

Quantum feedback in parametric down-conversion

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Abstract

We demonstrate a time-multiplexed all-optical scheme for the generation of higher-order Fock states. Our scheme exploits the effects of quantum feedback in parametric down-conversion (PDC), where one of the generated photons is sent back to the process and induces self-stimulation. This leads to an increased generation for the subsequent photon pair, and thus facilitates the generation of higher-order Fock states with rates beyond what could be achieved with standard PDC. We present a characterisation of the self-stimulation using correlation measurements, and discuss further steps towards Fock state generation.

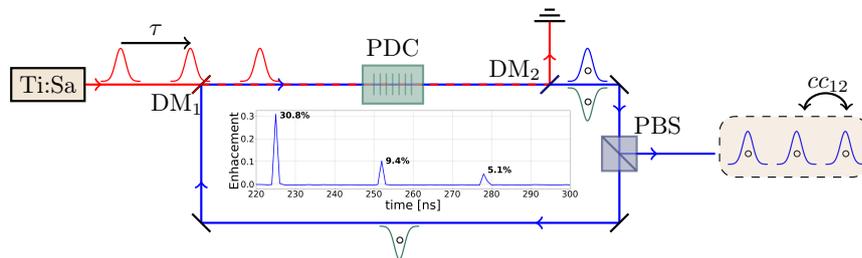


Figure 1: Setup for state generation: Laser pulses (red) optically pump the PDC source to generate photon pairs. One photon (blue) is detected, whereas its cycling partner (green) stimulates the PDC process. Time trace showing enhanced PDC generation probabilities for subsequent pump pulses. The maximum enhancement for neighbouring pulses is 30.8%. Ti:Sa, titanium sapphire pump laser; DM₁ and DM₂, dichroic mirror; PBS, polarizing beam splitter; PDC, parametric down conversion; cc₁₂, correlation counts time bin one and two; τ , repetitionrate of the laser.

Fock states $|n\rangle$ can serve as resources for generating more complex quantum states (e.g. $N00N$ states in [1]). The efficient generation of higher-order Fock states with $n > 1$ is an outstanding problem in this context. Typically, these states are generated from parametric down-conversion (PDC), where the detection of n photons in one output mode heralds the presence of n photons in the other mode. This approach intrinsically suffers from strict limitations regarding generation probabilities and thus generation rates [2]. One way to mitigate these limitations is to utilise quantum feedback; one arm of the PDC is fed back to the process to self-stimulate the generation of subsequent PDC states [3]. Here, we demonstrate increased PDC generation probabilities by combining a dispersion-engineered PDC source [4] with a time-multiplexing architecture, which facilitates a resource efficient implementation of the above scheme. A detailed sketch of our setup is shown in Figure 1. Our PDC source is driven by pulses from an ultrafast oscillator, and it generates polarization non-degenerate photon pairs. One of the photons, the idler, is directly detected; the other photon, the signal, is fed back to the process and temporally overlaps with the subsequent pump pulse, thus stimulating the generation of further photon pairs. By evaluating the PDC generation probability conditioned on the detection of a first photon, we demonstrate an increase of up to $(30.8 \pm 0.6)\%$ compared to a situation without quantum feedback (see graphs in Figure 1). Further, we demonstrate that this effect spreads over more than one pulse, allowing to generate correlations between several pulses. In a next step, we will probe the feedback arm to demonstrate the generation of higher-order Fock states conditioned upon the detection of n subsequent photons. Going beyond, we have already shown that this setup is, in principle, capable of generating more general tensor network states, which are an important resource for quantum information processing applications [5].

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