Plasma pair-production dynamics in ultra intense electromagnetic fields

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Due to the continuous development of ultra-intense laser fields, much interest has recently been devoted to strong field dynamics of plasmas. For a field strength approaching the Schwinger critical field, new phenomena enters the picture, in particular electron positron pair production can take place. Here we apply the so called Dirac Heisenberg Wigner (DHW) formalism [1], to study plasma phenomena of this type self consistently. The DHW formalism is based on a Wigner transformation of the Dirac equation, also accounting for the vacuum expectation values of the free Dirac field operators. Focusing on the simplest case of electrostatic plasma waves, the 16 scalar DHW-equations are reduced to a set of 4 scalar equations, that together with Ampere's law constitute a closed set. Firstly, the linear dispersion relation for Langmuir waves is derived from these equation. It is found that the dispersion relation shows several new features due to the quantum relativistic treatment. Importantly, for high enough plasma density, there is a new damping mechanism due to electron-positron pair creation.

Next, to connect with previous results [2,3], the reduced system is also studied for a prescribed electric pulse, and we obtain agreement with previous works [2,3], see Fig. 1. Furthermore, earlier findings are extended by computing the full momentum dependence (i.e., also including the dependence on the momentum perpendicular to the electric field), see Fig 2.

Next, we turn the attention to the case of fully nonlinear Langmuir waves, with a field strength close to the Schwinger critical field. It is found that for large initial electric field (close to the critical field) the waves are damped even in the absence of resonant particles, due to the creation of electron-positron pairs. After an initial phase of pair-production, the process naturally switches to its reverse counter-part, electron positron annihilation accompanied by a growth in the electric field strength. The dependence of the dynamics on the initial values for the electric field, temperature and density are studied. We find that the process of pair-production can be turned off when the empty states have too high energy for pair production to be feasible. The consequences of our findings are discussed.

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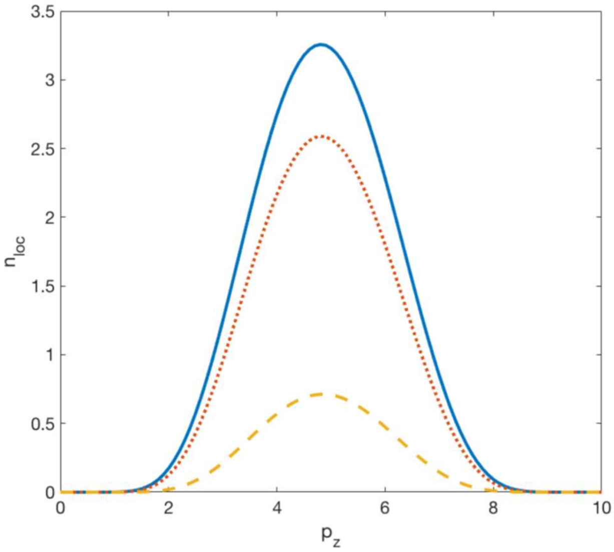

Figure 1. The number of pairs $\tilde{n}_{\rm loc}(\mathbf{p}, t \to \infty)$ as a function of the normalized parallel momentum p_z/m for three different values of the normalized perpendicular momentum $p_\perp/m$, the solid curve has $p_\perp/m = 0$, the dotted curve has $p_\perp/m = 0.2$ and the dashed curve has $p_\perp/m = 0.5$.

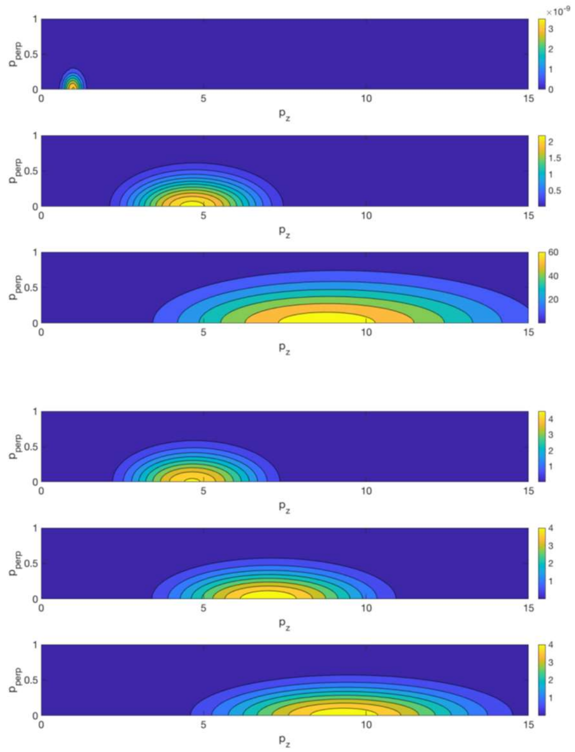

Figure 2. Number of pairs $\tilde{n}_{\rm loc}(\mathbf{p})$ for: a) different amplitudes of the electric fields E=0.1,0.5,1 (the upper subfigure), b) different time duration τ=10,15,20 (the lower subfigure).