Using cavity QED to create single photons and optical cat-states

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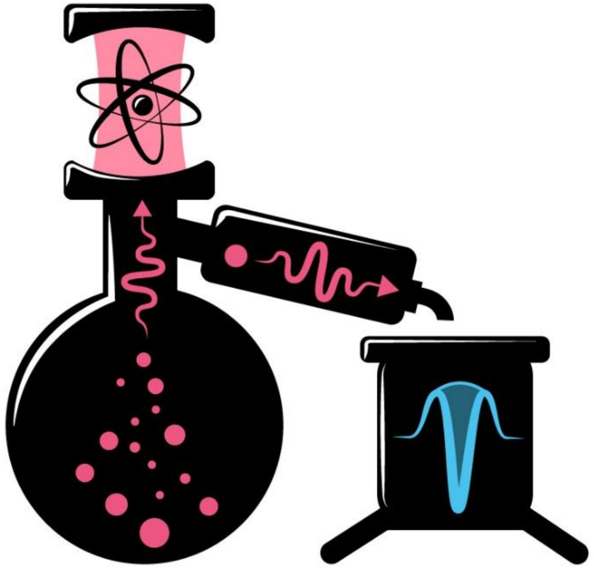
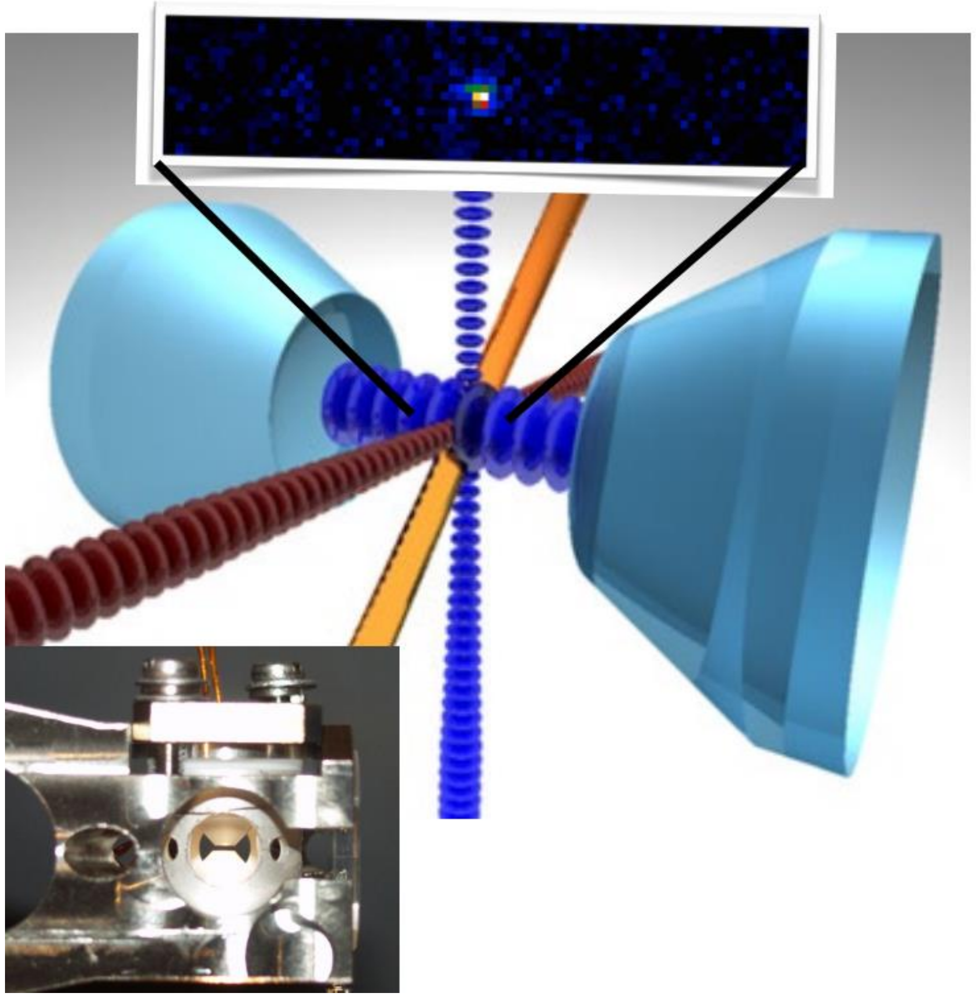
Hacker, B., Welte, S., Daiss, S. et al. Deterministic creation of entangled atom–light Schrödinger-cat states. Nature Photon 13, 110–115 (2019)



Severin Daiss, Stephan Welte, Bastian Hacker et al. Single-Photon Distillation via a Photonic Parity Measurement Using Cavity QED. Phys. Rev. Lett. 122, 133603

Experimental Setup



Atom trapping in 3D optical lattice:
- High trap frequencies (>100kHz) [7]
- Tight confinement (<15nm)
- Full control over the atomic position

Intra-cavity Sisyphus cooling: [6]
- Fast cooling close to the ground state
- Fluorescence imaging of the atom

Cavity parameters

T_{M1} = 4 ppm, T_{M2} = 92 ppm, "single-sided"

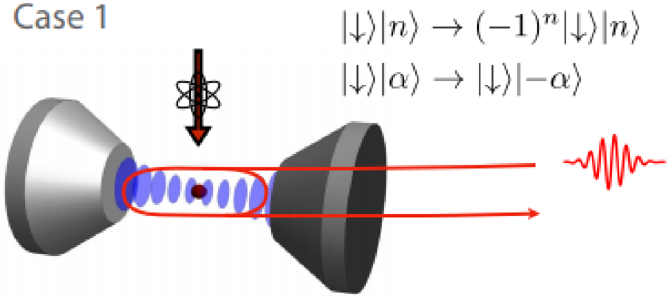
Losses = 7 ppm, F ≈ 60000

$(g, \kappa, \kappa_{out}, \gamma) = 2\pi\,(7.8, 2.5, 2.3, 3.0)$ MHz

Cooperativity $C = g^2/(2\kappa\gamma) = 4.1$

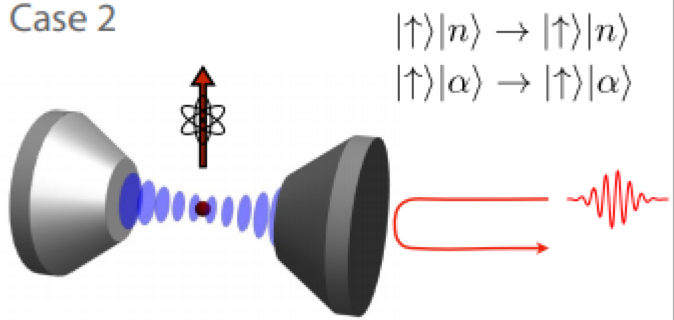
Phase Shift mechanism and sketch of experimental Setup

Case 1



Atom in $|\downarrow\rangle$: Impinging photons can enter the cavity before being reflected.

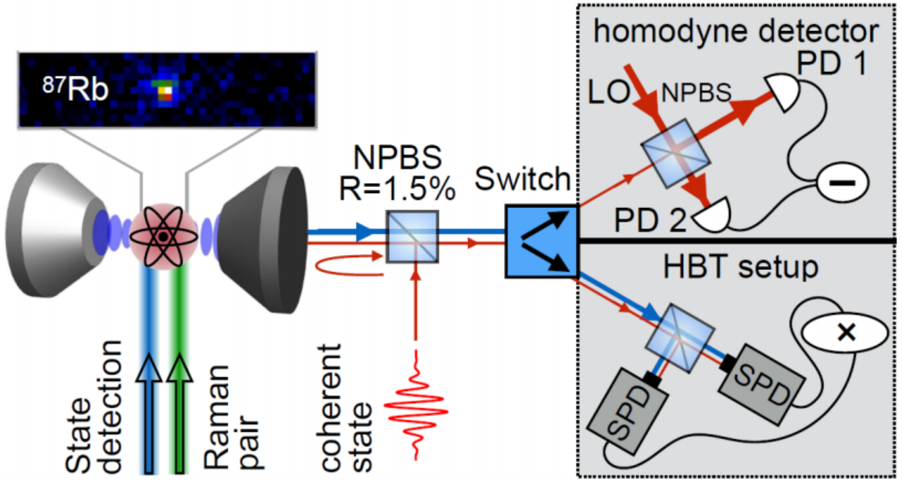
Case 2



Atom in $|\uparrow\rangle$: Strong coupling leads to a normal mode splitting such that resonant photons are reflected without entering.

Due to destructive interference on the coupling mirror: π phase shift [5, 6] on the total wavefunction whenever a single photon can enter the cavity, i.e. the atom is not coupling ($|\downarrow\rangle$).

Simplified schematic of the experimental setup



Truthtable with higher photon Fock-states:

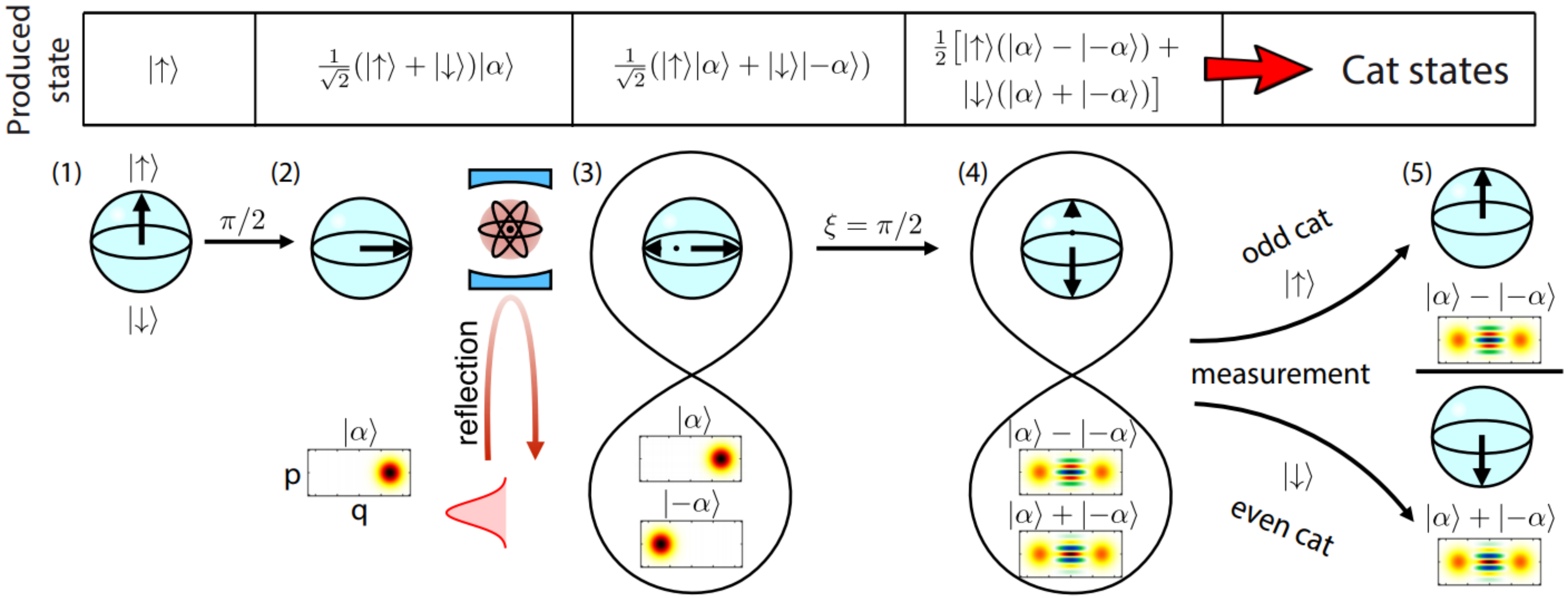
$$|\downarrow\rangle|n\rangle \rightarrow (-1)^n|\downarrow\rangle|n\rangle$$
$$|\uparrow\rangle|n\rangle \rightarrow |\uparrow\rangle|n\rangle$$

Coherent state in Fock basis

$$|\alpha\rangle = e^{-\frac{|\alpha|^2}{2}} \sum_{n=0}^{\infty} \frac{\alpha^n}{\sqrt{n!}} |n\rangle$$

[5] L. -M. Duan, H. J. Kimble, Scalable Photonic Quantum Computation through Cavity-Assisted Interactions, PRL 92, 127902 (2004).
[6] A. Reiserer et al., Nondestructive Detection of an Optical Photon, Science 342, 1349 (2013).

Experimental protocol for cat-state production

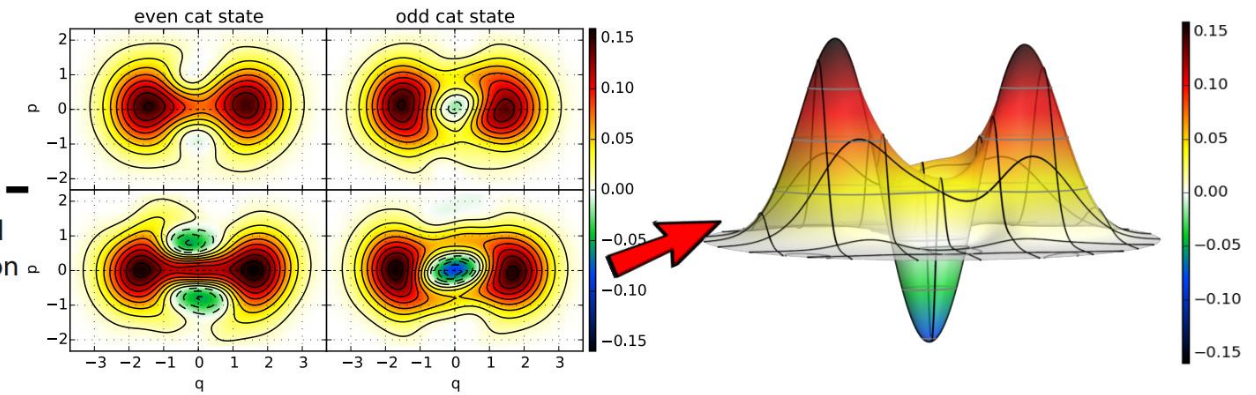


Scan of cat parameters

Even and odd cat states

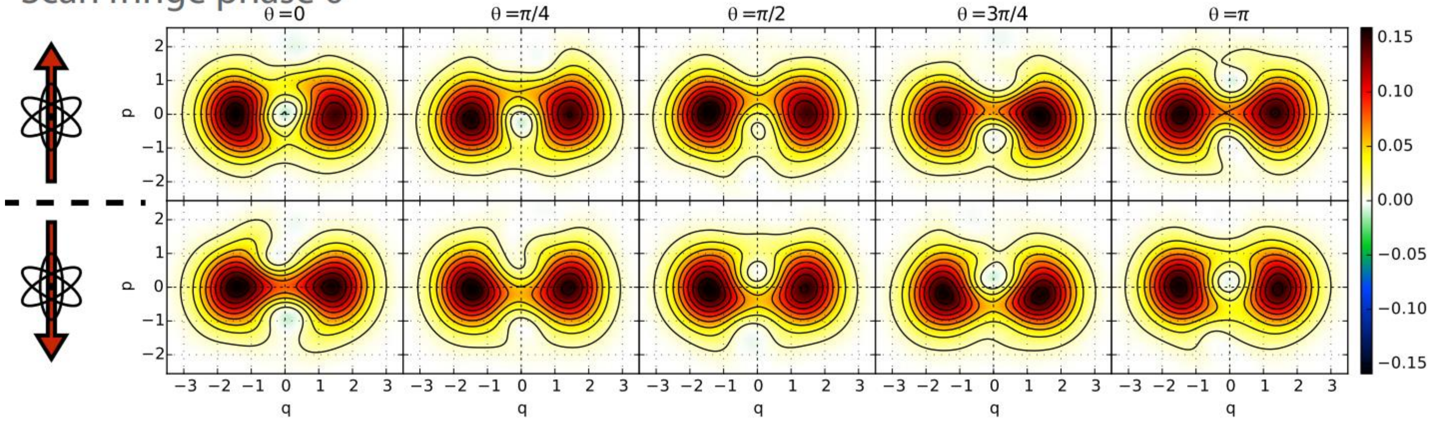
uncorrected data

data corrected for propagation and detection losses

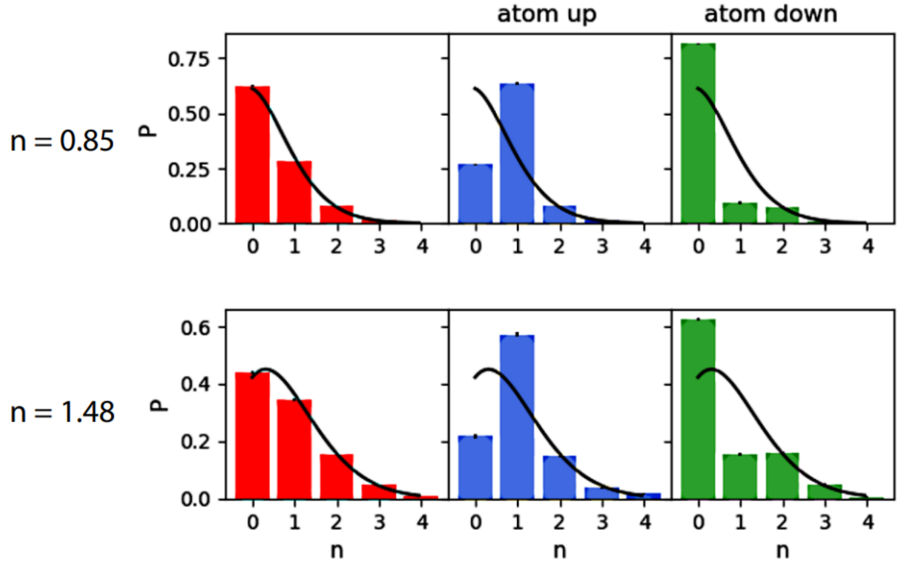


Losses limit the size of the cat states with negativity: Cavity losses: 19%. Propagation and detection losses: 25%

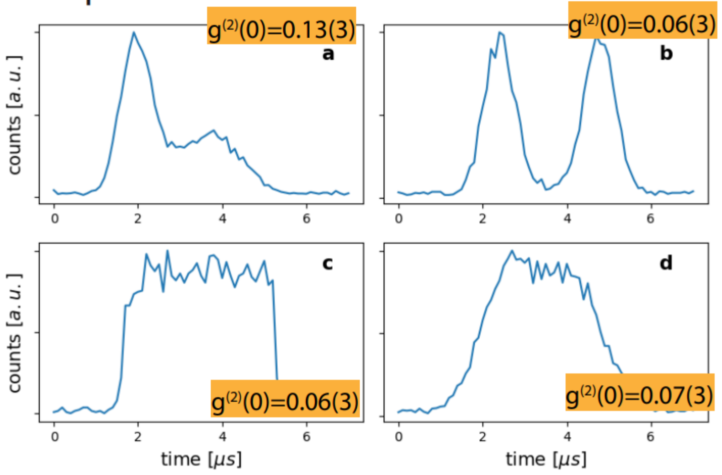
Scan fringe phase θ

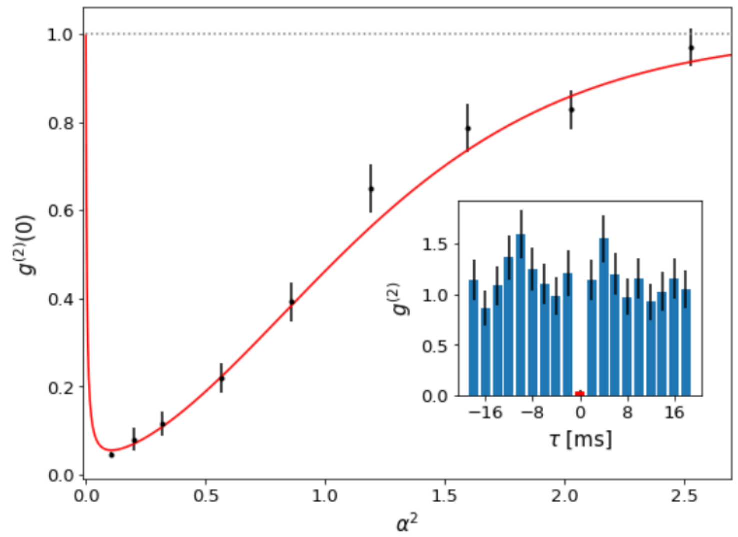


Distillation of single photons



Possibility for different temporal photon shapes:





Lowest value limited by dark counts.