A tunable electron beam source using density down-ramp trapping

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Previous experiment

![Diagram of experimental setup]

- Scintillating screen
- Dipole magnet
- Target
- Laser beam

Previous experiment

Previous experiment

Density down-ramp injection
Density down-ramp injection

\[ \lambda_p \approx \frac{2}{\pi c \omega_p} \omega_p = \sqrt{\frac{q e n}{\epsilon_0 m_e}} \]
Density down-ramp injection

\[ \lambda_p \approx \frac{2\pi c}{\omega_p} \]

\[ \omega_p = \sqrt{\frac{q_e^2 n_e}{\epsilon_0 m_e}} \]
Density down-ramp injection

\[ \lambda_p \approx \frac{2\pi c}{\omega_p} \]

\[ \omega_p = \sqrt{\frac{q_e^2 n_e}{\epsilon_0 m_e}} \]
Gaussian laser pulse: $a_0 = 1.8$, FWHM laser focus 18 µm, 30 fs FWHM temporal duration

\[ \frac{dQ}{dE}(x) \text{ [arb. units]} \]

\[ n_e [10^{18} \text{ cm}^{-3}] \]

\[ x [\text{mm}] \]

\[ E [\text{MeV}] \]

\[ \frac{\partial n}{\partial x} \]

\[ L \]
Setup

Constant slope, Vary lower density

Vary slope, Constant lower density
Constant slope, Vary lower density
Setup

Constant slope, Vary lower density

Vary slope, Constant lower density
CALDER-Circ

- PIC-code
- Quasi-3D
- Cylindrical symmetry
- Azimuthal Fourier Modes
- Mainly developed at LOA and CEA
- Reduces the computational load

Charge

Varying lower density

\[ |\frac{\partial n}{\partial x}| = 0.1 \frac{n_1}{\lambda_{p1}} \]
\[ |\frac{\partial n}{\partial x}| = 0.76 \frac{n_1}{\lambda_{p1}} \]
Varying lower density

\[ Q = k \left( \frac{\partial n}{\partial x} \right) \left( n_1 - n_2 \right) \]
Varying lower density

\[ Q = k \left( \frac{\partial n}{\partial x} \right) (n_1 - n_2) \]
Charge

Varying lower density

\[ Q = k \left( \frac{\partial n}{\partial x} \right) (n_1 - n_2) \]

Varying down-ramp steepness

\[ \left| \frac{\partial n}{\partial x} \right| = 0.1 \frac{n_1}{\lambda_{p1}} \]

\[ \left| \frac{\partial n}{\partial x} \right| = 0.76 \frac{n_1}{\lambda_{p1}} \]

\[ Q = k_1 \left( \frac{\partial n}{\partial x} \right) L \frac{n_1}{\mu m} \]
Charge

Varying lower density

\[ Q = k \left( \frac{\partial n}{\partial x} \right) (n_1 - n_2) \]

Varying down-ramp steepness

\[ Q = k_1 \frac{\partial n}{\partial x} L + k_2 L \]
Bubble expansion

- Bubble radius
- Plasma wavelength $\lambda_p$
- Laser, $a_0$, $W_0$
- Beamloading, $Q$
Bunch length

\[ \left| \frac{\partial n}{\partial x} \right| = 0.76 \frac{n_1}{\lambda_{p1}}, \text{ no BL} \]
Bunch length

$\left| \frac{\partial n}{\partial x} \right| = 0.76 \frac{n_1}{\lambda p_1}$, no BL

$L_{eb} = C_1 \Delta \lambda_p$
Bunch length

\[ L_{eb} = C_1 \Delta \lambda_p \]
Bunch length

\[ L_{eb} = C_1 \Delta \lambda_p + C_2 Q^2 \]
Expansion speed

Gentle down-ramp

Sharp down-ramp
Emittance
Gentle transition
Gentle transition
Gentle transition
Gentle transition
Gentle transition
Gentle transition
Gentle transition
Gentle transition
Gentle transition
Gentle transition
Steep transition
Steep transition
Steep transition
Steep transition
Steep transition
Steep transition
Steep transition
Summary

With a density down-ramp, we can
- Control bunch charge
- Control bunch length
- Control bunch emittance

However, not entirely independently
A tunable electron beam source using trapping of electrons in a density down-ramp in laser wakefield acceleration

Henrik Ekerfelt¹, Martin Hansson¹, Isabel Gallardo González¹, Xavier Davoine² & Olle Lundh¹

One challenge in the development of laser wakefield accelerators is to demonstrate sufficient control and reproducibility of the parameters of the generated bunches of accelerated electrons. Here we report on a numerical study, where we demonstrate that trapping using density down-ramps allows for tuning of several electron bunch parameters by varying the properties of the density down-ramp. We show that the electron bunch length is determined by the difference in density before and after the ramp. Furthermore, the transverse emittance of the bunch is controlled by the steepness of the ramp. Finally, the amount of trapped charge depends both on the density difference and on the steepness of the ramp. We emphasize that both parameters of the density ramp are feasible to vary experimentally. We therefore conclude that this tunable electron accelerator makes it suitable for a wide range of applications, from those requiring short pulse length and low emittance, such as the free-electron lasers, to those requiring high-charge, large-emittance bunches to maximize betatron X-ray generation.