

The multimode four-photon Hong-Ou-Mandel interference

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Abstract

The conventional two-photon Hong-Ou-Mandel (HOM) interference plays an important role in order to testify the degree of indistinguishability of photons. Recently, multiphoton quantum interference is in focus of research since it is a crucial ingredient of boson samplings and a promising tool for a high dimensional entanglement [1]. In this research we investigate both theoretically and experimentally the properties of the four-photon HOM interference. Photons are created via type-II parametric down-conversion (PDC) source. We show how the number of Schmidt modes influences the interference pattern and coherent length of the photon, and leads to a switching between bunching and antibunching effects.

In this work we consider four photons generated in the type-II PDC process in a KTP waveguide. Dispersion properties of KTP allow to engineer a single Schmidt mode source as well as a multimode source by changing a pulse duration or by chirping the pump pulse. The type-II PDC source creates two photon pairs having two different polarization which were splitted up in two arms of an interferometer by a polarization beam splitter. By making them have the same polarization, we let them interfere on a beam splitter and finally they are detected.

The joint spectral amplitude (JSA) which describes mathematically the PDC process is:

$$F(\omega_s, \omega_i) = e^{-\frac{(\omega_s + \omega_i - \omega_p)^2}{2\Omega^2}} \operatorname{sinc}\left(\frac{L}{2}\Delta k\right) e^{i\frac{L}{2}\Delta k} e^{iD(\omega_s + \omega_i - \omega_p)^2}, \quad (1)$$

where Δk is the phase mismatch determined the momentum conservation of the process, L and Ω are respectively the length of the crystal and the pump spectral bandwidth, D is a constant which determines an additional quadratic spectral phase of the chirped pulse.

In Figure 1 the probability to detect two photons in both arms of the interferometer (P_{22} probability) is presented. The theoretical simulations (red curve) and the experimental results (black dots) are coincide and show that with increasing the number of Schmidt modes, namely enhancing drastically the pulse duration of the pump beam, an antibunching peak appears. Furthermore, the relation between the number of Schmidt modes and the antibunching behavior is confirmed by using of the chirped pump pulse. By fixing the spectral width and varying the spectral quadratic phase (chirp) of the pump laser, the PDC state with the chirped pulse is characterized by the same signal-idler spectrum as in the single-mode regime but the completely different mode structure.

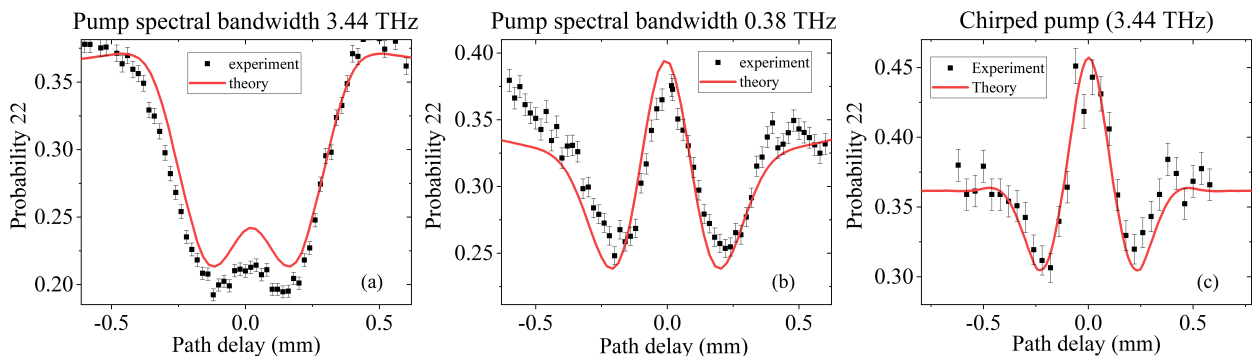


Figure 1: Comparison between theory and experiment of the P_{22} probability using different pump.

In conclusion, it was shown that it is possible to control the interference pattern, coherent length of photons and bunching properties of the four-photon HOM interference by modifying the number of Schmidt modes. The number of modes can be modified by different ways: by varying the pulse duration of the pump or by using a chirped pump pulse.

- [1] Y.-S. Ra, M.C. Tichy, H.-T. Lim, O. Kwon, F. Mintert, A. Buchleitner, Y.-H. Kim, *Nonmonotonic quantum-to-classical transition in multiparticle interference*, Proceedings of the National Academy of Sciences, **110**,1227-1231 (2013)