Two stage acceleration of protons in the interaction of high-energy lepton flows with background plasma

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We present particle-in-cell simulation studies on the interaction of high energy lepton flows with background electron-proton plasma, focusing on the acceleration processes of background protons due to development of electromagnetic turbulence. Such interaction may be found in the universe when plasma jets propagate in the interstellar medium. When an electron-positron beam is injected into the background plasma, the Weibel instability is excited, which finally leads to the development of plasma turbulence in the nonlinear stage. The turbulent electric and magnetic fields accelerate plasma particles via Fermi II type acceleration, where power-law energy spectra are found for electrons and protons. The accelerated protons provide a dissipative mechanism for the formation of collisionless electrostatic shock waves at a later time. Some pre-accelerated protons are further accelerated when passing through the shock wave front. Dependence of proton acceleration on the beam-plasma density ratio and beam energy is investigated. For homogeneous plasma, both acceleration mechanisms are found to be significant; In the case of inhomogeneous plasma, the proton acceleration in the plasma turbulence is dominant. The final energy of background protons increase with the density and kinetic energy of the lepton flow. These results may help explain the origin of high-energy cosmic rays.