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Control of laser-driven high-current relativistic electron beam and its application in generating compact radiation sources

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Beam-matter interaction is critical across a wide range of fields, including condensed matter physics, astrophysics, high-energy-density physics. The transport of electron beams, in particular, play a pivotal role in processes such as energy transfer, conductivity, and phase transitions, impacting phenomena ranging from gamma-ray burst and star formation in the universe to the creation of warm dense matter and confined thermonuclear fusion on Earth. Beyond fundamental research, beam-matter interaction drives the development of microwave tubes, free electron lasers, and tabletop accelerators, all of which have significant applications in both applied physics and industry.

The advent of short intense lasers has revolutionized the generation of relativistic electron beams (REBs), enabling unprecedented currents up to mega-amperes – surpassing any previously achievable in laboratory settings by several orders of magnitude. As these high-current REBs propagate through materials, the latter is immediately ionized into plasma, giving rise to various new phenomena. Transport of these high-current REBs in plasma is a fundamental issue relevant to high-energy-density space and laboratory plasmas, and has attracted much research interest. The problems involved include collisionless shocks, cosmic magnetic field generation, gamma-ray bursts, etc. It is also relevant to many applications, including inertial confinement fusion, compact particle and/or radiation sources. So far the underlying physics of high-current REB transport in plasmas, especially those involved with small spatial and temporal scales, are not yet well understood.

In this paper, I will introduce our recent research progress on the microscopic transport of REB in plasmas, and some interesting new results are obtained, including the nanoscale electrostatic modulation of REB in solid-density plasmas[1], branching[2-3] and anomalous stopping[4] of REB in porous materials. Based on these new phenomena, we have further extended the applications of REB in generating coherent radiation source and high-brilliance incoherent gamma-rays. In particular, we propose a new approach for producing coherent intense subcycle pulse by simply directing a REB into a plasma with a density up-ramp[5]. Super-channeling of high-current electron beam in stochastic structures is also discovered and this phenomenon can lead to extremely high conversion efficiency gamma-rays[6]. These results should be of much interest to researchers in many areas.

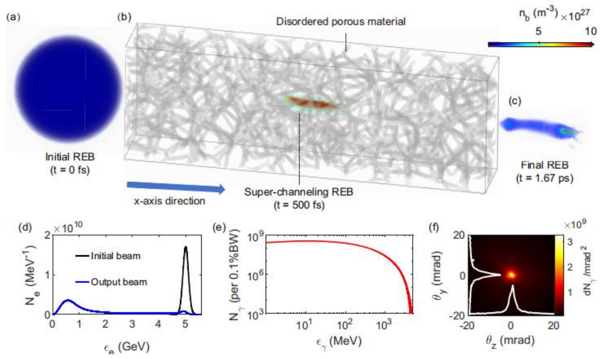

Fig. 1. REB super-channeling in disordered porous material and brilliant gamma-ray emission from our 3D PIC simulations.

References
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