Single-path Two-photon Interference Effects Between Spatial Modes

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Abstract. Enabled by recent advances, we demonstrate the first two-photon interference solely between transverse spatial modes of photons, in a single beamline. By also scaling the effect up to 4 dimensions, through spatial-mode multiports, we take a crucial step towards implementing single-path linear optical networks utilizing the high-dimensional state space of photon spatial modes.
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In current implementations of linear optical networks in photonic quantum information science, the path of the photons is considered one of the best degrees of freedom to encode quantum information. Path is used since it allows high-dimensional encoding of information through multiple photon paths, and multi-photon interference is straightforward to implement using beamsplitters and phase-shifters. However, scaling up the networks requires precise interferometric stability, which is only achieved in rigid integrated waveguide chips [1]. Since multi-photon interference, thus far, has not been demonstrated within the spatial mode degree of freedom, applications of quantum information science that use spatial modes, have not been able to reach their full potential.

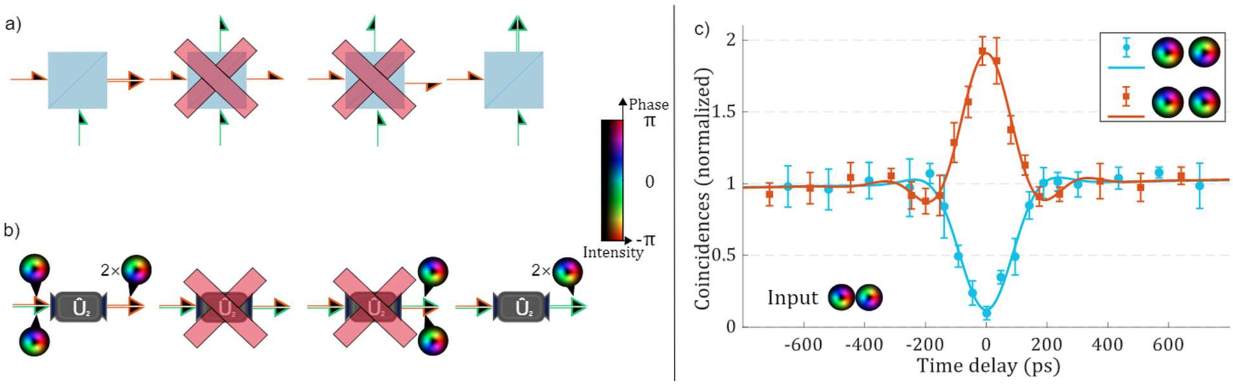

Figure 1 Sketch displaying the similarity and difference between two-photon interference a) between paths and b) between spatial modes. In the spatial mode case b), our photons stay in a single beamline while still undergoing a similar bunching as in the beamsplitter case a). In c), we show our results for two-photon interference between two spatial modes. We plot the coincident detections of photon pairs when one of the input photons is delayed in comparison to the other. If we project the photons on the same mode (first or last panel of b), we get a doubling in the measurement rate (orange data) at zero delay due to constructive interference. However, if we project on a state where the photons have orthogonal modes (the two middle options in b), our measurement rate approaches zero due to destructive interference (blue data).

Through the recently introduced techniques of multi-plane light conversion [2] and wavefront matching [3], we can perform any unitary spatial mode transformation [4]. Thus, we were able to demonstrate two-photon interference in a two-dimensional spatial mode state space (shown in Figure 1), which is a direct analogue to the original HOM experiment [5]. Moreover, by utilizing the ease of generating spatial mode superpositions and their high-dimensional state space, we were able to measure complex interference effects in multiple high-dimensional multiports. Thus, our results show that spatial modes can be used in future applications as single-path linear optical networks, for a broad range of quantum information schemes.

References

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