Direct quantum process tomography via measuring sequential weak values of incompatible observables

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The action of the standard projective measurement irrecoverably collapses a quantum state into one of the eigenstates of observable, resulting in maximum state disturbance. Due to the measurement disturbance, one cannot extract any information of a quantum state from the second measurement when the second observable does not commute with the first observable. However, weak measurement relaxes this constraint and opens the possibility of sequential quantum measurement for incompatible observables. Whilst such sequential weak measurement for incompatible observables has been reported to extract sequential weak values very recently [1, 2], these experiments might be regarded as classical experiments in the sense that the measurement interaction can be fully explained with the classical electromagnetic theory.

In this presentation, we present our experimental implementation of sequential weak value measurement for incompatible observables [3]. In particular, by making use of two-photon quantum interference for the measurement interaction, our experiment can be viewed as an unambiguous quantum implementation of sequential weak value measurement. And also, we show how the sequential weak value measurement can be used to perform direct quantum process tomography of a qubit channel.

In our experiment, two single-photons are prepared by spontaneous parametric down-conversion (SPDC) process. System and ancilla qubits are encoded, respectively, on the polarization and path modes of one of the photons. A meter qubit is encoded on the polarization mode of the other photon. In order to measure the sequential weak value for two non-commuting observables $\hat{A}$ and $\hat{B}$, we first apply two-qubit measurement interaction between system and ancilla qubits for the first observable $\hat{A}$. Then, the measurement interaction for the second observable $\hat{B}$ is realized by three qubit interaction between system, ancilla, and meter qubits. Finally, the measurement information in the ancilla qubit is erased by applying a particular projection measurement [4], resulting in the joint state of the system and the meter qubit as $|\psi\rangle_s|0\rangle_m + g\hat{B}\hat{A}|\psi\rangle_s|1\rangle_m$. Here, g is the measurement strength parameter. Finally, we project the system qubit onto the projector $\hat{\Pi}_s = |\phi\rangle\langle\phi|$, leaving the meter qubit in the state

$$|0\rangle_m + g\langle\hat{B}\hat{A}\rangle_w|1\rangle_m,$$

where $\langle\hat{B}\hat{A}\rangle_w \equiv \langle\phi|\hat{B}\hat{A}|\phi\rangle/\langle\phi|\psi\rangle$ is the sequential weak value for two observable $\hat{B}$ and $\hat{A}$.

Since the sequential weak value is registered in the meter qubit, it can be read out by obtaining certain expectation values for the meter qubit. For example, the real (imaginary) part of the weak value is obtained from $\langle\hat{\sigma}_x\rangle_m$ ($\langle\hat{\sigma}_y\rangle_m$). Figure 1 shows the measured expectation values for the meter qubit as a function of the weak measurement strength g. The dashed red lines are the first-order dependence of g, which

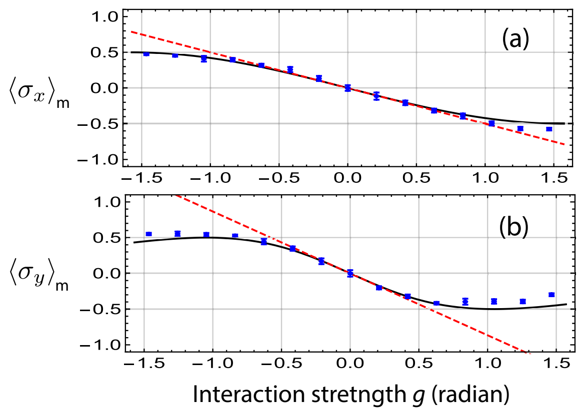

Figure 1: Extracting sequential weak values.

corresponds to the sequential weak values.

We also demonstrate the direct quantum process tomography via measuring sequential weak values of incompatible observables. A quantum process is completely characterized by the process matrix χ. A standard quantum process tomography requires tomographically complete set of measurements. Here, *direct* quantum process tomography refers that one can directly measure the process matrix elements. We will show how the quantum process matrix elements corresponds to the sequential weak values, demonstrating the experimental direct quantum process tomography via measuring sequential weak values.

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