Physical Sciences

Quantum walks of spatially extended path-entangled photons and dynamics of non-classical light in Glauber Fock photonic lattices

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Abstract

In this work we study the dynamics of squeezed states of light in Glauber-Fock photonic lattices. The behaviour of squeezing is investigated for different transverse positions of the squeezed state input. Our results show the revival and transfer of squeezing across the waveguide array. We also analyse the quantum walk of correlated and anti-correlated path-entangled photon states by studying the evolution of the coincidence rate at the output of the waveguide. We consider both the cases of small and large size lattice. In the case of a large lattice, we found that because of the quantum interference effect the dynamics of a separable state is significantly different in comparison to the path-entangled input states. For the case of small size lattice, we show the revival of the path-entangled input state.

Quantum walk of spatially extended path-entangled photons and dynamics of nonclassical light in Glauber Fock photonic lattices

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Introduction

• We study the quantum walk of non-classical light in a semi-infinite array of coupled waveguides having a square root law distribution for the coupling constants [1, 2].

• The quantum correlations for the separable and path entangled two photon initial states in these arrays uniquely depend on the input position. This feature is not encountered in the uniform arrays [3].

• We study the behaviour of squeezed state of light and the spatially extended state of light.

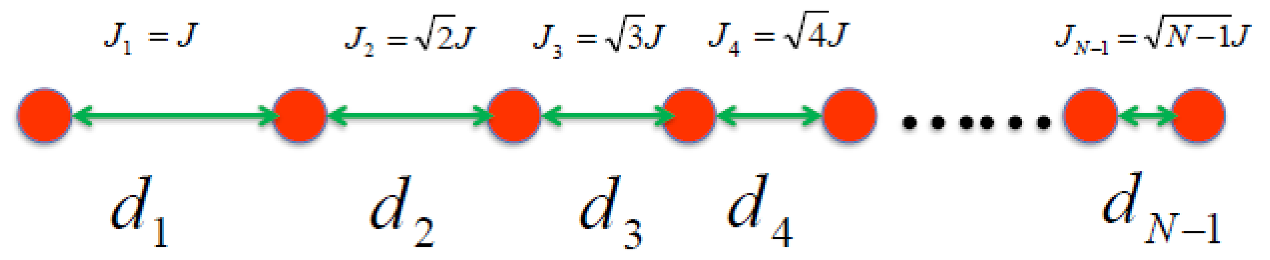
• The squeezed state that we consider in this work can be experimentally produced by the parametric down-conversion process.

• The parametric down-conversion process produces a squeezed state of light at high gain while single photon states are produced at low gain.

• We also analyse the quantum walk of spatially extended correlated and anti-correlated path-entangled photon states.

• The spatially extended correlated two photon initial state corresponds to the case in which both the photons will be fed into the same waveguide and has been experimentally generated.

Model for waveguide system



• The Hamiltonian for the coupled waveguide system is :

$$H = \hbar g \sum_{n=0}^{N-1} a_n^\dagger a_n + \hbar J \sum_{n=0}^{N-2} \sqrt{n+1}(a_n^\dagger a_{n+1} + a_{n+1}^\dagger a_n)$$

• In the weak coupling regime, C_n depends exponentially on the distance between the waveguides:

$$C_n = C_1 \exp[-(d_n - d_1)/\kappa]$$

• Consequently, the coupling dependence of the above Hamiltonian is readily achieved by inscribing the waveguides with separation given by :

$$d_n = d_1 - \kappa \log(\sqrt{n})$$

Squeezed light

• We first assume that squeezed light is coupled into the l^{th} *waveguide.*

$$|\zeta\rangle \equiv \frac{1}{\sqrt{\cosh r}} \sum_{n=0}^{\infty} \frac{\sqrt{(2n)!}}{2^n n!}\left(-\exp(i\phi)\tanh(r)\right)^n |2n\rangle$$

• Here r is the magnitude of squeezing and ϕ is related to the orientation of the squeezing ellipse.

• We investigate the squeezing aspect of the field in different waveguides.
• We introduce the quadrature operators for the j^{th} *waveguide given by*

$$q_j \equiv (a_j + a_j^\dagger)/\sqrt{2}$$
$$p_j \equiv (a_j - a_j^\dagger)/\sqrt{2}i$$

• We also define the squeezing factors given by:

$$s_j(q) \equiv (\Delta q_j)^2 - 1/2$$

$$s_j(p) \equiv (\Delta p_j)^2 - 1/2$$

•Thus squeezing occurs when one of these expressions becomes less than zero.

•The behaviour of squeezing is investigated for a variety of transverse positions of the squeezed state input.

Spatially extended path-entangled photons

• The photon pairs in the correlated state correspond to the state in which both photons will be fed into the same waveguide.

$$|\psi_C\rangle = \frac{1}{\sqrt{2N}}[(a_1^\dagger)^2 + (a_2^\dagger)^2 + \cdots + (a_N^\dagger)^2]|0\rangle$$

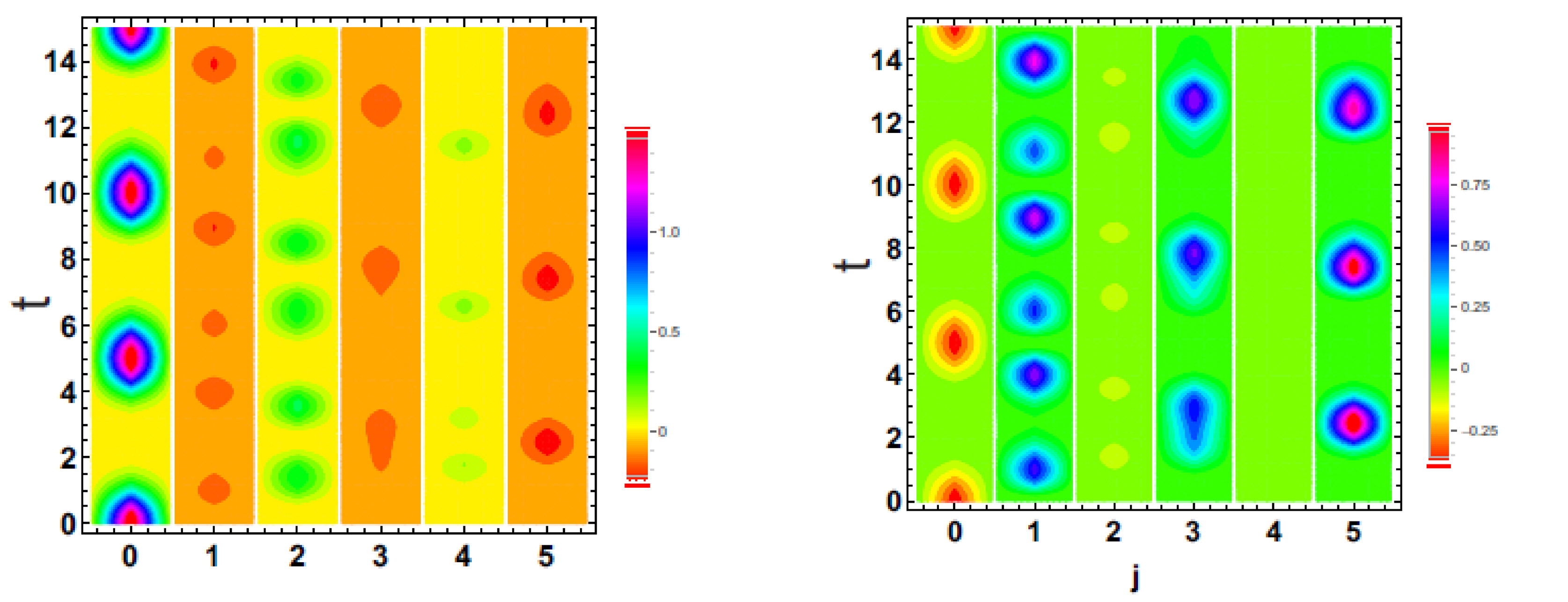
•An anti-correlated path entangled state corresponds to the state where the photon pair is always fed into the waveguides on opposite sides of the array. An example would be the state given by :

$$|\psi_A\rangle = \sqrt{\frac{2}{N}}[a_1^\dagger a_N^\dagger + a_2^\dagger a_{N-1}^\dagger + \cdots + a_{\frac{N}{2}}^\dagger a_{\frac{N}{2}+1}^\dagger]|0\rangle$$

• For comparison we also consider the separable state given by:

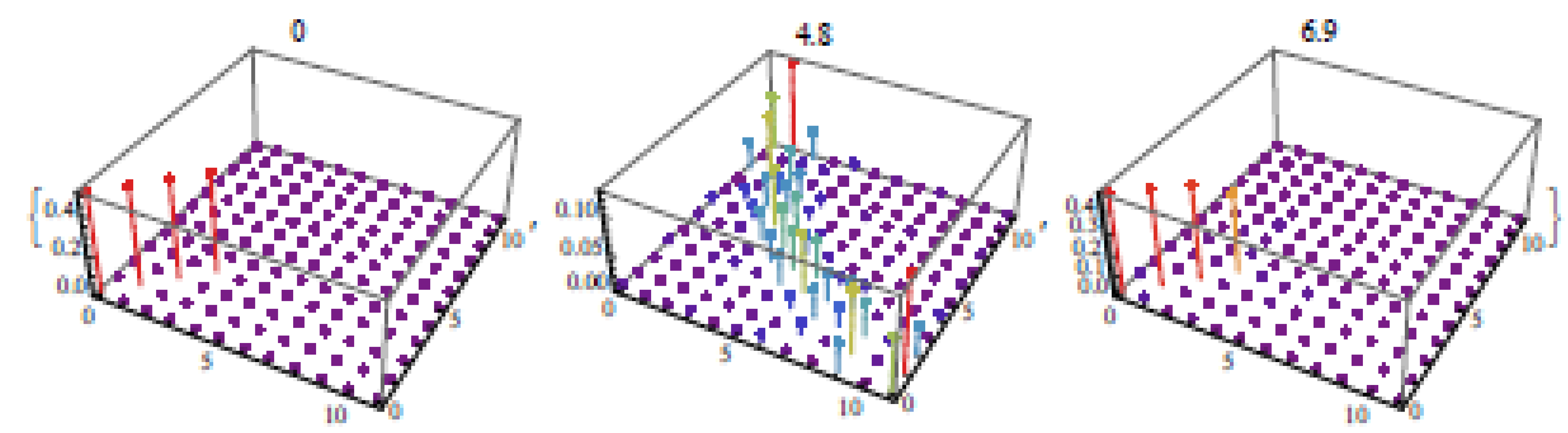
$$|\psi_s\rangle \equiv |0_0, 0_1, \ldots\ldots, 2_k, 0_{k+1}, \ldots., 0_{N-1}\rangle$$

Result and Discussion

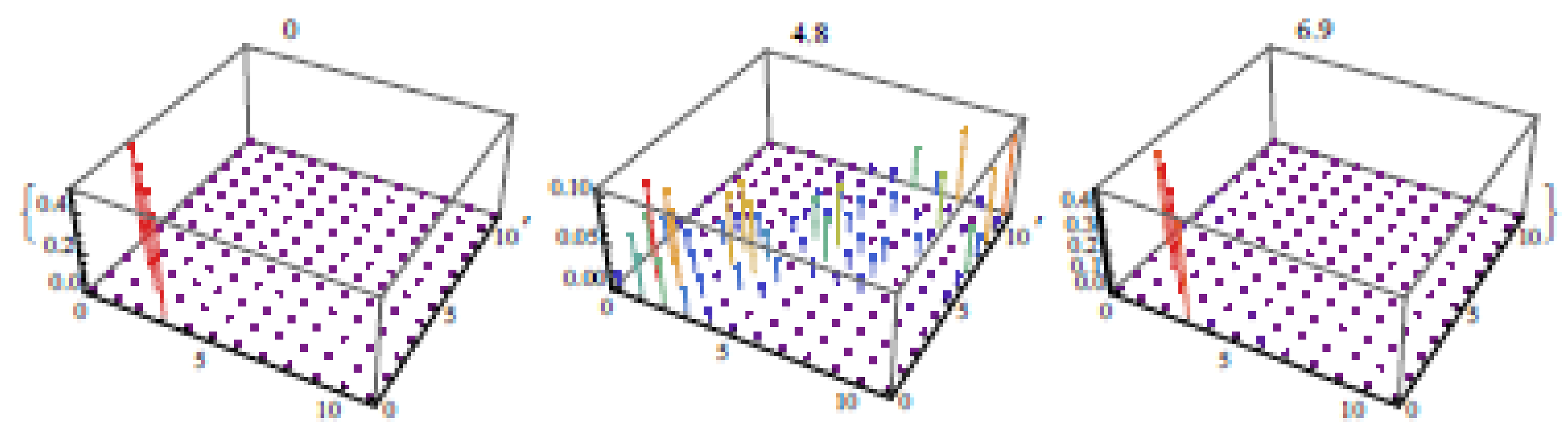


The left (right) part shows the variation of squeezing as a function of t for j = 0, . . . , 5, smeared out in the j direction. The magnitude and the phase of the squeezing parameter are chosen as r = 0.7 and ϕ = π respectively. The number of waveguides in the system is N = 6. The input is given to the zeroth waveguide. We see the revival of squeezing at the input waveguide.

Result and Discussion



Time evolution of two-photon correlation for the correlated state.



Time evolution of two-photon correlation for the anti-correlated state.

References

1. A. Perez-Leija, H. Moya-Cessa, A. Szameit, and D. N. Christodoulides, Opt. Lett. 35, 2010 (2010).

2. R. Keil, A. Perez-Leija, F. Dreisow, M. Heinrich, H. Moya-Cessa, S. Nolte, D. N. Christodoulides, and A. Szameit, Phys. Rev. Lett. 107, 103601 (2011).

3. A. Rai, G. S. Agarwal, and J. H. H. Perk, Phys. Rev. A 78, 042304 (2008).