

Shaping Laser Pulses with RL

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Reinforcement
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Ultra-short Laser Pulses

Ultrashort ($\leq 10^{-12}$ s) laser pulses are the **shortest systematic events humans can create**. They enable a range of applications, including:

① Particle acceleration

② Nuclear fusion

Scientists Achieve Nuclear Fusion Breakthrough With Blast of 192 Lasers

The advancement by Lawrence Livermore National Laboratory researchers will be built on to further develop fusion energy research.

Figure: Light traversing through matter, exchanging energy thereby accelerating particles.

Figure: NYT covering laser bursts used to achieve nuclear fusion ignition at the LLNL (USA), 2022.

Maximize Intensity by Minimizing Duration

Laser bursts convey energy in both **time** and **space**.

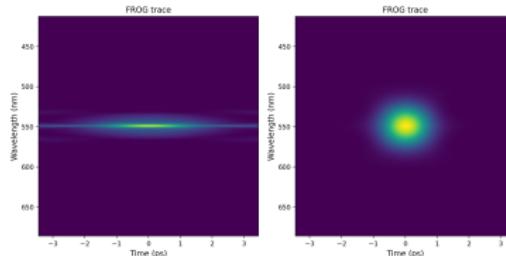


Figure: (left) Poorly temporally-focused pulse (right) Temporally-focused pulse

Particle acceleration & fusion ignition both require high-intensity bursts.

$$PI_t \propto \frac{2E}{\int I_\psi(t)dt}$$

Intensity grows when:

- Increases in the pulse energy, $E \uparrow$
- Decreases in pulse duration $\int I_\psi(t)dt \downarrow$

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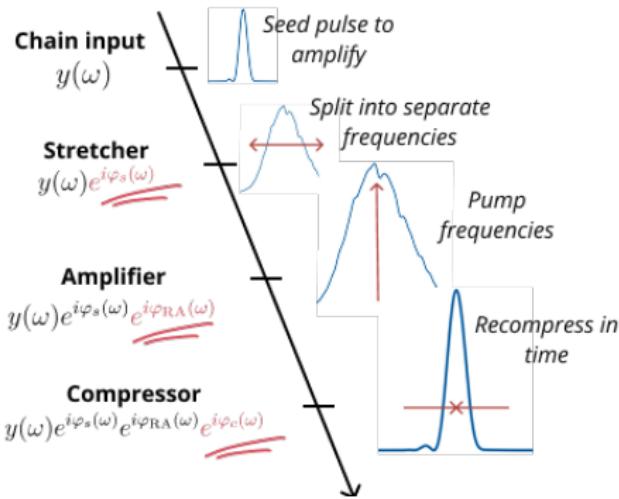
Minimizing Duration = Optimal Shaping

Figure: (left) Spectral pulse, phase in yellow (right) Resulting temporal profile.

Controlling the phase **in the frequency domain** impacts the pulse's duration **in the temporal domain**. Shaping consists of:

- ① Stretching the pulse into fundamental frequencies
- ② Amplifying the different frequencies (**non-linear**)
- ③ Recompressing in time, aligning frequencies yielding **constructive interferences**

Minimizing Duration = Optimal Shaping



Controlling the phase **in the frequency domain** impacts the pulse's duration **in the temporal domain**.

- ① In control Stretching the pulse into fundamental frequencies
- ② Out of control Amplifying the different frequencies (**non-linear**)
- ③ Out of control Recompressing in time, aligning frequencies yielding **constructive interferences**

① State reconstruction

- Lasting pico/attoseconds, ultra-short temporal profiles **cannot be directly measured**.
- Measuring the intensity achieved is a **destructive process**.

② (Unknown-)Dynamics dependant

- Shaping system's **parameters change day by day**, and not always for fully modelled reasons.
- The process of non-linear amplification/phase accumulation is itself not well understood

③ Fragile in real-world settings

- Real-world shapers are delicate machines needing proper care relatively to the control applied
- Besides being correct, **controls need to be appropriate**, both in (1) absolute and (2) relative terms.

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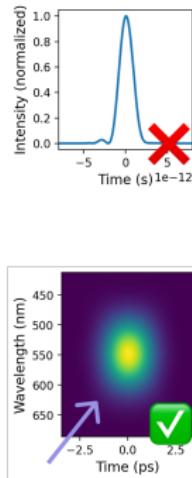
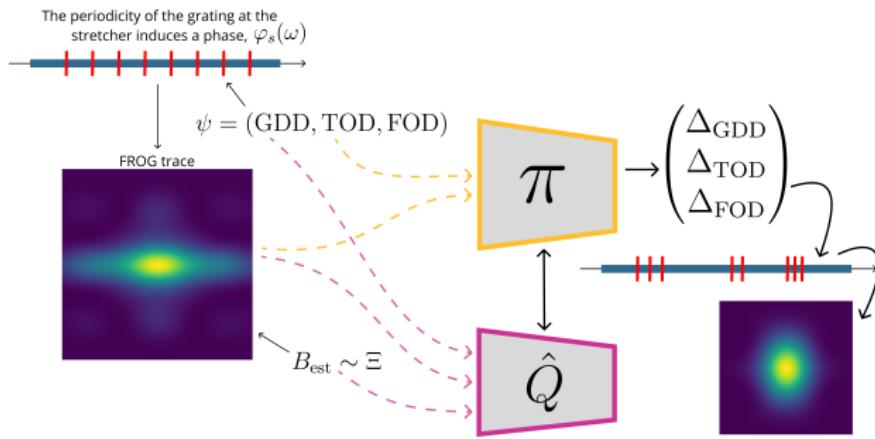
2 Shaping Laser Pulses

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Deep RL to the rescue (1/3)

① Use unstructured observations

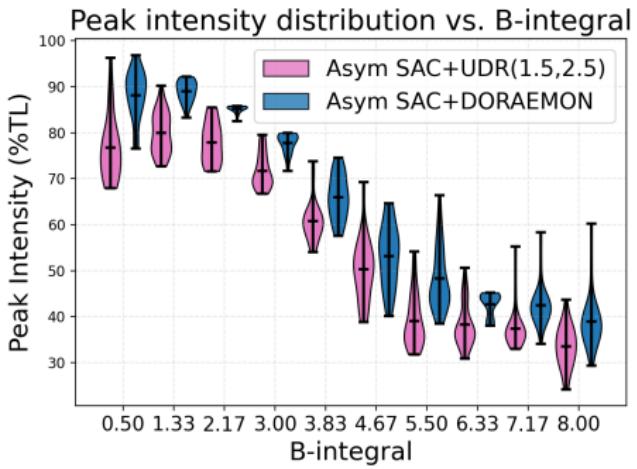
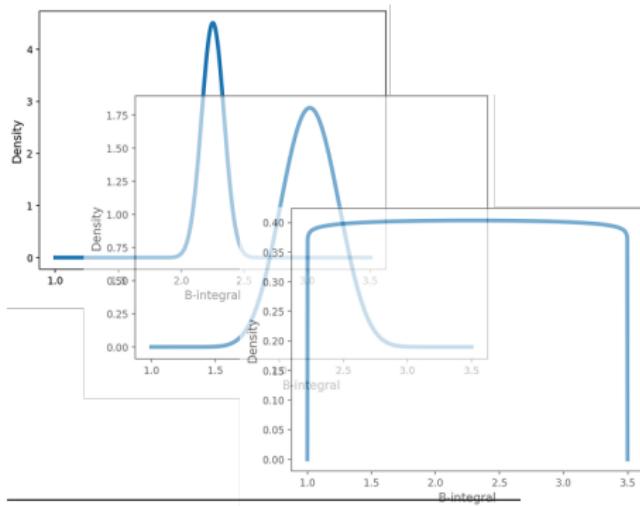
Bypass noisy pulse reconstructions, use raw diagnostics (images) only.
Diagnostic measurements are **not destructive**.



Deep RL to the rescue (2/3)

② Induce robustness to dynamics

Randomize dynamics over training by adapting a meta-distribution conditionally on performance ¹ **Automatically adapt the randomization distribution** based on performance during training.

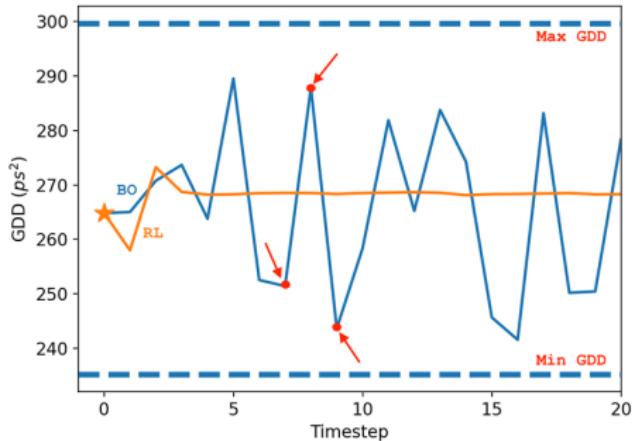


¹"Domain randomization via entropy maximization", Tiboni et al., ICLR 2024

Deep RL to the rescue (3/3)

③ Train in a (coarse) simulator

Avoid exploration on real-world systems by training in simulation, allocating erratic behavior to in-simulation training



Deep RL for pulse shaping

We train a controller to **safely tune laser parameters** for intensity maximization, **across dynamics** and using **image observations only**.

Conclusions

- We present a new method for shaping laser pulses using RL.
- Our method learns from images, bypassing noisy reconstruction.
- It is robust to changes in the dynamics thanks to entropy-driven DR.
- It is trained in simulation, ensuring (safe) exploration.

Code & testbed are both [open-source!](#)



Questions? Poster 21

