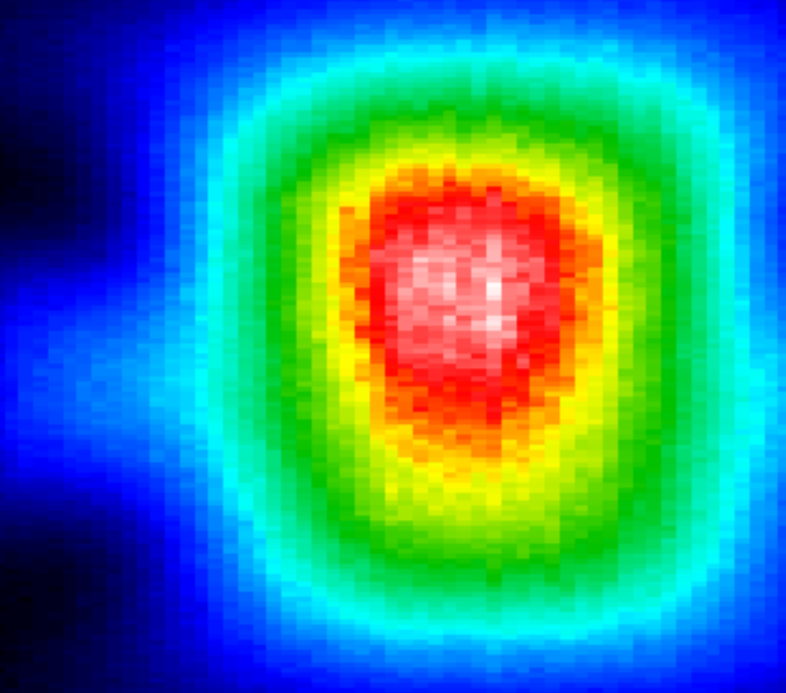
RECONSTRUCTION OF ULTRASHORT LASER PULSES FOR THEIR COMPRESSION IN A CONTROL LOOP.



Serhii Darahan

Summer Student @ X-ray Femtochemistry
and Cluster Physics Group, DESY

10.09.2025

HELMHOLTZ

DESY.

Motivation: why Pulse Shaping?

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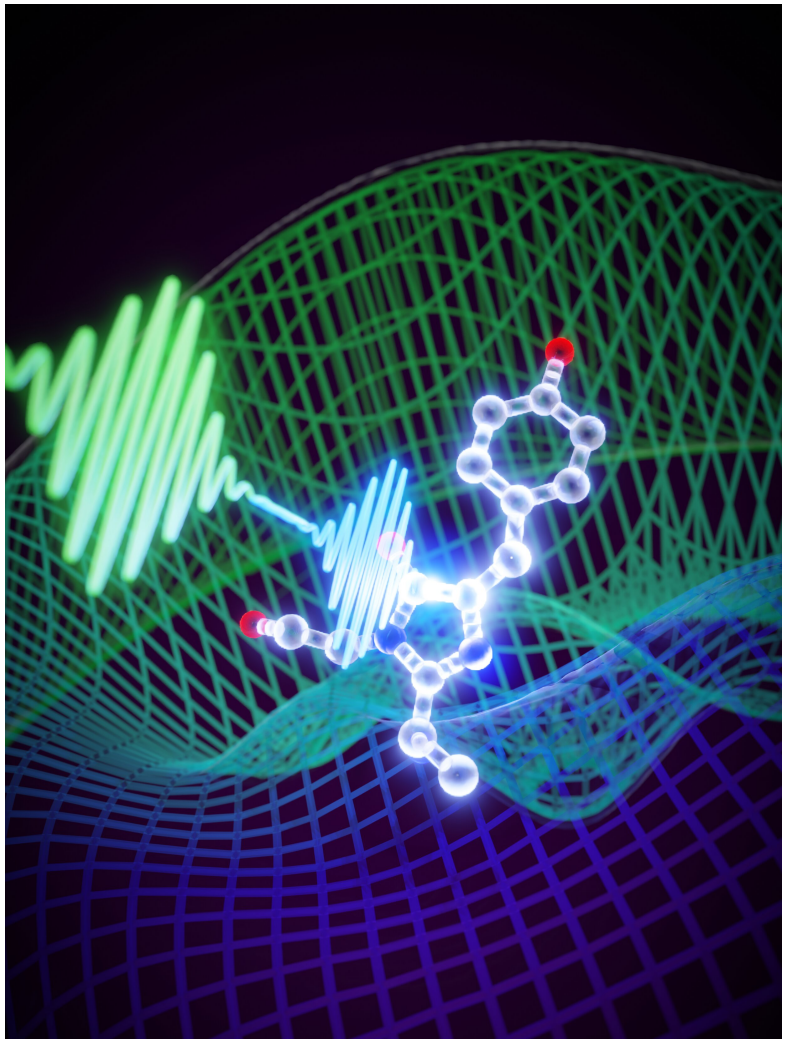
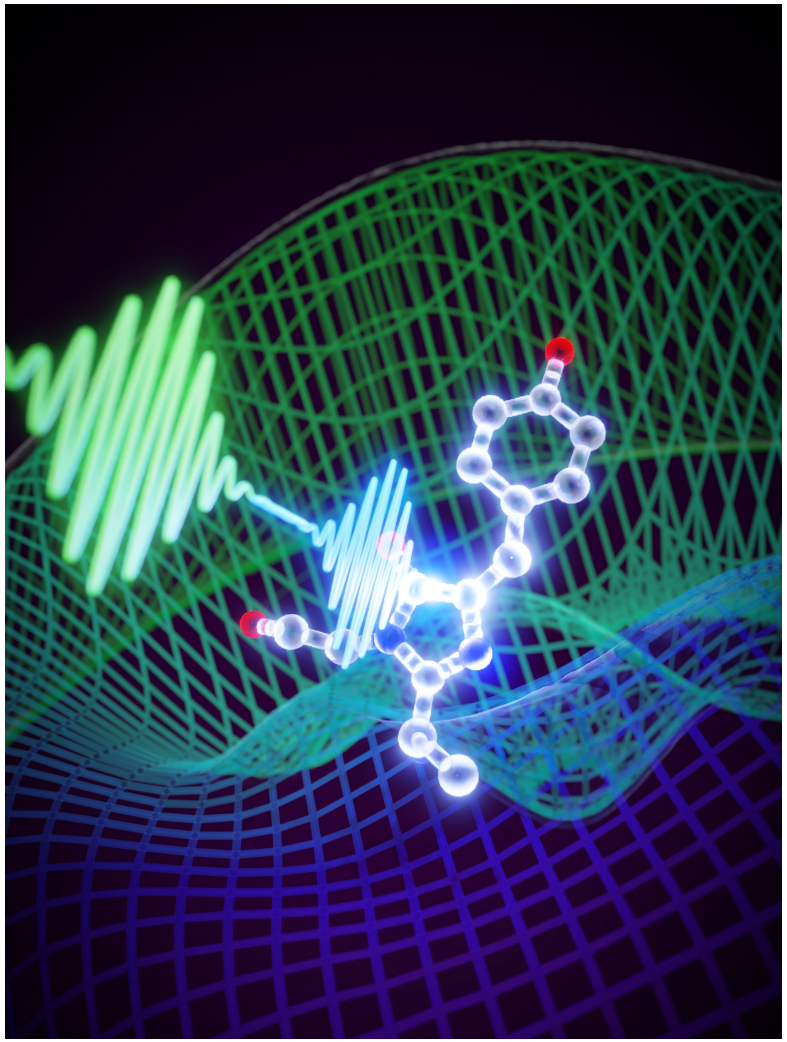


- Control light–matter interactions
  - Tailor the **phase and amplitude** of pulses to direct chemical reactions (***coherent control***)

Motivation: why Pulse Shaping?



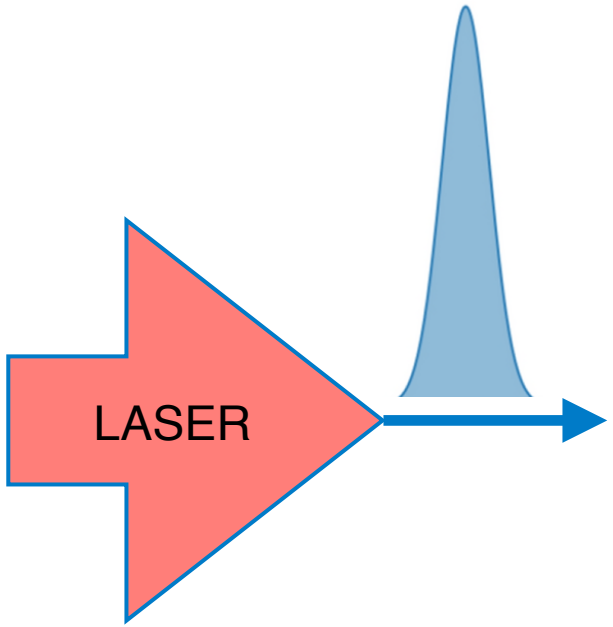
- Control light–matter interactions
  - Tailor the **phase and amplitude** of pulses to direct chemical reactions (***coherent control***)

- Compress pulses to extremes
  - Shorter pulses → finer pump–probe resolution
  - Higher peak power → stronger nonlinear effects (more efficient HHG for attosecond pulses)
  - Tailored control → selective excitation
  - Compression → efficient use of existing lasers

Goal of Experiment

General scheme: arbitrary tailored pulse

Goal of Experiment



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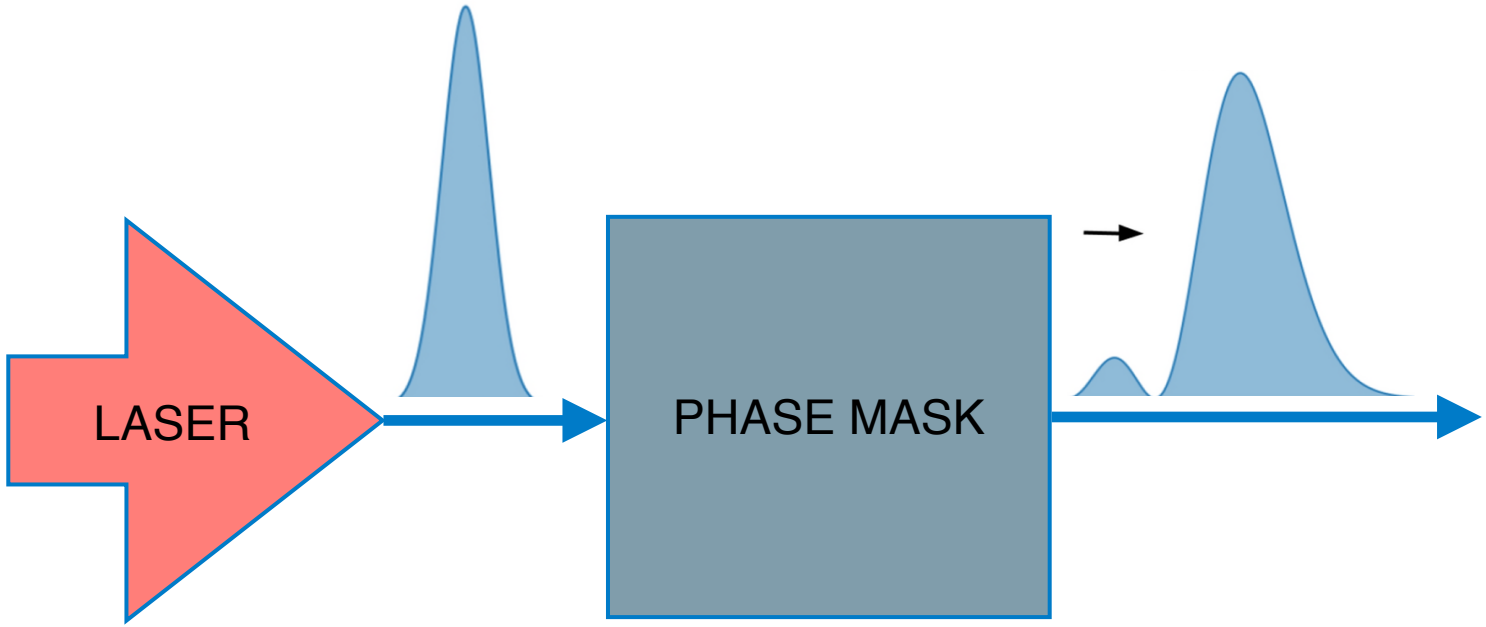

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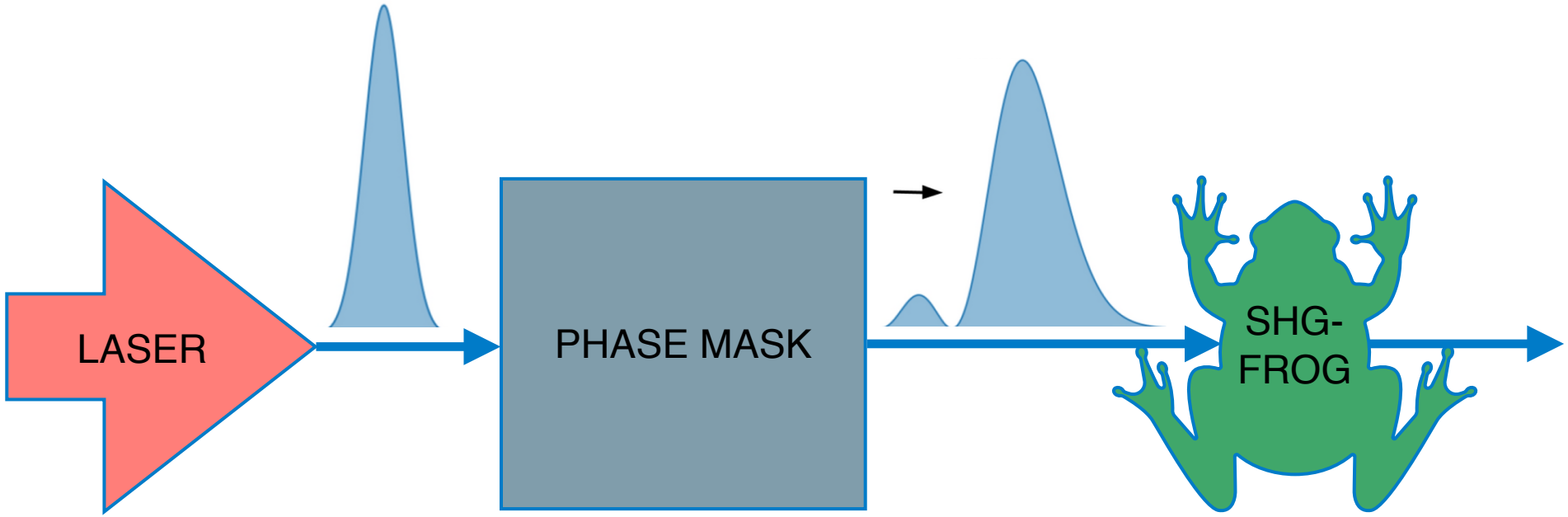

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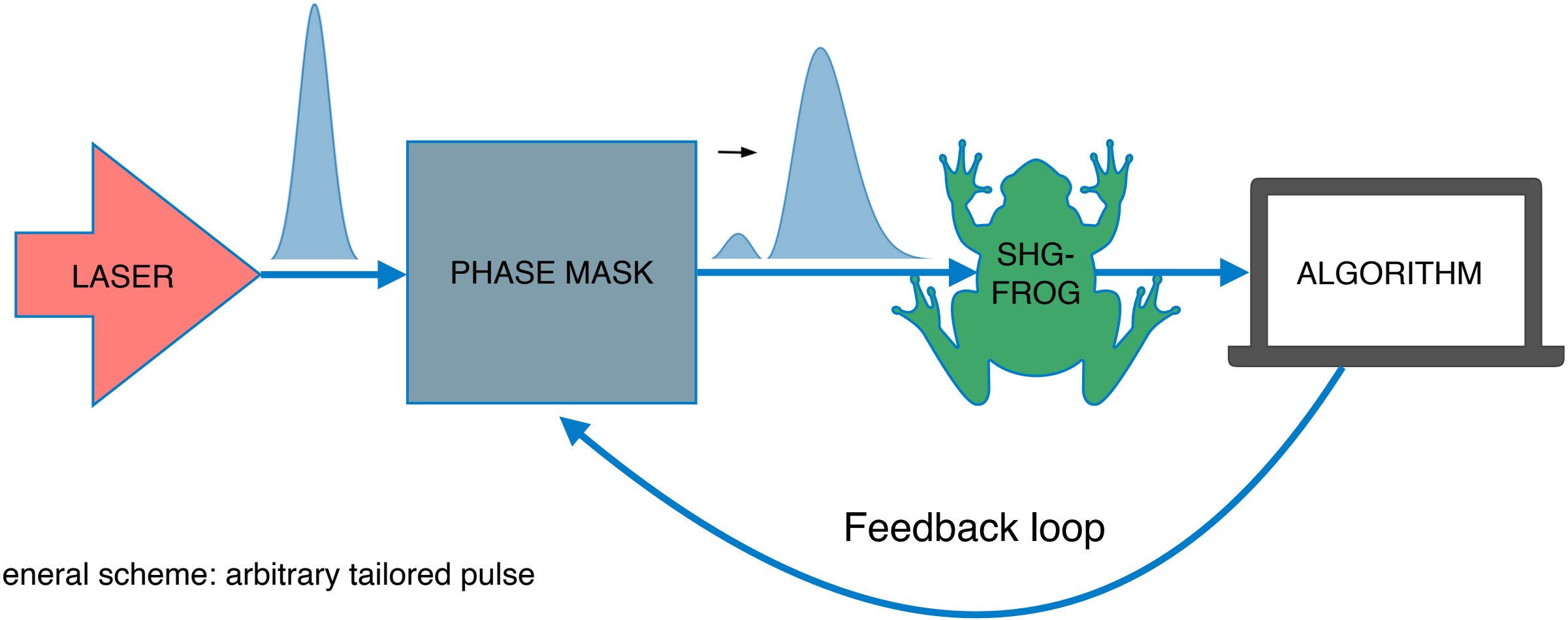

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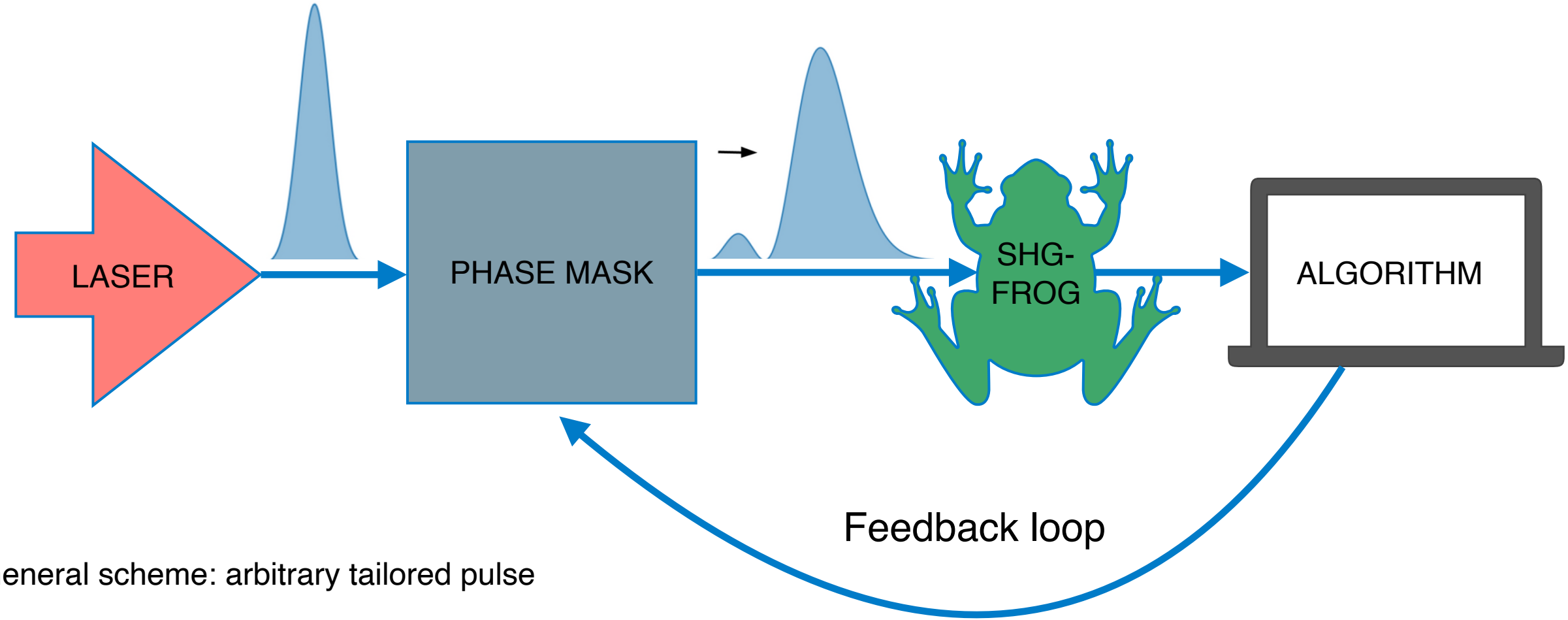
Our goal: Compress femtosecond pulses close to Fourier limit.



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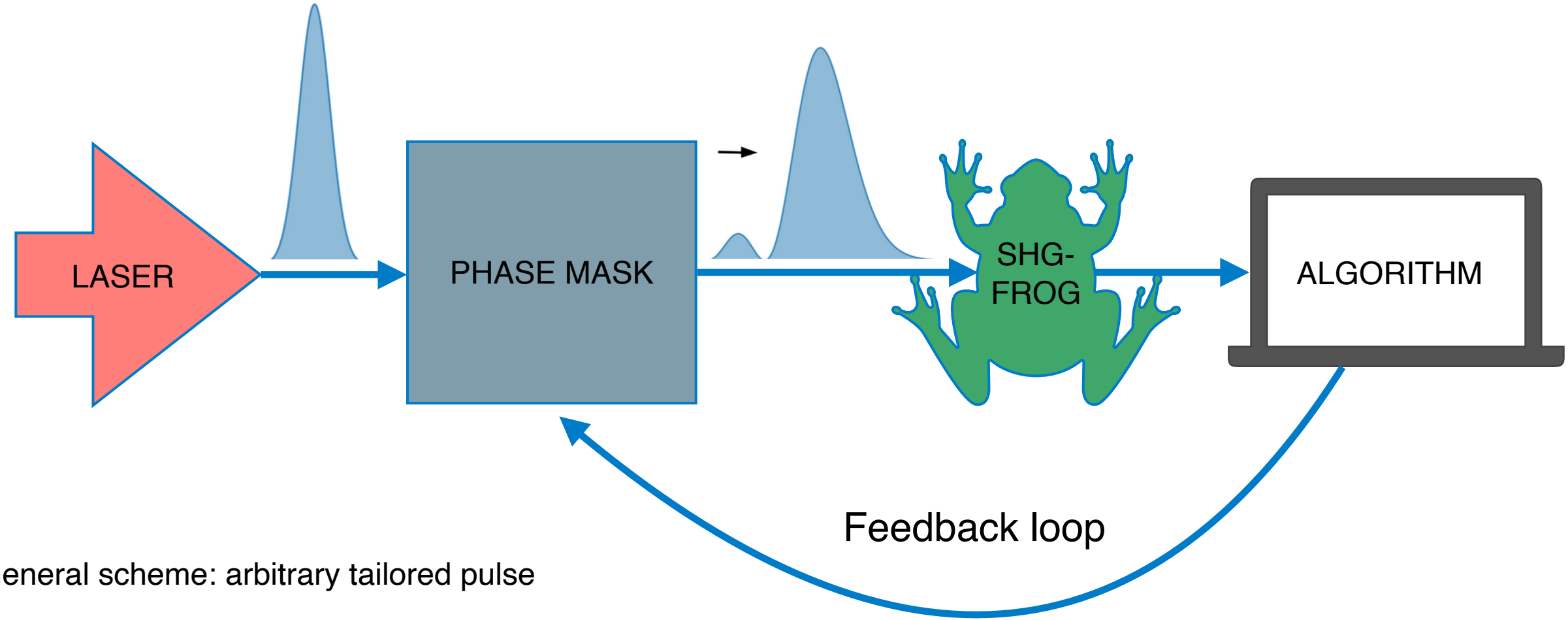
$$\Delta\tau\Delta\omega = 0.441$$



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4f Geometry and SLM

PHASE MASK

4f Geometry and SLM

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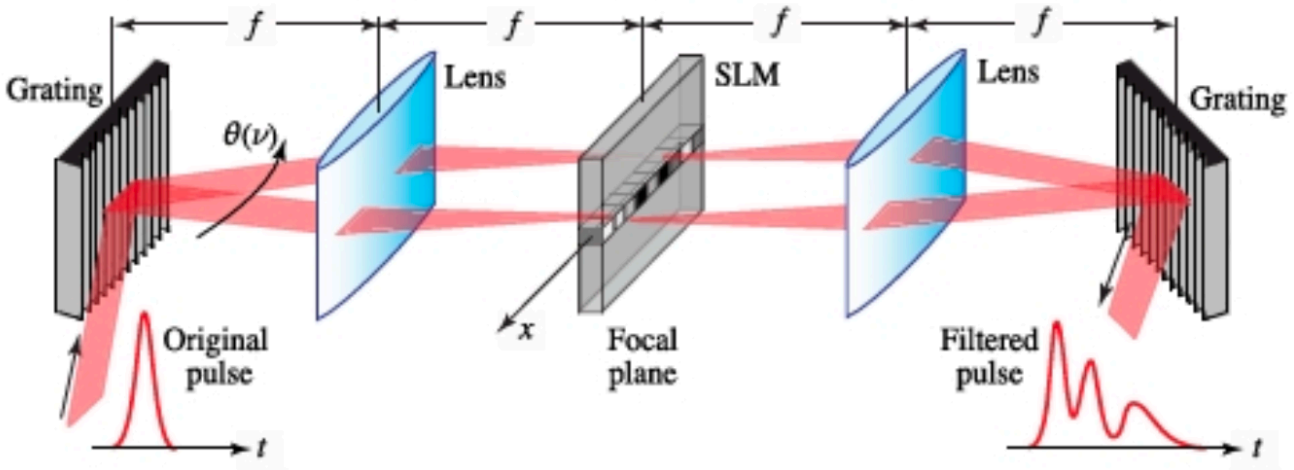
spectral decomposition, modulation at Fourier plane, recombination



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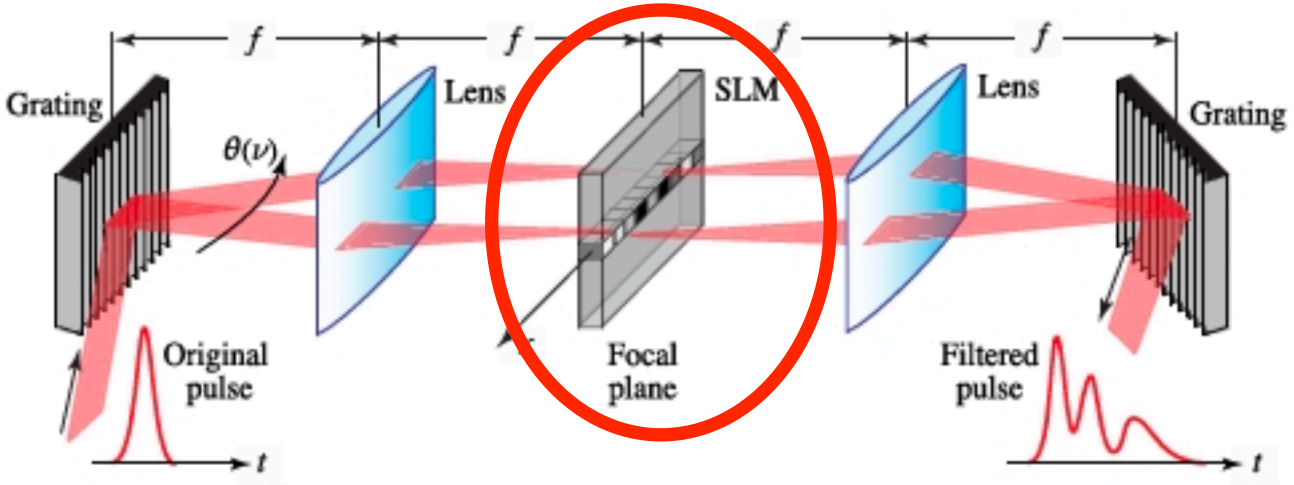

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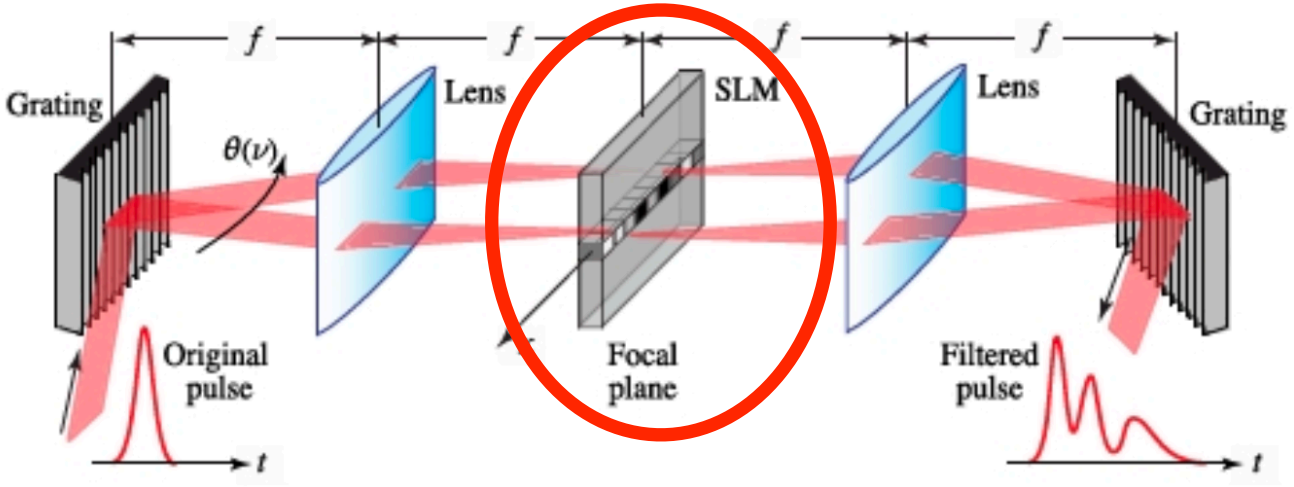

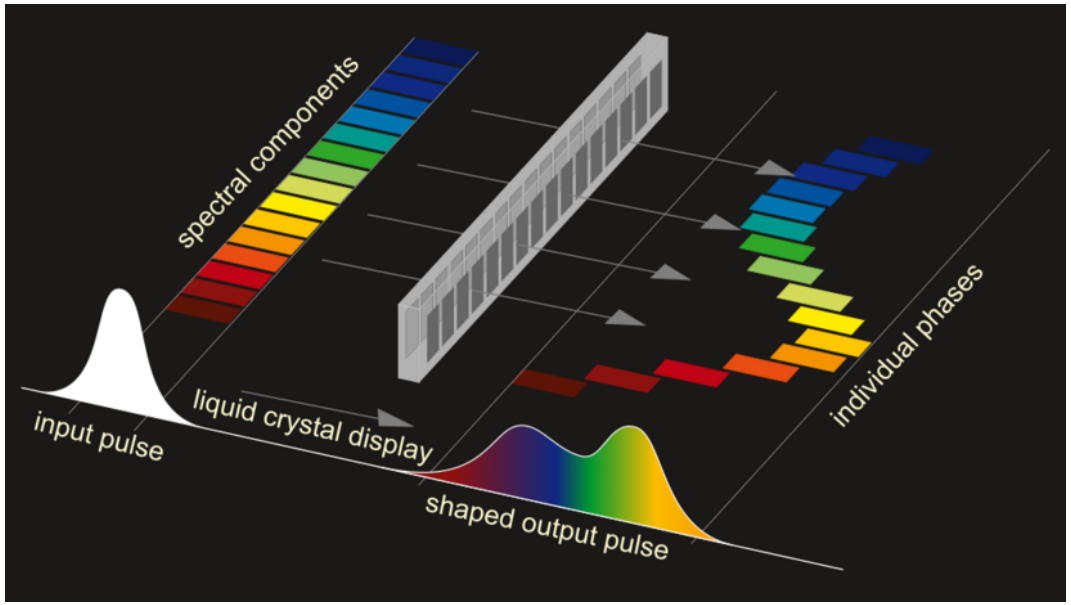

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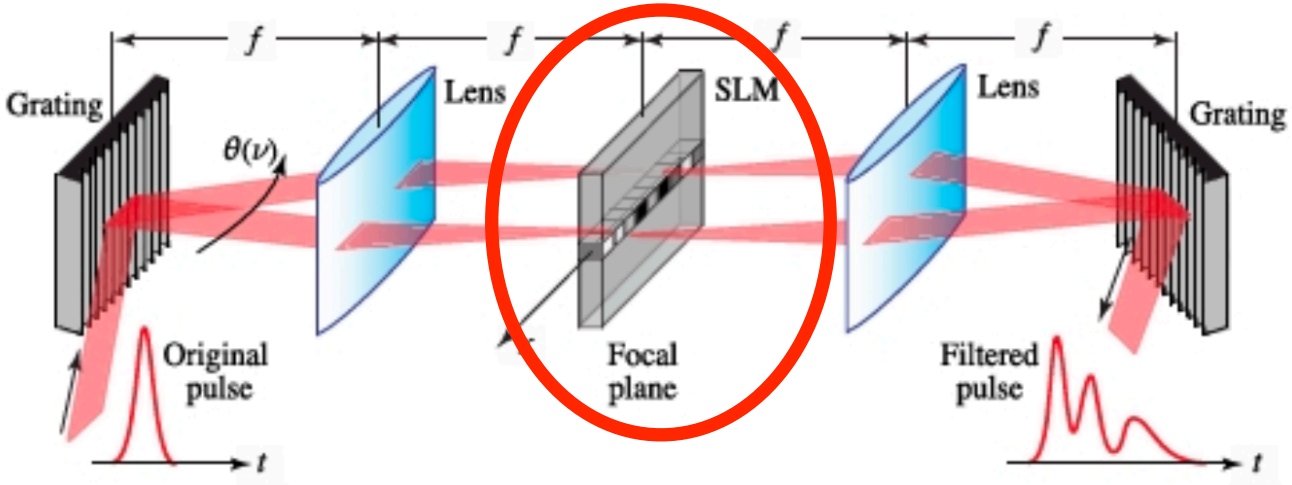
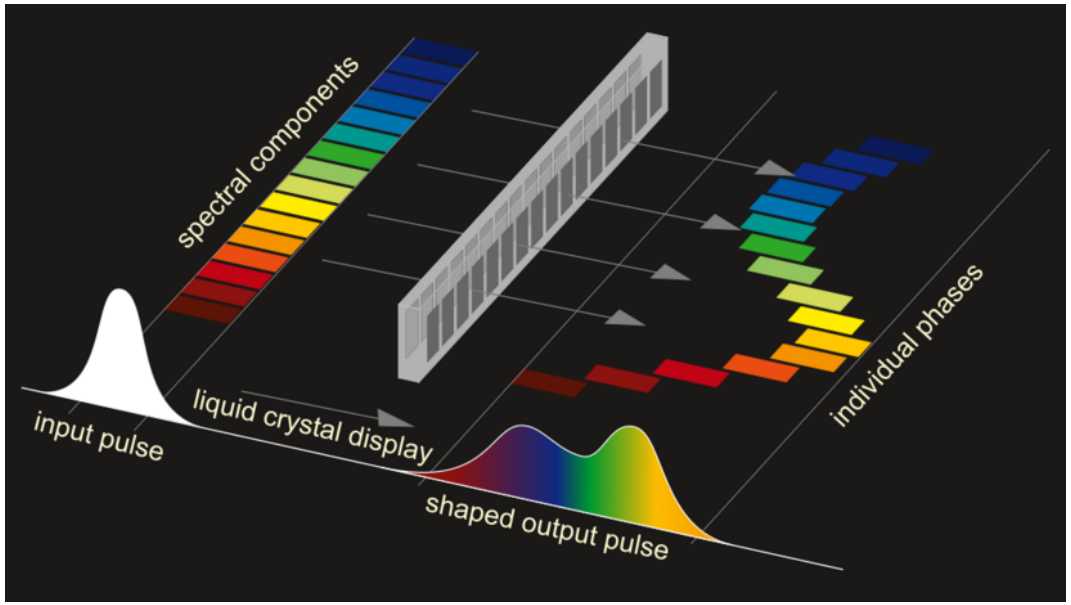
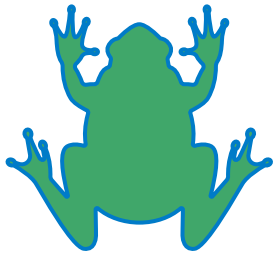




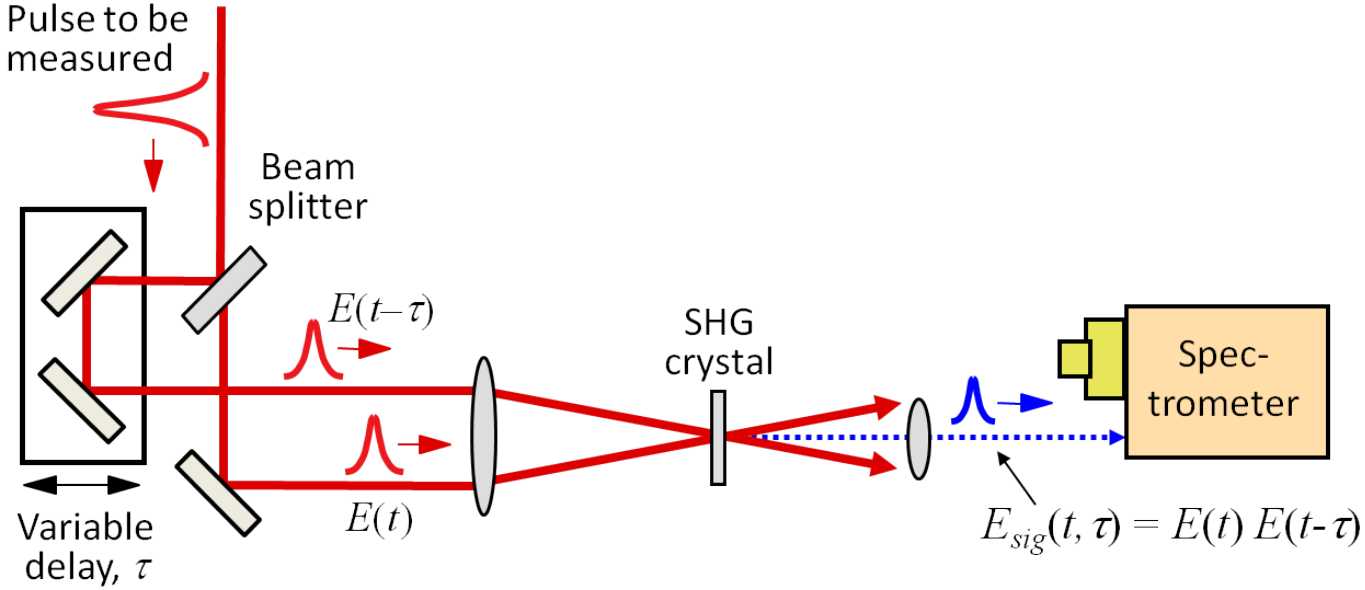
$$\Delta\phi = \frac{2\pi d}{\lambda}\Delta n$$

SHG and FROG



SHG and FROG

Frequency-Resolved Optical Gating (**FROG**)



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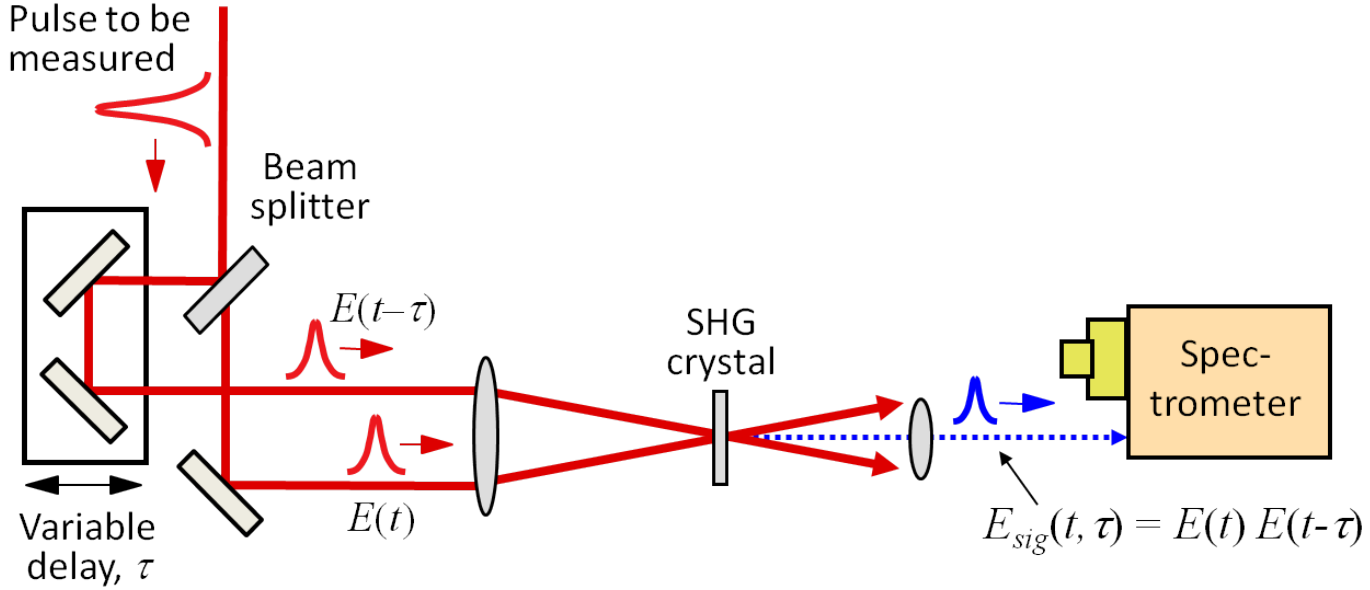

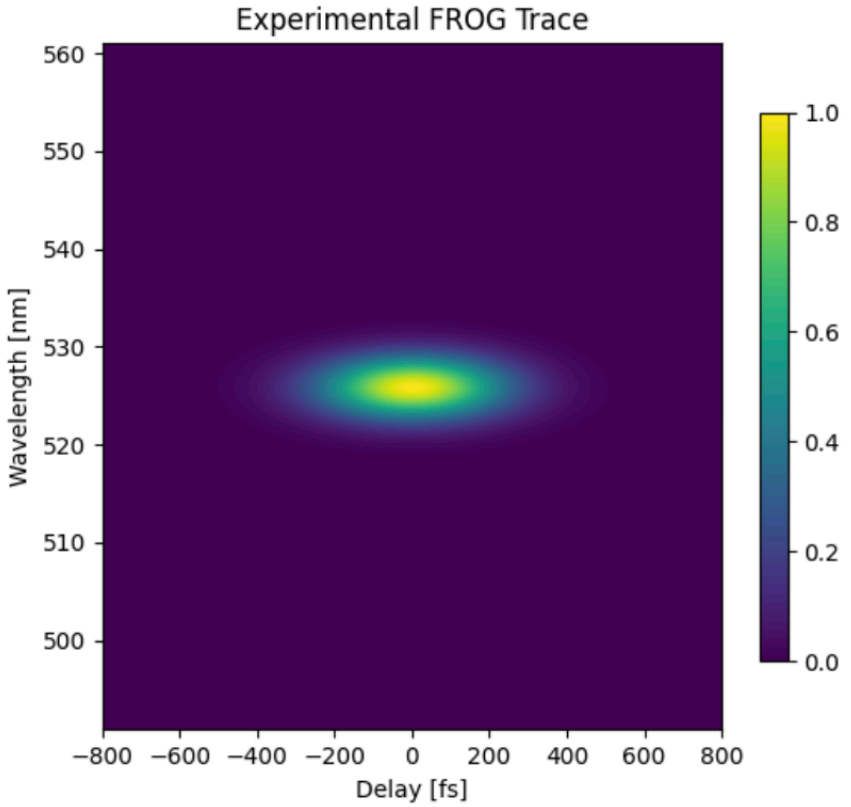

Experimental setup

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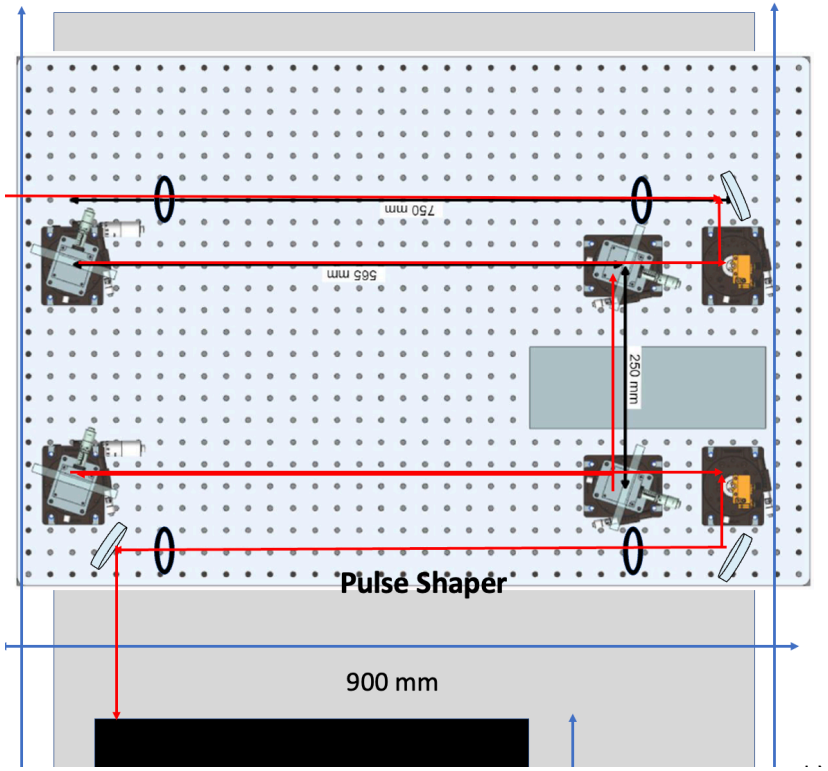

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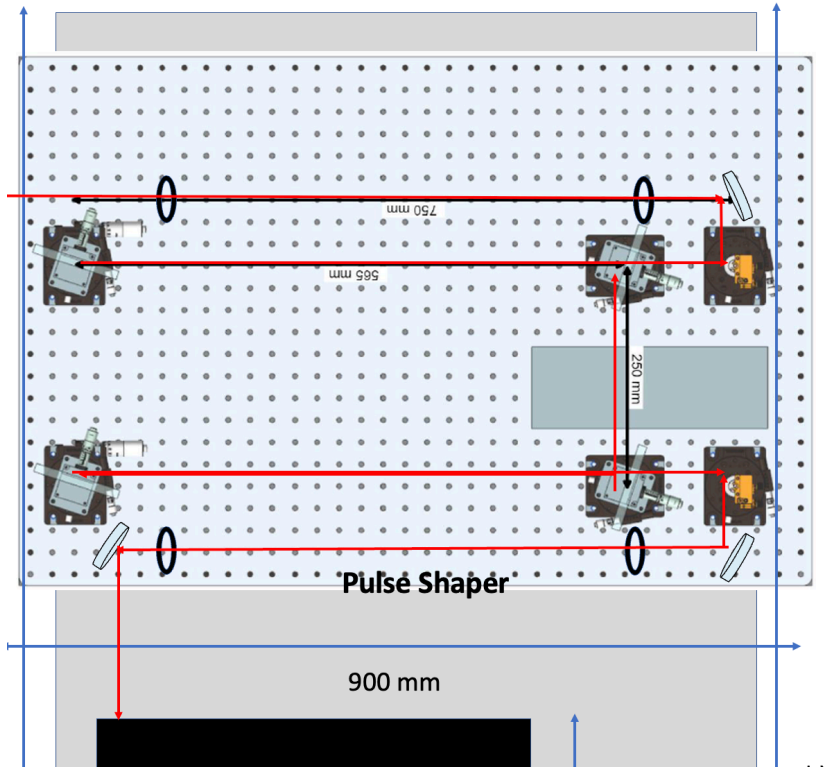
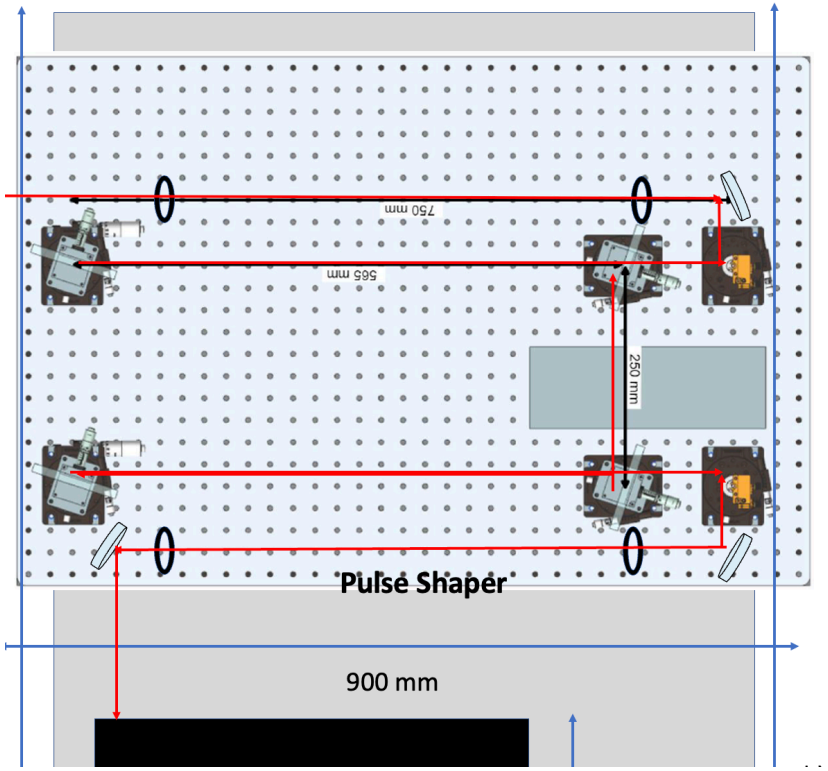


Cylindrical mirror

Experimental setup



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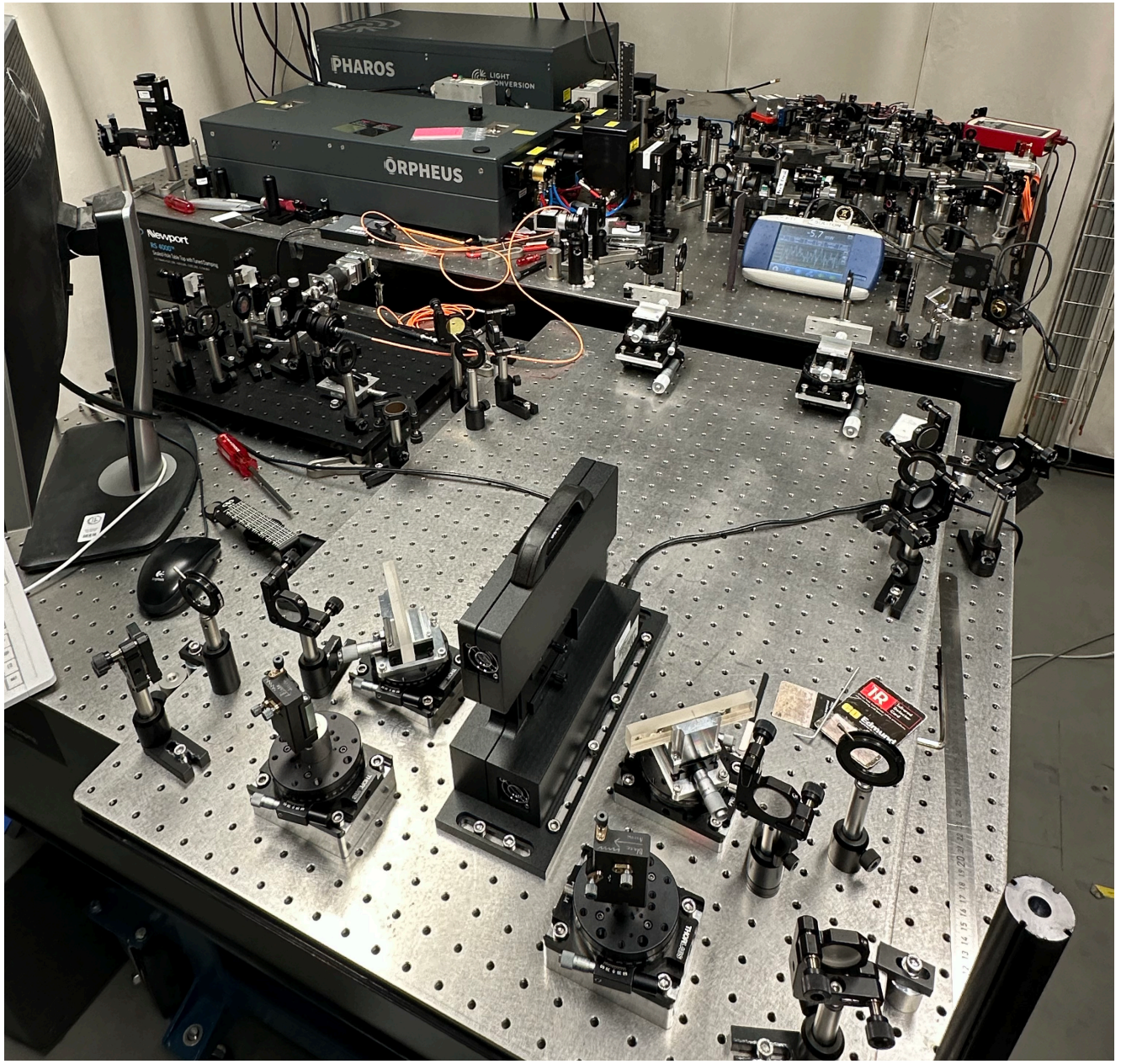

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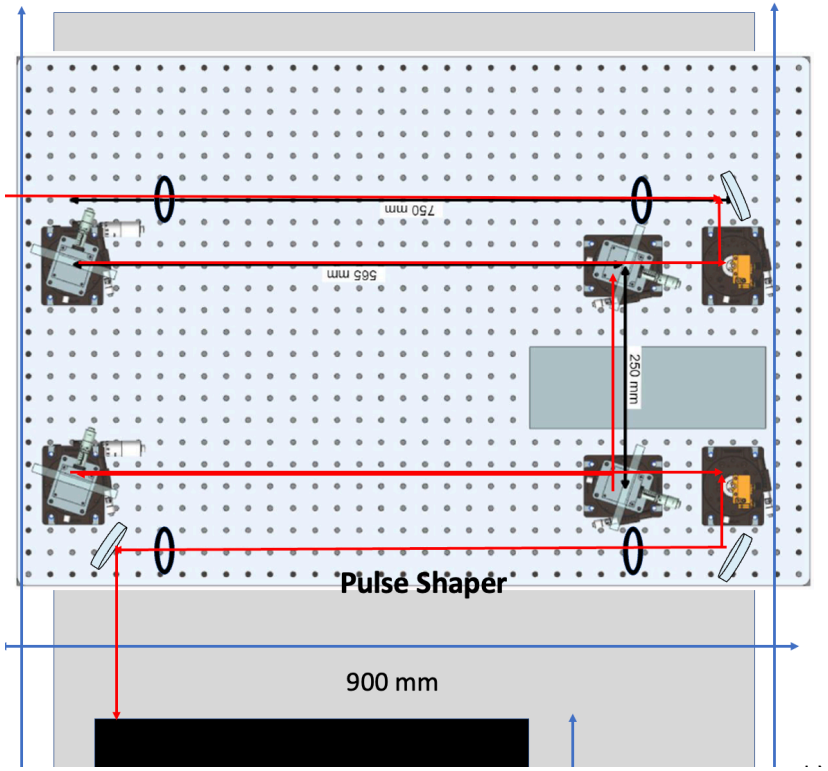

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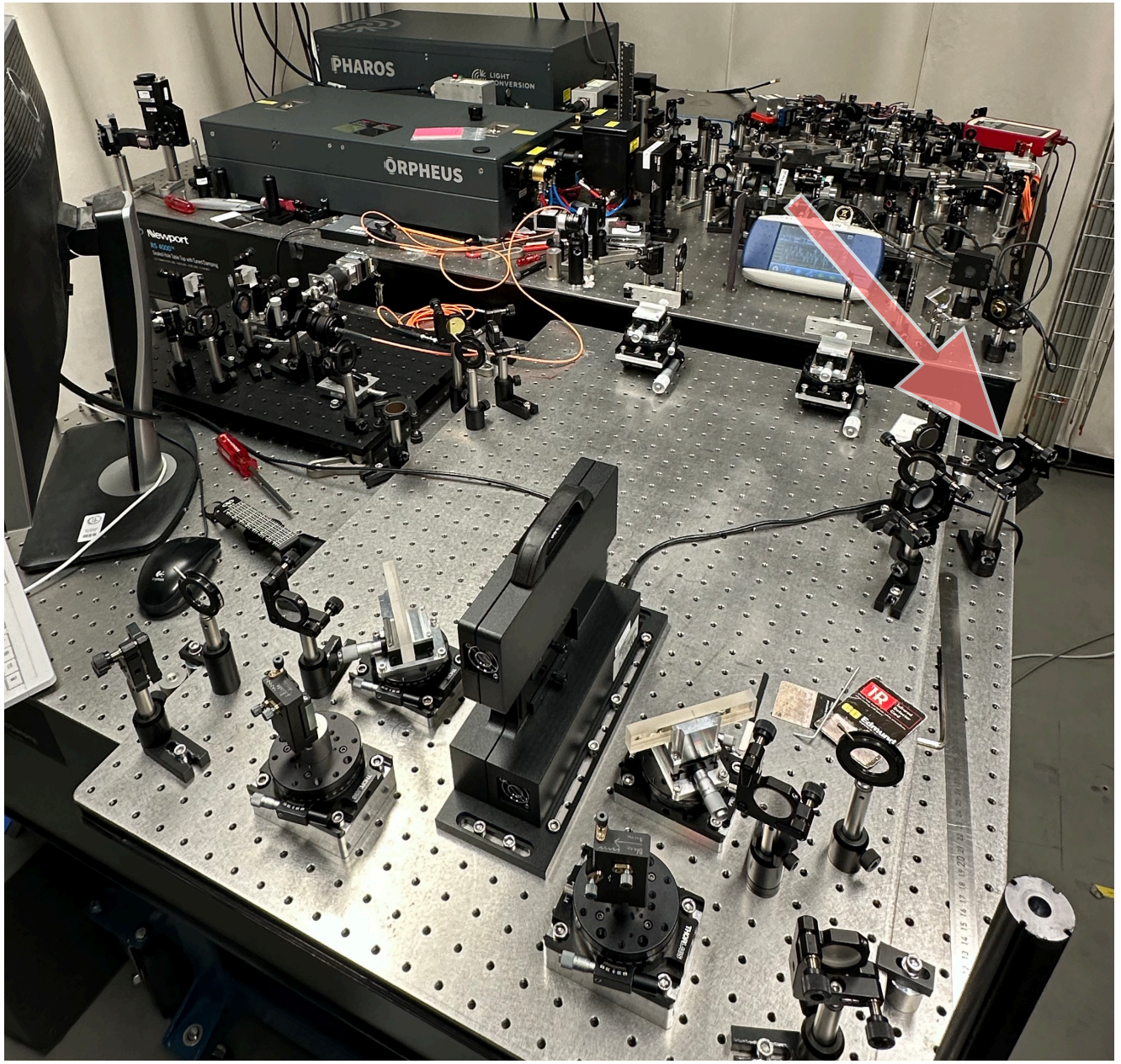

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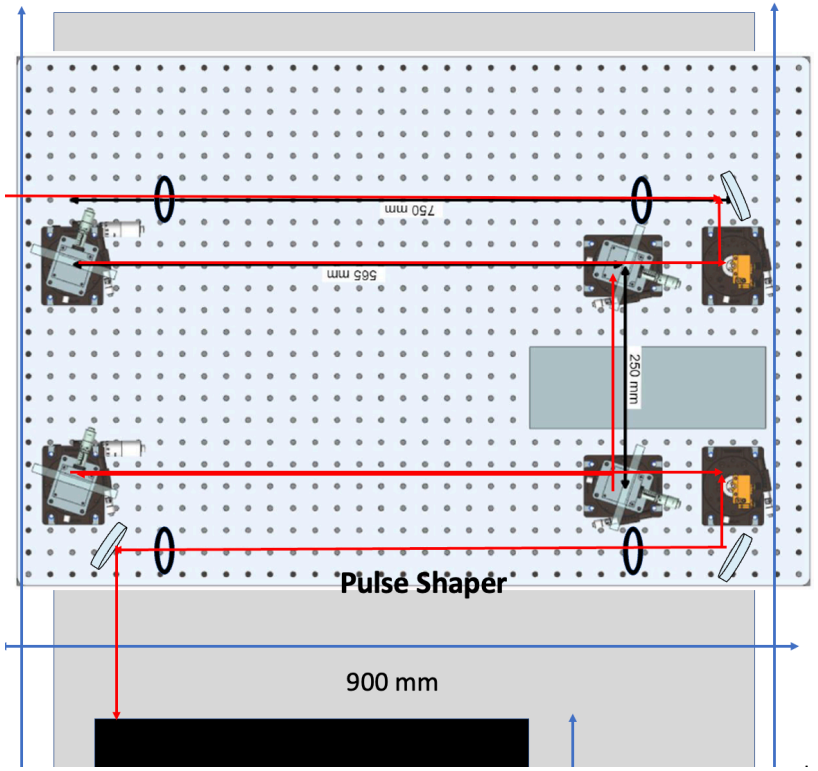

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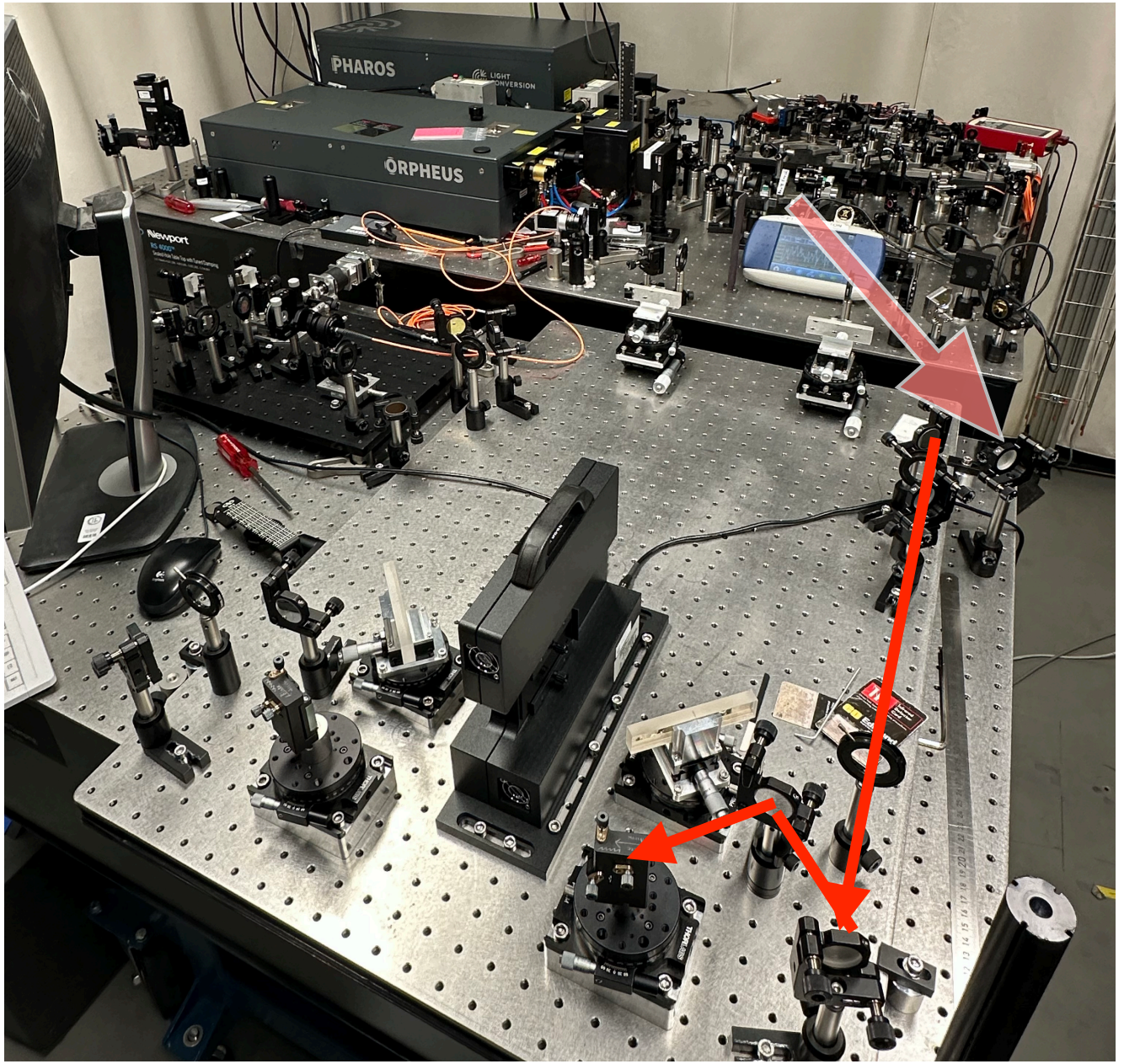

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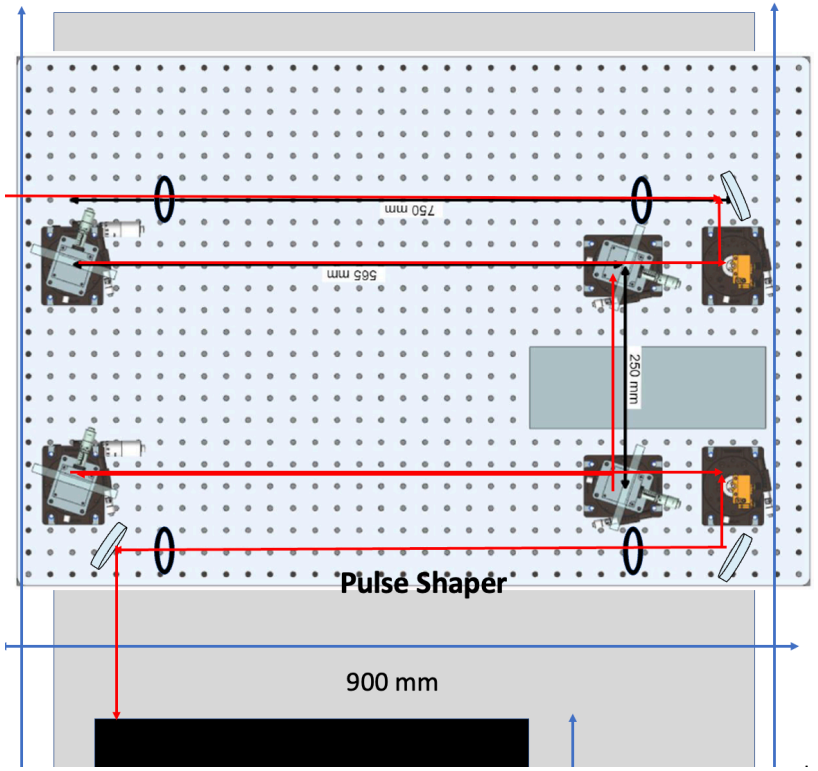

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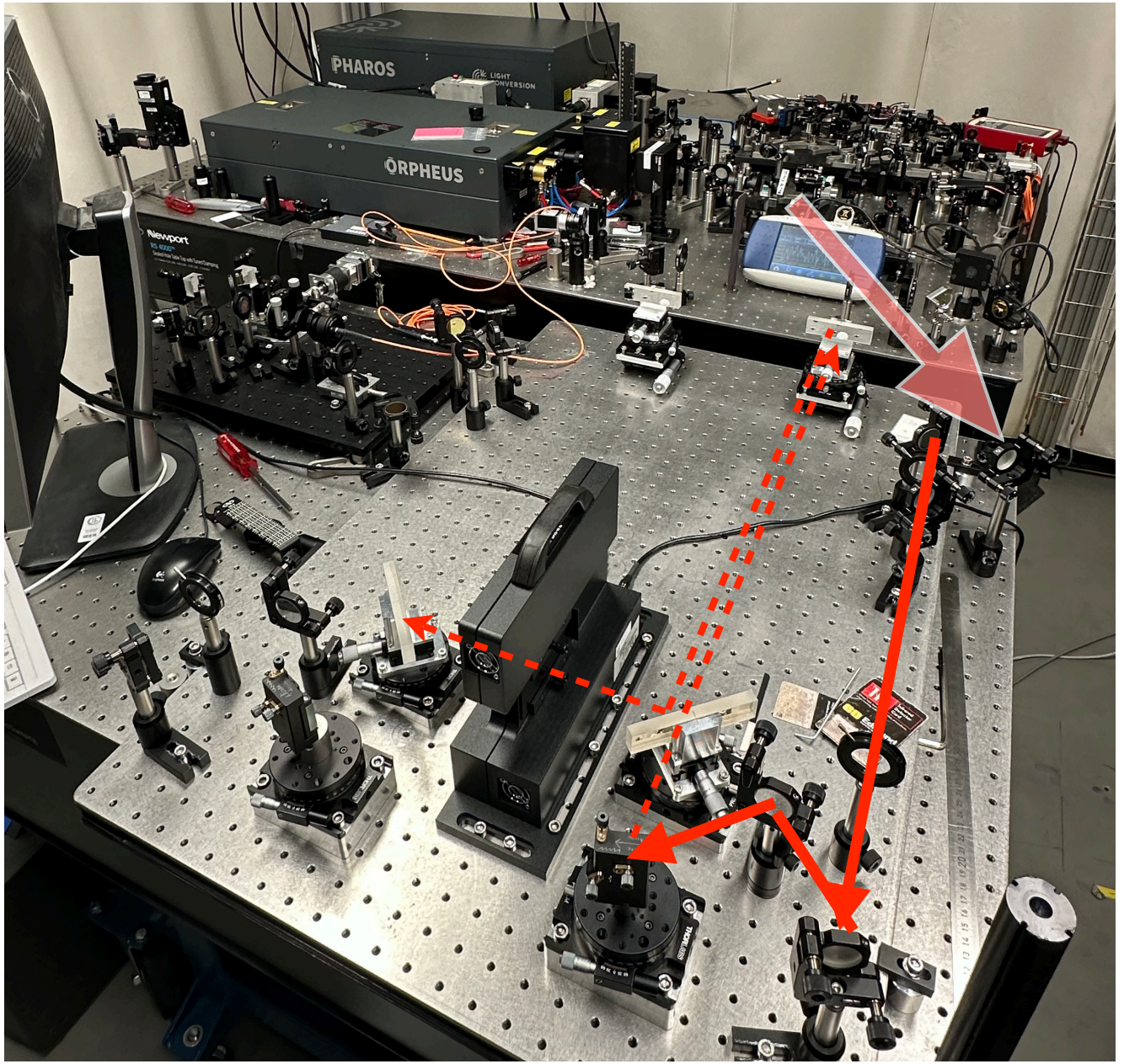

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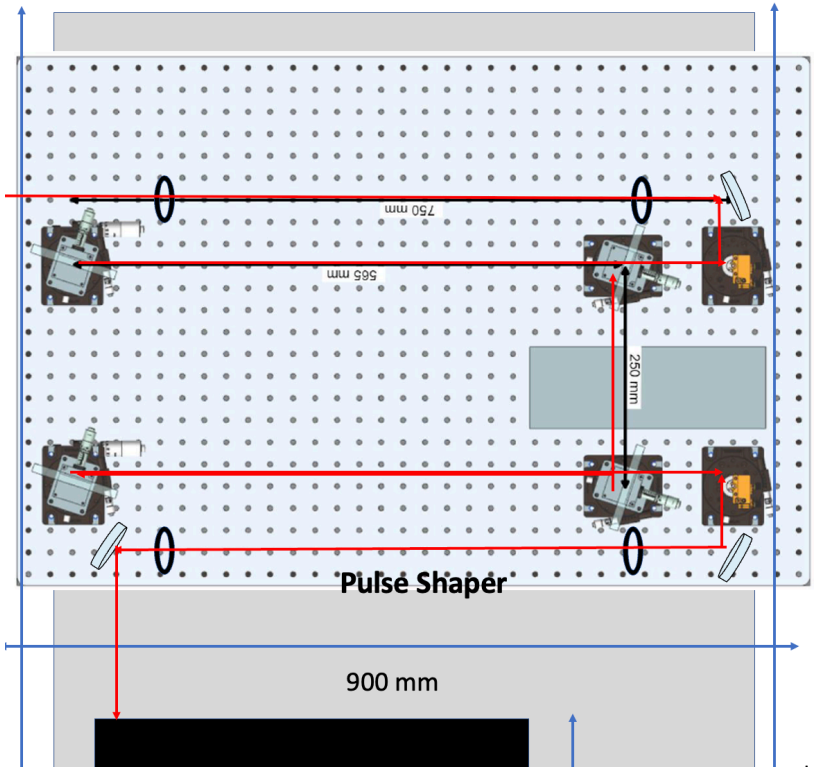

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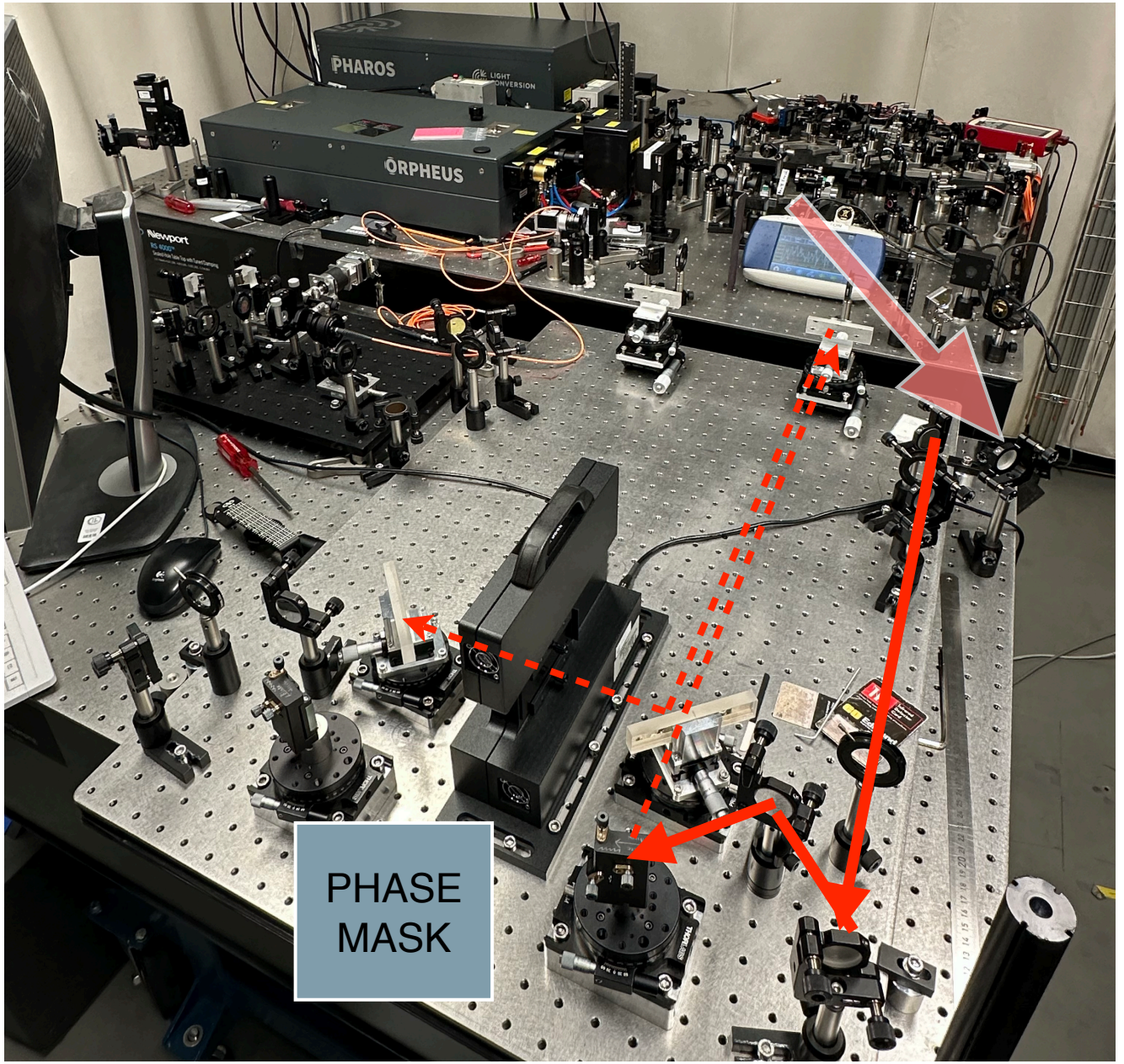

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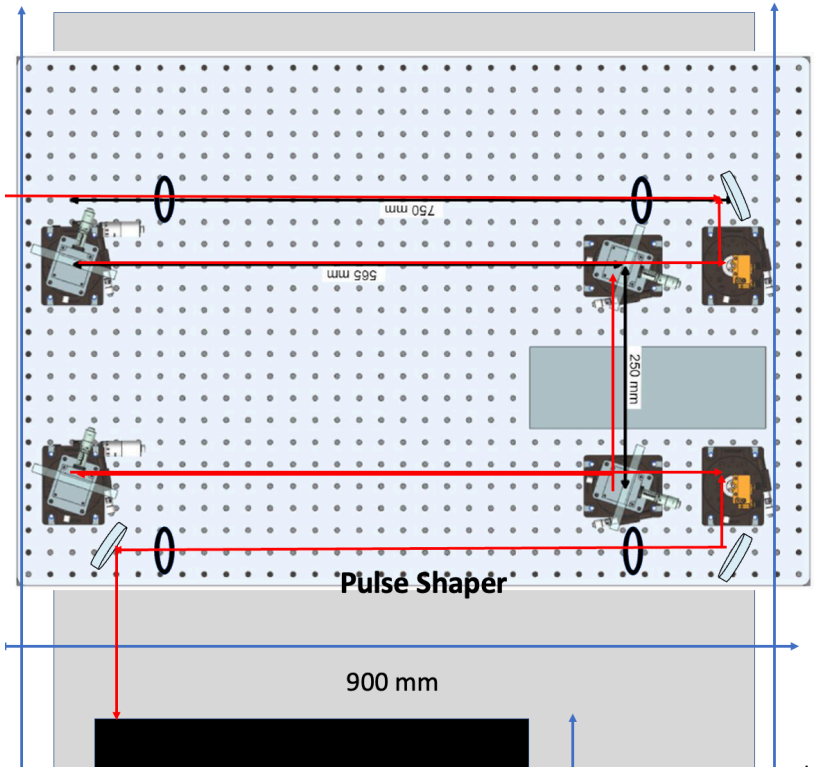

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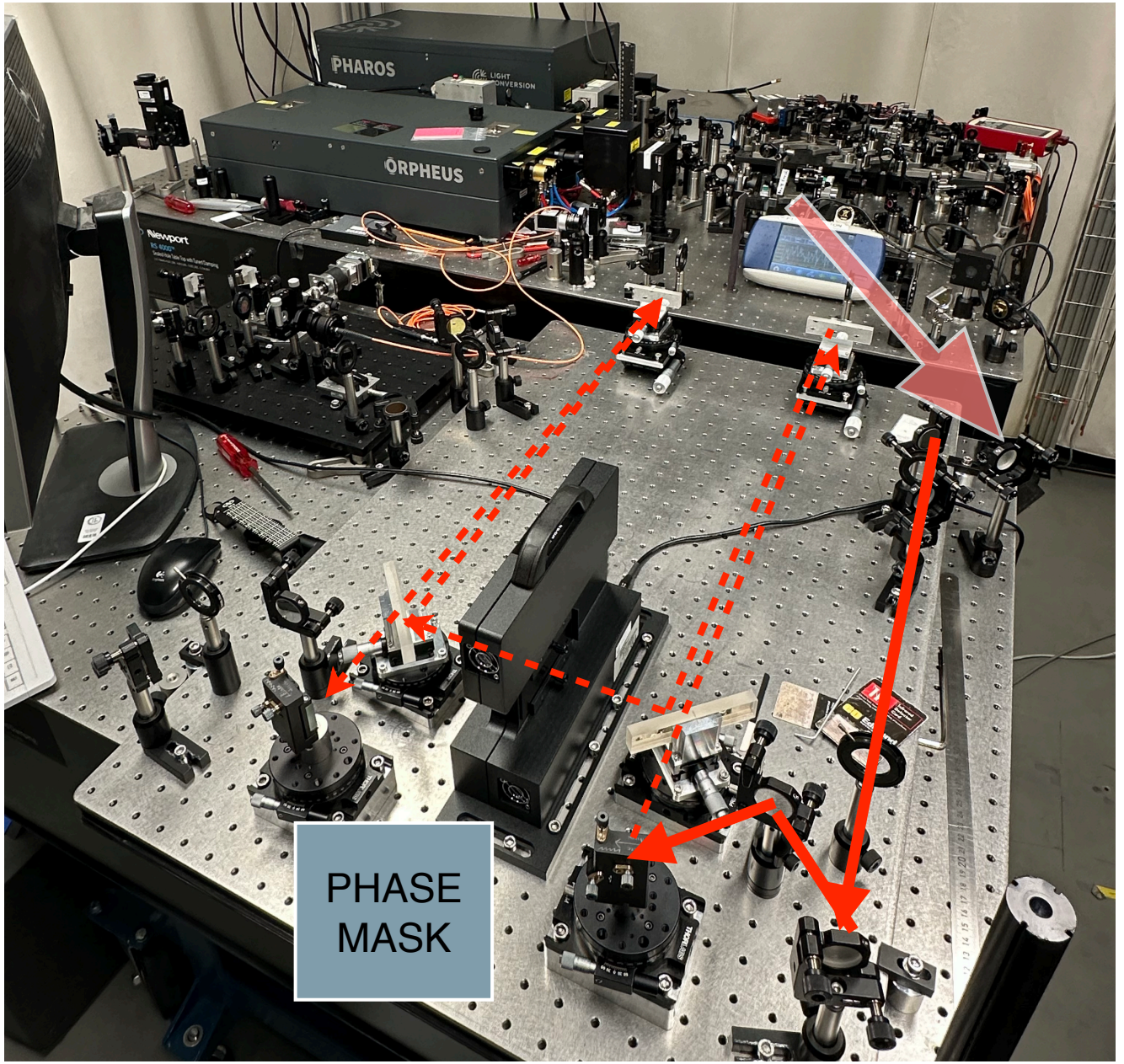

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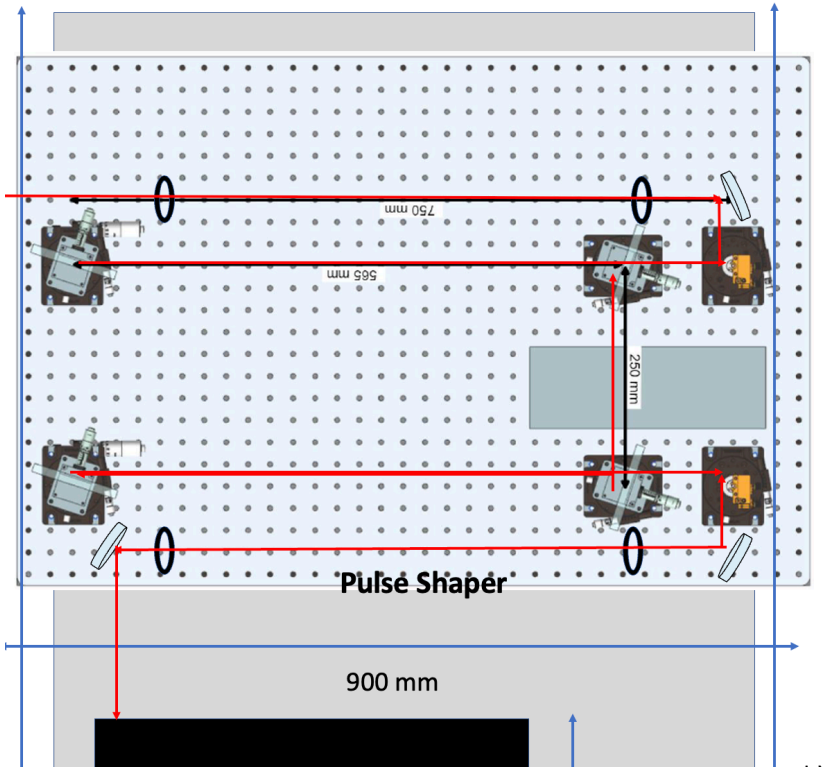

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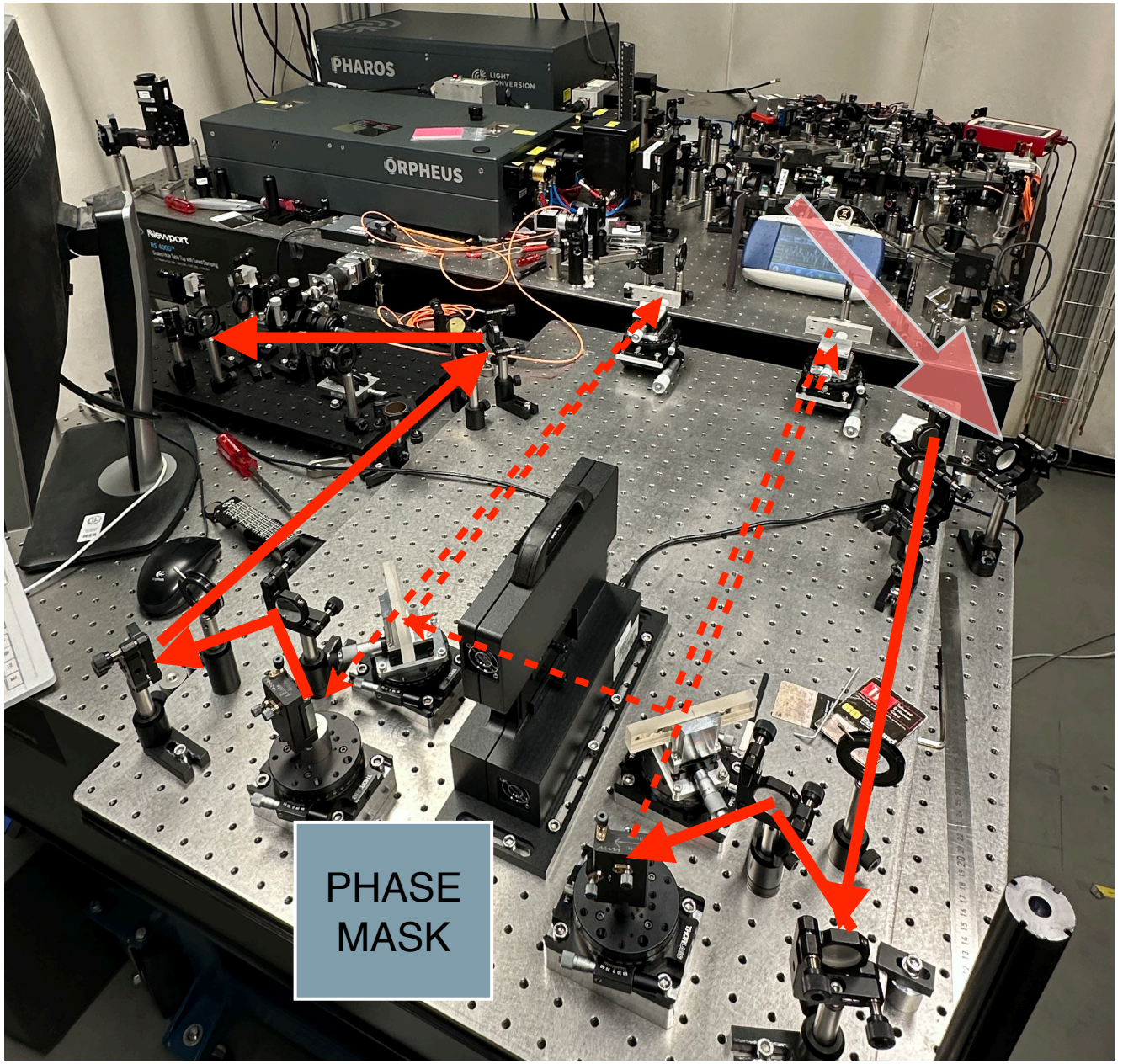

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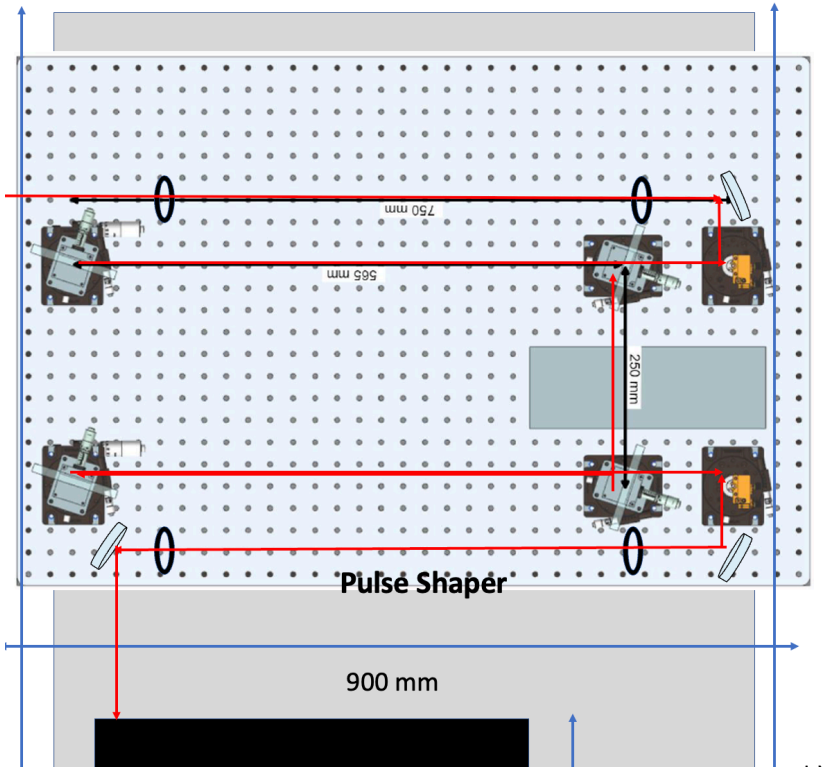

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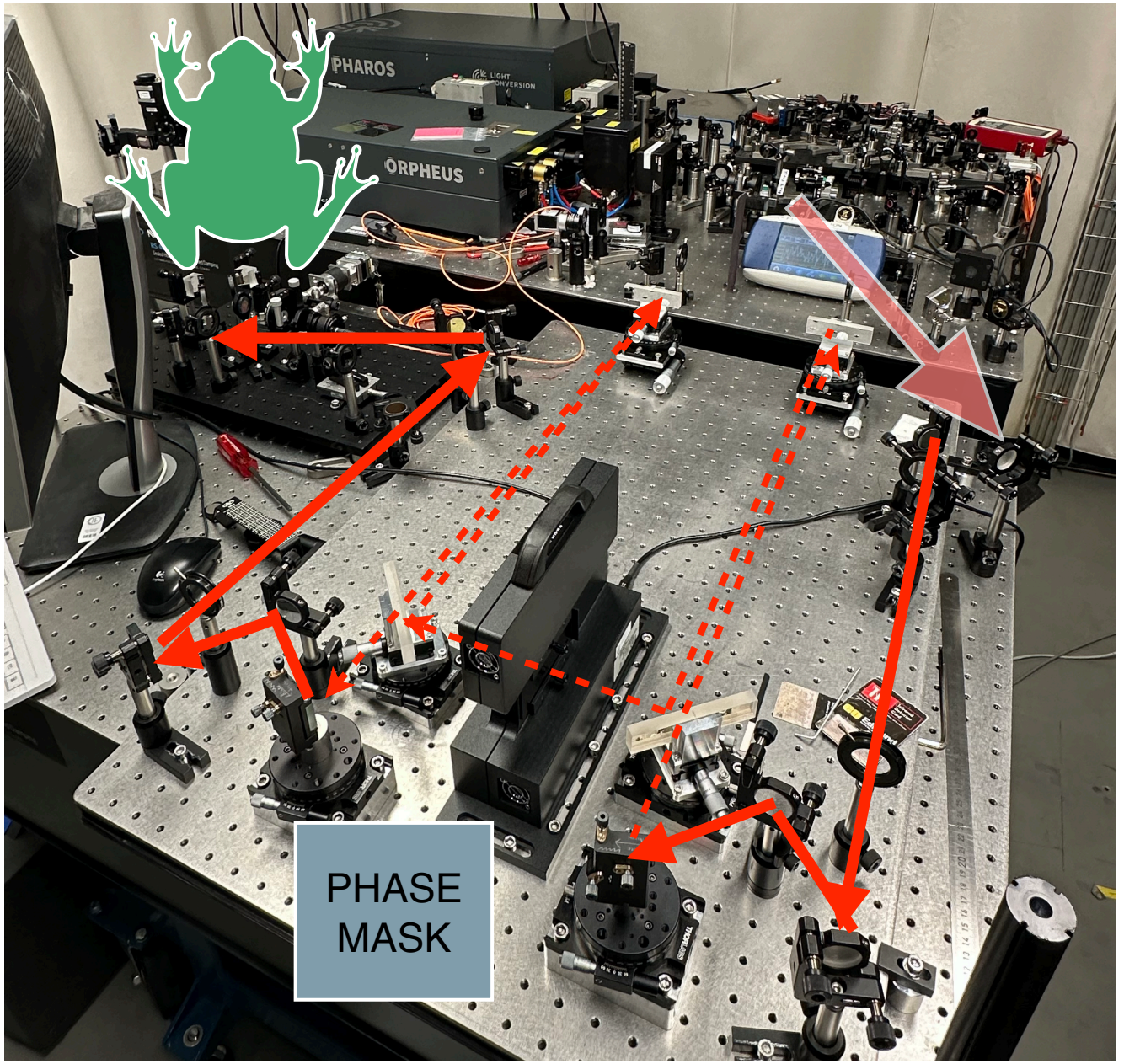
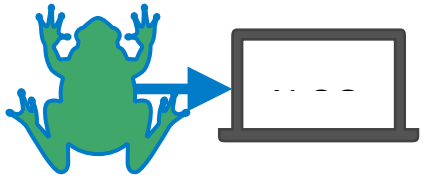


Pulse retrieval



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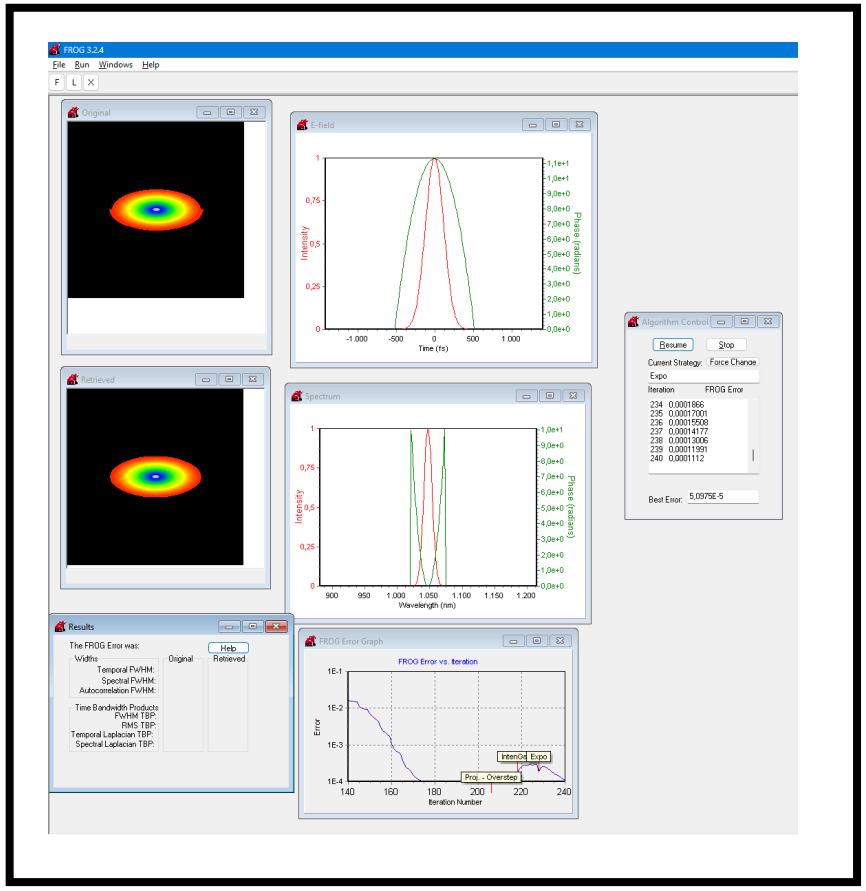

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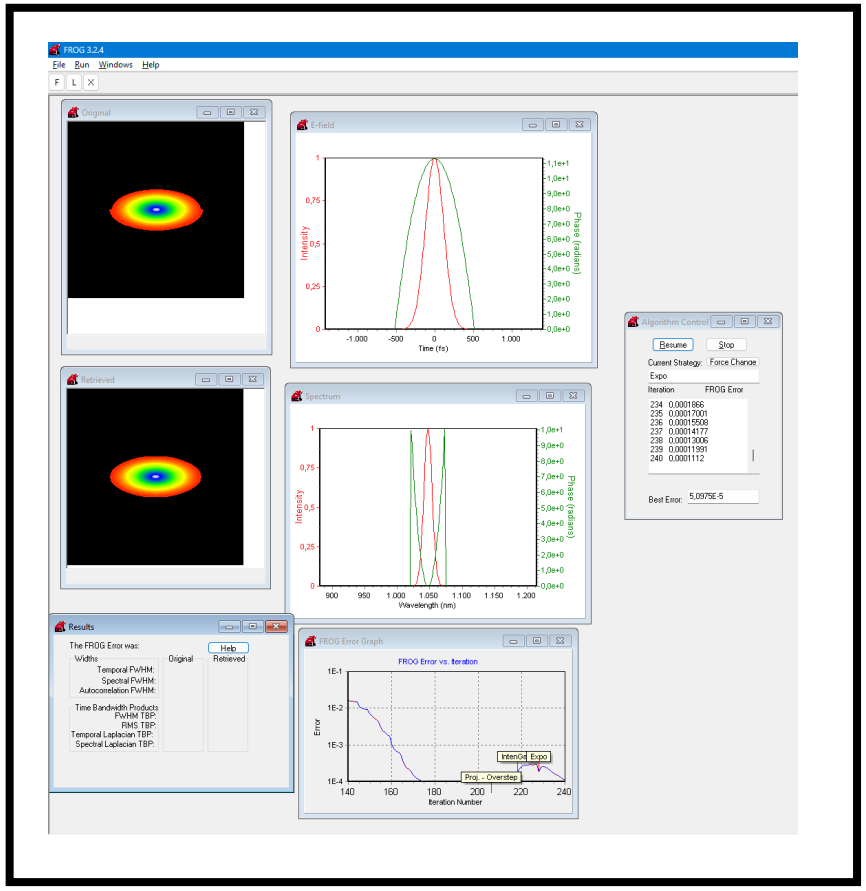
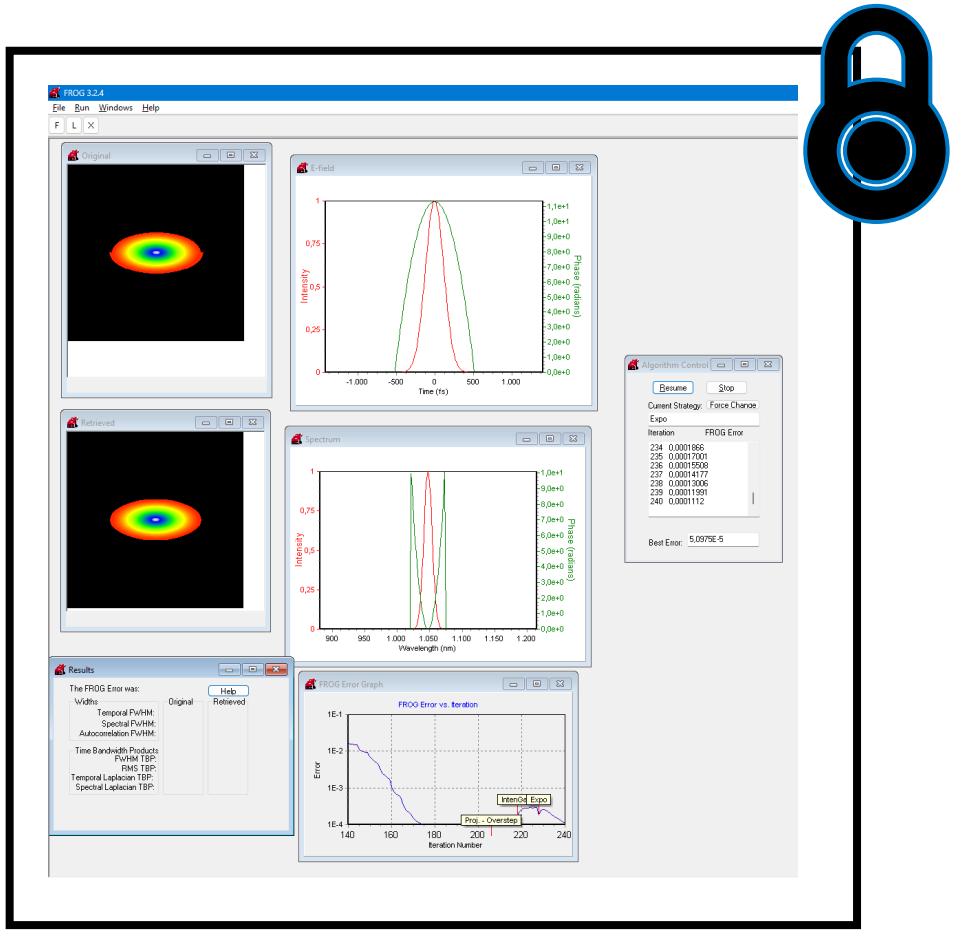


FROG from SWAMP Optics is industry standard - “Black box”

Pulse retrieval



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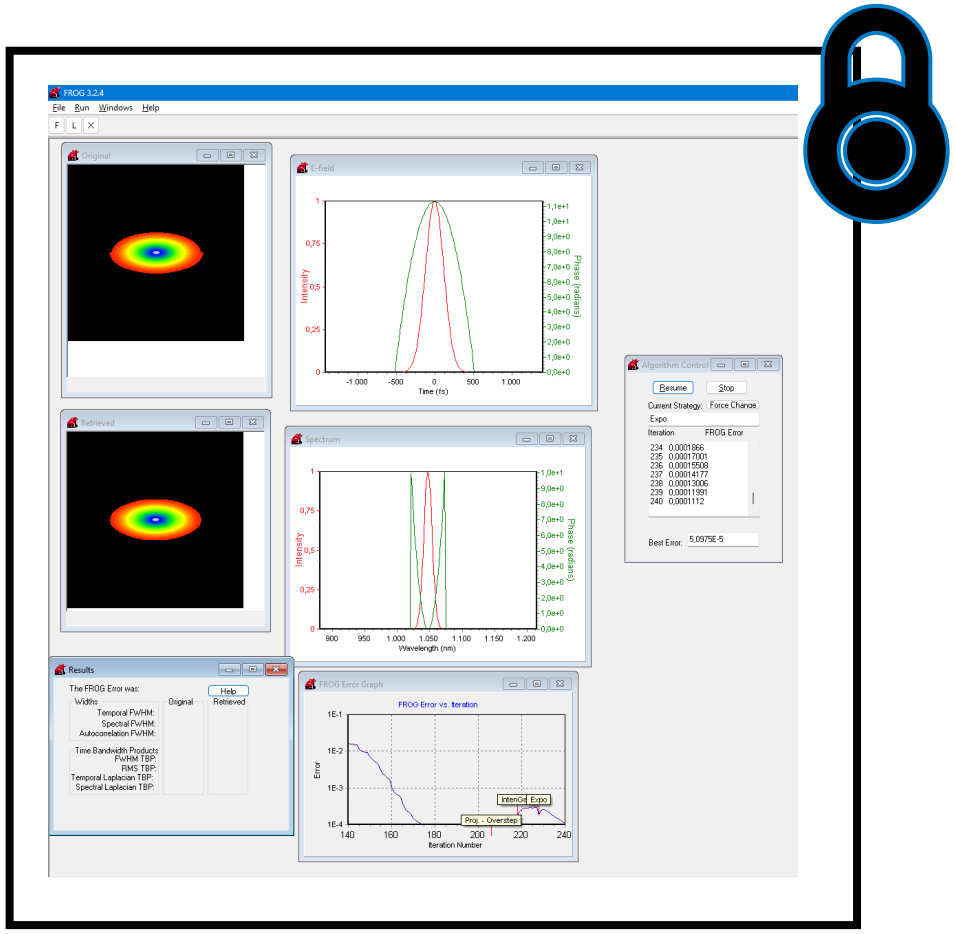

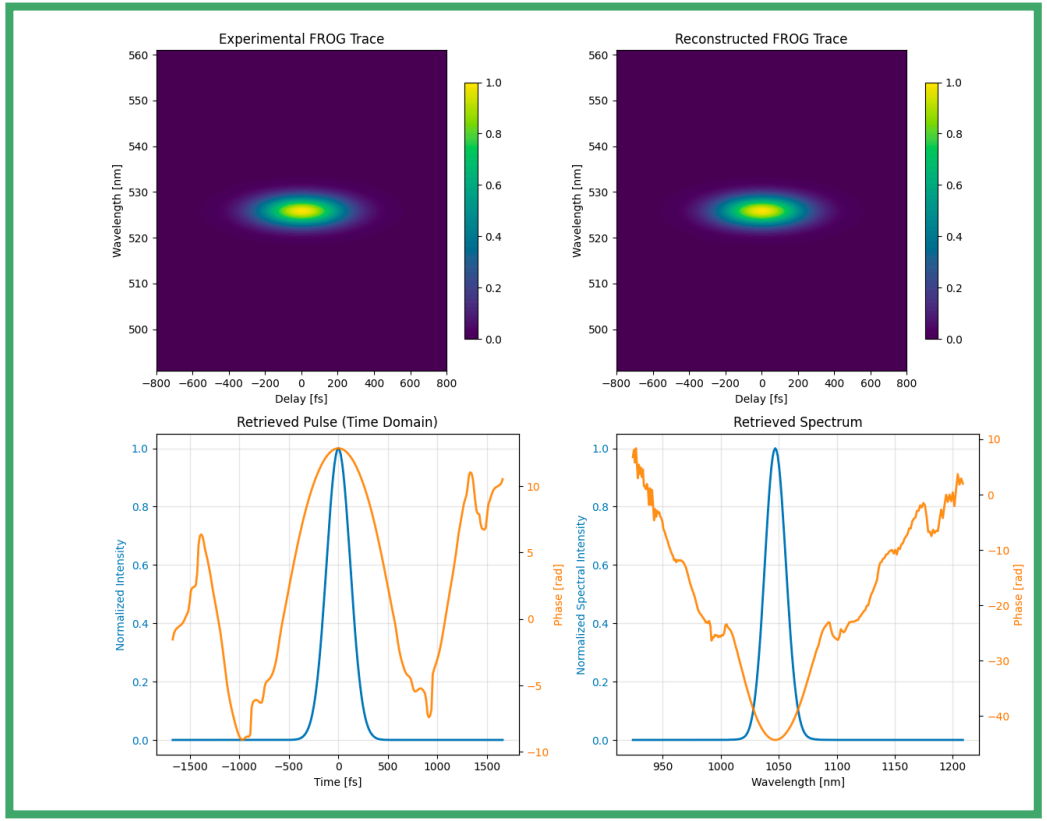

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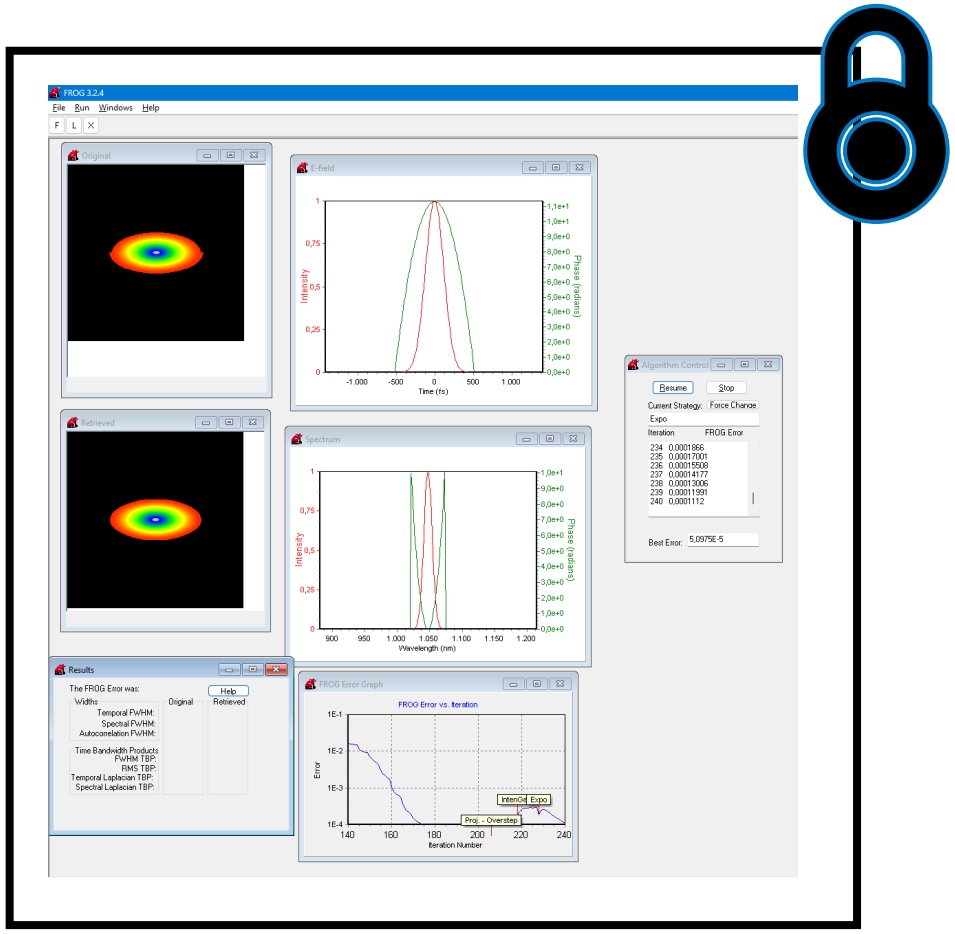

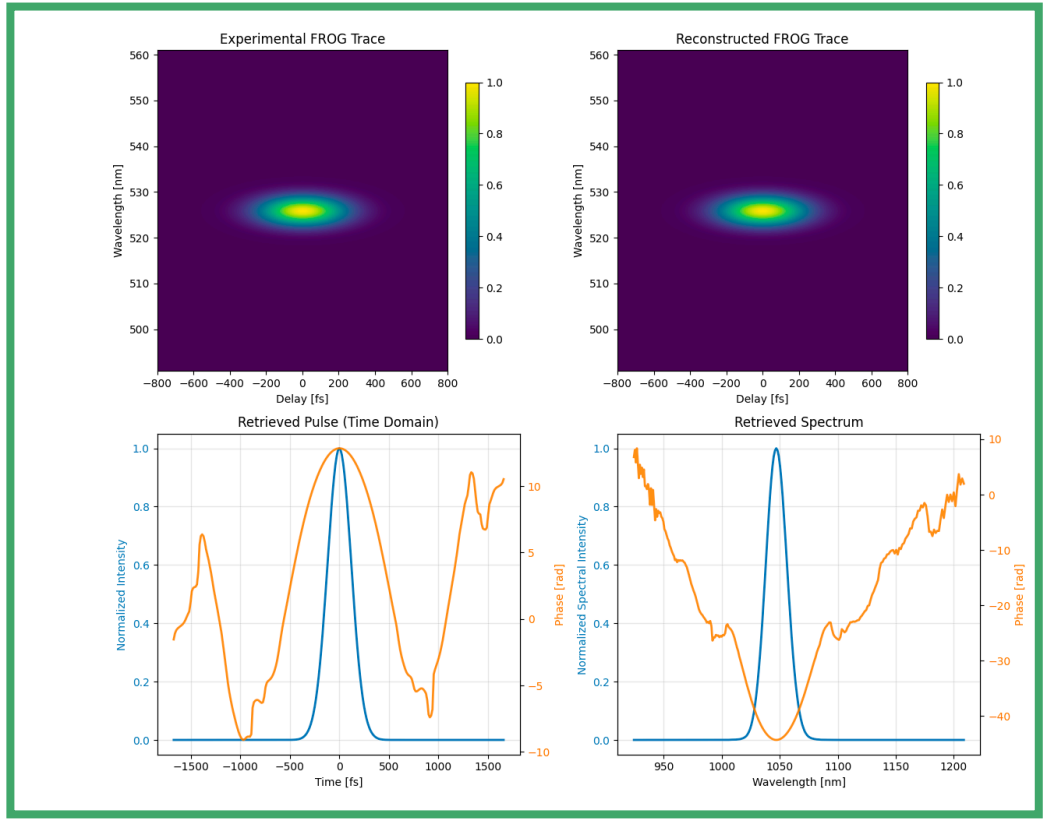

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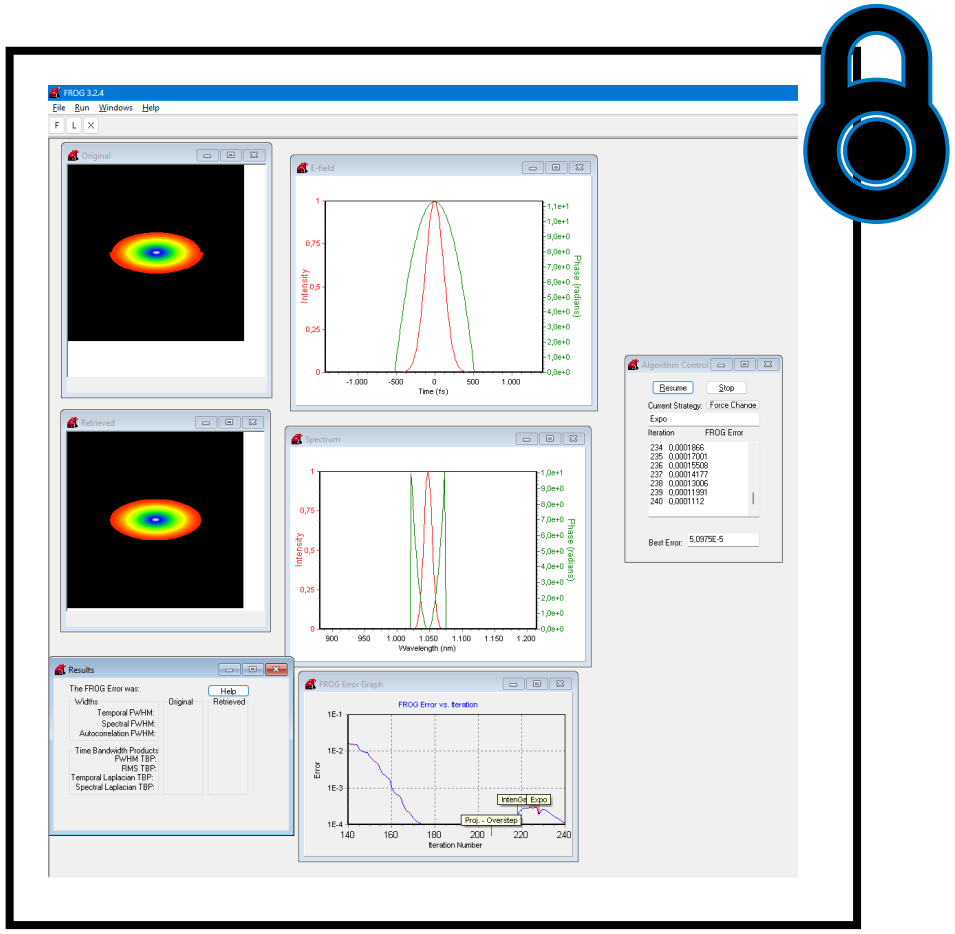
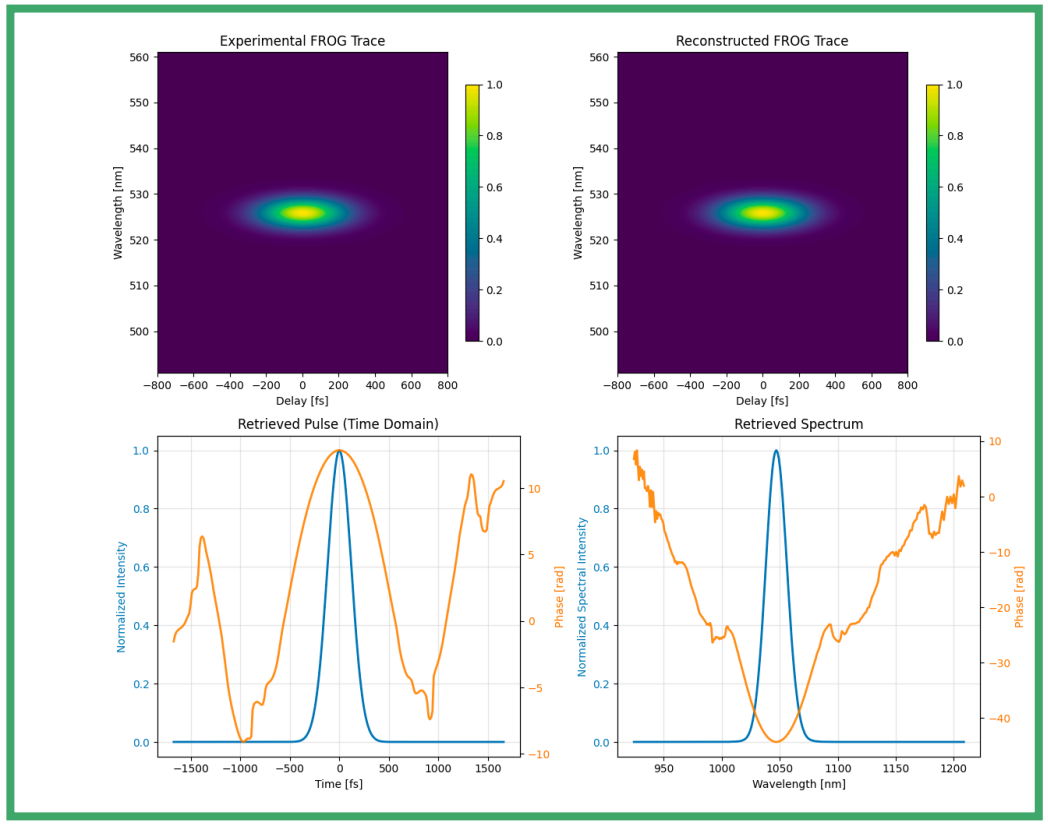
open source initiative®

In Alpha state

Pulse retrieval





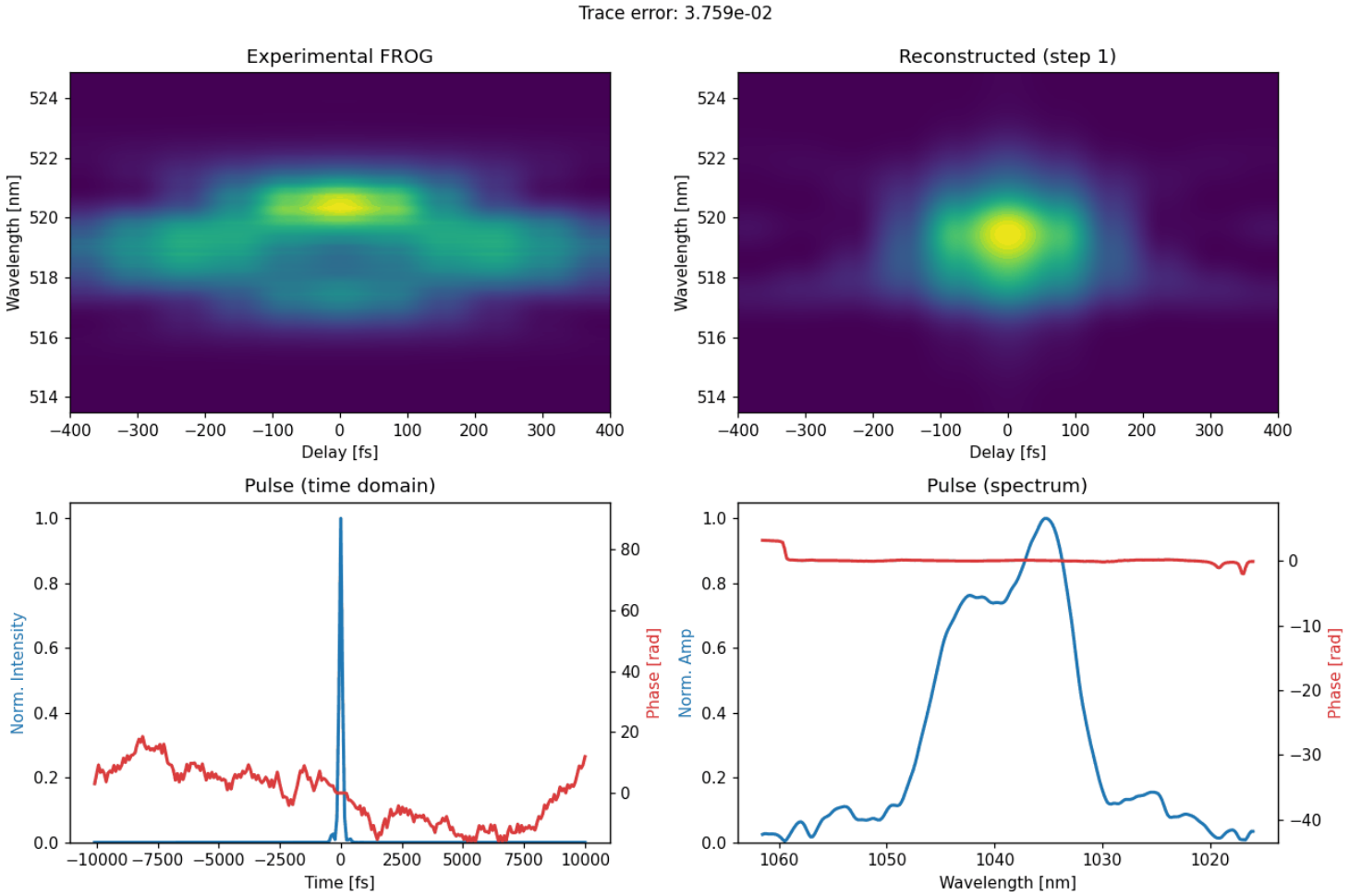
FROG from SWAMP Optics is industry standard - “Black box”

Pypret: -Reproduces SWAMP
-Runs faster
-Scriptable & scalable

open source initiative®

In Alpha state

Analysis of pulses with Pypret



100 steps ≃ 2 s
rate α=0.25

- Utilizes COPRA reconstruction algorithm, by N.Geib et. al. 2019

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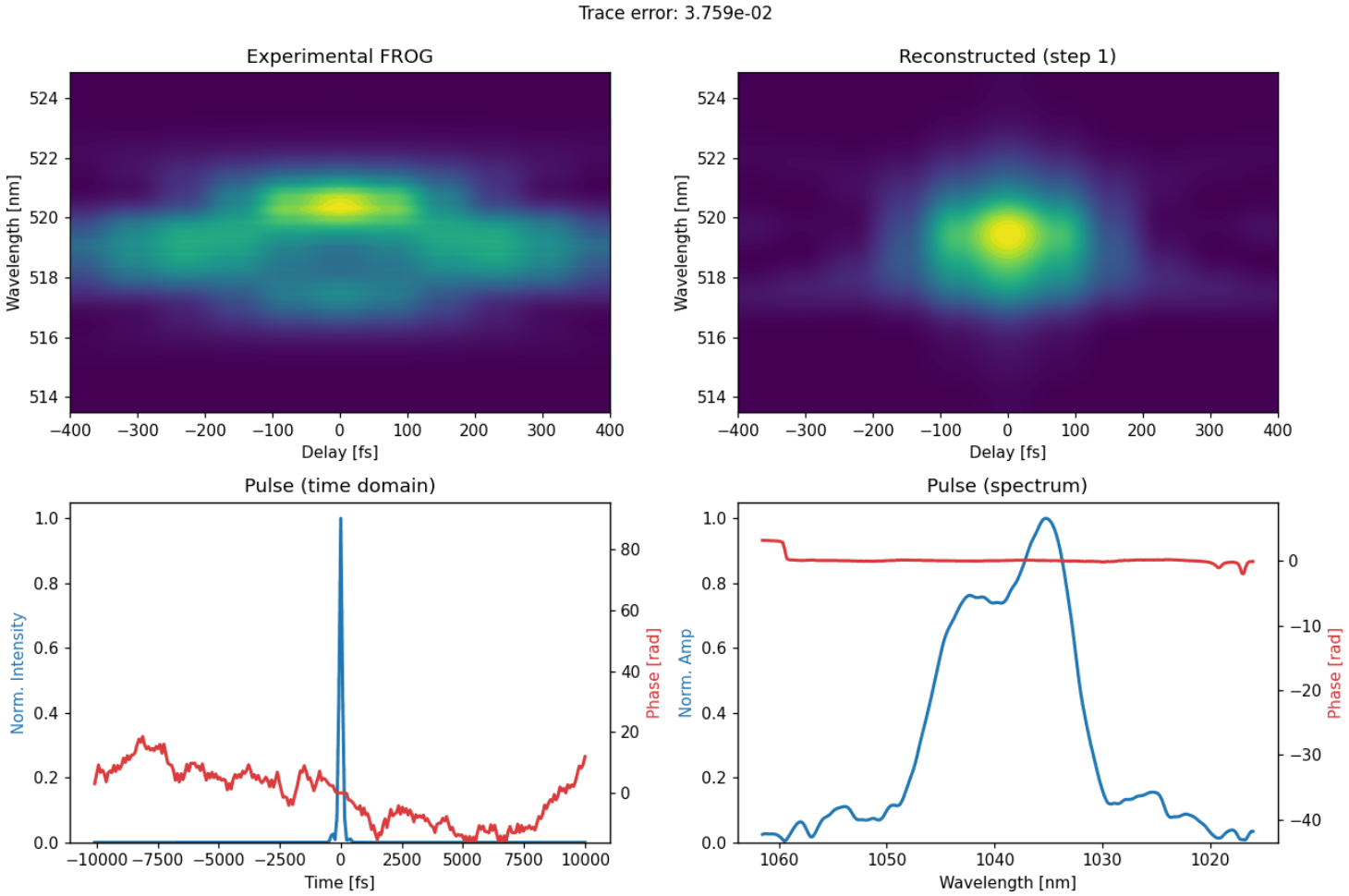

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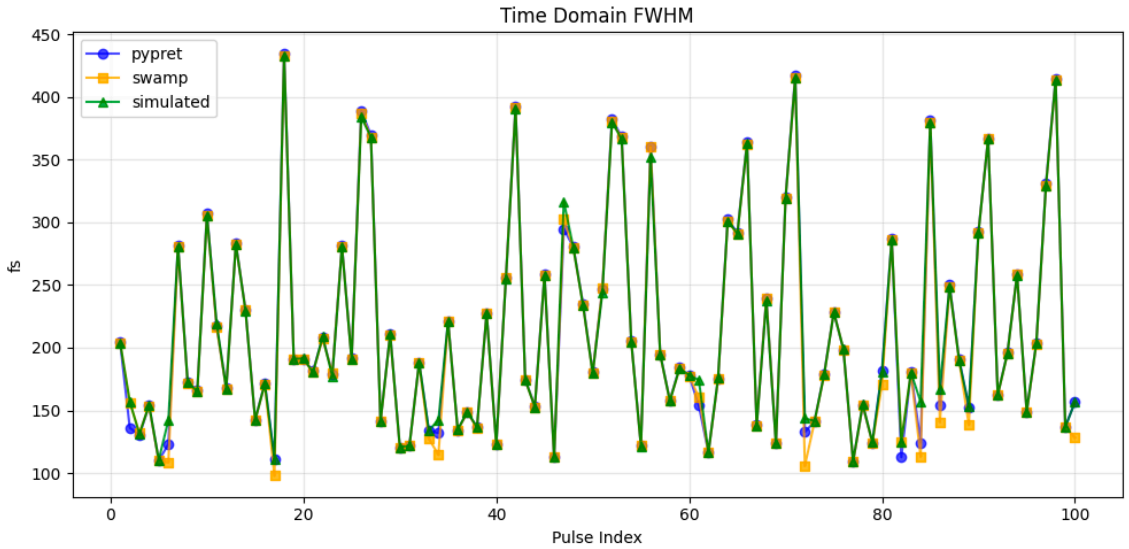
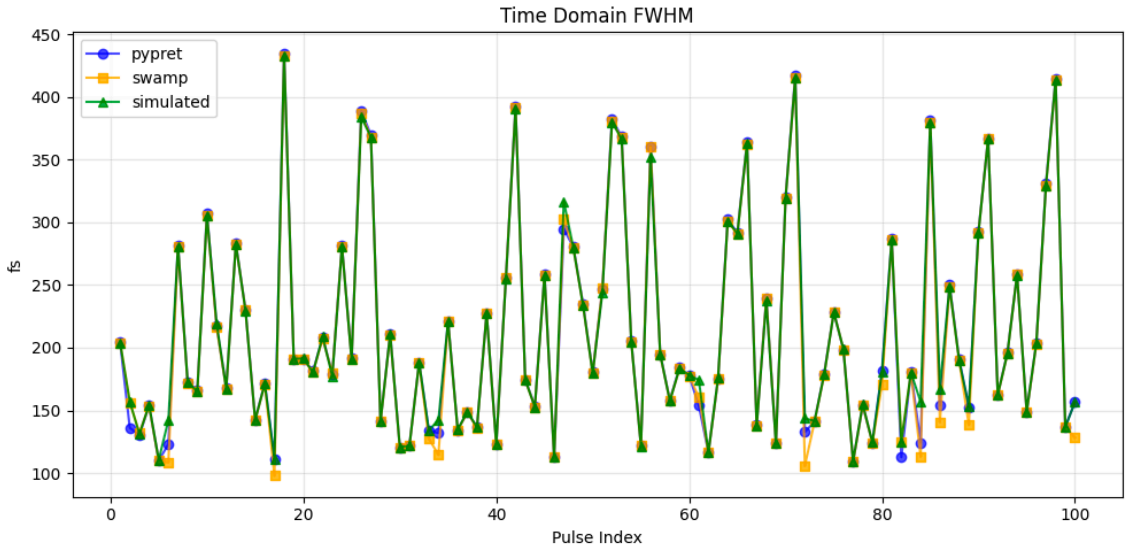
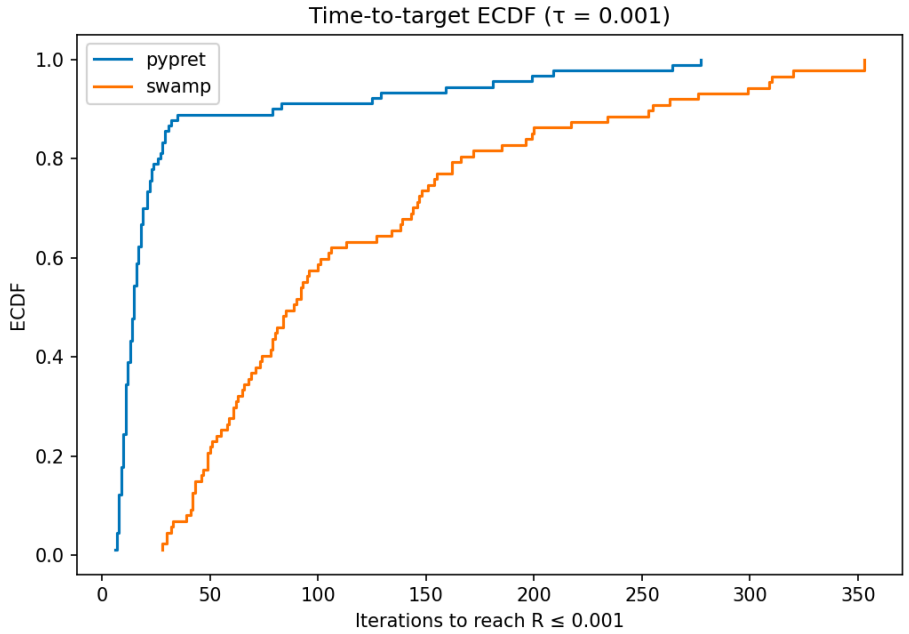


Implementation of Pypret:

- agrees with SWAMP well on simulated/exp. pulses
- Reproduces all metrics of the pulse (FWHM, TBP)

Comparison with SWAMP





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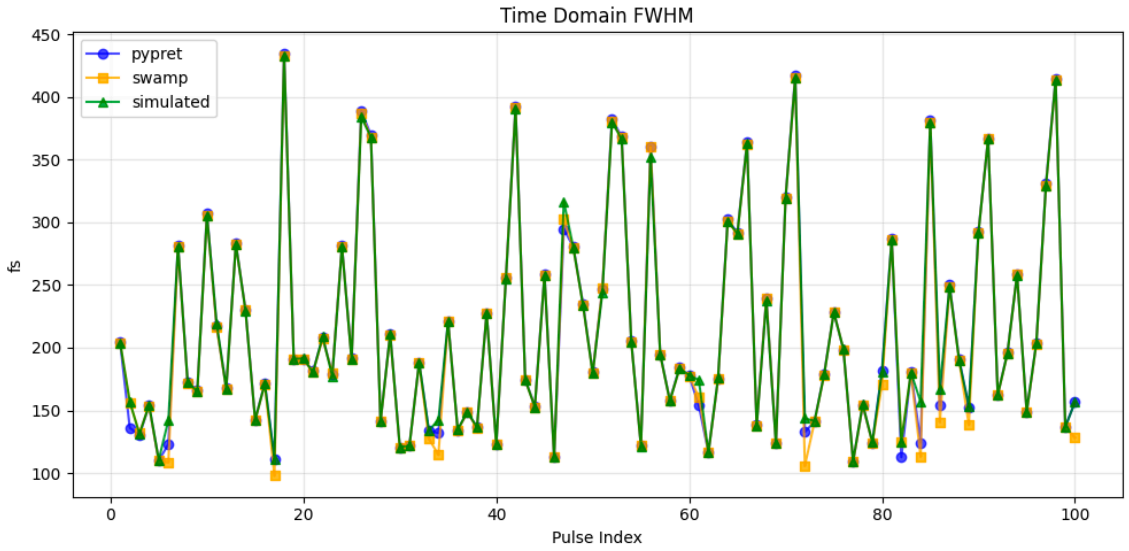

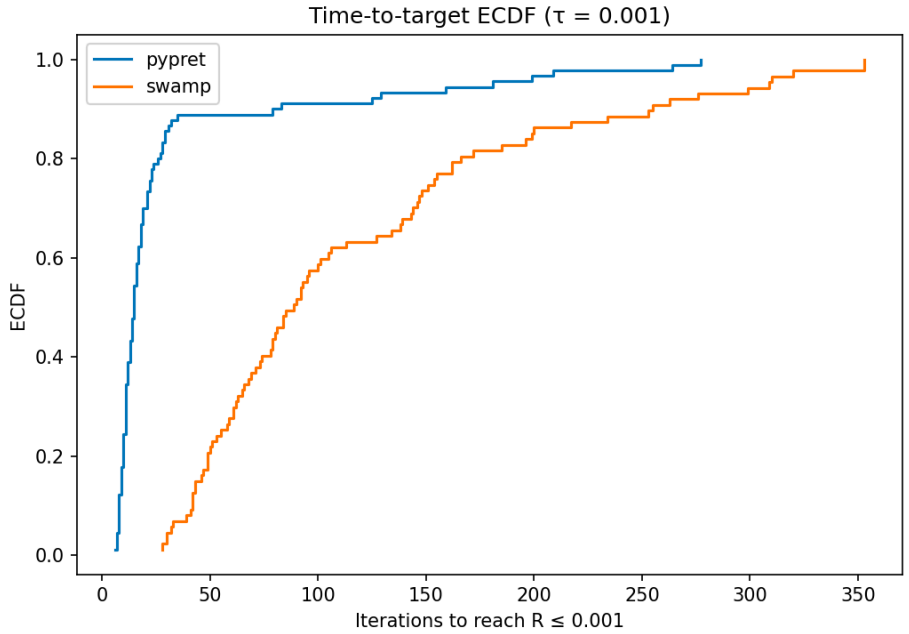

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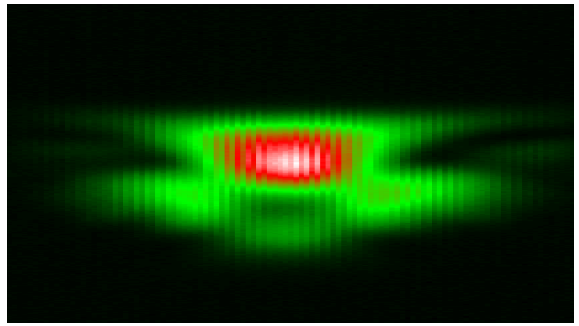
Pypret can be integrated into the Genetic Algorithm/ML loop for automatic retrieval/analytics of pulses

Pitfalls & Limitations

Pitfalls & Limitations



- Input traces need to be symmetric

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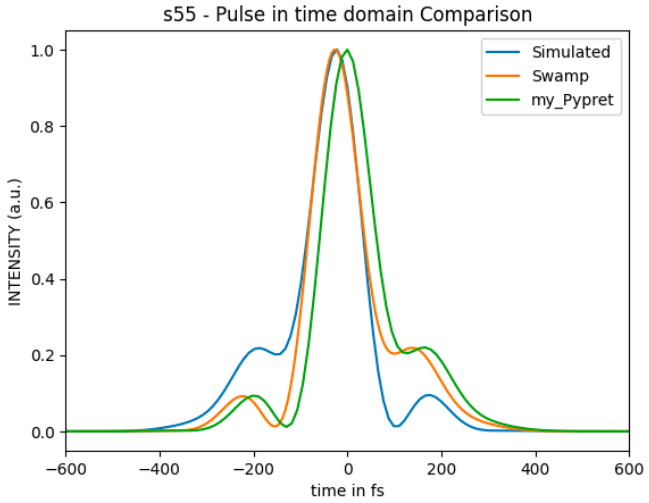

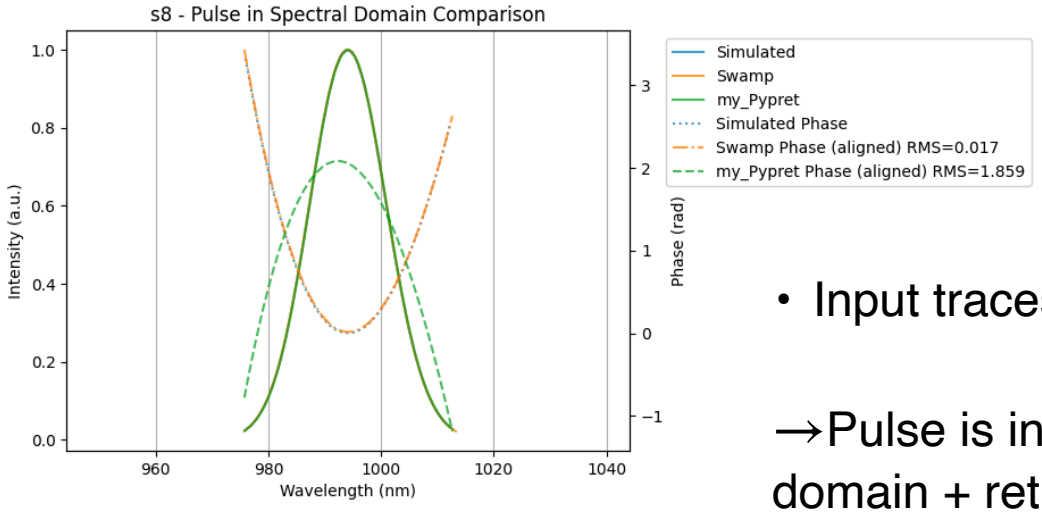

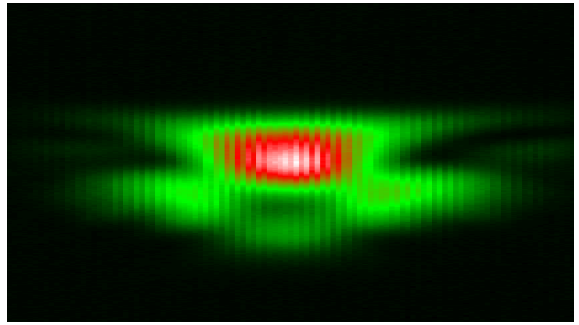

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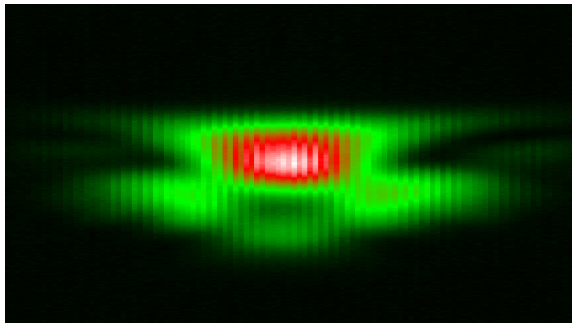
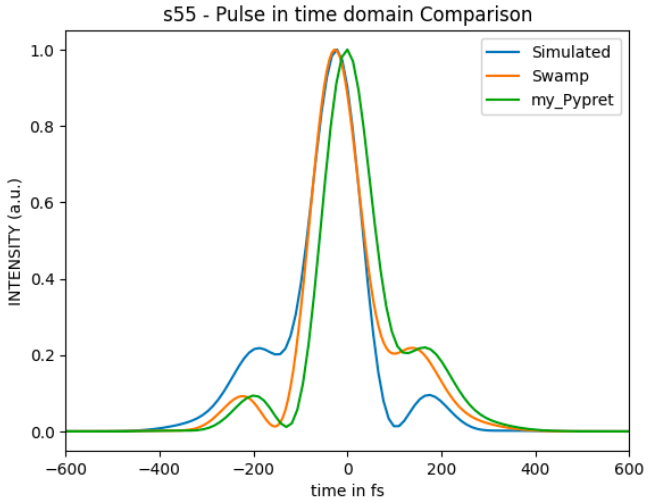
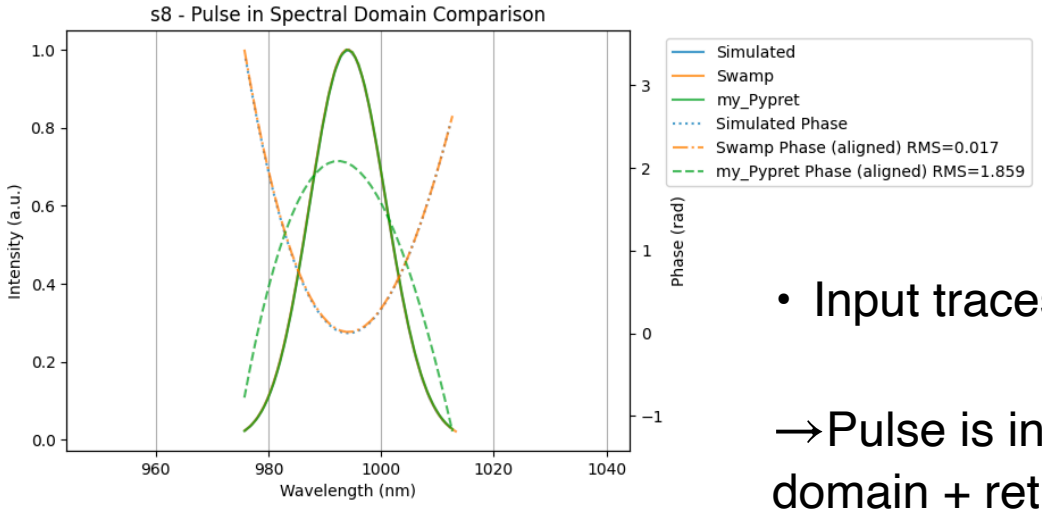
→Pulse is inherently unambiguous in time-domain + retrieval starts with random guess

→leads to 50/50 phase “flips”

Pitfalls & Limitations







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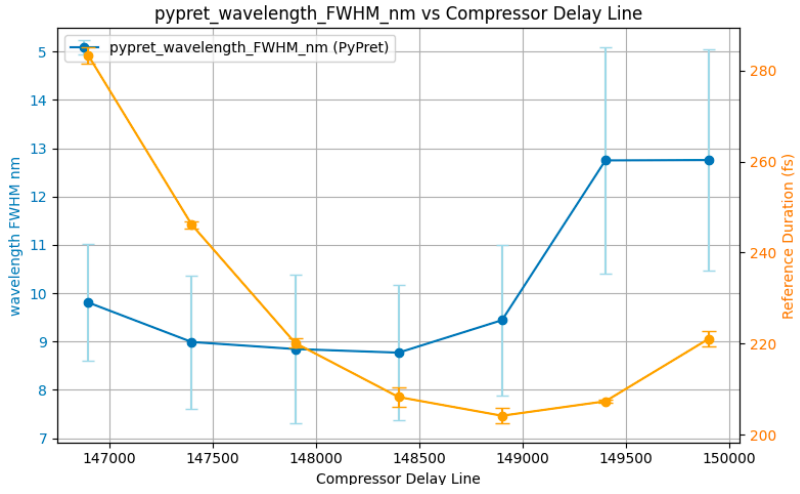
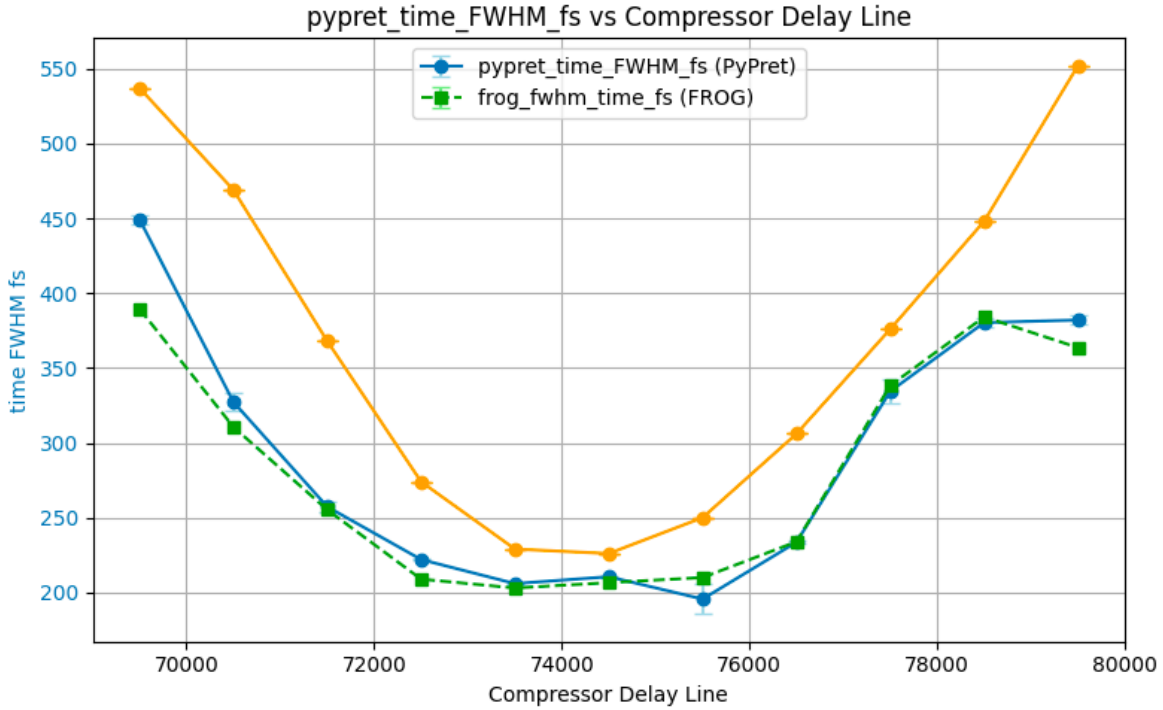


- Some metrics are fluctuating from shot-to-shot, especially spectral widths, spectral RMS etc.

Experimental data analysis

Experimental data analysis



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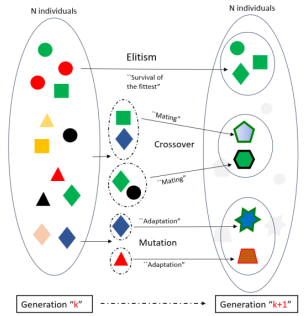
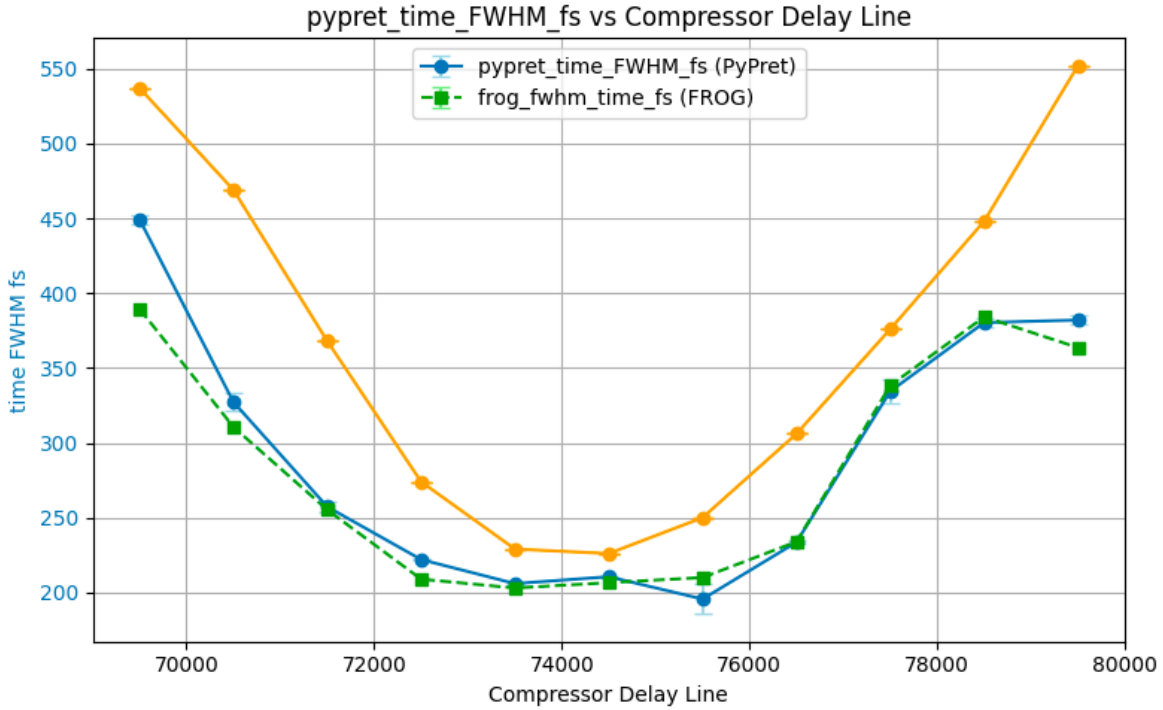
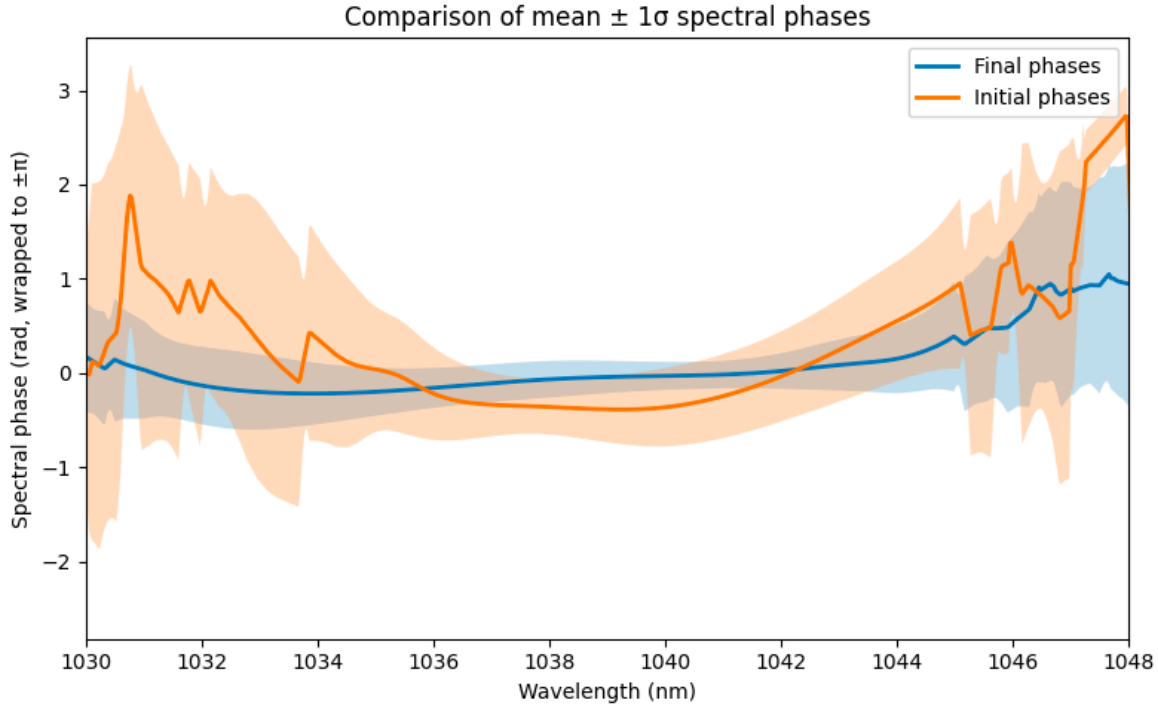


Reinforced learning:

$$\rightarrow \frac{I}{\Delta t}$$





- Tested on laser compressor-line sweep, in agreement with measured autocorrelation
- Was able to extract the phase after the GA compression, allowing to check target phase

Conclusions & Outlook

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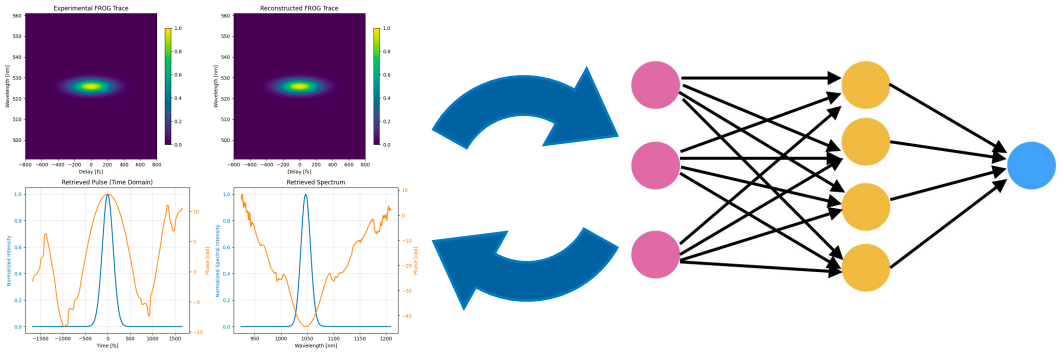
- Automatic retrieval enables reliable pulse metrics from SHG-FROG traces, enabling robust input for GA & ML-based pulse shaping and adaptive laser pulse compression.



THANK YOU!

Especially to the group members:
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Dr. Mahesh Namboodiri
Dr. Cheng Luo
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My supervisor - Hsuan-Chun Yao

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QUESTIONS?