Increasing the robustness of quantum correlated imaging to scattering

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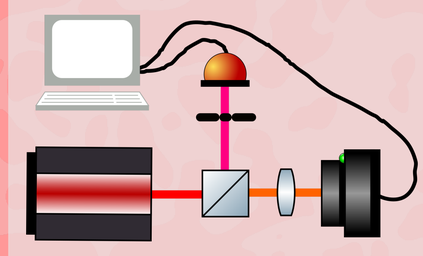
Motivation

Quantum correlated imaging (QCI) is a method of imaging an object while simultaneously measuring a property of that object at all positions. This is done by taking advantage of correlations between photons in an entangled pair[1-3].

Ghost imaging is a method of imaging an object indirectly via position and momentum correlations between a signal and idler beam[4].



Ghost imaging has been shown to be **robust against scattering** after an object[5].

Can this robustness be extended to QCI if components of ghost imaging are utilized in the system design?

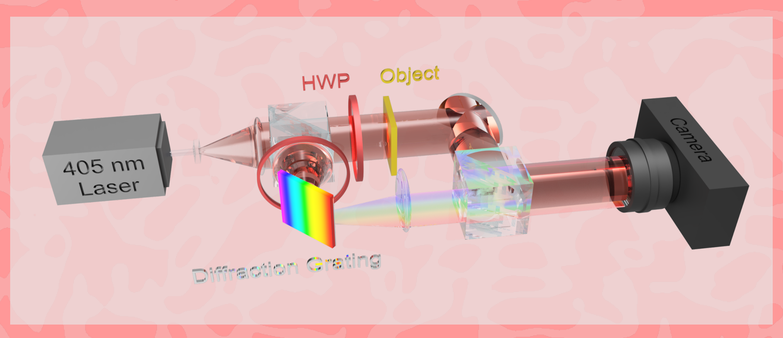
Designing a QCI System

A viable entangled photon pair source source must be chosen - SPDC is typically used.

- Each pair consists of both a **signal** and **idler** photon, and they traverse separate paths in the system
- For the sake of consistency, we will say that the idler is the photon which is always spatially resolved, while the signal is the other photon.

What second property is to be measured alongside spatial information must be decided upon.

- Once this second property is identified, then the method by which it is to be measured is chosen.



In quantum correlated hyperspectral imaging (QCHSI), the second property of interest is transmitted spectrum.

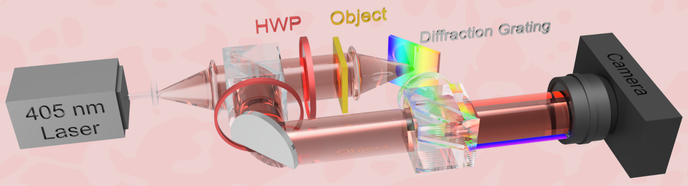
The chosen method of measurement is to utilize a diffraction grating and spatially measure the diffraction pattern to determine the spectrum of each photon.

There are two possible configurations of any QCI system depending on which arm the object is located in:

(1) **Direct imaging configuration** - the object is in the idler arm and thus directly spatially resolved (shown above for QCHSI).

(2) **Ghost imaging configuration** - the object is in the signal arm and thus indirectly spatially resolved using techniques from traditional ghost imaging (show below for QCHSI).

Most previous QCI systems have been designed using the regular imaging config above[1-3]. No QCHSI system has yet been designed in the ghost imaging config (right).



The current proposition is to design an experiment that shows the advantages of the ghost imaging configuration when scattering is present after the object in a QCI system.

Experimental Design

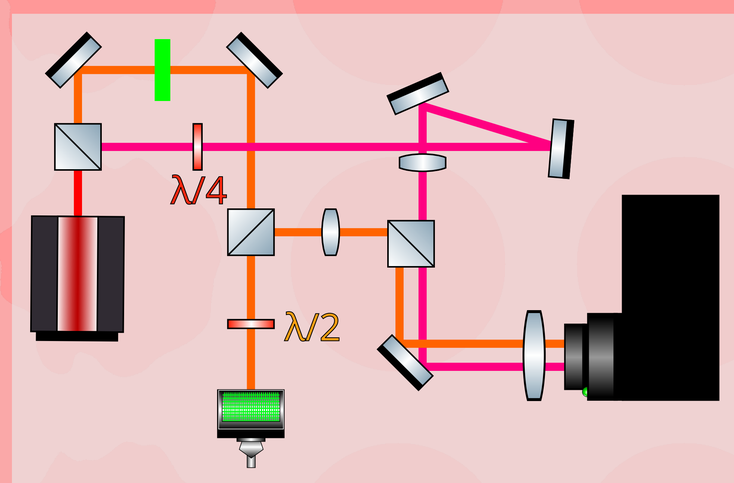
A system was designed which measures both a direct imaging configuration and ghost imaging configuration simultaneously for an object with controllable scattering. To accomplish this, the second property to be measured was chosen to also be spatial information.

Type-II SPDC was generated at 810 nm using a 405 nm CW laser to pump a ppKTP crystal.

A Thorlabs deformable mirror was used to control the scattering after the object.

A time-tagging camera with a 256x256 pixel resolution ~2 cm^2 sensor called the TPX3CAM was used to measure both the signal and idler beams.

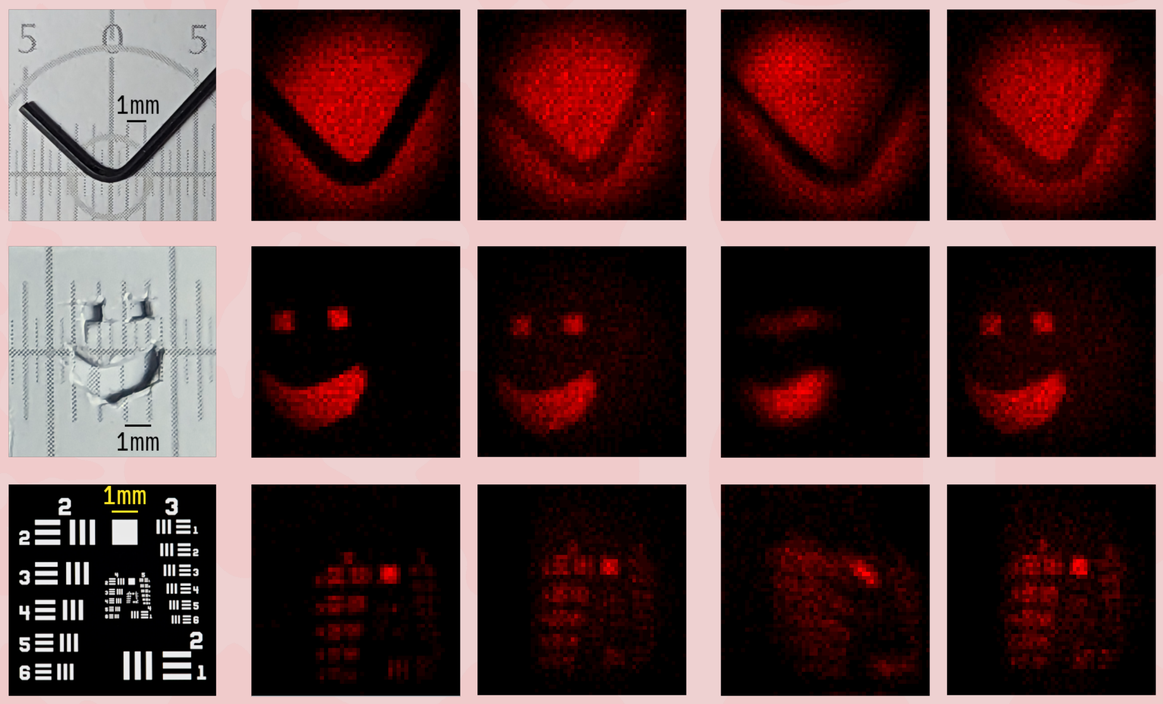
Three objects were used to show different size scales and geometries (see results figure for details).



Spatial information is measured at the end of both arms, and then temporally filtered to only consider photon pairs.

The distinction between the direct and ghost imaging configurations is made by looking at either the idler or signal spatial information, respectively

Results



The ghost imaging config is much more robust to the effects of scattering.

With minimal scattering there is minimal difference between the configs, with the direct imaging having notably better contrast.

The contrast of the ghost imaging could be improved with higher SPDC flux and more timing percision.

Magnification of the beams on the camera would improve the resolution (currently ~1/8 of the sensor per beam).

References and Acknowledgements

[1] Zhang Y. et al., arXiv:2204.05984, 2022.
[2] Zhang Y. et al., Phys. Rev. A, Vol. 105, L011701, 2022.
[3] Zhang Y. et al., arXiv:2212.12582, 2022.
[4] Pittman T. B. et al., Phys. Rev. A, Vol. 52, R3429-R3432, 1995.
[5] Dixon B. P. et al., Phys. Rev. A, Vol. 84, No. 5, 051803, 2011.

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