Autler-Townes spectroscopy in a Mn-doped InAs/GaAs quantum dot

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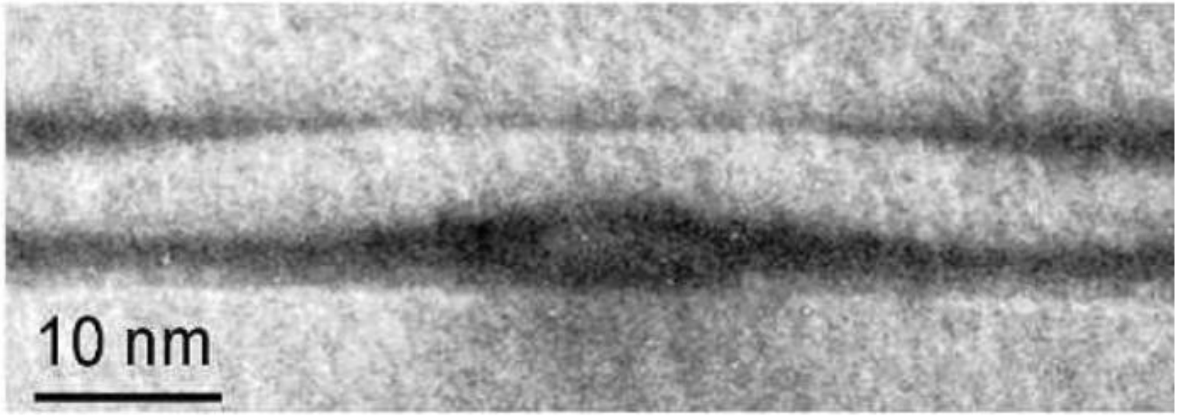
Mn-doped InAs/GaAs quantum dot

- Self-assembled InAs/GaAs quantum dot (QD)
- Applications
  - Single photon sources
  - Quantum memories



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  - Single photon sources
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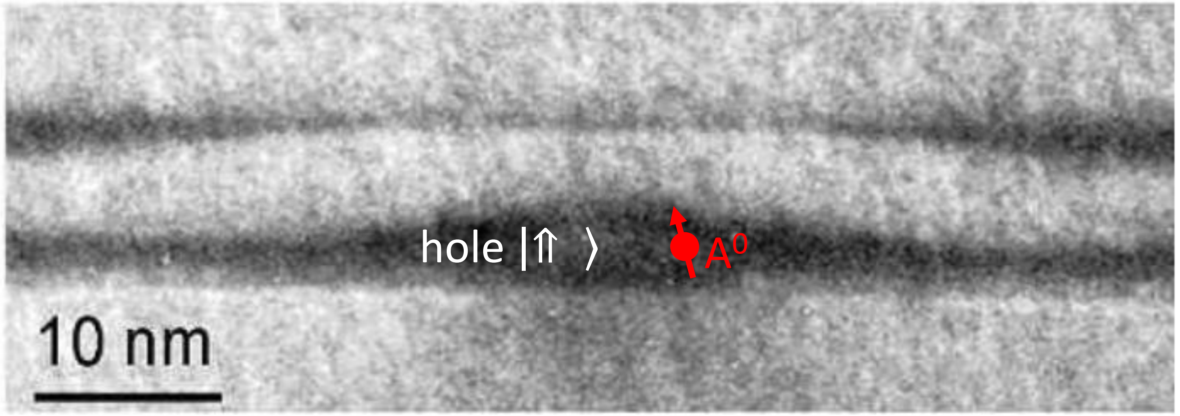
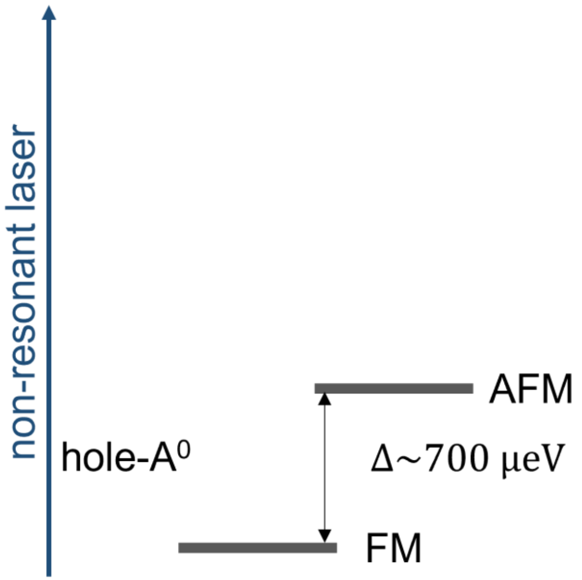
- QD with a single Mn dopant
- Single Mn dopant (A^0) provides a $|\pm 1\rangle$ spin state
- Exchange interaction with a confined hole:
  - ferromagnetic $|\pm 1, \pm\frac{3}{2}\rangle$, antiferromagnetic configuration $|\pm 1, \mp\frac{3}{2}\rangle$





A. Kudelski, et al., Phys. Rev. Lett. 99, 247209 (2007)
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- Optical transitions: Double Λ system

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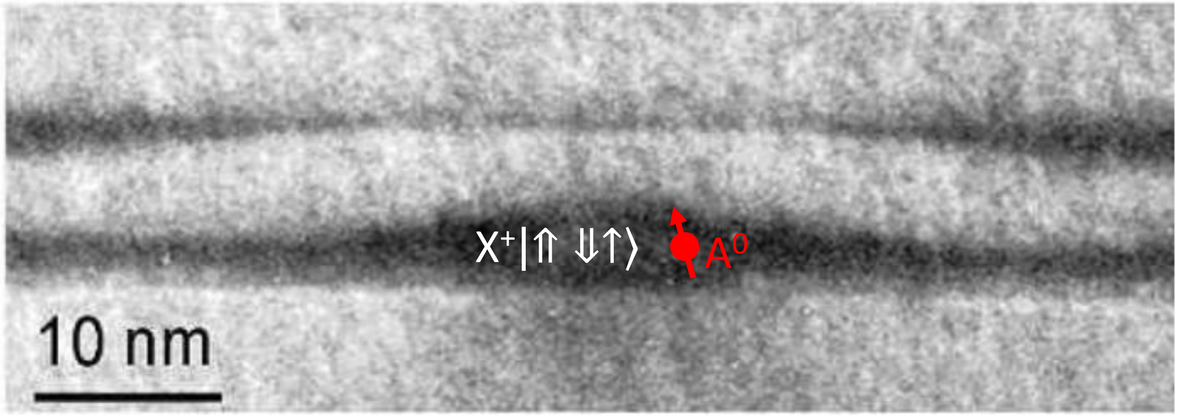
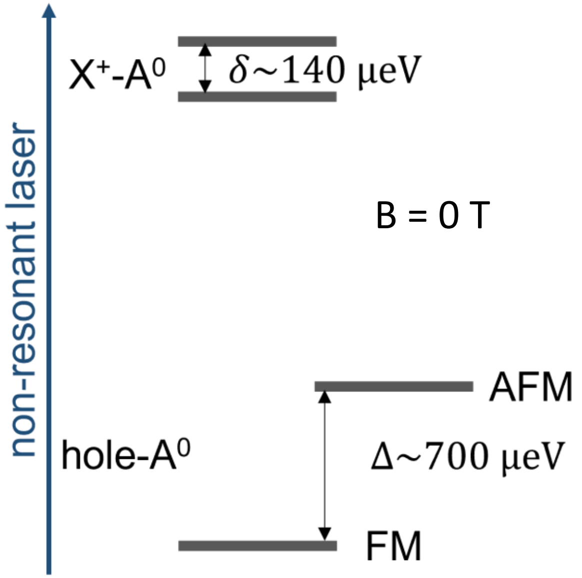
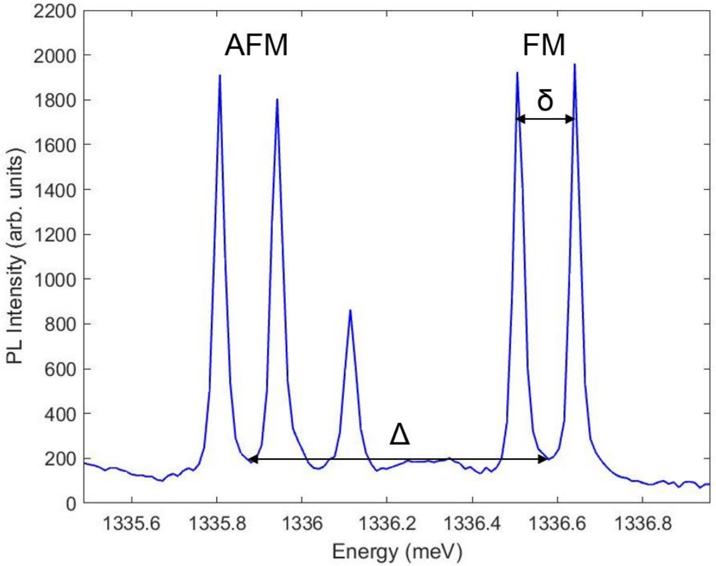
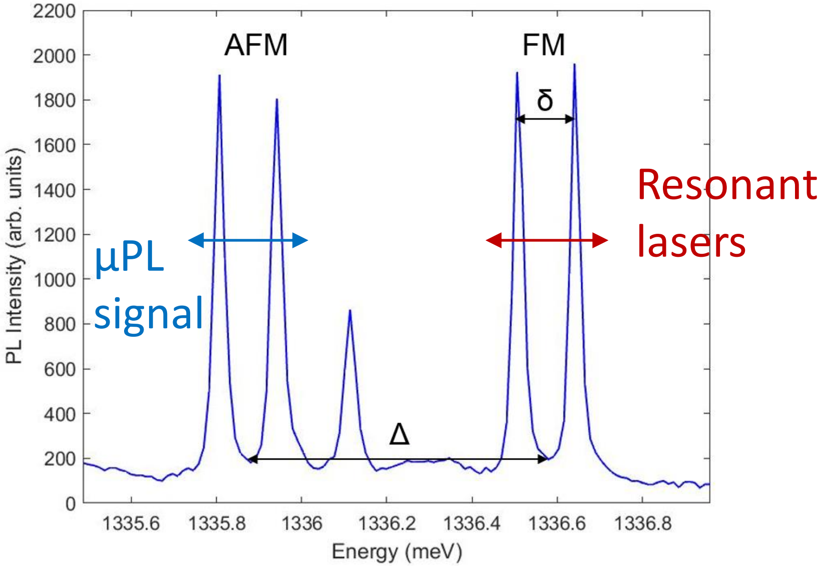


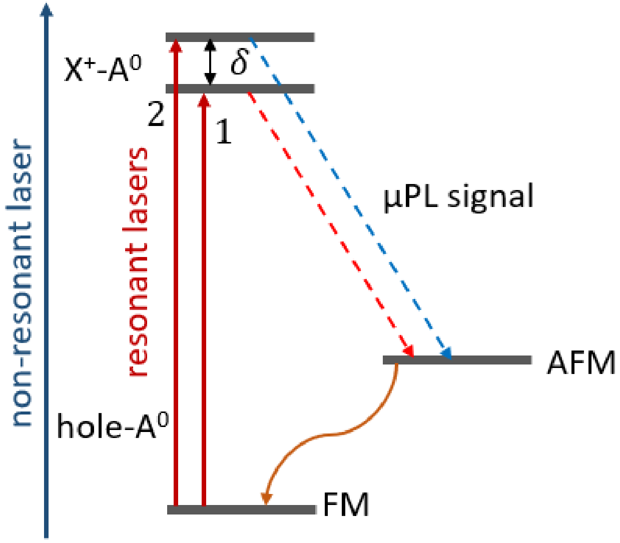


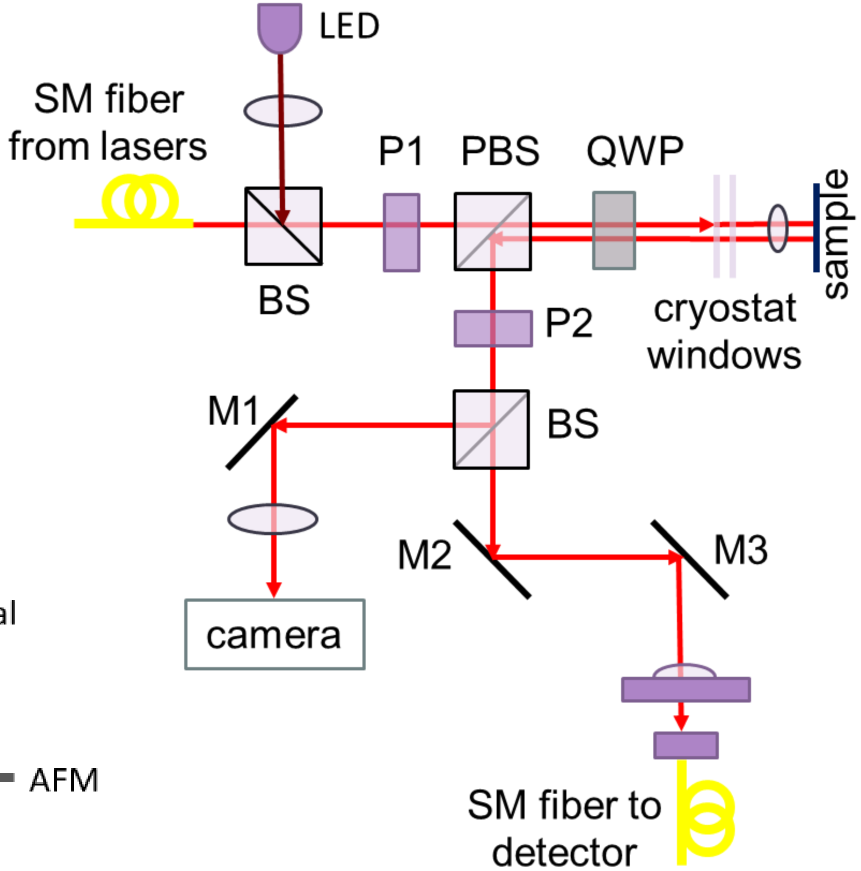


Motivation/Experimental setup

- Coherent probing of these transitions by resonant spectroscopy
- Dark field confocal microscope
- H/V cross-polarized configuration
- Typical laser extinction 10^6-10^7

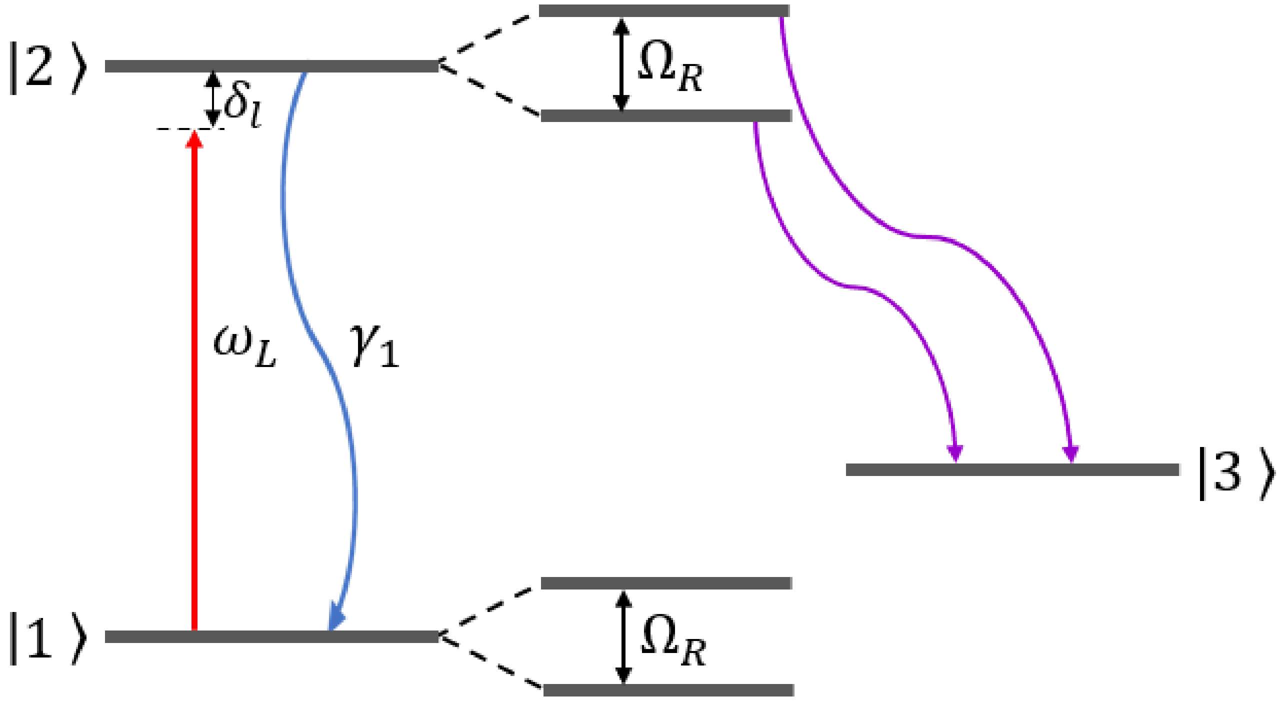




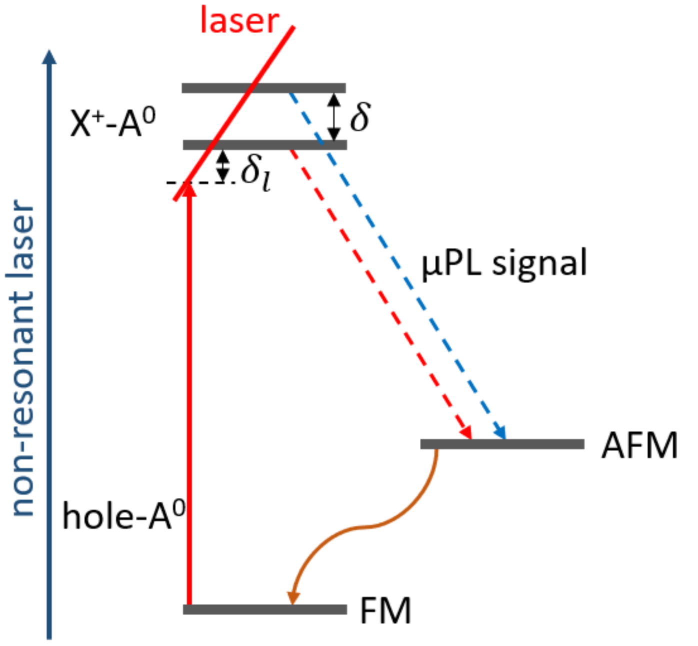


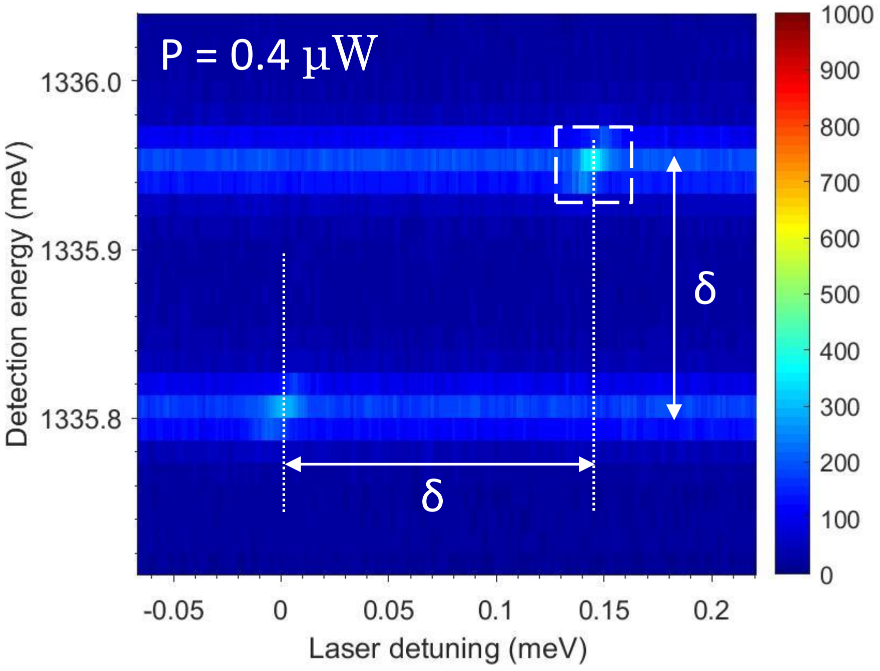
Optically driven QD near resonance

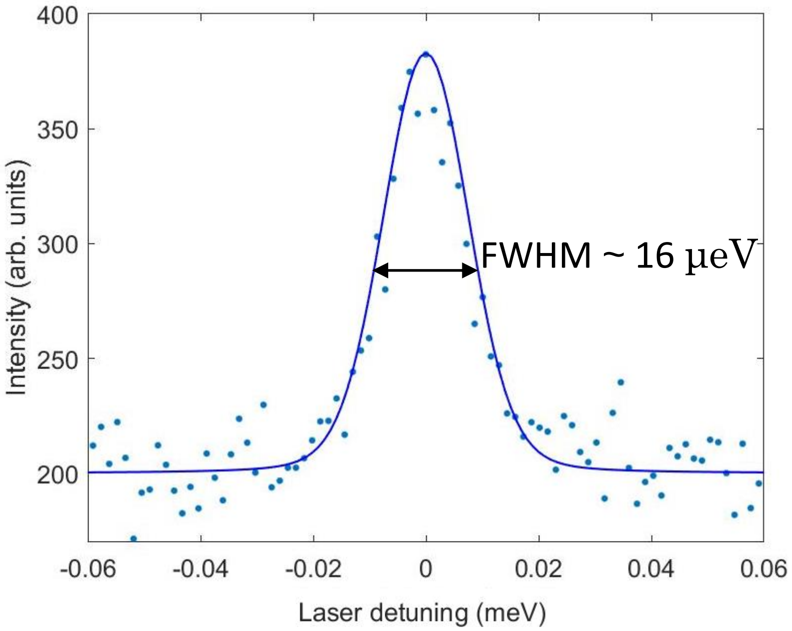
- Strong field light-matter interaction
- **Autler-Townes splitting**
- Sufficiently strong resonant driving field -> dressed states
- generalised Rabi frequency $\Omega_R = \sqrt{\Omega_0^2 + \delta_l^2}$
- Scales as $\Omega_R \sim \sqrt{P}$
- Autler-Townes effect observed in Λ system



Single-laser probing



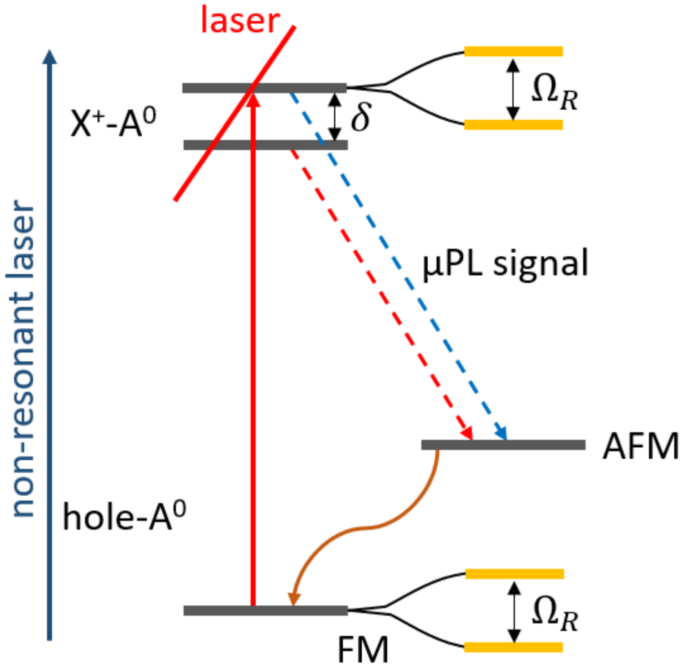




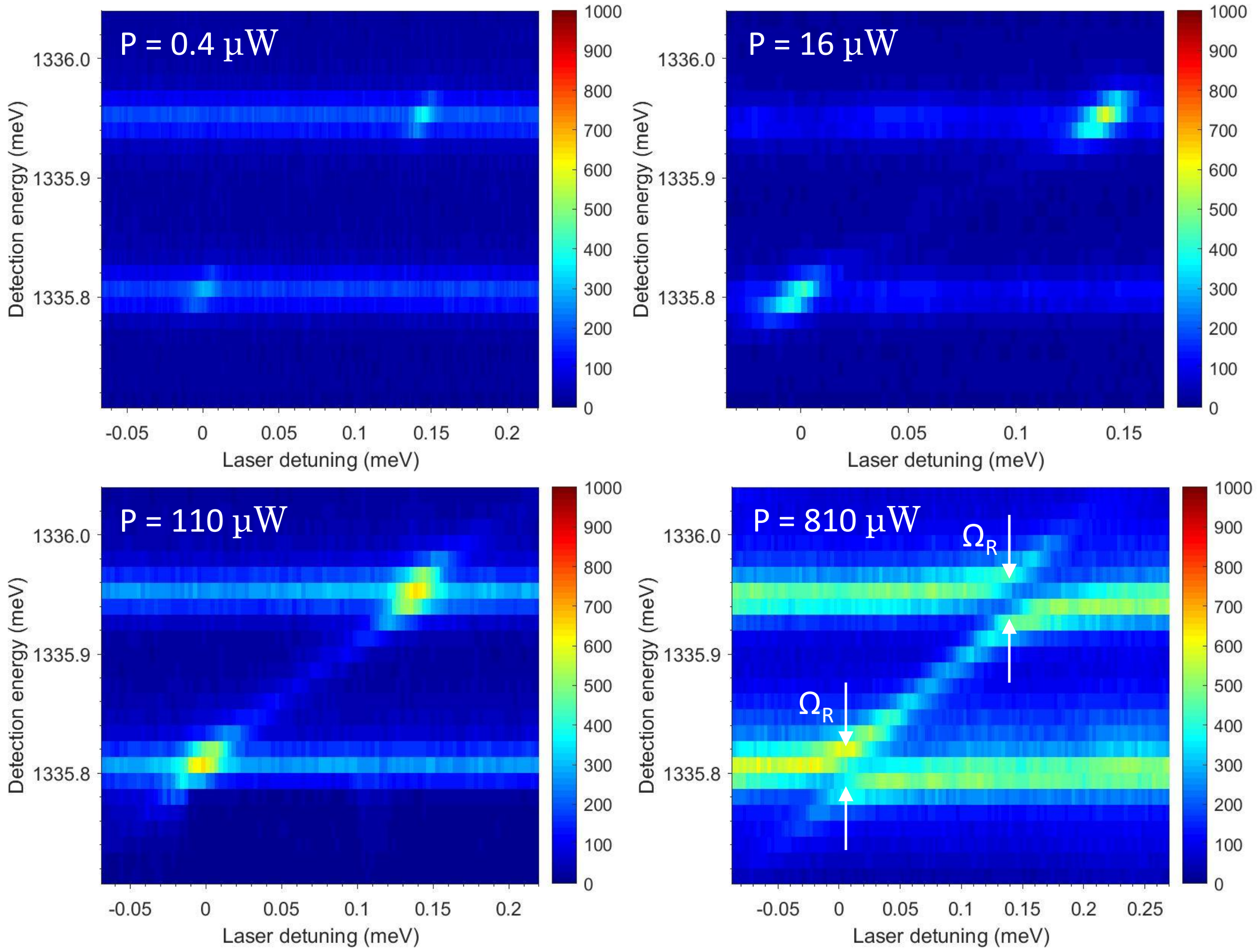
- ○ Resonance linewidth (~16 μeV)
- ○ Natural QD linewidth (~1.5 μeV)

→ Spectral diffusion

Single-laser probing



- What if we increase the power of resonant laser?
- Raman line
- Autler-Townes splitting Ω_R resolved



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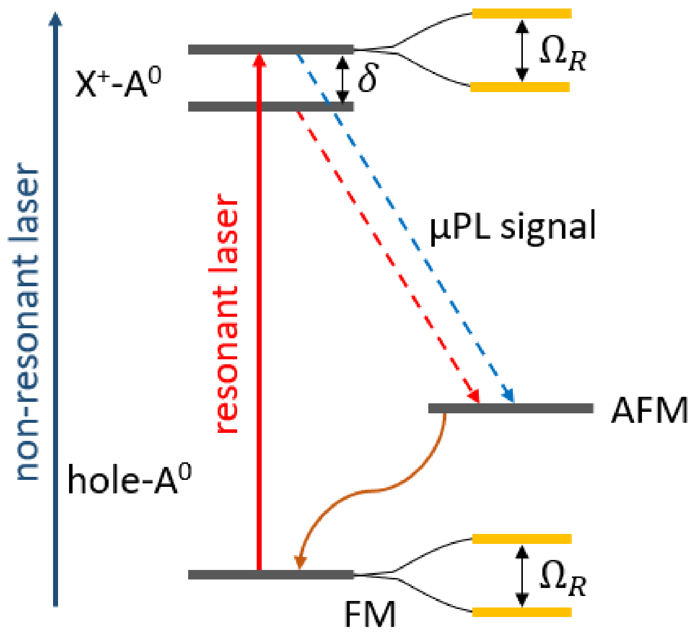
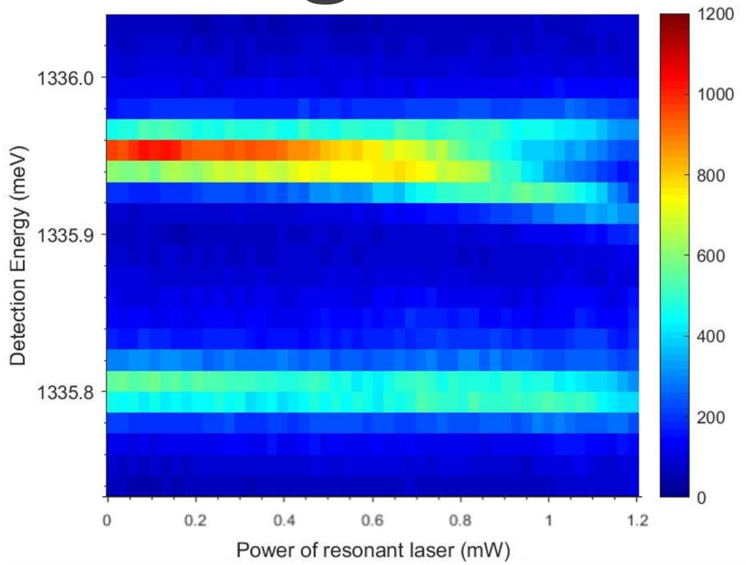
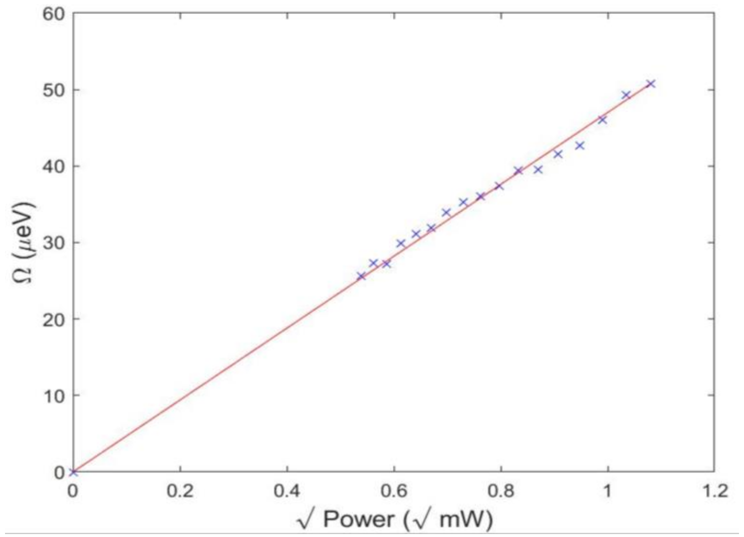


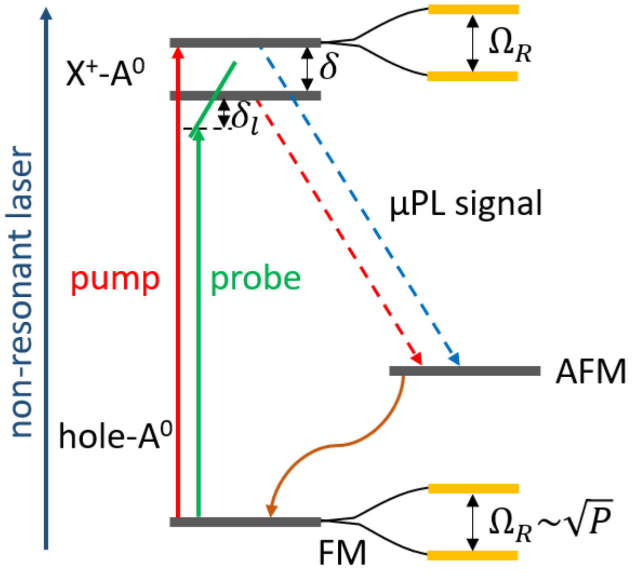


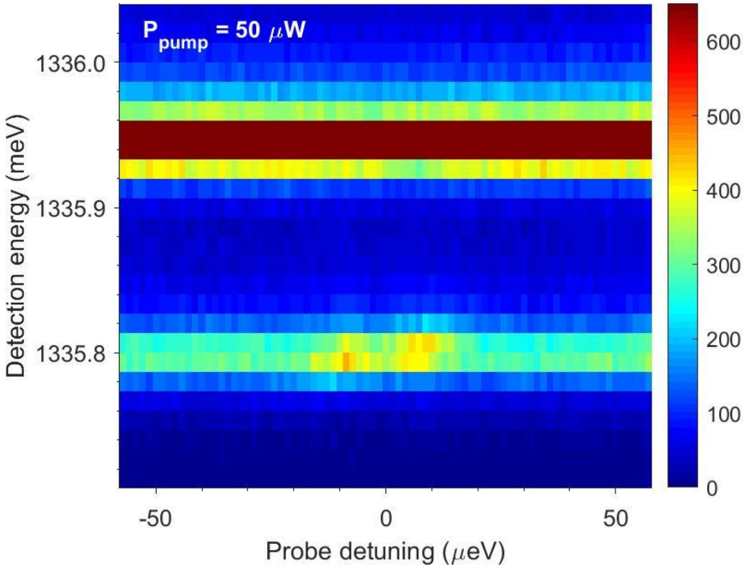


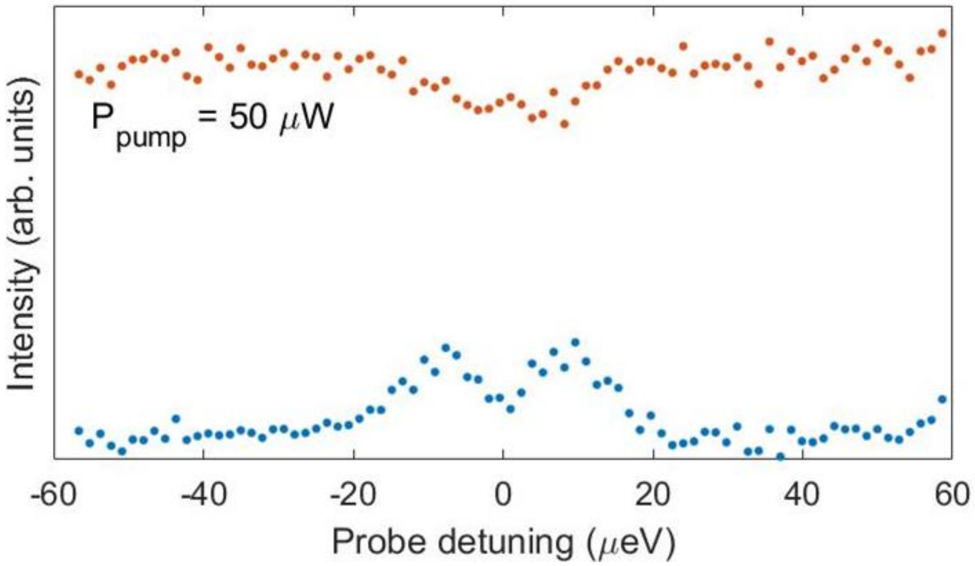
- Autler-Townes splitting Ω_R resolved
- Ω_R shows square root power dependence
- $\Omega_R = k\sqrt{P}$
- Saturation power $P \sim 1\ \mu W$

Two-laser probing

- AT splitting probed by second laser
- Fixed strong laser – pump
- Scanning laser of lower power – probe

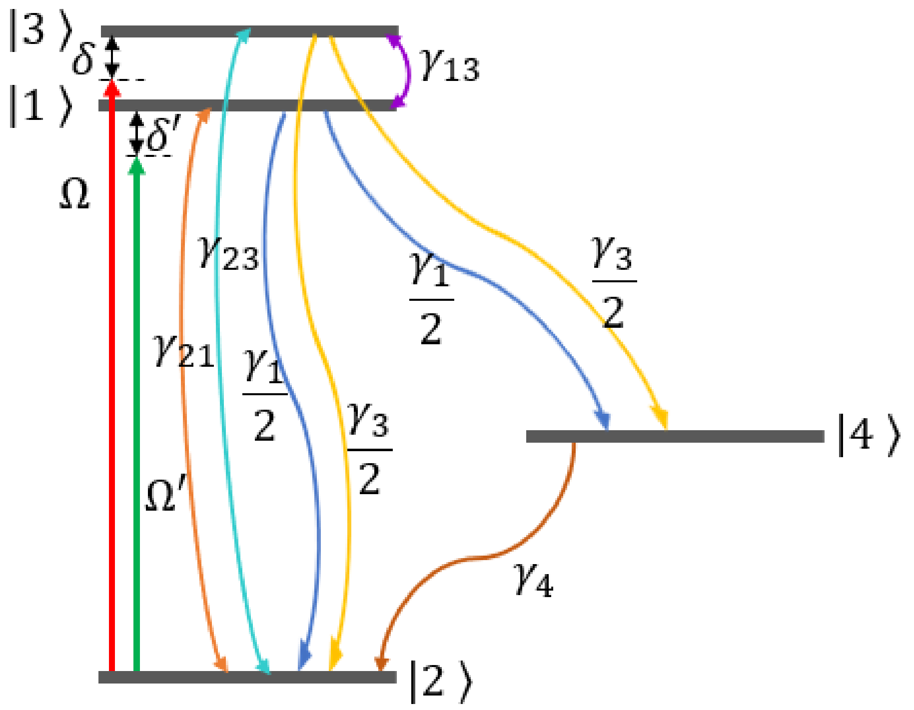






- Model that describes this system?

Model



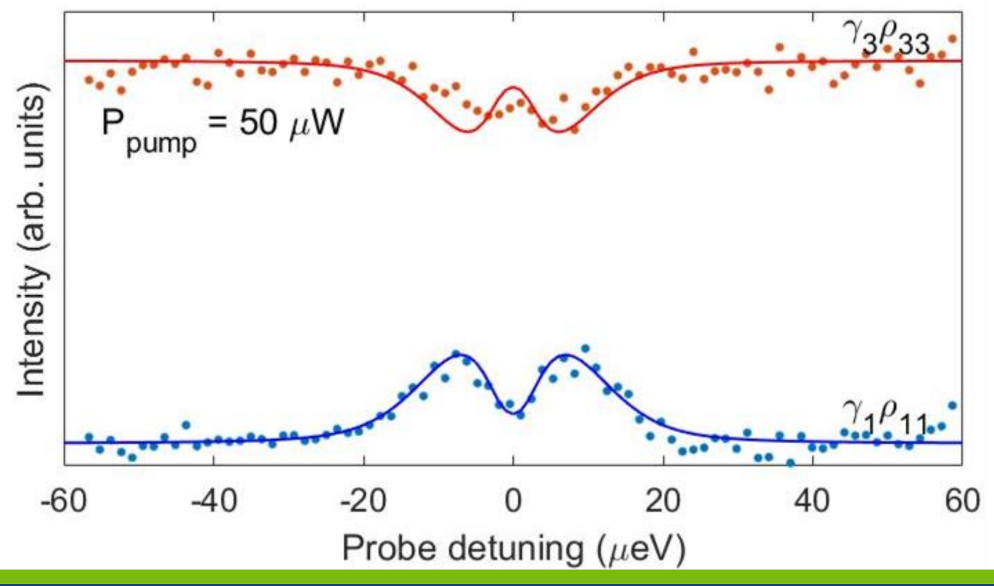
- Rabi frequencies

$(\Omega = k\sqrt{P},\ \Omega' = k'\sqrt{P'})$

- laser detunings δ, δ'
- population decay rate γ_i
- pure dephasing rate Γ_{ij}

$$\gamma_{21} = \frac{\gamma_1}{2} + \Gamma_{21}$$
$$\gamma_{13} = \frac{\gamma_1 + \gamma_3}{2} + \Gamma_{13}$$
$$\gamma_{23} = \frac{\gamma_3}{2} + \Gamma_{23}$$

- Density matrix equations
- Rotating wave approximation
- Steady-state regime
- Inhomogeneous broadening (assuming Gaussian distribution of (FWHM ~16 μeV))
- Numerical solution
- Parameters: $\gamma_1 = 1\ \mu eV, \gamma_3 = 1.1\ \mu eV,$
  $\gamma_4 = 0.07\ \mu eV, \Gamma_{21} = \Gamma_{23} = \Gamma_{13} = 0\ \mu eV$



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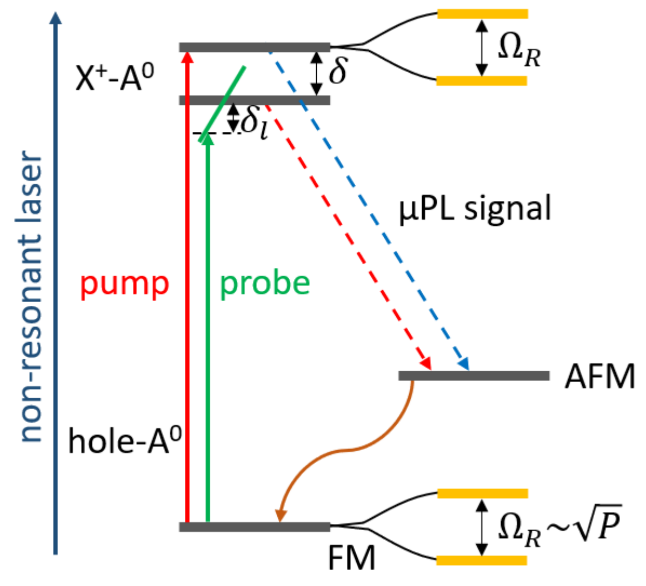
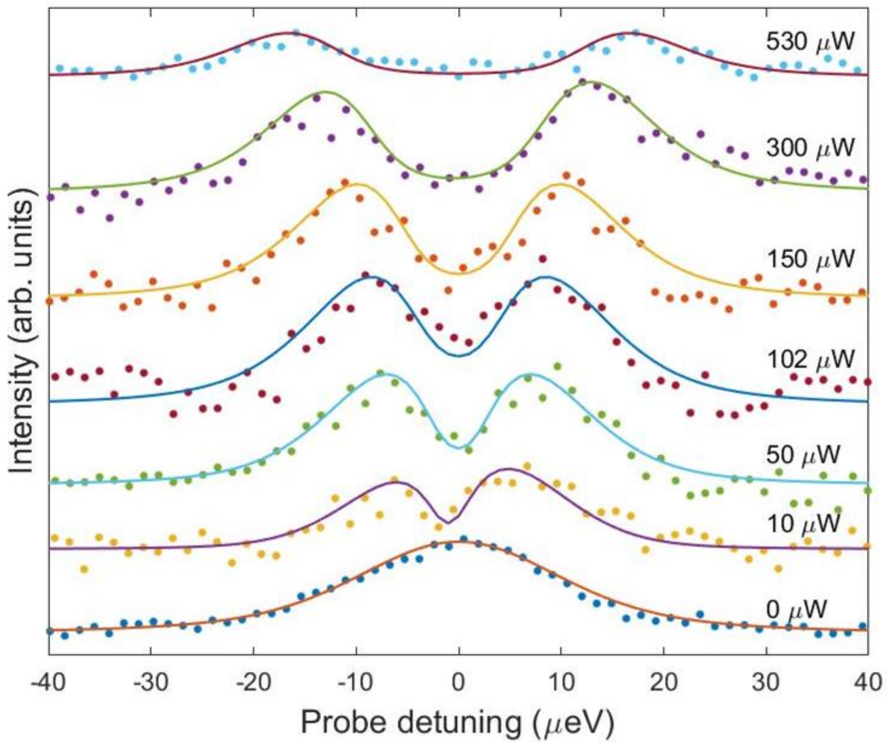
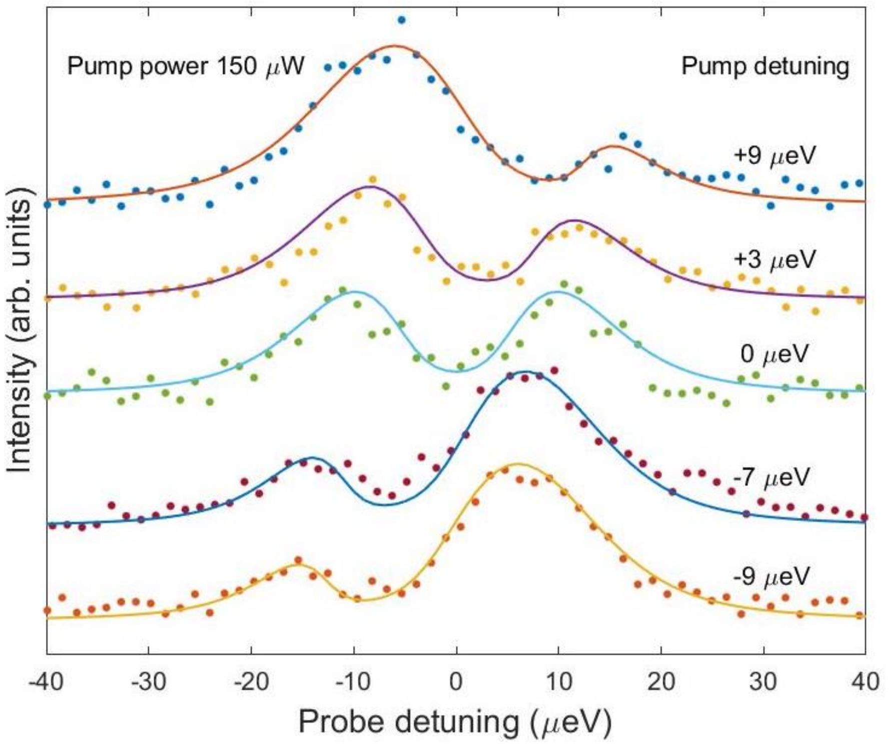
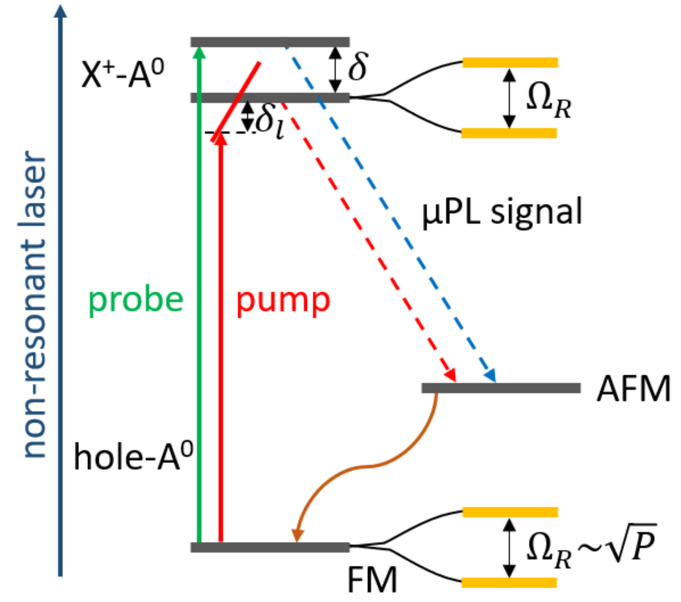


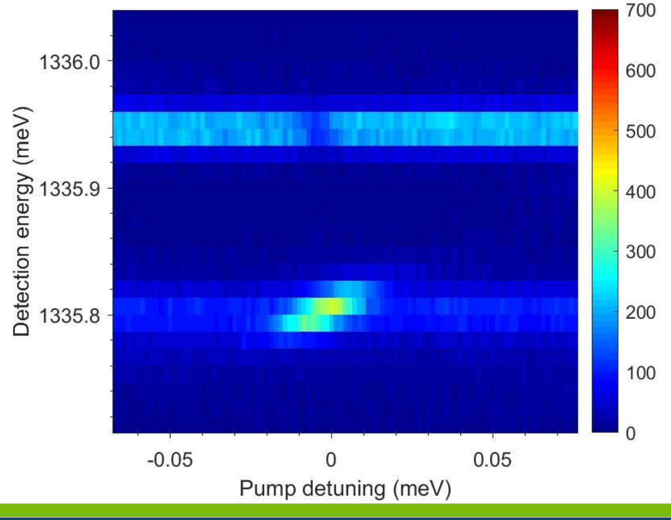




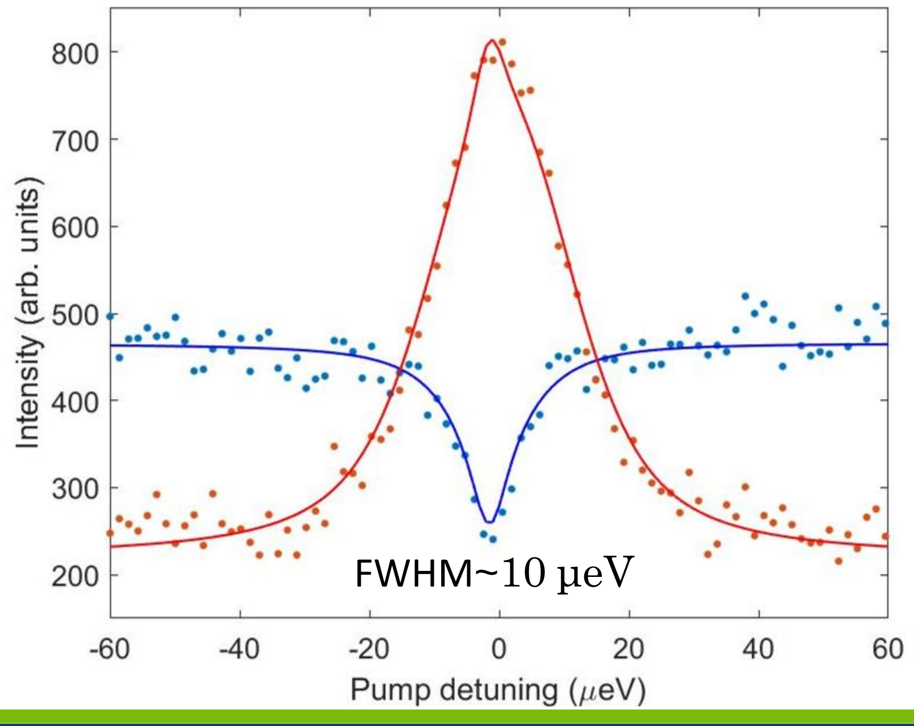
- Dependence on pump power and pump detuning
- No significant pure dephasing ($\Gamma_{21} = \Gamma_{23} = \Gamma_{13} = 0\ \mu eV$)
- γ_4 is small ($\gamma_1 = 1\ \mu eV, \gamma_3 = 1.1\ \mu eV, \gamma_4 = 0.07\ \mu eV$)

Two-laser probing





- Pump laser (11 μW), probe laser (1.3 μW)
- Dip with typical 10 μeV linewidth
- The two-laser resonance reveals the spin coherence of X⁺-A⁰ states.



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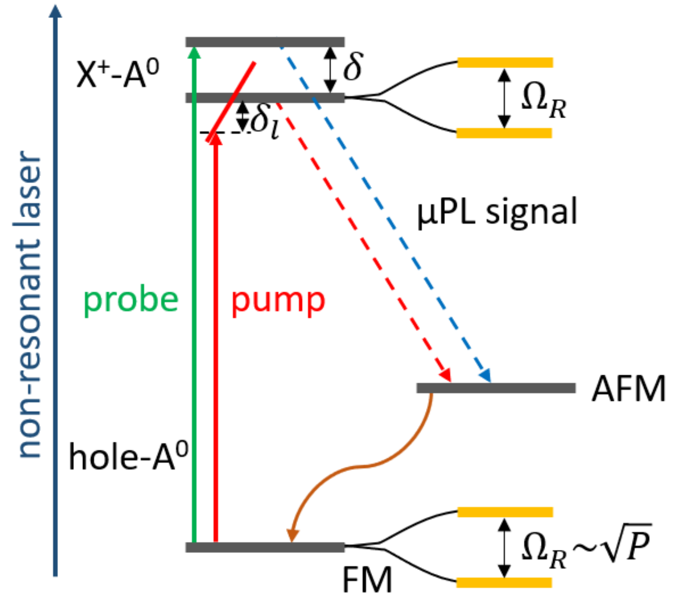

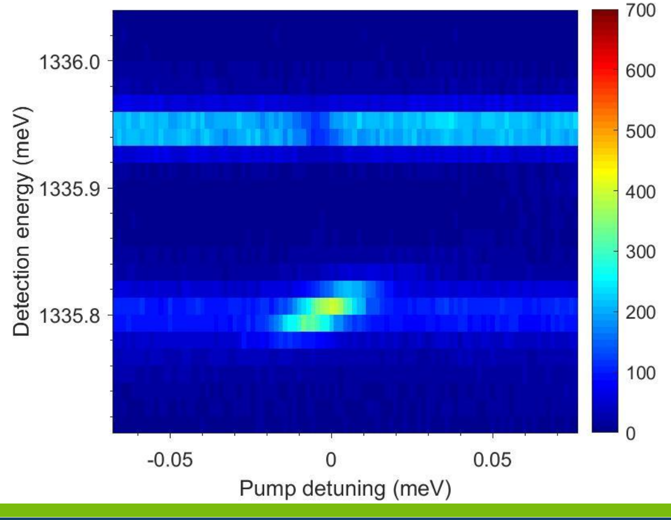

- Pump laser (11 μW), probe laser (1.3 μW)
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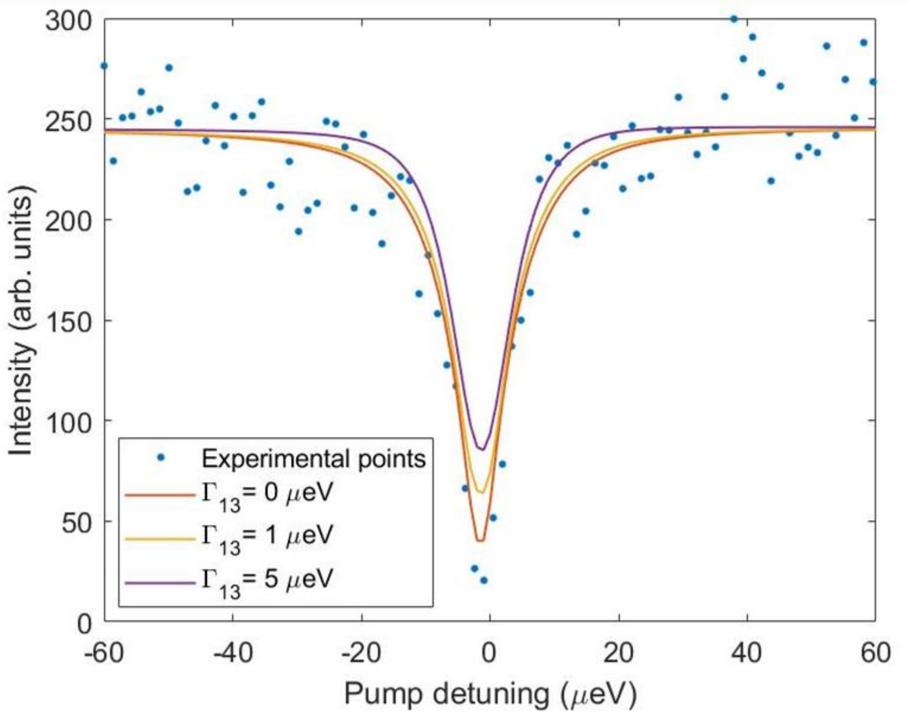
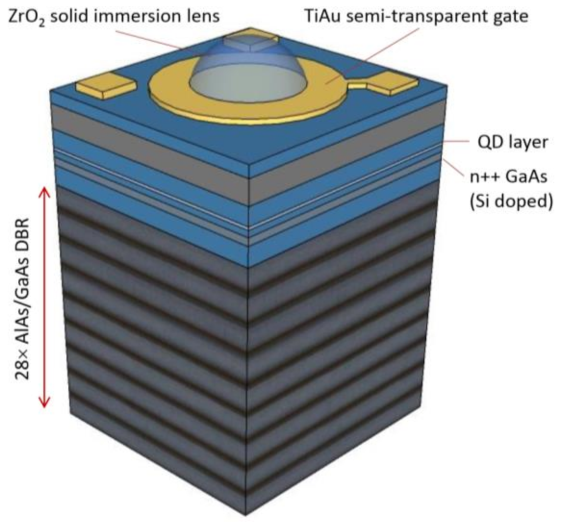
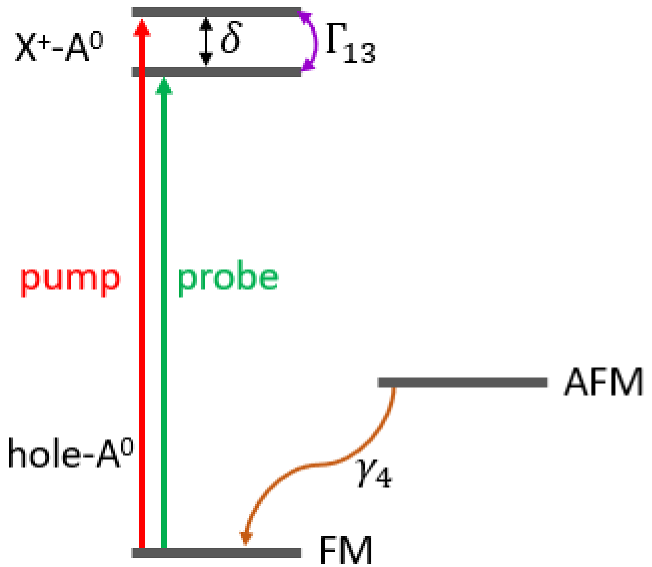


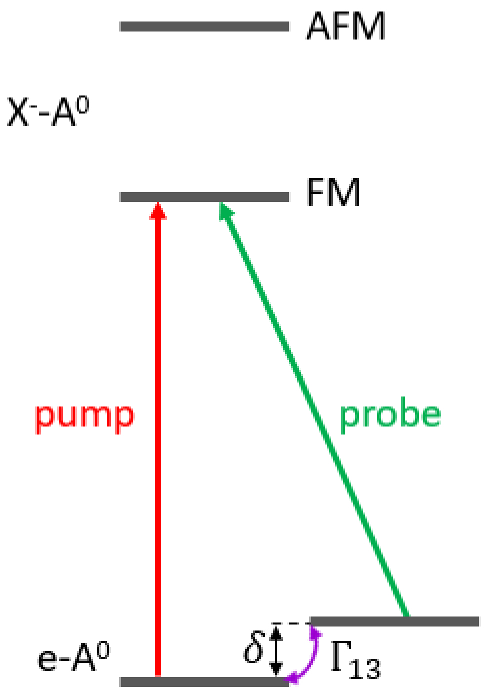
Conclusion and perspectives

- QD in cavity
- For X^+ trion, Γ_{13} is small
- Working with X^0 and X^- trions
- Coherent population trapping



W. B. Gao, et al., Nature 491, 426–430 (2012)





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