Optical Plasma Torch Electron Bunch generation in Plasma Wakefield Accelerators[1]

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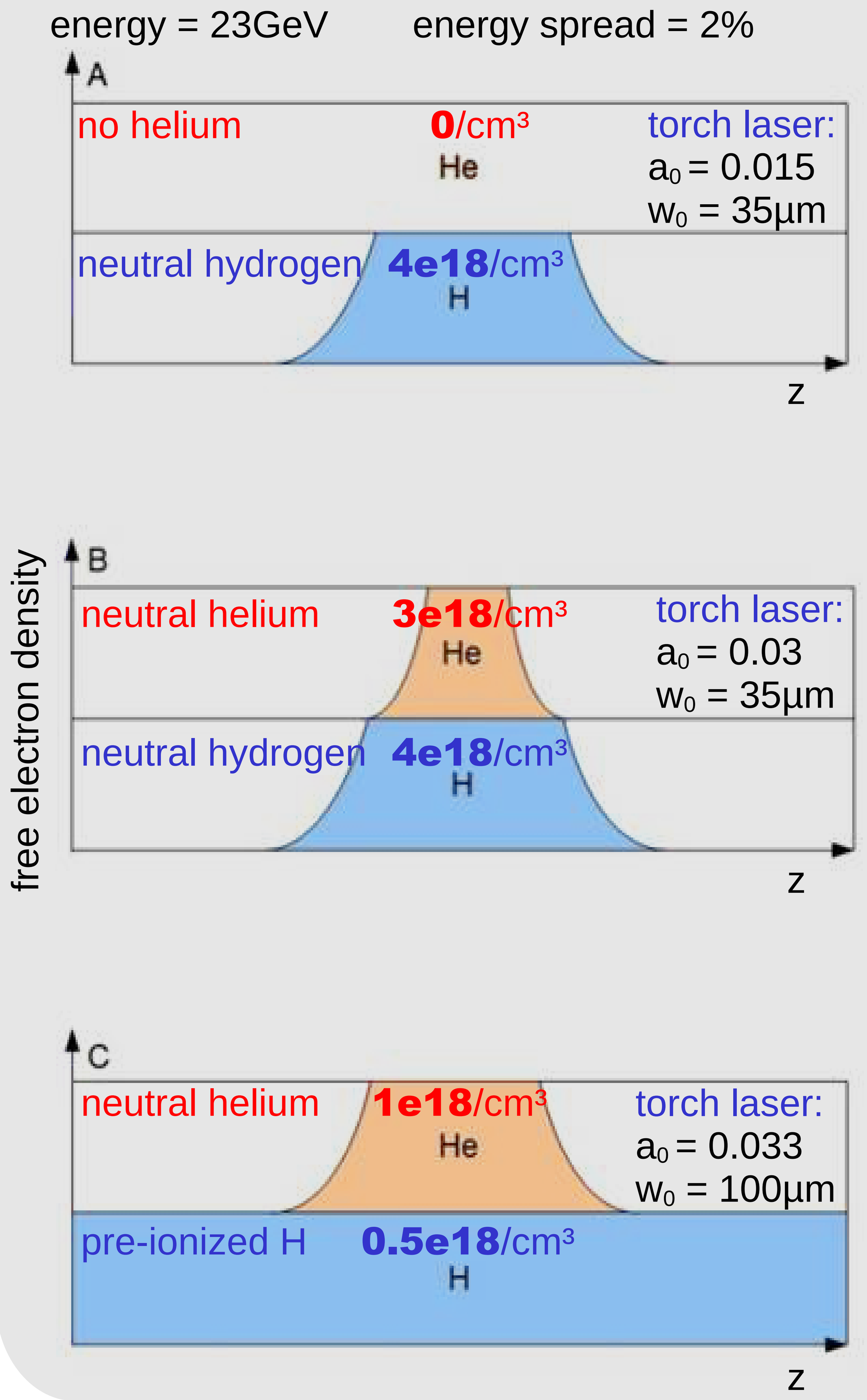
Abstract

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 straight forward to implement and easy to align. Hereby it is also suited for probing a wakefield and timing purposes.

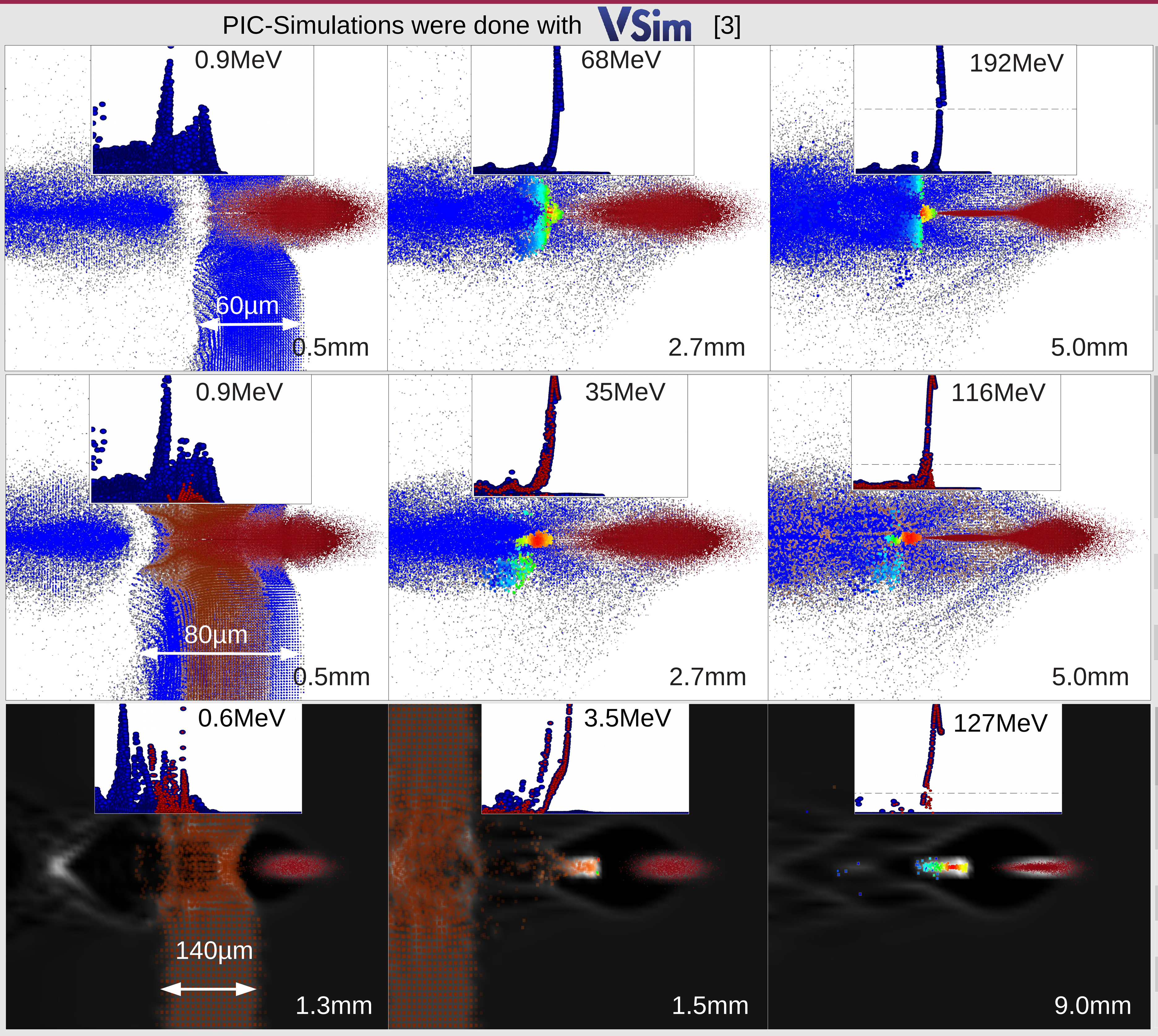
The Method presented in Faure *at al.* [2] for laser driven plasma wakefield acceleration differs substantiallly from this method, as it involves the need of hydrodynamical motion of gas molecules, and therefore generating an ion density perturbation on far slower time scales (ns). The plasma torch technique 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

FACET-class electron driver beam:
charge = 3nC, emittance = 2.25 mm mrad
σ_r = 12µm, σ_z = 27µm
energy = 23GeV, energy spread = 2%



PIC-Simulations were done with VSim [3]



H, density: **4e18**/cm³	
He, density: **0**/cm³	
Bunch parameters at 5mm, electrons with E > 100MeV	
emittance	5.3mm mrad
charge	36pC
mean energy	152MeV
energy spread	13.2%
peak current	2.5kA

H, density: **4e18**/cm³	
He, density: **3e18**/cm³	
Bunch parameters at 5mm, electrons with E > 20MeV	
emittance	11.7mm mrad
charge	0.3nC
mean energy	100MeV
energy spread	10.9%
peak current	11.5kA

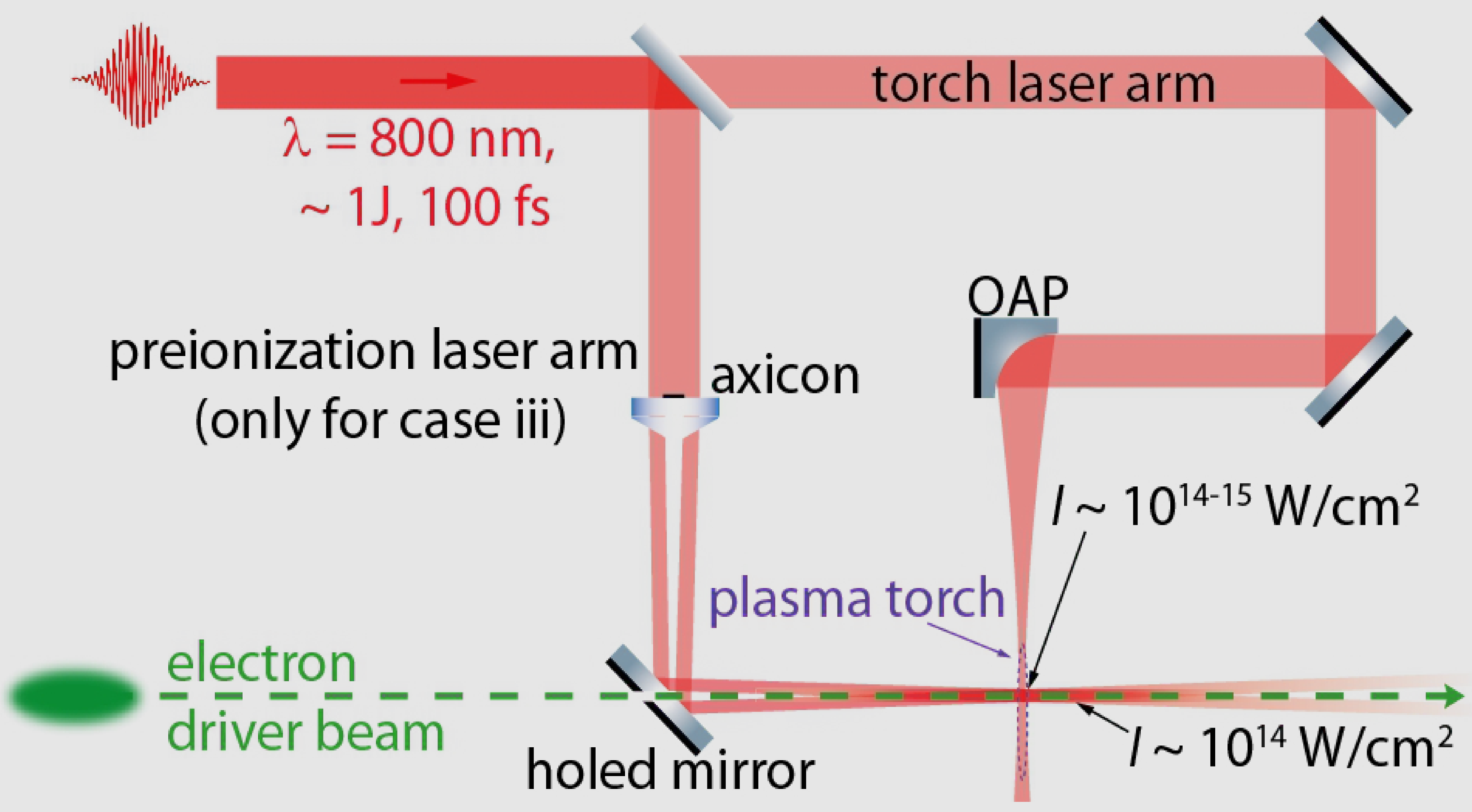
H, density: **0.5e18**/cm³	
He, density: **1e18**/cm³	
Bunch parameters at 9mm, electrons with E > 20MeV	
emittance	7.5mm mrad
charge	2.3nC
mean energy	90.2MeV
energy spread	23.2%
peak current	21kA

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.
- 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 torch densities the plasma wavelength within the torch is shorter allowing for a smaller torch width.
- Steep plasma ramps were reached, where the plasma density was doubled within ~10µm.
- Comparing simulations with and without torch confirms, that trapping is a direct consequence of the plasma torch.

Experimental Setup



An electron beam driver and one or two moderately synchronized laser pulses interact in an underdense medium with two species with different ionization thresholds such as H and He. One Ti:sapphire laser pulse is focused in order to generate the localized H/He plasma torch in the path of the electron beam driven blowout. In the pre-ionized case another, high-energy fraction of the laser pulse is used to preionize the H in order to allow for a stronger blowout.

[1] G. Wittig *et al.*, PRSTAB **18**, 081304 (2015)
[2] J. Faure *at al.*, Phys. Plasmas **17**, 083107 (2010)
[3] C. Nieter and J. R. Cary, J. Comput. Phys. **196**, 448 (2004).

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