Spin digitizer for high-fidelity readout of a cavity-coupled silicon triple quantum dot

F. Borjans, X. Mi & J.R. Petta, PRA **15**, 044052 (2021).

Uni Basel/IBM SPIN journal club

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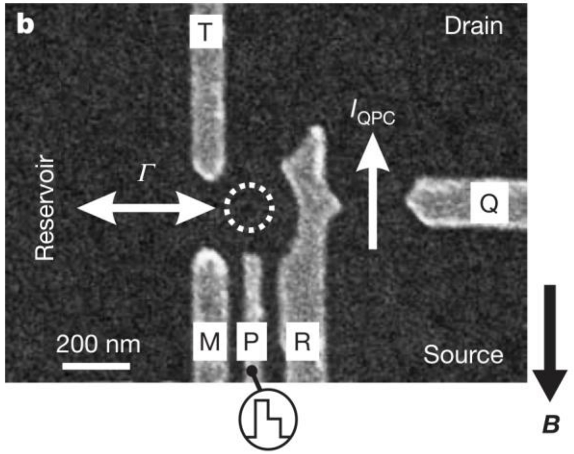
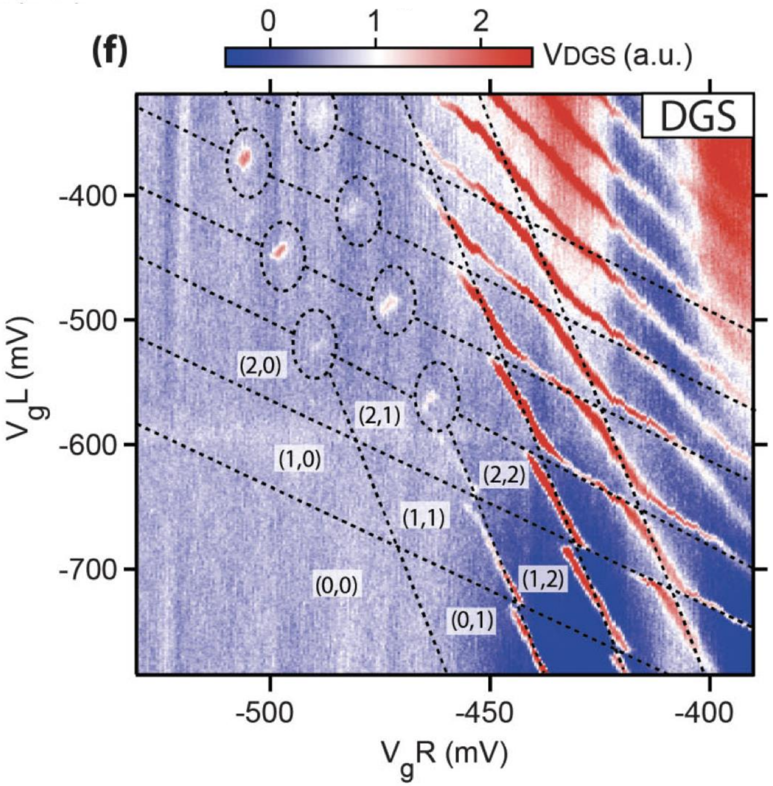
Presentation by Rafael Eggli

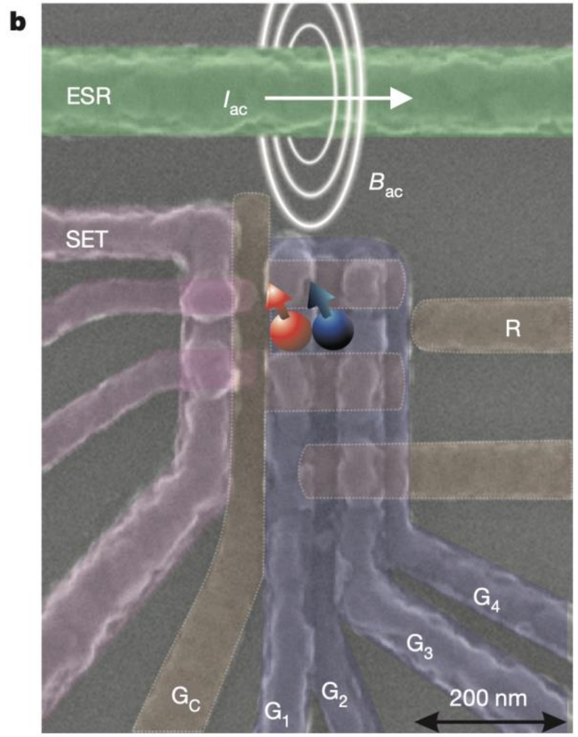
Motivation

- Improve readout of spin qubits in Si
- Typical problems:
  - Large footprint (dedicated charge sensor -> nearby dot)
- Dispersive Charge sensing:
  - Gate-based (smaller footprint)
  - Resonator on gate probes gate Z
  - Sensitivity limited
  - Constrained device tuning
  - Limited by tunnel rates

→ Single shot, “digized” readout over large gate-space region







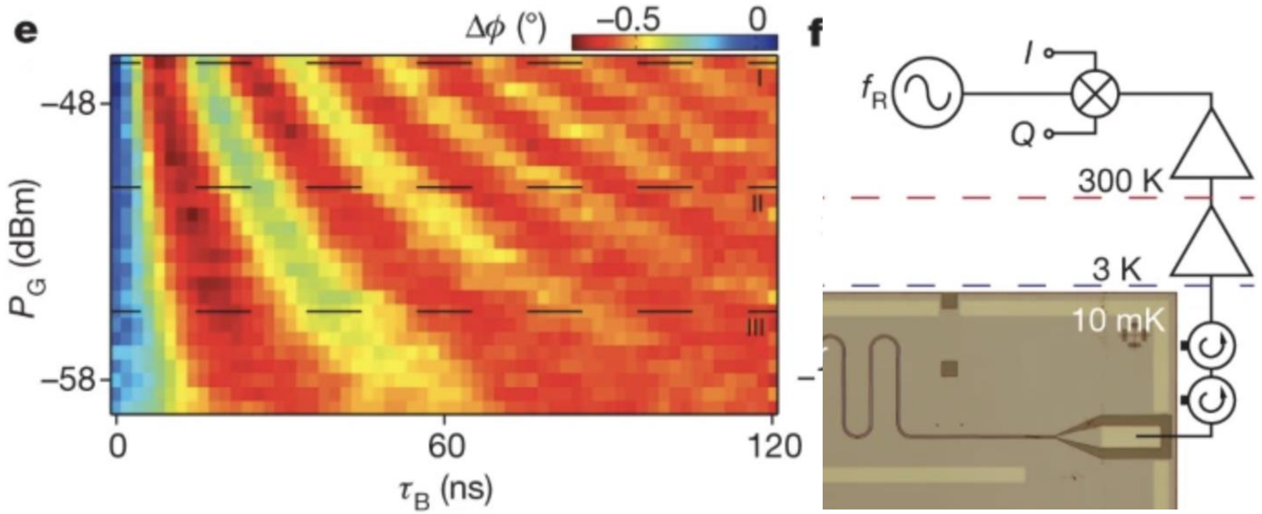
J.M. Elzerman et al., Nature, **430,** 431-435 (2004)
M. Veldhorst et al., Nature, **526**, 410-414 (2015)
J.I. Colless et al., PRL, **110,** 046805 (2013)

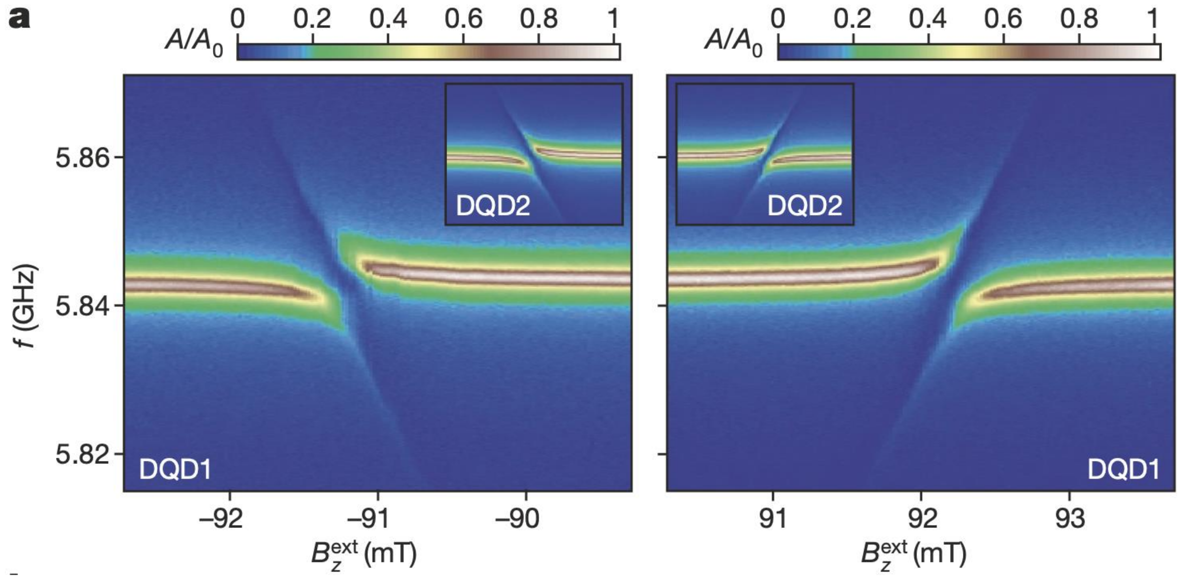
Previous achievements with cQED and QDs:

- Microwave resonator (Nb)
- On-chip cavity, $^{\lambda}/_{2}$
- Monitor transmitted Amplitude

& Phase

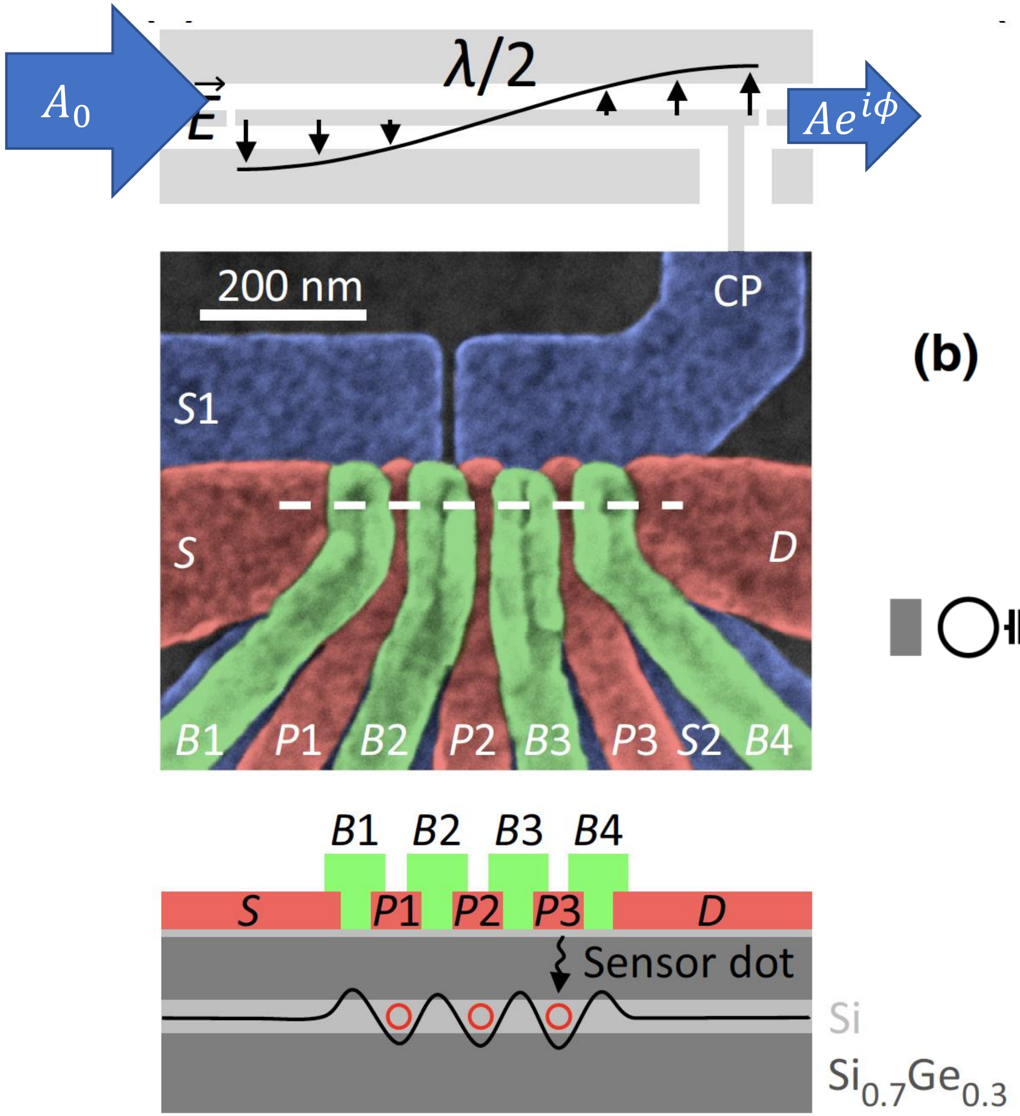
- InAs nanowire and Si qubits
- Strong spin-photon coupling
- Resonant microwave-coupling of two remote spins ($\mathrm{d} > 4mm$)





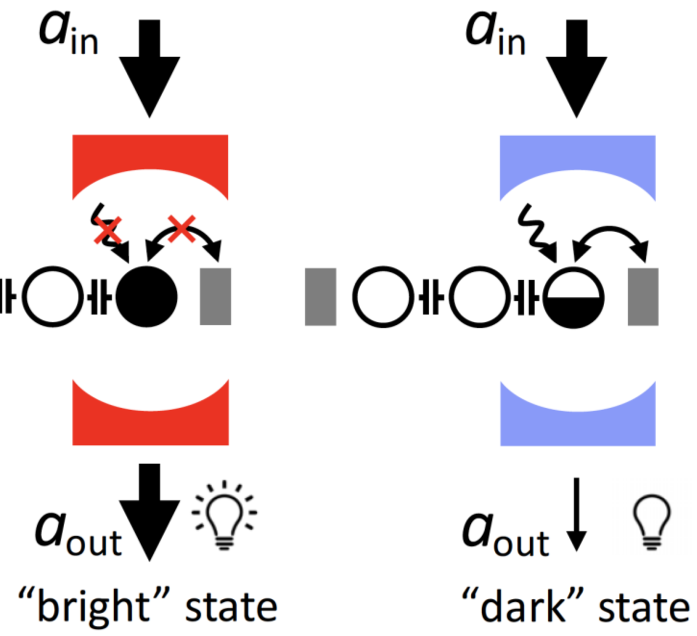
K.D. Petersson et al., Nature, **490,** 380 (2012)
X. Mi et al., Nature, **555**, 599 (2018)
F. Borjans et al., Nature, **577**, 195-198 (2020)

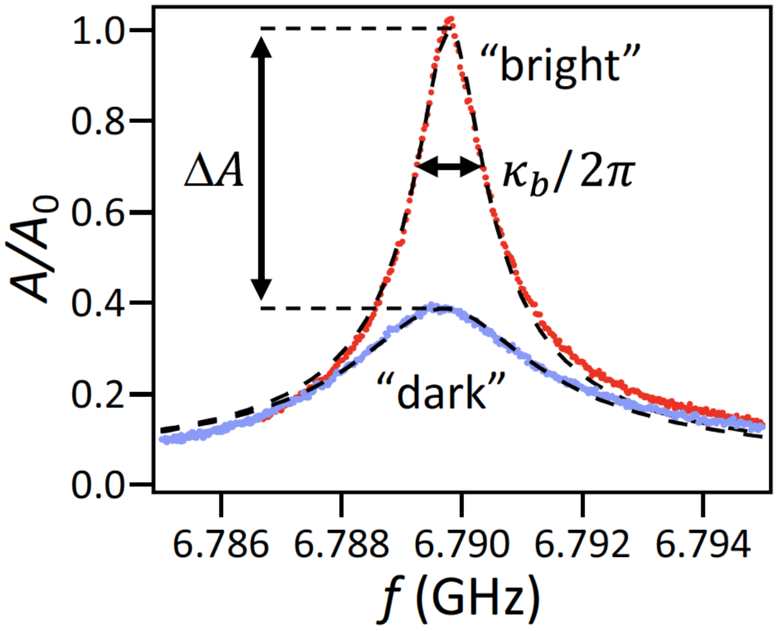
Device



- Triple QD Si/GeSi (isotopically purified) heterostructure
- CP galvanically coupled to resonator
- Couples to QD3 -> Dispersive charge sensing

(b)



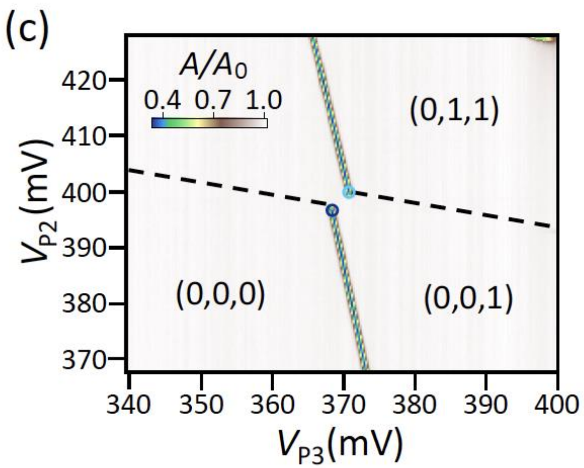


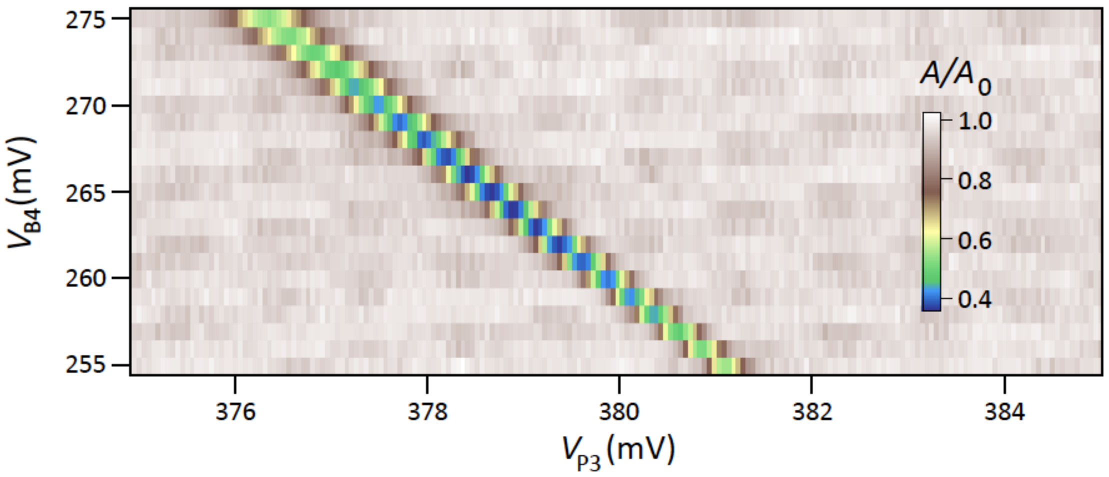
- Observe strong dispersive response

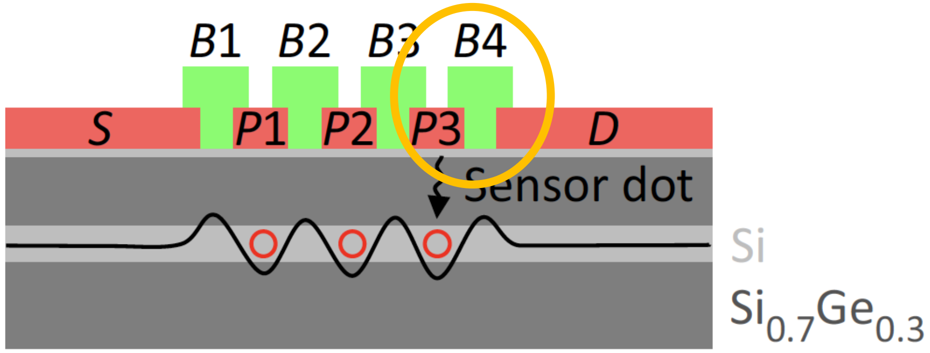
Reading out Dots 1 & 2

- Optimize dispersive signal to $A/A_0 \approx 0.4$
- Dots 1 & 2 are capacitively coupled to QD 3
- Loading electron to QD 2 shifts QD 3 resonances
- Shift $\Delta V = 2.1\, mV > \sigma_V = 0.27\, mV$

→ Digitally gates cavity transmission

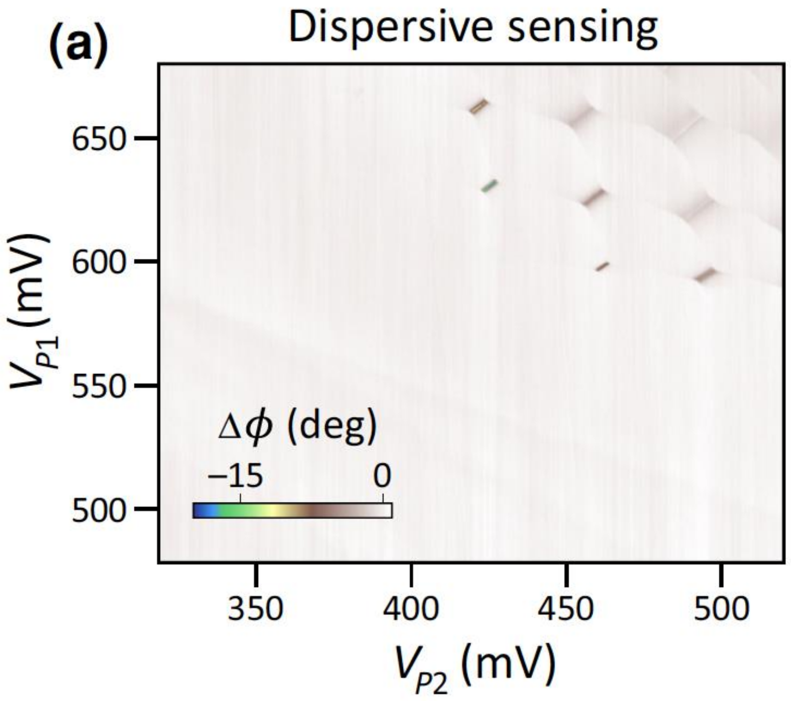


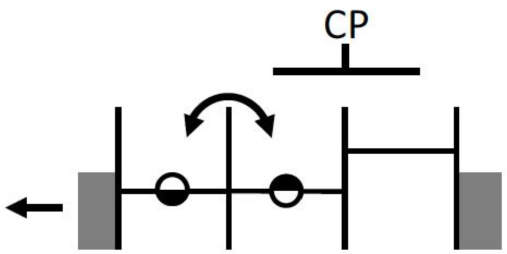




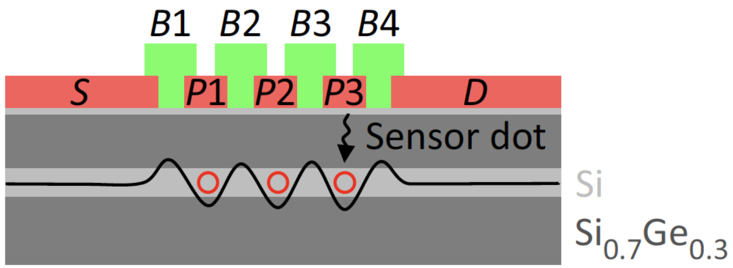
Two Readout Schemes

- «Conventional» dispersive charge sensing → limited visibility
- «Adaptive» charge sensing by tuning sensor to dark state
- Better contrast and large-scale sensitivity

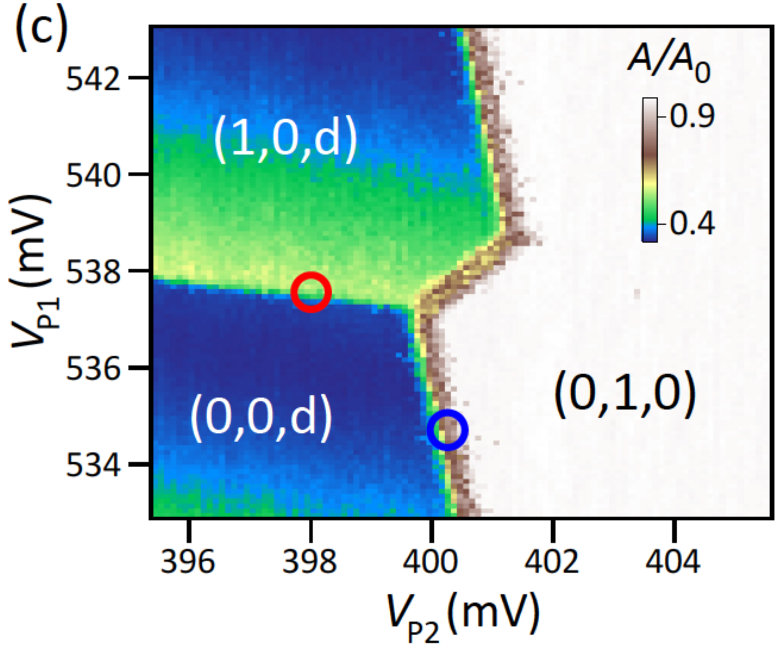




Sensor Performance

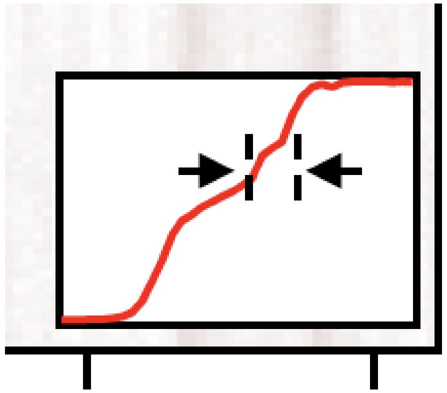


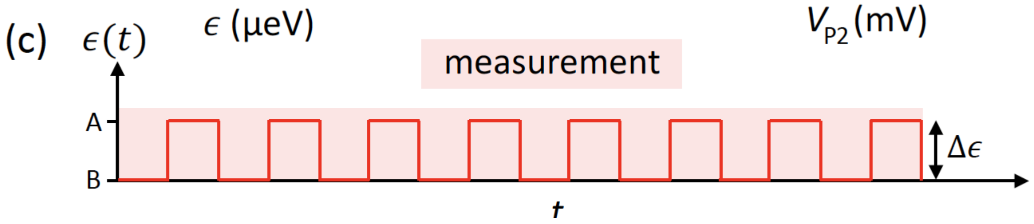
- Fixed V_{P3} at (0,0,d) transition, d: 0 ⟷ 1
- Time traces at (0,0,d) ⟷ (1,0,d) and (0,0,d) ⟷ (0,1,0) edges
- Histograms yield power SNR: $$SNR_{1(2)} = \left(\frac{\Delta A_{1(2)}}{\sigma_{1(2)}}\right)^2$$

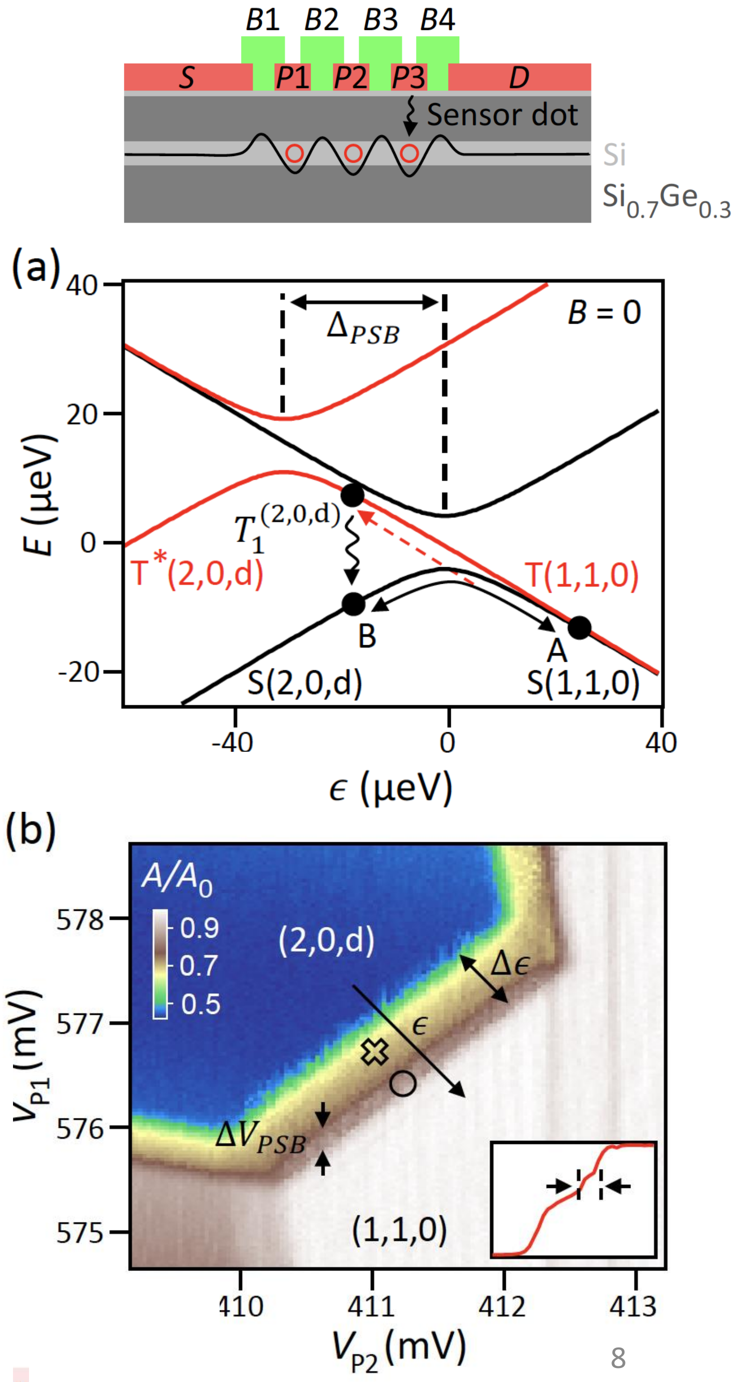


Pauli Spin Blockade Signatures

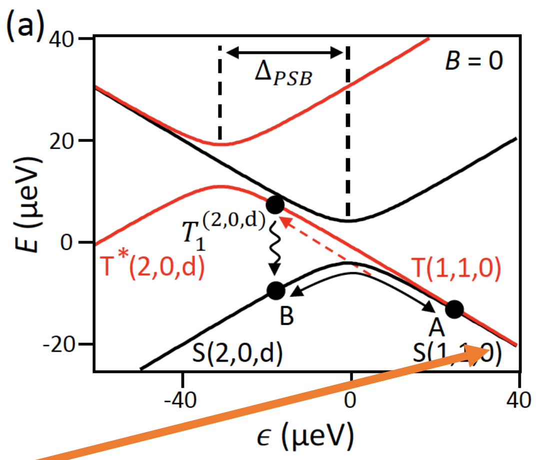
- PSB expected at (1,1,0) $\leftrightarrow$ (2,0,d) edge, $B = 0$
- Train of MW pulses ($0.5\ mV$; $400\ \mu s$) on P1 & P2
- Signal intensity: Time-averaged
- PSB increases time spent in bright state
- Plateau on transition: due to PSB



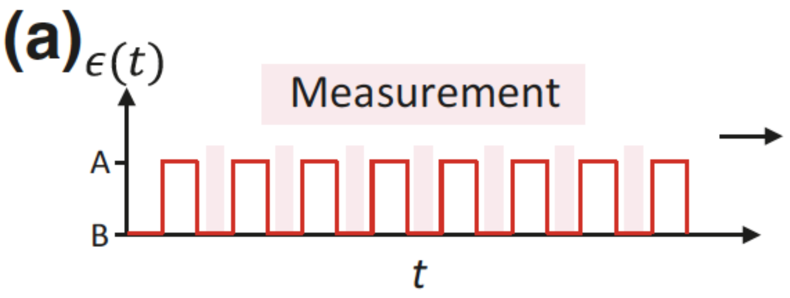


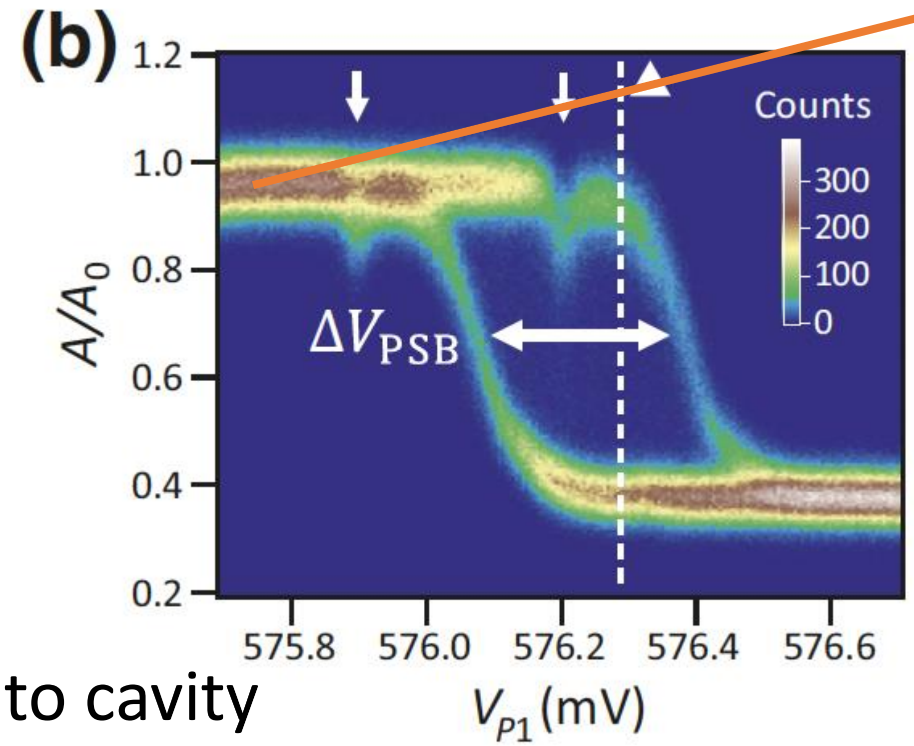


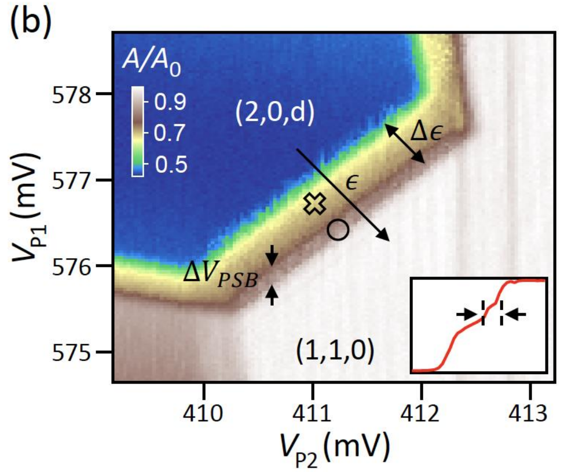
Single-Shot PSB Readout



- Directly probe the S-T transitions
- Measure after each pulse → Amplitude histogram
- Spin-dependent "bright" → "dark" transition voltages





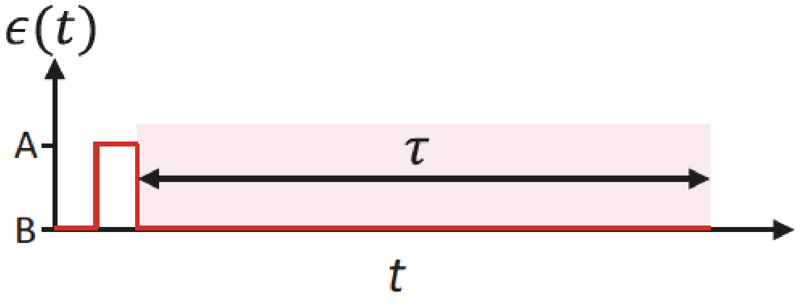


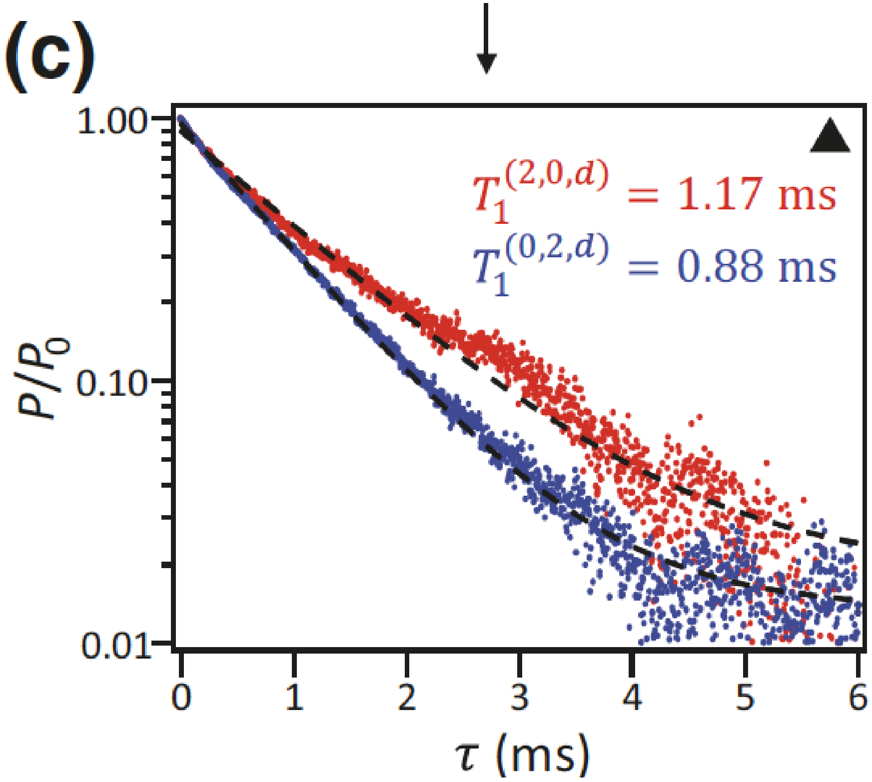
- Separation:
  - $\Delta V_{PSB} = 41\mu eV$

$\sim$ Expected valley splitting

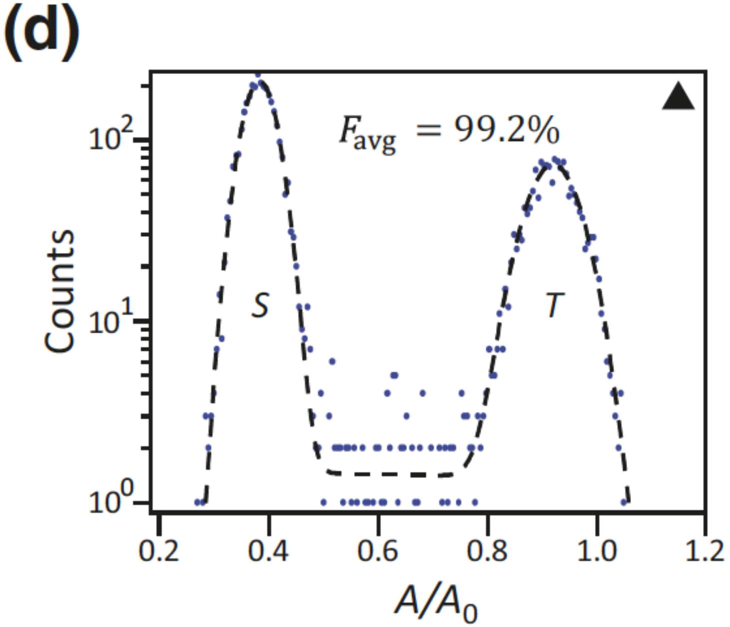
- Dents: dispersive coupling to cavity

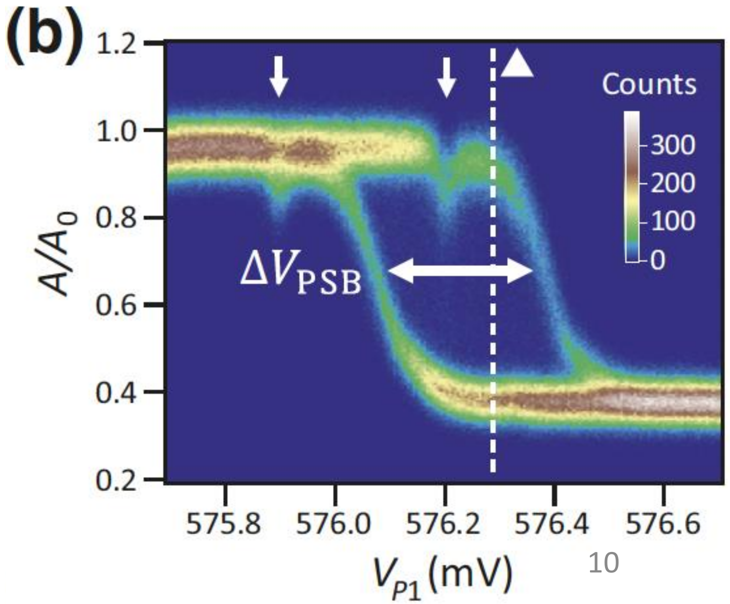
Spin Relaxation





- Vary dwell time τ after initialization to mixed state, ensemble of $10'000$ shots
- Exponential decay fit yields:
  $T_1^{(2,0,d)} = 1.17\,ms; \quad T_1^{(0,2,d)} = 0.88\,ms$
- Visibility: 98.4 %
- Fidelity: 99.2 %





Conclusion

- ”Digital” charge state readout
- Theoretical minimal integration times of $1.8\ - 5.6\ ns$
- High fidelity & visibility spin state readout
- Achieved through small sensor – target distances & strong quantum dot – cavity coupling
- Improvements: Reduce cavity coupling to QD1 & 2
    - Higher powers: Expect visibility $99.98\ \%$ and fidelity $99.99\ \%$
    - Integration time: $1\ \mu s$ (now $100\ \mu s$)
    - Quadruple dot to avoid need for reservoir near sensor

→ Very interesting approach, perhaps also for linear qubit arrays (FinFETs/GeSi-wires)

Thank you for your attention!