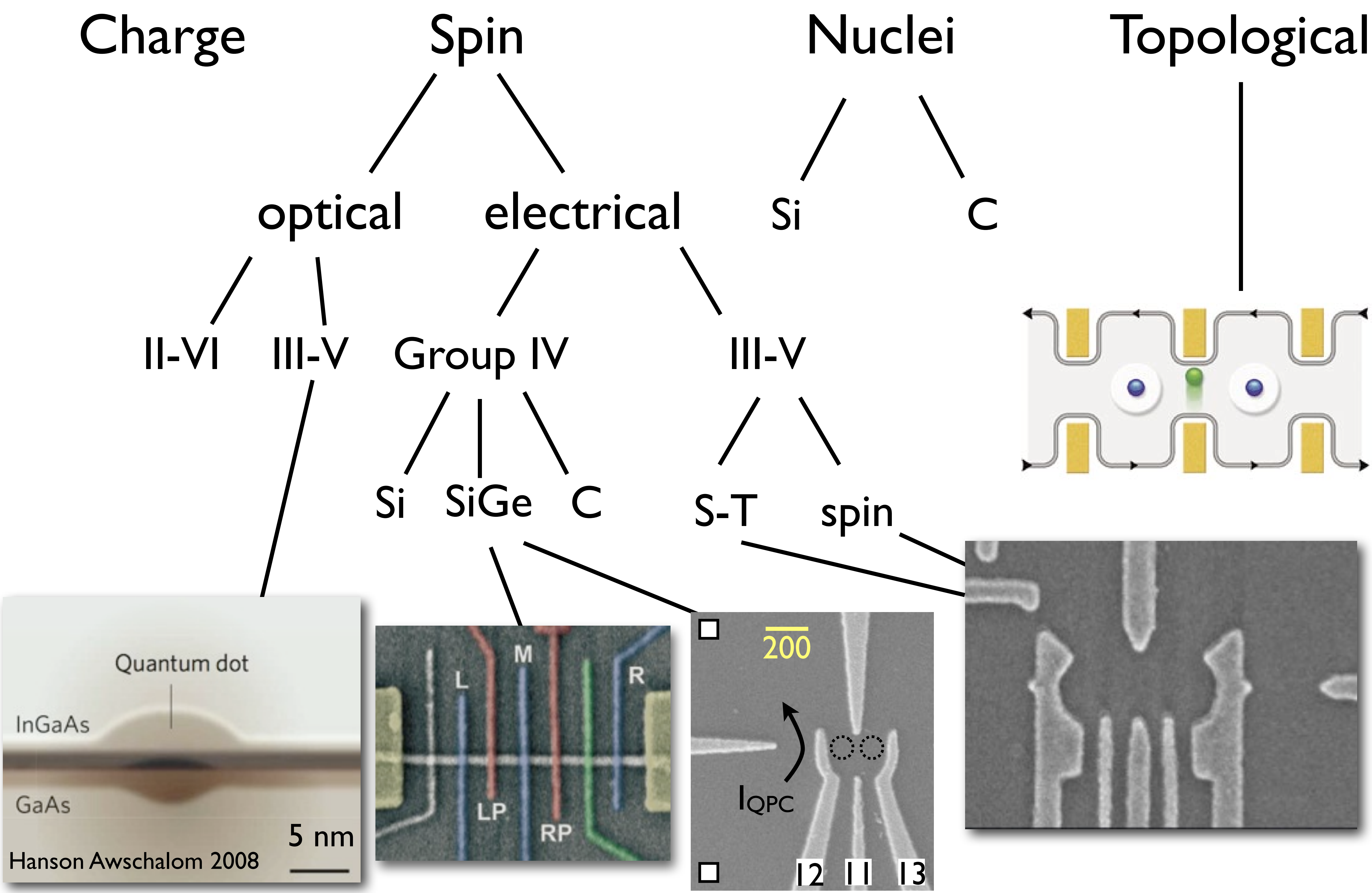
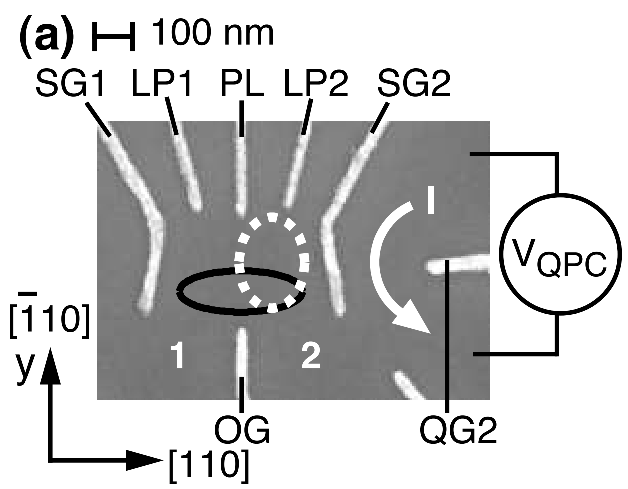
Semiconductor Qubits

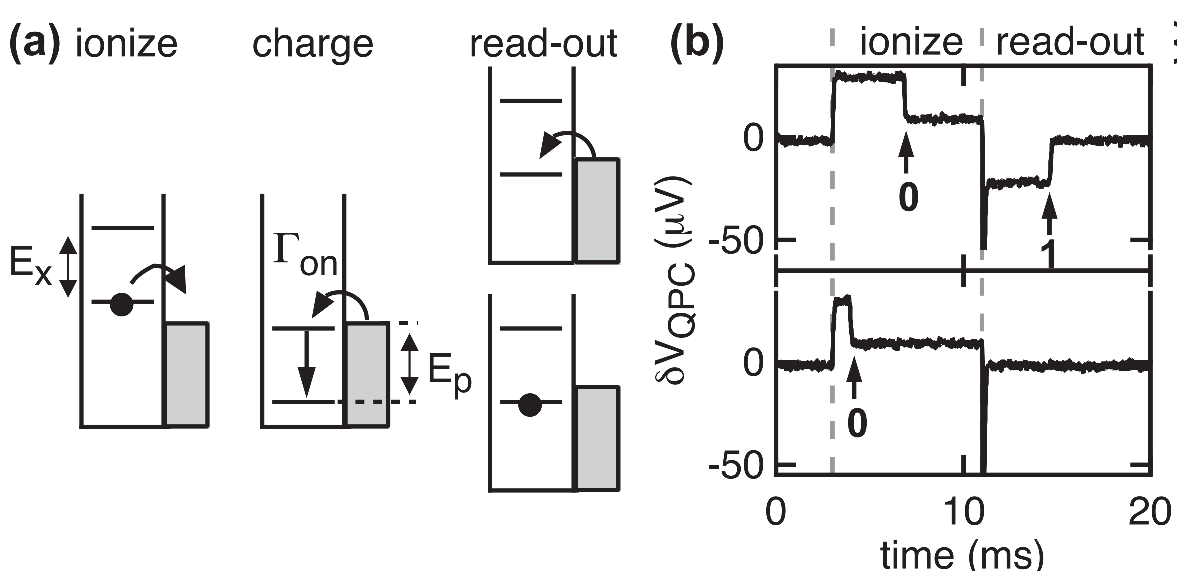


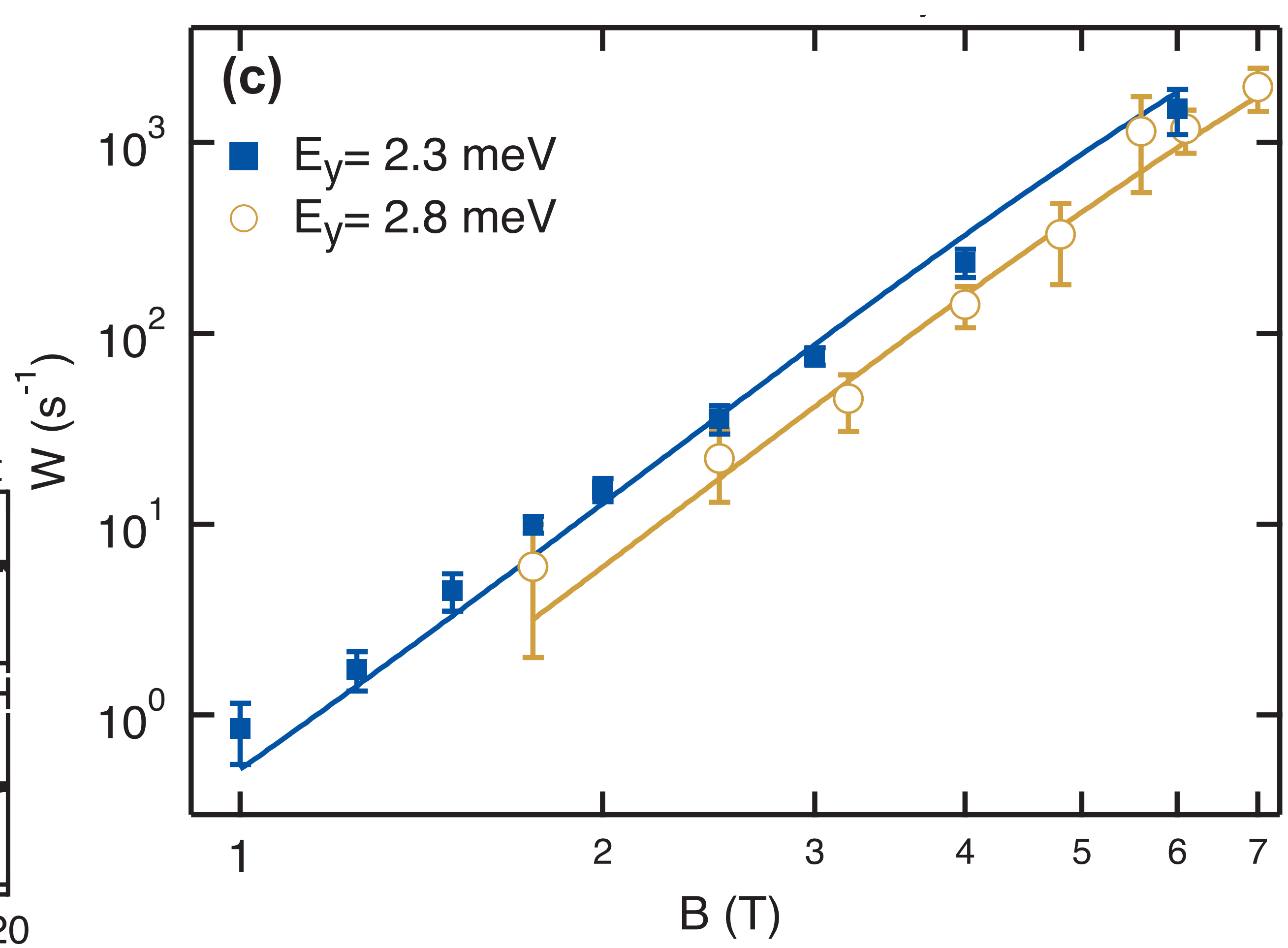
Electrical Control of Spin Relaxation in a Quantum Dot

S. Amasha,[1,*] K. MacLean,[1] Iuliana P. Radu,[1] D. M. Zumbühl,[2] M. A. Kastner,[1] M. P. Hanson,[3] and A. C. Gossard[3]
[1]Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
[2]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland
[3]Materials Department, University of California, Santa Barbara, California 93106-5050, USA
(Received 13 July 2007; published 30 January 2008)

We demonstrate electrical control of the spin relaxation time T_1 between Zeeman-split spin states of a single electron in a lateral quantum dot. We find that relaxation is mediated by the spin-orbit interaction, and by manipulating the orbital states of the dot using gate voltages we vary the relaxation rate $W \equiv T_1^{-1}$ by over an order of magnitude. The dependence of W on orbital confinement agrees with theoretical predictions, and from these data we extract the spin-orbit length. We also measure the dependence of W on the magnetic field and demonstrate that spin-orbit mediated coupling to phonons is the dominant relaxation mechanism down to 1 T, where T_1 exceeds 1 s.



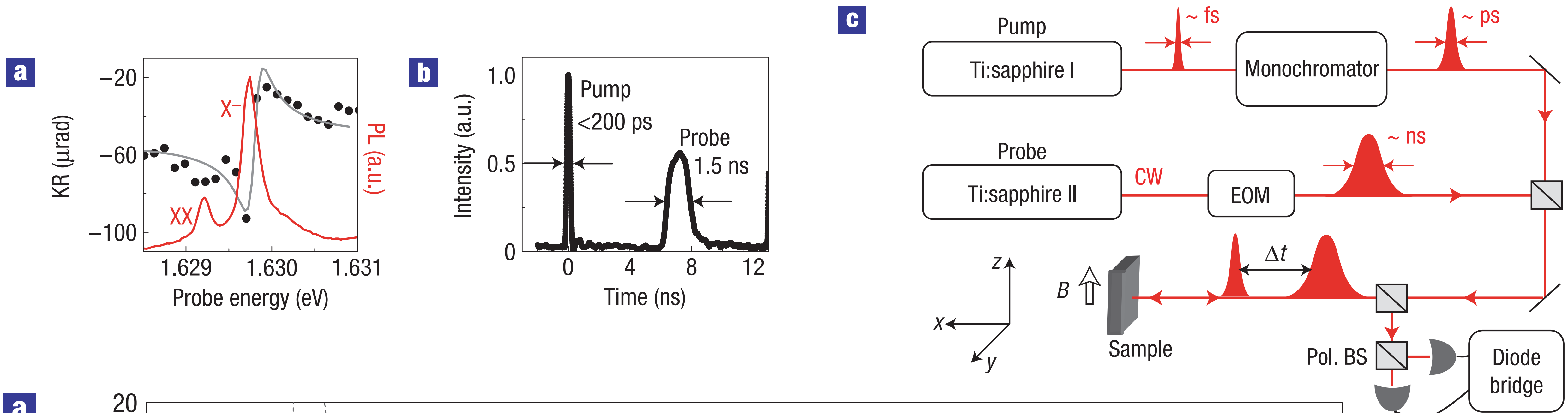




Optically detected coherent spin dynamics of a single electron in a quantum dot

see also:
J. Findley,
Atature, Imamoglu

M. H. MIKKELSEN, J. BEREZOVSKY, N. G. STOLTZ, L. A. COLDREN AND D. D. AWSCHALOM*



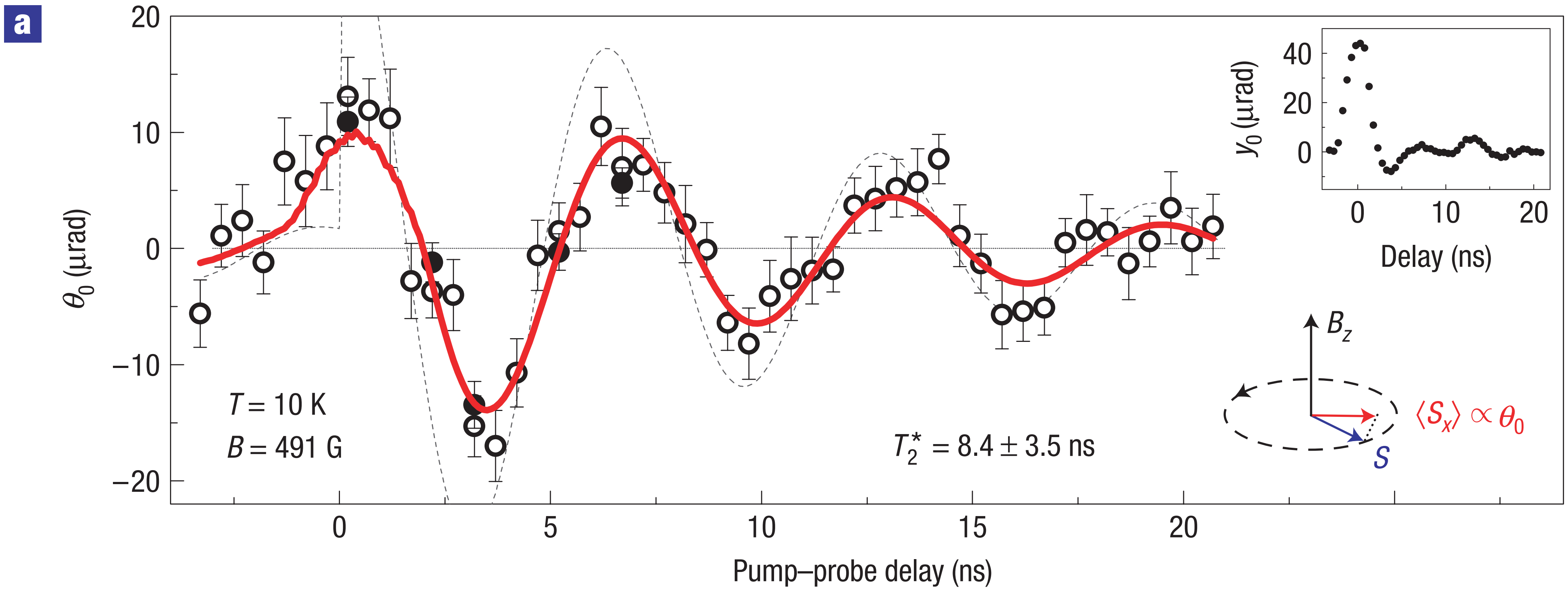
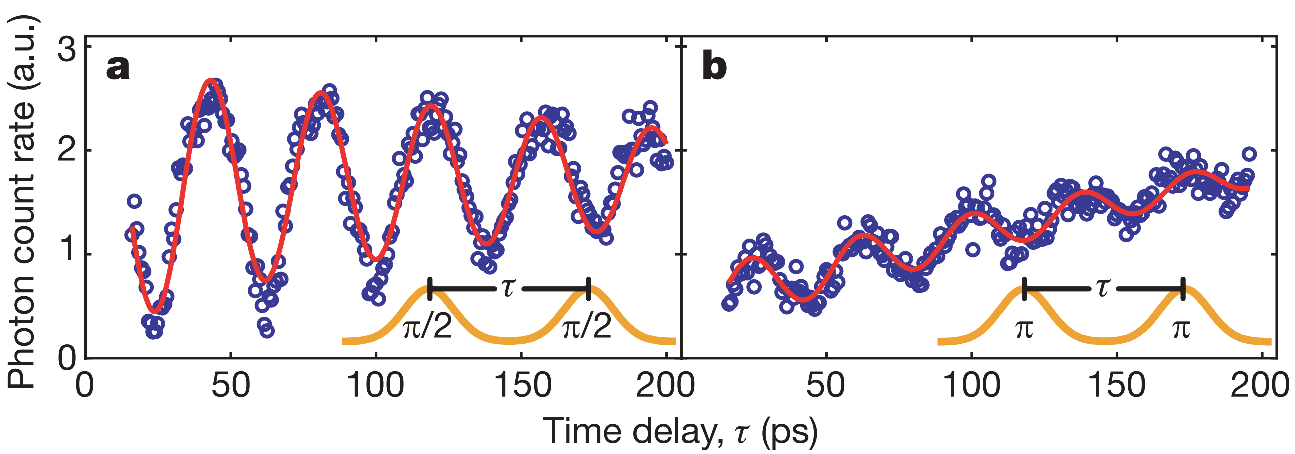


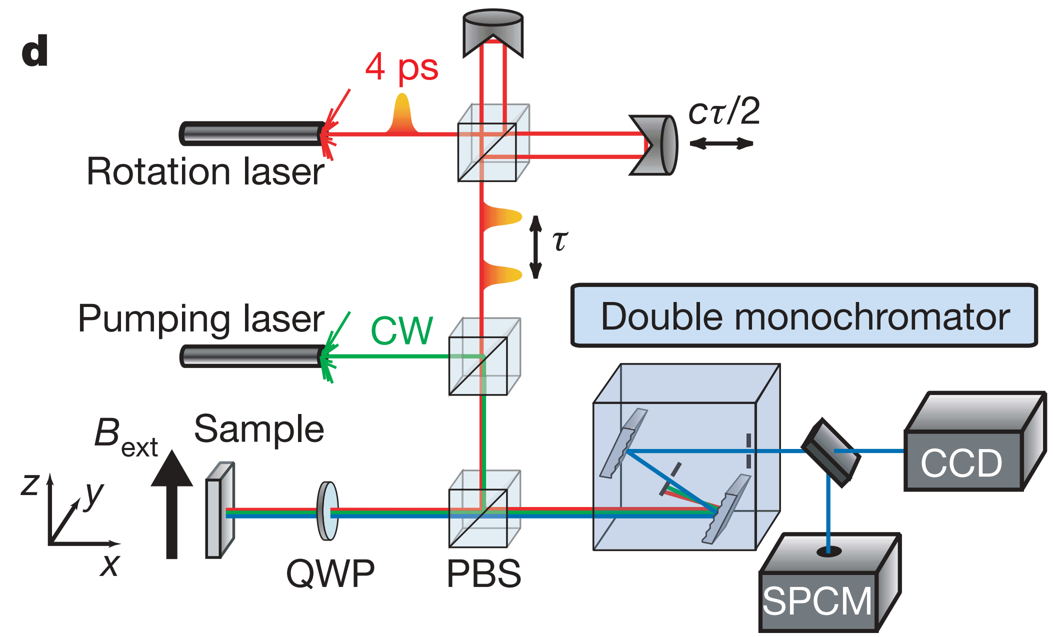
Figure 2 Coherent evolution of a single electron spin. a, Single-spin KR amplitude, θ_0, as a function of time, with 3-ns-duration probe pulses and $B = 491$ G. The solid line is a fit to equation (2) and the dashed line shows the solution of equation (2) without the probe-pulse convolution for the same fit parameters. The inset shows the offset, y_0. Error bars indicate the standard error as obtained from the least-squares fit to the KR spectra. The solid circles indicate the values of θ_0 obtained from the fits shown in **b**–**f**. **b**–**f**, KR angle as a function of probe energy at five different delays; solid lines are fits to equation (1), with a constant offset, y_0.

LETTERS

Complete quantum control of a single quantum dot spin using ultrafast optical pulses

David Press[1], Thaddeus D. Ladd[1,2], Bingyang Zhang[1] & Yoshihisa Yamamoto[1,2]





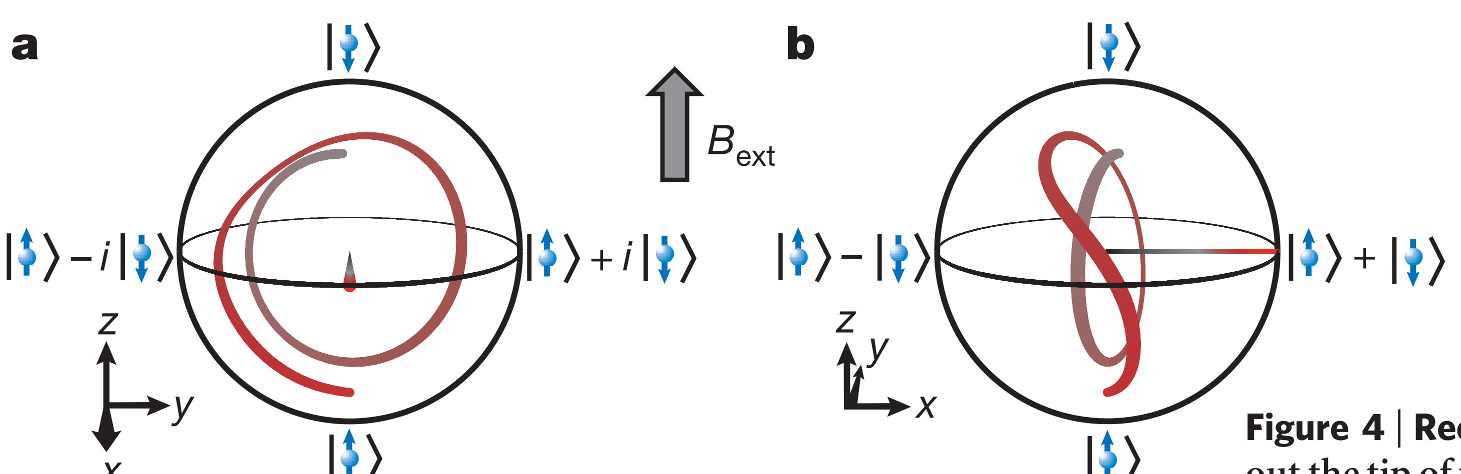
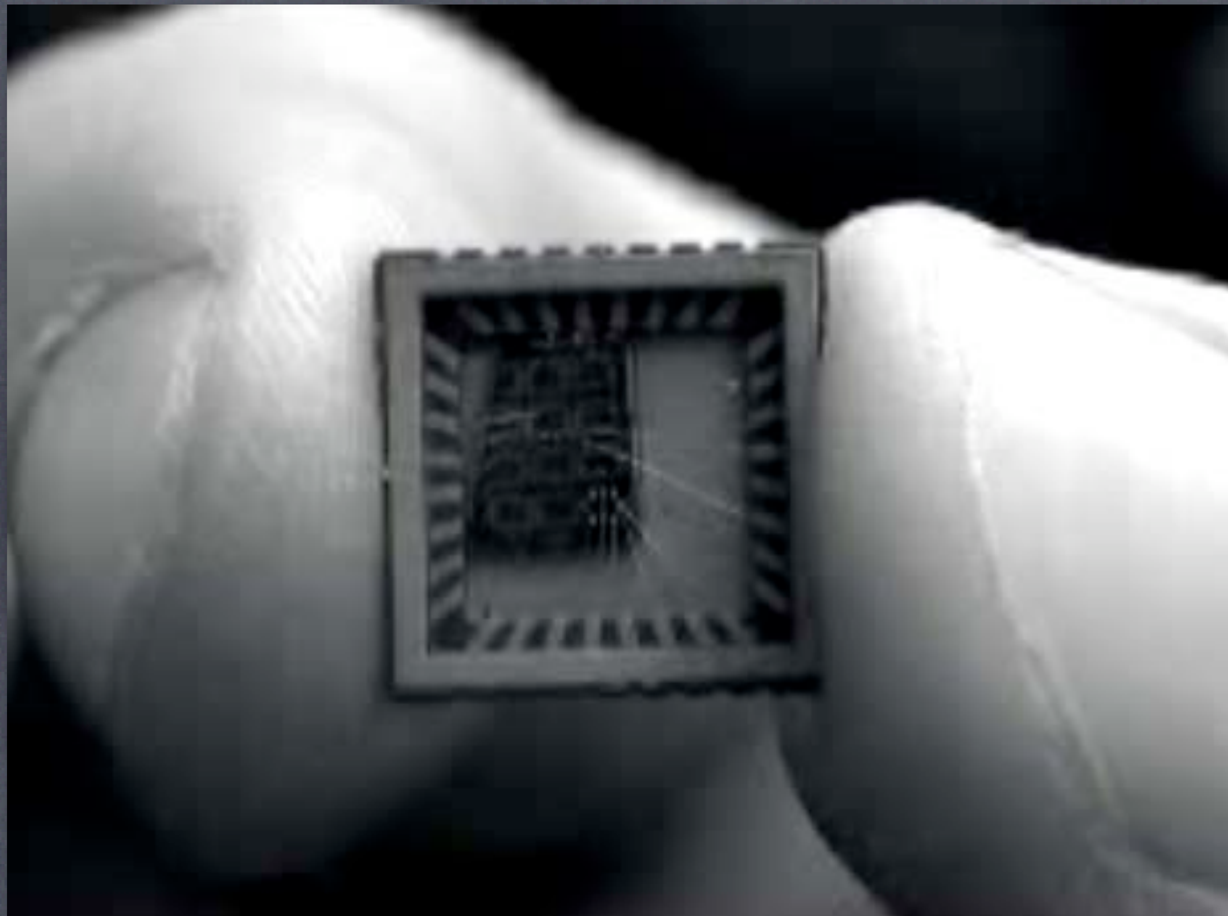
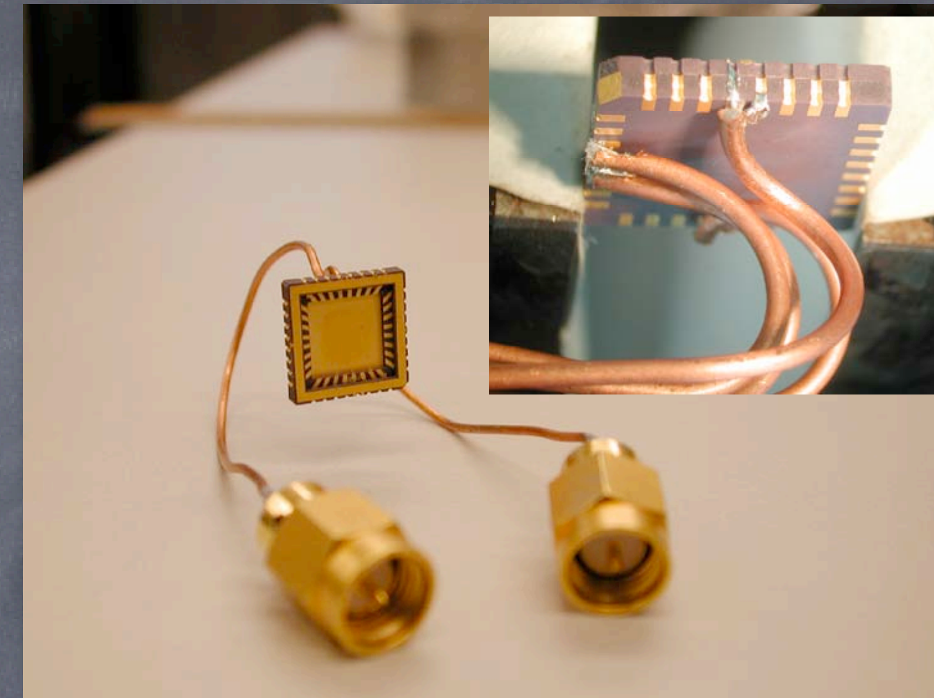
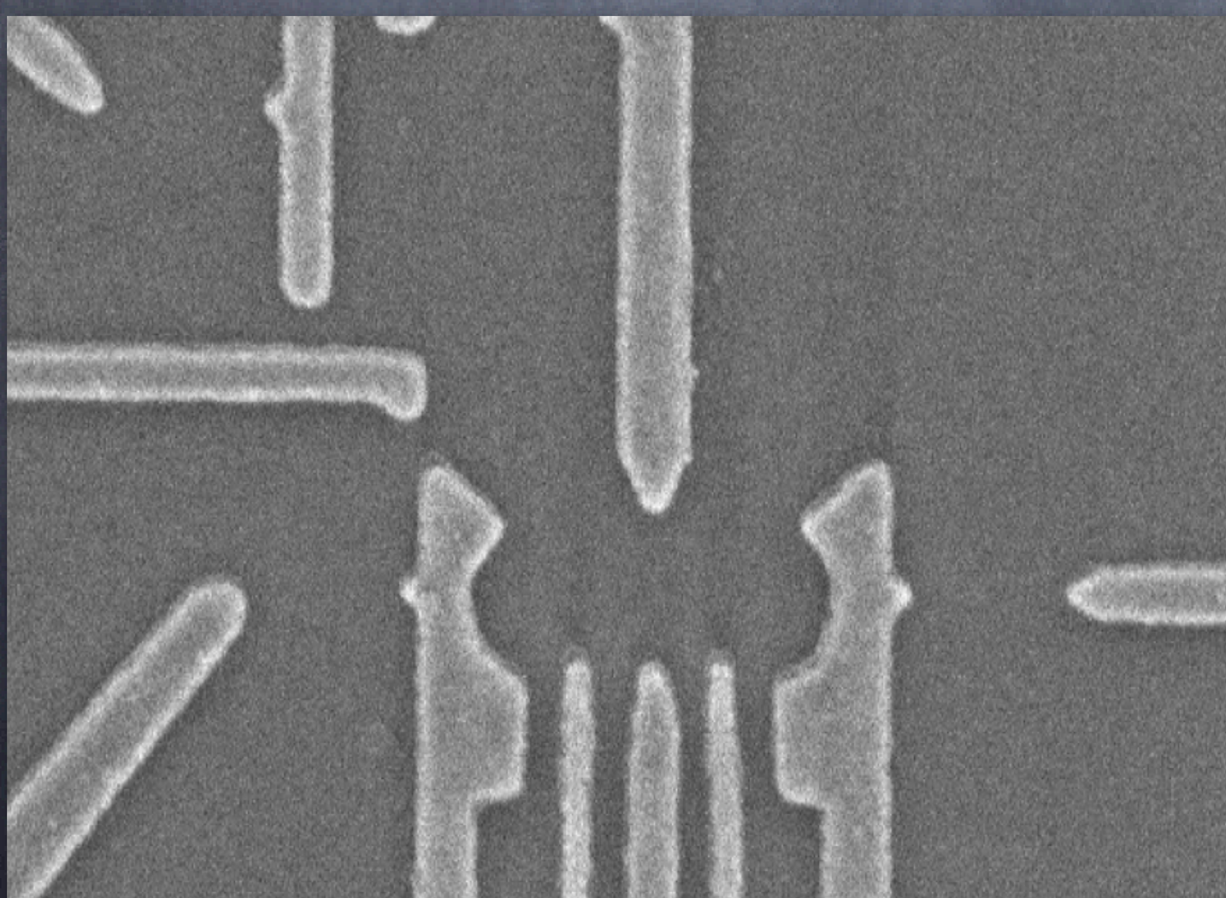
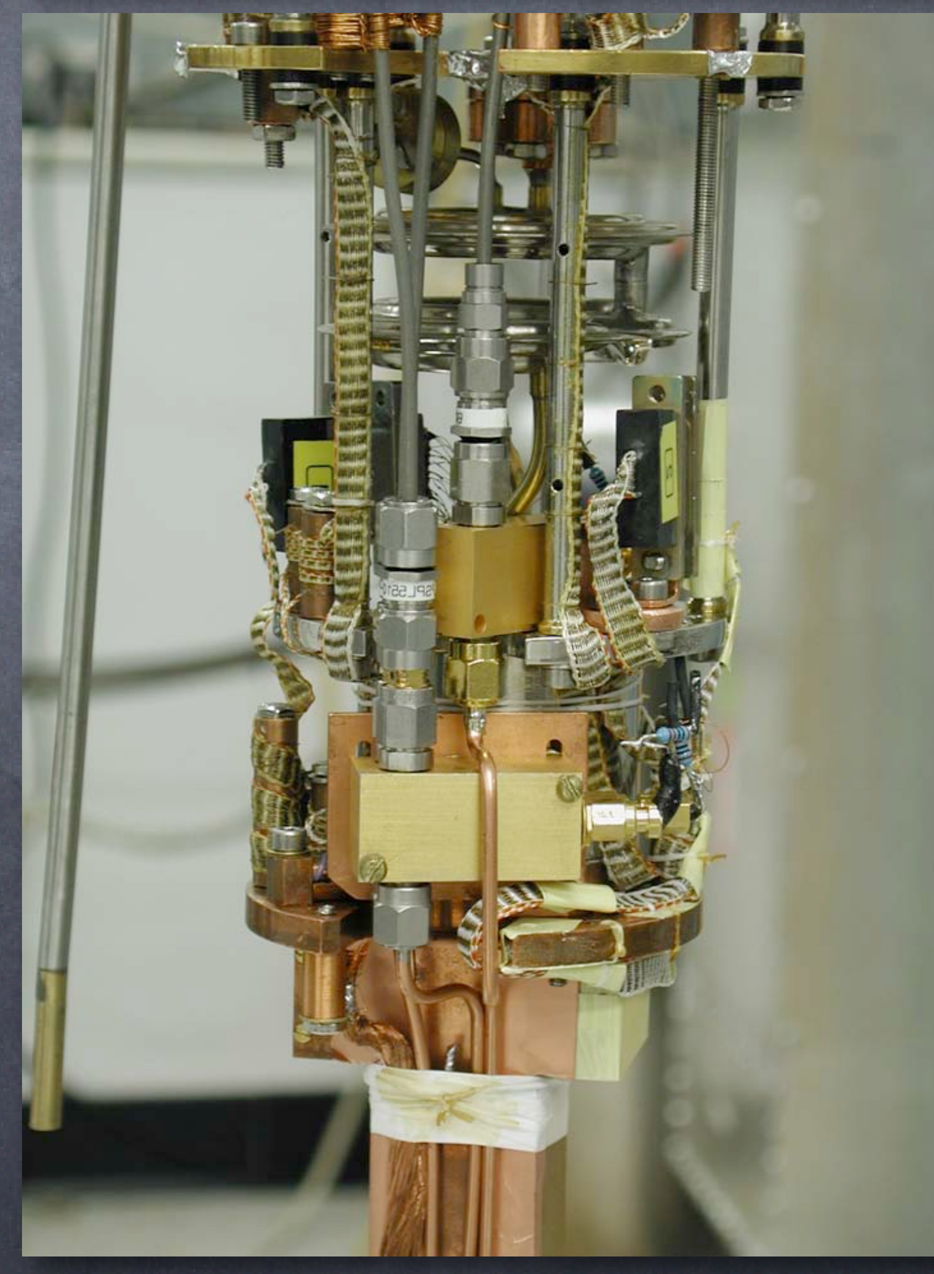


Figure 4 | Reconstructed evolution of the Bloch vector. The curves trace out the tip of the Bloch vector in the one-pulse (Rabi oscillation) experiment over the range of rotation angles $0 \leq \Theta \leq 3\pi$. The colour scale indicates the length of the Bloch vector, which shrinks exponentially with Θ. Views are from the perspective of the x axis (**a**) and the $-y$ axis (**b**) of the Bloch sphere.







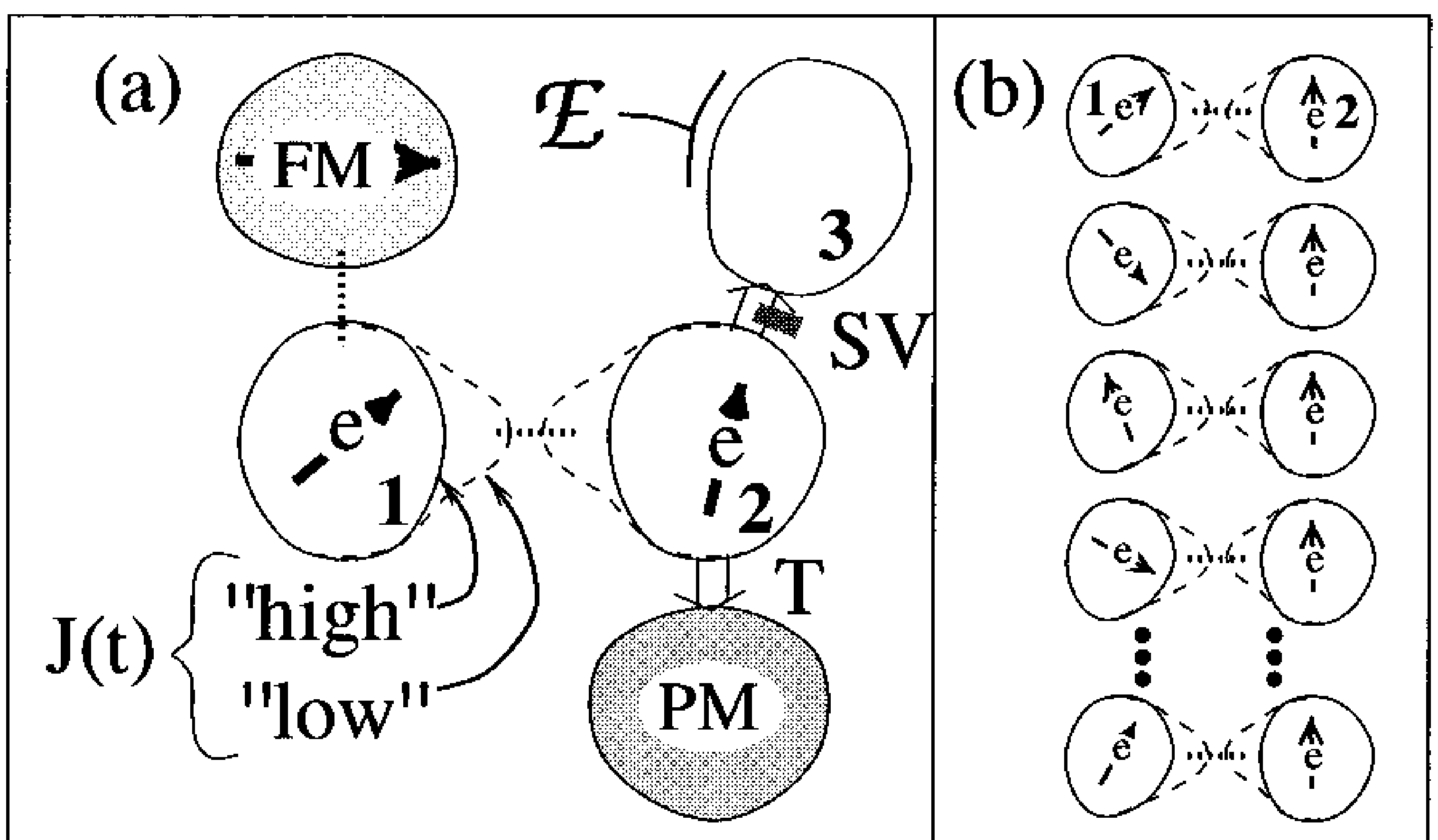


PHYSICAL REVIEW A VOLUME 57, NUMBER 1 JANUARY 1998

Quantum computation with quantum dots

Daniel Loss[1,2,*] and David P. DiVincenzo[1,3,†]
[1]*Institute for Theoretical Physics, University of California, Santa Barbara, Santa Barbara, California 93106-4030*
[2]*Department of Physics and Astronomy, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland*
[3]*IBM Research Division, T.J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598*
(Received 9 January 1997; revised manuscript received 22 July 1997)

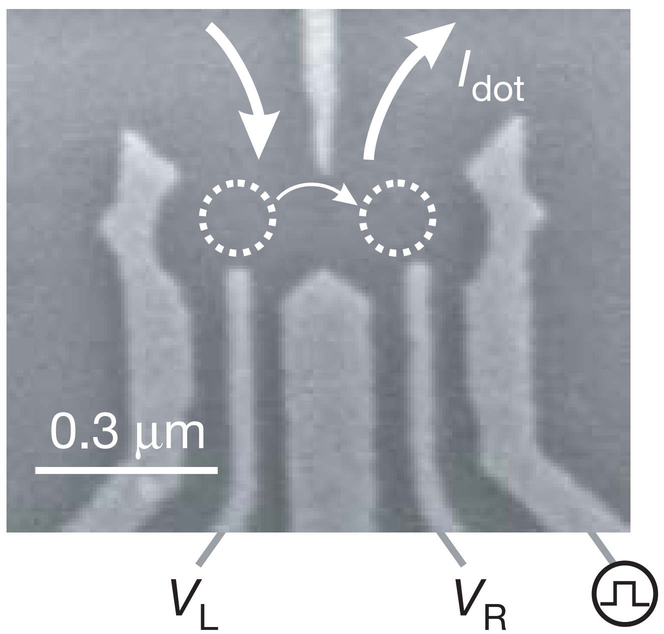
We propose an implementation of a universal set of one- and two-quantum-bit gates for quantum computation using the spin states of coupled single-electron quantum dots. Desired operations are effected by the gating of the tunneling barrier between neighboring dots. Several measures of the gate quality are computed within a recently derived spin master equation incorporating decoherence caused by a prototypical magnetic environment. Dot-array experiments that would provide an initial demonstration of the desired nonequilibrium spin dynamics are proposed. [S1050-2947(98)04501-6]

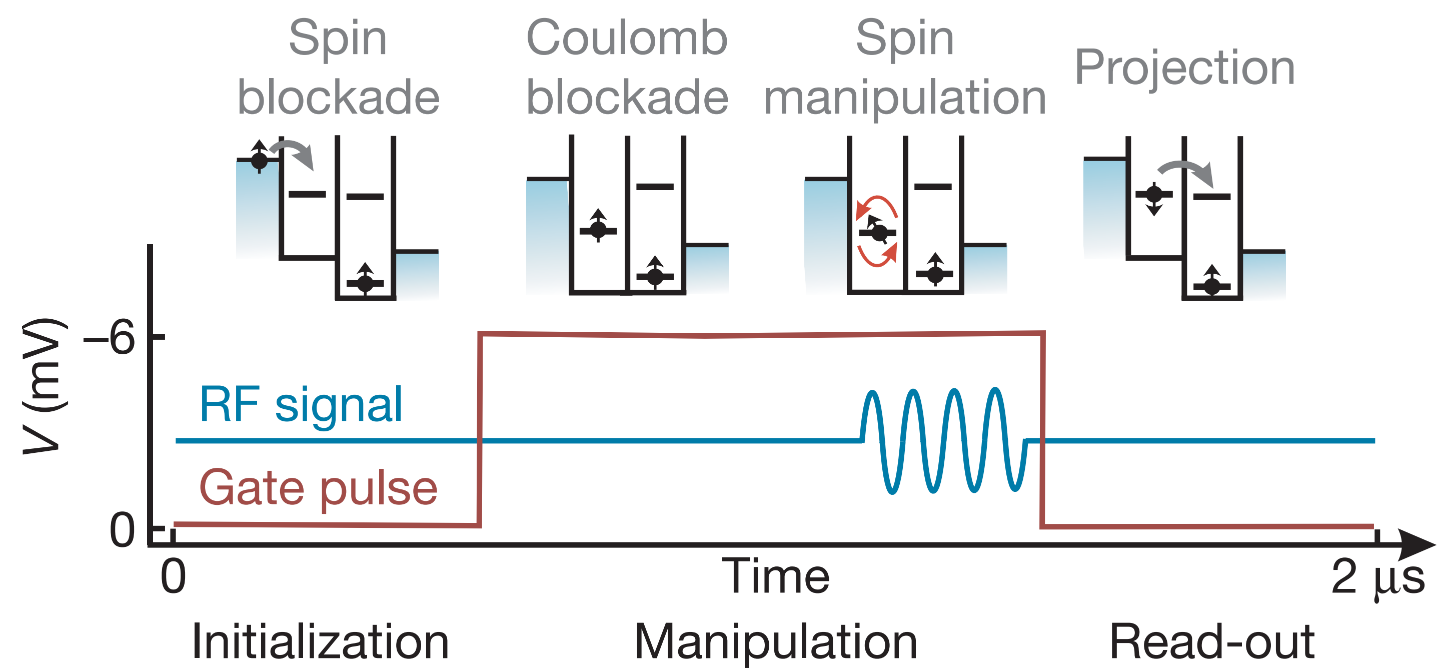


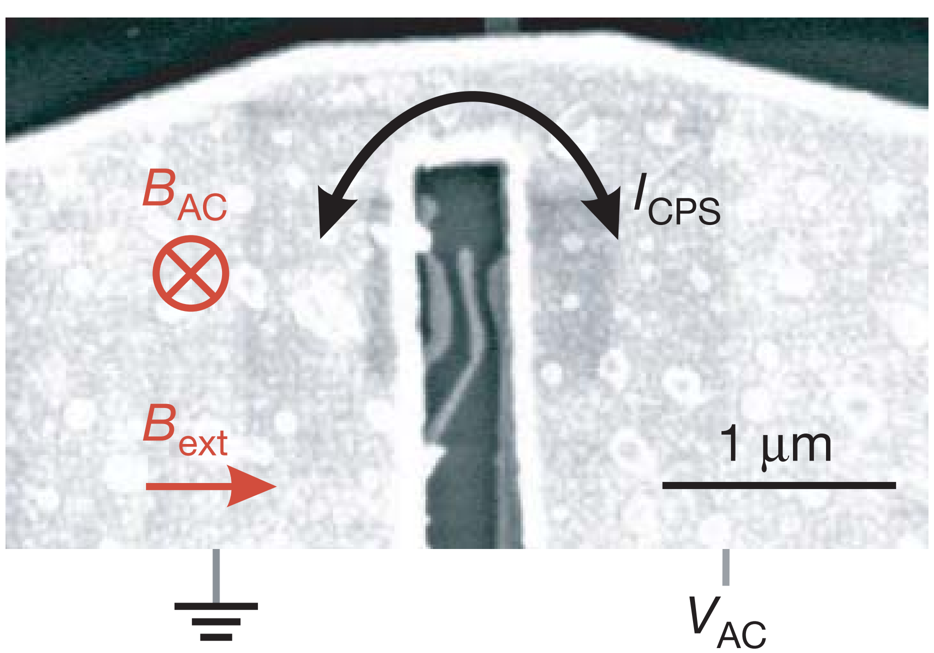
NATURE|Vol 442|17 August 2006

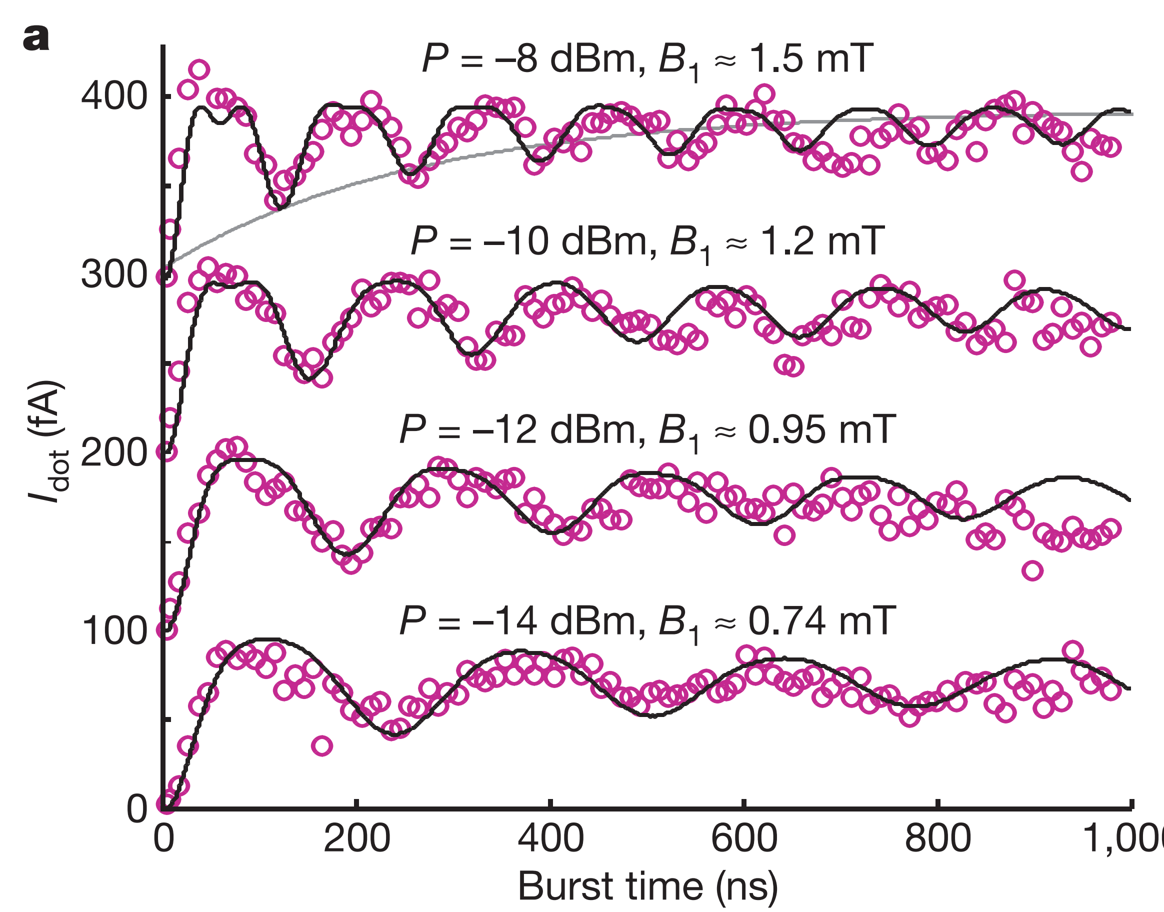
Driven coherent oscillations of a single electron spin in a quantum dot

F. H. L. Koppens[1], C. Buizert[1], K. J. Tielrooij[1], I. T. Vink[1], K. C. Nowack[1], T. Meunier[1], L. P. Kouwenhoven[1] & L. M. K. Vandersypen[1]



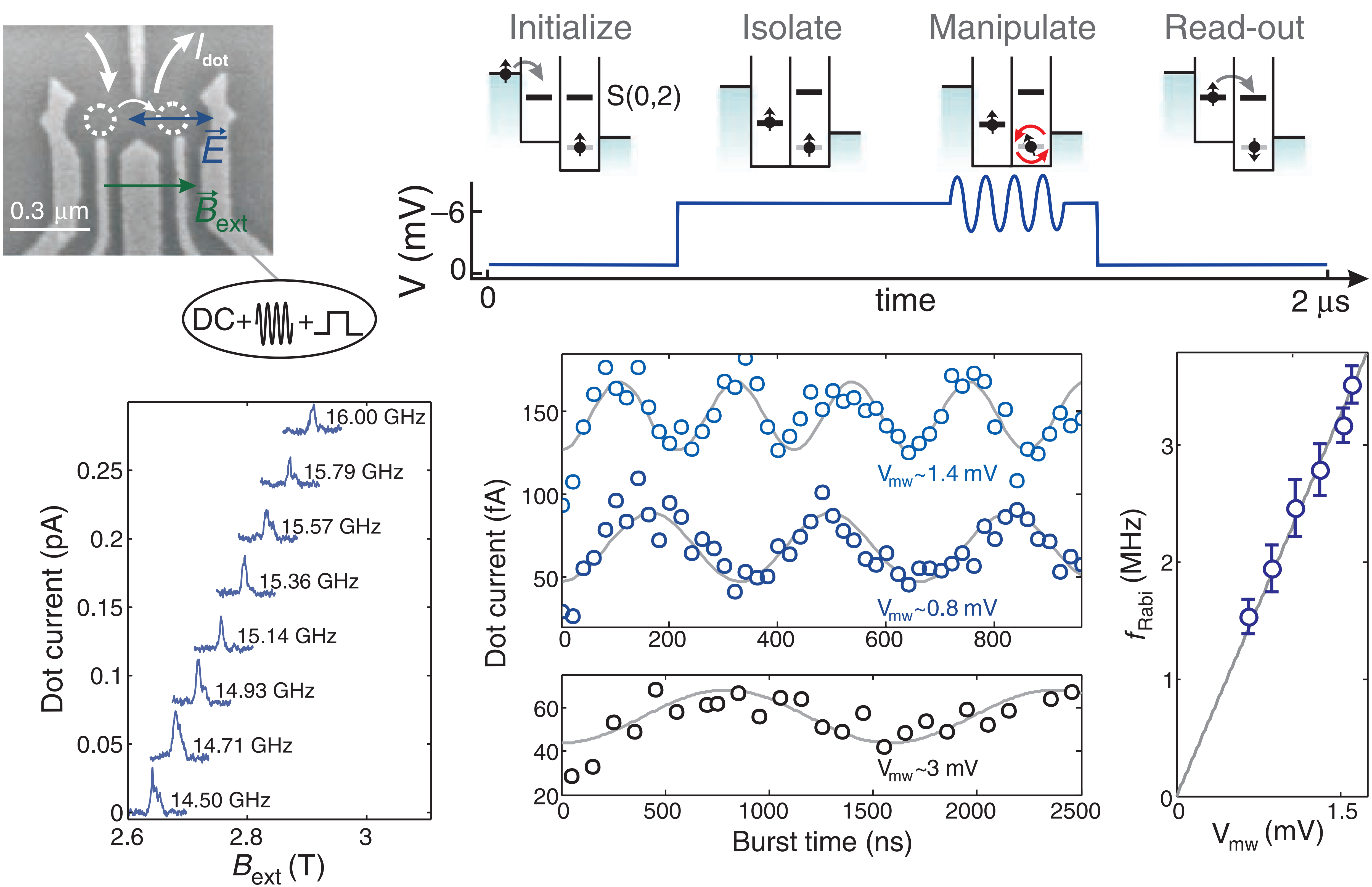




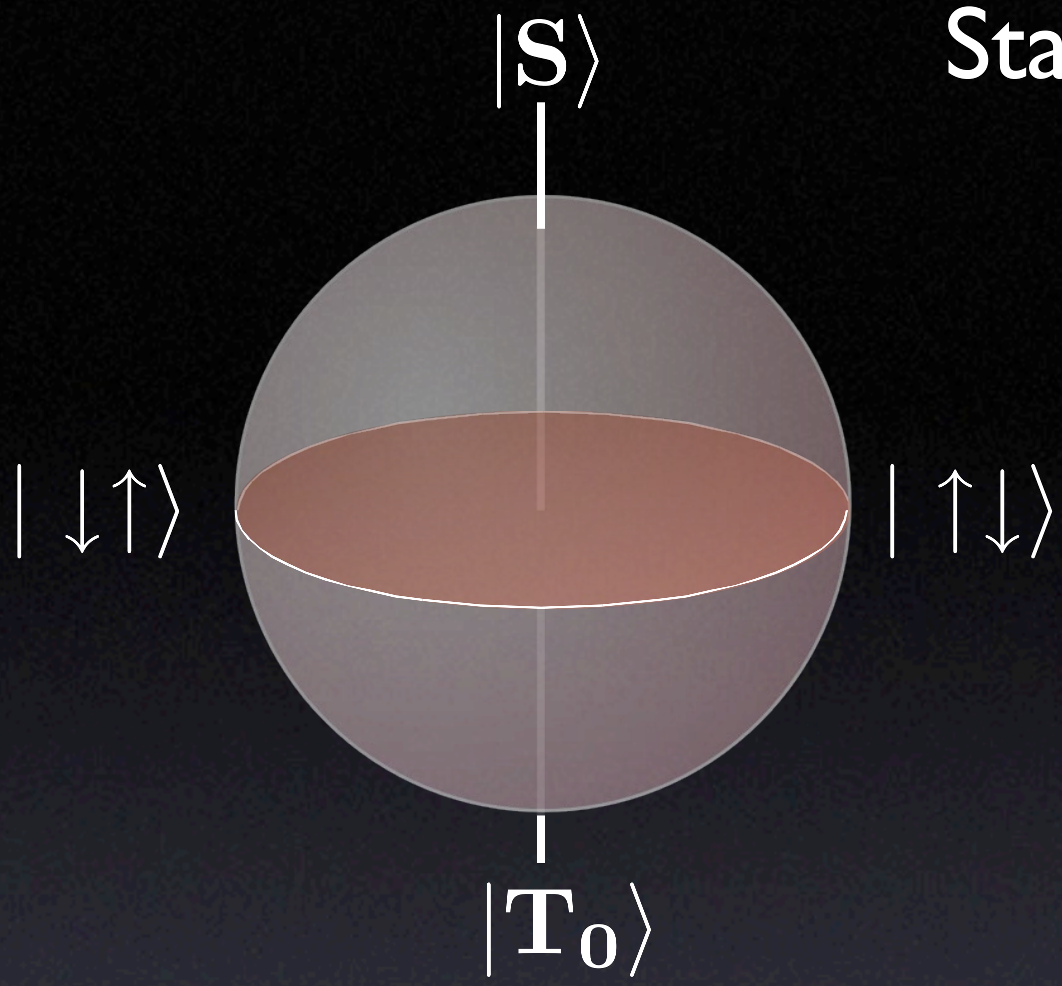


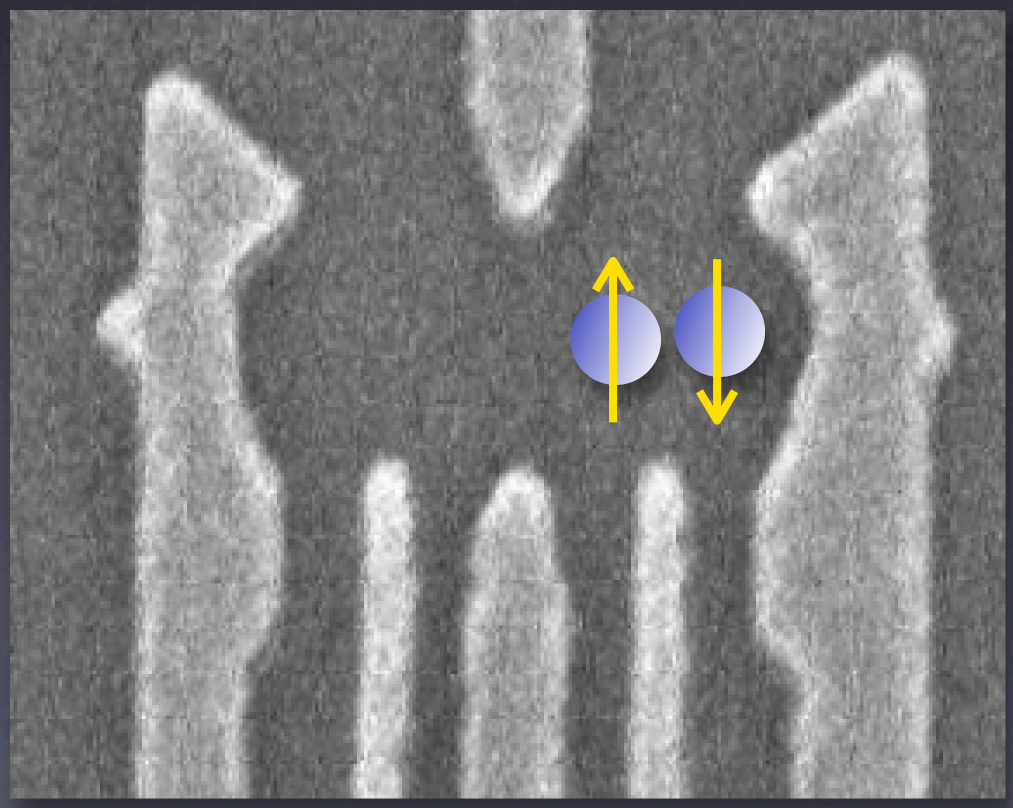
Coherent Control of a Single Electron Spin with Electric Fields

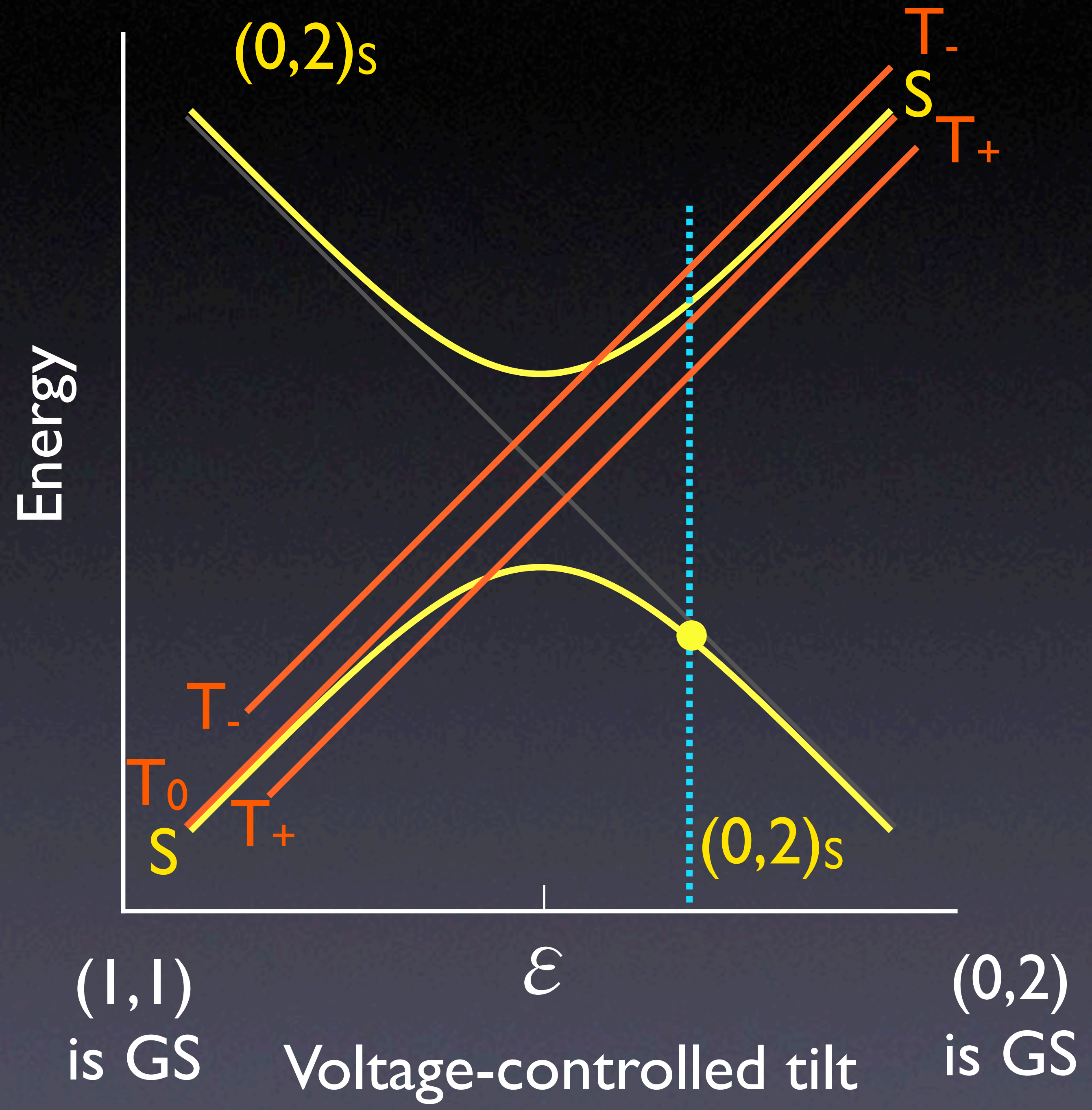
K. C. Nowack,*† F. H. L. Koppens,† Yu. V. Nazarov, L. M. K. Vandersypen*



State Preparation

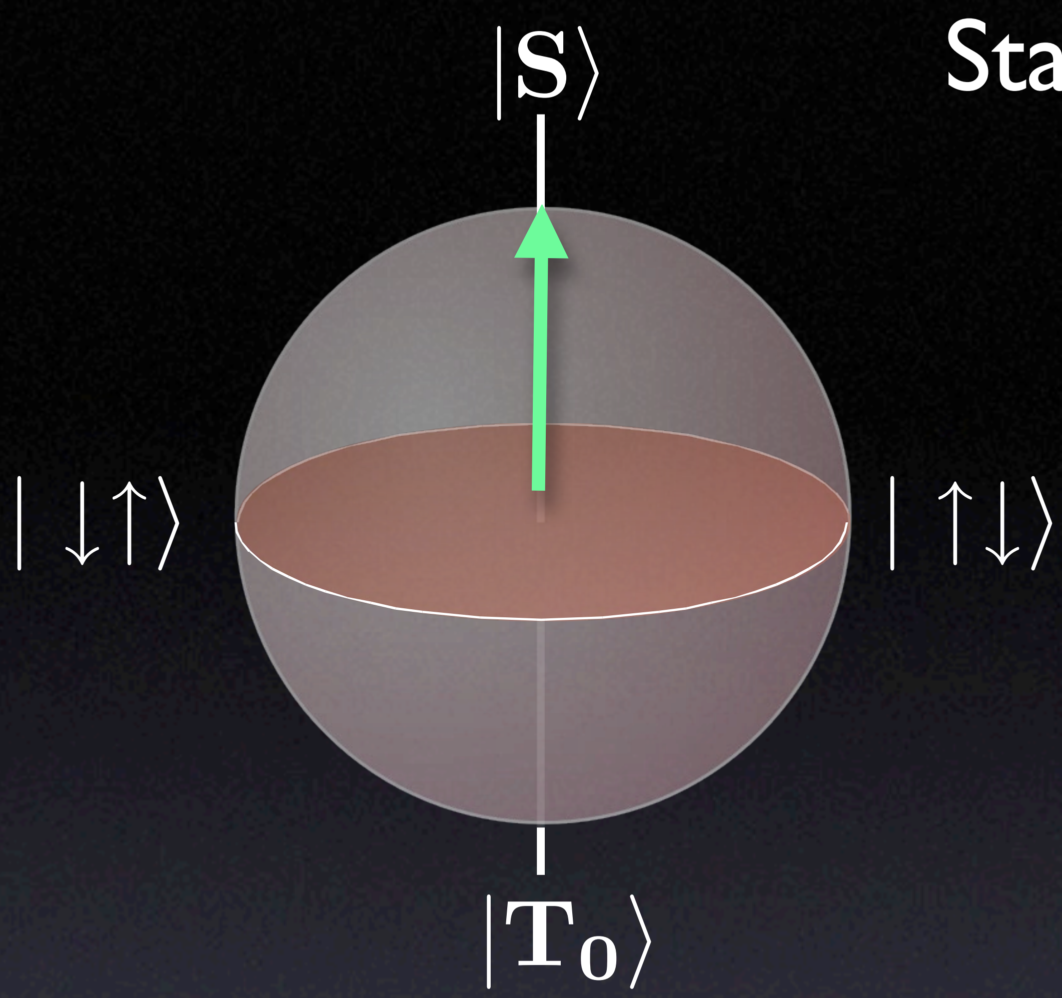


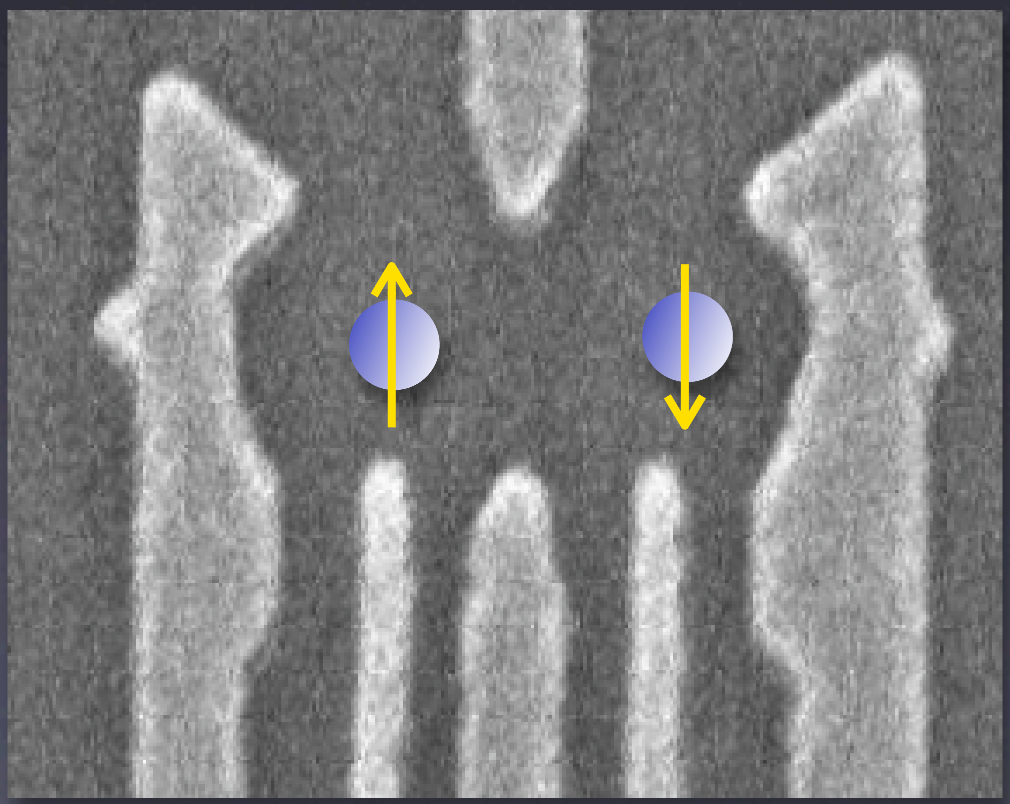


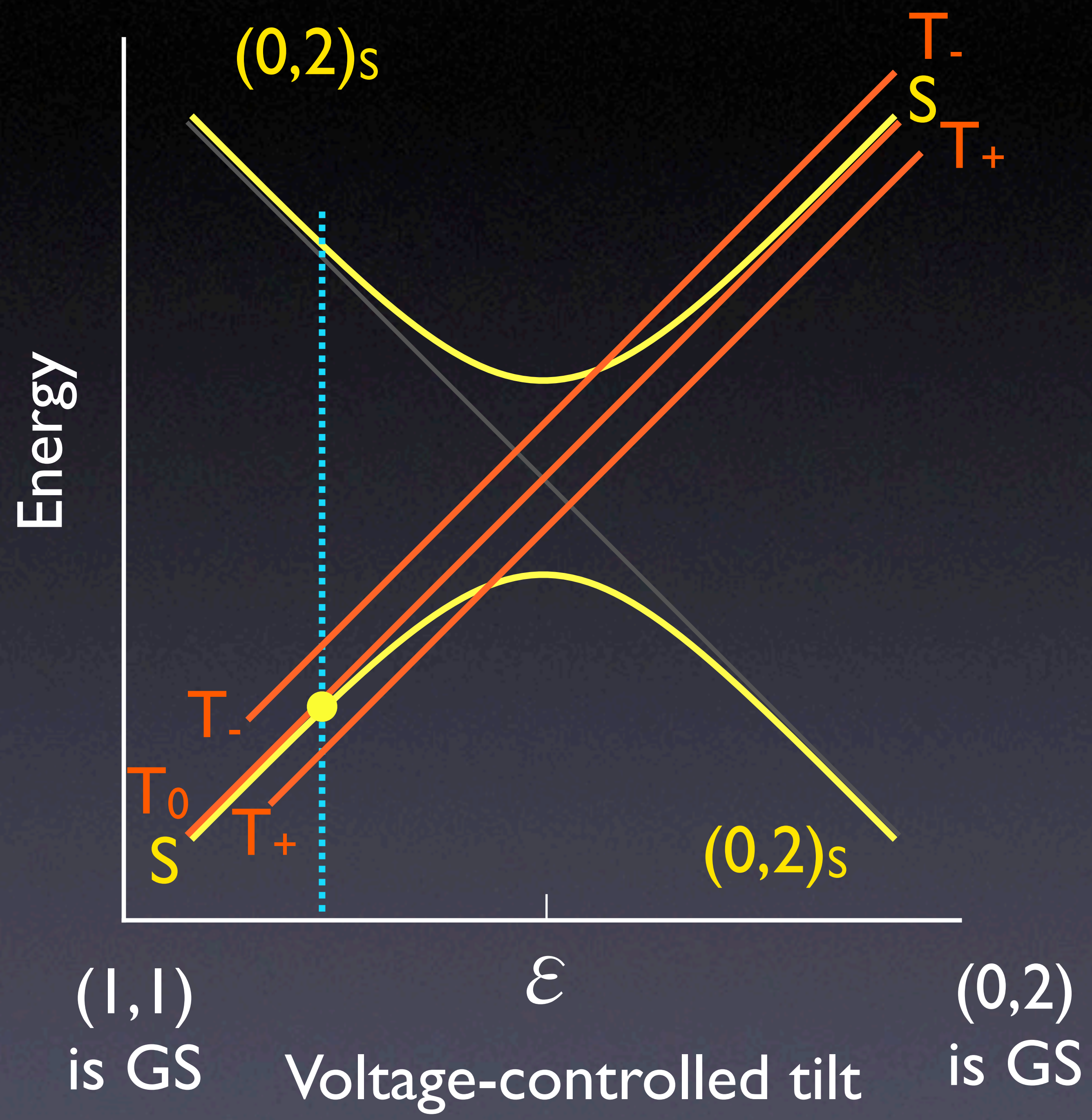


J. R. Petta, et al. (2005)

State Preparation

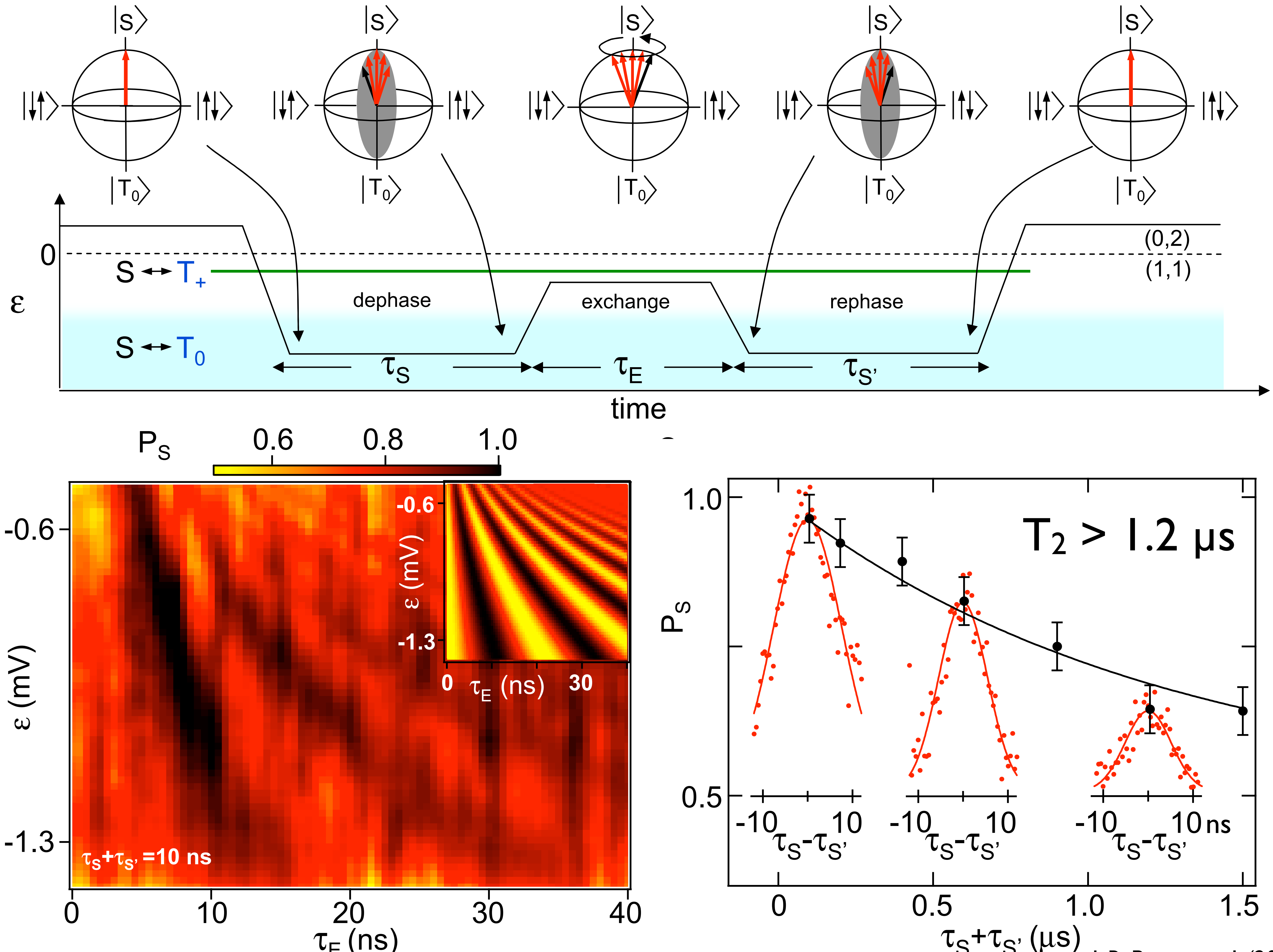






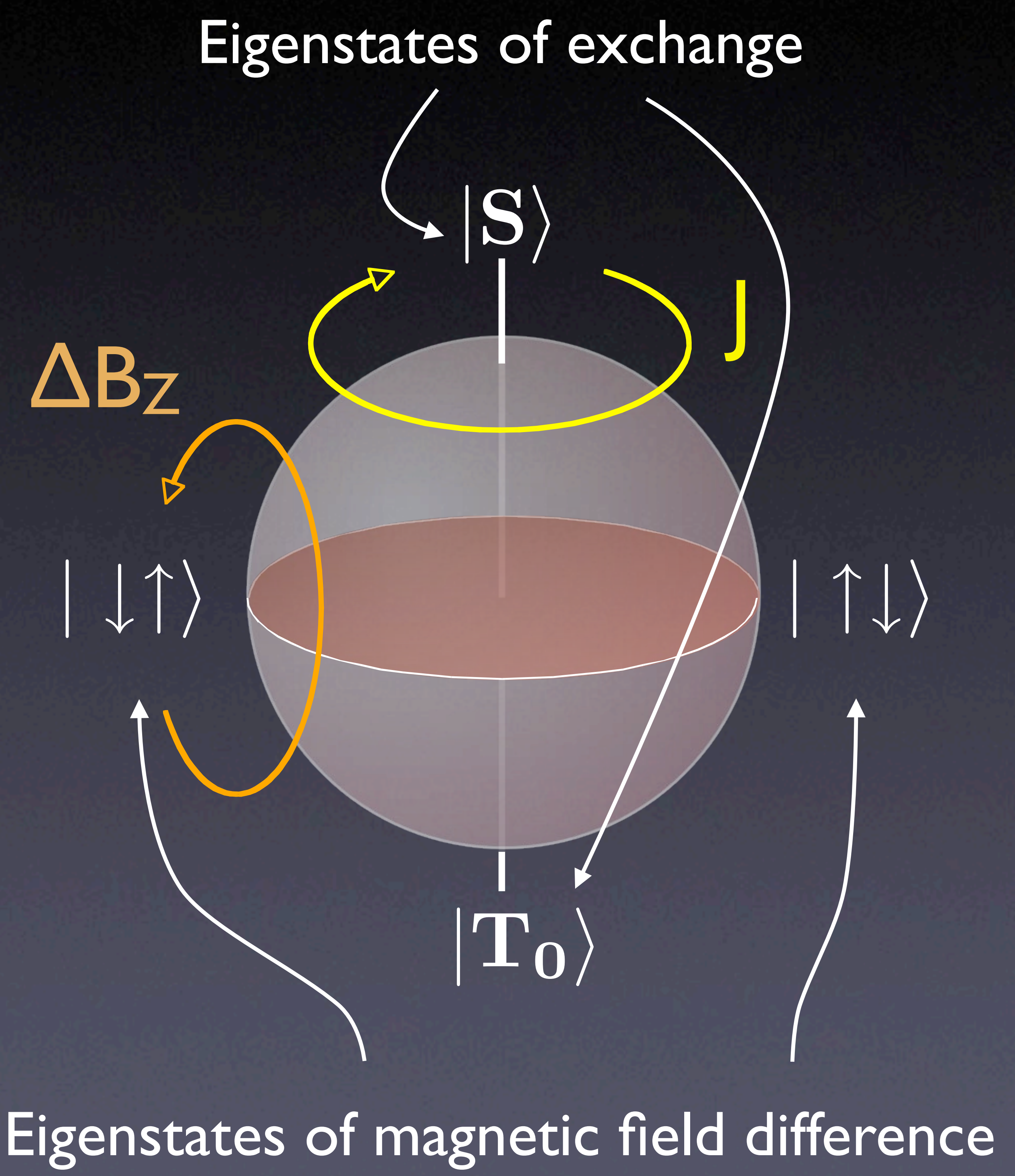
J. R. Petta, et al. (2005)

Hahn Echo in S - T_0 basis



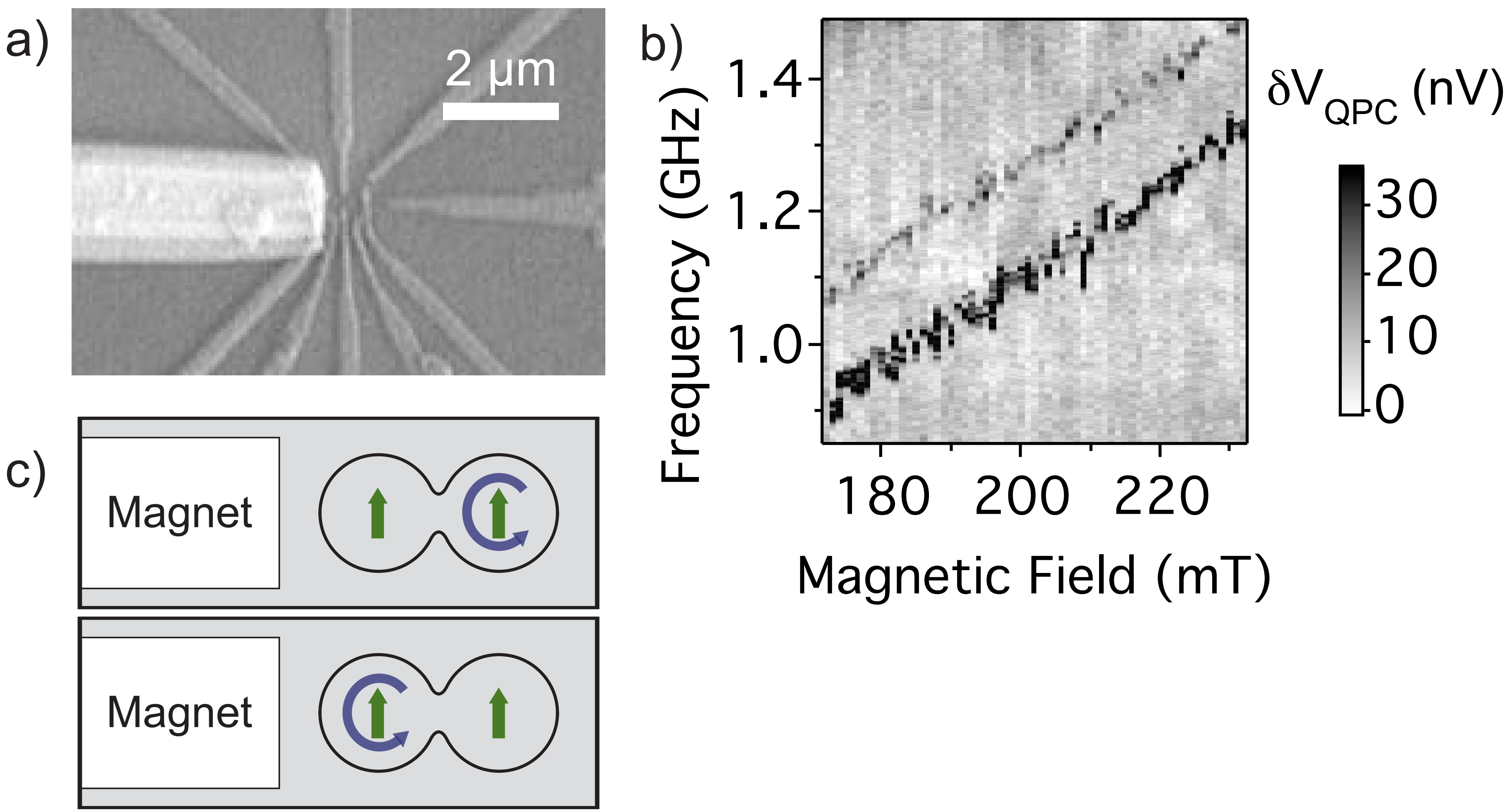
J. R. Petta, et al. (2005)

The fully controlled singlet-triplet qubit

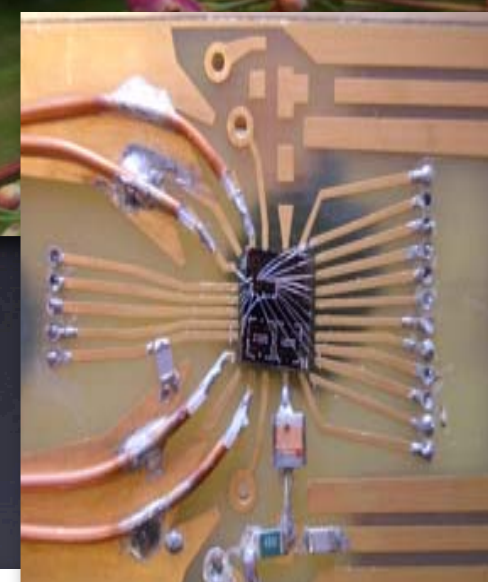


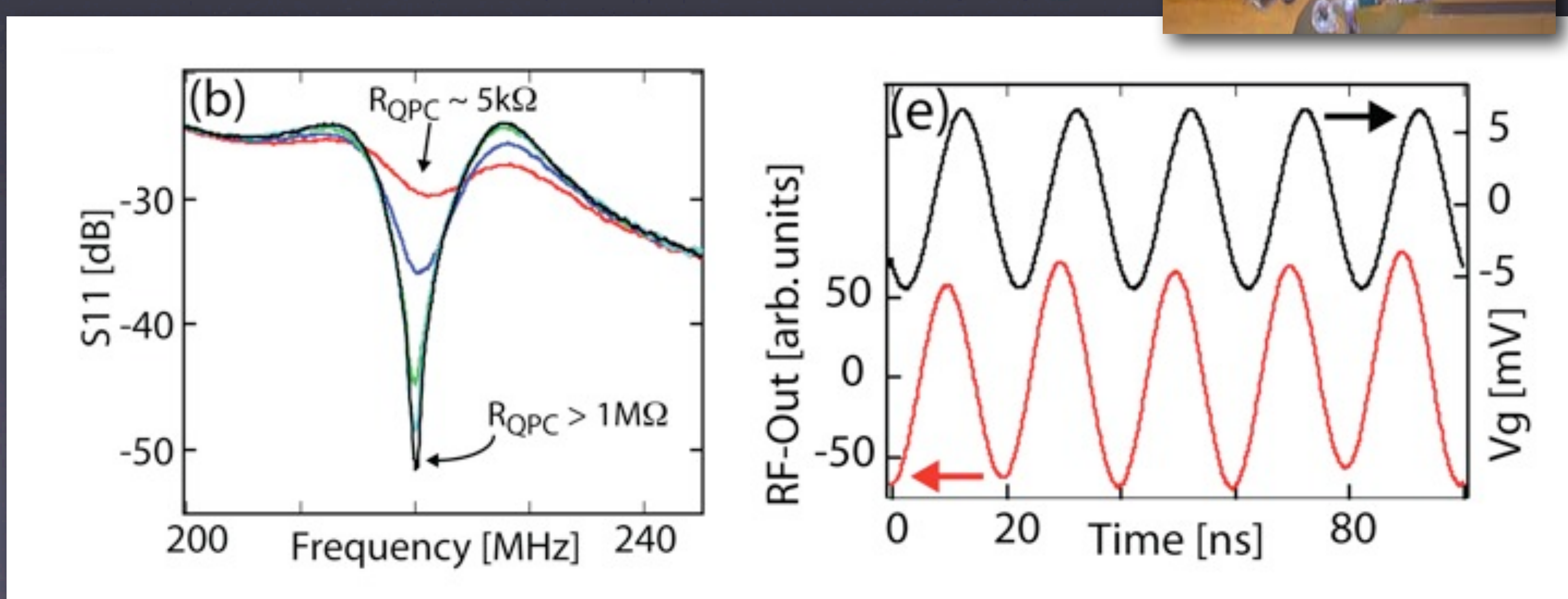
Hyperfine-Mediated Gate-Driven Electron Spin Resonance

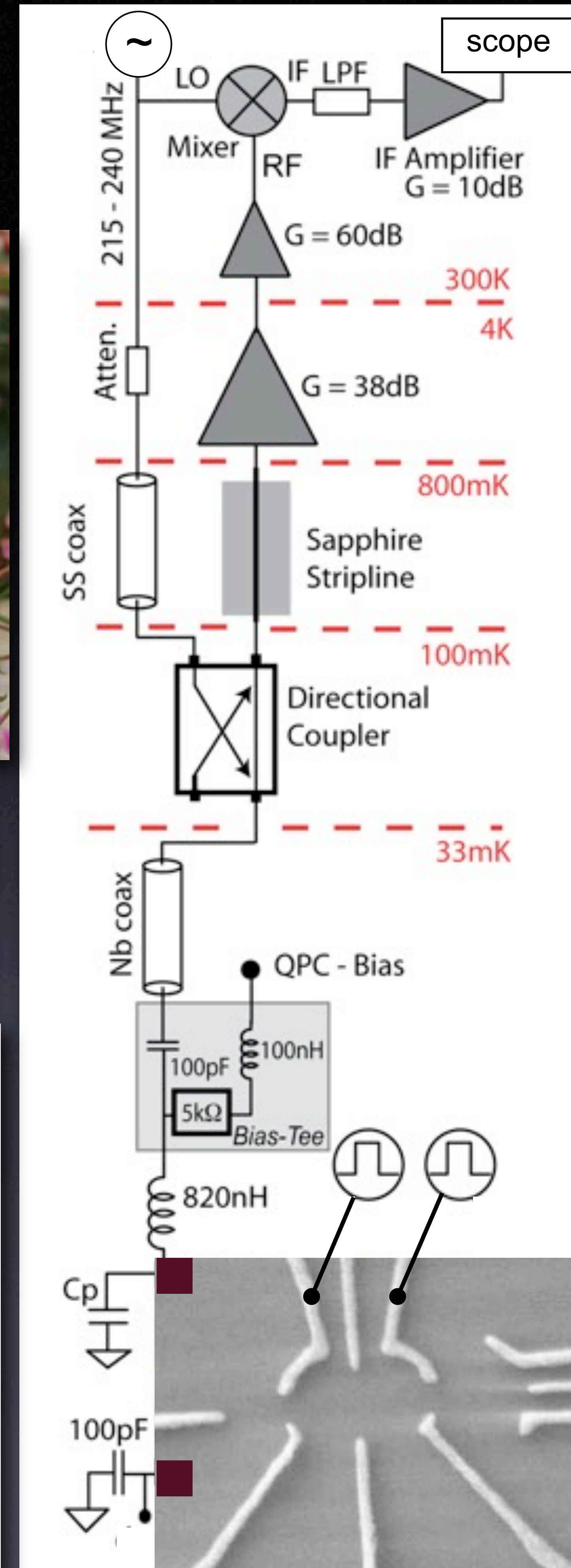
E. A. Laird,[1] C. Barthel,[1] E. I. Rashba,[1,2] C. M. Marcus,[1] M. P. Hanson,[3] and A. C. Gossard[3]



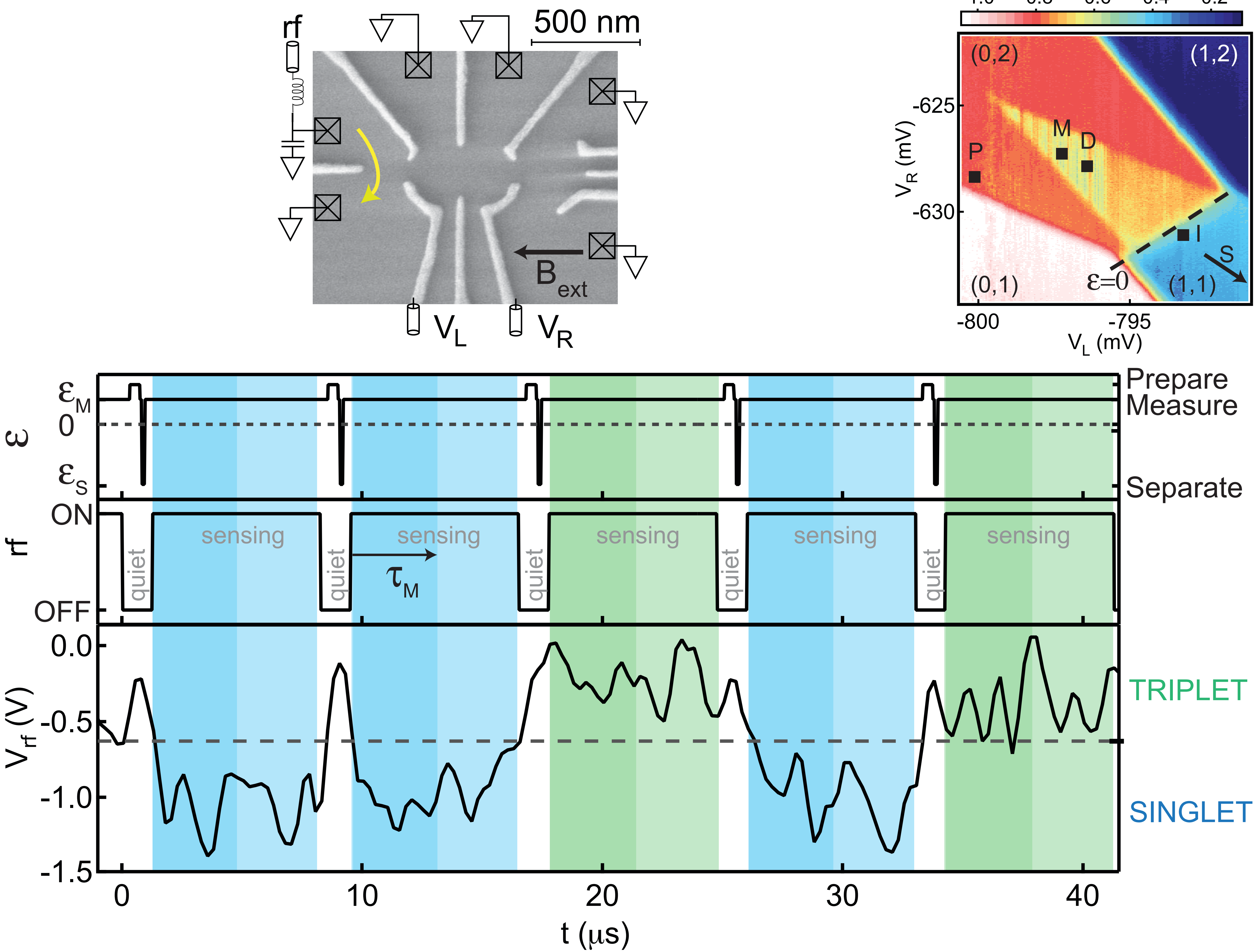
High-bandwidth QPC detection



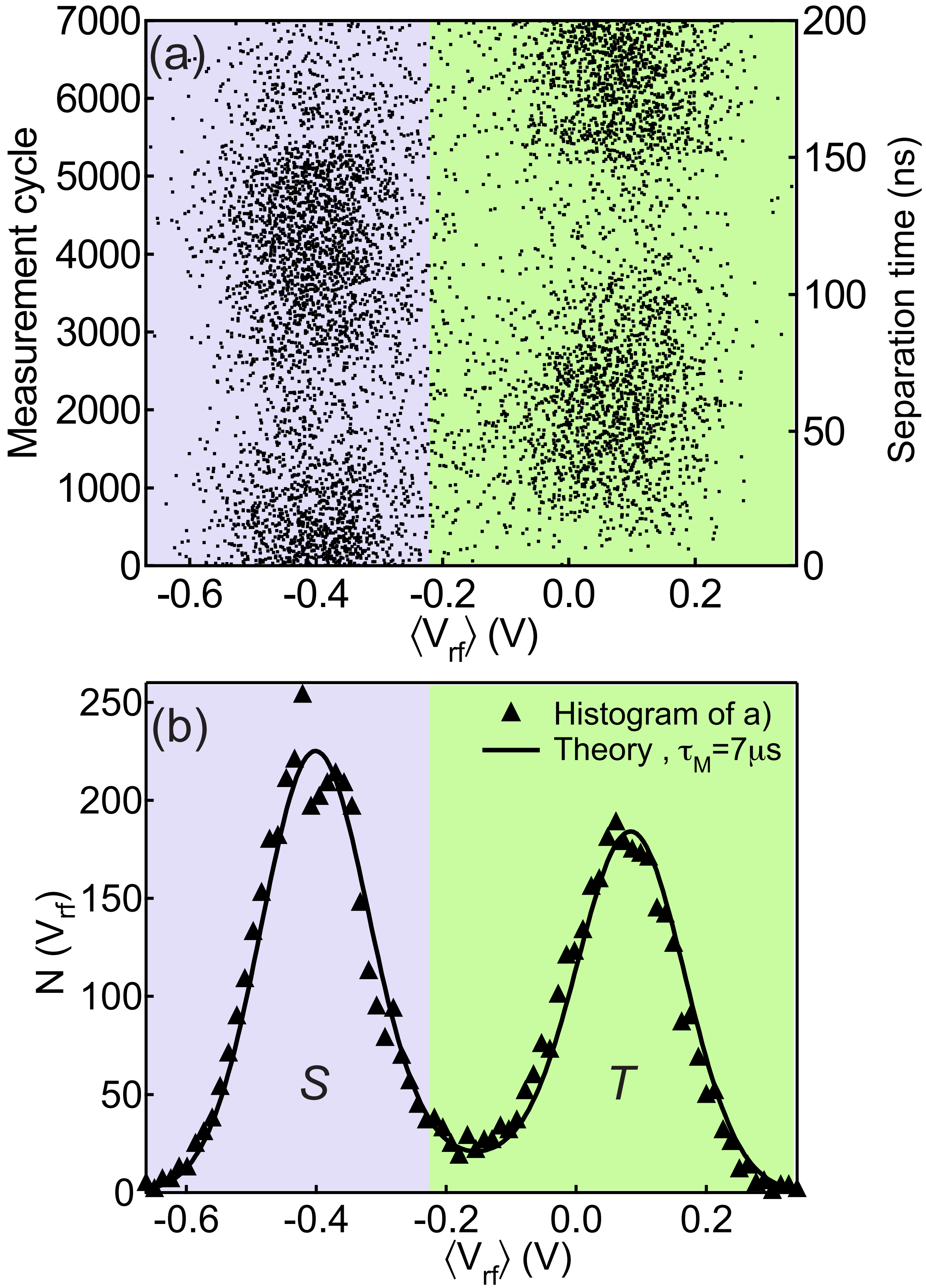




measurement of state-readout fidelity



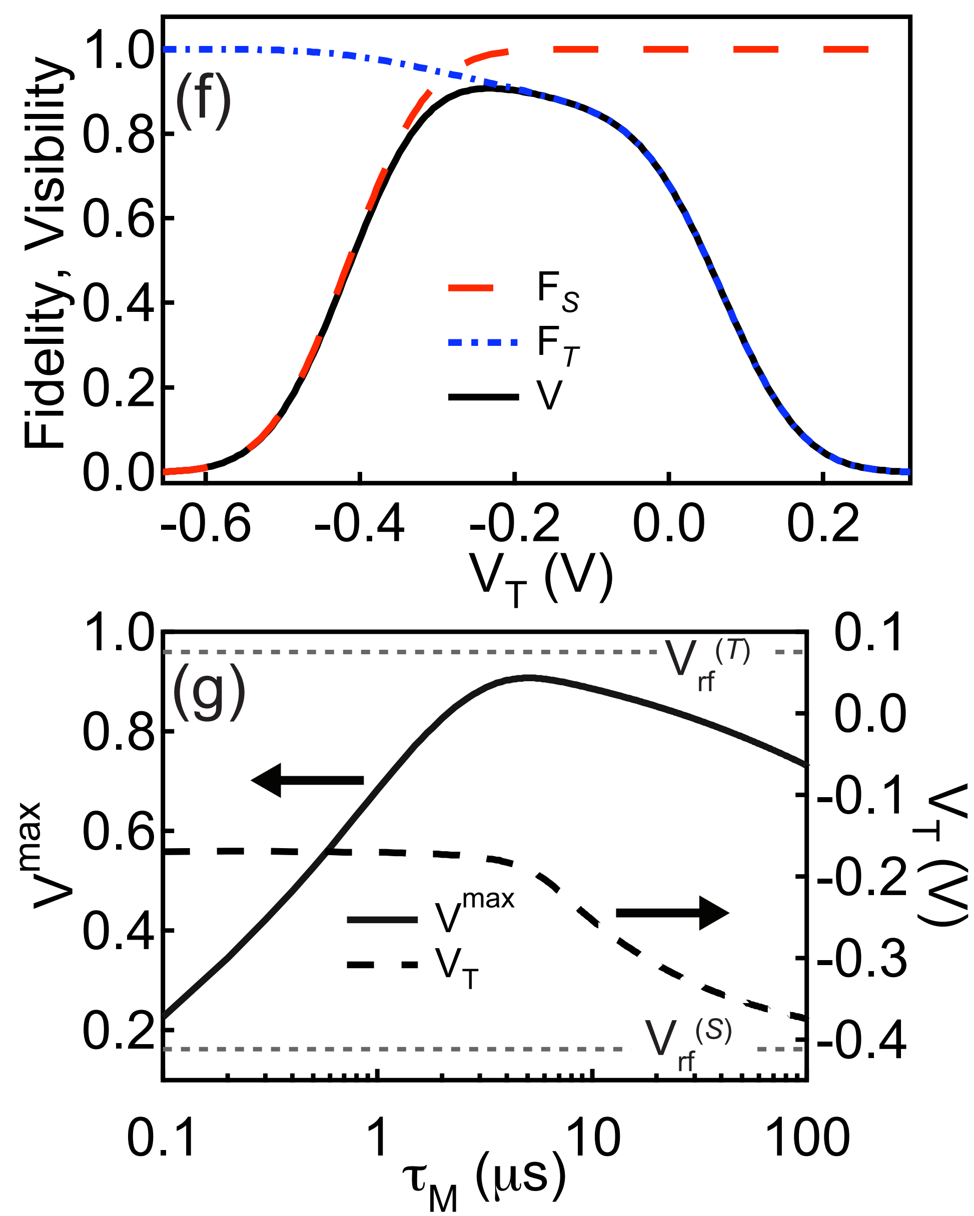
measurement of state-readout fidelity



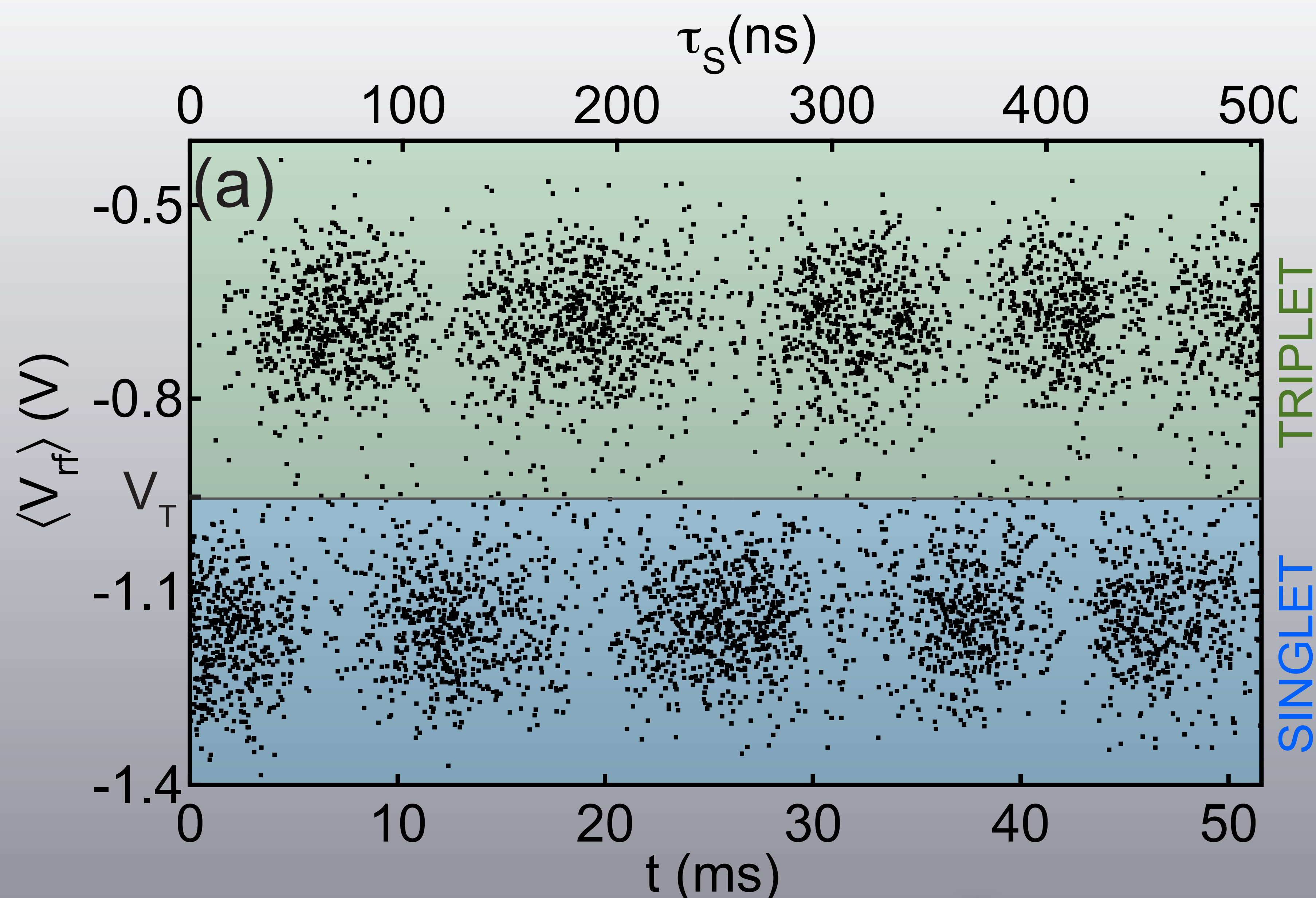
$$F_S = 1 - \int_{V_\mathrm{T}}^{\infty} n_S(V)dV,$$

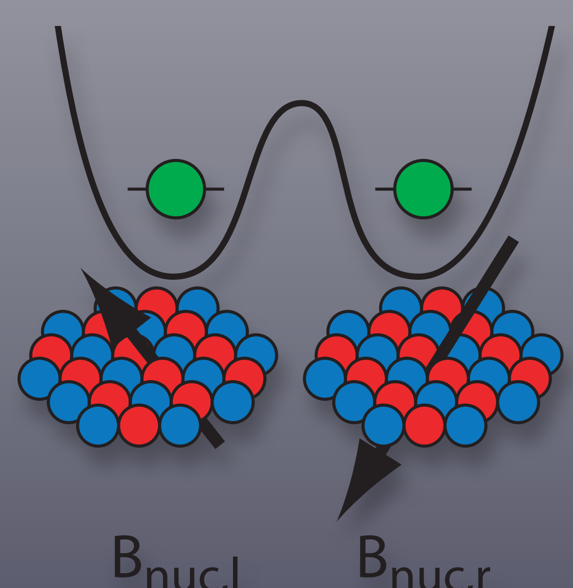
$$F_T = 1 - \int_{-\infty}^{V_\mathrm{T}} n_T(V)dV.$$

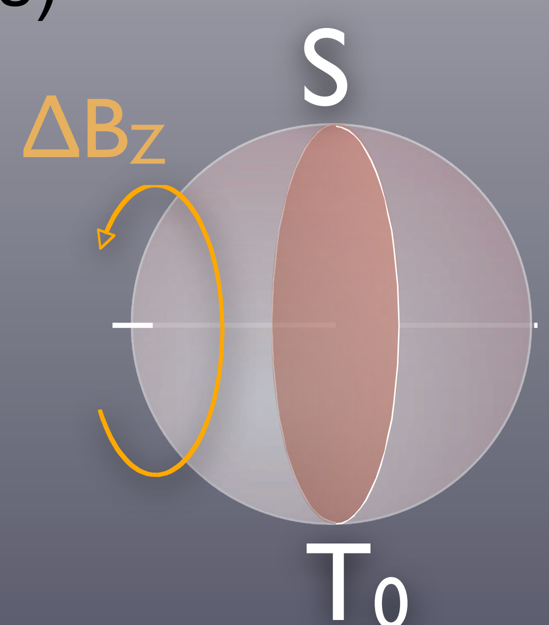
$$V = F_S + F_T - 1$$

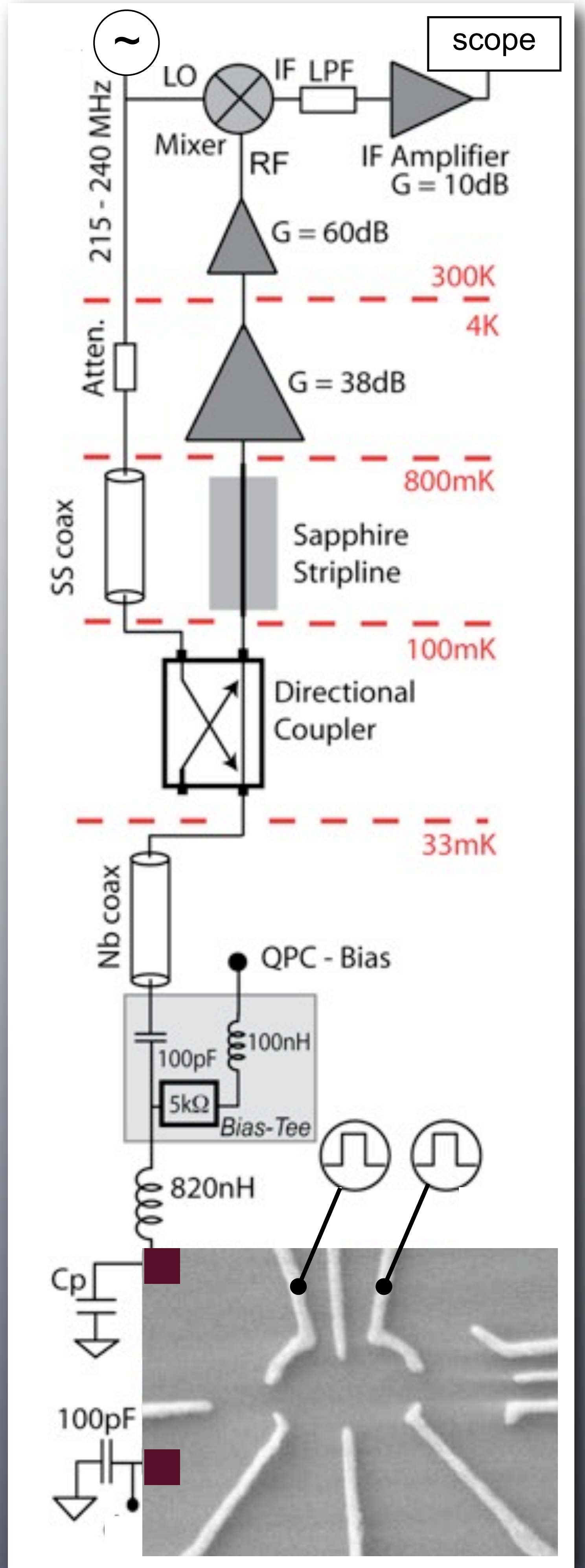


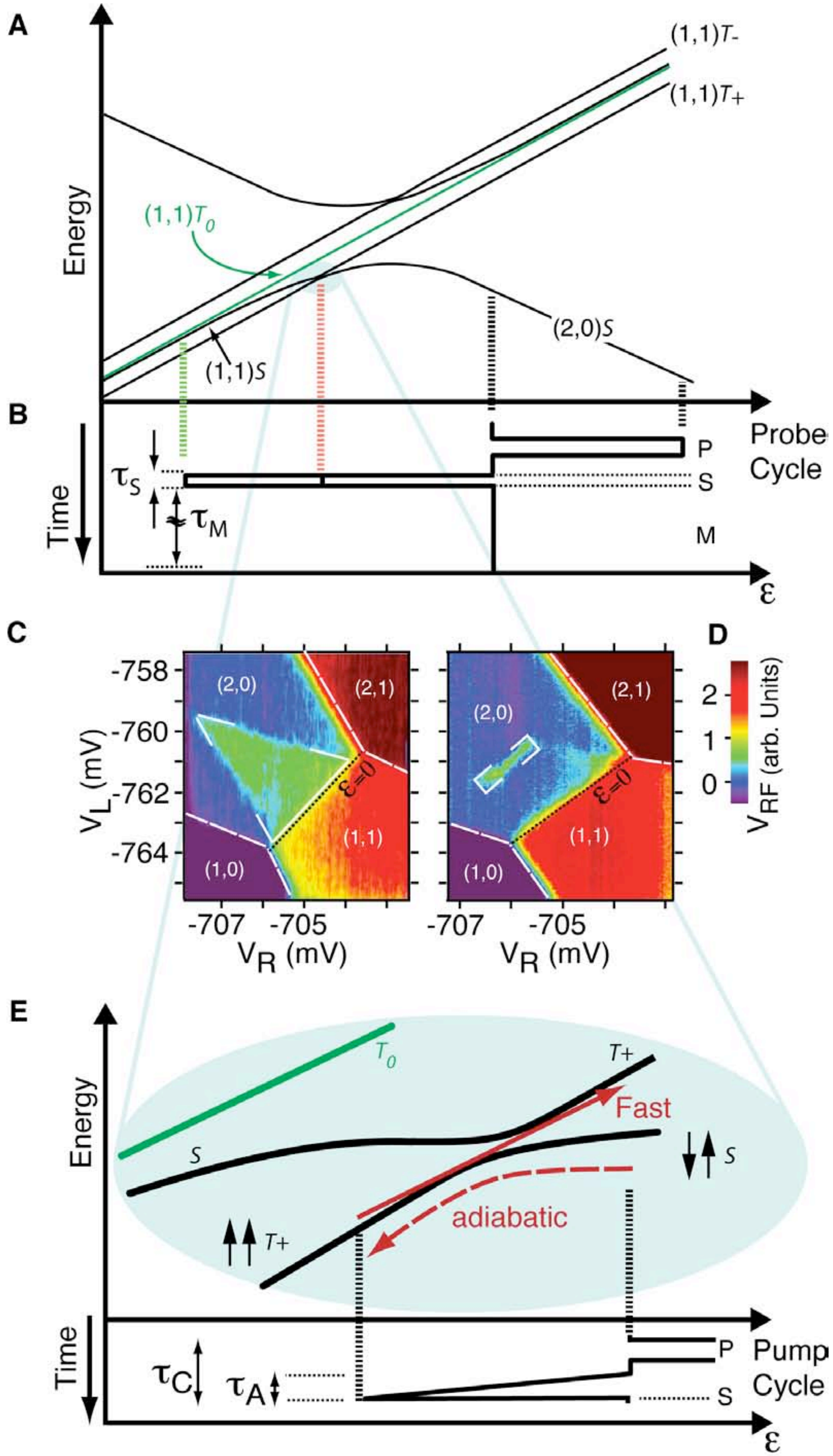
Single-shot S-T detection







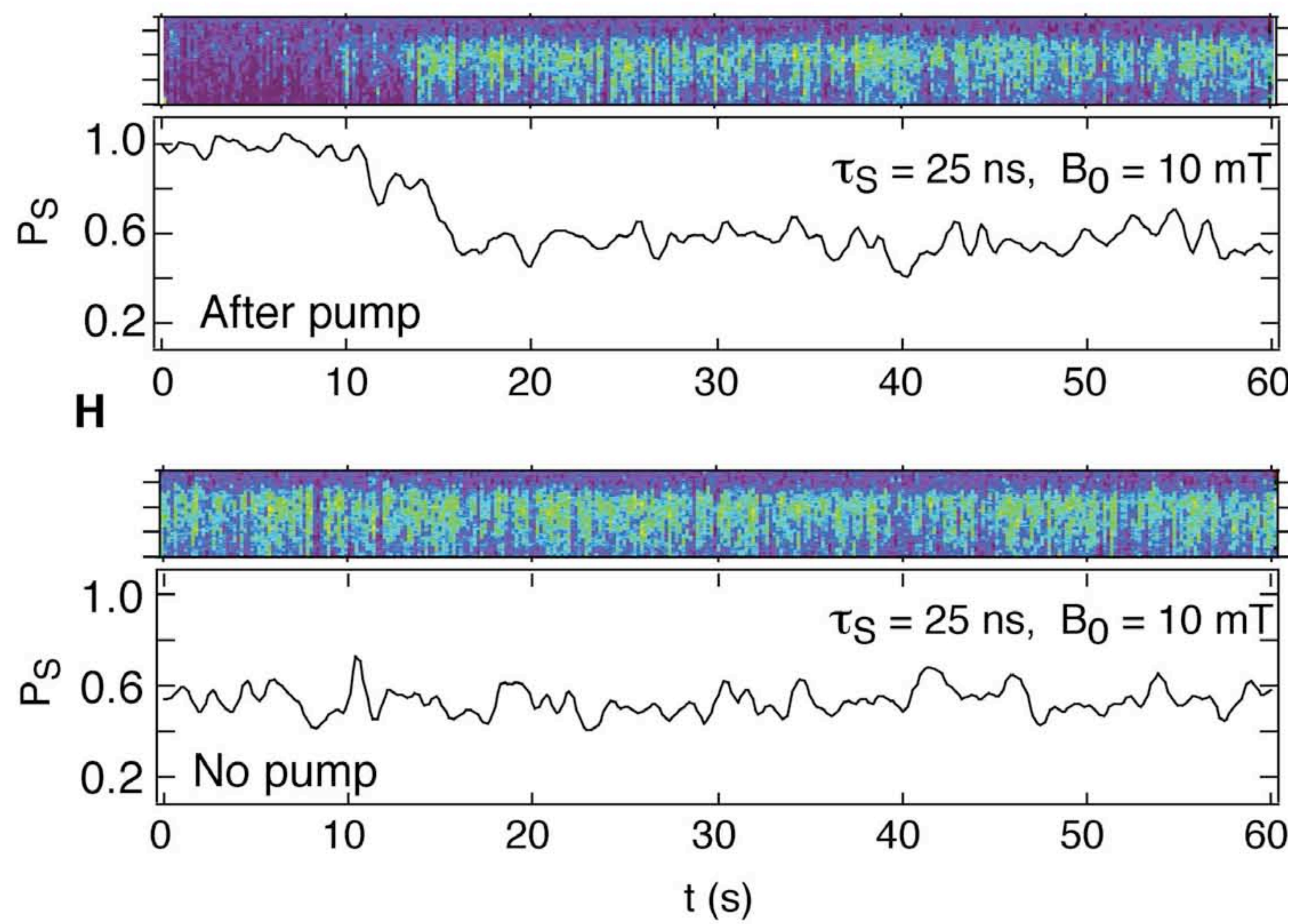




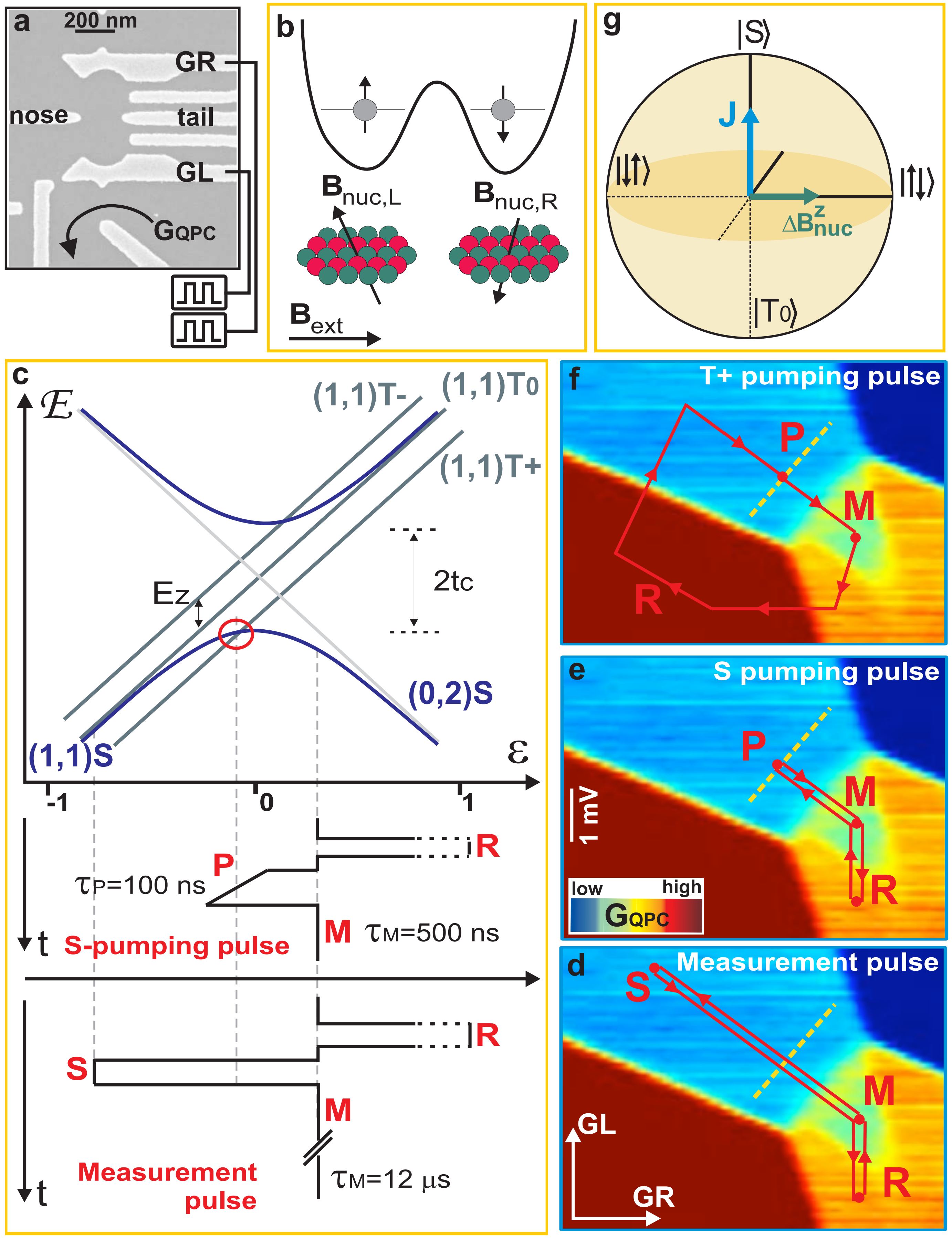
Suppressing Spin Qubit Dephasing by Nuclear State Preparation

D. J. Reilly,[1] J. M. Taylor,[2] J. R. Petta,[3] C. M. Marcus,[1*] M. P. Hanson,[4] A. C. Gossard[4]

Coherent spin states in semiconductor quantum dots offer promise as electrically controllable quantum bits (qubits) with scalable fabrication. For few-electron quantum dots made from gallium arsenide (GaAs), fluctuating nuclear spins in the host lattice are the dominant source of spin decoherence. We report a method of preparing the nuclear spin environment that suppresses the relevant component of nuclear spin fluctuations below its equilibrium value by a factor of ~70, extending the inhomogeneous dephasing time for the two-electron spin state beyond 1 microsecond. The nuclear state can be readily prepared by electrical gate manipulation and persists for more than 10 seconds.

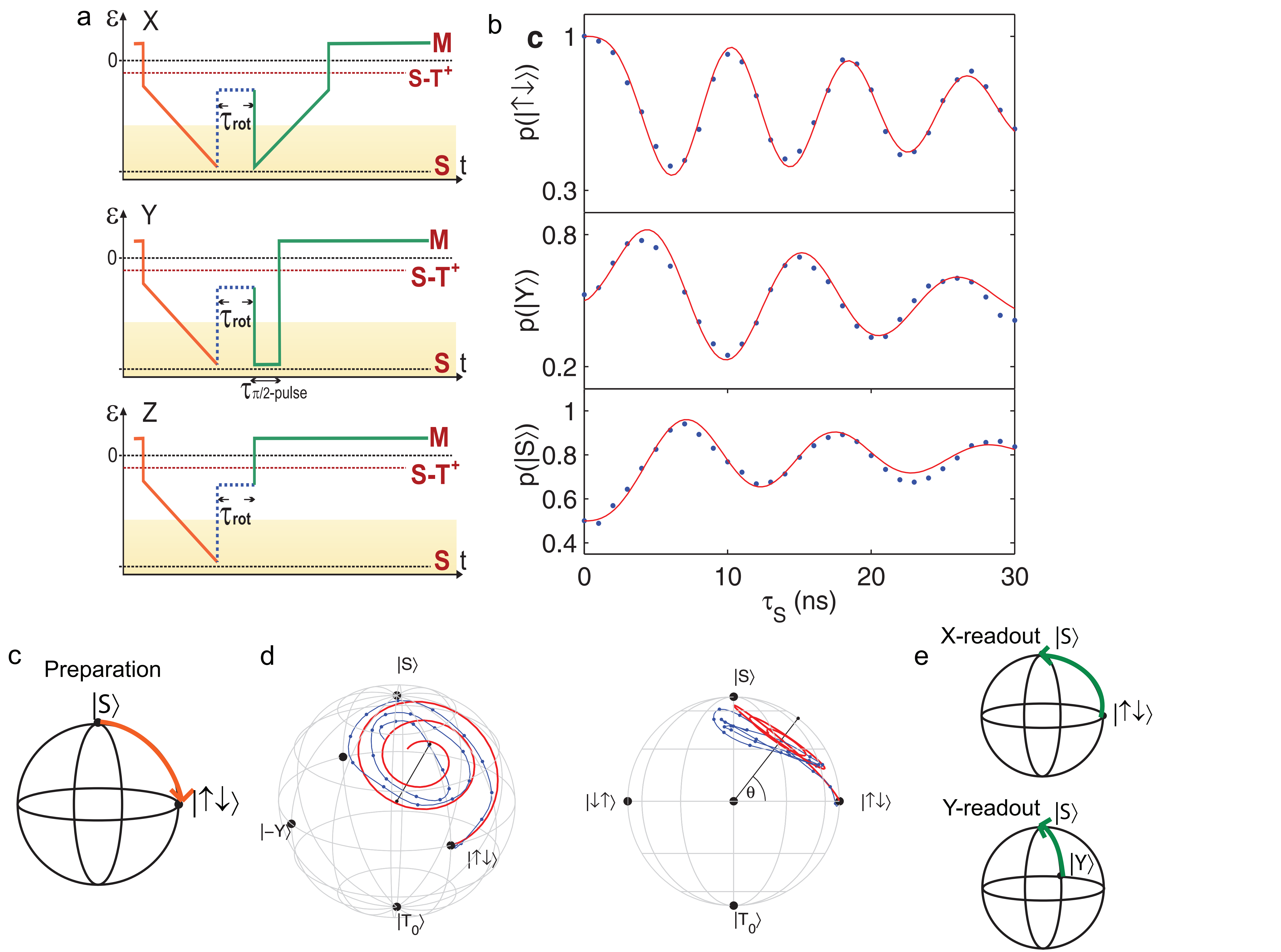


nuclear state preparation



Sandra Foletti, Hendrik Bluhm, Diana Mahalu, Vladimir Umansky, Amir Yacoby (2009)

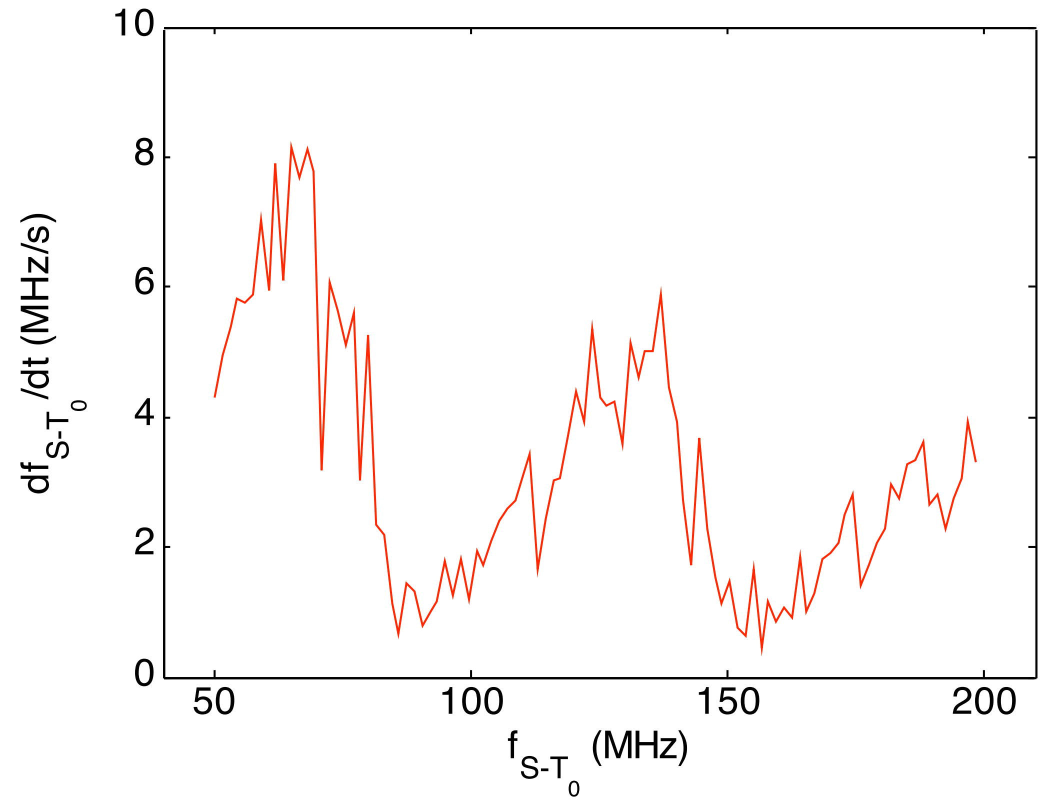
nuclear state preparation

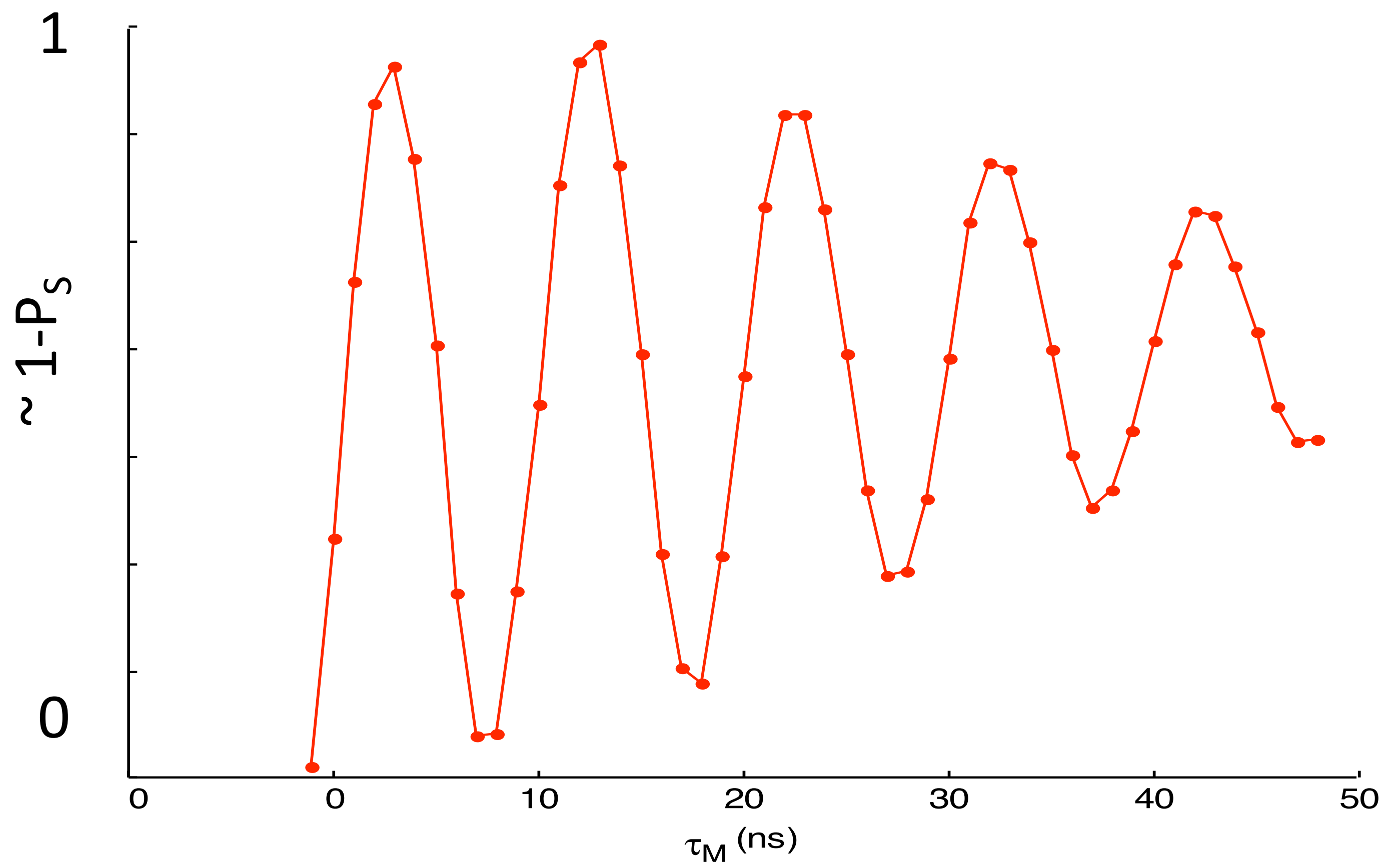


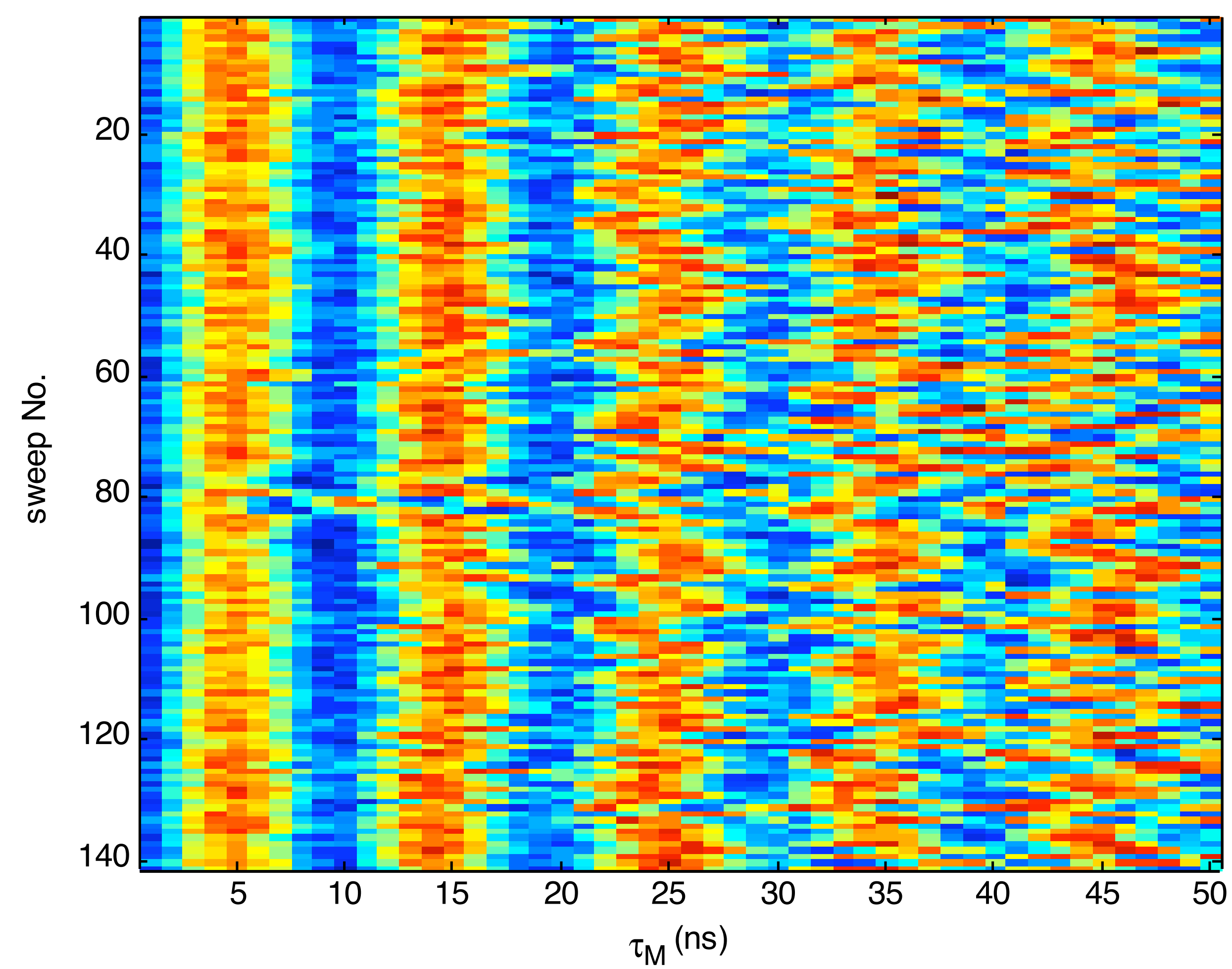
Sandra Foletti, Hendrik Bluhm, Diana Mahalu, Vladimir Umansky, Amir Yacoby (2009)

Feedback built into polarization pulses

Basic idea: design pulses such that polarization rate depends on current S-T_0 mixing rate.
=> Stabilization of S-T_0 mixing rate in conjunction with relaxation or antagonistic polarization pulse.







- Factor ~3 enhancement of T_2^*.
- Requires no software intervention

=> not limited by measurement speed

- Stable gradients for up to ~ 1h.

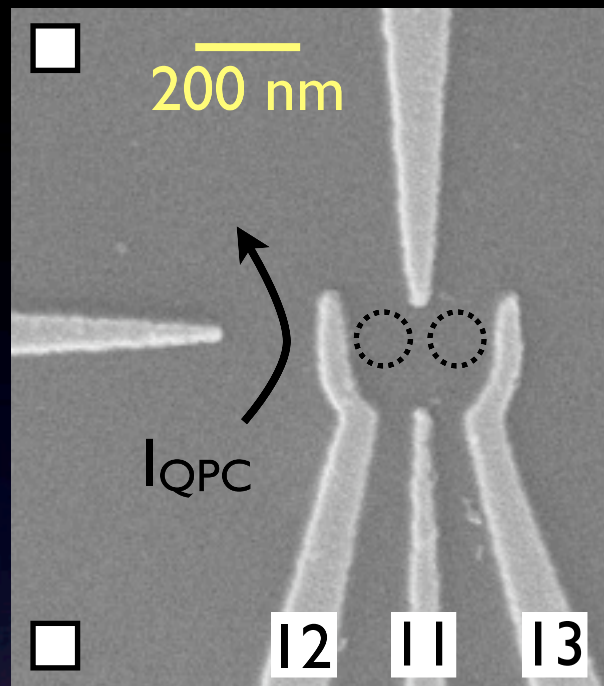
some mostly-zero-nuclear-spin materials

Isotope	Atomic mass (m_a/u)	Natural abundance (atom %)	Nuclear spin (I)
^{12}C	12.000000000*	98.93 (8)	0
^{13}C	13.003354826 (17)	1.07 (8)	$^1/_2$

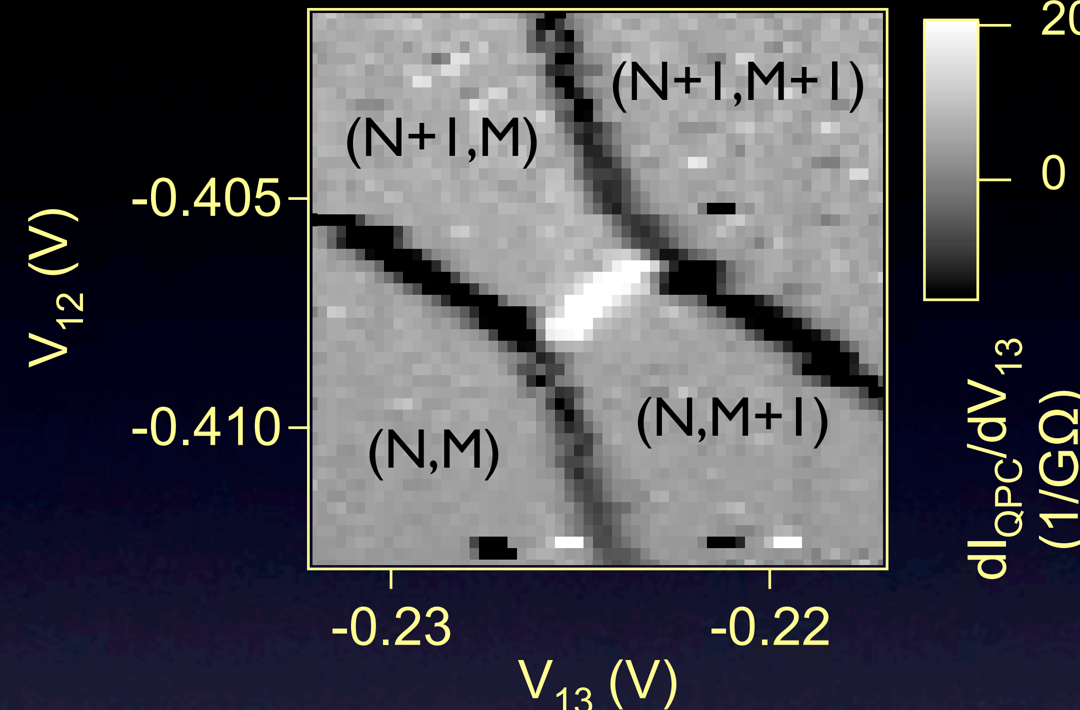
Isotope	Atomic mass (m_a/u)	Natural abundance (atom %)	Nuclear spin (I)
^{28}Si	27.9769271 (7)	92.2297 (7)	0
^{29}Si	28.9764949 (7)	4.6832 (5)	$^1/_2$
^{30}Si	29.9737707 (7)	3.0872 (5)	0

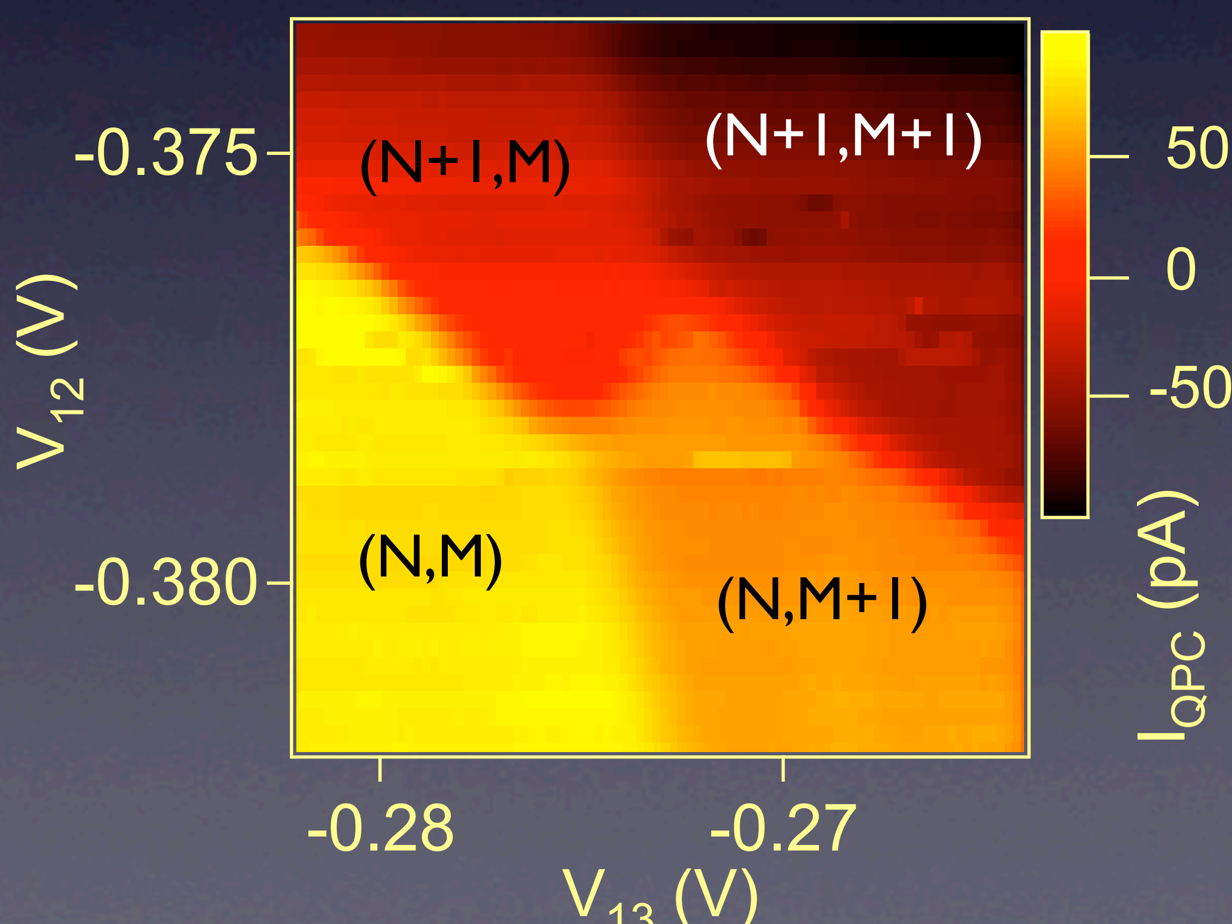
Isotope	Atomic mass (m_a/u)	Natural abundance (atom %)	Nuclear spin (I)
^{70}Ge	69.9242497 (16)	20.84 (87)	0
^{72}Ge	71.9220789 (16)	27.54 (34)	0
^{73}Ge	72.9234626 (16)	7.73 (5)	$^9/_2$
^{74}Ge	73.9211774 (15)	36.28 (73)	0
^{76}Ge	75.9214016 (17)	7.61 (38)	0

Tunable tunnel coupling in Si/SiGe double quantum dots

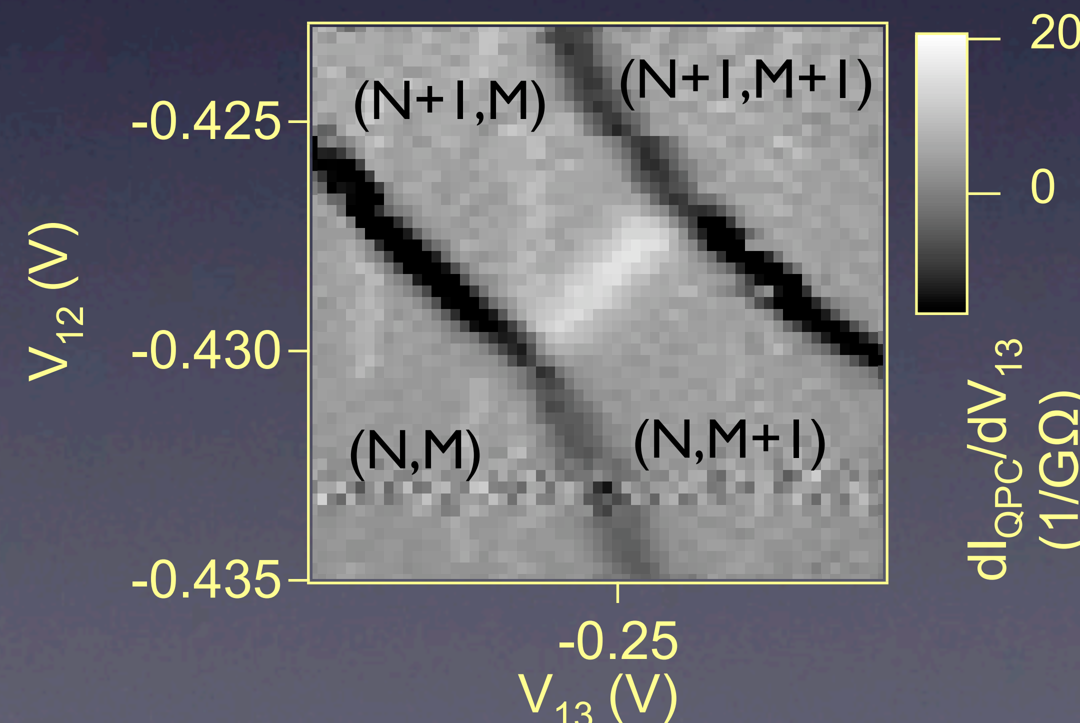


Weak tunnel coupling: V_{11} = -1.0 V



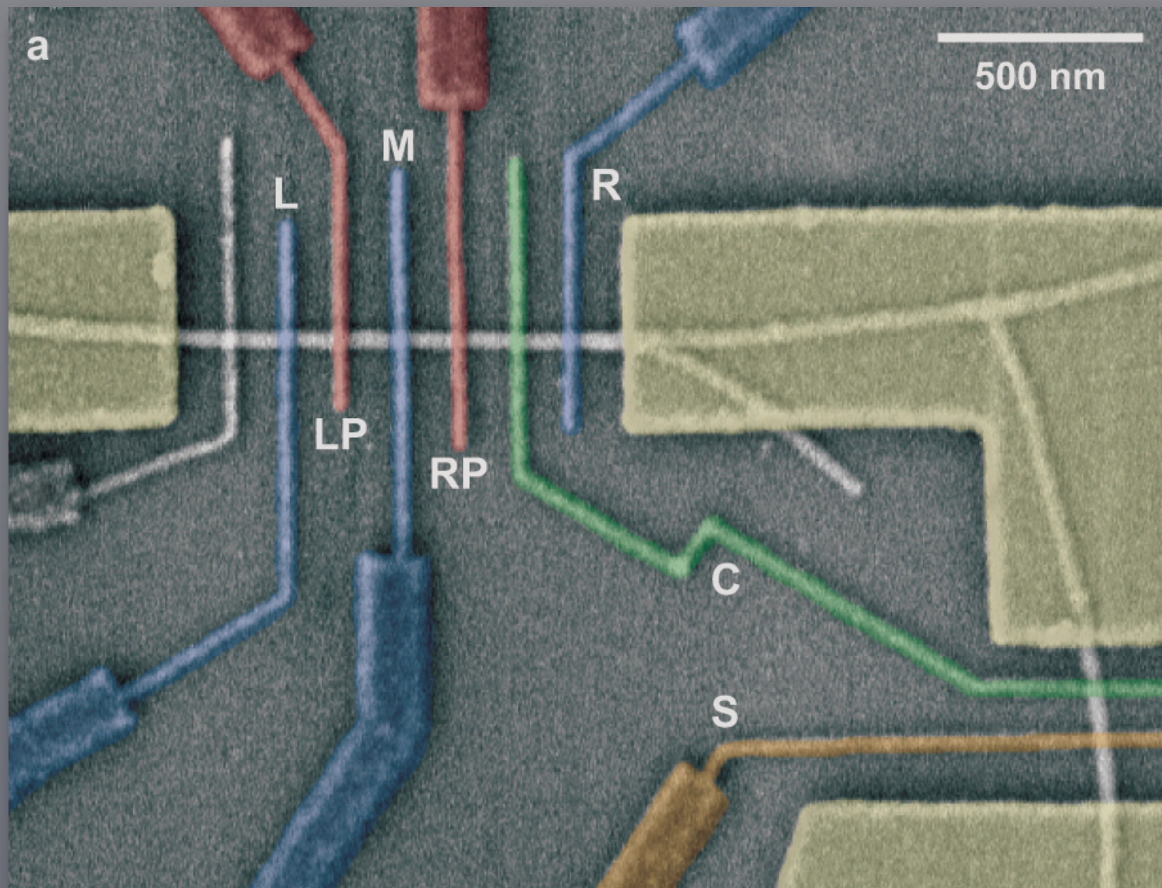


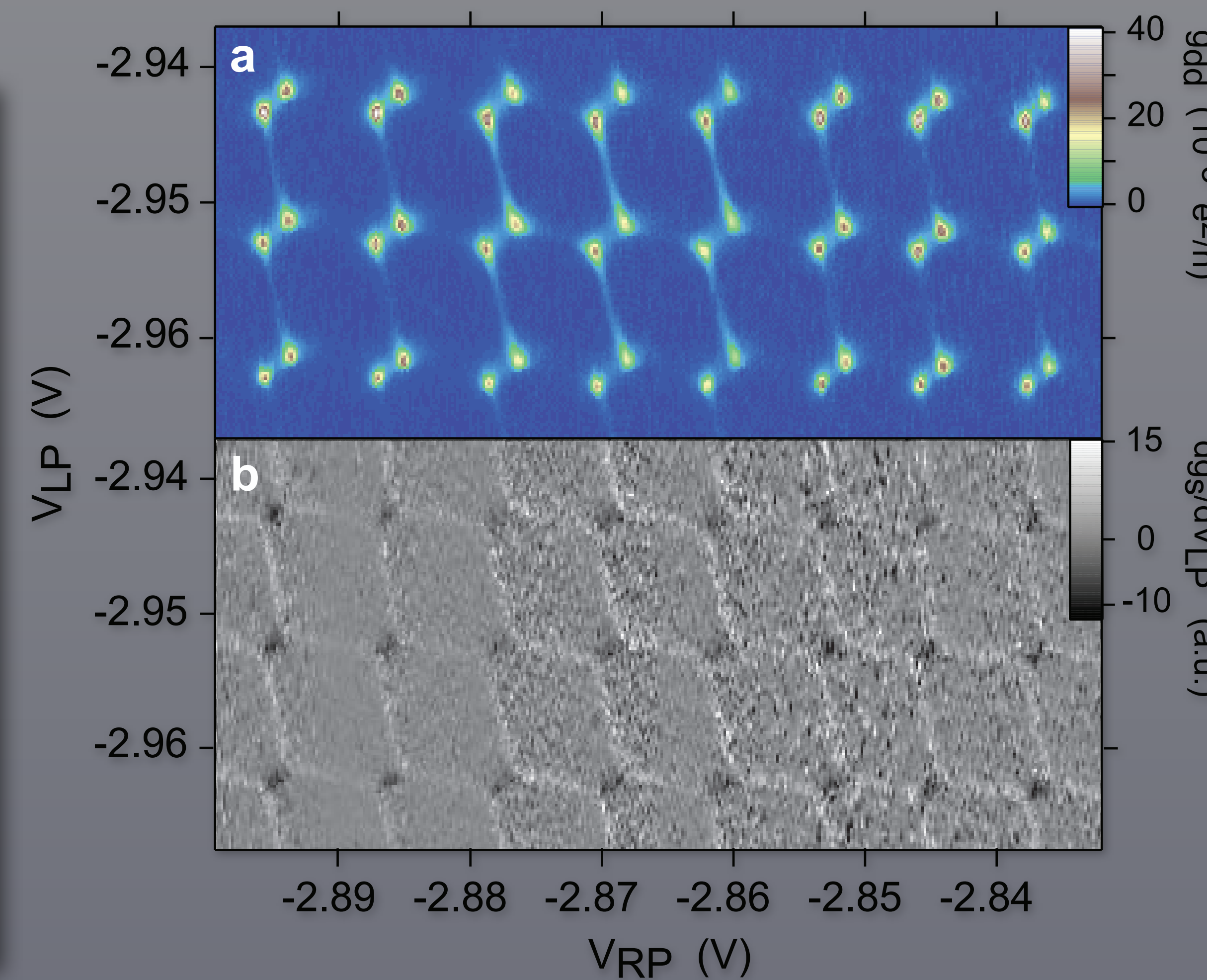
Strong tunnel coupling: V_{11} = -0.825 V

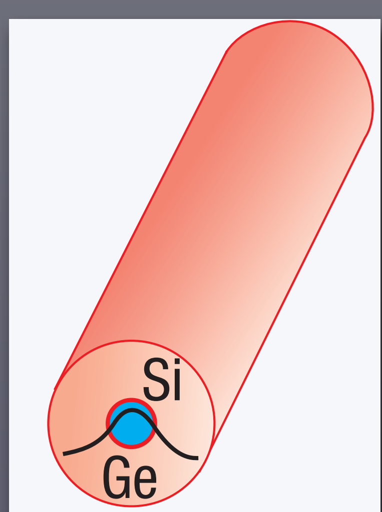


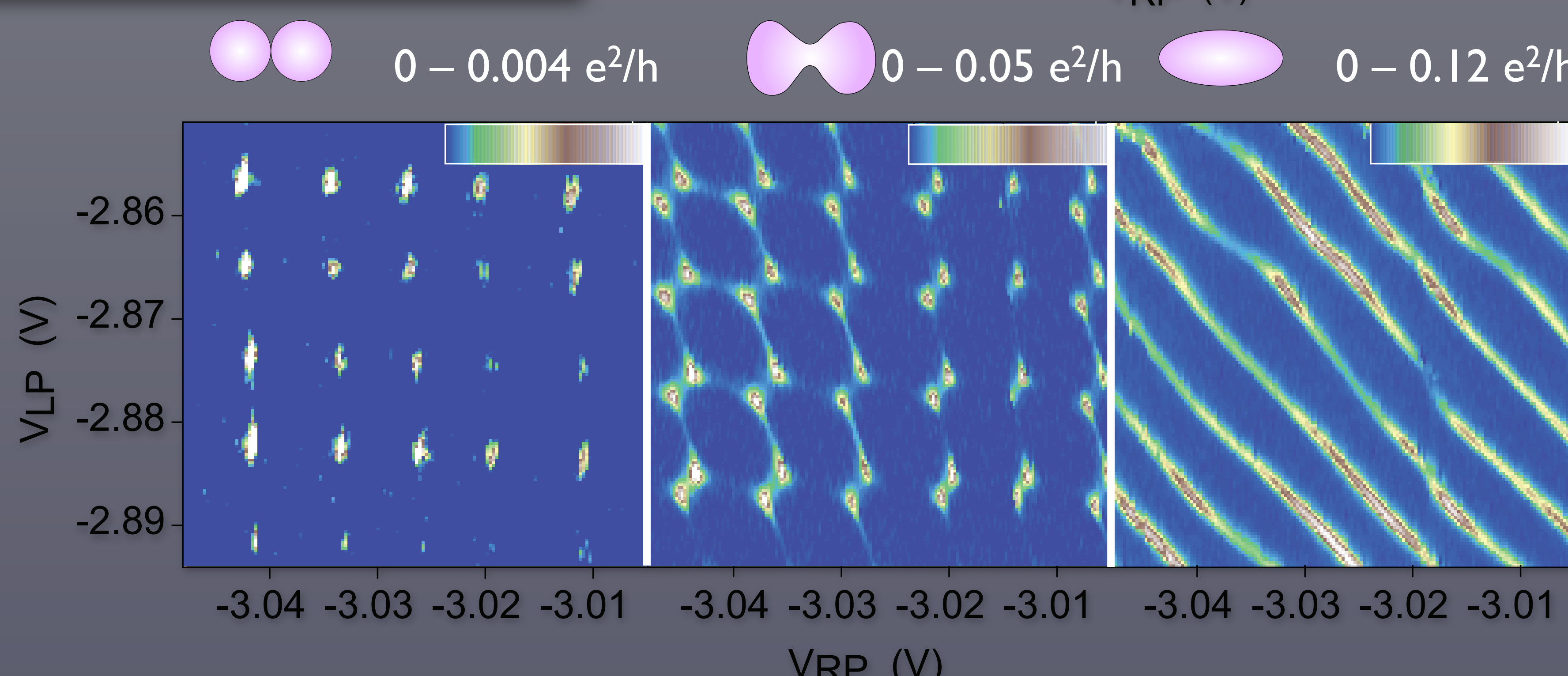
M. Eriksson, et al.

Si/Ge Nanowire with Integrated Charge Sensor





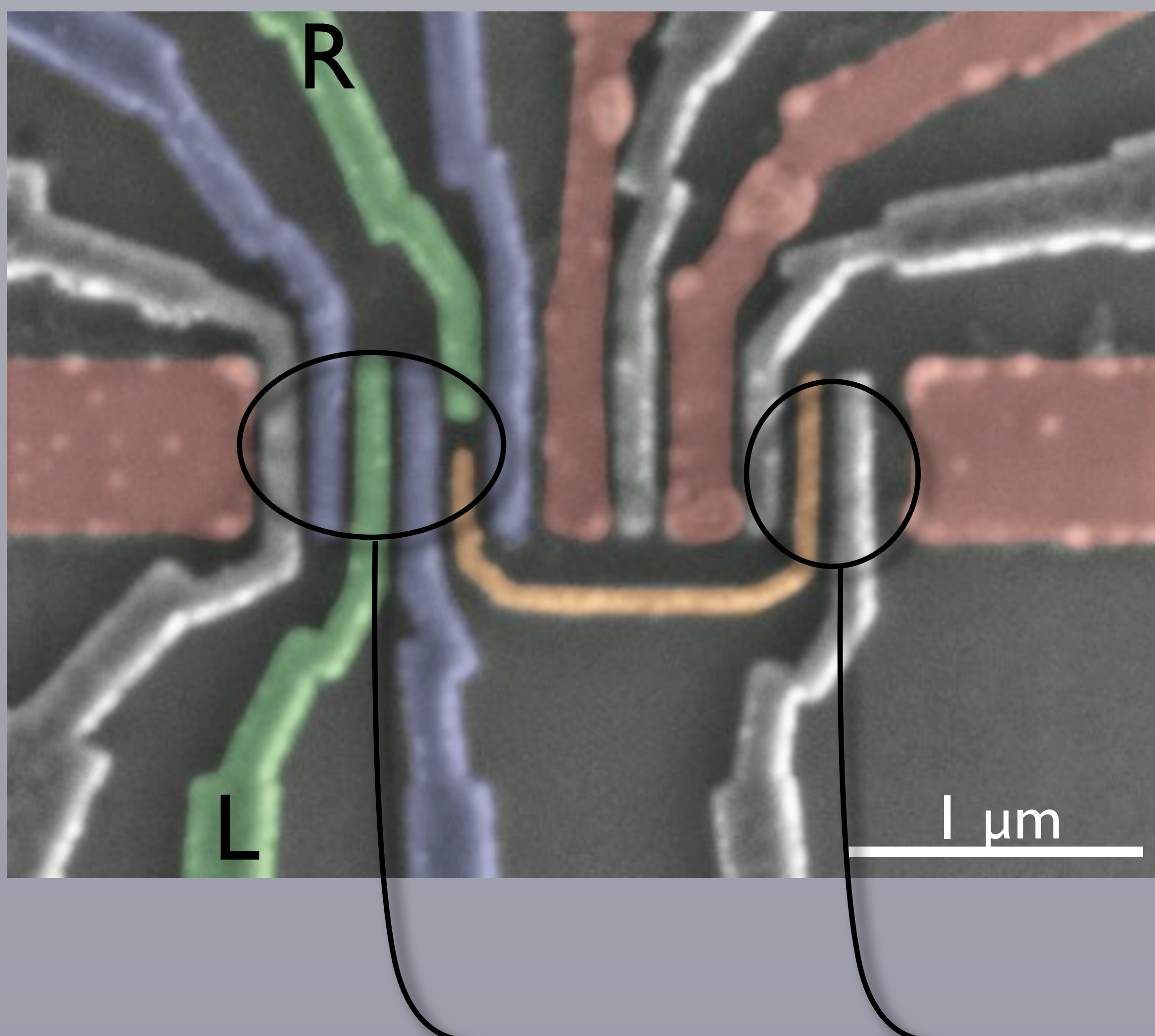




Yongjie Hu, Hugh O. H. Churchill, David J. Reilly, Jie Xiang, Charles M. Lieber, Charles M. Marcus, Nature Nanotechnology **2**, 622 (2007).

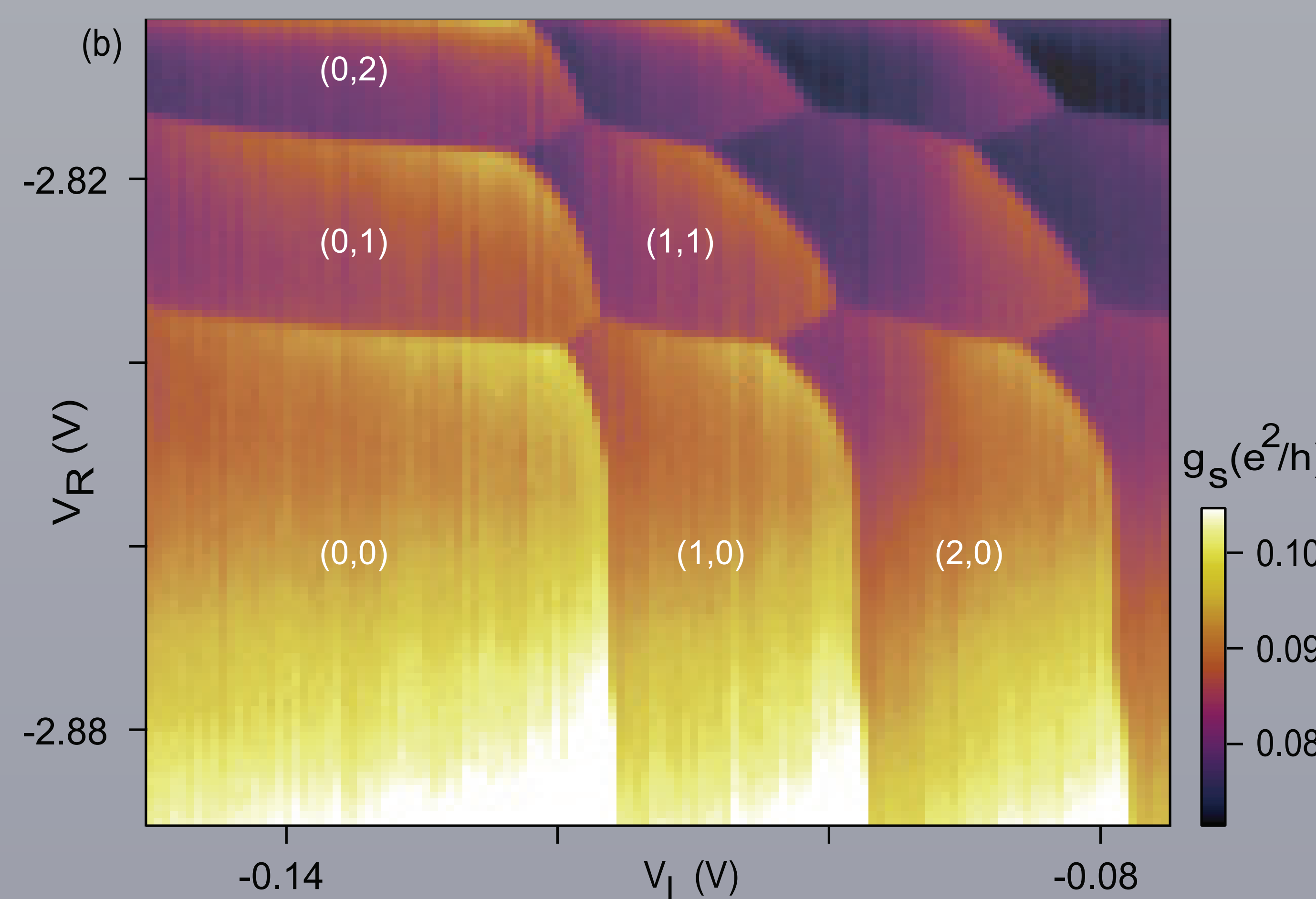
Nanotube Double Dot with Integrated Charge Sensor

Few-Electron Regime



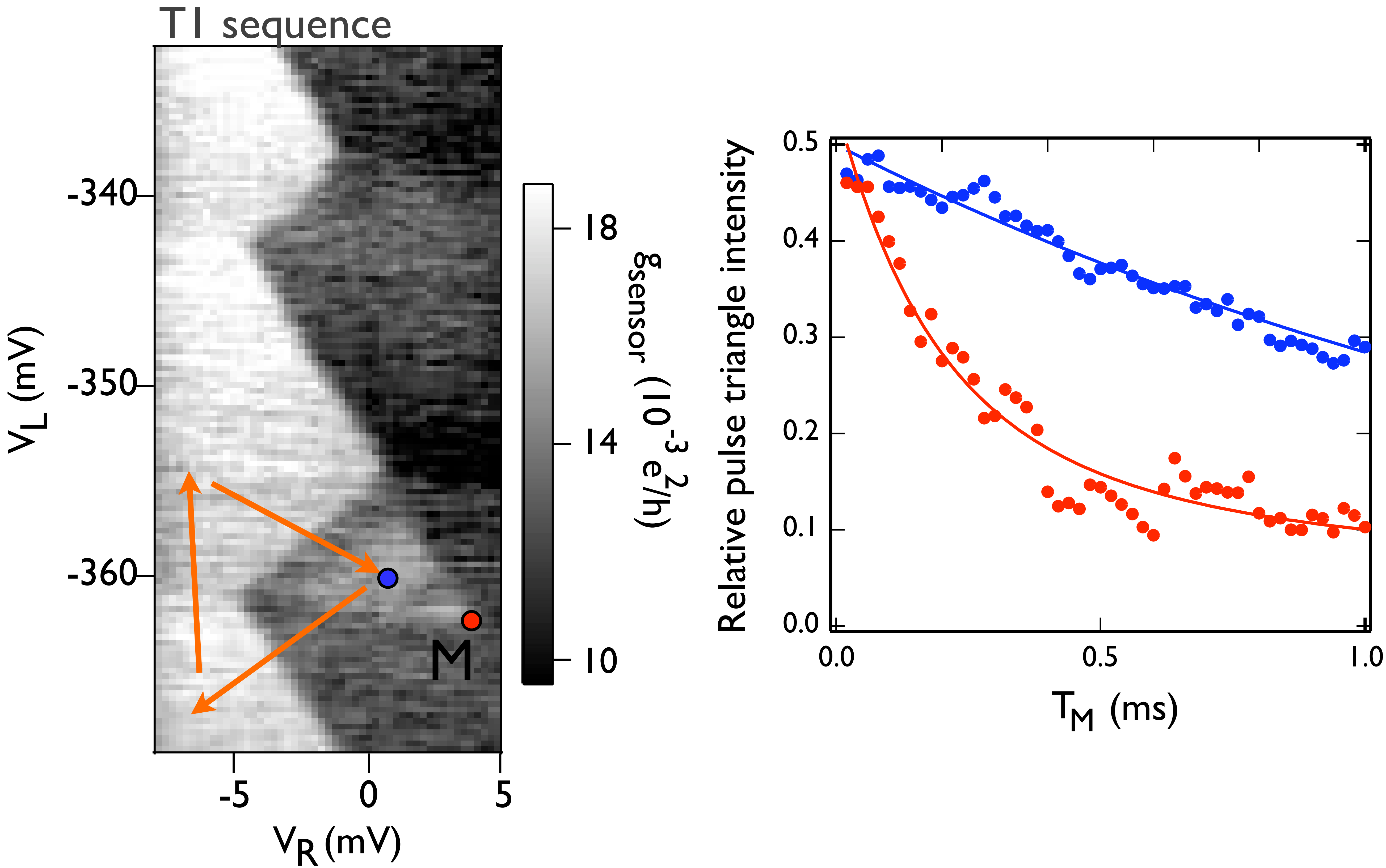
Double Dot Sensor

SENSOR SIGNAL



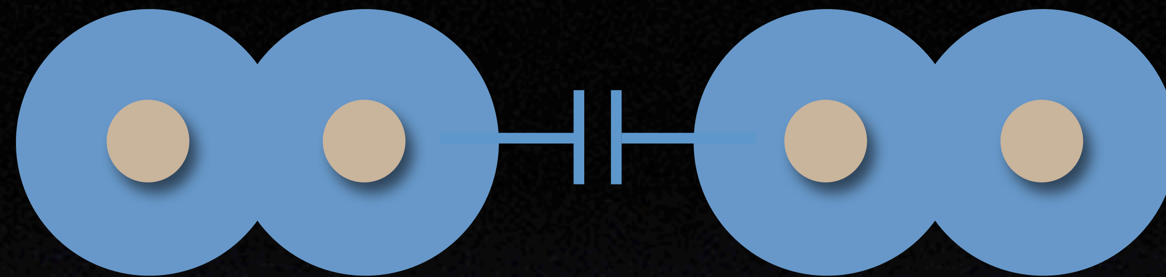
H. Churchill, (CMM) et al.

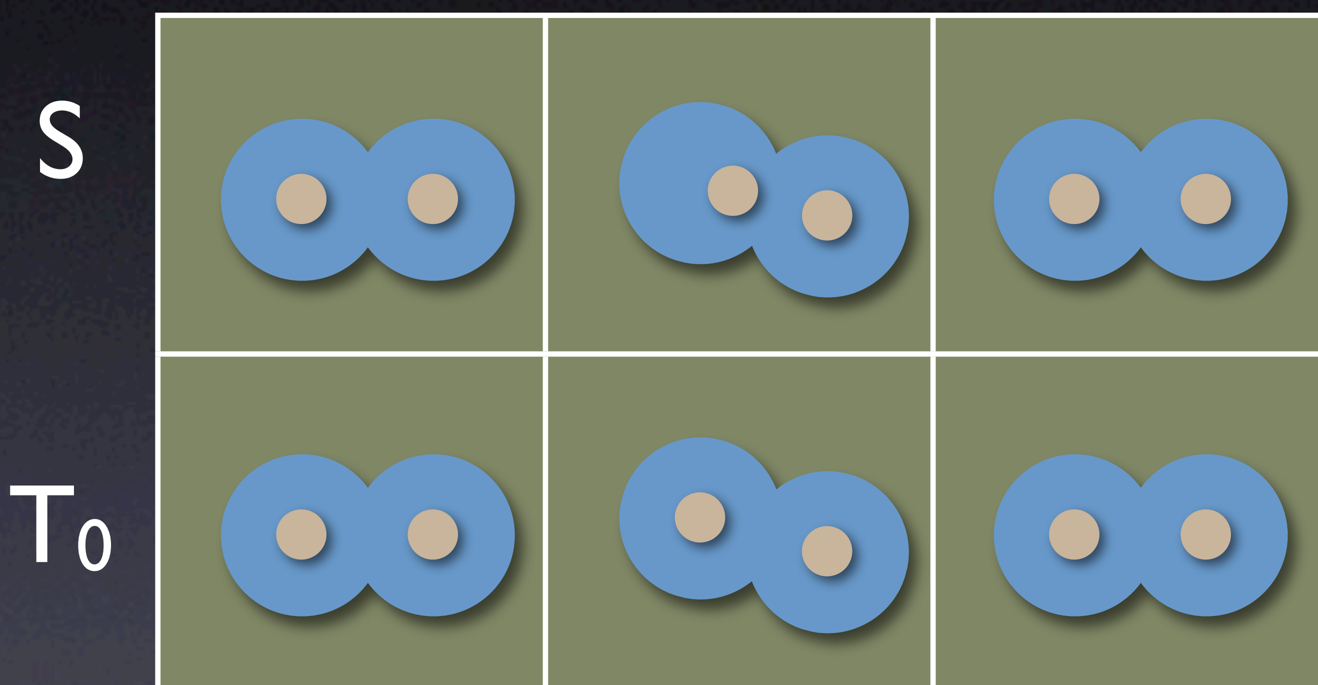
T1 measurement in ^{13}C tube

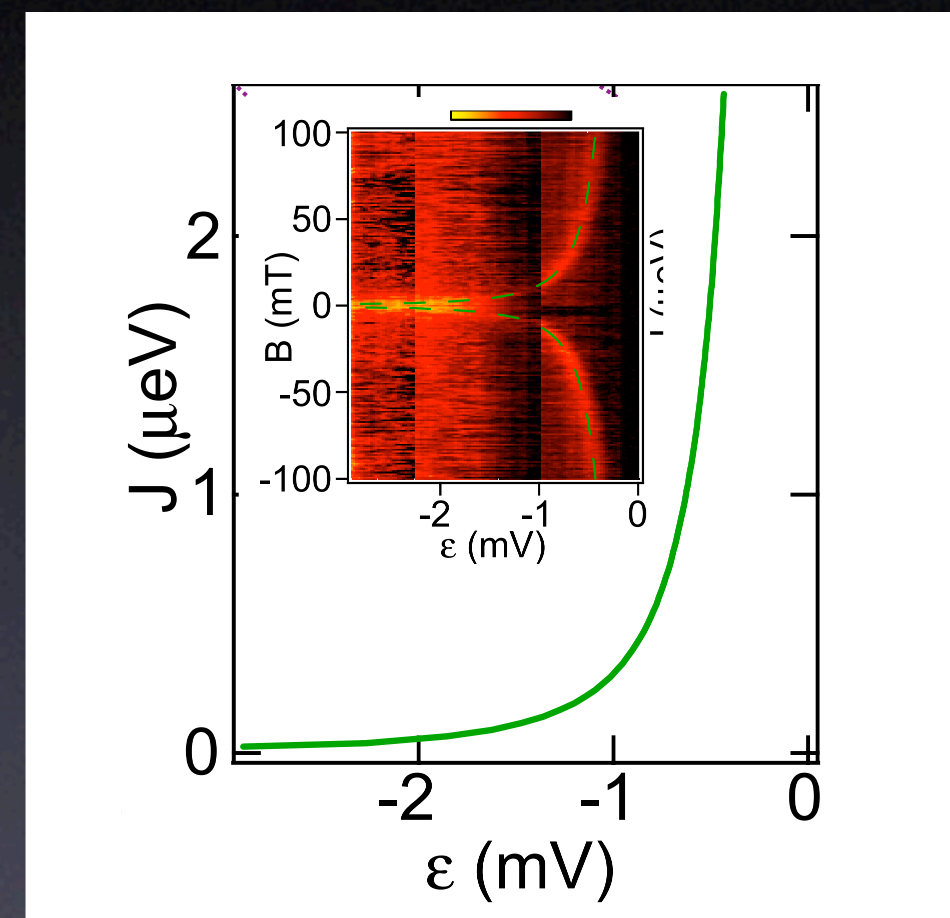


H. Churchill, (CMM) et al.

Electrostatic Two-Qubit Gate

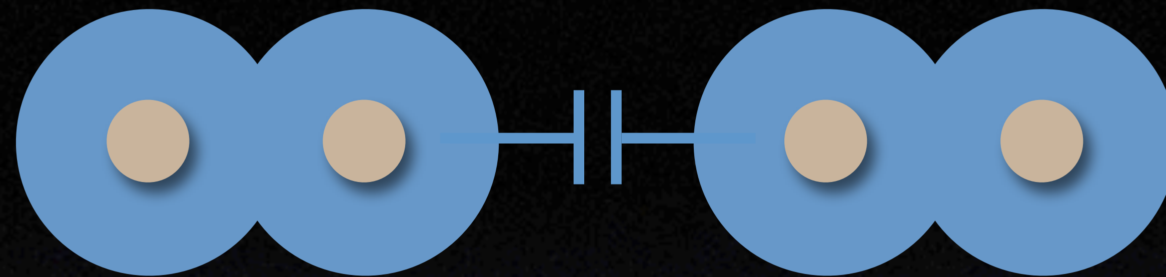


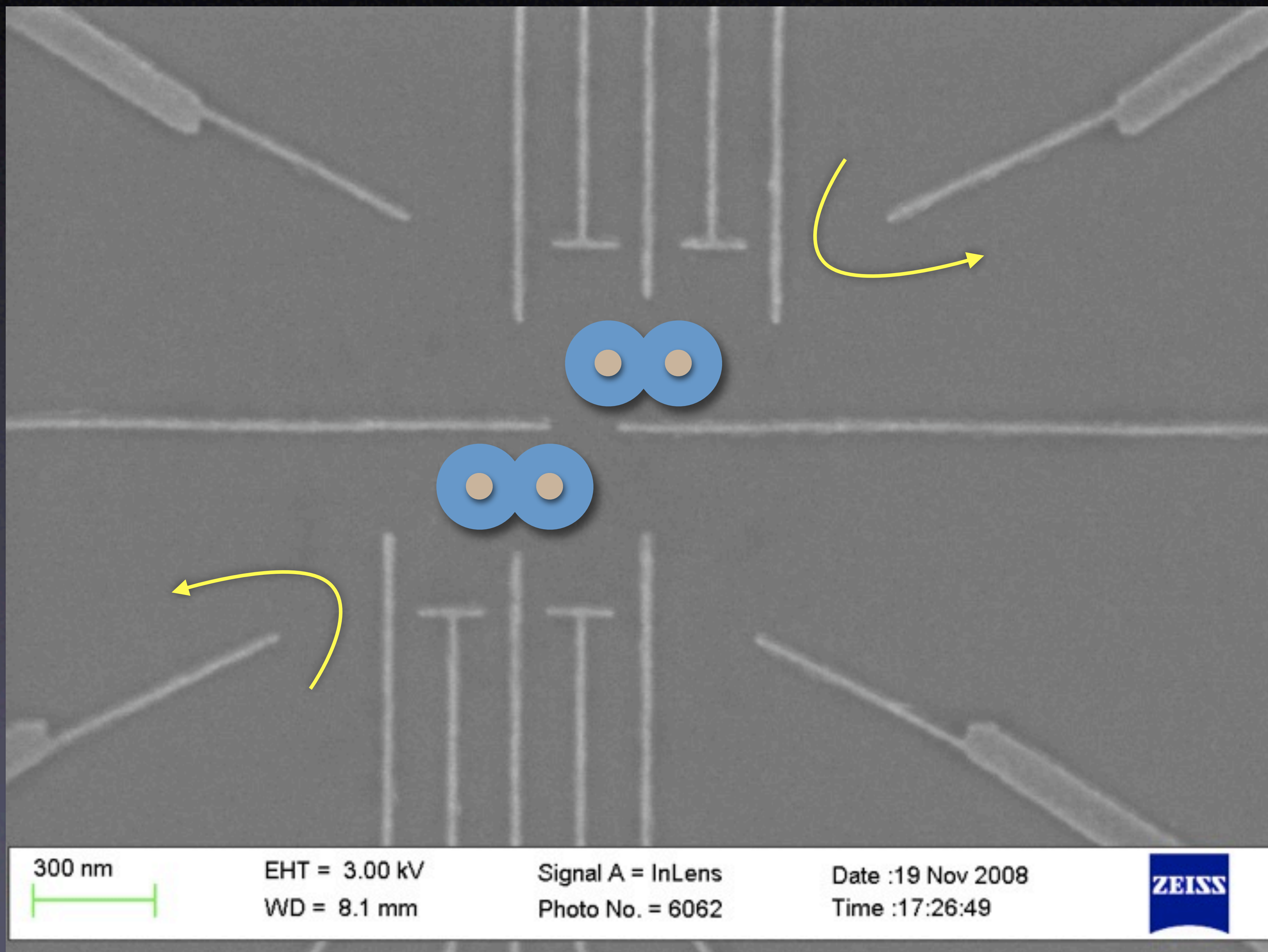




$$\frac{dJ}{d\epsilon} \sim 0 \qquad \frac{dJ}{d\epsilon} \sim \frac{\pi d}{e\tau} \qquad \frac{dJ}{d\epsilon} \sim 0$$

Electrostatic Two-Qubit Gate





E. Laird et al,
(CMM) et al.

Fault-tolerant architecture for quantum computation using electrically controlled semiconductor spins

J. M. TAYLOR[1]*, H.-A. ENGEL[1], W. DÜR[2], A. YACOBY[3], C. M. MARCUS[1], P. ZOLLER[2] AND M. D. LUKIN[1]

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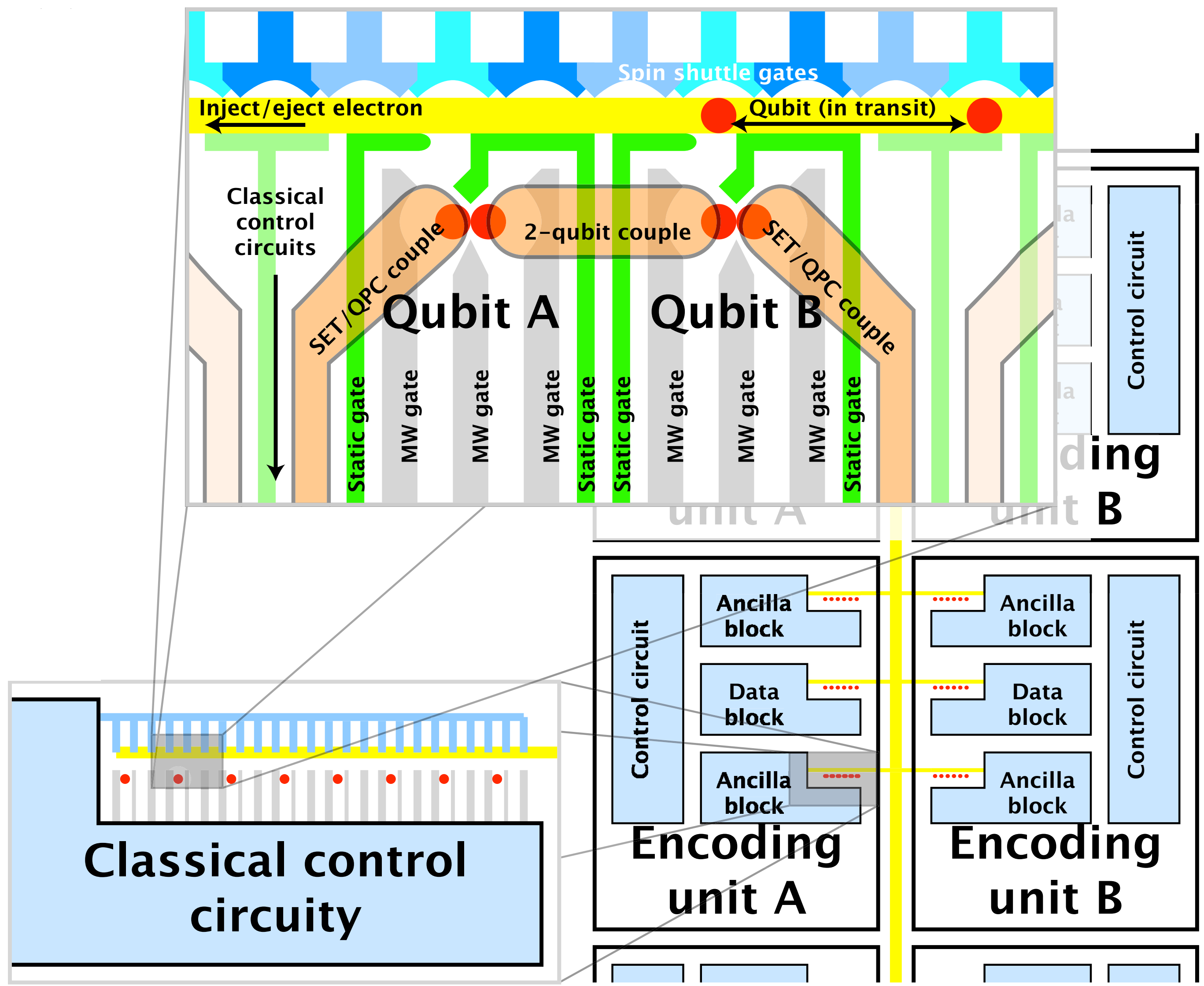
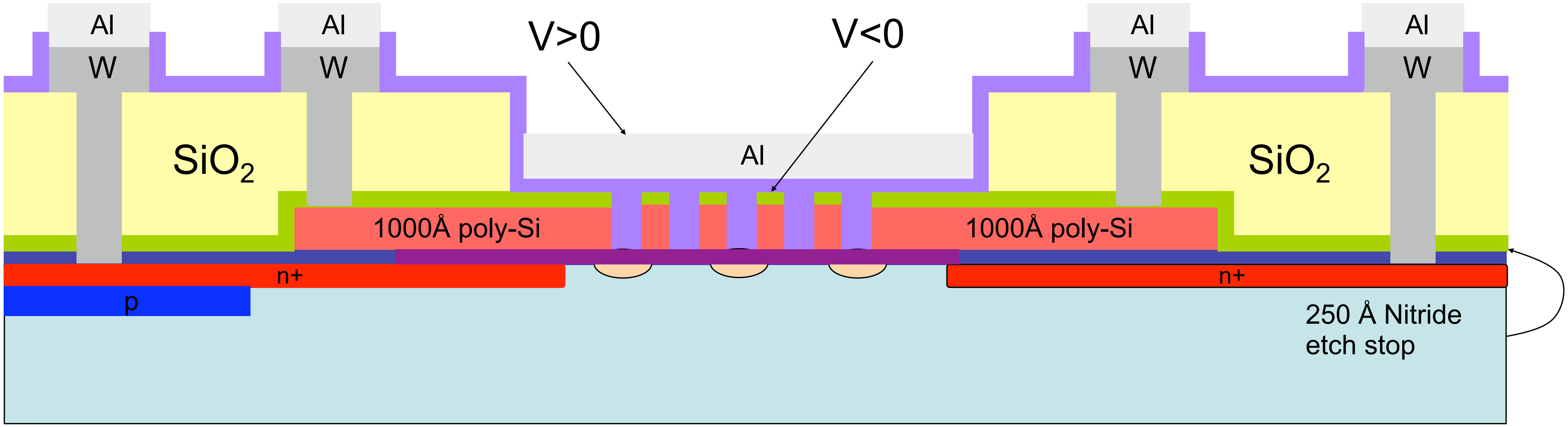
[2]Institute for Theoretical Physics, University of Innsbruck, and Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria
[3]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel



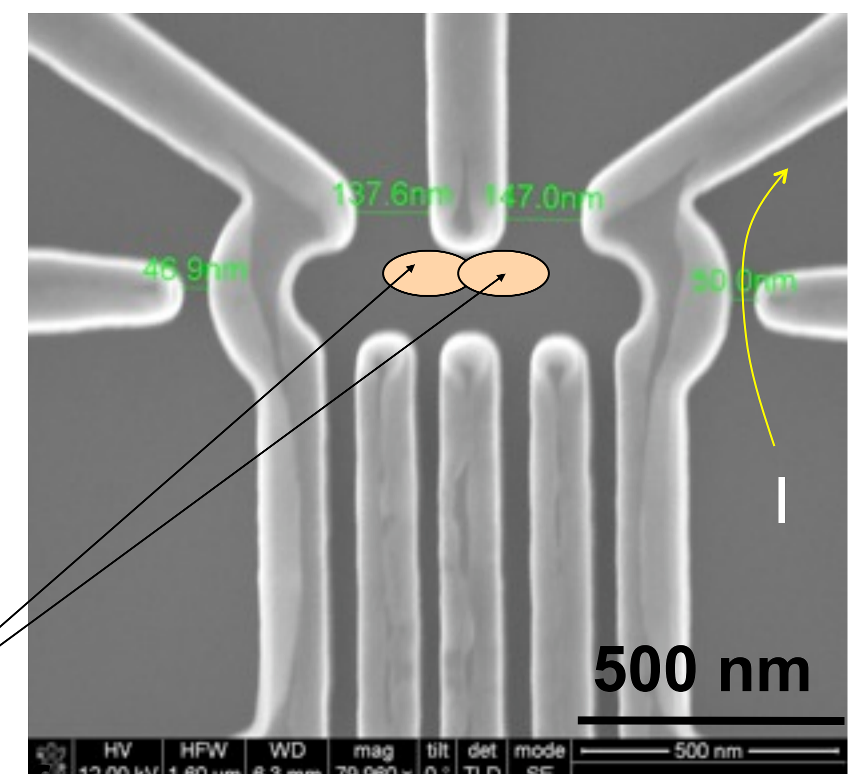
Quantum Information S&T

Silicon Qubit Approach



- *This work:* first attempt to translate Si MOS-DQD w/ GaAs geometry
- Accumulation gate forms two dimensional electron gas

- Z-gate: voltage modulated J interaction
- X-gate: local inductor or implanted Ge will be used to form controlled gradient in B-field
- CPHASE proposed for 2 qubit gate



Schematic location of 2 electrons

LOCKHEED MARTIN

Sandia National Laboratories

Topologically Protected Qubits from a Possible Non-Abelian Fractional Quantum Hall State

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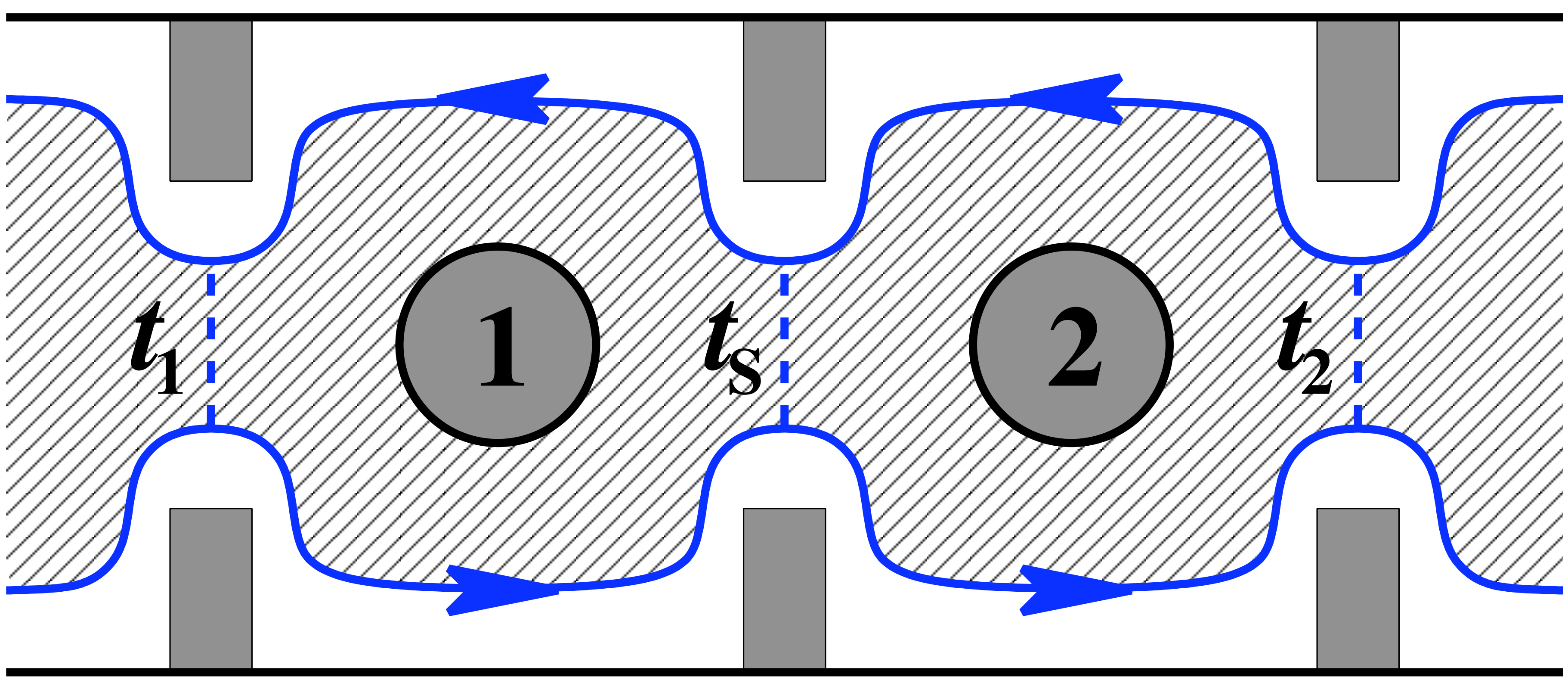
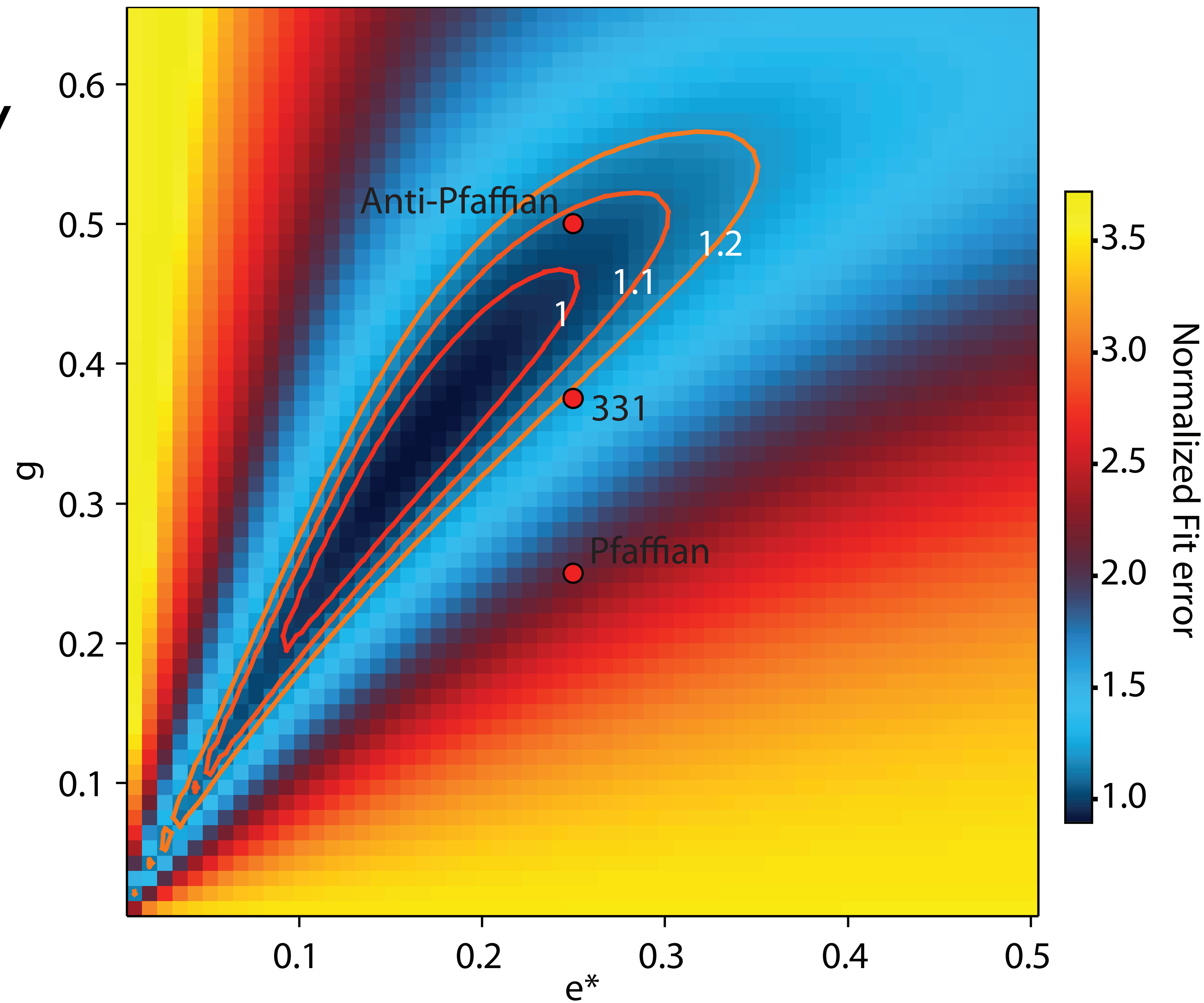
The Pfaffian state is an attractive candidate for the observed quantized Hall plateau at a Landau-level filling fraction $\nu = 5/2$. This is particularly intriguing because this state has unusual topological properties, including quasiparticle excitations with non-Abelian braiding statistics. In order to determine the nature of the $\nu = 5/2$ state, one must measure the quasiparticle braiding statistics. Here, we propose an experiment which can simultaneously determine the braiding statistics of quasiparticle excitations and, if they prove to be non-Abelian, produce a topologically protected qubit on which a logical NOT operation is performed by quasiparticle braiding. Using the measured excitation gap at $\nu = 5/2$, we estimate the error rate to be 10^{-30} or lower.

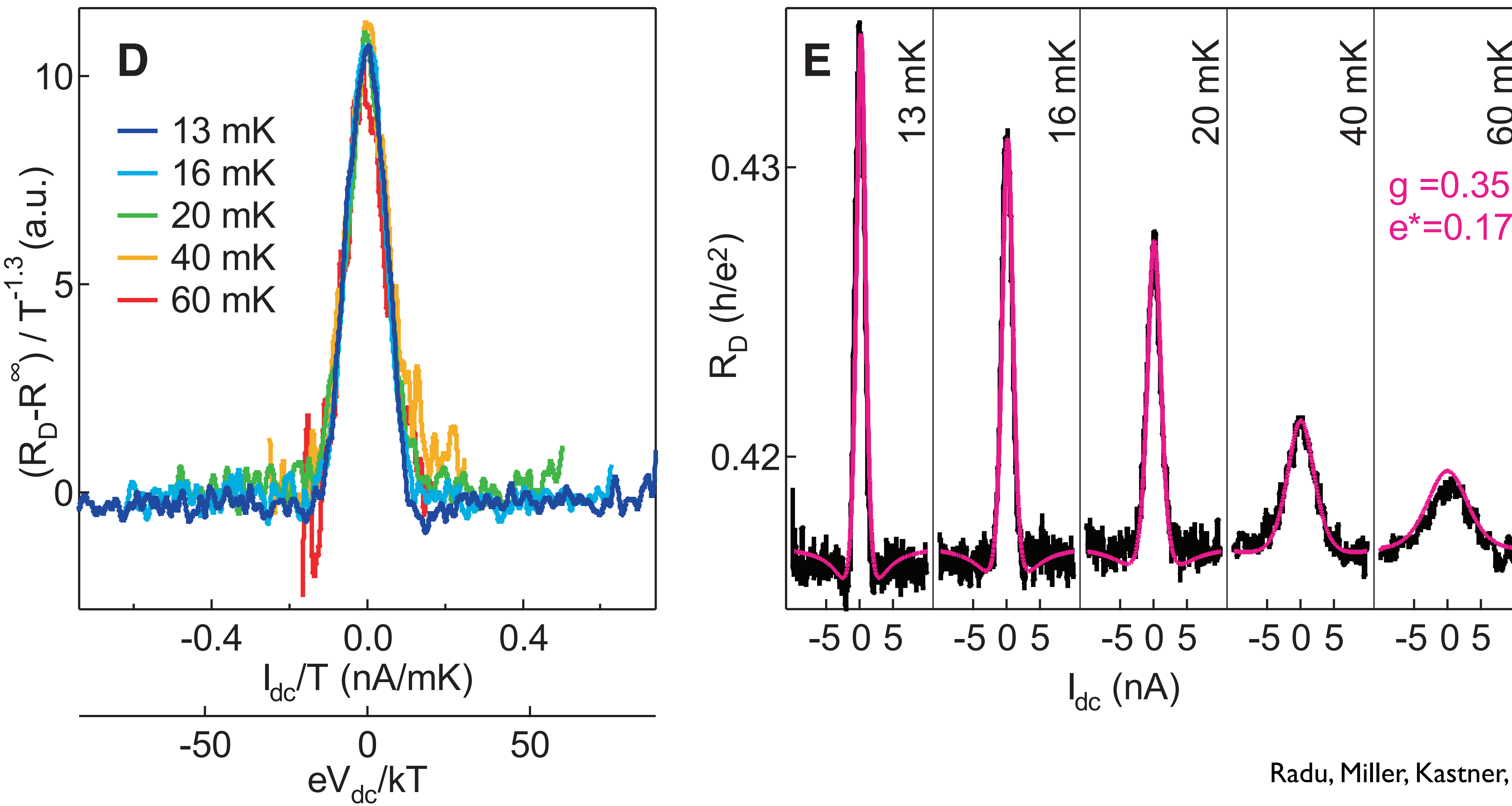


Comparing fit parameters to Wen theory

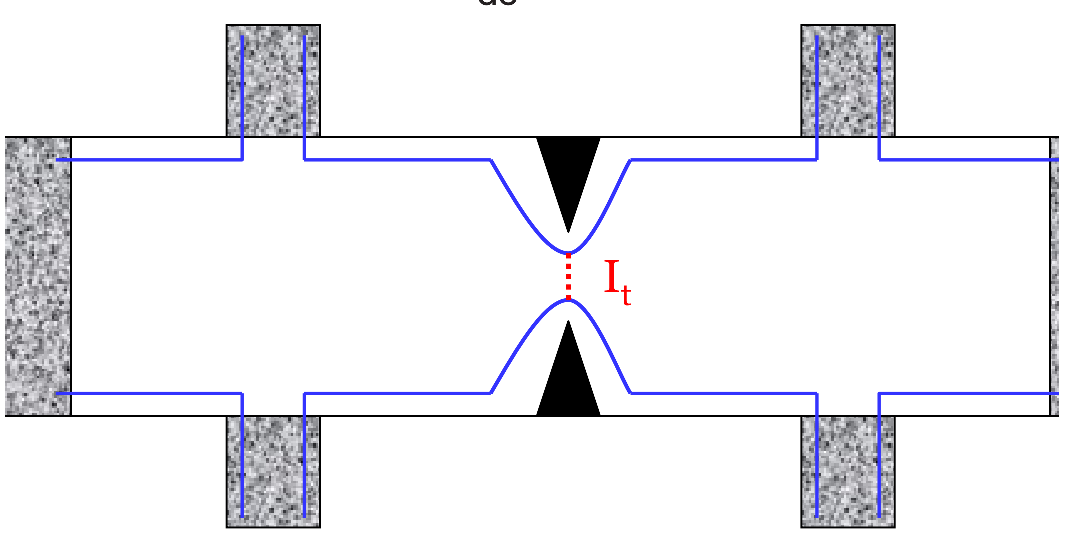


Radu, Miller, Kastner, CMM 2008.

Scaling of 5/2 zero-bias tunneling peak - Wen theory



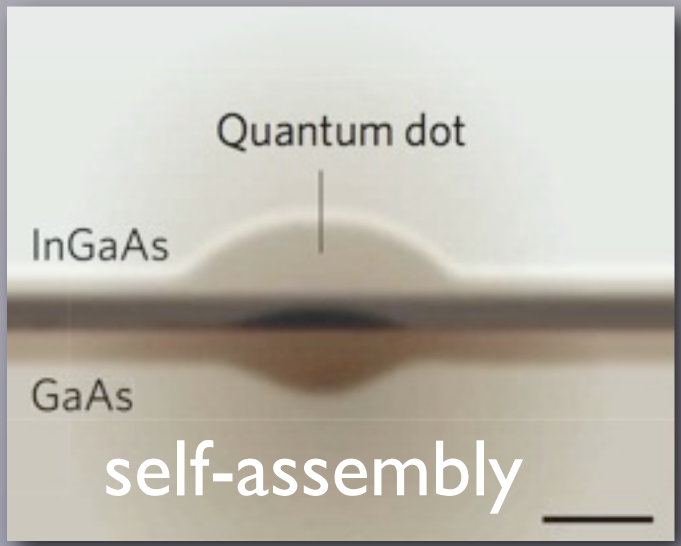
Radu, Miller, Kastner, CMM 2008.



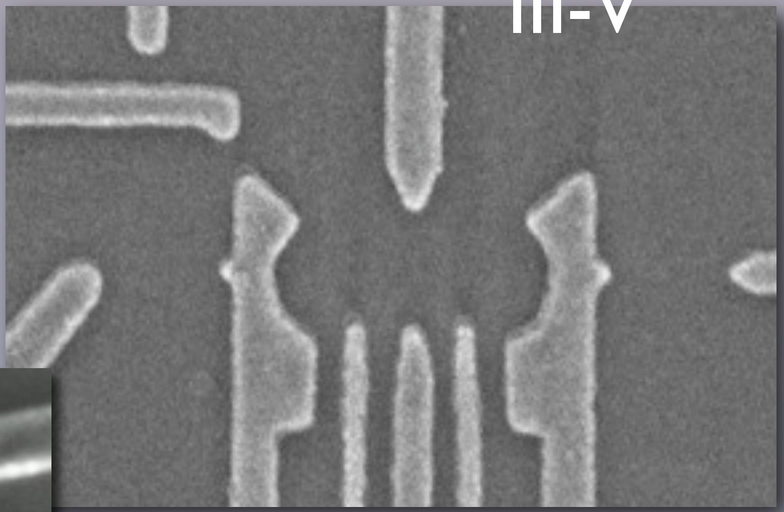
$$g_T = \frac{R_D - R_{xy}}{R_{xy}^2}$$

$$g_T = AT^{(2g-2)} F(g, \frac{e^* I_{DC} R_{xy}}{kT})$$

Conclusion: Many Implementations, Many Approaches With cooperation, hybrids will evolve.



III-V



nanowires