Filtered Photon Correlations of Fluorescence from a Driven Three Level Atom

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In this work we develop a theoretical approach to investigate the nature of the fluorescence emitted by a driven three level atom as studied by Gasparinetti et. al [1, 2]. Using trajectory theory to model a photon counting experiment, we employ frequency filtering techniques to isolate different peaks of the fluorescence spectrum [Fig. 1 (Left)] and explore the second order photon correlations.

The fluorescence is split and directed into two separate scanning interferometers (cavities) modelled as a cascaded system [3] with the Hamiltonian ($\hbar = 1$)

$$\hat{H} = \hat{H}_A + \Delta_a \hat{a}^\dagger \hat{a} + \Delta_b \hat{b}^\dagger \hat{b} + \frac{i}{2}\sqrt{\frac{\gamma\kappa_a}{2}}\left(\hat{\Sigma}^\dagger \hat{a} - \hat{\Sigma}\hat{a}^\dagger\right) + \frac{i}{2}\sqrt{\frac{\gamma\kappa_b}{2}}\left(\hat{\Sigma}^\dagger \hat{b} - \hat{\Sigma}\hat{b}^\dagger\right), \tag{1}$$

where $\Delta_a(\Delta_b)$ is the cavity resonance frequency detuning from the drive frequency, $\kappa_a(\kappa_b)$ is the full linewidth of cavity $a(b)$, $\hat{a}(\hat{b})$ and $\hat{a}^\dagger(\hat{b}^\dagger)$ are the photon annihilation and creation operators for cavity $a(b)$, γ is the atom decay rate and $\hat{\Sigma} = |g\rangle\langle e| + \xi|e\rangle\langle f|$ is the atom lowering operator with ξ the ratio of dipole moments for the two dipole transitions, $|g\rangle \leftrightarrow |e\rangle$ and $|e\rangle \leftrightarrow |f\rangle$; the atom has a ground state $|g\rangle$, an excited state $|f\rangle$ and an intermediate state $|e\rangle$ with respective eigen-frequencies, ω_g, ω_f and ω_e. The Hamiltonian for the driven atom is

$$\hat{H}_A = -\left(\frac{\alpha}{2} + \delta\right)|e\rangle\langle e| - 2\delta|f\rangle\langle f| + \frac{\Omega}{2}\left(\hat{\Sigma} + \hat{\Sigma}^\dagger\right), \tag{2}$$

where Ω is the driving field strength (Rabi frequency), $\delta = \omega_d - \omega_{fg}/2$ the detuning of the drive frequency from the two-photon transition and $\alpha = \omega_{fe} - \omega_{eg}$, where $\hbar\omega_{ij} = E_i - E_j$.

For a low driving strength Ω tuned to the two-photon resonance frequency $\omega_{fg}/2$, two single-photon peaks appear in the fluorescence spectrum corresponding to the cascaded decay of the atom [Fig. 1 (Left)]. The unfiltered photon correlation exhibits behaviour similar to that of a two-photon source [Fig. 1 (Right, black)]. By centering cavity a on the $|f\rangle \rightarrow |e\rangle$ transition ($\Delta_a = -|\alpha|/2$) and cavity b on the $|e\rangle \rightarrow |g\rangle$ transition ($\Delta_b = |\alpha|/2$), we find the auto-correlation of photons emitted by cavity a and the cross-correlation of photons emitted first by cavity a and after a delay τ by cavity b. We see anti-bunching for the $|f\rangle \rightarrow |e\rangle$ autocorrelation [Fig. 1 (Right, red)] and bunching for the $|e\rangle \rightarrow |g\rangle$ cross-correlation [Fig. 1 (Right, blue)]. As we increase the bandwidth for cavity b we find that the initial peak in the cross-correlation increases and becomes sharper as the response time of the cavity decreases.

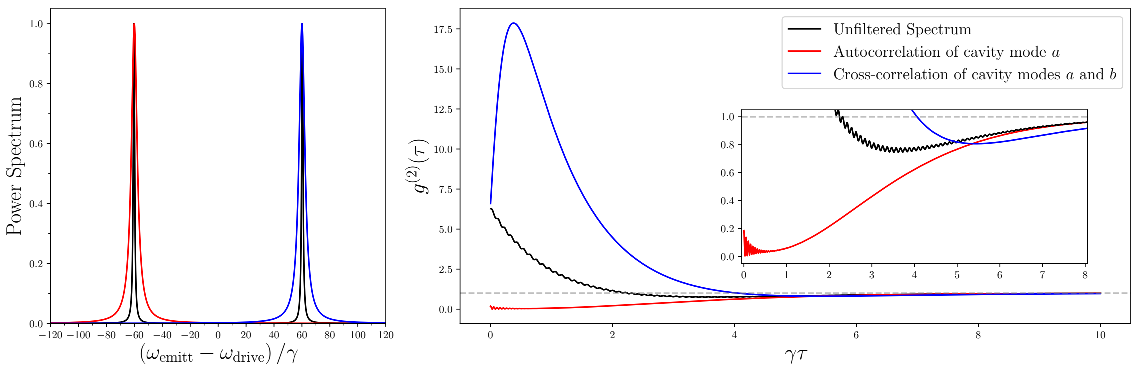

Figure 1: **(Left)** Fluorescence spectrum at two-photon resonance for a low drive strength (black). The filter profile for cavity $a(b)$ is shown in red (blue) over the peak it is resonant with. **(Right)** Correlation of the unfiltered fluorescence (black), filtered fluorescence (red), and the cross-correlated filtered fluorescence (blue). The parameters for these plots are, in units of γ, $(\Omega, \delta, \xi, \alpha, \Delta_1, \kappa_1, \Delta_2, \kappa_2) = (5.0, 0.0, 1.0, -120.0, -60.0, 5.0, 60.0, 5.0)$.

References

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