Effect of density gradient and laser spotsize on energy gain, energy spread, and total charge

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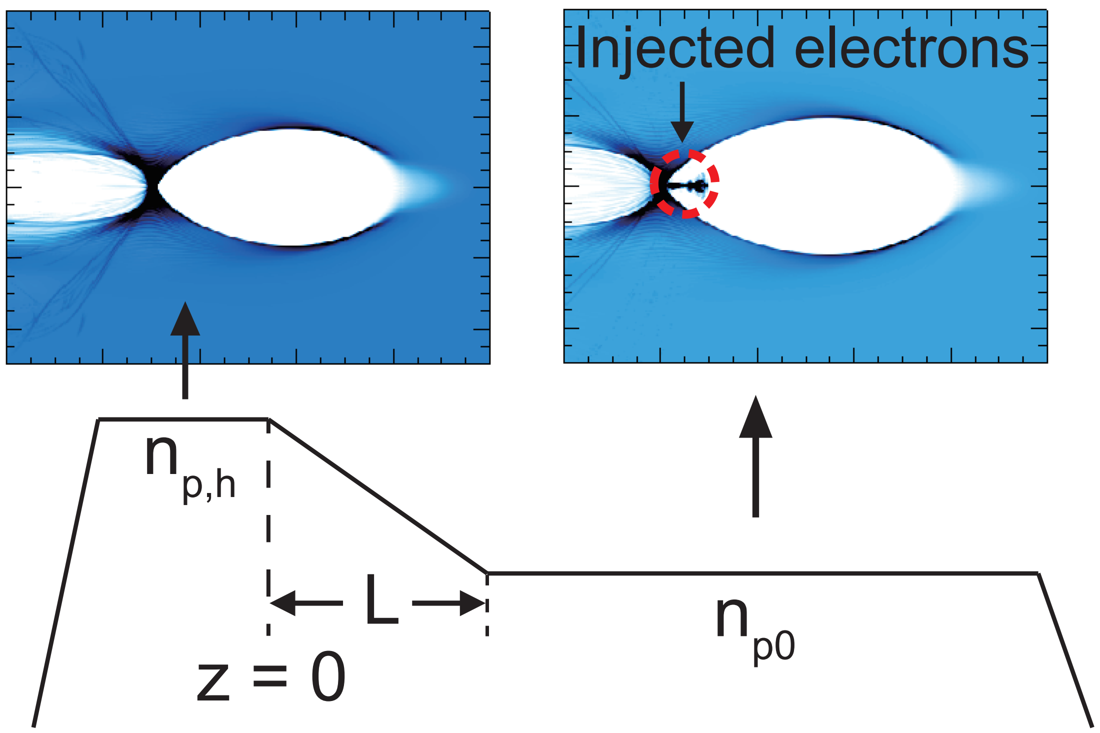
Controlled injection using density downramp

The phase velocity of the wake decreases with density triggering injection of plasma electrons



Wake phase velocity

$$v_\phi(z,t) = \frac{v_d}{1 - (d\omega/dz)\omega_p^{-1}(v_d t - z)}$$

For $\quad r_m \gg c/\omega_p \quad \lambda_{wake} \approx 2r_m \approx 4\sqrt{\Lambda}c/\omega_p$

$$v_\phi \approx v_d\left(1 - 4\sqrt{\Lambda}\frac{d\omega_p^{-1}}{dz}\right)$$

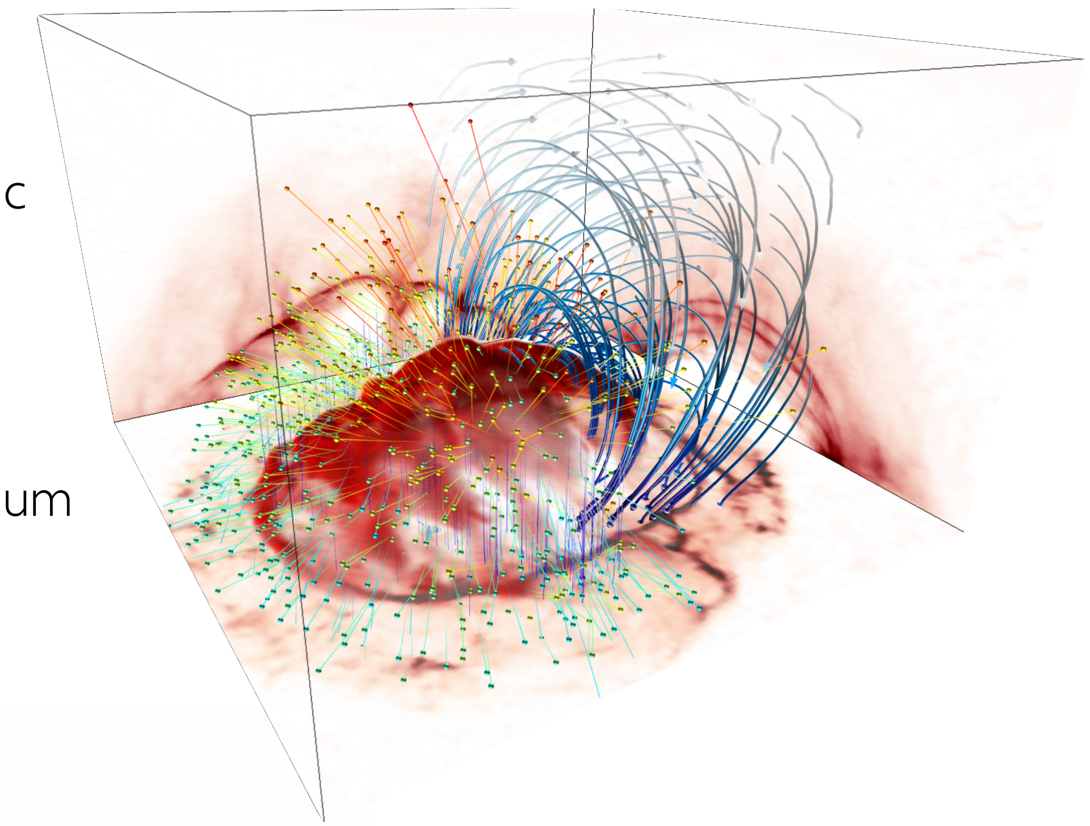
*X.L. Xu et al., arXiV, 1610.00788vl (Oct 2016)

Contents

OSIRIS 3.0

osiris framework

- Massivelly Parallel, Fully Relativistic Particle-in-Cell (PIC) Code
- Visualization and Data Analysis Infrastructure
- Developed by the osiris.consortium
  - ⇒ UCLA + IST



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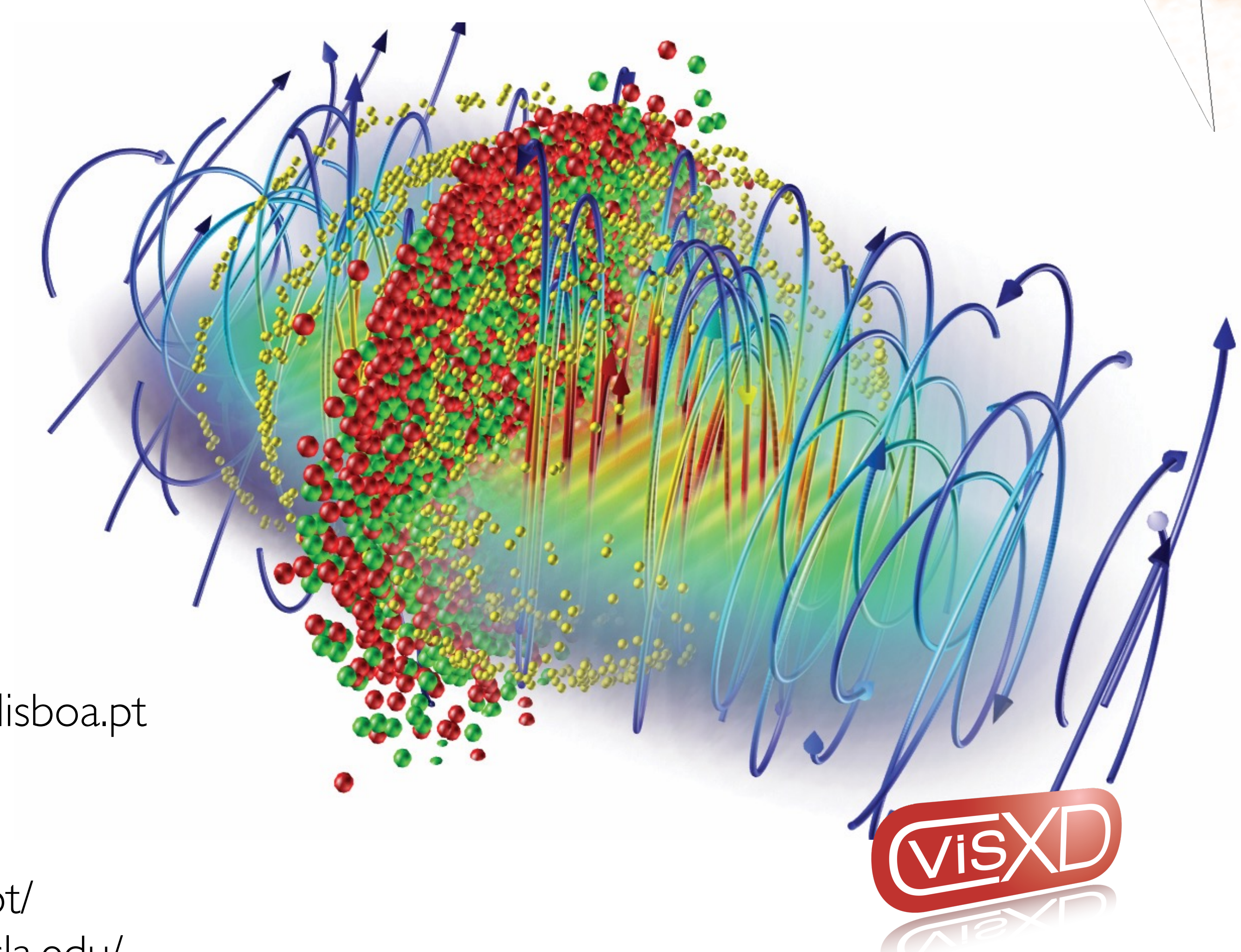
UCLA



code features

- Scalability to ~ 1.6 M cores
- SIMD hardware optimized
- Parallel I/O
- Dynamic Load Balancing
- QED module
- Particle merging
- GPGPU support
- Xeon Phi support

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Ponderomotive Guiding Center (PGC)*

Long distance LWFA (10-100 m)

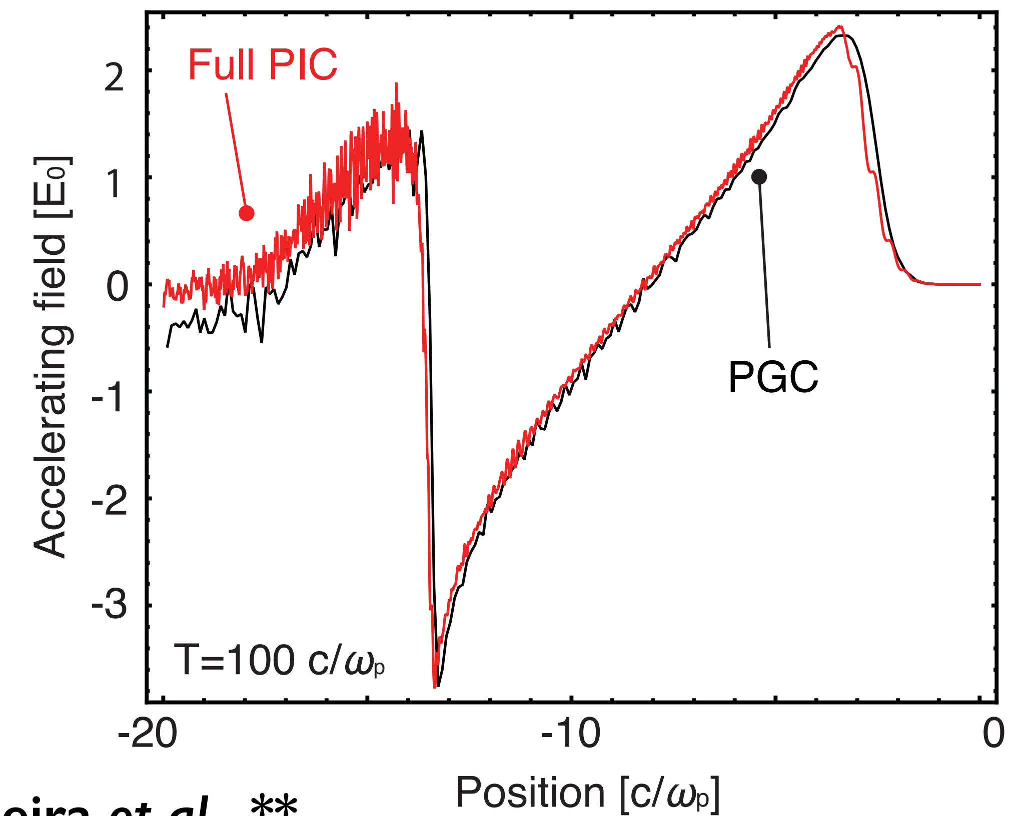
Significant challenges for PIC codes

- Large disparity of spatial scales propagation distance/ laser wavelength
- Algorithm must resolve the smallest scale in the simulation
- High resolution, large iteration count

PGC approximation

- Models laser envelope propagation
- Push particles using self consistent plasma fields and ponderomotive force

PGC in OSIRIS



J. Vieira *et al.*, **

Features

- Speed up ~$(\omega_0/\omega_p)^2$
- Boosted frame like computational savings
- Ultra-fast LWFA simulations
- Ionization energy depletion
- 3D, 2D slab/ 2D cylindrical

*D. Gordon, W. Mori, T. Antonsen, IEEE -TPS, 28 1135-1143 (2000)
** A. Helm, et al, 43rd EPS Conference, P1.073 (2016)

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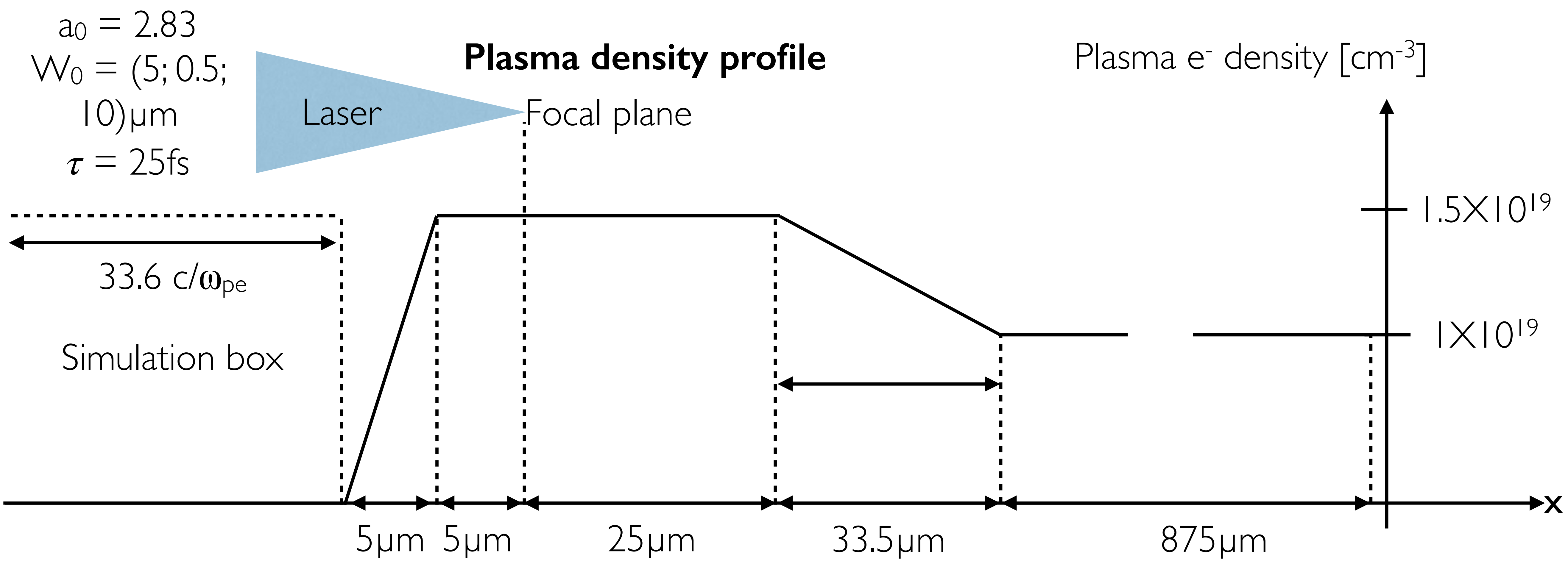
Setup for LWFA with down ramp injection using PGC algorithm with varying laser spot size



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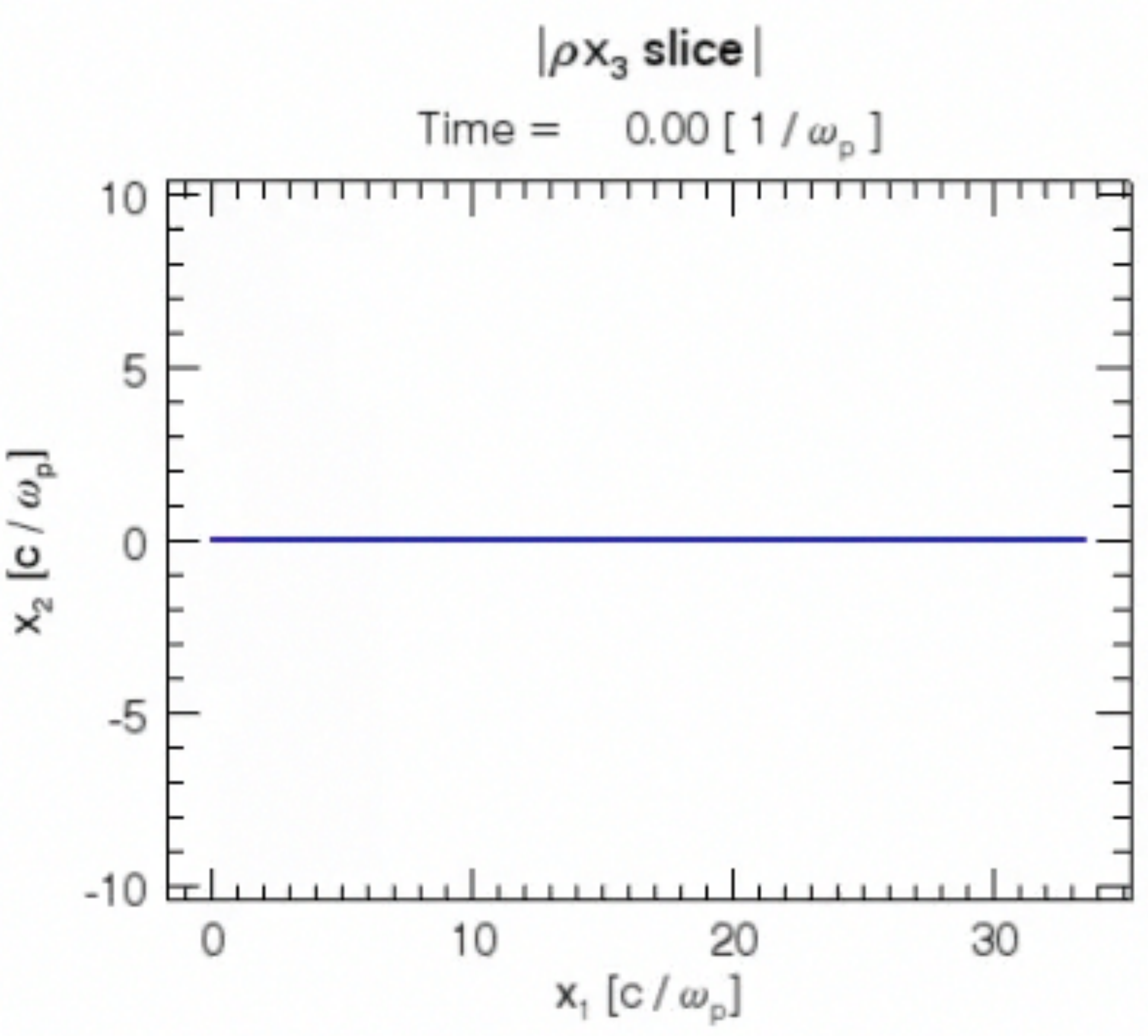
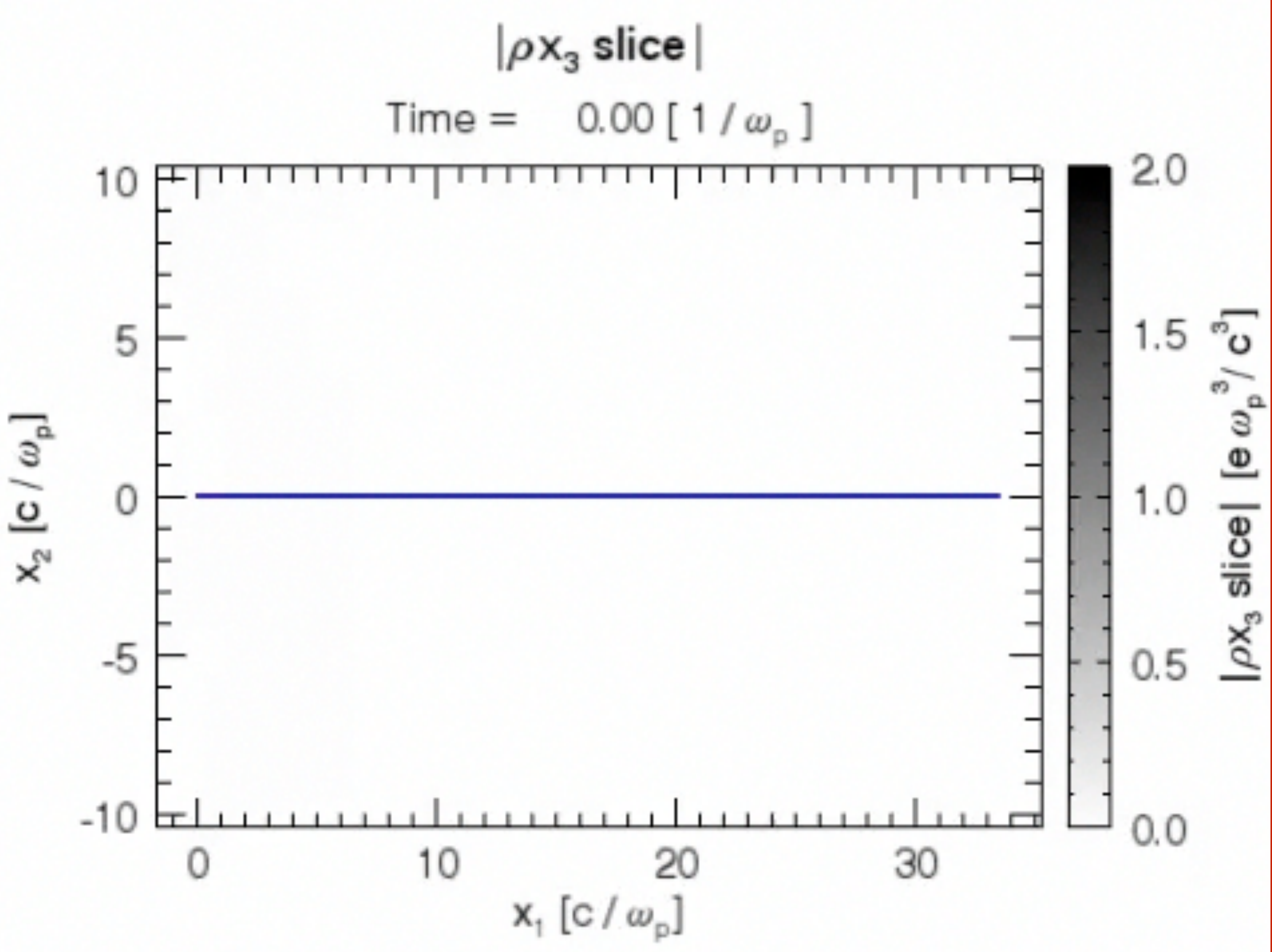
e⁻ injection using density downramp for varying spotsize

W_0= 5μm

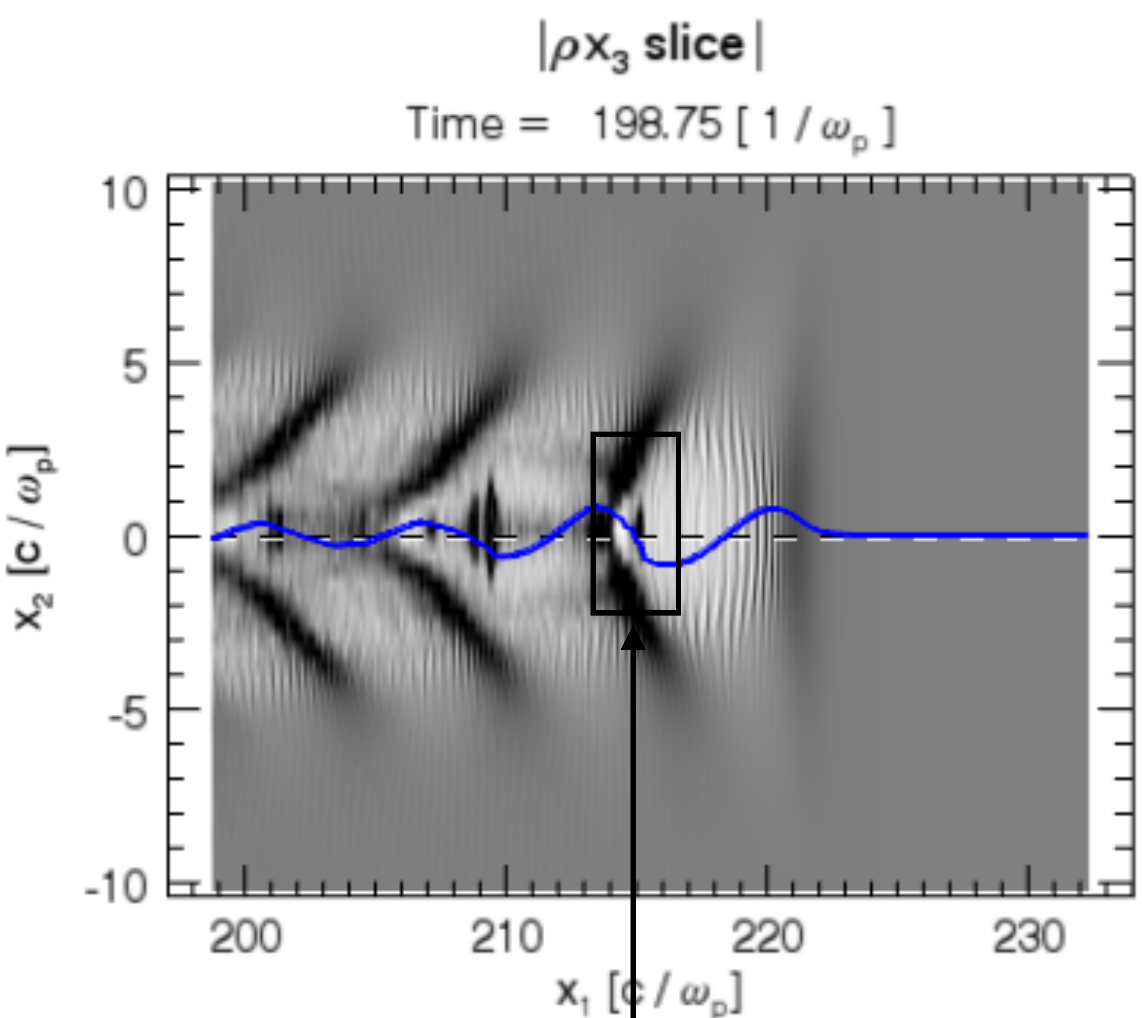


W_0 = 7μm

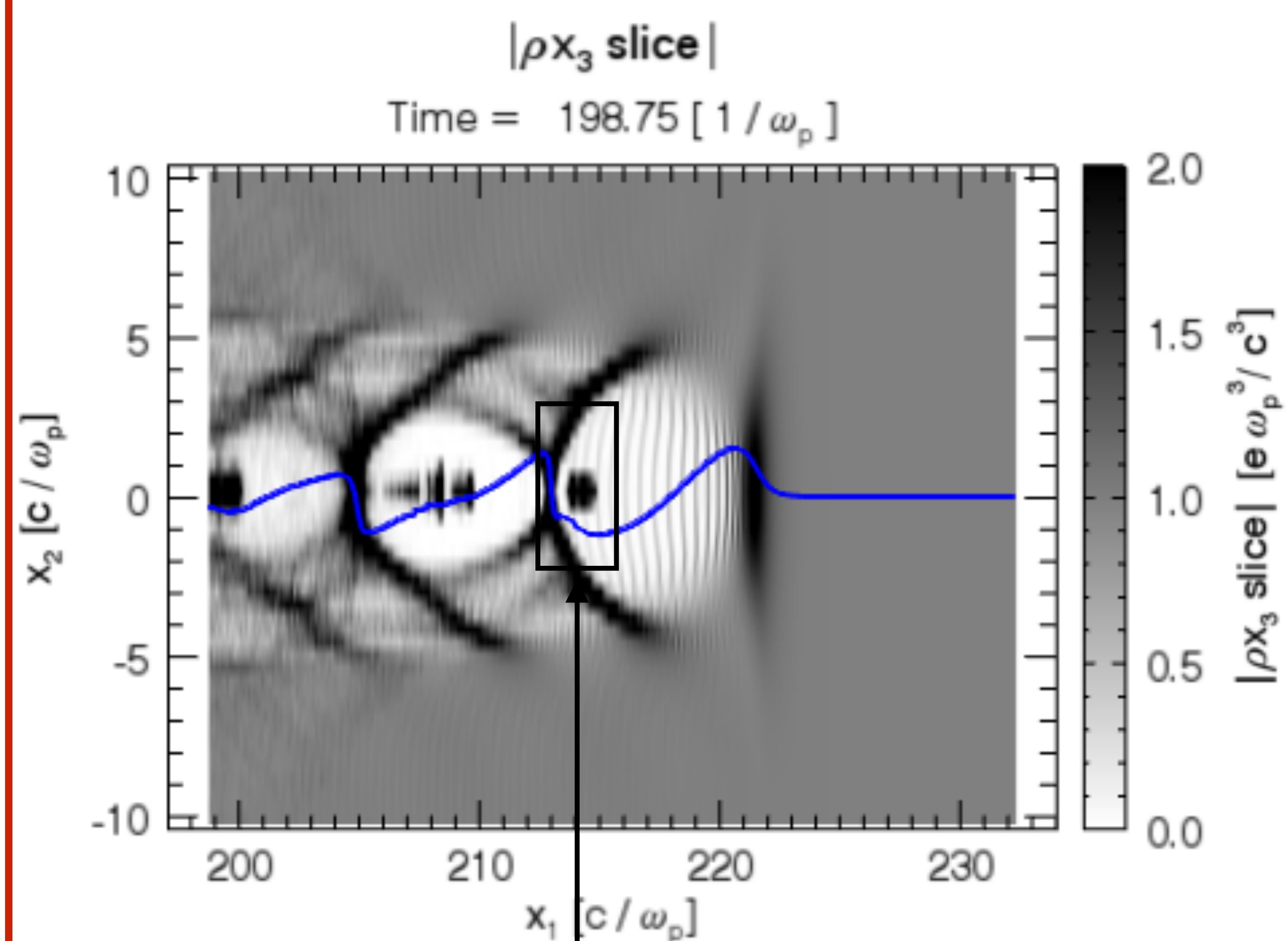


e^- injection using density downramp for varying spotsize

W_0= 5µm



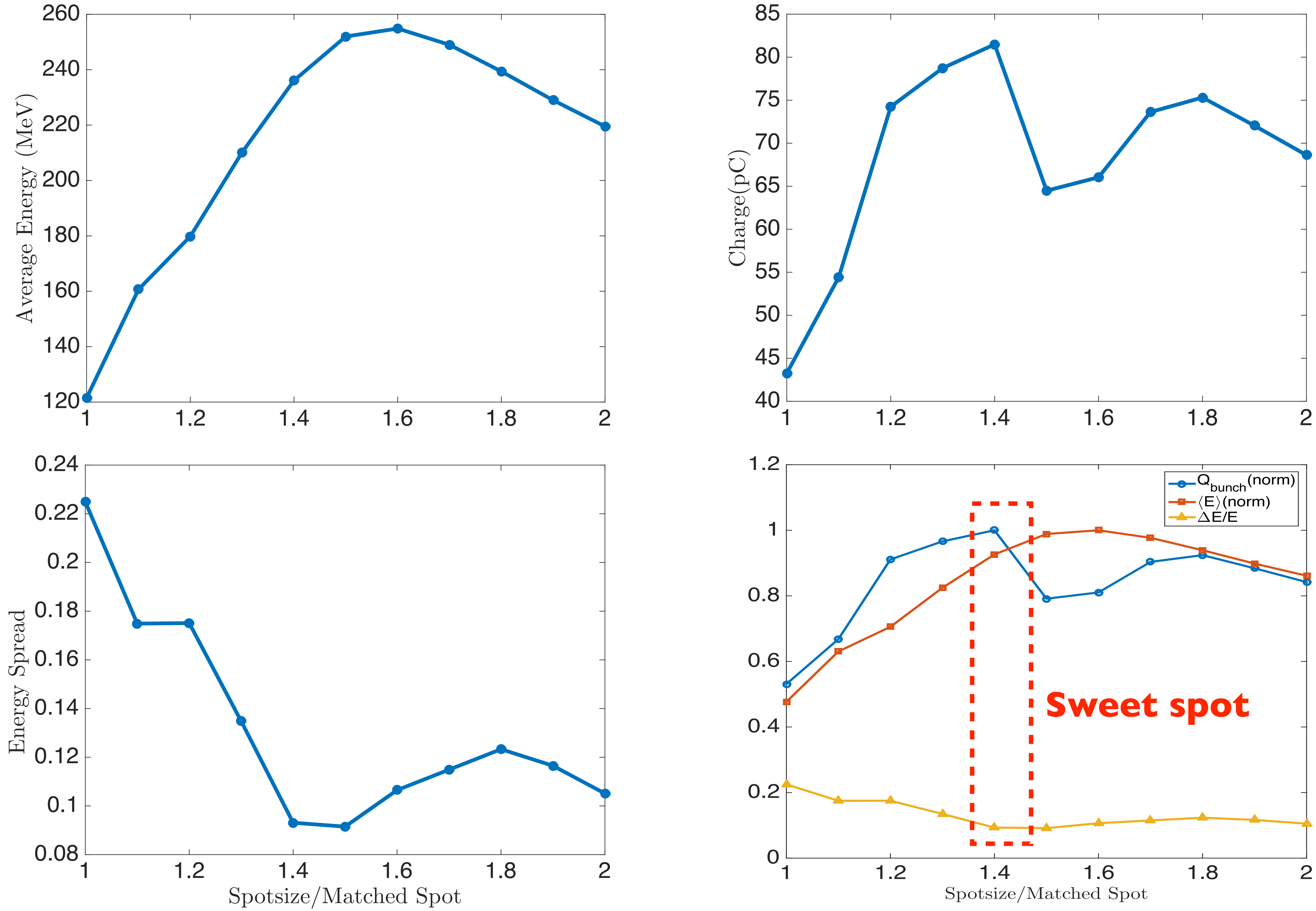
W_0 = 7µm



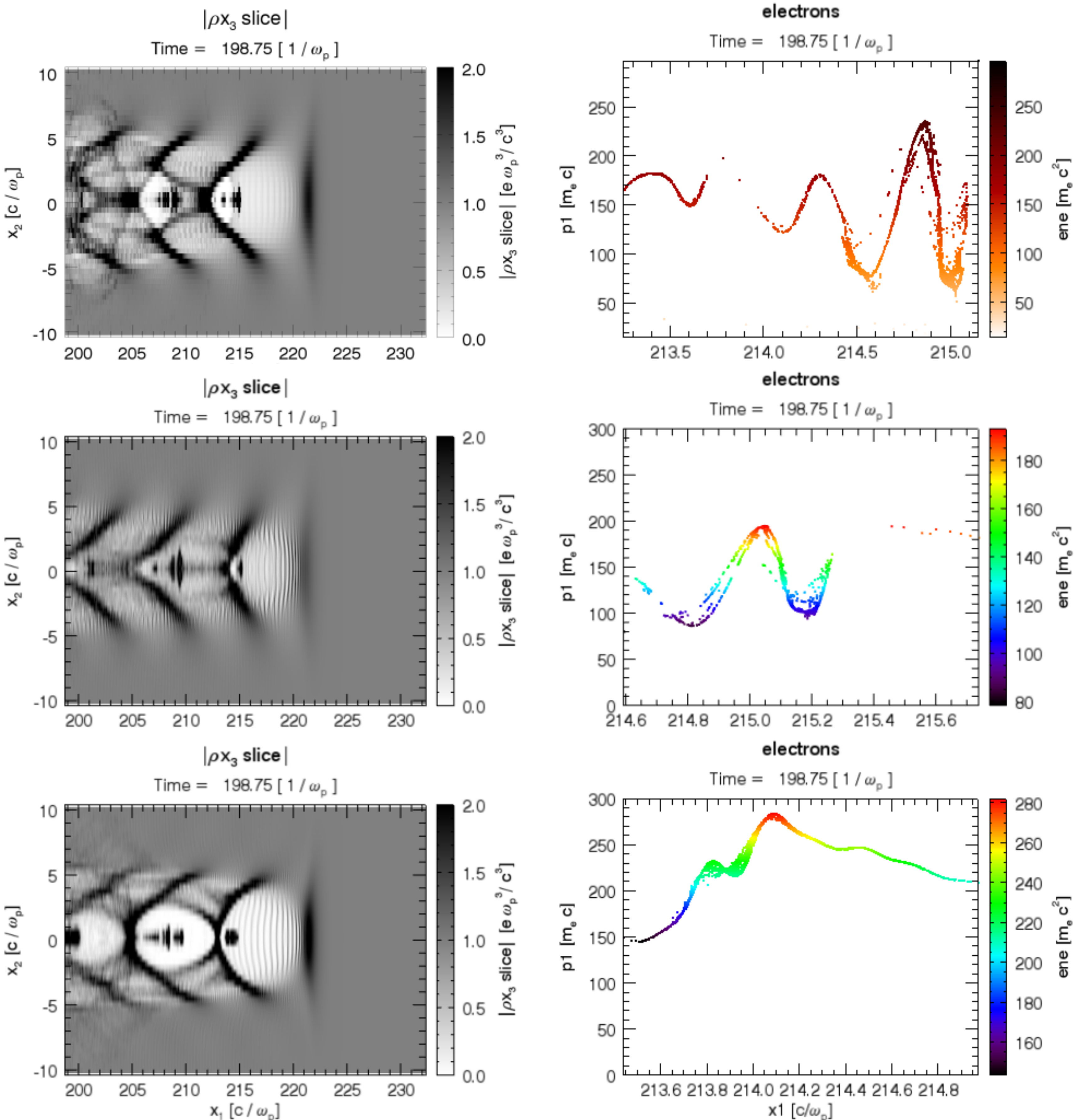
Accelerating field has a sharp gradient

Accelerating field has relatively flat gradient

Varying laser spotsize (keeping peak intensity and duration const.) affects average energy, energy spread and charge



Varying spotsize instead of power is more effective in reducing the energy spread

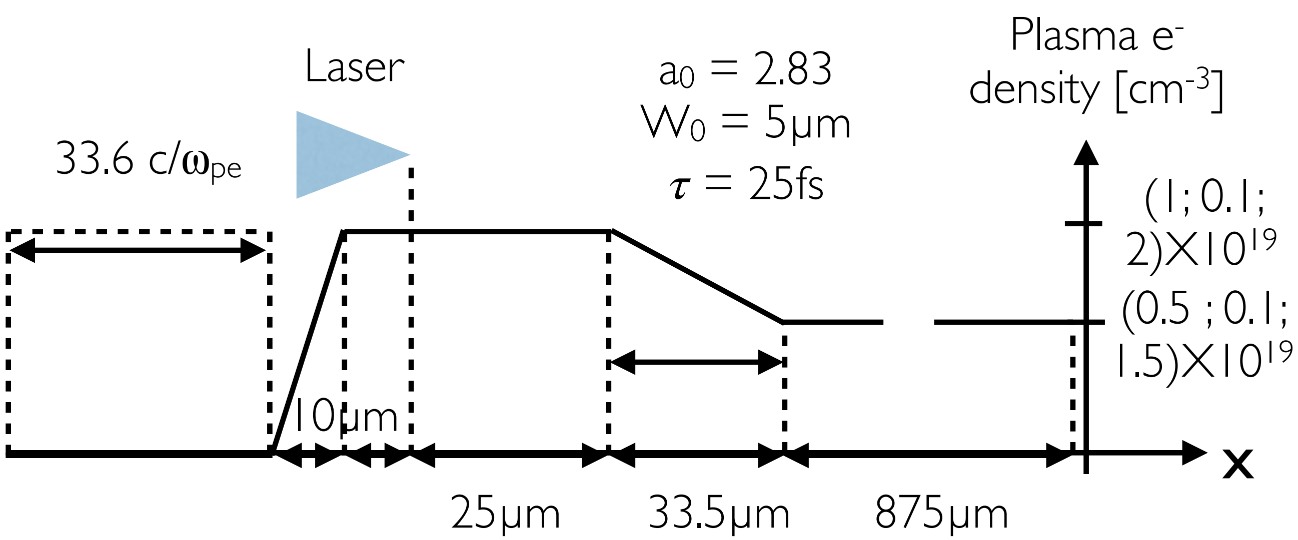


a_0=3.962 (Power=8.4X10^{12} Watts)
W_0=5μm
⟨E⟩ =42.3948 MeV
ΔE/ ⟨E⟩ =125.779 %
Q_{bunch}=490.657 pC

a_0=2.83 (Power=4.3X10^{12} Watts)
W_0=5μm
⟨E⟩ =121.47 MeV
ΔE/ ⟨E⟩ =22.49 %
Q_{bunch}=43.26 pC

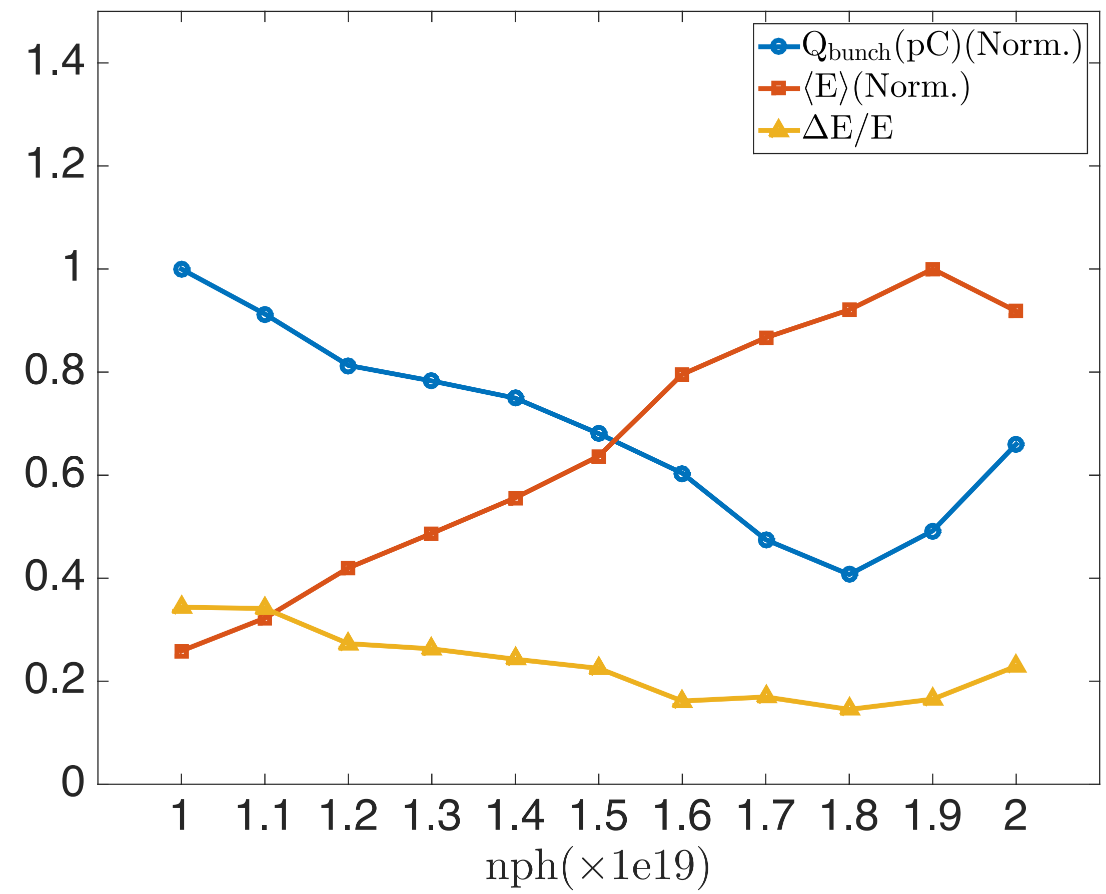
a_0=2.83 (Power=8.4X10^{12} Watts)
W_0=7μm
⟨E⟩ =236.10 MeV
ΔE/ ⟨E⟩ =9.31 %
Q_{bunch}=81.49 pC

Effect of density gradient



The plasma density is decreased linearly from n_{ph} to n_{p0} keeping the downramp length constant, i.e. L=33.5μm. n_{ph} is varied from 1e19cm^{-3} to 2e19cm^{-3} and n_{p0} from 0.5e19cm^{-3} to 1.5e19cm^{-3} keeping $\delta n = n_{ph} - n_{p0} = 0.5$e19cm^{-3}

Varying n_{ph} and n_{p0} with dn/ndx const.



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Electron injection using a density downramp
decrease in phase velocity facilitates controlled injection

Simulation set-up
simulation tools and parameters

Effect of laser spotsize and density gradient
influence on energy gain, charge and energy spread

Conclusions and next steps

Conclusions & Future Work

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Simulations with varying laser spotsize suggest

At 1.4 times of the matched laser spotsize, the accelerated electrons have high energy, have high charge and a very small energy spread ~ 9%

Simulations with varying n_{ph} and n_{p0} keeping the density scale length constant

The average energy of the electrons increases till n_{ph}=1.9 and then decreases

The energy spread decreases with n_{ph}=1.8 and then increases by a small amount

Future work

Simulations with varying spot size for n_{ph}=1.8 and n_{p0}=1.3, as the energy spread is minimum at these values of density.

The effect of spotsize on energy spread needs to be theoretically investigated