

Spectral Phase Algorithms for Reliable Reconstructions of Optical Waveforms (SPARROW)

Ebram Youssef^{1,2}, Mat Britton²

¹Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627

²Linac Coherent Light Source, SLAC National Accelerator Laboratory, Menlo Park, CA 94025

Introduction

Background:

Ultrashort pulses have a duration of picoseconds or shorter, typically on the scale of femtoseconds. Their characteristics, such as high time and spatial resolution, large bandwidth, and high intensity, make them beneficial in many applications, such as time-resolved spectroscopy [1].

Measurement dilemma:

The merits of ultrashort pulses raise fundamental challenges; as pulses become shorter, the ability to measure them becomes harder, requiring speeds higher than existing detectors and hardware. Resolved measurements of pulses are crucial, as pulse duration determines the temporal resolution of the experiment, and complex structures in the pulse can complicate interactions.

Full characterization:

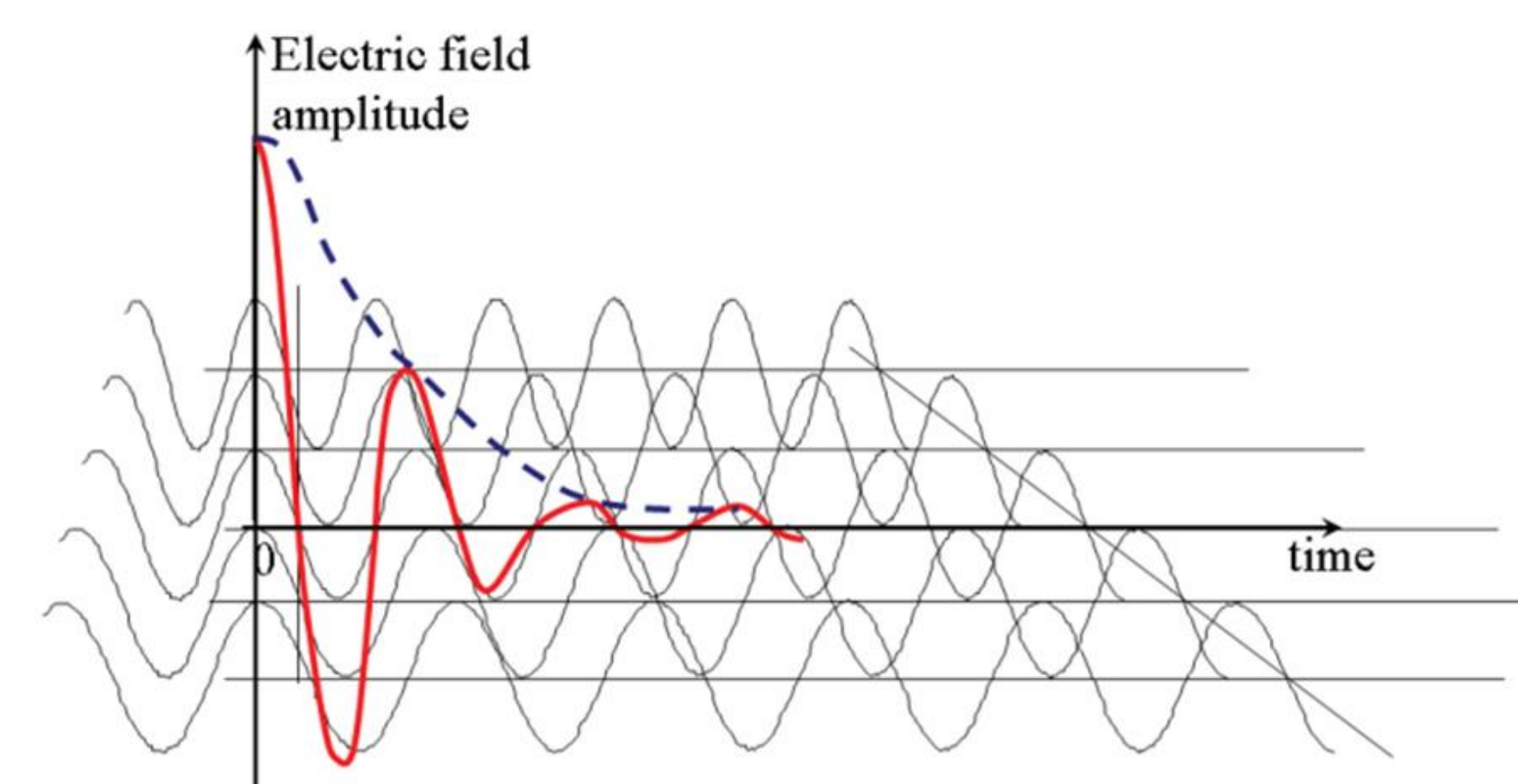
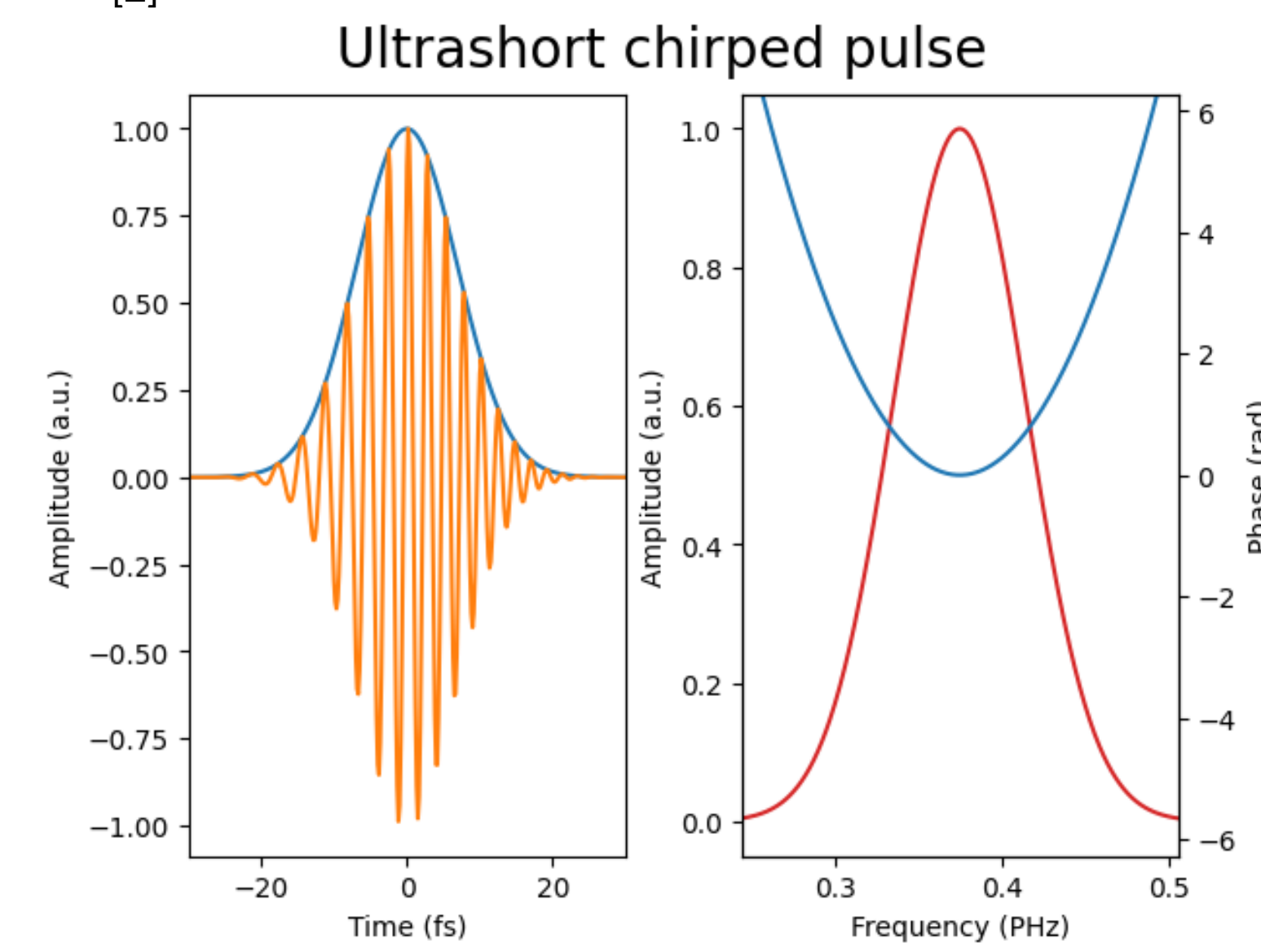
A pulse is defined in the time-domain by its electric field:

$$E(t) = \text{Re}\{\sqrt{I(t)} \exp(i\omega_0 t - i\varphi(t))\}$$

Equivalently, the pulse could be defined in the frequency-domain by the Fourier transform of the time-domain field:

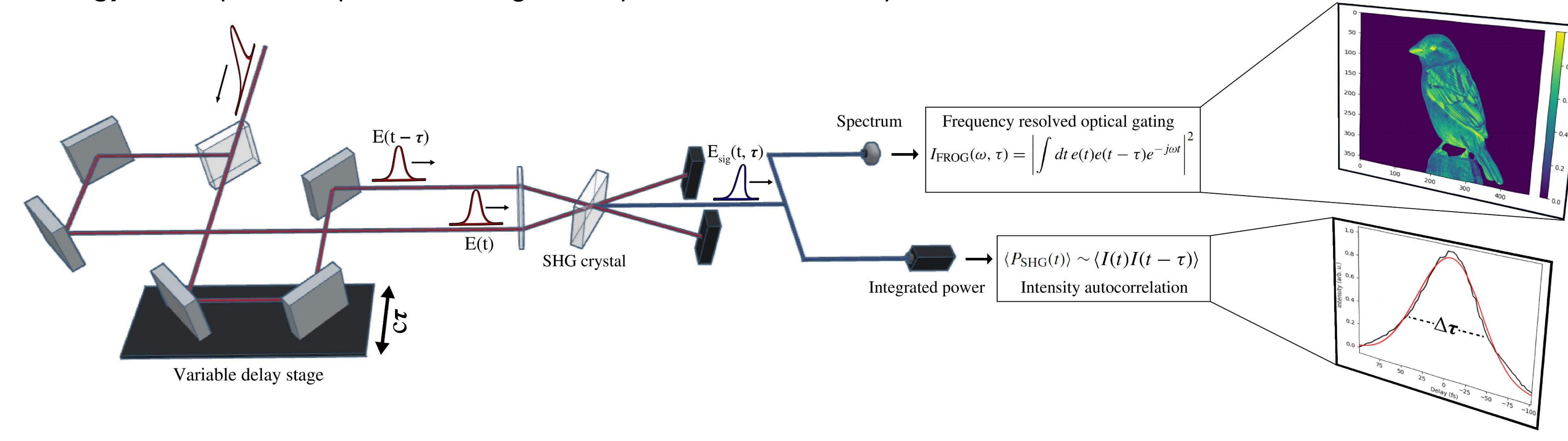
$$\tilde{E}(\omega) = \sqrt{I(\omega - \omega_0)} \exp(i\tilde{\varphi}(\omega - \omega_0))$$

Measuring both the intensity and phase in either domain provides complete information about the electric field, and hence full characterization of the pulse [2].

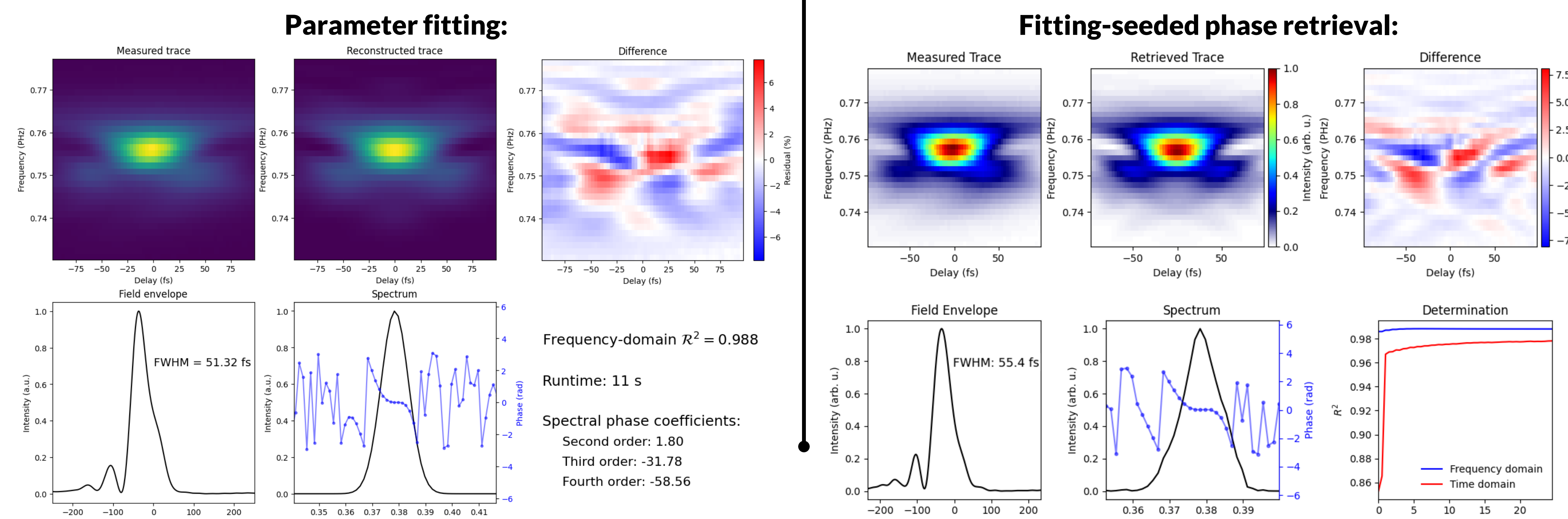
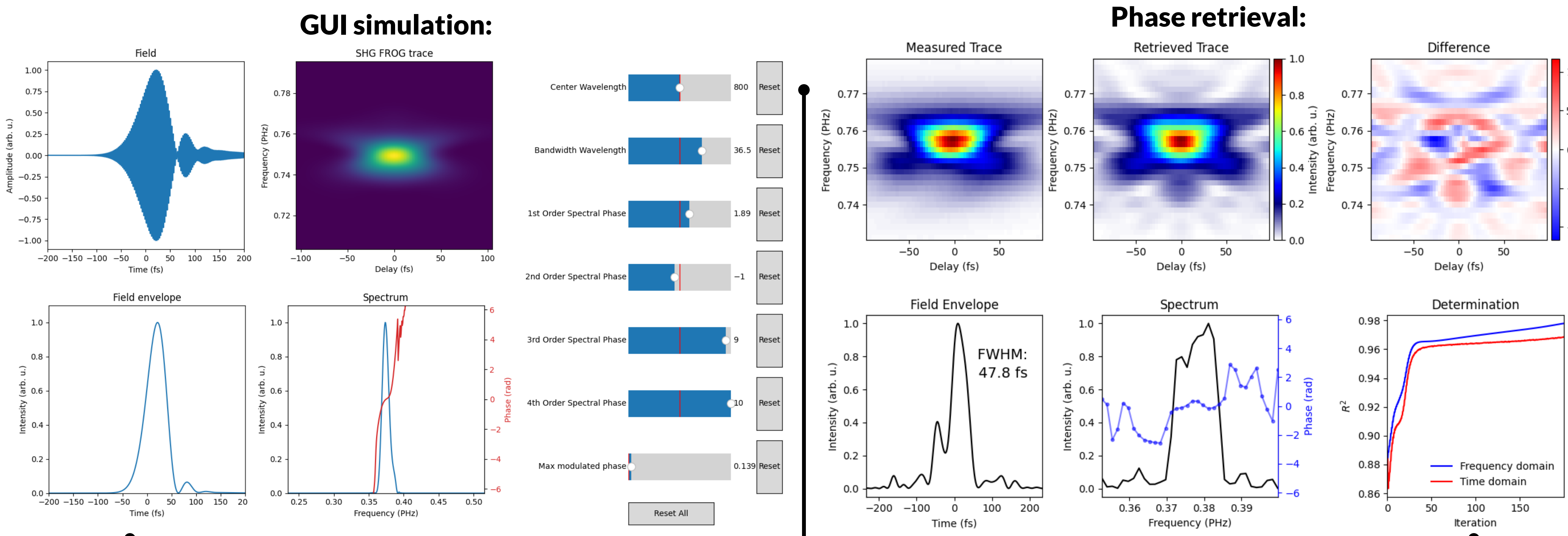


Measurement Techniques

Strategy: let the pulse sample itself through a delay-sensitive nonlinearity.

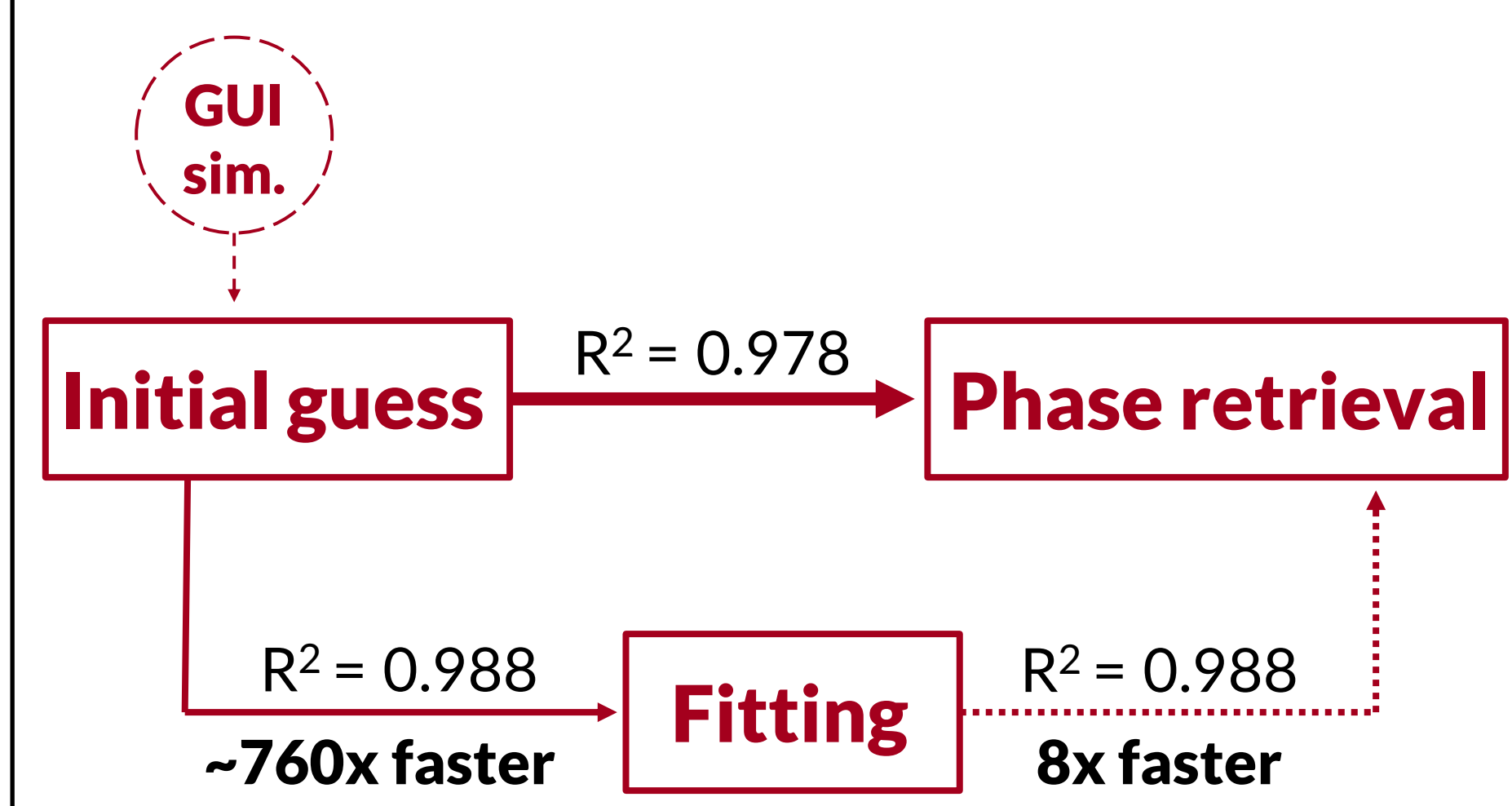


SPARROW Functionality



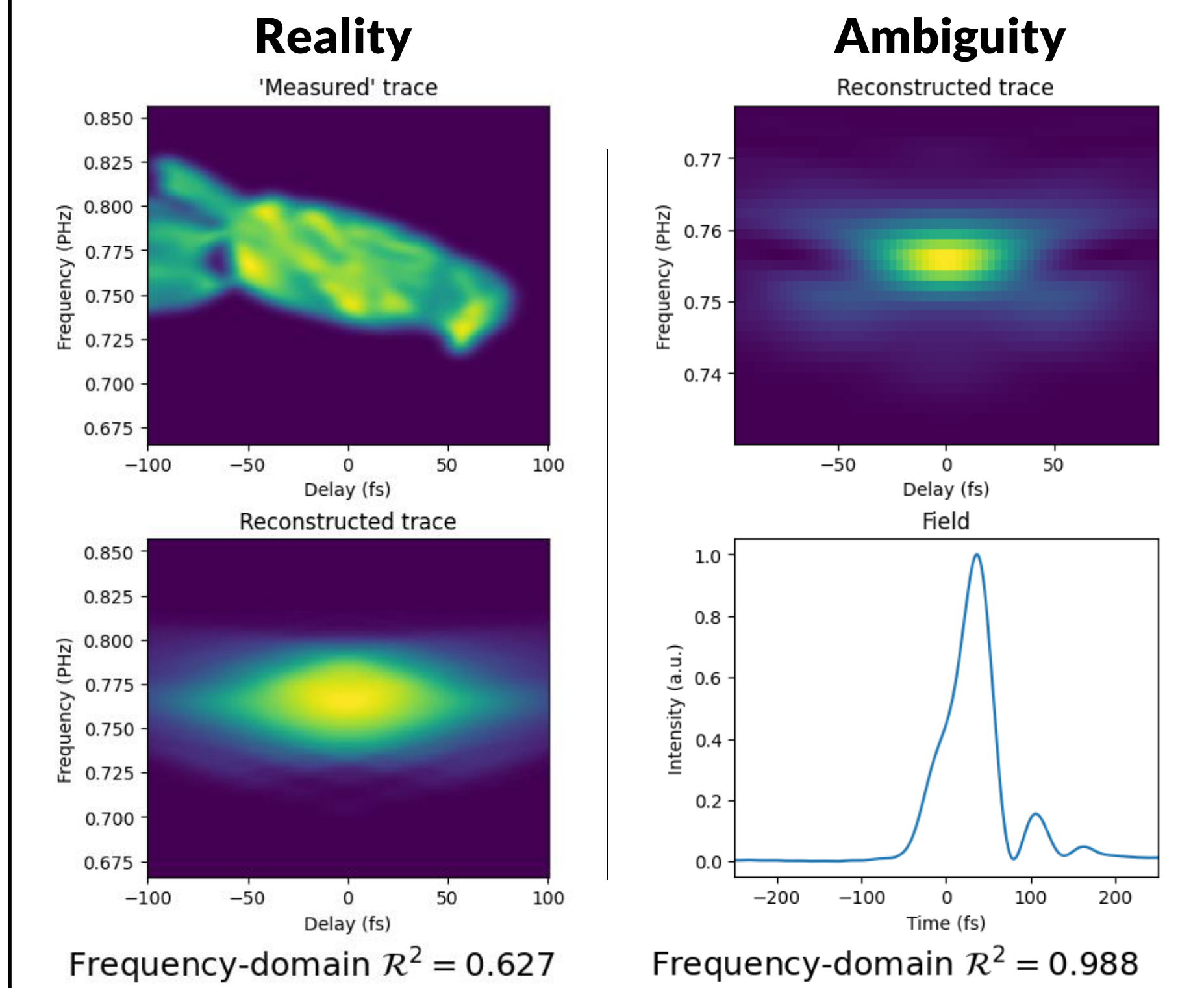
Final Thoughts

Performance and algorithm selection:



- Parameter fitting provides extremely fast results but uses a polynomial approximation of the spectral phase and assumes a Gaussian spectral amplitude.
- Phase retrieval is significantly more time-consuming but provides more robust results with little assumptions.
- Fitting-seeded phase retrieval is an intermediate solution with moderate speed and high accuracy.

Limitations:



Acknowledgements

I would like to thank my mentor, Mat Britton, for his continuous support, mentorship, and unparalleled insights. Additionally, I would like to thank the LCLS Laser Sciences group members, especially Mike Glowonia and Joe Robinson. Finally, I must thank SLAC and LCLS for this valuable opportunity and unique experience.

References:

- Weiner, A. M. (2009). Ultrafast Optics. Wiley.
- Rick Trebino et al; Measuring ultrashort laser pulses in the time-frequency domain using frequency-resolved optical gating. Rev Sci Instrum 1 September 1997; 68 (9): 3277-3295. <https://doi.org/10.1063/1.1148286>