# Laser-plasma accelerator driven soft-x-ray free-electron laser using beam phase-space manipulation

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**Abstract:** *Laser-plasma accelerators (LPAs) are a compact source of fs electron beams with kA peak currents and low (sub-micron, normalized) transverse emittance. Presently, the LPA beam energy spread (percent-level) hinders application to a free-electron laser (FEL). We discuss methods of beam phase-space manipulation after the LPA to achieve FEL lasing for experimentally demonstrated LPA electron beam parameters. We describe the application of a plasma-based lens for beam capture after the LPA and emittance preservation during transport to the FEL. Design of a demonstration LPA-driven FEL experiment will be presented. Methods of optical injection to improve the LPA beam brightness will also be discussed.*

Laser-plasma accelerators (LPAs) have the ability to generate ultra-high accelerating gradients (>10 GV/m), several orders of magnitude larger than conventional accelerators, and are actively being developed as compact sources of energetic electron beams. Electron beams with energies up to several GeV have been experimentally demonstrated using high-intensity lasers interacting in centimeter-scale plasmas. The electron bunches emerging from a laser-plasma accelerator are naturally short (of the order of a few fs, determined by the plasma wavelength), and intrinsically synchronized to the laser driver, making such a source ideal for ultra-fast science applications.

LPAs deliver high peak current beams (> kA) with low (sub-micron, normalized) transverse emittance, and, hence, it is natural to consider LPA beams as drivers for free-electron lasers (FELs). Although the 6-dimensional beam brightness of the LPA electron beam can be comparable to, or better than, state-of-the-art photo-cathode sources, the FEL application of LPA beams is presently hindered by the beam energy spread (few percent). Application of LPAs to FELs may be accomplished, using experimentally demonstrated LPA beam parameters, by beam phase-space manipulation and redistribution following the LPA. Longitudinal beam decompression, thereby reducing the beam slice energy spread, provides a path to FEL lasing. Transverse dispersion of the beam, coupled to a transverse gradient undulator may also be considered to mitigate the effects of the LPA beam energy spread.

Given the electron beam phase space characteristics exiting the LPA (large divergence and energy spread), beam transport presents a technical challenge, particularly in terms of beam quality preservation. Application of a plasma-based lens (capable of producing focusing field strengths >3000 T/m) for rapid beam capture and transport following the LPA greatly improves beam emittance preservation from the LPA to the FEL. A soft-x-ray FEL can be realized using experimentally demonstrated LPA beam parameters by employing plasma-based lenses for capture and a chicane for beam decompression. Shorter wavelength LPA-driven FELs may be realized using optical injection to improve the LPA beam brightness.