Monochromatic shadowgraphy and mid-infrared probing of LWFA

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Motivation

- Laser wakefield accelerator (LWFA): a more compact and less expensive electron accelerator gives shorter electron bunch duration and lower emittance compared to conventional rf accelerators
- Challenges of LWFA: pointing stability, energy and charge spread, etc.
- To overcome these challenges: a better understanding of the injection and acceleration mechanism can be provided by the comparison of complex simulations and direct observations

Laser Wakefield Acceleration

- Proposed by Tajima and Dawson in 1979^[1]
- A high-intensity laser pulse (> 10¹⁸ W/cm²) propagates through an underdense plasma, the ponderomotive force of the laser pulse
 expels electrons from high intensity region, forming periodic charge separation, so-called laser wakefield
- This charge separation gives an extremely high longitudinal electric field (> 100 GV/m @ $n_e \sim 10^{18}$ cm⁻³)
- Background electrons can be injected and accelerated by this longitudinal electric field to very high energy (~GeV) over a short distance



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• Illustration of LWFA in the bubble regime ^[2]: $\tau_p = 29$ fs (FWHM), $w_0 = 10 \mu m$, $a_0 = 4$, $n_e = 0.005 n_c$ (He plasma)

Few-cycle femtosecond NIR optical pulse generation

• Schematic of the few-cycle probe setup^[3]



- Split off a fraction from the main pulse, therefore probe pulses are intrinsically synchronized to the main pulse
- Reduce the size by a reverse bull's eye apodizing aperture
- Spectral broadened by self-phase modulation (SPM) inside an Argon or Neon filled hollow core fiber (HCF)
- Group delay dispersion compensated by chirp mirror pairs and glass wedges
- Resulting NIR ultrafast probe laser pulse (central wavelength @ 800 nm) with a duration < 4 fs (FWHM) and an energy ~300 μJ
- Due to the ultra short pulse duration (< 4 fs, FWHM), conventional fs pulse characterization methods such as FROG, SPIDER, and Wizzler are limited
- Two methods to characterize few-cycle femtosecond pulses:
- Stereo ATI Phasemeter, 3600 pulses are measured, over 86% of pulses are < 4 fs (FWHM)^[4]



 Schematic of a discrete dispersion scan (d-scan) setup ^[5]





Few-cycle pulse characterization



[2] T. Tajima and J.M. Dawson, Phys. Rev. Lett. 43; 267 (1979)

[3] M. B. Schwab et al., Appl. Phys. Lett. 103, 19118 (2013)

[4] D. Adolph et al., Appl. Phys. Lett. 110, 081105 (2017)

[5] Nils C. Geib et al., Opt. Lett. 45, 5295-5298 (2020)

[/] / . Savert et al., Thys. Nev. Lett. 113, 033002 (2013)

[8] W. Lu et al. Phys. Rev. ST Accel. Beams 10, 061301 (2007)

[9] I. H. Hutchinson, Plasma Phys. Control. Fusion 44 2603 (2002)

[10] M. C. Downer et al., Rev. Mod. Phys. 90, 035002 (2018)

[11] Michaël Hemmer et al., Opt. Express 21, 28095-28102 (2013)

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