Scientific accomplishments 2017

a) Scaling focusing
Recently, it has been demonstrated on rigorous mathematical grounds the validity of the scaling concept in nonlinear optics. This scaling is of high relevance in all applications and research infrastructures where intense laser pulses are used and manipulated, for example transported, focalized, and let to interact with atomic systems. The utility of the scaling principle becomes clear when it comes to the restrictions regarding the pulse energy or average power. We succeeded in a larger collaboration with the Lund University Sweden and ELI-ALPS Hungary to put on mathematical grounds the concept of scaling in nonlinear optics [1]. We intend to apply the scaling principles for designing the experiment geometries in both ELI-ALPS and ELI-NP sites.


b) Solving propagation equation
In solving the propagation equation

\[ \nabla^2 E_i(r, z, t) - \frac{1}{c^2} \frac{\partial^2 E_i(r, z, t)}{\partial t^2} = \frac{\omega^2}{c^2} (1 - \eta_{\text{eff}}) E_i(r, z, t) \]

we used a refractive index

\[ \eta_{\text{eff}}(n_o, n_e, r, z, t) = \sum_{i=0} \eta_0(n_i) + \sum_{i=0} \eta_2(n_i) E_i^2(r, z, t) - \frac{\omega^2}{2 \omega^2} \]

which includes the dispersion \( \eta_0 \) as well as nonlinear refractive index \( \eta_2 \) of neutrals and ionic species, quantities which we cannot find in the literature so we needed to calculate them.

We calculated the refractive index using the Lorentz-Lorenz relation

\[ \frac{4\pi}{3} N \alpha(\omega) = \frac{n^2(\omega)-1}{n^2(\omega)+2} \]

assuming one knows the wavelength-dependent polarizability \( \alpha(\omega) \) of the given atom/molecule

\[ n(\omega) = \sqrt{\frac{3 + 8\pi N \alpha(\omega)}{3 - 4\pi N \alpha(\omega)}} \]

On the other hand, the wavelength-dependent polarizability can be easily computed using ab initio quantum chemistry methods, taking into account the instantaneous dipole moment induced by the external field. We developed a program script which is able to generate automatically the wavelength dependent polarizabilities, using the Gaussian 09 [1] program suite.

An increased intensity (10^{18} \text{ W/cm}^2, a_0 \approx 1) induces fluctuations in electron plasma density \( \delta n / n \) which brings more effects in propagation [2]. When we account for these fluctuations we can write the refractive index in the linear approximation as:

\[ \eta_{\text{eff}}(n_o, n_e, r, z, t) = \eta_0(n_o) + \eta_2(n_0) E_i^2(r, z, t) - \frac{\omega^2}{2 \omega^2} \left\{ 1 + \frac{\delta n}{n} - \frac{< a^2 >}{2} - 2 \frac{\delta \omega}{\omega} \right\} \]
Here $a(t)=eA(t)/(m_0c^2)$ is the normalized vector potential, being $A(t) = -\int E(t)dt$, while the quantity $\tilde{\delta}n/n_0 = (n-n_0)/n_0$ is the normalized density perturbation associated with the electrostatic wake in the linear limit $a^2 < 1$. Introducing these additional terms in the expression for the refractive index was done, is under testing and the details will be presented, together with preliminary results on plasma fluctuations, including modeling the bubble formation during propagation.


c) **Coherent beam combining and field calculation**

Several configurations for coherent combination were investigated. The configurations have to be compatible with the existing geometrical constraints of the experimental areas for 10PW beams. We give here the method we developed for coherent beam combining. This method preserves the cylindrical coordinates for beam transport i.e. to calculate diffraction integral, but a rectangular 3D grid is built over the superposition region and the field is calculated over this grid. Hence, several configurations were computed and analyzed.

In order to have the full structure of the electromagnetic field, both in space and in time, we further studied various ways to compute and represent the combined pulses. A 3D representation of the field generated by two combined pulses was realized for the absolute value of the combined complex field, showing the interference structure and also the real part of the field showing the fast oscillations of the field.

d) **Design of the diagnostic system**

One further step in the direction of the experiment is to identify the method to visualize the spot size of the combined beams as the fundamental radiation reflection or as the third harmonic of the fundamental. Several designs of optical layouts were studied, one being depicted in figure below. It uses a flat fused silica piece of glass as beam sampler and a spherical mirror to transport the 100x100 micrometer² image of the spot on a thin solid target and then a UV compatible microscope objective. Several alternatives will be analyzed in practice, to compare the impact of the optical aberrations on the quality of the image.