Entanglement Witnesses 2.0 with Two Detectors

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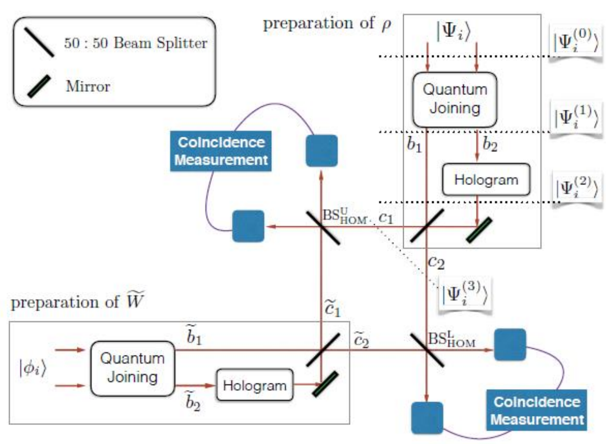
Abstract: An entanglement witness (EW) is an observable detecting entanglement for a subset of states. Recently, the so-called EW 2.0 has been proposed as a framework that makes an EW twice as powerful due to the general existence of a second (lower) bound, in addition to the (upper) bound of the very definition. In this work, we show that, via the technique called quantum joining exploiting orbital angular momentum degrees of freedom, an EW can be in general realized with two detectors only. The experimental proposal is presented with a single Hong-Ou-Mandel interferometry in which only two detectors are applied regardless of the dimensions or the number of modes of quantum systems.

1. Introduction to the style guide, formatting of main text, and page layout

Entanglement witnesses (EWs) are a general tool to detect entangled states. They are observables that have non-negative expectation values for all separable states but not for some entangled states. Namely, for all separable states σ_{sep}, it holds that $\mathrm{tr}[W\sigma_{sep}] \geq 0$ but $\mathrm{tr}[W\rho] < 0$ for some entangled states ρ. Recently, it has been shown that EWs can be improved twice powerful in the framework of EW 2.0 [1,2]: there exist lower and upper bounds on a non-negative and unit-trace observable X such that $L \leq \mathrm{tr}[X\sigma_{sep}] \leq U$ for all separable states σ_{sep}. Note that X can be interpreted and prepared as a quantum state. Therefore, estimation of the expectation value may correspond to observing interference of two quantum states.

2. Results

Suppose that a bipartite state ρ is given and unknown. One may be interested to find if the state is entangled or not even before identifying the state itself. In this case, EWs are useful. We here present an experimental scheme that realizes EW 2.0 with two detectors only. That is, we aim to estimate the expectation value $\mathrm{tr}[X\rho]$ to find if the state ρ is entangled and show that it can be realized with two detectors only via the technique called quantum state joining exploiting orbital angular momentum (OAM) degrees of freedom of photons.



The scheme is shown in the figure. A two-photon polarization state ρ is initially prepared. After quantum state joining, a single-photon polarization is produced with paths b1 or b2, and, depending on the path, OAM degrees of freedom is encoded by the hologram. Two spatial modes interfere via the 50 : 50 beam splitter: the resulting single-photon four-dimensional state of polarization and OAM degrees of freedom appears in c1 or c2 with probabilities 1/2, respectively. The HOM effect appears when two photons pass the same beam splitter together, which happens with the overall probability 1/2. The expectation value can be estimated in the coincidence measurement.

3. References

[1] Joonwoo Bae, Beatrix Hiesmayr, and Dan McNulty, "Linking entanglement detection and state tomography via quantum 2-design", arXiv:1803.02708, to appear in *New Journal of Physics.*
[2] Joonwoo Bae, Dariusz Chruscinski, and Beatrix Hiesmayr, "Entanglement Witness 2.0: Compressed Entanglement Witnesses", arXiv:1811.09896
[3] Chang Jian Kwong, Simone Felicetti, Leong-Chuan Kwek, and Joonwoo Ba, "Entanglement Detection with Single Hong-Ou-Mandel Interferometry" *arXiv:1606.00427*.