Plasma Wakefield Acceleration and the AWAKE Experiment at CERN

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Plasma-based particle accelerators (PBPAs) made remarkable experimental progress over the last decade. In particular, particle-beam driven accelerators known as plasma wakefield accelerators (PWFAs) have first demonstrated energy gain of more than 40GeV in less than a meter of plasma and have later demonstrated narrow final energy spread and reasonable energy transfer efficiency. In these experiments electrons were both driving the wakefields, sustained by an relativistic, electro-static plasma wave, and experiencing the acceleration. However, reaching energies of interest for high-energy or particle physic applications requires either staging multiple PBPAs or drive bunches carrying large amounts of energy. Proton bunches produced for example by the CERN SPS (~400GeV/p+) or LHC (~7TeV/p+) carry tens to hundreds of kJ of energy potentially. These drivers could alow for excitation of wakefields and acceleration of a witness electron or positron bunch over very long distances (~km) and for reaching very high energies (~TeV), as demonstrated in numerical simulations.[1] However, these bunches are long (~10cm) and not suitable to driving large amplitude wakefields since the wakefield amplitude scales inversely with the bunch length and can reach the GV/m level only with bunches <1mm.

Bunches longer than the plasma wave period are subject to a transverse self-modulation instability[2] (SMI) that transforms the long, continuous bunch into a train of bunches separated approximately by and somewhat shorter than the plasma wave period. Once formed, this train can resonantly drive large amplitude wakefields.

The AWAKE[3] experiment at CERN, the first p+-driven PWFA experiment, is aiming at studying the SMI of proton bunches and at demonstrating the acceleration of witness electrons by the associated wakefields.

The first experiments will start towards the end of 2016, with the external injection of electrons starting in 2017. Typical parameters for the experiment are: p+ bunch energy 400GeV, length ~12cm, population 3x1011, focused to ~220µm, plasma density 7x1014cm-3, length 10m and radius >1mm. The plasma is created by laser field-ionization of a rubidium vapor. The short (~100fs) laser pulse also serves to seed the SMI by abrupt ionization and thus to determine the start of the wakefields. The witness electron bunch is produced by a RF photo-injector gun and is synchronized with the ionizing pulse and thus with the wakefields.

I will introduce the PWFA and show sample results of past experiments. I will then explain the physics at play for the SMI and for the AWAKE experiment. I will describe the AWAKE setup and introduce expected results.

[1]Caldwell et al., Phys. Plasmas 18, 103101 (2011)

[2]Kumar et al., Phys. Rev. Lett. 104, 255003 (2010)

[3]AWAKE Collaboration, Plasma Phys. Control. Fusion 56 084013 (2014)