Response of bounded plasma column to dense charged particle beams

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Studies of radially-bounded plasmas at setups having a direct relationship to particle beam-driven plasma wakefield acceleration (PWFA). The problem was solved in the linear approximation for uniform plasmas and beams of densities much lower than the plasma density. Later studies focus on effects of radial plasma non-uniformity, long term evolution of nonlinear plasma waves and beam instabilities.

Recently, the experiment AWAKE[1] at CERN have generated interest in interaction of dense proton beams with low-density plasmas. In AWAKE, three overlapping beams (laser, proton, and electron) propagate through the 10 meter long gas cell filled with the rubidium vapor. The short laser pulse creates the uniform plasma column with a sharp boundary. The proton beam self-modulates and drives a high-amplitude plasma wave that is witnessed by the electron beam. Since the laser pulse cannot penetrate foils, there are orifices between the gas cell and high-vacuum upstream and downstream beam lines. The rubidium vapor leaks through the orifices and condenses on cold walls of expansion volumes attached to both ends of the gas cell. The laser pulse ionizes the divergent vapor stream and creates the radially uniform plasma of a constant radius and density that gradually reduces away from the orifice. The wakefields excited in this plasma by the particle beams are rather weak to disturb the high-energy proton beam, but sufficient for changing trajectories of lower-energy electrons and modifying electron trapping conditions.

In our studies of the bounded plasma response to ultrarelativistic charged particle beams we used both linear analytical theory and the results of numerical simulations performed by LCODE[2]. This approach allowed us to investigate the response in the wide range of plasma densities and corresponding plasma regimes. Despite a variety of linear and non-linear plasma response effects, we discovered a strong defocusing region near the plasma cell inlet in the AWAKE experiment. Passing through it, the witness beam to be injected into the plasma will be totally destroyed. To avoid this effect we proposed a new injection scheme is called “oblique”.

[1] E. Gschwendtner, et al., Nuclear Instr. Methods A **829**, 76 (2016).

[2] A.P.Sosedkin, K.V.Lotov, Nuclear Instr. Methods A **829**, 350 (2016).