Observation of One-way Einstein-Podolsky-Rosen steering

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Abstract: We prove and experimentally demonstrate that EPR-steering can be rigorously asymmetric, unlike Bell tests, by constructing quantum states which are steerable in one direction, whilst two-way steering is impossible with arbitrary quantum measurements.

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Quantum entanglement is a key resource for quantum information and communication tasks, such as teleportation, entanglement swapping and quantum key distribution. Within the hierarchy of quantum correlations, Einstein-Podolsky-Rosen (EPR) steerable states are distinguished from both entangled and Bell-nonlocal states by their inherent asymmetry. These nonlocal correlations allow to observe 'steering' that is when measuring one system affects the measurement results on the other system. In principle, two parties (Alice and Bob) who share certain entangled states may be able to complete the protocol if Alice tries to steer Bob's measurement outcomes, but not vice versa. This is known as one-way steering [1].

This feature has been previously demonstrated for the restricted class of Gaussian measurements [2, 3], but that is not fully general. There exist cases where states that are one-way steerable for Gaussian measurements are two-way steerable (i.e. not fundamentally asymmetric) for more complicated measurements. In fact, for the general case of positive-operator-valued measures (POVM) even the theoretical existence of one-way steering has only recently been settled [4].

Here, we proved and then observed one-way steerability of an experimentally accessible class of entangled polarisation states - so-called Werner states [5]– in this general setting [6]. Our high heralding efficiency photon source enabled us to violate the steering inequality by 6 standard deviations in one direction, whilst closing the detection loophole [7]. In the other direction, tomographic reconstruction verified the creation of a state that was provably unsteerable for arbitrary quantum measurements. Further we tested our experimental results against a recently derived necessary condition for steerability of arbitrary two-qubit states with loss for general POVMs [8]. In this work we aim to give a conclusive answer to one-way steering. While specific states can be conclusively proven to be one-way steerable, the experimental generation remains challenging. Generated states in a laboratory environment usually differ from the ideal states. We tested our experimentally generated Werner-like states, having a 99% fidelity with a Werner state, against this practical necessary condition. However, we will show that proving non-steerability remains an open question with the robustness of this experimental data and will outline what would be the requirements to settle the question of one-way steerability. We will conclude this talk by giving an overview of the latest developments of EPR-steering in integrated photonics. This will emphasize the strong foundational significance of steering and pave the way for robust and innovative demonstrations of quantum technologies.

References

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