Quantum interference effects can be observed in the rate of single-photon detection

Kevin J. Resch, J. S. Lundeen and A. M. Steinberg
Department of Physics, University of Toronto, Toronto, CANADA

1) Motivation
- Avalanche Photo-Diodes (APDs) are integral to quantum-information experiments, but their response to single photons and photon pairs is not well-understood.
- We show that the “standard model” for photon detection is inadequate for high-efficiency APDs (i.e., Detection rate is not just proportional to \( \alpha \langle a | a \rangle \)).
- We disprove the common wisdom and show that nonclassical effects can be seen in the singles rate of a single-photon detector.

2) Downconversion
- A high-frequency pump photon (400nm) can be spontaneously converted into 2 lower-frequency photons (800nm) in a material with a nonzero \( \chi^{(2)} \).
- Energy and momentum conservation are satisfied in the process. These constraints lead to entanglement in energy, momentum, time-of-emission, polarization, and photon number.

3) Hong-Ou-Mandel Interferometer

4) Typical HOM Output
- Until this work, the nonclassical HOM effect has been visible only in coincidence rates, and has been constrained by featureless singles rates.
- This is because the interference does not change the intensity of the light, but changes the number of photon pairs at the expense of single photons.

5) Single Detector Photon Counting Rate using the Nonlinear Detection Model

6) Nonlinear model for APDs
- 100% efficient APDs, operating in Geiger mode, cannot tell the difference between 1 photon and 2 photons within the dead time. This means that single-photon detectors do not really measure intensity, but have a significant nonlinear response for even a couple of photons.
- Real detectors, however, are not 100% efficient and we use a simple model to describe their behaviour:

7) Experimental Setup
- Polarization-based HOM interferometer

8) Coincidence and Singles Rate Vs. Relative Delay

9) Singles Dip Visibility Vs. Collection Efficiency

10) Summary
- New efficiency dependent quantum effect
- The momentum and energy relaxation timescales in Si are ~50-100fs. This type of technique may allow measurements of these times as well as probe issues of decoherence.
- Future work will include more precise tests of the model by improved background measurement techniques.

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