Quantum non-Gaussian multiphoton light

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Abstract

We propose a faithful hierarchy of genuine n-photon quantum non-Gaussian light for connections between quantum devices and for diagnostic of multiphoton sources and processes in quantum technology. We experimentally witnessed 3-photon quantum non-Gaussian light.

Individual photons as bosonic elementary particles have been subjects of a detailed quantum analysis already for many decades. It is intensified now due to their importance for quantum technology. First, a single photon antibunching was measured as incompatible with classical coherence theory. This measurement became canonical for single photon sources. After many years, broadband homodyne detection allowed indirect estimation of their continuous variable nonclassical features. Their visualization in a phase space of continuous amplitude of electric field by a Wigner probability density function shows multiple negative concentric annuli for Fock states of light. Wigner functions are used to distinguish different Fock states of light, however, without any proof yet that they really form a faithful hierarchy. A faithful hierarchy of n-photon quantum non-Gaussianity would reliably recognize that, for a given order n, an observed state is statistically incompatible with any mixture of Fock-state superposition up to n-1 photons modified by an arbitrary Gaussian phase-space transformation. Unfortunately, such a faithful hierarchy based on the negative parts of Wigner function has not been discovered yet and it would be anyway applicable only if overall losses were below fifty percent. Since a large variety of experimental platforms emitting or transmitting light does not suppress the losses so much, a lack of theoretical tools witnessing genuine n-photon quantum non-Gaussianity limits optical diagnostic of quantum processes in matter, current fast development of multiphoton sources and their applications in quantum technology.

A large gap between basic nonclassical light and light with negativity of Wigner function was partially covered when a loss-tolerant direct measurement of single-photon quantum non-Gaussianity was proposed and immediately experimentally tested. Advantageously, these criteria use only basic multi-photon correlation measurements, commonly applied to verify nonclassicality. The quantum non-Gaussianity criteria conclusively prove that light is not compatible with any mixture of Gaussian states, even beyond fifty percent of loss. In difference to the tests of nonclassicality, such test of quantum non-Gaussianity can already recognize a much narrower set of states, approaching closer to ideal single photon states. That property of single photon states has been already proposed to be applicable as a security indicator of single-photon quantum key distribution and as a probe of quantum photon-phonon-photon transfer.

The extension to multi-photon light allows wider applications in diagnostic of quantum processes, but our new criteria [1] did not still form the faithful hierarchy of quantum properties and therefore, such genuine n-photon quantum non-Gaussian state cannot be directly witnessed under large optical loss. Discovery of the hierarchy is currently crucial for ongoing exploration of light emitted by higher order nonlinear processes and for current development of multiphoton sources. In this talk, we present the faithful hierarchy of sufficient conditions for genuine n-photon quantum non-Gaussian state and, simultaneously, we experimentally verified the hierarchy by photon counting measurement of light up to three photons under 6.5 dB of optical loss [2]. Under such loss, negative Wigner function cannot be observed. Our criteria can conclusively confirm that observed genuine n-photon quantum non-Gaussian statistics is beyond statistics produced by any mixture of superposition of n-1 photons possibly modified by any Gaussian transformation. We further analyzed and experimentally verified robustness of the genuine multiphoton state under background noise. All these results qualify this faithful loss-tolerant hierarchy presented here to be both of fundamental interest and also directly applicable in many laboratories.

[1] I. Straka, L. Lachman, J. Hloušek, M. Miková, M. Mičuda, M. Ježek, and R. Filip, *Quantum non-Gaussian multiphoton light*, npj Quantum Information **4**, 4 (2018).

[2] L. Lachman, I. Straka, J. Hloušek, M. Ježek, and R. Filip, *Faithful hierarchy of genuine n-photon quantum non-Gaussian light*, arXiv:1810.02546v1.