Evaluating the performance of Photon-Number-Resolving detectors

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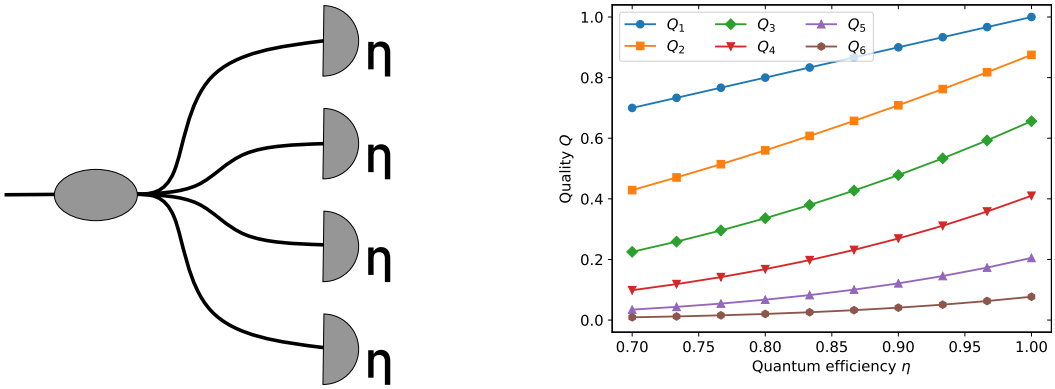
Abstract

We analyze the performance of photon-number-resolving (PNR) detectors and introduce a figure of merit for the accuracy of such detectors. We have simulated various PNR detectors based on multiplexed single-photon "click detectors". We conclude that the required quantum efficiency is very high (> 90%)in order to achieve even moderate (up to a handful) photon resolution

We have analyzed the performance of PNR-detectors, and in particular those based on multiplexing of single photon detectors that are only capable of differentiating between zero and more than zero photons, so-called "click detectors". Such an 1:4 array is schematically shown in Fig. 1, (a). The motivation for focusing of such detectors is that superconducting nano-wire detectors typically operate in click-detector mode, they have high quantum efficiency, low dark count rate, and they do not need cryogenic cooling below 4 K.

Any PNR detector will have a highest photon number n for which it will be able to resolve the detected photon number. Using a quality measure Q that is the lowest probability of correctly predicting the incident photon number for all photon numbers less or equal to n, we have analyzed various arrays for different click-detector quantum efficiencies and dark count rates. An example is plotted in Fig. 1, (b).



(a) (b)

Figure 1: (a) A schematic illustration of a multiplexed PNR-detecon single photon click-detectors. (b) Simulation result of the PNR quality for an 8-array of click-detectors with negligible dark count rates. Reaching a quality larger than 0.5 for many photons requires a very high quantum efficiency.

As is clear from the figure, which is drawn for an eight element array, a click-detector quantum efficiency of about 0.75 is needed to resolve even two photons with $\geq 50\%$ probability ($Q \geq 0.5$). Due to the finite size of the array, the maximum number of photons one will be able to resolve with $\geq 50\%$ probability is three, even with unit click-detector quantum efficiency. This limit is imposed by the finite chance that two or more photons impinge on the same click-detector after the (random) 1:8 splitting assumed in the figure. For comparison, an ideal, unit quantum efficiency 32-array will be able to resolve seven photons. Reducing the click-detector quantum efficiency to 0.9 reduces the PNR-capability of the 32-array to four with $\geq 50\%$ probability.

Restricting the input set of photon number distributions, e.g., the set of Poissonian distributions will improve the situation somewhat as this restriction already gives some *a priori* knowledge.

[1] M. Jönsson and G. Björk, *Evaluating Performance of Photon-Number-Resolving Detectors*, e-print arXiv 1812.05422.