Power-law electron acceleration due to Levy jumps in turbulent wakefield driven by an intense laser pulse

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The origin of cosmic rays has been on open question for more than one century. The nonthermal feature and wide rage energy spectrum of cosmic ray particles draw scientists' attentions. The diffusive shock acceleration (DSA) is the standard model to address the acceleration mechanism of galactic cosmic rays, however, the origins of extragalactic cosmic rays are unascertained

Recently, wakefield acceleration has been considered as a possible mechanism to explain the cosmic ray acceleration [1]. According to the similarity principle in laboratory astrophysics, we use an intense laser pulse to instead of the large amplitude light precursor waves to model upstream plasma experimentally by considering the two important governing parameters in the wakefield acceleration: the normalized wave amplitude and the ratio between plasma and light frequency [2].

Our experimental evidence shows that the laser-driven turbulent wakefields nonthermally accelerate electrons and universally generate power-law spectra with an index of -2 independent of the governing parameters.

To address the power-law spectra, we performed a 1D PIC ($a_0 = 40, \tau = 30$ fs, $n_0 = 0.2\, n_c$) to obtain the nonthermal distribution function, as shown in Figure 1.

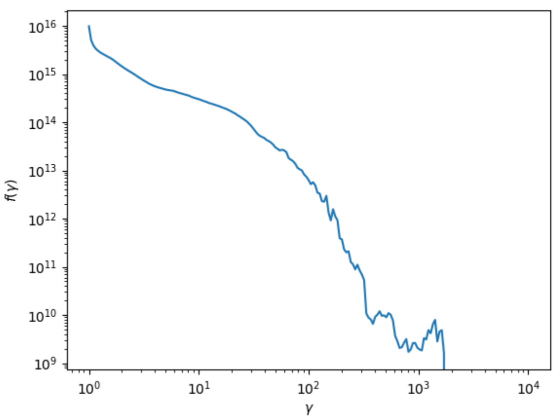

Figure 1. Energy distribution function.

We track the energy γ time history of each particle to resolve the particle motion in the turbulent wakefields and estimate the transition probability density (TPD) $\Psi(\gamma, \Delta\gamma)$ which is a function of the jump of energy γ in each random event $\Delta\gamma$, as shown in Figure 2 (final $\gamma = 107$) and Figure 3 (final $\gamma = 124$) [3]. It is found that the TPD can be described by single Lorentzian function Lorentzian-Gaussian function when final $\gamma > 124$ and final $\gamma < 107$, respectively. We can conclude that the Levy's jump dominates the acceleration when electron energy is at the tail of the distribution; At lower energy region, the thermalization due to the damp of laser pulse leads to the acceleration is contributed by both Levy's jump and Brownian motion.

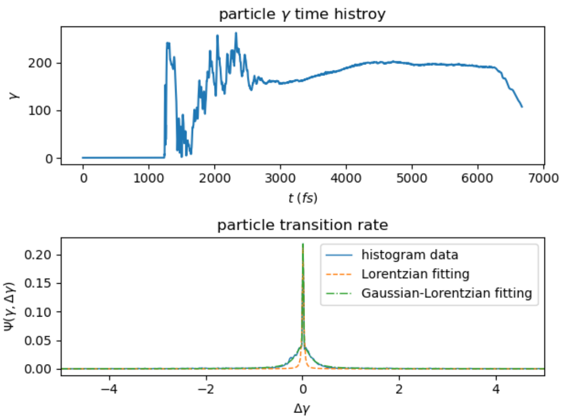

Figure 2. Time history and TPD for final $\gamma = 107$.

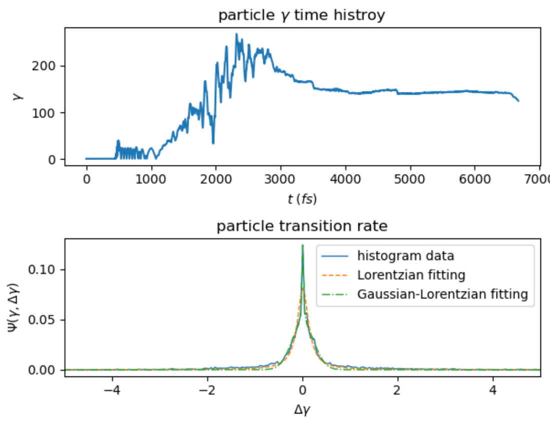

Figure 3. Time history and TPD for final $\gamma = 124$.

References

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