Click Detection of Nonclassical Phase-Space Distributions

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We implement the direct sampling of negative phase-space functions via unbalanced homodyne measurement using click-counting detectors [1]. The negativities significantly certify nonclassical light in the high-loss regime using only a small number of detectors which cannot resolve individual photons. We apply our method to heralded single-photon states and experimentally demonstrate the most significant certification of nonclassicality for only two detection bins. By contrast, the frequently applied Wigner function fails to directly indicate such quantum characteristics for the quantum efficiencies present in our setup. Therefore, we realize a robust and reliable approach to characterize nonclassical light in phase space under realistic conditions.

The reconstruction of a quantum state in phase-space requires information-complete measurements of, e.g., quadratures [2] or the displaced photon-number statistics [3]. However, in many practical scenarios, such optimal detection schemes are not accessible because of experimental limitations, such as non-unity detection efficiencies and a limited resolution of adjacent photon numbers. A particular example are so-called quasi-photon-number-resolving or click-counting detectors. From such information-incomplete detection schemes, a click versions of phase-space functions can be directly sampled via unbalanced homodyne detection [4]. Here, we report on the direct sampling of such phase-space functions of heralded single-photon states [1]. The resulting phase-space functions directly show negativities even for quantum efficiencies significantly below 50%. We confirm the theoretical prediction from Ref. [4] that fewer detection bins lead to more significant signatures of nonclassical light.

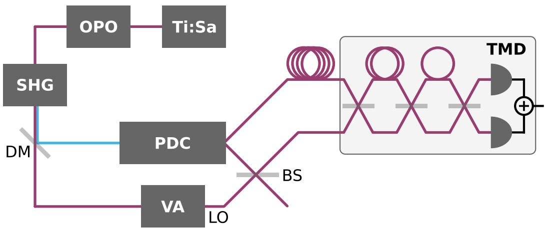

Figure 1: Experimental setup (see text for details).

The principle experimental setup is shown in Fig. 1. Photon pairs are generated in a parametric down-conversion (PDC) process. One of the photons is displaced with an intensity controlled local oscillator (LO) at an asymmetric beam splitter (BS), while the other photon is used for the heralding. Both photons are recored with a time-multiplexed detector (TMD) with a resolution of up to $N = 8$ bins. Fewer bins can be achieved via clustering of bins [1].

From the recorded click statistics, we directly sample the phase-space functions and their statistical errors [1, 4]. For the four-bin detection $(N = 4)$, our rotationally symmetric, sampled phase-space distribution P_N is shown in Fig. 2. The experimental results are compared with a analytical model. Importantly, our analysis works even in the high-loss regime and requires no knowledge about the detection losses. The clear negativities around the origin of the phase space certify the nonclassical character of the quantum state. Note that our sampling method does not require sophisticated data postprocessing, which means that optimization strategies and the estimation of the overall losses become superfluous.

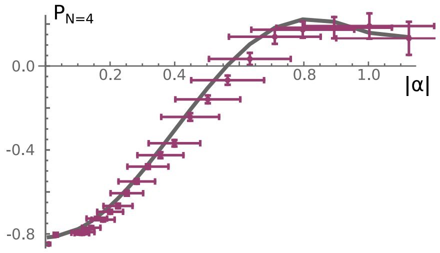

Figure 2: The point-wise sampled phase-space function of a single photon recorded with four detection bins is shown and compared with the theoretical model (solid curve).

Furthermore, we experimentally verify the surprising theoretical finding in Ref. [4] that fewer detection bins lead to an improved verification of nonclassicality. Therefore, we analyzed the data for two, four, and eight detection bins and sampled the corresponding phase-space functions for our single photon state [1]. We compared the significances of the negativities for the three cases for a quantitative assessment. We find indeed that a reduced number of detection bins leads to a more significant verification of nonclassicality in phase space. For only two detection bins, we verify the nonclassicality with a significance of 186 standard deviations.

In summary, we experimentally realized a technique which provides a practical and robust tool for the characterization of nonclassical light in phase space.

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