Femtosecond electron microscopy of the laser-plasma wakefield dynamics

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Nowadays laser-plasma-based wakefield accelerators are capable to deliver GeV-level femtosecond electron bunches crucial for emerging applications in medicine, industry, and fundamental science. Many of these applications critically require the precise characterization of the accelerated electron bunch as well as the plasma wakefield that largely affects the bunch's quality. Advanced diagnostics of such highly transient, microscopic bunch and field structures, however, remains very challenging. In the experiments presented here, we address this challenge with a novel technique we name as femtosecond ultrarelativistic electron microscopy, which utilizes a high-energy electron bunch from another laser-plasma accelerator as a probe. This single-shot electron microscopy allows us to characterize several important processes existing in the nonlinear plasma wakefield, including the fine structure of the highly nonlinear plasma wave, accelerated electron beam structure and its evolution, and more impressively, the entire transition from laser driven wakefield to electron bunch driven wakefield (see Figure 1), all with very high spatiotemporal resolution. We anticipate that these results will significantly advance the understanding of the complex laser-beam-plasma dynamics and also provide a powerful diagnostic tool for the real-time optimization of plasma accelerators.

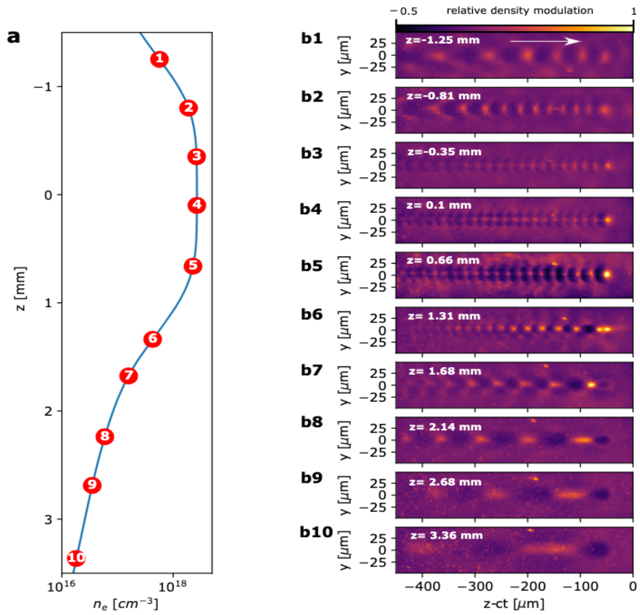

Figure 1 Experimental observation of the wakefield dynamics at ten different positions. (a) Probed positions along the gas target and its corresponding plasma density (log scale). (b1)-(b10) Experimental snapshots of the plasma wake at the positions in the plasma marked in (a). The white arrow in the first subplot indicates the wake propagation direction