LPAW 2023
Laser and Plasma Accelerators Workshop 2023
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Phase matched photon acceleration from Optical to XUV in a beam driven wakefield

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The propagating density gradients of a plasma wakefield may frequency upshift a trailing witness laser pulse, a process known as 'photon acceleration'. In uniform plasma, the witness laser will eventually dephase because of group delay. We find phase matching conditions for the pulse using a tailored density profile. An analytic solution for a 1d nonlinear plasma wake with an electron beam driver indicates that, even though the plasma density decreases, the frequency shift reaches no asymptotic limit, i.e. is unlimited provided the wake can be sustained. In fully self-consistent 1d particle-in-cell (PIC) simulations, more than 40 times frequency shifts were demonstrated. In quasi-3d PIC simulations frequency shifts up to ten times were observed, limited only by simulation resolution and non-optimized driver evolution. The pulse energy increases in this process, by a factor of five, the pulse is guided and temporally compressed by group velocity dispersion, resulting in the resulting XUV laser pulse having near-relativistic ($a_0 \sim 0.4$) intensity.

Acknowledgments

This work was supported by AFOSR grant FA9550-19-1-0072 and NSF grant 1804463. Computational resources were provided by Advanced Research Computing at the University of Michigan.