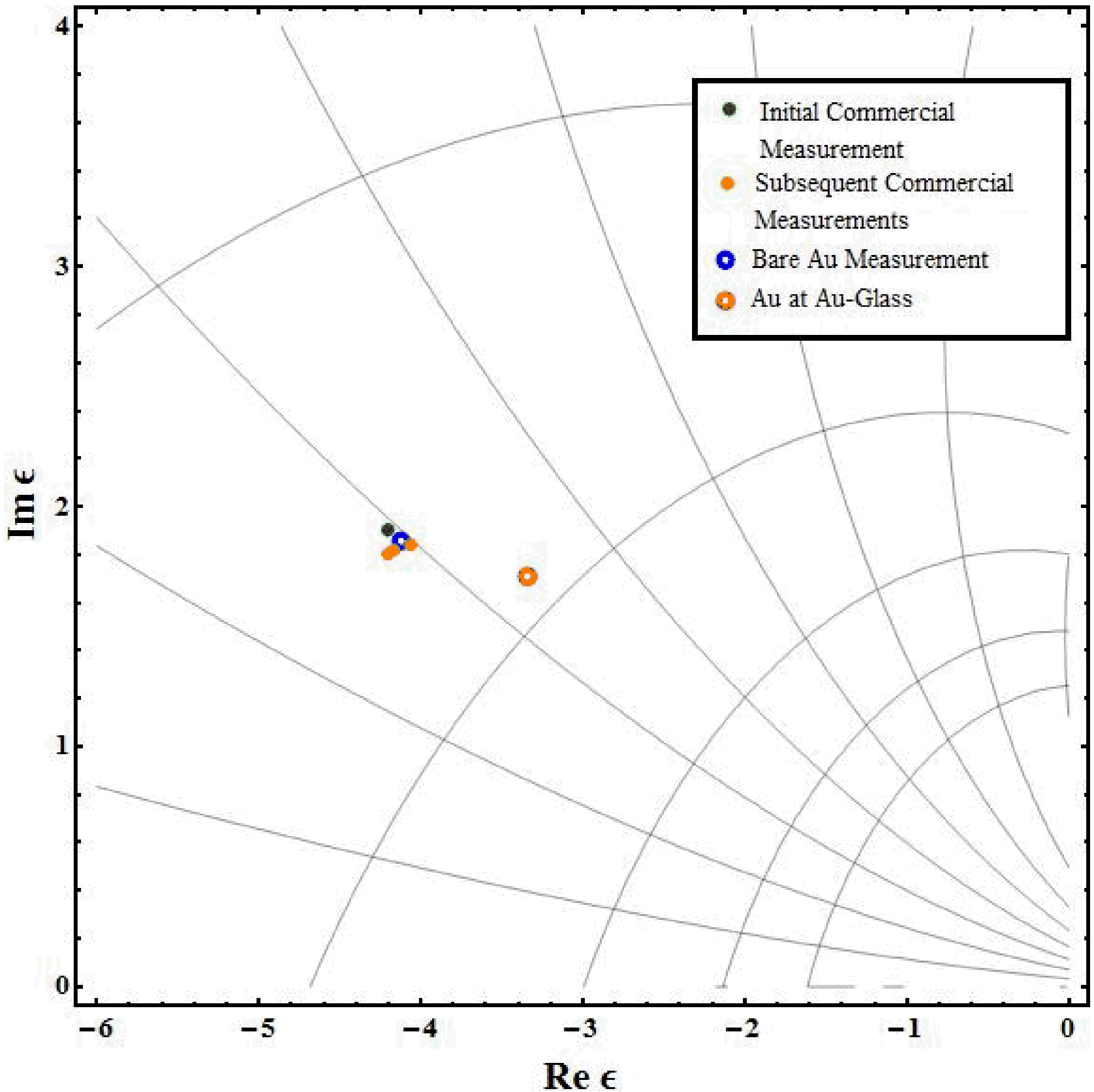
$$\sigma(\omega) = \frac{\sigma_0}{1 + i\omega\tau} = \frac{\sigma_0}{1 + \omega^2\tau^2} - \frac{i\omega\tau\sigma_0}{1 + \omega^2\tau^2}$$

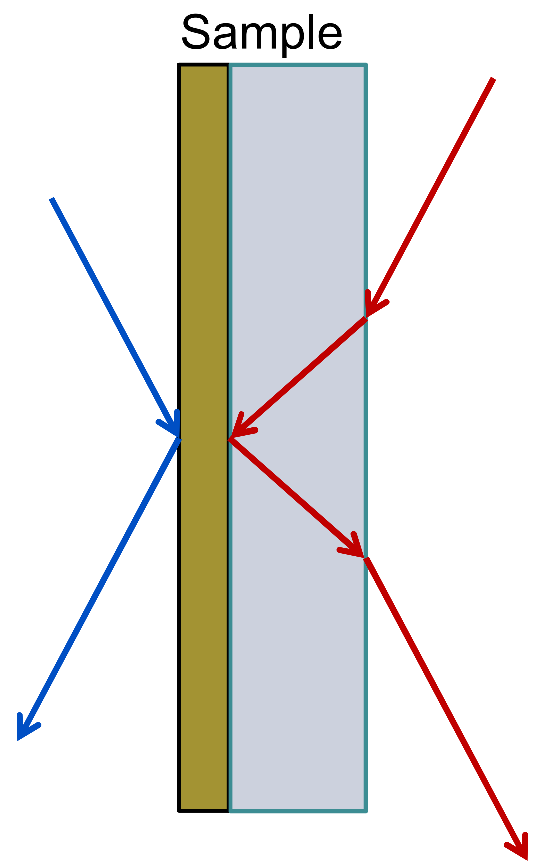
$$\kappa_0 = LT\sigma_0$$

$$L = 2.44x10^{-8}\, W\Omega\mathrm{K}^{-2}$$

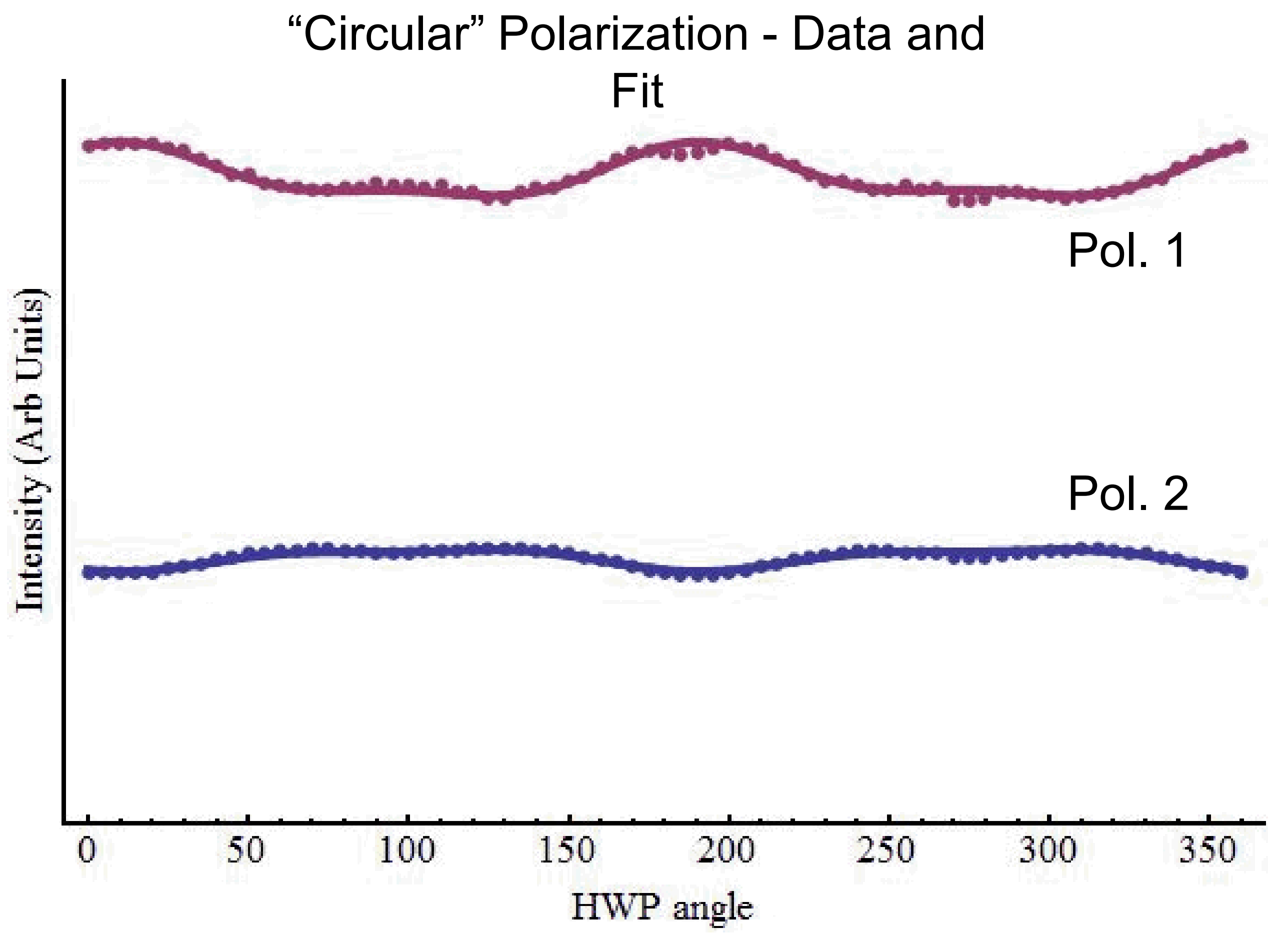
- The dielectric value is found through ellipsometry.
- The electrical conductivity can be directly calculated from the dielectric.
- Using the Drude model, a DC electrical conductivity can be estimated.
- Finally, using the Wiedemann-Franz law a DC thermal conductivity can be approximated.

Our ellipsometer showed good agreement with the commercial unit under static conditions



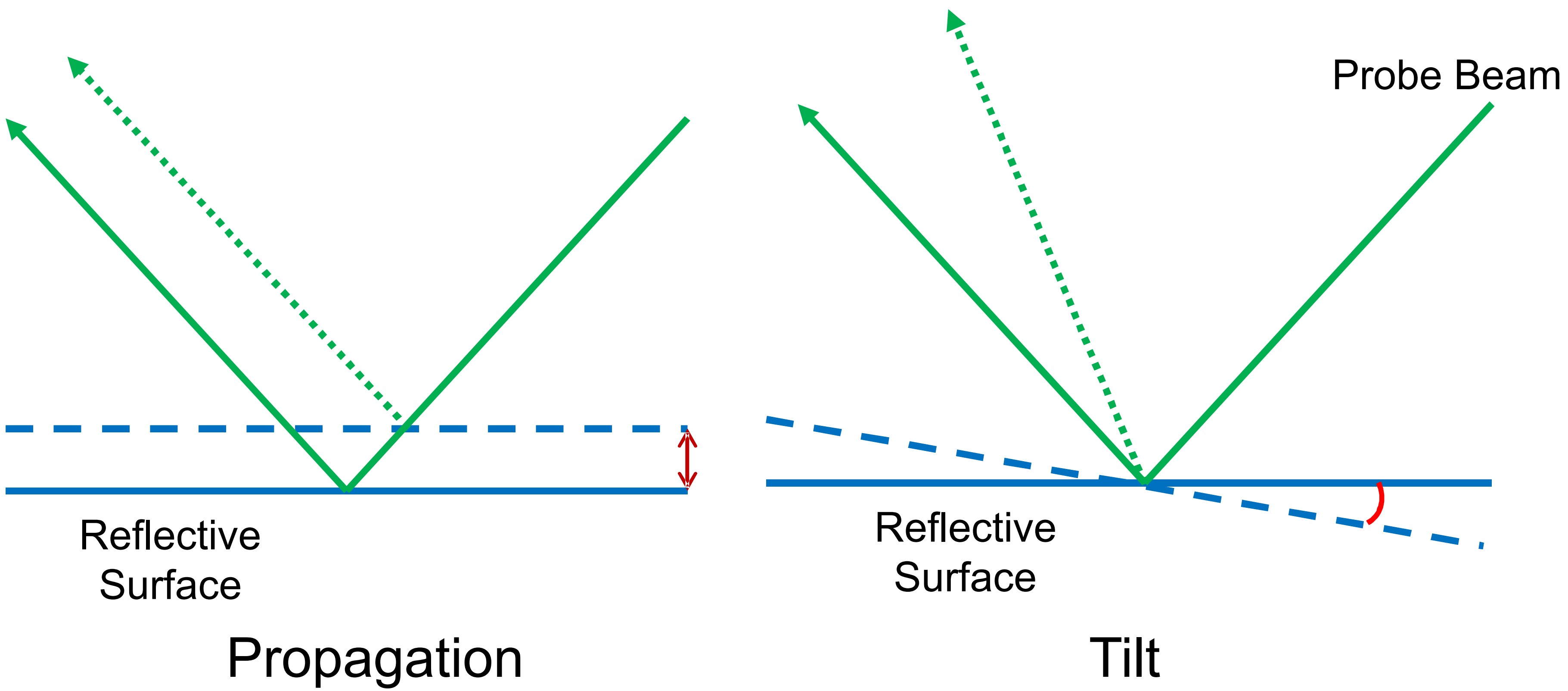


The sensitivity of ellipsometry measurements requires thorough characterization of optics

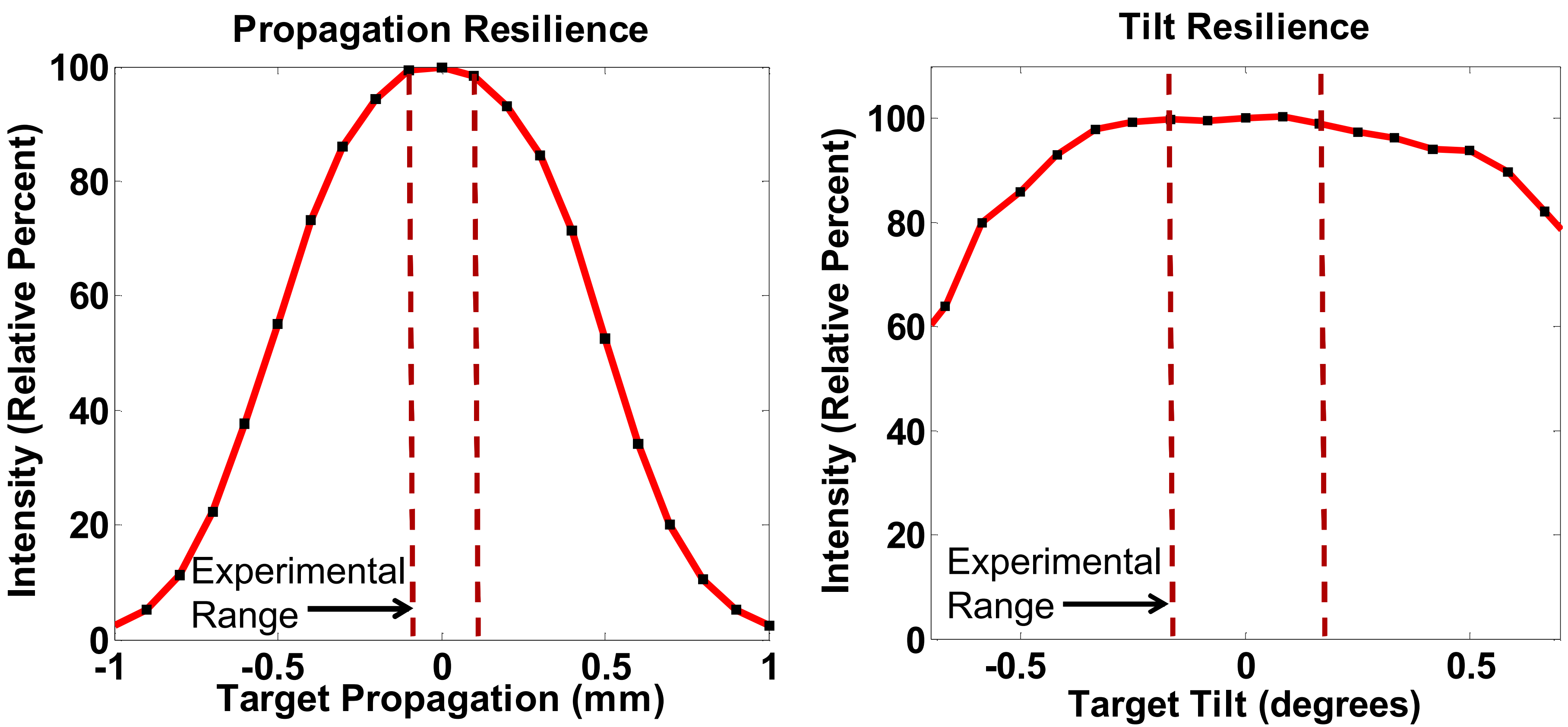


Error Corrections from fit:
HWP – Pi + .0377
QWP – Pi/2 + .004

Our targets exhibit two types of movement that can affect light collection



We characterized our signal resilience to target propagation and tilt

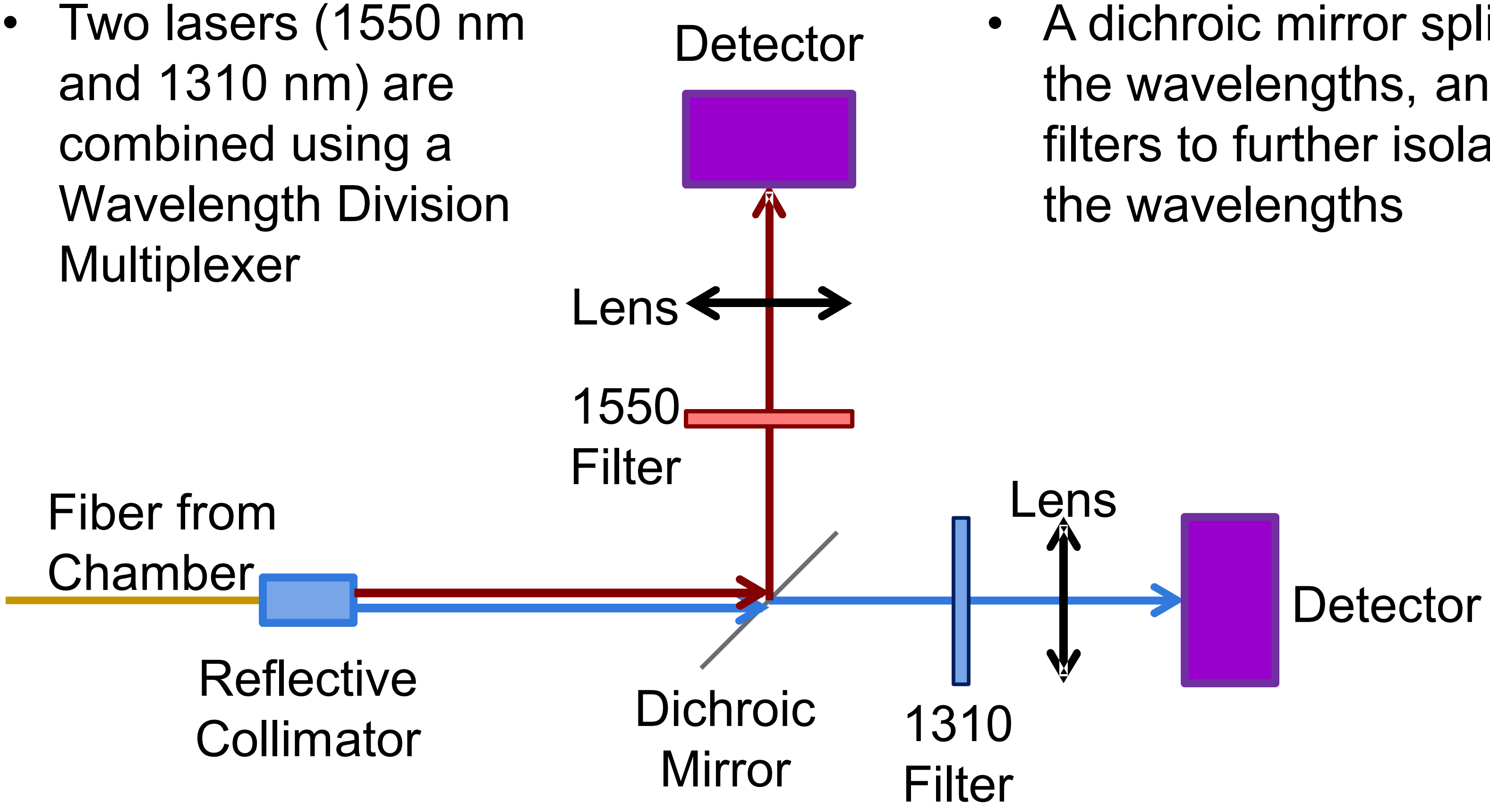


We find that our measurement keeps relatively strong signal within expected target movements.

With a few additions, our ellipsometer can take measurements at two wavelengths simultaneously

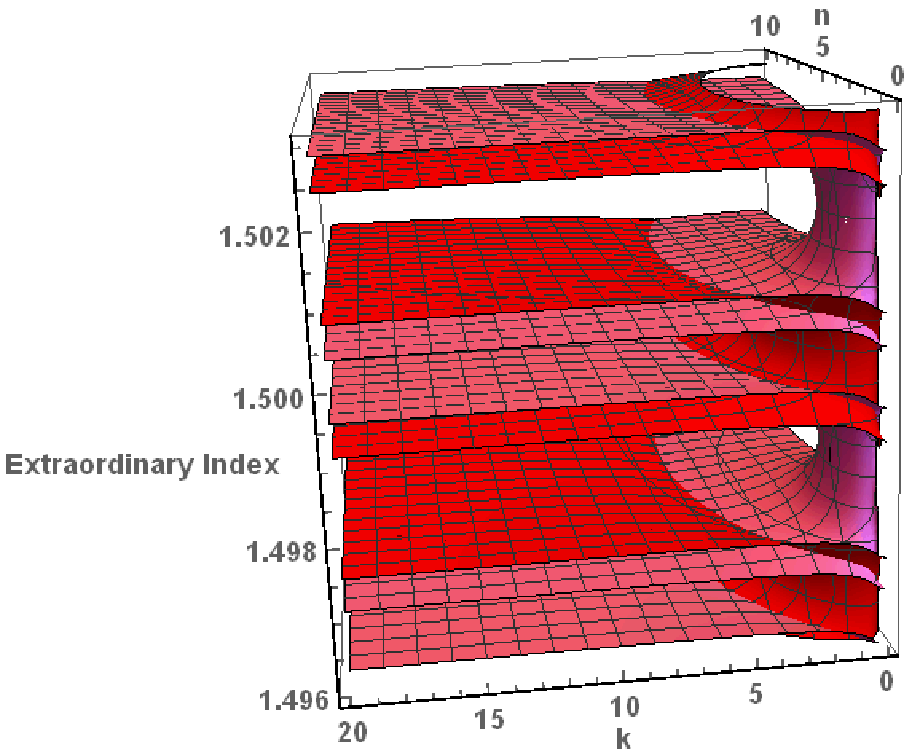
- Two lasers (1550 nm and 1310 nm) are combined using a Wavelength Division Multiplexer

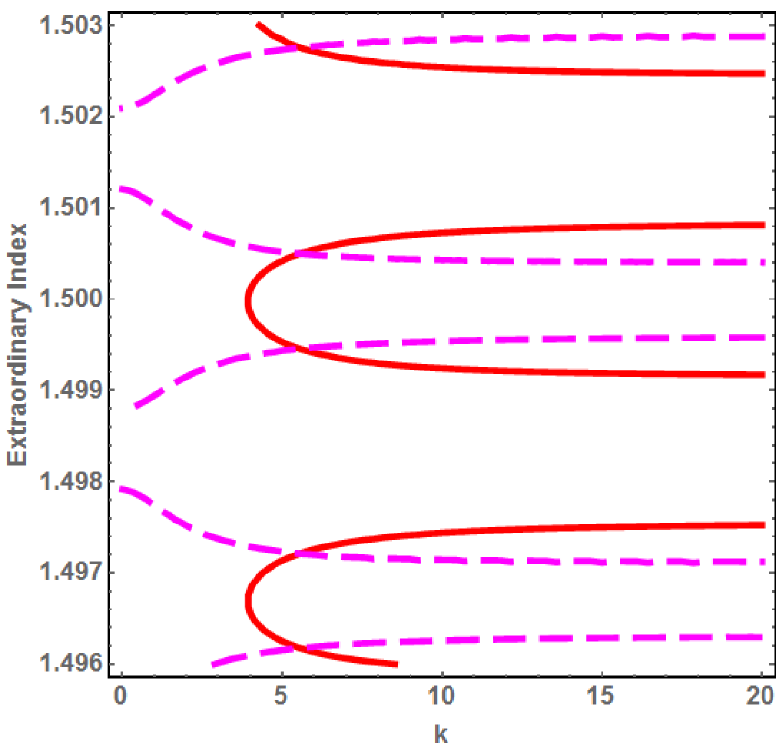
- A dichroic mirror splits the wavelengths, and filters to further isolate the wavelengths



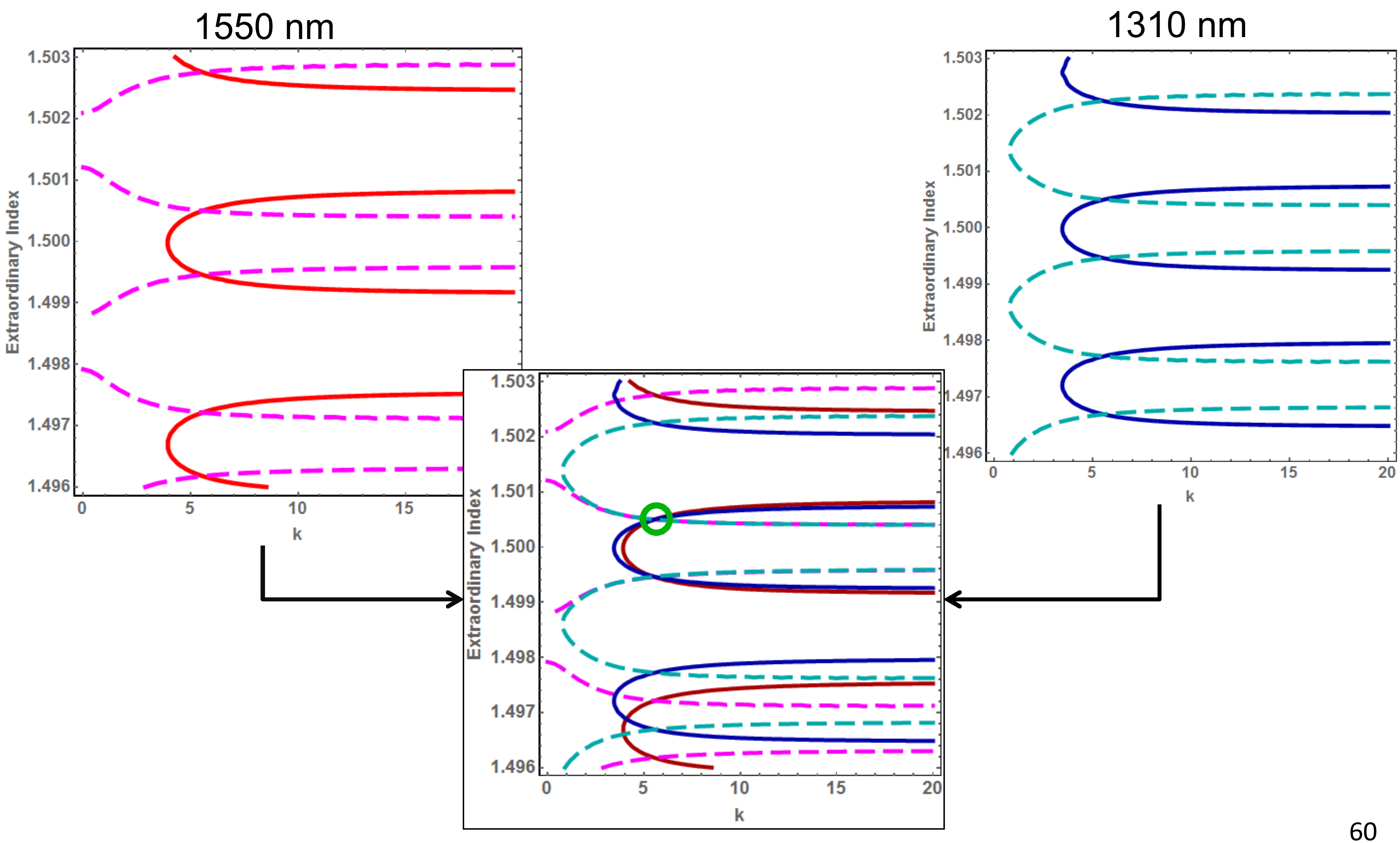
The dual-wavelength design also removes some of the reliance on time traces

- Now consider a steady birefringent layer
- Try to determine the birefringence and material index from the steady signal
- With a single wavelength there are multiple solutions

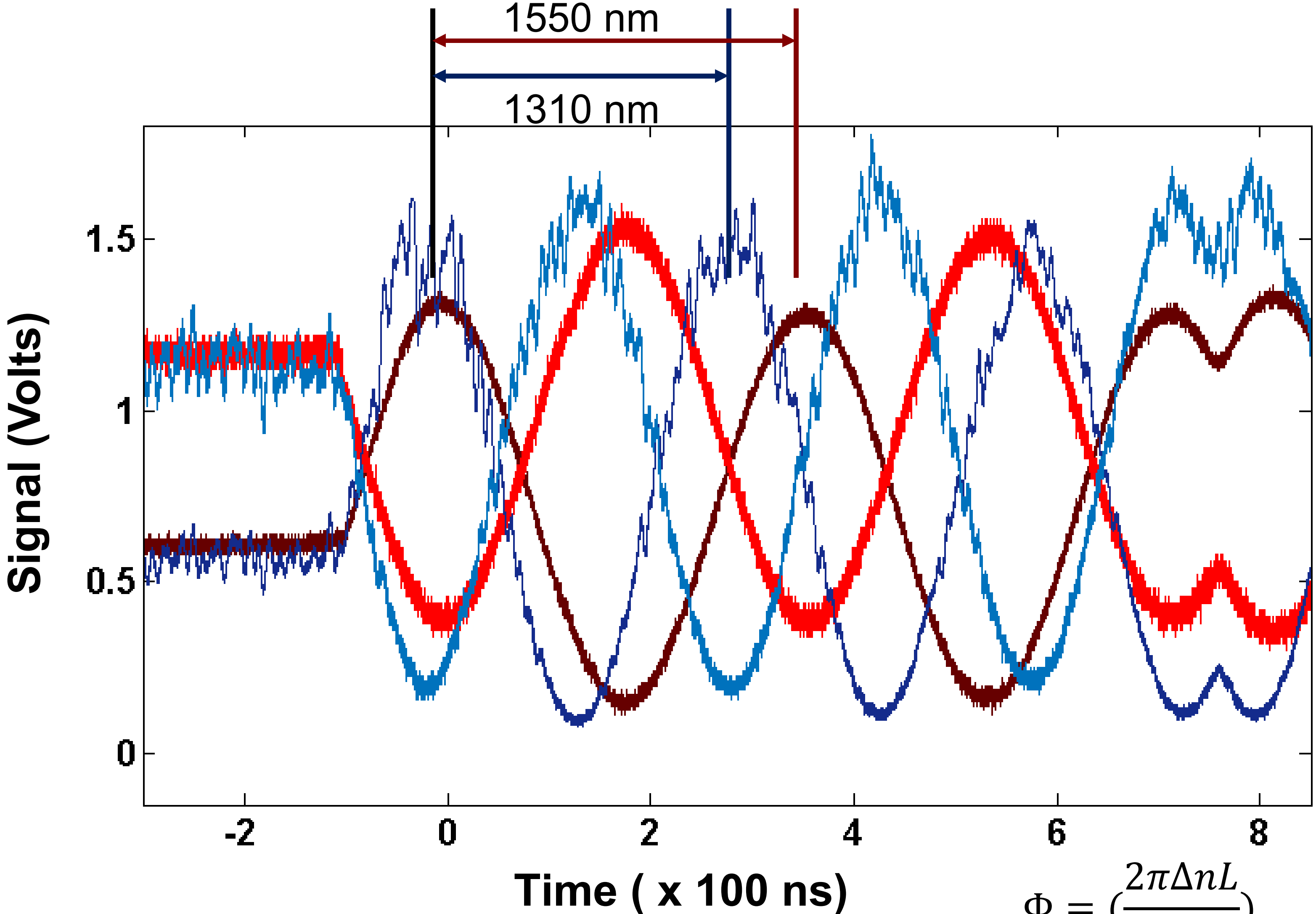




By combining the two, we narrow down the correct intersection point

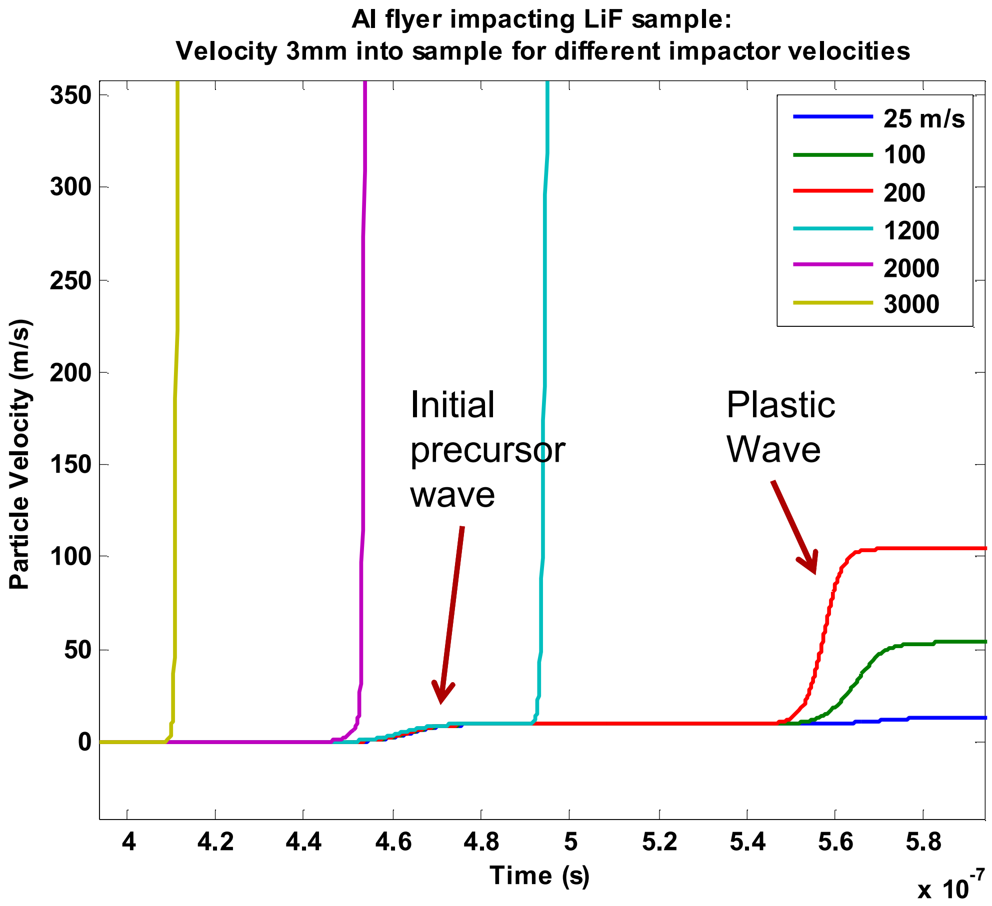


Dual Wavelength Data



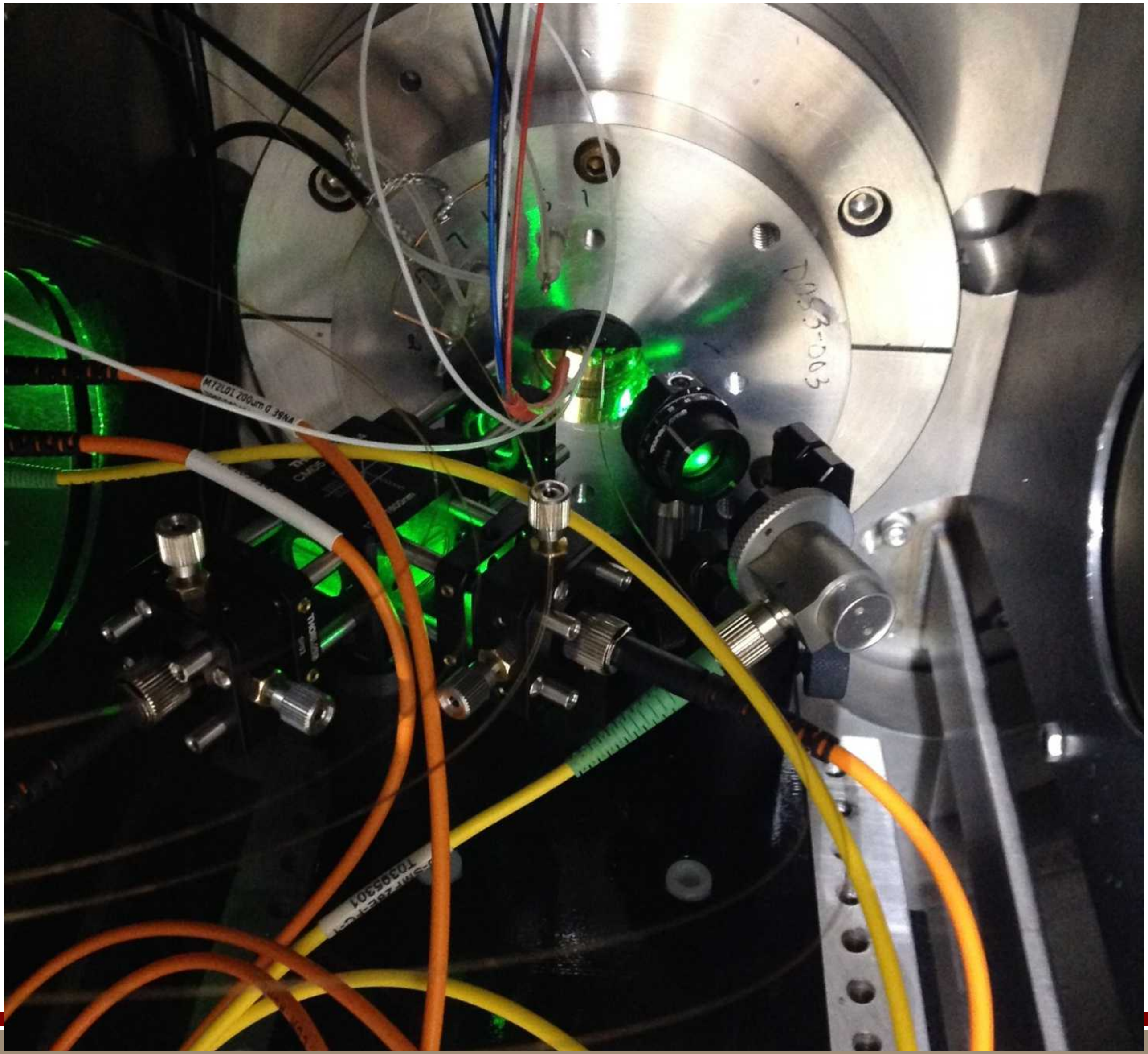
$$\Phi = \left(\frac{2\pi \Delta n L}{\lambda_0}\right)$$

To gain a better understanding of the birefringence behavior we are using LASLO, a 1-D hydrodynamic code



This simulation shows an example of overdriving an elastic precursor; at a flyer speed of 2000 m/s the signs of the precursor have all but vanished.

Shot Setup



The Fresnel equations establish the theoretical basis for ellipsometry

These equations define the complex reflection and transmission coefficients for light at a material interface.

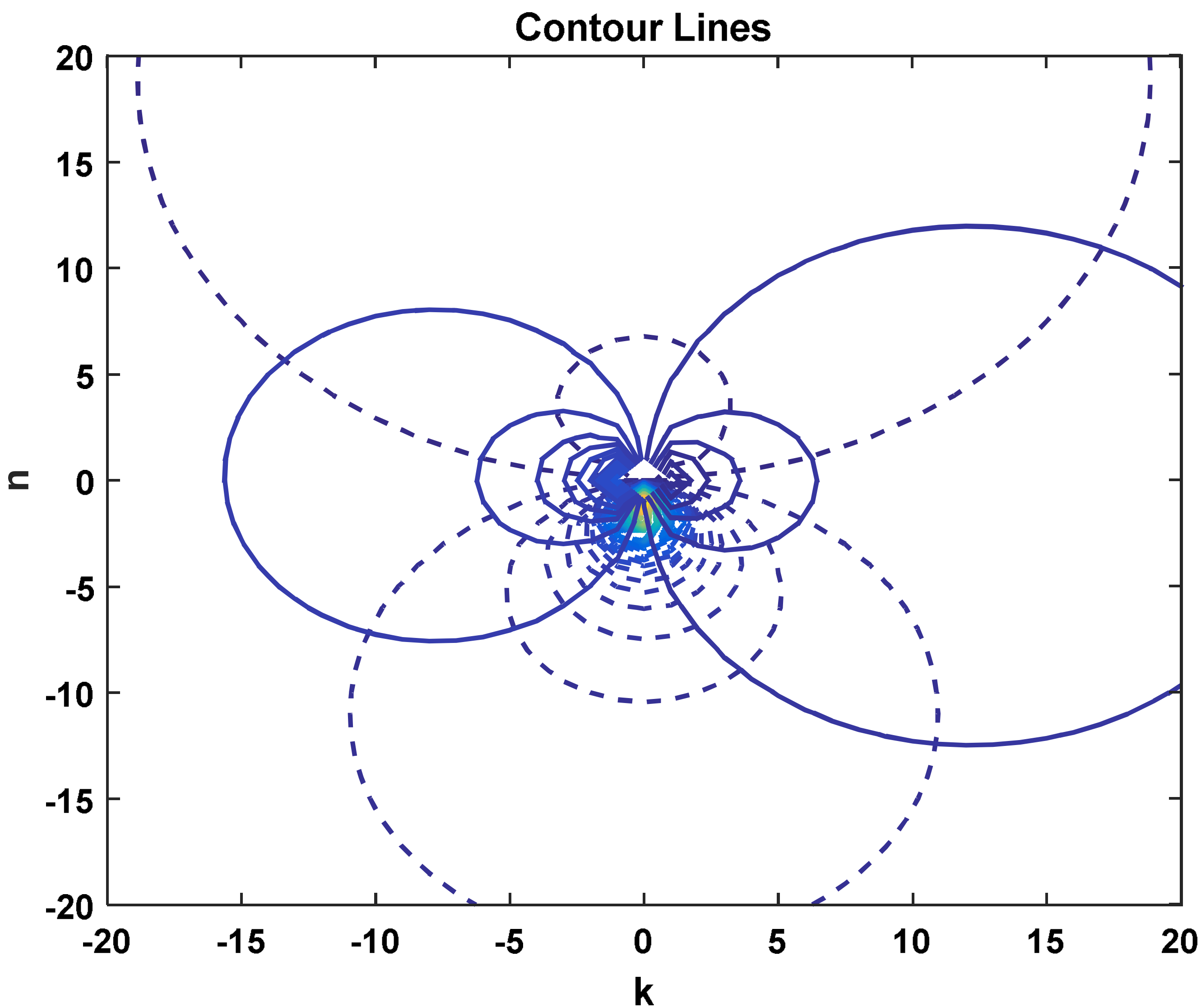
$$r_{12} = \frac{(\tilde{n}_1 - \tilde{n}_2)}{\tilde{n}_1 + \tilde{n}_2} \qquad t_{12} = \frac{2\tilde{n}_1}{\tilde{n}_1 + \tilde{n}_2}$$

$$\tilde{n}_j = n_j \, (1 - \frac{n_a^2}{{n_j}^2 \, (\sin\theta)^2})^{\frac{q}{2}},$$

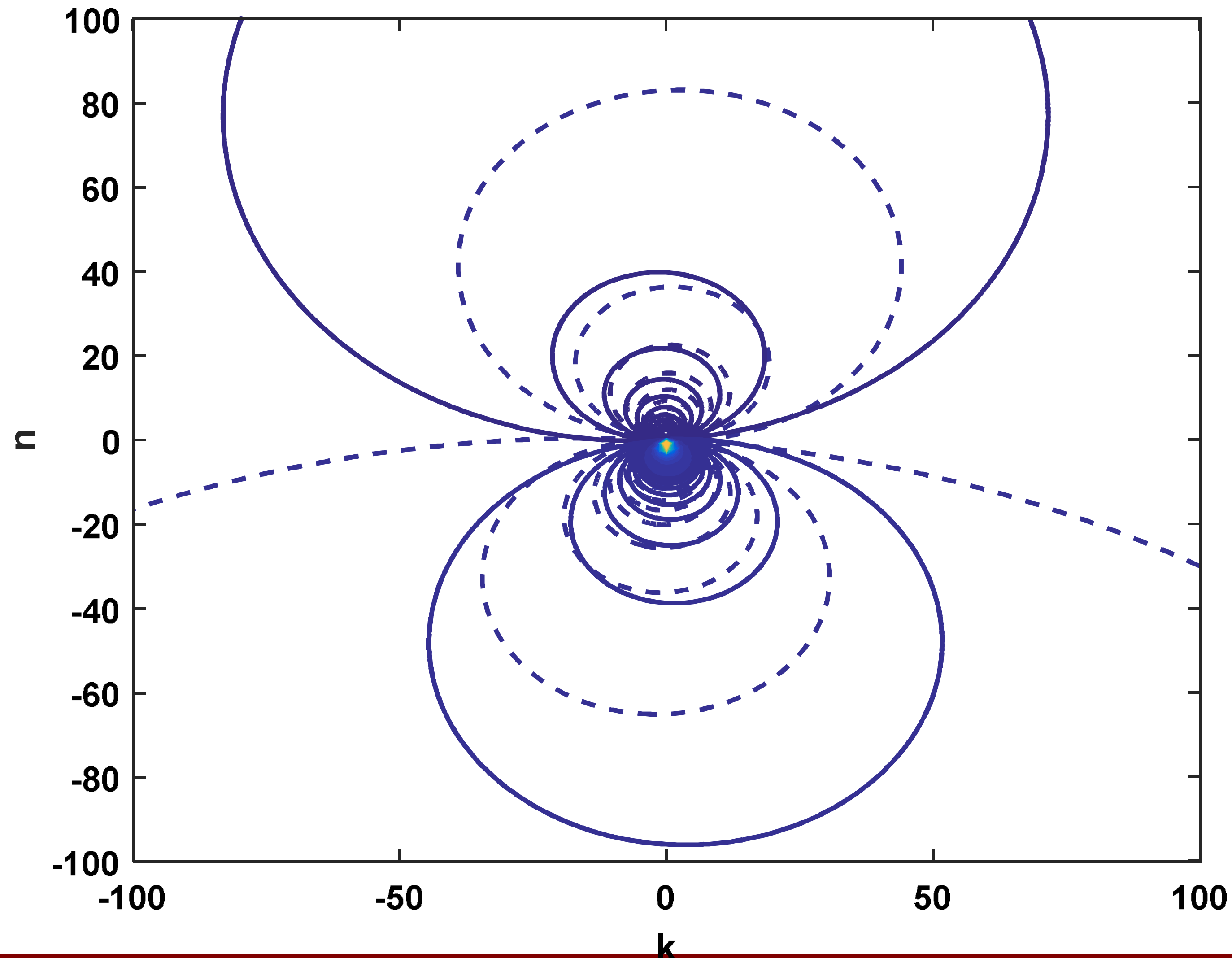
"q" represents the polarization state (q=1 for s-pol. and q=-1 for p-pol.), and n_a is the index of refraction for the ambient material, typically air or vacuum. Also note that "n" here is being used to represent the complete complex index, n+ik.

By tracking the interaction at each interface, we establish an equation for the change of polarization which depends on the indices of refraction of the sample.

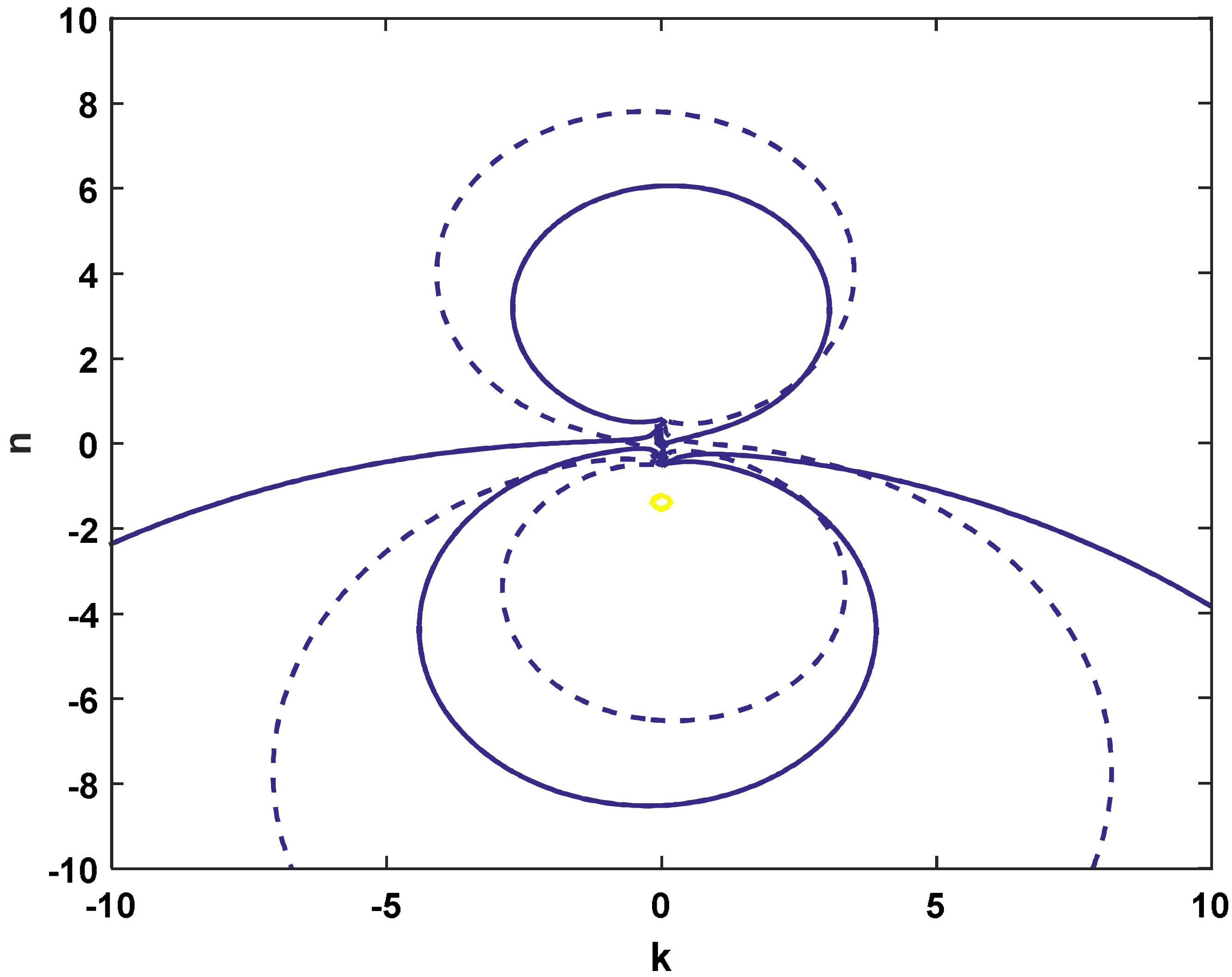
Contour lines of constant signal ratio and sum from analysis method



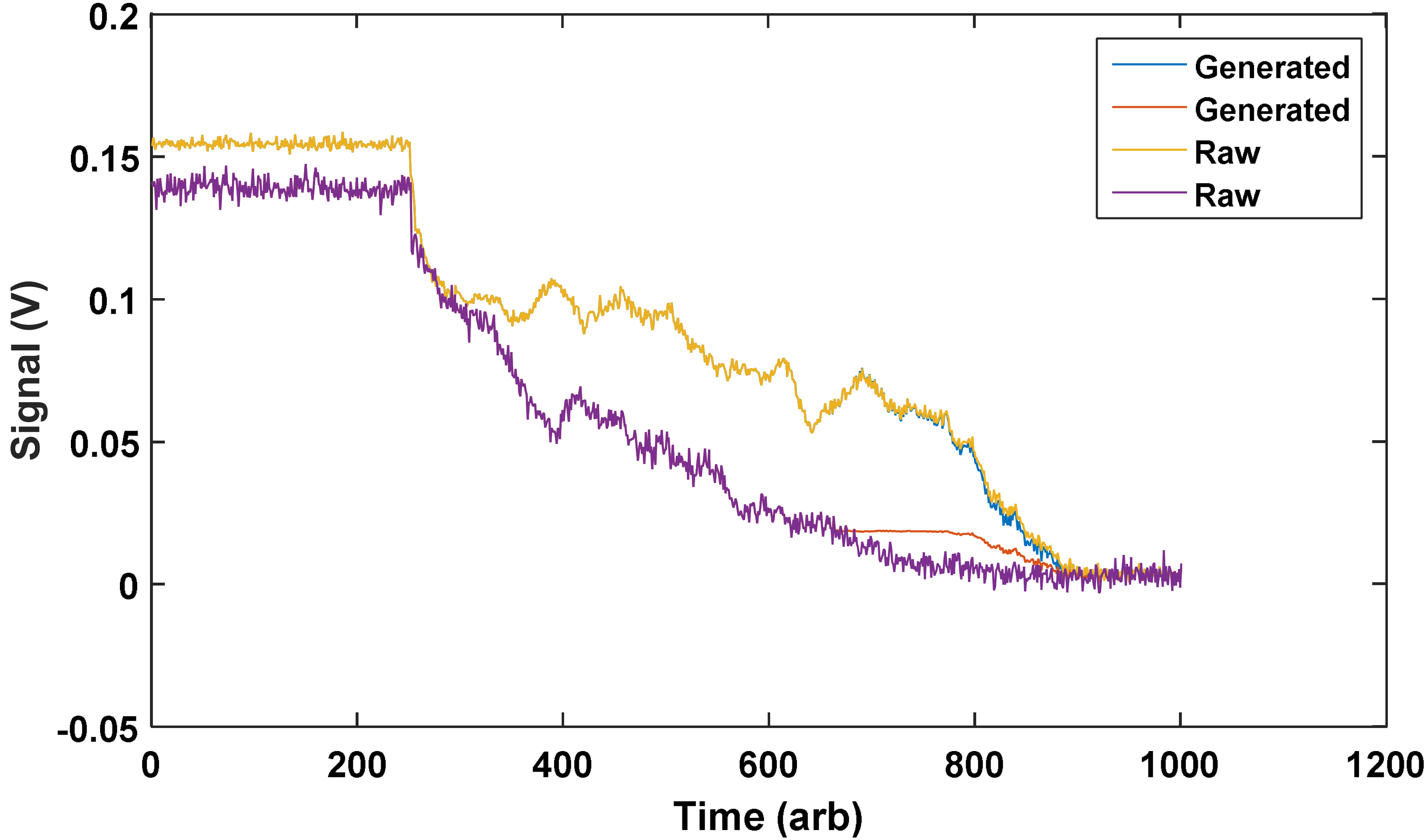
Contours: Signal 1, Signal 2



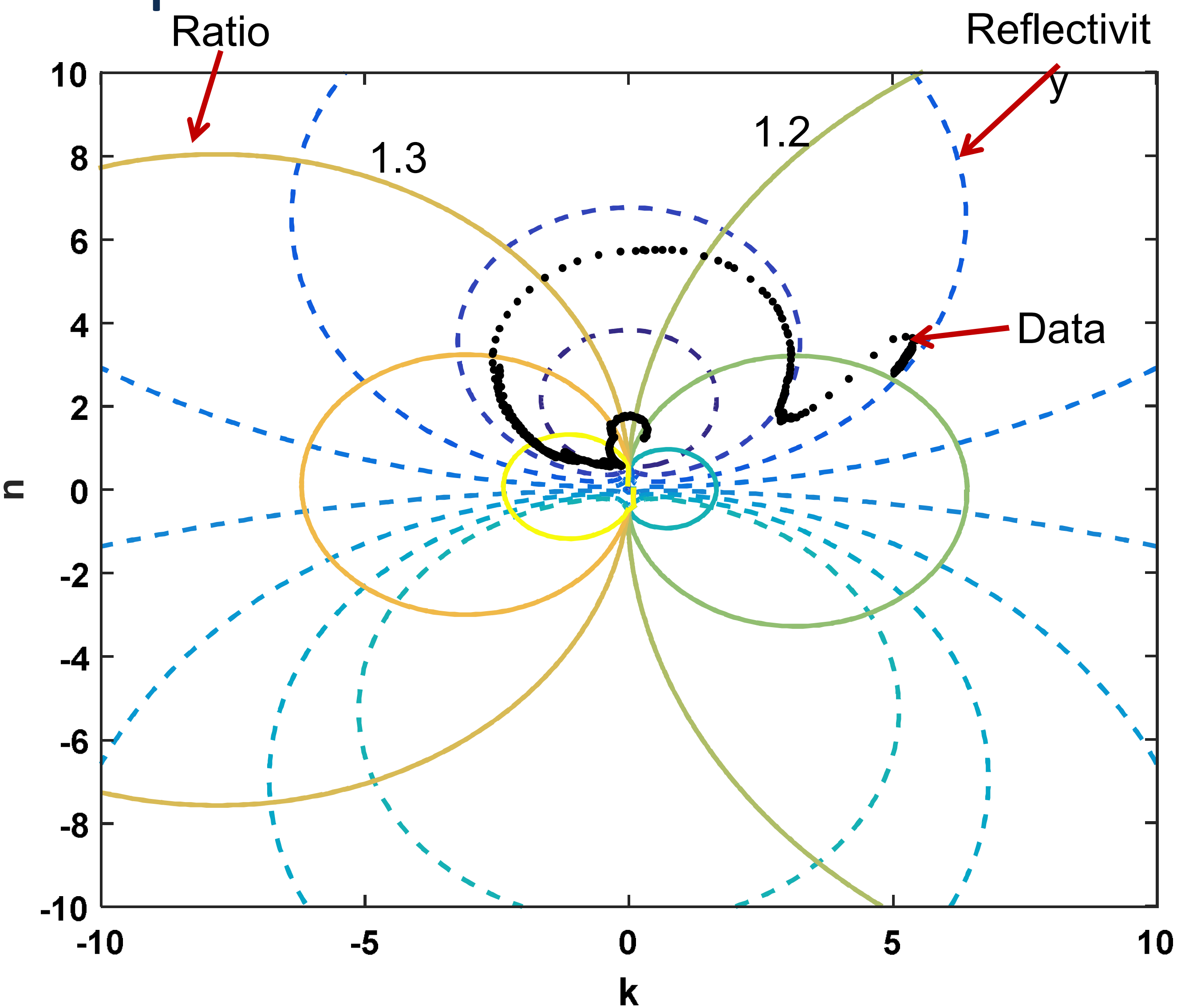
Contours: Signal 1, Signal 2



The material properties from the analysis do reproduce the signal, indicating the fitting algorithm is finding good minima

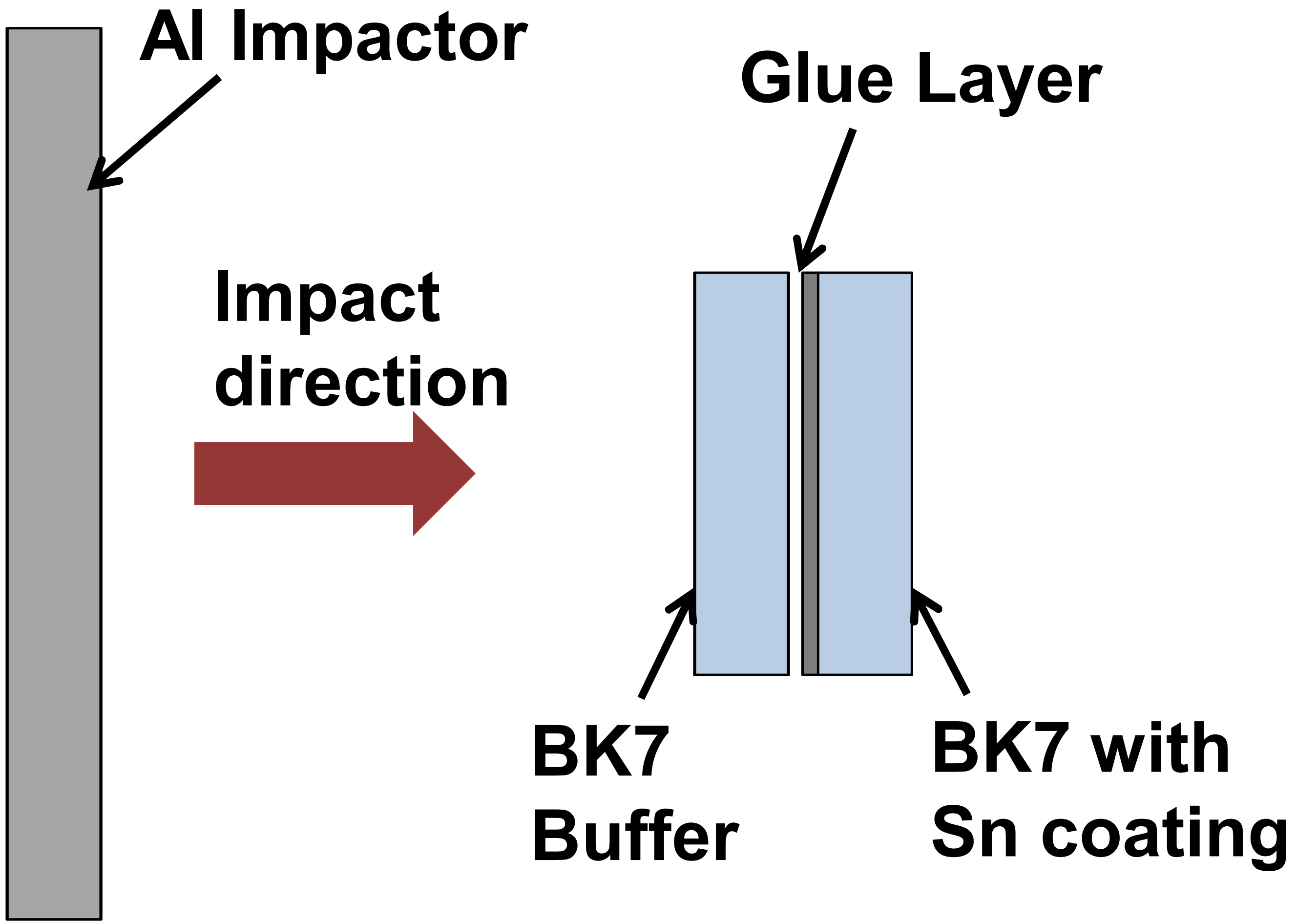


The found solution overlaid onto the contour plot

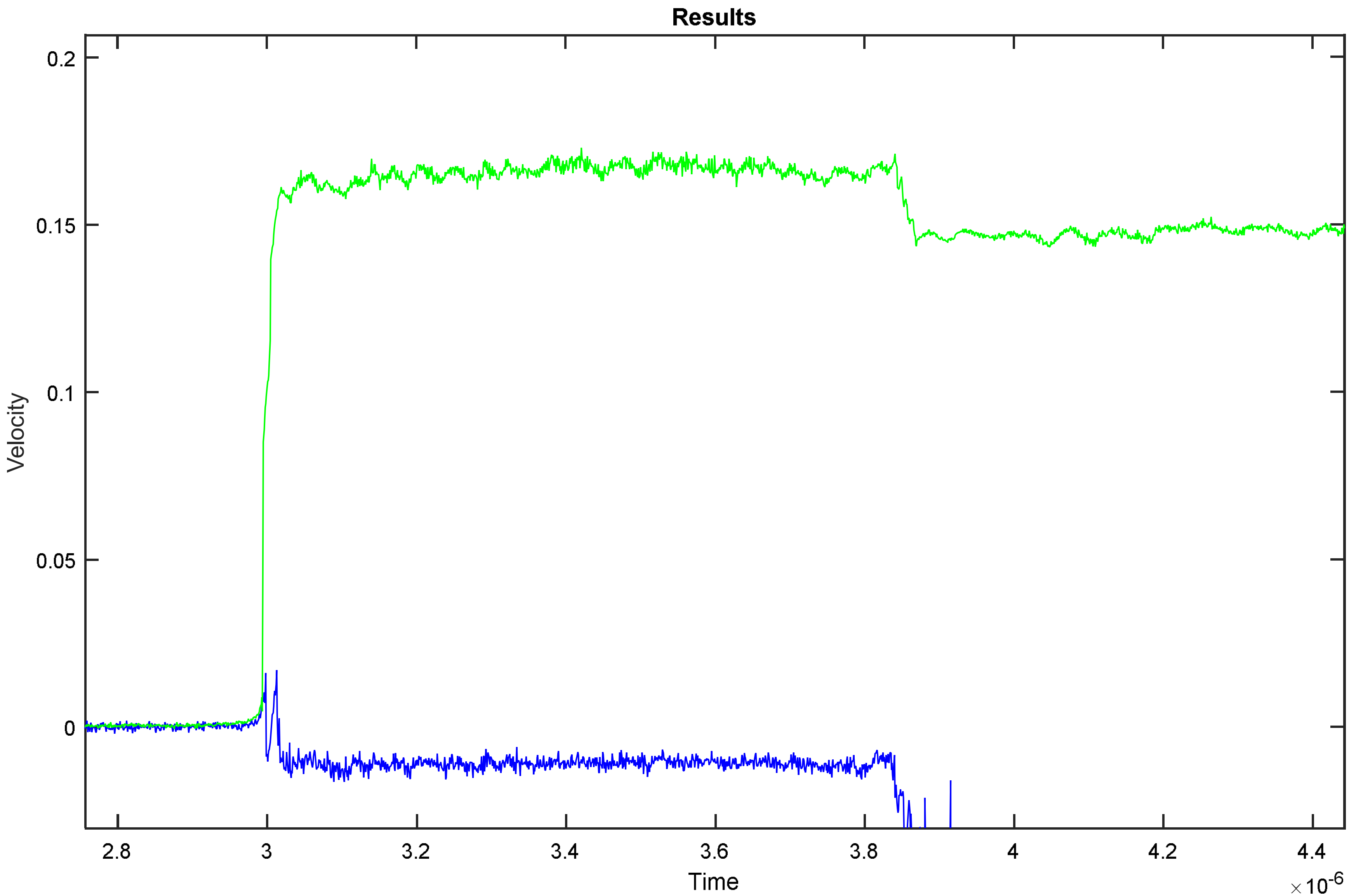


TARGET CONFIGURATION ELLIPSOMETRY EXPERIMENTS

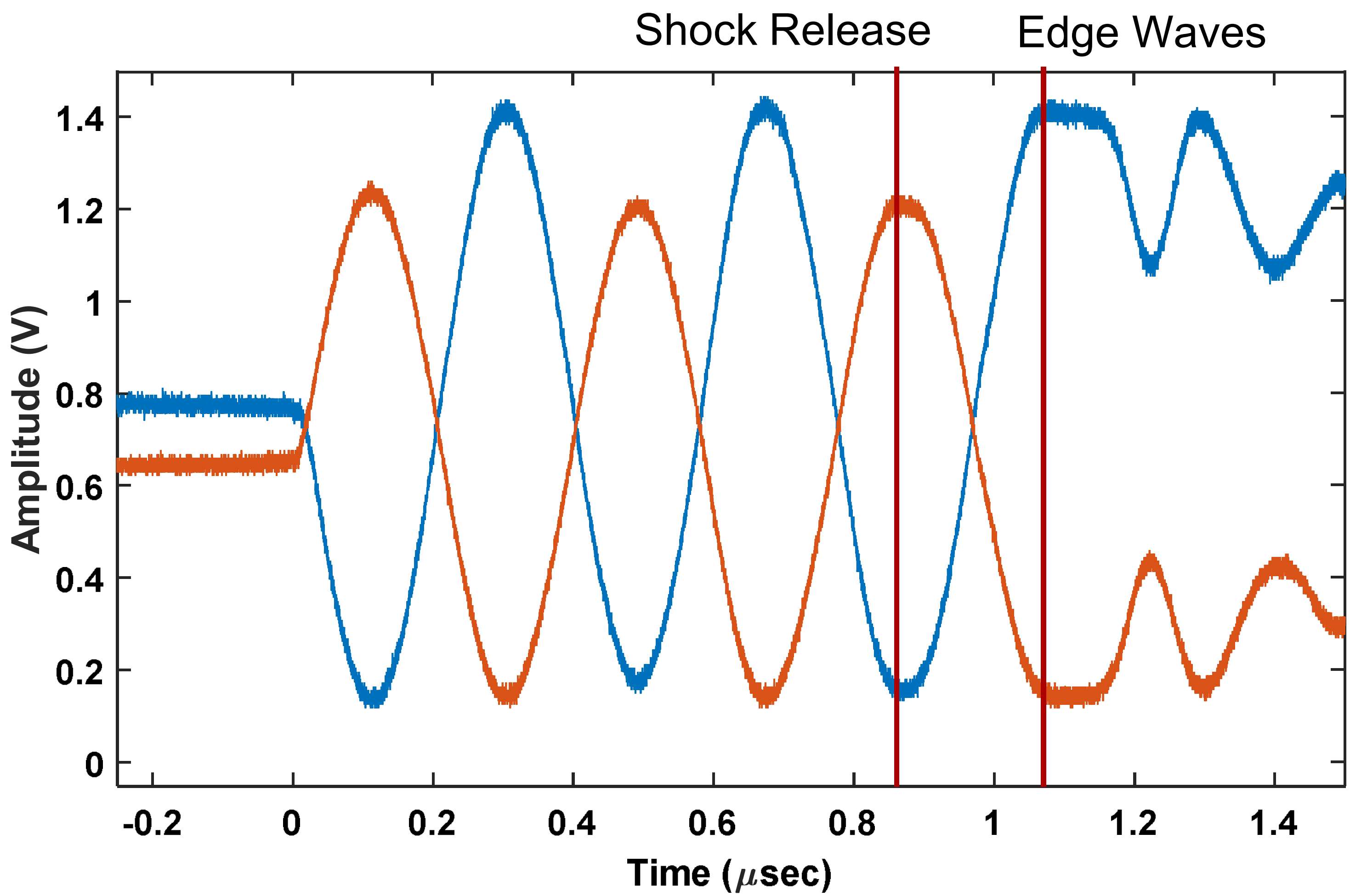
Shot 1 Configuration – Back to Basics



Shot 1 VISAR

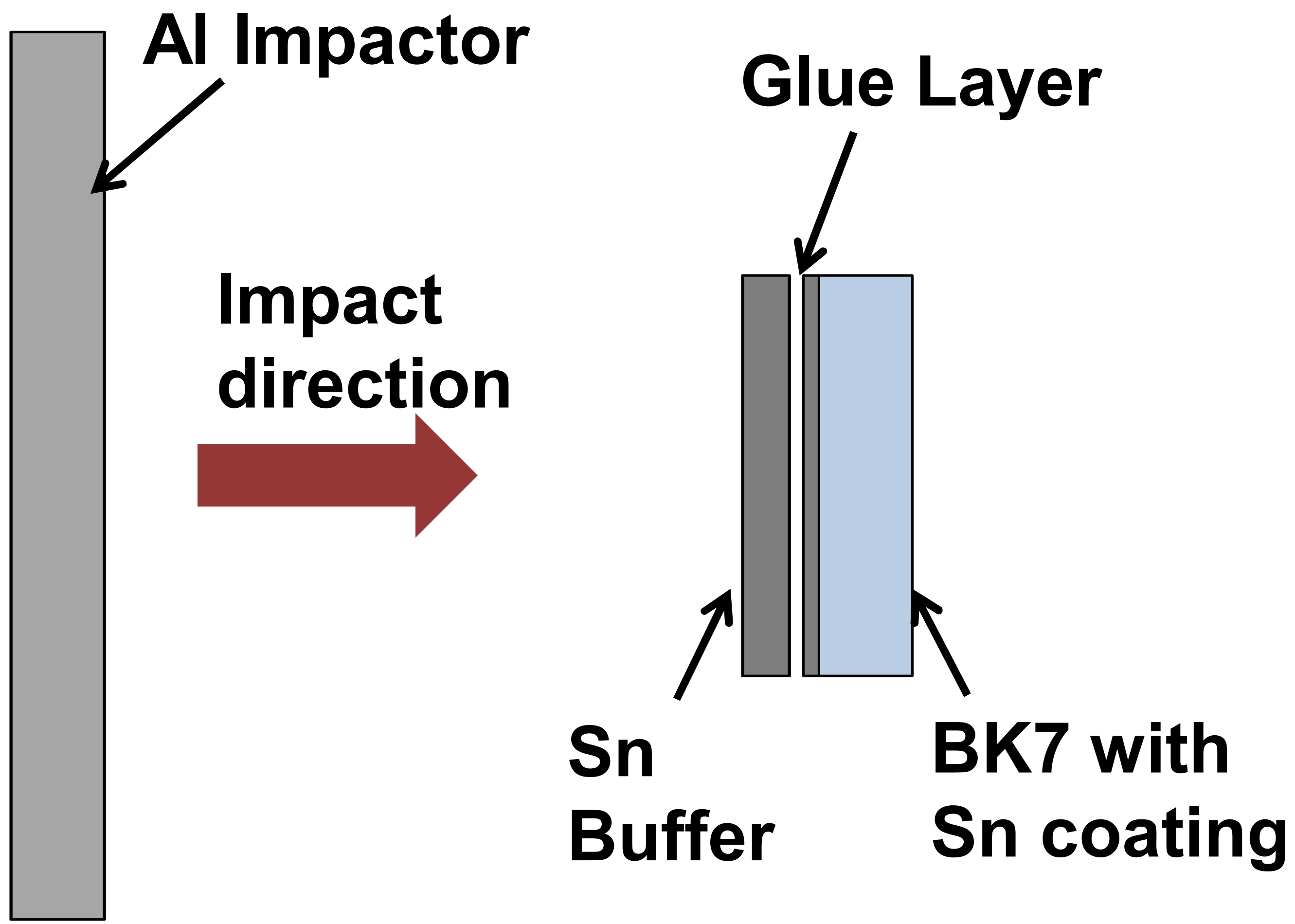


Shot 1 Ellipsometry

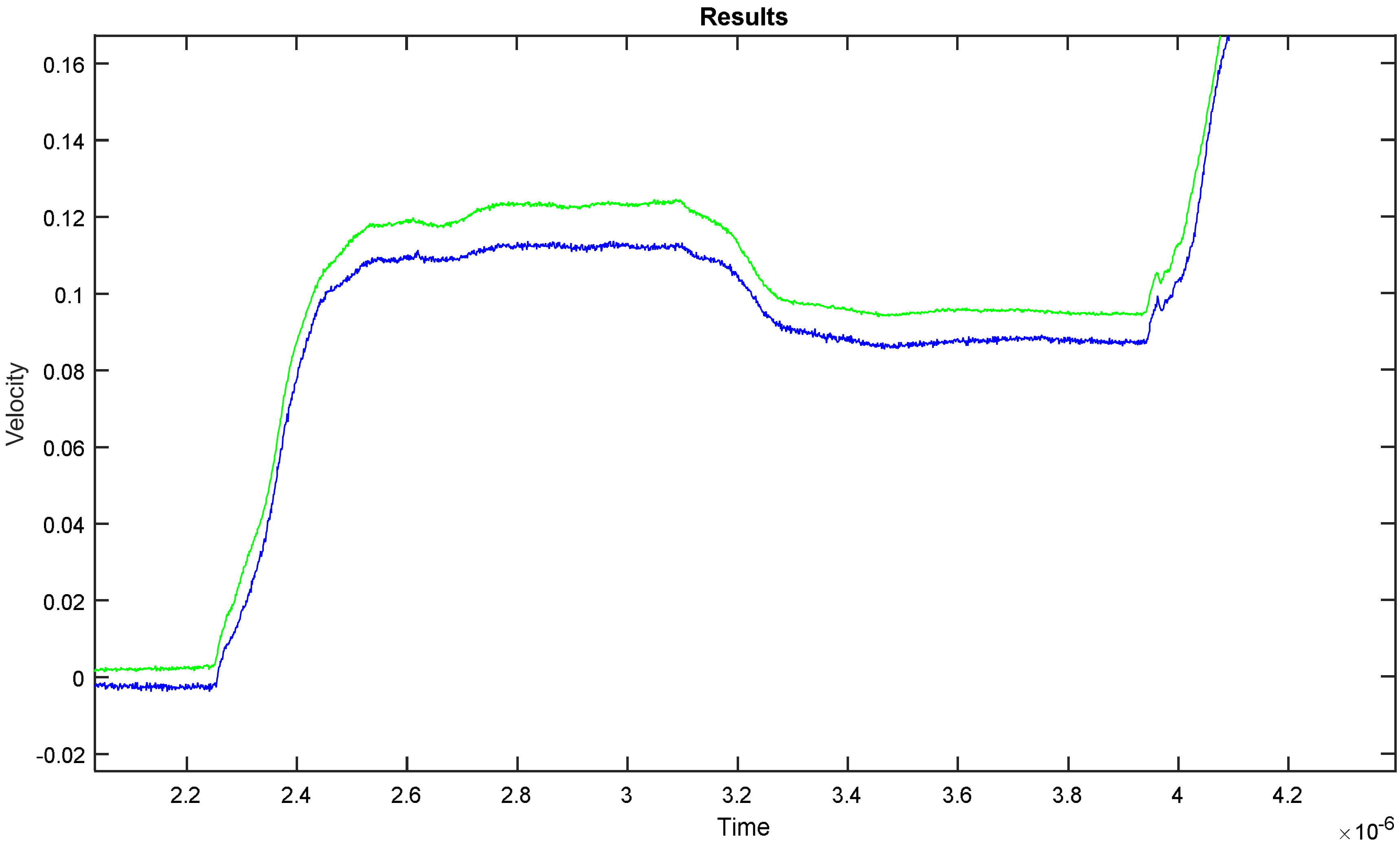


- Clean signal, as expected
- Still some uncertainty from sinusoidal amplitude (signal doesn't reach zero)

Shot 2 Configuration – Metal Buffer

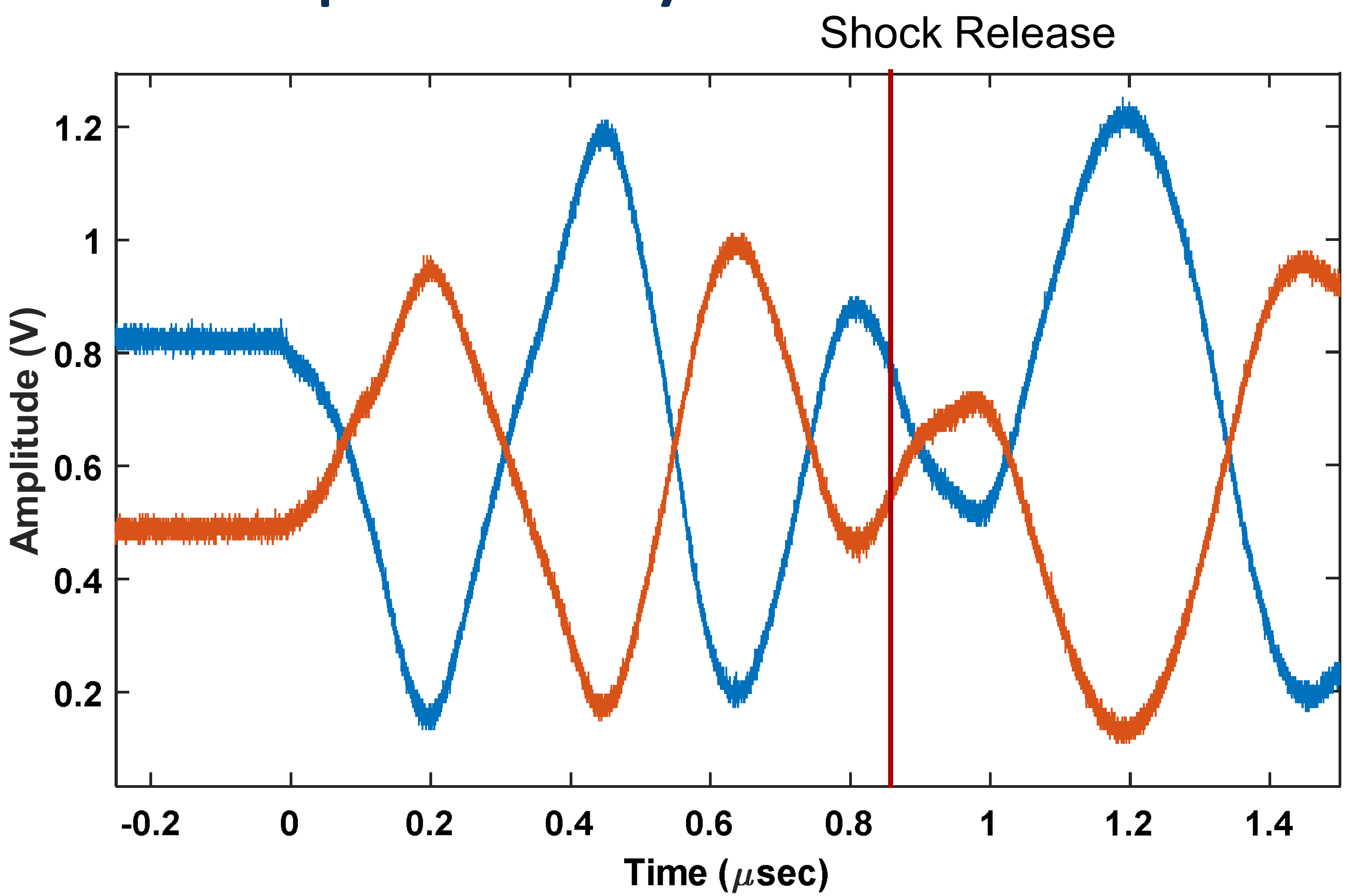


Shot 2 VISAR



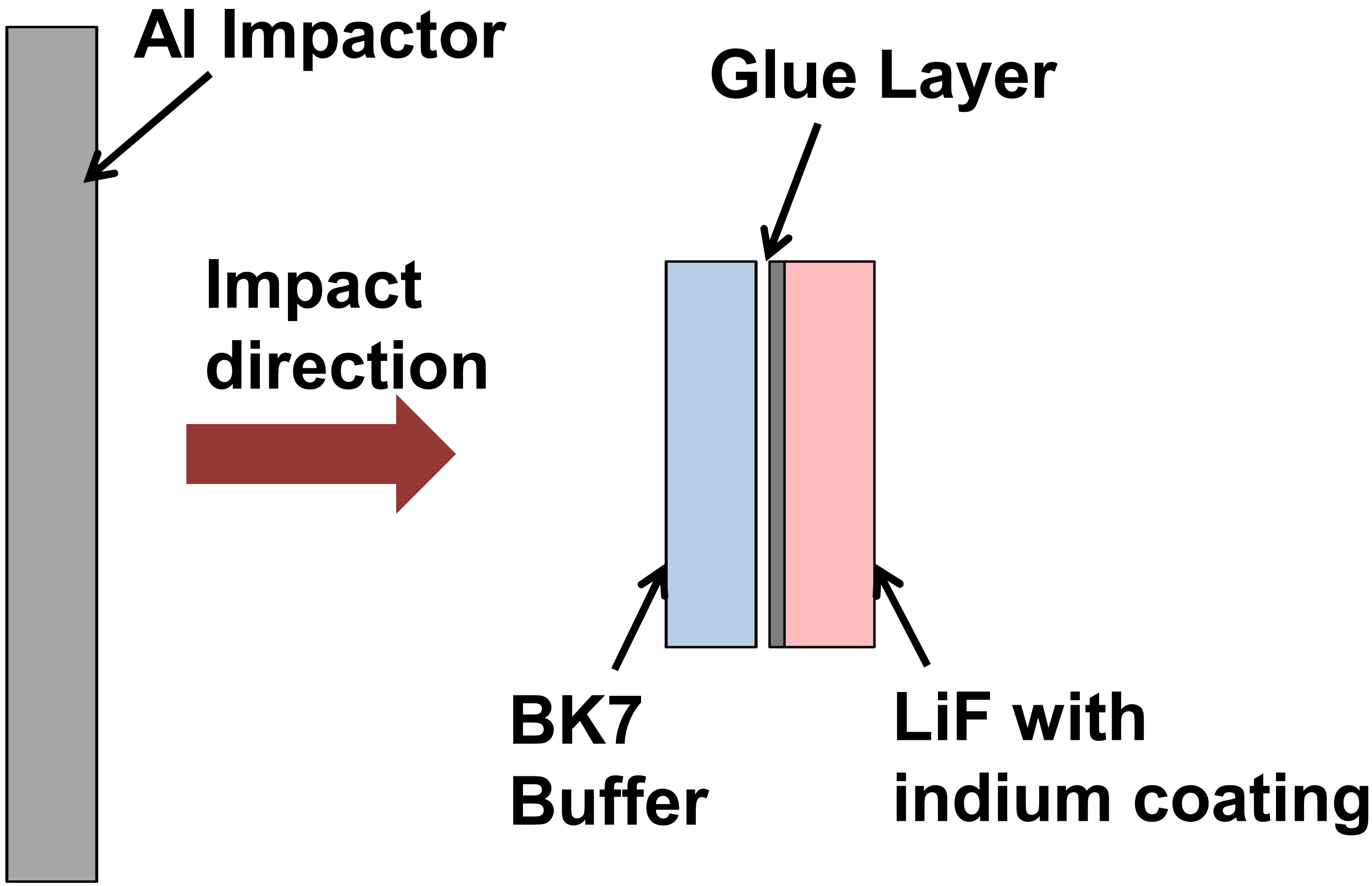
There seems to be more of a ramp wave here – unclear why
As well as a small precursor from the tin

Shot 2 Ellipsometry

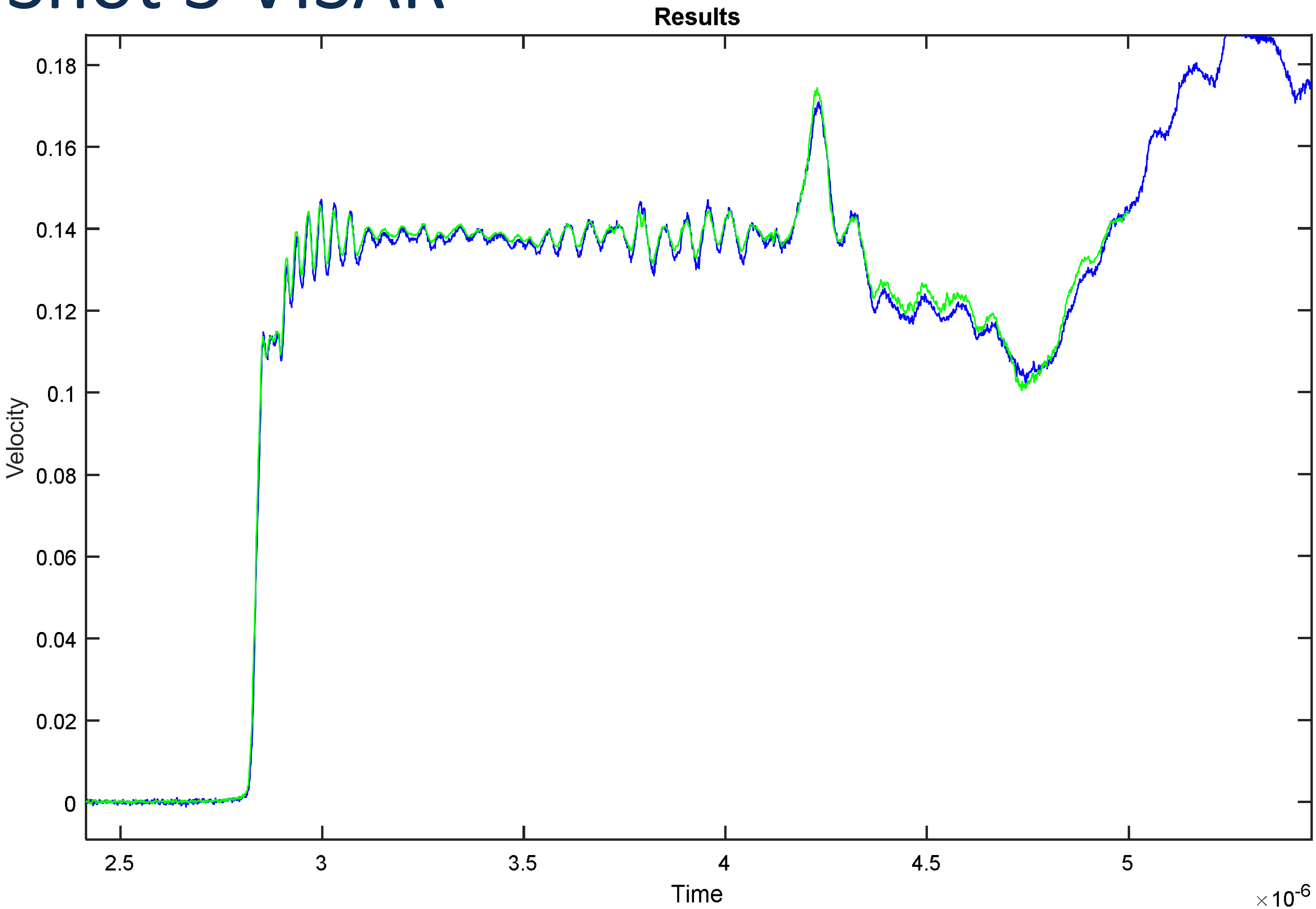


- Slow start likely a result of the ramp-like behavior
- Initial sine wave seems more triangular
- Shock release point may be a bit uncertain due to ramp behavior

Shot 3 Configuration – LiF window

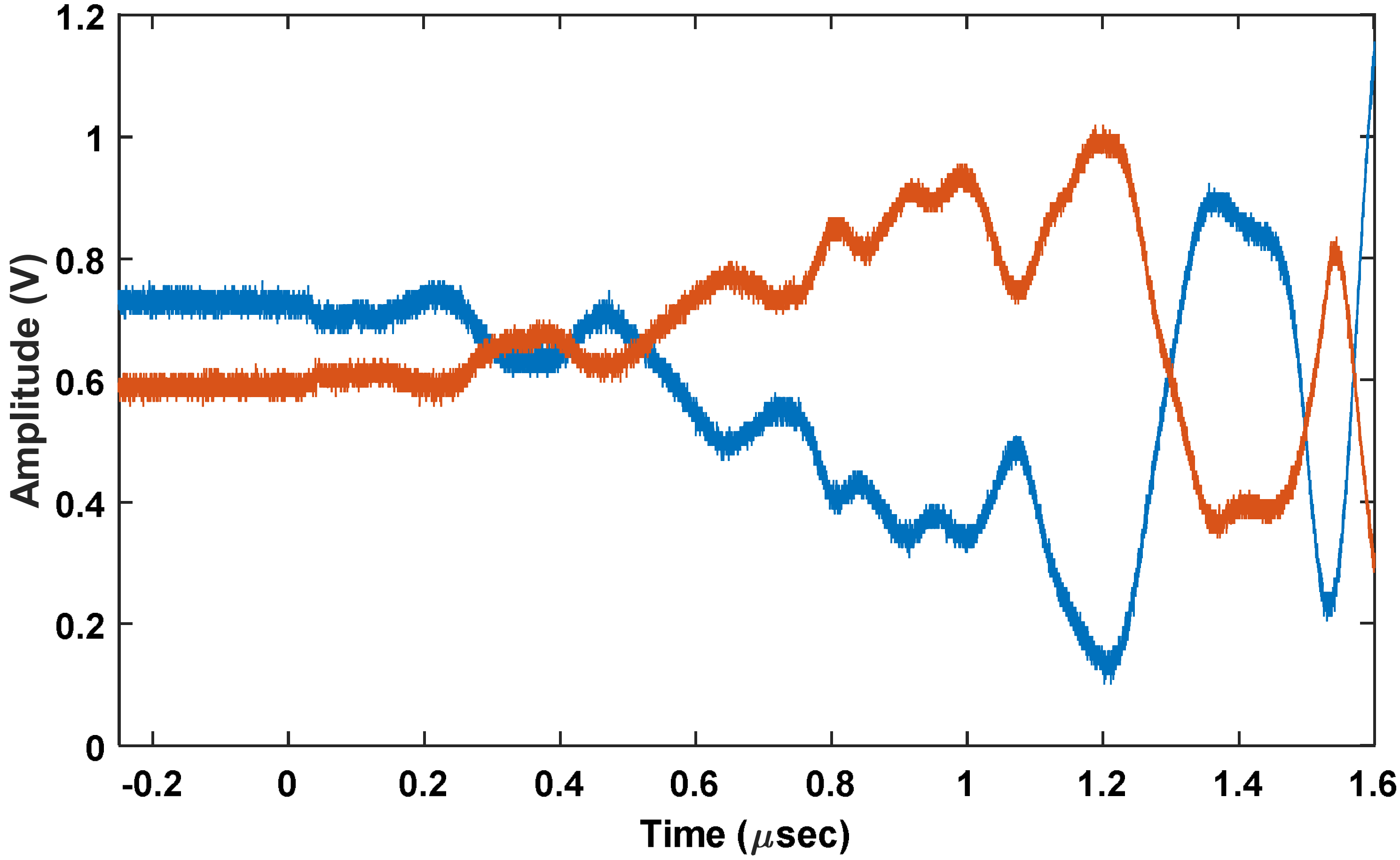


Shot 3 VISAR



Prominent ringing in the VISAR signal. It is not clear what caused this.

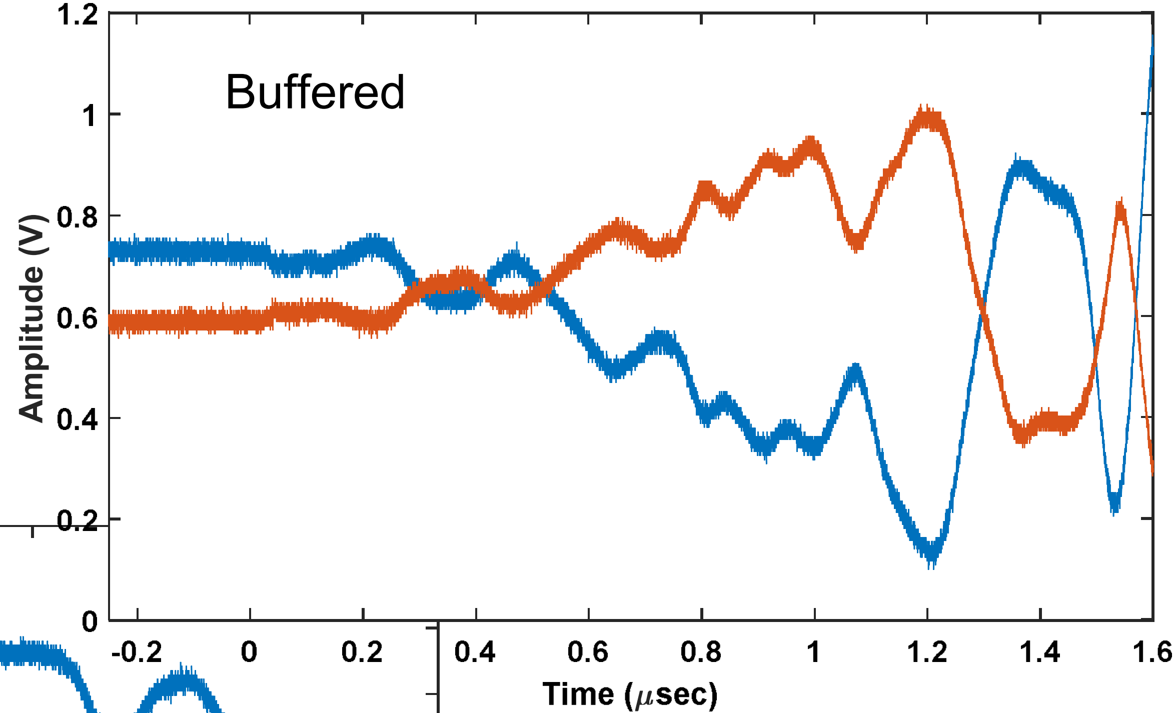
Shot 3 Ellipsometry

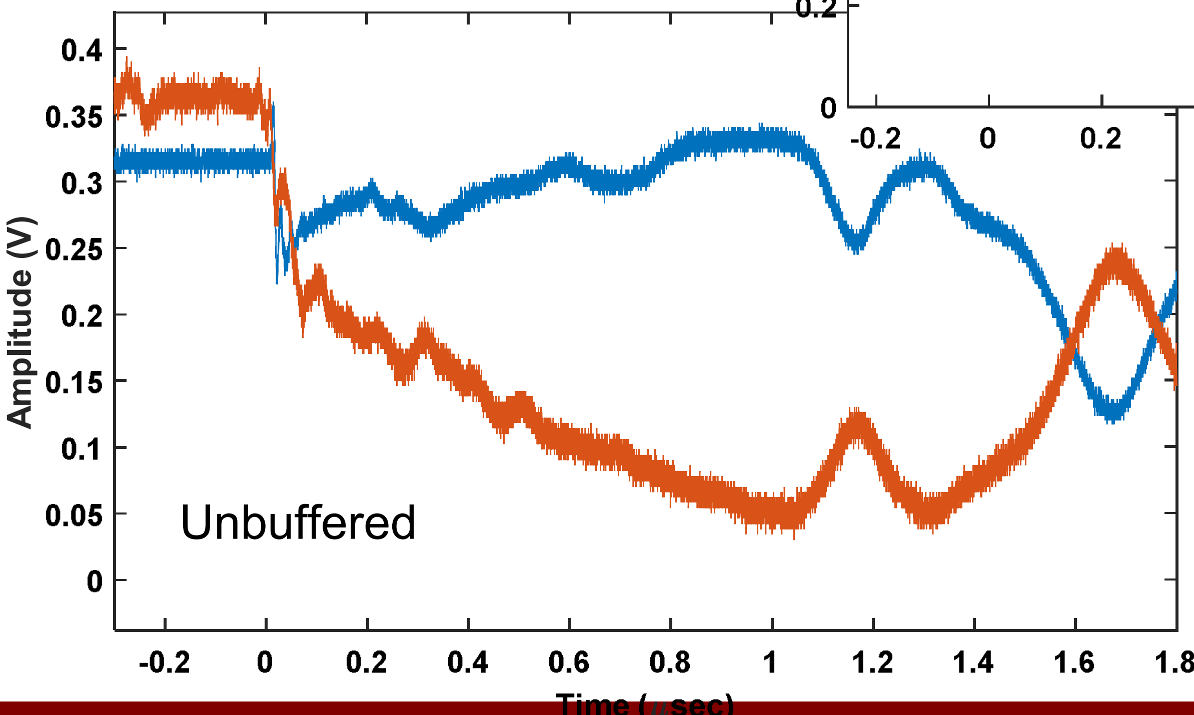


- Edge wave effects kick in before shock release

Comparison of LiF window experiments

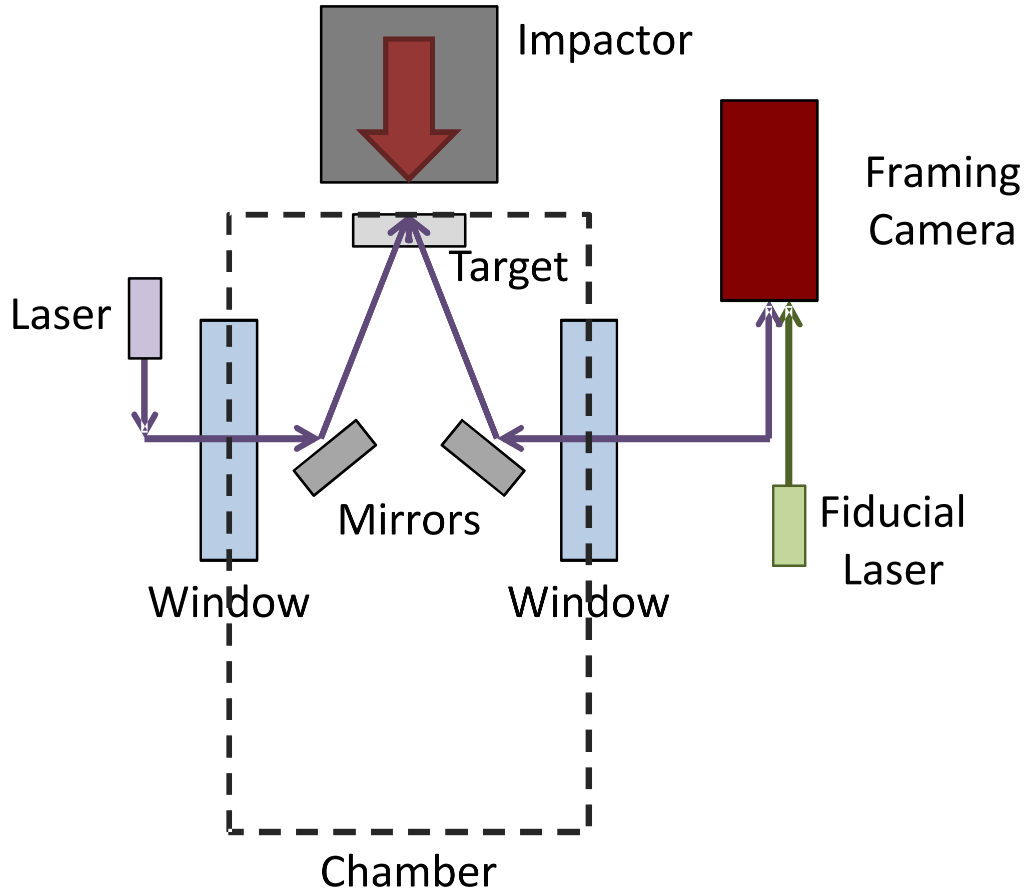
- Both experiments seem to exhibit a similar qualitative behavior
- Overdriving LiF (at STAR) will hopefully exhibit a more straightforward response



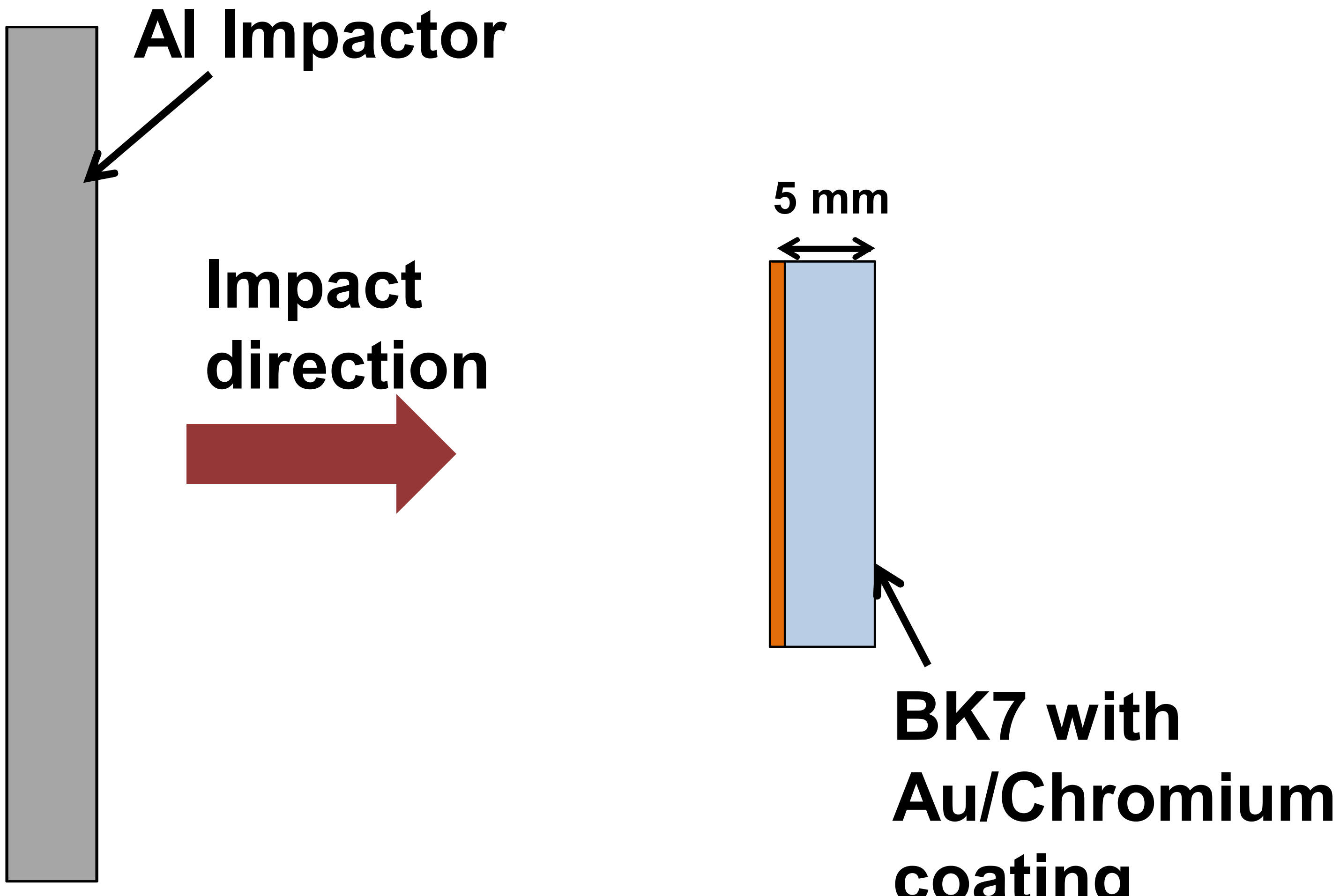


TARGET CONFIGURATION FRAMING CAMERA EXPERIMENTS

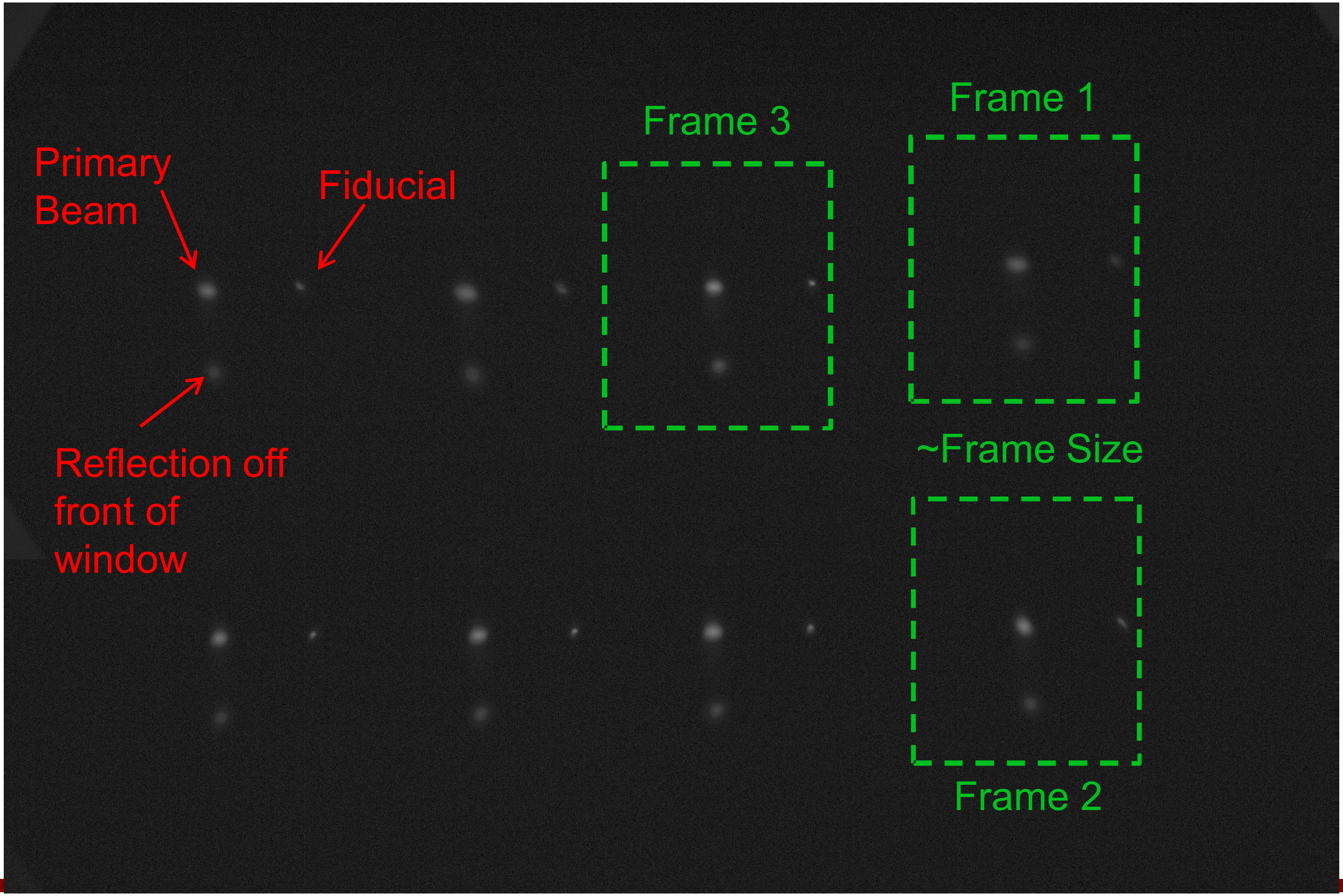
Experimental Layout



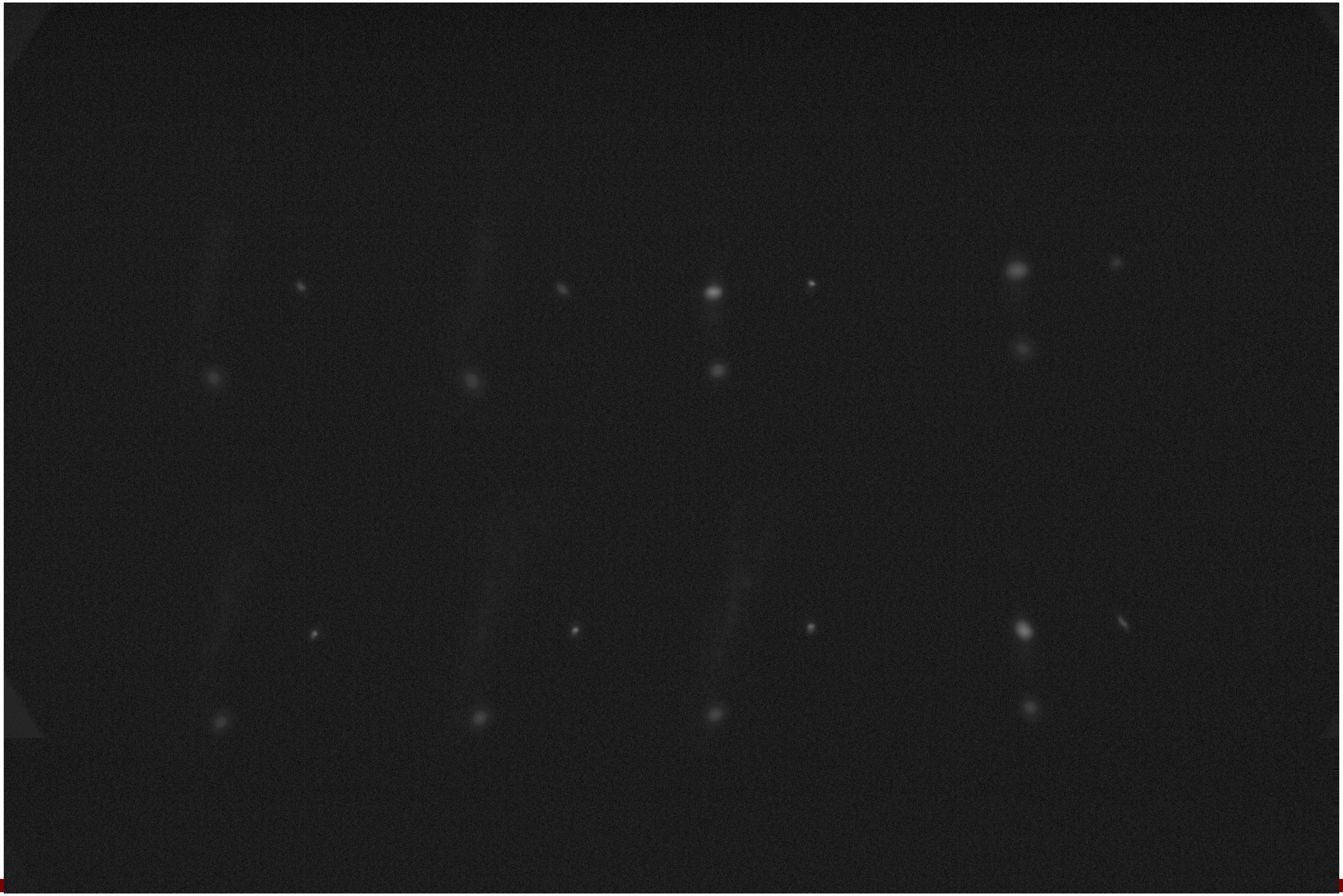
Shot 1 Configuration



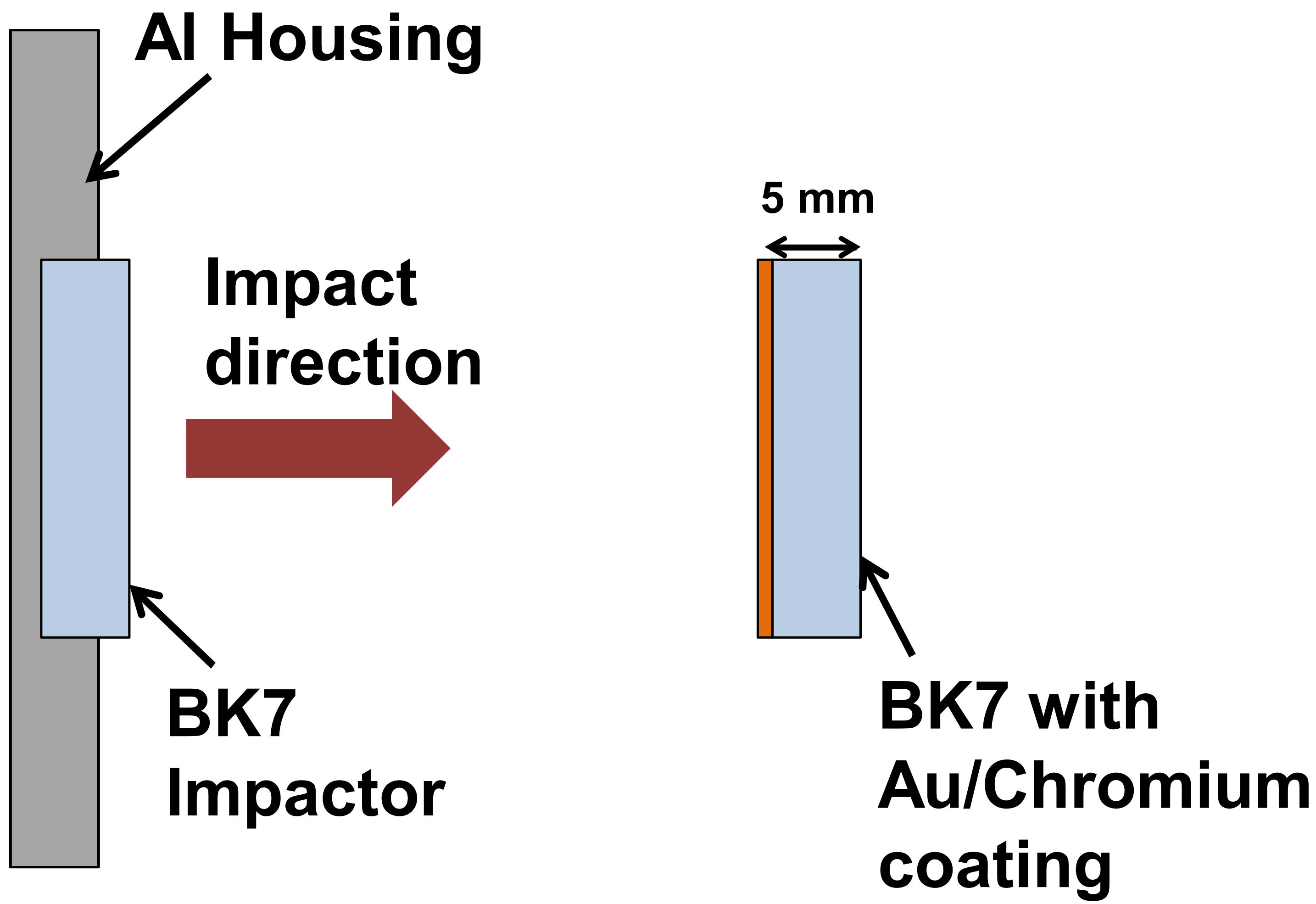
Pre-shot 1


Primary Beam
Fiducial
Reflection off front of window
Frame 3
Frame 1
~Frame Size
Frame 2

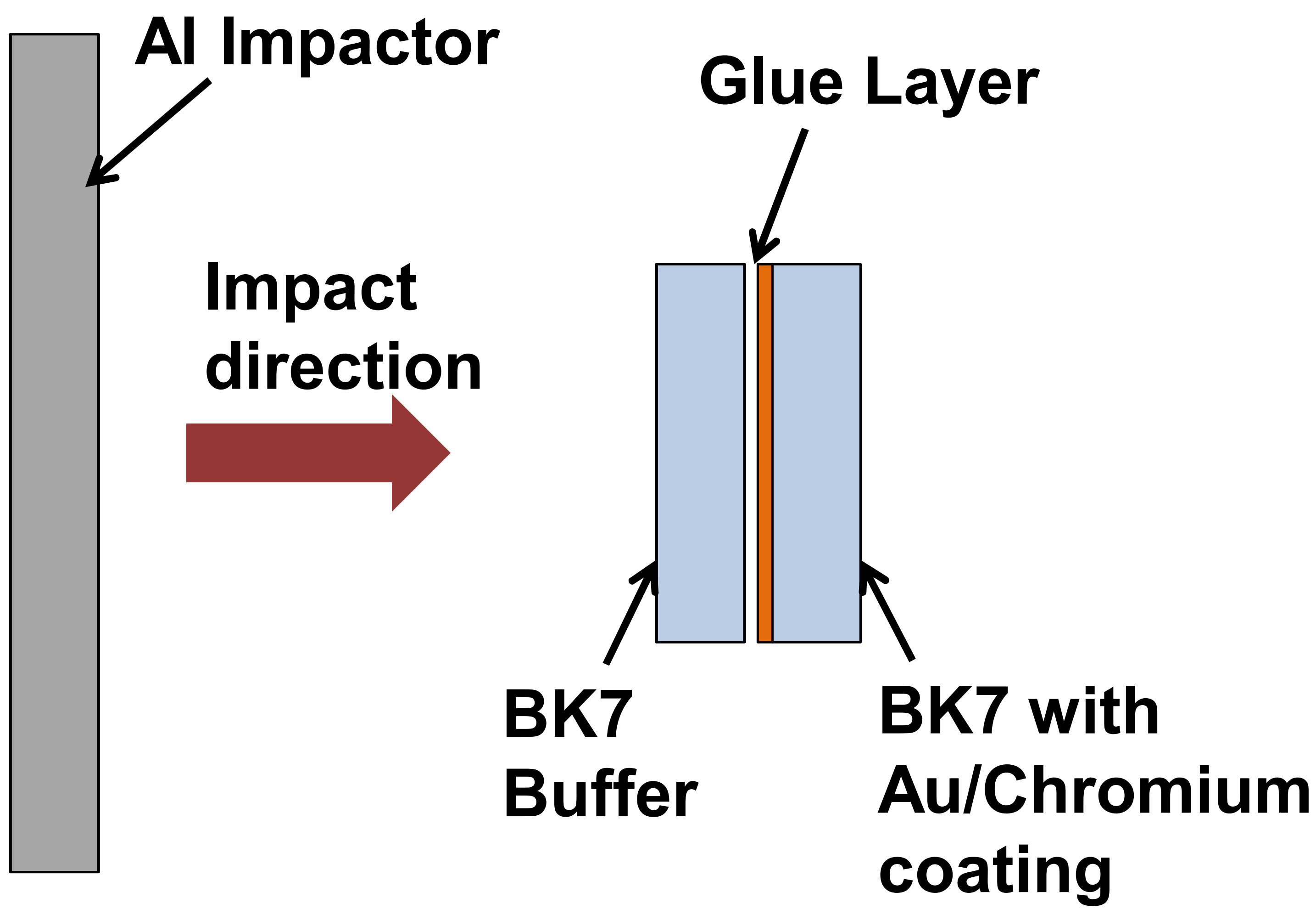
Shot 1



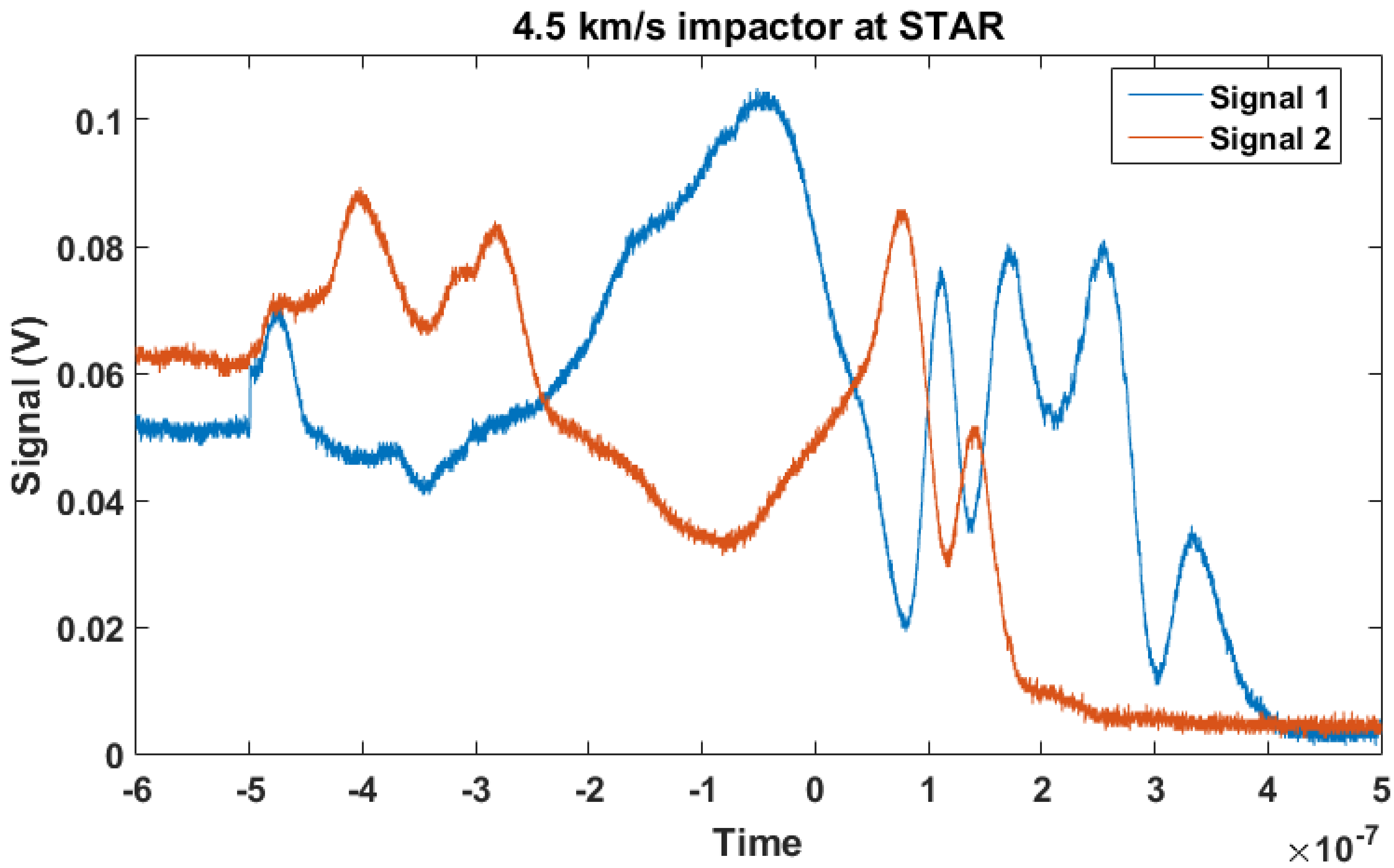
Shot 2 Configuration

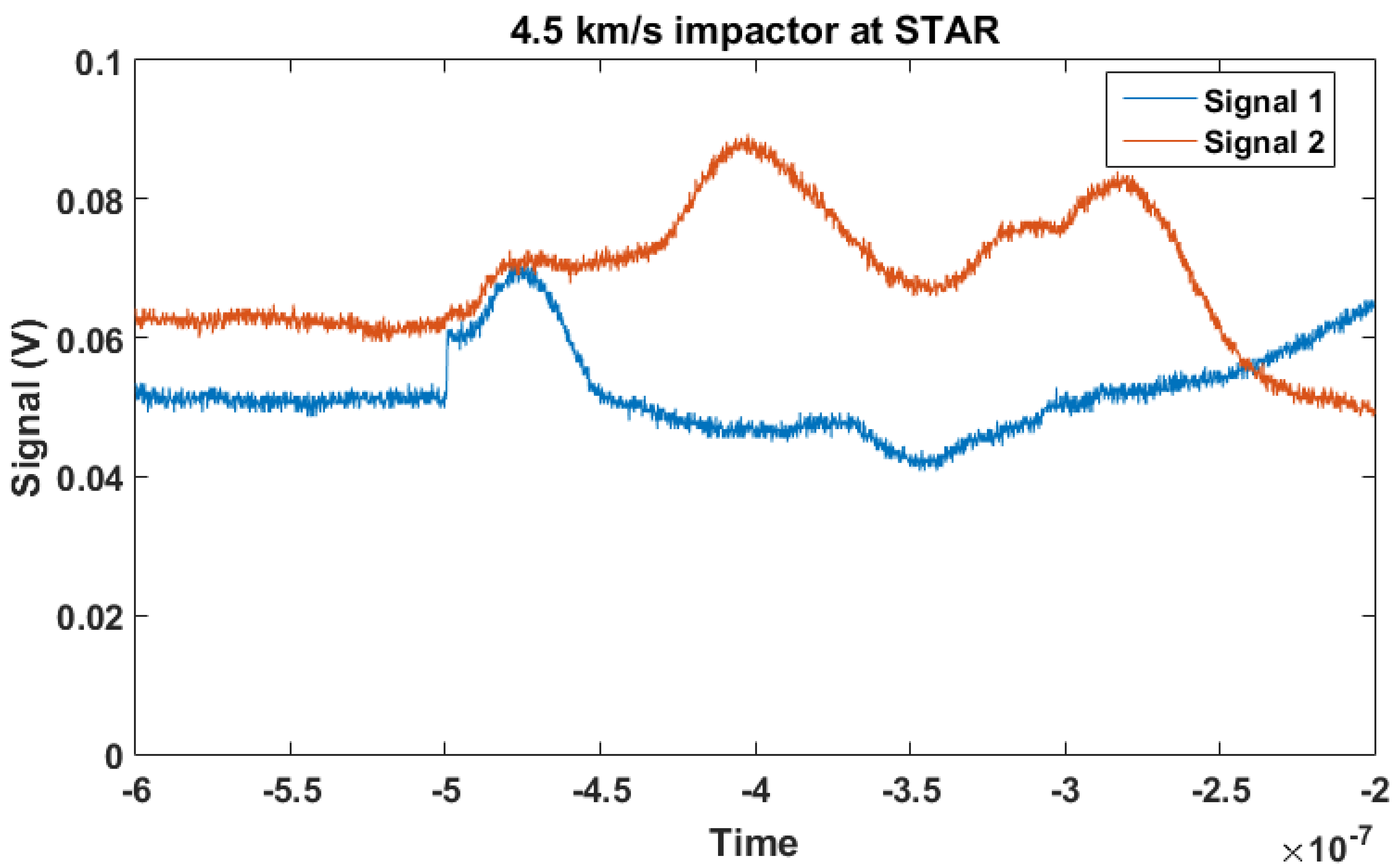


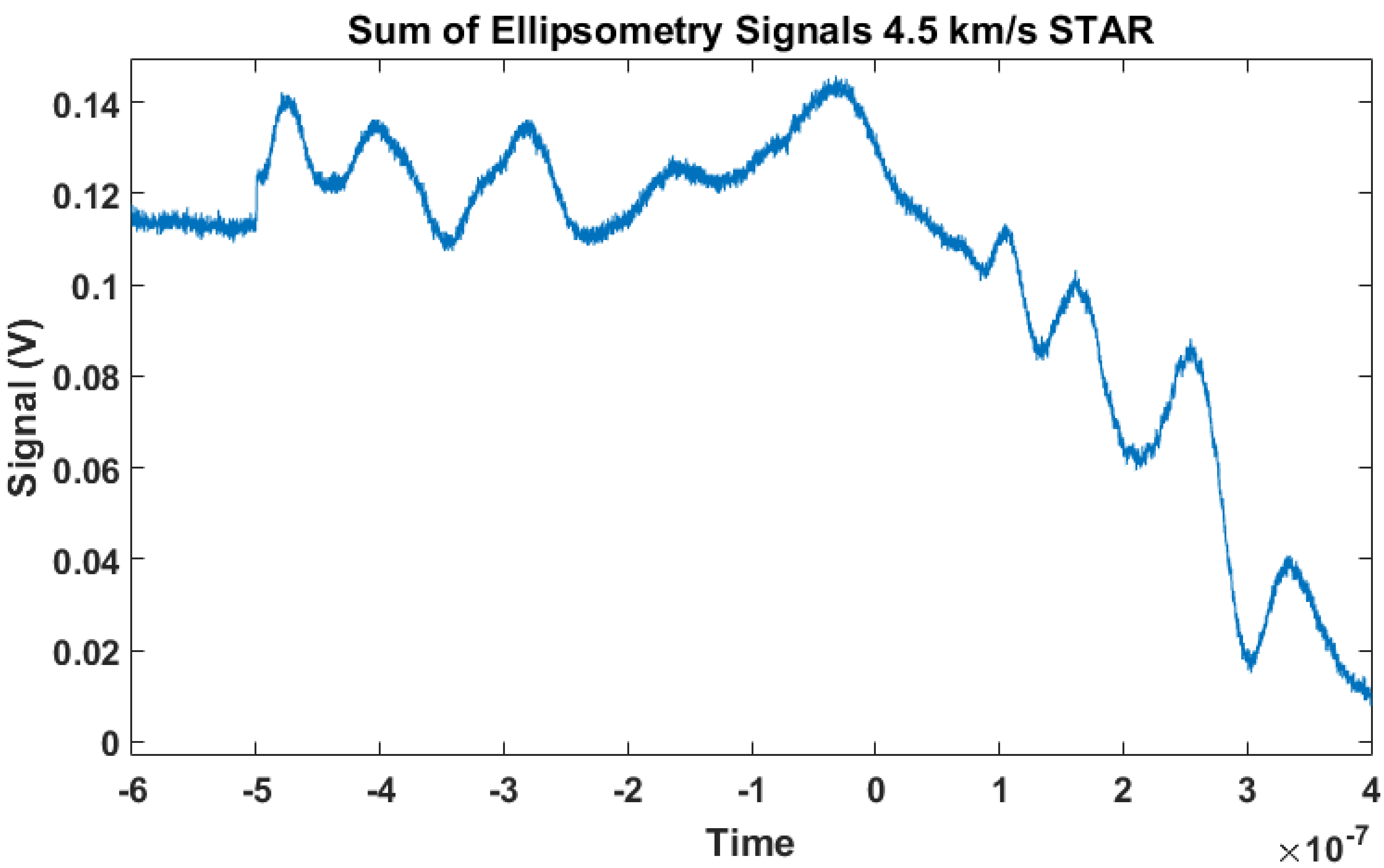
Shot 3 Configuration

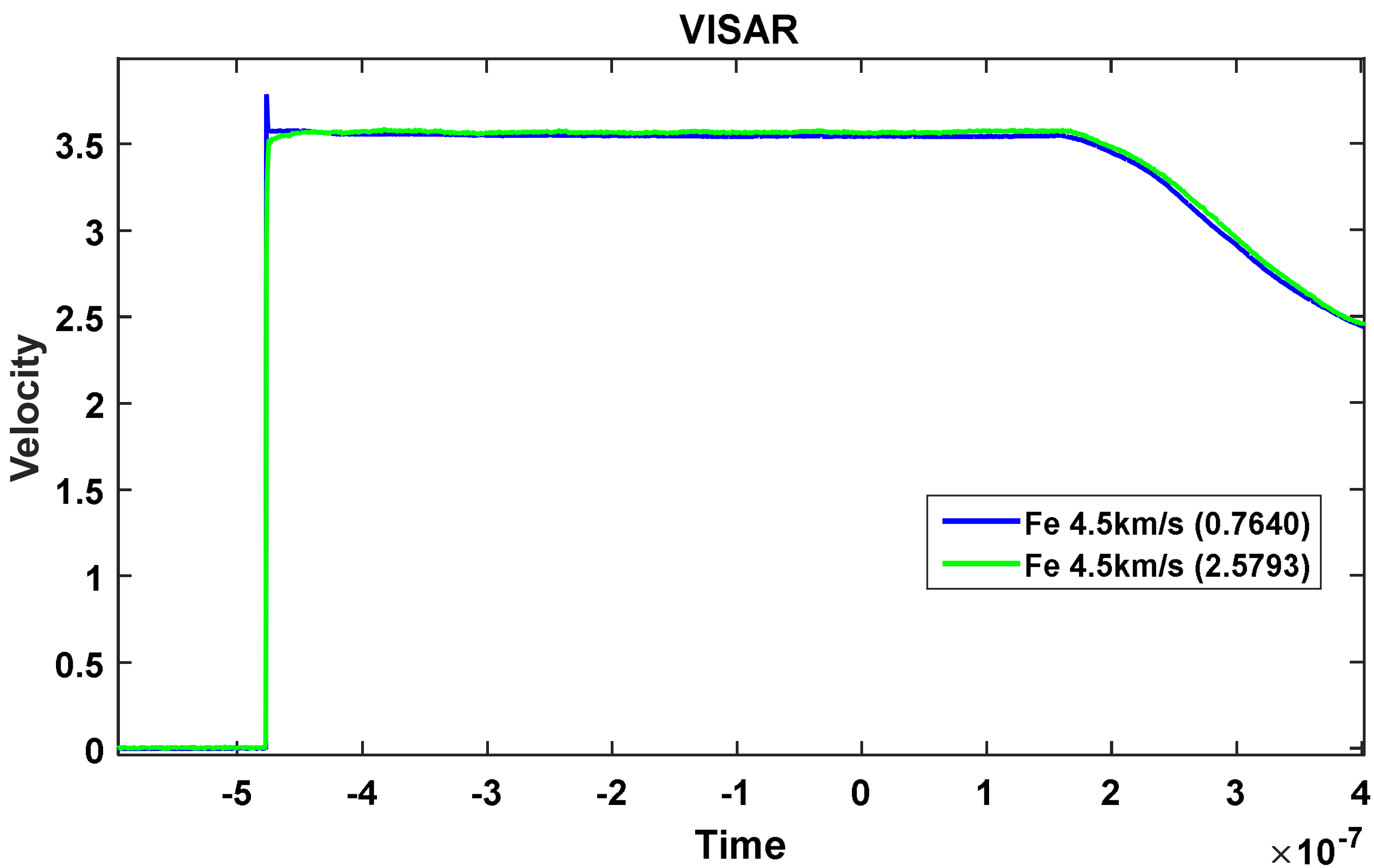


DATA FROM A 4.5 KM/S IMPACTOR ONTO FE AT THE STAR FACILITY


4.5 km/s impactor at STAR
Signal 1
Signal 2
Signal (V)
0.1
0.08
0.06
0.04
0.02
0
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
Time
×10-7


4.5 km/s impactor at STAR
Signal 1
Signal 2
Signal (V)
0.1
0.08
0.06
0.04
0.02
0
-6
-5.5
-5
-4.5
-4
-3.5
-3
-2.5
-2
Time
×10-7


Sum of Ellipsometry Signals 4.5 km/s STAR
Signal (V)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-6
-5
-4
-3
-2
-1
0
1
2
3
4
Time
×10-7



VISAR
Velocity
3.5
3
2.5
2
1.5
1
0.5
0
-5
-4
-3
-2
-1
0
1
2
3
4
Time
×10-7
Fe 4.5km/s (0.7640)
Fe 4.5km/s (2.5793)