SAND2020-1860C

A Valley Hot-Spot Driven Singlet-Triplet Qubit in a Silicon MOS DQD

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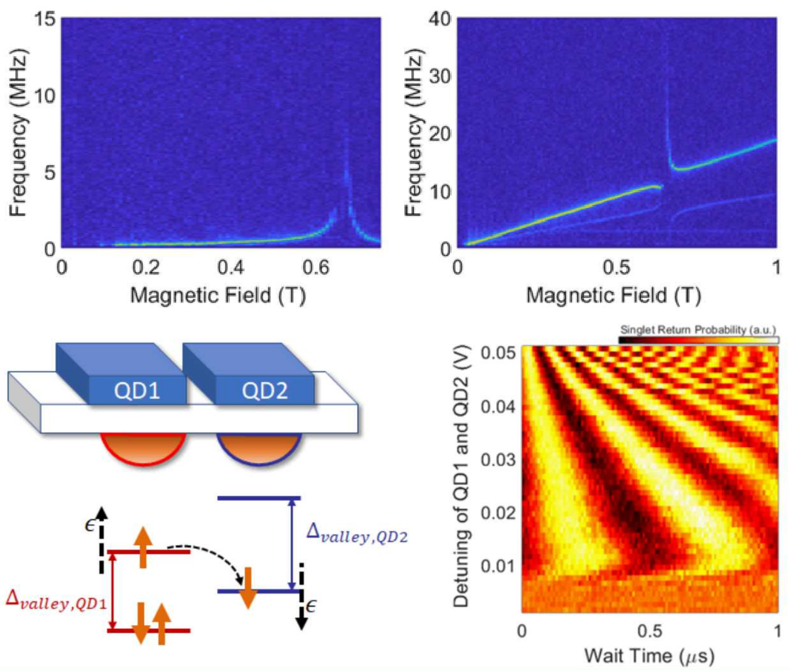

Outline

- DQD Device
- Intervalley Hot Spot Spin-Orbit Interaction
- Voltage Control of Intervalley Coupling
- Charge Noise Spectroscopy
- Summary

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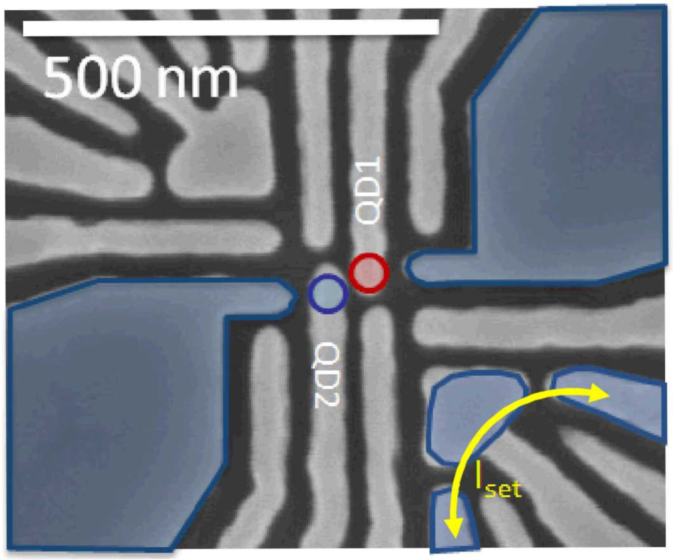
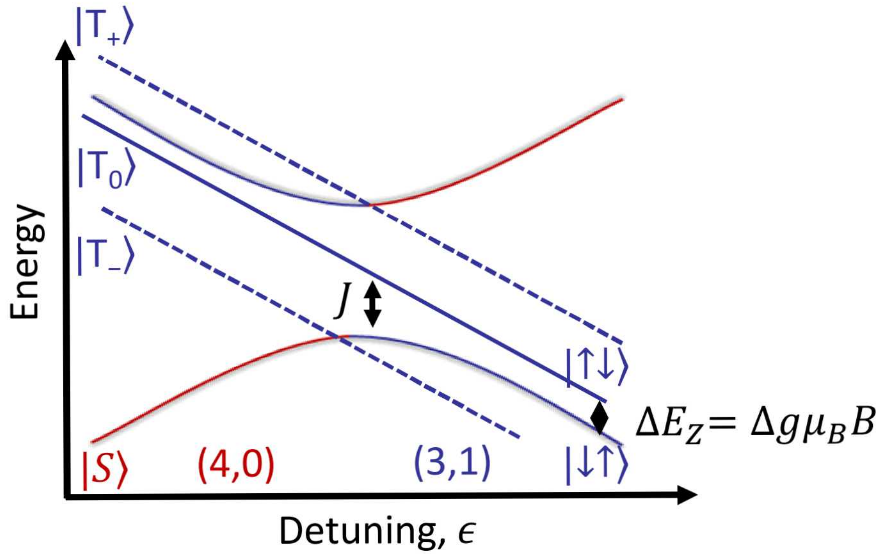
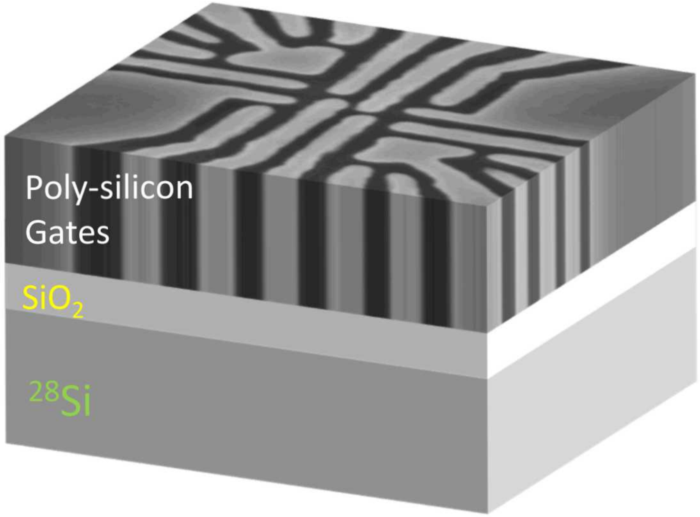
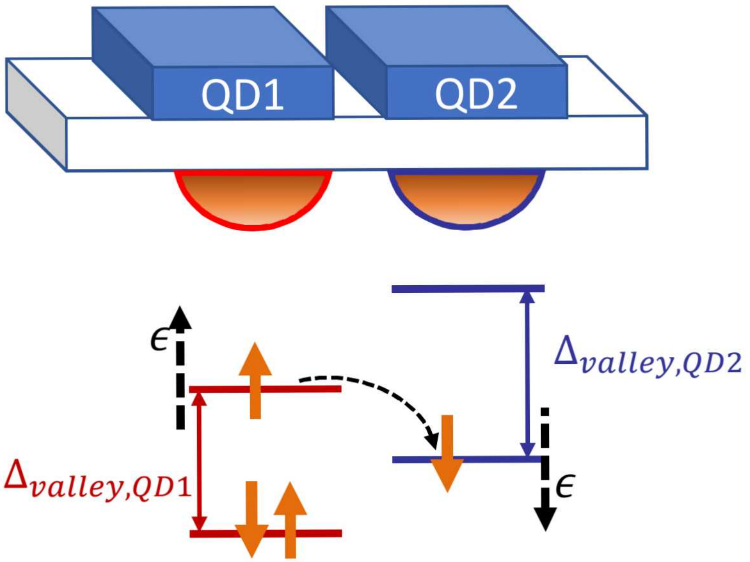
Sandia MOS DQD Platform

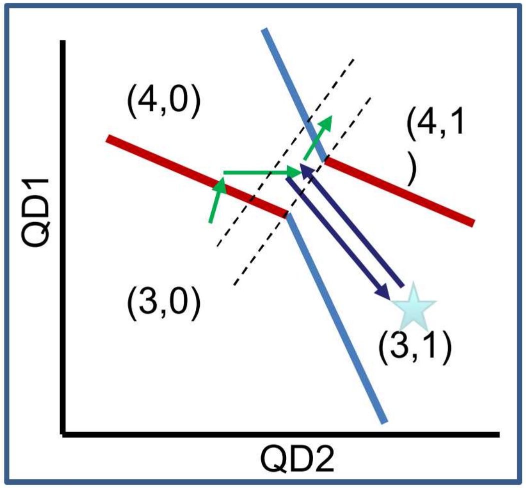


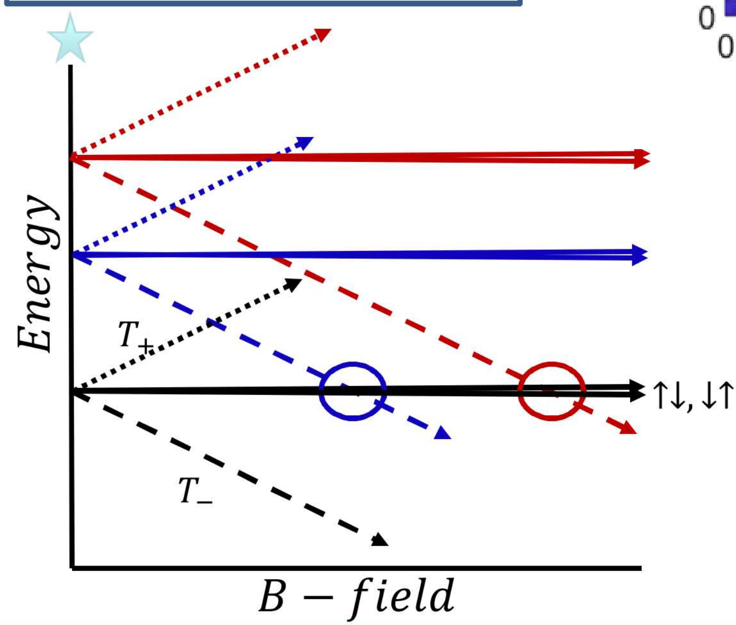


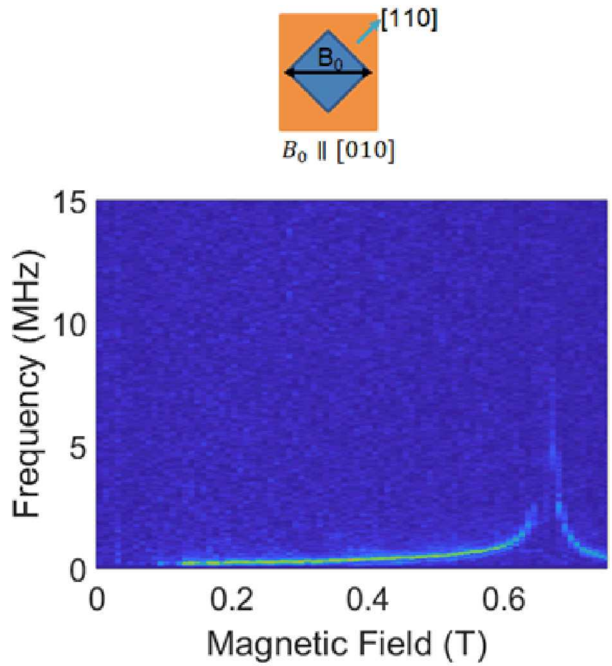


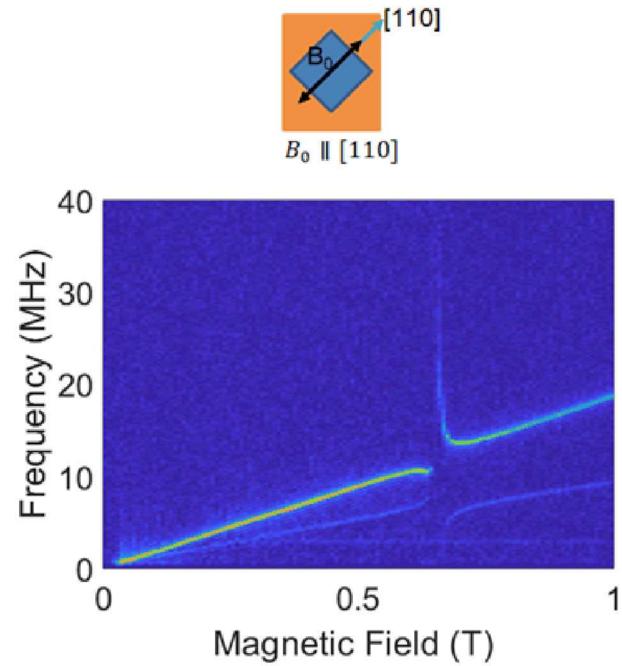


Intervalley Hot Spot Spin-Orbit Interaction





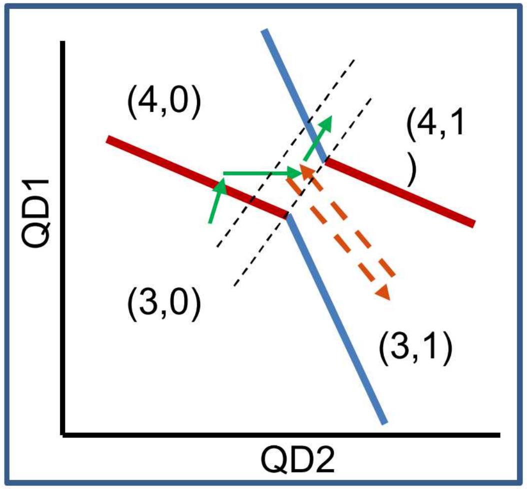


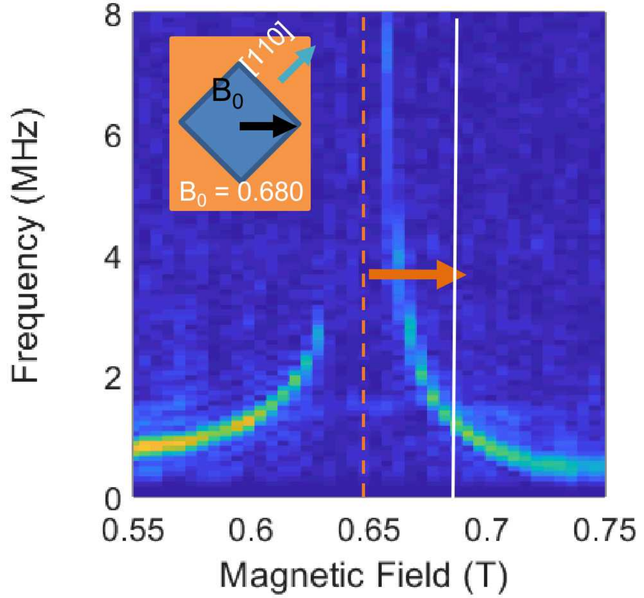


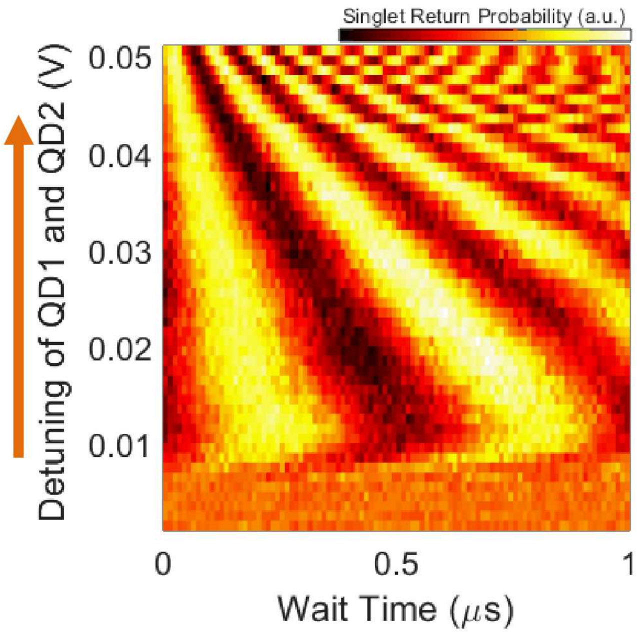
$$
\begin{array}{cc}
 & \begin{array}{ccc} |{\downarrow\uparrow}\rangle & |{\uparrow\downarrow}\rangle & |T_-^*\rangle \end{array} \\
H = & \begin{pmatrix} B\delta & 0 & 0 \\ 0 & -B\delta & \gamma \\ 0 & \gamma^* & \Delta_{VS} + (\delta - g\mu_B)B \end{pmatrix}
\end{array}
$$

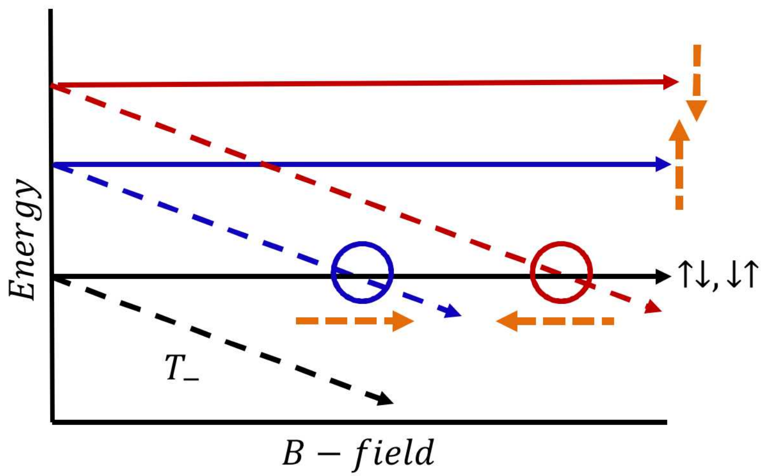
δ = intra-valley SOC strength
γ = inter-valley SOC strength
Δ_{VS} = valley splitting

Voltage Control of Intervalley Interaction





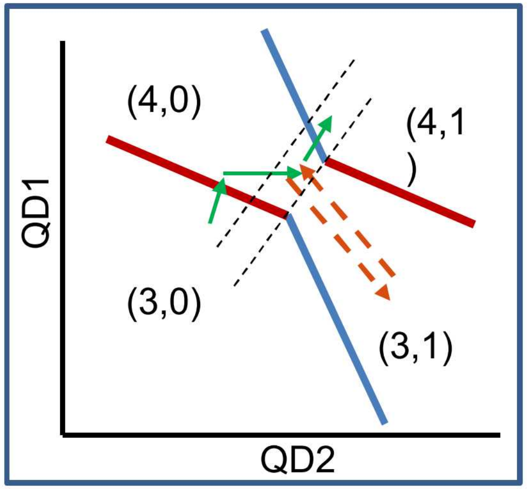


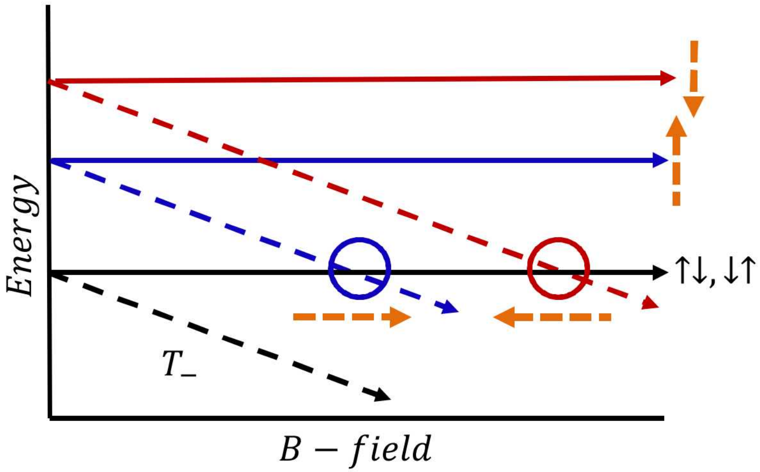


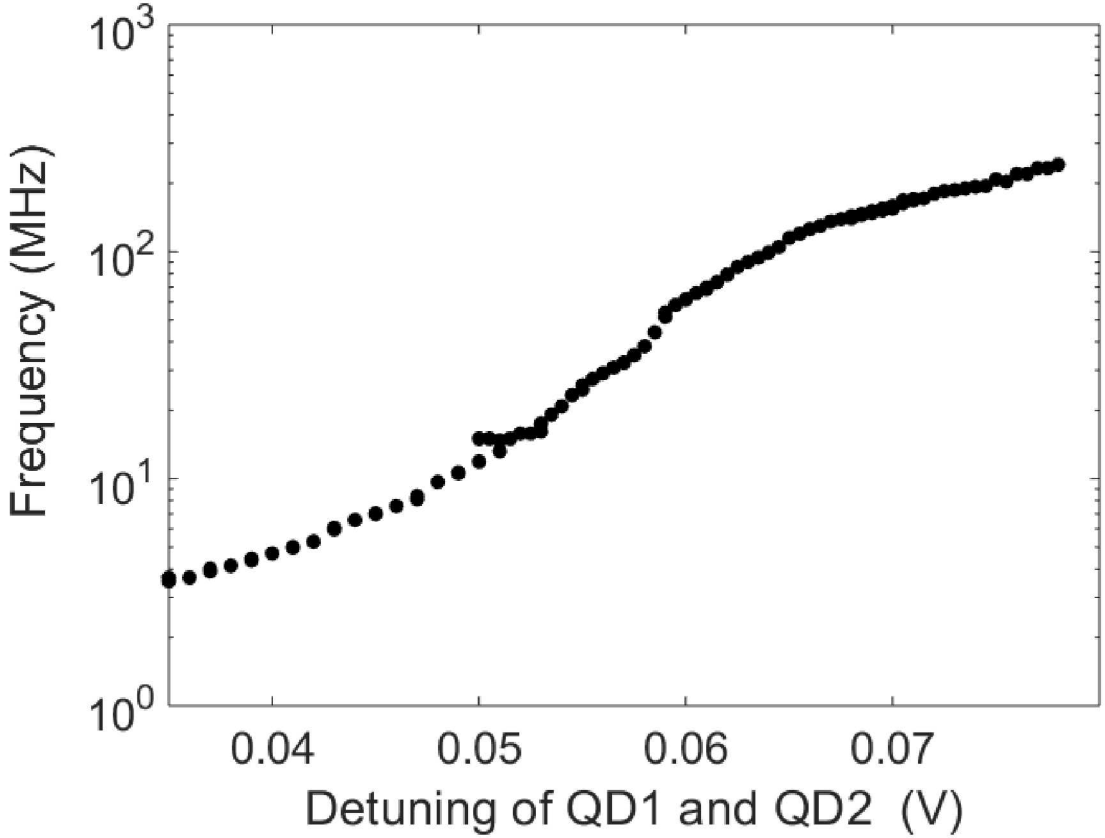
V_{QD1} decreases → $\Delta E_{Valley,QD1}$ decreases
V_{QD2} increases → $\Delta E_{Valley,QD2}$ increases

Voltage tuning valley splitting modulates intervalley interaction

Fast Qubit Drive Frequency

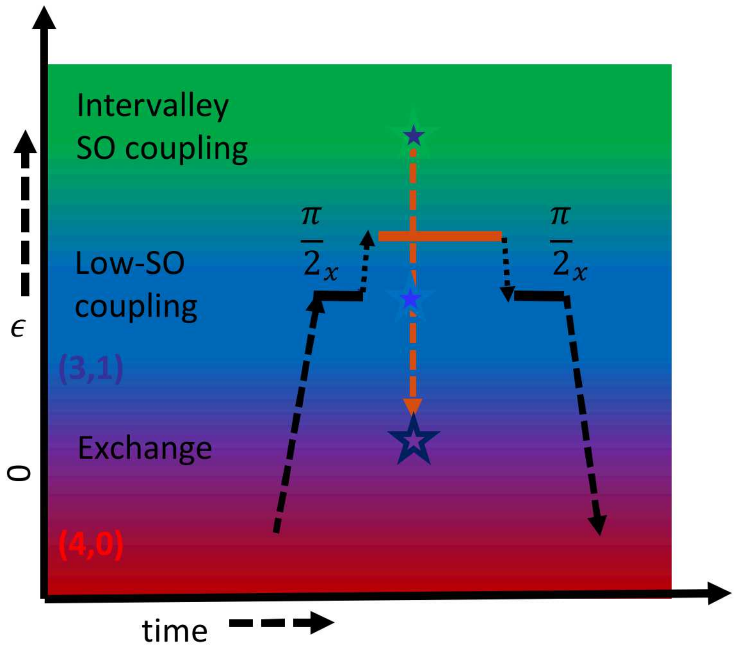




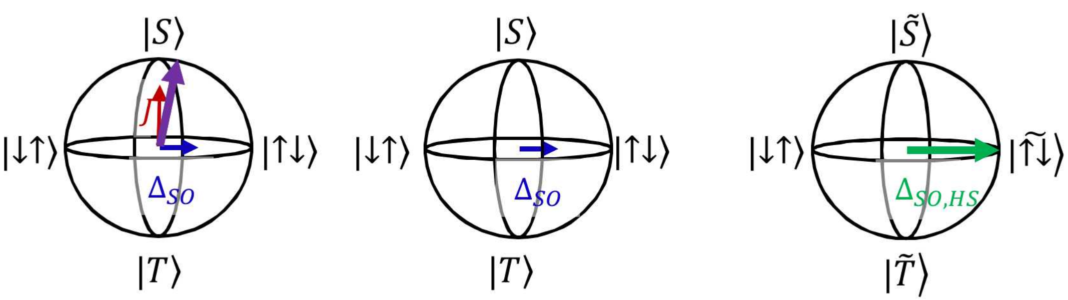


Qubit frequencies > 200 MHz

Valley Hot Spot S/T Qubit Control



Exchange | Low-SO Δg | Intervalley SO



Shallow Detuning | Moderate Detuning | Near Hot-Spot

Redefine qubit basis

$|{\downarrow\uparrow}\rangle$

$|\widetilde{\uparrow\downarrow}\rangle = -w_-|{\uparrow\downarrow}\rangle + w_+|T_-^*\rangle$

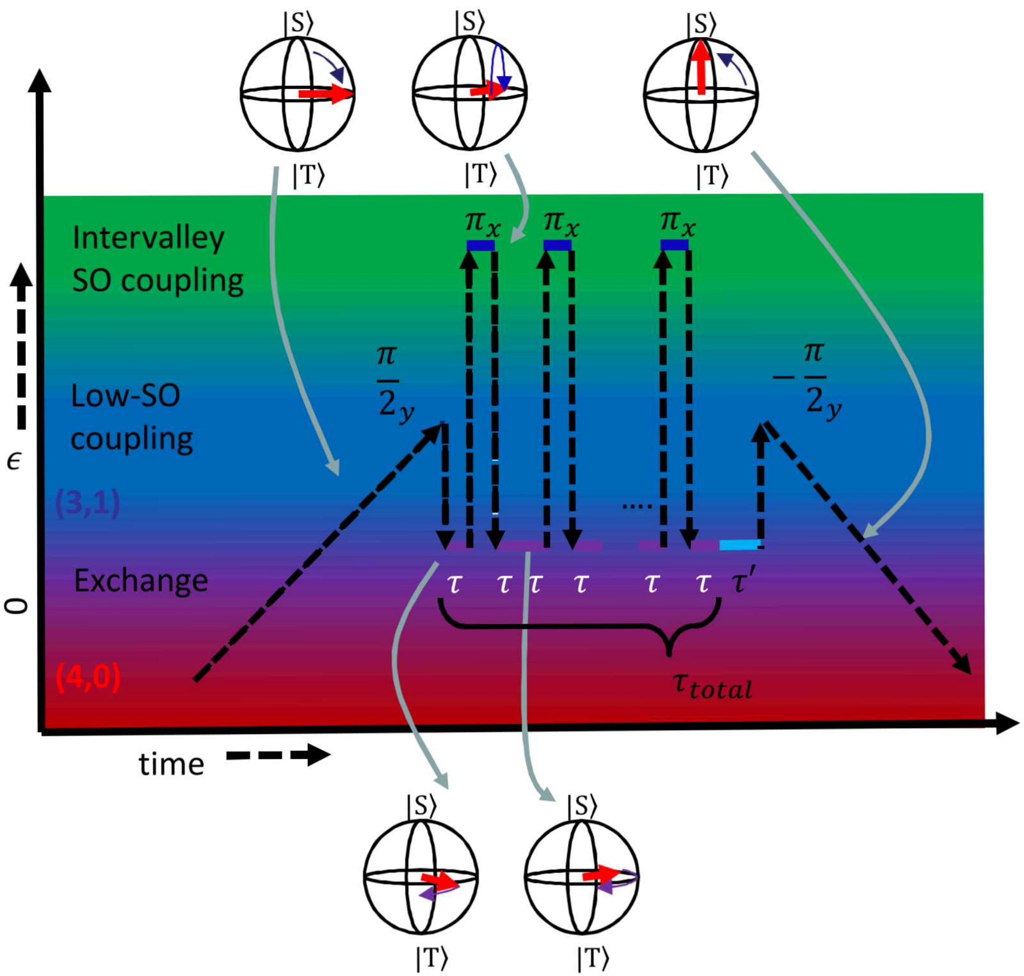
$|\widetilde{T_-^*}\rangle = w_+|{\uparrow\downarrow}\rangle - w_-|T_-^*\rangle$

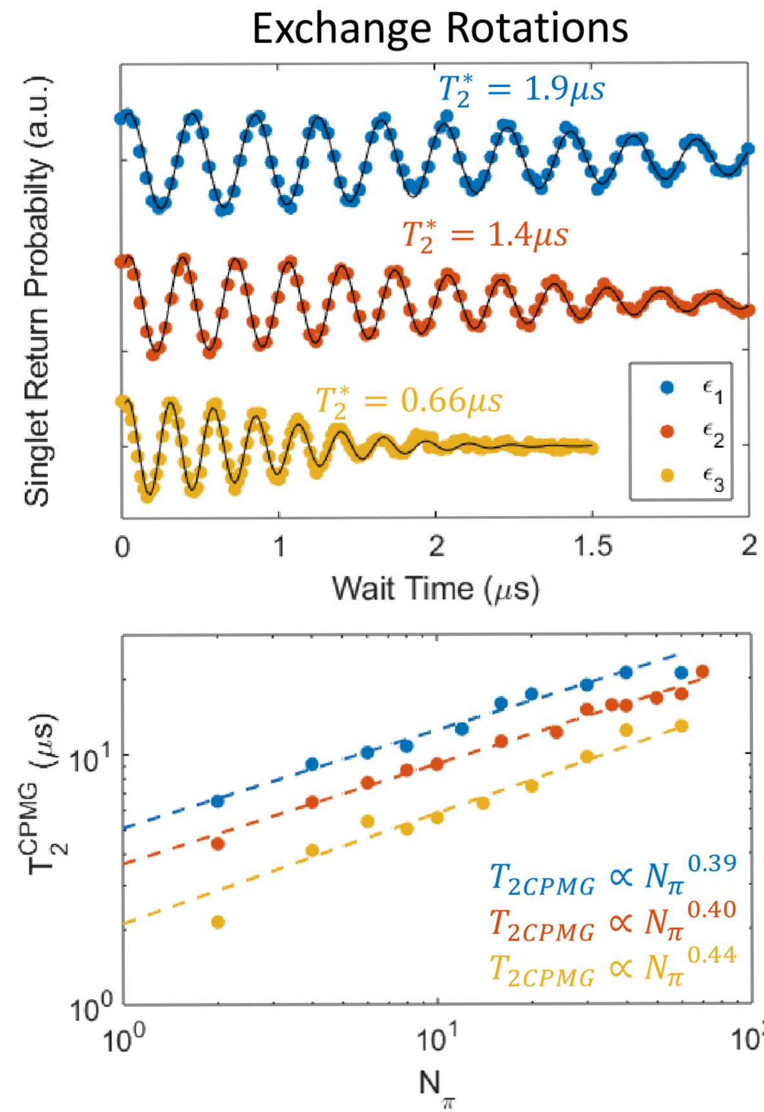
$|\tilde{S}\rangle = \frac{1}{\sqrt{2}}\left(|{\downarrow\uparrow}\rangle - |\widetilde{\uparrow\downarrow}\rangle\right)$

$|\tilde{T}\rangle = \frac{1}{\sqrt{2}}\left(|{\downarrow\uparrow}\rangle + |\widetilde{\uparrow\downarrow}\rangle\right)$

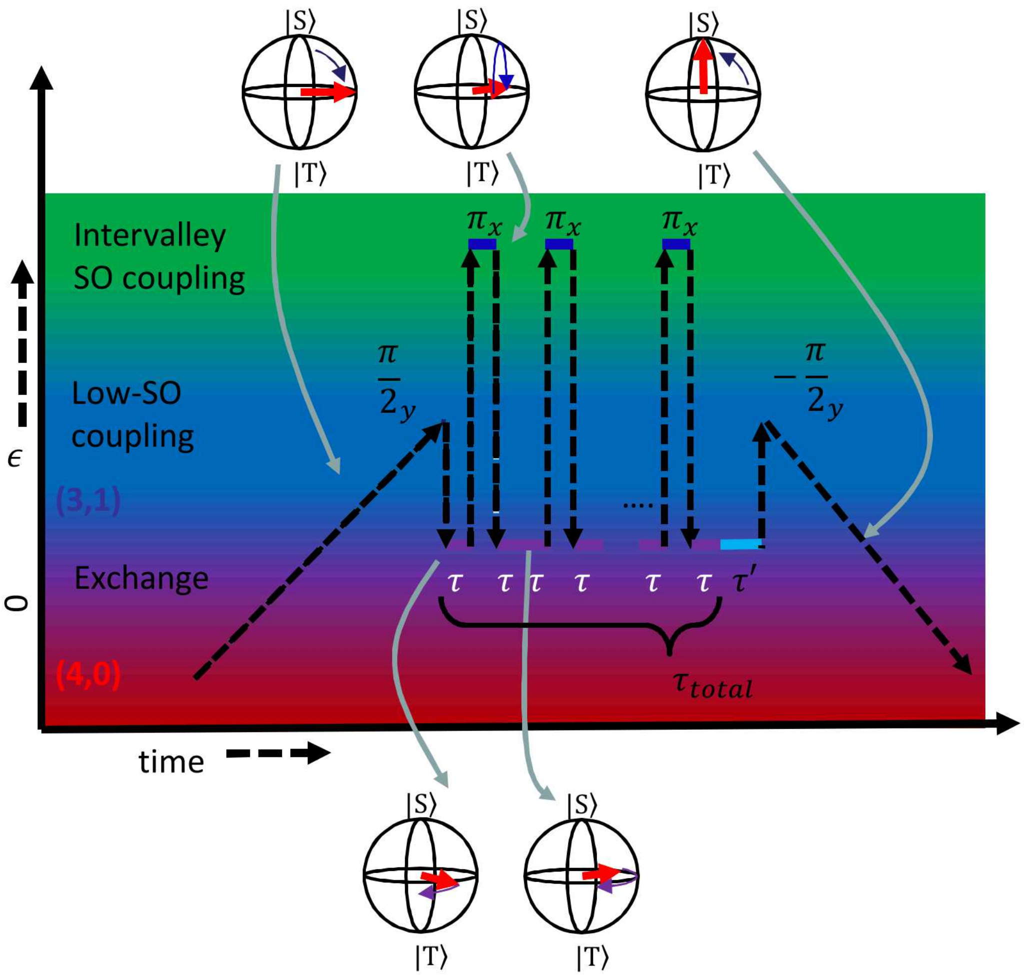
$$w_\pm = \sqrt{\frac{1}{2} \pm \frac{\Delta_{VS} + (\delta - g\mu_B)B}{2\sqrt{|\Delta_{VS} + (\delta - g\mu_B)B|^2 + 8|\gamma|^2}}}$$

CPMG to Extend Coherence





CPMG as a Noise Filter



For a given N_π:

- CPMG prolongs qubit coherence by refocusing noise on time scales longer than the time between pulses.
- Noise power is calculated from T_2^{CPMG}

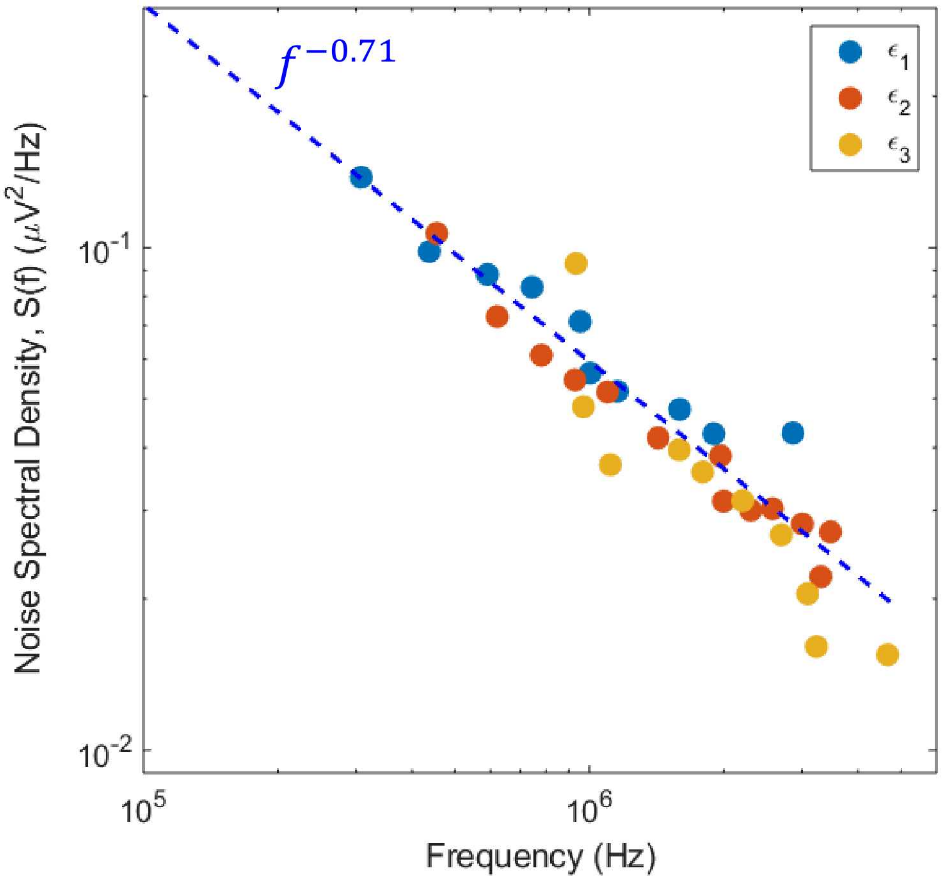
$$f_{N_\pi} = \frac{1}{(2 \cdot \tau_{1/e} + t_{\pi_x})} = \frac{N_\pi}{T_{2,N_\pi}^{CPMG}}$$

$$S(f_{N_\pi}) = \frac{\pi^2}{4 \cdot T_{2,N_\pi}^{CPMG}}$$

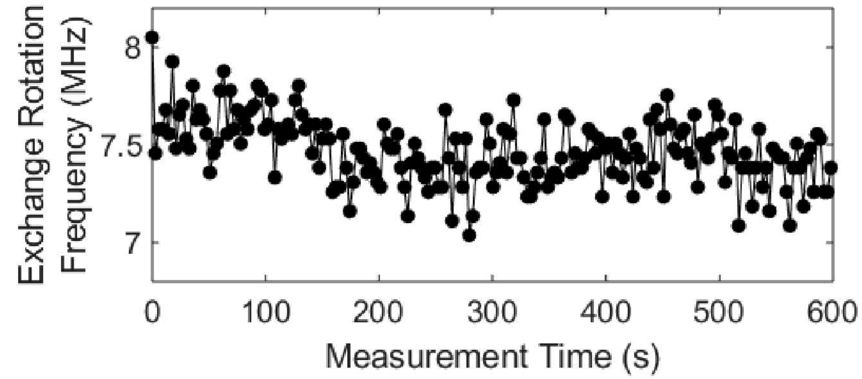
Muhonen, J. T. et al. *Nat. Nanotech.* 9, (2014)
Yoneda, J. et al. *Nat. Nanotech.* 13, (2018)
K. W. Chan, et al Phys. Rev. Applied 10, (2018)

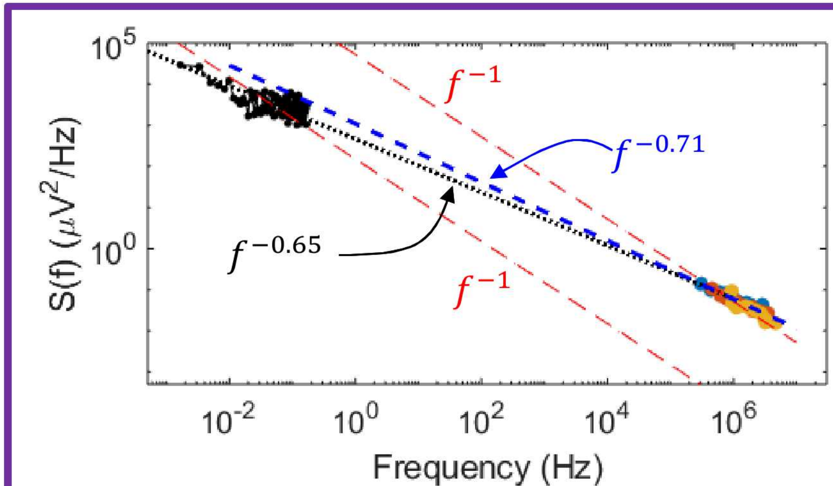
Charge Noise Spectroscopy

CPMG noise spectroscopy



Exchange Frequency Drift



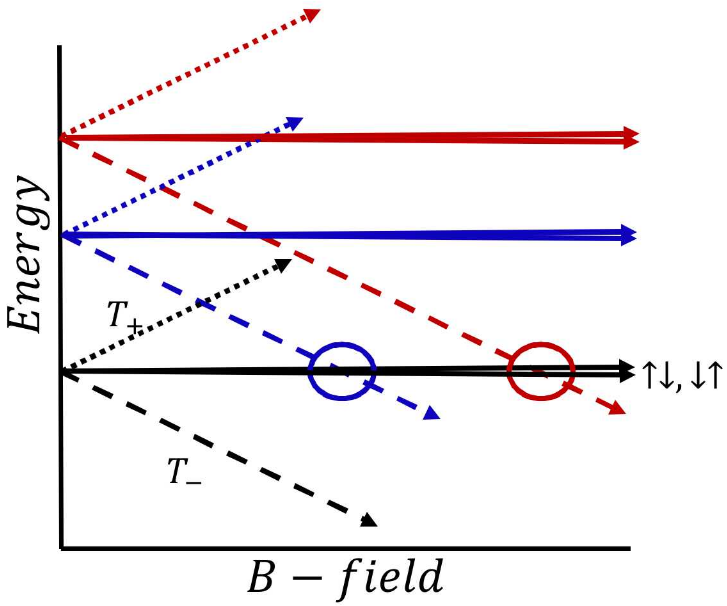


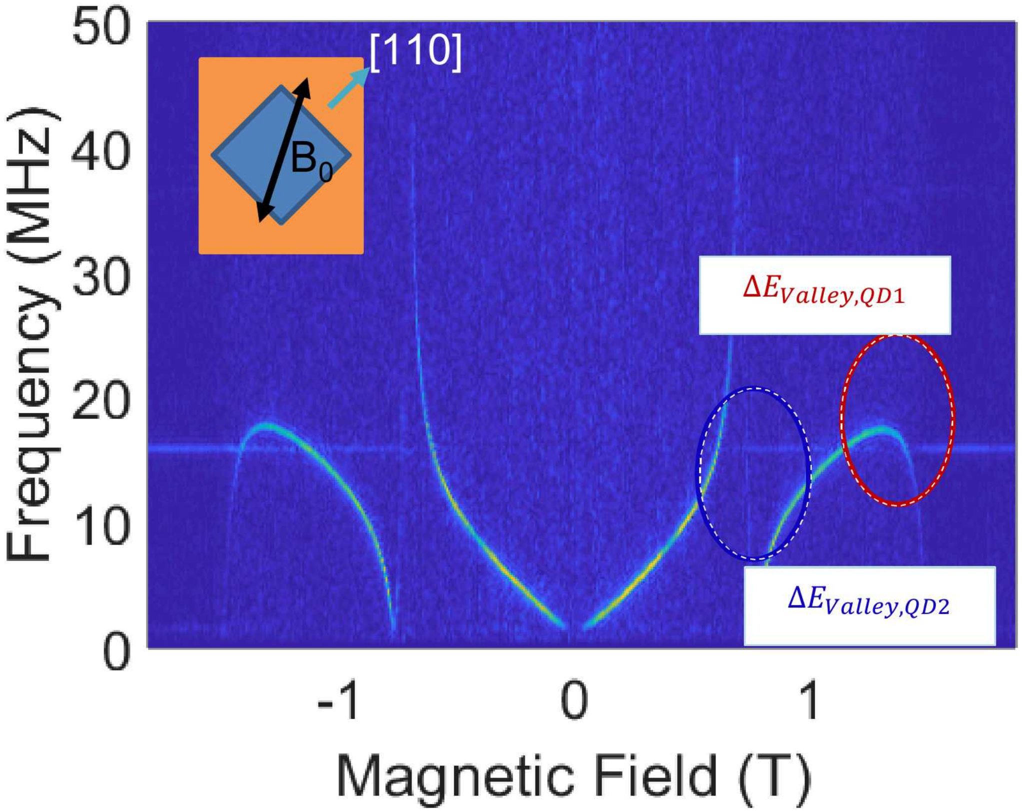
Summary

- Novel operating mode of a S/T qubit
  - Exploits an intervalley SO interaction
  - Qubit frequencies exceeding 200MHz
- High-orthogonality and fast electrical-only qubit control.
  - High-speed modulation between three qubit control regimes
- Fast CPMG refocusing pulses allow for a probe of high frequency charge noise
  - $S(f) \sim f^{-0.71}$ over 9 orders of magnitude

Extra Material

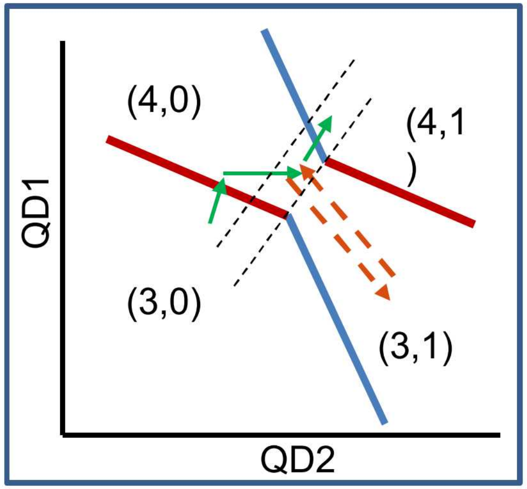
Measure of QD Valley Splitting

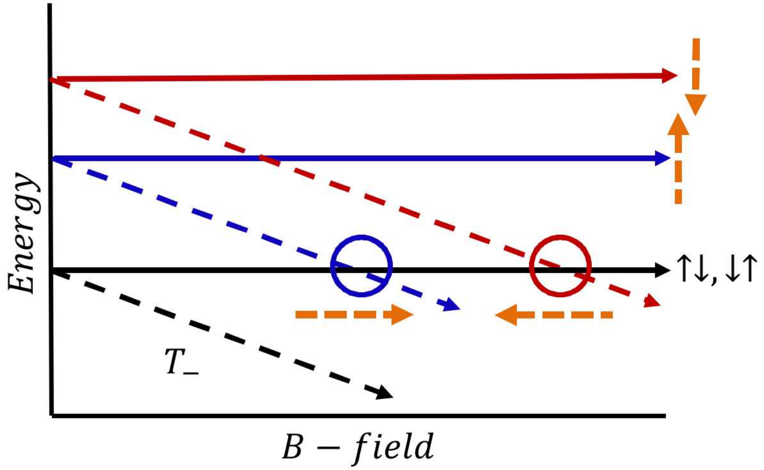


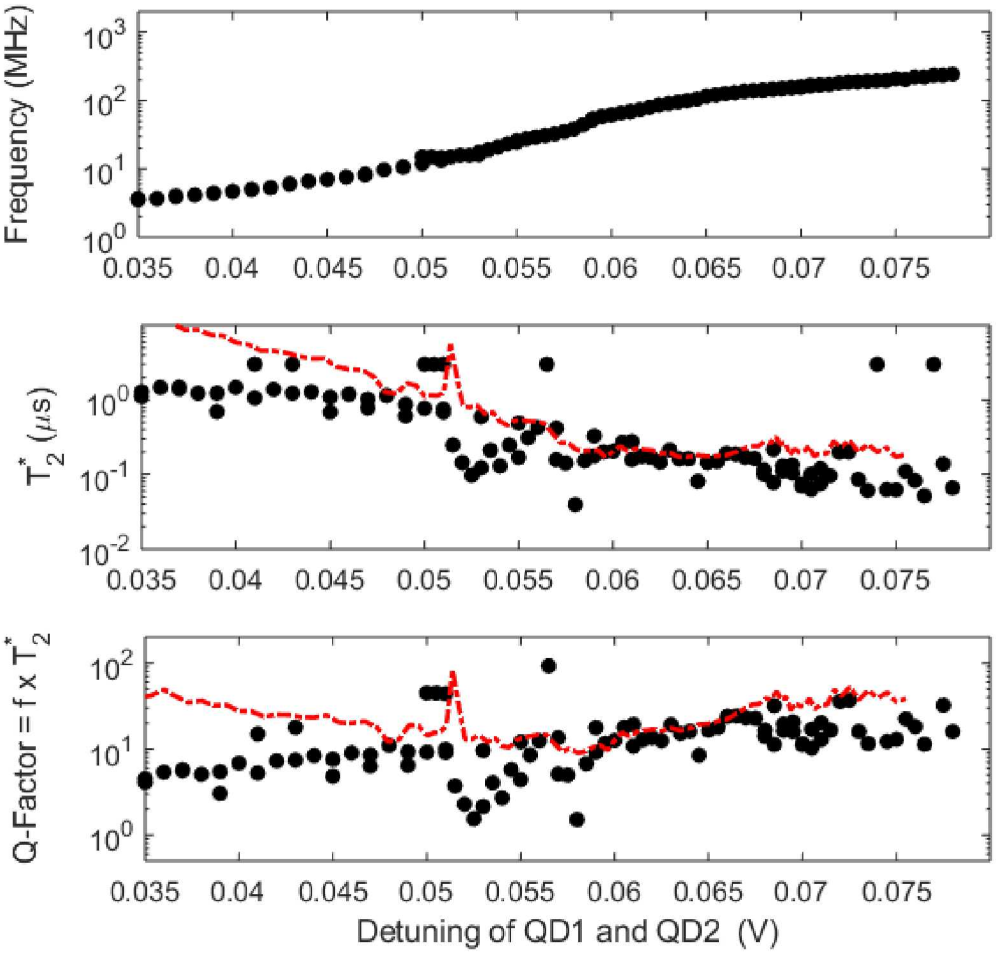


Accurate measure of valley splitting in each QD

Voltage Tuning of Valley Splitting

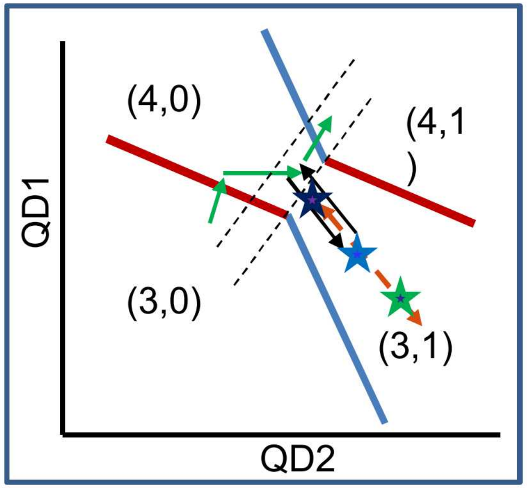


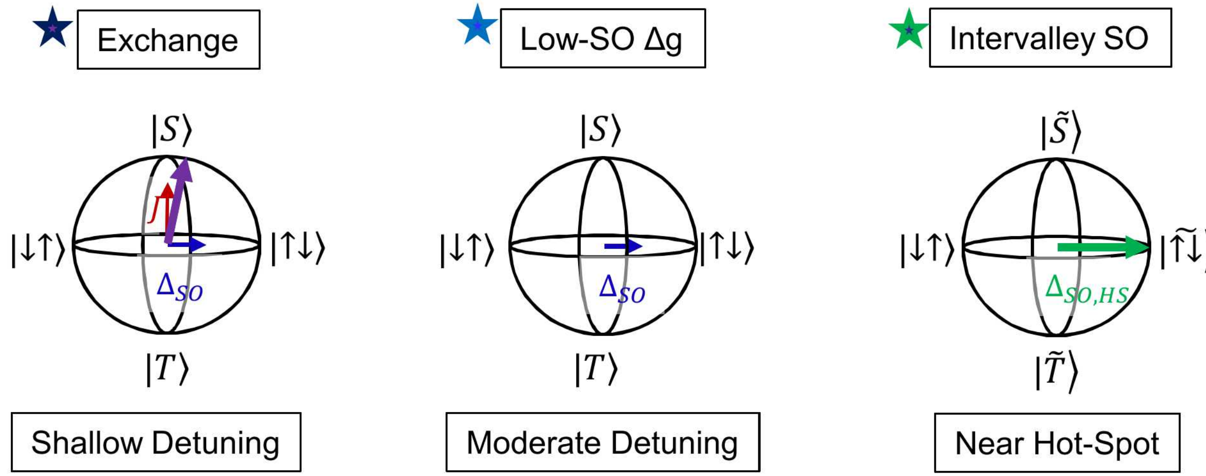


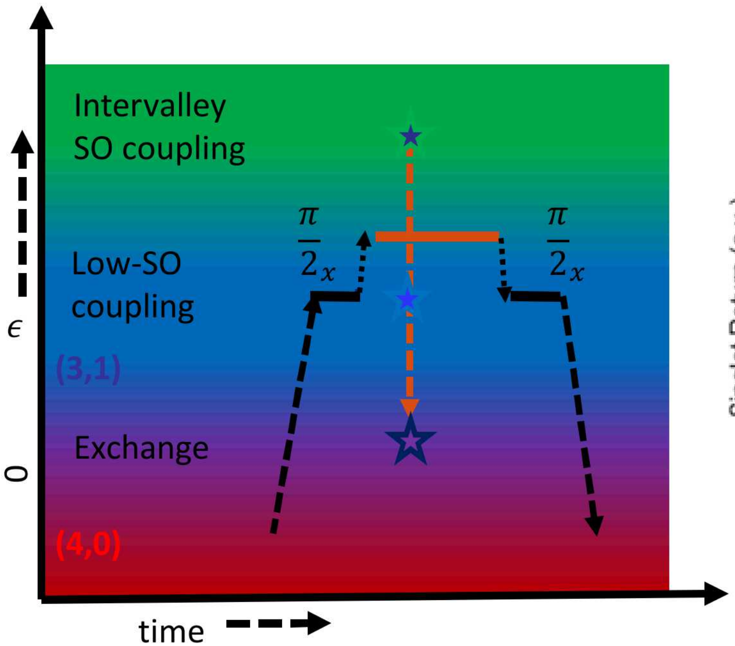


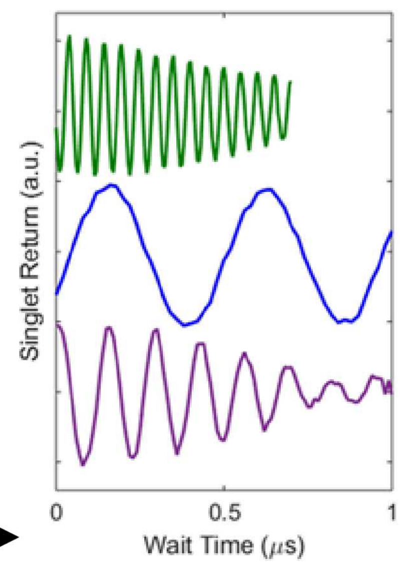
Qubit frequencies > 200 MHz
Dephasing mechanism changes with tuning

Valley Hot Spot S/T Qubit Control









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