Laser-Plasma Acceleration Beyond the Diffraction and Dephasing Limits

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For the last decades, the development of Laser-Plasma Accelerators (LPAs) has attracted high interest thanks to the capacity of plasma to produce and sustain extremely high electric fields. The accelerating gradients in plasma accelerators can exceed 100 GV/m, which is three orders of magnitude larger than those obtained in metallic-cavity accelerators, thus promising very compact alternatives to conventional linear machines [1]. However, a high field is not the only ingredient required for high multi-GeV energy gains, as the accelerated beam has also to follow this field over long distances. Today the identified main challenges for LPA are the diffraction and depletion of the driver laser, and the dephasing of the accelerated beam with the driven plasma waves. Diffraction and pump depletion cause laser intensity to fall during the acceleration, eventually suppressing the wakefield, while dephasing results from the mismatch between the phase velocity of the accelerating field and the one of the electron beam, and it leads the electron beam towards a decelerating phase of the wake.

Here we discuss two approaches for tackling these limitations and increasing the beam energy. We will present the first experimental demonstration of acceleration of quasi-monoenergetic electron beams at the GeV level in a plasma waveguide created by a quasi-Bessel machining beam shaped by an axiparabola mirror [2,3]. Another concept employs an advanced optical shaping of the laser driver that allows a diffraction-free propagation over a long distance while controlling the group velocity of the laser [4], thus greatly extending the effective dephasing length [5].

References

[1] E. Esarey, C. Schroeder and W. Leemans, Review Modern Physics 81, 1229-1285, (2009)
[2] S. Smartsev, et al. Optics Letter 44, 3414-3417 (2019).
[3] K. Oubrerie, et al. Light Science & Applications 11, 180 (2022)
[4] K. Oubrerie, I. A. Andriyash, R. Lahaye, S. Smartsev, V. Malka and C. Thaury, Journal of Optic 4, 045503 (2022)
[5] C. Caizergues, S. Smartsev, V. Malka and C. Thaury, Nature Photonics 14, 475-479 (2020)

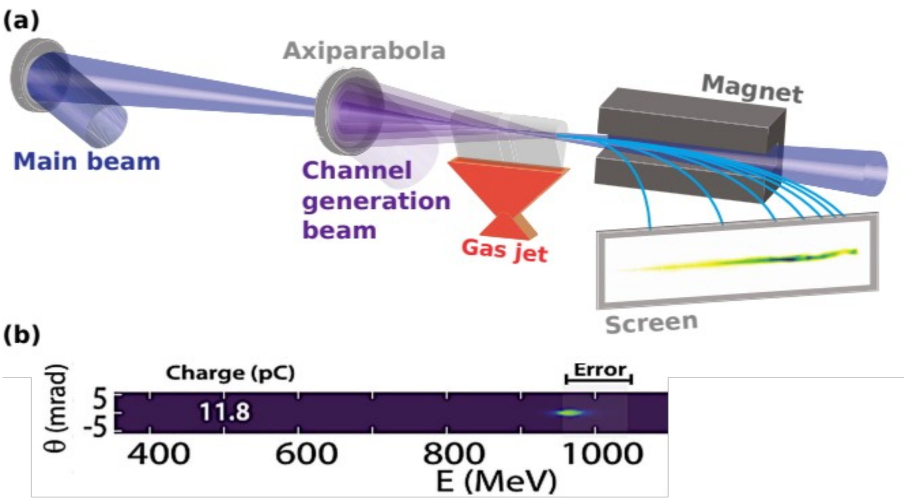

Figure 1. Electron acceleration in a laser-generated plasma channel. (a) A 5 mJ beam, *the channel generation beam*, is used to create a 15 mm long plasma waveguide. The *main beam* is then coupled into this waveguide to accelerate electrons up to the GeV level. (b) Example of a mono-energetic electron beam at 1 GeV.