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QPAD modeling of wake excitation and acceleration in meter-long beam-ionized plasma at FACET-II

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FACET-II, a new 10 GeV electron beam facility at SLAC National Accelerator Laboratory for R&D on beam physics and novel acceleration techniques [1, 2], has been commissioned this year. One major research effort is on further development of the Plasma Wakefield Acceleration scheme (E300). The experimental results from the first run of the E300 experiment at FACET-II has shown evidence of high-efficiency wake excitation and energy depletion of the drive beam in beam-ionized hydrogen or helium gases. This self-ionization of both hydrogen and helium came as somewhat of a surprise since the calculated peak current in the beam was not high enough to field ionize these atoms. Fortunately, multiple diagnostics showed that the drive beam frequently had much narrower, higher current peaks. We therefore model the drive beam as having an ~80 fs Gaussian temporal shape with a peak current of 4.7 kA that has a much higher current spike (>50 kA, ~4 fs). To explain these results, a quasi-3D quasi-static particle-in-cell code QPAD [3] was used. We find that such a beam with a high current spike can indeed ionize both gases via ADK (He) or MO-ADK (H2) ionization model. The current spike was placed such that up to 30 to 40% of the drive beam charges did not lose any energy to agree with experimental observations. Once the plasma was formed by the spike, the rest of the beam with nb>np, rapidly forms a wake and transfers up to ~70% of the remaining beam energy to the wake. The model qualitatively reproduced the maximum energy loss as a function of gas pressure, energy gain seen at high pressures, pump depletion and betatron oscillations seen in the experiment.

References
[1] C. Joshi, et al., "Plasma wakefield acceleration experiments at FACET II." Plasma Phys. Control. Fusion 60, 034001 (2018).
[2] V. Yakimenko, et al., "FACET-II facility for advanced accelerator experimental tests." Phys. Rev. Accel. Beams 22, 101301 (2019).
[3] F. Li, et al., "A quasi-static particle-in-cell algorithm based on an azimuthal Fourier decomposition for highly efficient simulations of plasma-based acceleration: QPAD" Comput. Phys. Commun. 261, 107784 (2021).

Acknowledgments

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