Generation of optical Schrödinger cat states by number-resolved squeezed photon subtraction*

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Abstract: We have generated and measured an approximation of an optical Schrödinger cat state by photon subtraction from a squeezed state. Using single-photon avalanche photodiode detectors and photon-number-resolving transition edge sensors, we were able to extract Wigner distributions for one *or* two photons subtracted from the squeezed state, resulting in both an odd and even cat state. The one-photon-subtracted Wigner distribution shows measured negative features (without any correction), indicating quantum character. The Wigner distribution of the two-photon-subtracted state is negative after correcting for homodyne losses. A full statistical analysis is under way to quantify the magnitude and fidelity of the cat states generated.

OCIS codes: (270.6570) Squeezed States; (270.1670) Coherent optical effects

1. Introduction

The generation of optical Schrödinger cat states poses a challenging problem in the field of quantum optics. While every quantum state is very susceptible to interaction with the environment (loss), optical cat states are particularly susceptible and can lose their quantum character very rapidly. Because of this, only a few groups have succeeded in generating an approximation to an optical cat state so far [1-4]. We have implemented a method that relies on the subtraction of one or two photons from a squeezed light state. By heralding on the detection of these photons, an approximation to an optical cat state is created, which theoretically increases its size and fidelity compared to a true cat state with those numbers of photons being subtracted. Detection of the heralding photons was accomplished by single-photon avalanche photodiodes (APDs) and high detection efficiency (DE) photon-number-resolving transition edge sensors (TES). The high DE of the TES allows for much higher data rates compared to the APDs.

2. Generation of Optical Cat States

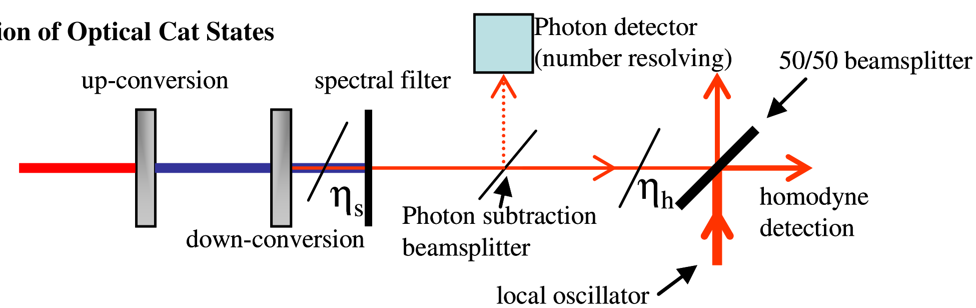

Fig. 1. Experimental scheme for generation of optical cat states by squeezed photon subtraction.

Figure 1 shows our experimental scheme. A femtosecond laser pulse is sent into a 150 µm thick $KNbO_3$ crystal to create second harmonic up-conversion, which is then used to pump the down-conversion crystal, a 200 µm thick, $KNbO_3$ crystal. The down-conversion process creates a squeezed vacuum state. From this squeezed state, we subtract one or two photons. Detection of these subtracted photons heralds the homodyne measurement of the cat state. We model a noisy squeezed state as a pure squeezed state that has passed through a beamsplitter with transmissivity η_s, which we define as the 'purity' of the squeezed state. We infer η_s from the observed squeezing and anti-squeezing noise levels and by correcting for the homodyne detection efficiency (η_h = 83%) and electrical noise background (2.5%). To increase the squeezing purity and decrease the homodyne loss, we temperature-tune (phasematch) the non-linear crystal and we shape the pulse width of our local oscillator to get the best overlap with our squeezed state.

3. Measurement and Results

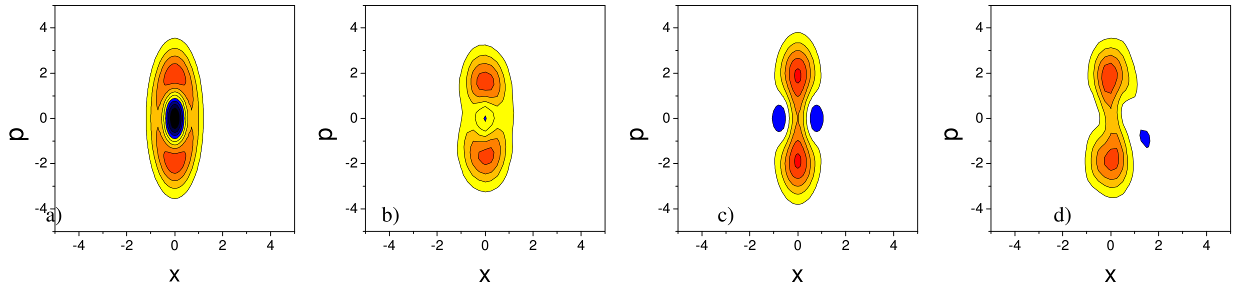

Fig. 2. One- and Two-photon subtraction data heralded with APDs.
a) One-photon Wigner distribution corrected for homodyne loss. b) One-photon raw data tomography.
c) Two-photon Wigner distribution corrected for homodyne loss. d) Two-photon raw data tomography.

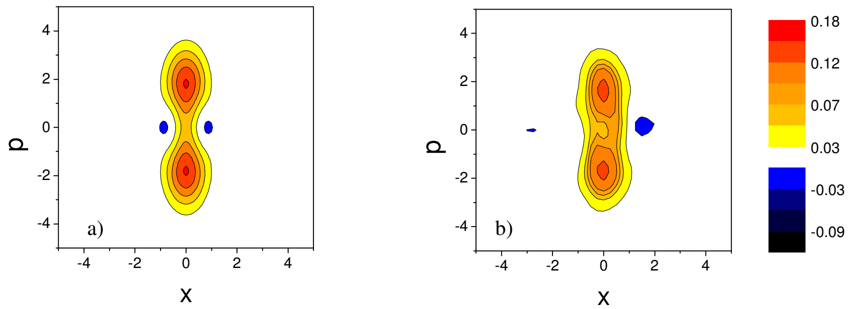

Fig. 3. Raw tomography for two-photon subtraction data, heralded with the TES detector. a) Corrected for homodyne loss. b) Raw tomography

Table 1: Wigner distribution minima obtained from the raw data tomography and corrected for homodyne loss. The two-photon raw data tomography has two values, corresponding to the minima at each side

Wigner distribution minimum					
One-photon subtraction (APD)		Two-photon subtraction (APD)		Two-photon subtraction (TES)	
Raw	Corrected	Raw	Corrected	Raw	Corrected
-0.008	-0.136	+0.005/+0.007	-0.015	+0.004/-0.010	-0.003

Figure 2 shows the Wigner distributions obtained for the one- and two-photon subtraction cases, respectively. Both were heralded using APDs. The determined Wigner distribution minima for all cases are given in Table 1. Figures 2a and 2c show the Wigner distributions, corrected for the known homodyne loss. Both corrected distributions yield a minimum value of -0.136 and -0.015 for the one- and two-photon subtractions, respectively. Both of those distributions are based on a model that describes the Wigner distributions for the one- and two-photon-subtractions, similar to the one-photon-subtraction model published earlier by Ourjoumtsev et al [1]. Figures 2b and 2d show the full tomography of the raw data for both cases. The negativity of the raw Wigner distribution for the one-photon-subtraction is -0.008. There is no significant negativity for the two-photon-subtraction raw data measured with two APDs. Figure 3 shows the correction and raw tomography of the data obtained using the TES as a herald. Like in the APD case, we do not observe a significant quantum character, as the uncertainty of the measured distribution is large. However, we were able to directly observe the quantum character of this state for the first set of 2,500 datapoints (not shown). We speculate that the photorefractive effect present in our $KNbO_3$ crystals degrades the fidelity of our state [5]. After a few tens of minutes, the photorefractive effect causes the wavefront to change and hence the observed state to degrade. However, by using the high detection efficiency TES to allow for faster measurement times, choosing good spots on the crystal and measuring on these spots for a short time only, we expect to be able to directly measure the quantum character of the two-photon subtracted state soon.

5. References

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