Determining Time of Initial Motion for Upshifted PDV

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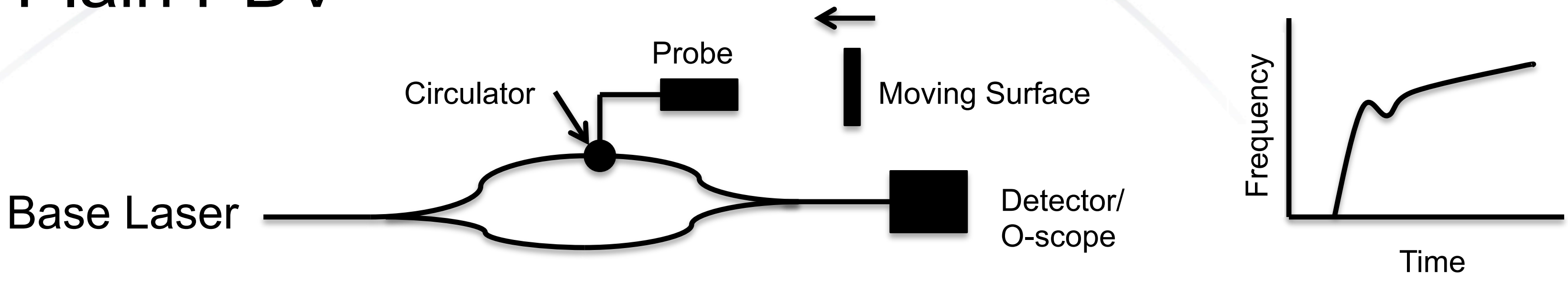
Motivation

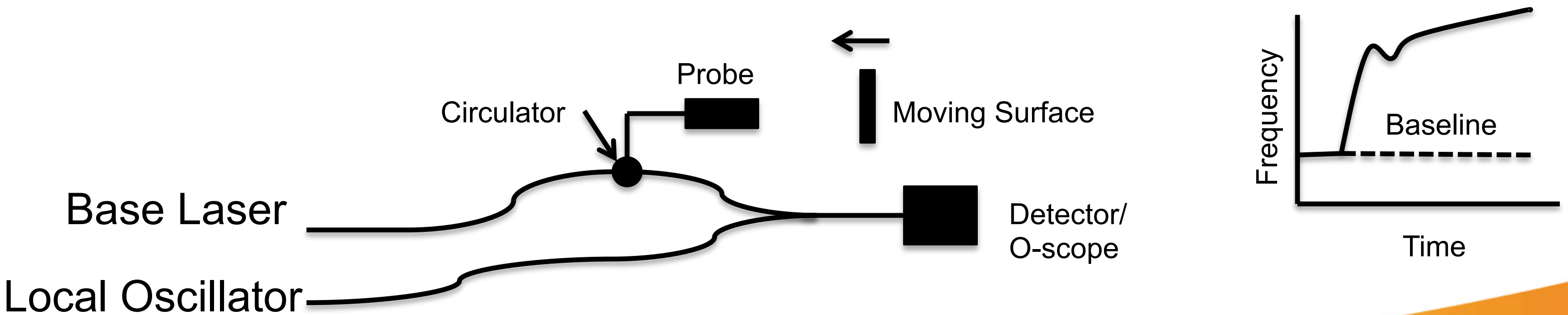
- TIM (time of initial motion) can be a powerful constraint on important physics and the quality of the experiment built.
- Precisely determine TIM to better understand physics such as:
  - Detonation Velocity
  - Shock Propagation
- The method presented here can be automated.
  - Code is efficient and can be run early after experiment.

Methods

- Plain PDV



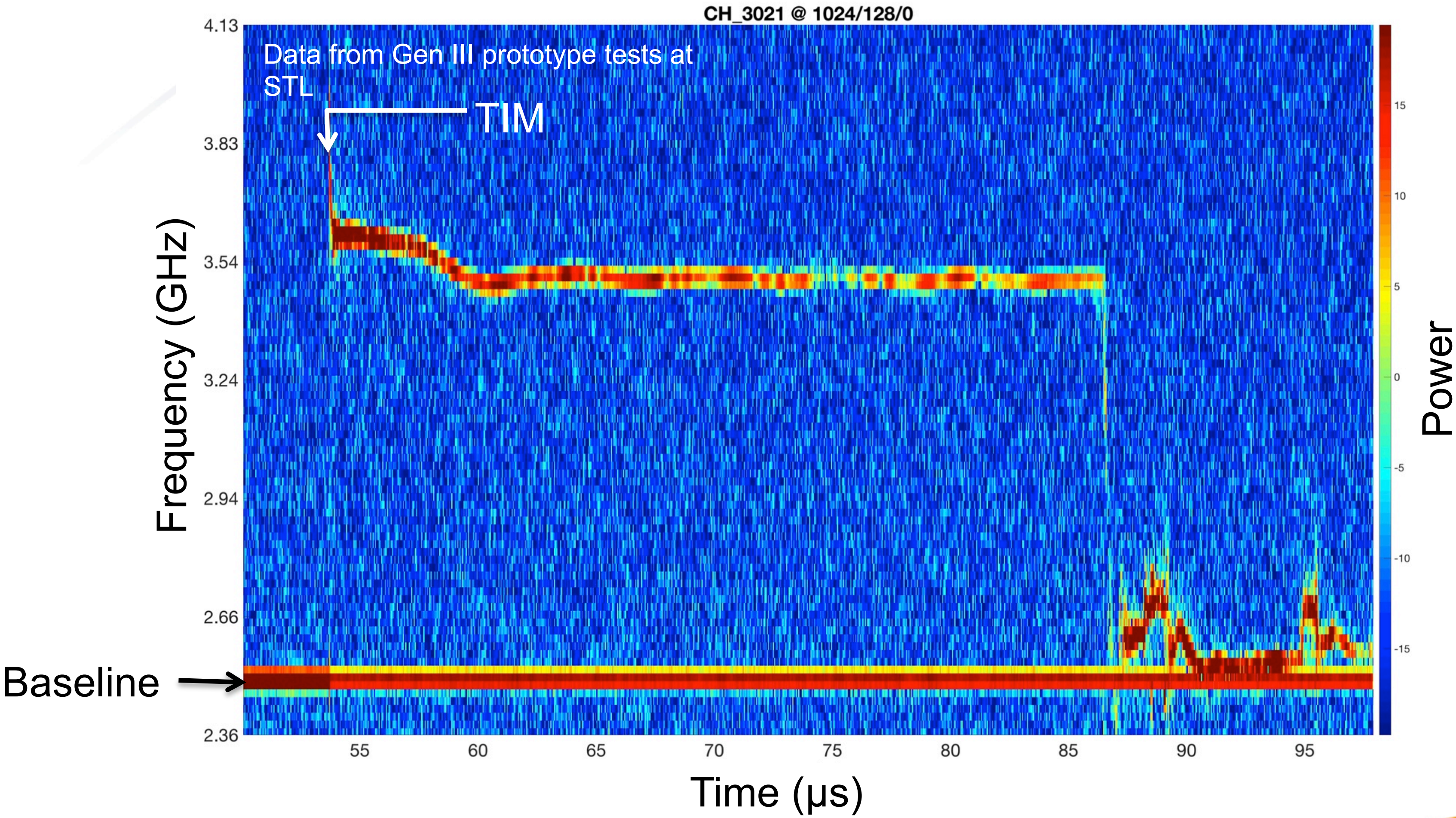
- Upshifted PDV



Methods

- Analysis is in frequency domain.
- Analysis uses the “baseline” to determine TIM.
  - Real and imaginary parts of FFT
  - Power
  - Phase Angle

Methods: Spectrogram



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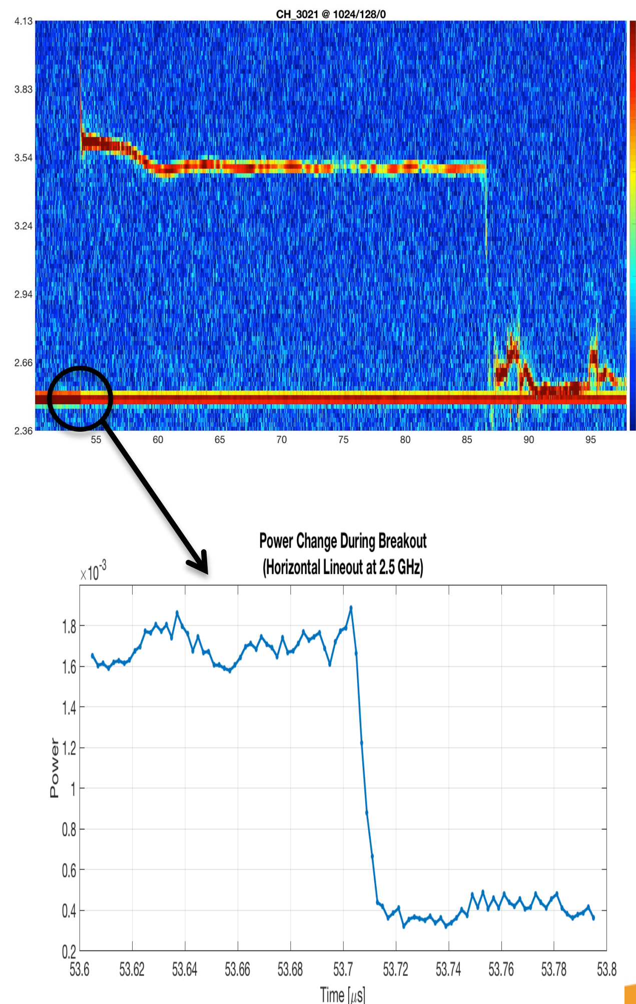
Methods: Horizontal Lineout

- Perform FFT on data using an analysis time window (~10 ns).
- Obtain power and phase information from baseline frequency.
- Plot power/phase information over selected time range (~200 ns around TIM).



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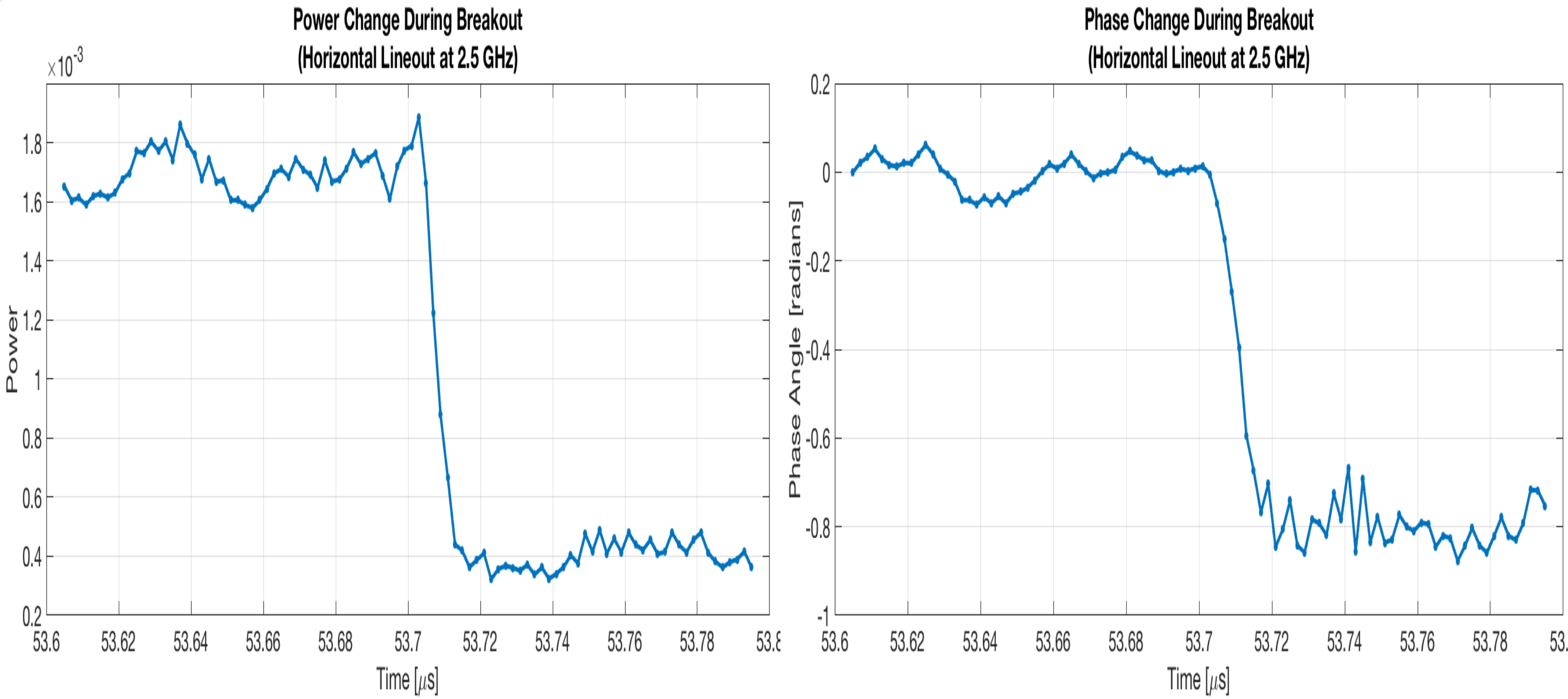
Methods: Baseline



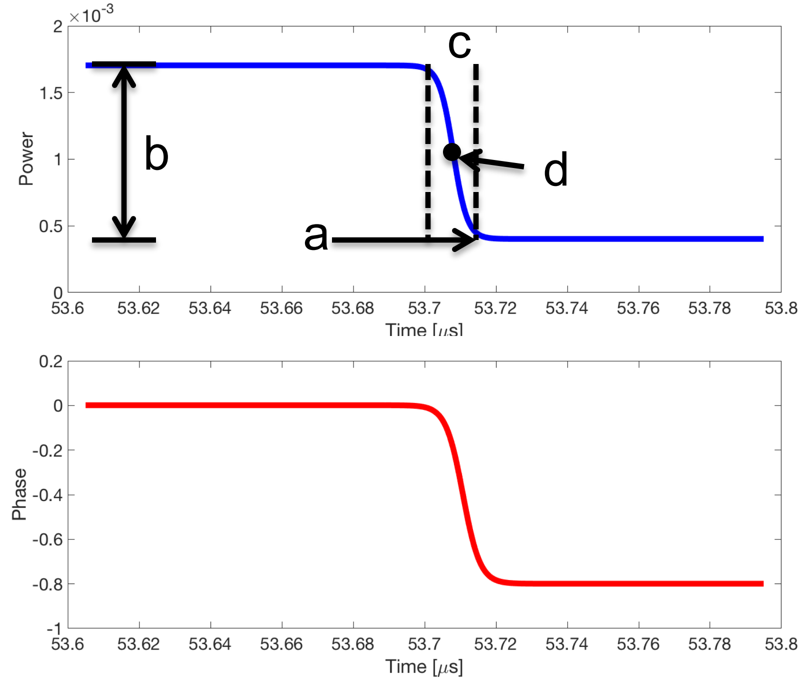
- A rounded step function can be used to model power and phase lineouts on the baseline.

Methods

- Use χ^2 minimization to simultaneously fit a rounded step function to the power and phase of the baseline.

$$Power_{\exp} = a + \frac{b}{1+e^{-c(t-d)}}$$

$$Phase_{\exp} = h + \frac{f}{1+e^{-g(t-d)}}$$



- Only d is in common between functions.

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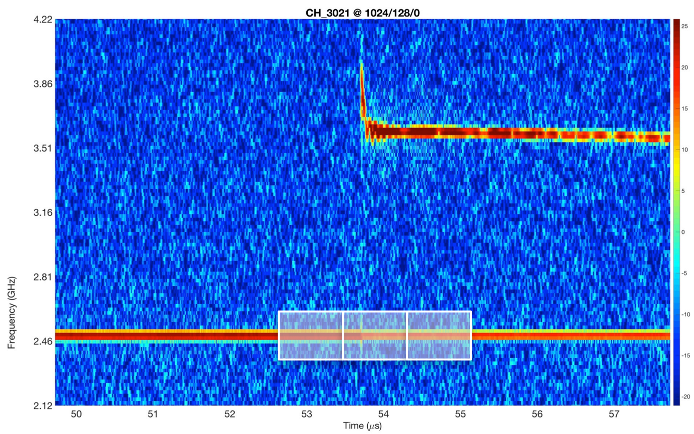
Methods

$$\chi^2 = \sum_i \left[\frac{(Power_{obs,i} - Power_{\exp,i})^2}{\sigma^2_{power}} + \frac{(Phase_{obs,i} - Phase_{\exp,i})^2}{\sigma^2_{phase}} \right]$$

- σ's are obtained from the standard deviation of the power and phase on the baseline before or after TIM
  – Worst case σ's

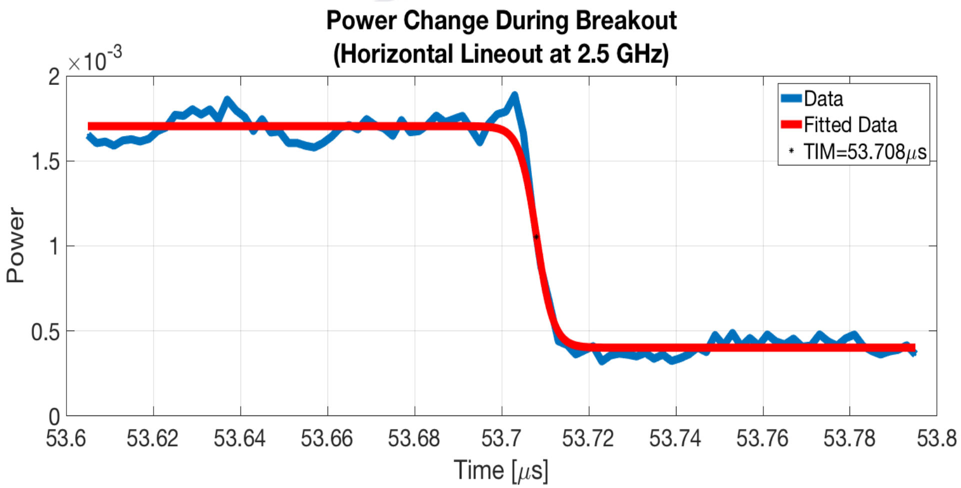


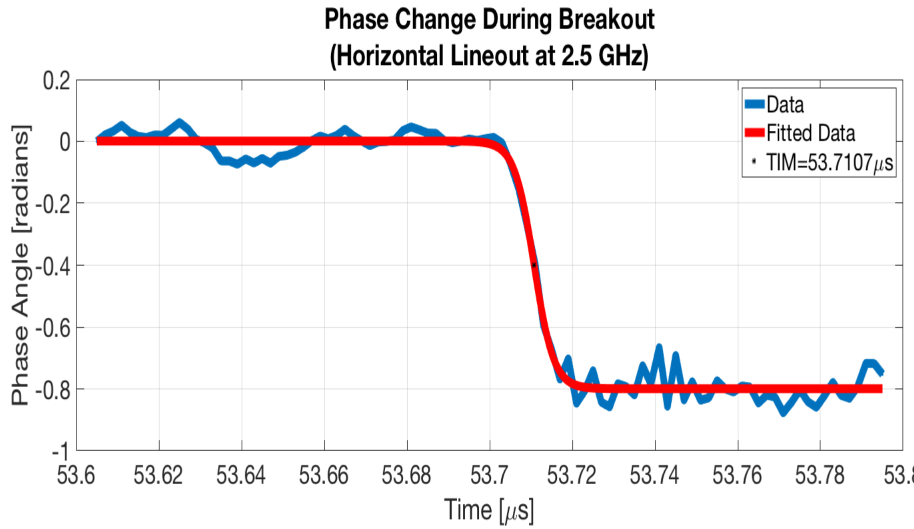
- χ^2 minimization is performed using a MATLAB nonlinear minimizer.

Methods: Uncertainties

- Obtained using a standard (statistically rigorous) technique.
  - Calculate standard deviation of χ^2 residuals.
  - Calculate Jacobian of step function.
  - Covariance Matrix = $std^2 * inv(J^T * J)$
  - Standard error is then the square root of diagonal of covariance matrix.

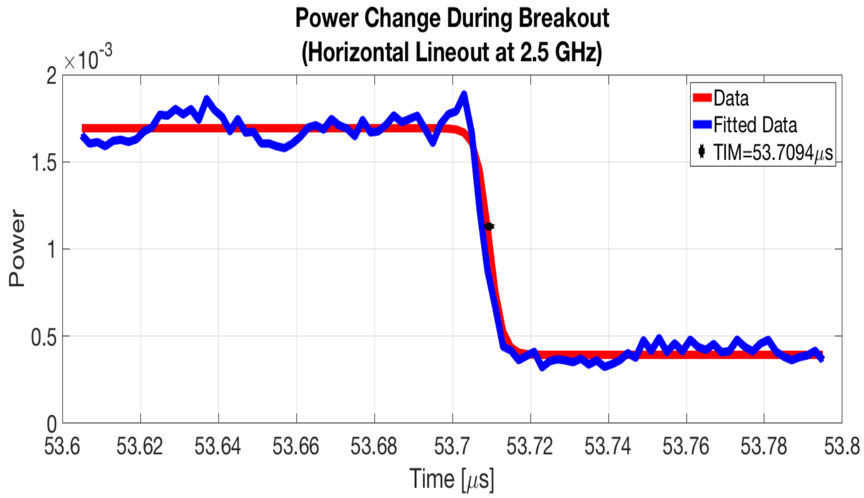
Methods: Independent Fits

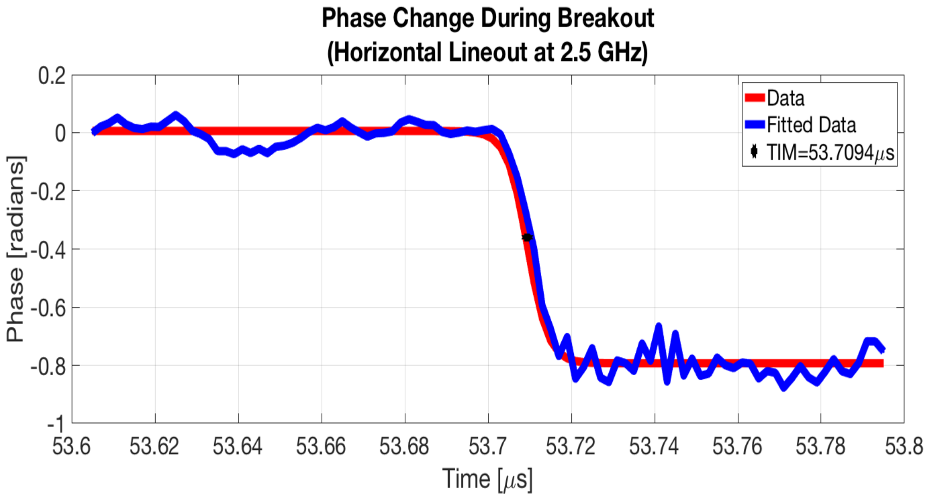




- Fitting power and phase independently produces different TIM (~3 ns in this case).
- Independent fits give first guess for MATLAB's minimizer to jointly fit both phase and power.

Methods: Joint Fit

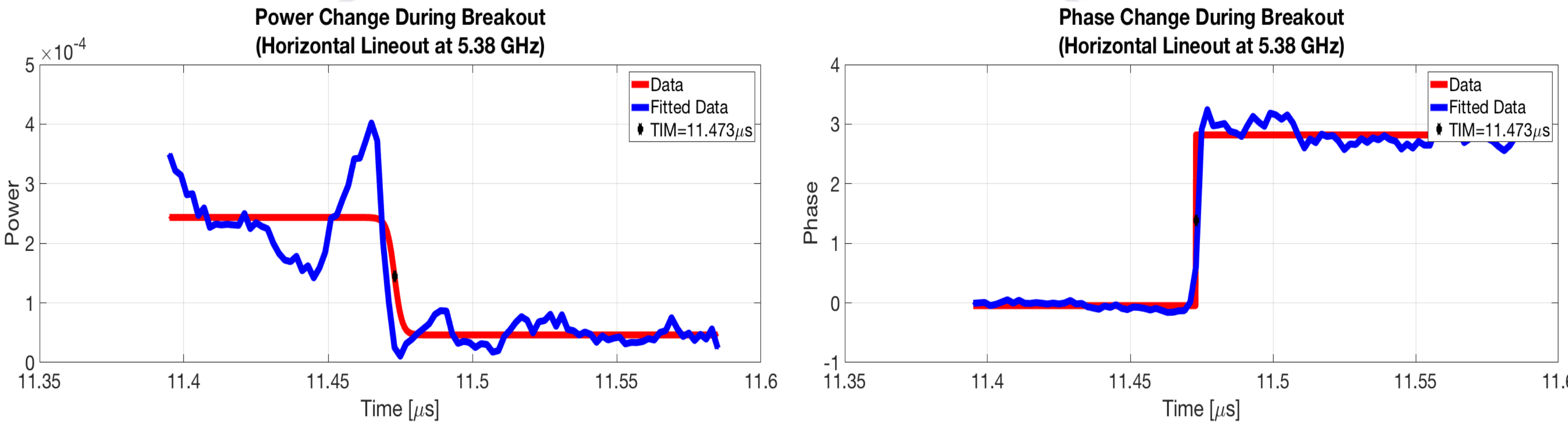




53.7094 μs +/- 1.4259 ns (95% confidence interval)

- Joint fit utilizes both power and phase to obtain a the TIM.

Methods: Joint Fit



11.473 µs +/- 1.548 ns (95% confidence interval)

- The component (power or phase) with less noise and/or sharper step will drive the fit.

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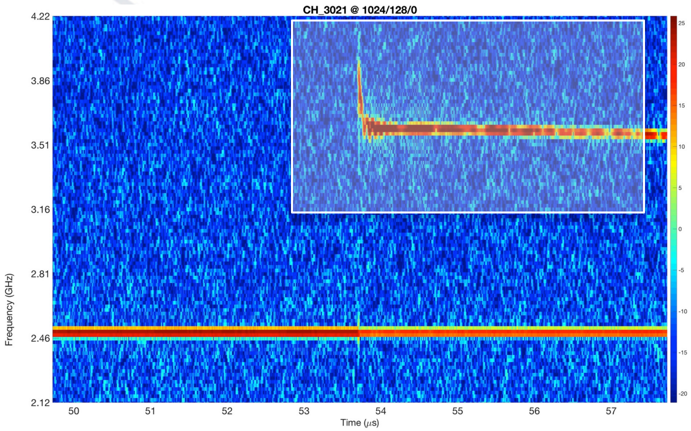
Future Work

- Implement an analysis of initial time of motion on the signal region.



- Use ROI's to semi-automate code.
- Should step sharpness parameter be a function of the velocity of a sweeping wave and spot size and analysis window?

Results

- This method calculates TIM (with uncertainties) in the frequency domain using both power and phase (or equivalently real and imaginary parts).
- For signals with good SNR, TIM uncertainties can be on the order of ns.
- Algorithm is coded in MATLAB, numerically efficient, and will be automated.