A tunable electron beam source using density down-ramp trapping

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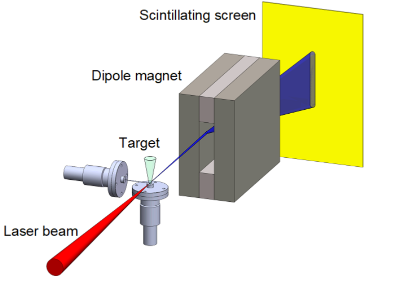
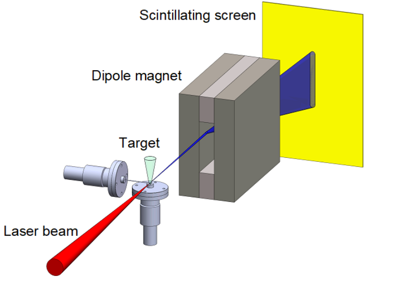
28th of September

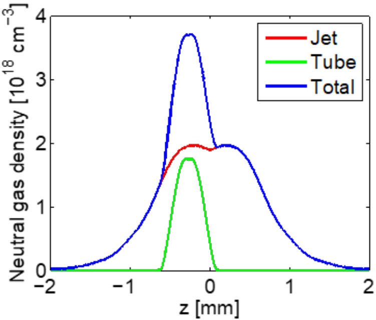
EAAC 2017 Elba

Previous experiment



Previous experiment





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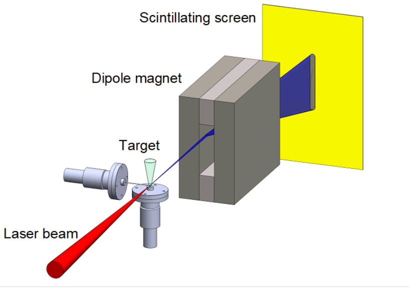

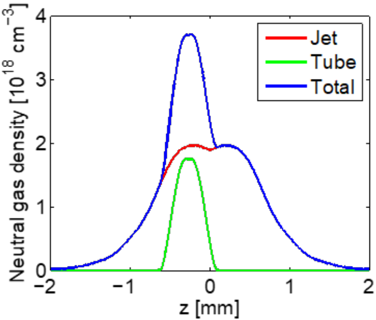

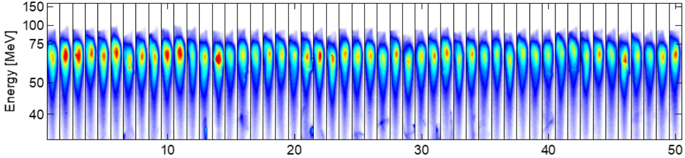

Hansson, Martin, et al. "Down-ramp injection and independently controlled acceleration of electrons in a tailored laser wakefield accelerator." Physical Review Special Topics-Accelerators and Beams 18.7 (2015): 071303.

Density down-ramp injection

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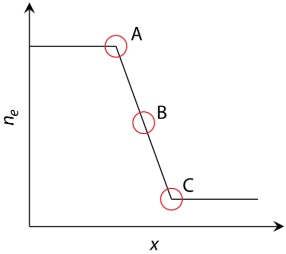
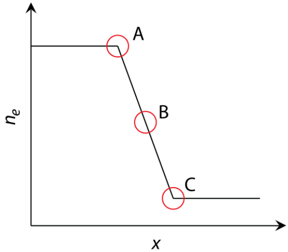


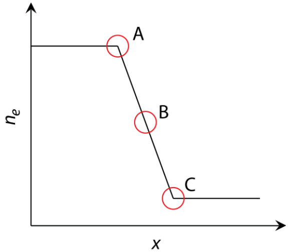
Density down-ramp injection



$$\lambda_p \approx \frac{2\pi c}{\omega_p}$$

$$\omega_p = \sqrt{\frac{q_e^2 n_e}{\epsilon_0 m_e}}$$

Density down-ramp injection



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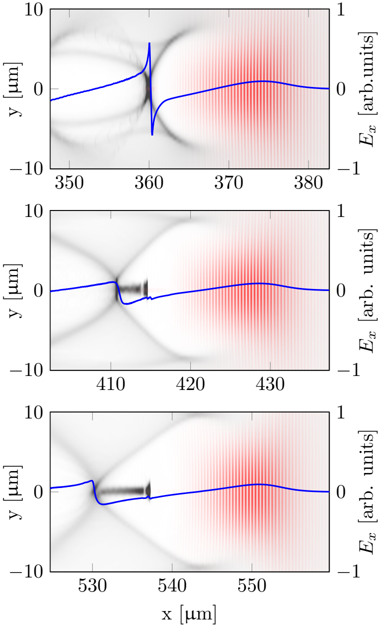
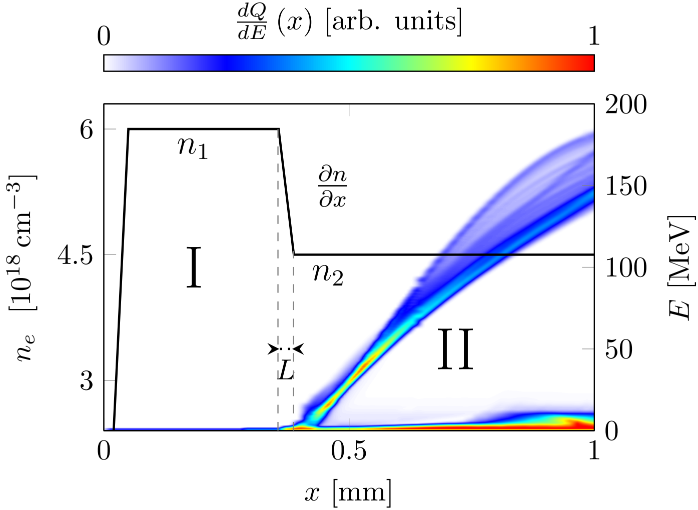


Gaussian laser pulse: $a_0 = 1.8$, FWHM laser focus 18 μm, 30 fs FWHM temporal duration



Setup

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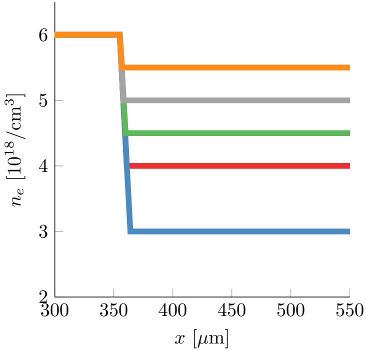
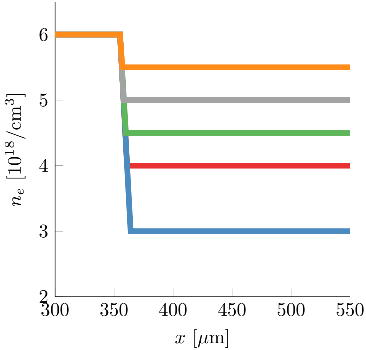
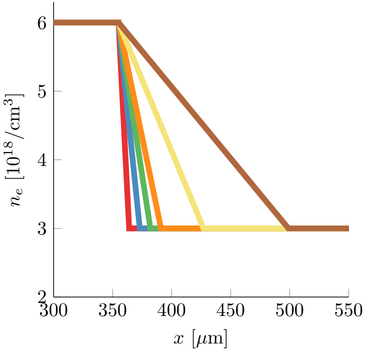


Constant slope, Vary lower density

Setup



Constant slope, Vary lower density



Vary slope, Constant lower density

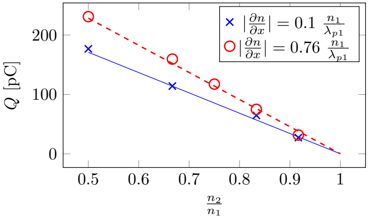
CALDER-Circ

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

Lifschitz, A. F., et al. "Particle-in-Cell modelling of laserplasma interaction using Fourier decomposition." Journal of Computational Physics 228.5 (2009): 1803-1814.

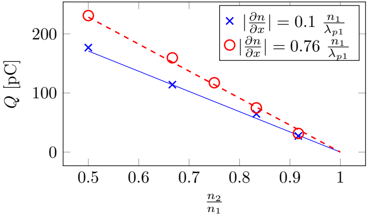
Charge

Varying lower density



Charge

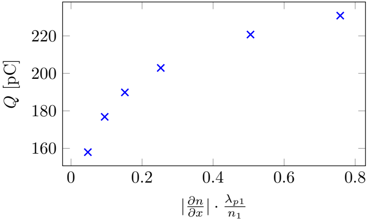
Varying lower density



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

Charge

Varying down-ramp steepness



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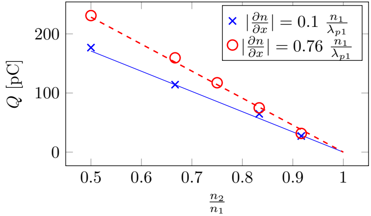

$$Q = k\left(\frac{\partial n}{\partial x}\right)(n_1 - n_2)$$

Charge

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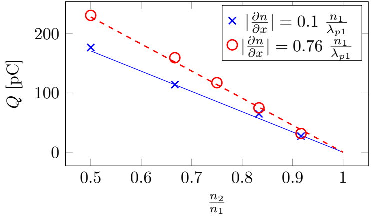

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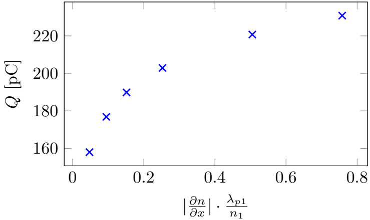

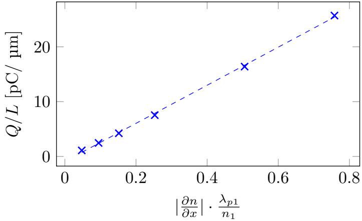

Charge

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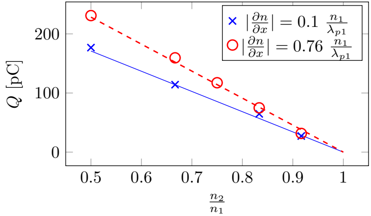

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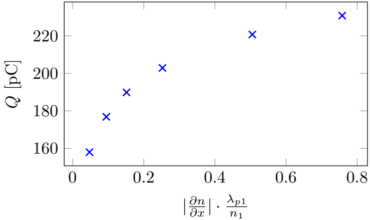
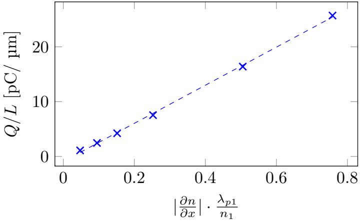
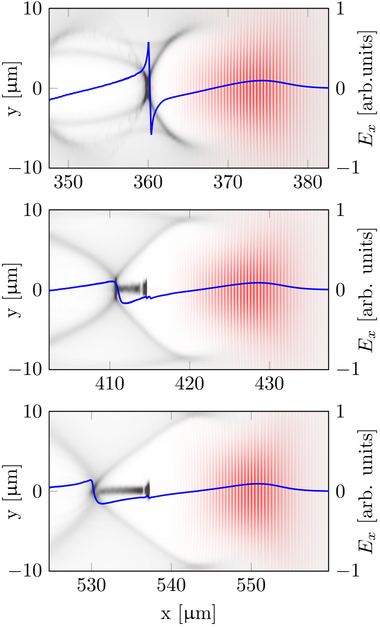




$$Q = k_1 \frac{\partial n}{\partial x} L + k_2 L$$

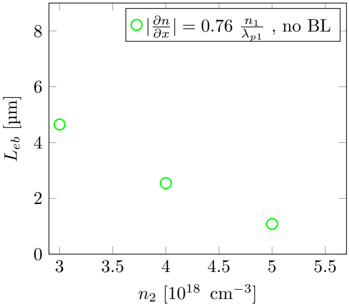
Bubble expansion



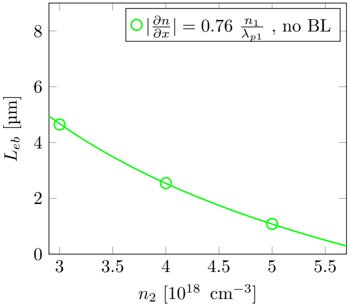
Bubble radius

- Plasma wavelength λ_p
- Laser, a_0, W_0
- Beamloading, Q

Bunch length

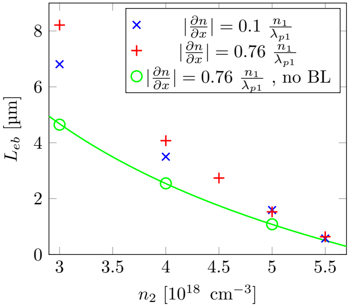


Bunch length



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

Bunch length



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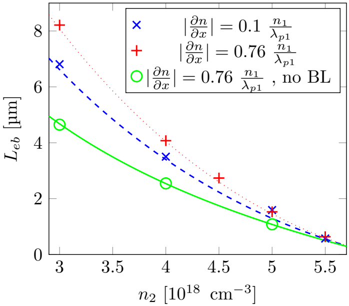
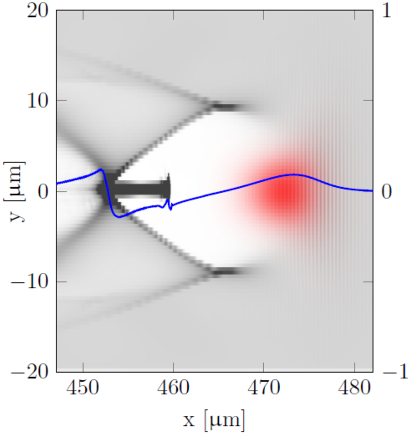


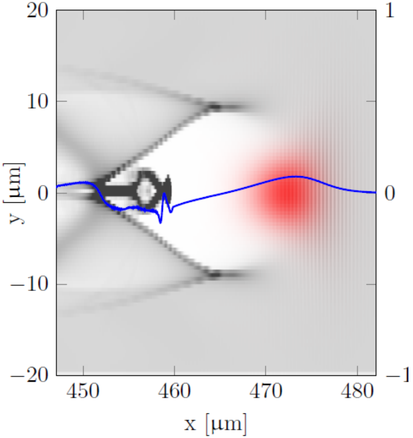
$$L_{eb} = C_1 \Delta\lambda_p + C_2 Q^2$$

Expansion speed

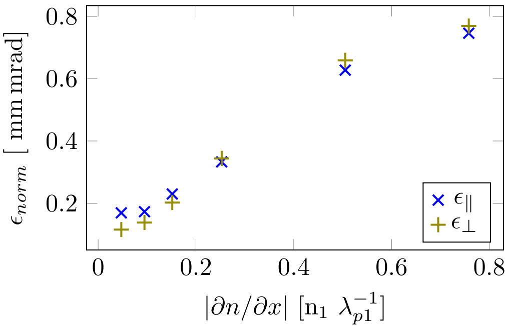
Gentle down-ramp



Sharp down-ramp

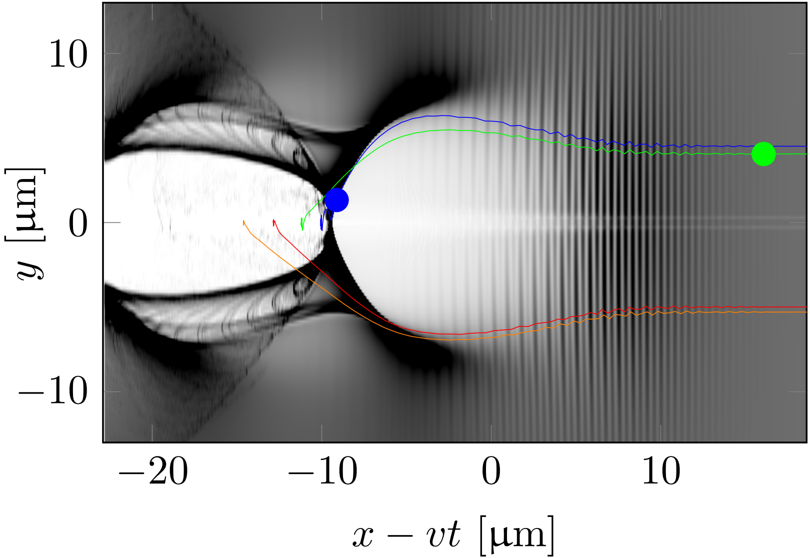


Emittance



ϵ_{norm} [mm mrad]
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
$|\partial n/\partial x|$ [n_1 λ_{p1}^{-1}]
$\epsilon_{\parallel}$
$\epsilon_{\perp}$

Gentle transition



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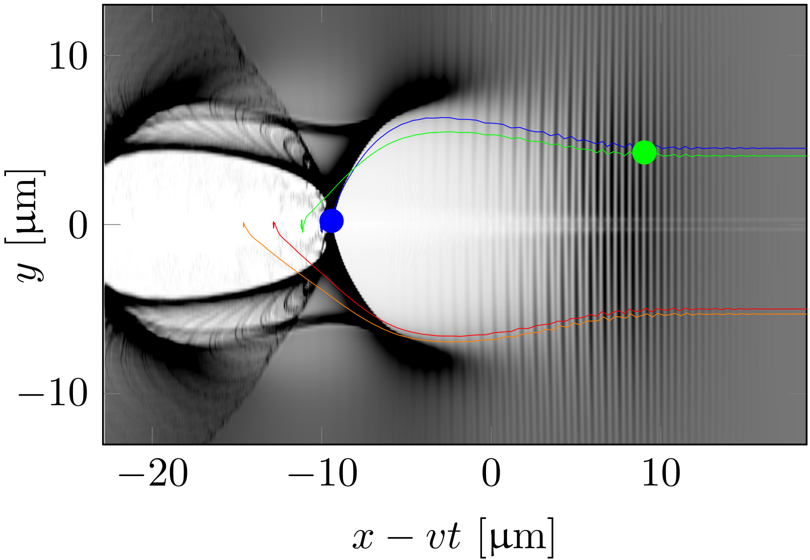

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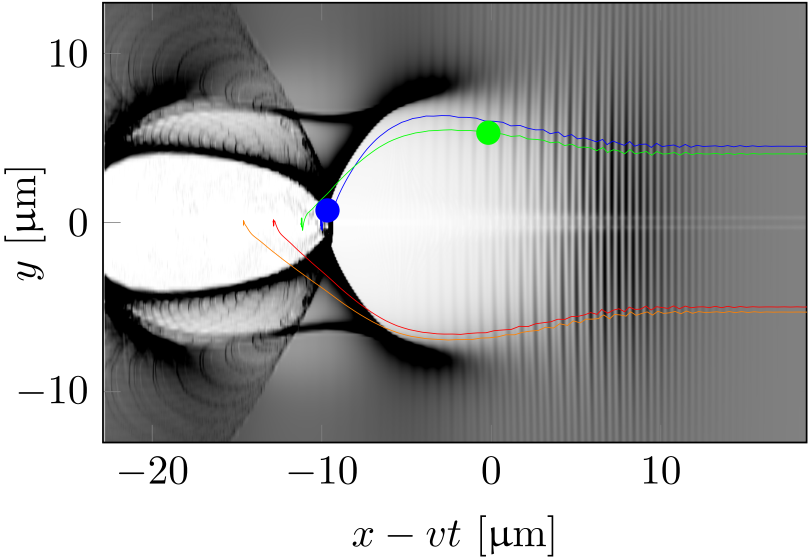

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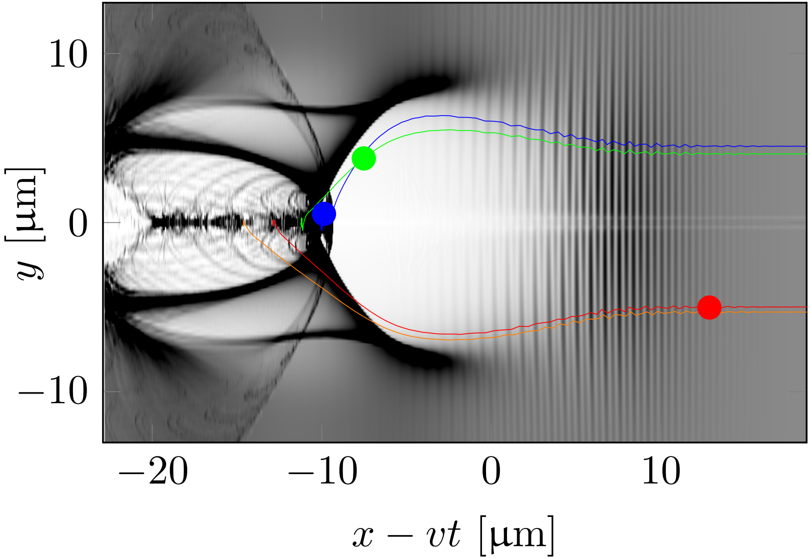

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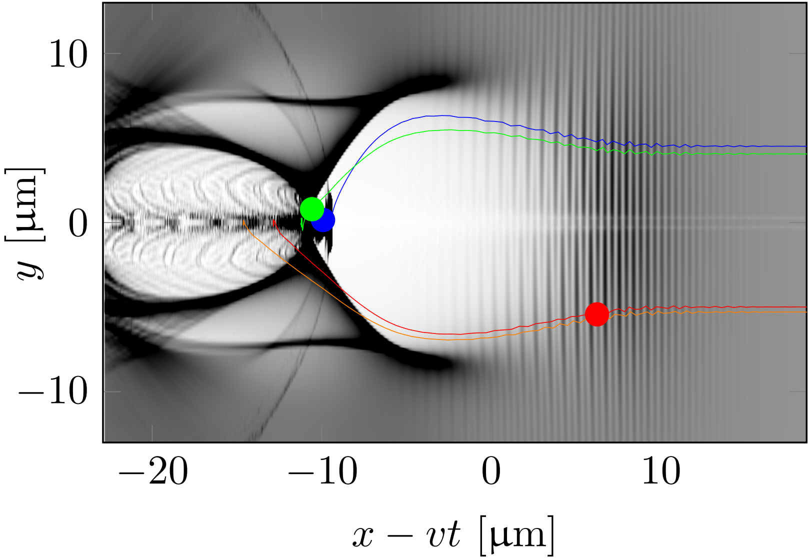

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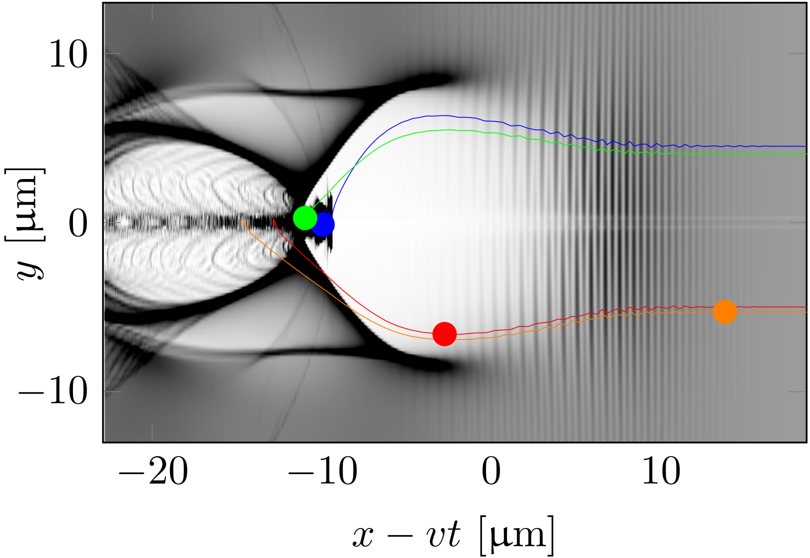

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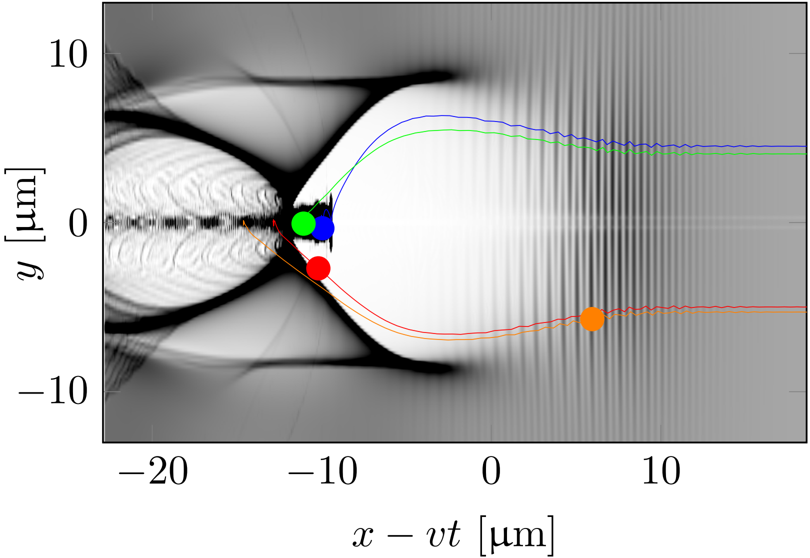

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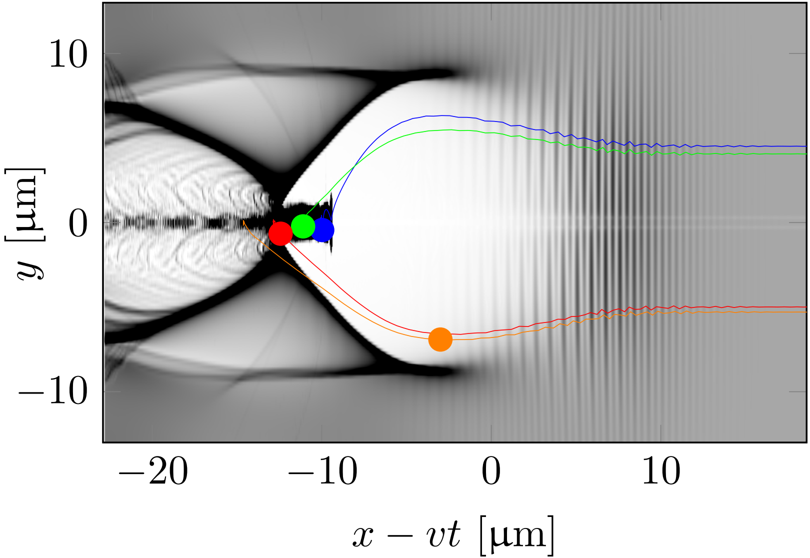
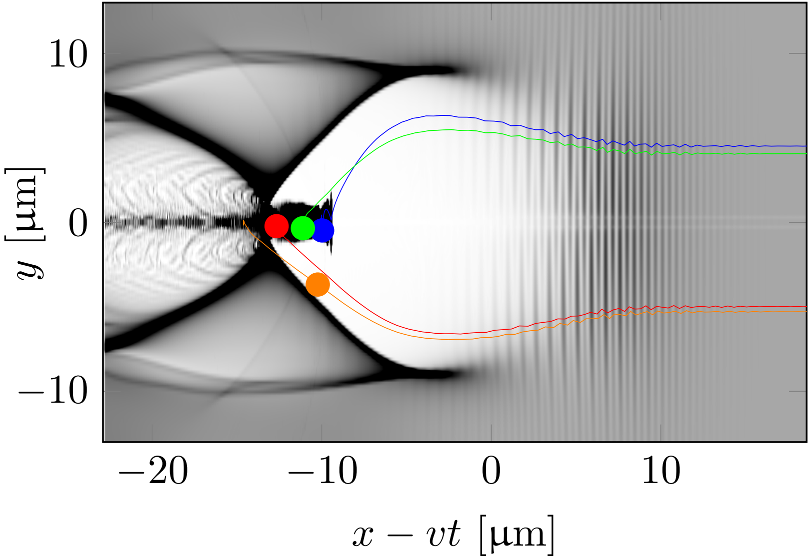


Gentle transition



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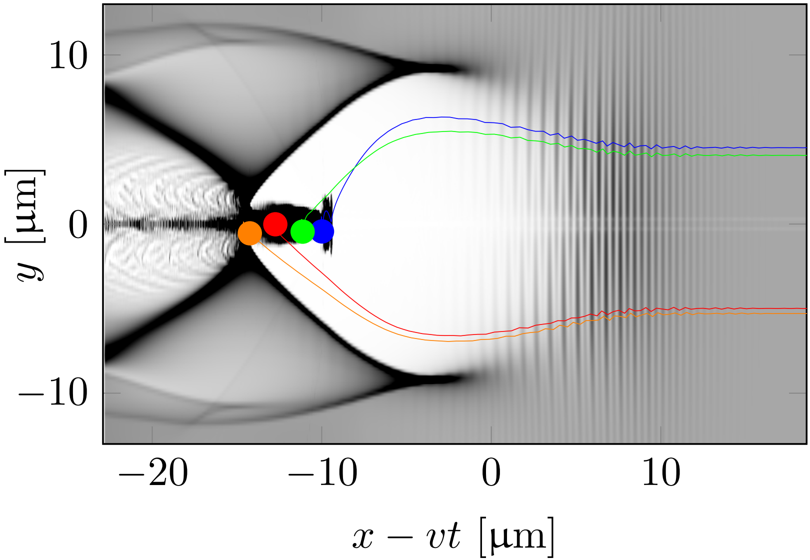
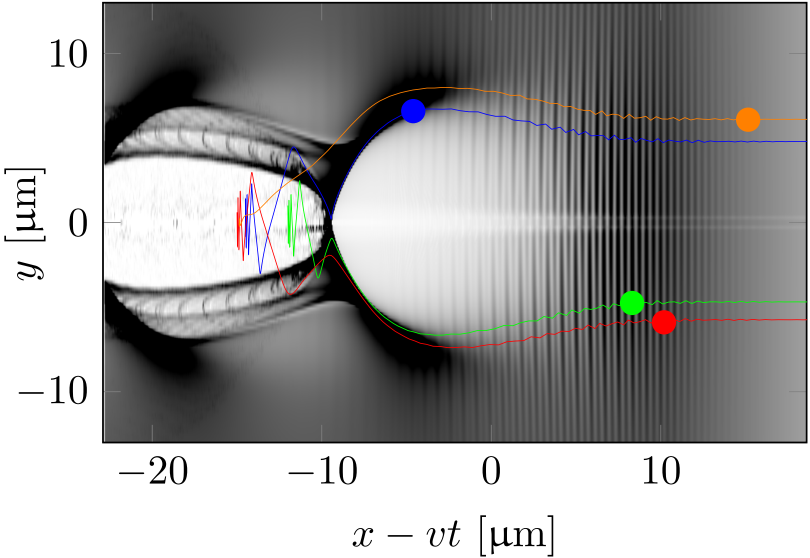


Steep transition



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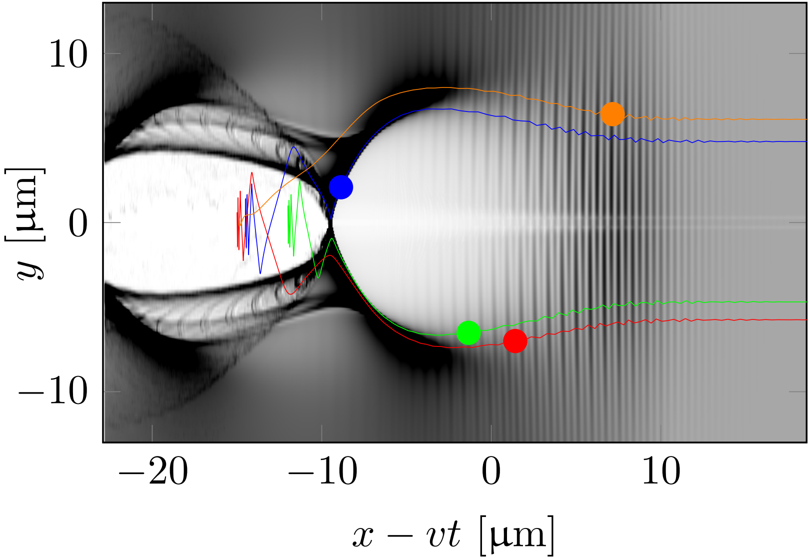

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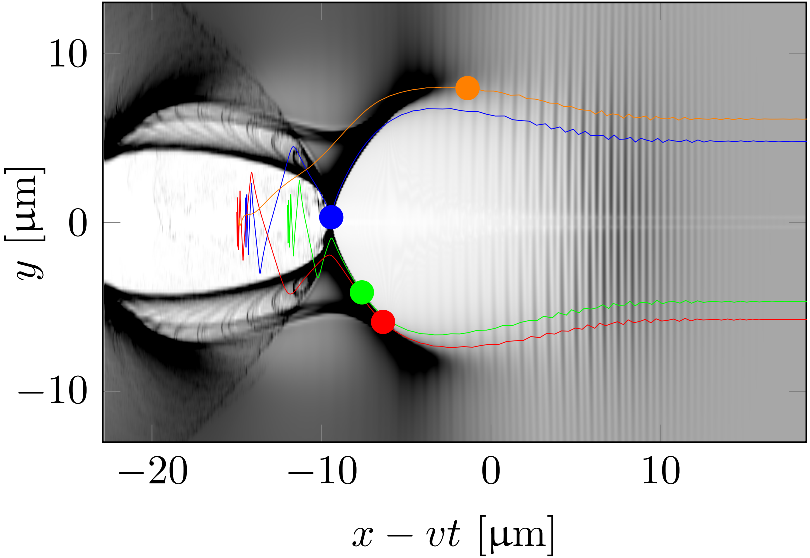

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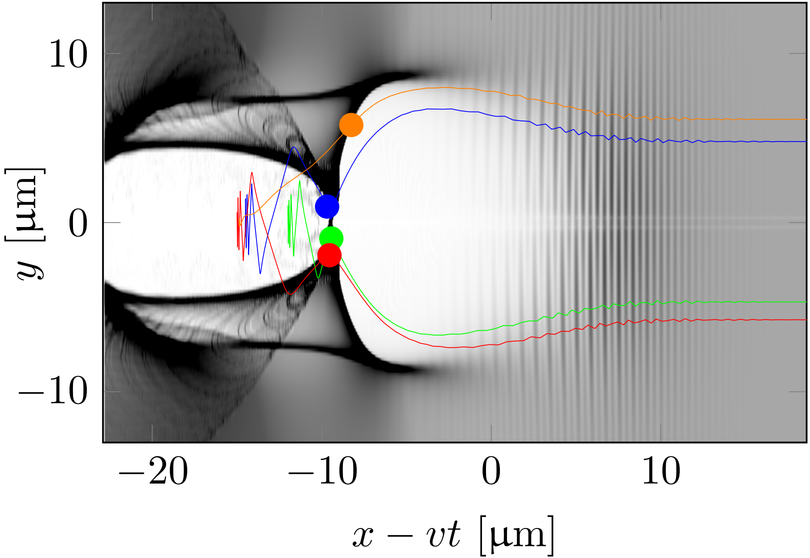

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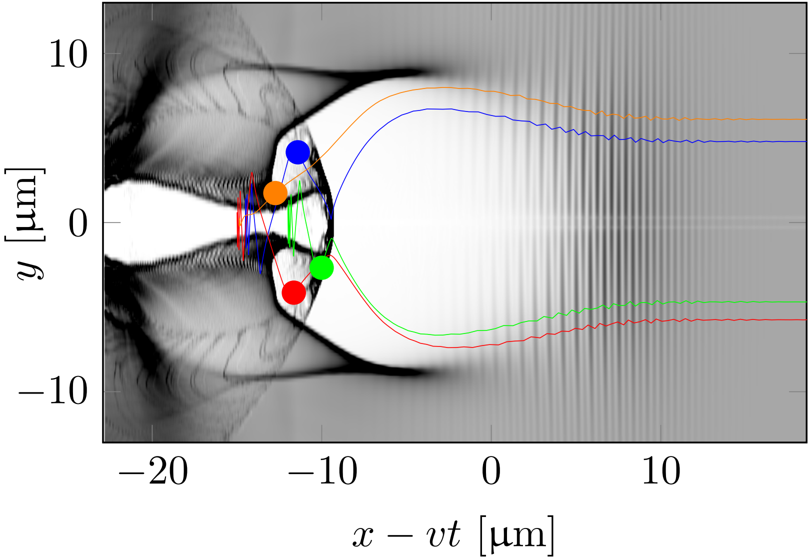

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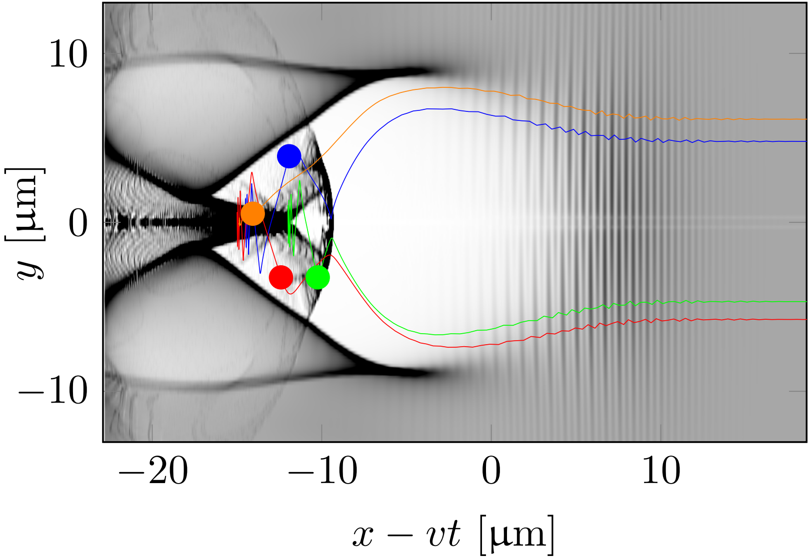

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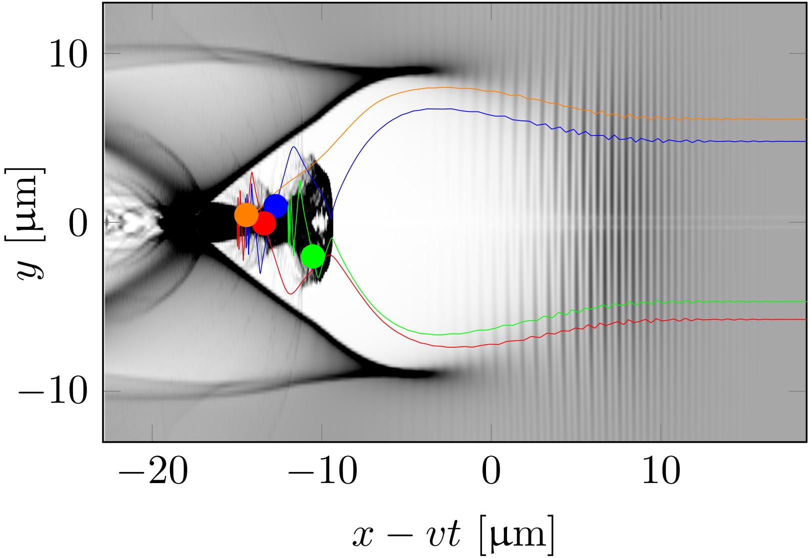

Summary

With a density down-ramp, we can

- Control bunch charge
- Control bunch length
- Control bunch emittance

However, not entirely independently

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A tunable electron beam source using trapping of electrons in a density down-ramp in laser wakefield acceleration

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Henrik Ekerfelt[1], Martin Hansson[1], Isabel Gallardo González[1], Xavier Davoine[2] & Olle Lundh[1]

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.

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