Homogeneous and Identical Focusing of Train of Relativistic Positron Bunches in Plasma

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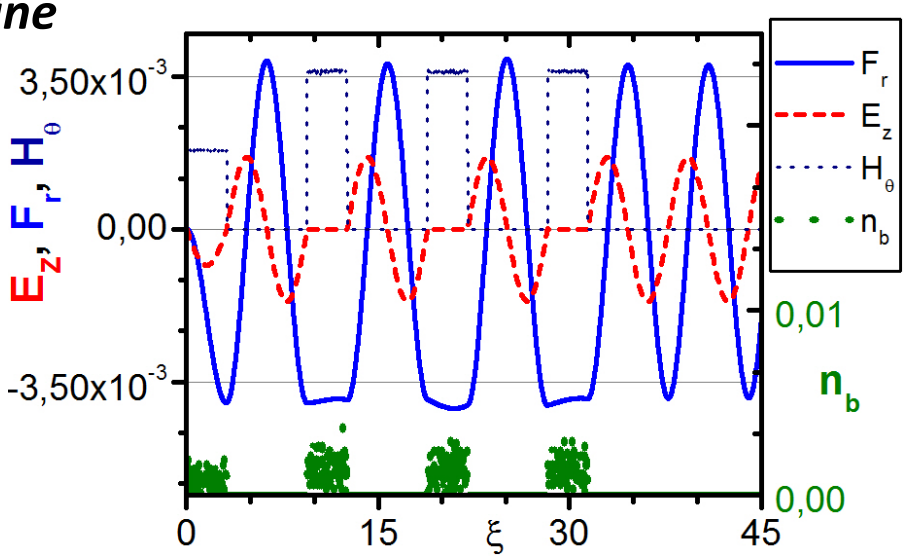
WG8 - Positrons



The focusing mechanism in the plasma, in which all electron bunches of a train are focused identically, has been proposed in

G. Hairapetian, P. Devis, C. Joshi, C. Pelegrin, T. Katsouleas. 1995.

Ya. Fainberg, M. Ayzatsky, V.Balakirev et al. 1997.

V.I. Maslov, I.N. Onishchenko, I.P. Yarovaya. 2013.

K.V. Lotov, V.I. Maslov, I.N. Onishchenko et al. 2012.

V.I. Maslov, I.N. Onishchenko, I.P. Yarovaya. 2014.

J.-H.Rockemann et al. 2018.

C.O'Connell et al. 2002.

M.C.Tompson et al. 2006.

S.Yu.Kalmykov et al. 2006.

The purpose of the article

- find and study the mechanism of focusing of a sequence of relativistic positron bunches in plasma, in which all positron bunches of sequence are focused identically and uniformly

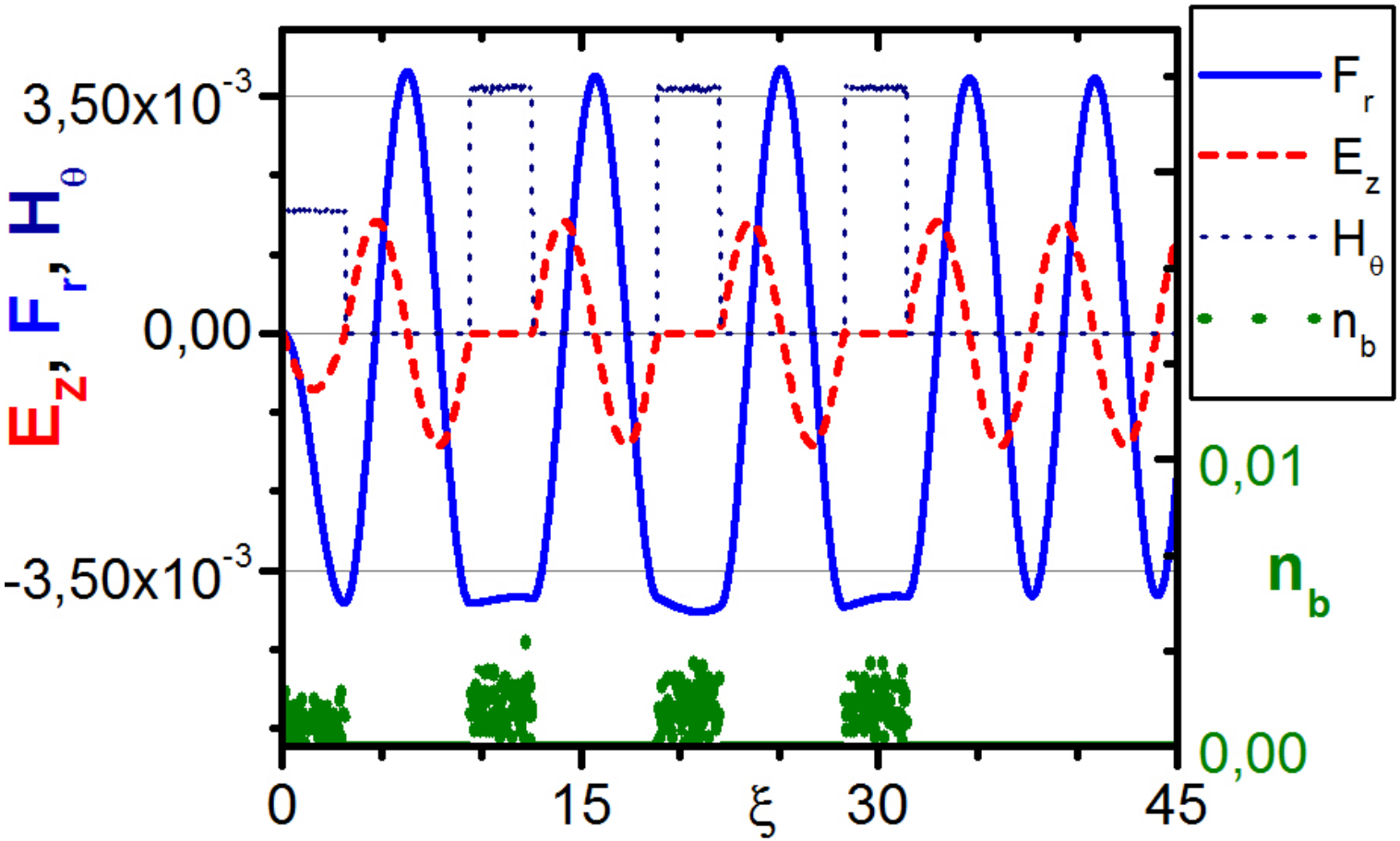
Focusing of electron and positron beams by wakefield, excited in plasma, in electron-positron collider is very important.

Increasing the efficiency of the collider:

- **reducing divergence;**
- **reducing the energy scattering.**

The lenses for relativistic positron bunches are researched here by numerical simulation by 2.5D code LCODE*

*K.V. Lotov (1998).

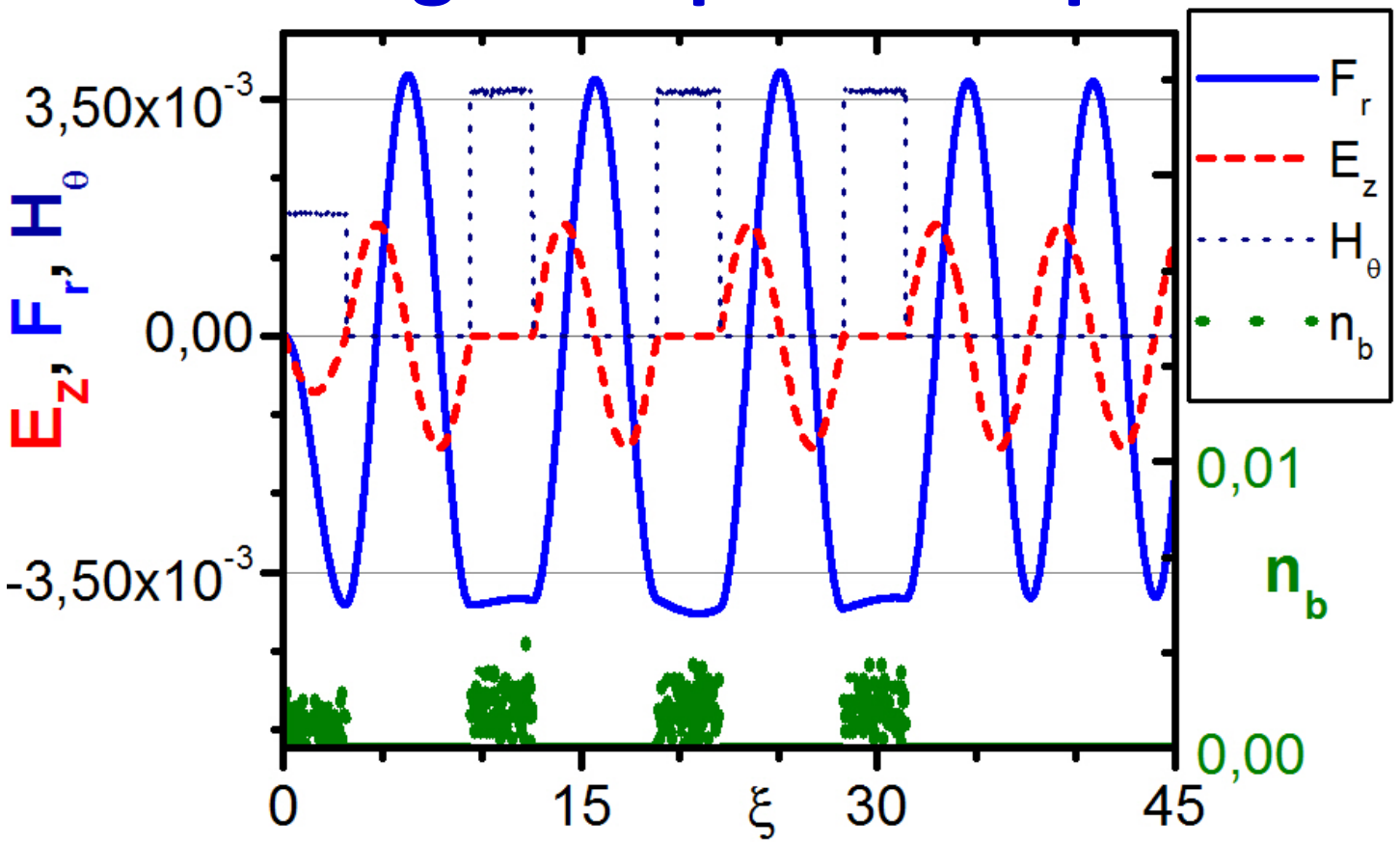


Two cases is considered:

- **4-bunches case;**
- **10-bunches case.**

Two plasma lenses for positrons.

Focusing of sequence of positron bunches



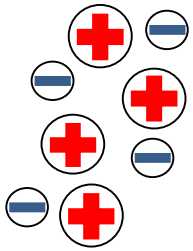
Density of bunches n_b (green), longitudinal wakefield E_z (red), radial wake force F_r (blue) and manetic field H_θ (dark blue)

Focusing of sequence of positron bunches, length of each bunch equals half of wavelength $\xi_b=\lambda/2$, because in this case the wakefield has maximal value at increase of bunch length of the same density. We use the charge of first bunch, equal in two times smaller than charge of each next bunch. Distance between bunches is 1.5λ.

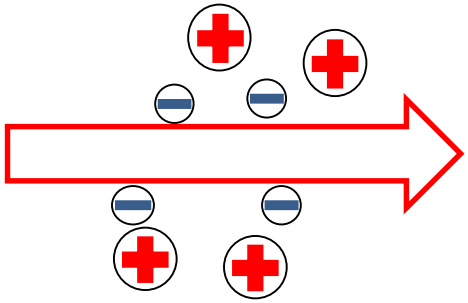
$$Q_1=Q/2,\ Q_i=Q,\ i=2,\ 3,\ 4\ \ldots,\ \xi_{i+1}-\xi_i=1.5\lambda.$$

Physical model of the focusing

1. Quasi-neutral state

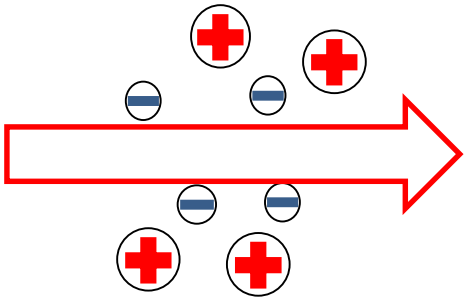


2. Positron bunch



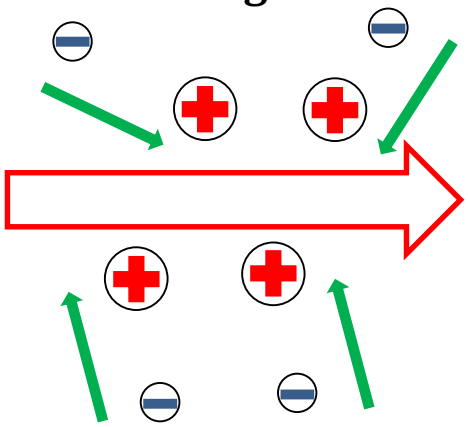
Focus increase

3. Inertia moving, scattering



Focus decrease

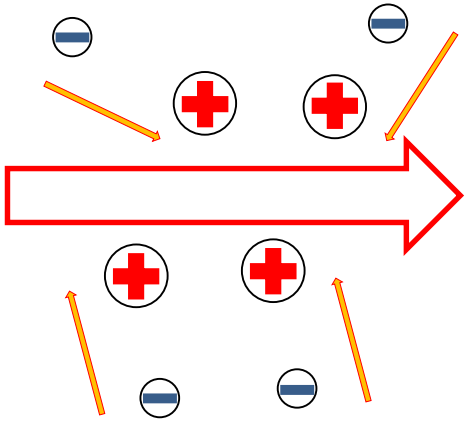
4. Uncompensated charge



Electron backward "focusing" force

increase →

5. Oscillation process

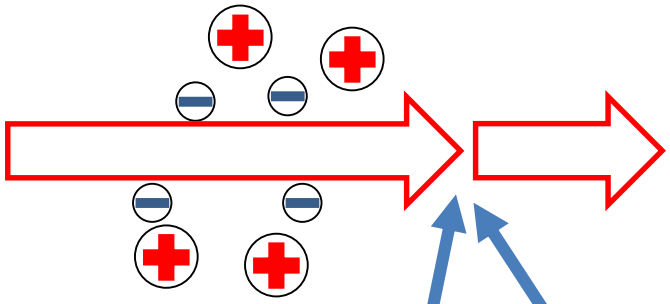


Electron backward force

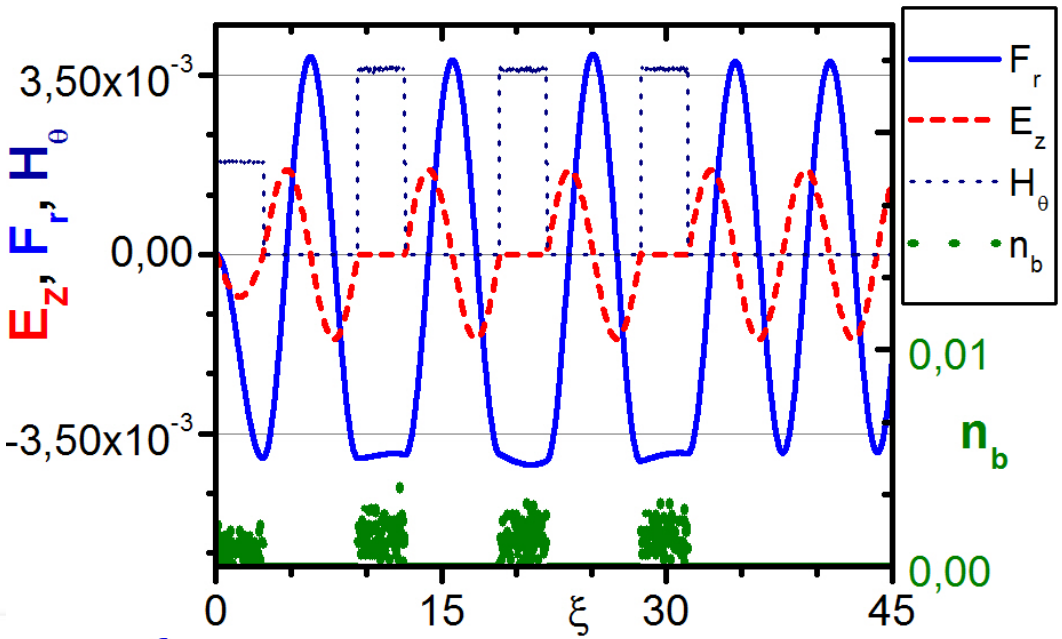
→ *decrease*

Physical model of the focusing

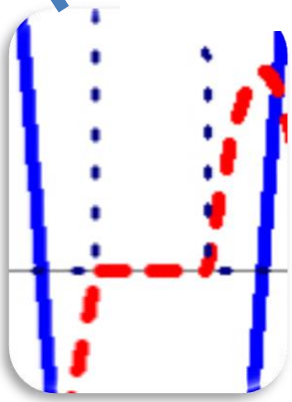
6. Return to axis.
Charge compensation



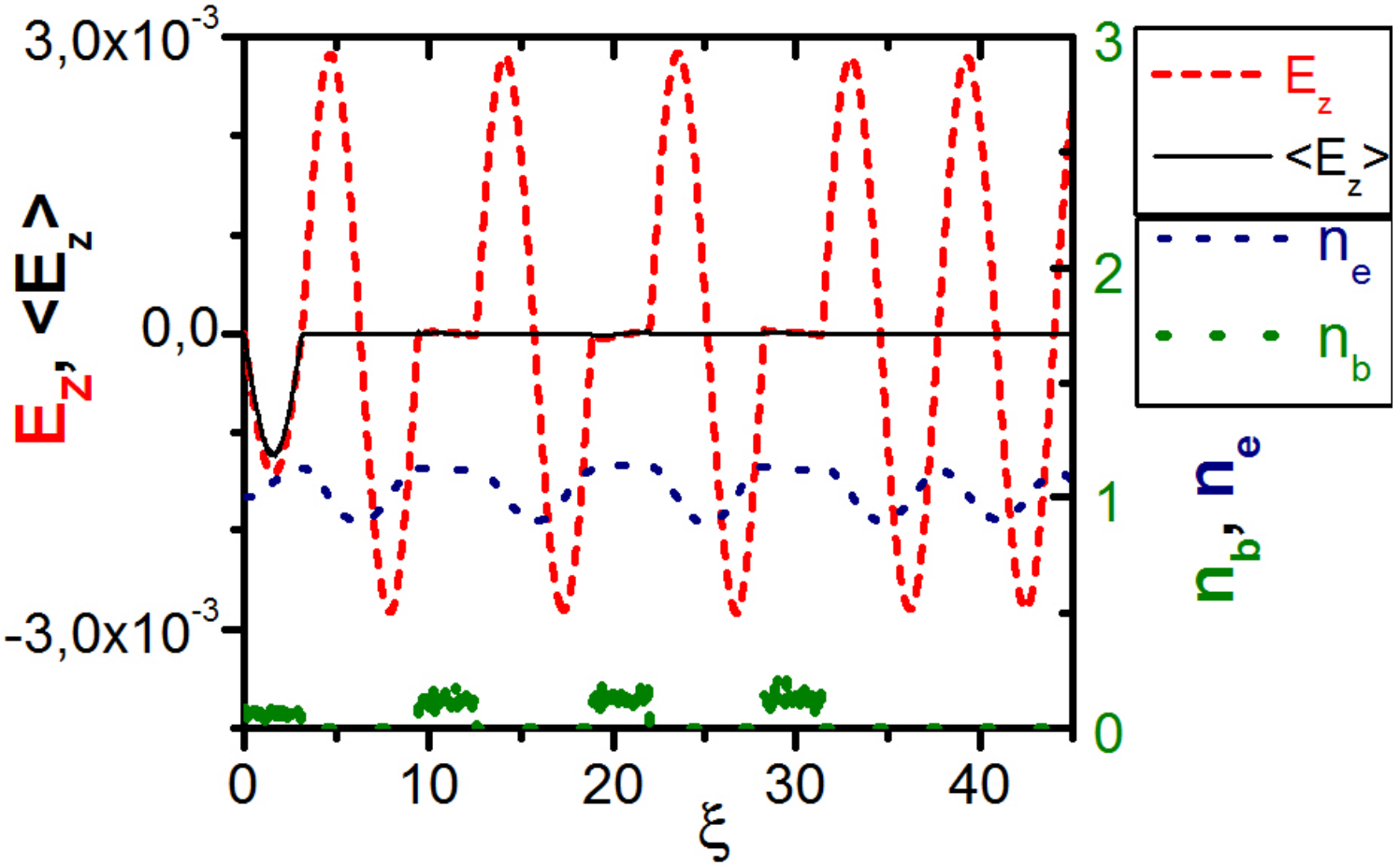
Second bunch



Fr is constant

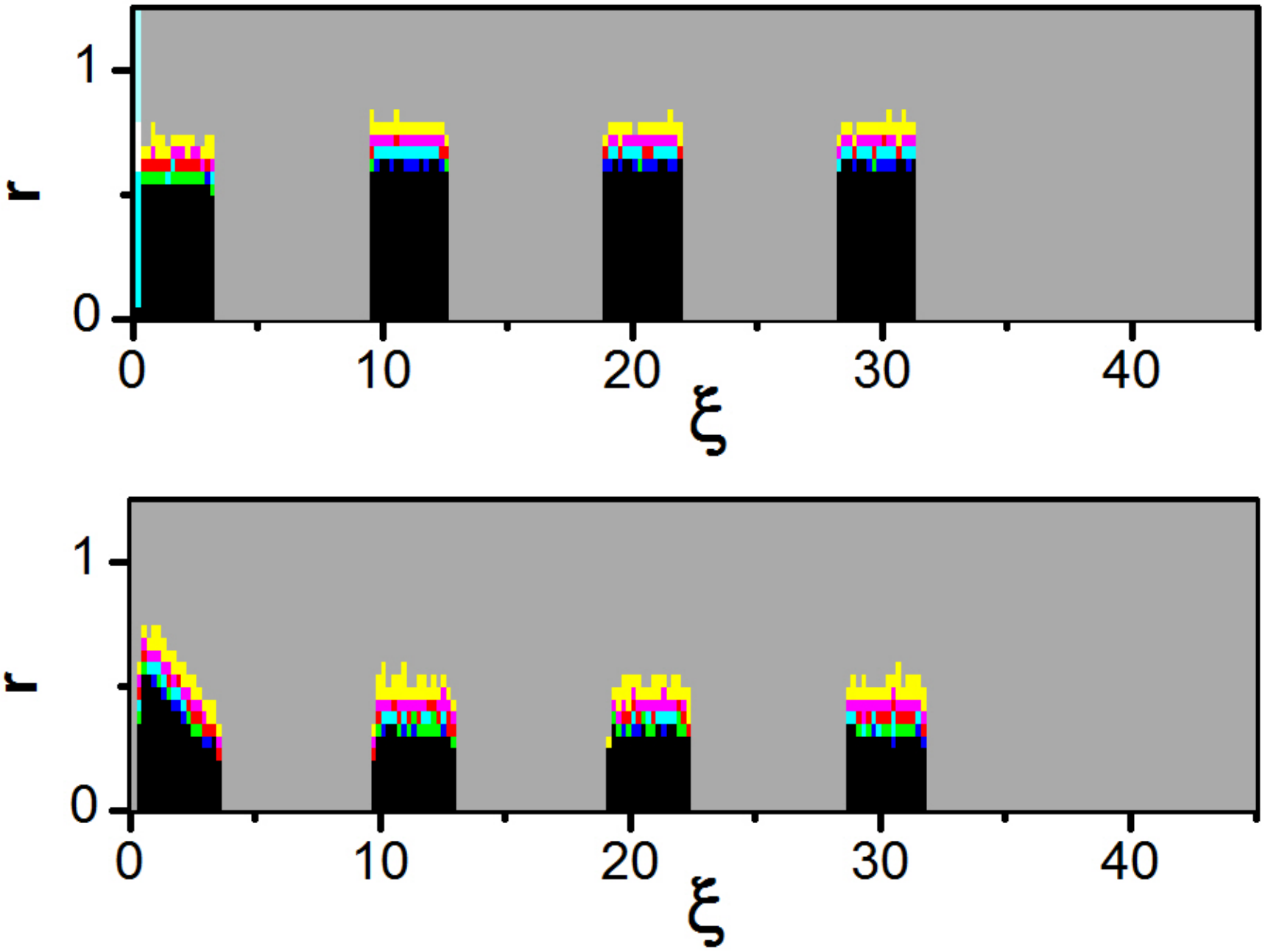


Wakefield is 0



Plasma electron density n_e (black) in wakefield, longitudinal wakefield E_z (red), density of bunches n_b (dark green) and $<E_z>=\int dr\ r\ E_z n_b / \int dr\ r n_b$ (black) coupling rate of bunch with wakefield E_z

Such ideal focusing connected with formation of flat elevations of plasma electron density n_e in regions, occupied by bunches, which neutralize charges of bunches and focuse them.



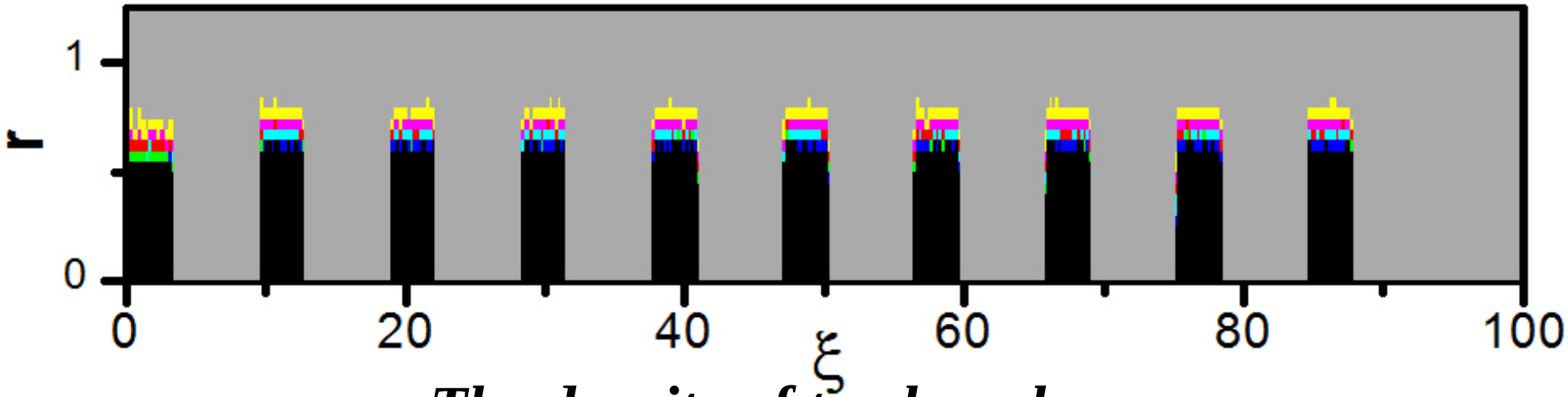
The density n_b of bunches before and after focusing

Qualities of wakefield lens

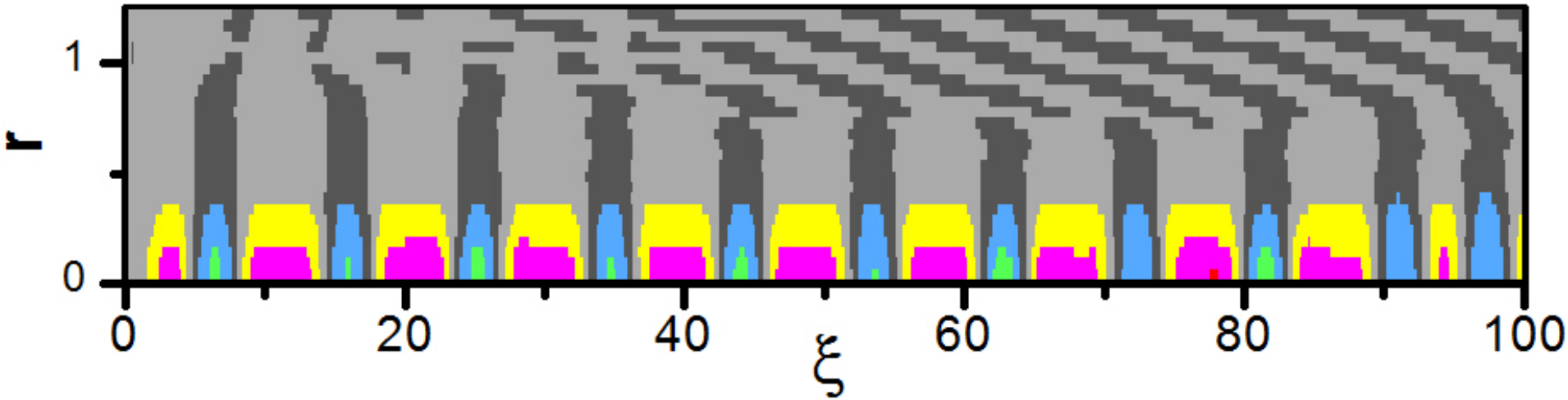
This wakefield lens has following qualities:

- radial wake force F_r does not approximately depend on coordinate in regions, occupied by bunches (with the exception of first bunch), $F_r \approx const$, i.e. lengthy bunches are focused identically;
- only first bunch is decelerated;
- identical focusing force effects on all bunches (with the exception of first bunch);
- longitudinal wakefield equal zero $E_z=0$ in regions, occupied by bunches (with the exception of first bunch).

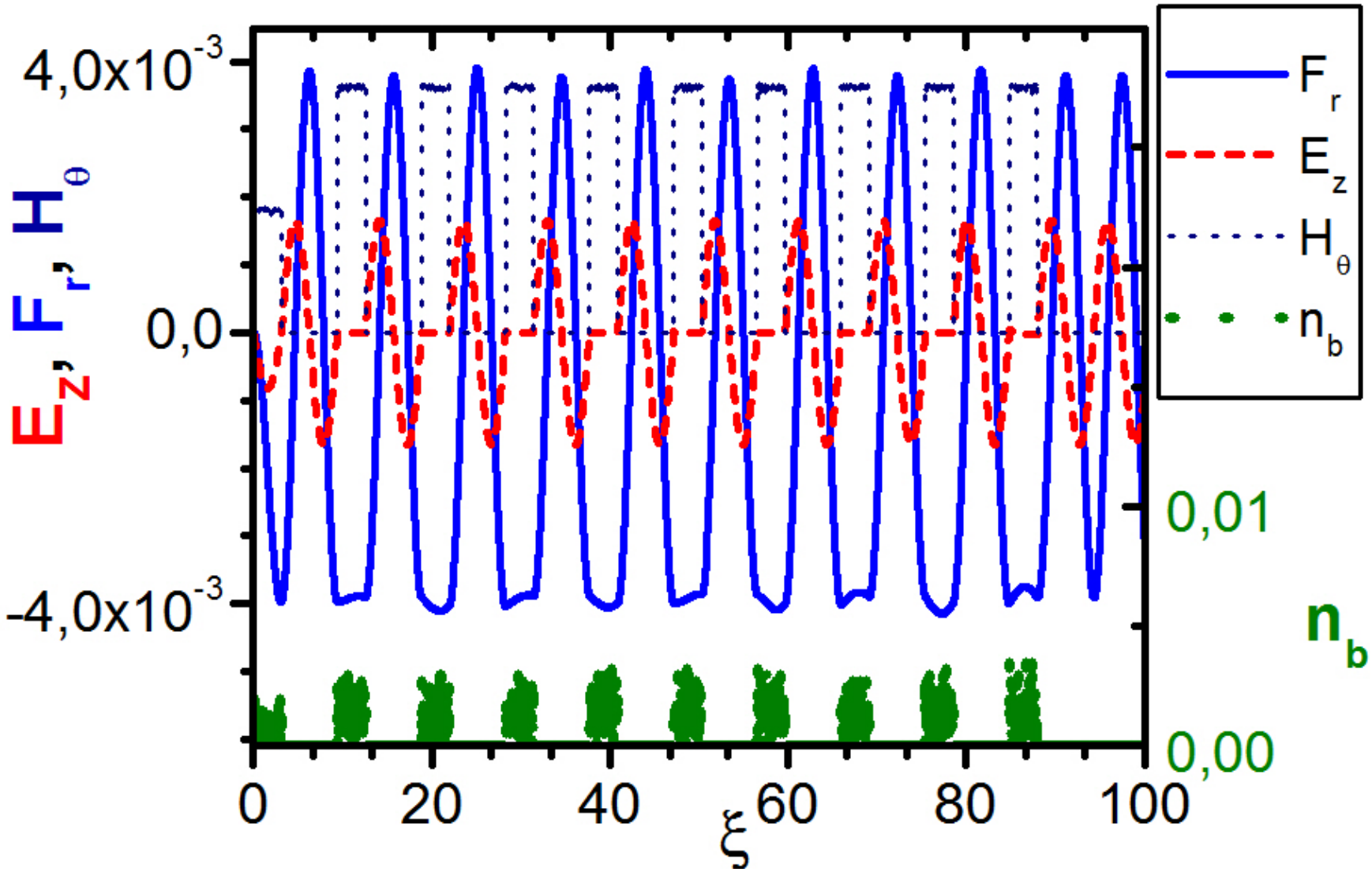
These results are right and for larger number of bunches.



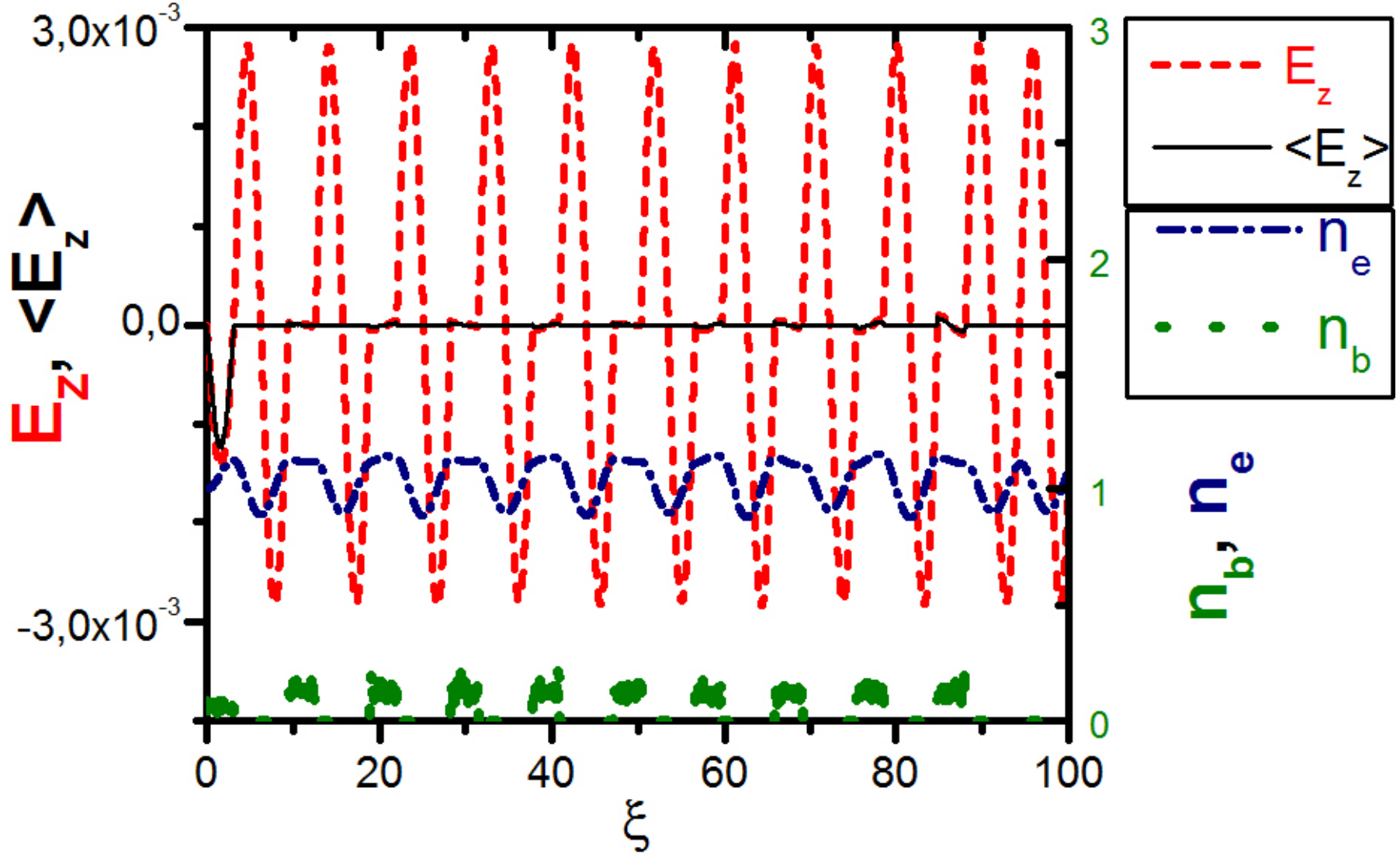
The density of ten bunches



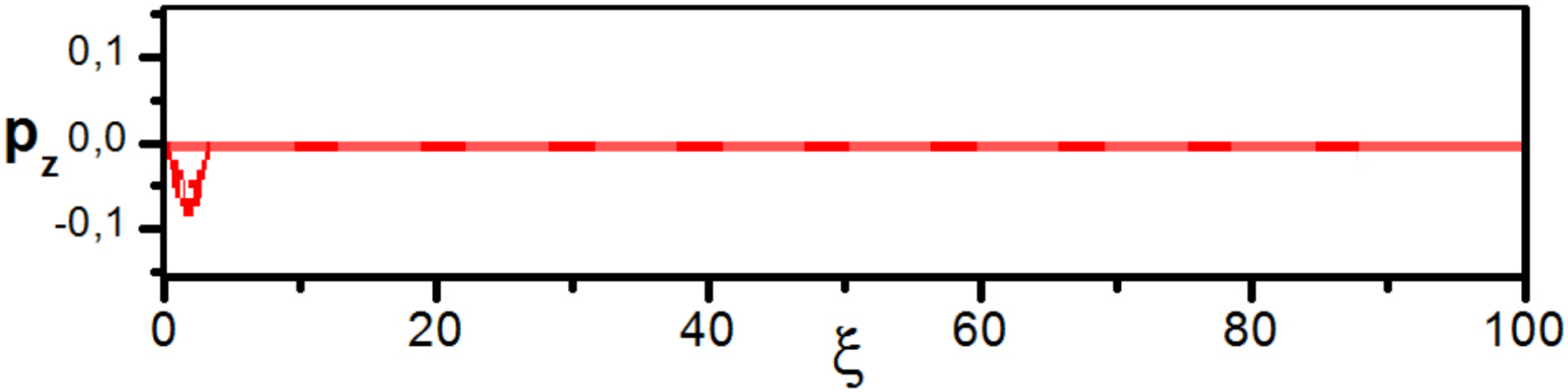
Plasma electron density n_e in wakefield, excited by ten bunches



The density of bunches n_b (dark green), longitudinal wakefield E_z (red), radial wake force F_r (blue) and manetic field H_θ (dark blue)



The density of bunches n_b (dark green), plasma electron density n_e (black), longitudinal wakefield E_z (red) and $<E_z>$ coupling rate of bunch with wakefield E_z (black)



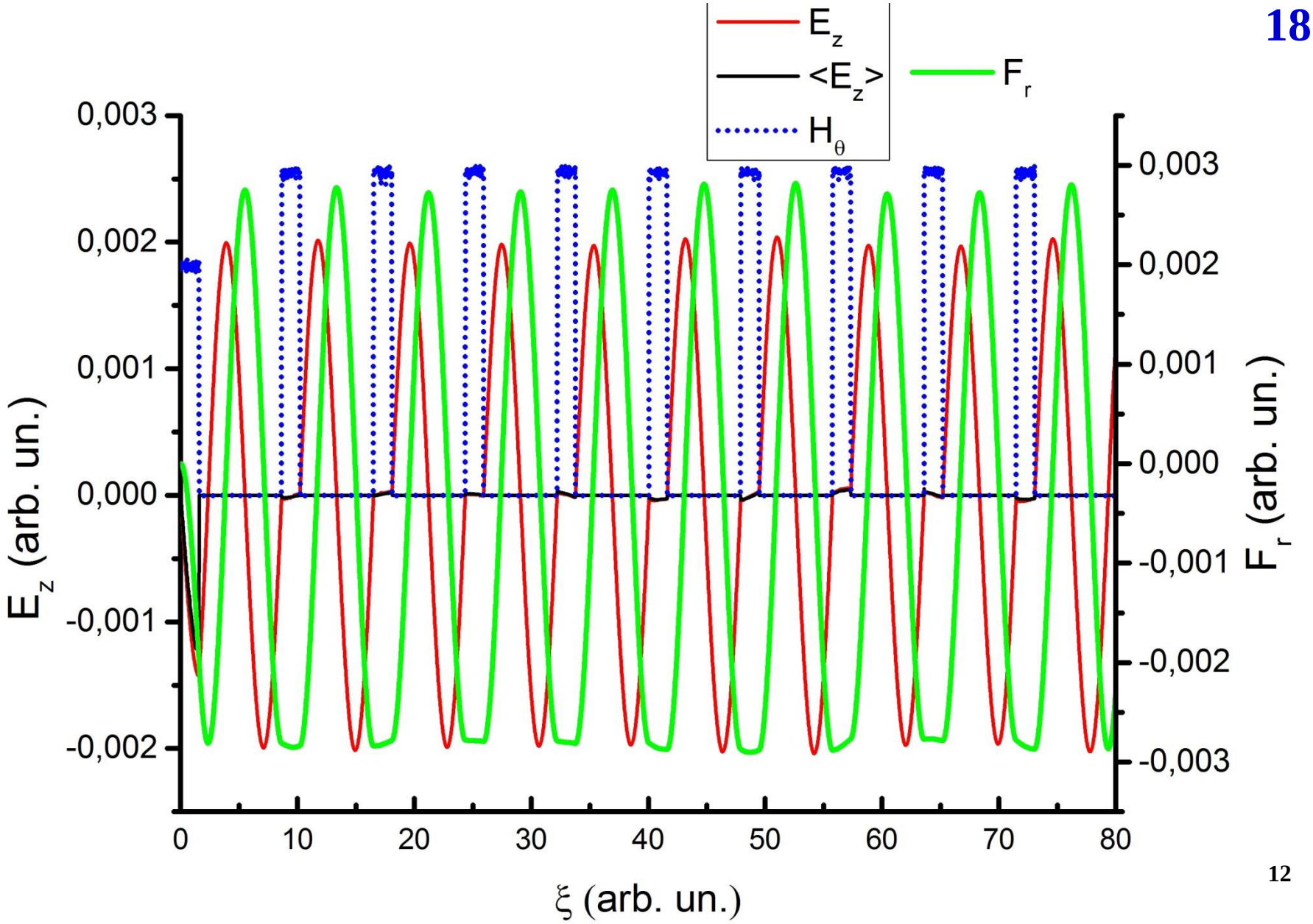
Change of longitudinal momentum of bunches P_z at wakefield excitation. N is the number of wavelengths

There is the 2nd type of plasma lens with homogeneous and identical focusing.

The second type of lens has the following set of parameters:

- **the charge of all bunches is in $\sqrt{2}$ times larger than the charge of the 1st bunch.**
- **The interval between the bunches is $(n+1/8)\lambda$, n=1, 2, …**

Only the 1st bunch is in the finite decelerating field. Other bunches are in the zero longitudinal electric field. only the 1st bunch exchanges energy with the wakefield.



Dependences for the 2nd lens type (10 bunches)

CONCLUSIONS

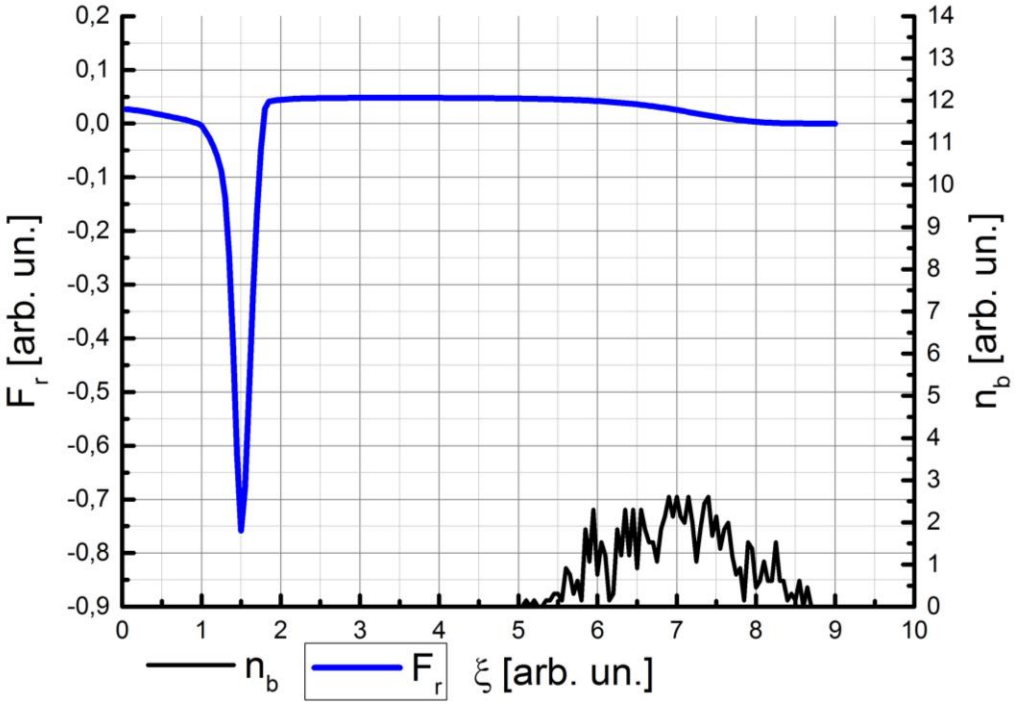
- **Almost all bunches of sequence can be focused identically and uniformly.**
- **it is necessary that bunches have lengths, equal λ/2, the charge of 1-st bunch equals half of the charges of the other bunches, the distance between them equals 1.5λ.**

(or the conditions for the second lens type)

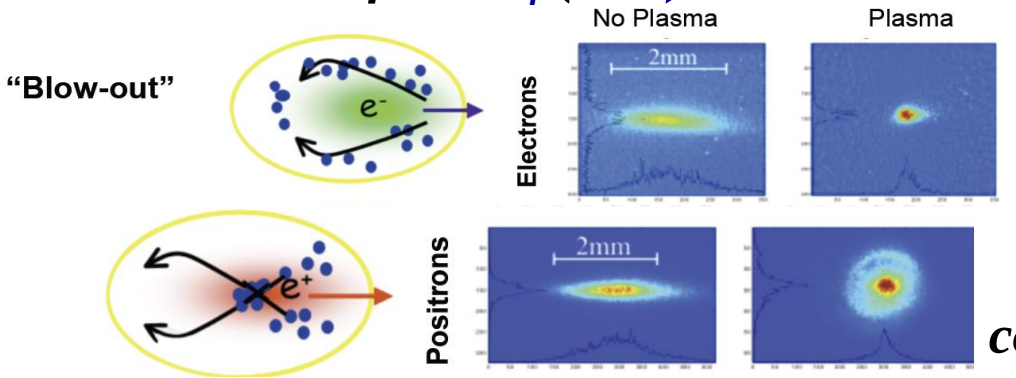
- **It is shown that only 1-st bunch is in finite $E_z \neq 0$. Other bunches are in zero longitudinal electrical wakefield $E_z=0$. Hence the 1-st bunch interchange by energy with wakefield.**
- **The subsequent bunches do not interchange by energy with wakefield and the amplitude of wakefield does not change along sequence.**

- **Radial wake force F_r in regions, occupied by bunches, is approximately constant along bunches.**

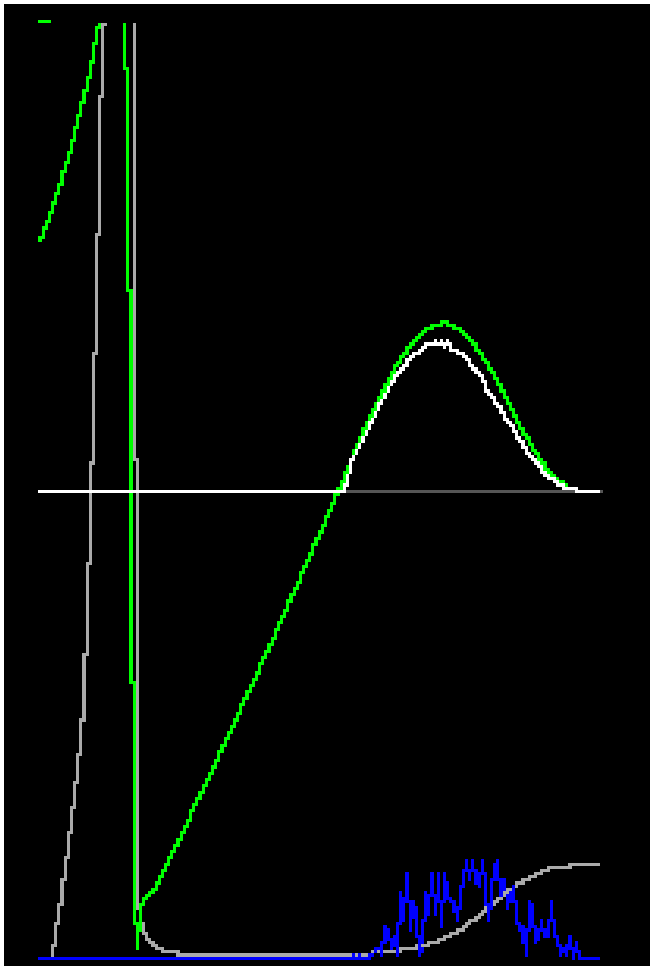
Bad Focusing of Long Positron Bunch in Blow-out Regime



The density of bunches n_b (black) and radial wake force F_r (blue)



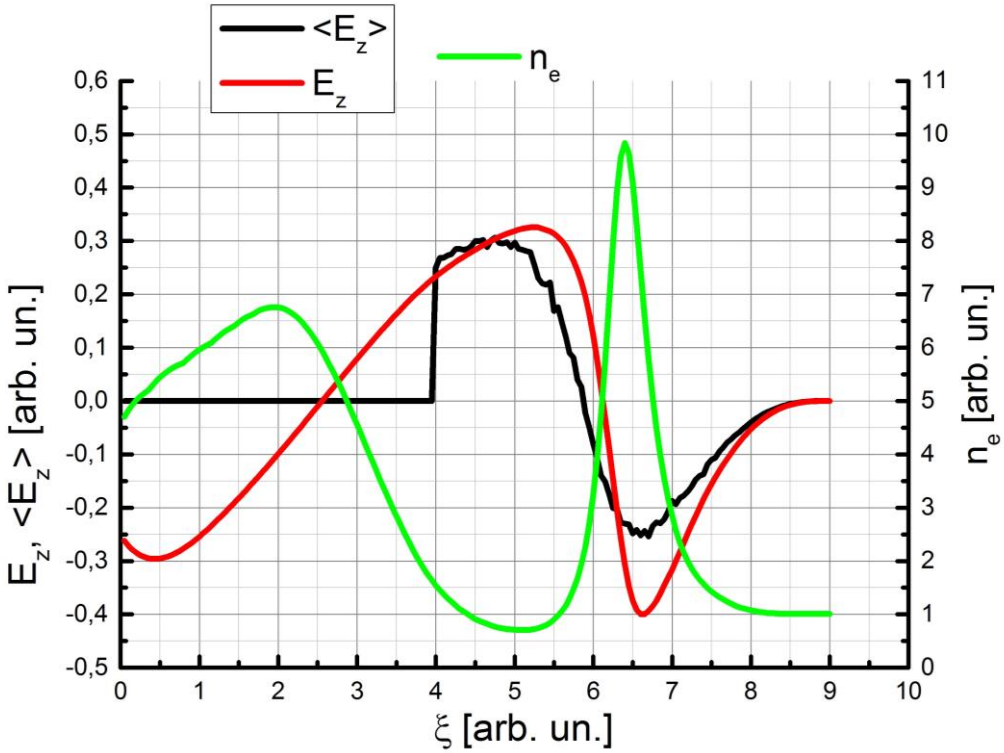
Phys. Rev. Lett. 90. 205002 (2003),
Phys. Rev. Lett. 101. 055001 (2008)



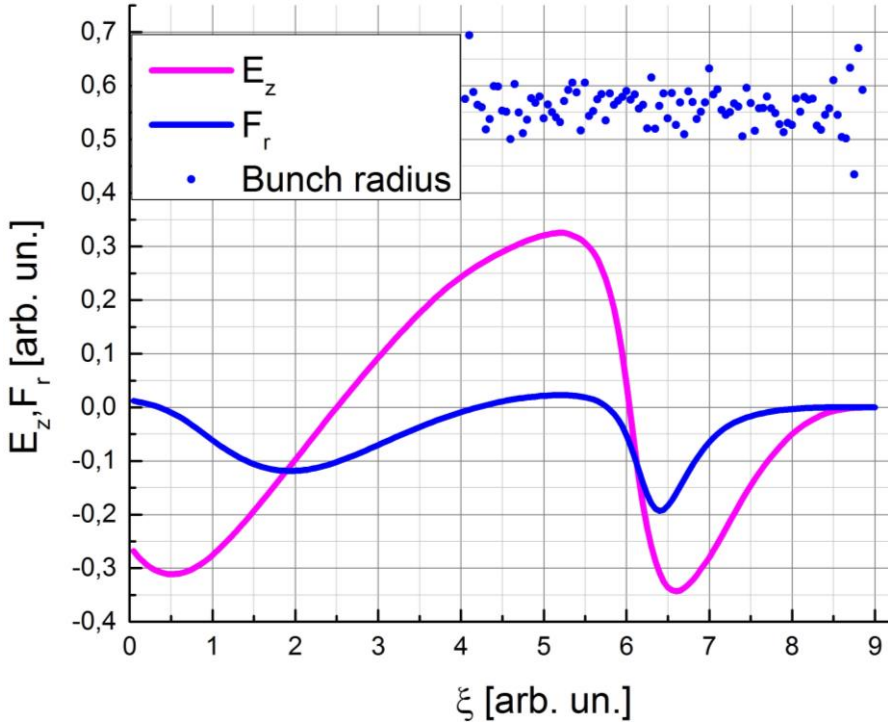
The density of bunches n_b (blue), longitudinal wakefield E_z (green), $\langle E_z \rangle = \int dr\, r\, E_z n_b / \int dr\, r n_b$ (white) coupling rate of bunch with wakefield E_z and density of plasma electrons n_e (gray)

SLAC

Bad Focusing of Long Positron Bunch in Blow-out Regime



The longitudinal wakefield E_z (red), $\langle E_z\rangle = \int dr\, r\, E_z n_b / \int dr\, r n_b$ (black) coupling rate of bunch with wakefield E_z and density of plasma electrons n_e (gray)



The longitudinal wakefield E_z (red) and radial wake force F_r (dark blue)

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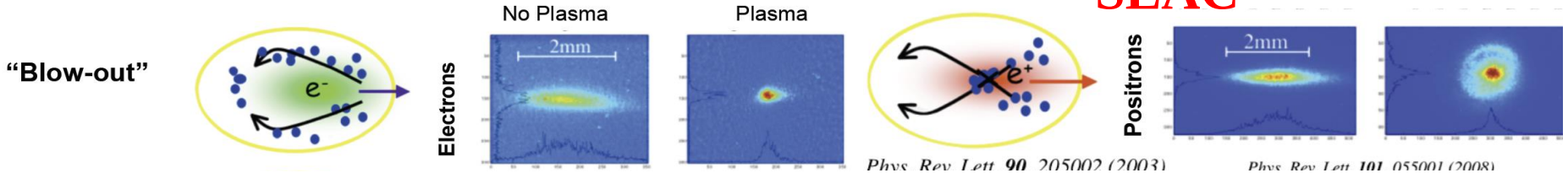
SLAC



Phys. Rev. Lett. 90. 205002 (2003), Phys. Rev. Lett. 101. 055001 (2008)

Thank you
for your attention