Zemax simulations for laser propagation in plasma waveguides

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Abstract

Plasma-based waveguides are currently employed for laser wakefield acceleration to extend the focal region of laser beams. Indeed, a parabolic transverse plasma density profile can be formed in a dielectric capillary as a thermal consequence of a gas discharge. In this work, we report on a new ray tracing model, based on the Zemax software, able to simulate the envelope of a laser beam propagating through a plasma waveguide. Thanks to the tools offered by Zemax, an ideal interferometry measurement will be shown.

Zemax model

$$n_e(r) \cong n_0 + \frac{\Delta n}{r_m} r^2 \Rightarrow \boxed{\frac{d^2R}{dz^2} = \frac{1}{Z_M^2 R^3}\left(1 - \frac{\Delta n}{\Delta n_c} R^4\right)} \Rightarrow \text{Laser envelope oscillation: guiding!}$$

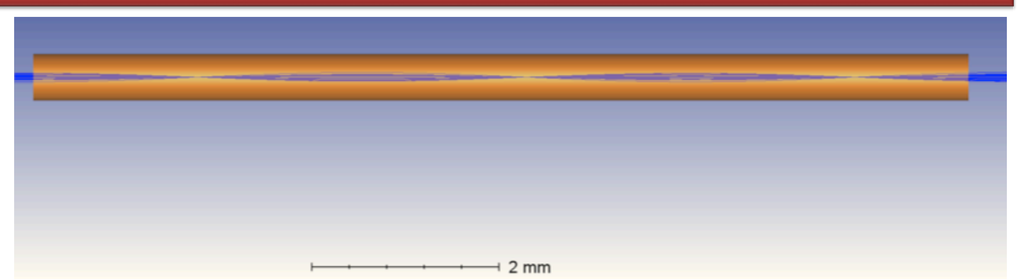

Fig 1. Beam propagation through a straigth capillary

Zemax editor provides Non-Sequential (NSC) framework where user can design his own optical system in the 3D space. The most interesting point offered by Zemax is the «customability»: defining a dispersion curve for a new material, designing a particular object geometry etc.
For our aim, we wrote a custom DLL to define a parabolic refractive index profile, like for a GRadient- INdex (GRIN) structure, starting from plasma parameters. In detail, starting from a parabolic electron density profile $n_e(r) = n_0 + (\Delta n / r_m^2)\, r^2$, with n_0 the on-axis density, Δn the density variation on the transverse plane and r_m the capillary radius.

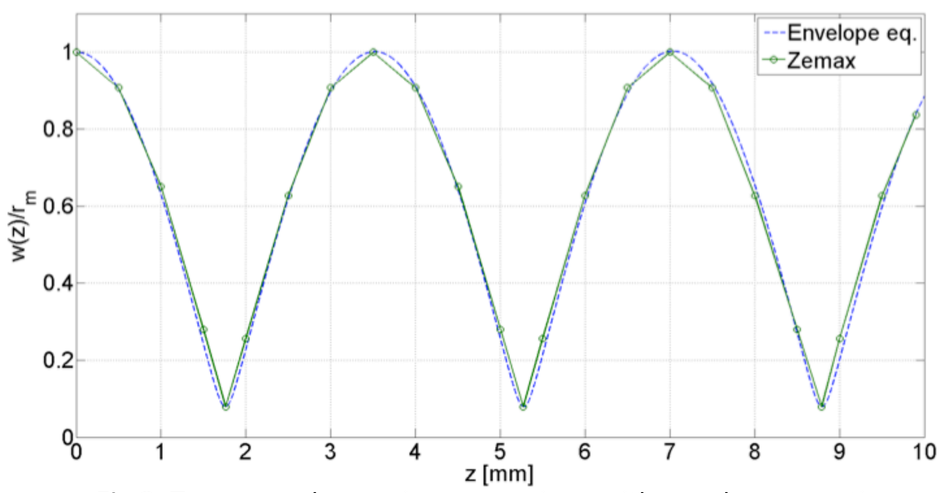

Fig 2. Transverse beam size comparison with envelope equation.

Simulation results

Simulation parameters:

λ=800 nm
n_0=1x10^{18} cm^{-3}
dn=5x10^{18} cm^{-3}

r_m=500 um
1x10^6 rays
4 mm x 4 mm detector (2000x2000 pixels)

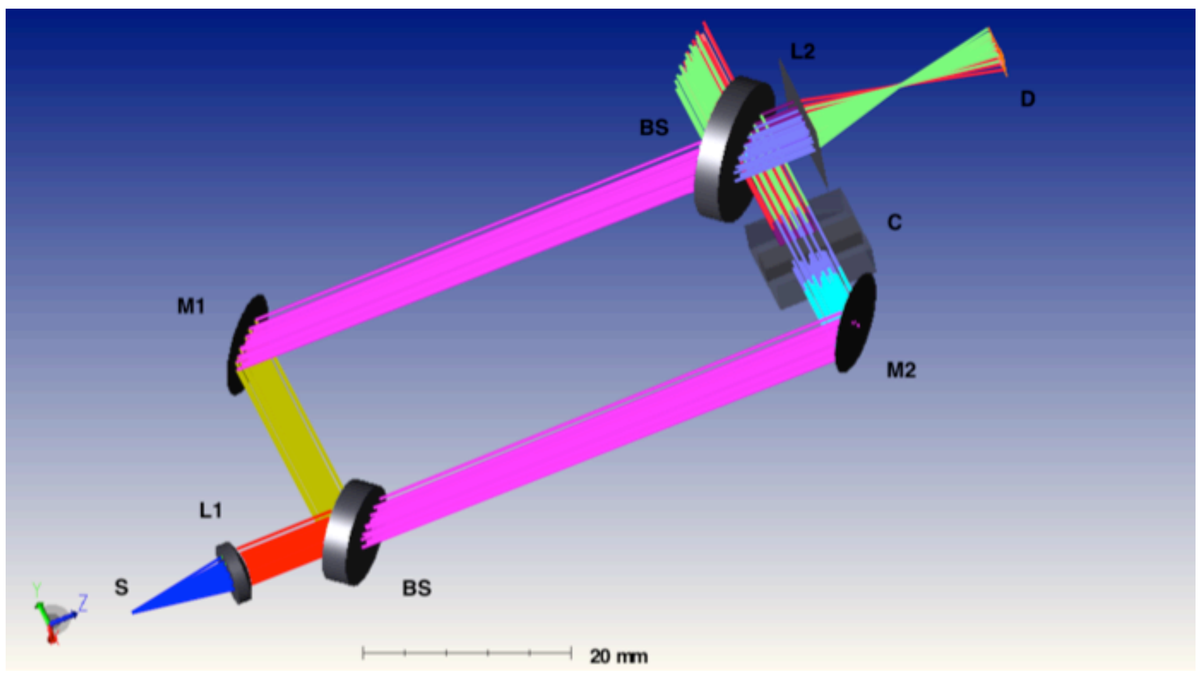

Fig 3. Optical interferometric system as designed by Zemax.

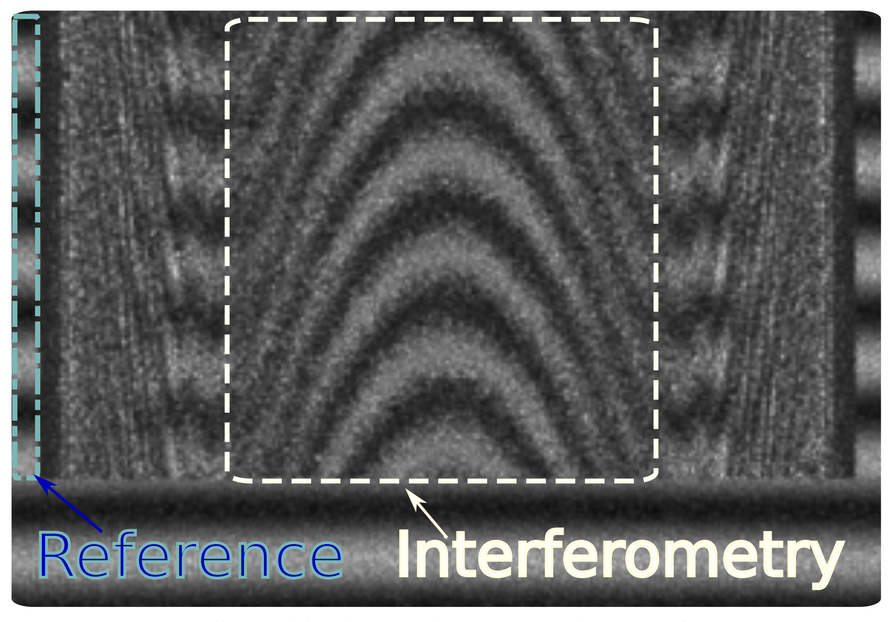

Fig 4. Image collected by beam detector at the interferometer exit.

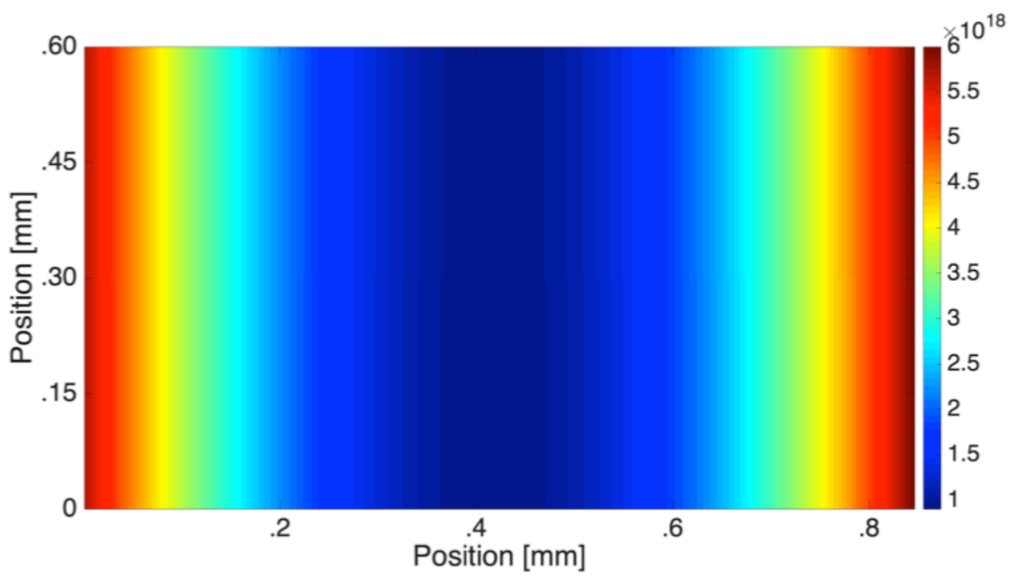

Fig 5. 2D density map as retrieved from Fig. 4.

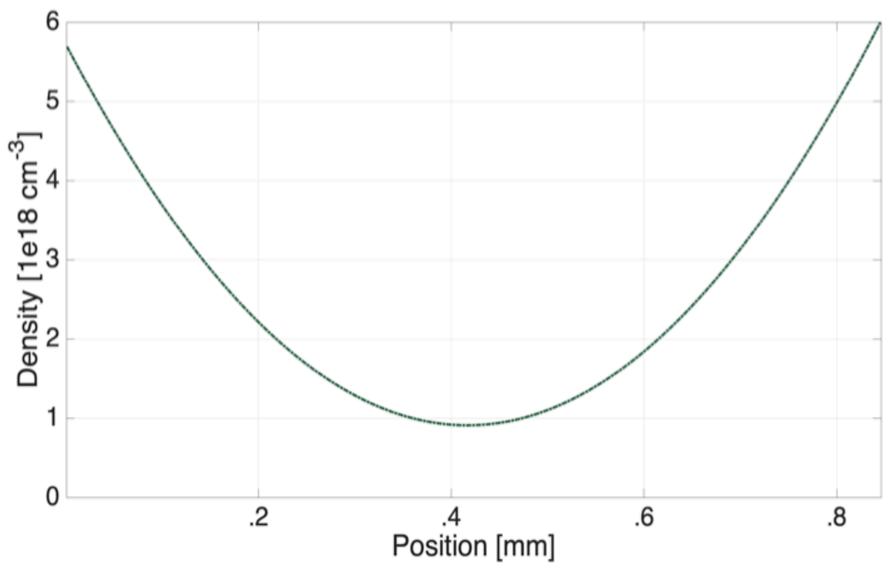

Fig 6. Line profile of Fig. 5.