NIF Power Sensor Deconvolution Uncertainty

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New signal processing methods will improve the accuracy of NIF beamline diagnostics by 2-3%

Motivation

NIF has over 100 power sensors on its beamlines to measure pulse shape via a photodiode and digital oscilloscope. To improve power sensor accuracy, a deconvolution is performed using the oscilloscope's known Impulse Response Function (IRF). Currently, the deconvolved result has no error bars: the measurement's uncertainty would be a useful metric for anyone working with NIF shot diagnostics.

This project is focused on two aspects of the deconvolution problem in the context of NIF diagnostics:

1. How can we quantify the uncertainty of the deconvolved result?
2. How can we minimize the uncertainty (in a percent error sense)?

Approach

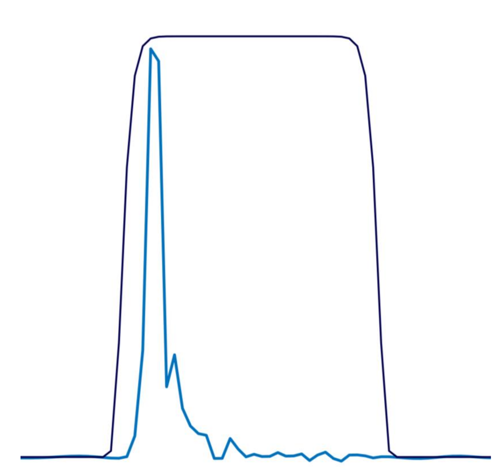
Setup and Model:

- NIF power sensor system modeled and simulated in MATLAB.
- NIF shot data used as ground truth for analysis.
- Noise drawn from a standard normal distribution added to truth signals to mimic the noisy environment.

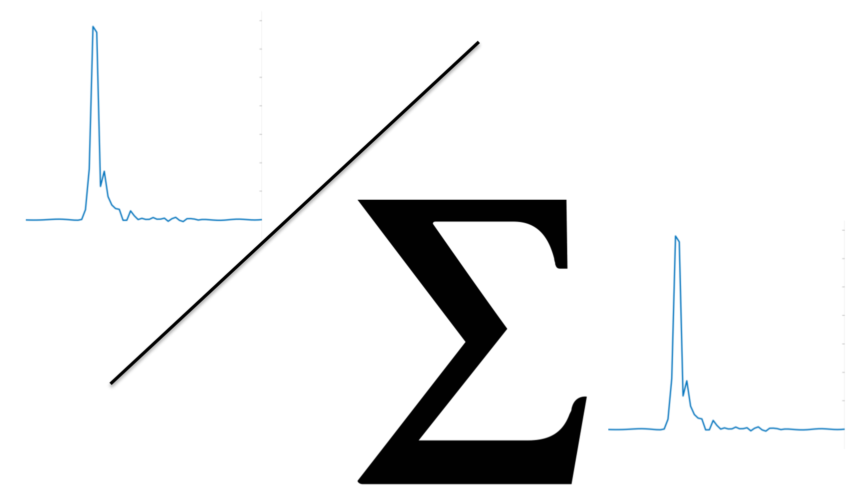
Methods:

1. Mask the IRF: Multiply the IRF with a Super-Gaussian mask optimally designed to eliminate low SNR regions.
2. Normalize the IRF: Divide the IRF by the sum of its entries to reduce any bias introduced by the noise.
3. Deconvolve: Convolution Theorem provides an analytical expression to deconvolve a signal given the IRF via the Fourier Transform.
4. Monte Carlo Error Analysis: Simulate 10,000 deconvolutions, each with new noise, and quantify the uncertainty.

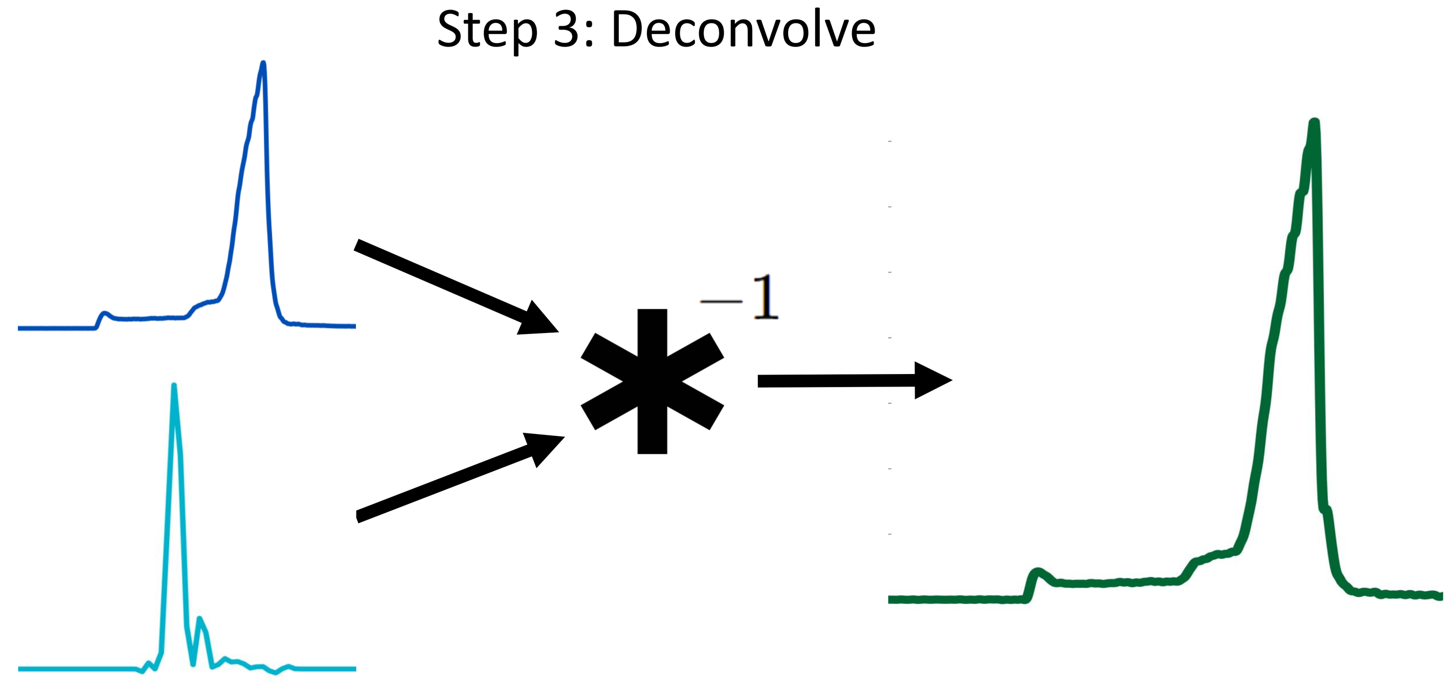
Step 1: Mask the IRF



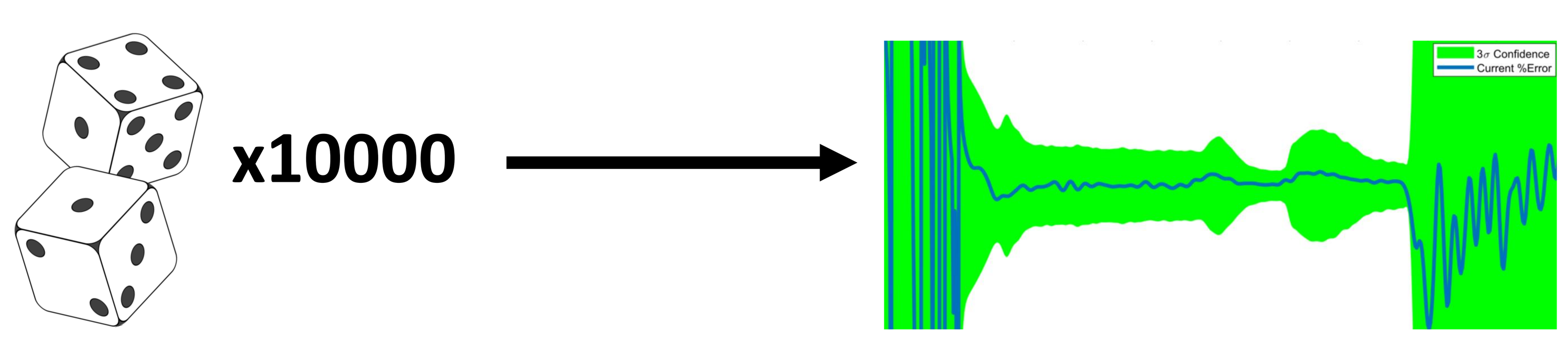
Step 2: Normalize the IRF



Step 3: Deconvolve

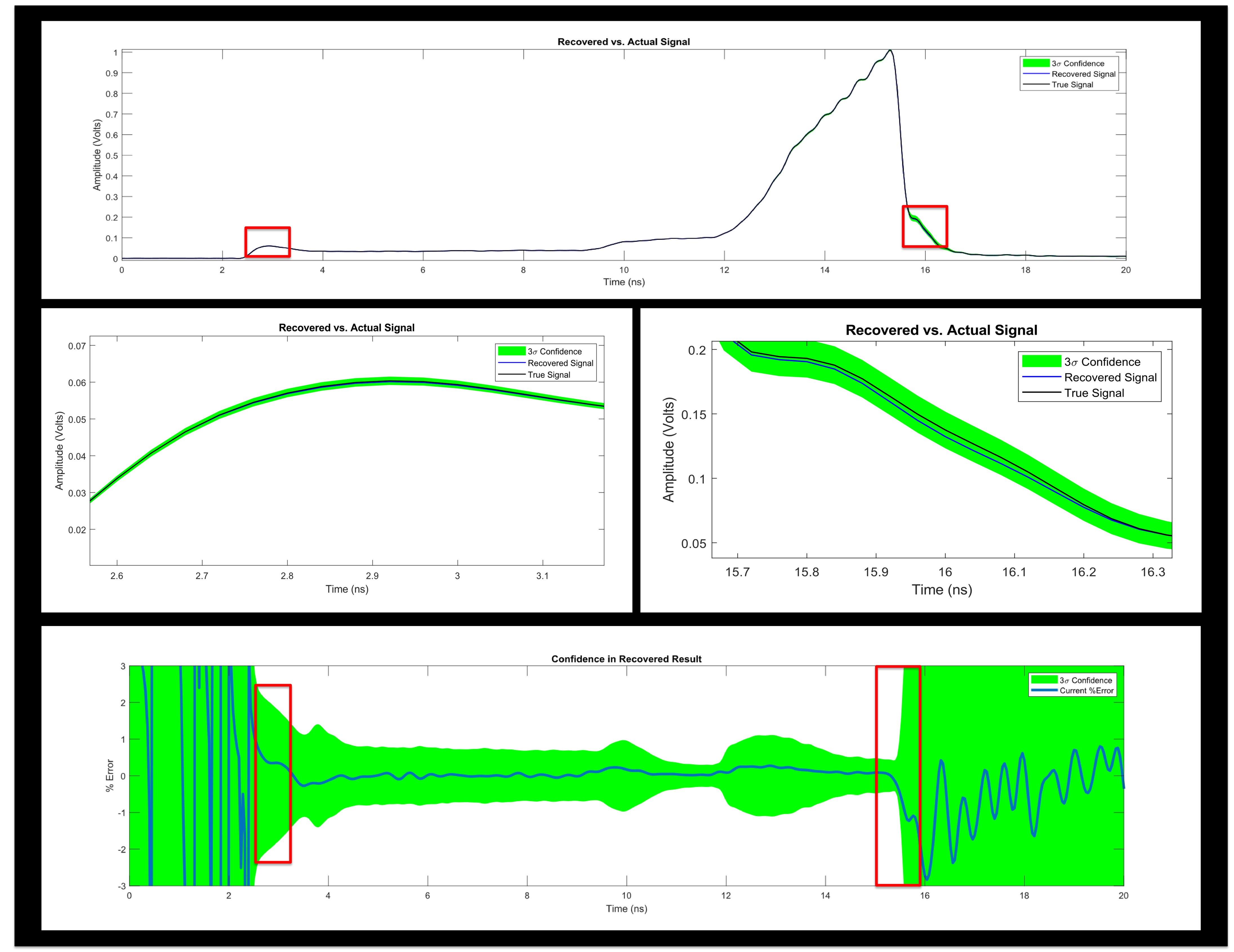


Step 4: Monte Carlo Error Analysis



Results

The Monte Carlo simulation successfully produced error bars on the deconvolved result. It showed that the previous deconvolution and signal processing techniques recovered a result with 4-5% error. The new methods of masking and normalization have improved certainty down to 1-2% error.



Monte Carlo simulation gives a 99.7% confidence interval that our recovered result is within 1-2% of the true signal.

Conclusions

The IRF masking algorithm and normalization improve our measurement fidelity by removing low SNR regions and reducing noise bias. The Monte Carlo error analysis is robust to future changes. Future NIF power sensor measurements will be more accurate and have error bars. Future work includes studying the effects of multi-channel stitching on the power sensor measurement.

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