Experimental observation of a quantum Cheshire cat using a weak measuring device

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Abstract

We experimentally demonstrate the spatial separation of the photon and its polarization, known as the Quantum Cheshire cat effect. A pre- and post-selected photonic quantum system is subject to a weak measuring device to probe where the photon and its polarization property can be found. Intriguingly, a quantum pointer after the weak quantum measurement indicates that the polarization can be found at the path the photon did not take.

It is very natural to assume that physical properties should not be separated from objects that carry them. However, the quantum theory allows such phenomenon to happen for pre- and post-selected system. This counterintuitive quantum effect, so called the quantum Cheshire cat effect [1], was named after the famous novel of Alice's Adventure in Wonderland by Lewis Carroll. In order to observe the quantum Cheshire cat, implementing a nondestructive weak measuring device is crucial to simultaneously probe both the physical property and the carrier's location. While observing the quantum Cheshire cat, the physical property and the carrier's location should be weakly probed with a measuring device to leave the quantum state with a negligible disturbance. To date, experimental observations of the quantum Cheshire cat effect have been realized with a single neutron as well as with a single photon [2, 3]. However, their observations relied on weakly disturbing elements instead of a true weak measuring device. In this presentation, we report the experimental observation of the quantum Cheshire cat effect with a weak measuring device. To investigate the quantum Cheshire cat effect, we employ single-photon pairs generated by spontaneous parametric down conversion (SPDC). The elements of quantum Cheshire cat, namely the body (photon) and the grin (polarization), are indirectly probed with a quantum pointer using another single photon, where both the body and the grin are weakly measured without destroying the photon itself.

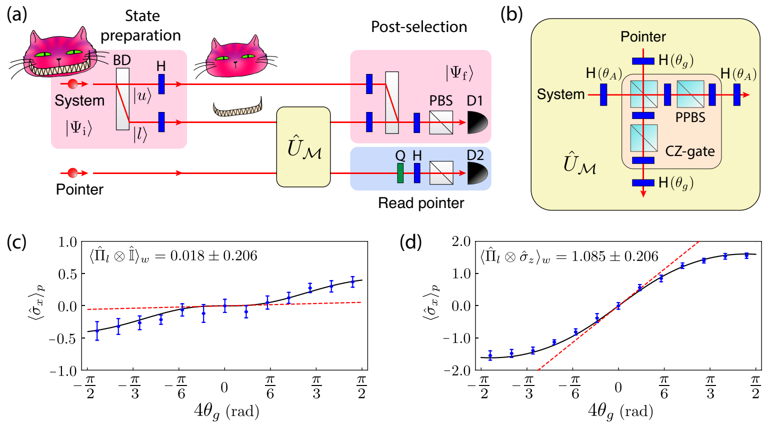

Fig. 1 (a) Experimental schematic to observe the quantum Cheshire cat. (b) The measurement interaction $\hat{U}_{\mathcal{M}}$ is implemented via a linear optical entangling gate. The expectation $\langle \hat{\sigma}_x \rangle_p$ of pointer qubit is measured as a function of θ_g. The weak values for observables (c) $\hat{\Pi}_l \otimes \hat{\mathbb{I}}$ and (d) $\hat{\Pi}_l \otimes \hat{\sigma}_z$ are extracted from the first-order dependence of θ_g from the polynomial fit. H (half-wave plate), Q (quarter-wave plate), BD (beam displacer), PBS (polarizing beam splitter), PPBS (partially polarizing beam splitter).

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