IOP Conf. Series: Journal of Physics: Conf. Series **875** (2017) 042005 doi:10.1088/1742-6596/875/5/042005

Electron-positron pair production in space-time-dependent colliding laser pulses

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Synopsis The Schwinger pair-production process in the presence of two counter-propagating linearly polarised laser pulses is studied by means of a non-perturbative numerical technique. The spatial finiteness of the pulses is taken into account, i.e. the problem is examined beyond the standing-wave approximation.

Electron-positron pair production (PP) from the vacuum in strong external backgrounds is a fundamental non-linear phenomenon predicted by quantum electrodynamics. It is well-known that in a purely electric static field the PP probability is negligible unless the field strength is close to the Schwinger critical value $E_c = m^2c^3/(|e|\hbar) = 1.3 \times 10^{16}$ V/cm. This limit can be effectively lowered if the external field oscillates with time. Let E and ω be the characteristic strength of the external field and its frequency. With the aid of the dimensionless adiabaticity parameter $\xi = |eE|/(mc\omega)$, the non-perturbative (tunneling) and the multiphoton regimes can be distinguished by $\xi \gg 1$ and $\xi \ll 1$, respectively. We focus on the intermediate case $\xi \sim 1$.

Due to the recent rapid development of laser technologies (ELI, XFEL and other facilities), a substantial interest in non-perturbative PP has been revived. In this context a collision of two counter-propagating laser pulses appears to be a very promising scenario. Most theoretical studies carried out so far approximated the resulting field by a spatially homogeneous background depending solely on time (see [1, 2, 3] and references therein). This approach is called the dipole approximation (DA). However, the influence of the spatial variations of the external field as well as its magnetic component may play a very important role in the PP process [4]. In order to analyse these effects, one can take into consideration the spatial variations of the carrier assuming that the envelope is still homogeneous in space. The resulting field becomes a standing wave oscillating with time.

Within the present study we go beyond the standing-wave approximation (SWA) taking into account the spatial dependence of both carrier and envelope. The patterns established within SWA are strongly modified once the pulses contain a small number of cycles. We provide a numerical analysis based on our non-perturbative technique developed previously [5]. By solving the Dirac equation in the momentum representation, we obtain the PP probabilities and study the spectrum of particles created.

In Figure 1 we present the mean number of electrons produced as a function of the x-component of their momentum ($\vec{E} \parallel \vec{e}_x$, $\vec{B} \parallel \vec{e}_y$ and z is the propagation direction). In these computations $\xi = 0.5$ for an individual pulse (in the presence of two pulses ξ effectively equals unity), $\omega = 0.5\ mc^2/\hbar$ and the number of cycles $N = 2$. The results were obtained within DA, SWA and beyond these approximations ("exact calculations"). We observe that for the case of a small number of cycles ($N \sim 1$) neither DA nor SWA provides accurate predictions. Within our study this issue is investigated in detail.

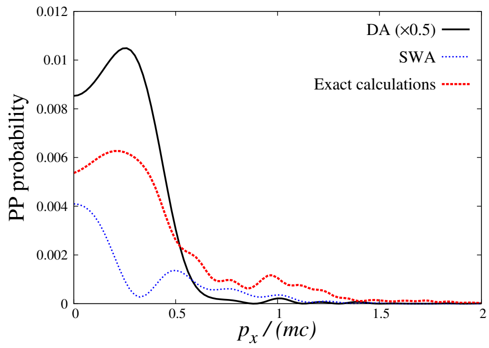

Figure 1. The PP probability as a function of p_x (the field parameters are given in the text).

This work was supported by RFBR (Grant No. 16-02-00334) and SPbU (Grants No. 11.65.41.2017 and 11.38.237.2015). I. A. A. acknowledges the support from G-RISC funded by the German Federal Foreign Office via DAAD.

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