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Self-Modulation Instability of a Wide and Long Relativistic Proton Bunch in Plasma

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When a long relativistic charged particle bunch travels in plasma, it undergoes the self-modulation instability. The bunch is converted into a train of microbunches that can resonantly drive large amplitude wakefields.
The Advanced WAKefield Experiment (AWAKE) at CERN has proven that the instability can be seeded using a relativistic ionization front copropagating within the proton bunch or using a preceding electron bunch, and that electrons can be injected and accelerated in the plasma wakefields driven by the self-modulated proton bunch.
We present experimental results showing that, when increasing the transverse size of the long proton bunch propagating in a 10-m-long plasma (plasma electron density $n_{pe} = 10^{14}$ cm^{-3}) without seed wakefields, the microbunch train is visible only in the tail of the bunch.
This can be explained considering that the growth rate of the instability becomes smaller when decreasing the charge density of the bunch.
However, when seeding the instability with the relativistic ionization front, microbunches develop and seeded self-modulation occurs even at plasma electron densities on the order of 10^{12} cm^{-3}.
Preliminary results and implications of these effects for the design of a proton-driven plasma wakefield accelerator (AWAKE Run 2) will be discussed.

Acknowledgments

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