Ultimate Quantum Sensitivity Through Inner-Variable Resolved Two-Photon Interference

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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, these techniques are routinely employed for the measurement of differences in the values of given photonic parameters, such as colours, arrival times and polarisations [1].

However, despite recent advances that pushed the precision of two-photon interference techniques for the estimation of photon delays to the attosecond regime [2], these techniques are still fundamentally hindered by the distinguishability of the photons at the detectors caused by the difference in the physical parameters we wish to estimate: the less the wavepackets of the two photons overlap, the more the photons become distinguishable at the detectors, the less visible is their interference, and thus the less sensitive is the technique.

Here, we present a two-photon interference approach that overcomes the limitation of overlapping wavepackets. In particular, it allows the estimation of the delay or the transverse relative position at the balanced beam splitter of two photons independently of the overlap of their wavepackets. This technique is based on correlation measurements that resolve the frequencies of the two photons [3] or their transverse momenta [4], and it allows us to achieve the ultimate quantum precision, given by the quantum Cramèr-Rao bound [5]. Interestingly, we show that this sensitivity can be arbitrarily increased by employing photons with broader distributions in the resolved variable.

Applications of the delay sensing technique range from more feasible imaging of nanostructures, including biological samples and nanomaterial surfaces for the estimation of delays. For the spatial case, our technique lays the foundations for the development of feasible sensing schemes of the transversal displacement induced on a single-photon beam, e.g., by a refractive mean or a tuneable beam displacer, and more feasible super-resolution bioimaging at the single-photon level, such as single-molecule localization microscopy with quantum dots.

References

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