Group Meeting Talk

# Single hole spin relaxation probed by fast single-shot latched charge sensing

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# Background

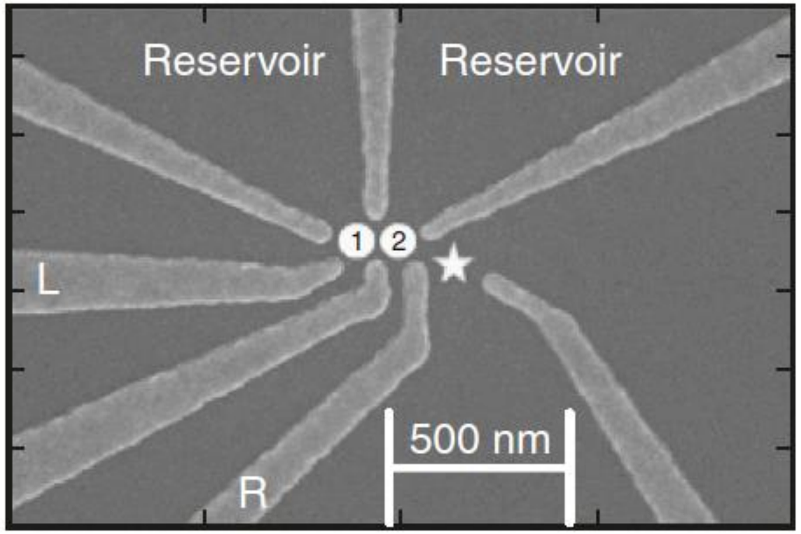
- B up to several mT: flip-flop interactions with nuclear spins
  - Electrons in gated GaAs QDs: 10-100 ns near zero field (Hanson et al., 2007), ~70 μs at 100 mT (Petta et al., 2005); dependence of $T_1 \propto B^{-3}$
  - Holes in GaAs: Hyperfine interaction strength is an order of magnitude weaker, translating to an improved $T_1$ (~1 ms in InGaAs sample at 250 mT (Gerardot et al., 2008))

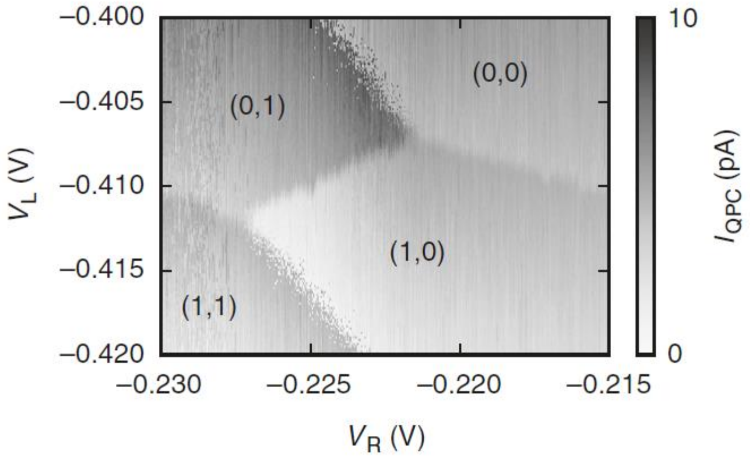
- Higher B: Spin relaxation via phonon-mediated SOI
  - Electrons in GaAs: $T_1$ ~ 1 s at 1-2 T (Amasha et al., 2008), $T_1 \propto B^{-5}$
  - GaAs hole sample: $T_1$ ~ 300 ns at B=0.5 T (Wang et al., 2016)
  - Theory for holes: $T_1 \propto B^{-5}$ for Dresselhaus SOI, $T_1 \propto B^{-9}$ for Rashba SOI (Bulaev et al., 2005) & exact functional relationship depends on structural properties of QD (e.g. shape, size, thickness, strain)

# Latched charge sensing technique

- Idea: Convert short-lived spin states into long-lived metastable charge states
- Hole GaAs dot: Strong spin-flip tunneling due to SOI suppresses spin-to-charge conversion with Pauli-blockaded state
- Charge detection in the system is not sufficiently fast for spin-selective time-resolved tunneling to leads
- Paper: Fast single-shot measurements of spin states for single hole in GaAs via latched charge state

# Sample layout

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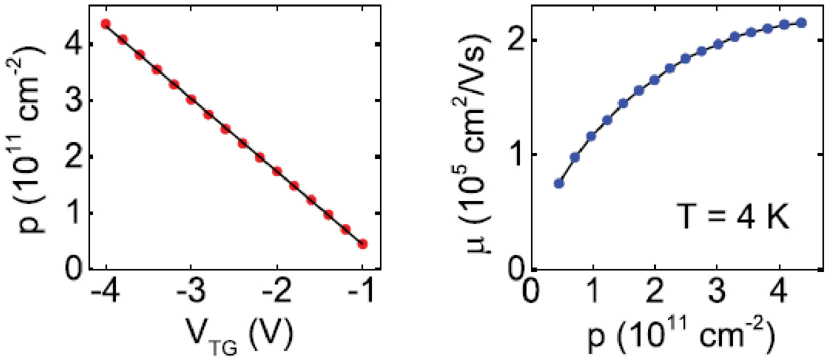
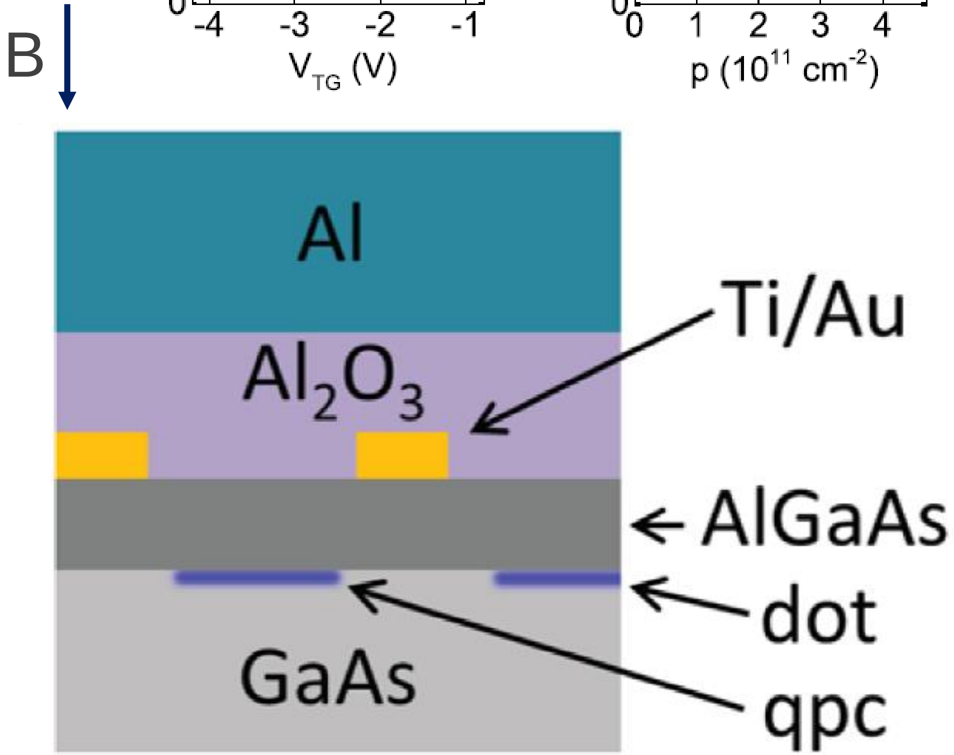



L. A. Tracy et al., Appl. Phys. Lett. **104**, 123101 (2014)

# Spin readout protocol

- Pulse sequence applied to left gate $V_L$
- Tunneling rates:

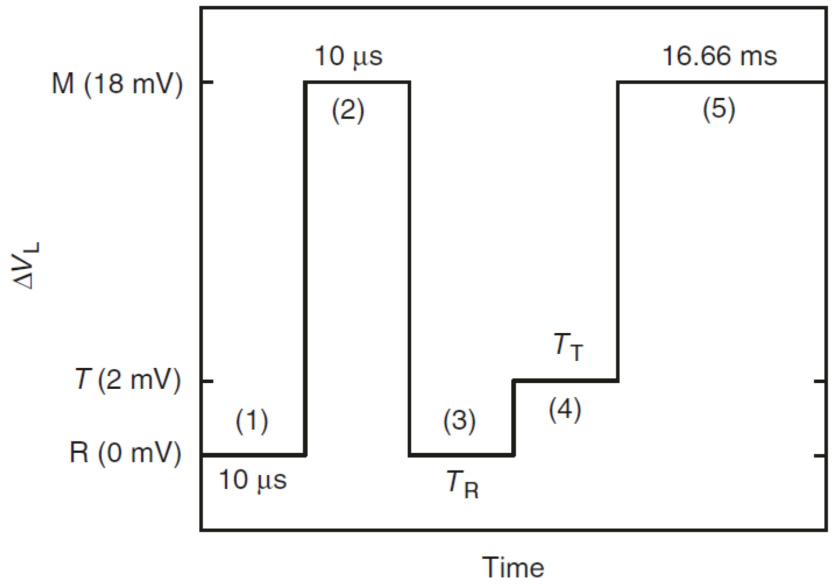
Tunneling to right lead ~ 2 MHz

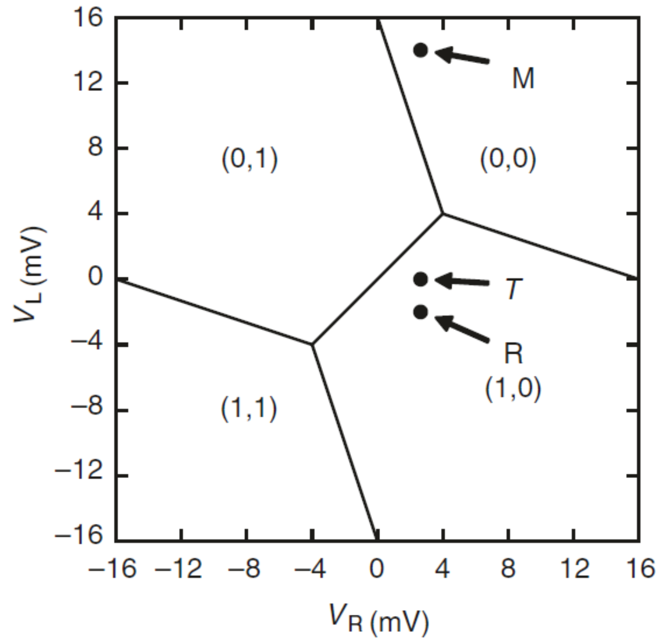
Tunneling to left lead ~ 100 MHz

Resonant interdot tunneling ~ 50 MHz

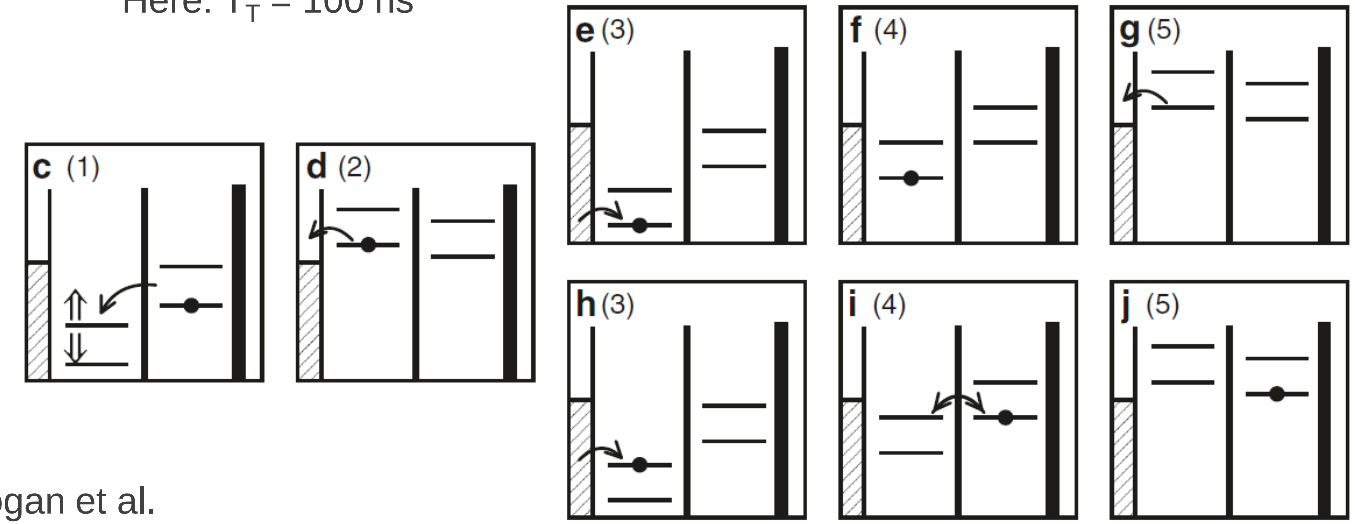
Inelastic interdot tunneling ~ 0.5 MHz

- Detected latched charge (0,1) [(0,0)] corresponds to spin up [down] in left dot




Here: $T_T$ = 100 ns

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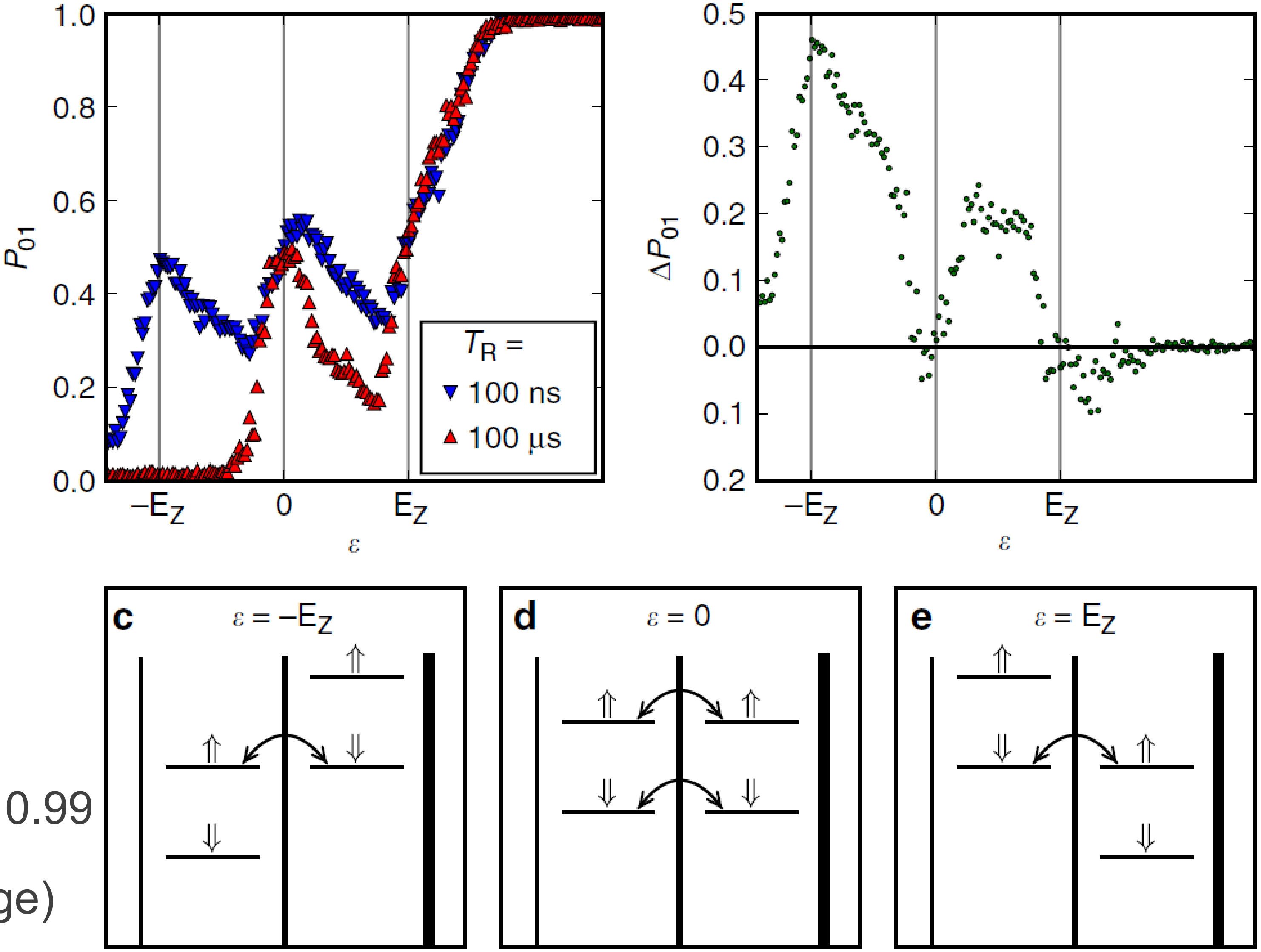
# Protocol sensitivity

- Average probability $P_{01}$ in 1000 measurements depending on detuning ε for two different values of $T_R$
- Change in $\Delta P_{01}$ indicates sensitivity to spin relaxation at different detuning
- $\varepsilon \gg E_Z$ : Sensitivity is lost as initial alignment (1) becomes inverted ($P_{01} \sim 1$)
- Fidelity of protocol: F↓ = P((0,0)|L↓)) = 0.99 F↑ = P((0,1)|L↑)) = 0.52 (distributed charge)

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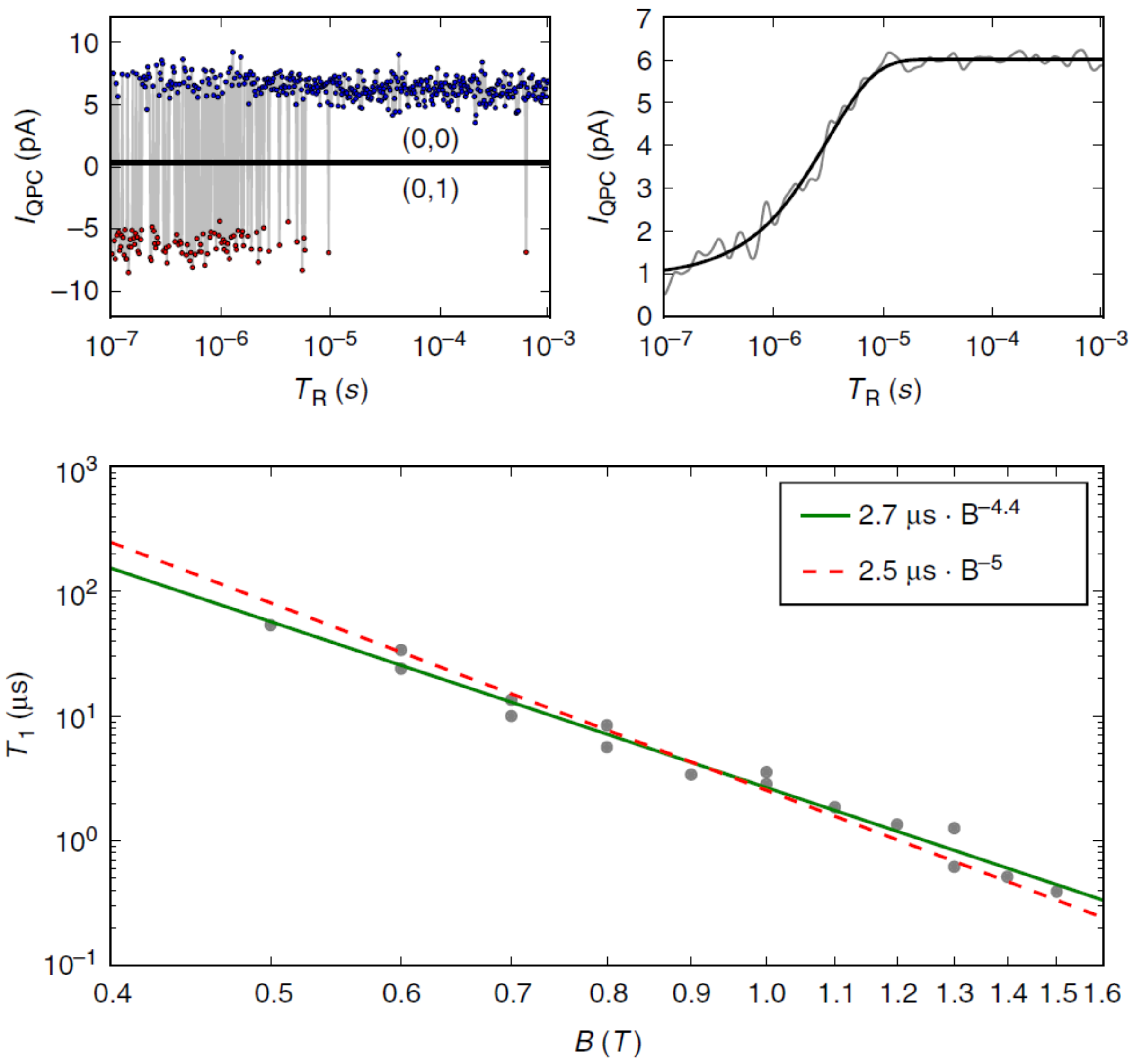
# Extraction of $T_1$

- Measure single-shot $I_{QPC}$ values
- Gaussian averaging of 1000

measurements for each $T_R$

- Fit to $I_{\mathrm{QPC}}(T_{\mathrm{R}}) = I_0 + I_1\left(1 - e^{-T_{\mathrm{R}}/T_1}\right)$

in order to obtain $T_1$ for different B

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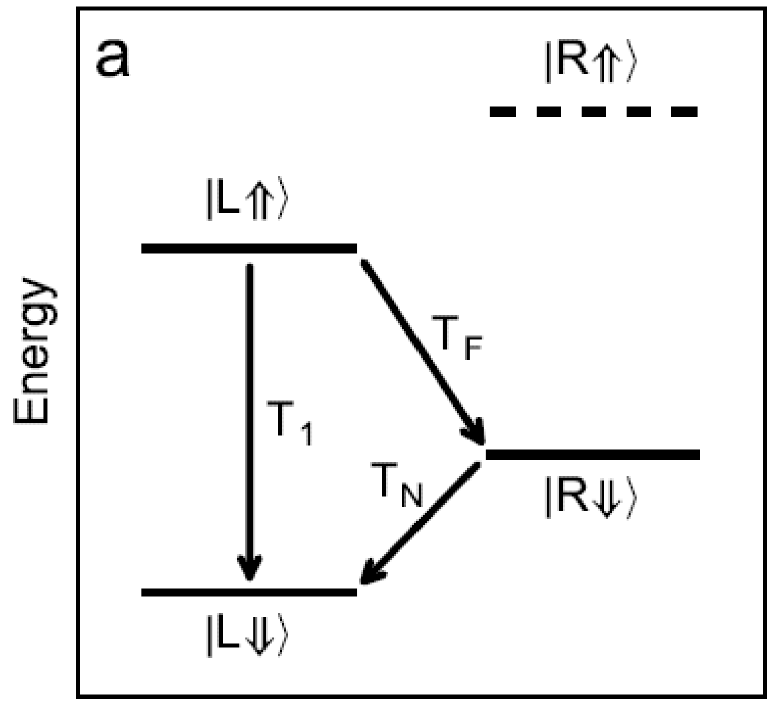
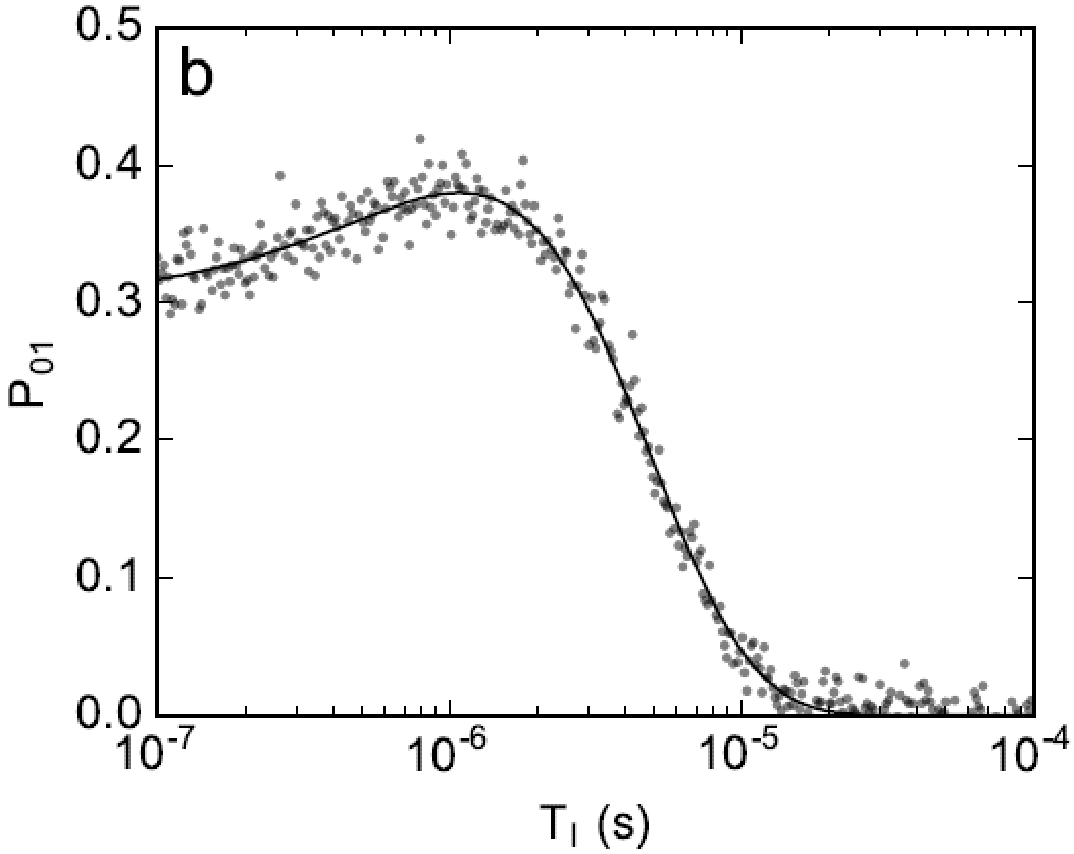
# Summary

- Measured $T_1$ ~400 ns at 1.5 T up to ~60 μs at 0.5 T with latched charge sensing technique
- $T_1 \propto B^{-4.4}$ in this range, indicating dominance of Dresselhaus SOI
- For low magnetic field, scaling of holes $\propto B^{-5}$ is promising (compared to $B^{-3}$ for electrons in GaAs, limited by hyperfine interactions)

# Initial state characterization

Hold for variable time $T_I$ (after stage four) at $\varepsilon = -E_Z/2$ to characterize initial occupancy

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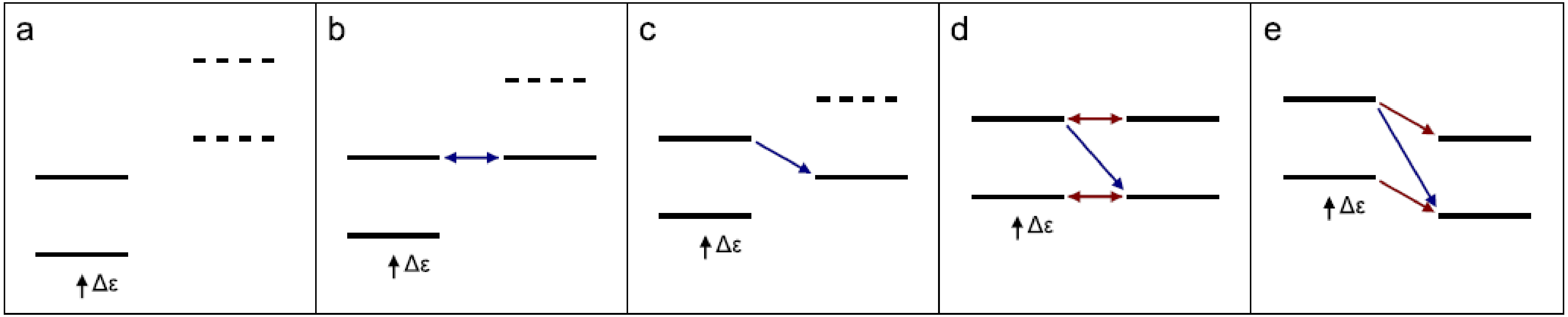
# Measuring sensitivity

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