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Single and two hole spin qubits formed in lateral GaAs/AlGaAs double quantum dots

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Outline

- Why hole spins?
- Device layout
- High-bias transport
- Spin-orbit blockade at $B=0$, B_N~0
- Hybrid single-spin hole qubit
- Two-spin hole qubit
- Conclusions

Potential advantages of holes in GaAs

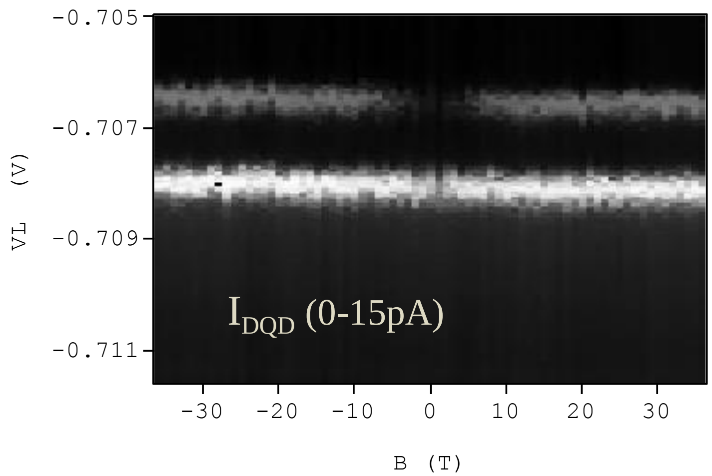
Direct bandgap for hybrid spin-photon devices

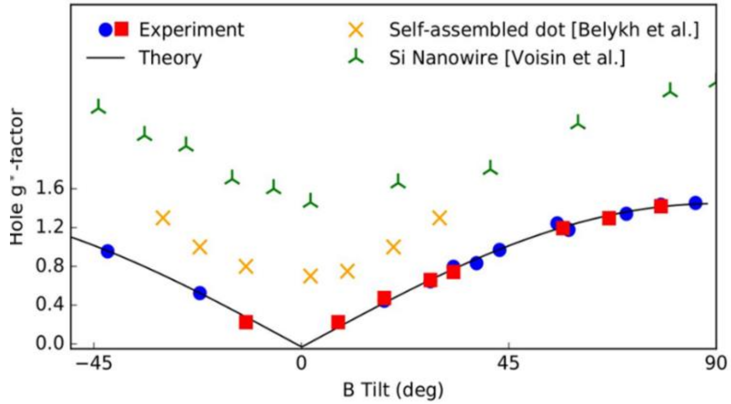
Reduced hyperfine decoherence

Strong and controlled spin-orbit coupling for fast spin rotations

In situ tunable g-factor

Controlled SO-mediated S-T_- coupling

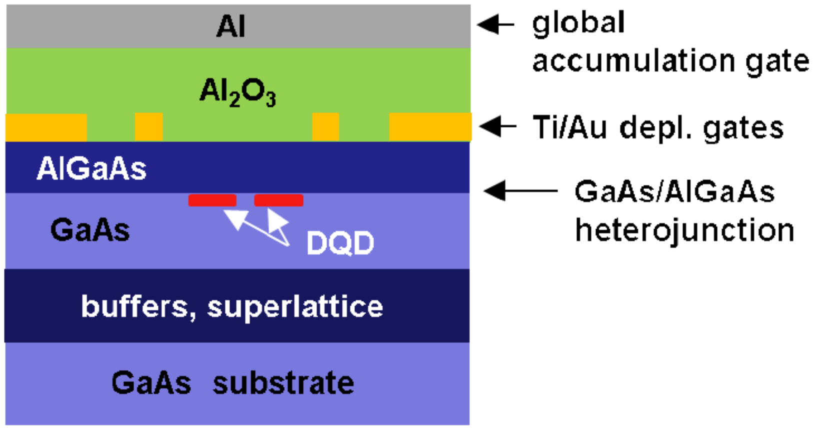


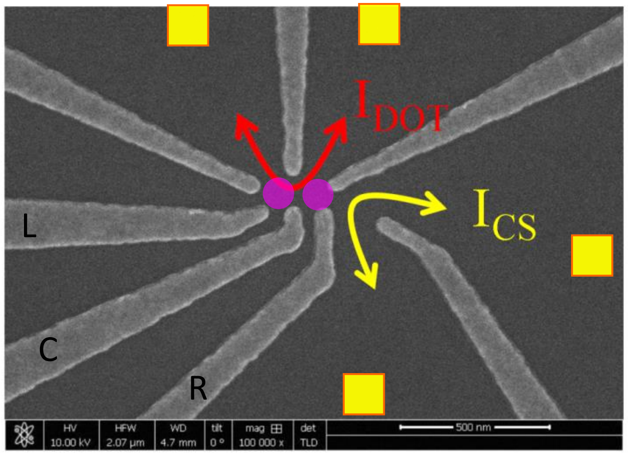


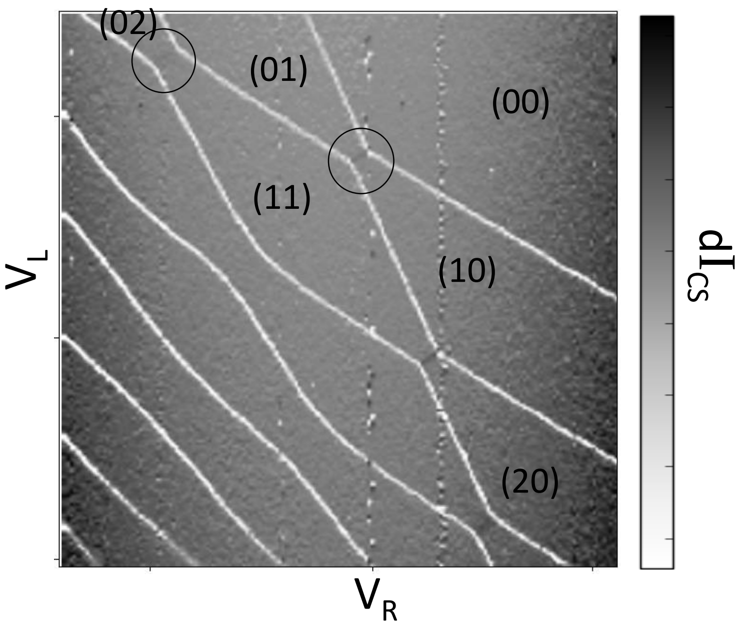
Bogan et al., Phys. Rev. Lett. (2017)

Device vertical and horizontal layouts

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

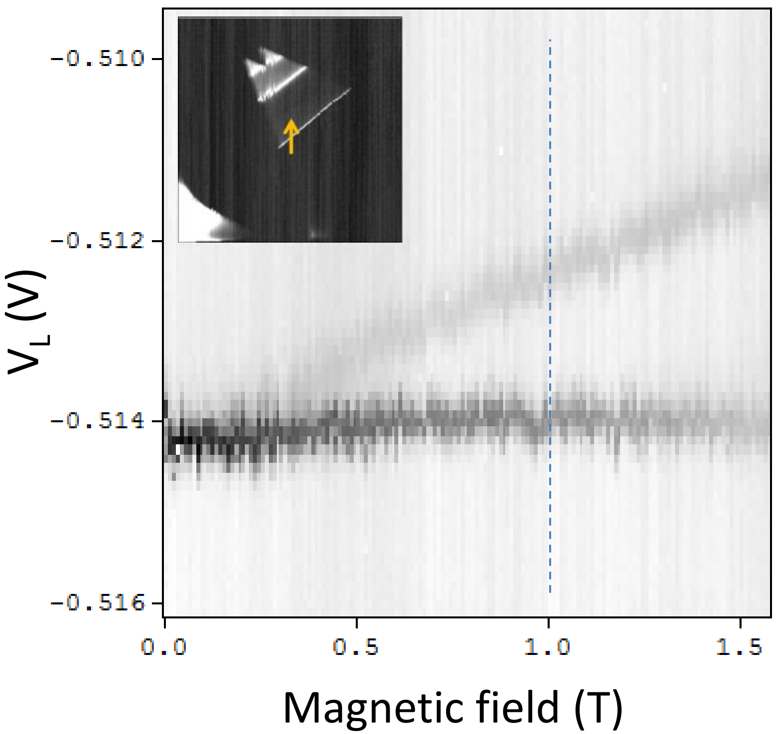


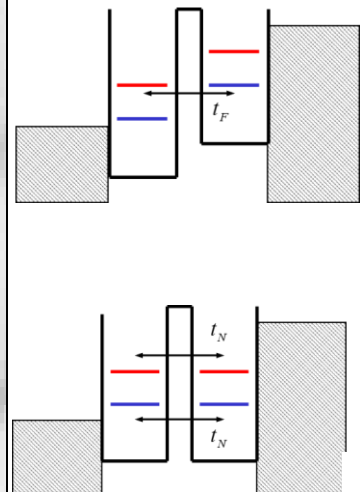


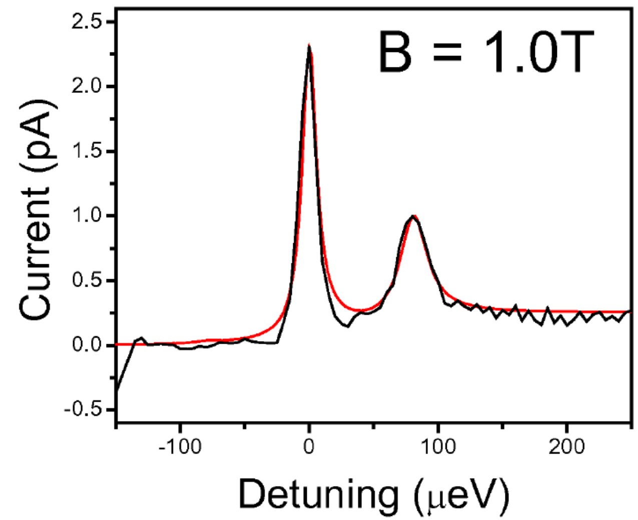


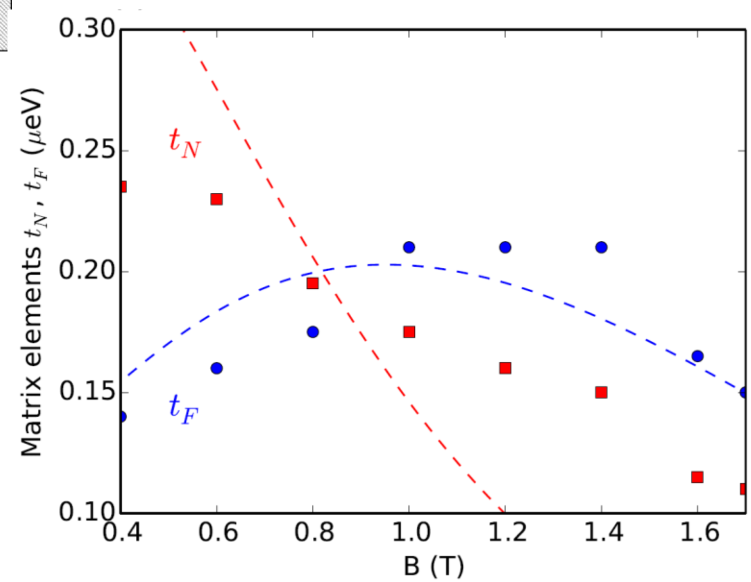
Measurements performed at T ~ 100 mK

Single hole: t_F and t_N tunneling matrix elements









A. Bogan et al. arXiv:1711.03492

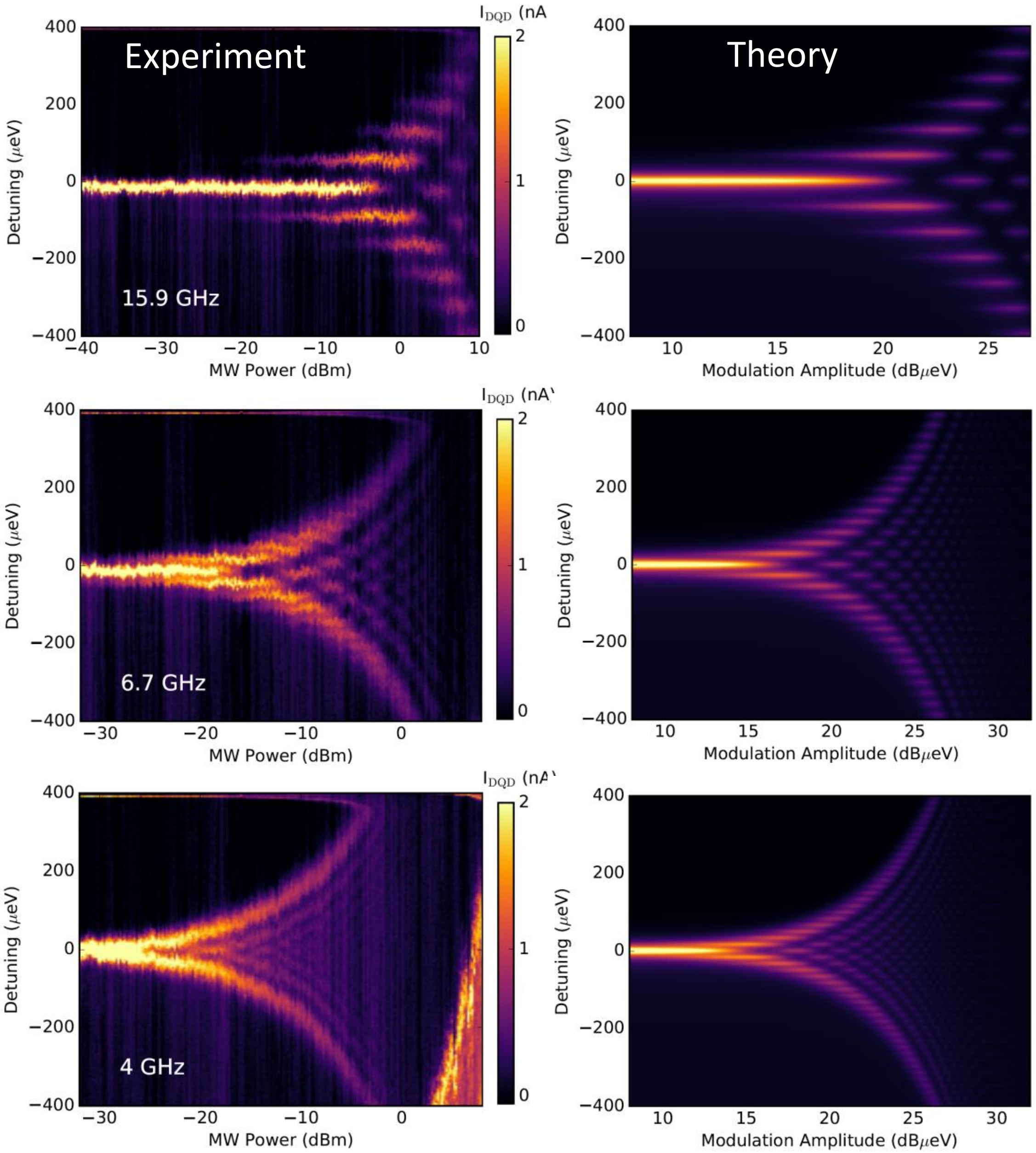
For electrons see:

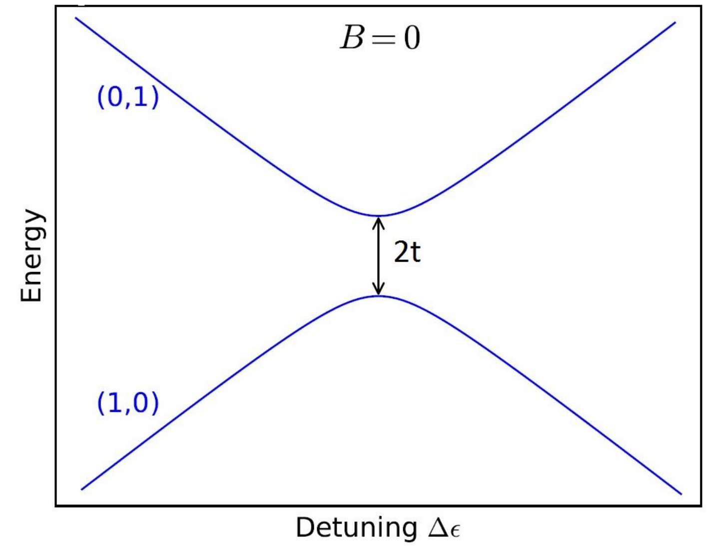
T. Fujita et al. PRL (2016)

V. F. Maisi et al PRL (2016)

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

A. Bogan et al. arXiv:1711.03492

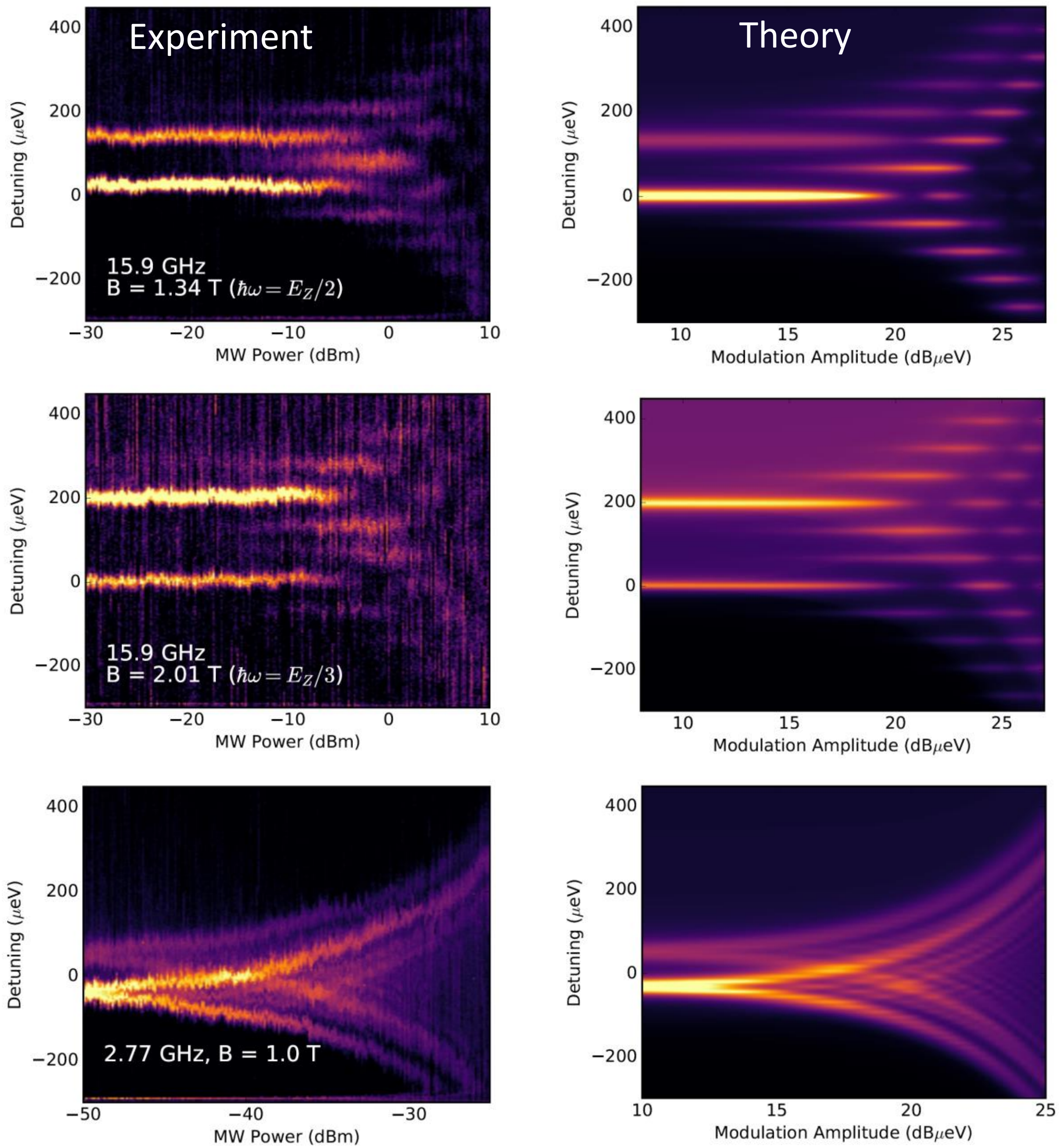




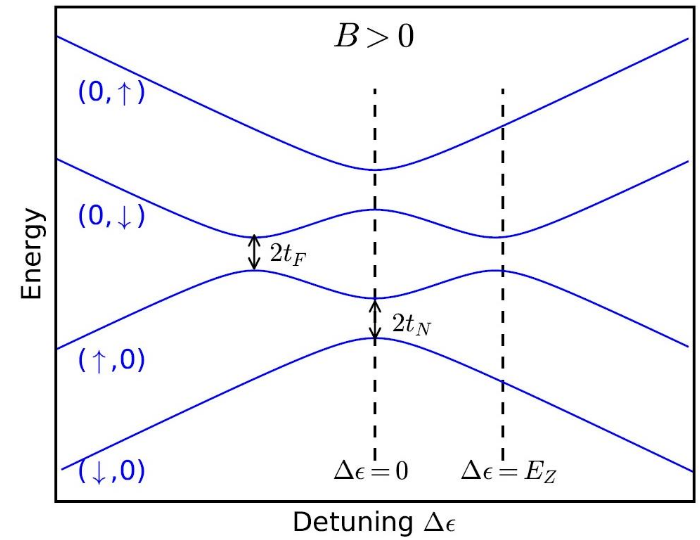
$$t = \sqrt{t_N^2 + t_F^2}$$

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

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

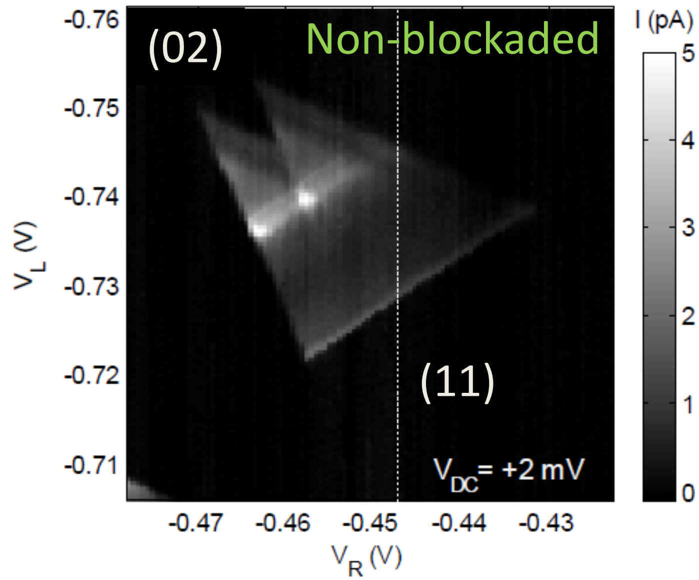


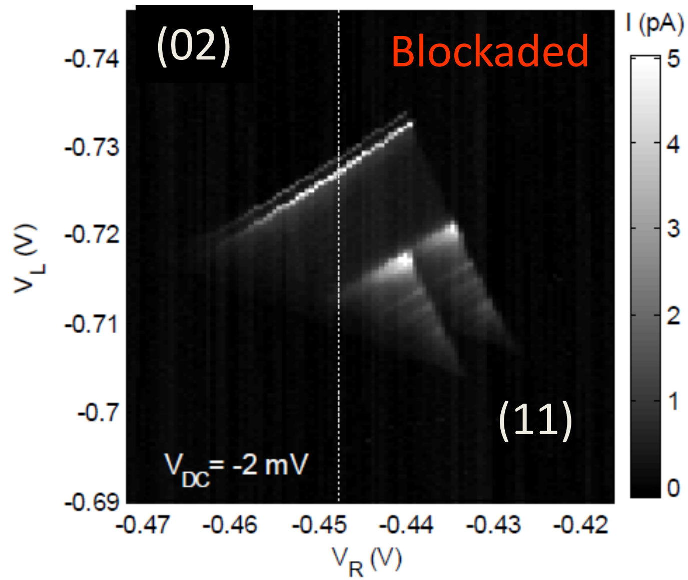
A. Bogan et al. arXiv:1711.03492

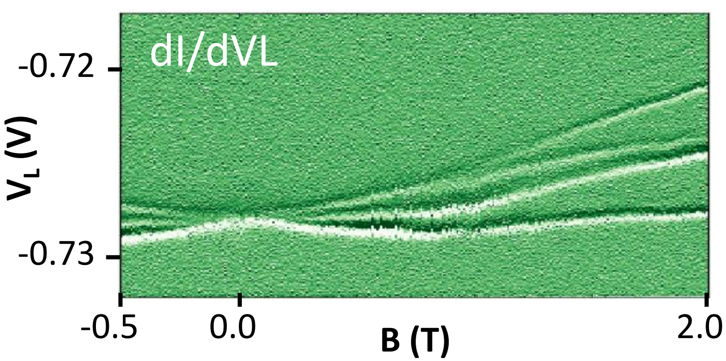


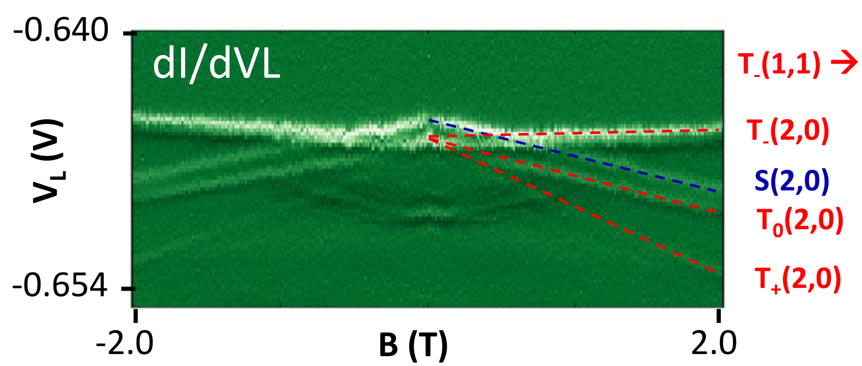
$T_{2F}^* \sim T_{2N}^* \sim 100$ps

High-bias transport in two-hole regime

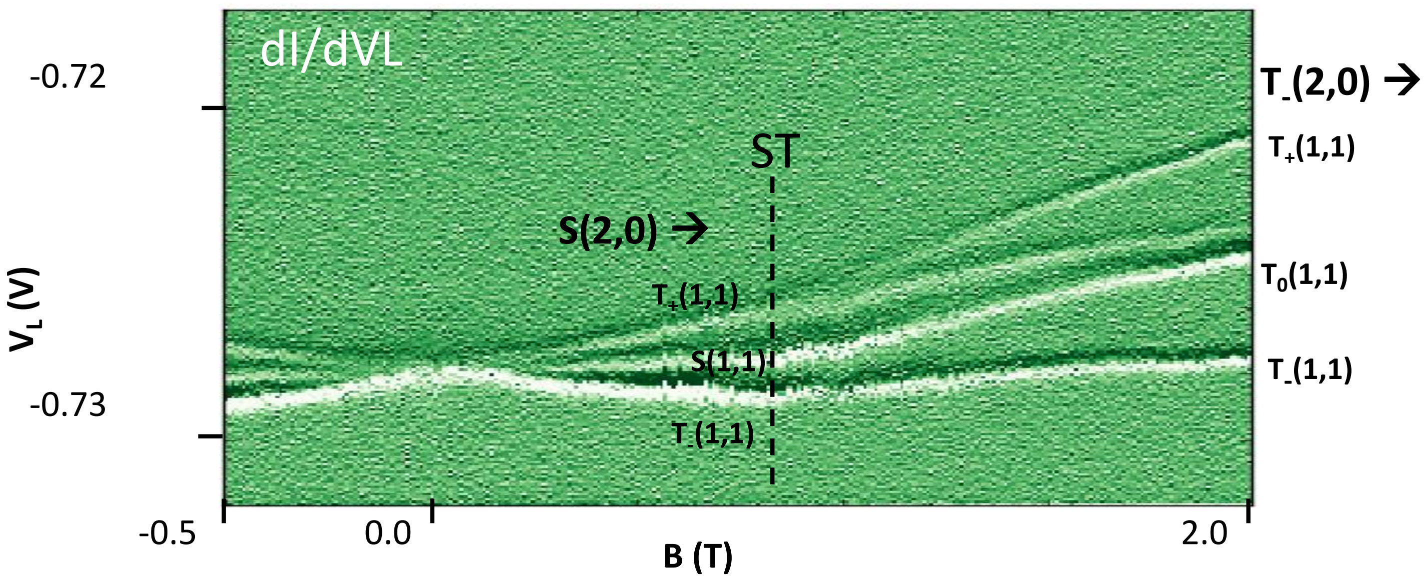








High-bias transport in non-blockaded direction



ST is singlet-triplet transition of the ground state from S(2,0) to T_-(2,0)

Examples of high-bias transport vs magnetic field

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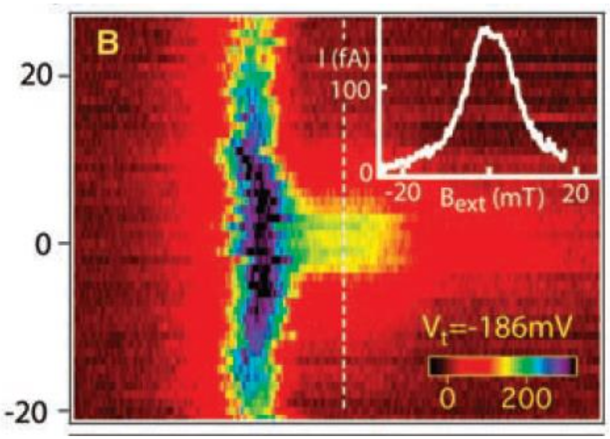
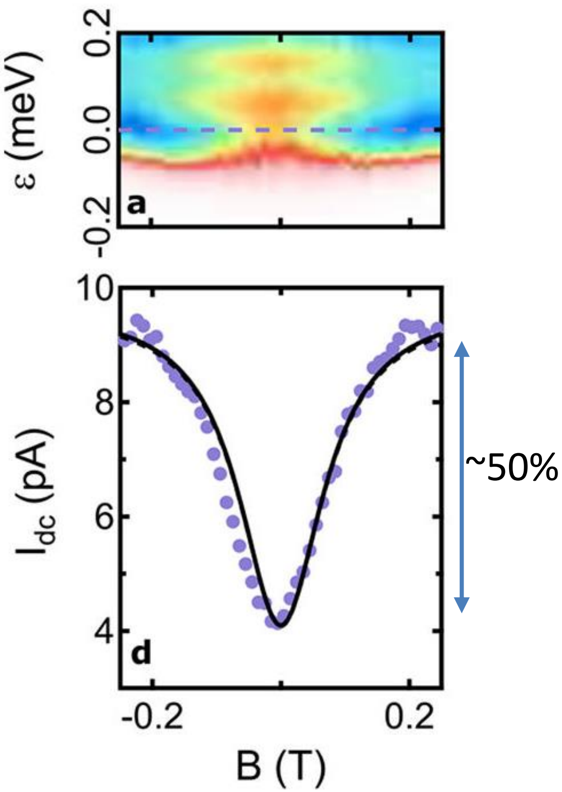


n-GaAs DQD

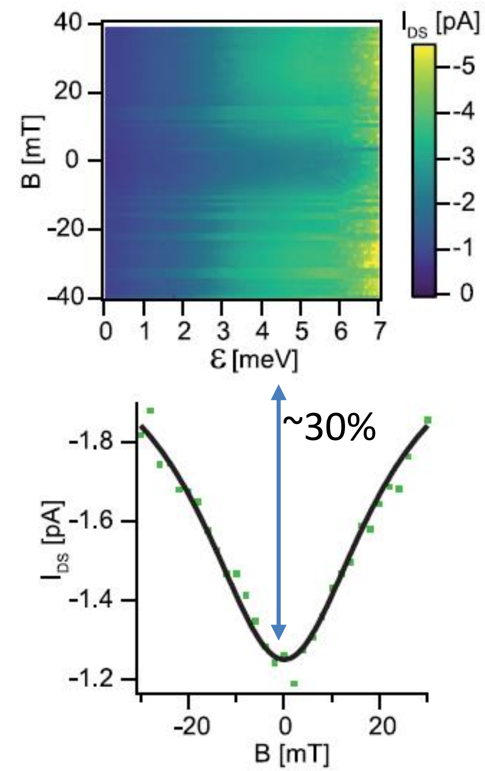
F. H. L. Koppens et al.
Science (2005)

$I(B=0)/I_{max} \sim 0.5$



p-GaAs DQD

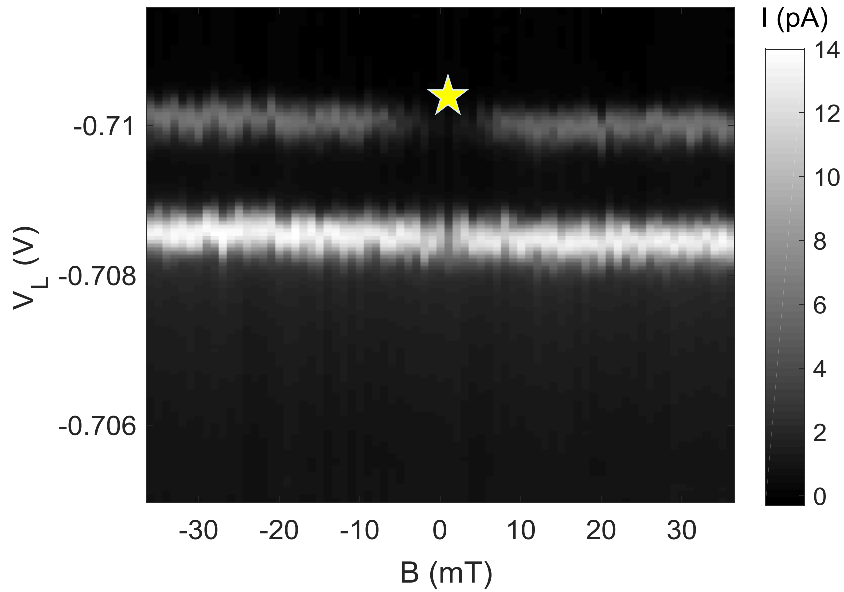
D. Q. Wang et al.
Nano Lett. (2016)

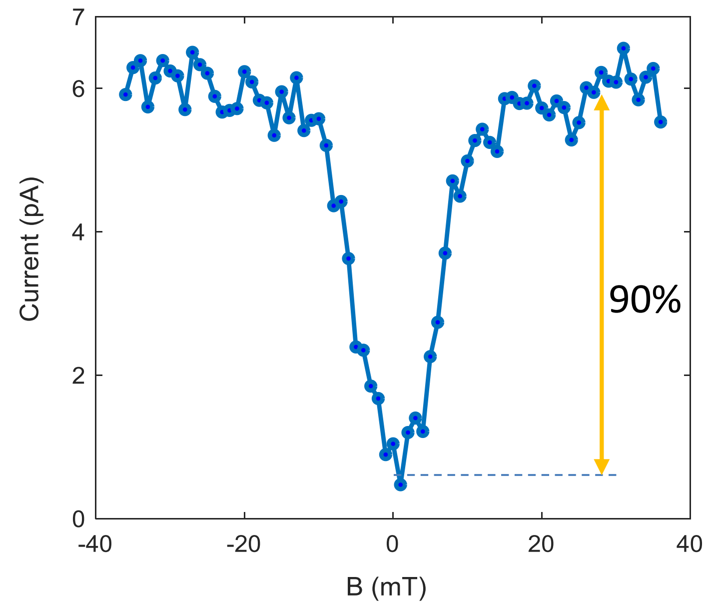


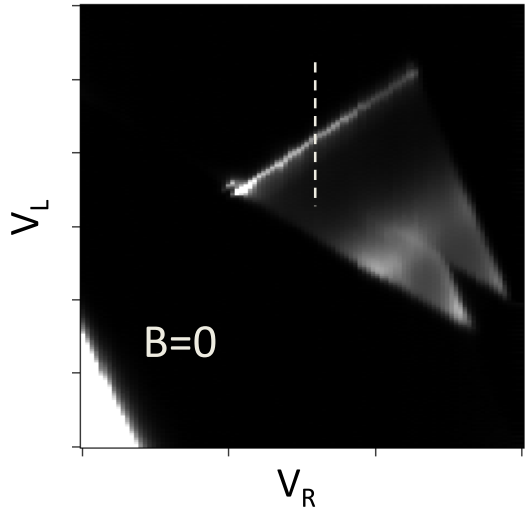
p-Si DQD

Bohuslavskyi et al.
Appl. Phys. Lett. (2016)

Hole spin-orbit blockade at zero magnetic field



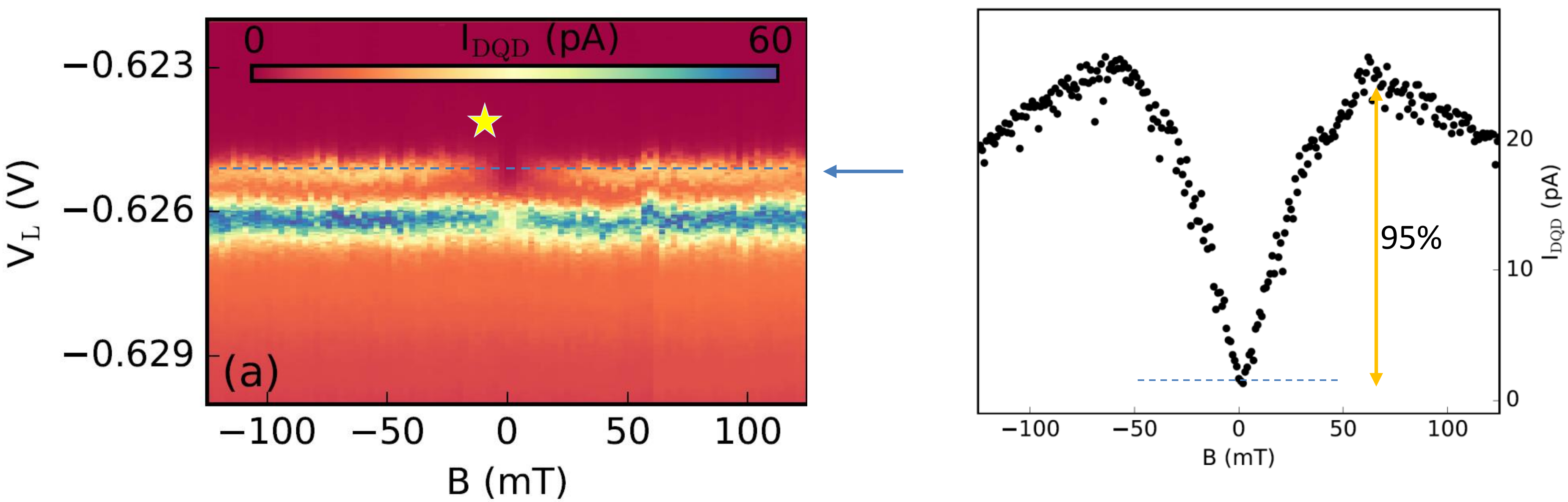




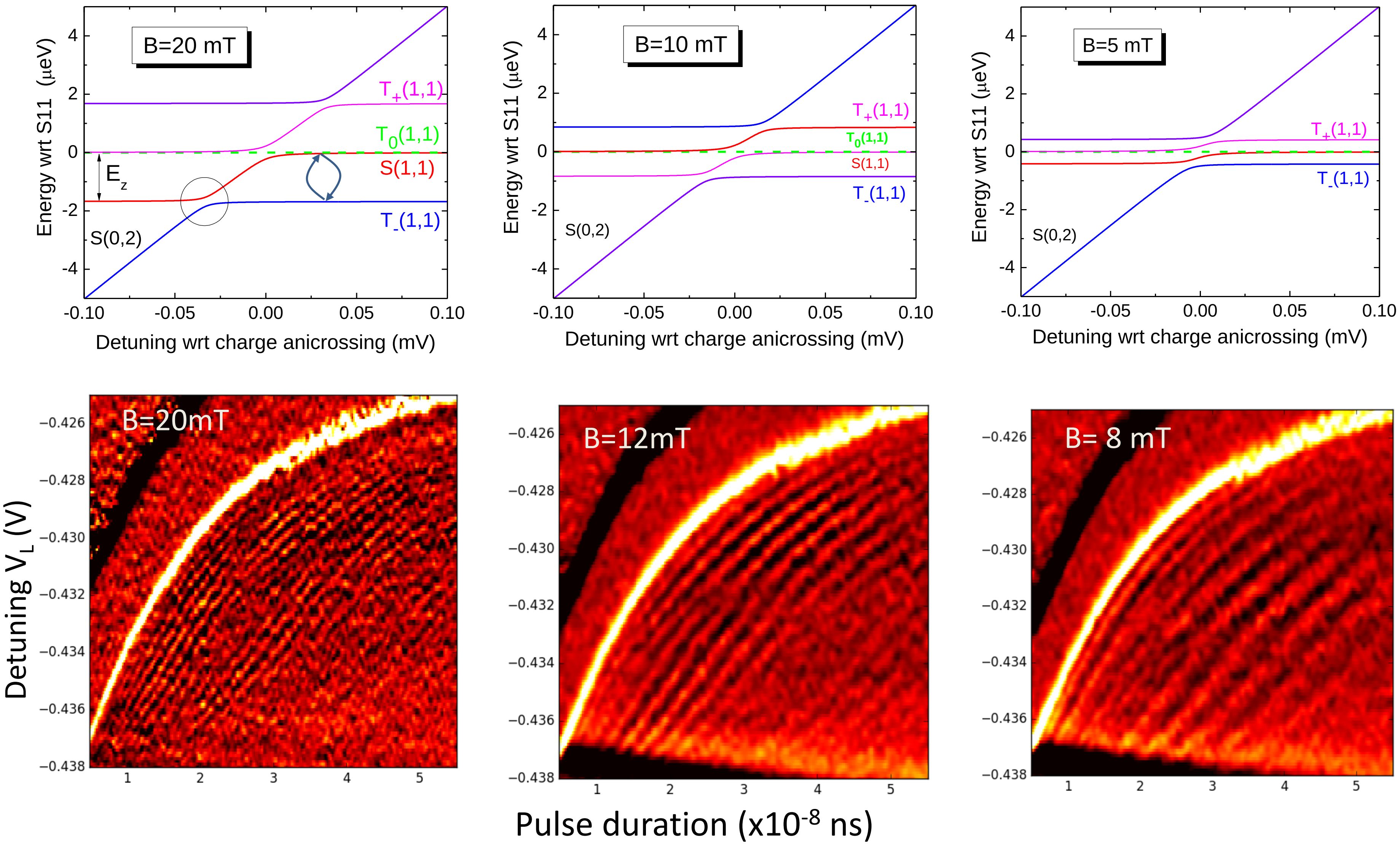
$I(B=0)/I_{max} << 1$ =>

Hyperfine coupling is suppressed

Another example of spin-orbit blockade



LZS oscillations probing two-spin qubit at different magnetic fields



Spin-funnel measurements for electron and hole singlet-triple systems

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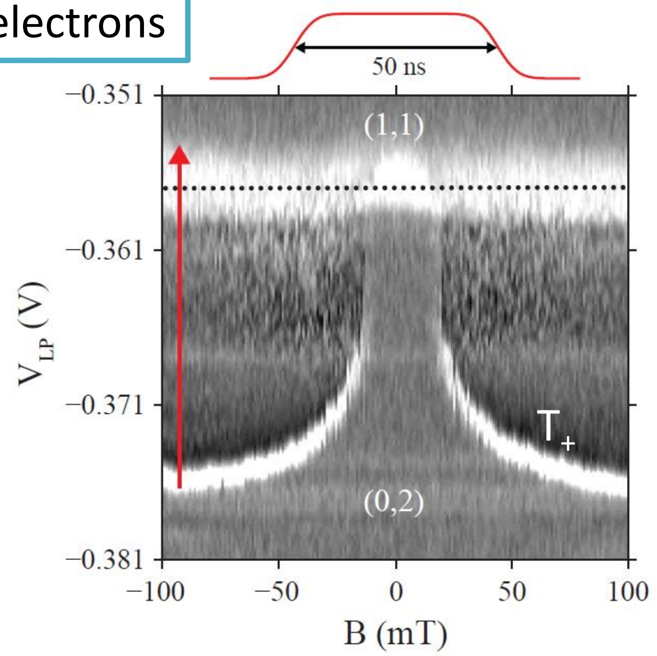
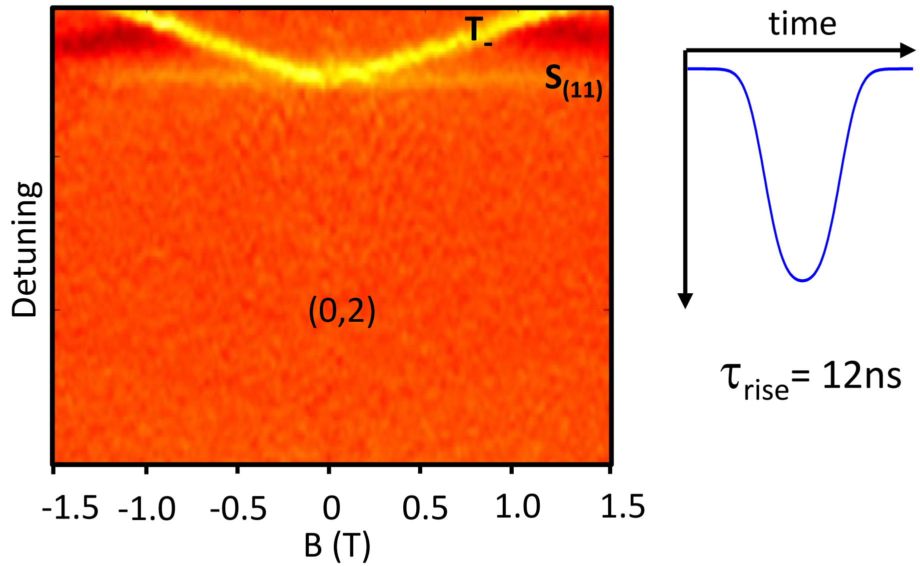
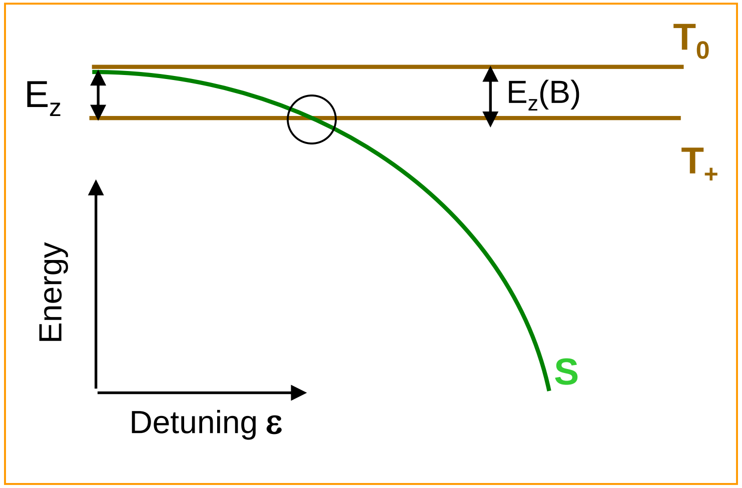
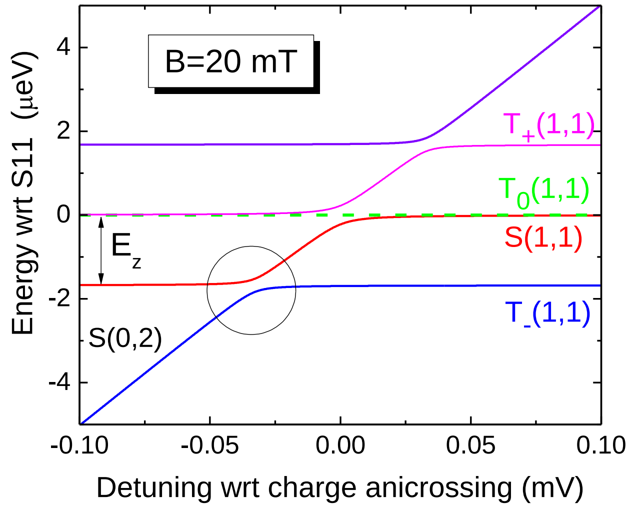
electrons



holes

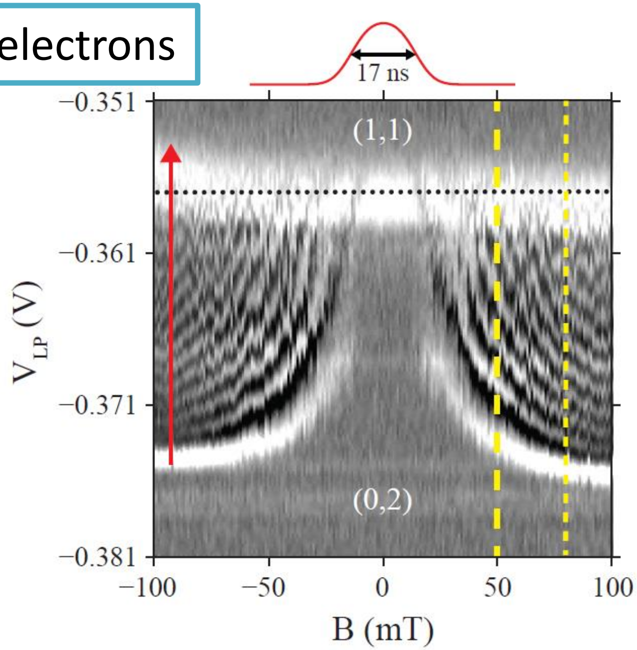




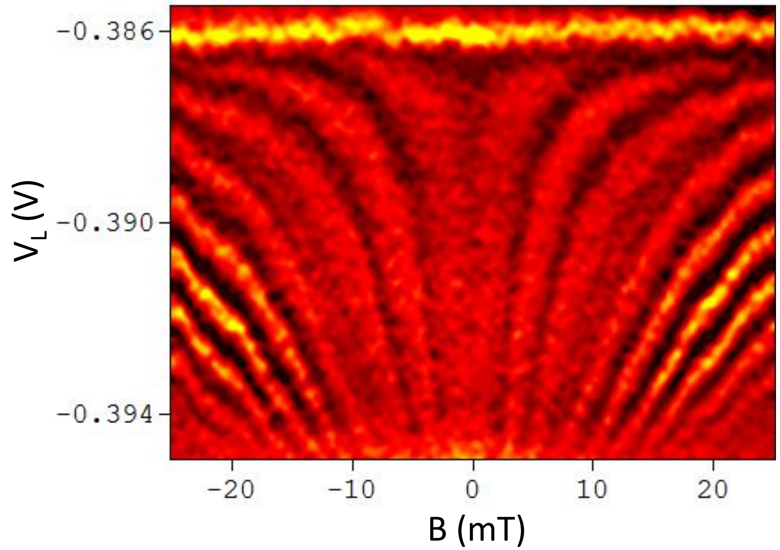


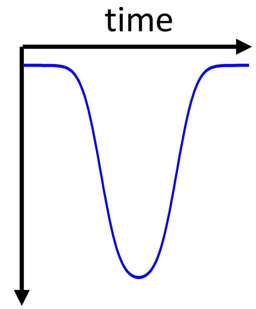
Coherent LZS funnels for electron and hole singlet-triple systems

electrons



holes





Summary

- ***A few hole spin system has been realized and studied via high-bias transport and LZS coherent manipulation techniques.***
- ***The hole spin physics is dominated by the strong spin orbit interaction.***
- ***Hyperfine interaction is substantially reduced***