Study of high-order super-gaussian and realistic laser profiles in Laser Wakefield Acceleration using azimuthal Fourier decomposition

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The advent of ultra short high intensity lasers has paved the way to new and promising, yet challenging, areas of research in the laser-plasma interaction physics. The success of constructing petawatt femtosecond lasers, for instance the Apollon laser in France, will help understanding and designing future particle accelerators and next generation of light sources. Achieving this goal intrinsically relies on the combination between experiments and massively parallel simulations. So far, Particle-In-Cell (PIC) codes have been the ultimate tool to accurately describe the laser-plasma interaction especially Laser WakeField Acceleration (LWFA). Nevertheless, the numerical modelling of laser plasma accelerators in 3D can be a very challenging task. This is due to the large disparity between the scales involved in this process. In order to make such simulations feasible with a significant speed up, we need to use reduced numerical models which simplify the problem while retaining a high fidelity. Among these models, Fourier field decomposition in azimuthal modes for the cylindrical geometry [1] is a promising reduced model especially for physical problems that have close-to-cylindrical symmetry which is the case in LWFA. This geometry has been implemented in the open- source code Smilei [2].

So far, most theoretical and numerical studies in LWFA have dealt with ideal gaussian laser profiles. However, ultra-short PW laser pulses are not exactly ideal gaussian beams. In fact, before focusing, the intensity delivered by the laser exhibits a higher-order super-gaussian distribution in the transverse plane and a profile close to an Airy disk at the focal plane. Therefore, we studied the features induced by high-order super-gaussian transverse laser profiles fitting the measured intensity profile of the Apollon laser in the near field. We also directly introduced the experimental data of the Apollon laser intensity and phase profile in the simulation in order to investigate the impact of real laser imperfection on electron acceleration. These simulations have been run in close-to-cylindrical geometry with an optimal number of azimuthal modes based on energy error minimisation, so we can achieve both speed up and fidelity. Simulations' outputs have been compared to those performed in full 3D Cartesian geometry to ensure agreement and discuss differences.

References

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