Antiresonance Phase shift in strongly coupled cavity QED

C. Sames et al., PRL **112**, 043601 (2014).

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Group summary

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Experiments with single photons and individual atoms
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1 director
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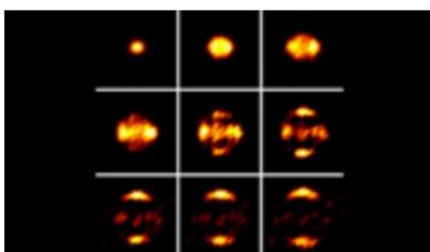
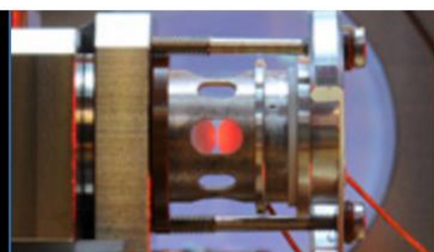
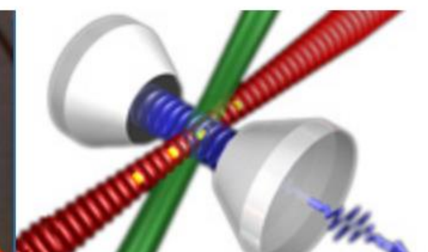
1 postdoc
5 technicians
3 assistants
16 doctoral candidates
4 master student



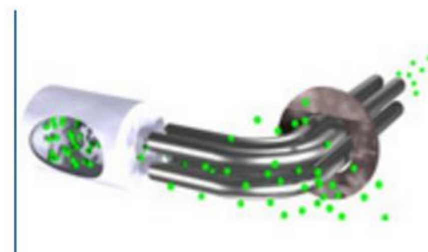
▸ **Bose Einstein Condensation (BEC)**



▸ **Cavity Quantum Electrodynamics**

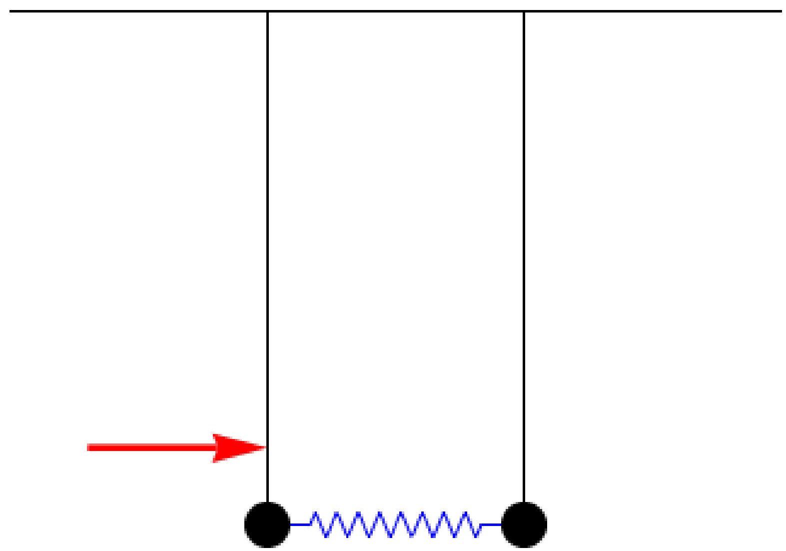


▸ **Quantum Information Processing**



▸ **Cold Polar Molecules**

Anti-resonance of coupled oscillators



- At anti-resonance frequency, one oscillators has a minimum in the aplitude and large shift in oscillation phase.

- Anti-resonances are caused by destructive interference between an external driving force and an interaction with another oscillator.

Anti-resonance of coupled oscillators

- $$\begin{cases} \ddot{x_1} + 2\gamma_1 \dot{x_1} + \omega_1^2 x_1 - 2g\omega_1 x_2 = 2F\cos\omega t \\ \ddot{x_2} + 2\gamma_2 \dot{x_2} + \omega_2^2 x_2 - 2g\omega_2 x_1 = 0 \end{cases}$$

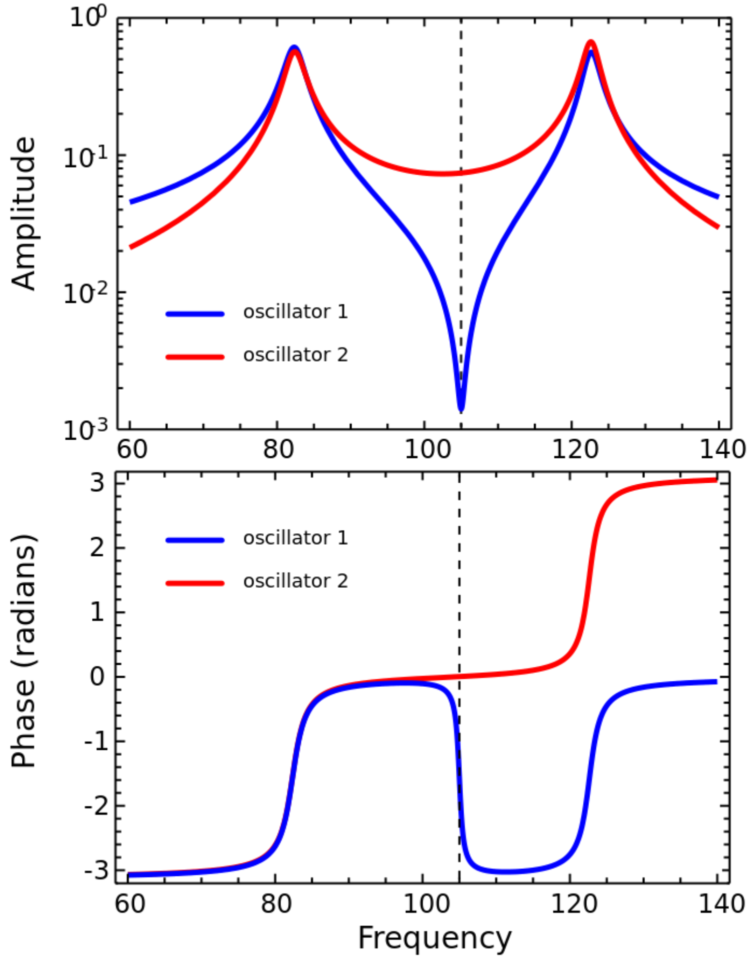
- $$\begin{cases} \alpha_1 = \omega_1 x_1 + ip_1/m_1 \\ \alpha_2 = \omega_2 x_2 + ip_2/m_1 \\ \Delta_i = \omega - \omega_i \end{cases}$$

In rotating frame of ω, with r.w.a.,

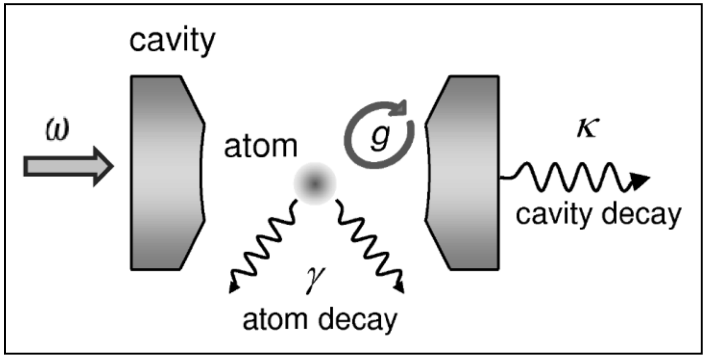
- $$\begin{cases} \dot{\alpha_1} = i(\Delta_1 + i\gamma_1)\alpha_1 - ig\left(\frac{\omega_1}{\omega_2}\right)\alpha_2 + iF \\ \dot{\alpha_2} = i(\Delta_2 + i\gamma_2)\alpha_2 - ig\left(\frac{\omega_2}{\omega_1}\right)\alpha_1 \end{cases}$$

Steady state solution is

- $$\begin{cases} \alpha_{1,ss} = \frac{-F(\Delta_2 + i\gamma_2)}{(\Delta_1 + i\gamma_1)(\Delta_2 + i\gamma_2) - g^2} \\ \alpha_{2,ss} = \frac{\omega_2}{\omega_1}\frac{-Fg}{(\Delta_1 + i\gamma_1)(\Delta_2 + i\gamma_2) - g^2} \end{cases}$$



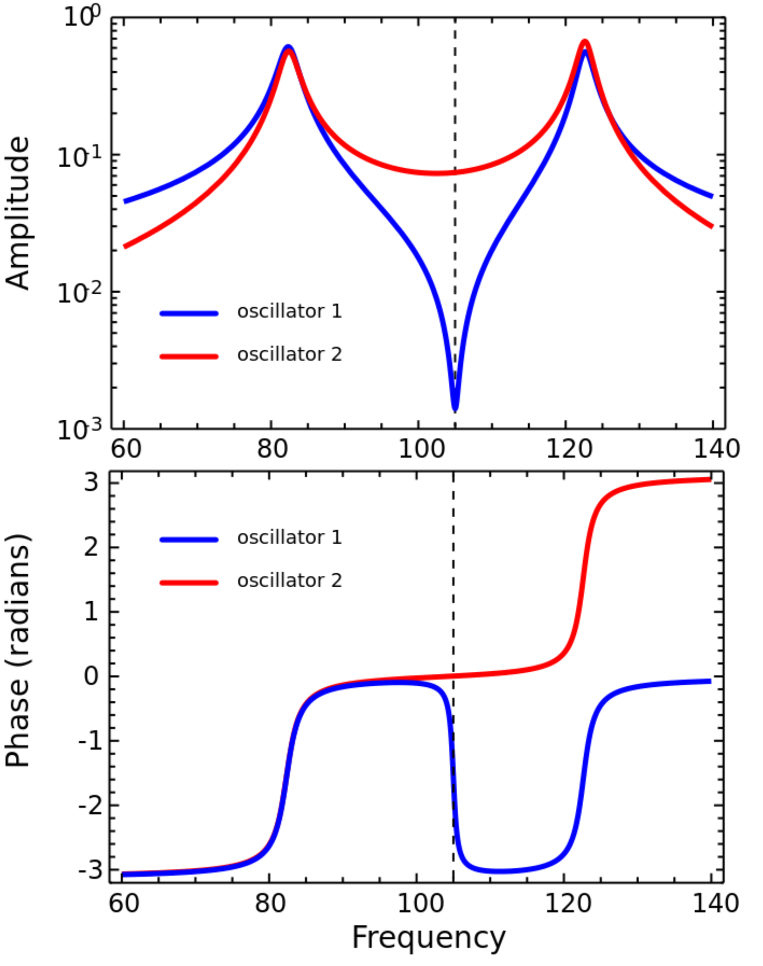
Anti-resonance of atom-cavity system



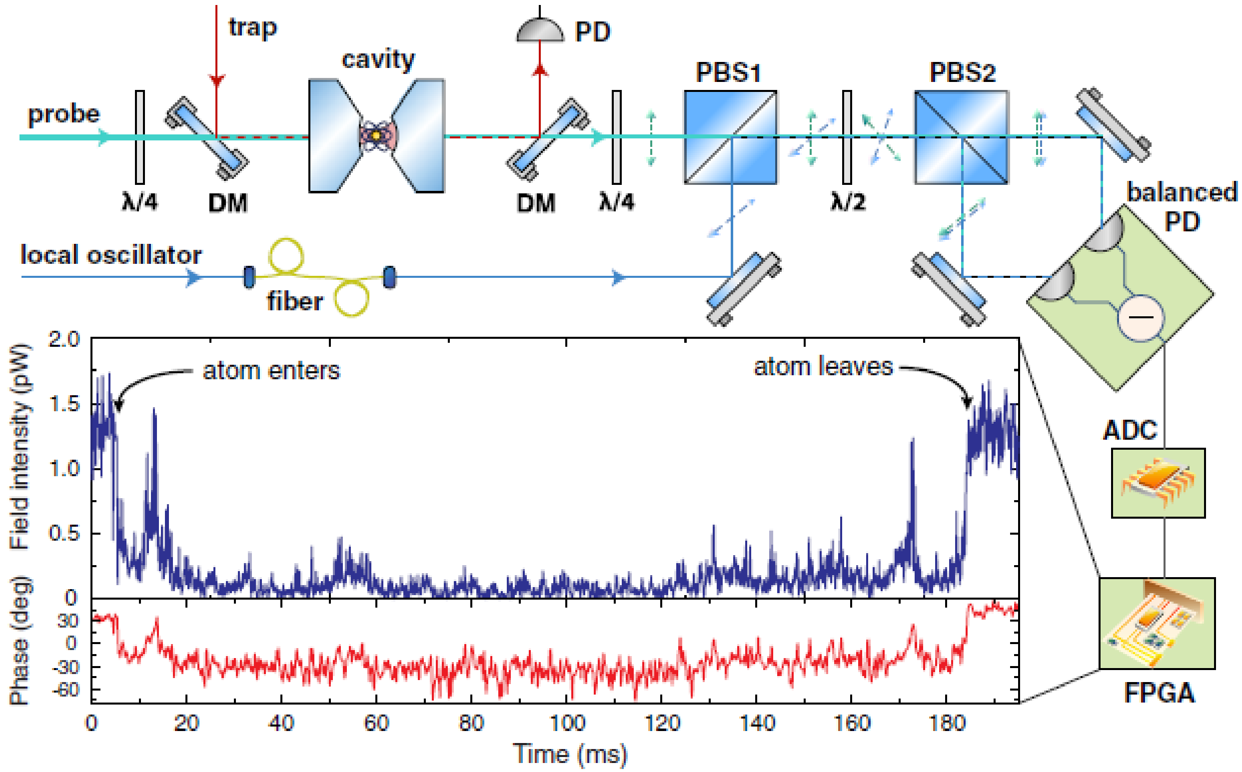
$$\langle \hat{a} \rangle = \frac{\eta(\Delta_{\rm pa} + i\gamma)}{(\Delta_{\rm pa} + i\gamma)(\Delta_{\rm pc} + i\kappa) - g^2}$$

$$\begin{cases} \Delta_{pa} = \omega - \omega_{atom} \\ \Delta_{pc} = \omega - \omega_{cavity} \end{cases}$$

$$※ \begin{cases} \alpha_{1,ss} = \frac{-F(\Delta_2 + i\gamma_2)}{(\Delta_1 + i\gamma_1)(\Delta_2 + i\gamma_2) - g^2} \\ \alpha_{2,ss} = \frac{\omega_2}{\omega_1} \frac{-Fg}{(\Delta_1 + i\gamma_1)(\Delta_2 + i\gamma_2) - g^2} \end{cases}$$

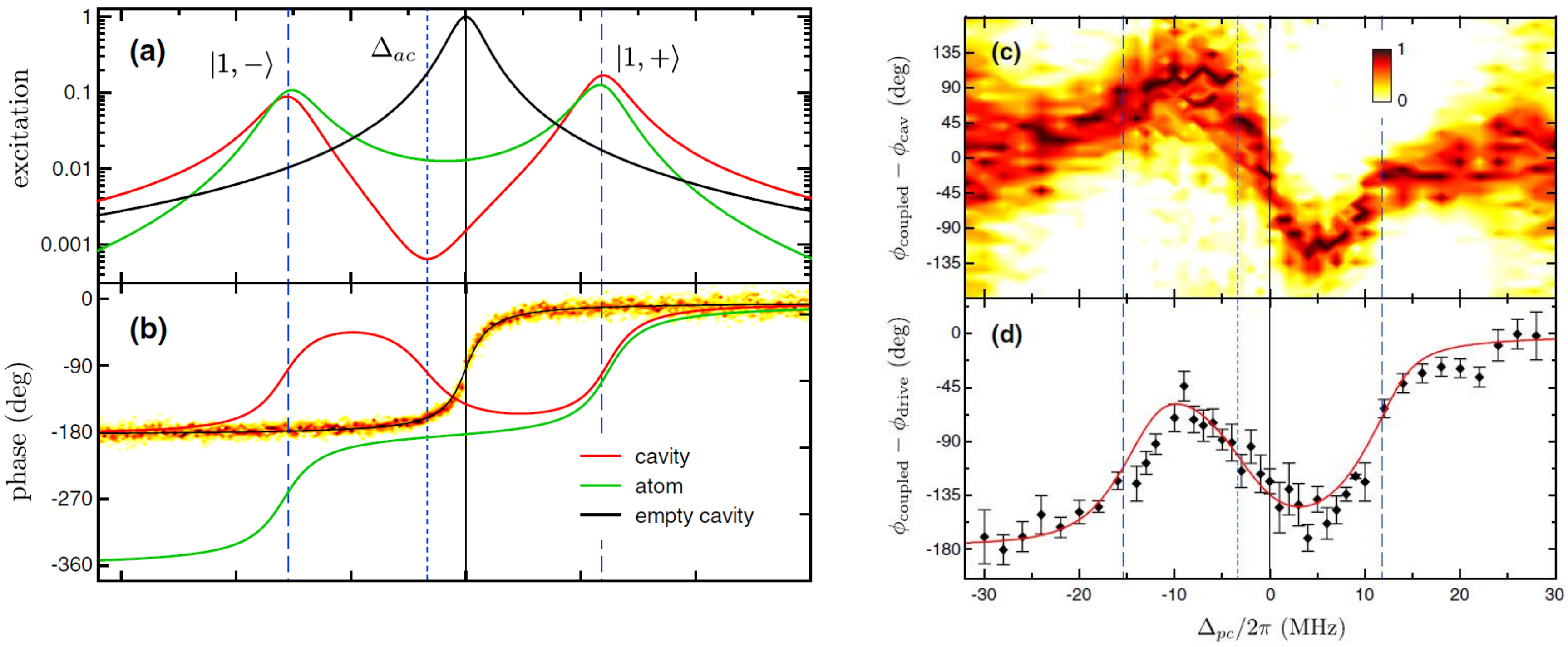


3. Experimental setup



- Single ^{85}Rb in intra-cavity dipole trap (785nm)
- Heterodyne measurement
- Strong coupling: $(g_0, \gamma, \kappa)/2\pi$=(16, 3.0, 1.5)MHz
- ω_{atom} is controllable by ac Stark shift

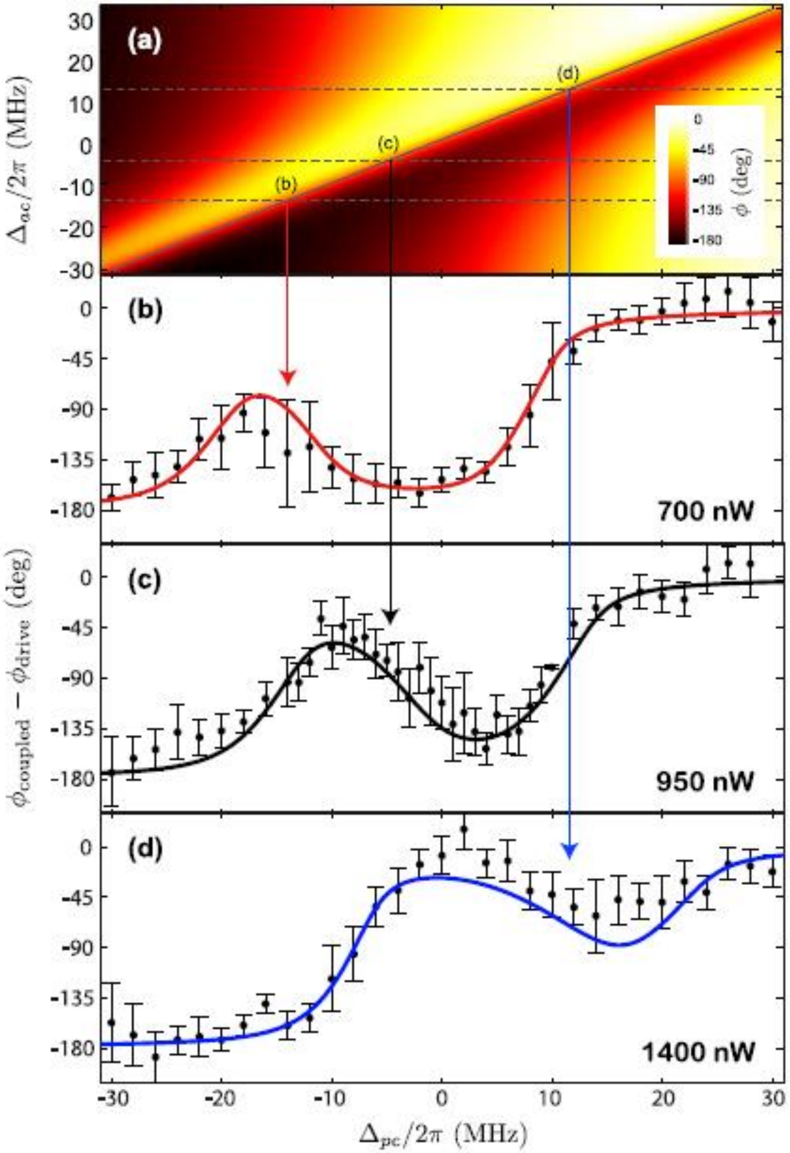
4. Result: Δ_{pc} vs. phase shift



- Anti-resonant frequency is at $\Delta_{pa} = 0$. i.e. $\Delta_{pc} = \Delta_{ac} = -3MHz$
- Negative slope occurs at anti-resonant frequency.

$$\langle \hat{a} \rangle = \frac{\eta(\Delta_{pa} + i\gamma)}{(\Delta_{pa} + i\gamma)(\Delta_{pc} + i\kappa) - g^2}$$

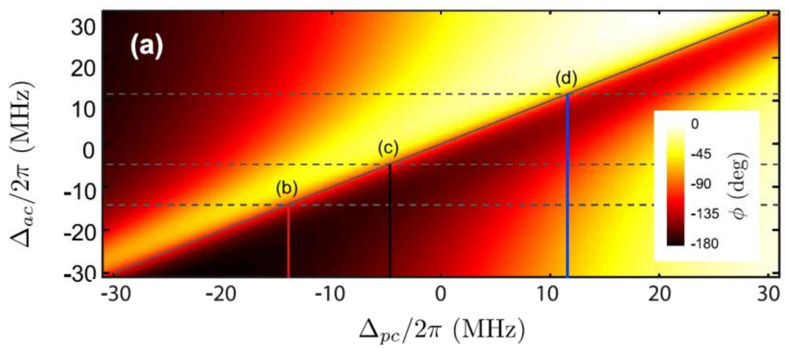
5. Result: Δ_{pc} vs. phase shift, varying Δ_{ac}

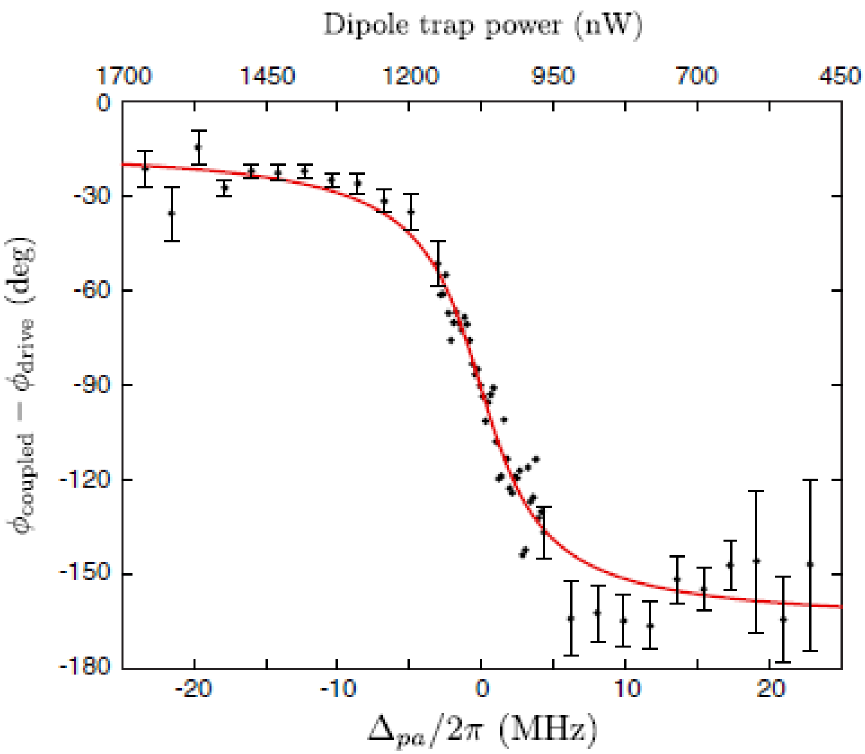


- $\Delta_{ac} = (-14, -5, 12)MHz$
- Netagive slope is at anti-resonant frequency.

$$\langle \hat{a} \rangle = \frac{\eta(\Delta_{\mathrm{pa}} + i\gamma)}{(\Delta_{\mathrm{pa}} + i\gamma)(\Delta_{\mathrm{pc}} + i\kappa) - g^2}$$

5. Result: Δ_{pa} vs. phase shift





- $\Delta_{pc} = 0MHz$.
- $\Delta_{pa} = \Delta_{\mathrm{ca}}$ is controlled by dipole trap power.
- 140 degree of phase shift is largest yet observed from a single emitter.

$$\langle \hat{a} \rangle = \frac{\eta(\Delta_{\mathrm{pa}} + i\gamma)}{(\Delta_{\mathrm{pa}} + i\gamma)(\Delta_{\mathrm{pc}} + i\kappa) - g^2}$$