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Limits for heralding higher-order Fock states

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Abstract

We report on our theoretical and experimental findings for using heralded spontaneous parametric down conversion (SPDC) to generate higher order Fock states. By introducing a new method based on matrix multiplication we are able to investigate the effects of spectral multimodeness and losses for this process. We find absolute limitations for the generation probability due to the intrinsic probabilistic nature of this process as well as a fundamental trade-off between heralding probability and state fidelity. We compare our theoretical findings with experimental data showing very high agreement with our theory.

Higher-order Fock states are an essential resource for many quantum applications (e.g.[1,2]). Today SPDC is the most-widely used technique to generate these states. However, the effects of losses and multimodeness have a non-trivial effect on the heralded state. We introduce a new framework based on matrix multiplication to solve this problem [3]. With this method we reveal fundamental limits for the generation probability of higher order Fock states due to the probabilistic nature of SPDC. We also analyze the state fidelity of the heralded state towards an ideal n-photon Fock state and show a fundamental trade-off between the generation probability and the state fidelity (Fig 1(b)).

In order to verify our theoretical results we used a type-II PDC process in a periodically poled potassium titanyl phosphate (KTP) waveguide to generate a two-mode squeezed vacuum state. These two modes (signal and idler, both centred around 1535 nm) are separated on a polarizing beam splitter and detected with transition edge sensors (TES) enabling photon number resolved measurements. The measurement is in high agreement with our theoretical findings (cf. Fig 1(a)).

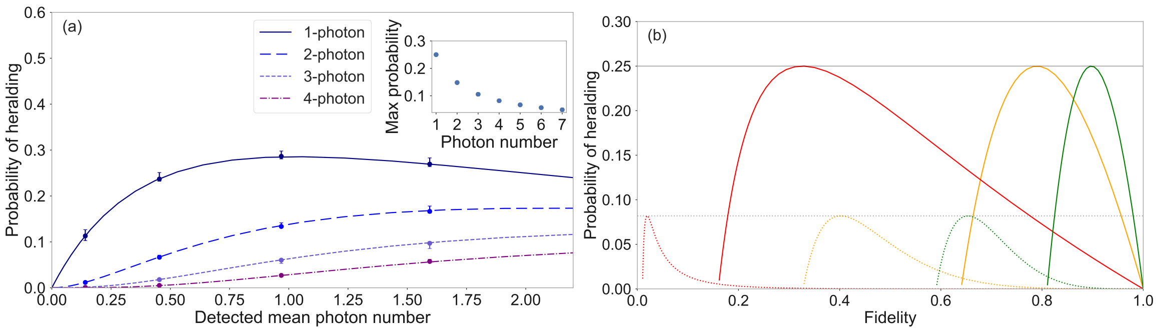

Figure 1: (a) Detected mean photon number versus heralding probability for experimental data (dots) and theory (colored lines) with spectral multimodeness (K=1.61) and detection efficiencies (idler: 0.59 and signal: 0.64) as the only free parameters. The inset show the maximal heralding probability versus photon number. (b) Trade-off between state fidelity and heralding probability for a heralded single photon (solid lines) and a heralded four-photon state (dashed). Curves are parametric plots where the pump power is varied. The trade-off increases with higher losses as shown for three different transmission values in the heralding arm of 0.9, 0.8 and 0.4 (green, blue, red respectively).

With these results it is possible to identify the optimal parameters for new experiments requiring Fock states from SPDC under the consideration of multimodeness and losses.

[1] Ourjoumtsev et. al., *Generation of optical 'Schrödinger cats' from photon number states*, Nature **448**, 784-786 (2007)

[2] Holland et al., *Interferometric Detection of Optical Phase Shifts at the Heisenberg Limit*, Physical Review Letters **71**, 1355-1358 (1993)

[3] Tiedau et al., *On the scalability of parametric down-conversion for generating higher-order Fock states*, arXiv:1901.03237