Exploring single-photon recoil on free electrons

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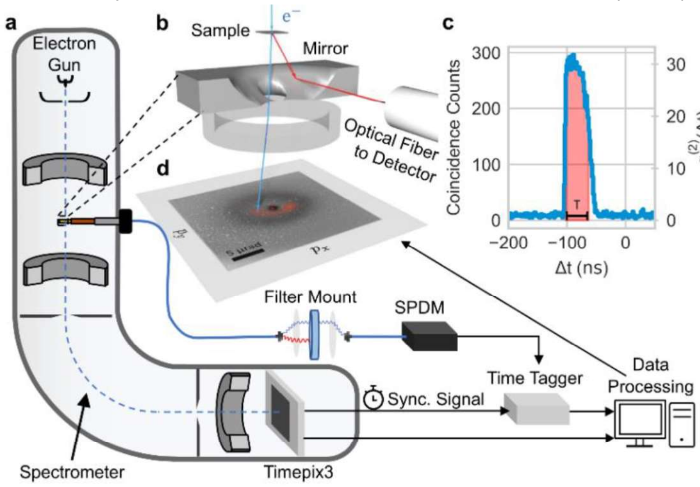
In our recent publication [1], we use novel correlative measurements of electrons and the coherent cathodoluminescence (CL) photons they emit when interacting with a sample to investigate energy-momentum conservation on the single particle level. Similar approaches have recently been used to map modes in photonic structures [2] and distinguish competing CL emission pathways [3].

Inside an FEI Tecnai F20 transmission electron microscope (TEM) we illuminate a thin silicon membrane with a collimated 200 keV electron beam. We collect the emitted CL photons using an ellipsoidal mirror and capture the transmitted electron on a Timepix3-based direct electron detector, as shown in the figure below. Crucially, we detect both the photon and the transmitted electron in a time-resolved manner, with a precision on the order of nanoseconds. In conjunction with a low (~pA) beam current, this allows us to match which photon originates from which electron.

Performing low angle diffraction measurements in this time-correlated manner allows us to resolve the momentum transfer (~µrad) involved in single photon emission. I will highlight the additional insights this technique provides: how it can be used to selectively investigate electrons that emitted CL, to trace back the origin of CL photons to their production mechanism or to produce the surprising effect that is known in the photonics community as “ghost imaging” [4]. Finally, I will explain the potential pathway these results open towards investigating quantum entanglement in electron-photon pairs.

[1] A. Preimesberger et al., Phys. Rev. Lett. 134, 096901 (2025).
[2] A. Feist et al., Microscopy and Microanalysis 29, 382 (2023).
[3] N. Varkentina et al., Sci. Adv. 8, eabq4947 (2022).
[4] M. J. Padgett and R. W. Boyd, Phil. Trans. R. Soc. A 375, 20160233 (2017).



Experimental Setup: (a) Collected photons and transmitted electrons are detected in a time resolved manner. (b) A sample holder equipped with ellipsoidal mirrors is used to collect CL photons. Electrons and photons are coincidence matched according to their time difference, which is shown as a histogram in (c). The low angle diffraction pattern (d) for the coincidence-matched electrons (in red) differs significantly from the unmatched image (in grayscale).