LWFA of externally injected electron bunches in guiding structures

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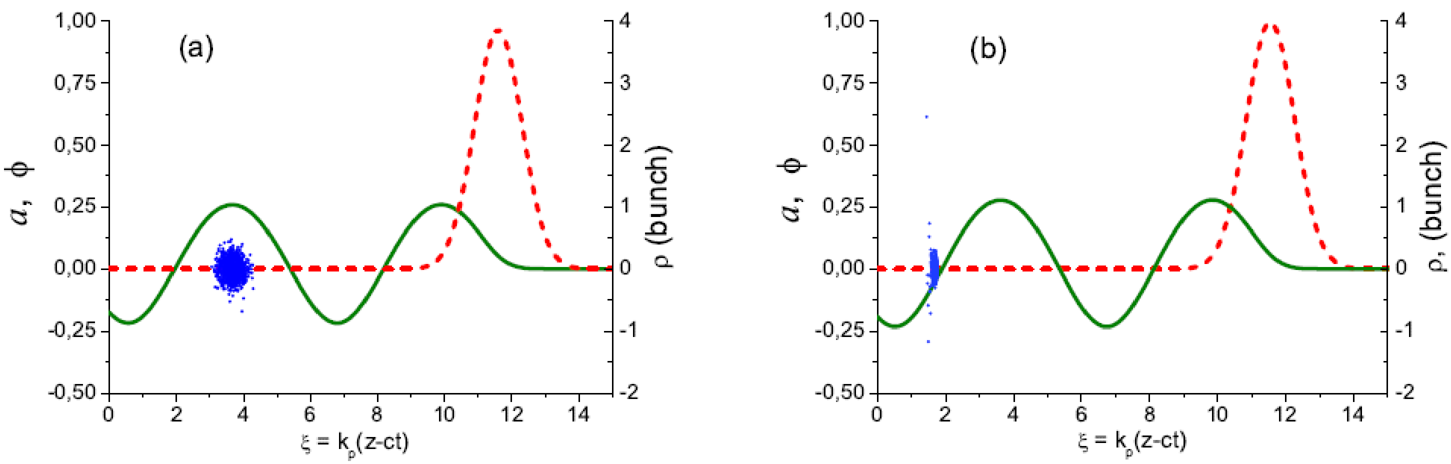
Low energy electron bunch injection at the maximum of the WF potential *to minimize the energy spread*

Computer simulation by the code LAPLAC

Initial energy of electrons $\boldsymbol{E_{inj}} = \mathbf{1.9}\ \boldsymbol{mc^2}$ and normalized emittance $\boldsymbol{\sigma_N} = \mathbf{0.346}$ **mm×mrad**

The radial bunch dispersion was $\sigma_{r,inj} = 1.88$ μm ($k_p\sigma_{r,inj} = 0.148$, $k_pR_{rms} = 0.214$)
Longitudinal dispersion $\sigma_{z,inj} = 2.3$ μm (FWHM bunch duration = 23 fs, $k_p\sigma_{z,inj} = 0.18$)

$$\varphi(\xi_{inj}) - \varphi(\xi_{tr}) = E_{inj}/mc^2 - \left[\left(1-\gamma_{ph}^{-2}\right)\left(E_{inj}^2/m^2c^4 - 1\right)\right]^{1/2} - 1/\gamma_{ph}$$



At the entrance of the matched plasma channel, the laser pulse envelope was Gaussian in both longitudinal and transverse directions with laser wavelength $\lambda_0 = 0.8$ μm, amplitude $a_0 = 0.964$ and FWHM pulse duration $\tau_{FWHM} = 50$ fs, and waist radius $r_0 = 68.2$ μm
P_L=145 TW, P_L/P_{cr}=0.854, at plasma density on the axis $n_0 = 1.75 \times 10^{17}$ cm^{-3}, $\gamma_{ph} = 100$.

From 1-D theory in the stationer wakefield for test particles

The compressed length of the trapped bunch can be estimated through the wakefield potential at the phases of injection and trapping:

$$L_b = \frac{1}{2} k_p L_{b0}^2 \frac{\left|\partial^2 \phi(\xi_m)/\partial \xi^2\right|}{\partial \phi(\xi_{tr})/\partial \xi}$$

Injected RMS bunch length $k_p L_{b0}$=0.41

$k_p L_{rms}$=0.07 *obtained in the simulations*

The upper estimate for the minimal electron energy spread:

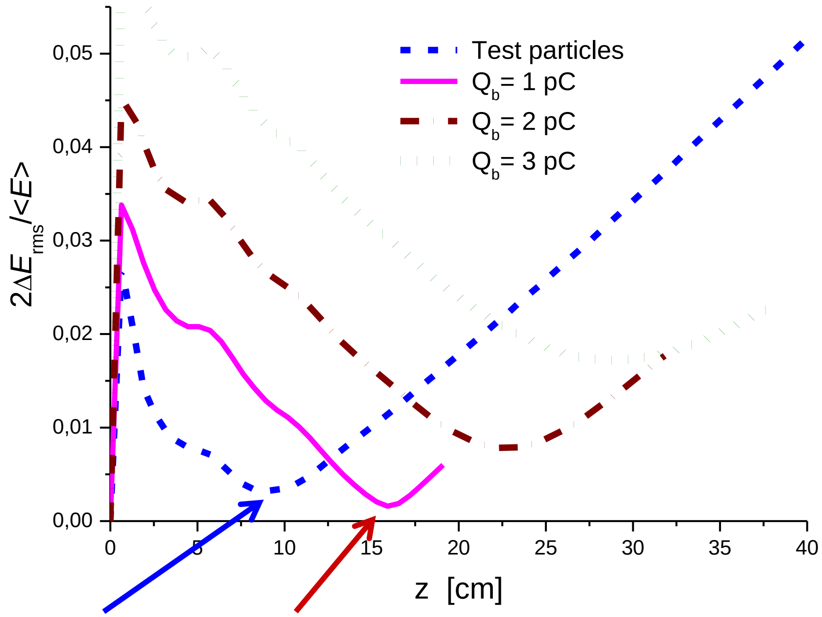
$$\Delta E_f = 2\sigma_E \approx 4|e| k_p \frac{d\phi}{d\xi_f} \frac{E_{\mathrm{inj}}^2}{m^2 c^4} \sigma_{z,\mathrm{inj}}.$$

$2\Delta E_{rms}/\langle E \rangle \approx 0.002$

the maximum energy of the bunch electrons at the "focusing" point is limited to a value

$$E_f \approx 2\gamma_{\mathrm{ph}} mc^2 (1 - 2\gamma_{\mathrm{ph}} |e| \phi(\xi_{\mathrm{df}})/mc^2)$$

Beam loading effect (self-action of the bunch charge) in the LWFA



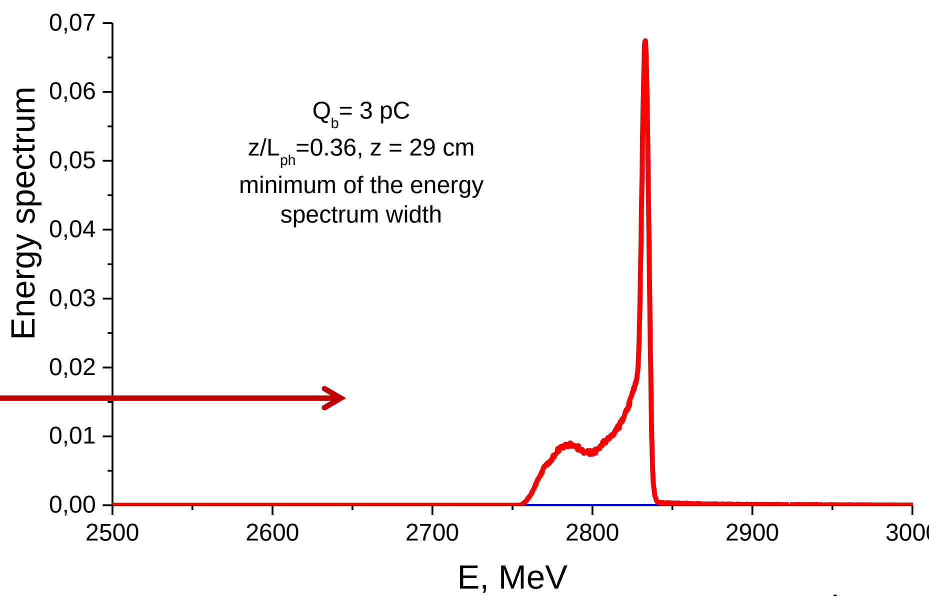
0.0032 **0.0016 - Q_b= 1 pC**

$N_{load} \sim n_0 k_p^{-3} = 3.6\text{x}10^8$ --> 60 pC

for Q_b= 3 pC, the minimal energy spread :

$2\Delta E_{rms}/\langle E\rangle = 2\%$

$\Delta E_{FWHM}/\langle E\rangle = 0.2\%$



N E Andreev, V E Baranov and H H Matevosyan (2017) Laser and Particle Beams. *submitted*

Conclusion on the electron acceleration in guiding structures

- **Stable and controllable laser propagation and wakefield generation over tens of Rayleigh length in guiding structures are demonstrated**
- **Acceleration of electrons to GeV energies in cm-scale capillaries is achieved**
- **Loading effect can be controlled and used to optimize electron bunch parameters for a low energy spread (but it limits the bunch charge!)**
- **LWFA can provide acceleration of polarized electron bunches to high energies**
- **Complete analysis and experiments on multistage acceleration that preserve high-quality electron bunches are needed to demonstrate the key element of the collider concept**