Ultimate Quantum Sensitivity and Computational Speed-Up in Multiphoton Interference by Resolving the Photonic Inner Modes

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Multiphoton quantum interference underpins fundamental tests of quantum mechanics and quantum technologies, including applications in quantum computing, quantum sensing and quantum communication.

We show how the differences in the states of interfering photons can be exploited as a remarkable quantum resource for both quantum sensing applications and quantum computational speed-up by employing sampling measurements that resolve the photonic inner-mode parameters, such as frequency and time, providing a quantum advantage with respect to techniques which ignore such information.

Indeed, standard two-photon interference techniques are fundamentally hindered by the distinguishability of the photons at the detectors caused by the difference in the physical parameters we wish to estimate and are unable to reach the ultimate quantum precision in nature.

We present a two-photon interference technique that overcomes these limitations, allowing us to estimate with the ultimate quantum precision the delay between two photons independently of the overlap of their wave packets in the time domain. This technique is based on sampling correlation measurements that resolve the frequencies of the two photons interfering at a beam splitter [1]. The sensitivity can be increased by decreasing their temporal bandwidth, even at values smaller than their delay when standard two-photon interferometers become inoperable. The same technique can be extended to the estimation of other physical parameters by resolving their conjugate degree of freedom, *e.g.* the estimation of the spatial separation between the photons through resolving their transverse-momenta [1]. Applications include the characterization of two-dimensional Nanomaterials, the analysis of biological samples and super-resolution imaging.

We also show both theoretically [2-6] and experimentally [7,8] how multiphoton interference with states of single or multiple photons enables the characterisation of multiphoton networks and states, the generation of multipartite entanglement, and scales-up boson sampling demonstrations of quantum computational speed-up. This is possible even with non-identical photons by harnessing the full multiphoton quantum information stored in the photonic wave packets by sampling measurements in their inner-mode parameters, such as frequency and time.

References

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