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Numerical Investigation of Polarization Dynamics in Strong-Field QED

Yan-Fei Li[1], Xian-Zhang Wu[1], Yue-Yue Chen[2], Yu-Tong Li[3, 4]
[1] Department of Nuclear Science and Technology, Xi'an Jiaotong University,
[2] Department of Physics, Shanghai Normal University, Shanghai, China
[3] Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, CAS,
[4] School of Physical Sciences, University of Chinese Academy of Sciences
e-mail (speaker): liyanfei@xjtu.edu.cn

The primary QED processes involved in the physics driven by the new generation of PW (petawatt) lasers include the electron's incoherent photon emission process under an external field (nonlinear Compton scattering, NCS) and the decay of high-energy photons into electron-positron pairs (nonlinear Breit-Wheeler process, NBW). Recent research has shown that the effect of electron-spin and photon polarization on these processes can exceed 10%, making them non-negligible. Additionally, polarized electrons, positrons, and photon beams generated through QED polarization effects serve as irreplaceable probes in experimental high-energy physics, materials science, and other fields. For instance, high-energy polarized photons provide critical insights into polarization-dependent phenomena, such as photon-photon scattering and pair production in strong electromagnetic fields, particularly within nonlinear QED regimes. Such beams can also enable laboratory-scale investigations of astrophysical radiation mechanisms, including gamma-ray bursts and black hole jet emissions, by facilitating controlled studies of polarization effects and high-energy interactions. Additionally, these highly polarized gamma-ray beams are indispensable for calibrating advanced detectors in high-energy astrophysics missions, thereby improving the precision of cosmic gamma-ray polarization measurements. As such, the purification of photon polarization in γ-ray sources is a longstanding challenge critical for leveraging the potential of polarized γ rays in scientific research and practical applications.

In this tall, we present a three-step theoretical framework to calculate QED polarization dynamics in ultra-intense laser-electron beam interactions. Building on this methodology, we propose novel schemes to produce "spin-polarized relativistic electron sources," "polarized high-brilliance gamma-ray sources," and "spin-polarized positron sources" via ultra-intense lasers. Recently, we demonstrate that highly linearly polarized GeV γ-rays can be generated via nonlinear Compton scattering using unpolarized electrons (Fig. 1). Although the photon polarization is initially negligible (~0%) at the high-energy spectral edge, we show that it can exceed 90% in a single interaction. This enhancement is mediated by vacuum dichroism, which induces asymmetric photon decay (pair production) between polarization states.

References

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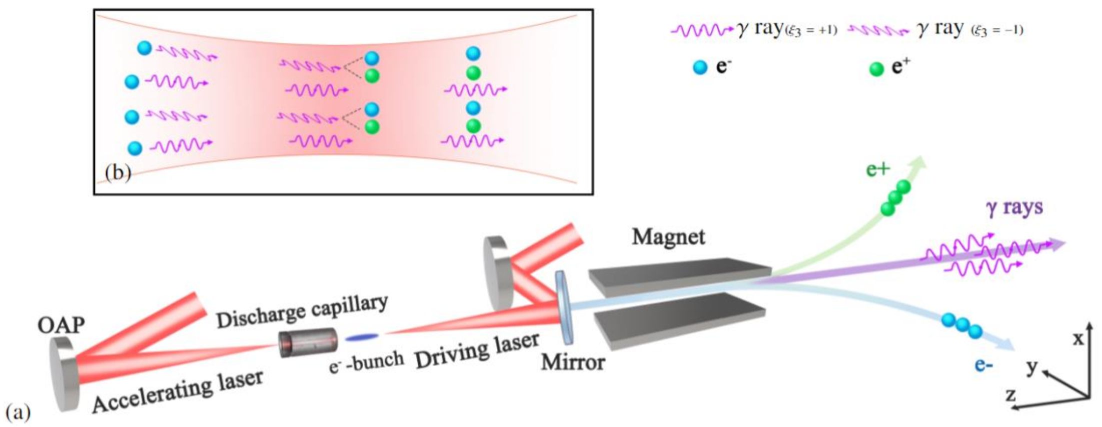

FIG. 1. Scenario for generating highly polarized γ rays via ultraintense-laser-electron interactions. (a): A linearly polarized laser pulse (polarization along the x-axis) propagates along the +z direction and collides head-on with an unpolarized electron beam from a laser plasma accelerator, producing linearly polarized γ rays (also polarized along the x-axis). A magnet is used to isolate the desired γ rays from electrons and positrons. (b): The polarization degree is significantly enhanced by vacuum dichroism, which arises from the asymmetric pair production between opposite polarization states of photons as they propagate in the laser field.