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Nonlinear Thomson Scattering: Velocity Asymmetry Inherent in Electron Figure-8 Motion

M. Ware, L. Robins, K. Barr, A. Jones, Y. Sun, N. B. Sá, and J. Peatross
Department of Physics and Astronomy, Brigham Young University, Provo, UT 84602, USA
ware@byu.edu

Abstract: We present measurements of nonlinear Thomson scattering in both emission hemispheres. The asymmetries in these measurements unambiguously confirm for the first time the figure-8 motion of electrons in the average rest frame.

1. Measurements of Polarization Resolved Nonlinear Thomson Scattering

We measure light scattered from low-density free electrons in an intense laser focus using single-photon counting techniques. A polarizer in the collection system resolves fundamental, 2nd, and 3rd harmonic photons into orthogonal component corresponding to azimuthal and longitudinal lines on the emission sphere. The linearly polarized laser field propagates along the axis of the emission sphere, from the 'south' pole to the 'north' pole ($\theta = 0$).

Figure 1 shows a schematic of the experimental setup. A collection lens images the interaction region onto the end of a 105 μm fiber connected to a single-photon counter over a range of collection angles. Azimuthal rotation is accomplished via rotation of the laser polarization.[1] Longitudinal rotation is accomplished by moving the collection lens setup about an axis that contains the interaction region.

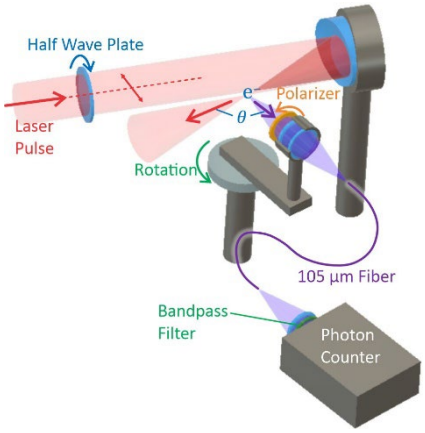

Fig. 1 Photon collection and detection setup.

Electrons are donated from helium in an otherwise evacuated chamber, backfilled to a fraction of a Torr. The 800 nm, 40 fs, 50 mJ, 10 Hz laser pulses ionize the helium early during the rising edge of each pulse. The pulses are focused to a $w_0 = 3$ μm radius using an off-axis parabola. The intensity in the laser focus exceeds 2×10^{18} W/cm^2, which causes electrons to move relativistically.

Individual electrons execute the well-known figure-8 trajectory (see Fig. 2) in the intense laser field, due to both the electric and magnetic fields of the laser.[2] Electrons also drift forward, owing to momentum imparted from the rising edge of the pulse. This induces a redshift when photons are viewed from the side. We observe photons through bandpass filters, redshifted by 12% from their nominal harmonic wavelengths with 5% bandwidth.

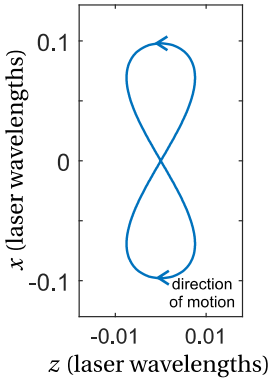

Fig. 2 Motion of electron in average rest frame. The laser polarized along x and propagates in the positive z direction.

2. Results

Figure 3 shows measured 2nd harmonic photons at 06° and 120° degrees on the emission sphere (i.e. ± 30° from the equator). The nonlinear Thomson scattering is measured for separate orthogonal detector polarizations. The top-to-bottom dimension of the figure-8 electron trajectory gives rise to scattered photons with azimuthal polarization, and the side-to-side dimension gives rise to scattered photons with longitudinal polarization [3]. By measuring both polarizations of second and third harmonic over the entire emission sphere, one can unambiguously prove the figure-8 motion [4].

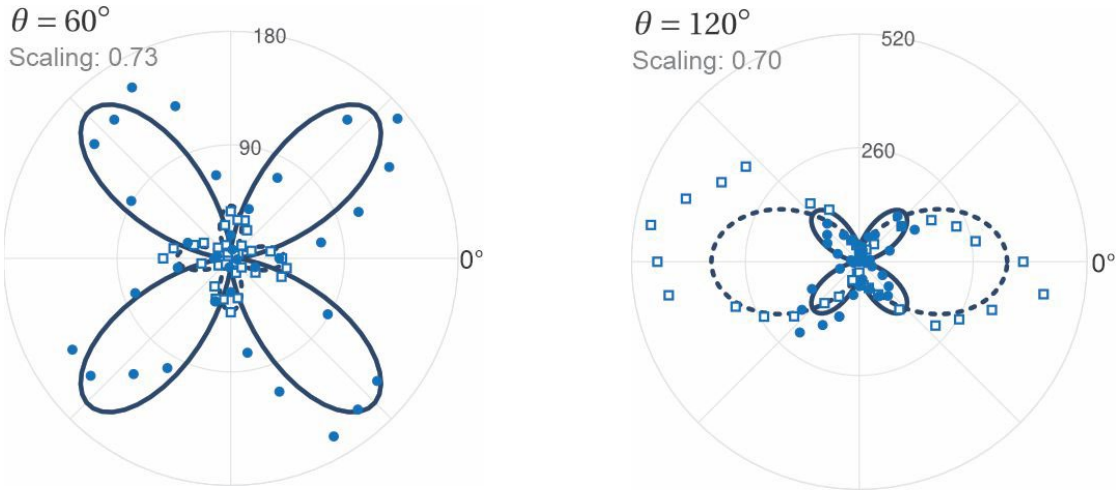

Fig. 3 Measurements of azimuthal (blue) and longitudinal (green) polarization of 2nd harmonic nonlinear Thomson scattering. The data is obtained around the 'latitude' lines at 60° (left) and 120° (right) from the direction of laser propagation.

Notice the strong asymmetry in the emission patterns between the 'northern' (60°) and 'southern' (120°) hemispheres. Although the Lorentz drift influences this asymmetry, its primary cause is independent of the drift. As individual electrons execute their periodic motion, at both the top and bottom of the figure-8, they move in the direction opposite the laser propagation. This causes electrons to emit much more longitudinally polarized light into the 'southern' hemisphere (opposite laser propagation). This measurement demonstrates the direction of electron travel around the figure-8.

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3. References

[1] S. Y. Chen, A. Maksimchuk, and D. Umstadter, "Experimental observation of relativistic nonlinear Thomson Scattering," **396**, 653 - 655 (1998).

[2] E. S. Sarachik and G. T. Schappert, "Classical Theory of the Scattering of Intense Laser Radiation by Free Electrons," Phys. Rev. D **1**, 2738 - 2753 (1970).

[3] B. Pratt, N. Atkinson, D. Hodge, M. Romero, C. Schulzke, Y. Sun, M. Ware, and J. Peatross, "Experimental Confirmation of Electron Figure-8 Motion in a Strong Laser Field," Phys. Rev. A **103**, L031102 (2021).

[4] M. Romero, L. Robins, A. Stevens, N. Sa, Y. Sun, M. Ware, and J. Peatross, "Nonlinear Thomson Scattering: Velocity Asymmetry Inherent in Electron Figure-8 Motion," Opt. Express, (under review, 2024).