Generation of spectrally uncorrelated photon pairs by parametric down conversion

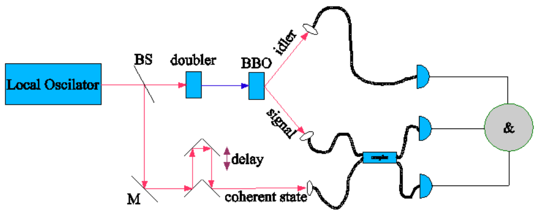
Piotr Kolenderski,[1] Wojciech Wasilewski,[2] Konrad Banaszek[1]

[1]Institute of Physics Nicolaus Copernicus University, ul. Grudziadzka 5, 87-100 Torun, Poland
[2]Physics Department, Warsaw University ,ul. Hoza 69, 00-681 Warsaw , Poland

Motivation

Quantum communication protocols and the operation of quantum logic gates based on linear optical elements depend on the purity of photon states. Therefore, it is very important from the practical and fundamental points of view to have a source of pure single photon wave packets. Following the recent theoretical proposals[1], in order to achieve this goal we consider the conditions which must be fulfilled by a nonlinear BBO crystal to produce photons with uncorrelated spectra. The degree of correlations can be characterised by measuring interference visibility in a Hong-Ou-Mandel interferometer.

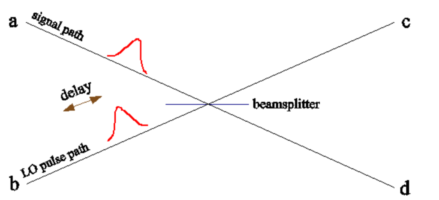
Experimental Setup



A femtosecond pulse from a Ti:saphire oscillator is split on a beamsplitter BS. Blue beam from the doubler pumps BBO crystal which produces polarization-entangled ,spectrally-uncorrelated photon pairs by parametric down conversion. The signal and a weak coherent state from the attenuated LO beam interfere in the coupler. The idler photon is used as a trigger.

Hong-Ou-Mandel Interferometer

In our case the beamsplitter is 50/50 so the probability of detecting one photon at each output port is zero, assuming perfect indistinguishability.. If we make a small enough we can neglect terms proportional to α^2 and higher, thus recovering the standard effect of two-photon interference



$$|1\rangle_a|\alpha\rangle_b \rightarrow \exp[-|\alpha|^2/2]\{r|1\rangle_c|0\rangle_d + t|0\rangle_c|1\rangle_d + \alpha rt\sqrt{2}(|2\rangle_c|0\rangle_d + |0\rangle_c|2\rangle_d) + O(\alpha^2)\}$$

Method

Our goal is to find such parameters for type I BBO crystal (length and cut angle) and laser pulse (beam waist and pulse spectral width) to have spectrally uncorrelated photon pairs in optical fibers at 780nm. The biphoton wave function in the fibers reads:

$$|\Psi\rangle \approx |0\rangle + \varepsilon\int d\omega_s d\omega_i \Phi(\omega_s,\omega_i) a_s^+ a_i^+ |0\rangle$$

$$\Phi(\omega_s,\omega_i) = \int d\mathbf{k}_s^\perp d\mathbf{k}_i^\perp \exp(-\tfrac{1}{2}\Delta\omega^2 t_p^2 - \tfrac{1}{4}w_p^2\Delta k_\perp^2)\,\mathrm{sinc}(\tfrac{1}{2}\Delta k_z L)\,u_s^*(\mathbf{k}_s^\perp)u_s^*(\mathbf{k}_s^\perp)$$

where Ω_p is pump central frequency ,t_p pulse duration , w_p pump beam waist , L length of the crystal ,Θ crystal cut angle and

$$\Delta k_z = k_z^p(\omega_s+\omega_i, \mathbf{k}_s^\perp + \mathbf{k}_i^\perp, \Theta) - k_z^s(\omega_s, \mathbf{k}_s^\perp) - k_z^i(\omega_i, \mathbf{k}_i^\perp)$$

$$\Delta k_\perp = |\mathbf{k}_s^\perp + \mathbf{k}_i^\perp|$$

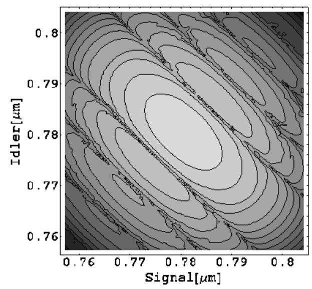
$$\Delta\omega = \Omega_p - \omega_s - \omega_i$$

We collect photons into single mode optical fibers with $\boldsymbol{u}_s(\boldsymbol{k})$ and $\boldsymbol{u}_i(\boldsymbol{k})$ defined as the fiber modes LP_{01}.The approximations made here do not go beyond first order perturbation analysis. The gaussian approximation[2] of sinc function has not been done and dispersion relations are kept in the exact form in the numerical calculations. The length of the crystal is chosen in such a way that all pump frequencies are converted. In order to have spectrally uncorrelated photon pairs we numerically look for such parameters which make $\Phi(\omega_s,\omega_i)$ function factorizable. In general, the Schmidt decomposition for the function reads:

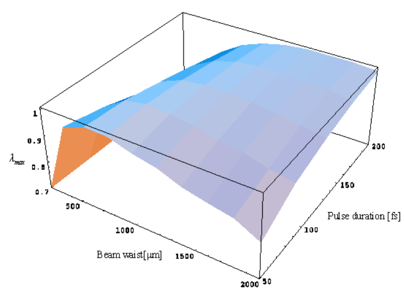
$$\Phi(\omega_s,\omega_i) = \sum_n \sqrt{\lambda_n}\psi_n(\omega_s)\varphi_n(\omega_i)$$

By discretizing the parameters of Φ on the domain around half the pump frequency[3] and performing singular value decomposition we are able to obtain numerical approximation of $\{\lambda_n\}$ coefficients. The value of λ_1 equal unity means that after idler photon detection the signal photon is in a pure spectral mode which interferes with the LO attenuated coherent state.

Results



Frequency map of $Log|\Phi(\omega_s,\omega_i)|$. The brighter colour the higher value. We integrate accurate expression so there are local extremes caused by sinc function.



The map of the highest value of $\{\lambda_n\}$ coefficients for beam waist and pulse duration for L=1mm, Θ=31°, Ω_p=390nm ,w_p=w. The highest result is *0.999499 for t_p=120fs and w=1mm.*

Additional information

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