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Chromatic Emittance Evolution in Plasma-Based Accelerators

We present the first analytic theoretical model describing the chromatic transverse dynamics of an electron beam in a nonlinear plasma-based accelerator that can account for the evolution of the projected, longitudinal sliced, and energy sliced emittance. Beginning with a description of single particle motion, the evolution of the beam moments and centroid position for each slice is calculated. In our approach, the longitudinal dependence of energy gain due to the beam loading of the wake is included. This permits a 6D, slice-by-slice (energy or longitudinal) analytic prediction of the beam evolution at any point within an adiabatic plasma source for the first time. It includes effects from both transverse mismatch and transverse offsets of the beam. We show that the amount of beam emittance growth in plasma ramps is directly related to the integrated plasma density profile independent of the ramp shape, so long as the ramp is adiabatic. We also show how our theory can predict the optimal length for a high-brightness plasma injector stage for a given target beam energy and energy spread. Using our theoretical framework, researchers will be empowered to design emittance-preserving plasma accelerators with less reliance on expensive particle in cell simulations. In addition, they will be able to better predict and interpret the observed behavior of the beam, permitting informed parameter adjustments for performance optimization.

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