Quantum technology of non-classical light: single photon and beyond

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The *single photon Fock state* |1> is one of the most fundamental states of the light field. It is highly non-classical and reveals the wave-particle duality of light most strikingly. Its marginal distributions are of non-Gaussian shape and its Wigner function exhibits a strong negativity around the origin of the phase space.

As the first step, we have applied the technique of *pulsed optical homodyne tomography* to the state |1> prepared by conditional measurements on a photon pair produced in parametric down-conversion [1]. In our experimental setup (Fig.1) we employ a mode-locked Ti:Sapphire-laser in combination with a pulse picker to obtain transform-limited 1.6-ps pulses at 790 nm. Most of the radiation is single-pass frequency doubled in an LBO-crystal and passed on to a BBO crystal for down-conversion. The down-converter is operated in a type I frequency degenerate, but spatially non-degenerate configuration. A single-photon counter is placed in one of the emission channels - labeled trigger - to detect photon pair creation events and to trigger the readout of a homodyne system placed in the other emission channel - labeled signal. In this way only those pulses are selected for homodyne measurements where a photon has been emitted into the signal channel, thus conditionally preparing single photon Fock states. The latter are then subject to a homodyne measurement using a small fraction of the original laser power as a local oscillator.

The statistical distribution of the pulsed homodyne detector output was then used to reconstruct the Wigner function (Fig. 2). The latter exhibits a well at the center reaching a classically impossible negative value. Various experimental imperfections (such as non-ideal spatial and temporal mode matching, losses in the signal beam path, dark counts etc.) caused an admixture of the vacuum |0> to the measured state, reducing the depth of the well.

Based on this experience, we are developing an experiment on production and characterization of *arbitrary* single-mode quantum-optical states. This is achieved via repeated two-photon down-conversion in a chain of nonlinear crystals with a set of coherent seed pulses fed into the trigger channel of each crystal [2]. The quantum state emerging in the common signal mode of the down-converting chain is determined by the choice of amplitudes and phases of the seed states and is conditioned upon simultaneous firing of single-photon counters placed into the trigger channel of each down-converter. The maximum number of terms in the output state's Fock representation is determined by the number of crystals in the chain.

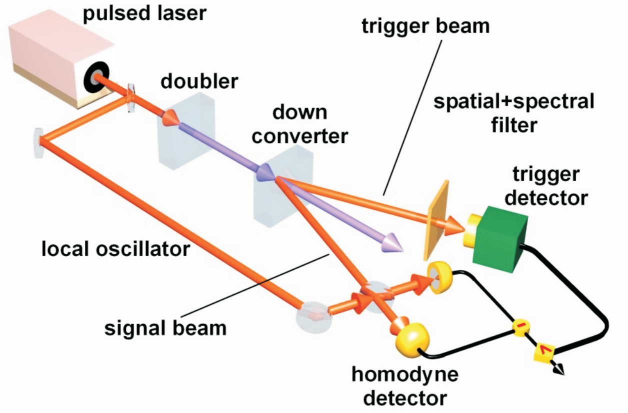

Fig. 1 *Schematics of the experimental setup. Twin photons are produced by parametric down-conversion. The homodyne measurement in the signal beam is conditioned on a count event in the trigger detector.*

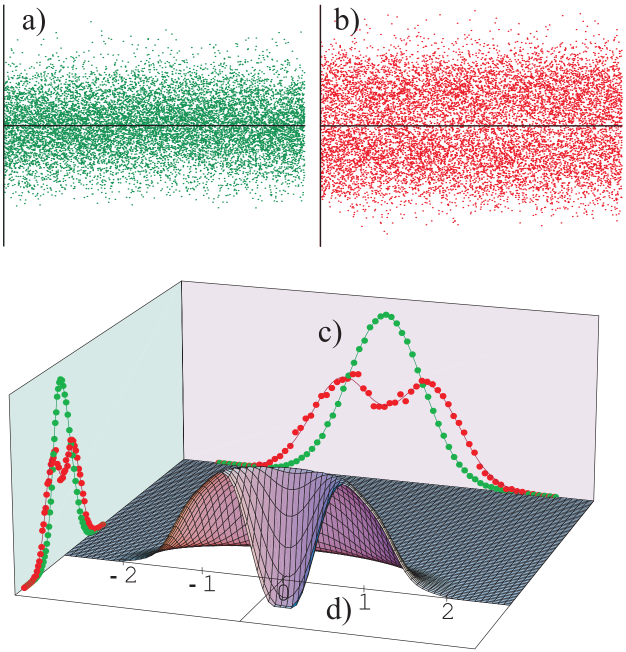

Fig. 2 *Experimental results of the quantum state measurement. Top: raw quantum noise data for the vacuum state (a) and the Fock state (b). Bottom: histograms of the data which correspond to the phase-randomized marginal distributions of the measured vacuum (green) and Fock (red) states (c); the reconstructed Wigner function (d) is negative near the origin point. A measurement effciency of 55% is achieved.*

In a separate effort, we intend to characterize, via the technique of quantum homodyne tomography, the entangled two-mode state $\left|\Psi^+\right\rangle = |1\rangle|0\rangle + |0\rangle|1\rangle$ generated by a photon incident on a 50/50 beamsplitter. The quantum states emerging from both beamsplitter output ports are subjected to balanced homodyne detection. By studying the correlations between the two homodyne detector outputs one can obtain the full Wigner function of $\left|\Psi^+\right\rangle$ and see interference effects demonstrating its nonlocal character in an entirely new fashion [3].

A successful completion of the above research program would mark a step towards developing *quantum technology of nonclassical light*, a new branch in the rapidly developing field of quantum technology.

[1] A. I. Lvovsky *et al.*, quant-ph/0101051

[2] J. Clausen *et al.*, quant-ph/0007050

[3] K. Jacobs and P. L. Knight, Phys. Rev. **A 54** , 3738 (1996)