DPP13-2013-001067

Abstract for an Invited Paper
for the DPP13 Meeting of
the American Physical Society

First experimental results on the self modulation instability (SMI) of long electron bunches in dense plasmas[1]

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We demonstrate experimentally for the first time the seeding of the self-modulation instability (SMI) by a relativistic electron bunch in a plasma. The long ($\approx 3.2\ ps$) bunch with a square current profile available at BNL-ATF drives wakefields with periods one to one seventh of the bunch length in plasmas in the $10^{15} \sim 10^{16}\ cm^{-3}$ density range. The effect of these MV/m range seed wakefields on the long bunch is observed as a periodic modulation of the bunch correlated energy spectrum after propagation along the 2 cm plasma. While it is the transverse wakefields that seed the SMI, the longitudinal wakefields are always accompanied by corresponding transverse wakefields. The seeding of the SMI by the sharp ($< \lambda_{pe}$) rising edge of the bunch is confirmed by the observation that the position of the first bunch in the modulated energy spectra does not change when the plasma density is varied. In an accelerator experiment this is a necessary condition to deterministically inject a witness bunch into the accelerating and focusing phase of the wakefields. Simulations [1] and experimental results confirm that the SMI does not grow significantly over the plasma length with the chosen 50 pC bunch charge. Simulation results also show that, with a 1 nC bunch charge, the SMI grows and saturates over the same length. However, due to dephasing between the bunch particles and the wakefields, the actual energy gain/loss is significantly lower than estimated from the peak accelerating field. We also observe in simulations that the finite radial plasma size and the radial plasma density profile expected in the capillary discharge do not significantly affect the development of the SMI. A number of SMI experiments are planned at major facilities (i.e. AWAKE at CERN, E209 at SLAC-FACET etc.). All of them will rely on seeding to observe the instability, using it to externally inject electrons in the wakefields or to mitigate the occurrence of the hose instability. The results presented here are an important seed for these major experiments. Detailed experimental and simulation results will be presented.

[1] R. A. Fonseca *et al.*, Lect. Notes Comp. Sci. vol. 2331/2002, (Springer Berlin/Heidelberg, (2002).

[1]Work Supported by US. DOE.