Electron beam chirp dexterity in staging laser wakefield acceleration

N. Pathak[1,2], A. Zhidkov[1,2], Z. Jin[1,2], Y. Mizuta[1,2], Z. lei[1,2], K. Matsukado[1] and T. Hosokai[1,2]

[1] Institute of Scientific and Industrial research (SANKEN), Osaka University, Japan,
[2] Laser Accelerator R&D, Innovative Light Source Division, RIKEN SPring-8 Center, Hyogo, Japan.

e-mail (speaker): naveenpathak@sanken.osaka-u.ac.jp

Laser WakeField Acceleration (LWFA) scheme has been widely accepted for its outstanding acceleration potential, however, its use in the real practical scientific and industrial applications is mainly limited by the relatively large energy spread of the accelerated beam. In general, the problem of energy spread in LWFA is associated with the three fundamental reasons: (i) an uncontrolled or continuous self-injection of the electrons in the laser wakefield, (ii) charge density of the injected electron beam beyond the beam loading limitation and (iii) the non-uniform profile of the wakefield strength in the longitudinal direction. Even in the idealistic case, where the electron self-injection is strictly controlled and localized both in space and time, and the electron beam density is kept well below the beam loading effect, the problem of the energy spread still persists. This is because of the non-uniformity in the longitudinal electric or acceleration field of the plasma wave. Plasma wave, being oscillatory, has periodically varying acceleration (or deceleration) phase along its wavelength. For an under-loaded LWFA, in the accelerating (or decelerating) phase the profile of the longitudinal electric field can be approximated as linear profile or chirp [1]. If the longitudinal extent of the electron beam is comparable to the scale length of the acceleration phase of the plasma wave (which is typical for LWFA), then this linear chirp of the electric field will be imprinted on the energy spectrum of the electron beam during the acceleration process. As a result, an initially unchirped electron beam will eventually develop a positive chirp in the energy spectrum. This problem can be partially mitigated by injecting an electron beam in LWFA with an initially negative energy chirp.

The negative energy chirp of the electron beam will partially compensate the positive chirp introduced by the plasma wave. However, it is noteworthy that during the interaction process with the plasma wave the phase-space of the electron beam is gradually rotated in accordance with the chirp of the wakefield. Therefore, the effect of the self-induced dynamic chirp on the energy spread of the electron beam cannot be completely compensated for long plasma lengths. How long the effect of the negative energy chirp of the electron beam will be maintained is depends on the strength of the plasma wave, initial mean energy and initial energy spread of the injected electron beam.

In this presentation we will discuss the usefulness of injecting a negatively chirped electron beam, in the context of multi-stage LWFA, in order to achieve very narrow energy-spread along with high charge density. Such multi-stage LWFA configuration may pave path for the ongoing quest of seeding the free electron laser (FEL) with electron beams generated from the laser driven compact plasma accelerators.

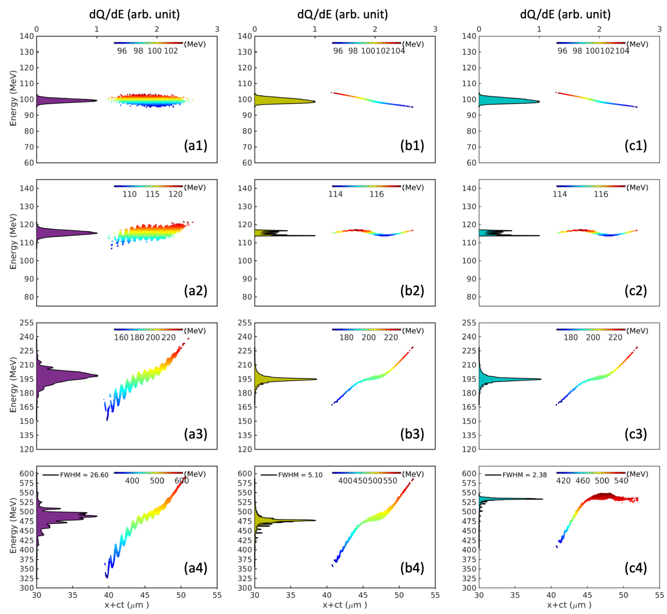

Fig. *Dynamic evolution of the longitudinal phase-space and the corresponding energy spectrum of an initially unchirped electron beam (a1-a4), negatively chirped electron beam (b1-b4) and negatively chirped electron beam in longitudinally tailored plasma density profile (c1-c4).*

References:

[1] N. Pathak, A. Zhidkov, T. Hosokai, Phys. Plasmas **28**, 053105 (2021).