SUBNANOSECOND ANALYSIS OF COMPLEX VELOCITY PROFILES

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This work describes progress at the Los Alamos Operations (LAO) of National Securities Technology (NSTec) in developing sub-nanosecond analysis capability for Photon Doppler Velocimetry (PDV)/triature data. We are developing analysis techniques that will ultimately provide fine time resolution for PDV/triature data. The application of these techniques to simulated data and laser-driven shock data are presented. The simulated data were generated with a “complex” velocity profile provided by Los Alamos National Laboratory to help determine uncertainties on expected velocity profiles of interest. The simulated triature data include gain and phase discrepancies that might be expected in actual data. The triature analysis flow applies a forward modeling technique to resolve these gain and phase discrepancies. Using the resolved gain and phase discrepancies, the fine time resolution techniques successfully extract rise times of a few hundred picoseconds (and less) for the simulated data. Pre- and post-experiment characterization techniques to resolve gain and phase discrepancies are also described here, although the analysis has the capability to extract such information from data. In addition, NSTec applied these analysis capabilities to laser-driven shock data to extract velocities of 2,500 m/s with subnanosecond rise times. Comparisons of these analysis results are made with corresponding VISAR diagnostic results.

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Outline

- Adaptive Down Conversion
- VISAR – Like analysis
- Omega filter analysis
- Simulation with Results
- Triature
- Forward Modeling
- Lissajous
- Triature Results (with Single PDV)
- VISAR Results
- Conclusion

Single Channel Analysis: Adaptive Down Conversion

1. Interpolate data with FFT approach to double sample frequency
2. Compute FFT power spectrum at greatest overlap as possible.
3. Extract velocity and bandwidth as function of time
4. Convert to frequency
5. Integrate to obtain phase, *Φ(t)*
6. Compute mixing functions *cos(Φ(t))* and *sin(Φ(t))*
7. Multiply each mixing function by the data, *D(t)*
8. Low pass filter the products, *PC(t)* and *PS(t)*
9. Regenerate data using *sin(Φ(t))* and *cos(Φ(t))* mixing function

In phase, $I(t) = PC(t)\cos(\Phi(t)) - PS(t)\sin(\Phi(t)) \approx D(t)/2$

Out of Phase, $Q(t) = PS(t)\cos(\Phi(t)) + PC(t)\sin(\Phi(t))$

$\approx D(t)/2$ out of phase by 90 degrees

Compute phase as $\phi(t) = a\tan(Q(t)/I(t))$

Refined velocity as $v(t) = \frac{(\lambda/2)}{2\pi}\frac{d(\Phi(t))}{dt}$

We use polynomial fit to calculate time derivative

Single Channel Analysis: VISAR Like

Begin with data sets:

In phase, $I(t) = A(t)\cos(\phi(t))$, and

Out of phase, $Q(t) = A(t)\sin(\phi(t))$

Generate $I'(t) = I(t+dt) = A(t)\cos(\phi(t) + 2\pi f\Delta t)$, and

$$Q'(t) = Q(t+dt) = A(t)\sin(\phi(t) + 2\pi f\Delta t)$$

Note: $(Q'I - I'Q)/(I'I + QQ') = \tan(2\pi f\Delta t)$

Unfold Velocity as

$$v(t) = \left(\frac{\lambda}{4\pi\Delta t}\right)\tan^{-1}\left(\frac{Q'I - I'Q}{I'I + QQ'}\right)$$

As in VISAR (equivalent to two point slope calculation)

Single Channel Analysis: Omega Filter

From Wikipedia, the free encyclopedia

106	$\frac{d^n f(t)}{dt^n}$	$(i\omega)^n F(\omega)$	$(i2\pi f)^n F(\nu)$	Generalized derivative property of the Fourier transform

```
Pro FFTdYdT, Data, dYdt, N, dt

    I                         = complex(0,1)

  ;; frequency filtering for time derivatives
    Omega                     = 2.0*3.1415926*lindgen( N ) / float(N)/ dt
    NegIndex                  = lindgen( N / 2 )
    Omega[N - NegIndex]       = -Omega[NegIndex + 1]
    Omega[N/2]                = 0

  ;; time derivative
    dYdt                      = float( FFT( Omega*I*FFT( Data, -1), 1))

End
```

Single Channel Analysis: Omega Filter, cntd

Begin with data sets:

In phase, $I(t) = A(t)\cos(\phi(t))$, and Out of phase, $Q(t) = A(t)\sin(\phi(t))$

Normalize: $A(t) = \sqrt{I^2(t) + Q^2(t)}$

$$i(t) = \frac{I(t)}{A(t)} = \cos(\phi(t)) \text{ and } q(t) = \frac{Q(t)}{A(t)} = \sin(\phi(t))$$

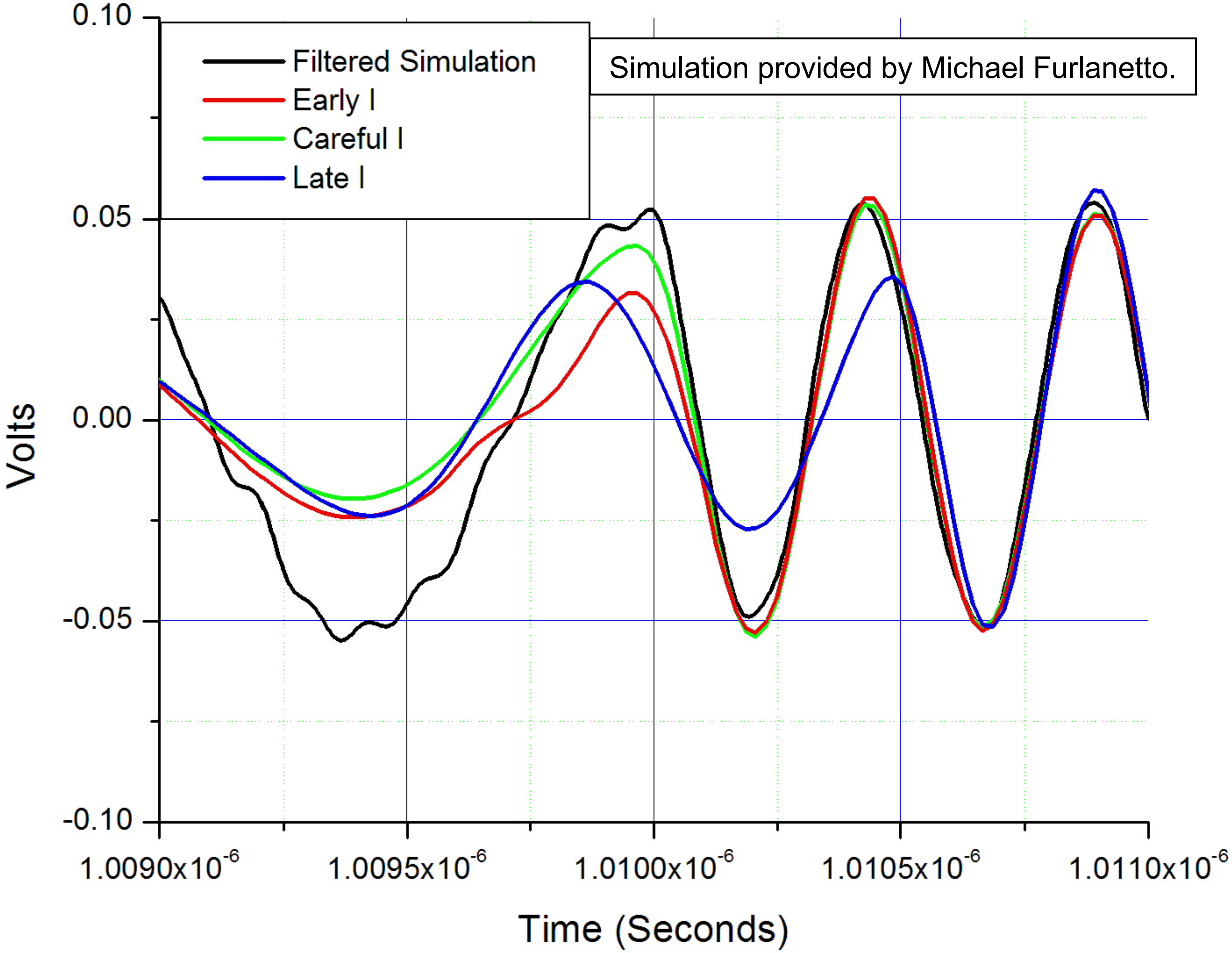
Use Omega filter to compute time derivatives of $i(t)$ and $q(t)$ as

$i_\omega(t) = -\omega q(t)$, and $q_\omega(t) = \omega i(t)$, respectively.

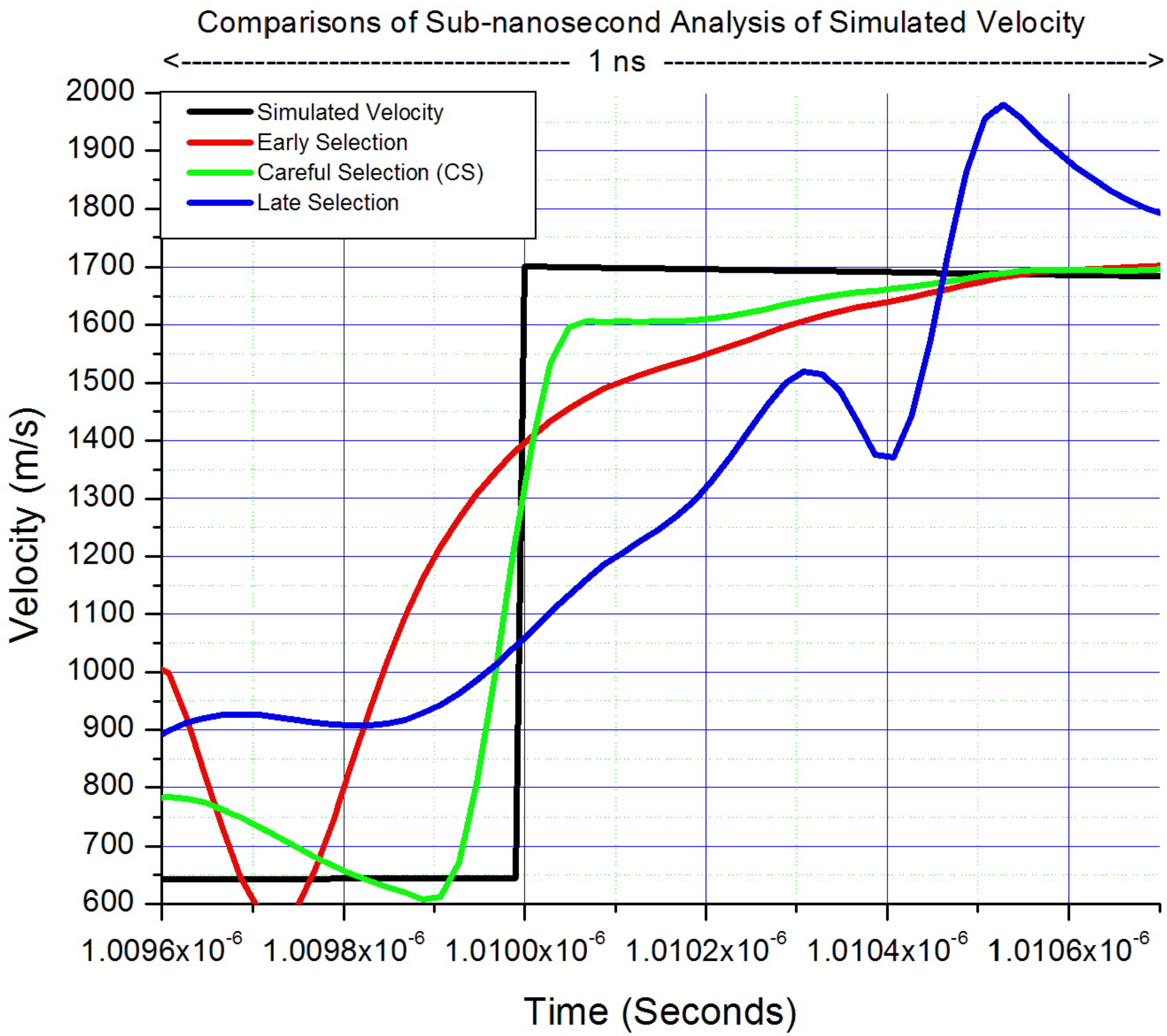
Note that $\omega(t) = i(t)q_\omega(t) - q(t)i_\omega(t)$,

Compute velocity as $v(t) = \left(\frac{\lambda}{4\pi}\right)\omega(t)$

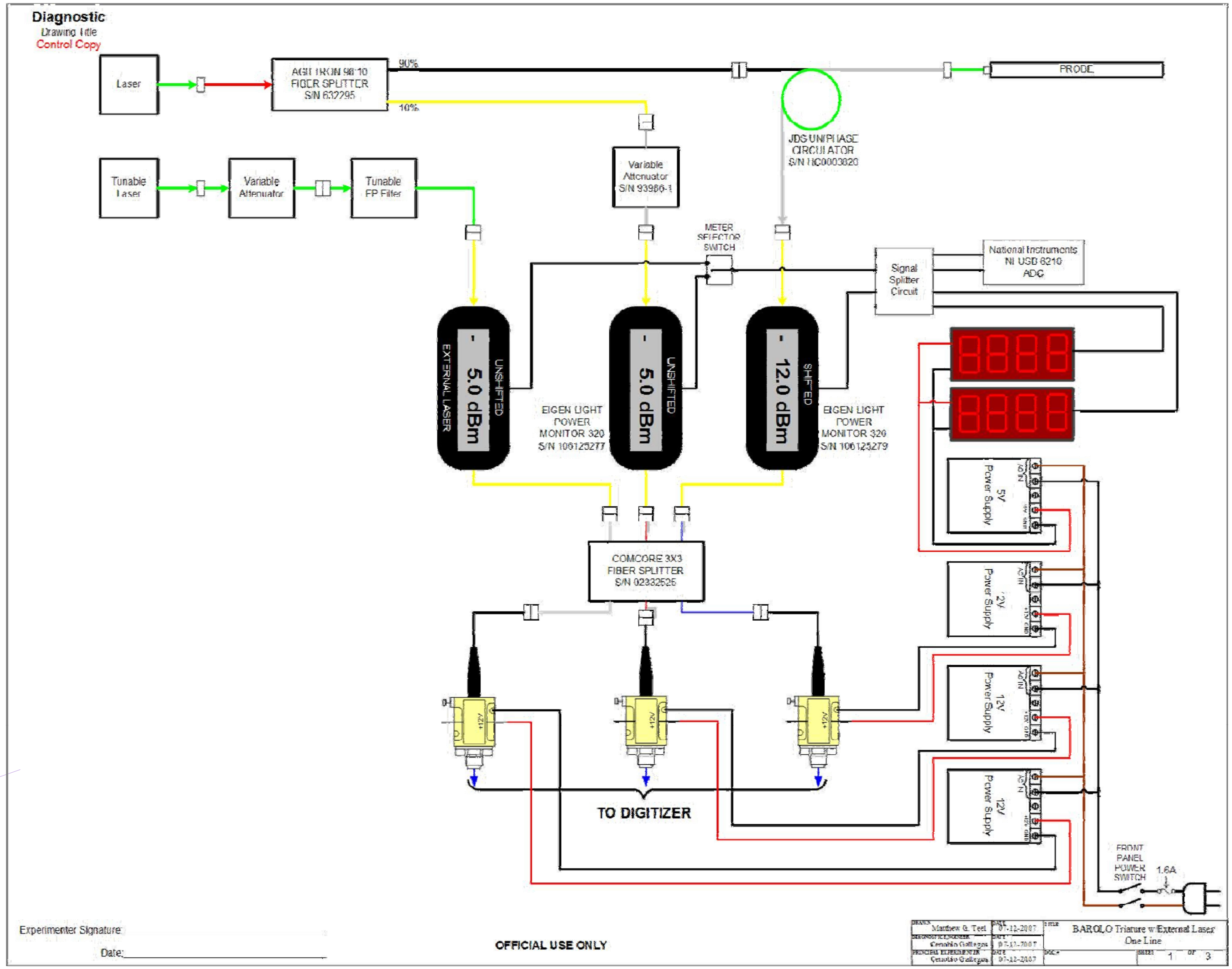
ADC at 800MHz bandwidth
Wave forms at break out



ADC at 800MHz bandwidth



Triature: Phase/Gain Characterizations



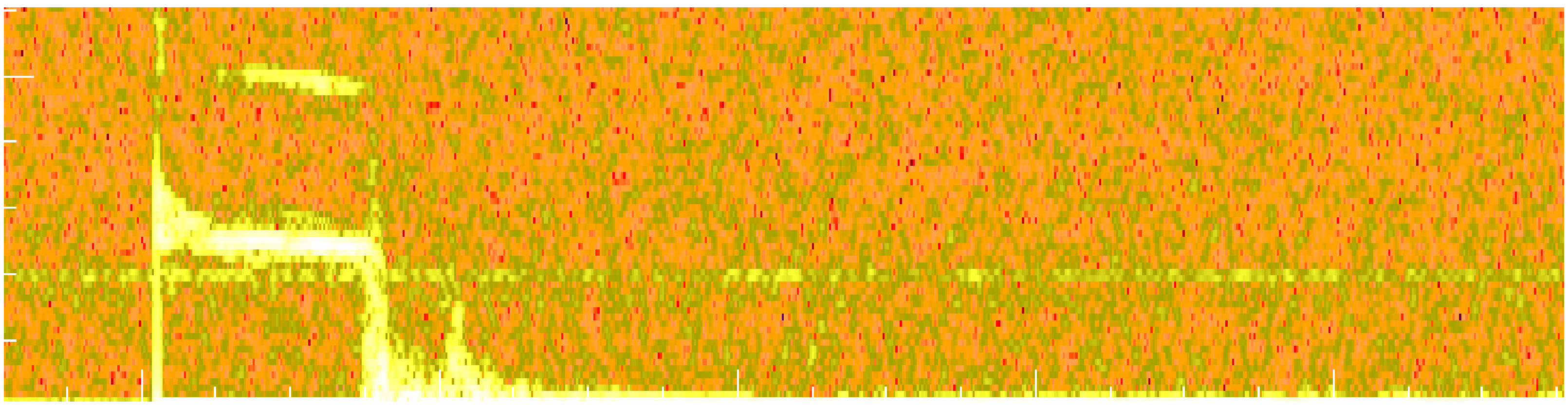
Triature: Issues

Uncertainties in phases

- splitter should be $120^\circ \rightarrow$ resolved

Response in detectors

- gains $\rightarrow$ resolved
- uncorrected time delays



Triature: Forward Modeling

Finding relative phases and gains between Triature channels by modeling one channel by another.

Example : Model Channel 1 with Channel 3 (ADC Results)

Begin with Channel 1 : $I_1 \sin(\pi/4) + Q_1 \cos(\pi/4)$ and assume Channel 03 is stationary,

$$I_3 = \cos(\phi) \qquad Q_3 = \sin(\phi)$$
$$I_1 = \cos(\phi - \Delta\phi_{13}) \qquad Q_1 = \sin(\phi - \Delta\phi_{13}).$$

Find I_1 in terms of I_3 and Q_3,

$$\begin{aligned} I_1 &= \cos(\phi - \Delta\phi_1) \\ &= \cos(\phi)\cos(\Delta\phi_{13}) + \sin(\phi)\sin(\Delta\phi_{13}) \\ &= I_3 \cos(\Delta\phi_{13}) + Q_3 \sin(\Delta\phi_{13}) \end{aligned}$$

$$\begin{aligned} Q_1 &= \sin(\phi - \Delta\phi_{13}) \\ &= \sin(\phi)\cos(\Delta\phi_{13}) - \cos(\phi)\sin(\Delta\phi_{13}) \\ &= Q_3 \cos(\Delta\phi_{13}) - I_3 \sin(\Delta\phi_{13}). \end{aligned}$$

Function used to fit Channel 1, $F = g_{13} I_1 \sin(\pi/4) + g_{13} Q_1 \cos(\pi/4)$

where initialy $g_{13} = \dfrac{\sqrt{\sum I_3^2 + \sum Q_3^2}}{\sqrt{\sum I_1^2 + \sum Q_1^2}}$ and $\Delta\phi_{13} = 120^\circ$

Triature: Forward Modeling, continued

From the best fit we get the parameters g_{13} and $\Delta\phi_{13}$. Similarly we can find g_{12} and $\Delta\phi_{12}$.

From the Triature data we can write,

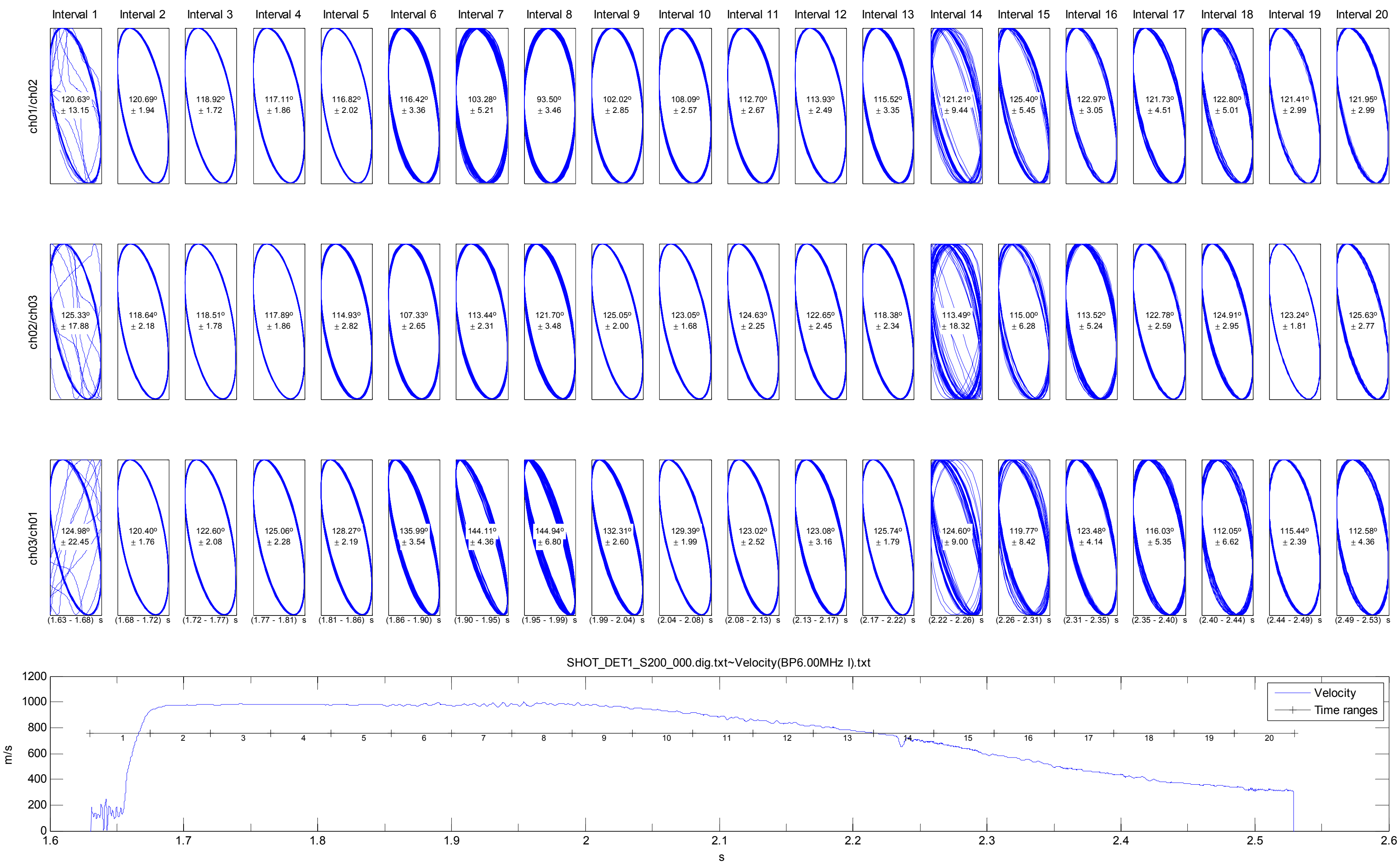
$$Ch01 = \cos(\phi)$$
$$Ch02 = \cos(\phi + \Delta\phi_{12}) = \mathrm{I}_1 \cos(\Delta\phi_{12}) - Q_1 \sin(\Delta\phi_{12})$$
$$Ch03 = \cos(\phi - \Delta\phi_{13}) = \mathrm{I}_1 \cos(\Delta\phi_{13}) + Q_1 \sin(\Delta\phi_{13})$$

Doing some algebra we get,

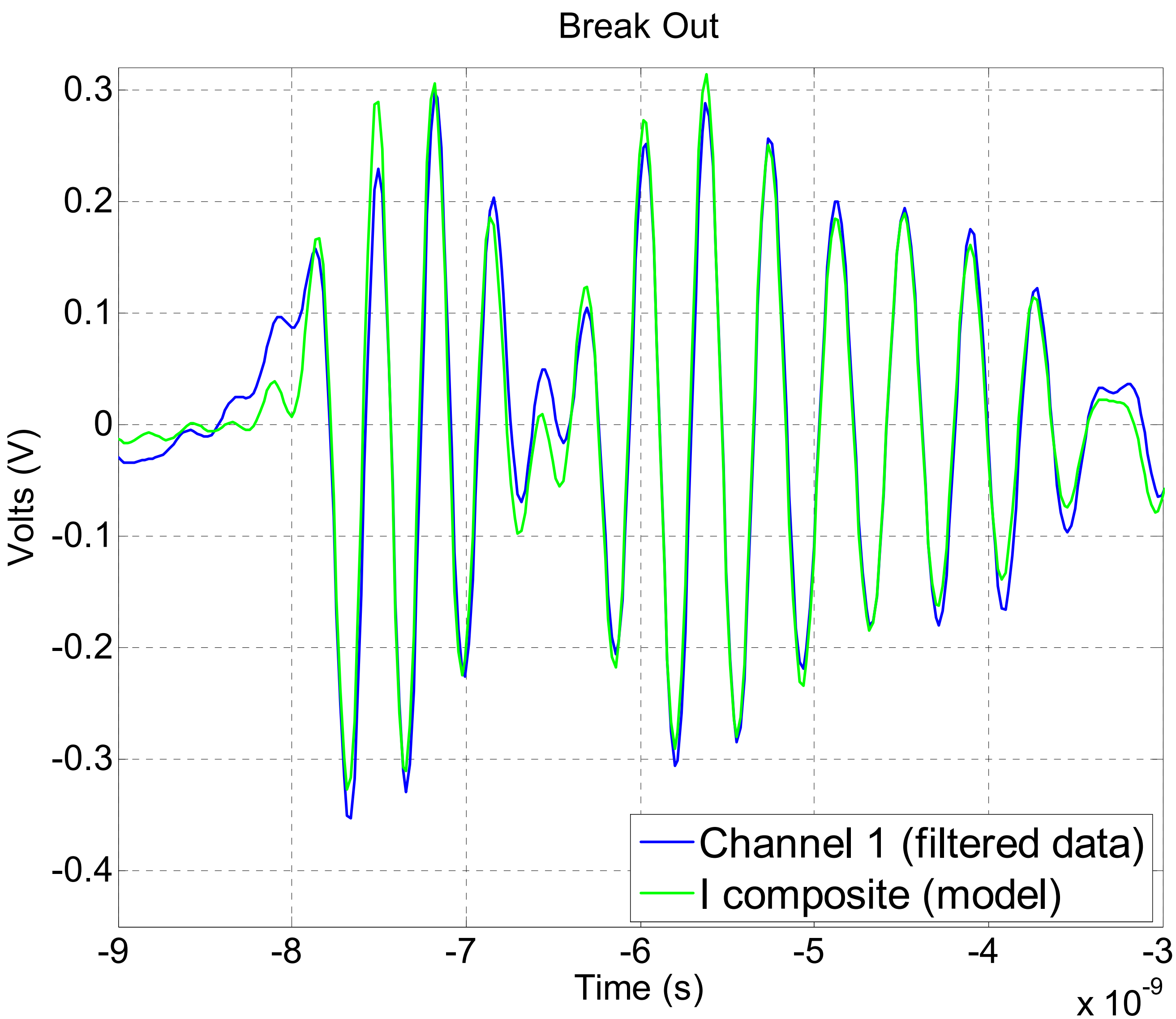
$$I_{composite} = \frac{Ch02\sin(\Delta\phi_{13}) + Ch03\sin(\Delta\phi_{12})}{\cos(\Delta\phi_{12})\sin(\Delta\phi_{13}) + \cos(\Delta\phi_{13})\sin(\Delta\phi_{12})}$$
$$Q_{composite} = \frac{Ch03\cos(\Delta\phi_{12}) + Ch02\cos(\Delta\phi_{12})}{\sin(\Delta\phi_{12})\cos(\Delta\phi_{13}) + \sin(\Delta\phi_{13})\cos(\Delta\phi_{12})}$$

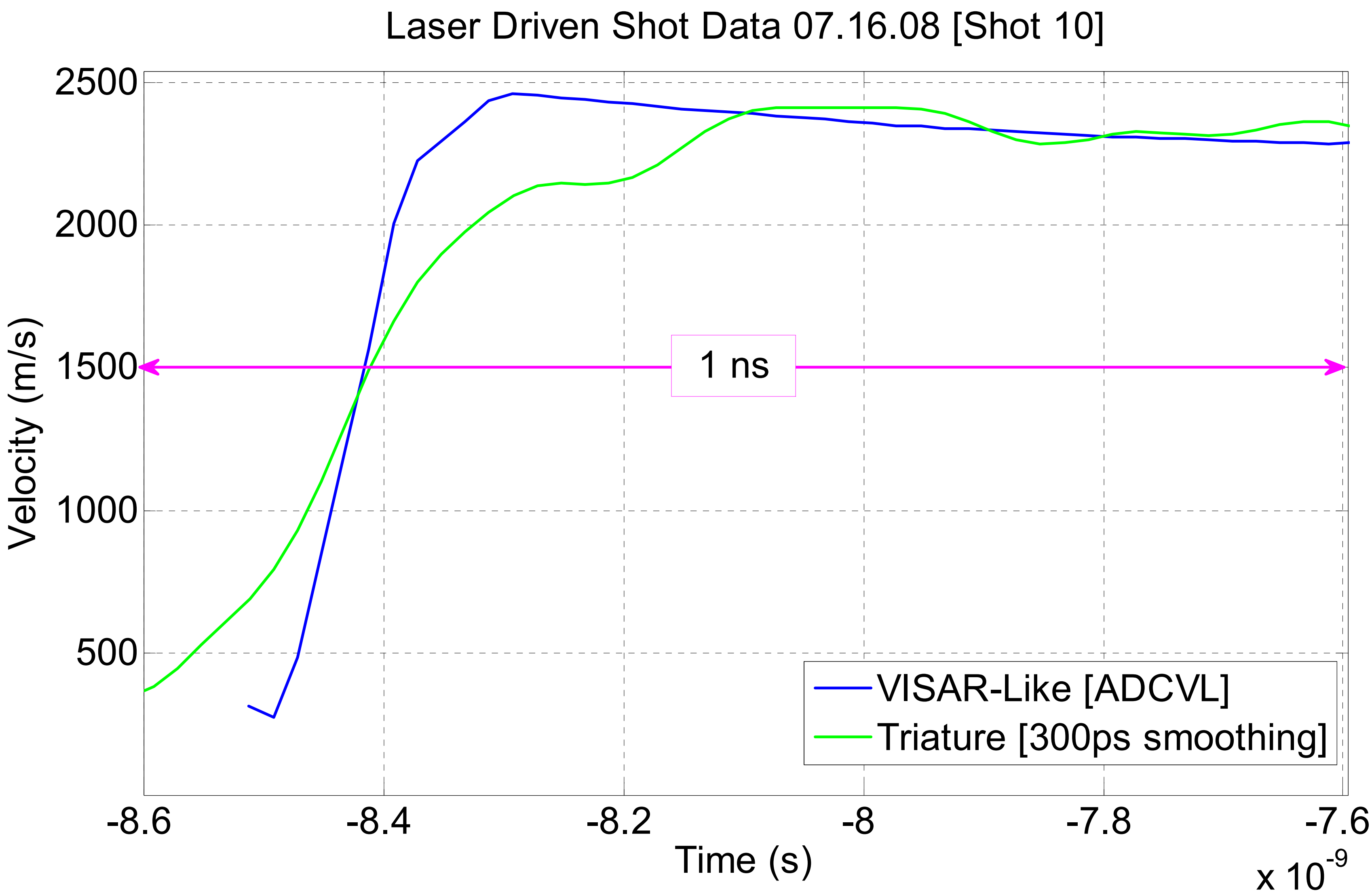
Triature: Lissajous (as suggested by Will Hemsing)

Powder Gun Shot October



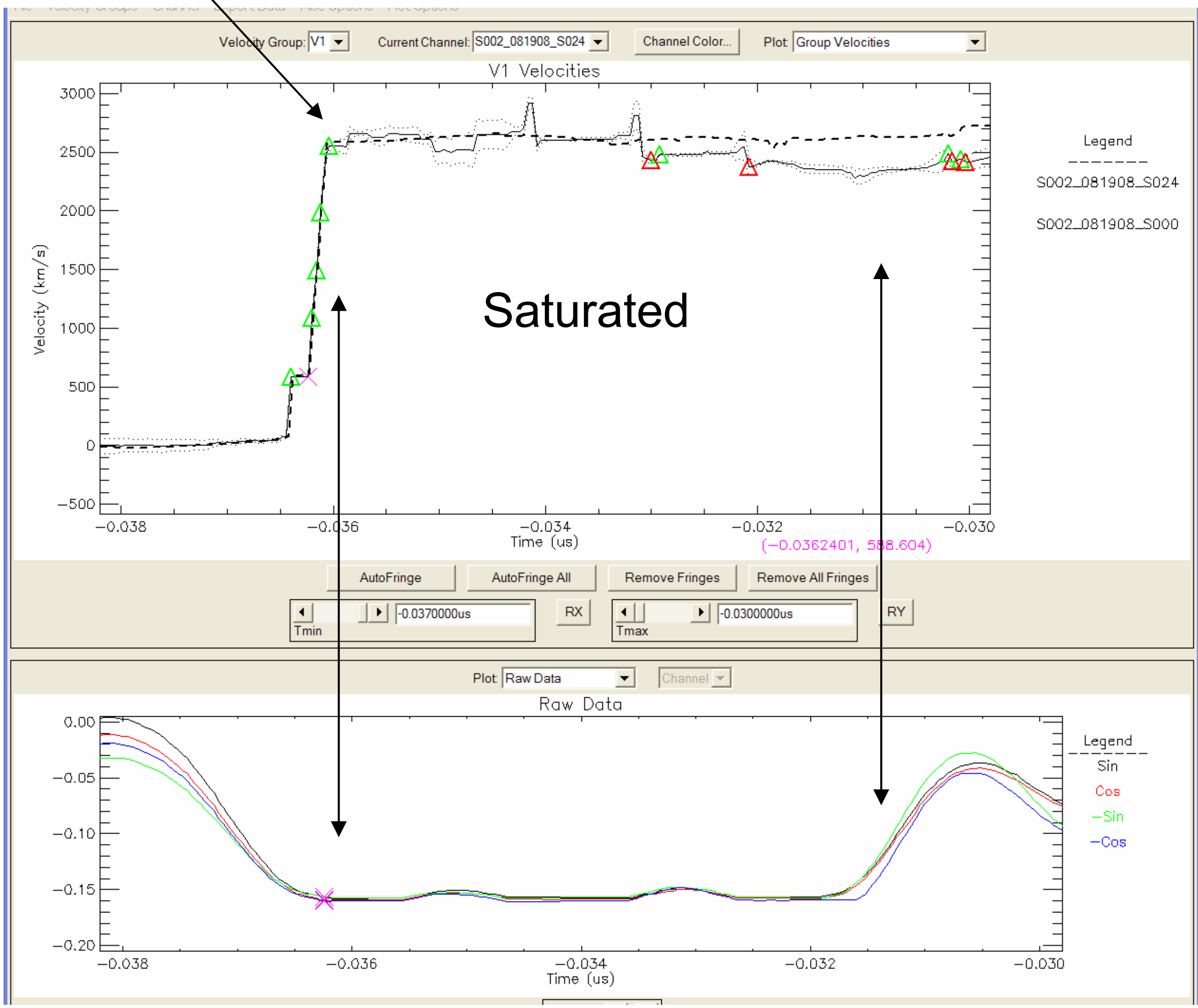
Data vs. Model




Laser Driven Shot Data 07.16.08 [Shot 10]
2500
2000
1500
1000
500
Velocity (m/s)
1 ns
VISAR-Like [ADCVL]
Triature [300ps smoothing]
-8.6
-8.4
-8.2
-8
-7.8
-7.6
Time (s)
x 10^-9

Fringes not added past this point in time.

2008-20-08 shot 2



Conclusions

- Sub-nanosecond time resolution in single PDV and Triature analysis.
- Need to finalize tools for ADC processing.
- Forward modeling recovers phase shifts and gains of Triature data. Need technique to resolve time delays.
- Lissajous methods support Triature results.
- Resolve “ringing” in Triature (possibly due to baseline or uncorrected time delays).