Acceleration of electrons in the plasma wakefield of a proton bunch

High-energy particle accelerators have been crucial in providing a deeper understanding of fundamental particles and the forces that govern their interactions. To increase the energy of the particles or to reduce the size of the accelerator, new acceleration schemes need to be developed. Plasma wakefield acceleration, in which the electrons in a plasma are excited, leading to strong electric fields (so called 'wakefields'), is one such promising acceleration technique. Experiments have shown that an intense laser pulse or electron bunch traversing a plasma can drive electric fields of tens of gigavolts per metre and above—well beyond those achieved in conventional radio-frequency accelerators (about 0.1 gigavolt per metre). However, the low stored energy of laser pulses and electron bunches means that multiple acceleration stages are needed to reach very high particle energies. The use of proton bunches is compelling because they have the potential to drive wakefields and to accelerate electrons to high energy in a single acceleration stage. Long, thin proton bunches can be used because they undergo a process called self-modulation, a particle-plasma interaction that splits the bunch longitudinally into a series of high-density microbunches, which then act resonantly to create large wakefields. The Advanced Wakefield (AWAKE) experiment at CERN uses high-intensity proton bunches in which each proton has an energy of 400 giga-electronvolts, resulting in a total bunch energy of 19 kilojoules to drive a wakefield in a ten-metre-long plasma. Electron bunches are then injected into this wakefield. Here we present measurements of electrons accelerated up to two giga-electronvolts at the AWAKE experiment, in a demonstration of proton-driven plasma wakefield acceleration. Measurements were conducted under various plasma conditions and the acceleration was found to be consistent and reliable. The potential for this scheme to produce very high-energy electron bunches in a single accelerating stage means that our results are an important step towards the development of future high-energy particle accelerators.

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