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Observation of carrier-envelope phase effects in a high-repetition rate laser-plasma accelerator

Jérôme Faure[1]
[1] LOA, CNRS, Institut Polytechnique de Paris, Palaiseau, France
e-mail (speaker): jerome.faure@ensta.fr
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Laser wakefield acceleration [1] is an emerging technique for accelerating electron bunches to relativistic energies in very short distances using ultra-intense laser pulses. It relies on the excitation of an intense plasma wave, or wakefield, that is able to trap and accelerate electrons in a single arch of the wakefield, thereby generating femtosecond relativistic electron bunches. Because of their extremely short duration and natural synchronization with the laser pulse, these electron bunches are of great interest for probing matter on femtosecond time scales via pump-probe experiments, possibly offering unprecedented temporal resolutions for studies in structural dynamics in condensed matter, e. g. using ultrafast electron or X-ray diffraction. Laser generated electron beams could also be used for high resolution non-destructive testing with gamma-rays for industrial applications, or also for providing new radiotherapy protocols with very high energy electrons. Such applications require high stability, massive data averaging and would therefore benefit greatly from a high repetition rate electron source.

In this context, our group has started the further miniaturization of laser-plasma accelerators by using small-scale and high-repetition rate lasers. We use laser pulses of 3 mJ only and composed of a single optical cycle (3.5-fs duration) in order to drive a plasma wakefield accelerator at kHz repetition rate. Electrons are then trapped and accelerated in the 10 MeV range in less than a hundred microns [2,3]. We will discuss and review the physics of the various acceleration mechanisms that allowed us to produce highly stable beams for up to 12mMillions of shots during more than 5 hours [4].

When using near-single-cycle laser pulses, the carrier-envelope phase (CEP), i.e. the relative position between the laser envelope and the field oscillation, starts to matter because it defines the actual waveform of the laser electric field. In a series of recent experiments, we were able to show that the CEP has a clear impact on the plasma response and the laser plasma acceleration process [5,6].

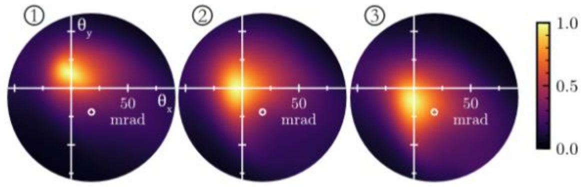

Figure 1: Dependence of the electron beam pointing to the carrier-envelope phase. 1: CEP , 2: CEP, 3:CEP

The beam pointing of the accelerated electron beam oscillates in phase with the carrier-envelope phase of the laser, as can be seen in figure 1, while the electron beam energy depends weakly on the CEP, see figure 2. Numerical simulations explain this observation through asymmetries of the plasma waves which are locked to the carrier-envelope phase. These asymmetries translate into the off-axis trapping of the electron beam. These results imply that we achieve waveform control of relativistic electron dynamics in laser-plasma interaction. Our results pave the way to high-precision, sub-cycle control of the electron phase space distribution in plasma accelerators, enabling the production of attosecond relativistic electron bunches and x rays.

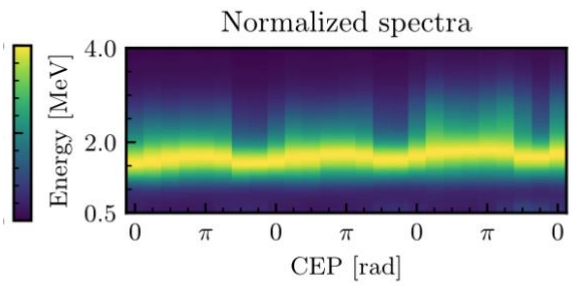

Figure 2: Dependence of the electron beam energy distribution to the carrier-envelope phase.

References

[1] Esarey et al., Rev. Mod. Phys. **81**, 1229 (2009)
[2] Guénot et al., Nat. Photonics **11**, 293 (2017)
[3] Faure et al., Plas. Phys. Cont. Fus. **61**, 014012 (2019)
[4] Rovige et al., PRAB **23**, 093401 (2020)
[5] Huijts et al., Phys. Rev. X **12**, 011036 (2022)
[6] Rovige et al., EPJST (2022)