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Nonlinear Depletion and Dephasing in Laser Wakefield Accelerators[1]

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Pump depletion and electron dephasing lengths are conventional figures of merit used to assess laser-plasma accelerators. Scaling laws associated with these lengths can be of considerable utility in the design of multi-GeV acceleration stages. While approximate expressions for these lengths have been known for some time, such expressions are not particularly accurate. Through a comprehensive numerical study, we have obtained a detailed description of laser depletion and electron beam dephasing. The rate of energy deposition into the plasma by the laser and, correspondingly, the pump depletion length, is a non-linear process dependent on both the laser pulse amplitude and length and the ratio of the plasma density to the critical density. The combination of dephasing length and depletion length give a measure of the efficiency of the transfer of energy from the laser to the accelerated beam; any laser energy remaining after the beam has propagated a dephasing length is not available for acceleration. Our numerical studies have found that the evolution of a resonant laser pulse proceeds in two phases. In the first phase the pulse envelope is modified by group velocity dispersion resulting in pulse steepening and slight pulse shortening. The central wavenumber of the pulse is slowly reduced as energy is deposited in the plasma (the well-known redshifting). The second phase of evolution occurs after the pulse reaches it's minimum length at which point, the pulse length rapidly lengthens, loosing resonance with the plasma. A consequence of this lengthening is a significant reduction in accelerating gradient, effectively terminating the energy gain of the beam. We present a comprehensive examination of these effects over a wide range of laser and plasma parameters. We also present results concerning the rate at which laser energy is deposited in the plasma. We conclude with an examination of the laser energy remaining when the beam reaches the dephasing limit.

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