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Synthetic Optical Imaging for Investigating Injection Radiation in Hybrid LPWFAs

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We present a synthetic optical imaging plugin for PIConGPU, that enables self-consistent imaging of plasma structures in laser-plasma accelerators. By integrating electromagnetic fields from the PIC simulation and propagating them via Fourier methods onto a virtual screen, we generate synthetic images that resemble experimental measurements. This approach allows direct comparison with experiments, providing insights into plasma dynamics and laser-plasma interactions.

A key focus of the study is an unexplained radiation signal in hybrid LPWFAs employing photo cathode injection. While experimentally observed and significant for timing calibration, its underlying physics remains elusive. Using our synthetic diagnostic, we reproduce this signal in simulations for the first time, linking it to plasma structures and cavity dynamics. By analyzing the images alongside 3D, time-resolved density distributions, we trace the formation of distinct scattering patterns, offering new perspectives on plasma dynamics.

These results highlight the potential of synthetic optical imaging to improve experimental diagnostics in laser-plasma accelerators, such as shadowgraphy, and to deepen our understanding of scattering processes in wakefield acceleration.

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