Numerical representation of tightly focused ultra-short laser pulses with different beam modes

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Recent progresses in development of broad-band laser systems lead to the stable production of nearly single-cycle pulses at high repetition rates [1] which then require tight focusing optics in order to reach highly relativistic intensities, needed for laser-plasma experiments [2,3]. Most of the laser-driven particle acceleration schemes rely on particle-in-cell simulations [4] where the laser pulses are usually initialized with Gaussian transverse profiles, employing the paraxial approximation at the beginning of the interaction. For tightly focused ultrashort pulses, however, more accurate description is needed, otherwise the arising numerical artifacts may detrimentally affect the simulation outcome.

We present a general analytical-numerical framework [5] going beyond the paraxial description for the laser electric and magnetic fields valid up to the near single-cycle pulse durations and focused beam spot sizes following [6,7] employing light-cone coordinates. We introduce corrections regarding spatial-temporal coupling which arise during the solution of the wave equation, and corrections for the vector components of the electric- and magnetic-fields that could give precise initial fields for existing Maxwell-solvers ready to be used in particle-in-cell simulations.

We found that our corrections introduce orders of magnitude accuracy improvements in the laser fields even with different beam and pulse profiles. We combine this framework with beams based on the multimodal decomposition on the real Laguerre-Gaussian mode basis, to model pulses that have - more realistic- high order super-Gaussian (nearly flat-top) profiles away from the focus in the same way.

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