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Dispersion Management and Pulse Length Tuning in the EPAC CPA Laser System

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Abstract

Needed: Minimizing the residual dispersion in the CPA system to achieve high irradiance and high temporal contrast

Approach: Using a grating-prism stretcher based on transmission gratings with high diffraction efficiency across the spectral range

Result: The calculated residual dispersion is negligible up to the 5th order

Motivation

Femtosecond PW lasers (EPAC: E_p = 30 J, t_p < 30 fs [1]): applications in plasma physics, generation of bright X-rays and γ-rays, compact particle accelerators

Required:

- high irradiance $I_{pulse} = \frac{E_{pulse}}{\pi w_{focus}^2 \Delta t_{pulse}} > 10^{21}\ W/cm^2$
- high temporal contrast → **an order of magnitude higher using transmission gratings in the pulse stretcher [2]**

Challenge: minimizing the residual dispersion of the CPA system up to the fourth or fifth order (GDD_{res}, TOD_{res}, FOD_{res} and $FiOD_{res}$) by using the degrees of freedom in the stretcher design.

State-of-the-art approaches

1. Using 3 degrees of freedom in a grating stretcher - insufficient:

- separation distance of the gratings
- incidence angle – limited to $\theta_{Littrow}$ ± 1º for transmission gratings with high diffraction efficiency at spectral bandwidth > 100 nm
- line density

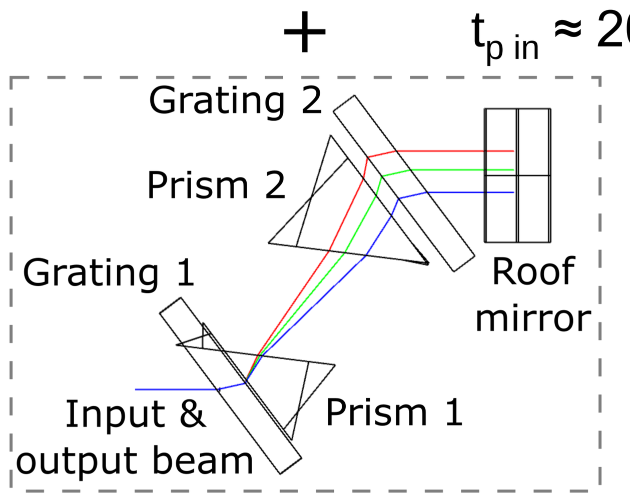
Drawback: tight tolerance of $\frac{\Delta \text{material dispersion}}{\text{material dispersion}}$ in the CPA system [3]

2. Using 6 degrees of freedom in a grating-prism stretcher: demonstrated using reflective stretcher gratings [4], but not using transmission gratings yet

Our design: grating-prism stretcher + Offner stretcher

Optical material

\+ $t_{p\ in}$ ≈ 20 ps

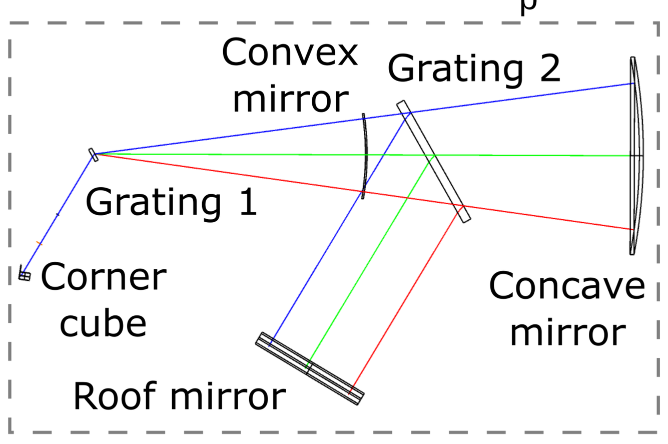


Grating-prism stretcher

Grating 2 and the roof mirror: on a motorized translation stage → tuneable $t_{p\ CPA}$: 22 fs – 50 ps

B-integral < 0.04 in the Offner stretcher

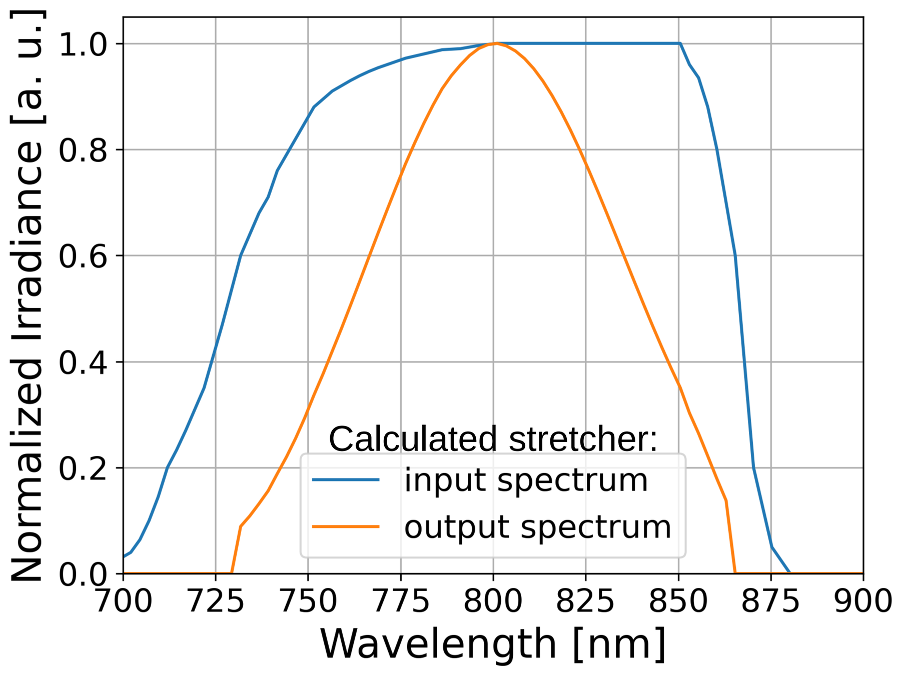
\+ t_p ≈ 130 ps



Offner stretcher t_p ≈ 4 ns

\+

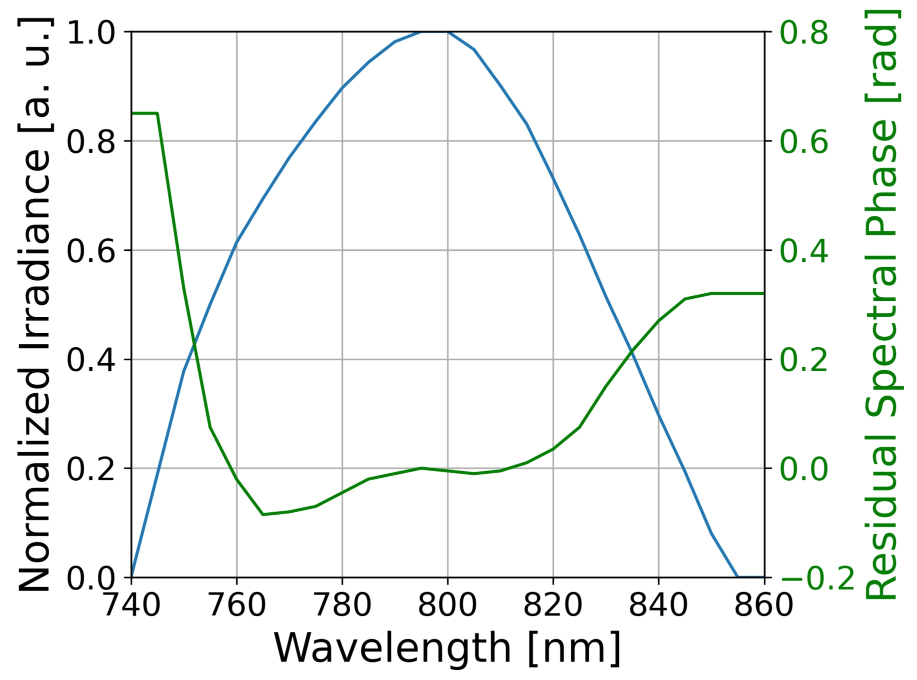
Compressor ⟶ $t_{p\ CPA}$

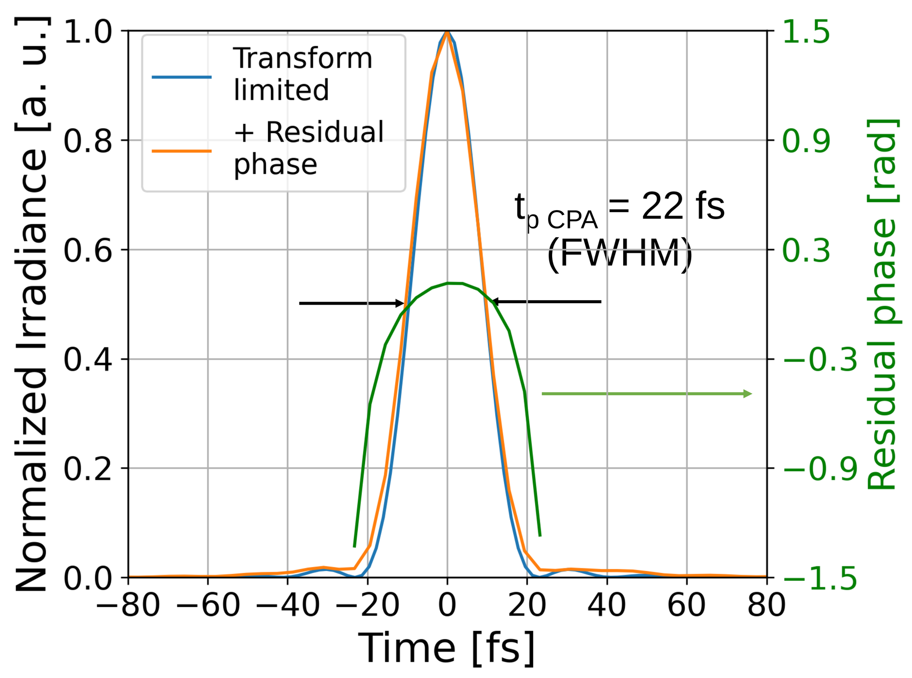


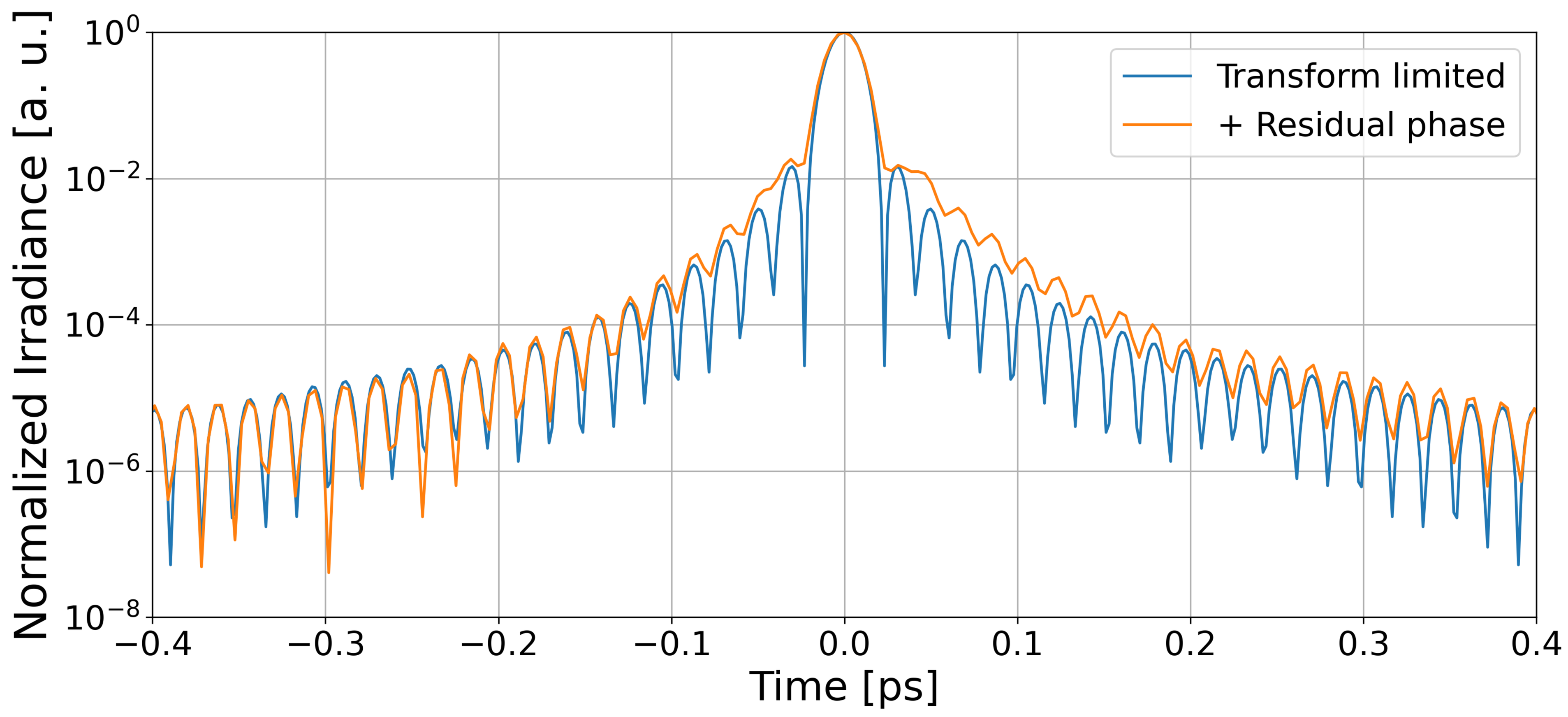
Pulse compression: calculated results

	Grating parameters			Prism parameters		
	Line density [lines/mm]	Incidence angle [º]	Separation distance [mm]	Material	Apex angle [º]	Separation distance [mm]
Grating-prism stretcher	1500	36.76 = $\theta_{Littrow}$ - 0.1°	7	Fused silica	46	45
Offner stretcher			1006	-		

6 degrees of freedom: flexible dispersion allowing $\frac{\Delta \text{material dispersion}}{\text{material dispersion}}$ = 100% and the CPA residual dispersion minimized up to the 5th order

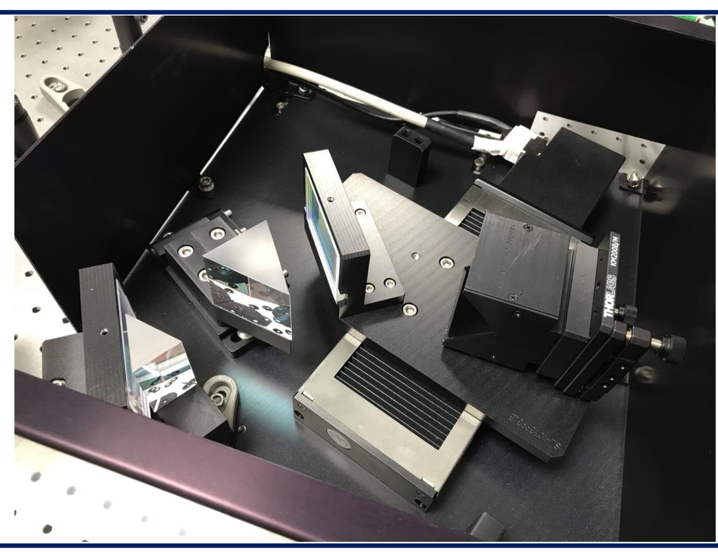






Grating-prism stretcher: experimental results

- A prototype was tested to compress the output of the VOPPEL ps OPCPA to t_p < 20 fs
- The aligned EPAC grating-prism stretcher ⟶ Measured efficiency > 50%



References

[1] P. Mason, N. Stuart, J. Phillips, R. Heathcote, S. Buck, A. Wojtusiak, M. Galimberti, T. Pinto, S. Hawkes, S. Tomlinson, R. Pattathil, T. Butcher, C. Hernandez-Gomez, J. Collier, "Progress on Laser Development at the Extreme Photonics Applications Centre," Conference on Lasers and Electro-Optics (CLEO)/Europe, ca_8_2, (2023).

[2] Yunxin Tang, Chris Hooker, Oleg Chekhlov, Steve Hawkes, John Collier and P. P. Rajeev, "Transmission grating stretcher for contrast enhancement of high power lasers," Optics Express, **22**, 29363, (2014).

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