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Photon Vortex Generation in Nonlinear Compton Scattering via Quantum Feynman Framework

With the advancement of intense laser technology, nonlinear Compton scattering (NCS), in which multiple laser photons are absorbed and a single high energy photon is emitted, has been actively investigated to probe electron and photon dynamics in strong electromagnetic fields [1].

Taira et al. proposed, based on classical electrodynamics calculations, that NCS with circularly polarized photons could generate “photon vortices,” where the spin angular momenta of N incident photons are transferred to the total angular momentum

$\hbar N$ of the emitted photon [2], where N is the number of the absorbed photons. Recent experimental efforts have begun to explore the generation of such vortices, that is, gamma ray photons carrying orbital angular momentum (OAM), by using circularly polarized and spatially structured laser beams in NCS setups. These developments show the growing need for quantum theoretical frameworks that can interpret and support such experiments.

Many theoretical studies of NCS have used the local constant field approximation (LCFA), which treats the laser as a classical background field and is effective in the ultra intense regime [3]. However, in experiments aiming to produce photon vortices, laser fields of moderate intensity are typically used to identify the absorption of individual photons. In such situations, the LCFA becomes less suitable.

To address this, we apply a Feynman diagram approach using cylindrical wave functions for both electrons and photons [4]. This formalism allows a fully quantum description of the process, where the discrete absorption of a finite number of photons is explicitly included. While the LCFA gives only the expectation value of the number of absorbed photons, our method can determine the exact number absorbed in each event. This provides a complementary viewpoint that is especially useful in regions where quantum effects from individual photon absorption and angular momentum transfer become important.

Through this approach, we aim to improve the understanding of how vortex photons are generated in NCS and to offer predictions that can be tested in future experiments involving structured light fields. We hope that our results will help in designing new experiments that explore and control orbital angular momentum in high energy photons, and that our framework will contribute to the broader study of strong field quantum electrodynamics across a wide range of laser intensities

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