

Active nonperturbative stabilization of the laser-plasma-accelerated electron beam source

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Laser plasma accelerators have the ability to produce high-quality electron beams in compact, all-optical-driven configurations, with the electron beams uniquely suited for a wide variety of accelerator-based applications. However, fluctuations and drifts in the laser delivery to the mm-scale plasma target (the electron beam source) will translate into electron beam source variations that can limit their utility for demanding applications like light sources. Based on previous work in developing a nonperturbative diagnostic for the high-power laser delivery at focus [1], we present a full four-dimensional active-stabilization system for the laser (transverse laser focus position and laser pointing angle in both transverse planes) and experimentally demonstrate how, as a result of the laser stabilization, critical parameters in the electron beam source were stabilized. Through the use of an energy resolved imaging system for the electron beam, we directly monitor the jitter in the transverse electron beam source location. Furthermore, the dispersion in the orthogonal plane to the magnetic spectrometer was recorded for each shot which is tied to the source pointing angle of the electron beam and, in part, driven by the angle of the laser at the interaction point. Our laser stabilization system reduced variation in the electron beam source location from ~ 12 to $3\text{ }\mu\text{m}$ and reduced the dispersion jitter of the electron beam by 20%.

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I. INTRODUCTION

Laser plasma accelerators (LPAs) provide a means for achieving electron beams (e-beams) of multi-MeV to GeV energy levels through the mm-scale acceleration of charged particles via laser-driven plasma wakefields [2–7]. The e-beam quality can match that realized with conventional radio frequency (rf) based particle accelerators, with added advantages of compactness, cost, and intrinsic femtosecond synchronization to other hyperspectral sources. The ultra-short high-peak-current nature of LPA beams can enable novel light sources, attracting interest in developing betatron x rays [8] for applications like bioimaging [9], x-ray free-electron lasers for nonlinear dynamics and single-shot imaging [10], and Compton/Thomson-scattered gamma-ray and x-ray sources for medical and nuclear security applications [11,12]. Plasma based colliders are also a candidate for a future high energy collider [13].

Despite LPAs offering promising applications, using them as alternatives to conventional rf linacs presents several unique challenges that must be addressed. For example, in contrast to a standard rf photoinjector, beams generated in plasma wakefields are typically micron scale in all spatial dimensions. The initial trajectory of these beams is strongly tied to the propagation and evolution of the wakefield, which itself is predominantly determined by the angle and position of the wakefield driving laser. Naturally then, the transverse stability of the LPA-generated beams is strongly coupled to the stability of the drive laser.

Future applications of LPAs like colliders and XFELs require transverse jitter of the electron beam to be a small fraction of the electron beam size. This fact, coupled with the micron scale source size, implies micron to submicron transverse jitter of the drive laser at focus will be required. Given that a focused laser driver is tens of microns in transverse size, drive lasers will need to be stabilized to a fraction of a percent of a beam size [14,15].

Sources of perturbations that lead to LPA drive laser instability include environmental vibrations that couple into optical components, thermal variations to optical surfaces, and open-air turbulence. In addition, thermal drifts inside laser progenitor cavities result in long-term drift of the propagating laser field. The resolved frequency content of these fluctuations has been shown to exceed 100 Hz in the position spectrum and approach 10 Hz in the angle

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