Supplemental Document

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Supplement DOI: https://doi.org/10.6084/m9.figshare.12469235

Parent Article DOI: https://doi.org/10.1364/OPTICA.389322 optica

Photonic realization of quantum resetting: supplementary material

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Compiled May 17, 2020

This document provides supplementary information to "Photonic realization of quantum resetting," https://doi.org/10.1364/OPTICA.389322. In this supplemental, we discuss the details of the experimental setup and the results of extra experiment with a free Hamiltonian $\mathcal{H}_0 = \sigma_y/2$. These details and results presented here will help readers to understand our work more clearly.

1. EXPERIMENTAL SETUP

As shown in Fig. 1 in main text, for each entangled photon pair source, a 300 mW pulsed ultraviolet laser is focused onto the sandwich-like geometry BBO crystal [1], which consists of two 2-mm-thick BBO crystals and a 44-μm-thick true-zero-order HWP, with the same waist $\omega_0 \simeq 150\ \mu$m. Further, we use a YVO_4 crystal with a thickness of 2.3 (0.715) mm cut at 45° with respective to the propagation direction in the horizontal plane to compensate spatial walk-off in the arm of extraordinary (ordinary) ray, and a 1.36 (0.39) mm thick YVO_4 cut at 90° to compensate temporal walk-off (see Fig. S1). To eliminate the frequency correlations between independent pairs, we select bandpass filters with 3.6 nm to spectrally filter both signal and idler photons. With this filter setting, the respective twofold coincidence court rate of three entangled photon pairs are $\sim$ 135000 Hz, $\sim$ 156000 Hz, $\sim$ 102000 Hz, correspond overall efficiency is 23.7%, 24.0%, 23.6% and visibility in $|D\rangle$ / $|A\rangle$ basis is 95.2%, 96.7%, 97.0%. With finely adjusting the distance of each photon, we make sure that the photons overlap on the PBSs well for both two circuit, and we eventually obtain an average fourfold coincidence rate of $\sim$21 s^{-1} with a corresponding Hong-Ou-Mandel visibility of 89.5% in $|D\rangle$ / $|A\rangle$ basis.

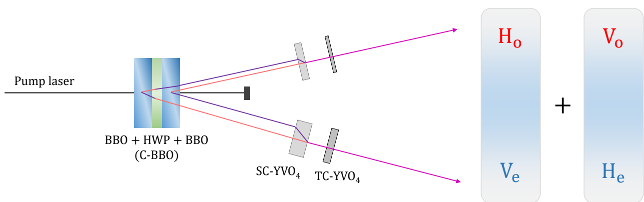

Fig. S1. Sandwich-like BBO+HWP+BBO geometry for generating entangled photons

2. NOISE ANALYSIS

An important experimental challenge in the resetting process is noise control. The noise of our setup as shown in main text is mainly from the higher order spontaneous parametric down-conversion (SPDC) process and the temporal distinguishability between different photon pairs.

Here, we primarily analyze the noise from the higher order SPDC process in our experiment, include circuit I and circuit II. In general, we define the p as the downconversion probability, M as the repetition frequency of the pulsed ultraviolet laser, η as the overall collection efficiency which combine with the link, coupling and detection efficiency. Therefore, we can obtain $p_1 = 0.0316$, $p_2 = 0.0356$, $p_3 = 0.0241$ based on coincidence count rate $C = p \cdot M \cdot \eta$.

During quantum resetting protocol, we assume the effect of high-order emission on target system qubit s and qubit i which entangled with the target system can be regard as white noise model with probability $(1-\nu)$, under this scenario, the single photon state and two photons entangled state after resetting can be described as a Werner-like state:

$$\begin{aligned} \rho_{reset} &= \nu\rho_{ideal} + (1-\nu)\cdot\frac{I^{\otimes 1}}{2}, \\ \rho_{reset,\ Ent} &= \nu\rho_{ideal,\ Ent} + (1-\nu)\cdot\frac{I^{\otimes 2}}{4}. \end{aligned} \tag{S1}$$

We consider the noisy contribution from our two circuits (see Fig. S2), for circuit I and circuit II,

$$\begin{aligned} \nu^{I} &= \frac{p^3}{p^3+4p^4}, \\ \nu^{II} &= \frac{p^3}{p^3+5p^4}. \end{aligned} \tag{S2}$$

According to the average downconversion probability $\overline{p} = 0.0304$, the theoretical fidelity of target system ρ_s of circuit I and circuit II can be calculated as

$$\begin{aligned} F^{I} &= \mathrm{Tr}(\rho^{I}_{ideal}\cdot\rho^{I}_{reset}) = 0.9458, \\ F^{II} &= \mathrm{Tr}(\rho^{II}_{ideal}\cdot\rho^{II}_{reset}) = 0.9340. \end{aligned} \tag{S3}$$

The theoretical fidelity of two-photon entangled state ρ_{si} of circuit I and circuit II can be calculated as

$$\begin{aligned} F^{I}_{Ent} &= \mathrm{Tr}(\rho^{I}_{ideal,\ Ent}\cdot\rho^{I}_{reset,\ Ent}) = 0.9187, \\ F^{II}_{Ent} &= \mathrm{Tr}(\rho^{II}_{ideal,\ Ent}\cdot\rho^{II}_{reset,\ Ent}) = 0.9010. \end{aligned} \tag{S4}$$

Moreover, the temporal distinguishability between different photon pairs, dark count of single photon detectors, white light noise in laboratory and the imperfections of optical elements (PBS, HWP, etc.) also may lead to the loss of fidelity. In the experiment, the average fidelity of single photon state after the resetting process for circuit I is $F = 0.870 \pm 0.012$ and $F = 0.874 \pm 0.016$, and the average fidelity for circuit II is $F = 0.869 \pm 0.021$. The entanglement fidelity for Circuit I is $F = 0.805 \pm 0.017$ and $F = 0.811 \pm 0.024$, and the entanglement fidelity for Circuit II is $F = 0.807 \pm 0.033$. Although the experimental value are smaller than the theoretical prediction, in our opinion they are rational and reliable.

3. SUMMARY OF EXPERIMENTAL RESULTS

For a clear illustration, we give the summary of our experimental results in Table. S1. In our experiment, we successfully reset the target system with different free Hamiltonians, different interactions, different initial states and different Evolution time. The all results prove that our setup could reset a really uncontrolled target system with acceptable fidelity.

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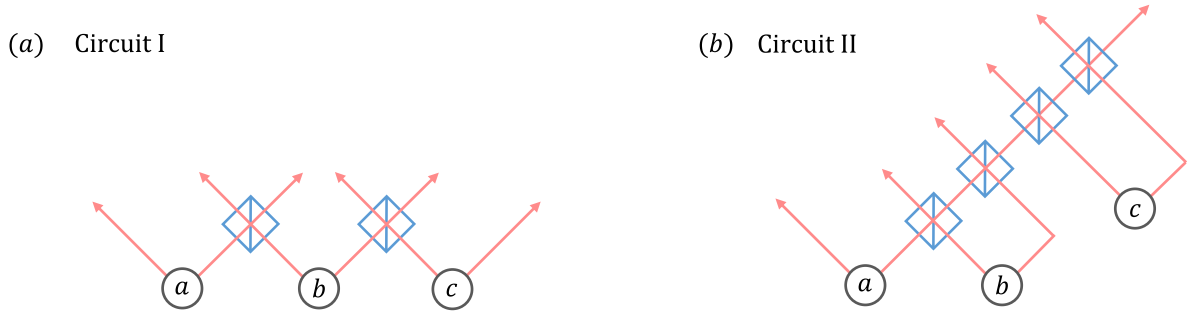

(a)

	a	b	c	
correct	1	1	1	p^3
noise	2	1	1	$4p^4$
	1	2	1	
	1	1	2	
	2	0	2	

(b)

	a	b	c	
correct	1	1	1	p^3
noise	2	1	1	$5p^4$
	1	2	1	
	1	1	2	
	2	0	2	
	2	2	0	

Fig. S2. **Noise contribution from double-pair emission.**

Free Hamiltonian	Interaction	Average fidelity with different Evolution time	Average fidelity with different initial states	Entanglement fidelity	CHSH value
$\sigma_z/2$	SWAP	0.858 ± 0.013	0.870 ± 0.012	0.805 ± 0.017	2.13 ± 0.05
$\sigma_y/2$	SWAP	0.870 ± 0.015	0.874 ± 0.016	0.811 ± 0.024	2.19 ± 0.05
$\sigma_z/2$	$(I \otimes H) \cdot G_{PBS} \cdot (X \otimes I)$	0.858 ± 0.024	0.869 ± 0.021	0.807 ± 0.033	2.26 ± 0.08

Table S1. **Summary of experimental results.**