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Filamentation of a Relativistic Proton Bunch in Plasma

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Filamentation instability can occur in plasma wakefield accelerators as well as in astrophysical media. This instability takes place when a charged particle bunch streams through a plasma with skin depth smaller than the bunch transverse size, so that the plasma return current flows within the bunch. Repulsion between opposite currents tends to reinforce any initial transverse perturbation or anisotropy in the current density profiles, causing the instability to grow, transforming the bunch into multiple high-current-density transverse filaments.
Occurrence of filamentation generates magnetic fields, by converting part of the kinetic energy stored in the bunch into magnetic energy. This process is one of the plausible candidates for magnetization of astrophysical media, as well as for the magnetic fields enhancement that could explain phenomena such as long-duration afterglow of gamma-ray bursts and collisionless shocks.
At the AWAKE experiment at CERN, we observed the early stage of filamentation (predicted by theory to occur in the form of the oblique instability) of a relativistic, wide proton bunch traveling in plasma [1], and we estimated the amplitude of the magnetic field that it generated. We discuss the implications for the design of a plasma wakefield accelerator.

[1] L. Verra et al. (AWAKE Collaboration), Phys. Rev. E 109, 055203 (2024)

Working group

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