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Ion motion and hosing suppression in self-modulated plasma wakefield acceleration

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With more than 10 kJ, currently available proton bunches at CERN were proposed as drivers for large amplitude wakefields capable to accelerate e-s to the TeV scale in Km long plasmas - proton driven plasma wakefield acceleration (PDPWFA). Unlike typical LWFA or PWFA experiments, which use ultra-short, 10-100 micrometer long drivers, proof-of-principle PDP-WFA experiments will employ 10 cm long proton bunches, encompassing tens-hundreds of plasma wavelengths, and operating through the self-modulation instability (SMI). In this talk we explore and give solutions to some of the challenges posed by future PDPWFA experiments. We find that background plasma ion motion can occur in low Z plasmas (e.g. H, He). In this scenario, the motion of background plasma ions can lead to the suppression of focusing/accelerating wakefields, resulting in the early saturation of SMI and preventing particle acceleration. Ion motion is mostly due to the transverse plasma ponderomotive force, but can be fully avoided in experiments by using high Z plasmas (e.g. Ar, Rb). We address the competition between hosing instability (HI) and SMI and provide the conditions for stable, hosing-free self-modulated plasma acceleration. Despite having similar growth rates to SMI, we find that hosing damps after the SMI saturation. Damping occurs due to betatron frequency detuning along the self-modulated bunch due to wakefield secular growth. The potential of the PDPWFA motivated several self-modulation experiments using electrons and positrons. The approved E209 experiment at SLAC FACET for instance will explore key physics of future PDPWFA experiments with currently available lepton bunches. We show that SMI of electrons and positrons can differ at SLAC FACET. We find that SMI of 20 GeV e-/e+ SLAC FACET bunches can occur in less than 1m, leading to 10-20 GV/m wakefields, and to multi GeV e-/e+ energy gain/loss.