Plasma wakefield excitation by a bunched proton beam

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Proton beams are perspective drivers for plasma wakefield acceleration because of their high energy content. However, a large length of available proton bunches requires them to be micro-bunched either by an external system, or by the plasma itself. The plasma creates the micro-bunches through the self-modulation instability, which, if properly controlled, ensures the optimal spacing of the micro-bunches [1]. However, roughly three quarters of the initial beam charge are lost during this process, so the plasma bunching is inefficient. Pre-bunching by an external system can be more charge efficient [2], but produces equally spaced bunches, while the micro-bunch charge can vary according to the charge distribution in the initial proton bunch.

We study wave excitation by equally spaced micro-bunches that form the bunch train. If the bunches are spaced at exactly the plasma frequency, then later bunches are partly defocused by the wakefield of earlier ones, and the train as a whole is unstable. The optimum bunch-to-bunch distance depends on the bunch number in the train. Consequently, by simply adjusting the train period, we cannot put all bunches to favorable phases simultaneously. By varying the bunch charge, however, it is possible to reach the optimum positioning of the micro-bunches with respect to the plasma wave. The optimum distribution of the bunch charge is exponential, and the exponent depends on the difference between the plasma wavelength and the train period. The leading front of the initial Gaussian beam can be, to some extent, approximated by the exponent. Therefore, for any initial proton bunch there exists an optimum difference between the plasma wavelength and the train period, which maximizes the excited wakefield. For the optimized micro-bunch train prepared from the SPS 400 GeV proton beam, the energy gain of accelerated electrons can be as high as 150 GeV in the plasma of the density $7\ 10^{14}\text{cm}^{-3}$

References

[1] K.V.Lotov, Phys. Plasmas 22, 103110 (2015).
[2] I. Sheinman, A. Petrenko, Proc. RuPAC2016, St. Petersburg, Russia, p.303-306.