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Stable, Efficient and High Quality Plasma Wakefield Positron Acceleration

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Next generation high energy electron-positron colliders are highly desirable for precision studies of the Higgs Boson and discovering physics beyond the standard model [1]. Current radio-frequency accelerators are limited by the accelerating gradients due to breakdowns, thus advanced acceleration schemes with high gradient, high efficiency and great beam quality are in demand.

Plasma wakefield accelerator (PWFA) has achieved several breakthroughs in electron beam acceleration to provide large acceleration gradients and high energy transfer efficiency while maintaining excellent beam quality [2]. Most groundbreaking results to date have been obtained using an intense electron bunch to excite a nonlinear wake that accelerates a witness electron bunch. However, it is not effective for positron acceleration because the volume at the very back of such wakes where the wakefield is both accelerating and focusing for positron is extremely small.

This report explores the physical conditions and feasible approaches necessary for achieving stable, efficient, and low-energy spread positron wakefield acceleration. We examine two key scenarios: positron acceleration in hollow plasma channels and in the blowout regime.

In the first scenario, we leverage the interaction between a hollow plasma channel and an asymmetric driving electron beam to generate a stable wake structure suitable for positron acceleration [3]. The self-consistent interaction between the positron beam and plasma boundary electrons enables high-efficiency, uniform positron acceleration. Three-dimensional particle-in-cell simulations indicate that energy extraction efficiencies of several tens of percent, along with energy spreads on the order of 1%, can be achieved simultaneously.

For the positron acceleration in the blowout regime, theoretical modeling and simulations reveal notable differences between positron and electron beam loading in plasma. Novel beam loading effects specific to positrons make efficient and uniform acceleration possible. Additionally, these mechanisms show potential for achieving high-transformer-ratio positron acceleration, as well as the simultaneous acceleration of both electron and positron beams. These results provide valuable insights for applying PWFA technology in future high-energy colliders.

We are also preparing to conduct experimental validation of these findings using high-energy positron beams from BEPC II.

References

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