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Plasma Accelerators Race to 10 GeV and Beyond

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This paper reviews the concepts, recent progress and current challenges for realizing the tremendous electric fields in relativistic plasma waves for applications ranging from tabletop particle accelerators to high-energy physics. Experiments in the 90's on laser-driven plasma wakefield accelerators at several laboratories around the world demonstrated the potential for plasma wakefields to accelerate intense bunches of self-trapped particles at rates as high as 100 GeV/m in mm-scale gas jets. These early experiments offered impressive gradients but large energy spread (100%) and short interaction lengths. Major breakthroughs have recently occurred on both fronts. Three groups (LBL-US, LOA-France and RAL-UK) have now entered a new regime of laser wakefield acceleration resulting in 100 MeV mono-energetic beams with up to nanoCoulombs of charge and very small angular spread. Simulations suggest that current lasers are just entering this new regime, and the scaling to higher energies appears attractive. In parallel with the progress in laser-driven wakefields, particle-beam driven wakefield accelerators are making large strides. A series of experiments using the 30 GeV beam of the Stanford Linear Accelerator Center (SLAC) has demonstrated high-gradient acceleration of electrons and positrons in meter-scale plasmas. The UCLA/USC/SLAC collaboration has accelerated electrons beyond 1 GeV and is aiming at 10 GeV in 30 cm as the next step toward a "plasma afterburner," a concept for doubling the energy of a high-energy collider in a few tens of meters of plasma. In addition to wakefield acceleration, these and other experiments have demonstrated the rich physics bounty to be reaped from relativistic beam-plasma interactions. This includes plasma lenses capable of focusing particle beams to the highest density ever produced, collective radiation mechanisms capable of generating high-brightness x-ray beams, collective refraction of particles at a plasma interface, and acceleration of intense proton beams from laser-irradiated foils.