P4: Entangled Electron-Photon Pairs and How to Find Them

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Entanglement is one of quantum mechanics' most precious resources. As such it has been studied extensively in photon-based systems, leading to advancements in quantum communication, computing, and sensing. Its integration into transmission electron microscopy (TEM) presents a promising avenue for enhancing imaging techniques and developing free electrons into a new quantum platform [1-3]. Recent technological advancements have enabled time-correlated detection of electron-photon pairs in TEMs [2-7], which provides an important foundation for exploring its potential.

A critical aspect of harnessing entanglement in TEMs is the ability to certify quantum correlations *without* relying on specific assumptions about the quantum state. This state-agnostic approach ensures robust and unbiased verification of entanglement, facilitating a comparison with other quantum technologies. In our work [8], we propose a method to certify entanglement between single electrons and the photons they generate via coherent cathodoluminescence. Such correlations are required for entanglement-based imaging techniques that may lower the shot-noise. By employing mutually unbiased measurements in position and momentum [9], our protocol estimates the minimum entanglement present in the pair.

We will present the quantum-mechanical background, how entanglement is applied in other fields and where it might be found in TEM-generated electron-photon pairs. On that basis we will explain the subtleties of our method and how it can certify quantum correlations without underlying assumptions on the state. Finally, we will present the feasibility of our method based on experimental measurements on a specifically adapted TEM.

By bridging the gap between theoretical concepts and implementation, our approach lays the groundwork for integrating methods from quantum information theory into TEMs and vice versa.

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