Obtaining Accelerated Electron Bunch of Good Quality in Plasma Wakefield Accelerator*

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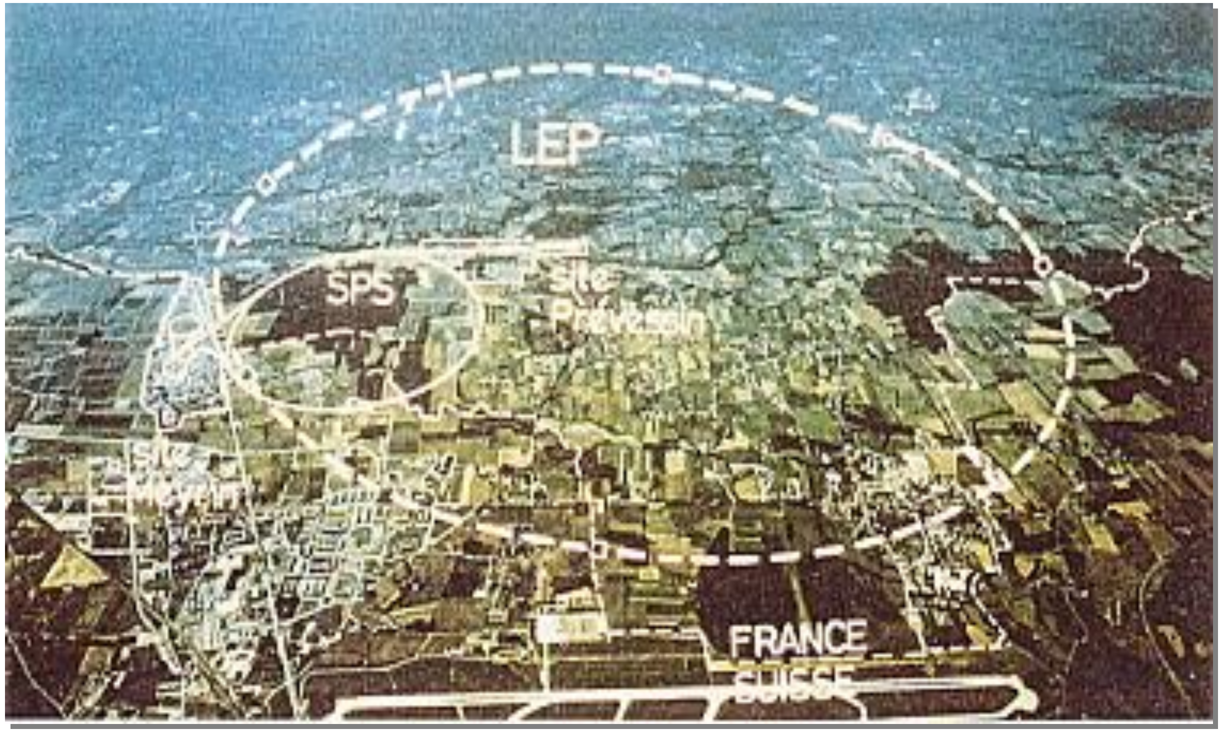
Problems of Modern Accelerators

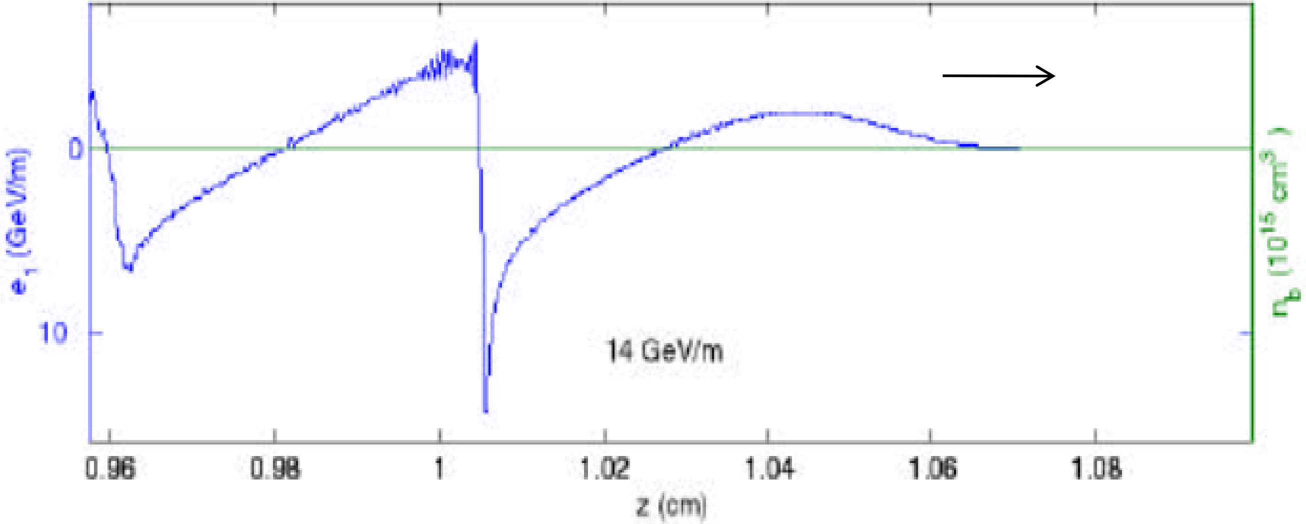


Large Hadron Collider (LHC)
Circumference of the main accelerating ring - 27 km
Maximum energy - 6.5 TeV

Big sizes
↓
High cost
↓
Cause?
↓
Small acceleration gradients

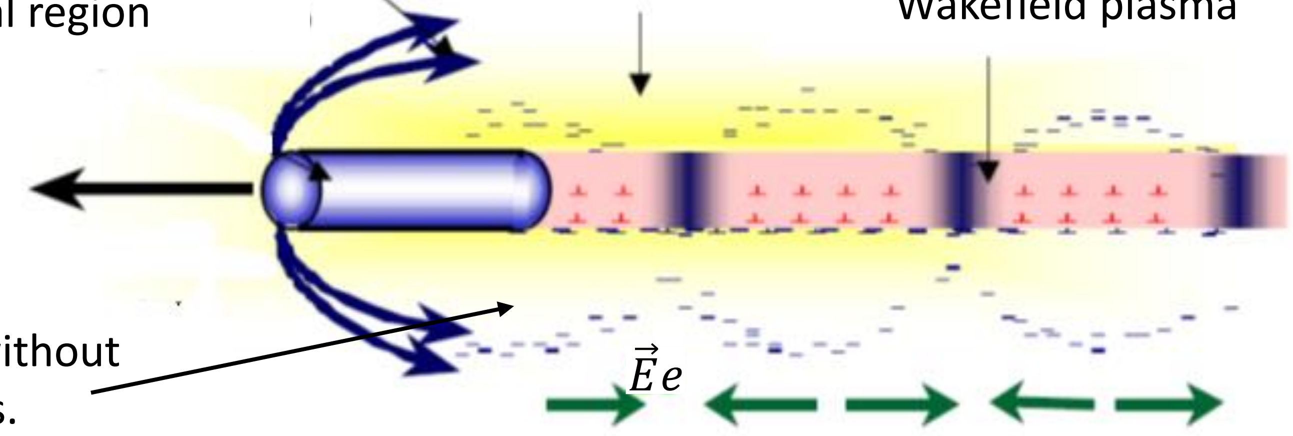
Accelerating Gradient Problem

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

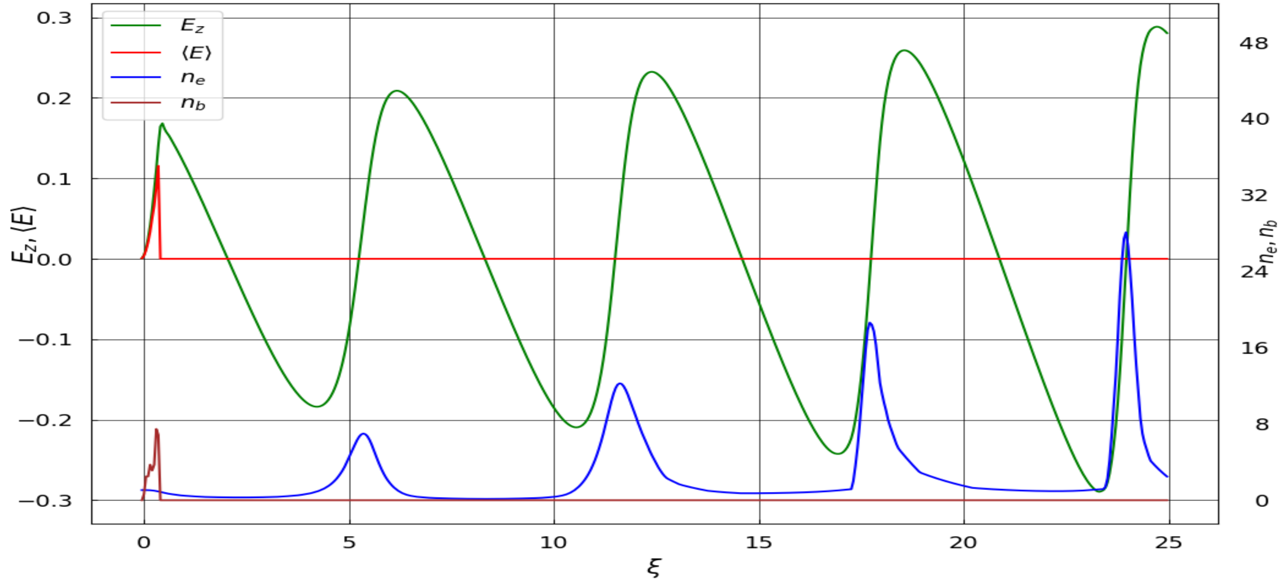


Plasma wakefield accelerators are capable of withstanding accelerating gradients up to 100 GV / m.
Leemans W.P. et al. 2014; Gonsalves A.J. et al. 2019; Blumenfeld I. et al. 2007.

The Operating Principle of Wakefield Accelerator



Excitation of the wakefield by an electron bunch.

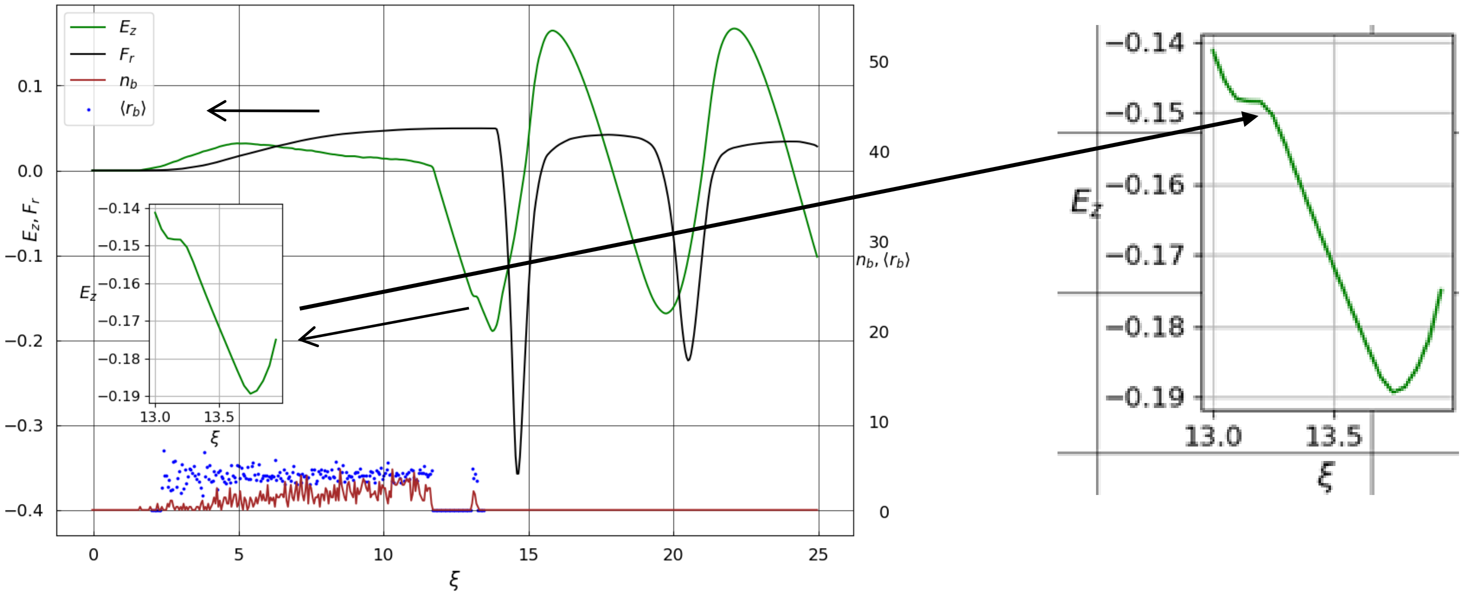


An example of the excitation of such a field by a short electron bunch, with a charge distributed along the cosine, from minimum to maximum values.

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 : $E_z(z) = const$.



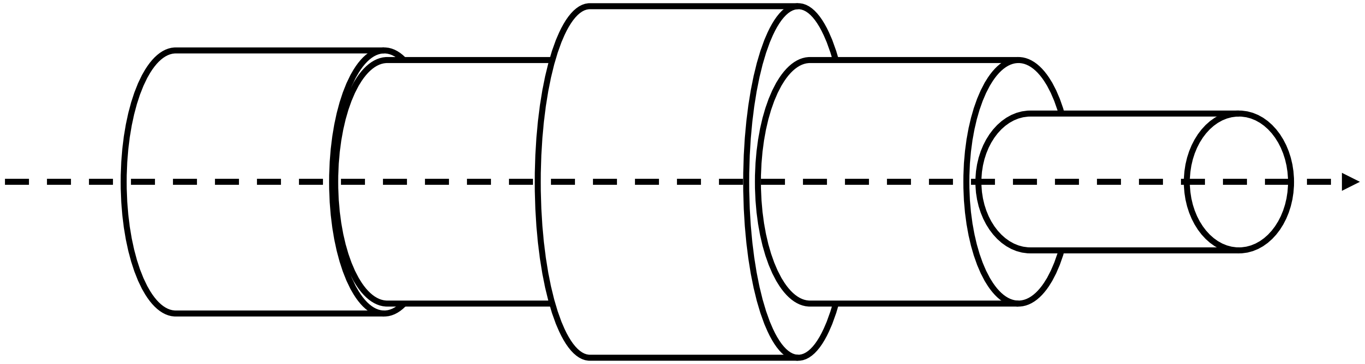
$E_z(z) = const$ – all electrons are accelerated by the same acceleration.

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)

Modeling a Short Driver and Long Witness Situation

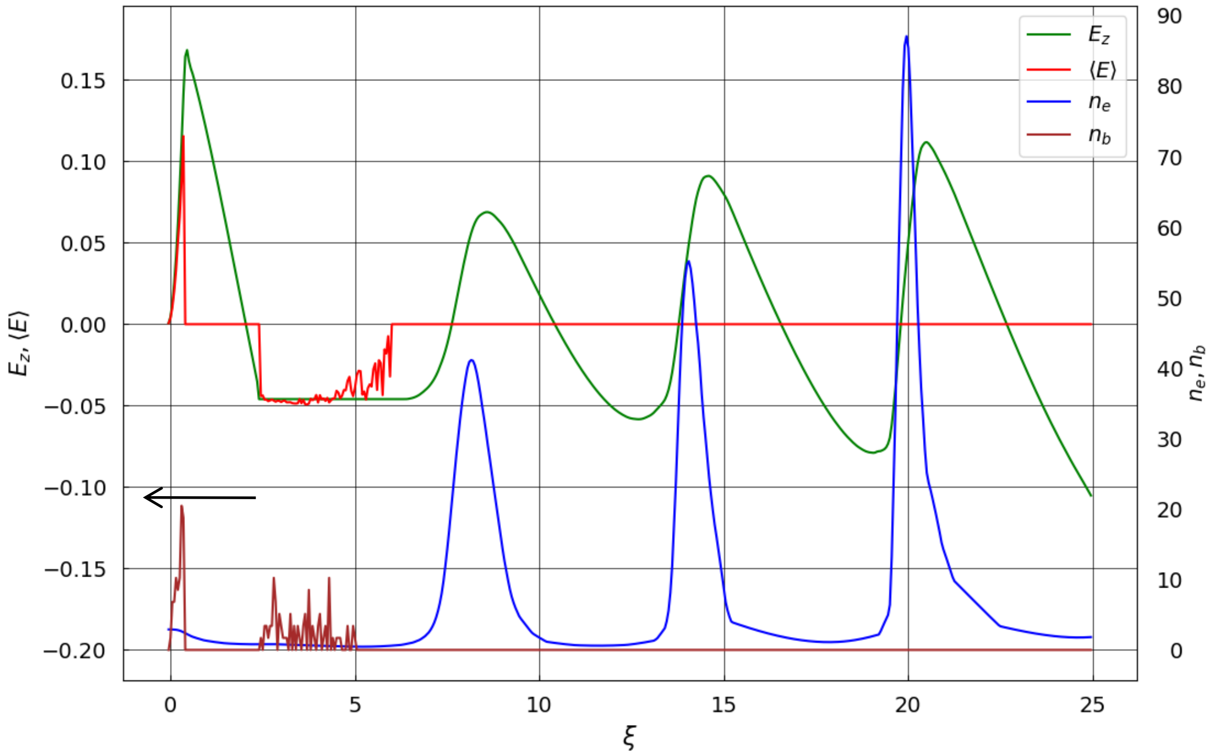


Figure 1: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.06 of bubble length. The maximum current of bunch-driver is equal to I_b = 5.015kA. The maximum current of bunch-witness is equal to I_b= 0.9 kA.

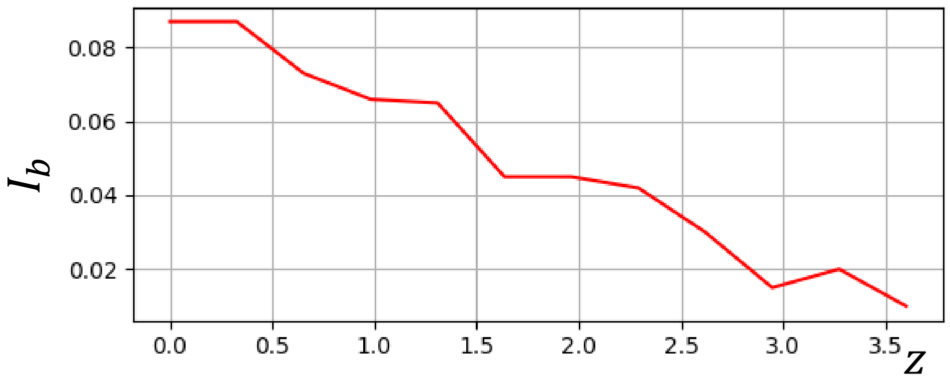


Figure 1a: Current distribution for a witness bunch. Dimensionless parameter, measured in 10 kA.

Modeling a Short Driver and Long Whitness Situation

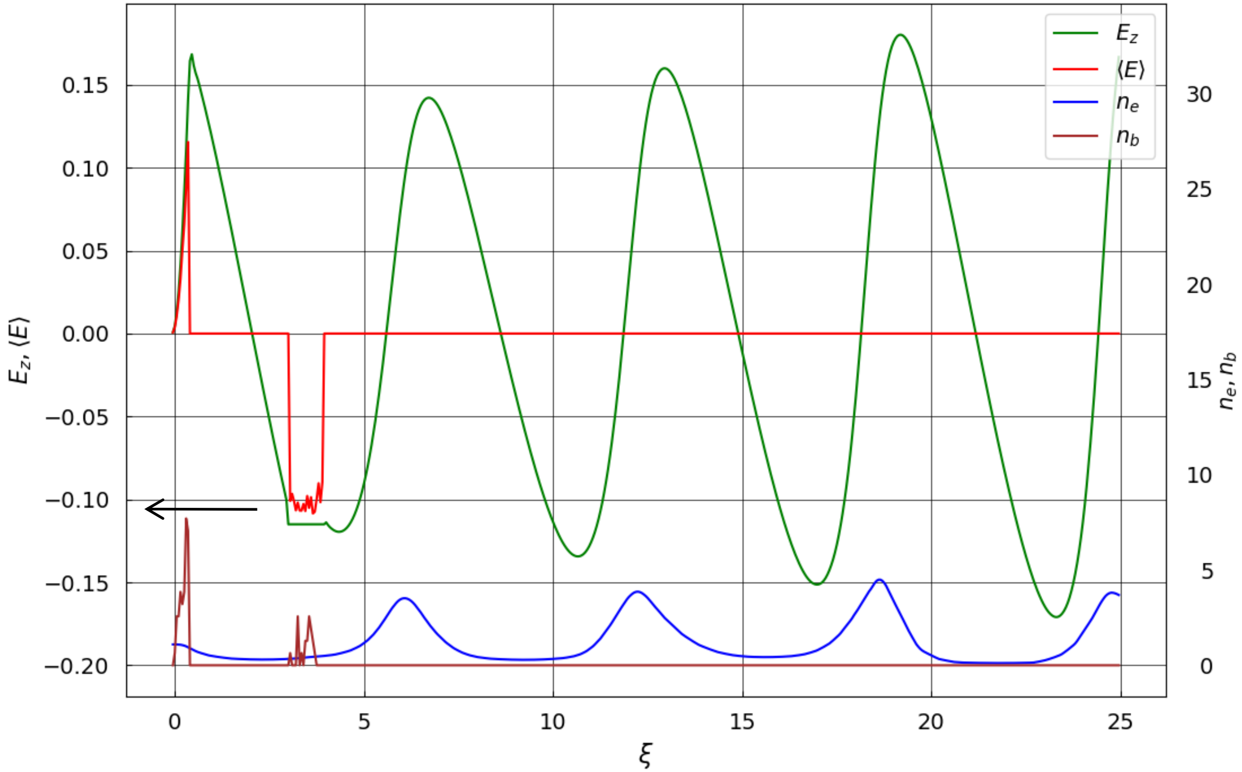


Figure 2: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.06 of bubble length. The maximum current of bunch-driver is equal to I_b= 5.015 kA. The maximum current of bunch-witness is equal to I_b= 0.7 kA.

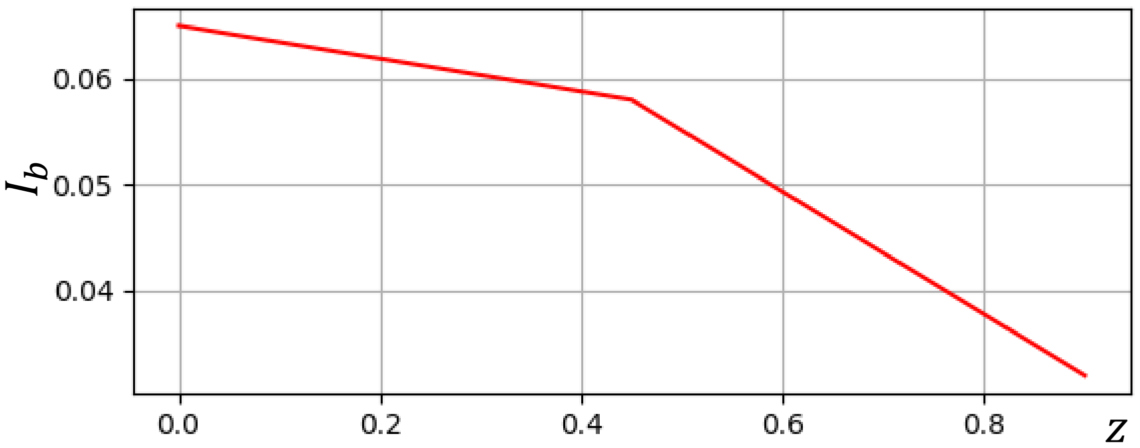
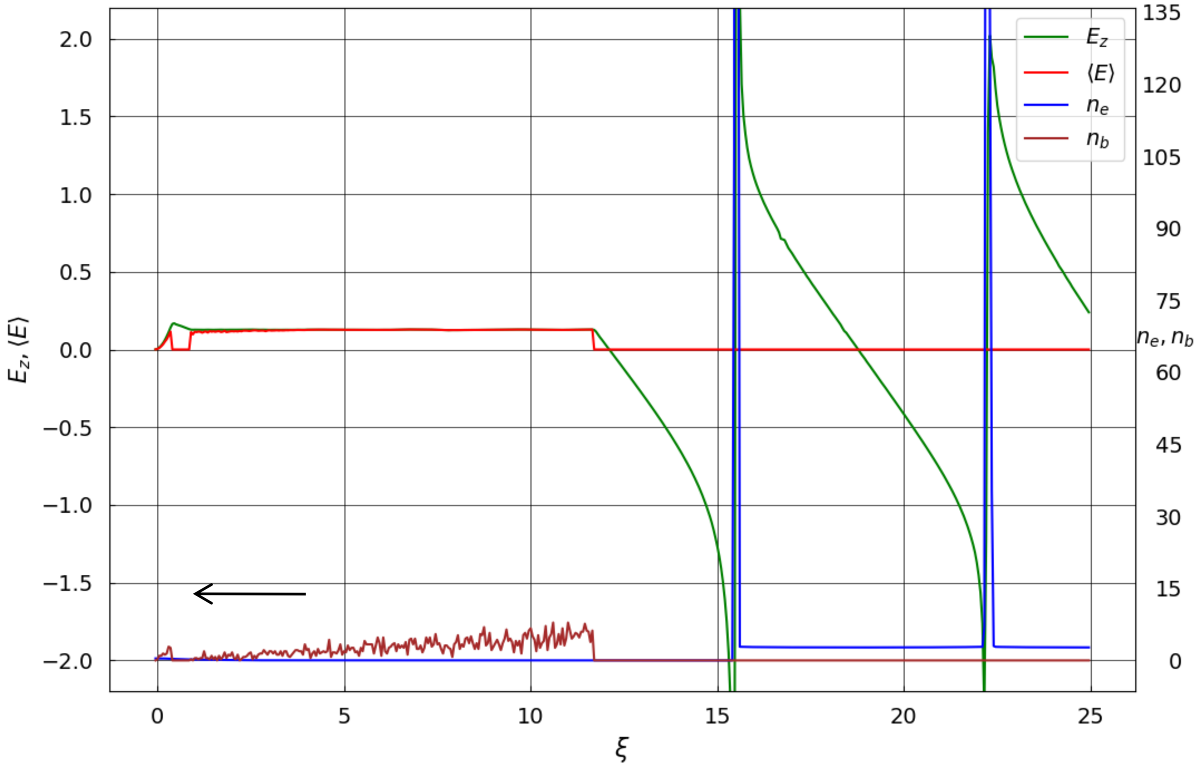


Figure 2a: Current distribution for a witness bunch. Dimensionless parameter, measured in 10 kA.

Modeling a Long Driver Situation



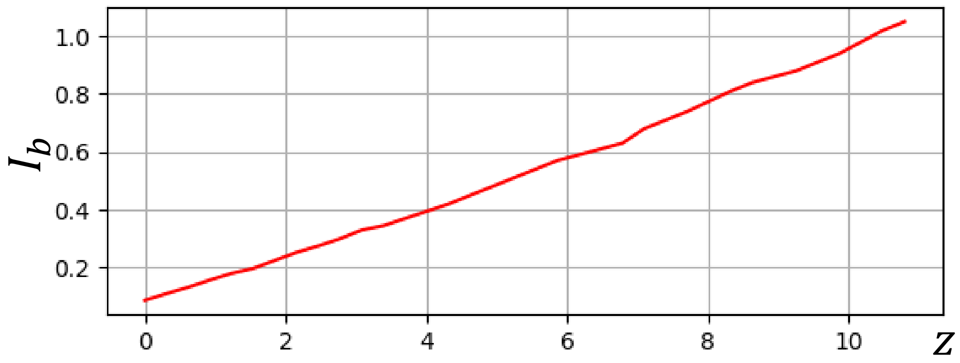


Figure 3a: Current distribution for a driver bunch. Dimensionless parameter, measured in 10 kA.

Figure 3: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-driver, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-precursor is equal to 0.06 of bubble length. The maximum current of bunch-precursor is equal to I_b= 5.015 kA. The maximum current of bunch-driver is equal to I_b= 11 kA.

Modeling the Situation of a Longer Driver and Long Witness

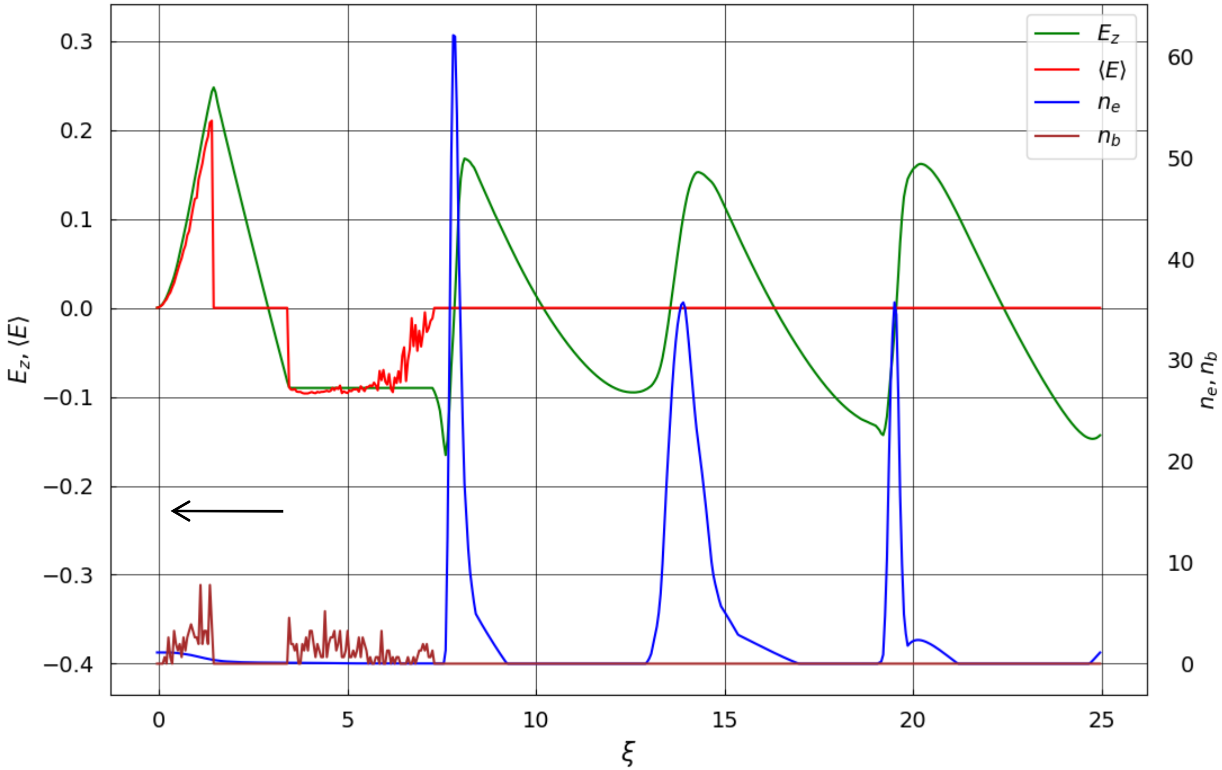


Figure 4: The on−axis wakefield excitation Ez by bunch−driver and plateau formation on Ez(ξ) by bunch−witness, ξ =z−Vbt. Densities of bunches nb on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch−driver is equal to 0.23 of bubble length. The maximum current of bunch−driver is equal to Ib=3 kA. The maximum current of bunch−witness is equal to Ib=1.5 kA.

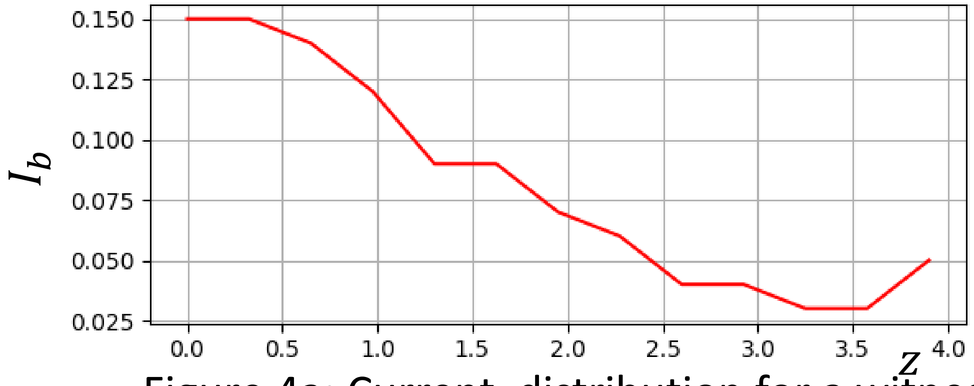
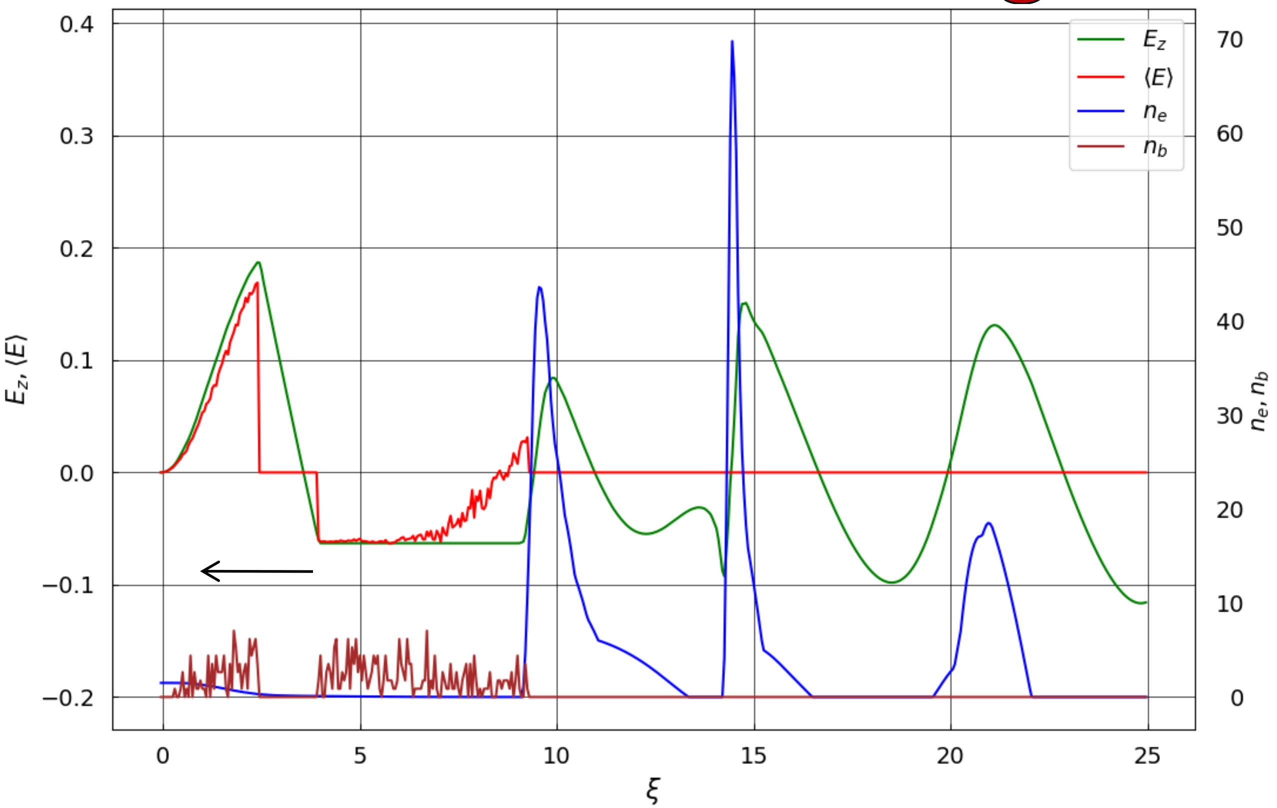


Figure 4a: Current distribution for a witness bunch. Dimensionless parameter, measured in 10 kA.

Modeling the Situation of an Even Longer Driver and Long Witness



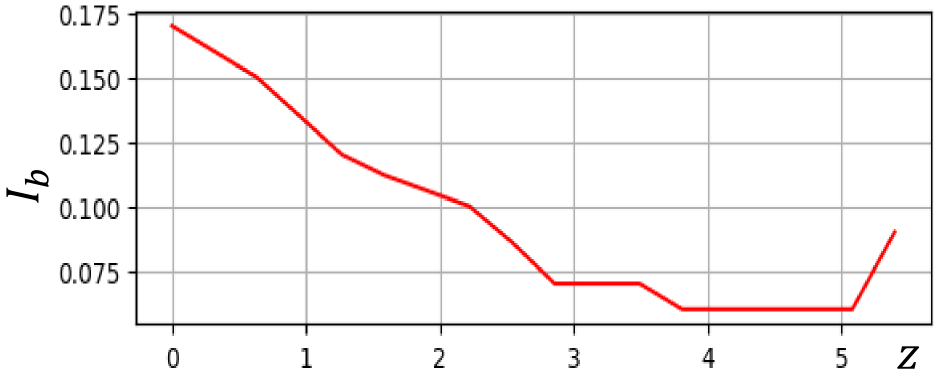


Figure 5a: Current distribution for a witness bunch. Dimensionless parameter, measured in 10 kA.

Figure 5: 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. 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 0.33 of bubble length. The maximum current of bunch-driver is equal to I_b= 2kA. The maximum current of bunch-witness is equal to I_b= 1.76kA.

Simulation results

We begin by considering a small bunch-driver. In Fig. 1, Fig. 2, one can see the appearance of a self-consistent accelerating field, a plateau type. It is clearly seen that the sign of the accelerating field in these cases is opposite to the sign of the decelerating field of the bunch-driver, when, as in Fig. 3, due to the fact that the bunch-precursor is extremely close to the main bunch-driver, the signs of the decelerating fields for both bunches are the same. Also, it can be noted that the maximum dimensions of the accelerated beam directly depend on the proximity to the bunch-driver.

Fig. 4, Fig. 5 show the obtained beams of maximum length, which form an accelerating wakefield, such as a plateau. It can be noted that the larger the bunch-driver is, the larger the bunch-witness can be obtained.

Conclusions

- Excitation of the wakefield in plasma by small bunches-drivers and its transformation by bunches-witness is considered
- The dependence of the transformer ratio on the length of the witness bunch was investigated for various driver bunches.
- For this system, the assumption about the local influence of small sections of the witness bunch on the longitudinal accelerating field was confirmed.

References

[1] S. Romeo, M. Ferrario, A.R. Rossi Phys. Rev. Accel. Beams. 23 (2020) 071301.

[2] T. Katsouleas et al. Particle Accelerators. 22 (1987) 81.

[3] V.I. Maslov et al. Problems of Atomic Science and Tech-nology. 6 (2020) 47.

[4] A.P. Sosedkin, K.V. Lotov Nucl. Instr. & Meth. in Phys. Res. A. 829 (2016) 350.

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