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Measurement of coherent substructures within laser-wakefield-accelerated electron beams

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Electron beams exiting laser wakefield accelerators (LWFAs) can have complicated substructures based on injection and interactions with the laser and accelerating cavity. Such structures could effectively pre-bunch the beam for a free electron laser (FEL). This would not only shorten the undulator length necessary for self-amplified spontaneous emission, but also improve the longitudinal coherence of the FEL . Indeed, the injection process can even be tailored to pre-modulate LWFA electron beams for just this purpose [1]. For such a goal to be realized, these microstructures must be measured and their origins understood. Here we use multispectral coherent optical transition radiation (COTR) imaging to experimentally diagnose LWFA accelerated electron beams. COTR is sensitive to the portion of the beam that is bunched at the measured wavelength. Multi-spectral imaging obtains Fourier components of the microbunched substructure that help reveal composite features of the ensemble beam. These observed features correspond to features observed in PIC simulations. We have measured COTR from three different injection regimes – down-ramp, ionization, and self-injection – and identified characteristic radiation patterns from each regime. We identify likely origins of these structures in the LWFA process. Using information contained within these patterns we comment on the shape of the beam as well as the microstructures present. Using physically reasonable assumptions, we present a three-dimensional spatial reconstruction of the coherent portion of the beam.

[1] Xu, Xinlu, et al. “Generation of ultrahigh-brightness pre-bunched beams from a plasma cathode for X-ray free-electron lasers.” Nature communications 13.1 (2022): 1-8.

Acknowledgments

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