Quantum optimal precision by resolving inner-variable two-photon correlations

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Two-photon interference is a powerful tool for robust precision sensing. We demonstrate time-delay and spatial-displacement estimation with quantum-optimal precision based on inner-variable resolving detection, reducing uncertainty even with experimental imperfections harnessing otherwise hidden beating oscillations.

Two-photon interference plays an important role in modern high-precision measurement techniques. As the second-order correlations between two photons impinging on the two faces of a beam-splitter are highly sensitive to the differences between the photons and are not affected by changes in their relative phases, these techniques are routinely employed for the measurement of differences in the values of given photonic parameters, such as colours, arrival times, polarisations, and transversal positions. Moreover, recent theoretical works have shown that a two-photon interference approach based on inner-variable resolved correlation measurements overcomes the limitation of overlapping wave packets that typically limits the working range of sensing techniques based on two-photon interference [1,2].

Here we show two distinct experimental realizations of this approach, the first for the estimation of time delays between photons through frequency-resolving detectors [3], the second for the estimation of transverse displacement between the photons through resolving the photonic transverse momenta [4]. We show theoretically via Fisher information analysis that this approach achieves the quantum optimal precision. Experimental data align well with the predictions of quantum estimation theory, demonstrating a significant reduction in the uncertainty of the estimation even in presence of experimental imperfections, such as finite resolutions of the detectors and reduced interference visibility. We show that the origin of such a quantum advantage resides in the observation of beating oscillations that are normally averaged out when performing a standard two-photon coincidence experiment. We discuss how such an approach can be applied to disparate domains, finding applications in bio-imaging, nano-imaging, single-molecule localization microscopy and exoplanet localization.

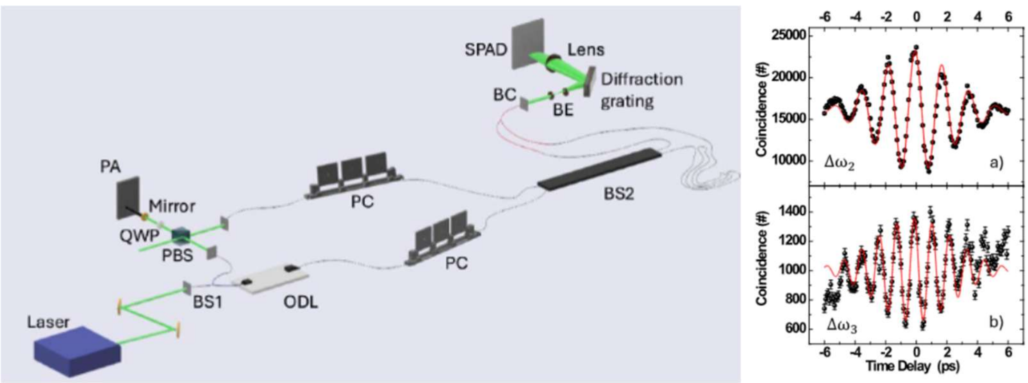

Fig. 1. (Left) Experimental setup of the frequency-resolved approach. (Right) Beating oscillations for different pairs of frequencies.

References

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