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Simulations of laser-driven ion acceleration using the quasi-cylindrical PIC code CALDER-CIRC and application to the PETAL facility

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Target normal sheath acceleration (TNSA) of ions from laser-irradiated solid foils is a well-known, robust and widely used method. Numerical simulation of this process using PIC codes is, however, very challenging. Indeed, very small space and time steps are required to resolve the plasma skin depth and plasma period at the solid densities considered, while large spatiotemporal domains are needed to capture the full scales of ion acceleration. In addition, the hot electrons' transverse expansion, which strongly affects the dynamics and spatial distribution of the accelerating sheath field, can only be correctly described in a 3D geometry. In particular, such electron dilution is underestimated in 2D geometry, leading to significant overestimation of the final ion energy. Despite this limitation, 2D PIC simulations often appear to be the only reasonable option due to the excessive computational cost of 3D simulations.
As an alternative, we investigate here the benefit of using the quasi-cylindrical PIC code CALDER-CIRC [1] to describe TNSA over experimentally relevant scales. This code employs a field decomposition into a few Fourier modes along the poloidal angle, thus enabling reduced 3D simulations at a computational cost close to that of 2D Cartesian simulations. This method, originally developed for laser wakefield acceleration, remains valid if the plasma fields retain a quasi-cylindrical symmetry. To illustrate both its potential and limitations, we will compare simulations of a typical TNSA setup carried out using CALDER-CIRC and the 2D and 3D Cartesian versions of CALDER.
Moreover, we will report on a CALDER-CIRC simulation of TNSA under conditions relevant to the PW PETAL laser (~450 J energy, ~600 fs pulse duration, ~50 µm focal spot). The effect of the laser prepulse on the relativistic laser interaction and the acceleration processes will be analyzed.

[1] A. F. Lifschitz et al., Particle-in-cell modelling of laser-plasma interaction using Fourier Decomposition, J. Comp. Phys. 228, 1803 (2009).

Working group

Theory and computation

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