Directly Characterizing Quantum Measurement via Weak Value

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Abstract

Instead of conventional reconstruction schemes, the direct characterization of quantum states and processes have been realized via weak measurement. Nevertheless, most optical implementation of weak measurement employed two degrees of freedom of a single photon, making it unaccessible to direct measurement of quantum measurement. Here, we experimentally demonstrate a weak-measurement scheme based on quantum nondemolition(QND) measurement to directly measure a measurement apparatus.

Typically, the technique of quantum measurement tomography is used to determine a measuring device. Provided a complete set of input quantum states and the corresponding responses, the generalized positive-operator valued measure(POVM) can be reconstruted according to the Born's rule, which is similiar to quantum state tomography.

In 2011, Jeff et.al proposed a scheme to directly measure the quantum wavefunction[1]. The core of this method is to establish a mapping relationship between the probability amplitude of wavefunction and weak value. In addition, this method has been recently extended to directly measure the polarized state of photons, high-dimensional orbital-angular-momentum state or even a quantum process.

The weak value of an observable $\hat{A}$, first put forward by Aharanov, Albert and Vaidman[2], is formulated as

$$\langle \hat{A} \rangle_w = \frac{\langle \psi_f | \hat{A} | \psi_i \rangle}{\langle \psi_f | \psi_i \rangle}, \tag{1}$$

showing a good symmetry for pre-selected state $|\psi_i\rangle$ and post-selected state $|\psi_f\rangle$. In a retrodictive approach, a POVM element $\hat{\Pi}_n$ corresponds to a 'pre-measurement state', leading us towards to direct measurement of a quantum measuring apparatus.

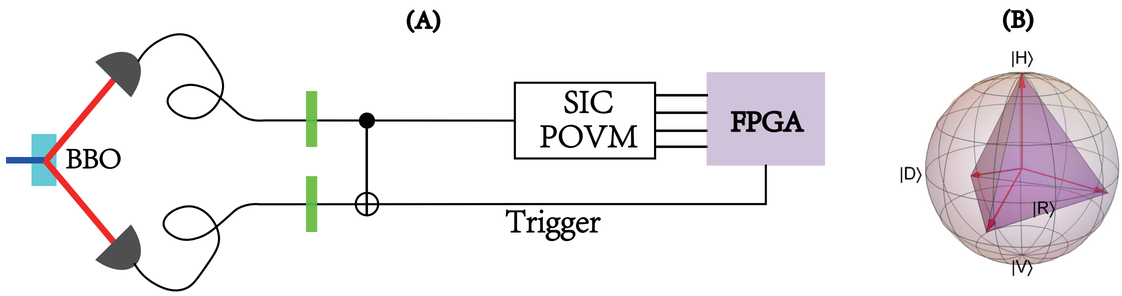

Figure 1: Schematic Diagram for Direct Characterization of SIC POVM.

Here, we report a weak-measurement scheme using a CNOT gate, which is a typical QND measurement[3]. Figure.1(A) illustrates the schematic diagram of our experimental setup. Two photons, generated by spontaneous parametric down conversion(SPDC) incident into a CNOT gate. The polarization DOF of two photons respectively refers to the quantum system and the meter state. From the coincidence counts of the trigger and the four outputs of SIC POVM, we can directly derive the SIC POVM, as is shown in Figure.1(B).

In summary, we have introduced a new method to directly characterize the quantum measurement. Our work sheds new light on both the applications of weak measurement and quantum measurement tomography.

[1] Jeff S. Lundeen, et al, Nature **474**,188 (2011).

[2] Aharonov, et al, Physical Review Letters **60,14**,1351–1354 (1988).

[3] Pryde, G J et al, Physical Review Letters **94,22**, 220405–4 (2005).