Hybrid, Atom and Photon Boson Sampling

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Hybrid boson sampling scheme merging cavity-QED and quantum-gas technologies is proposed and analyzed [1,2]. It reveals the quantum advantage and overcomes limitations of widely discussed photon boson sampling and recently proposed atom boson sampling [3-6]. Multipartite entanglement and squeezing required for computational ♯P-hardness (quantum advantage) of sampling are self-generated inside a multi-mode cavity via atom-photon and atom-atom interactions. This eliminates the no-go factors of a pure photon sampling as well as the necessity to develop single-atom detectors for a pure atom sampling since it turns out that sampling just photons from the system of interacting atoms and photons is enough for demonstrating quantum advantage. The main no-go factors of the pure photon sampling are the losses on the beam splitters and phase shifters as well as dephasing due to imperfect synchronization of different external sources of photons. The negative effect of these factors grows with the number of optical channels. Recent intensive studies show that populous photon sampling schemes employing linear interferometers cannot evince quantum advantage, and alternative schemes are needed [7–10].

Computational ♯P-hardness of hybrid boson sampling statistics is revealed based on the hafnian master theorem [11-13]. We propose to build an apparatus that would generate a string of random photon numbers by one-time synchronous multi-detector measurement of these numbers, while generation of the same numbers by means of classical computers would require a long computation time exponentially growing with the size of the string. It is within reach for the current cavity-QED and ultracold-gas technologies. Demonstrating multipartite entanglement and squeezing possessing hafnian-based complexity just within the photon sampling statistics in the 'multimode cavity + BEC gas' system even for a small number of modes would be already greatly important as a proof-of-principle experiment.

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