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Towards an experimental entanglement witness between a swift electron and a cathodoluminescent photon

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Introduction

Entanglement [1, 2] lies at the heart of quantum mechanics and is key to many quantum optics experiments. The high resolution and flexibility of transmission electron microscopy (TEM), mitigated by challenges regarding electron beam damage of sensitive specimens [3], motivate the development of free electron quantum optics to bring quantum imaging techniques into electron microscopy. Coherent cathodoluminescence (CL) photons [4] provide a promising avenue towards demonstrating and utilizing quantum entanglement phenomena in the TEM [5].

Objectives

We aim to demonstrate a viable entanglement witness experiment between CL photons and primary electrons in a transmission electron microscope.

Materials and Methods

We use an FEI Tecnai F20 microscope equipped with a custom CL set-up and a Gatan GIF 2001 energy filter (see figure). 200 keV electrons are transmitted through a 50 nm thick silicon membrane and collected on a Timepix3 camera, where their time of arrival is stamped with 50 ns accuracy. CL radiation from the electron"s interaction with the specimen is collected by a parabolic mirror and directed out of a window in the TEM. Photons are then focused and steered to a single photon counter capable of time stamping individual photons for coincidence matching with the originating electrons.

Results

Using our coincidence-counting set-up, we are able to detect energy and momentum transfer between single electron-photon pairs [6]. We take advantage of these direct correlations for our entanglement witness experiments. We place a line grating in the photon path, in either the image plane or the Fourier plane, to establish mutually unbiased bases [5] and experimentally determine the joint probability distribution for our electron-photon coincidence pairs. If the joint uncertainty measurement resolution violates bounds set by Heisenberg"s uncertainty principle, then we can confirm that the electron-photon pairs are entangled. We will present preliminary results on electron-photon pair correlations, and discuss the probability of entanglement given the position and momentum resolution limits we achieve.

Conclusion

We demonstrate an experiment suitable for witnessing entanglement between a free electron in a TEM and a coherent CL photon. Using the resolution obtained in each bases, we rigorously quantify the joint uncertainty product required to confirm or deny the entanglement witness requirements.

References

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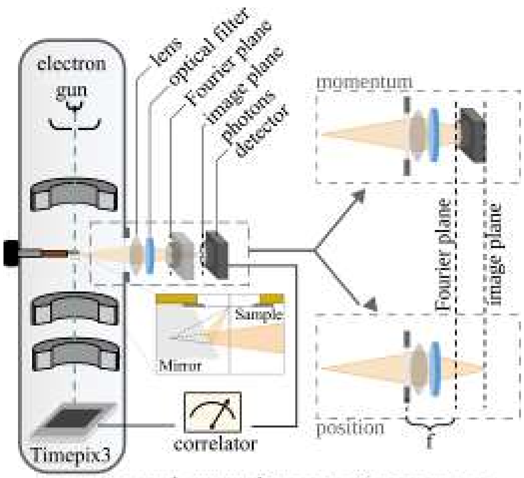
Fig. 1



Experimental entanglement witness set-up,
performing coincidence counting
between free electrons and photons