Deterministic generation of two-photon number state

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Abstract: The two-photon number state generated in a usual two-photon polarization interferometer is always inductive: the coincidence detection which is necessary for identifying the state also destroy the the state. This fact is confirmed by comparing the single-photon detection rates to the coincidence-detection rate. We then experimentally demonstrate a novel quantum interferometer, in which a deterministic two-photon number state can be generated.

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In quantum interference experiments involving two-photon fields of spontaneous parametric down-conversion, if the single-photon detectors available today were truely 100% efficient and were able to resolve multi-photon exitations, the single-detection rate would be constant even if second-order quantum interference is present as the total number of photons remain constant. However, all commercially available single-photon detectors rely on the avalanche proccess of silicon or indium-garlium-arsenide photodetectors and, therefore, even at an ideal 100% efficiency, these detectors cannot resolve a single-photon incidence from a two-photon incidence.

Consider, the usual balanced two-photon interferometer demonstrated by Hong, Ou, and Mandel. $|1\rangle$ and $|1\rangle$ enters the beamsplitter through two different input ports and, at the two output ports, a coherent superposition of $|2,0\rangle$ and $|0,2\rangle$ appears as a result. Therefore, a "dip" in coincidence rate is expected when the interferometer is scanned. Similar "dip" is expected for a single-detector count rate as well, as these detectors would reveal $|2\rangle$ as just one count or one photon: less photons will be registered if quantum interference is present. This sort of experiment was first reported in Ref. [1] and we have confirmed this result recently using a different experimental setup [3].

Consider now a well-known EPR setup: there is a half-wave plate in one arm of the interferometer and polarizers are installed in front of the detectors [2]. In this case, if both polarizers are oriented at $45°/45°$ $(45°/-45°)$, a dip (peak) in the coincidence is observed when the interferometer is scanned. This coincidence detection clearly signals the detection ofl the two-photon number state $\frac{1}{\sqrt{2}}(|0,2\rangle + |2,0\rangle)$ and $|1,1\rangle$, respectively. The state preparation of this kind is, however, a posteriori one: the coincidence detection which is necessary to identify the state also destroy the state and the overal photon number state that reach the detector is different from the state identified by the coincidence detection.

To show this, we have performed a usual two-photon polarization interferometer experiment described above with a half-wave plate in one arm and polarizers in front of the detectors. When the polarizers angles are both 45°, minimum coincidence (or null coincidence in theory) is observed, which signals $\frac{1}{\sqrt{2}}(|0,2\rangle + |2,0\rangle)$. In this case, we expect to see a dip in the single-counting rate as well and we have observed this dip (not shown due to page limitation.) Now, when the polarizers are anti-parallel, the coincidence peak is observed. This means that $|1,1\rangle$ has been detected. However, if all the photons that reach the detectors have this state, a peak in the single-count rate should be observed. The experimental data show the opposite: a dip in the coincidence count was observed for this case as well.

Our analysis shows that this is due to the fact that, in fact, only a fraction of photons that reach the detectors have the state $|1,1\rangle$, which is then identified by the coincidence detection. It is because the polarizers, which are used for observing coincidence peak and dip, modifies the photon statistics after the polarizer due to quantum interference. Therefore, switching between the states $\frac{1}{\sqrt{2}}(|0,2\rangle + |2,0\rangle)$ and $|1,1\rangle$, is not possible using this kind of interferometer.

Is it then possible to deterministically choose the states $\frac{1}{\sqrt{2}}(|2,0\rangle + |0,2\rangle)$ and $|1,1\rangle$ without relying on inductive coincidence measurement? Here, we wish to report a novel interferometer which allows us to switch between the two states deterministically [3]. The outline of the experimental setup can be seen in Fig. 1. A 3 mm thick type-II BBO crystal is pumped by ultrafast pump pulse with central wavelength of

390 nm and pulse duration of approximately 120 fsec. A pair of SPDC photons with the center wavelength of 780 nm emerges from the crystal as two separate cones, one belonging to the e-ray (V-polarized) and the other belonging to the o-ray (H-polarized) of the crystal. Here we are interested in the intersections of the two light cones at which the polarization of the single-photons cannot be defined. These two spatial modes make up two input ports of an ordinary beamsplitter. F1 and F2 are 20 nm spectral filters. Note that no polarizers are used in this experiment. Qurartz plates QP1 and QP2 (600 μm thick) are used to add, by tilting QP2, a fine delay between the vertical and the horizontal components of the photon. Coincidence peak-dip transition can be made by tilting quartz plates QP2 and is observed as a function of τ [3].

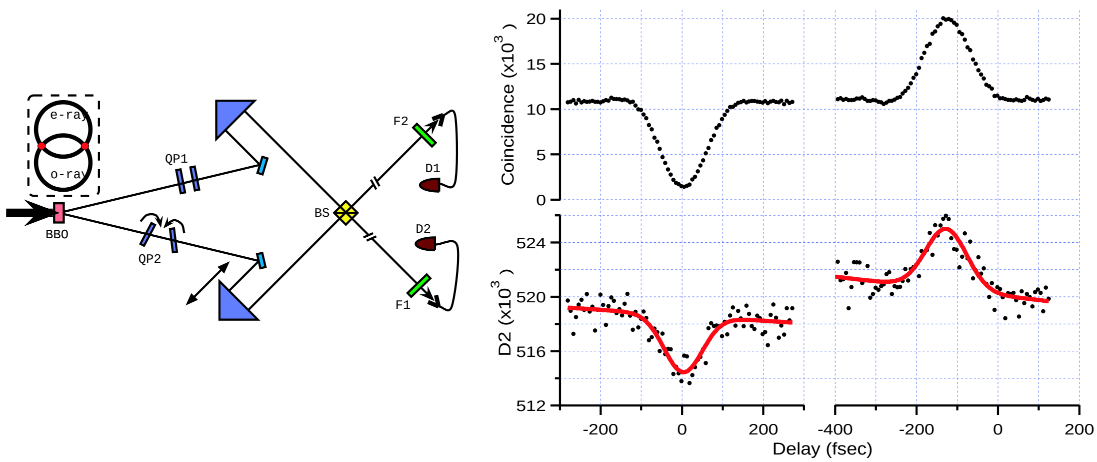

Fig. 1. Experimental setup and data. The peak (dip) in the coincidence count rate corresponds to the peak (dip) in the single detection rate.

The data shown in Fig. 1 clearly show that coincidence peak (dip) corresponds to the single-counting rate peak (dip). This clearly demonstrates that all the photons that reach the detectors are either $\frac{1}{\sqrt{2}}(|2,0\rangle + |0,2\rangle)$ or $|1,1\rangle$ and we are able to deterministically choose between the two states by adjusting QP2. This is intrinsically different from our earlier experiments in which only the photons that are identified post-selectively by coincidence circuit are in the desired state. Coincidence detecion is necessary and it only enables us to infer the state already detected. By exploiting the novel quantum interference effect described in this paper, we are able to prepare $|1,1\rangle$ and $\frac{1}{\sqrt{2}}(|2,0\rangle + |0,2\rangle)$ deterministically.

Differentiating these two cases were done by using the fact that single-photon detectors cannot distinguish $|1\rangle$ from $|2\rangle$. Insensitivity of single-photon detetors to multi-photon excitations, which is usually considered as a disadvantage, has shown to be, quite surprisingly, useful for differentiating two different two-photon number states. We will also discuss details of the single-cound rate probabilities on different input states in the talk.

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