Towards Ghost Imaging by Correlation Measurements of Electron-Photon Pairs

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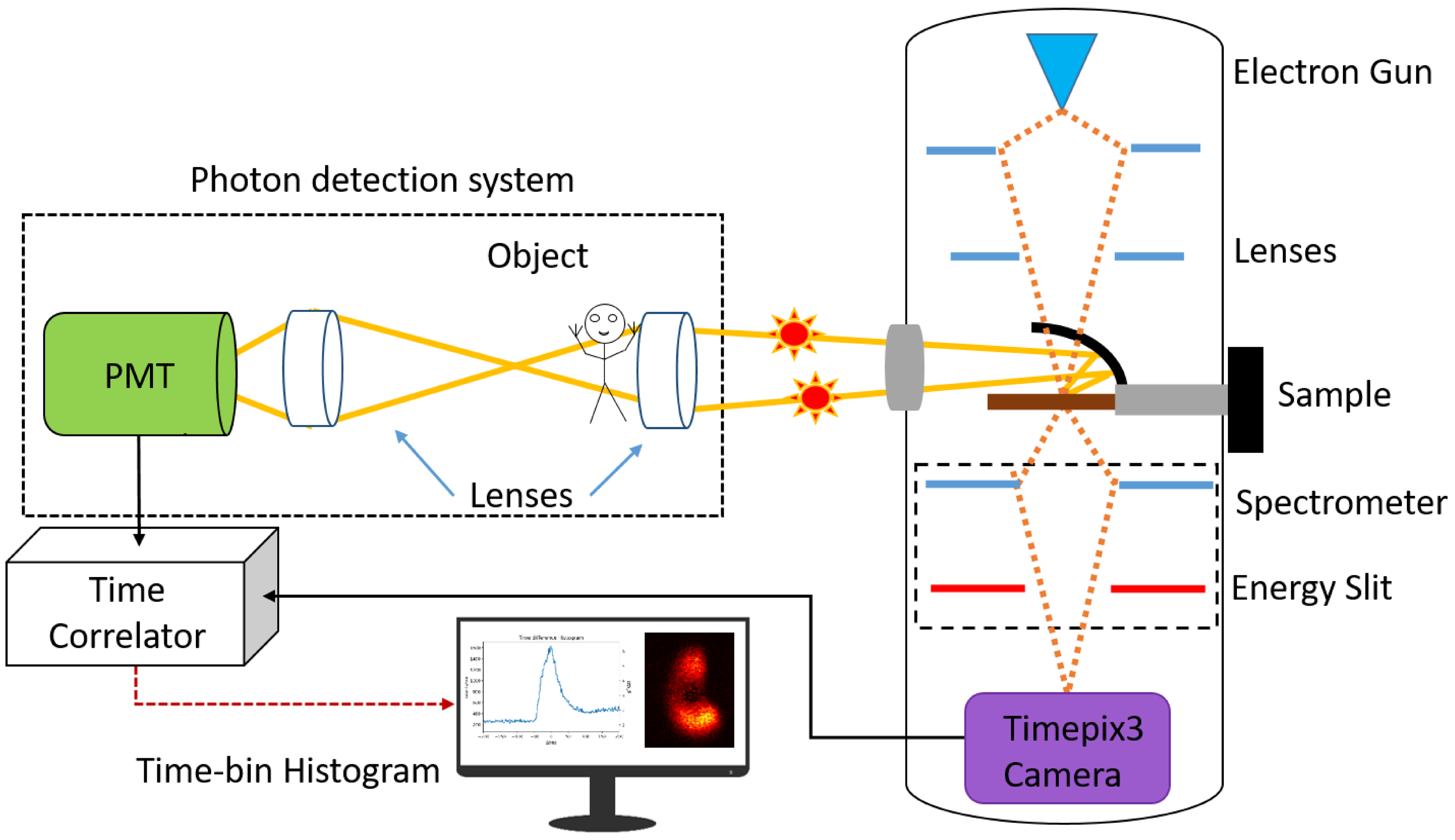
Introduction

In recent years, fast electron microscopy has garnered increased interest within the scientific community. Particularly, temporal correlation measurements have proven to dramatically enhance the useful signal by suppressing background noise [1, 2]. Here, we introduce a new method of imaging at the intersection of quantum optics and electron microscopy.

Ghost imaging, also known as coincidence imaging, of an object is a method in classical and quantum physics that involves constructing an image by gathering information from past correlation measurements [3]. We perform coincidence measurements using electron-photon pairs which are correlated in momentum and position.

To produce correlated electron-photon pairs we use a transmission electron microscope (TEM) working at an acceleration voltage of 200 keV to illuminate a thin monocrystalline silicon membrane of 100 nm thickness. Primary electrons scatter inelastically inside the membrane and undergo a small momentum deflection, simultaneously emitting coherent photon emission through a process known as cathodoluminescence (CL) [4]. As a result, the emitted photons are correlated in momentum and position with the transmitted electrons.

We guide correlated photons through an object, which we are interested in imaging, and detect electrons directly with a pixelated camera. Despite electrons never directly interacting with the object, we are able to perform ghost imaging of the object through correlated electron-photon pairs.



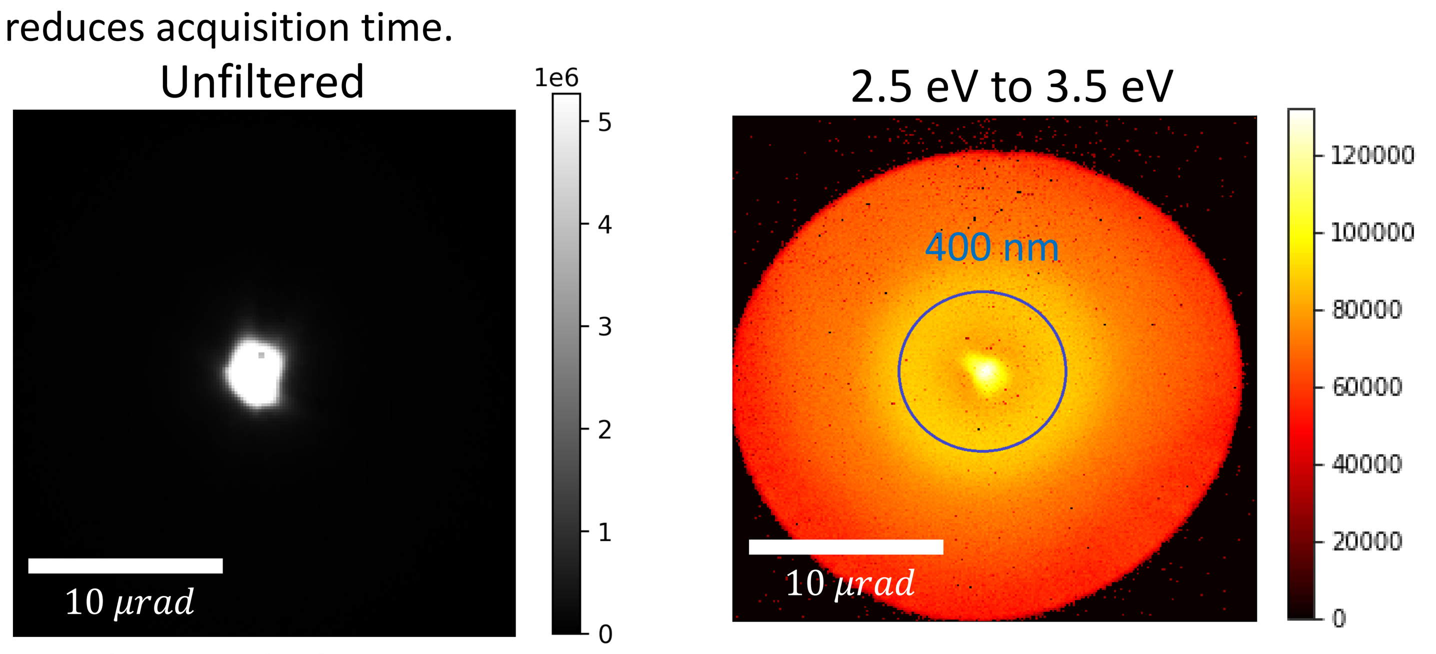
Experimental Setup

Electron detection:

To register transmitted electrons we use a time-resolved pixelated direct electron detection camera (Advascope, Timepix3), the resulting signal undergoes time stamping via the device's internal clock, offering a remarkable resolution of 1.6 nanoseconds.

We image the sample in diffraction mode, therefore, the Timepix3 camera detects deflection angles of the electrons. However, we are interested in registering only those electrons that participated in the cathodoluminescence process of emitting photons with corresponding energy. In this experiment the spectrometer is set to filter energy losses of 2.5-3.5 eV (EFTEM), which corresponds to photons in the visible range of ~400 nm.

Moreover, since the photon production and collection efficiency with respect to one electron is 10^{-5}, filtering electrons not associated with cathodoluminescence dramatically increases the signal-to-noise ratio (SNR) and reduces acquisition time.

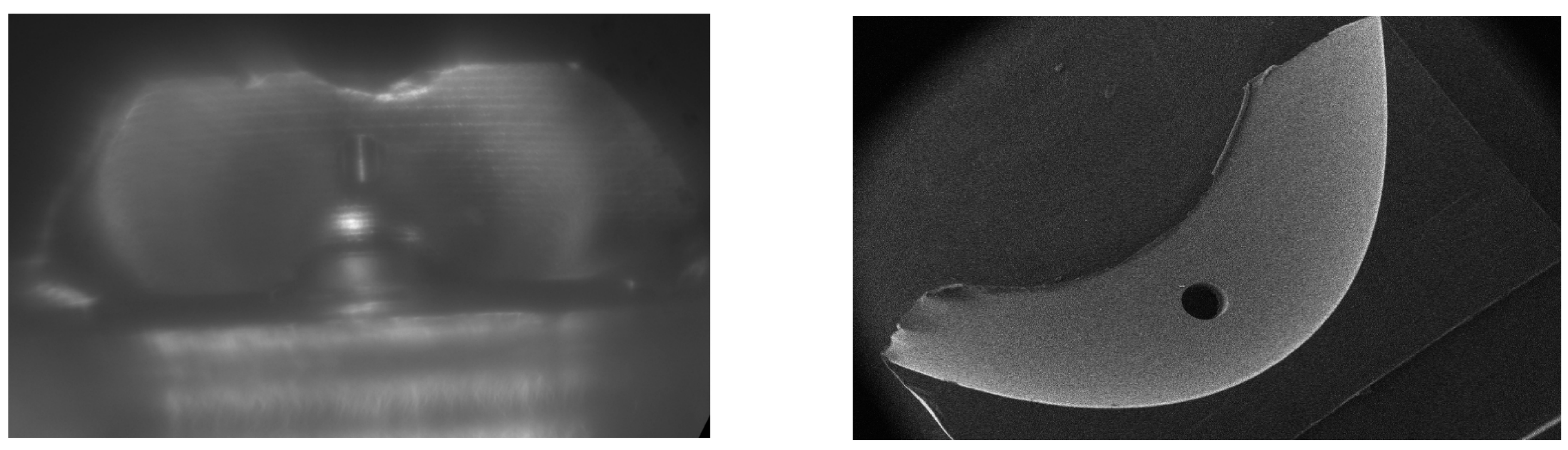


Photon detection by parabolic mirror:

To collect cathodoluminescence parabolic mirror, which gathers emitted CL photons and directs them through a window to the object placed in the optical detection system. Afterwards, we use a PMT incapable of directly recording an image to detect CL photons.

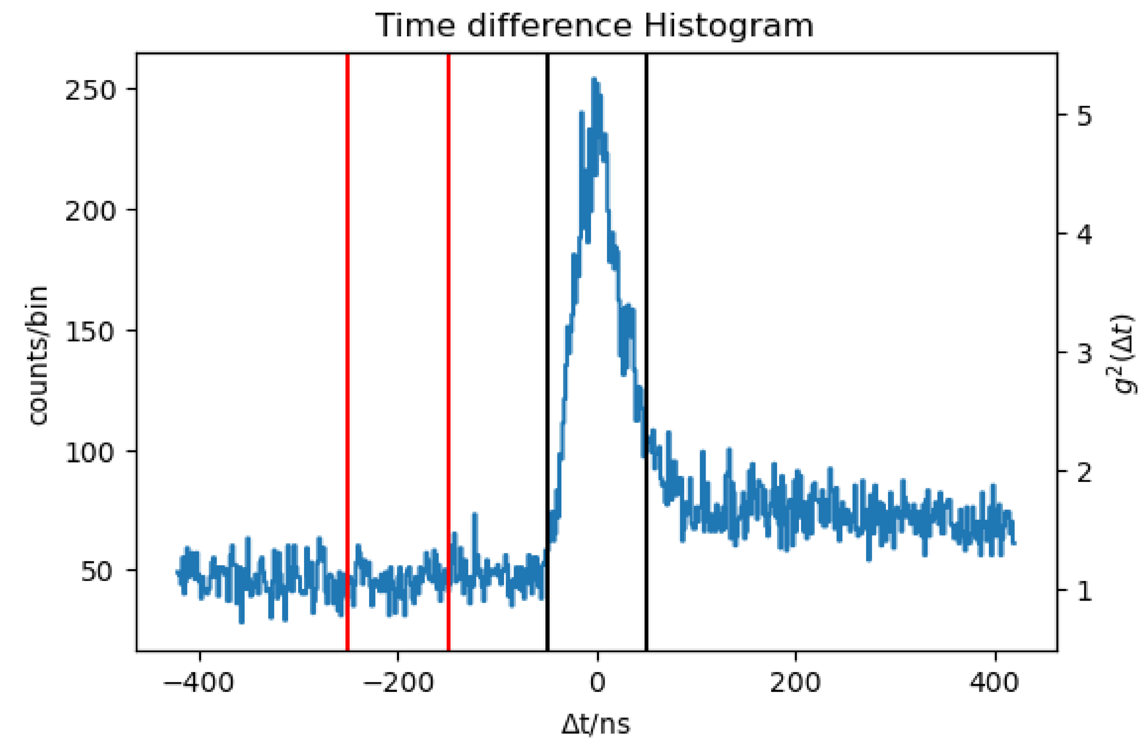
CMOS image of the mirror in the TEM chamber

SEM image of the mirror

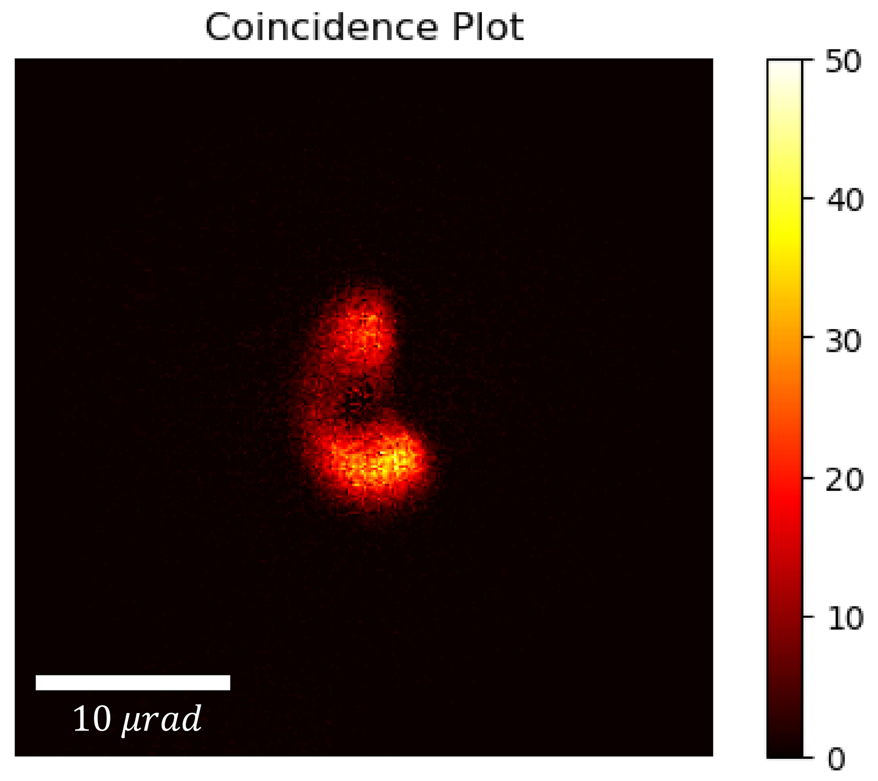


Coincidence Measurements

Correlated measurements are conducted using a time correlator (Swabian Instruments, Time Tagger Ultra). We register a coincidence event when both an electron and a photon are detected within a time window of 100 ns. Each photon is uniquely paired with the electron closest in time.



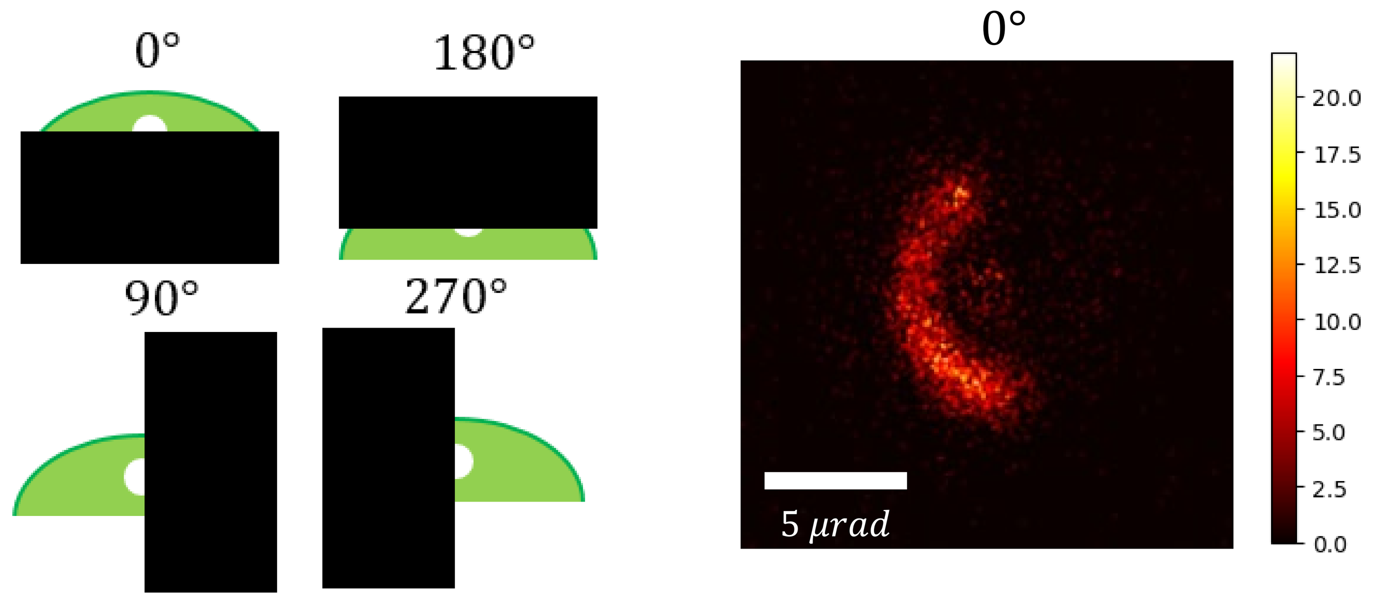
The resulting coincident histogram has a full width at half maximum (FWHM) of 80 ns. Black bounds represent electron-photon coincidences, red bounds correspond to background coincidences. To improve SNR we subtract background coincidences from real signal. The following plot is obtained by capturing correlated electrons with the Timepi3 camera.

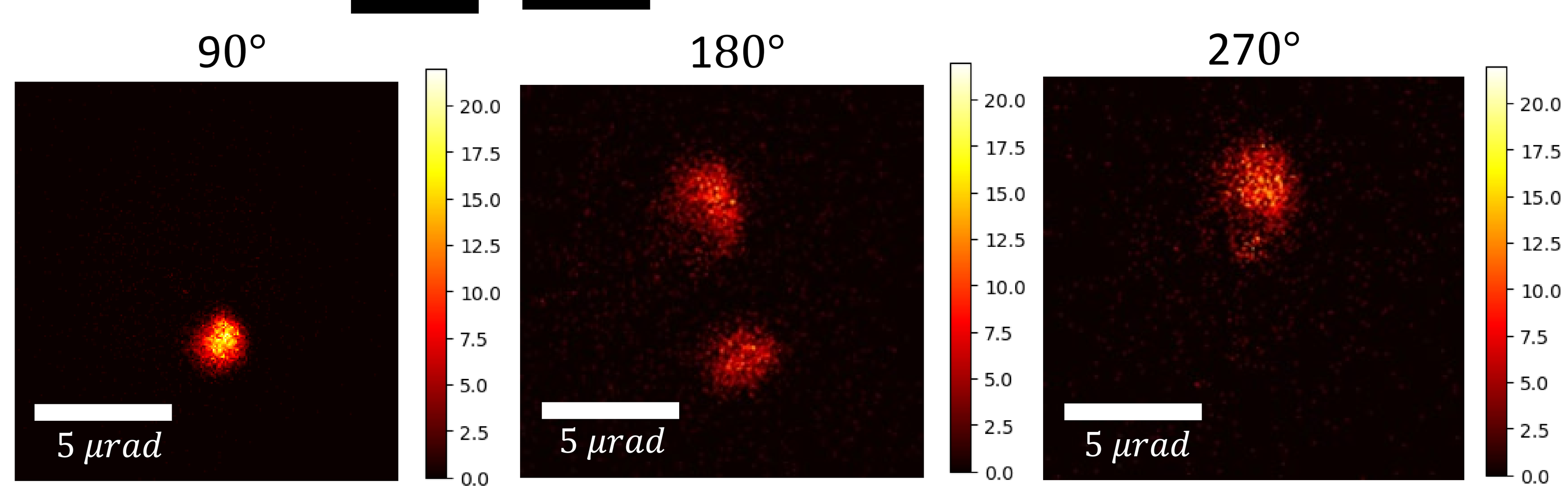


Although electrons don't directly interact with the mirror, in the presented coincidence plot we are able to observe a ghost image of the parabolic mirror and even small features such as the beamhole with a size of 300 μm.

Ghost Imaging

Since we collect electrons in diffraction space, the object for imaging should be also placed in the diffraction space of the emitted CL photons. In current experiments we examine ghost images of tailored apertures, which always covers half of the mirror.





In the presented coincidence plots we are able to witness different positions of tailored apertures with respect to the initial shape of mirror.

Although the tape is a fairly large object to image, we are confident that these small steps will open up the possibility for ghost imaging with correlated electron-photon pairs.

Future Experiments

Future plans involve correlation measurements in imaging mode with improved spatial resolution of the optical setup, enabling ghost imaging of finer structures. We are confident that investigating correlated individual events will reveal exciting phenomena and pave the way for experiments utilizing electron-photon coincidences inspired by quantum optics of photon pairs.

References

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