Current of Produced Pairs in Time Dependent Electric Field

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In recent years, substantial research has focused on strong field physics, where various quantum electrodynamics (QED) effects are prominent (see [1,2]). The rapid advancements in laser intensities have been a key motivator for this research [1–3]. Despite consistent progress, current laser peak electric fields remain well below the critical field strength $E_{cr} \approx 1.3 \times 10^{18}$. However, proposals exist to use plasma-based methods to amplify current laser fields to reach the Schwinger limit [4]. Research on ultra-high intensities, particularly those nearing or exceeding the Schwinger limit, has focused on Schwinger pair creation in a vacuum [5–10]. Key areas of study include understanding the interaction between temporal and spatial field variations [6–8], comparing different computational methods [5,7], and optimizing the geometry of colliding laser pulses to maximize pair creation [9].In fields of sufficient strength, a significant number of pairs are created, generating plasma currents that alter the original fields, making the back-reaction through Ampère's law important. When dynamics are initiated with a Sauter pulse [10] or a constant initial electric field, the system oscillates with a plasma frequency proportional to the peak electric field. In the present paper, we intend to study how the dynamics are modified when a time-dependent strong field is applied to a vacuum. In this case, the question enters the picture about defining a timedependent particle number not only asymptotic early and late times but during the presence of the field. Naively, this concept is not well-defined for such non-equilibrium processes because the particle number at intermediate times depends on a choice of reference states that define particles and antiparticles. Despite this, the final late-time particle number is independent of this basis choice. In non-equilibrium quantum field theory, defining particle numbers at intermediate times requires selecting a basis of states that can vary with the system's dynamics. This choice affects the distinction between particles and antiparticles and, thus, the particle number at any given intermediate time. How can one make any generic statements about the intermediate time behavior? One possibility for investigating this is considering a unique and well-defined quantity at intermediate times. The prime candidate for this is the current density. It is observable and, thus, at least in principle, measurable. However, in the present work, we also discussed generic features of other observable (particle number and energy densities, pressure). These may help better understand the dynamical system's intermediate time behavior.

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