# Beam quality preservation in a laser-plasma accelerator with external injection in the context of EuPRAXIA


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Over the past decades the production of multi-GeV electron beams from laser-plasma-based accelerators has been successfully demonstrated. However, the overall quality of electron beams produced in plasma accelerators is not yet good enough for realization such applications like free-electron-laser, high-energy physics detector tests etc. To satisfy the requirements of these user-applications, produced electron beams should have the sufficient stability, reproducibility and quality.

## SIMULATION PARAMETERS

2D PIC simulation with the code OSIRIS [1].

### ✧ Plasma:

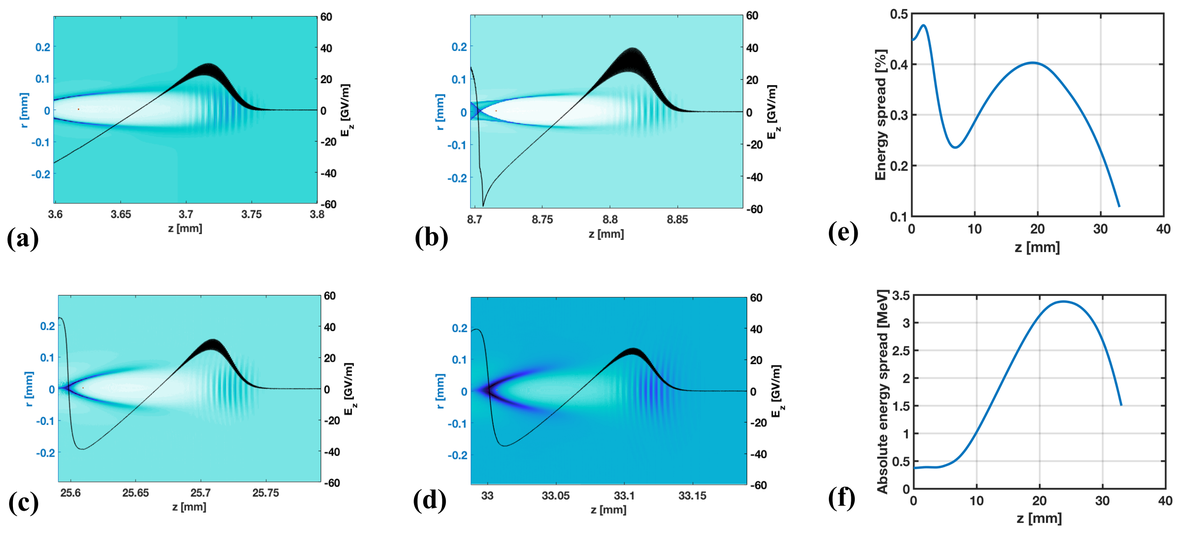
- density $n_0 = 10^{17}$ cm$^{-3}$; $\lambda_p = 105.6$ μm;
- plasma ramp has a shape close to cubic polynomial function;
- plasma ramp length: $\lambda_p$, $7\lambda_p$ and $50\lambda_p$ (105.6 μm, 739.2 μm and 5280 μm).

### ✧ EuPRAXIA laser:

- $a_0 = 3.1$;
- pulse length 100 fs (FWHM);
- spot size 64 μm (FWHM);
- 953.47 TW power; energy 101.5 J;
- wavelength 800 nm.

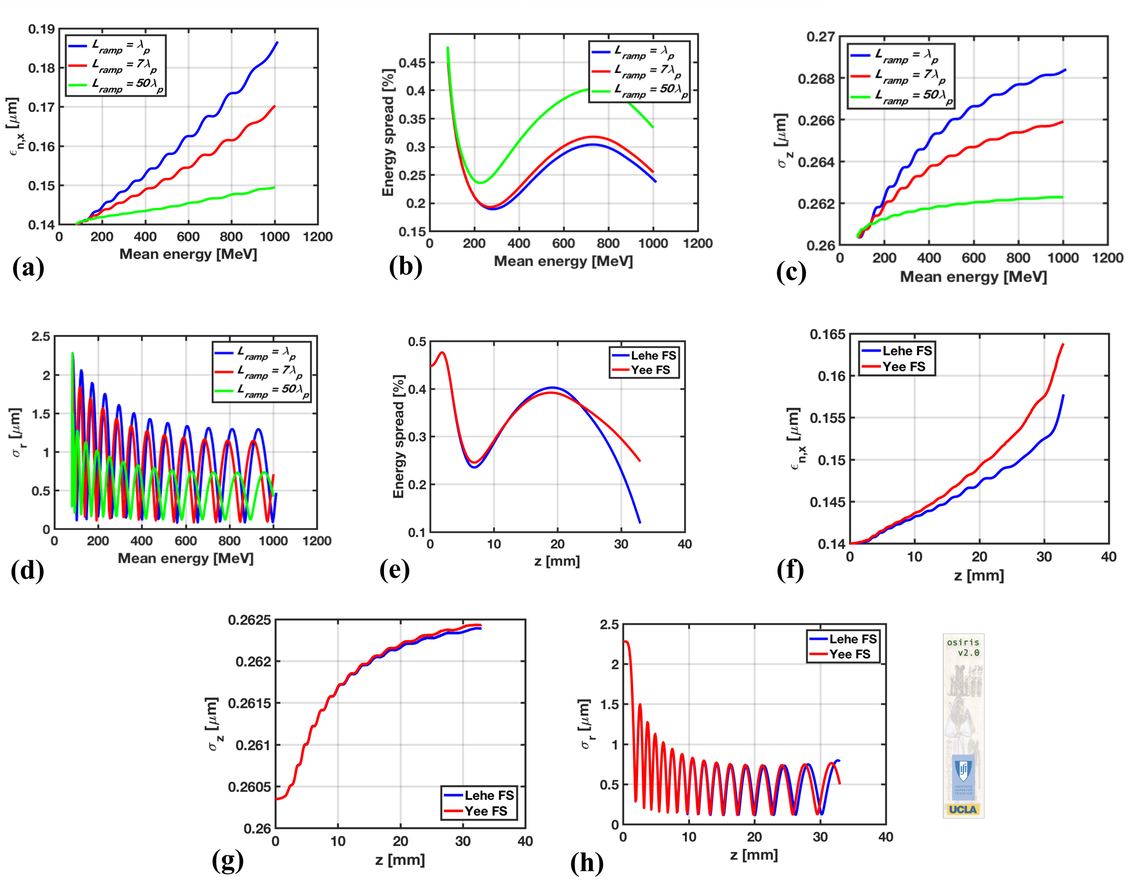
## ARES ELECTRON BEAM [2]

| Parameters | at the plasma entrance | after acceleration to 1 GeV | | | |
|---|---|---|---|---|---|
| Plasma ramp length, $L_{ramp}$ | | $\lambda_p \simeq 0.1$ mm | $7\lambda_p \simeq 0.74$ mm | $50\lambda_p \simeq 5.3$ mm | |
| Charge [pC] | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 |
| Energy [MeV] | 83.5 | 1003 | 1002.5 | 1001.8 | 1001.8 |
| Rel. energy spread [%] | 0.45 | 0.24 | 0.25 | 0.333 | 0.336 (0.9%) |
| $\sigma_z$ (RMS) [μm] | 0.26 | 0.268 | 0.266 | 0.262 | 0.262 |
| $\sigma_r$ (RMS) [μm] | 2.28 | 0.152 | 0.707 | 0.416 | 0.522 |
| Norm. transv. emittance, $\varepsilon_{n,x}$ [μm] | 0.140011 | 0.1856 | 0.1703 | 0.1495 | 0.154 (3%) |
| Long. box size | | | 201.7 μm | | |
| Propagation distance [mm] | | 23 | 23.3 | 25.6 | 26.7 |
| | | | Lehe FS | | Yee FS |

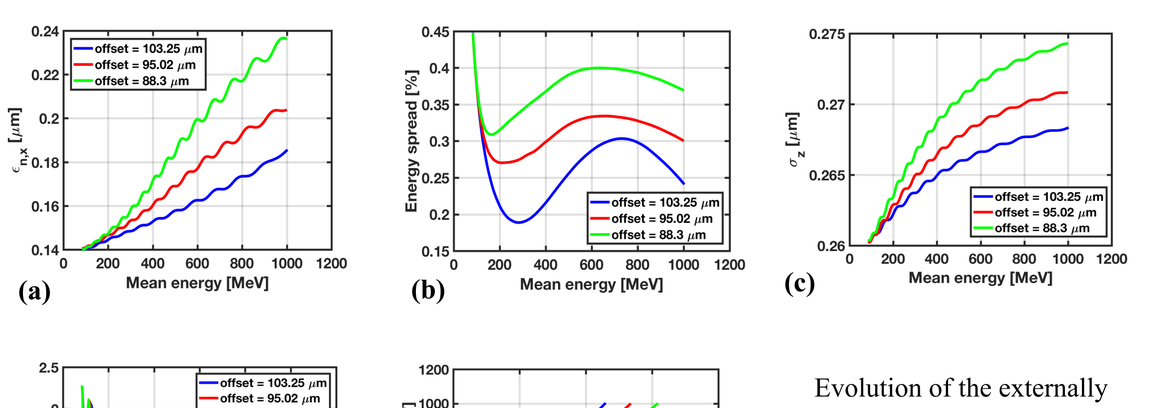



Density distribution of the injected electron beam and the plasma at z = 3.6 mm (a), z = 8.7 mm (b), z = 25.6 mm (c), z = 33 mm (d), relative energy spread (e) and absolute energy spread (f). Plasma ramp = 5.3 mm. Offset between the electron beam center and the laser pulse center = 103.25 μm.

| Parameters | at the plasma entrance | after acceleration to 1 GeV | | |
|---|---|---|---|---|
| Offset between the electron beam center and the laser pulse center | | 103.25 μm | 95.02 μm | 88.3μm |
| Charge [pC] | 0.74 | 0.74 | 0.74 | 0.74 |
| Energy [MeV] | 83.5 | 1003 | 1000.3 | 1001.5 |
| Rel. energy spread [%] | 0.45 | 0.24 | 0.3 | 0.369 |
| $\sigma_z$ (RMS) [μm] | 0.26 | 0.268 | 0.271 | 0.274 |
| $\sigma_r$ (RMS) [μm] | 2.28 | 0.152 | 0.974 | 1.384 |
| Norm. transv. emittance, $\varepsilon_{n,x}$ [μm] | 0.140011 | 0.1856 | 0.2 | 0.236 |
| Long. box size | | 201.7 μm | | |
| Propagation distance [mm] | | 23 | 26.8 | 30.9 |

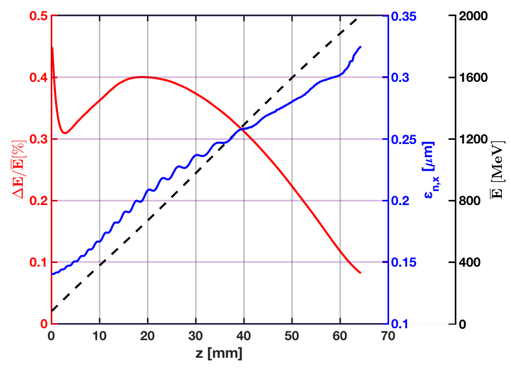



Evolution of the externally injected electron beam properties during acceleration to 1 GeV: normalized transverse emittance (a), relative energy spread (b), longitudinal bunch length (c) and bunch width (d). Plasma ramp = 0.1 mm, 0.74 mm, 5.3 mm. Offset between the electron beam center and the laser pulse center = 103.25 μm. Comparison between the Yee and Lehe field solvers (e, f, g, h).

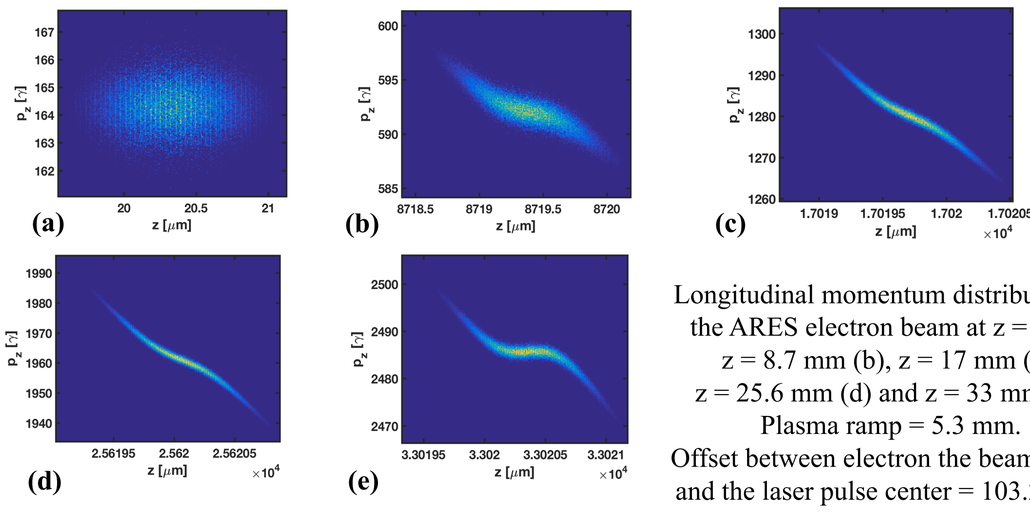



Evolution of the externally injected electron beam properties during acceleration to 1 GeV: normalized transverse emittance (a), relative energy spread (b), longitudinal bunch length (c), bunch width (d) and mean energy (e).

## 2 GeV electron beam with ΔE/E < 0.1%




Evolution of the externally injected electron beam properties during acceleration to 2 GeV: relative energy spread (red solid curve); normalized transverse emittance (blue solid curve); mean energy (black dashed curve). Plasma ramp = 0.1 mm. Offset between the electron beam center and the laser pulse center = 88.3 μm.




Longitudinal momentum distribution of the ARES electron beam at z = 0 (a), z = 8.7 mm (b), z = 17 mm (c), z = 25.6 mm (d) and z = 33 mm (e). Plasma ramp = 5.3 mm. Offset between electron the beam center and the laser pulse center = 103.25 μm.

## Summary

The effect on emittance growth can be diminished by tailoring the longitudinal plasma density profile. To avoid degradation of the relative energy spread during acceleration, the electron beam should be injected at a proper phase and its longitudinal size should be much shorter than the plasma wave length.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### References


1. R. Fonseca et al., Lect. Notes Comput. Sci. 2331, 342 (2002); R. Fonseca et al., Plasma Phys. Control. Fusion 50, 124034 (2008).
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