Plasma Accelerator for Unstable Particles

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In plasma-wakefield acceleration, phase-locking of non-relativistic particles does not occur due to the significant difference between the group velocity of the driver (which travels nearly at the speed of light) [1,2] and the particles' velocity. Heavier particles (in comparison to electrons) with a finite lifetime, *e.g.* muons [3] and pions, are thus traditionally excluded from this acceleration method.

Recently, cutting-edge methods have been devised for shaping the spatio-temporal spectrum of electromagnetic wave packets that produce pulses with variable group velocities [4, 5, 6]. These pulses can propagate with subluminal group velocities, making them suitable candidates to drive acceleration wakes for slower particles. We demonstrate, with theory and numerical calculations, that such property, combined with a tailored density profile for the plasma, can give us the necessary control over the velocity of the wake to unlock the possibility of accelerating these particles from non-relativistic to relativistic velocities in a single acceleration stage in a plasma accelerator.

Our theoretical model, which predicts the plasma density profile and energy gain as a function of the initial particle velocity and mass, shows that muons and pions can accelerate from initial velocities around 0.9c to 0.99c in a plasma with a length on the order of millimeters. These conclusions are in very good agreement with quasi-3D particle-in-cell simulations with the code OSIRIS [7], which also show that 3 Joules lasers could be used to accomplish this goal.

[1] T. Tajima and J. M. Dawson, Physical Review Letters **43**, 267 (1979).
[2] C. Joshi, Physics Today **56** (6), 47 (1993).
[3] K.R. Long, *et al*. Nature Physics volume **17**, 289–292 (2021).
[4] A. Sainte-Marie *et al*., Optica **4**, 1298-1304 (2017).
[5] Froula, D.H., Turnbull, D., Davies, A.S. *et al*., Nature Photonics **12**, 262–265 (2018).
[6] H. Kondakci, Y. F. Abouraddy, Nature Communications **10**, 929 (2019).
[7] R.A. Fonseca *et al*., Phys. Plasmas Control. Fusion **55**, 124011 (2013).