Reconstructing Wigner negativity from true single photons emitted by quantum dot single-photon source

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Direct Wigner function measurement [1] based on photon-number counting is a sensitive method to characterize photonic states in a continuous-variable context with resources typical for discrete variables. This method is based on direct photon-number measurement through homodyne correlation at the state generated by quantum interference of weak laser (local oscillator) and the target state. In contrast to the more established homodyne measurement [2], the direct measurement enables to quantify the quality of the displacement and distinguish it from optical loss via monitoring the photon-bunching strength [3]. This displacement quality together with the knowledge of the experimental optical losses is essential to the precise reconstruction of the Wigner function. This has been pioneered on the example of a heralded single Fock state [4], however, it has not been explored for the optimal experimental configuration or with deterministic single-photon sources until now.

Here, we use high brightness true single-photon source based on a semiconductor quantum dot (QD) device [5] to improve the direct Wigner function measurement method. First, we demonstrate efficient homodyne photon-correlation techniques to optimize mode-matching of the local oscillator to the single-photon wavepacket based on monitoring strength of their photon bunching. By tailoring laser light in different degrees of freedom, we maximize the overlap up to 76% [3]. This represents a record value reported with semiconductor-QD sources, slightly limited by the mismatch between the temporal profile of the two fields and the low-frequency charge noise of the single-photon source originating from its complex solid-state environment.

Second, we compare two different acquisition methods to reconstruct the target-state photon-number distribution by its deduction either from pseudo-photon number resolving (PPNR) detection with four parallelized detectors or zero-photon (ZP) detection probability under controlled and calibrated attenuation derived from single-detector clicks [6]. After optical loss and mode-matching corrections of the measured signal, we, for the first time, reconstruct the single-photon Wigner function of a QD-cavity device. The maximum-likelihood Wigner reconstruction fed with the ZP dataset enables retrieval of the expected Wigner function [7], even up to relatively high displacement where the PPNR method fails for photon-number resolution limited to four.

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