

Genuine High-Dimensional Quantum Steering

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Abstract. We theoretically formalise and experimentally demonstrate a notion of genuine high-dimensional quantum nonlocal steering. We show that high-dimensional entanglement combined with judiciously chosen local measurements leads to a stronger form of steering, provably impossible to obtain via entanglement in lower dimensions. Exploiting the connection between steering and incompatibility of quantum measurements, we derive simple two-setting steering inequalities for certifying the presence of genuine high-dimensional steering. We report the experimental violation of these inequalities using macro-pixel photon-pair entanglement demonstrating genuine high-dimensional steering in dimensions up to $d = 15$.

Keywords: high-dimensional entanglement, quantum steering, quantum information

High-dimensional entanglement has revolutionised the field of quantum information and communication by surpassing qubit-based systems in the capacity of the information they can encode, their robustness against noise [1], and stronger form of nonlocal correlations they exhibit. A key problem is then to certify and characterise this entanglement. This is challenging not only due to the large number of parameters in the Hilbert space, but also because experimentally available data is typically limited. Nevertheless, significant progress has been reported in scenarios assuming fully characterised measurement devices [2,3].

In this work, we address the problem of certification of entanglement from the point of view of quantum steering. The latter represents a form of quantum correlations intermediate between entanglement and Bell nonlocality [4]. Quantum steering relaxes the strict technological requirements of Bell nonlocality by assuming an uncharacterised or untrusted measurement device only on one side. However, theoretical tests of steering developed so far can only witness the presence of entanglement without capturing its high-dimensional nature [5-7]. Here we develop a notion of genuine high-dimensional quantum steering, showing that this approach is effective for certifying high-dimensional entanglement in a one-sided device-independent (black-box) scenario. We demonstrate steering in an experimental setup where we produce high-quality photonic bipartite states entangled in

their discretized transverse position-momentum [3]. We design mutually unbiased projective measurements and implement them using spatial light modulators (SLMs), resulting in two-photon correlations measured in any high-dimensional basis. By applying our steering witness on these measurements, we demonstrate steering with a record local dimension of 15 in a 31-dimensional space [8]. Our results open various promising avenues in the implementation of experimental semi-device independent protocols, which exploit the enhanced possibilities that high-dimensional entangled systems have to offer in terms of higher information capacity and robustness to noise.

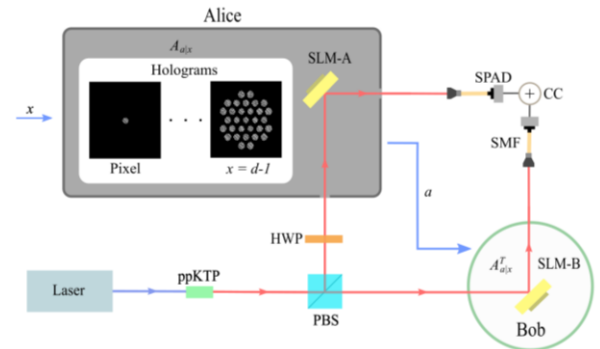


Figure 1. One photon from an entangled photon pair and a classical dit x are distributed to the untrusted party, Alice. She generates holograms on SLM-A to perform the projection $A_{a|x}$ onto outcome a for the given basis x and passes a to the trusted party, Bob. Bob performs the projection $A_{a|x}^T$ on the conditional state $\sigma_{a|x}$ according to the steering inequality [8]. Coincident photon detection events are then used to evaluate the steering inequality, allowing us to certify genuine high-dimensional steering.

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