Contribution ID: **225** Type: **Invited Oral**

Multi-GeV electron bunches from an all-optical laser wakefield accelerator

Monday, 7 November 2022 09:20 (30 minutes)

Conventional RF electron accelerators are limited by breakdown potentials to ~100 MeV/m. This poses significant economic and practical obstacles for the construction of new, high energy particle accelerators which can be used as advanced light sources, or as colliders to probe new fundamental physics regimes. Laser Wakefield accelerators (LWFAs), which can achieve acceleration gradients 1000 times greater, offer a promising alternative for the next generation of accelerators.

LWFAs use the plasma waves (wakes) driven by an ultra-intense laser pulse to accelerate electron bunches to near luminal velocities. For maximal energy gain, the wave needs to be driven over tens of centimeters in a low-density (~$1 \times 10^{17} cm^{-3}$) plasma. This poses a natural problem since an ultra-high intensity laser pulse will diffract on a much shorter scale, reducing the intensity below that required to drive a wake in the plasma. We have recently demonstrated two methods, based on optical field ionization (OFI), to generate low-loss, meter-scale plasma waveguides (in hydrogen plasma) where high intensity guided modes can propagate hundreds of Rayleigh lengths [1,2].

In this talk we will discuss the methods for optically generating plasma waveguides to enable meter scale LWFAs and the first successful implementation of the technique to accelerate electron bunches up to 5 GeV in a 20 cm all-optical LWFA [3]. We will present transverse plasma interferometry, guided mode images and optical spectra, electron beam profiles, and electron spectra collected during experimental campaigns on the ALEPH laser at Colorado State University, as well as particle in cell simulations to supplement the physical picture of the acceleration process.

[1] B. Miao, et al. Optical guiding in meter-scale plasma waveguides, Phys. Rev. Lett. 125, 074801 (2020)
[2] L. Feder et al., Self-waveguiding of relativistic laser pulses in neutral gas channels, Phys. Rev. Res. 2, 043173 (2020)
[3] B. Miao et al., Multi-GeV electron bunches from an all-optical laser wakefield accelerator, Phys. Rev. X 12, 031038 (2022)

Acknowledgments

This work was supported by the U.S. Department of Energy (DE-SC0015516, LaserNetUS DE-SC0019076/FWP#SCW1668, and DE-SC0011375), and the National Science Foundation (PHY1619582 and PHY2010511).

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Session Classification: Plenary

Track Classification: Plenary Sessions: Invited Talks