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lpaw23@tecnico.ulisboa.pt

Tailoring density downramp injection in particle-driven wakefield accelerators

Céline Hue[1], Anton Golovanov[1], Sheroy Tata[1], Yang Wan[1], Sébastien Corde[2], Victor Malka[1]

[1] *Weizmann Institute of Science, Rehovot, Israel,*
[2] *Laboratoire d'Optique d'Apliquée, Palaiseau, France*

anton.golovanov@weizmann.ac.il

An increasingly considerable attention is paid recently to the LWFA–PWFA coupled staged plasma accelerators [1] in the objective of producing high-energy and high-quality electron beams with plasma based acceleration. In this concept, an electron beam produced in the first (laser-wakefield acceleration or LWFA) stage is used as a driver for the second (plasma-wakefield acceleration or PWFA) stage. The witness beam in the second stage can be produced using plasma density downramp injection. For the accelerator to be efficient, one of the important steps is to optimize the driver-to-witness energy transfer efficiency in the PWFA stage. The beam currents of both the driver and the witness beams play decisive roles in optimizing the energy transfer efficiency. The production in the first (LWFA) stage of the current profile finely tuned for the use in the second stage is studied in Ref. [2].

In this work, we focus on the driver bunch dynamics and the injected witness bunch properties in the PWFA stage. We find that the wakefield produced by the driver bunch with a flattop current profile (which models the possible driver bunch current profile produced in the LWFA stage [2]) is stable both in its strength and its structure right until the moment of the driver's collapse due to its energy depletion. This happens when the energy of electrons in the longitudinal slice that receives the maximum deceleration force decreases to zero, but the energy of the driver is still not fully depleted. The maximum driver-to-plasma energy transfer rate can thus be calculated, and plasma density of the second stage can be optimized to reach the optimal efficiency.

The witness beam current injected with plasma density downramp is then studied. It is found that the witness beam current is dependent on the properties of the bubble. An effective current $J_{\text{eff}} = J_d \left(\xi_B/\lambda_p\right)^{2/3}$, where J_d is the characteristic driver beam current, ξ_B is the characteristic driver bunch length and λ_p the plasma wavelength, is introduced to quantify the wakefield size and power. A linear relationship between the injected witness beam current and the effective current is found.

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References

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