Quantum interference with distinguishable photons through indistinguishable pathways

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Abstract: We report a two-photon interference experiment in which the individual photons have very different properties. The interference is observed even when no effort is made to mask or erase the distinguishing features before the photons are detected. The effect can only be understood as the interference between two two-photon amplitudes.

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Interference is observed when an event can occur by any of several alternate pathways. If an experiment is performed in which it is possible to determine which of the alternate pathways was actually taken, then the interference is lost. For two-photon interference, indistinguishable alternate pathways for a pair detection event lead to the interference. This principle has been clearly demonstrated by Hong, Ou, and Mandel with a pair of photons and a beamsplitter [1]. If the two photons have the same polarizations and overlap at the beamsplitter, then quantum interference between two pair detection pathways, both photons reflected (r-r) or transmitted (t-t) at the beamsplitter, occurs and a null is observed in the coincidence rate. If the photons are orthogonally polarized, however, and/or if they arrive at the beamsplitter at different times, then the quantum interference disappears, since the photons' polarizations and/or times of arrival make it possible, *in principle*, to distinguish between the two event pathways leading to a pair detection or coincidence count. In order to recover interference it is necessary to "erase" this distinguishing polarization/timing information with, for example, properly oriented polarizers and/or appropriate delay lines.

Here, we report a quantum interference experiment in which the detected photons retain their distinguishing information [2]. The photons approach the beamsplitter at different times and with different polarizations and spectra. They propagate directly to the detectors without passing through compensating/masking elements. Nonetheless, quantum interference is observed in the joint detection rate. We explain this counter-intuitive result as the interference between two-photon wavepackets.

An outline of the experimental setup is shown in Fig. 1. A 3-mm thick type-II BBO crystal is pumped by an ultrafast laser and attention is restricted to the intersections of the cones made by the e-ray and the o-ray exiting the crystal. These two spatial modes are directed by mirrors to the two input ports of an ordinary non-polarizing beamsplitter. The output ports are monitored by single-photon counting detectors. Broadband (20 nm) spectral filters preceding the detectors help to reduce background counts. A set of quartz rods and quartz plates inserted in each arm of the interferometer introduce a group delay of roughly 668 fsec between the V- and H-polarized photons. It is important to note that the photon pair in this experiment is *not* polarization entangled. Note also that unlike usual two-photon state experiments, polarizers are not used in this experiment.

Quantum interference is observed as the delay between the two arms is adjusted. This can be seen as the peak and dip shown in Fig. 1. The two different data sets correspond to two different phase settings, i.e., two different orientations of the quartz plates QP2. Tilting the quartz plates changes not only the relative delay between the orthogonally polarized modes, but also the total path length for the two polarizations. The latter is reflected as an offset between the peak and dip.

We note here that the photons approach the beamsplitter with very different properties: they are orthogonally polarized, have different spectra, and approach at different times. It is somewhat surprising, then, that high visibility interference is observed even though the photons' properties are not altered before the detection process, i.e., no elements are introduced after the beamsplitter to mask the distinguishing information.

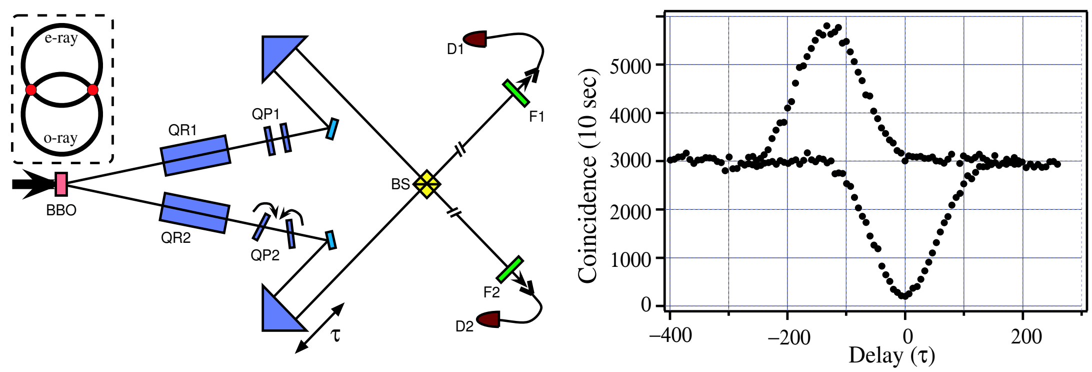

Fig. 1. Experimental setup and data. Note that no polarizers are used before detectors. The peak-dip visibillity is about 93%.

This counterintuitive result can only be understood as the interference between two two-photon or biphoton wavepackets [2]: interference is observed only if the two pathways (r-r and t-t) leading to a particular coincidence event are indistinguishable. Typically, this is possible only if the photons themselves are indistinguishable before being detected. That is not the case here, since the detected individual photons always have orthogonal polarizations and arrive at different times. The pathway indistinguishability arises, instead, from the two different ways that a particular photon can reach the *beamsplitter*. Recall that each input path may have a photon of either polarization. Consequently, the detection of a horizontally polarized photon at detector D1, for example, does not make it possible to determine whether that photon was reflected or transmitted at the beamsplitter. Thus, the interference effect does not depend on the presence of polarizers before the detectors. This prediction has been confirmed experimentally: with a polarizer in front of each detector, we have observed that the interference visibility is indeed independent on the angles of the polarizers [2].

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References

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