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## Numerical simulation study of the propagation of a short electron bunch and a long proton bunch in a plasma ramp

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A particle bunch propagating through plasma will induce a non-linear response when  $n_b \gg n_{e0}$  [1]. A positively charged bunch will attract plasma electrons, which will flow-in to the propagation axis, creating a filament [2]. This will sustain defocusing fields for negatively charged particles.

In the Advanced Wakefield Experiment (AWAKE) [3], in which a long proton bunch drives high amplitude wakefields

for electron acceleration through self-modulation [4], there is a plasma density ramp at the entrance and exit of the plasma [5].

The density in the plasma ramp can be up to five orders of magnitude lower than that of the long plasma. In such a low

density, the proton bunch drives a plasma electron filament on axis. We present a numerical study performed with the particle-in-cell code LCODE [6] using parameters similar to those of the experiments. We show that the plasma ramp would have a detrimental effect, in terms of charge reduction or emittance growth, both for a seed electron bunch placed inside of the proton bunch and for an electron bunch injected in a second plasma for acceleration [7], if that plasma had a density ramp at the entrance.

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