Benchmarking quantumness of a two-photon quantum walk simulator

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Abstract

Discrete time quantum walks (DTQW) constitute an experimentally attractive approach to harness quantum mechanics for simulations and other computational tasks. Owing to the simple structure – local coin rotations and nearest-neighbour shifts – optical time-multiplexing has been used successfully to implement and demonstrate various proof-of-principle applications of single-particle DTQWs. To take full advantage of quantum mechanics, implementation of multiple walker DTQWs are necessary. In this work we propose a benchmarking protocol, based on the well-known Hong–Ou–Mandel effect, to assess the degree of quantumness in bosonic two-particle quantum walk implementations. We apply this benchmarking on a two-photon time-multiplexing implementation of DTQWs.

Single particle DTQWs are a versatile theoretical tool useful in simulating various transport phenomena and in solving computational problems such as searching. While in the single walker regime it is known to offer only a quadratic speedup over classical random-walk based algorithms, employing multiple walkers can be used to attain a quantum advantage in solving computational or sampling problems. Optical time-multiplexing [1, 2] offers an efficient platform for implementing quantum walks with programmable complex dynamics, compatible with multi-walker scenarios, including boson sampling [3].

In our present work we address the problem of assessing the level of quantumness maintained by the apparatus implementing a two-particle quantum walk. We propose a benchmarking protocol applicable to a pair of indistinguishable bosonic walkers on a 1D line, based on the well-known Hong–Ou–Mandel effect [4]. The protocol consists of using the apparatus to prepare two orthogonally polarised single photons in suitably shaped states extended over multiple discrete positions and letting them interfere after a joint linear transformation, corresponding to a situation studied earlier in the continuous context [5]. Coincidences are recorded between detection events from the two polarisations as a function of the delay between the two photons. The resulting dip can be interpreted as a discretised generalisation of the usual HOM dip, with its depth characterising the overall quantumness of the entire process, and the shape depending on the initially prepared photon states. We revisit the notion of coincidence within the discretised framework, distinguishing strict and loose coincidences. We show how these coincidences can expose the quantum statistics of the walkers, and present explicit procedures to benchmark the suitability of a given DTQW implementation to perform multi-walker protocols. We report on the experimental benchmarking results on our time-multiplexing setup [2]. While the benchmarking protocol has been formulated in the language of optics, the results are general and can be applied to any bosonic DTQW platform.

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