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Recent progresses of plasma wakefield acceleration studies at IHEP

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Laser or charged particle beam driven plasma wakefield accelerators (PWAs) are considered to be the accelerators of the next generation. Because of their extremely high acceleration gradient in the order of 1~100 GeV/m which is 3 to 4 orders of magnitude higher than conventional radio-frequency (RF) accelerators, PWA provides us the possibility to accelerate particles exceeding the energy frontier using facilities with affordable sizes.

Although PWA has such huge advantage in the acceleration gradient, its output beam quality is not as good as RF accelerators. Especially, the energy spread is usually larger and the charge is lower for the output beam in PWAs compared with RF accelerators. In Figure 1(a) we show the comparison of the energy spread vs. beam charge from typical PWAs and the RF accelerators. We can see that the energy spread and beam charge are contradictory parameters for PWAs. Although one single parameter of the output beam from a PWA may have reached that from RF accelerators, to achieve simultaneous high charge and low energy spread in a PWA still remains challenging. This drawback strongly limits the application range of PWAs.

Our plasma acceleration group at Institute of High Energy Physics (IHEP), Chinese Academy of Sciences, has been doing works for high quality PWAs, especially for achieving both high charge and low energy spread in PWAs. Based on the injection theory [1], we have proposed a few new injection schemes for the optimization of the beam quality. The first is the scissor-cross ionization injection scheme [2], in which we use a trigger laser colliding with the drive laser with an acute angle θ, so that the ionization injection is occurred only during their collision as illustrated in Figure 1(b), and the beam with $\sim 1\%$ energy spread and $\sim 40\,\mathrm{pC}$ charge can be produced. The second is the interference injection by coaxial lasers [3], 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 $\sim 170\,\mathrm{pC}$ 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 $\sim 1\,\mathrm{nC}$ charge can be produced. These new injection schemes produce beams with the energy spread and the beam charge approaching that of the RF accelerators as shown in Figure 1(a).

We have also studied the long-term behavior of electrons in a PWA for its future applications in high energy physics. Based on the 3D betatron oscillation model, we have derived the long-term equations of motion without resolving the betatron frequency [5, 6]. We have found new phenomena including the precession of the elliptical trajectory in the betatron phase shift dominant regime as shown in Figure 2(a) and the elliptical trajectory narrowing in the radiation reaction dominant regime as shown in Figure 2(b) [6]. This study is useful for future PWAs with extremely long distances and high energies.

References

[1] Ming Zeng et al., New J. Phys. **22**, 123003 (2020).
[2] Jia Wang et al., Plasma Phys. Control. Fusion **64**, 045012 (2022).
[3] Jia Wang et al., Matter Radiat. Extremes **7**, 054001 (2022).
[4] Jia Wang et al., arXiv:2304.10730 (2023).
[5] M. Zeng and K. Seto, New J. Phys. **23**, 075008 (2021).
[6] Yulong Liu and Ming Zeng, Phys. Rev. Accel. Beams **26**, 031301 (2023).

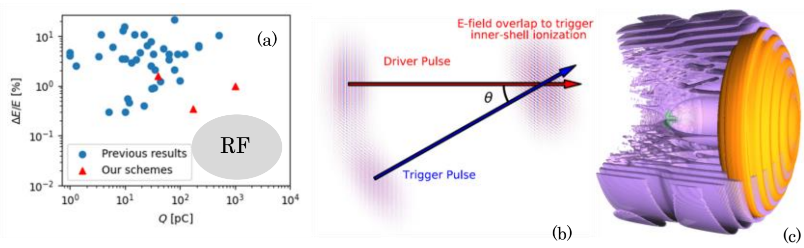

Figure 1. (a) The energy spread vs. beam charge for typical PWA output beams from previous results, and for our injection schemes including (b) scissor-cross ionization injection [2], (c) interference injection by coaxial lasers [3], and injection by tightly-focused drive laser [4] (not illustrated here). The typical beam quality for a RF accelerator is in the gray region in (a).

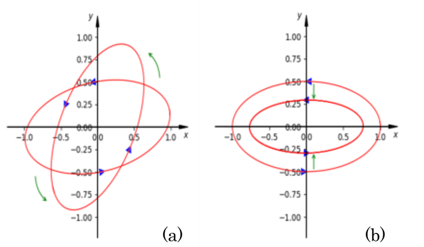

Figure 2. Evolution of the particle trajectory (red ellipse) in the transverse plane of a PWA, in (a) the betatron phase shift dominant regime and (b) the radiation reaction dominant regime.