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Investigation of The Single and Two Hole Lateral Quantum Dot System

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Hole Device:

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Theory:
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ICSNN 2018

National Research Council Canada Conseil national de recherches Canada

Sandia National Laboratories

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Canada

Motivation

Electron Spin Qubit Coherence Times	T_2 – spin coherence	T_2^* - spin dephasing
dopant-free, isotopically-purified **Si^{28}**	28 ms†	120 us
modulation-doped **GaAs**	0.9 ms†	80 ns

† using CPMG pulses

But what about DiVincenzo Criteria 6 and 7?

6. Interconvert stationary and flying qubits
7. Transmit flying qubits between distant locations

Potential Advantages of Holes in Lateral GaAs QDs

Direct Bandgap

No Valley Complications

Weaker hyperfine decoherence

J.Fischer et al. PRB78 155329 (2008)
R.Fallahi et al. PRL 105,257402 (2010)

Tunable g-factor (a) measure of LH-HH mixing

(b) Zero g-factor required for  to  transfer schemes

Gaudreau et al., Semicond. Sci. Techn. (2017)

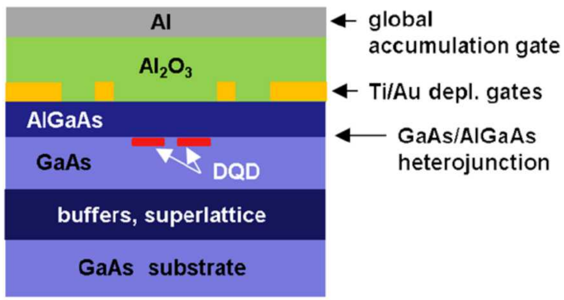
Fast spin-orbit rotations

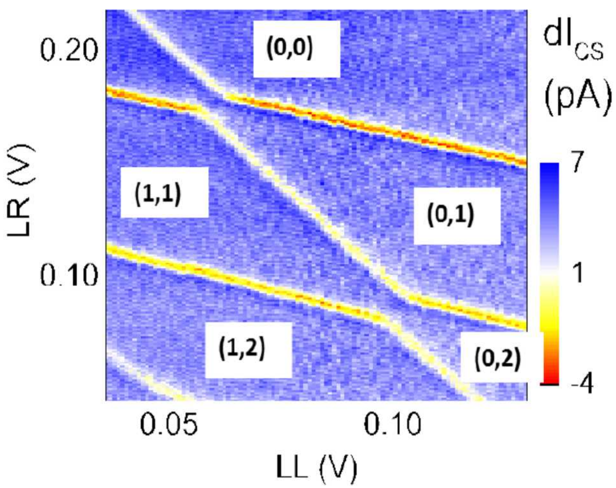
Sandia P- Double Quantum Dot Device

Sandia

L. A. Tracy, et al. *"Few-hole double quantum dot in an undoped GaAs/AlGaAs heterostructure," APL, v. 104, 123101 (2014).*

SANDIA REPORT SAND2015-8132 (October 2015)





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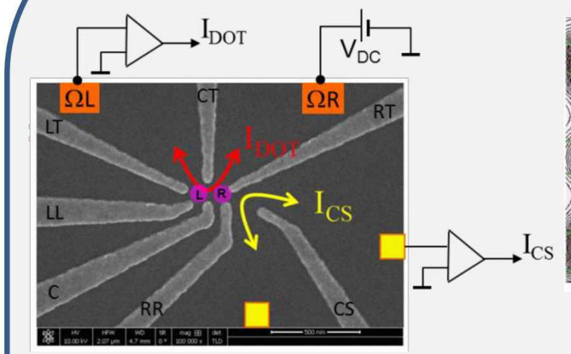
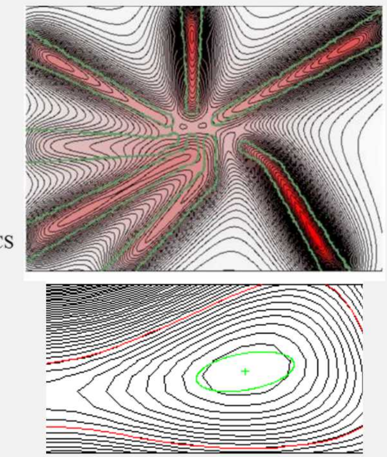
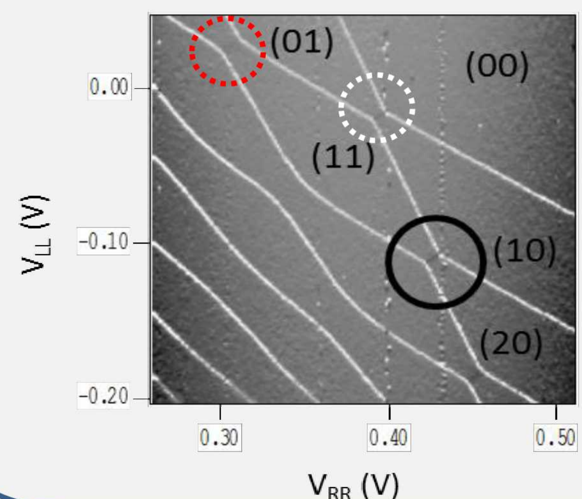


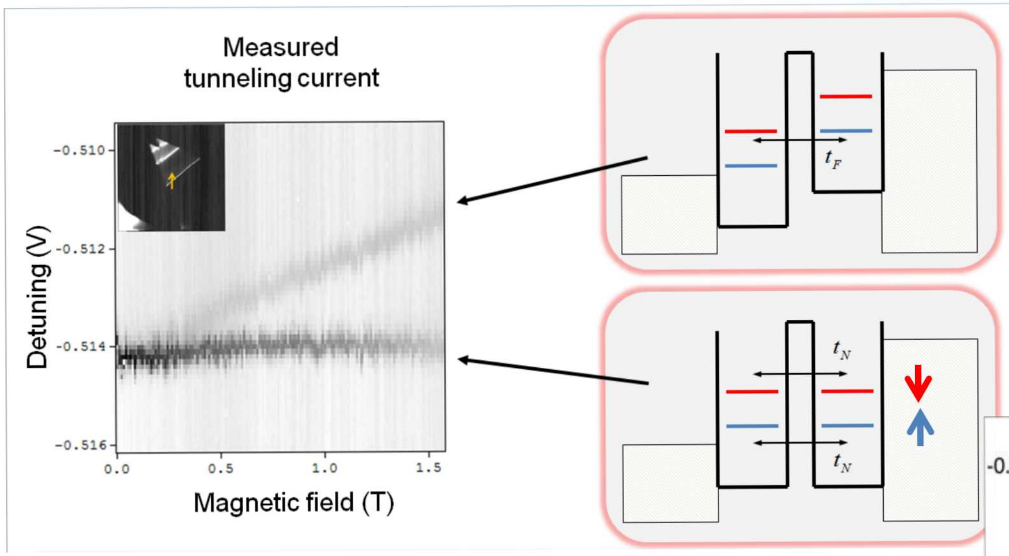




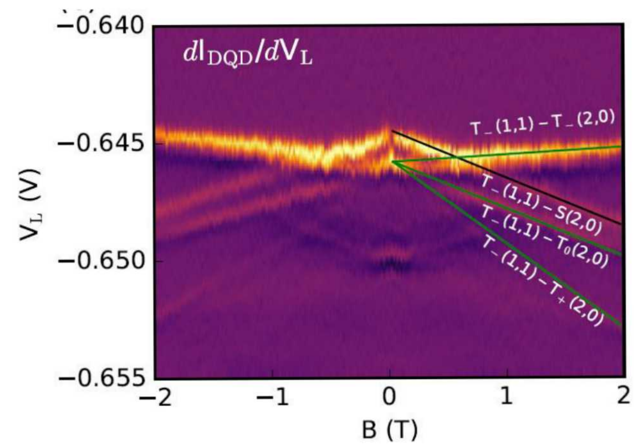
One and Two Hole regimes in a Magnetic Field

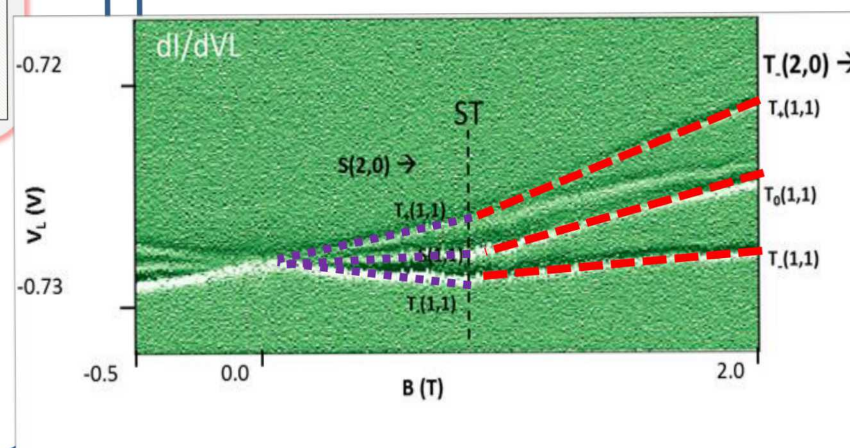
Bogan et al. PRL (2017)

Single Hole



Two Holes





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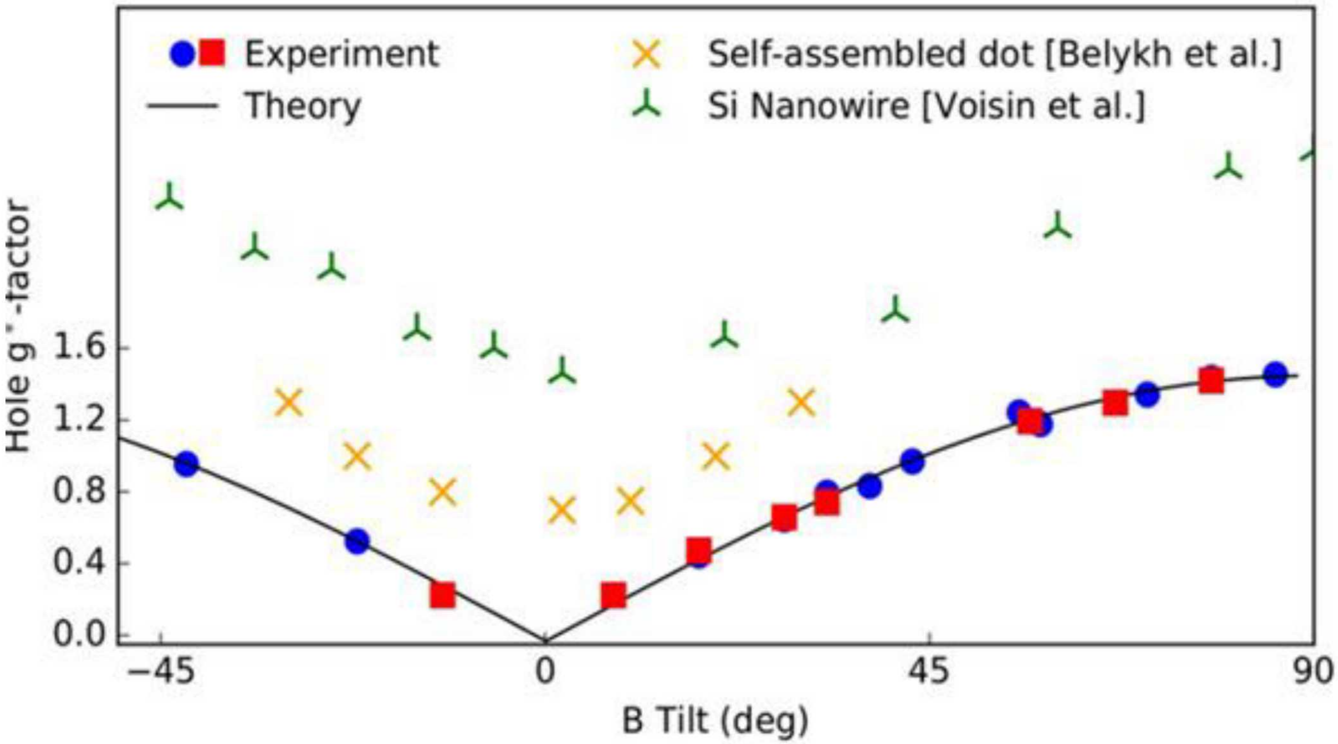
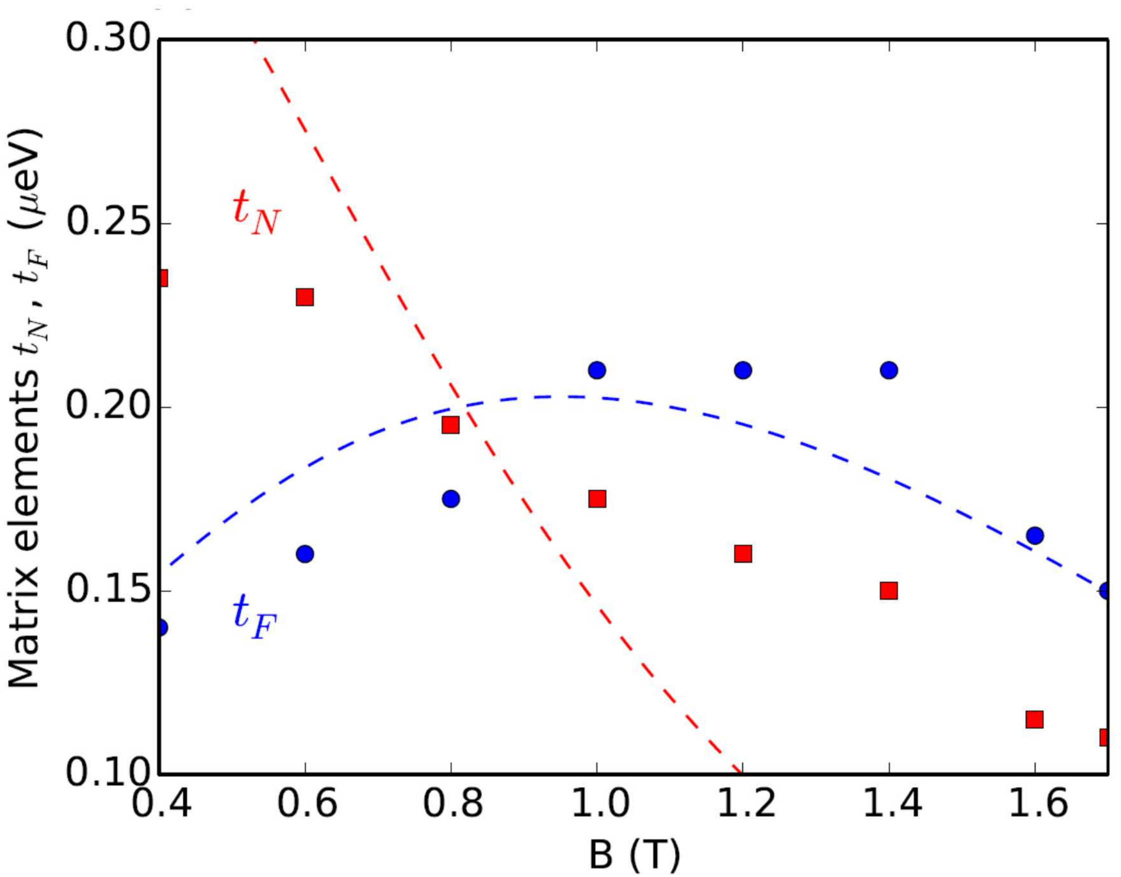
G-factor vs Tilt



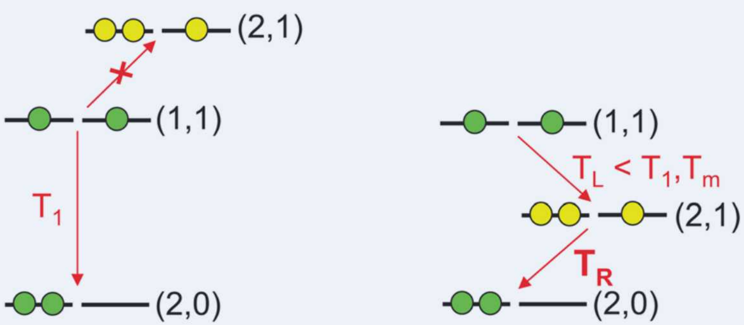
Bogan et al., Phys. Rev. Lett. (2017)

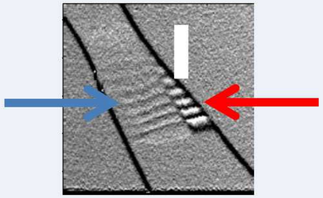
Tunnel Matrix Elements



Enhanced Readout/Measurement via Latching

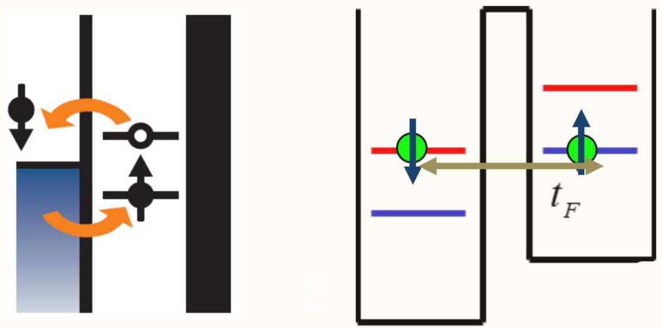
Spin Qubit Readout



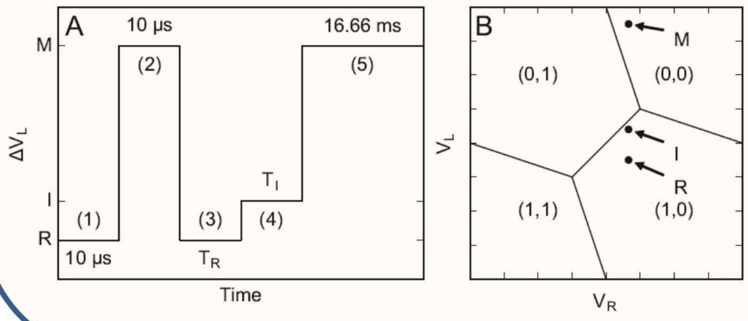


Studenikin et al., Appl. Phys. Lett. **101,** 233101 (2012).

T1 - Measurement



J.M.Elzerman et al. Nature (2004)



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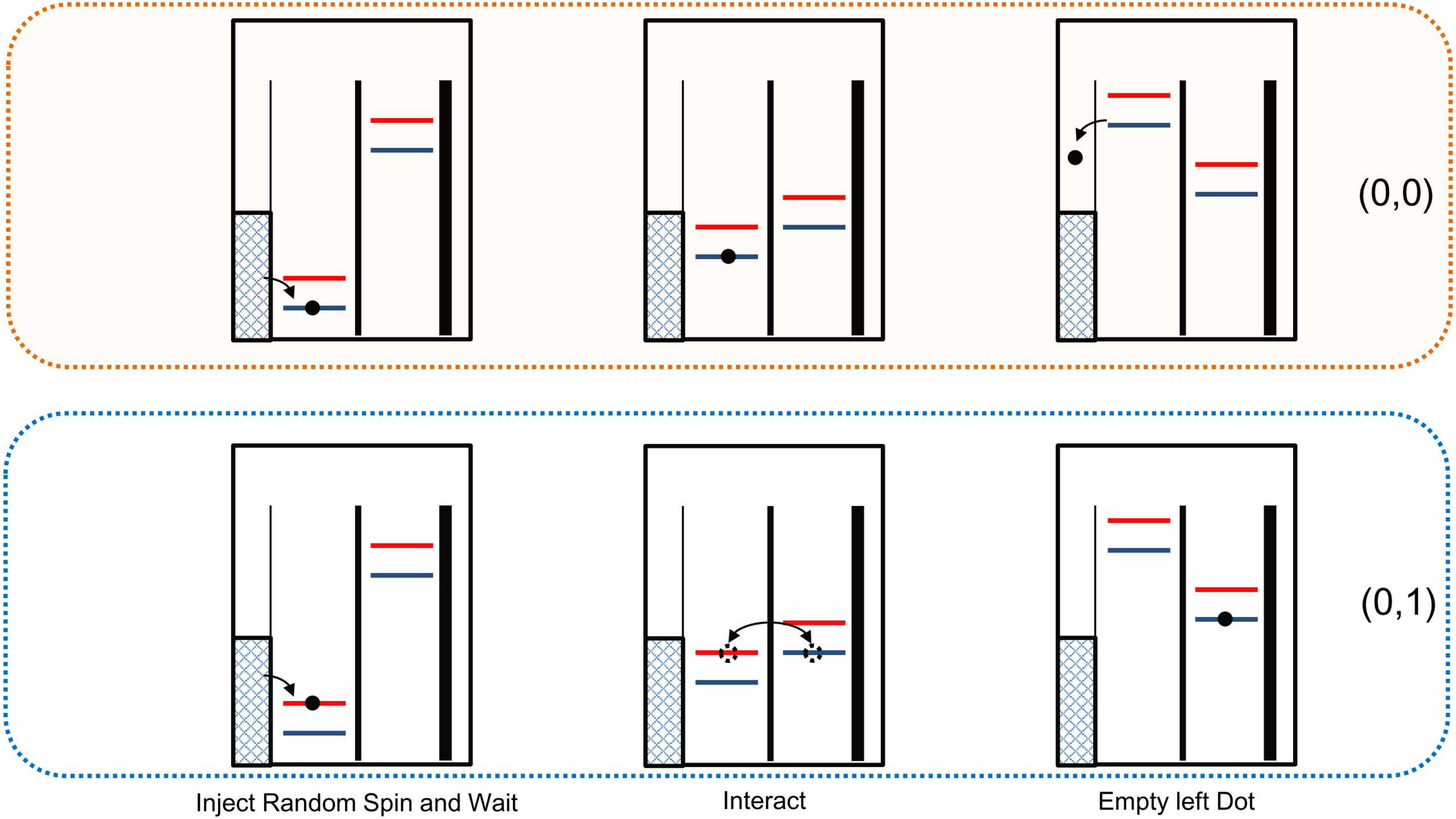
T1 Protocol taking advantage of spin-flip tunneling

S.Studenikin et al. submitted



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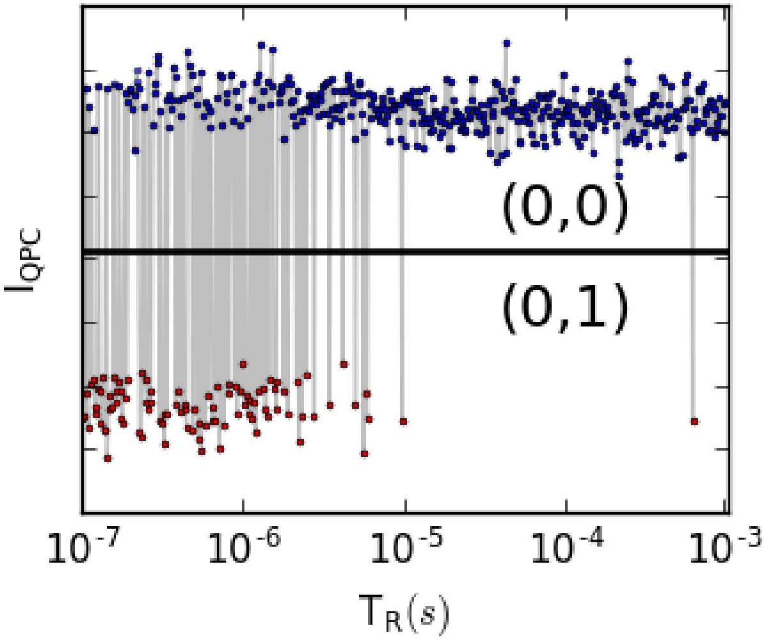
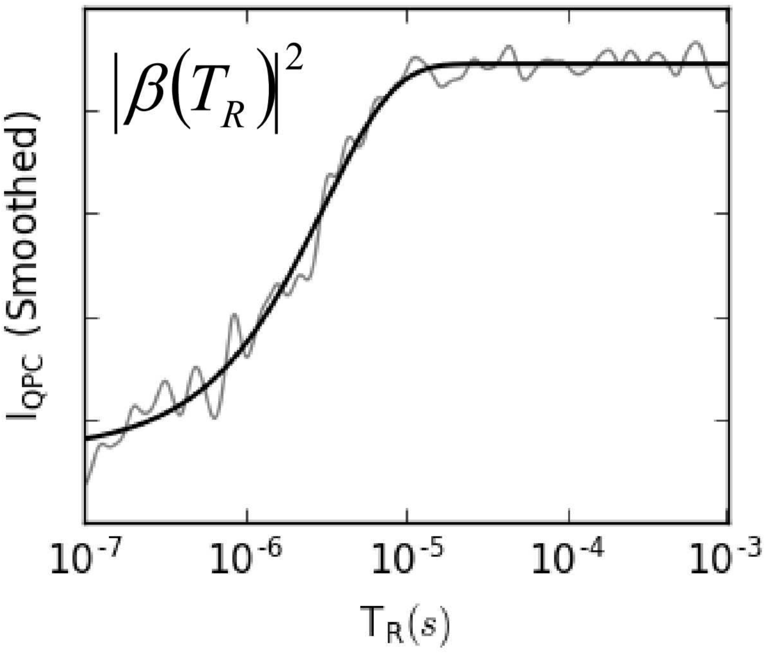
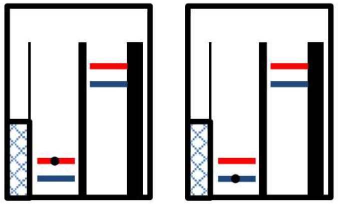
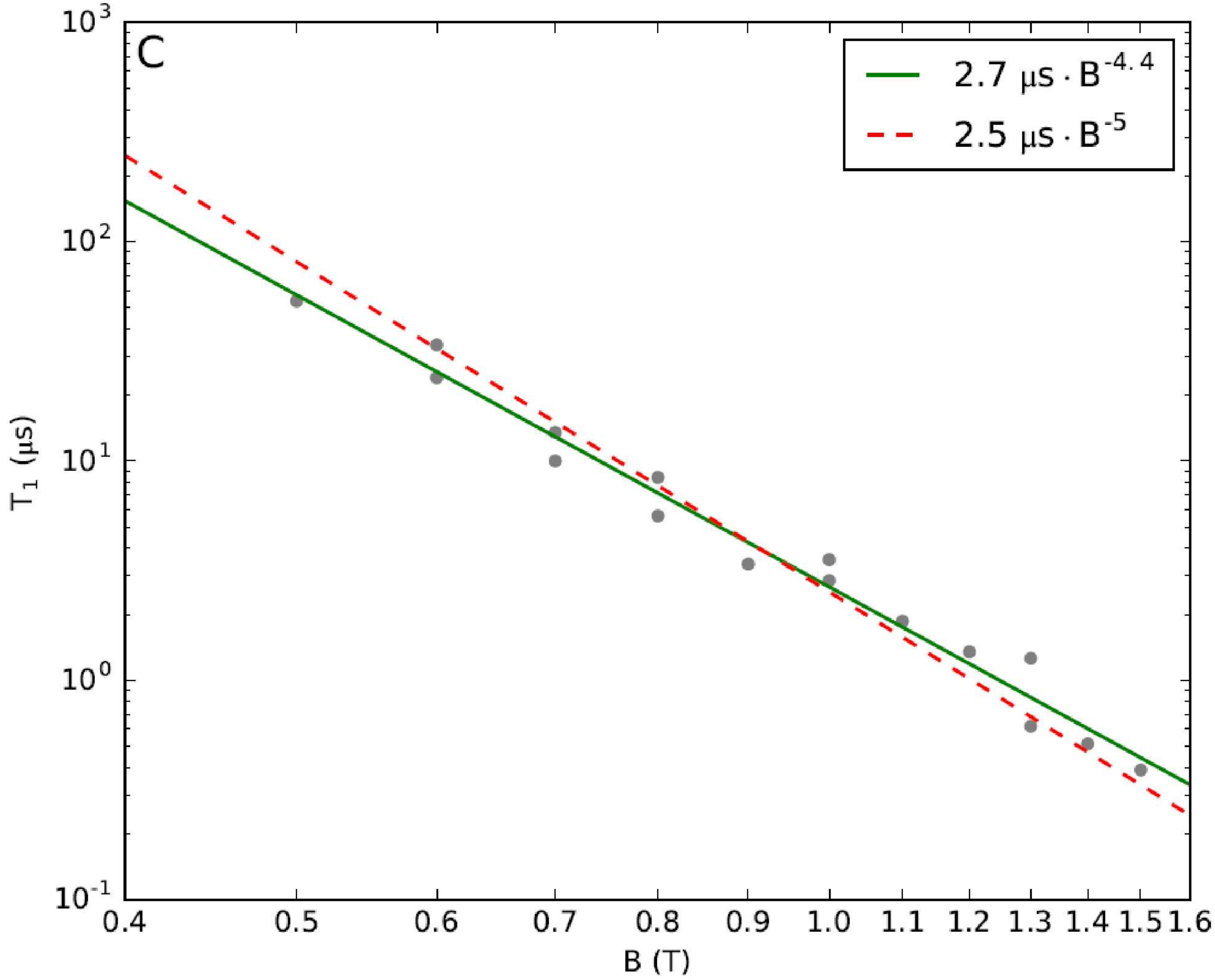
Single Shot Readout







B Dependence of T1 (Phonon assisted S-0)



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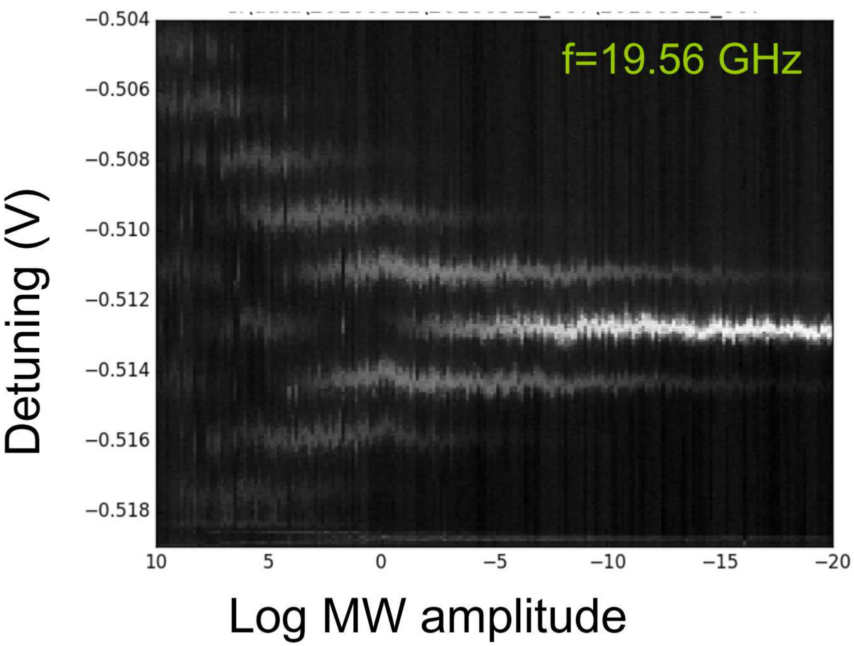
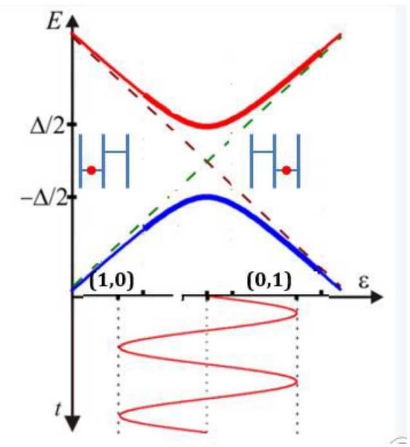
Landau-Zener-Stuckelberg Inteferometry



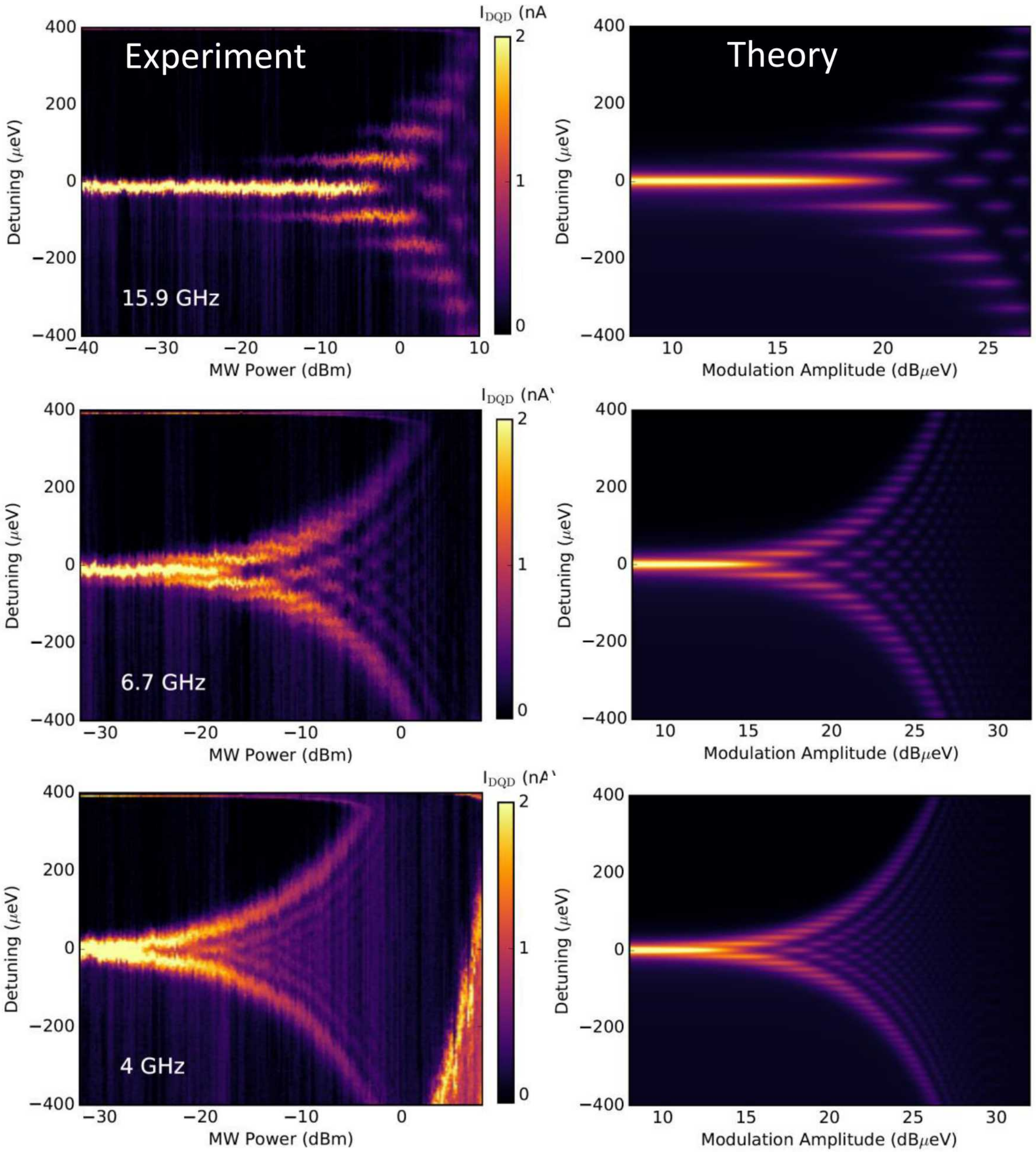
Zero magnetic field

$$t^{(n)} = t\ J_n\left(\frac{V}{\hbar\omega_{MW}}\right)$$

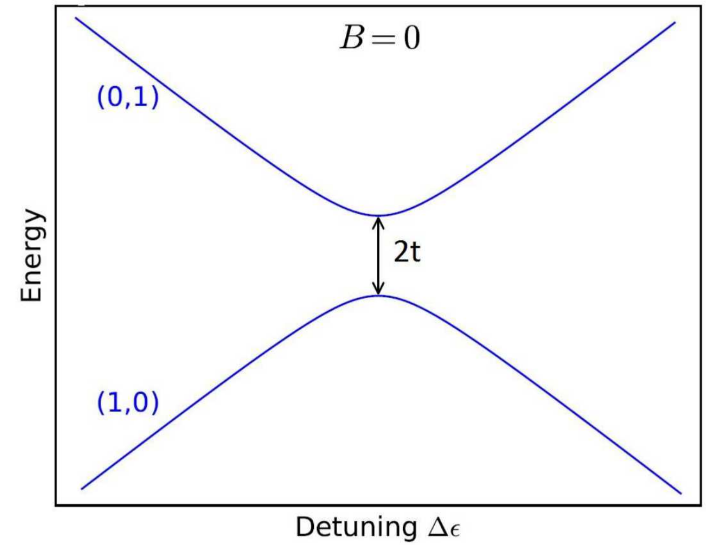


For electrons:
Oosterkamp et al., Nature **395**, 873; Schreiber et al., Nature Comm. **2,** 556, Gonzalez-Zalba et al., Nano Lett. **16,** 1614; Stehlik et al., PRB **86,** 121303; Forster et al., PRL **112,** 116803

LZS oscillations of a single-hole charge qubit at B=0



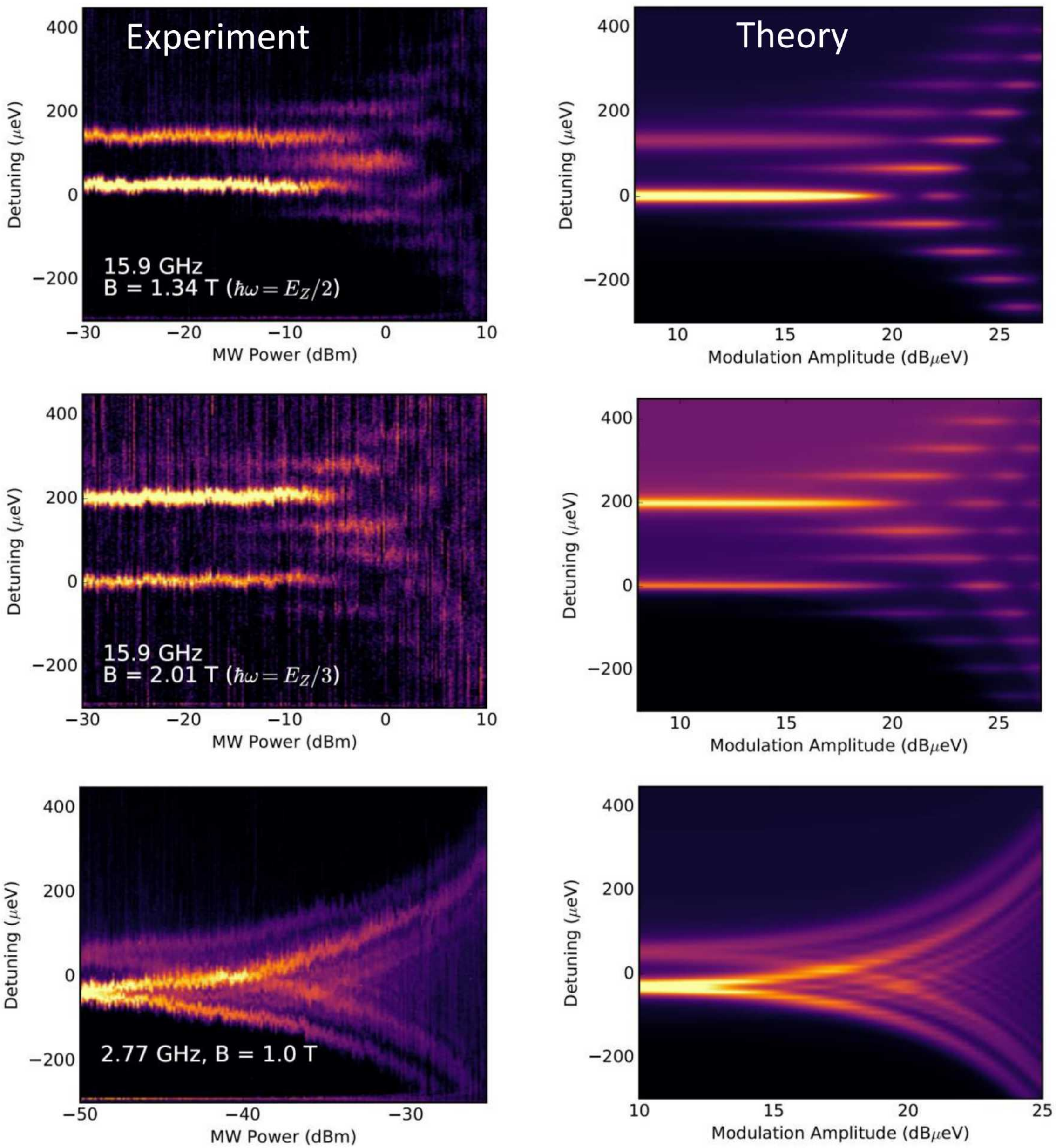
A. Bogan et al. PRL (2018)



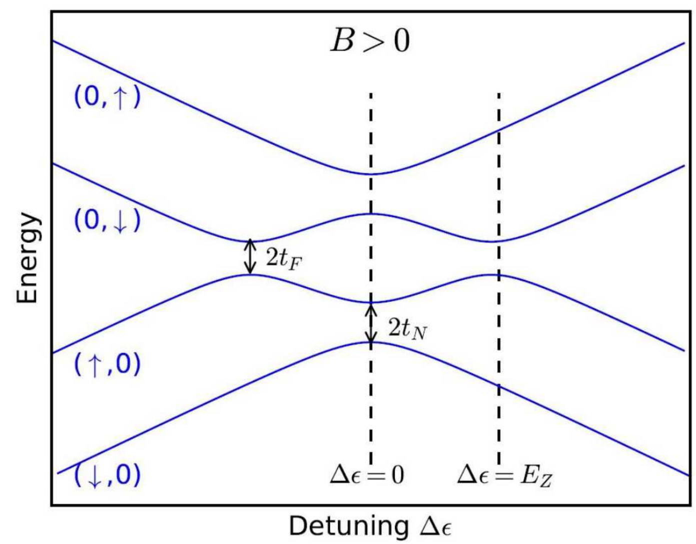
$$t = \sqrt{t_N^2 + t_F^2}$$

$$t^{(n)} = t \; J_n\left(\frac{V}{\hbar\omega_{MW}}\right)$$

Single-hole hybrid spin-charge qubit at B>0

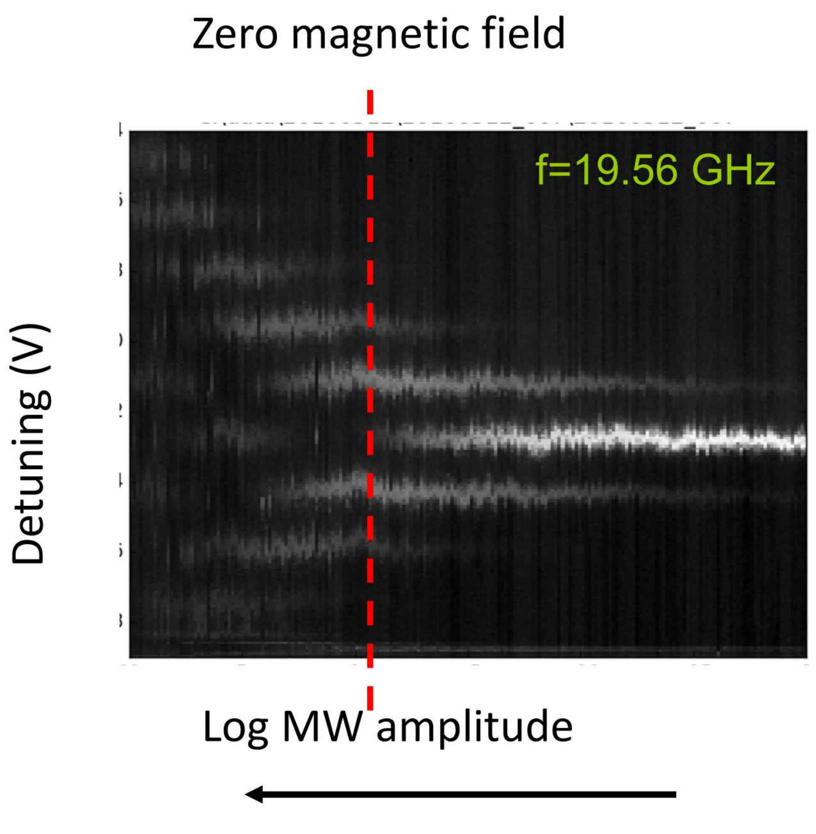


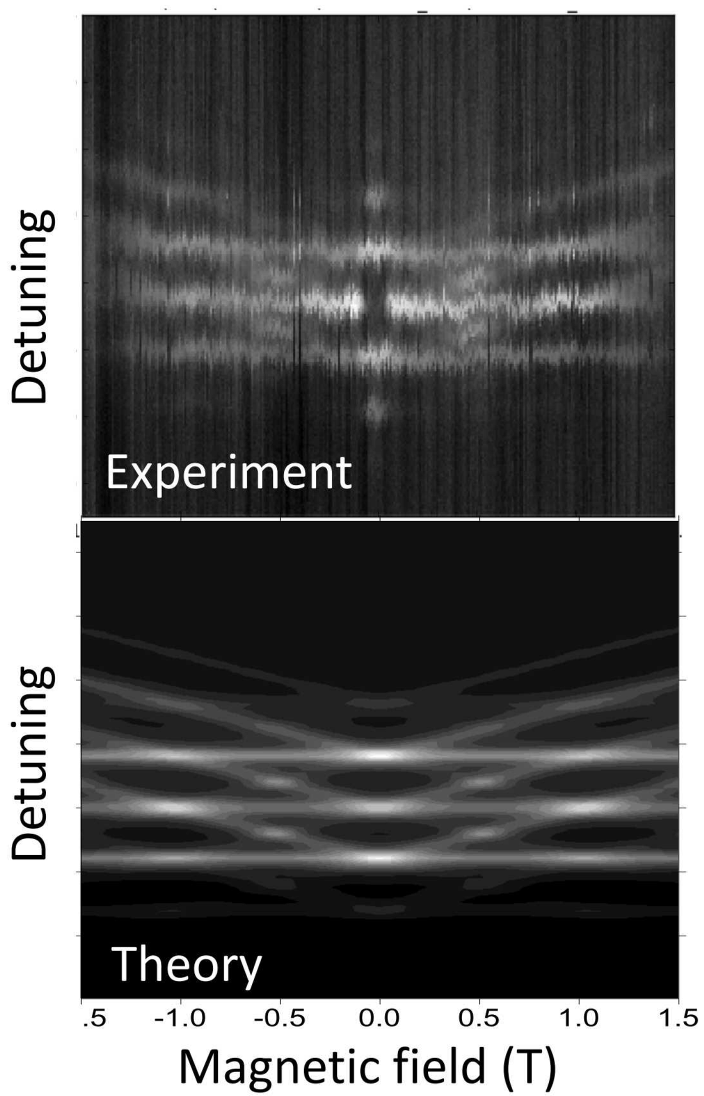
A. Bogan et al. PRL (2018)



$T_{2F}^* \sim T_{2N}^* \sim 100\text{ps}$

Magnetic field dependence of LZS





Pattern splits into
spin-conserving and spin-flipping PAT

Spin-not gate

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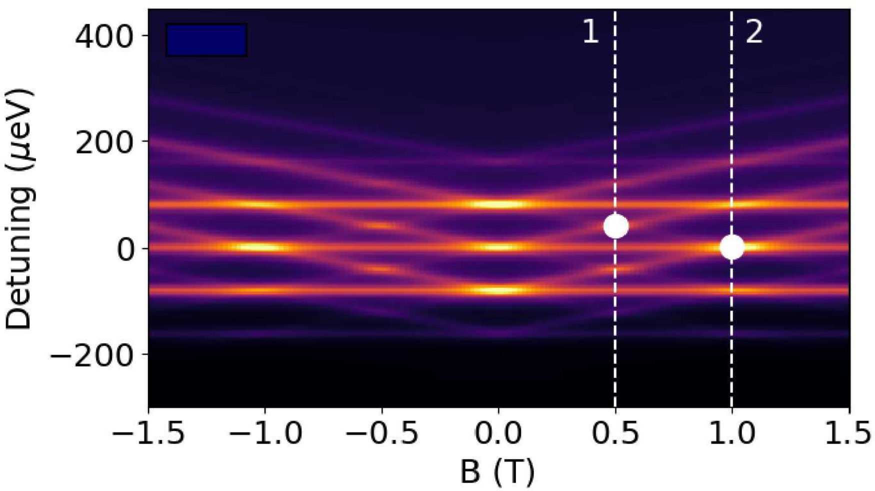
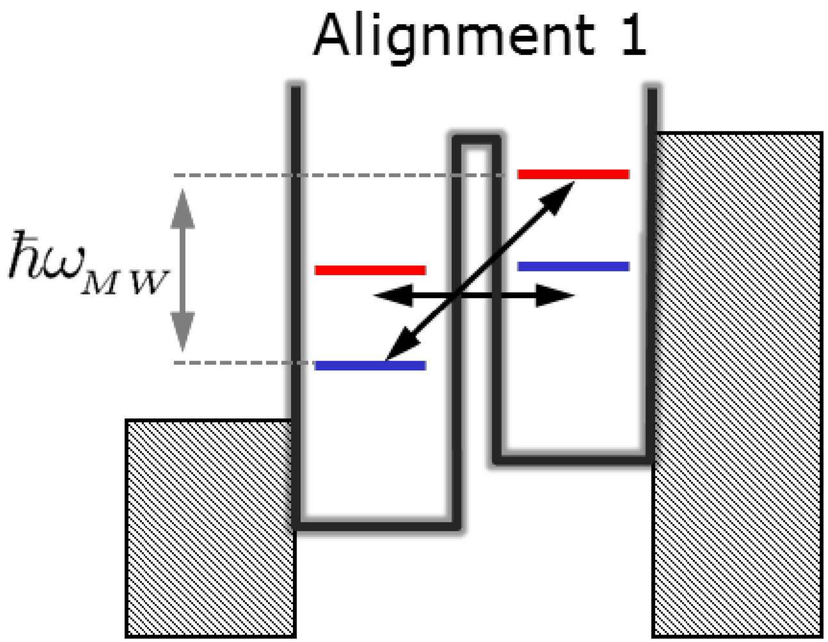




Two spin-flip transitions:

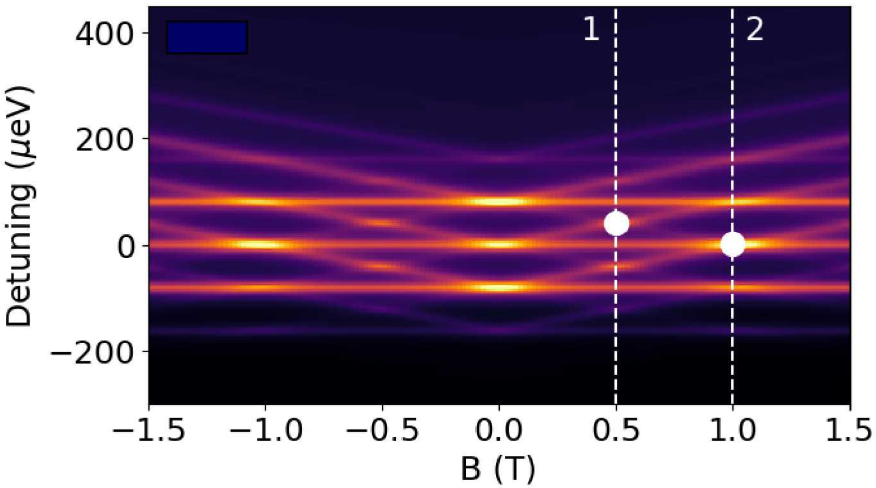
n=0 order: $\Uparrow_L \leftrightarrow \Downarrow_R$

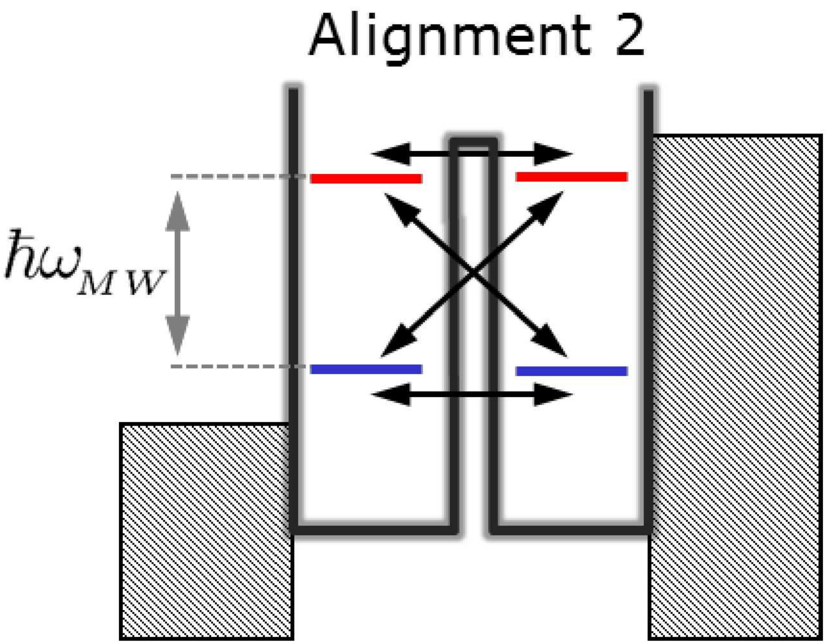
n=1 order: $\Downarrow_L \leftrightarrow \Uparrow_R$

Possibility of the complete NOT gate

$$\alpha\left|\Uparrow_L\right\rangle + \beta\left|\Downarrow_L\right\rangle \leftrightarrow \alpha\left|\Downarrow_R\right\rangle + \beta\left|\Uparrow_R\right\rangle$$

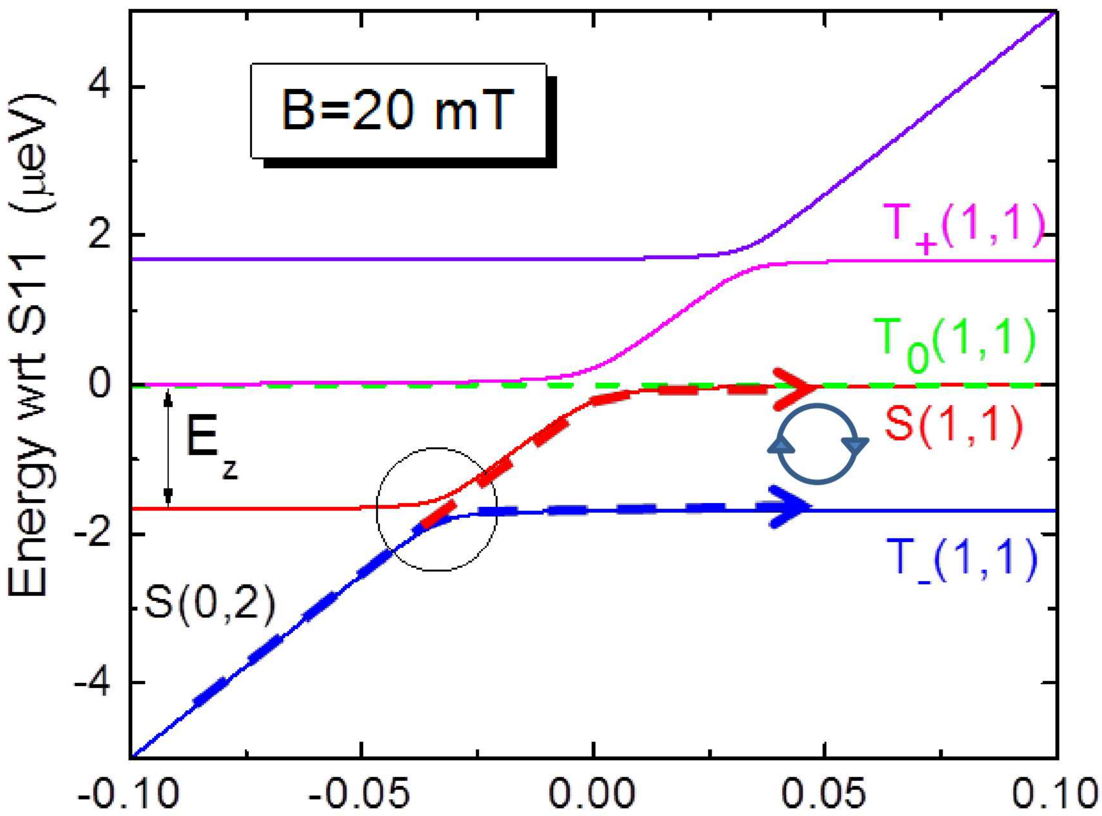
Interference loops



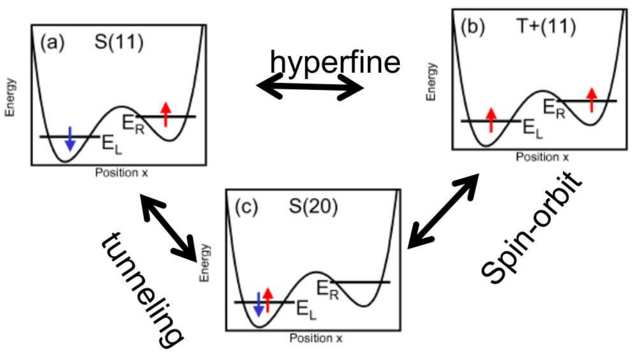


Multiple photon-assisted tunneling pattern
- possibility of novel quantum interference phenomena

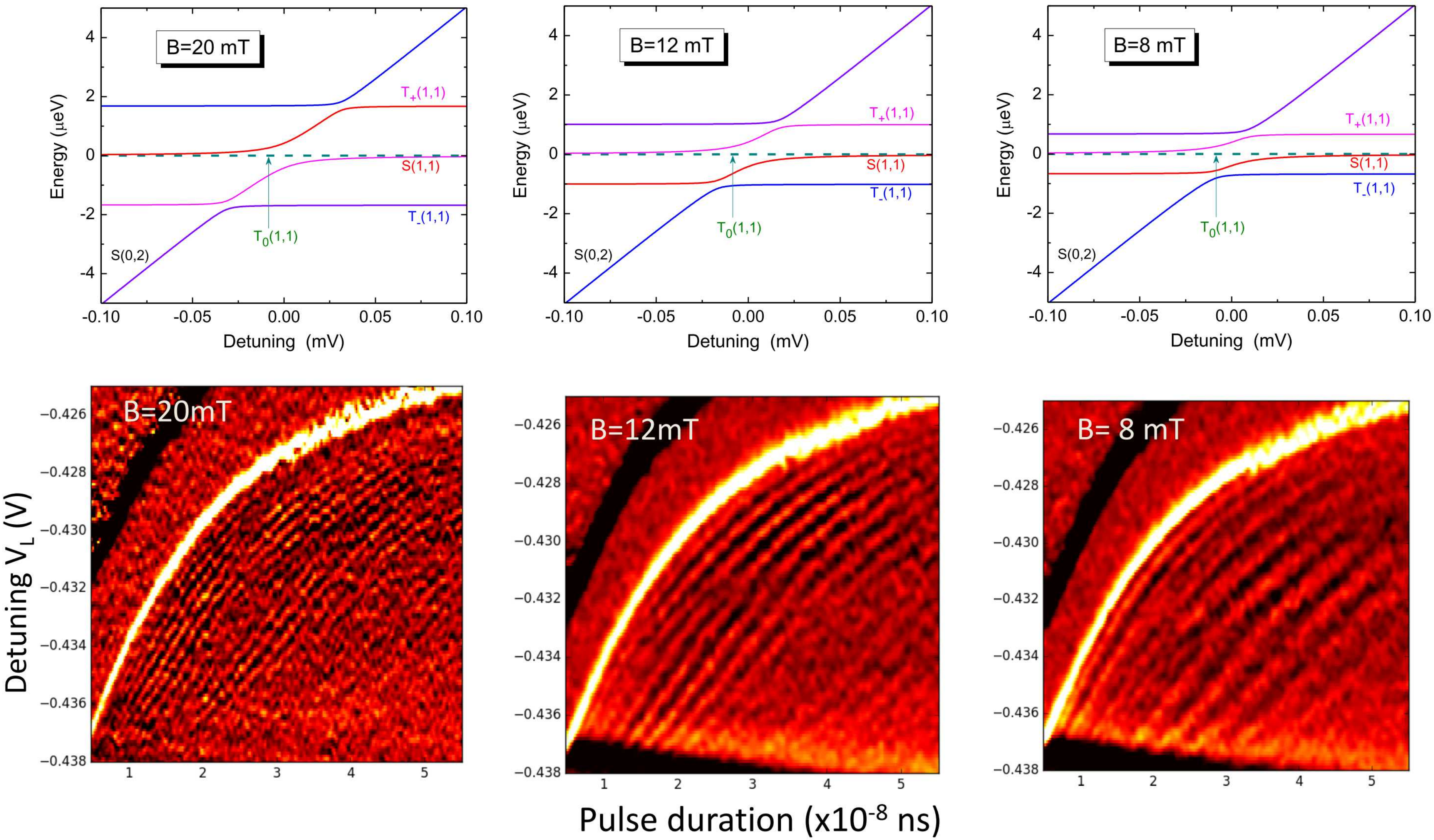
2 Hole LZS



Detuning (mV)

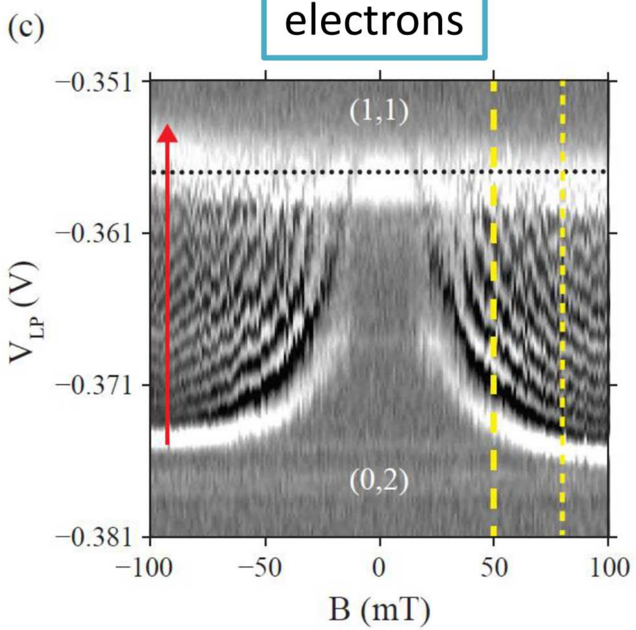


LZS oscillations probing two-spin qubit at different magnetic fields

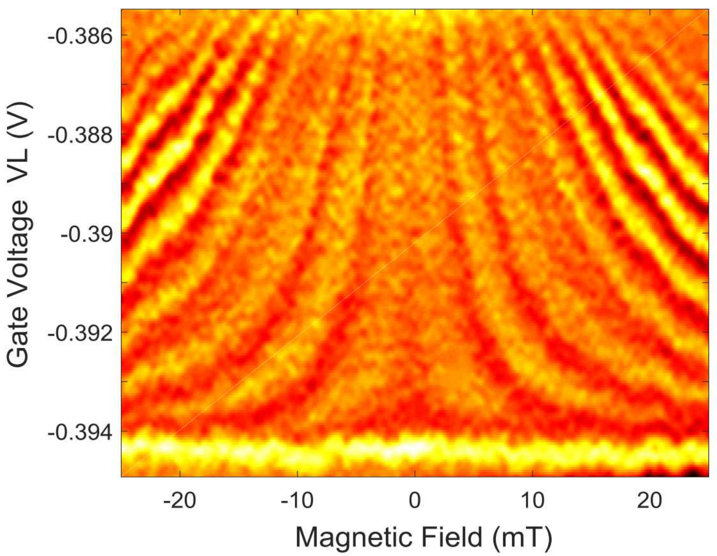


Coherent LZS funnels for electron and hole singlet-triple systems

electrons



holes



Conclusions

Spin-flip and non spin-flip tunneling similar order of magnitude due to strong S-O

Strong g-factor dependence on tilt - g~0 for in plane field

Single shot spin relaxation of single holes measured using latching technique
- B dependence consistent with Phonon mediated Dresselhaus S-O

LZS interferometry for single hole provide opportunities for novel functionalities due to spin-flip tunneling and spin-flip photo-assisted tunneling

LZS between S and T_- for two holes observed involving S-O (not hyperfine) coupling