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Experiment friendly entanglement witness for multipartite entanglement in atomic frequency combs

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Atomic frequency comb, an atomic ensemble with comb shaped optical transition, is useful for multimode photonic quantum memory where a photon is absorbed collectively over the teeth of the comb resulting in a multipartite entangled state. The teeth of the comb constitute the individual subsystems participating in the entanglement. Since each tooth of the comb consists of a macroscopic number of atoms (typically several thousand), the atomic frequency comb (AFC) system presents an entirely different class of entangled state, which we call the colossal entangled state, i.e., multipartite entanglement between macroscopic systems.

In this work we propose an experimentally realizable witness and entanglement measure for the colossal entanglement in the AFC systems which is the entanglement between the teeth of the AFC. The witness is achieved in two steps. First we determine the minimum number of teeth coherently absorbing the photon, i.e., the coherence depth, from the signal to noise ratio of the light coming out of the AFC system. We argue that coherence depth is synonymous to entanglement depth, i.e., the minimum number of provably entangled systems, for the case when exactly one photon is present in the system. However, higher photon number component in the photonic states can cause differences between the coherence depth and the entanglement depth. We rectify this problem by estimating the probabilities P0 of no photon and P1 of having exactly one photon in the AFC system and using the bound on P1 for a given P0 and entanglement depth derived in [Hass et al. 2014]. Our method requires no prior knowledge of the number of teeth and is scalable. Furthermore, the method uses only macroscopic quantities to estimate the entanglement in the system, hence, is a suitable choice for the experimental demonstration of genuine multipartite entanglement. We have numerical and experimental results to support our entanglement witness.

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