Abstract

We present a novel and very robust scheme for optical triggered electron bunch generation in plasma wakefield accelerators. In this technique a quasi-stationary plasma column is ignited prior the arrival of the plasma wave by a transversally propagating, focused laser pulse. This localized optical plasma torch is easy tunable by shifting the laser focal position and spot size and causes a strong distortion of the plasma blowout during passage of the electron driver bunch, leading to collective alteration of plasma electron trajectories and to controlled injection. The proposed method is more flexible and faster when compared to hydrodynamically controlled gas density transition methods and it fits experimentalist’s needs as it is straightforward to implement and easy to align. Hereby it is also suited for probing a wakefield and timing purposes.

The Method presented in Faure et al. [2] for laser driven plasma wakefield acceleration differs substantially from this method, as it involves the need of hydrodynamical motion of gas molecules, and therefore generating an ion density perturbation on far slower time scales (ns). The plasma torch technique is not applicable in the laser driven case. It allows better control of the plasma density profile, because the plasma shape is a direct measure of the applied laser profile, enabling very steep density gradients on fs time scales.

Three different schemes in hydrogen/helium gas mixture

![Diagram](image)

Summary

- Two different kinds of injection occur:
  1) In neutral hydrogen the blowout is significantly amplified within the torch and its front is shifted forwards. This is because the driver beam ionization front is near its density maximum and therefore the blowout starts nearly at the center of the driver beam. This results in less driver charge contributing to drive the wakefield. Within the torch, the drive beam creates a strong blowout starting from the drive beam’s tip, with all drive beam current contributing. Leaving the plasma torch is shifting the blowout back again, resulting in trapping of electrons. The plasma wavelength is not affected.
  2) In the pre-ionized scenario the plasma wavelength is shortened during passage of the plasma torch resulting in electron injection due to the plasma downramp at the end of the torch.

- Witness bunch properties can be controlled by both hydrogen and helium density:
  1) The relative height of the torch is given by the ratio of densities n_H/n_He. This is determining the difference of the plasma wavelengths within and outside the torch, thereby, the trapping position can be tuned.
  2) The total torch density can be varied to change the total amount of trapped electrons. Both possibilities to influence the witness bunch are coupled.
  a) The torch width was chosen to fit approximately one plasma wavelength, to allow the blowout to close within the torch. This defines the ability to trap electrons, e.g. for high torques the plasma wavelength within the torch is shorter allowing for a smaller torch width.
  b) Steep plasma ramps were reached, where the plasma density was doubled within ~10µm.
  c) Comparing simulations with and without torch confirms, that trapping is a direct consequence of the plasma torch.

Experimental Setup

![Diagram](image)

- \( \lambda = 800 \text{ nm, } \sim 1J, 100 \text{ fs} \)
- Preionization laser arm (only for case iii)
- Axicon
- Torch laser arm
- Electron driver beam
- Plasma torch
- Hole mirror
- \( I \sim 10^{14} \text{ W/cm}^2 \)
- Gas pulse

References


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