Measured Photoemission from Electron Wave Packets in a Strong Laser Field

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Abstract

We report a measurement of the radiation from free electron wave packets emitted out the side of an intense laser focus. QED predicts that the emitted radiation is independent of wave packet size, and numerical modelling predicts a scattering rate on the order of a photons every few laser shots for each electron. In contrast, the first-quantized picture suggests a dependence on wavepacket size, with suppression of emission by typically two orders of magnitude in a direction perpendicular to laser propagation for large wavepackets. Our experimental measurement confirms the QED theoretical predictions.

In the ionization process, electron wave functions are typically initially localized in both momentum and position, but can quickly spread to become comparable in size to the wavelength of the driving field. This is especially true if the wave function ionizes over several laser cycles. It is interesting to consider how a large electron wave packet scatters radiation when different parts of the same wave function oscillate out of phase in the driving laser field.

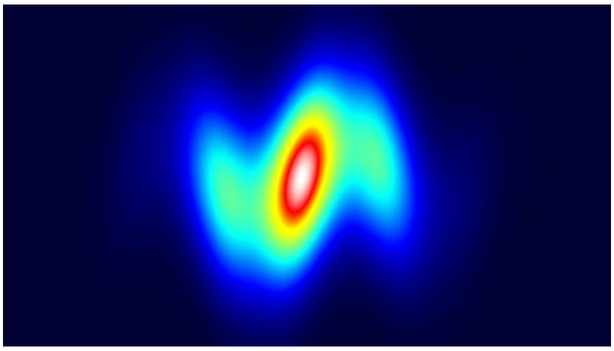

Fig. 1. Plot of an electron wave packet interacting with a laser field.

Figure 1 plots a cross-section of an initially Gaussian free electron wave packet that has spread while interacting with a plane-wave laser field. Different parts of the wave function move in different directions, which in the semiclassical model gives the appearance that interference is possible between the emissions from the various parts of the packet

In contrast to this semiclassical picture, quantum electrodynamics (QED) predicts [1-3] that an electron radiates with the strength of a point emitter, regardless of the spatial extent of its wave packet. A comprehensive theoretical treatment of photoemission by a single-electron wave packet in a laser field, both within a relativistic semiclassical framework and within a full quantum electrodynamic [2,3] shows that different momentum components of an electron wave packet do not interfere if the stimulating field is unidirectional. This result stems from energy-momentum conservation. Only one momentum component of the initial electron wave packet can contribute to a particular mode of a scattered photon-electron pair. This indicates that the size of the electron wave packet does not influence the amount of radiation. This result is in contrast with intuition one might take from classical electrodynamics, where radiation from an extended charge distribution does interfere destructively when different regions of the distribution oscillate out of phase with each other.

We report on the experimental confirmation of the QED prediction. In this experiment, first proposed in [3], a short laser pulse (~40 fs, 20 mJ) is focused in dilute helium at around 10^{-5} Torr. The laser liberates the electrons from the helium, and accelerates them to modestly relativistic levels. We measure a distinct redshifted signal at the level of a few photons per shot collected by a 0.2 steradian imaging system. Using careful spatial, temporal, and spectral filtering, this signal can be distinguished from the very high amount of background light present. We compare this measured signal to the signal predicted by computation modelling of electrons in the focus [4], and find that the measured signal is indeed well predicted by the radiation from point-electron calculations rather than diffuse electron charge densities.

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