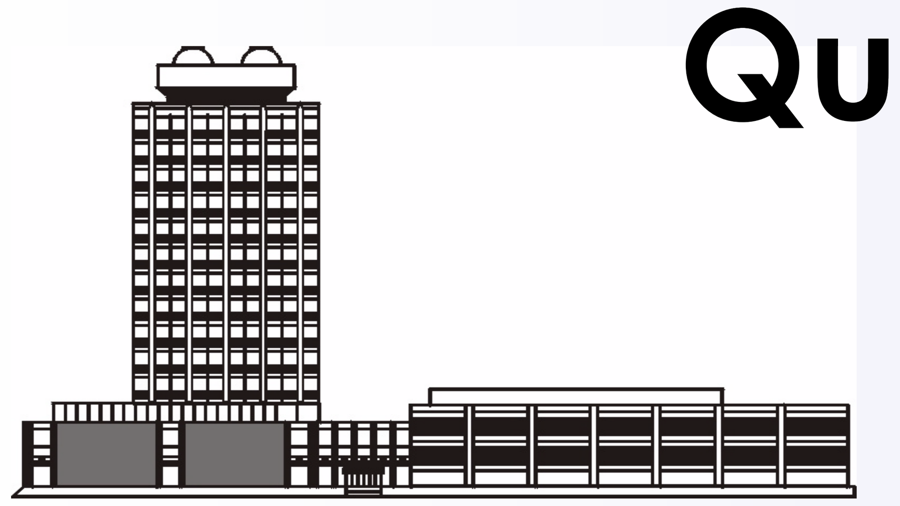

Quantum interference effects can be observed in the rate of single-photon detection

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VELUT ARBOR ÆVO

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 (ie. Detection rate is not just proportional to $\langle a^\dagger a\rangle$)**
- **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 $c^{(2)}$**

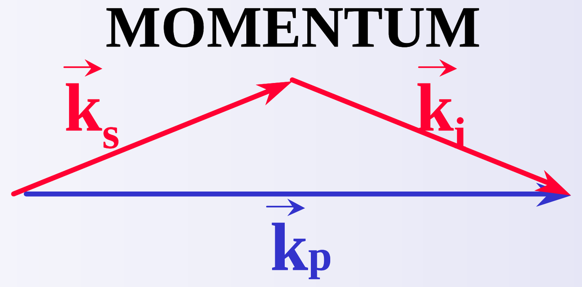
$$w_p \longrightarrow w_s + w_i$$

- **Energy and momentum conservation are satisfied in the process. These constraints lead to *entanglement* in energy, momentum, time-of-emission, polarization, and photon number**

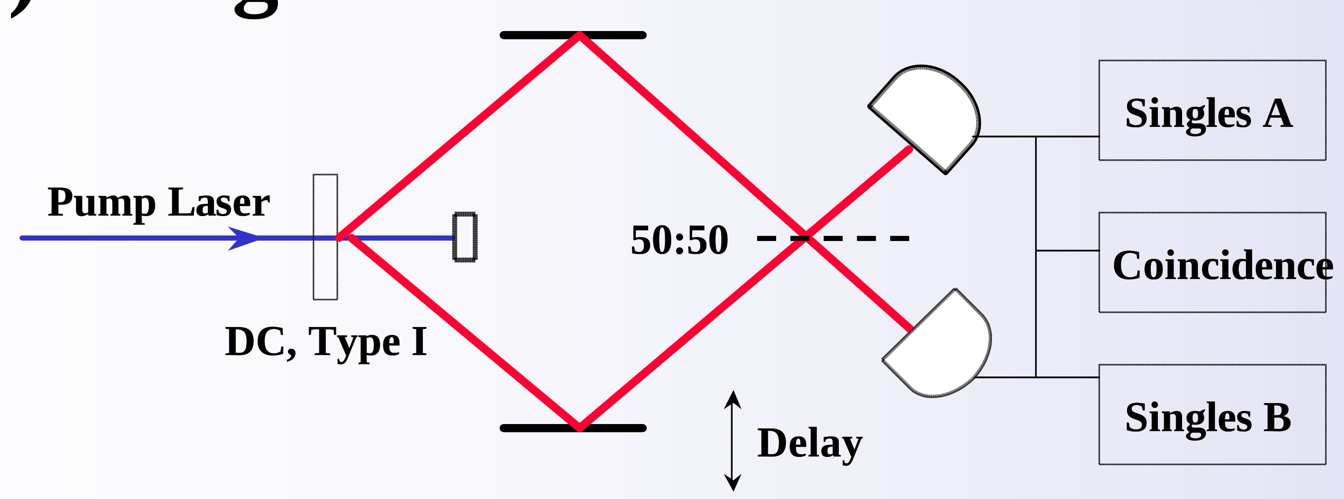
ENERGY

$$w_p = w_s + w_i$$

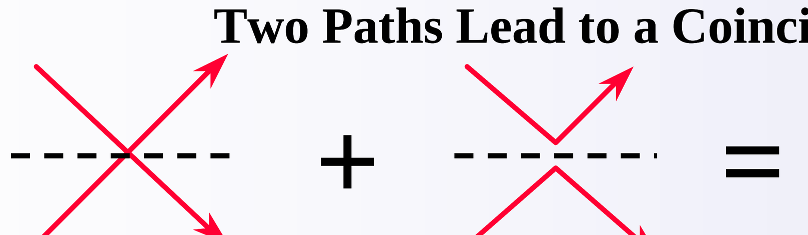
MOMENTUM



3) Hong-Ou-Mandel Interferometer



Two Paths Lead to a Coincidence Event

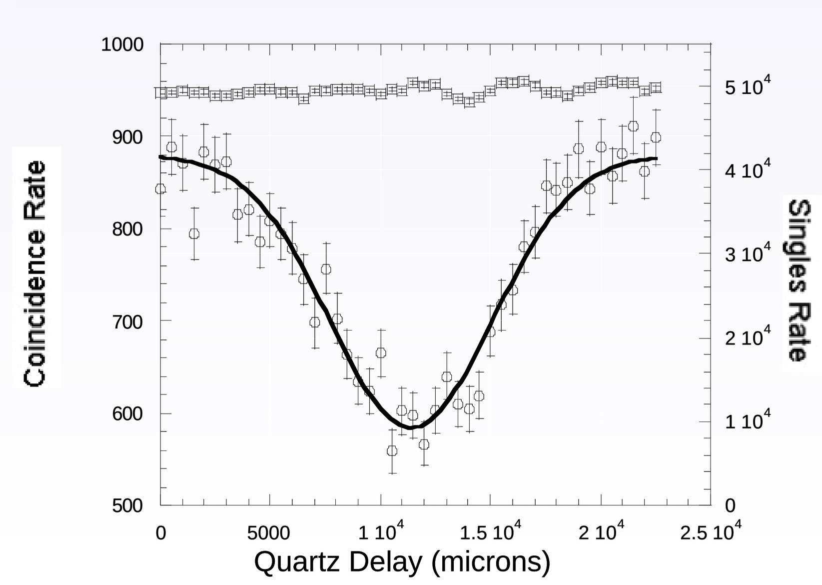


0, **if the paths are balanced**

1/2, **if the paths are unbalanced**

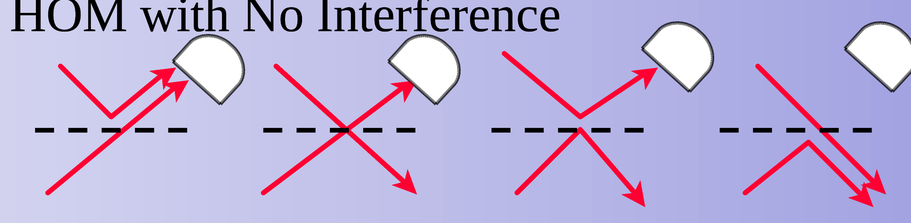
4) Typical HOM Output

- **Until this work, the nonclassical HOM effect has been visible only in coincidence rates, and has been contrasted 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

HOM with No Interference

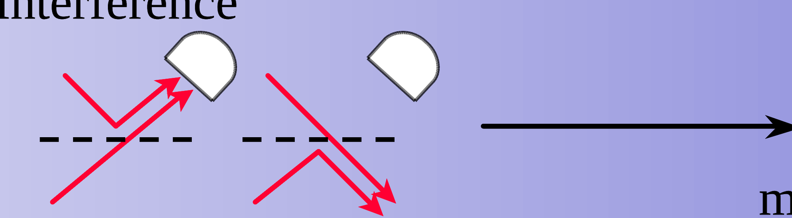


$\langle n\rangle = \langle a^\dagger a\rangle = 1$

Nonlinear model prediction:

$\eta - \eta^2/4$

HOM with Interference



$\langle a^\dagger a\rangle = 1$

Nonlinear model prediction:

$\eta - \eta^2/2$

Predicted Singles Dip Visibility = h/(4-h)

6) Nonlinear model for APDs

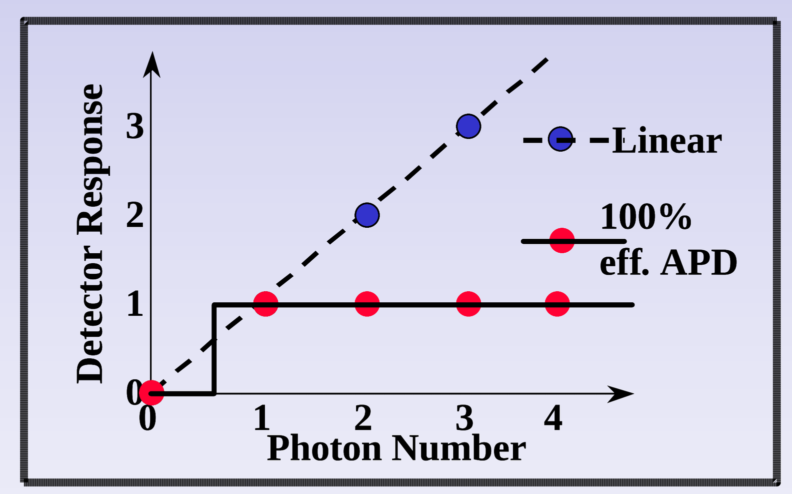
- **100% efficient APDs, operating in Geiger mode, cannot tell the difference between 1 photon and 2 photons within the dead time. This means that single-photon detectors do not really measure intensity, but have a significant nonlinear response for even a couple of photons.**
  (ie 2´ P(1 photons) ¹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

$P_{1photon}$: h

$P_{2photons}$: h+(1-h)h

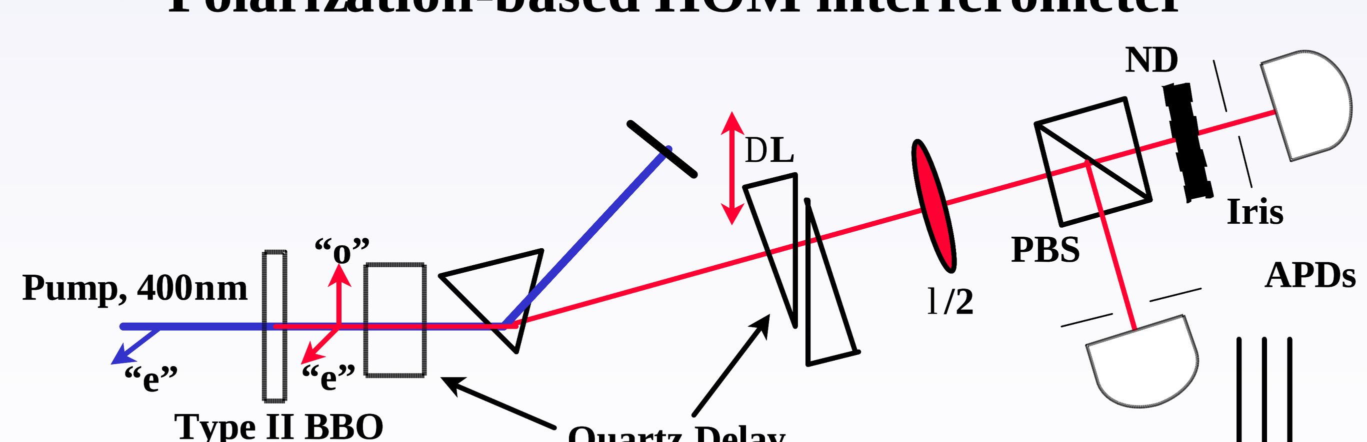
=2h-h²

h is the collection efficiency



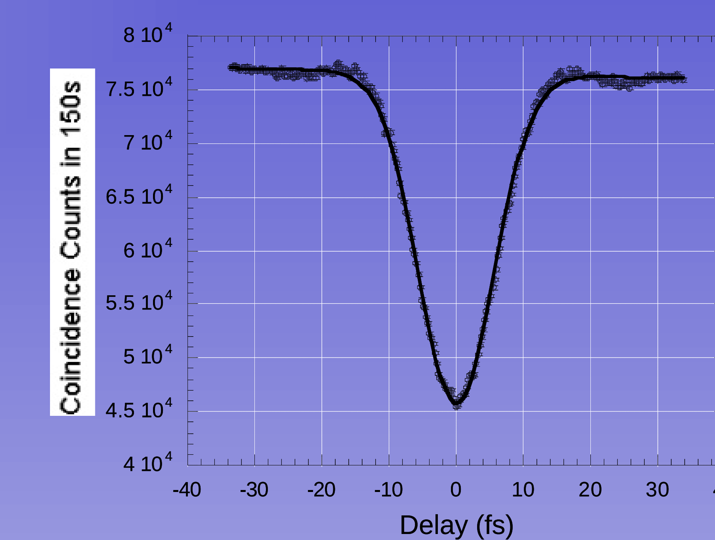
7) Experimental Setup

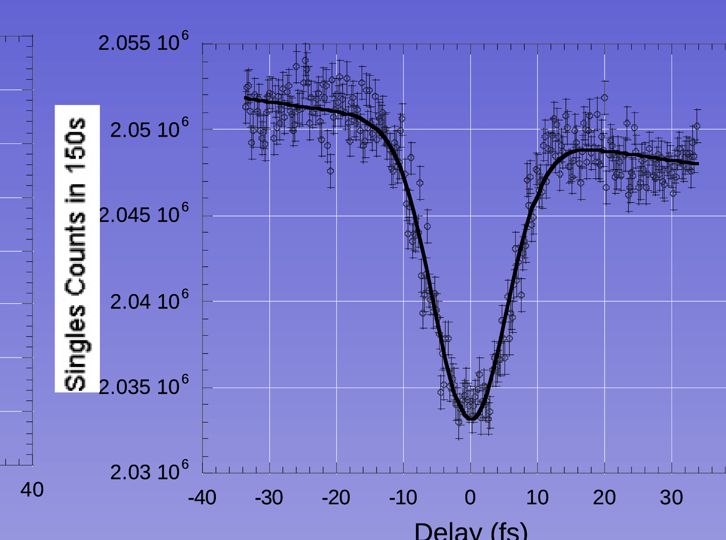
- **Polarization-based HOM interferometer**



G. Di Giuseppe et al., PRA *56*, R21 (1997)

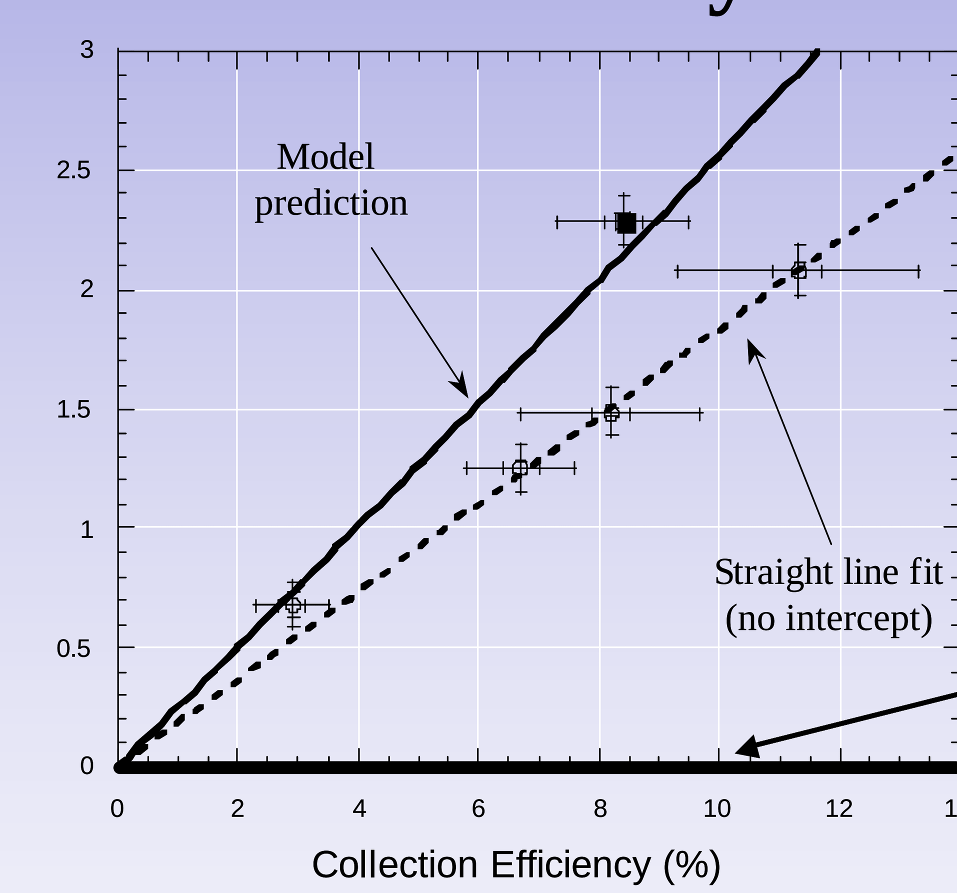
8) Coincidence and Singles Rate Vs. Relative Delay





Visibility = 39.39% Visibility = 0.82%

9) Singles Dip Visibility Vs. Collection Efficiency



The square-law detector has no dip in singles

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.**

Funding is gratefully acknowledged from Photonics Research Ontario, NSERC and the Walter C. Sumner Foundation

K. J. Resch, J.S. Lundeen, and A.M. Steinberg, *Physical Review A*, 63, 020102(R) (2001).