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Pair Production in time-dependent Electric field at Finite times

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A strong classical electromagnetic or gravitational background can lead to vacuum instability and produce particle-antiparticle pairs. This extraordinary property of quantum field theory has far-reaching implications for understanding the generation of particle-antiparticle pairs in the presence of a strong electric field[6]; particle creation in the expanding universe[25]; black hole evaporation as a result of Hawking radiation[22-24]; and Unruh radiation, in which particle number is seen by an accelerating observer[20-21]. The process of particle creation from the quantum vacuum was first studied in 1951 by Schwinger under a constant electric field, and this phenomenon is known as the Schwinger effect[1]. This particle creation paradigm has crucial importance for non-equilibrium processes in heavy-ion collisions[2-4] as well as astrophysical phenomena and the search for nonlinear and nonperturbative effects in ultraintense laser systems[7-8].
Particle production is the process of evolving a quantum system from an initial equilibrium configuration to a new final equilibrium configuration via an intermediate non-equilibrium evolution caused by a strong field background. Quantitative description of particle production at all times in a time-dependent electromagnetic field is not possible due to the absence of unique separation into positive and negative energy states at intermediate times and these positive and negative states are well-defined only at asymptotically early and late times where the field vanishes. A common approach is to define particle number in terms of an adiabatic basis using the Bogoliubov transformation[9-12,26]. In the adiabatic basis, we examine the problem of pair production in a time-varying spatially uniform electric field $\mathbf{E}(t)=(0,0,E_0 \,\mathrm{sech}^2(t/\tau))$ which has been studied by various authors[13-18], who calculated the number of particles created at the asymptotic time but the problem of particle production at the finite time is not studied. Actually, we looking for the evolution of the quantum system at some initial time t_0 in the vacuum state but now what will be the properties of the quantum system at finite time t? We choose a finite time t in the multiple of the pulse duration (τ) of the given electric field ($T = \tau, 2\tau, 3\tau, \ldots$) and see what happens to the system properties at that time. The finite time behavior of particle production in the Sauter-pulse field is studied. To study the dynamical behavior of particle production, the one-particle momentum distribution function $f(\mathbf{p}, t)$ is an important quantity in the description of the particle production process in the time-dependent electric field.The time evolution of the particle distribution function $f(\mathbf{p}, t)$ in momentum space is studied for $E_0 = 0.2$ and $\tau = 10$ in non-perturbative regime with the Keldysh parameter (\gammma = 0.5).
Here, we discuss both longitudinal and transverse momentum spectrums to understand what happened to the quantum system after a finite time in the process of particle production from the vacuum in a linearly polarized time-dependent Sauter field.
The longitudinal momentum (canonical momentum along the field/ p_z)spectrum of the created particle shows a complex behavior of splitting and manifests oscillation arising at the finite time where the electric field nearly vanished and this oscillating structure can be understood in the Dynamical Tunneling picture[19].
The transverse momentum (canonical momentum perpendicular to the field) spectrum of the created particle shows only the splitting of smooth structure and the absence of quantum interference, which is an obvious interference effect that occurs only in the direction of the electric field.

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