Probing the Susceptibility of a Nonlinear Material via Two-Photon Interference

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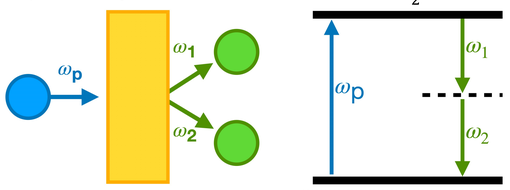
Abstract

We modeled the Hong-Ou-Mandel effect for a two-photon state modified by a nonlinear sample interaction and studied how the interaction with a sample material affected the output coincidence signal. We found expressions for coincidence detection rates as a function of time delay between Hong-Ou-Mandel input paths. We present plots of these coincidence detection for when the biphoton coherence frequency bandwidth is greater than the nonlinear sample's resonance linewidth.

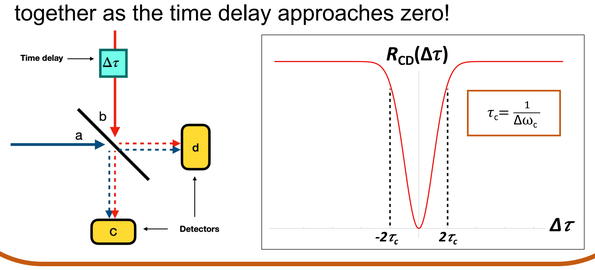
Parametric Down- Conversion

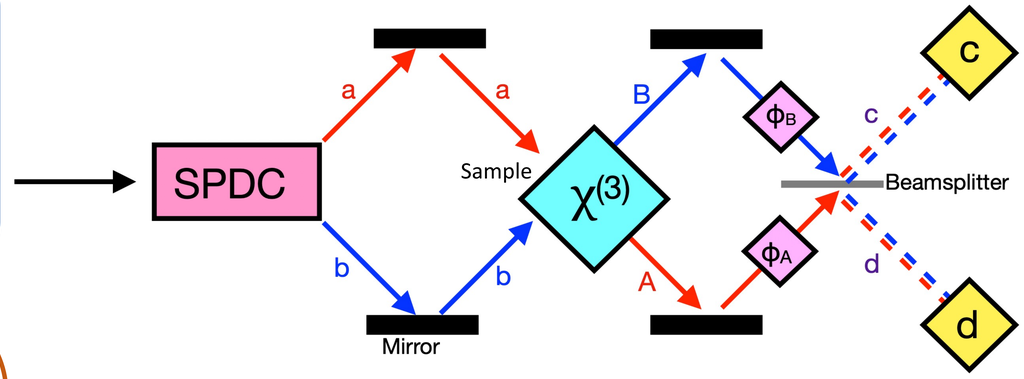
- Spontaneous parametric down-conversion (SPDC) is a process by which one photon creates an entangled photon pair.
- This photon pair will share a joint wavefunction, known as the joint spectral amplitude (JSA) $\Psi_{JSA}(\omega_1,\omega_2)$
- The specific frequencies of photons ω_1 and ω_2 are unknown, but they will add up to the initial frequency ω_p approximated with a gaussian probability distribution centered about $\frac{\omega_p}{2}$.



The Hong-Ou-Mandel Effect

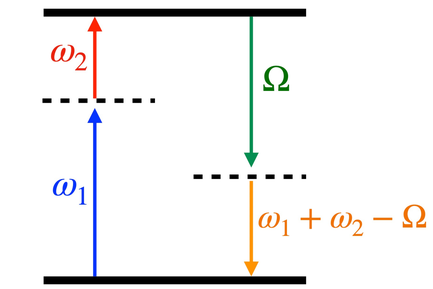
- Two photons on two different paths interact with a time delay before interacting with a beamsplitter.
- The coincidence rate R_{CD} is a measure of how often detectors c and d make a simultaneous photon detection, and it is a function of a time delay τ.
- Note the characteristic dip in coincidence detection rates $R_{CD}(\tau)$, meaning that the photons exit the same port together as the time delay approaches zero!





Our proposed interferometry scheme, in which the photons interact with a sample before interacting with the beamsplitter.

Sample Interaction

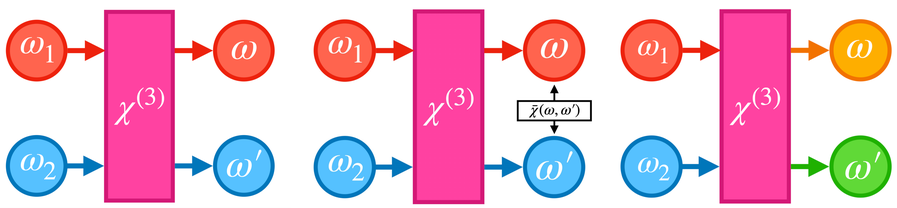


$\Psi_{JSA}(\omega_1, \omega_2) \rightarrow \chi_{eff}(\omega_1, \omega_2)\Psi_{JSA}(\omega_1, \omega_2)$

- A material's polarization response is characterized by its susceptibility χ_{eff}.
- First order (linear) responses are proportional to the electric field, while third order (nonlinear) responses are proportional to the electric field cubed.
- A third order nonlinear response depends on three different frequency components.
- We are studying the case in which two photons are absorbed and two are emitted, with no frequency changes.

Two-photon input state: $|\Psi_{TOT}\rangle = \mathrm{Cos}\left(\frac{\alpha}{2}\right)|\Psi_L\rangle + \mathrm{Sin}\left(\frac{\alpha}{2}\right)|\Psi_{NL}\rangle$

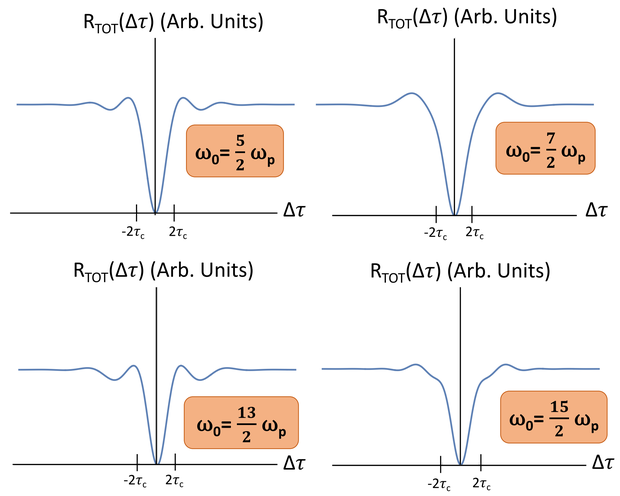
Coincidence rate: $|A_{TOT}|^2 = |A_L|^2 + |A_{NL}|^2 + 2\mathrm{Re}\{A_L^* A_{NL}\}$



Modeling of three different two-photon, nonlinear interactions with a sample. In order: linear interaction, pairwise degenerate four-wave-mixing, and four-wave-mixing.

Coincidence Rates vs. Time Delay

$\Delta\omega = \frac{1}{4}\Delta\omega_c$



Δτ – time delay
Δω – nonlinear sample's resonance linewidth
$\Delta\omega_c$ – biphoton coherence frequency bandwidth
ω_p – pump frequency
ω_0 – resonance frequency
α – interaction strength parameter

Acknowledgments

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Future Work

We have yet to model the coincidence rate relation in the case where non-degenerate four-wave-mixing is well phase-matched. Future work could extend our results to account for this. Furthermore, future work could also entail extracting information about the nonlinear susceptibility from the coincidence detection signal via Fourier analysis.