Stability analysis of plasma photocathode produced ultrahigh brightness electron beams

Fahim A. Habib1,2, T. Heinemann1,2, A. Knetsch2, P. Scherkl1, D. Ullmann1, A. Beaton3, G.G. Manahan1, A. Sutherland1,2, G. Kirwan1, L. Boulton1,2, A. Nutter1,2, D.L. Bruhwiler2, J. Carry3, M. Hogan3, V. Yakimenko3, J.B. Rosenzweig4 & B. Hidding1

University of Strathclyde, SUPA, & The Cockcroft Institute, *Deutsches Elektronen-Synchrotron (DESY), 
†SLAC National Accelerator Laboratory
*Helmholtz-Zentrum Dresden-Rossendorf (HZDR), †RadioSoft LLC, ‡University of Colorado Boulder & Tech-X Corporation, ‡University of California.

Abstract

We report on demonstration of plasma photocathode in particle-driven Wakefield acceleration (PWFA) obtained within the "E-210: Trojan Horse PWFA" collaboration at SLAC National Accelerator Laboratory FACET. Further, we identify key experimental limitations and study them in a systematic jitter analysis utilizing 3D Particle-In-Cell (PIC) code. The results from this study indicate that the electron beam parameter shot-to-shot stability can be comparable to the state-of-the-art rf-based accelerators. These findings are very encouraging for the forthcoming experimental campaigns at SLAC FACET-III e.g. "E-310: Trojan Horse-II" and "E-313: Multibunch dechirper for ultrahigh 6D brightness beams".

Motivation

The plasma photocathode particle-driven Wakefield accelerator (TH-PWFA) is a promising path towards electron beams with ultrahigh 6D-brightness, multi-GeV energies and sub-% energy spread in a single PWFA acceleration stage [1, 2]. These electron beams with superior are opening the path towards key applications such as XFEL, ICS, and HEP [2, 3, 4, 5].

E-210: Demonstration of 90° plasma photocathode injection

• Demonstration of two injection methods in PWFA for the first time [5]
• Plasma torch injection: All-optical density downramp injection
• Trojan Horse injection: Plasma photocathode injection in 90° geometry
• Two component noble gases (Hydrogen/Helium) are used to decouple acceleration from injection
• Both regimes accessible in the same set up by tuning laser energy and timing [5]

Plasma Torch: time-of-arrival (TOA)<0

3D PIC Simulation of plasma torch injection

Plasma Photocathode: time-of-arrival (TOA)>0

3D PIC Simulation of 90° plasma photocathode injection

Stability analysis of plasma photocathode towards FACET-II experiments and beyond

• Wide plasma channel (e.g. channel radius rC ≥ 2 × RC) allows stable PWFA operation at larger plasma wavelength (e.g. λC ≥ 250 μm) [3]
• Stable witness beam acceleration over meter distances → multi-GeV beams
• Longer plasma wavelength relaxes alignment and timing requirements → impact on witness beam properties is significantly reduced
• Witness beam energy stability at sub-% level may be possible

Wide plasma channel

Waterfield evolution in a wide plasma channel

Publications embargo

Publications embargo

References & Acknowledgment


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Conclusion

• Plasma torch and Plasma photocathode injection work in PWFA even under sub-optimal conditions → Path towards ultra-high quality electron beams
• Plasma channel width limits energy gain and witness beam parameter stability
• Wider plasma channels allow stable acceleration over meter distance
• Longer plasma wavelength may enable sub-% energy spread beams with nm radial normalized emittances [2] and reduces alignment and timing requirements
• Witness beam parameter stability is comparable with rf-based accelerators
• Results are promising towards applications such as XFEL, ICS and HEP