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QPAD: Highly efficient quasi-static particle-in-cell algorithm based on azimuthal decomposition

Quasi-static (QS), particle-in-cell (PIC) algorithms are extremely efficient methods for modeling plasma-based acceleration (PBA) driven by an intense laser or particle beam. Compared to conventional PIC methods, QS-PIC codes can speed up simulations by several orders of magnitude due to the larger time-steps permitted. These computational savings permit high-fidelity modeling of intractable physical problems such as hosing and ion motion in PBA. Recently, we proposed and implemented a new hybrid PIC algorithm, QPAD [1], that combines the QS algorithm with a quasi-3D Fourier azimuthal decomposition [2]. QPAD decomposes the electromagnetic fields, charge and current density into azimuthal Fourier harmonics on a cylindrical grid, which reduces the algorithmic complexity of a 3D code to that of a 2D code. It can therefore provide several orders of magnitude speedup over standard 3D QS codes and is uniquely suited for high fidelity simulations over long distances, parameter scans, and optimization problems. QPAD features an azimuthally decomposed ponderomotive guiding center (PGC) algorithm for modeling laser-plasma interactions, a robust predictor-corrector pusher for modeling highly nonlinear wakes, and implementations of Arbitrarily structure laser (ASTRL) pulses. Examples of QPAD simulations of beam-driven and laser driven wakefields, plasma matching sections, realignment of the witness beam, and fully self-consistent efficient beam loading stages for the electron arm of a LC are presented. Comparisons with fully 3D explicit PIC codes are also presented.

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[1] F. Li et al., CPC, 261, 107784 (2021).
[2] A. F. Lifschitz et al., JCP, 228, 1803–1814 (2009).

Working group

WG7 : Linear Colliders

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