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Production of small energy spread and high charge beams in laser wakefield accelerators

Ming Zeng, Dazhang Li, Jia Wang
[1] Institute of High Energy Physics, Chinese Academy of Sciences
e-mail (speaker): zengming@ihep.ac.cn

The Laser Wakefield Accelerator (LWFA) is regarded as the accelerator of the next generation, because its three orders of magnitude higher acceleration gradient compared with the conventional radio-frequency (RF) accelerator. However, the quality of the output charged beam from a LWFA has been inferior to that from an RF accelerator for a long time, which hinders the wide application of the former.

Recently, several advancements are achieved to improve the output beam quality of the LWFA. For example, the electron energy gain has exceeded 10 GeV, the beam energy spread has been reduced to the permille level, and the beam charge has been increased to nanocoulomb level. However, these improvements are achieved in different experiments, and multi-parameter optimization is difficult. Especially, the small energy spread and large charge of the beam are usually contradictory in the optimization, as shown in Figure 1. To simultaneously reduce the energy spread and increase the beam charge is vital for the real application of LWFA.

We have proposed several injection schemes to improve the output beam quality. The first is the scissor-cross ionization injection scheme [1], in which we use a trigger laser colliding with the drive laser with an acute angle θ, so that the ionization injection occurs only during their collision as illustrated in Figure 1(b), and the beam with $\sim 1\%$ energy spread and ~ 40 pC charge can be produced. Recently, an experiment demonstrating this scheme has been performed, and is to be published. The second is the interference injection by coaxial lasers [2], in which we use a tightly focused trigger laser co-propagating with the drive laser to trigger the injection of background plasma electrons as illustrated in Figure 1(c). The trigger laser and the drive laser have similar intensities at focus to generate interference rings, so that the onion-like wakefield is created. The fast evolution of the wave front curvature of the trigger laser changes the effective phase velocity of the wakefield to trigger injection. The beam with $\sim 0.3\%$ energy spread and ~ 170 pC charge can be produced. The third is the injection by tightly-focused drive laser [4], in which the injection is triggered by the defocusing process of the drive laser, and the beam with $\sim 1\%$ energy spread and ~ 1 nC charge can be produced.

Moreover, through simulations, we have proposed a method to generate simultaneous small energy spread, large charge, and high energy transfer ratio from the laser to the beam. In this method, we use a tightly focused petawatt laser to focus slightly upstream a gaseous plasma source. The laser is later refocused in the plasma due to the self-focusing effect, which is called the plasma telescope mechanism [4]. This refocused laser pulse triggers self-injection of background plasma electrons, which form a high-quality beam with ~2 nC charge, ~3% energy spread and more than 10% energy transfer ratio from the laser to the beam [5]. Such high energy transfer ratio for the monoenergetic beam has never been observed in LWFA experiments.

References

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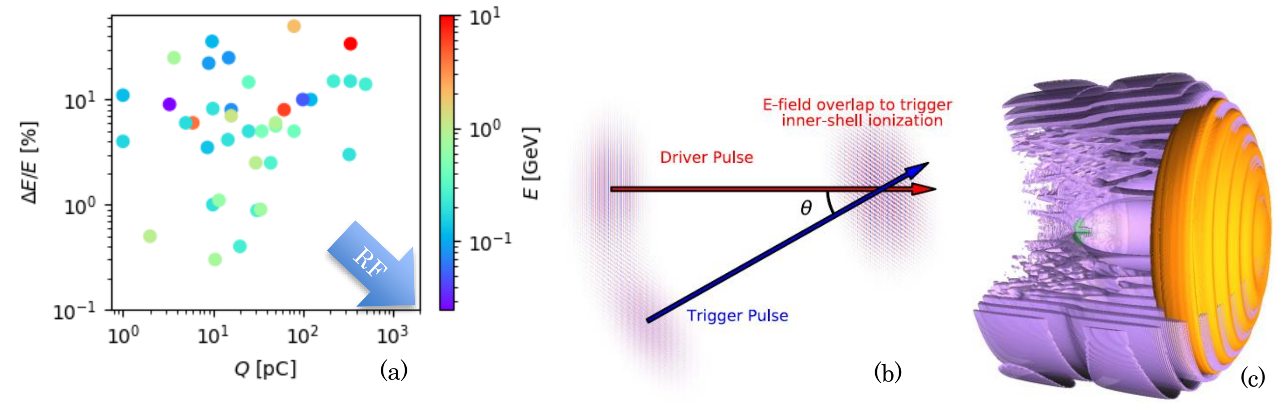

Figure 1. (a) A collection of output beam parameters from LWFA experiments in past two decades. We see the small energy spread and large beam charge are not simultaneously achievable. As a comparison, the RF accelerators commonly produce beams with the energy spread smaller than 0.1% and the charge larger than 1 nC. (b) Illustration of the scissor-cross ionization injection scheme [1]. (c) The onion-like wakefield structure created during the interference injection by coaxial lasers [2].