Pursuing Strong-Field QED Studies with multi PW lasers

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State-of-the-art high-power laser systems are beginning to make it possible to explore quantum electrodynamics (QED) in the nonperturbative regime, where electromagnetic fields approach or surpass the so-called critical “Schwinger” limit of QED [1]. In this extreme regime, phenomena such as Breit-Wheeler pair production, vacuum birefringence, and quantum radiation reaction are predicted to emerge — effects that remain unobserved in controlled laboratory settings. Reaching the required field strengths demands laser intensities around 2.3×10^{29} W/cm^2, far exceeding the present maximum of 10^{23} W/cm^2 [2]. A promising approach to access this regime involves Compton scattering between ultra-relativistic electron beams and ultra-intense laser pulses, offering a viable platform to investigate strong-field QED phenomena. Progress in laser-plasma accelerator technology, especially through laser wakefield acceleration (LWFA) [3], has created new opportunities for fully optical strong-field QED experiments, which are now being pursued by research groups worldwide.

In our recent study, we carried out experiments examining nonlinear Compton scattering in intense laser fields, where a multi-GeV electron simultaneously interacts with hundreds of laser photons. Using LWFA, we produced an ultra-relativistic electron beam and collided it with a high-intensity laser pulse, reaching field intensity half of Schwinger limit. This interaction generated high-energy gamma rays through multiphoton Compton scattering, with photon energies in GeV scale — well beyond the linear Compton scattering limit — marking the onset of the strongly nonlinear regime [4]. The observed gamma-ray spectra closely matched predictions from QED-PIC simulations and analytical models, reinforcing the theoretical understanding. These findings not only confirm nonlinear Compton scattering under strong-field conditions but also set the stage for future investigations into more intricate processes, such as nonlinear Breit-Wheeler pair production, as higher laser intensities and electron beam energies become achievable.

This work was supported by the Institute for Basic Science grant (IBS-R038-D1).

References

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