Experimental High-Dimensional Einstein-Podolsky-Rosen Steering

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Abstract

In this work, we demonstrate the HD steering effect by encoding with orbital angular momentum photons for the first time. More importantly, we have quantitatively certified the noise-suppression phenomenon in the HD steering effect by introducing a tunable isotropic noise. We believe our results represent a significant advance of the nonlocal steering study and have direct benefits for QIP applications with superior capacity and reliability.

Steering nonlocality is the fundamental property of quantum mechanics, which has been widely demonstrated in some systems with qubits. Recently, theoretical works have shown that the highdimensional (HD) steering effect exhibits novel and important features, such as noise suppression, which appear promising for potential application in quantum information processing (QIP). However, experimental observation of these HD properties remains a great challenge to date.

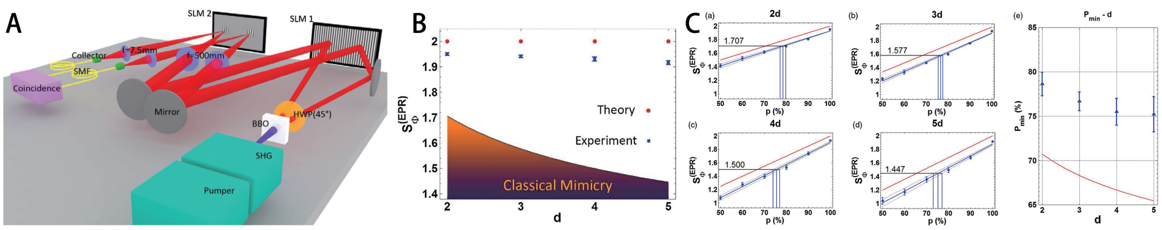

Figure 1: A. The experimental schematic of HD steering certification. B. Experimental results of coincidence measurement. (a) Experimental coincidence counts of jointly measuring state (b) Experimental values of the steering parameter versus different system dimension. C. Experimental results of steering certification with tunable isotropic noise. (a)–(d) Steering parameter $S_{\phi}^{(EPR)}$ for different percentage of isotropic noise in different dimensions. (e) Actual P_{min} for dimension 2 to 5. Errors were estimated assuming Poisson statistics.

We first constructed a genuine high-dimensional (HD) maximally entangled system using orbital angular momentum (OAM) photons and verified its steering nonlocality as shown in Figure A. The entangled OAM photons are generated through a spontaneous parametric down-conversion (SPDC) process, and the OAM states are manipulated with spatial light modulator (SLM) loading reconfigurable computer-generated holograms (CGH). We employed SLM1 as a regular diffraction grating and manipulated SLM2 loading designed CGHs, which correspond to the correlation measurement bases.

Figure B displays our experimental results of the steering parameter $S_{\phi}^{(EPR)}$ (see Ref. [1] for an overview) as a function of dimension d. We further explored how Alice's steerability varies with the dimension in the noisy environment. We introduced isotropic noise into the HD entangled system, and find that the extra dimension can improve the robustness of the system against isotropic noise. The blue triangles in Figure C(e) display the results of steering parameter versus dimension. Although the parameter decreases more and more slower, which indicates that the other noises (shot noise and crosstalk) start to overtake the isotropic noise, it still gives solid proof that the extra dimension can indeed strengthen the steering effect against the isotropic noise.

In summary, we have experimentally certified the steering nonlocality in a d-dimensional maximally entangled system by demonstrating violation of steering inequality for qudit with d up to 5. Furthermore, we propose a novel method to introduce a tunable isotropic noise into the entanglement system to quantitatively verify enhancement of the steering effect against isotropic noise by the extra dimension. We also discovered that while isotropic noise is suppressed by increasing the dimension, other noises like shot noise and crosstalk still increase. In fact, these negative effects could also be overcome by adopting a more powerful pumper or a more balanced entanglement source.

[1] C.-M. Li, Y.-N. Chen, N. Lambert, C.-Y. Chiu, and F. Nori, *Certifying single-system steering for quantum-information processing*, Phys. Rev. A **92**, 062310 (2015).