Optimal Field Shape, Accelerating Positron Bunch in Plasma Wakefield*

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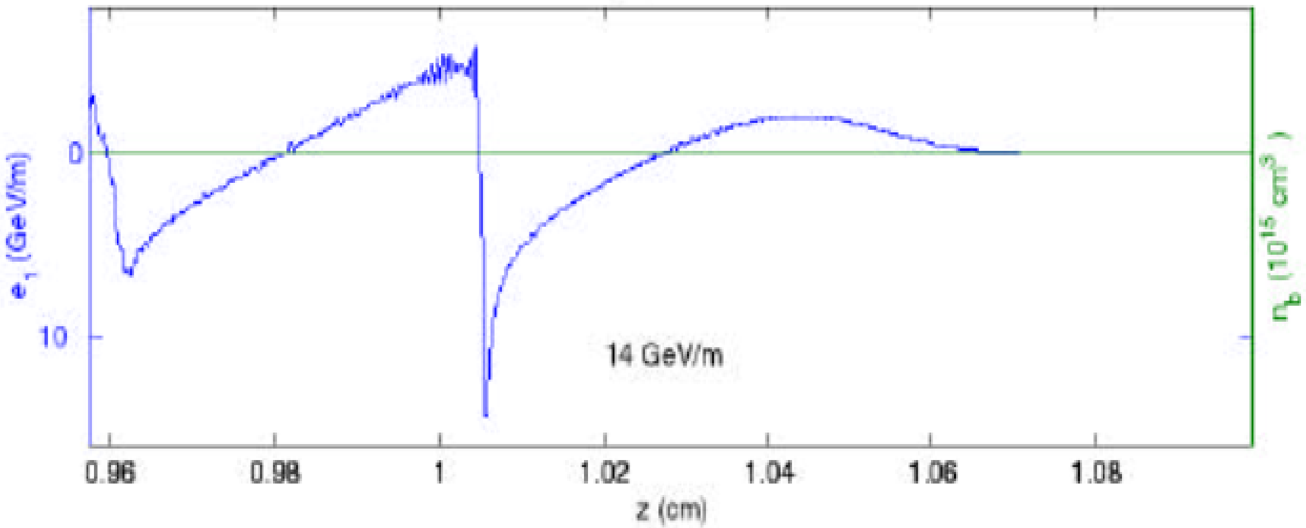
Accelerating Gradient Problem

In conventional accelerators, due to breakdown on metal walls, accelerating gradients are currently limited to about 100 MV / m (in reality, 20-30 MV / m).
Esarey E. et al. 2009

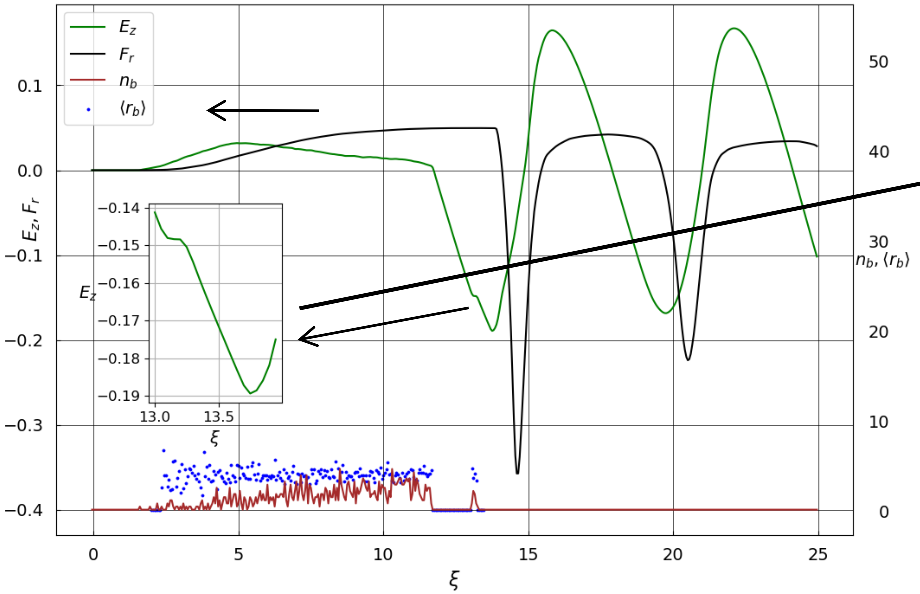


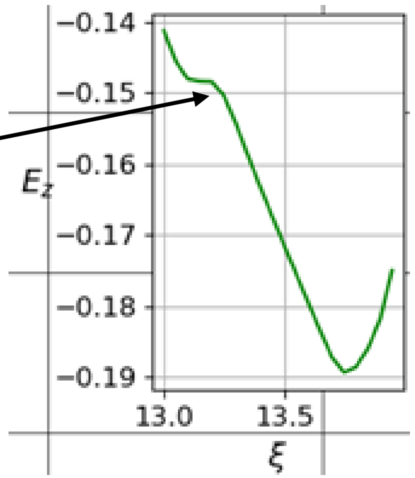
Plasma wakefield accelerators are capable of withstanding accelerating gradients up to 100 GV / m.
Leemans W.P. et al. 2014; Gonsalves A.J. et al. 2019; Blumenfeld I. et al. 2007.

High-quality Accelerated Beams

Beam acceleration occurs in dense plasma → Dynamic electromagnetic fields appear in plasma → These fields tend to focus the beam.

Over the entire length of the accelerated beam, it is necessary to achieve : $E_z(z) = const$.



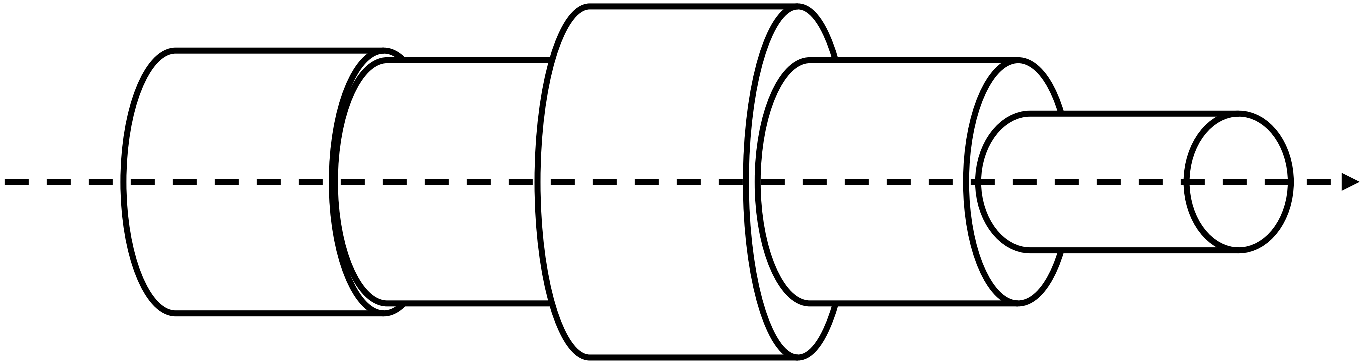


$E_z(z) = const$ – all electrons are accelerated by the same acceleration.

The Principle of Building a Bunch-Witness

The assumption of long witnesses with a constant field along its entire length.

Each piece of long witness creates a shelf locally, in its area.



Schematic view of a witness bunch made of pieces of constant density.

The method for finding the required distribution for a witness bunch is to achieve a linear field distribution, for each piece of the bunch independently (the previous parts of the bunch should not significantly affect the next)

Obtaining a Small Witness-Bunch, for a Very Long Driver-Bunch

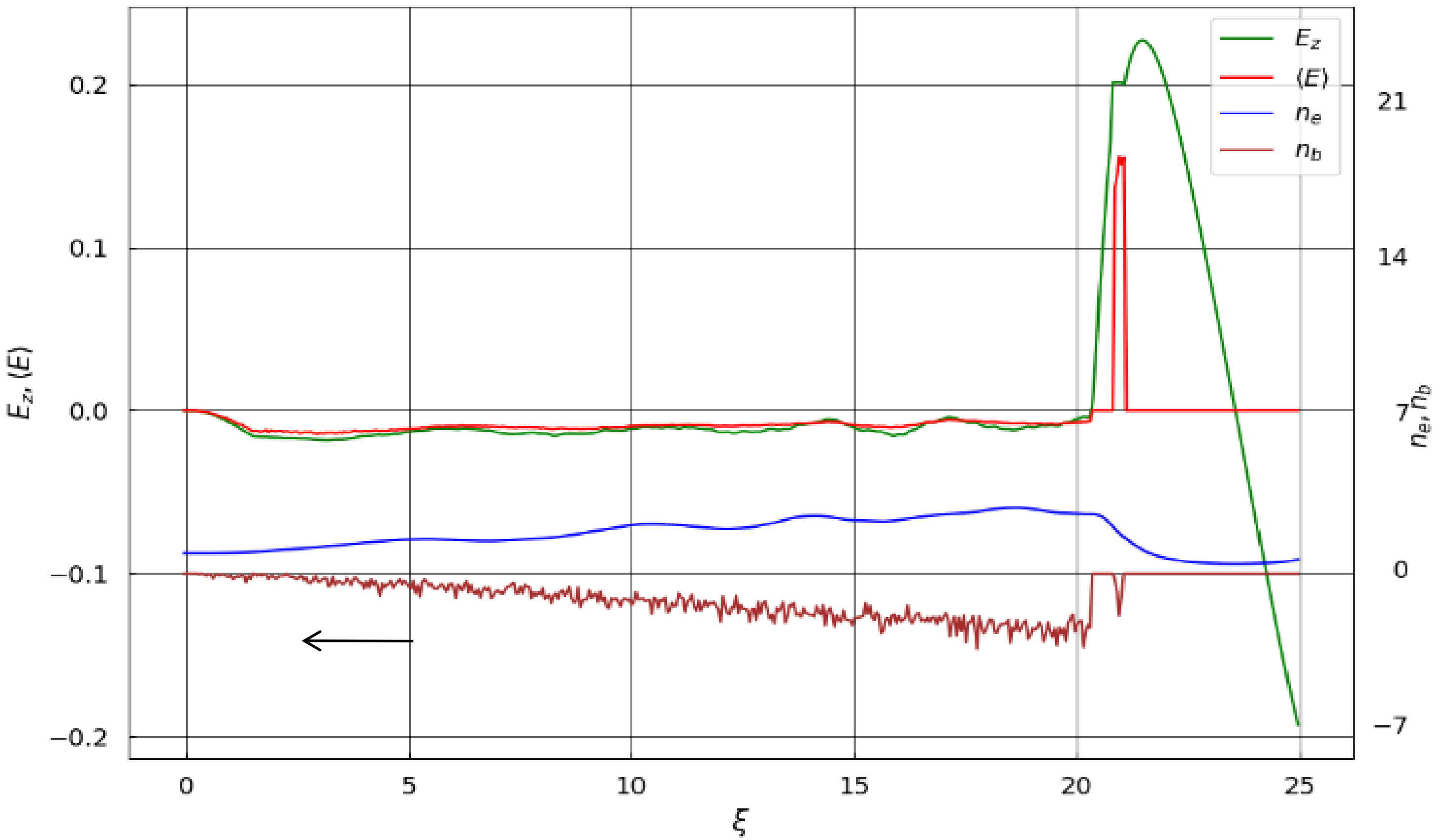


Figure 1: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of bunch-driver is equal to 3.8 of wave length. The maximum current of bunch-driver is equal to I_b=2.04kA. The maximum current of bunch-witness is equal to I_b=1.326 kA.

Obtaining a Small Witness-Bunch, for a Small Driver-Bunch

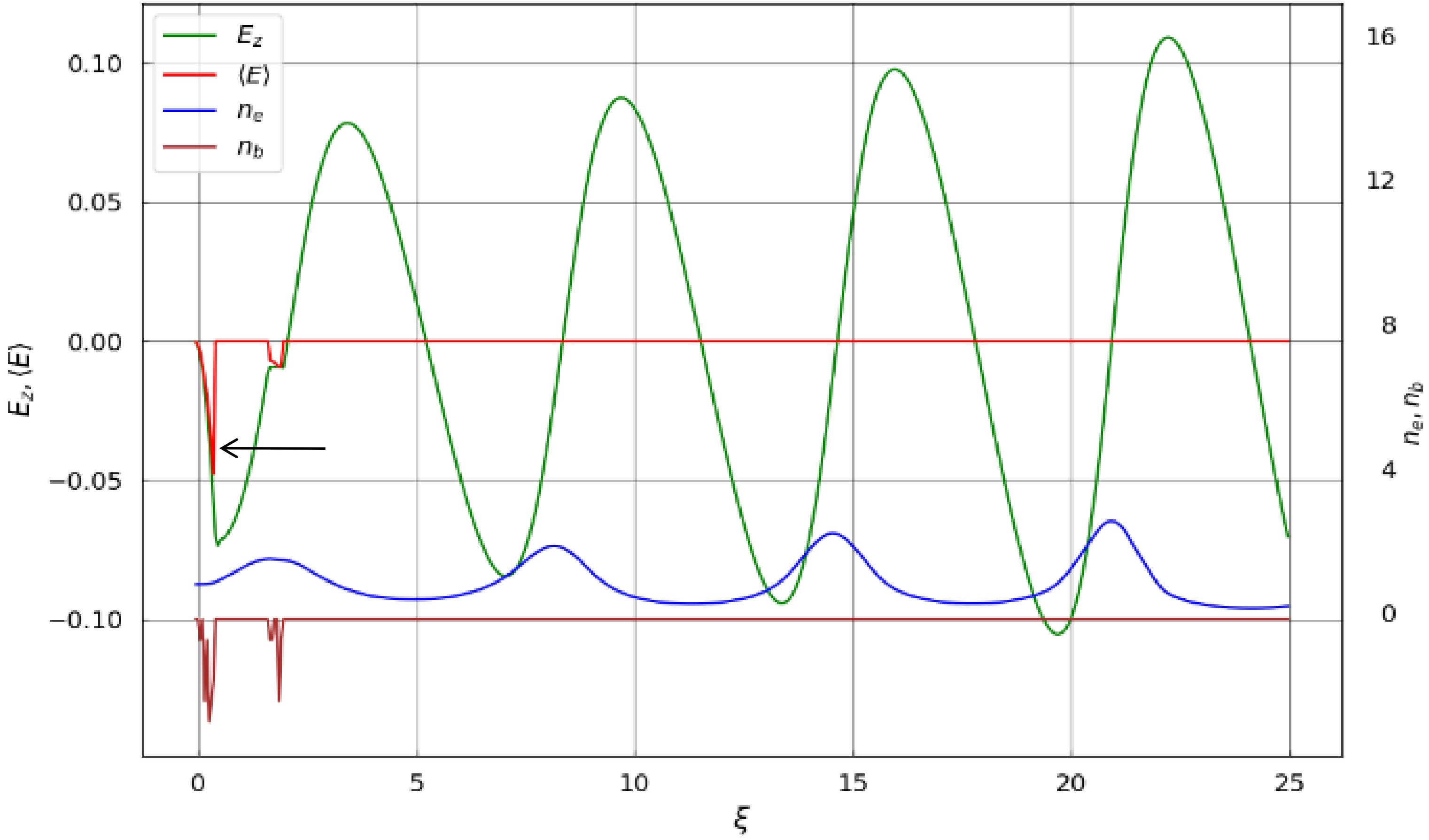


Figure 2: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by the second bunch, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.09 of bubble length. The maximum current of bunch-driver is equal to I_b=2 kA. The maximum current of the second bunch is equal to I_b=1.6 kA.

Obtaining a Long Witness-Bunch, for a Small Driver-Bunch

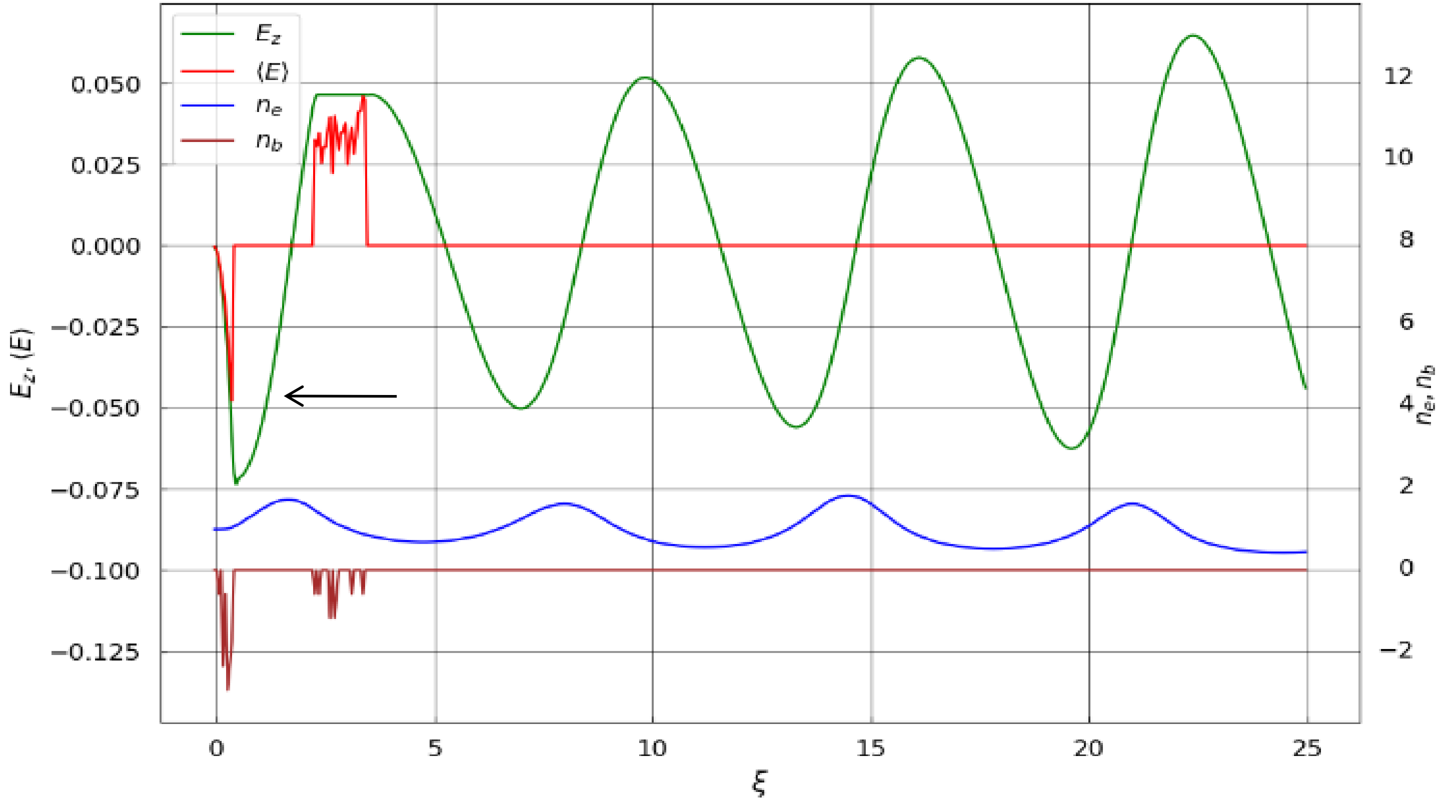


Figure 3: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.09 of bubble length. The maximum current of bunch-driver is equal to I_b=2 kA. The maximum current of bunch-witness is equal to I_b=0.4 kA.

Obtaining a Very Long Witness-Bunch, for a Small Driver-Bunch

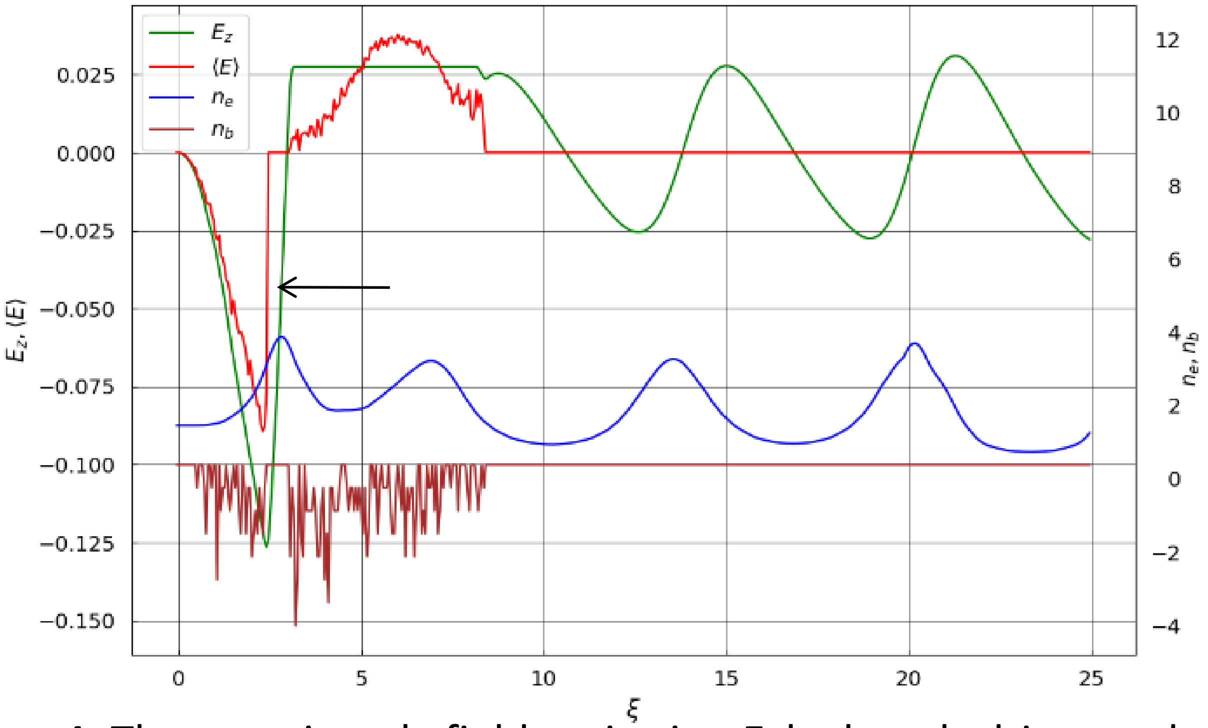


Figure 4: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.3 of bubble length. The maximum current of bunch-driver is equal to I_b=1 kA. The maximum current of bunch-witness is equal to I_b=1.19 kA.

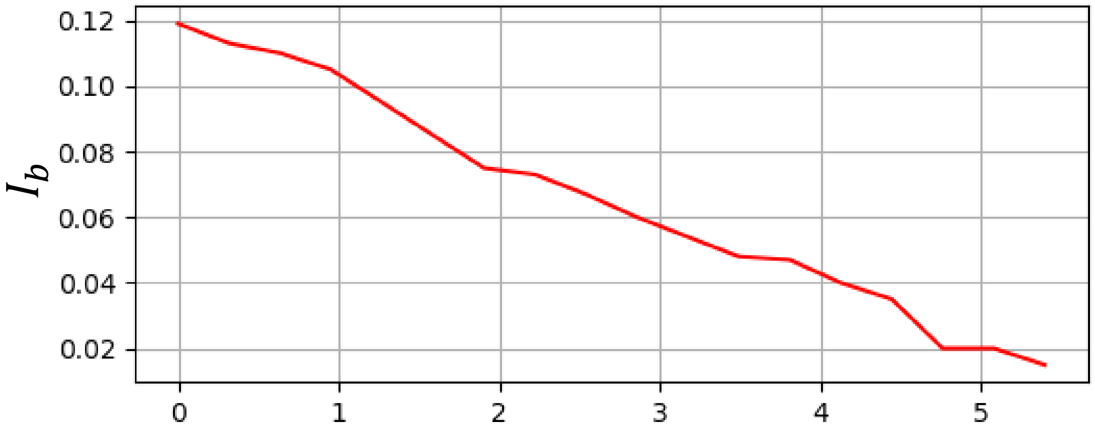


Figure 4a: Current distribution for a witness bunch. Dimensionless parameter, measured in 10 kA.

Simulation results

Figs. 1 - 2 show small positron witness-bunches with large and small transformer ratios, respectively (the transformer ratio is the ratio of the maximum accelerating field in the witness-bunch to the maximum decelerating field in the driver-bunch region). It can be seen that for a very long driver, it is possible to achieve not only a self-consistent field of plateau type, in the bunch-witness region, but also a very large transformer ratio, which, in fact, is responsible for the degree of acceleration.

Figs. 3 - 4 show the simulation results for positron witness-bunches of maximum length for driver-bunches of various lengths. It is seen that in both cases the accelerated witness-bunches occupy a rather large area of the bubble. However, the transformer ratio does not reach unity.

Conclusions

The formation of a longitudinal accelerating field for positron witness-bunches of various lengths is investigated.

Very long positron witness-bunches were obtained, which form a self-consistent accelerating field, such as a plateau.

For this system, the assumption about the local influence of small sections of the positron witness-bunch on the longitudinal accelerating field was confirmed.

References

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THANK YOU FOR YOUR ATTENTION