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Temporal characterizations of electron bunches from laser-plasma accelerator

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High power laser-driven electron sources [1,2] are considered to have potentials for applications in fast ignition [3], pump-probe study [4], and the construction of a table-top x-ray free-electron laser (XFEL) [5]. Among the particle acceleration schemes from laser plasma interaction, the laser wakefield acceleration (LWFA) [2], with the ultra-short and high-acceleration-gradient features, has invokes great interest worldwide. In the recent decade, the qualities of the electron beams had been improved in aspects of energy (> 8 GeV) [6] and relative energy spread (< 1%) [7]. This compact acceleration regime is considered to useful in the generation of table-top x-ray free electron laser and related ultra-fast studies.

The timing jitters and bunch durations of the electron bunches are important parameters for the application of LWFA in pump-probe studies, because those parameters partially determine the time resolution. However, single-shot electron timing monitoring had barely been conducted in the experiment. By introducing the electro-optic (EO) spatial decoding technique to LWFA, we succeeded in monitoring the temporal distribution of the electrons in a single shot [8-11]. Some of the results can be found in Figure 1. We observed that when using a laser with moderate intensity (~ 10^{17} W/cm^2), the electrons were not “jitter-free” as commonly assumed. An interesting phenomenon was discovered that the wavefront of the Coulomb field of the electron bunch had a spherical shape when observing at a position very close to the gas target. After that, by working with a relatively controlled injection regime and an intense laser (> 10^{18} W/cm^2), the electron timing fluctuations were optimized to less than 7 femtoseconds and the upper limit of the electron bunch durations were demonstrated to be less than few tens of femtoseconds. This research showed the capability of EO sampling as a real-time electron temporal diagnostic for laser plasma particle sources and the ultra-fast nature of the electron bunches from LWFA.

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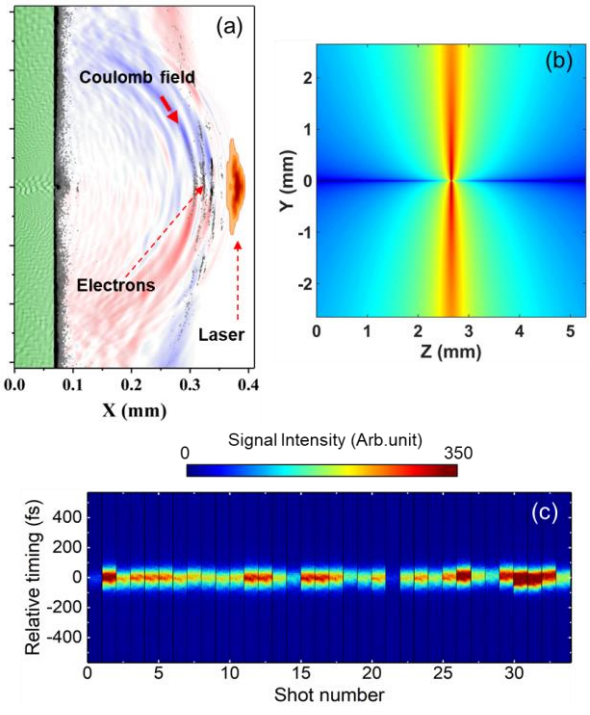

Figure 1: (a) Coulomb field structure when electrons emitted from plasma has a spherical shape; (b) Coulomb field of an electron propagating in free space; (c) Consecutive 34 shots of single-shot electron timing signals shows a jitter at femtosecond level.