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Laboratory Astrophysics and Plasma Wakefield Acceleration: Experimental Study of Magnetic Field Generation by Current Filamentation Instability of a Relativistic Proton Bunch in Plasma

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Current Filamentation Instability (CFI) 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 CFI generates magnetic fields within a non-magnetized background, by converting part of the kinetic energy stored in the bunch into magnetic energy. This process is in fact a plausible candidate 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.
We demonstrate with experimental results, in the context of the AWAKE experiment at CERN, that CFI occurs for a relativistic, wide proton bunch traveling in plasma. We discuss the implications for the design of a plasma wakefield accelerator and we show that the instability feeds the generation of magnetic fields.

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