Laser post-compression for dephasingless laser-wakefield experiments of electron acceleration

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Motivation

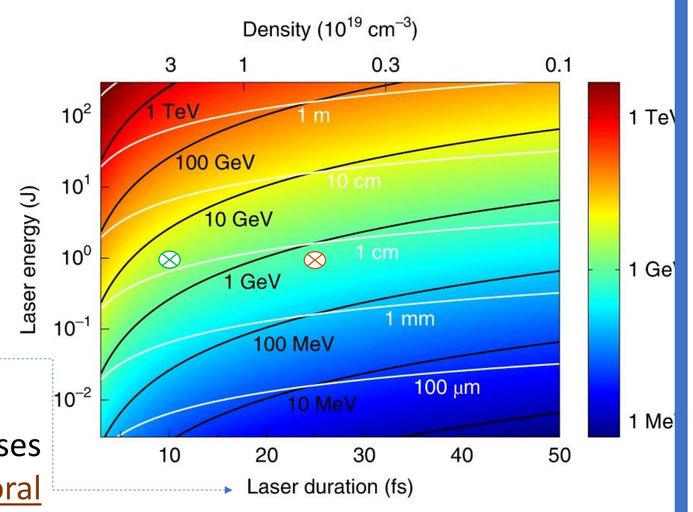
- Traditional accelerators are limited by the electric breakdown (~100 MeV/m)
- Laser-Plasma Accelerators allow much higher fields, but are limited by diffraction, laser depletion and dephasing

- Dephasingless laser wakefield electron acceleration: match the electron beam velocity with the laser velocity.

  - Energy gain:

$$\Delta W \propto W_L/\tau^2$$

  - Experimental setup: uses axiparabola + Spatio-Temporal Couplings (STC)



Caizergues et al, Phase-locked laser-wakefield electron acceleration, Nat. Photonics (2020)

Focusing mirror generating quasi-Bessel beam, with long focal line:

$$f(r) = f_0 + \delta(r)$$

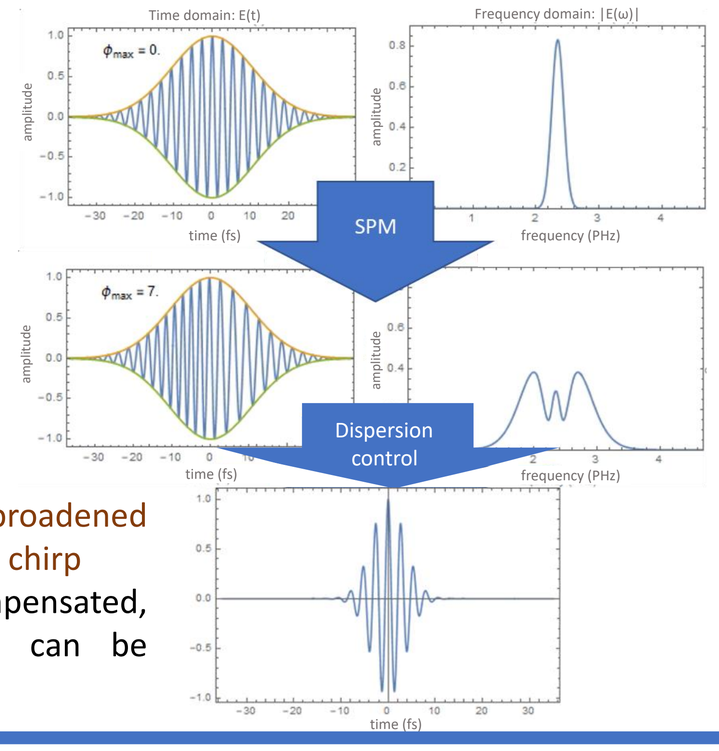
r is the position of the rays with respect to the center of the mirror – every ring of rays is focused at different longitudinal positions z

Laser temporal properties vary with the spatial position.
E.g., Spatial Chirp (SPC), Pulse-Front Tilt (PFT), **Pulse-Front Curvature (PFC) –** every ring in the laser beam profile has a different time delay w.r.t. the central spot

Self-Phase Modulation

- Self-phase modulation (SPM): 3rd order non-linear optical effect; light accumulates SPM phase when transmitted through an intensity-dependent refractive index (n_2) material (in time domain):

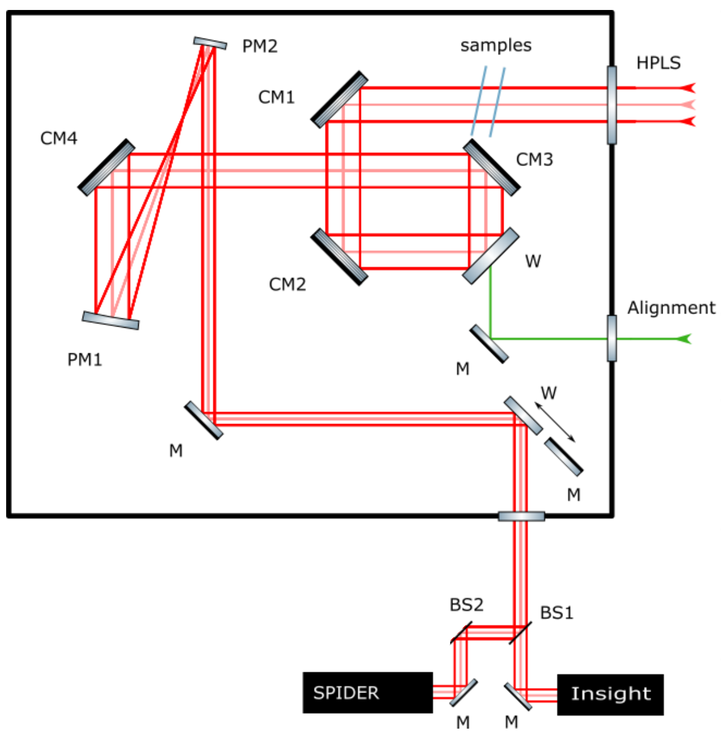
$$\Phi_{SPM} = 2\pi/\lambda_0 \cdot I_0 n_2 L$$



⇒ the original spectrum is broadened and the pulse gets temporal chirp

- If the dispersion is compensated, then the pulse duration can be consistently shortened

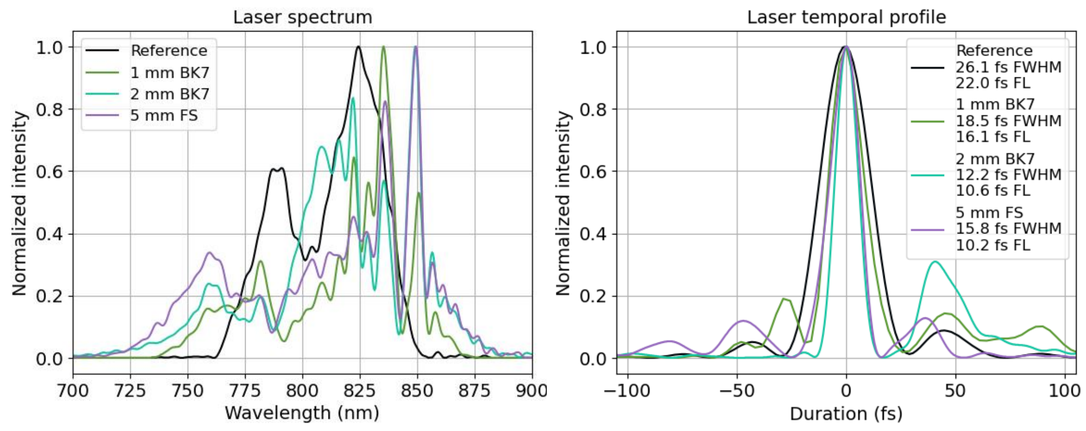
Experimental Setup



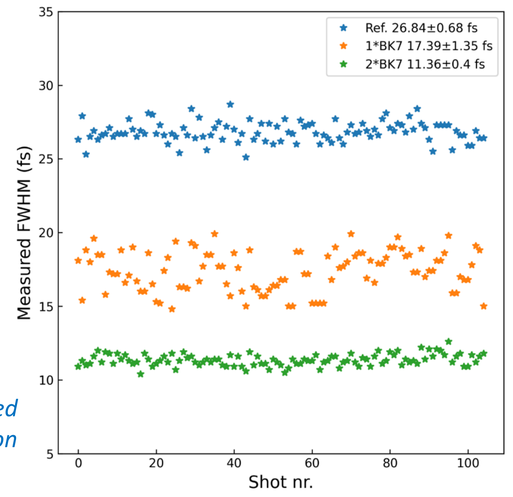
- 100 TW arm from HPLS @ ELI-NP: 1 J energy (half-power), 810 nm central wavelength, 26 fs pulse duration, 55 mm diameter, 10 Hz repetition rate
- Chirped mirrors (CM): – 75 fs² GDD each
- SPM materials: 2 plates of 1 mm BK7, one plate of 5 mm fused silica
- SPIDER measurements for the temporal/spectral profiles
- Insight Quadro measurements for the spatio-spectral profiles

Spectral Broadening Results

- Dispersion was adjusted using the Dazzler (Acousto-Optic Programmable Dispersive Filter) in the laser chain
- SPIDER measurements for SB pulses – at Dazzler configuration close to best compression for HPLS:



- Stability measurements: 100 shots for each case
- Pulse duration is stable enough to perform experiments with post-compressed pulses



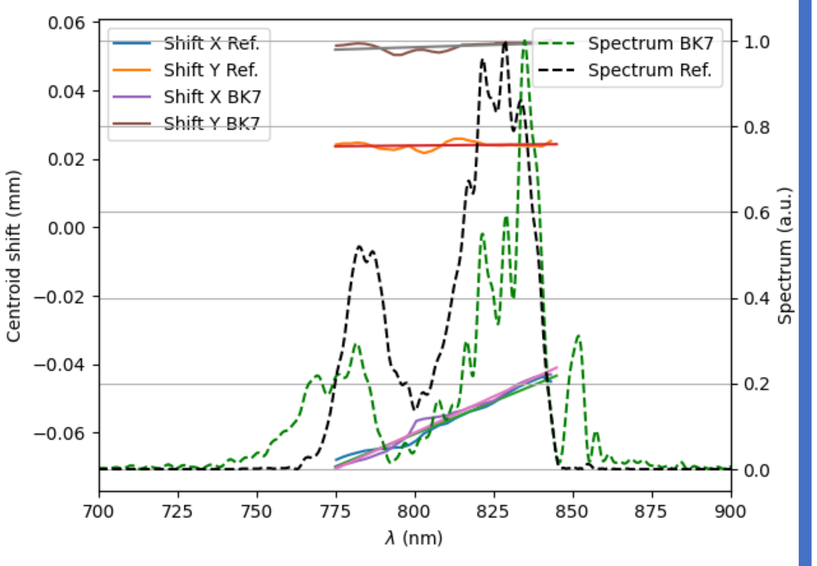
Bleotu et al, Four-cycle, stable, post-compressed 100 TW laser pulses – in preparation

Spatio-Temporal Coupling in Post-Compressed Pulses

- Insight technique is based on a Michelson interferometer setup, placed near the laser focal region

- It uses **Fourier transform spectroscopy + Gerchberg-Saxton algorithm** to determine the spectrally-resolved spatial profile of the laser

Borot and Quere, Spatio-spectral metrology at focus of ultrashort lasers: a phase-retrieval approach. Opt. Express (2018)



Spectral chirp measurements at laser focus: reference (black spectrum) and SB in 1 mm BK7 (green spectrum)

- The spatial chirp is $SPC_y = 0.4$ µm/nm and $SPC_x = 0$ for both cases, without and with 1 mm BK7 => SB does not introduce SPC in the focus, i.e., PFT in the collimated beam

Conclusion and Outlook

- Post-compression is a promising technique to increase the energy gain for laser electron acceleration, in dephasingless regime
- Further steps:
  - optimize the laser spatial profile after spectral broadening using Adaptive Optics
  - improve STC profile of the original laser, using STC measurements and optimizing the compressor gratings alignment
  - use a broadband STC device to measure the spatio-spectral profile, especially PFT and PFC

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