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Quantum Measurements Based on Photon Number Resolved Detection

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The characterization of any quantum system requires measurements, which allows an observer to gain information about a performed experiment. The theory of quantum measurements connects the properties of a quantum state, which is typically defined by its density matrix $\hat{\rho}$, and the description of the measurement devices, represented by a positive-operator-valued measure (POVM), with the probabilities of obtaining specific detection outcomes. The way on how we interpret our results depends, on the one hand, on the technical limitations of available detectors, and on the other hand, on our knowledge about the measurement apparatus. Up to recently no practical photon-number resolving detectors were available. Hence most research dealing with multi-photon states is based on homodyne tomography schemes. A time-multiplexing detector (TMD) that is capable to resolve photon statistics can be built from a fiber network followed by avalanche photo-detection. TMDs enable the direct measurement of count statistics, but their moderate efficiency hampers identifying the photon number of each signal state on a single-shot basis. The POVMs describing this detector correspond to loss-degraded photon number measurements, and a precise calibration of the losses can be utilized to recover the original photon number statistics in ensemble measurements by a loss inversion method. However, the knowledge of the photon statistics is not sufficient to completely characterize a state, because photon counting annihilates any information about the coherences between photon numbers. Nevertheless, TMD measurements can render a complete characterization of a density matrix $\hat{\rho}$, if the statistics of the displaced states are analyzed. We investigate the capabilities of detector tomography and loss-tolerant detection of photon statistics for the complete characterization of photonic states.