NUMER IDENTYFIKACYJNY // CONTRIBUTION ID

Competing quantum correlations in bosonic networks

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Quantum correlations are crucial for quantum information processing and quantum computation. In this presentation we investigate the role of correlations present inside modes on generation of the multi-mode correlations. We consider two frequency degenerate radiation modes described by bosonic creation (annihilation) operators, $a^\dagger(a)$ and $b^\dagger(b)$, respectively. The modes are damped with rate κ by coupling to independent squeezed vacuum fields establishing number of photons n and two-photon correlations m inside the modes. The multi-mode correlations can be generated between modes that start off as mutually independent by applying a coherent coupling process. We choose two type of couplings available in laboratories, the linear coupling which describes single photon exchange processes determined by the interaction Hamiltonian $ga^\dagger b + g^* b^\dagger a$, and the two-photon type coupling describing two-photon process determined by the Hamiltonian $ga^\dagger b^\dagger + g^* ba$. The two-photon coupling is known to entangle modes being in classical states [1], white the linear coupling is known to entangle modes only if the modes are in quantum states [2].

Using the input-output formalism simple analytic expressions are obtained for the populations of the modes, $\langle a^\dagger a\rangle$, $\langle b^\dagger b\rangle$, the single-mode two-photon correlation functions, $\langle aa\rangle$, $\langle bb\rangle$, and for the mutual (two-mode) correlation function, $\langle a^\dagger b\rangle$. In the case of the linear coupling the degrees of the two-photon correlations are

$$\eta_{ab} = \frac{|\langle a^\dagger b\rangle|}{\sqrt{\langle a^\dagger a\rangle\langle b^\dagger b\rangle}} = \frac{m}{n}\sin\psi\cos\psi\ , \quad \eta_{aa} = \frac{|\langle aa\rangle|}{\langle a^\dagger a\rangle} = \frac{m}{n}\cos^2\psi\ , \quad \eta_{bb} = \frac{|\langle bb\rangle|}{\langle b^\dagger b\rangle} = \frac{m}{n}\cos^2\psi\ , \quad (1)$$

and for the nonlinear coupling

$$\eta_{ab} = \frac{(2n+1)\sinh\psi\cosh\psi}{2n+(2n+1)\sinh^2\psi}\ , \quad \eta_{aa} = \eta_{bb} = \frac{m}{n}\left[1 - \frac{\sinh^2\psi}{2n+(2n+1)\sinh^2\psi}\right]\ , \quad (2)$$

where $\psi = \mathrm{arctanh}(g/\kappa)$. It is seen that the linear coupling generates the two-mode correlations by conversion of the two-photon correlations existing inside the modes, but the generation of the two-mode correlations by the nonlinear coupling is insensitive to the correlations existing inside the modes. We find that the two-mode correlations are generated by conversion of the increased (amplified) population of the modes. Despite the fact that the generation of the two-mode correlations is insensitive to the presence of the correlations inside the modes, the single-mode correlations decrease with the strength of the coupling to zero. This competition between the correlations leads to conversion of the correlations into the first-order coherence between the modes.

References

[1] R. Ghosh et al. "Interference of two photons in parametric down conversion". In: *Phys. Rev. A* 34 (1986), p. 3962.

[2] M.S. Kim et al. "Entanglement by a beam splitter: Nonclassicality as a prerequisite for entanglement". In: *Phys. Rev. A* 65 (2002), p. 032323.