Lens-less two-photon ghost imaging with tunable spatial correlations

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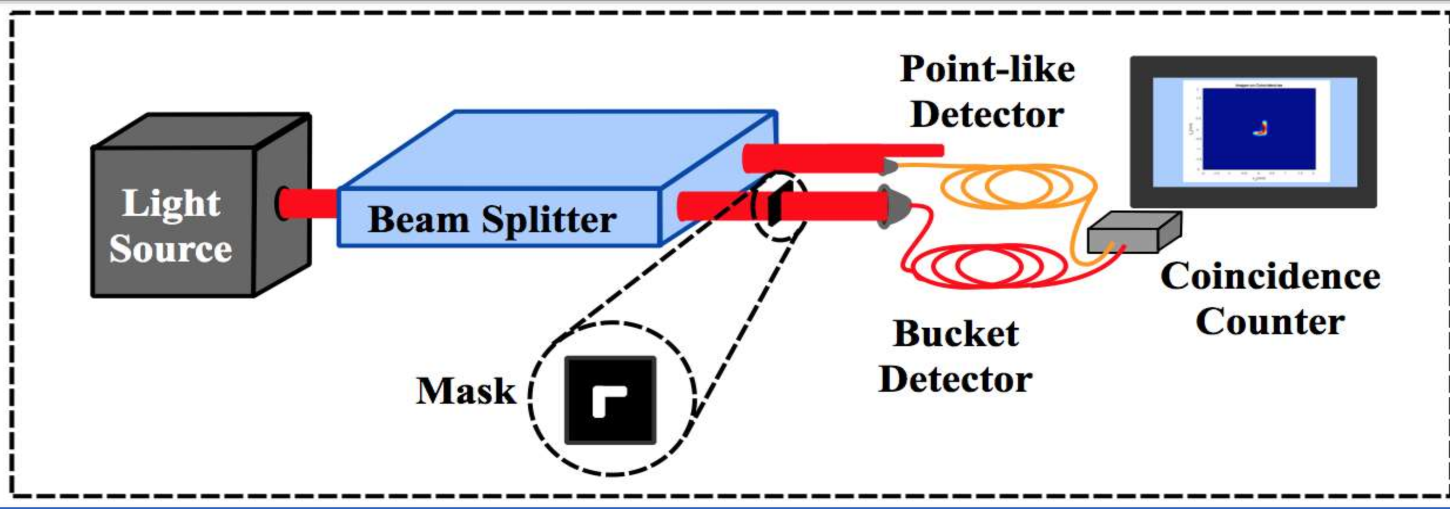
Introduction

In this work, we report the experimental control of the spatial correlations of paired photons and exploit this capability to study the effects of different spatial correlations on lens less-ghost imaging [1, 2]. Experimentally, we control the spatial correlations of paired photons produced by spontaneous parametric down conversion (SPDC) by using the waist of the pump beam as a tuning parameter [3, 4]. The effects of different types of spatial correlations on two-photon imaging experiments have been reported theoretically [5, 6]. We take advantage of the experimental capability we have, to control the spatial correlations in a unique setup to corroborate the theoretical prediction [7].



SPDC tunable spatial correlations

Biphoton-State

$$|\psi\rangle = \sum_{\sigma\neq\sigma'} \int d\mathbf{q}_s \int d\mathbf{q}_i \int d\Omega_s \int d\Omega_i \times \Phi_{\sigma\sigma'}(\mathbf{q}_s,\Omega_s;\mathbf{q}_i,\Omega_i)\,|\mathbf{q}_s,\Omega_s,\sigma\rangle\,|\mathbf{q}_i,\Omega_i,\sigma'\rangle\,,$$

where σ and $\sigma' \in \{e,o\}$ with mode function (MF) [8],

$$\Phi_{eo}(\mathbf{q}_s,\Omega_s;\mathbf{q}_i,\Omega_i) = \mathcal{N}\alpha(\Delta_0,\Delta_1)\beta(\Omega_s,\Omega_i) \times \mathrm{sinc}\left(\frac{\Delta_k L}{2}\right)\exp\left(i\frac{\Delta_k L}{2}\right).$$

Coincidence rate when an interferometric filter is placed in each arms

$$S_{eo}(\mathbf{q}_s;\mathbf{q}_i) = \left|\int d\Omega_s d\Omega_i f_s(\Omega_s) f_i(\Omega_i)\Phi_{eo}(\mathbf{q}_s,\Omega_s;\mathbf{q}_i,\Omega_i)\right|^2$$

It can be rewritten for a particular direction as

$$S^{\varrho}_{eo}(q^{\varrho}_s,q^{\varrho}_i) = \mathcal{N}_{\varrho}\exp\left[-\frac{1}{2}(\mathbf{Q}^{\varrho})^T\mathbf{\Sigma}^{-1}_{eo}\mathbf{Q}^{\varrho}\right] \quad \text{with} \quad C^{\varrho}_{ij} = \langle q^{\varrho}_i q^{\varrho}_j\rangle - \langle q^{\varrho}_i\rangle\langle q^{\varrho}_j\rangle$$

As a quantifier for the degree of spatial correlation, we used the *Pearson correlation coefficient.*

$$\kappa^{\varrho} = \frac{C^{\varrho}_{si}}{\sqrt{C^{\varrho}_{ss}C^{\varrho}_{ii}}}$$

Far-Field Ghost Imaging

The propagation of the MF of Biphoton-State

$$\Phi_{eo}(\boldsymbol{\rho}_A,\boldsymbol{\rho}_B) = \int d^2\mathbf{q}_s \int d^2\mathbf{q}_i \times G_s(\mathbf{q}_s,\boldsymbol{\rho}_A,z_A)G_i(\mathbf{q}_i,\boldsymbol{\rho}_B,z_B)\Phi_{eo}(\mathbf{q}_s,\mathbf{q}_i),$$

where $G_{\mu}(\mathbf{q}_{\mu},\boldsymbol{\rho}_j,z_j)$ with $\mu \in \{\mathrm{s},\mathrm{i}\}$ are the Green's function. For each arm the Green's Functions become:

$$G_s(\mathbf{q}_s,\boldsymbol{\rho}_A) = G(\mathbf{q}_s,\boldsymbol{\rho}_A,2f)$$

$$G_i(\mathbf{q}_i,\boldsymbol{\rho}_B) = G(\mathbf{q}_i,\boldsymbol{\rho}_B,2f)\times T(\boldsymbol{\rho}_B),$$

In the Fourier Plane , the mode function is

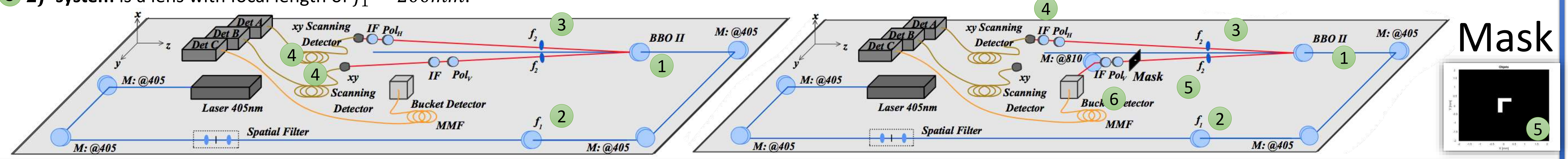
$$\Phi_{eo}(\boldsymbol{\rho}_A,\boldsymbol{\rho}_B) = C^2 T(\boldsymbol{\rho}_B)\Phi_{eo}\left(\frac{2\pi}{\lambda f}\boldsymbol{\rho}_A,\frac{2\pi}{\lambda f}\boldsymbol{\rho}_B\right). \quad (5)$$

Finally the coincidence rate become

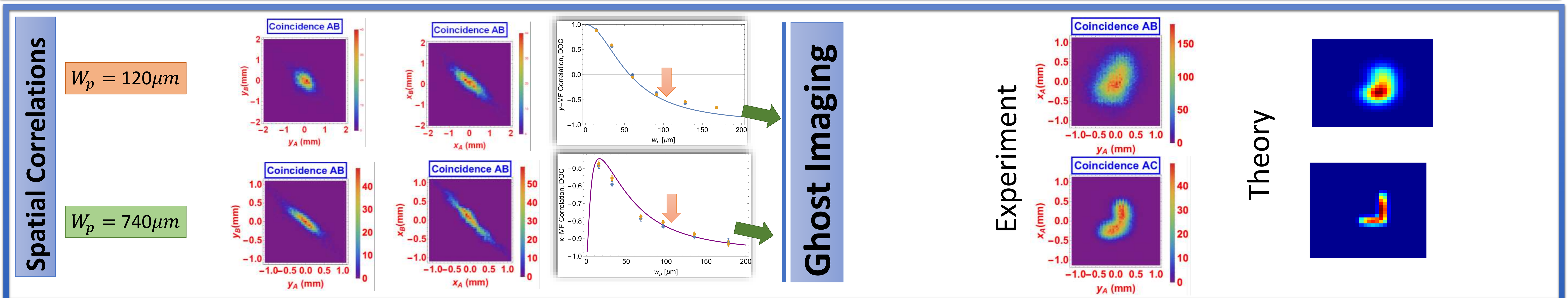
$$\mathcal{GI}_{eo}(\boldsymbol{\rho}_A) \propto \left|\int d^2\boldsymbol{\rho}_B T(\boldsymbol{\rho}_B)\Phi_{eo}\left(\frac{2\pi}{\lambda f}\boldsymbol{\rho}_A,\frac{2\pi}{\lambda f}\boldsymbol{\rho}_B\right)\right|^2.$$

Experimental Setup

1. **Light source** is produced by means of Spontaneous Parametric Down Conversion (SPDC) in a BBO type II. Using spatial filtering, a Gaussian profile is achieved.
2. **Waist Control** is achieved by means of a lens that beam focusing in the BBO type II.
3. **$2f$-system** is a lens with focal length of $f_1 = 200mm$.
4. **Scanning detector** consists of a single mode fiber placed in a xy translational platform.
5. **Mask** with L-form 0.5x0.5mm
6. **Bucket detector** consists of a multimode fiber and lens with focal length 11mm that collects all possible light.



Experimental Results



Conclusions

- We control the spatial correlations of pairs of photons, generated via SPDC, by modifying the spatial properties of the pump beam.
- we control the resolution of ghost imaging by tuning the spatial correlations.
- We observe the relation between the spatial correlations with the resolution and orientation of the ghost images

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