Isolated Attosecond γ-Ray Pulse Generation with Transverse Orbital Angular Momentum Using Intense Spatiotemporal Optical Vortex Lasers

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For higher-energy pulses, γ-ray pulses with ~MeV-level photons have garnered increasing interest due to their potential applications in nuclear physics, as typical reaction energies within the nucleus occur at the MeV scale. Traditionally, γ-rays have been efficiently generated via nonlinear Thomson/Compton scattering and nonlinear synchrotron radiation driven by relativistic lasers. To produce isolated attosecond γ-rays, an approach using Gaussian lasers was initially proposed, where an isolated attosecond electron slice (IAES) is directly accelerated from an ultra-thin target and subsequently collides with an additional relativistic laser to generate an isolated attosecond γ-ray pulse. However, this scheme faces two major challenges: the first is the significant divergence of the generated γ-ray pulse due to the large divergence angle of electrons, which is caused by the transverse ponderomotive force inherent to Gaussian laser fields; the second is the reliance on a two-laser system, which requires precise spatiotemporal synchronization between the lasers. To address the first issue, the Laguerre-Gaussian (LG) lasers have been suggested as potential solutions [1-2]. Such lasers characterized by their hollow intensity distribution and longitudinal orbital angular momentum, not only can generate γ-ray vortices, but also facilitate the creation of attosecond γ-ray trains. Importantly, these configurations offer improved beam divergence and enhanced brightness. However, despite their advantages, these pulses are not isolated. A natural progression is to add attosecond temporal confinement to the spatial-vortex LG lasers, which could potentially resolve this limitation.

In this paper, we propose using an intense circularly polarized (CP) STOV laser to generate a collimated, ultrabright, and isolated attosecond γ-ray pulse with TOAM in three-dimensional (3D) particle-in-cell (PIC) simulations. Electrons are extracted and accelerated by the STOV laser's fields, forming an IAES [3]. This slice collides with the reflected Gaussian-like laser front from a planar target to trigger the nonlinear Compton scattering process (NCS), producing a highly collimated (~4°), ultra-brilliant (~5×10^{24} photons/s/mm²/mrad²/0.1% BW at 1 MeV), and attosecond (~300 as) γ-ray pulse. Notably, such an isolated attosecond γ-ray pulse is hopeful to provide new opportunities for ultrahigh time resolution observation, nuclear selective excitation, and detection in nuclear science. Further, TOAM is successfully transferred from the STOV laser to the γ-ray pulse, providing new opportunities for such as modulating photonuclear reaction rates, uncovering novel spin phenomena, disentangling spin states and dual resonances, and introducing innovative multipolar analyses in photonuclear reactions.

References

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Figure 1

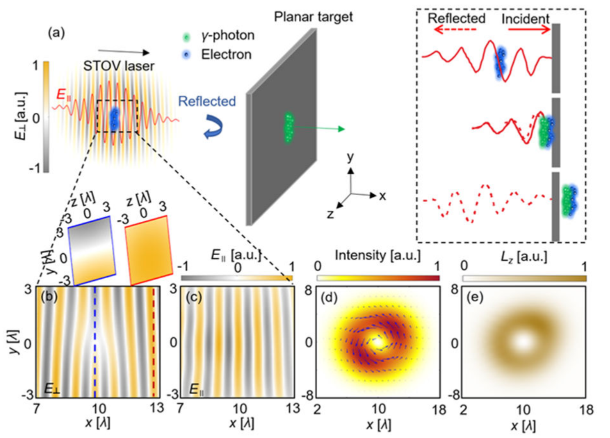

FIG. 1. Schematic of an isolated attosecond γ-ray pulse generation. An IAES collides with the self-reflected STOV laser, triggering the NCS process to generate the attosecond γ-ray pulse.