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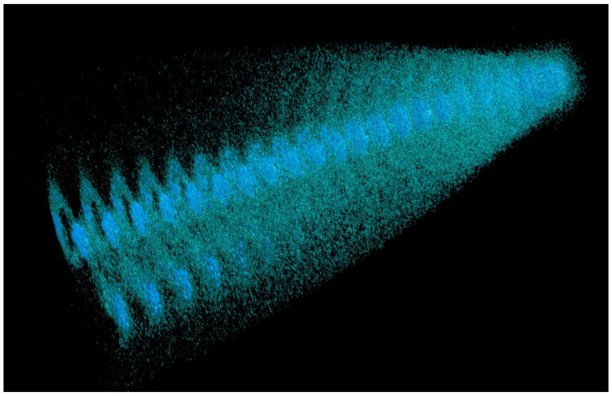
Two competing siblings

Meeting the two transverse instabilities that rule over long particle beams in plasmas

Relativistic particle beams can be used to generate high-amplitude plasma waves in a concept known as plasma wakefield acceleration. Since we are nowadays able to produce particle beams containing incredible amounts of energy (for example the proton beams at the Large Hadron Collider), these plasma waves could in theory accelerate a trailing electron bunch to TeV-scale energies in a single plasma stage [1]. However, it is difficult to produce high-energy proton bunches that are short with respect to the plasma wavelength, so we must rely on long particle bunches for plasma wakefield acceleration experiments for now.

When the size of the particle bunch extends beyond one plasma wavelength it becomes susceptible to two instabilities that act transversely. The **hose instability (HI)** causes the bunch centroid to oscillate with increasing amplitude, eventually breaking up the bunch. The **self-modulation instability (SMI)** acts on the bunch radius by modulating it with increasing amplitude, with the ultimate effect of fragmenting the initial bunch into a train of “microbunches” spaced at the plasma wavelength. This configuration is in turn ideal to resonantly excite a plasma wave, and the SMI is therefore associated with high-amplitude wakefields. This instability is exploited in the AWAKE experiment at CERN, for example [2].

Since the HI and the SMI grow at similar rates, they tend to compete. If the SMI is seeded strongly enough, for example, hosing is suppressed [3] (which is a convenient way to avoid it). When the initial seed levels are similar for both instabilities, however, they can couple to each other and evolve in a distinct regime where the oscillation of the centroid is asymmetrical and amplified.



Portion of a long proton bunch as it is subject to the coupled effect of the hosing and self-modulation instabilities inside a plasma (particle-in-cell simulation).

REFERENCES

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AUTHORS & CONTACT INFORMATION

Mariana Moreira
GoLP/IPFN, CERN
mariana.moreira@cern.ch