Wake fields effects in dielectric capillary

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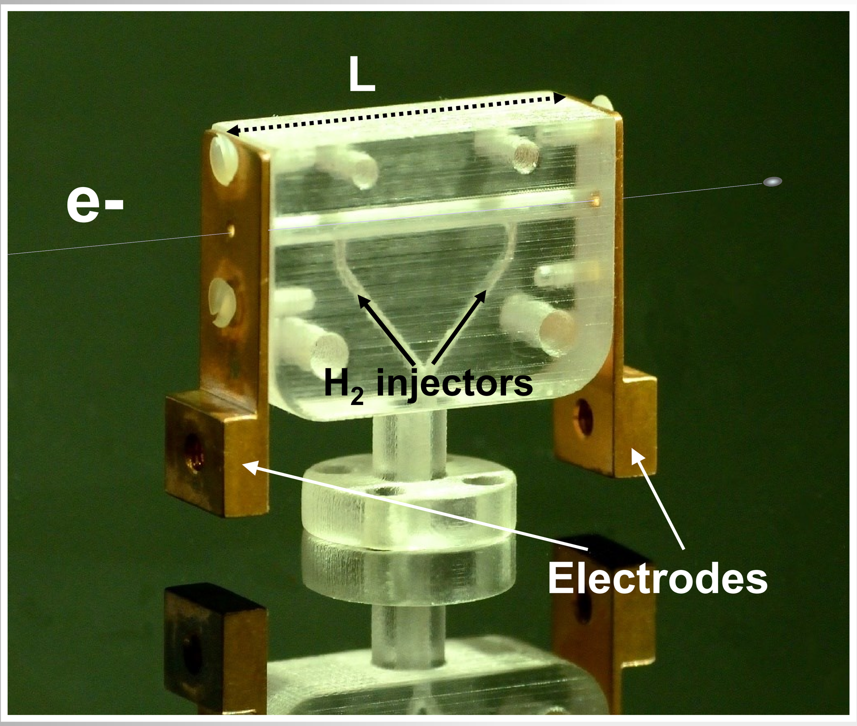
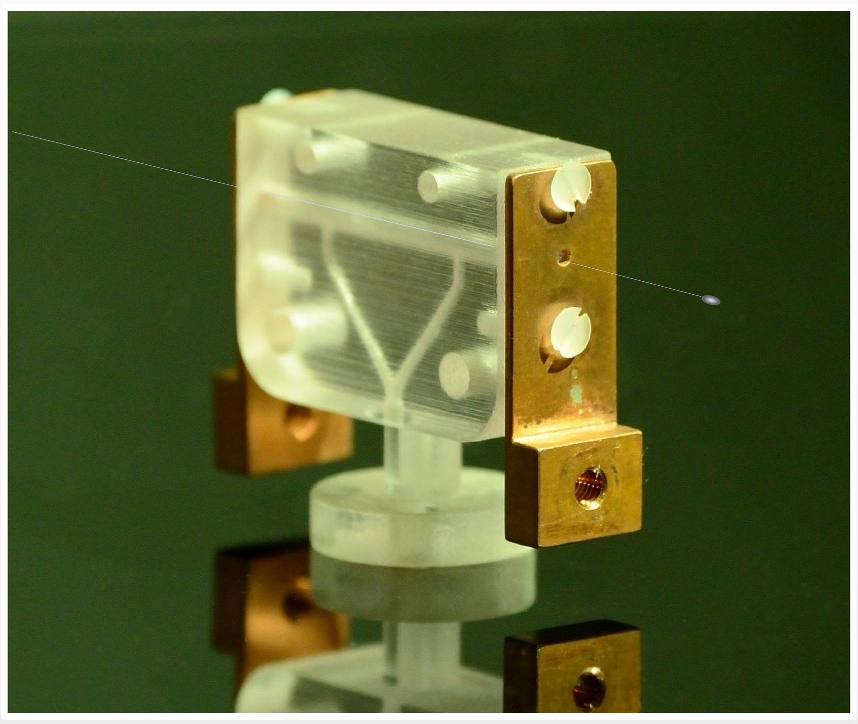
ABSTRACT

For plasma wake-field acceleration experiments (PWFA) that are foreseen at the SPARC_LAB test facility, we are going to use a gas-filled capillary plasma source composed of a dielectric capillary where the electron beam has to pass through it in order to achieve higher acceleration energies up to GeV level. In this acceleration scheme, wake fields produced by passing electron beams through dielectric structures can determine a strong beam instability that represents an important hurdle towards the capability to focus the high-current electron beam in the transverse plane. For this reasons, the estimation of the transverse wake-field amplitudes assumes a fundamental role in the implementation of the plasma wake-field acceleration. In this work, it will be presented a study to investigate which parameters affect the wake-field formation inside a cylindrical dielectric structure, both the capillary dimensions and the beam parameters, and it will be produced a quantitative evaluation of the longitudinal and transverse electric fields.

DIELECTRIC CAPILLARY





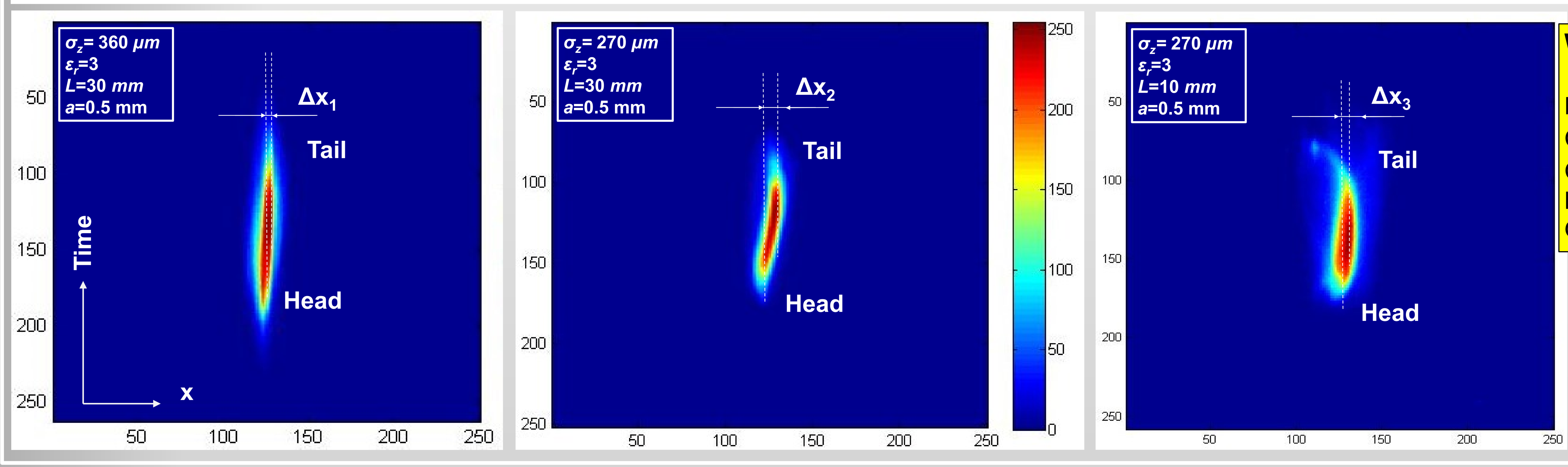
DIELECTRIC CAPILLARY

Lenght (L)	Internal radius (a)	External radius (b)	Permittivity (ε)
30 mm	0.5 mm	4 mm	3

We take into account the analysis of the wake fields acting on a single bunch that passes through the capillary in order to perform the dielectric wake-field acceleration (DWA). In this case, the wake fields will be generated by the single bunch and will act on the bunch itself, especially to the bunch's tail. The capillary used in our experimental set-up is a dielectric-lined cylindrical waveguide that is composed of a transparent plastic material. The inner radius is a=0.5, the length is L=30 mm and the dielectric constant εr=3.

EXPERIMENTAL MEASUREMENTS

Several experimental conditions have been considered in order to investigate the wake fields production as a function of both the beam parameters and the geometric features. The longer is the bunch, the smaller is the Wakefield's effect on the bunch itself. Also, the longer is the capillary, the larger is the Wakefield's effect on the bunch. The beam charge is 50 pC.



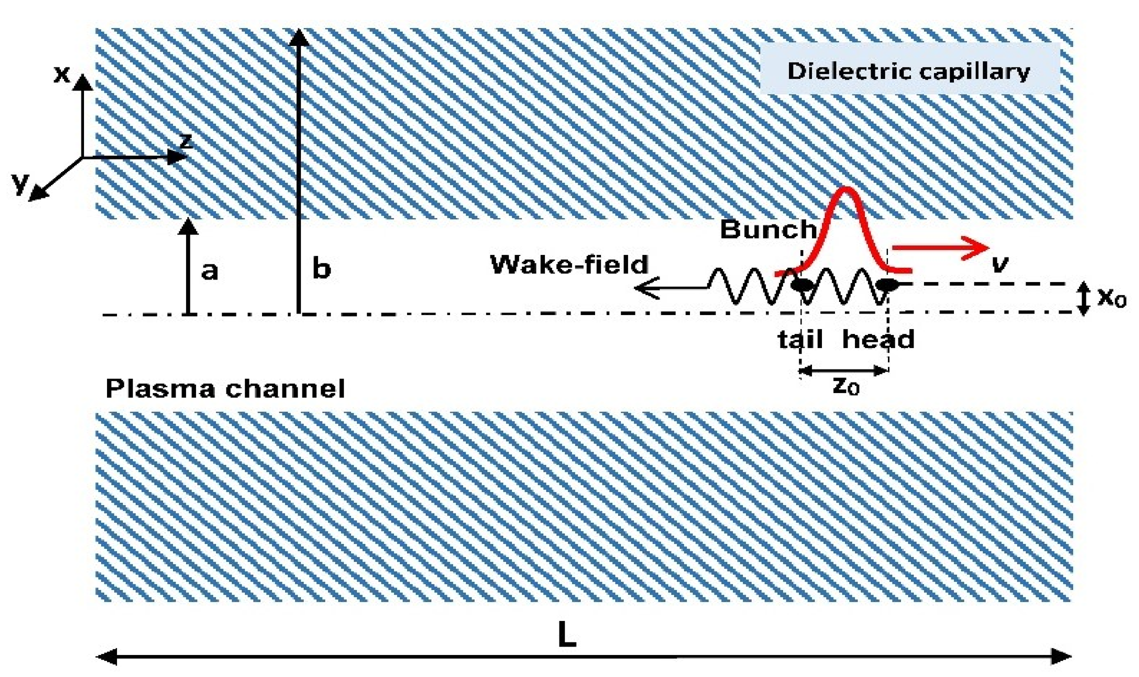
Wakefield's parameters:

Dielectric constant	ε_r
Capillary length	L
Channel radius	a
Bunch length	σ_z
Off-axis displacement	x_0

THEORETICAL MODEL

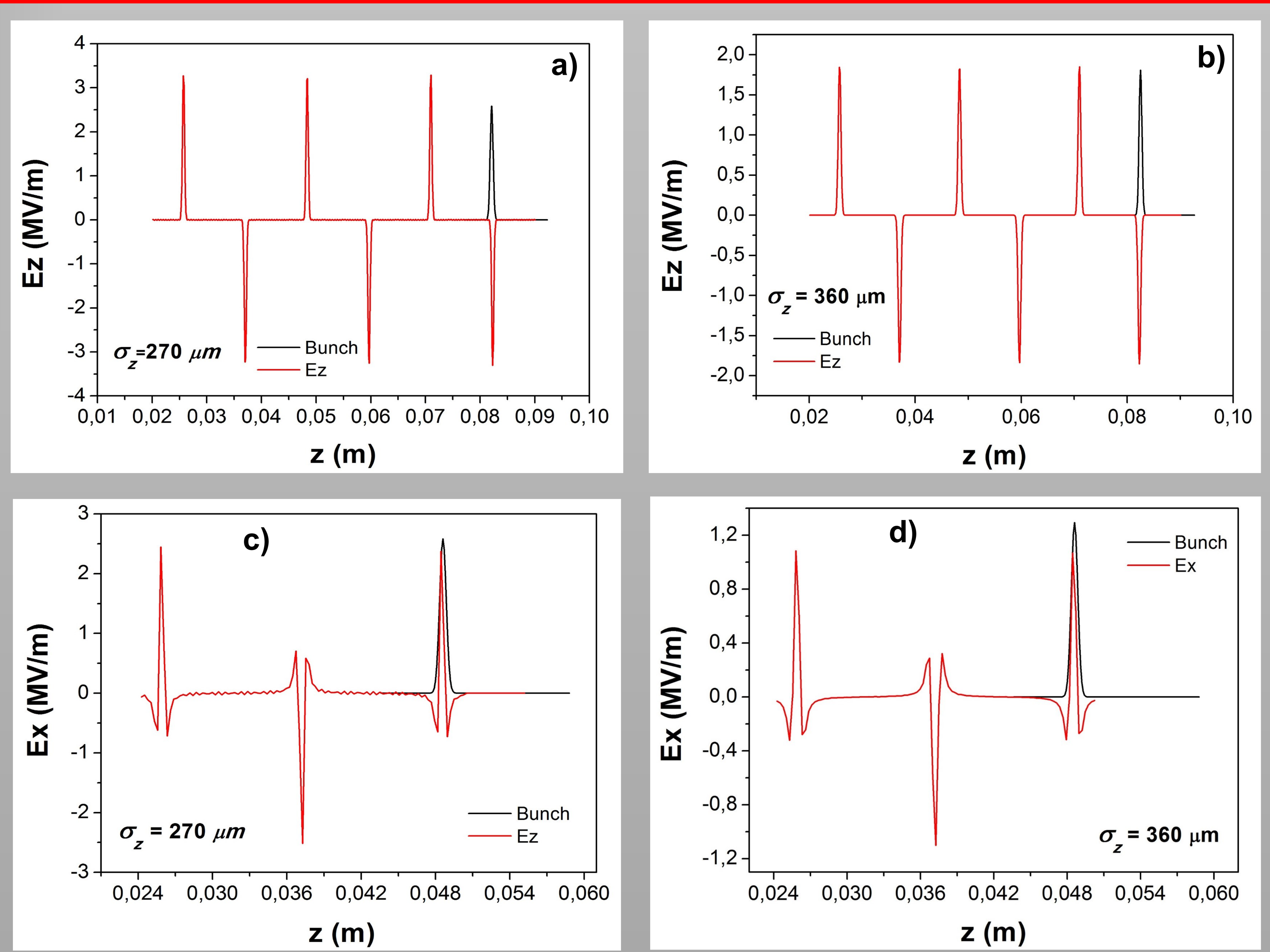
$$
\begin{cases}
E_z(z_{0,}t) = -\dfrac{N_b e}{2\varepsilon a}\sum_n \left[\dfrac{f_n(x)}{\alpha_n}\right] exp\left(-\dfrac{(\omega_n\sigma_z)^2}{4v^2}\right) exp\left(-i\dfrac{\omega_n}{v}z_0\right) \\[2ex]
E_x(z_{0,}t) = -\dfrac{iN_b e}{2\varepsilon a}\sum_n \left[\dfrac{g_n(x)}{\alpha_n}\right] exp\left(-\dfrac{(\omega_n\sigma_z)^2}{4v^2}\right) exp\left(-i\dfrac{\omega_n}{v}z_0\right)
\end{cases}
$$

Dielectric structure



WEAK-FIELD STRUCTURE

We have studied the wake-field generation by using a simplified 2D geometry, for which we have considered two parallel layers of dielectric material to simulate the dielectric capillary. We have considered, as a source for the wake fields, a bunch of charge Q moving with a constant velocity v in the plasma channel. The direction of motion of the bunch is along the z-axis, but it is misaligned with offset x_0 from the center axis. The distance between the head and the tail of bunch is z_0=z-vt.



- ✓ ***The higher is σ_z, the lower is the electric field E***
- ✓ ***The higher is the radius a, the lower is the electric field E***
- ✓ ***The higher is the offset from the center axis x_0, the higher is the electric field E***

RESULTS

Figures a) and b) show the longitudinal wake-field E_z calculated on the z-axis (x=0) as a function of the z-direction and taking into account up to n=150 TM-modes that go from 13.2 GHz to 3.8 THz. Figures c) and d) show the transverse wake-field E_x calculated on the z-axis (when off-axis displacement is x_0=100 μm) as a function of the z-direction and taking into account up to n=150 TM-modes. For wake-field studies it is very important to analyze the comparison between the duration time of the electric field and the bunch length. As you can see in the figures, the head of bunch generates the electric field behind itself, therefore it will not be affected by any field; on the contrary, the tail will undergo a transverse displacement, to the right or left depending on the sign of the field, because it follows the head and will be located in a z-position where the electric field reach a very high value. In fact, the longitudinal electric field can reach 3 MV/m (bunch length is 270 μm) with a good matching between bunch length and duration time of the wake-field. The transverse field reach 2.5 MV/m (bunch length is 270 μm). According to the equations above, the longer is the electron bunch, the lower is the electric field, both transverse and longitudinal. In this respect, Figures b) and d) show a reduction of the field amplitude, from 3 MV/m to 1.7 MV/m and from 2.5 MV/m to 1.1 MV/m, if the bunch length σ_z goes from 270 μm to 360 μm, respectively; also, it is clear that the matching gets worst when the bunch length grows.