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Laser-plasma acceleration beyond the diffraction and dephasing limits

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Laser-plasma acceleration is a technique for producing ultra-relativistic electrons that takes advantage of the ability of plasma to carry arbitrarily intense fields. In practice, fields of several hundred GV/m can be produced simply by focusing an ultra-intense laser pulse in a sub-critical plasma [1]. These fields, which are 3 orders of magnitude larger than those produced in conventional plasma accelerators, are nevertheless useless if the field is not maintained over a significant distance or if the accelerated electron beam does not remain trapped in it.

In practice, three phenomena limit the acceleration length in a laser-plasma accelerator: pump depletion, diffraction, and dephasing. Pump depletion, i.e. the laser energy transfer to the plasma wave, and laser diffraction tend to decrease the laser intensity during its propagation down to a level from which it can no more drive a steady plasma wave.

Dephasing originates from the difference in velocity between the electron bunch and the laser, which results in a progressive shift of the electron beam towards a decelerating phase of the electric field.

Here we discuss several approaches for tackling this limitations and increasing the beam energy: the rephasing technique, which extends the effective dephasing length [2], the acceleration in a laser-plasma waveguide, which prevents diffraction [3], and finally a dephasing-less, diffraction-free acceleration scheme that solves all three issues at once [4]. We will also present the first demonstration of the controlled injection of electron beams in a plasma waveguide which has allowed the production of quasi-monoenergetic electron beams at the GeV level. These results remove a major bottleneck to development of high energy plasma accelerators and pave the way to the stable production of high-quality, multi GeV beams [5].

[1] Esarey, E., Schroeder C. B. and Leemans, W. Review Modern Physics 81, 1229–1285, (2009).
[2] Guillaume, E. et al. Physical Review Letter 115, 155002 (2015).
[3] Smartsev, S. et al.Optics Letter 44, 3414–3417 (2019).
[4] Caizergues, C., Smartsev, S., Malka, V., and Thaury C. Nature Photonics 14, 475–479 (2020)
[5] Oubrerie, K. et al. arXiv:2108.03000 (2021)

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