Hong-Ou-Mandel Experiment Review

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Measurement of Subpicosecond Time Intervals between Two Photons by Interference

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Outline

Motivation

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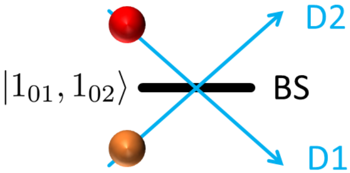
- This experiment allows measurement of subpicosecond time intervals between two photons
- The results of this experiment can not be interpreted using a classical description of radiation
- This technique is useful for single photon and distinguishably measure

Two Photon Interference

Two photons in a beamsplitter



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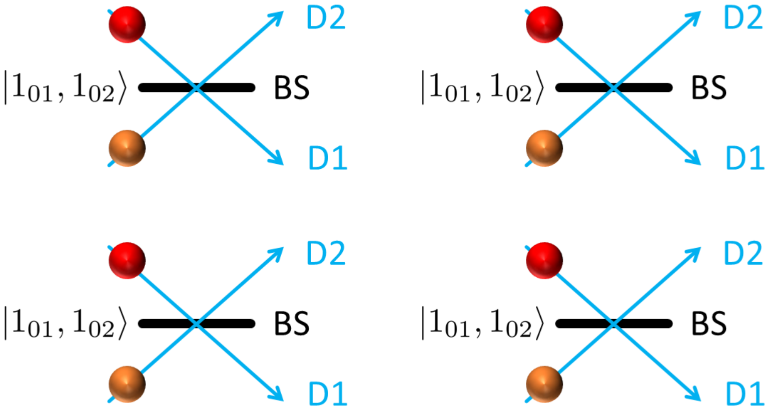

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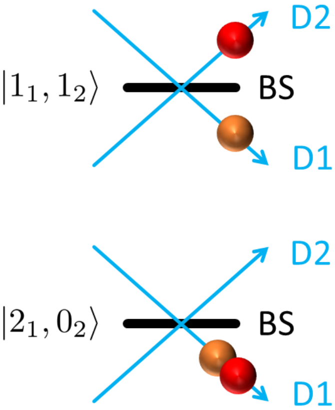

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- For $\color{red}{T = R = \frac{1}{2}}$, destructive interference results no coincidences detection

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$\phi(\omega_1, \omega_2)$ is some weight function peaked at $\omega_1 = \omega_2 = \frac{1}{2}\omega_0$

Joint Probability of Detection

- The joint probability of detection for both $\mathrm{D1}$ and $\mathrm{D2}$ at times t, $t+\tau$

$$P_{12}\left(\tau\right)=\left\langle \hat{E}_{1}^{\left(-\right)}\left(t\right)\hat{E}_{2}^{\left(-\right)}\left(t+\tau\right)\hat{E}_{2}^{\left(+\right)}\left(t+\tau\right)\hat{E}_{1}^{\left(+\right)}\left(t\right)\right\rangle$$

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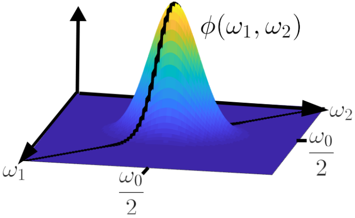

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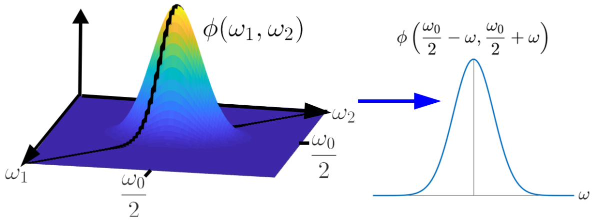

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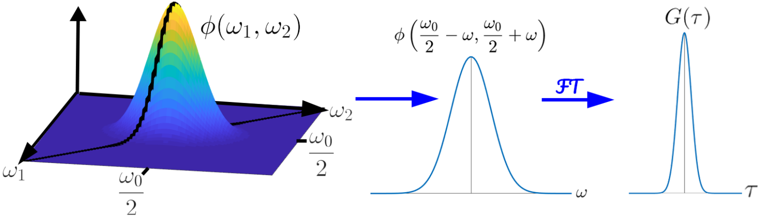

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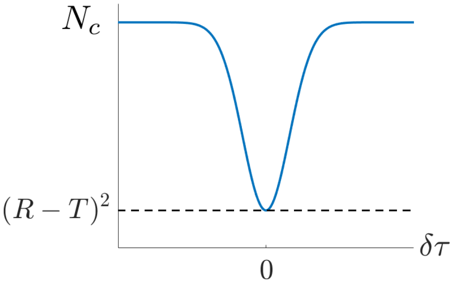

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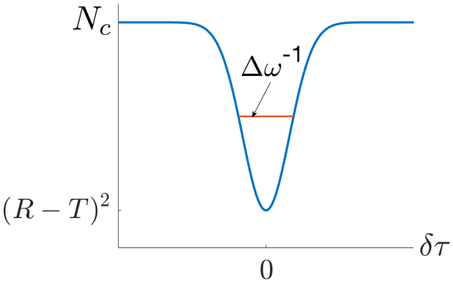

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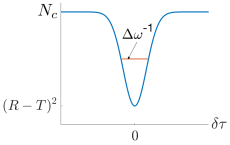
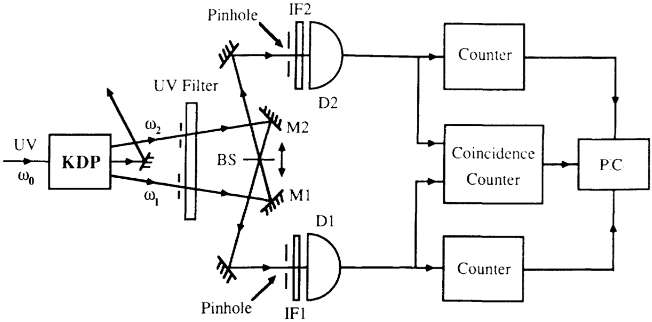


The vanishing of the coincidence rate is purely quantum

Experimental Setup



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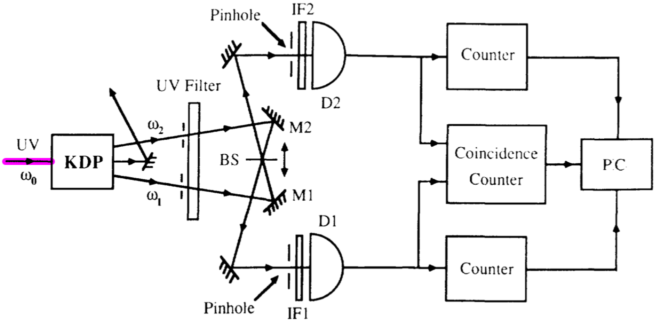

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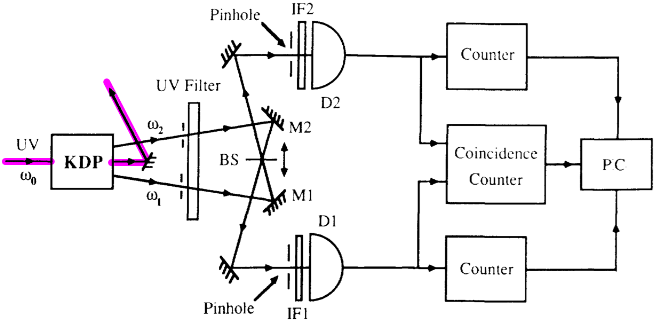

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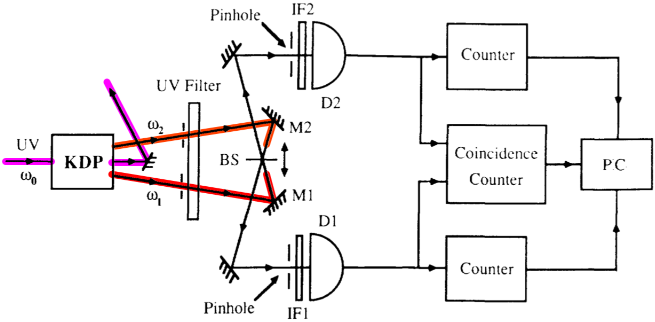

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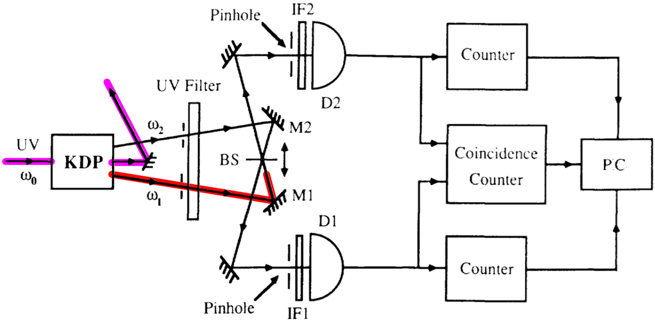

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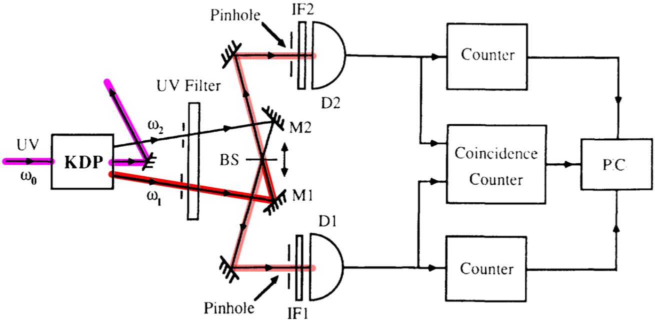

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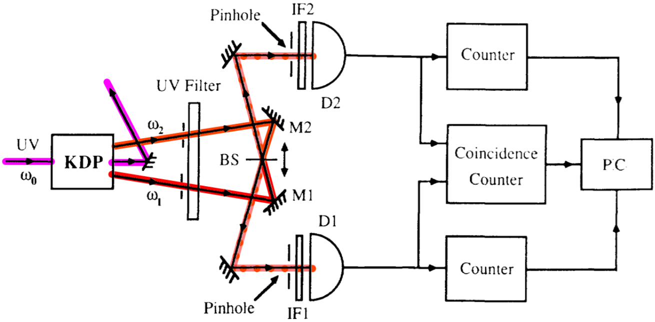

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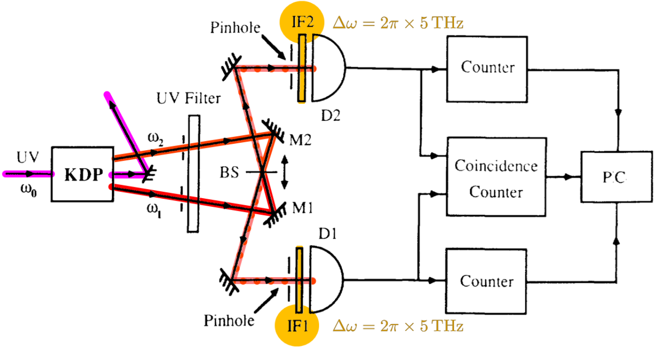

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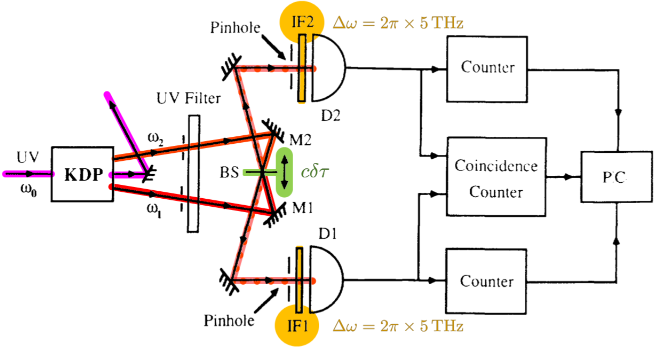

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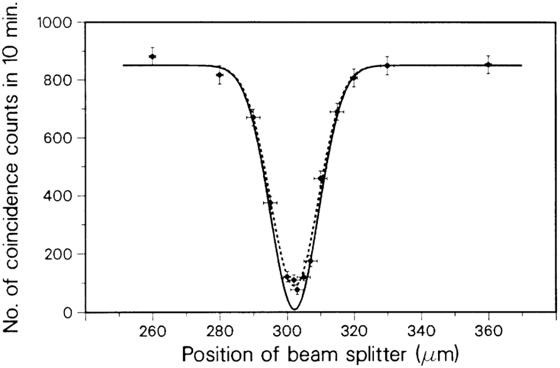
Results



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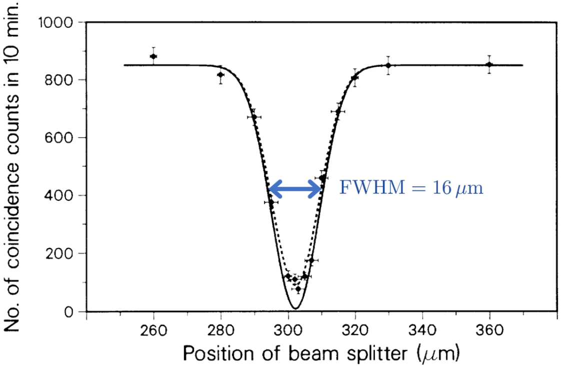

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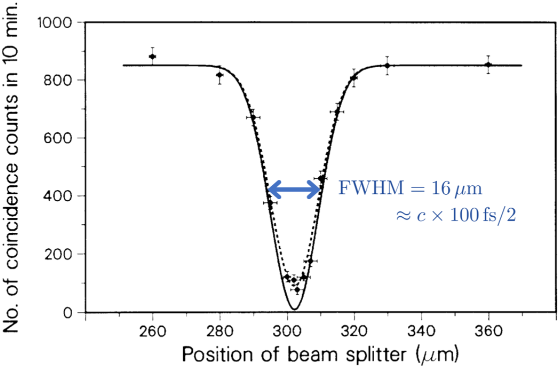

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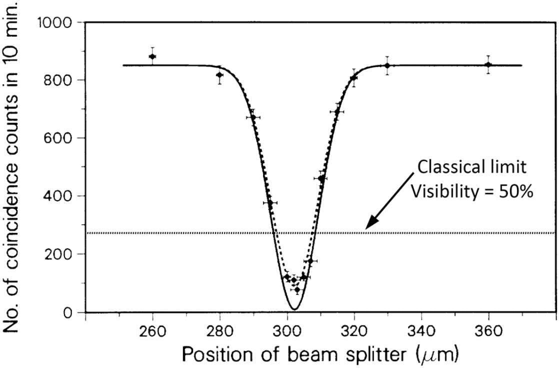

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Classical vs. Quantum Comparison

For $\tau \to \infty$

quantum and classical

$$P_{12}\left(\tau \to \infty\right) \to 1$$

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For $\tau \to 0$

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$$P_{12}\left(0\right) \to 0$$

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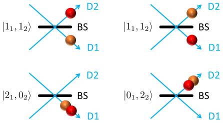

- The classical joint probability $P_{12}^{\mathrm{C}}(\tau) = \left\langle \mathcal{E}_1^{(-)}(t)\,\mathcal{E}_2^{(-)}(t+\tau)\,\mathcal{E}_2^{(+)}(t+\tau)\,\mathcal{E}_1^{(+)}(t) \right\rangle$ was calculated by Ghosh & Mandel in "*Observation of nonclassical effects in the interference of two photons*", PRL 59.17 (1987),

$$P_{12}^{\mathrm{C}}(\tau) = 1 - \frac{2\left\langle |e_1|^2 |e_2|^2 \right\rangle}{\left\langle \left(|e_1|^2 + |e_2|^2 \right)^2 \right\rangle} \cos(\Delta\omega\tau)$$

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$$\begin{aligned} 4\left\langle |e_1|^2 |e_2|^2 \right\rangle &\leq \left\langle |e_1|^4 \right\rangle + 2\left\langle |e_1|^2 |e_2|^2 \right\rangle + \left\langle |e_2|^4 \right\rangle \\ 0 &\leq \left\langle |e_1|^4 - 2|e_1|^2 |e_2|^2 + |e_2|^4 \right\rangle \\ 0 &\leq \left\langle \left(|e_1|^2 - |e_2|^2\right)^2 \right\rangle \end{aligned}$$

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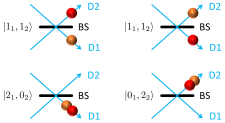

- The observed fourth-order destructive interference is a quantum effect

Conclusions

- Subpicosecond time intervals between two photons were measured by a fourth-order interference technique

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- This method does not require that path differences be kept constant to within a fraction of a wavelength – phase is irrelevant
- The results of this experiment can not be interpreted using a classical description of radiation

Thanks for your attention! Any questions?

Bonus - a citation from *The Principles of Quantum Mechanics* by P.A.M. Dirac (1939) p.9

"Each *Photon* then interferes only with itself. Interference between two different photons never occurs."

Hope you slept comfortably!