Laser-plasma based electron acceleration and its applications

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Recent advances of high-power lasers have engineered a new area of plasma physics, namely the relativistic laser plasma interaction. One of the most extraordinary phenomena from the interaction is the propulsion of a few electrons (pC ~ nC charge) to ultra-relativistic energies (GeV-class) while the bulk plasma remains slightly perturbed. To account for the few far-from-equilibrium electrons, individual particles have to be followed by using more first-principle type calculations such as the particle-in-cell simulation, and the single-particle dynamics is often treated. In this talk, we harness these tools and investigate such plasma-based accelerations in an ion channel for two major mechanisms, namely the laser wakefield acceleration (LWFA) and direct laser acceleration (DLA). A leading effect of the former is the excitation of high-amplitude plasma waves that can be well described in 1D by fluid pictures. Such waves develop singularities close to breaking, forming high-density spikes. We show how such electron spikes can be injected into the plasma wave in a controlled manner. The resulting acceleration of a dense electron sheet in the quasi-1D regime can produce strong attosecond light pulses via coherent synchrotron radiation. It may also serve as a relativistic electron mirror for coherent x-ray backscattering. In the DLA regime, electrons gain energy via resonances with the laser field. Controlled DLA for high-quality acceleration remains a challenge, largely due to a lack of thorough understanding of the very nonlinear resonances. We present a new insight into the resonance by isolating the role of electron propagation angle explicitly. This novel approach allows us to find the full resonances beyond the usual paraxial limit, and describe both paraxial and non-paraxial conditions, both first-order and high-order resonances in a single framework. It paves the way toward controlled electron trapping in DLA and collective beam analysis. Applications of the accelerations to light sources and nuclear/ultrafast science are also discussed.