Nonlinear Thomson Scattering Measured over Full Emission Sphere

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Abstract: We present first measurements of nonlinear Thomson scattering over the entire emission sphere. Inherent asymmetry in electron relativistic figure-8 motion gives different emission patterns in 'northern' and 'southern' hemispheres (with laser propagating along poles).

1. Measurements of Polarization Resolved Nonlinear Thomson Scattering

We use single-photon counting to measure light scattered from low-density free electrons in an intense laser focus. Fundamental, 2^{nd}, and 3^{rd} harmonic photons are polarization-resolved 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 ($\theta = 0$).

A schematic of the experimental setup is shown in Fig. 1. Photons are detected at various angles out the side of an intense laser focus. A collection lens images the interaction region onto the end of a 100 μm fiber connected to a single-photon counter. 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. Care must be taken to ensure that the imaging system remains aligned with the focus.

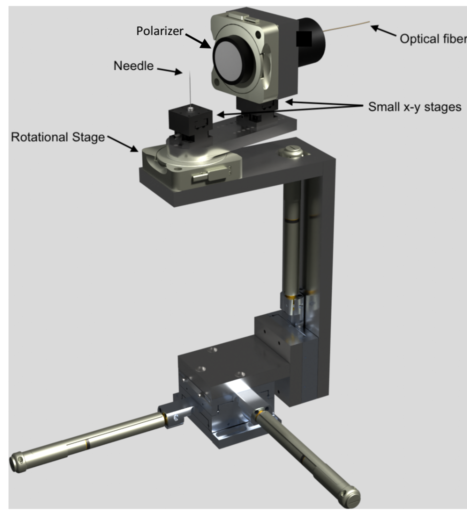

Fig. 1 Photon detection setup. A temporary needle aids in aligning the imaging system to the laser focus.

Electrons are donated from helium in an otherwise evacuated chamber, backfilled to a fraction of a Torr. The 800 nm, 40 fs, 60 mJ, 10 Hz laser pulses ionize the helium early during the rising edge of each pulse. The pulses are focused to a $w_0 = 3\ \mu$m radius using an off-axis parabola. The intensity in the laser focus exceeds $2 \times 10^{18}\ \mathrm{W/cm^2}$, which causes electrons to move relativistically.

In the intense laser field, individual electrons execute the well-known figure-8 trajectory (see Fig. 2), owing 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.

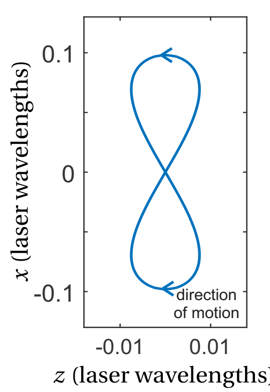

Fig. 2 Motion of electron in average rest frame. The laser polarized along x and propagates in the positive z direction.

2. Results

Figure 3 shows measured 2^{nd} harmonic photons at 60° and 120° degrees on the emission sphere (i.e. $\pm 30^\circ$ from the equator). The nonlinear Thomson scattering is measured for separate orthogonal detector polarizations. As was demonstrate previously,[3] 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. By measuring both polarizations, one can unambiguously prove the figure-8 motion.

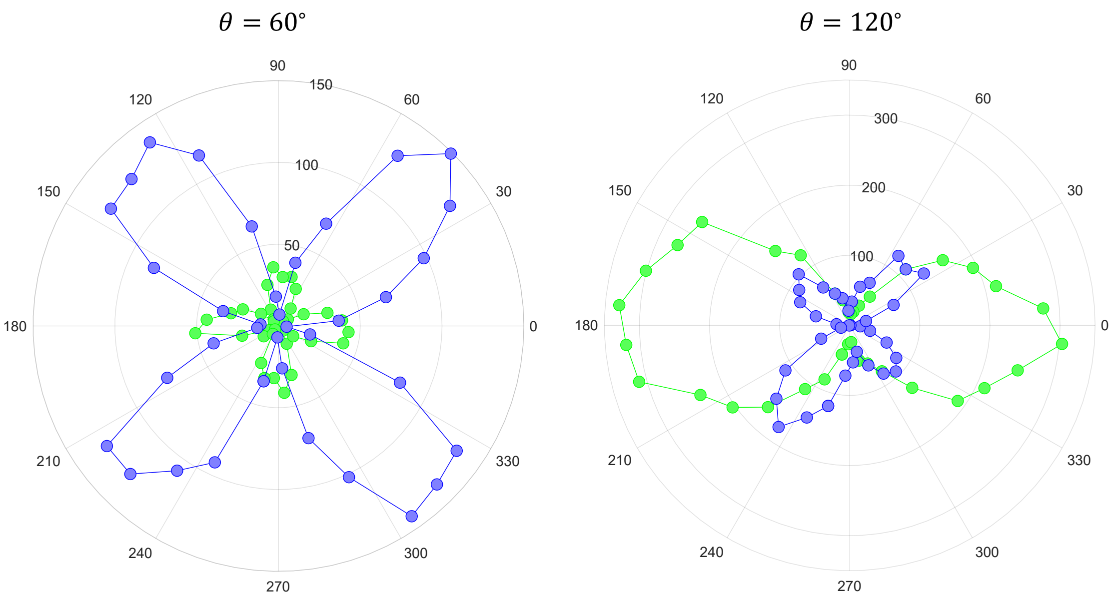

Fig. 3 Measurements of azimuthal (blue) and longitudinal (green) polarization of 2nd harmonic nonlinear Thomson scattering. The data is obtained around the 'latitude' line at $+30^{\circ}$ (left) and -30° (right) from the equator.

Going further, one notices a 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 (i.e. toward the 'north' pole). This causes electrons to emit much more longitudinally polarized light into the 'southern' hemisphere.

This work is supported by the National Science Foundation under grant No. 2207737.

3. References

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[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).