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Multi-proton bunch driven hollow plasma wakefield acceleration in the nonlinear regime

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Proton-driven plasma wakefield acceleration has been demonstrated in simulations to be capable of accelerating particles to the energy frontier in a single stage. However, its potential is hindered by the fact that currently available proton bunches are orders of magnitude longer than the plasma wavelength. Self-modulation instability enables the micro-bunching of long proton bunches and allows driving plasma waves resonantly, however, it causes a significant loss of protons and requires the interaction regime to be linear. In this paper, we propose to use a hollow plasma channel for the multiple proton bunch driven plasma wakefield acceleration and demonstrate that it enables the electron acceleration in the nonlinear regime with much stronger plasma waves excited. The simulations show that over 90% protons can be kept after 150 m propagation in the hollow plasma and the region where the protons can stay is expanded significantly. Most importantly, the witness bunch is accelerated to the energy frontier with well-preserved beam quality.

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