Cavity Quantum Electrodynamics With A Nearly Concentric Optical Cavity

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Motivation

Strong interaction between photons and neutral single atoms are usually observed in cavity quantum electrodynamics (CQED) systems with high finesse mirrors and small physical volume. An alternative to this is to operate the cavity in a near concentric configuration, which achieves small effective mode volume (if the atom is placed near the strongly focused region). This way, we can just use relatively low finesse mirrors (~ 100) with large physical separation between the mirrors (~ 10 mm) [1-3].

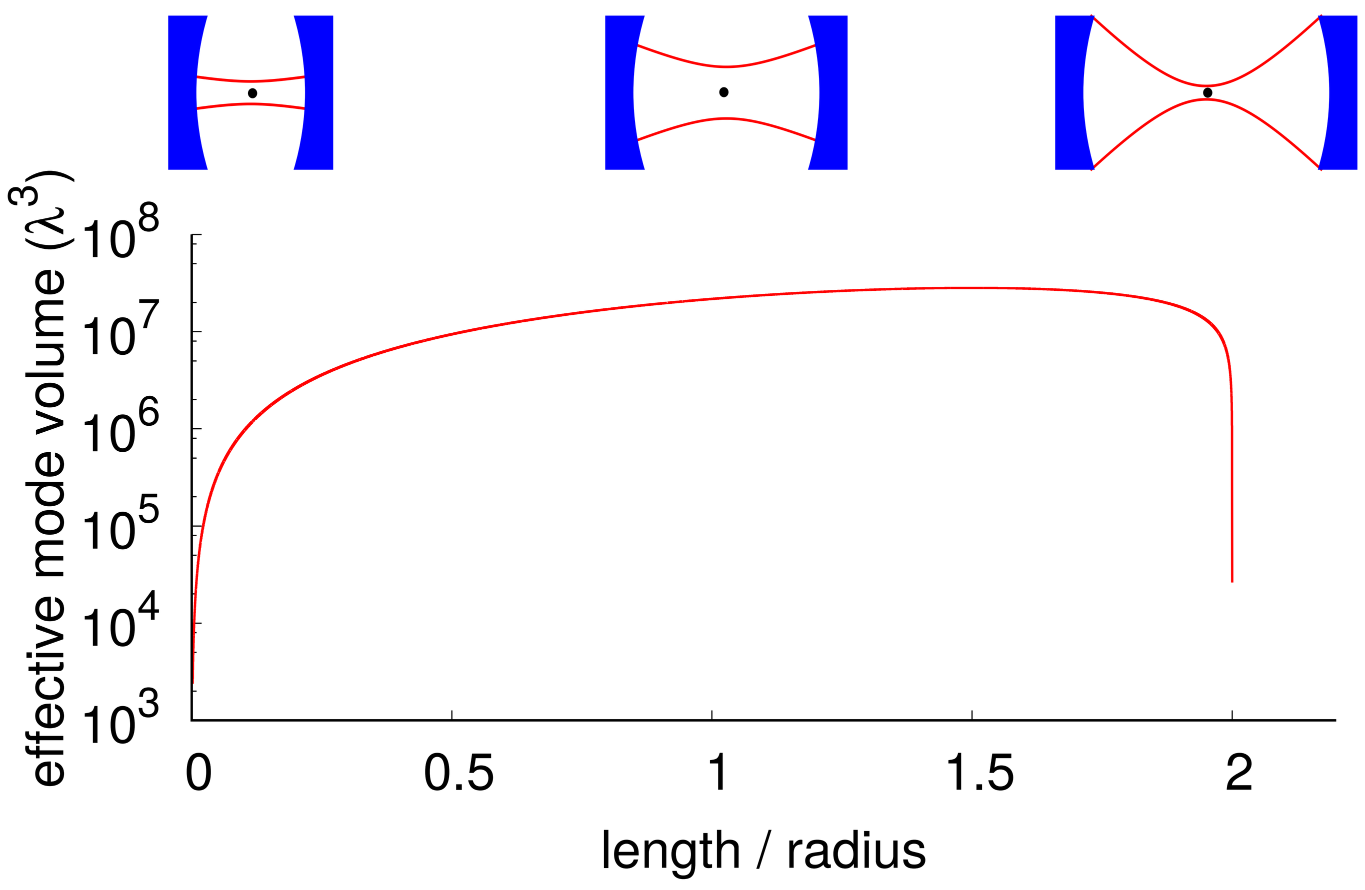

Figure 1: (Left) The cartoonish picture of our cavity. (Right) The calculated effective mode volume (coming soon). Ignore the current figure on the poster, it is just to bluff those not reading.

Cavity Construction

To couple the input mode into the cavity in the near concentric regime, we use anaclastic lens-mirror design, which reduces aberrations and cavity losses of the input mode. We move the mirrors with respect to each other using a 3-dimensional piezo (PZT).

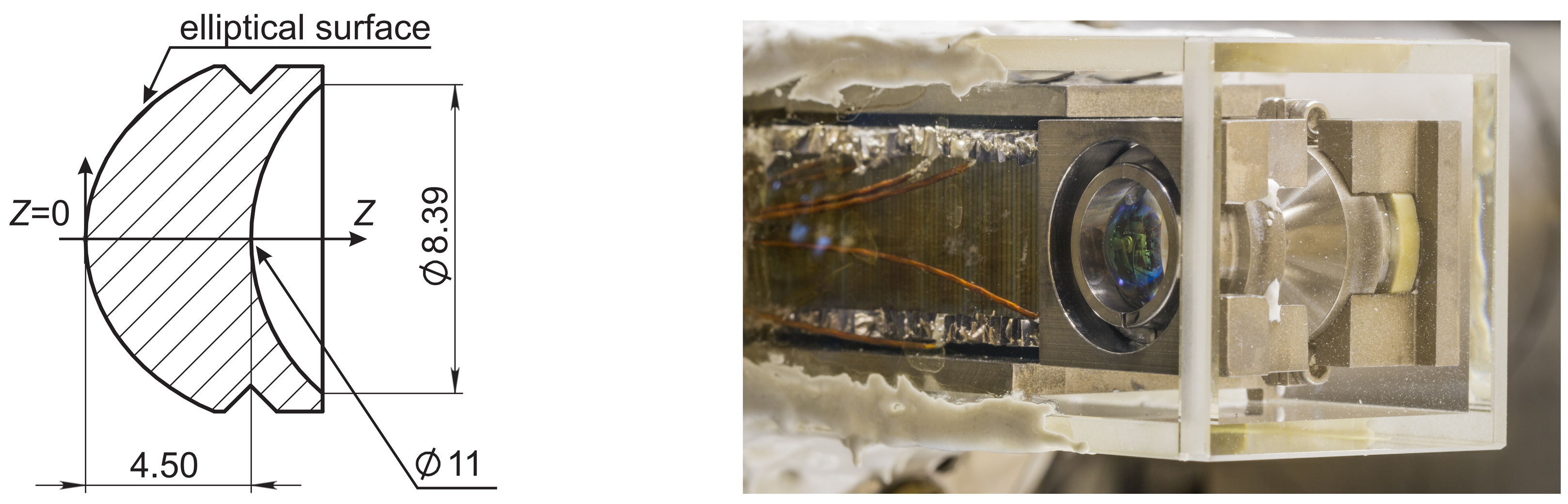

Figure 2: (Left) Anaclastic lens-mirror design. (Right) Anaclastic mirrors are controlled by a 3-axis PZTs for fine alignment.

Experimental Setup

Cold Rb atomic cloud is created inside the huge physical volume of the cavity using magnetic optical trap (MOT). Single atoms are loaded from the MOT to the cavity mode using far off resonant trap (FORT), after which we can perform experiments with a weak probe laser.

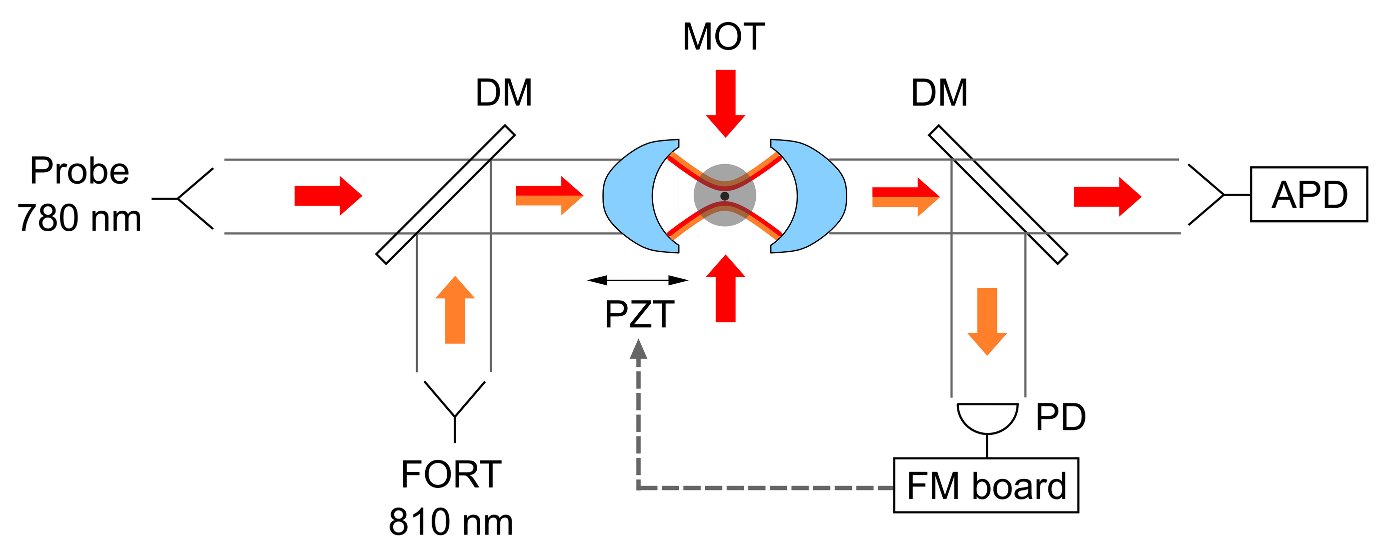

Figure 3: Experimental setup. Probe and FORT beams are combined using a dichoric mirror (DM) and coupled to the cavity, where the output mode is then split again using another DM. We use the output light from the FORT to stabilise the cavity length via frequency modulation (FM) technique.

Fluorescence Signal

To determine if single atoms are loaded in the cavity mode, we monitor the fluorescence originating from MOT laser on the cavity output. We trigger the start of the experiment when the fluorescence level exceeds a set threshold value.

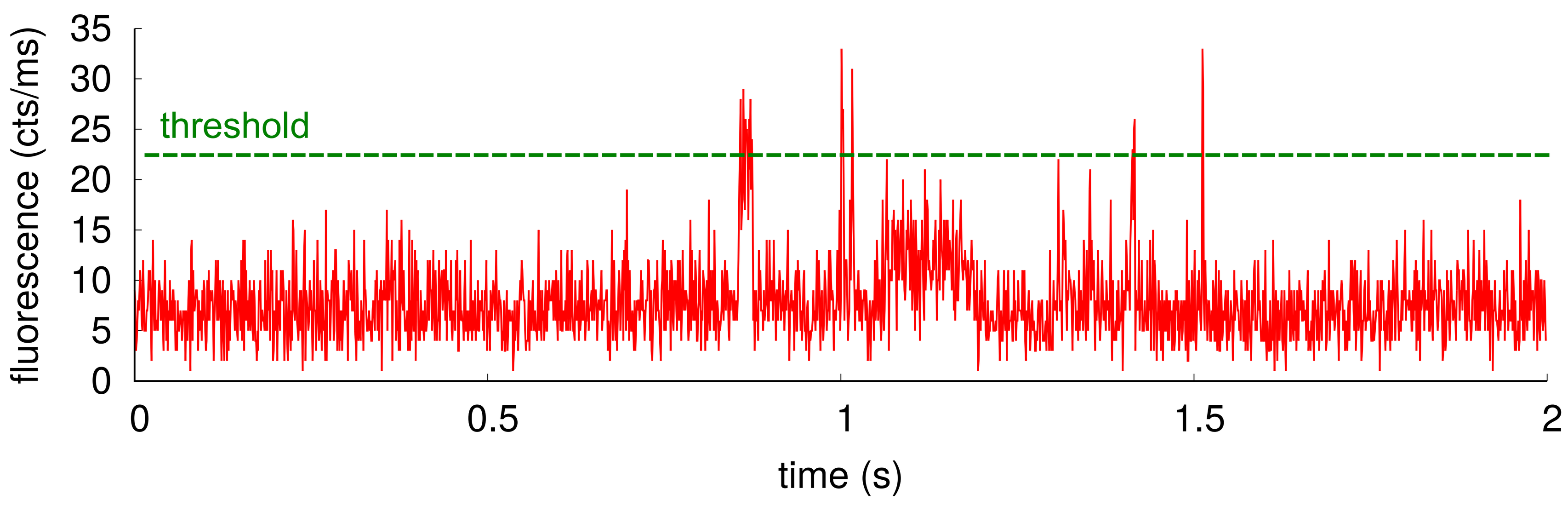

Figure 4: Fluorescence signal of the cavity (no triggering). Upon successful loading of single atoms, telegraphic quantum jump signals are observed.

After each triggering events, we monitor the fluorescence signal, from which we determine whether a single atom is trapped in the cavity mode (around 30% of all events).

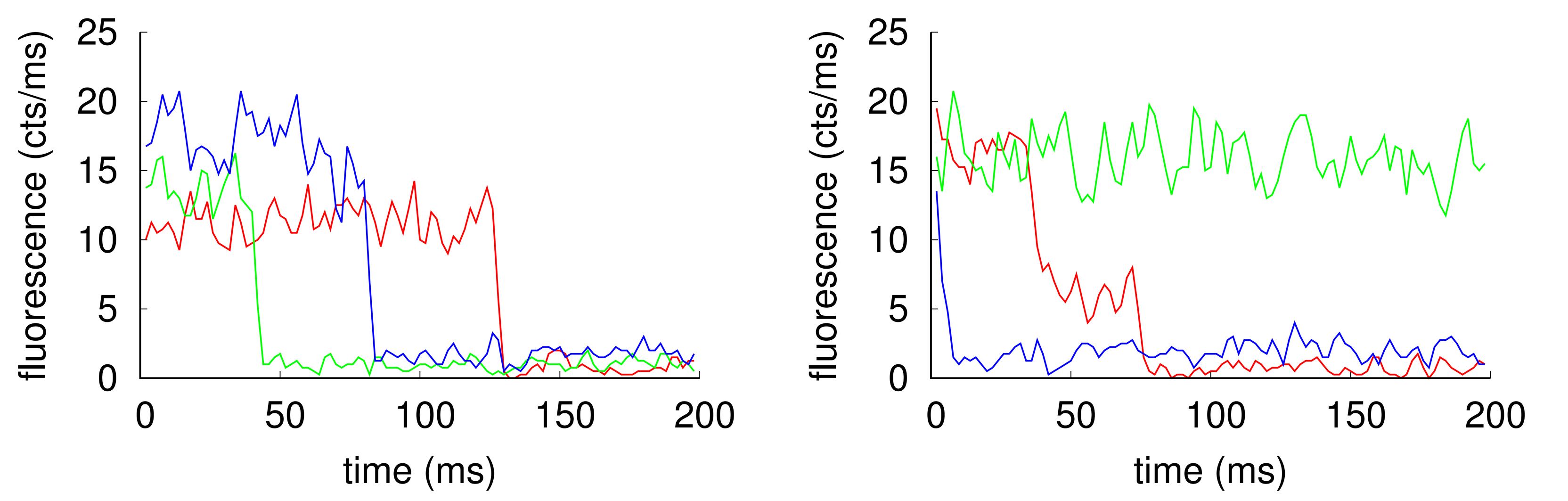

Figure 5: Sample of fluorescence signals (triggered) due to a single atom (left), or a few atoms or inconclusive - too short or too long (right).

Transmission Signal

After each successful triggering events, we send alternating pulses (1 ms long) of weak probe laser and MOT laser to monitor the transmission and fluorescence of the cavity. This dual-monitoring method allows us to post-select the single atom events and to determine when the trapped atom escapes out from the cavity mode.

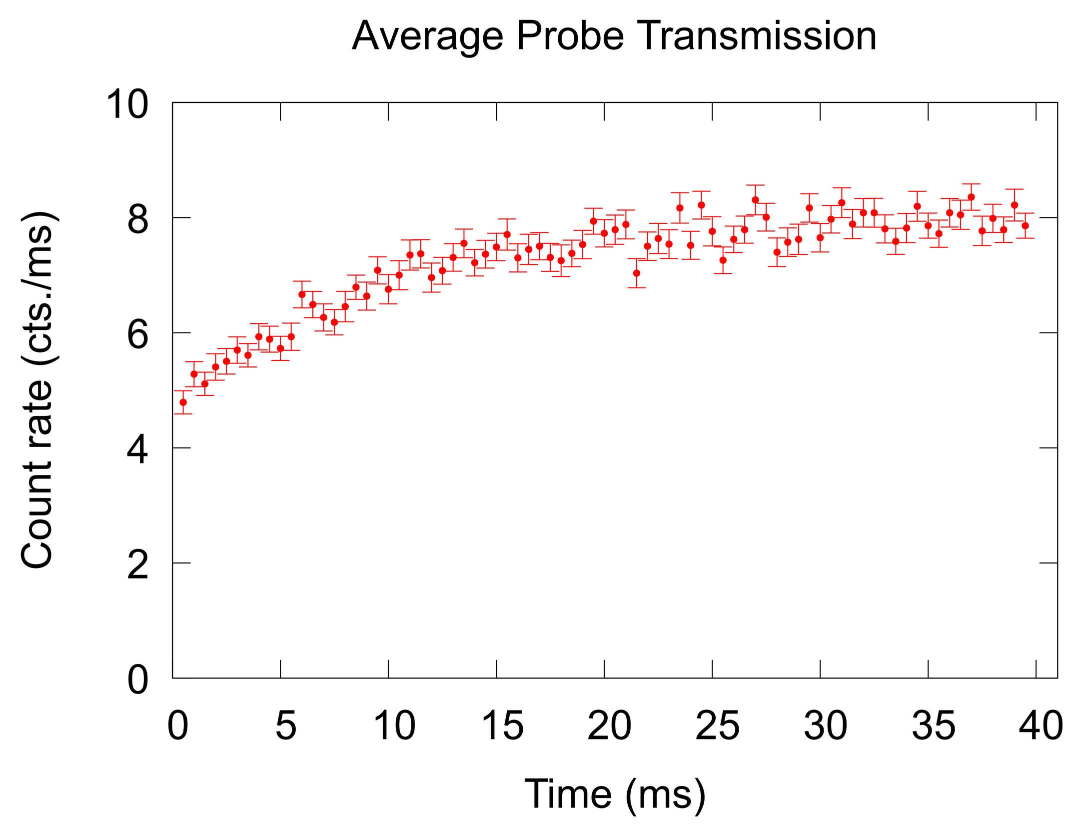

Figure 6: Average of fluorescence (left) and transmission (right) signal after each triggering events. The probe frequency is tuned to atom-cavity resonance to observe high extinction in the transmission signal.

Normal Mode Splitting

We observed normal mode splitting in the cavity transmission spectrum due to the presence of a single atom in the cavity mode. The CQED system parameters are estimated to be $(g, \kappa, \gamma) = 2\pi \times (10, 40, 3)\,\mathrm{MHz}$, with the single atom cooperativity $C = 0.4$.

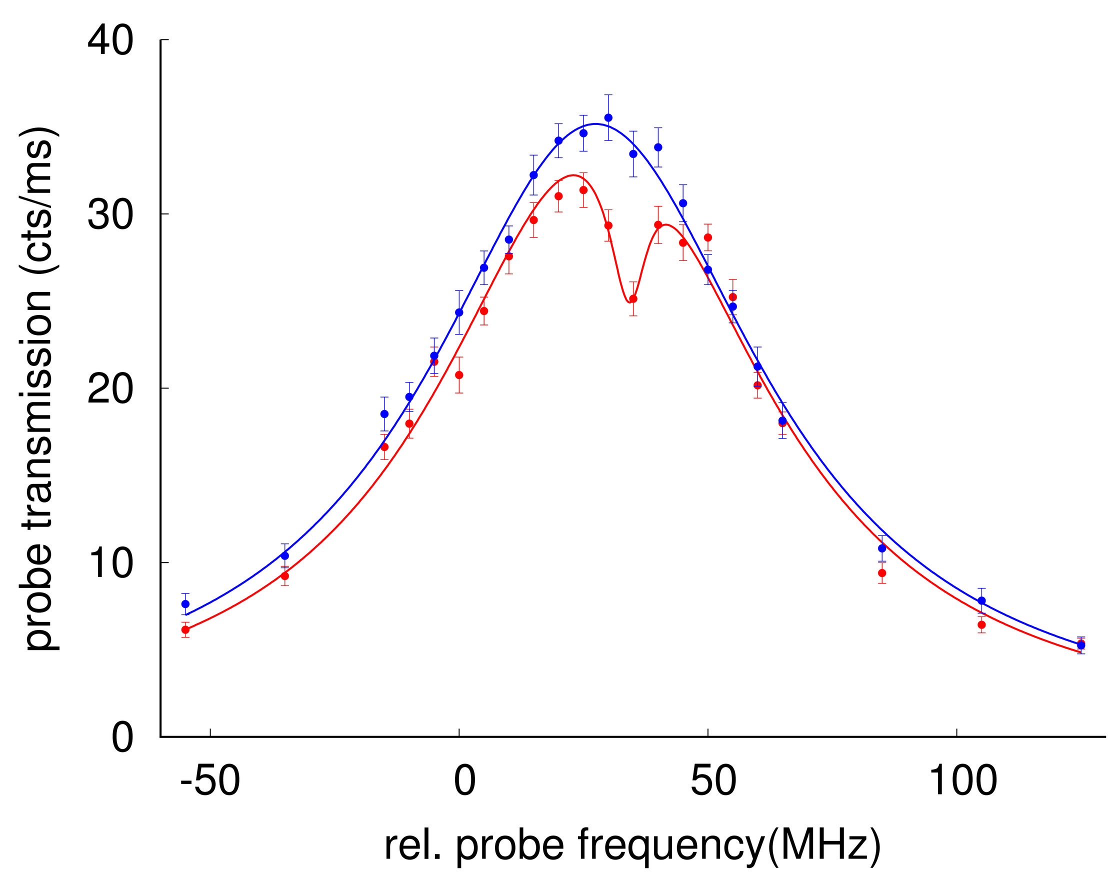

Figure 7: Cavity transmission spectrum of a weak probe laser, with no trapped atoms (blue) and a trapped single atom (red). The cavity is tuned close ($\sim 5\,\mathrm{MHz}$) to the atomic resonance (shifted $34 \pm 2\,\mathrm{MHz}$ from bare resonance due to a.c. stark shift from the FORT laser). The solid lines represent best fit to Lorentzian model (blue) and semiclassical CQED model (red).

Outlook

We demonstrate an operational intermediate coupling CQED system in nearly concentric regime with huge physical volume and relatively low finesse cavity. We hope to move towards strong coupling regime in the near future by replacing the cavity mirrors with the ones with higher finesse. Successful realisation of such CQED system will open opportunities for further explorations in strong atom-photon interaction and applications in quantum computing, in particular systems requiring huge physical volume and or low finesse mirrors.

References

[1] M.K. Tey et.al., New Journal of Physics **11**, 040311 (2009).
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[3] K. Durak et.al., New Journal of Physics **16**, 103002 (2014).