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Self-modulation and current filamentation instabilities of long and wide proton bunches in plasma

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A relativistic, charged particle bunch propagating in plasma is subject to various instabilities. *When the bunch is much longer than the cold plasma skin depth, it is subject to the self-modulation instability (SMI). This instability is routinely observed in the AWAKE experiment with narrow (200microns), long (7cm) proton bunches. Bunches wider than the skin depth are subject to the current filamentation instability (CFI). The proton bunch can be less focused (500microns). With a discharge source***, the plasma density can be quickly varied to cover a wide range of plasma skin depths, from larger to smaller than the wide bunch radius. The interaction could thus potentially cross the threshold for CFI to occur. At the same time, SMI may not occur with wide bunches in high-density plasmas.*

We plan on using both time-integrated and time-resolved images of the bunch after plasmas 3.5, 6.5 and 10m-long, to determine the ranges of occurrence of these two instabilities. Time-resolved images could evidence in a single event the evolution of CFI from multiple filaments, to coalescence into a single, broader filament. Varying plasma length, bunch charge and the mass of plasma ions (He, Ar, Kr) could yield information about development, growth rate and saturation of the instabilities. Understanding these instabilities is important for advanced accelerator concepts based on self-modulation, and for the generation of magnetic fields and associated radiation in astrophysics.

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Footnotes

*P. Muggli, AIP Conference Proceedings 1507, 594 (2012)N. Kumar et al., PRL 104, 255003 (2010).AWAKE Collaboration, PRL 122, 054802 (2019), M. Turner (AWAKE Collaboration), PRL 122, 054801 (2019), F. Batsch (AWAKE Collaboration), PRL 126, 164802 (2021), F. Braunmueller (AWAKE Collaboration), PRL 125, 264801 (2020), L. Verra (AWAKE Collaboration), PRL 129, 024802 (2022)R. Lee et al., PRL 31, 1390 (1973), B. Allen et al., PRL 109, 185007 (2012)***N. Lopes, this conference*

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Yes

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