Finite-Time Behaviour of Vacuum Instability: Electron-Positron Creation in Strong Electric Fields

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The phenomenon of particle-antiparticle generation from the vacuum in the presence of intense electric fields has recently garnered significant attention in the field of high-energy particle physics, particularly within the realm of early cosmology. While the theoretical concept of vacuum particle creation under the influence of strong electric fields was proposed many years ago[1-3], experimental validation of this phenomenon is still pending. Theoretical investigations rooted in kinetic theory[4-6] have revealed the existence of a dense quasi-particle plasma, even in electric fields below the critical Schwinger threshold. However, this quasi-particle plasma is intrinsically unstable and dissipates once the external field is deactivated, in contrast to the sustained plasma observed when a strong field pulse surpasses the critical threshold. Several proposals have been presented to detect the quasi-particle Electron-Positron Plasma (EPP) generated within the focal region of counter-propagating laser beams, and ongoing efforts are underway to approach electric fields nearing the Schwinger limit through the utilization of advanced X-ray laser facilities and other research facilities worldwide[7-8]. Traditionally, investigations in the field of vacuum particle production have primarily focused on elucidating the characteristics of the out-state, which represents the system's state after the external field has ceased. This research emphasis arises from the objective of identifying and observing free real particles in experimental settings. However, there is a growing interest in exploring the properties of intermediate states, also known as mid-states or non-asymptotic states[9]. These intermediate states correspond to the system during the interaction of quasi-particles in the presence of the external field, prior to reaching the final out-state. Exploring these intermediate states holds significant importance as it provides valuable insights into the dynamics and behavior of quasi-particles under the influence of the external field, thereby deepening our understanding of their interactions and potential experimental manifestations. In this study, we specifically investigate the electron-positron plasma (EPP) generated from the vacuum, which undergoes three distinct stages of evolution: the quasi-particle stage during the action of the electric field pulse, the transient period of EPP transmutation, and the final residual EPP (REPP) in the out-state, where particles exist on their respective mass shells. By thoroughly examining the particle distribution function, we provide a comprehensive description of the pair production process throughout all three stages. Notably, we scrutinize the momentum spectra of particles during non-asymptotic time intervals. This detailed analysis of particle numbers and spectra significantly enhances our understanding of designing laser pulses that effectively lower the critical electric field threshold. Moreover, it offers valuable insights into the time-dependent processes of pair recombination and the back-reaction of pairs. By shedding light on these fundamental aspects, our research expands the frontiers of vacuum particle production and establishes a solid foundation for future experimental endeavors investigating EPP created in strong electric fields.

References

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