Nanoelectronics:
Dots, Noise, Qubits, and New Materials

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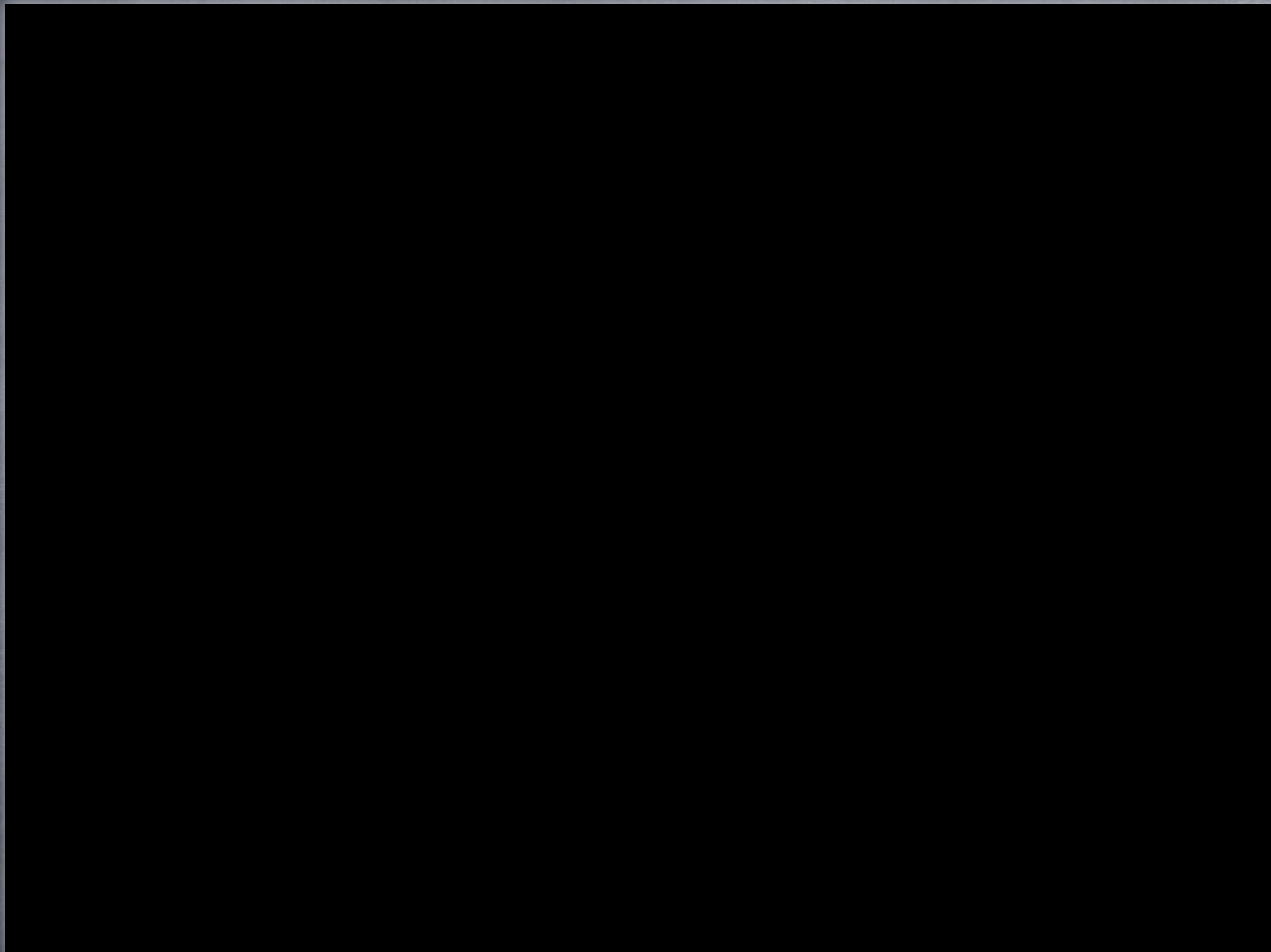
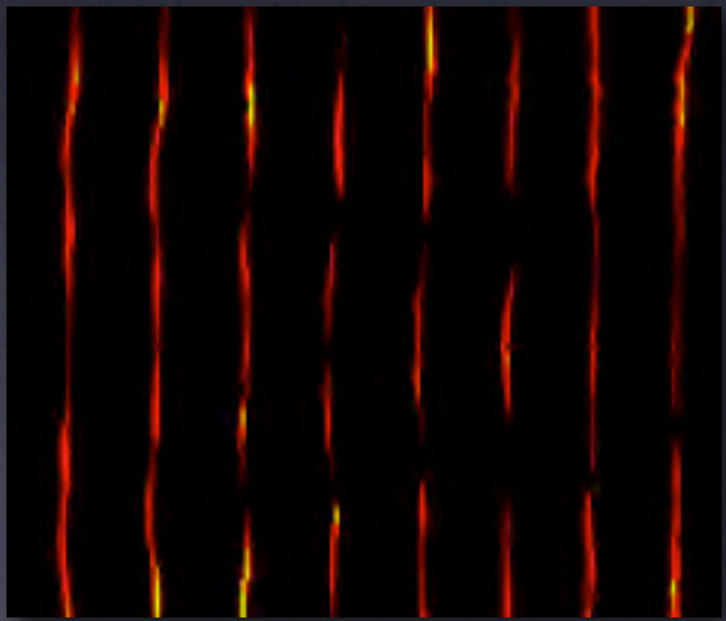
Support:
DARPA, ARO/ARDA, NSF

Outline:

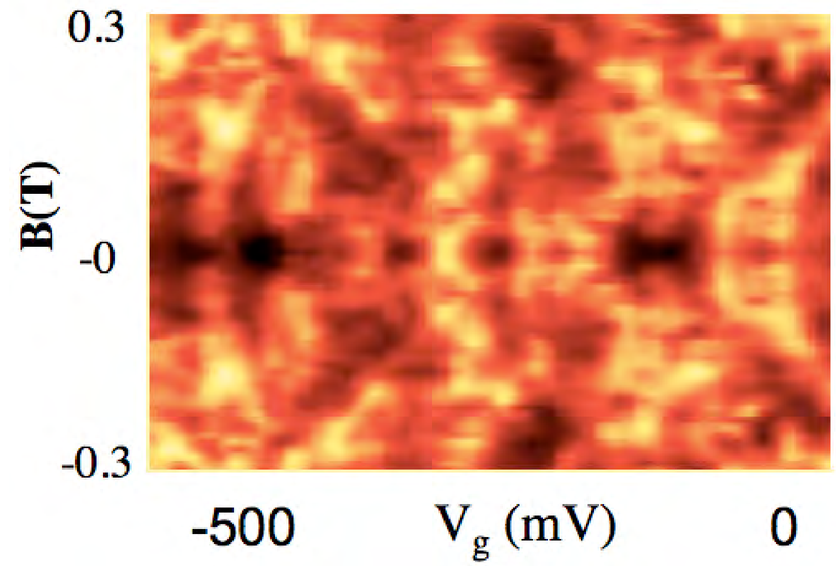
- Phase coherence in the Coulomb blockade regime
- Shot noise and noise correlations
- Double quantum dots
- Spin qubits
  - Electron spin as a sensitive probe of nuclear environment
  - Measuring and using the nuclear environment
  - Controlling the nuclear environment
  - New Materials

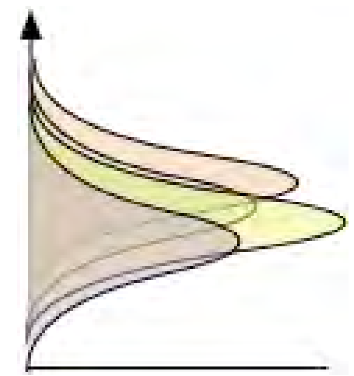


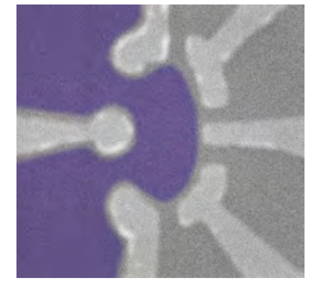
Phase coherence in the Coulomb blockade regime

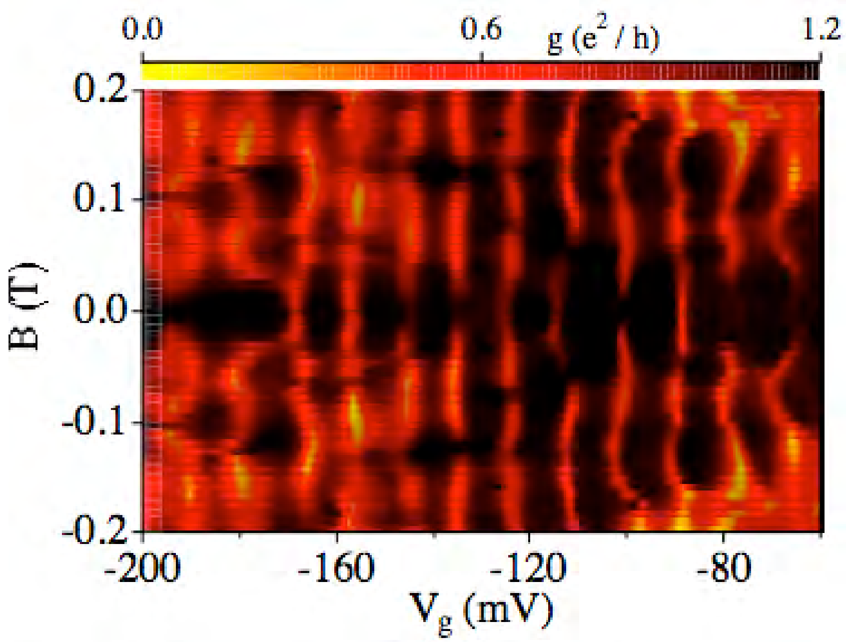


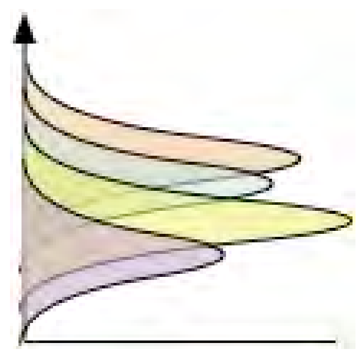
from open to tunneling dots

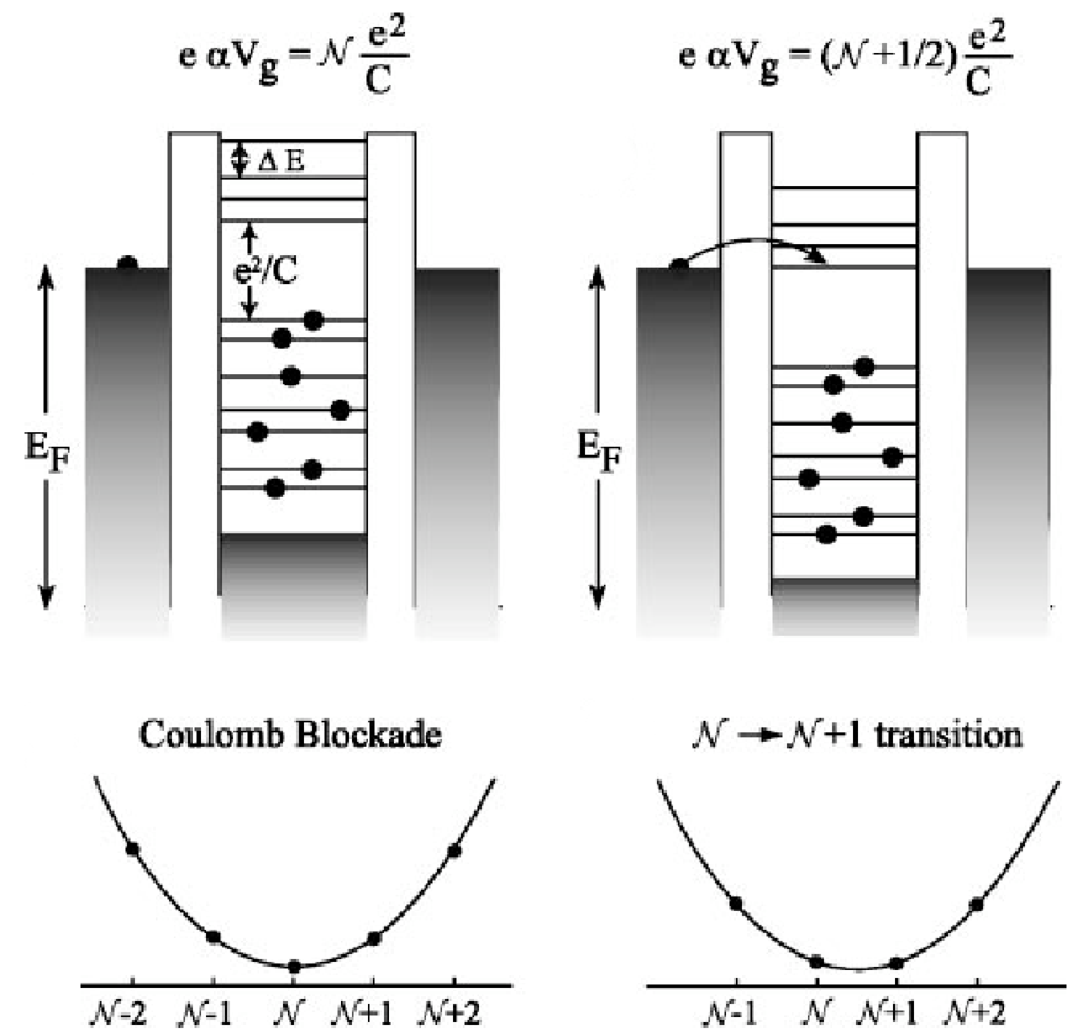


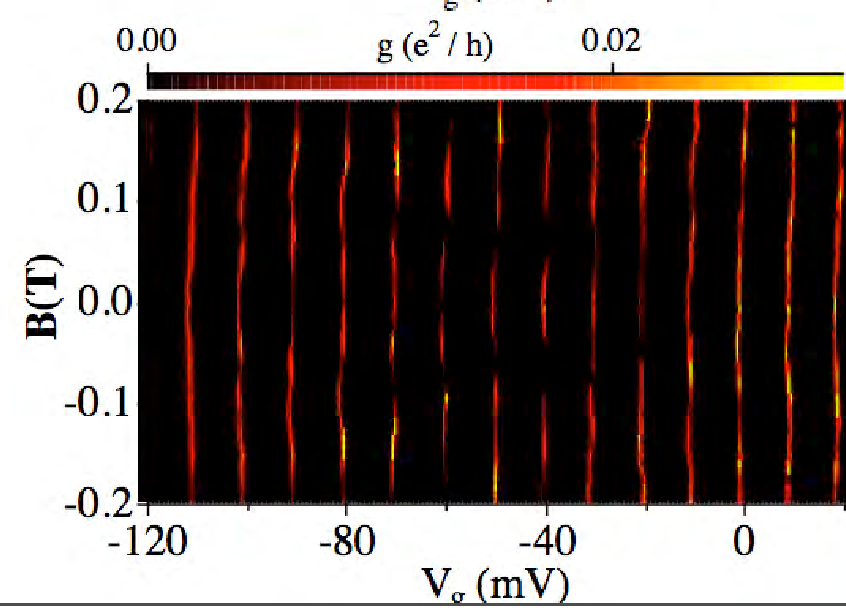


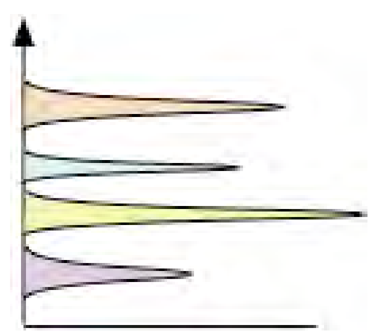


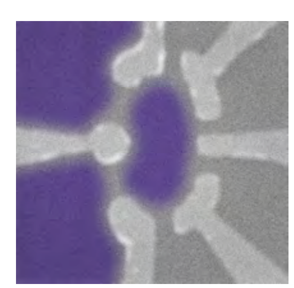




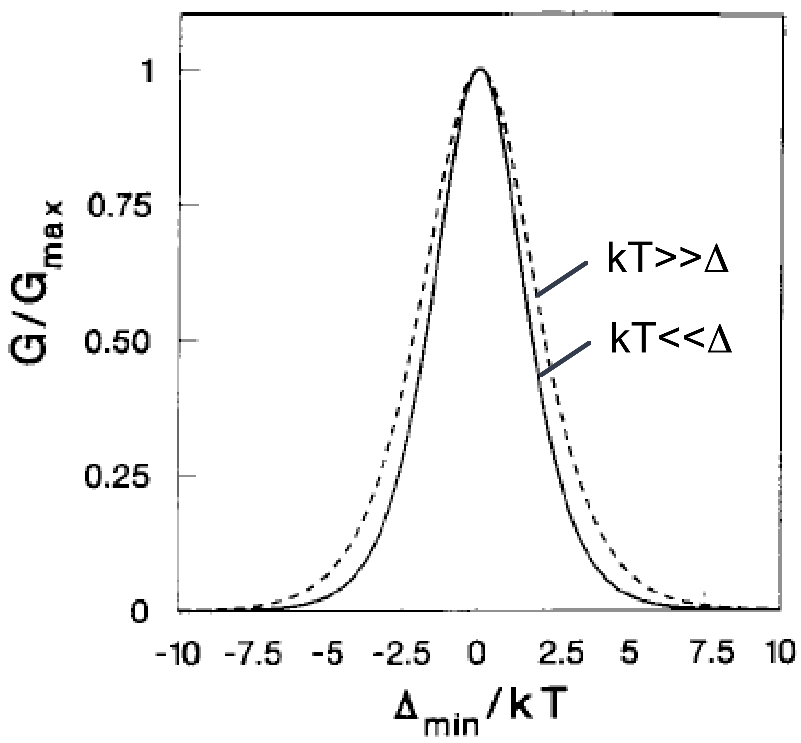


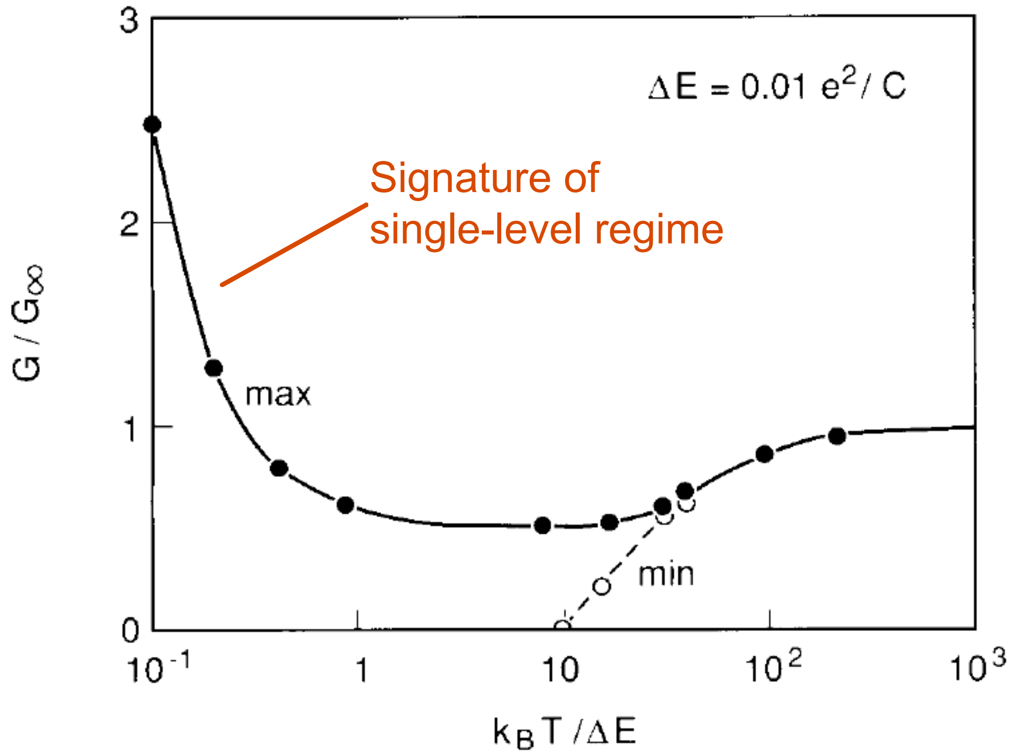


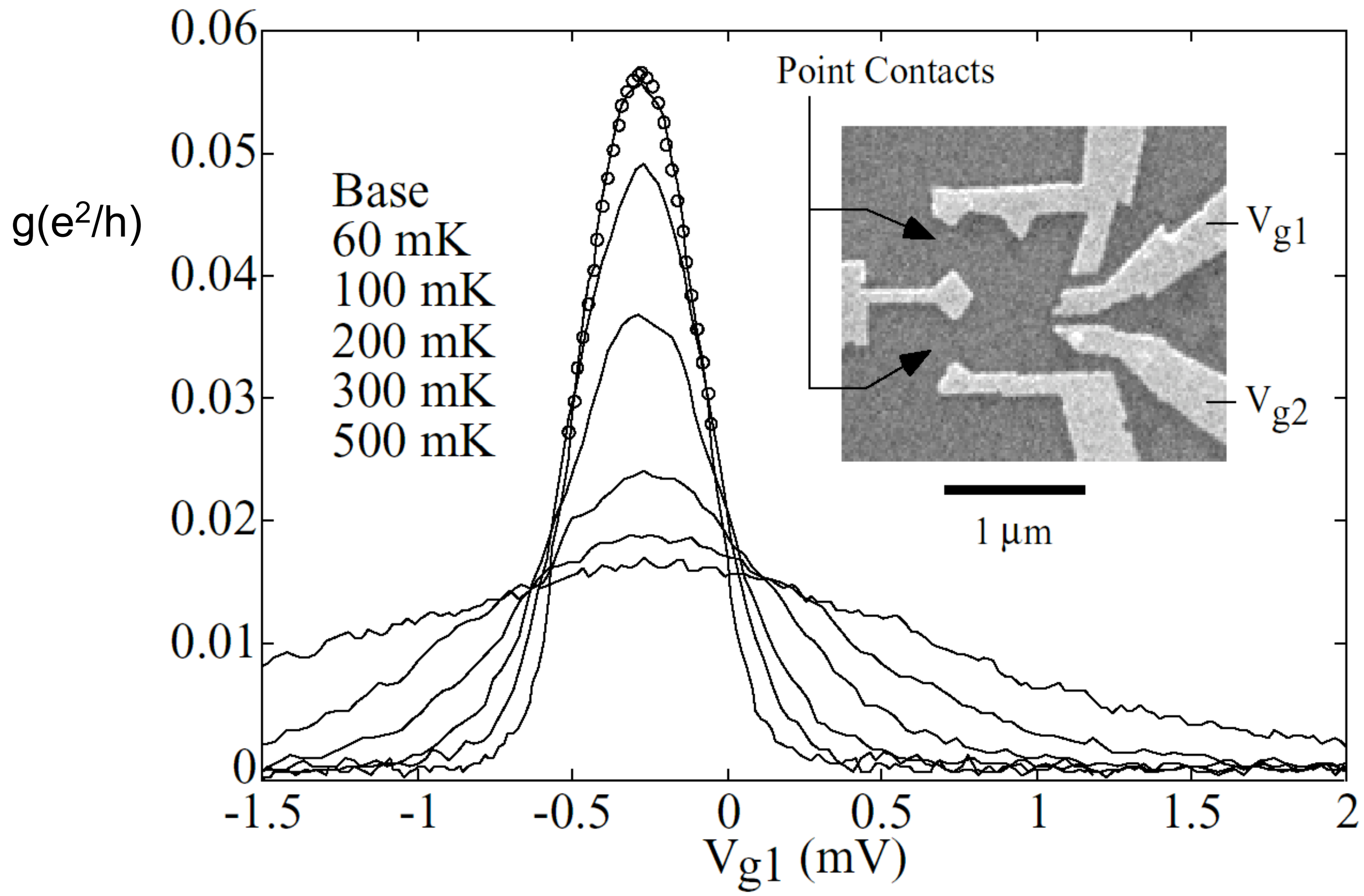




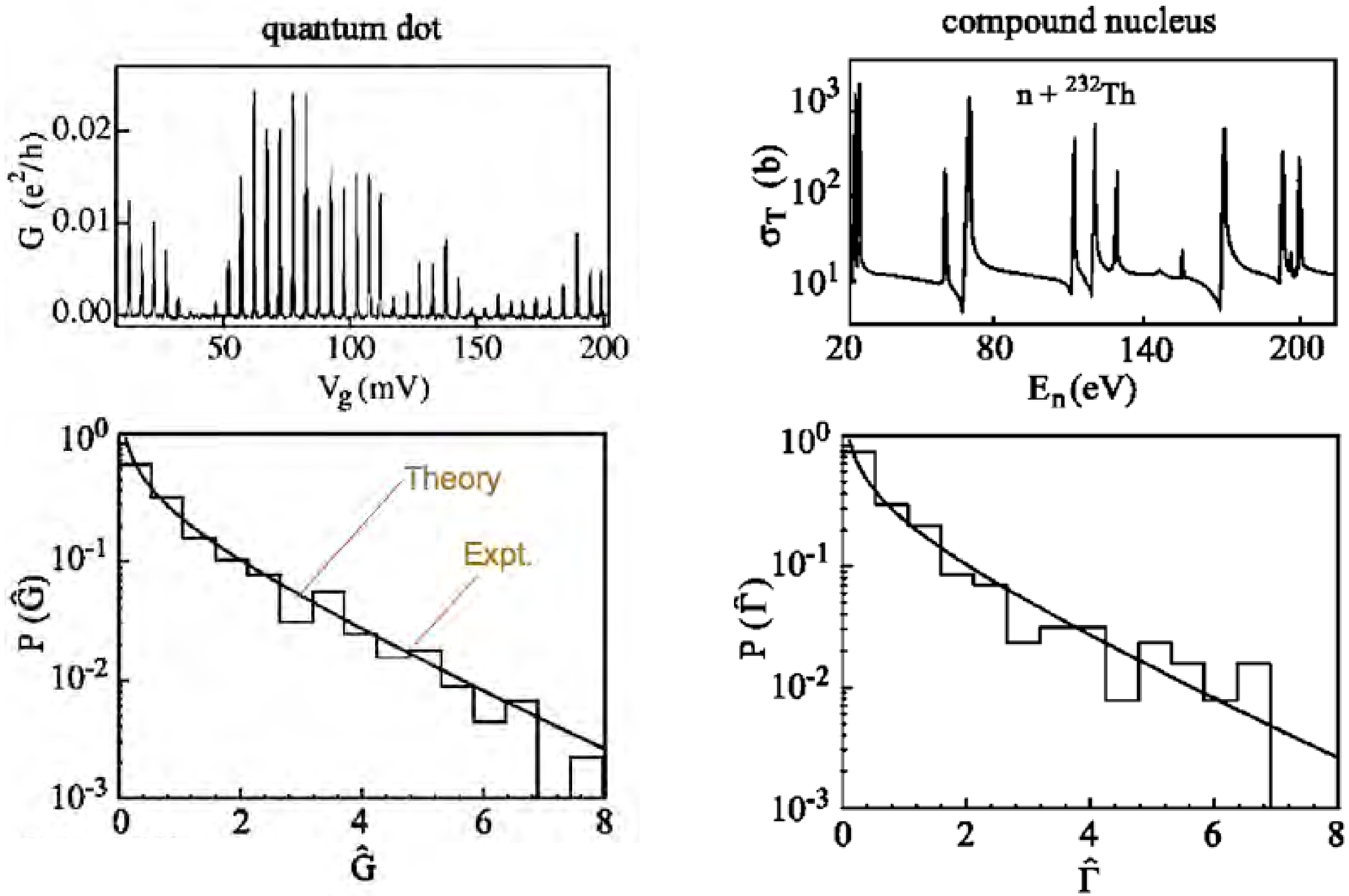
coulomb peaks







CB peak height (Porter-Thomas) statistics



J. Folk, et al. , Phys. Rev. Lett. **76** 1699 (1996).

Changing the Electronic Spectrum of a Quantum Dot by Adding Electrons

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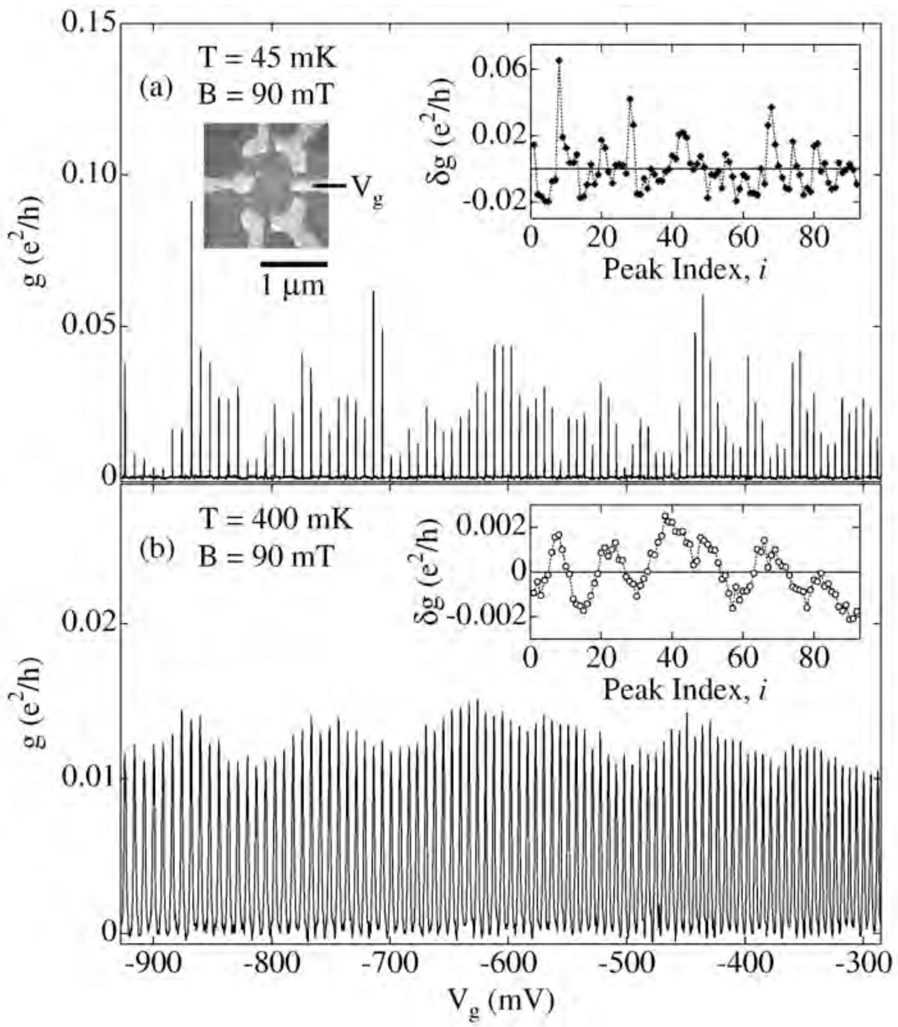


FIG. 1. Coulomb blockade peaks in conductance g as a function of gate voltage V_g at (a) 45 mK and (b) 400 mK from device 1. Insets: SEM micrograph of device 1. Peak height fluctuations δg_i extracted from these data sets.

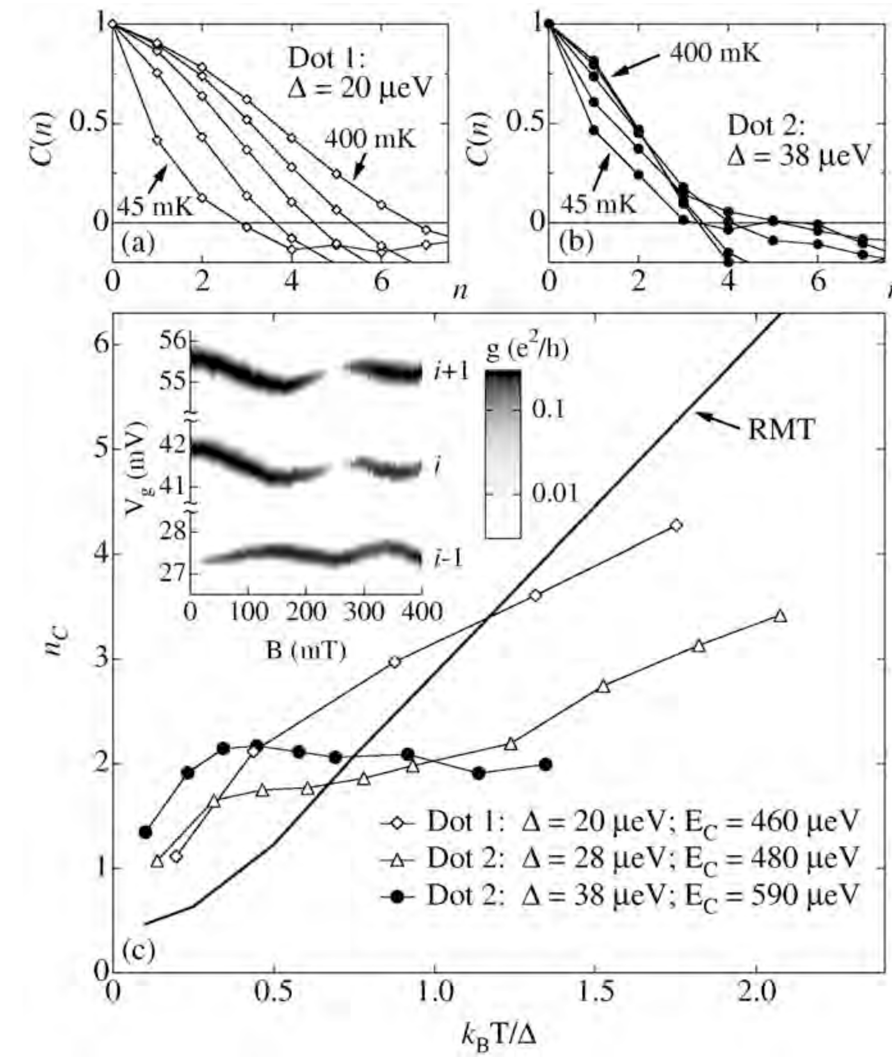
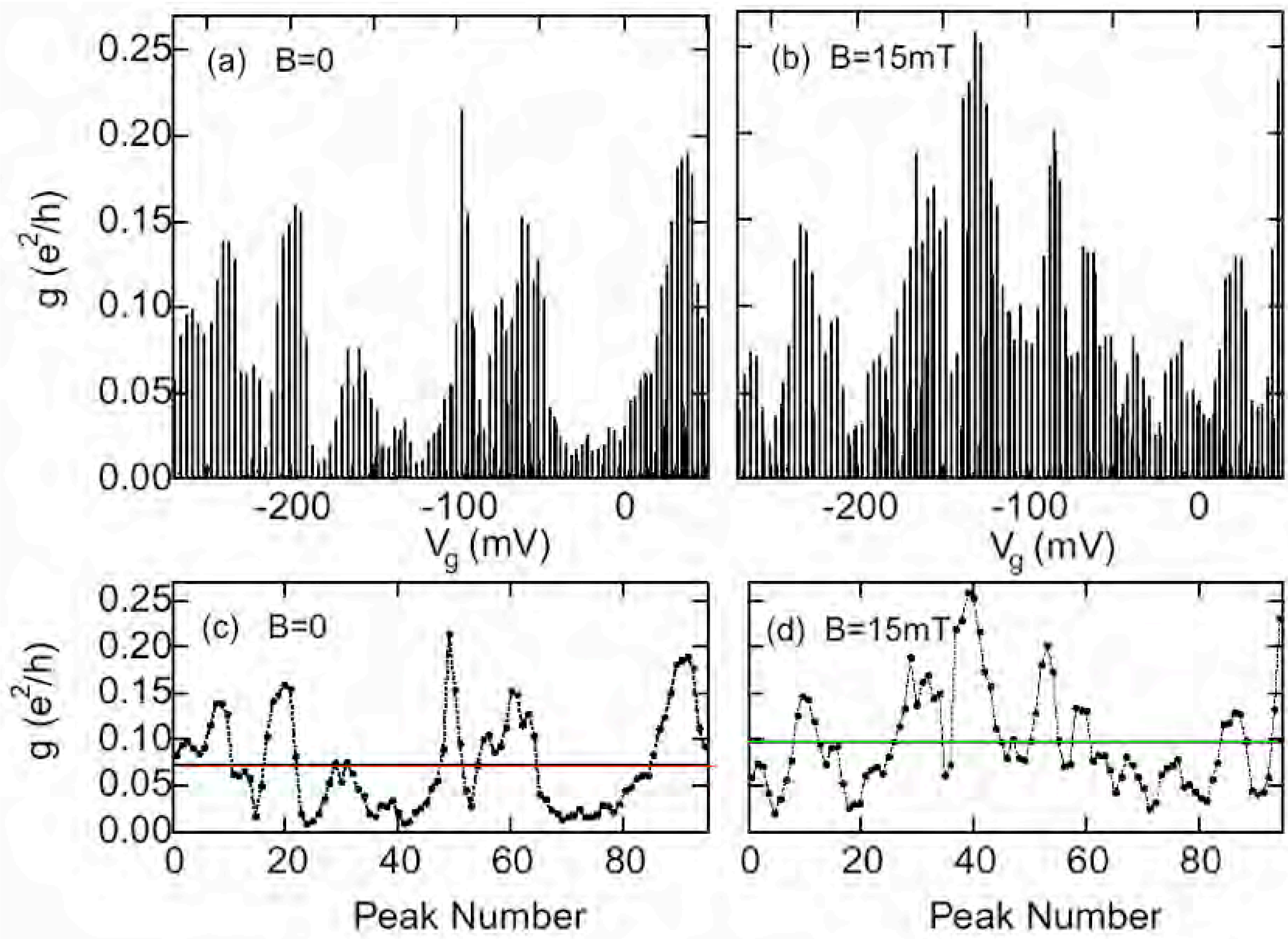


FIG. 2. Peak height correlations $C(n)$ at 45, 100, 200, 300, and 400 mK for (a) dot 1 and (b) dot 2. (c) Temperature dependence of correlation length n_c for different device configurations, and numerical RMT result. Inset: Gray-scale plots of conductance for three successive CB peaks, showing paired peaks i and $i+1$, presumably a spin pair.

“weak localization” of coulomb blockade



J. A. Folk, et al. , Phys. Rev. Lett. **87** 206807 (2001).

Quasiparticle Lifetime in a Finite System: A Nonperturbative Approach

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(Received 30 August 1996)

The problem of electron-electron lifetime in a quantum dot is studied beyond perturbation theory by mapping onto the problem of localization in the Fock space. Localized and delocalized regimes are identified, corresponding to quasiparticle spectral peaks of zero and finite width, respectively. In the localized regime, quasiparticle states are single-particle-like. In the delocalized regime, each eigenstate is a superposition of states with very different quasiparticle content. The transition energy is $\epsilon_c \simeq \Delta(g/\ln g)^{1/2}$, where Δ is mean level spacing, and g is the dimensionless conductance. Near ϵ_c there is a broad critical region not described by the golden rule. [S0031-9007(97)02895-0]

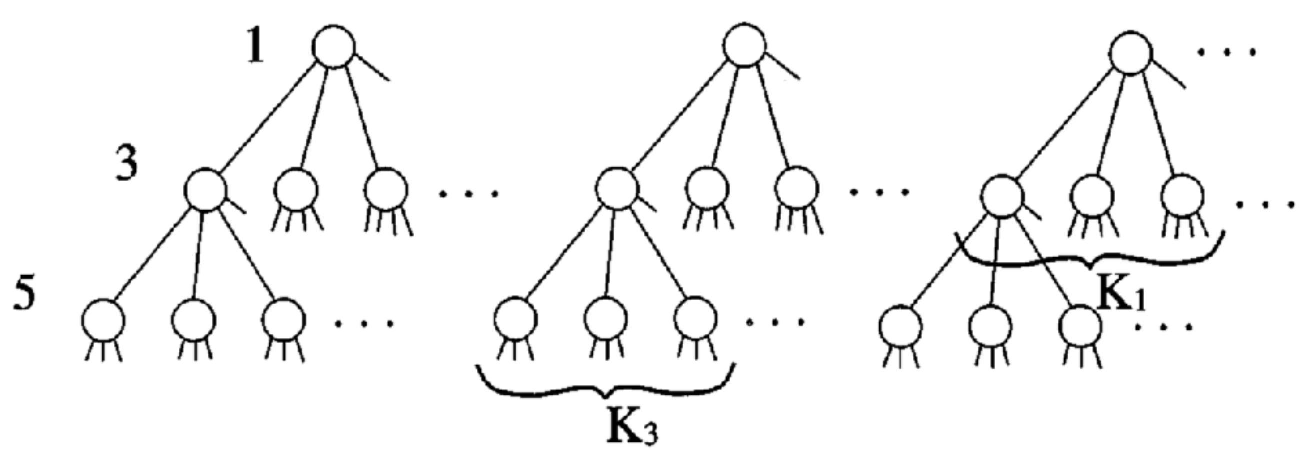
Below T*, quasiparticles cannot decay

$$T^* \sim \Delta \sqrt[4]{N}$$

Δ ~ 0.07 K for Area = 1 μm

Δ ~ 0.7 K for Area = 0.1 μm

Δ ~ 7 K for Area = 0.01 μm



Decoherence in Nearly Isolated Quantum Dots

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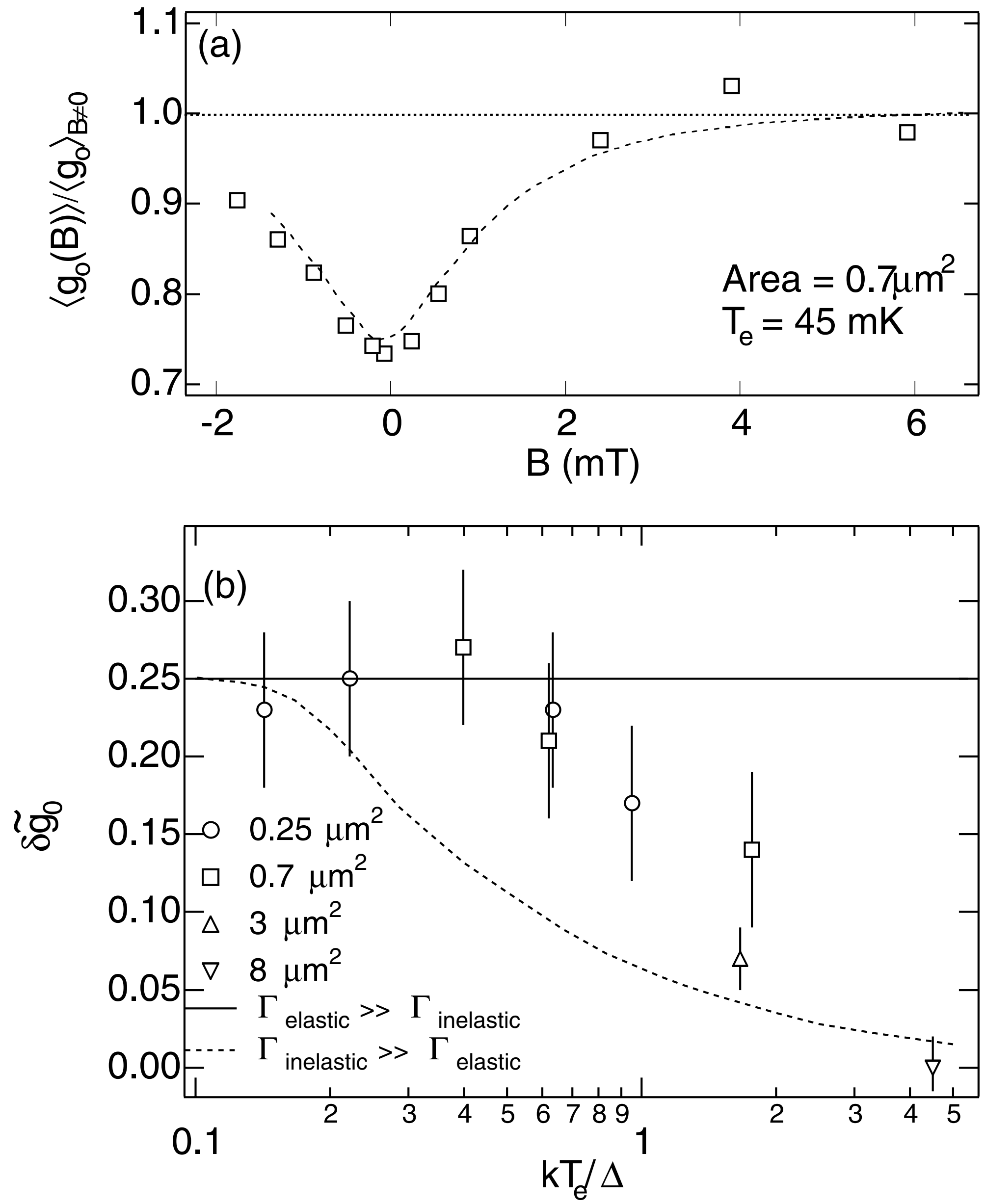

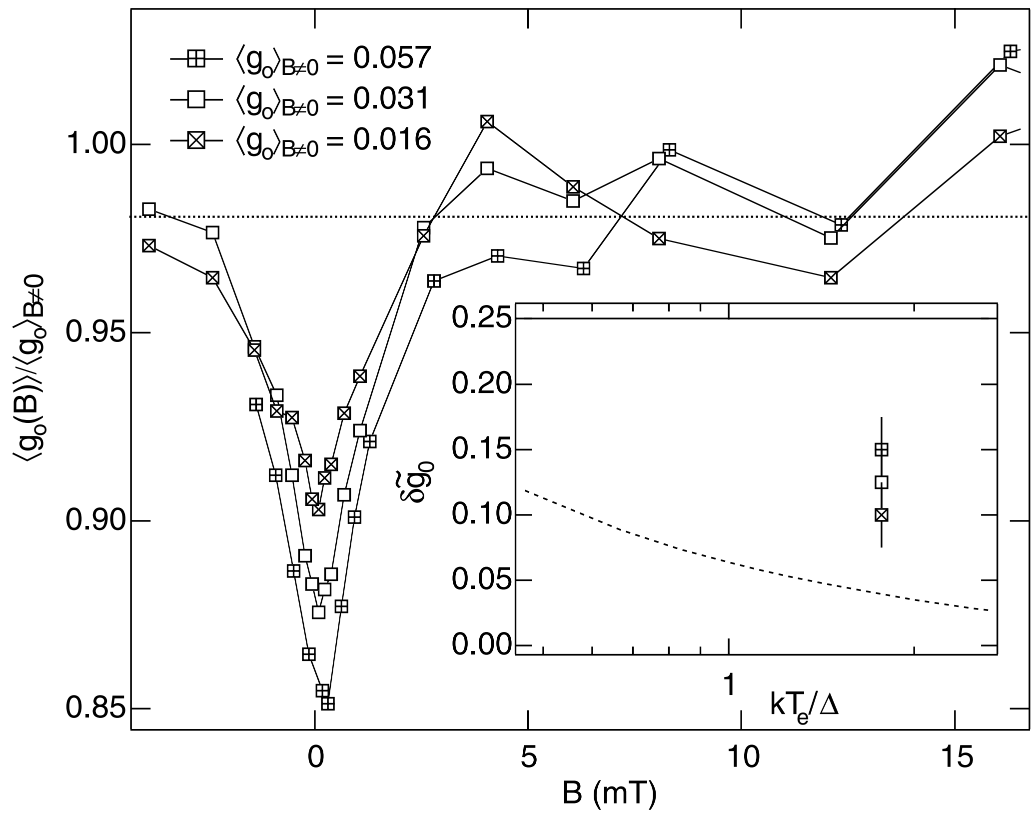

Area (μm^2)	Δ (μeV)	N	E_{th} (μeV)	E_{c} (μeV)	ϵ^{**} (μeV)
0.25	28	400	250	400	75
0.7	10	1400	150	290	32
3	2.4	6000	75	110	10
8	0.9	16 000	45	65	5

$$G_{\text{el}} = \frac{e^2}{kT} P_{\text{eq}}(N) \left\langle \frac{\Gamma^{\text{l}}\Gamma^{\text{r}}}{\Gamma^{\text{l}} + \Gamma^{\text{r}}} \right\rangle_N \qquad G_{\text{in}} = \frac{e^2}{kT} P_{\text{eq}}(N) \frac{\langle \Gamma^{\text{l}} \rangle_N \langle \Gamma^{\text{r}} \rangle_N}{\langle \Gamma^{\text{l}} + \Gamma^{\text{r}} \rangle_N}$$

theory:

C. W. J. Beenakker, H. Schomerus, and P. G. Silvestrov, Phys. Rev. B **64**, 033307 (2001).

Y. Alhassid, Phys. Rev. B **58**, 13 383 (1998).

VOLUME 88, NUMBER 13 PHYSICAL REVIEW LETTERS 1 APRIL 2002

Dephasing Times in Closed Quantum Dots

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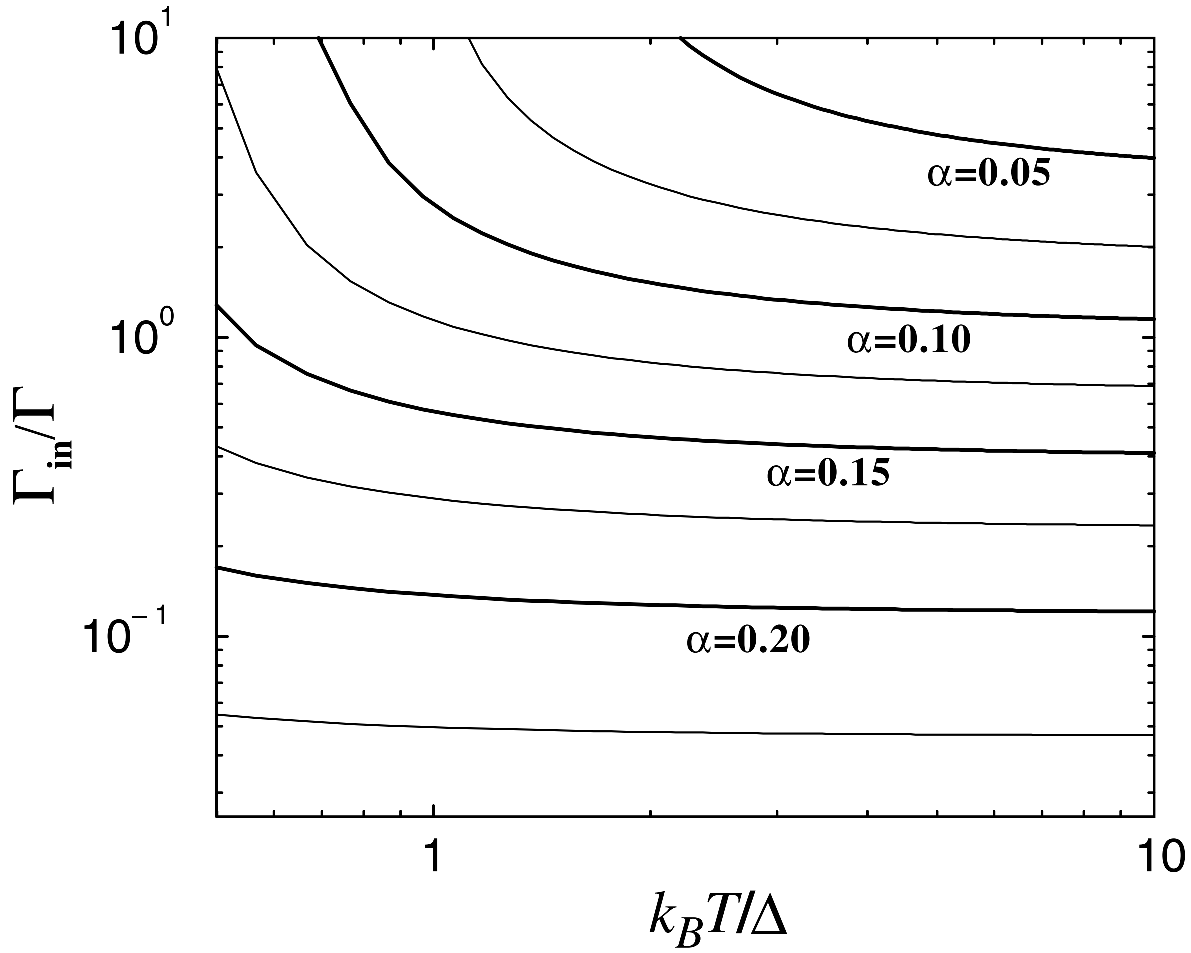
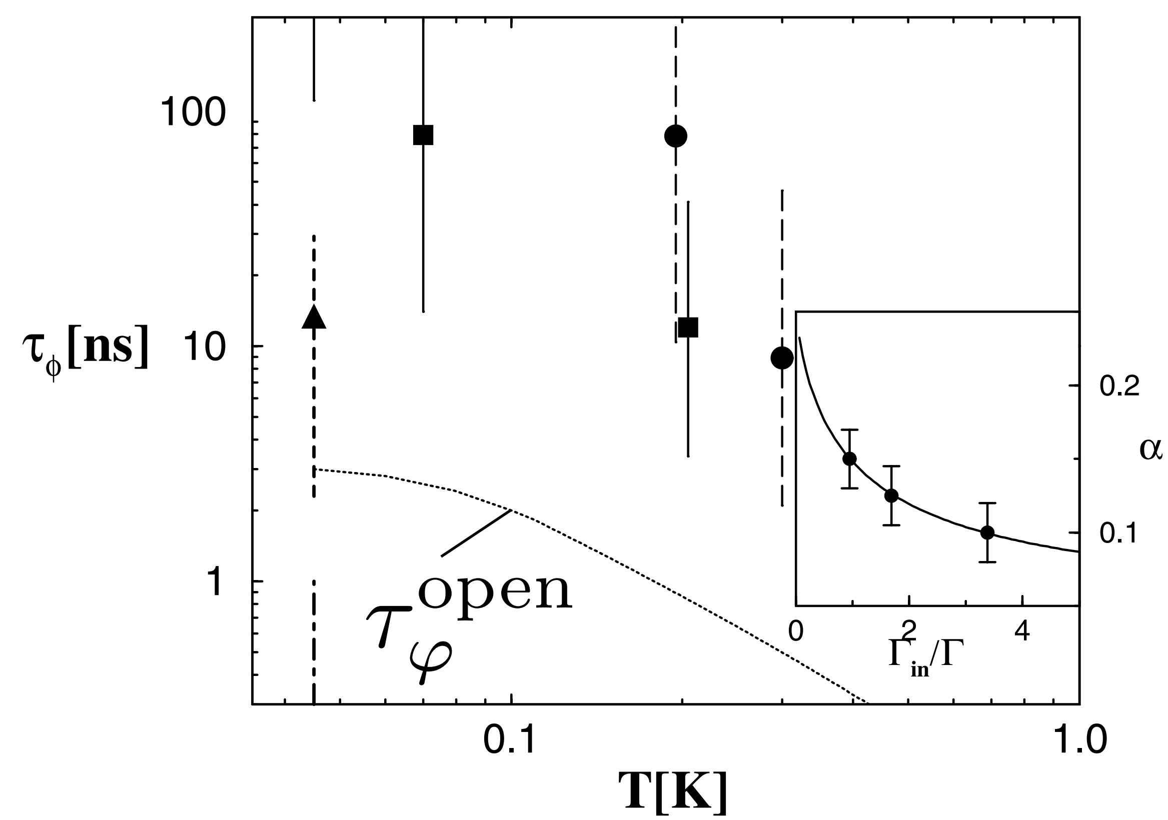
(Received 29 October 2001; published 14 March 2002)

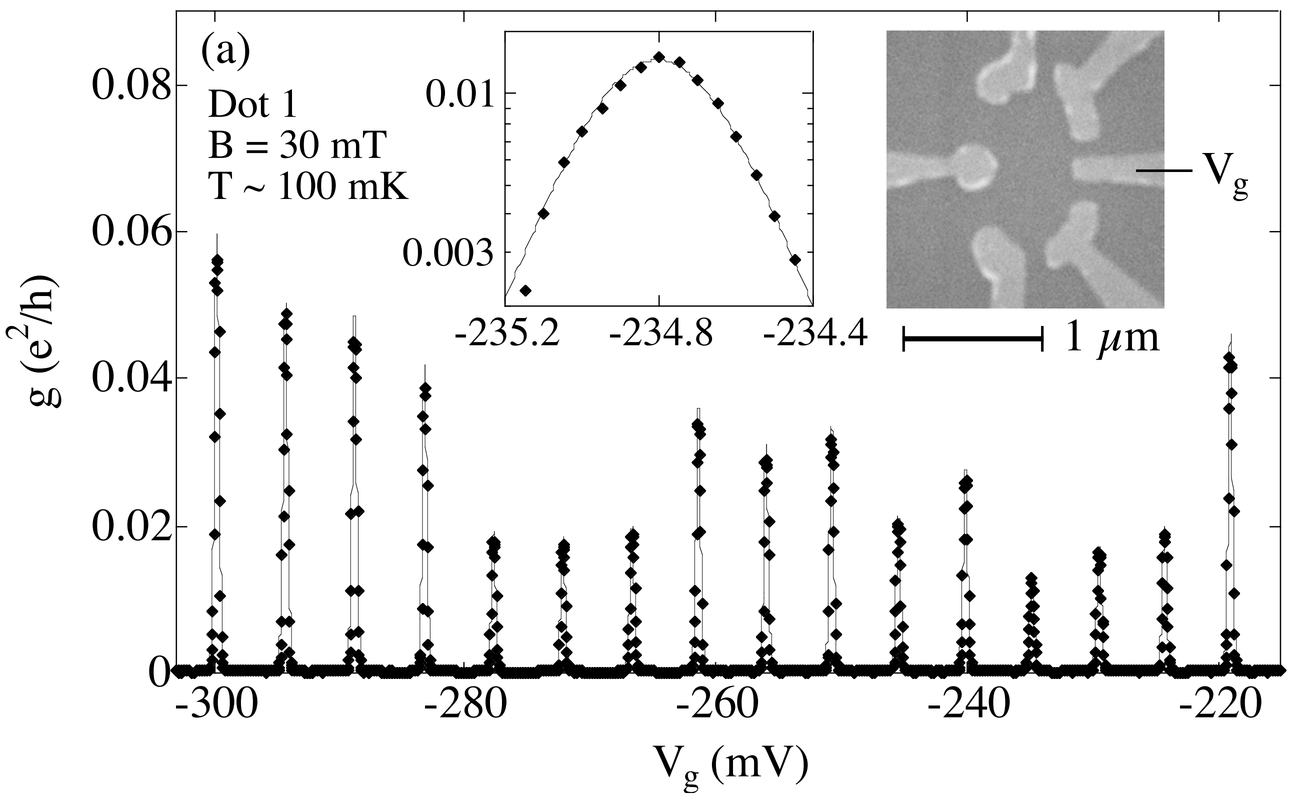
$$\alpha = (\langle G^{\max}\rangle_{B\neq 0} - \langle G^{\max}\rangle_{B=0})/\langle G^{\max}\rangle_{B\neq 0}$$

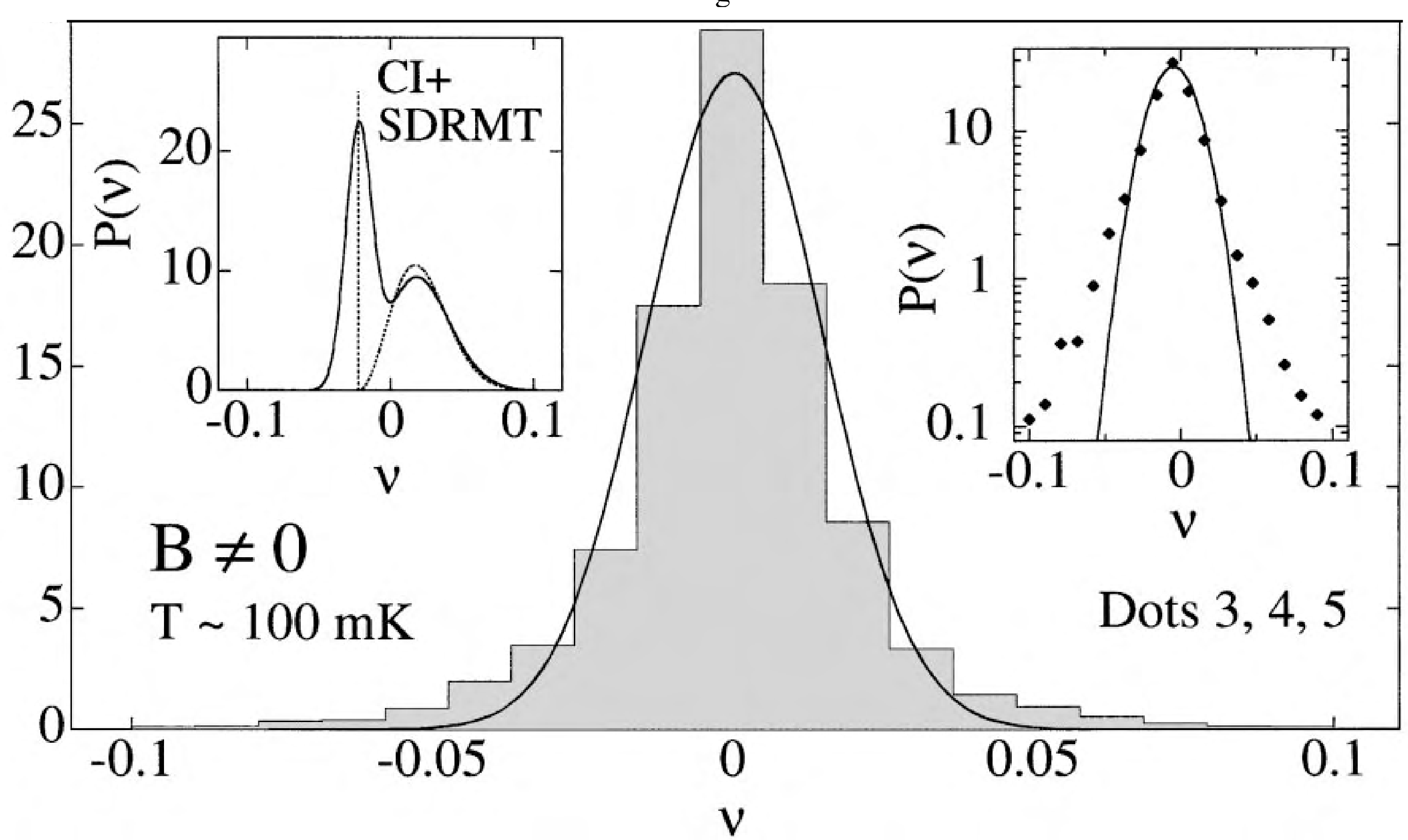




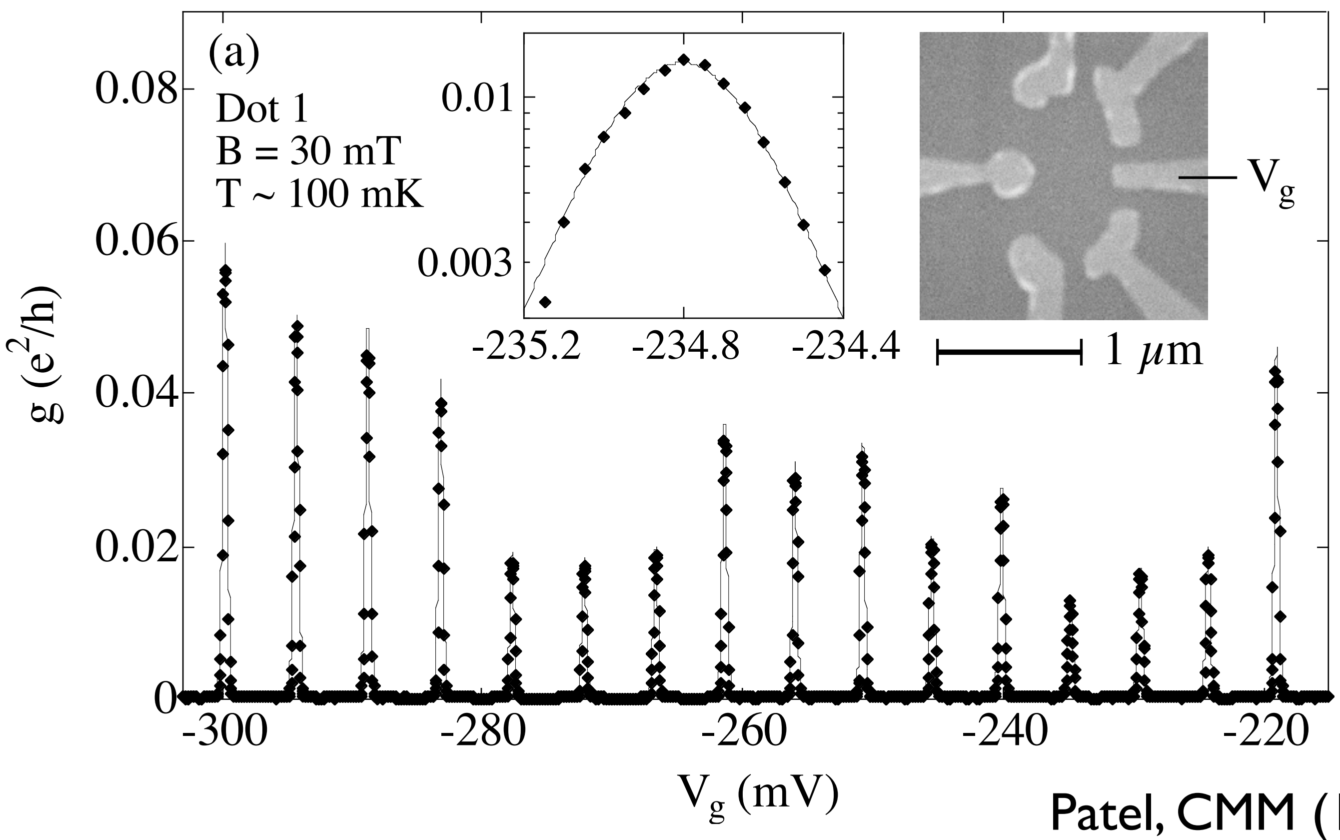
Area (μm^2)	Δ (μeV)	N	E_{th} (μeV)	E_c (μeV)	ϵ^{**} (μeV)
0.25	28	400	250	400	75
0.7	10	1400	150	290	32
3	2.4	6000	75	110	10
8	0.9	16 000	45	65	5

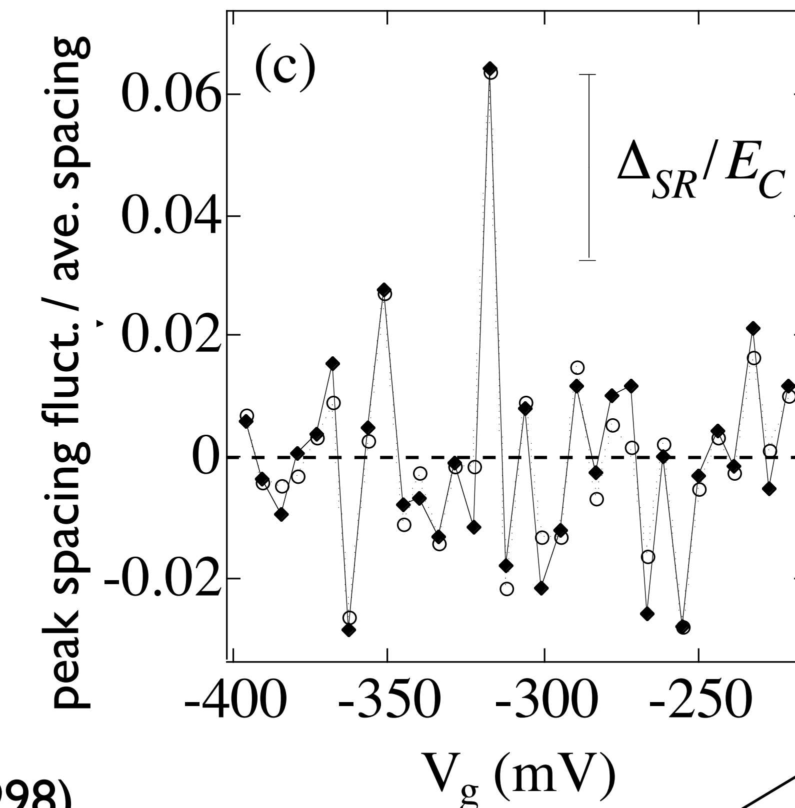
Statistics of Coulomb Blockade Peak Spacings



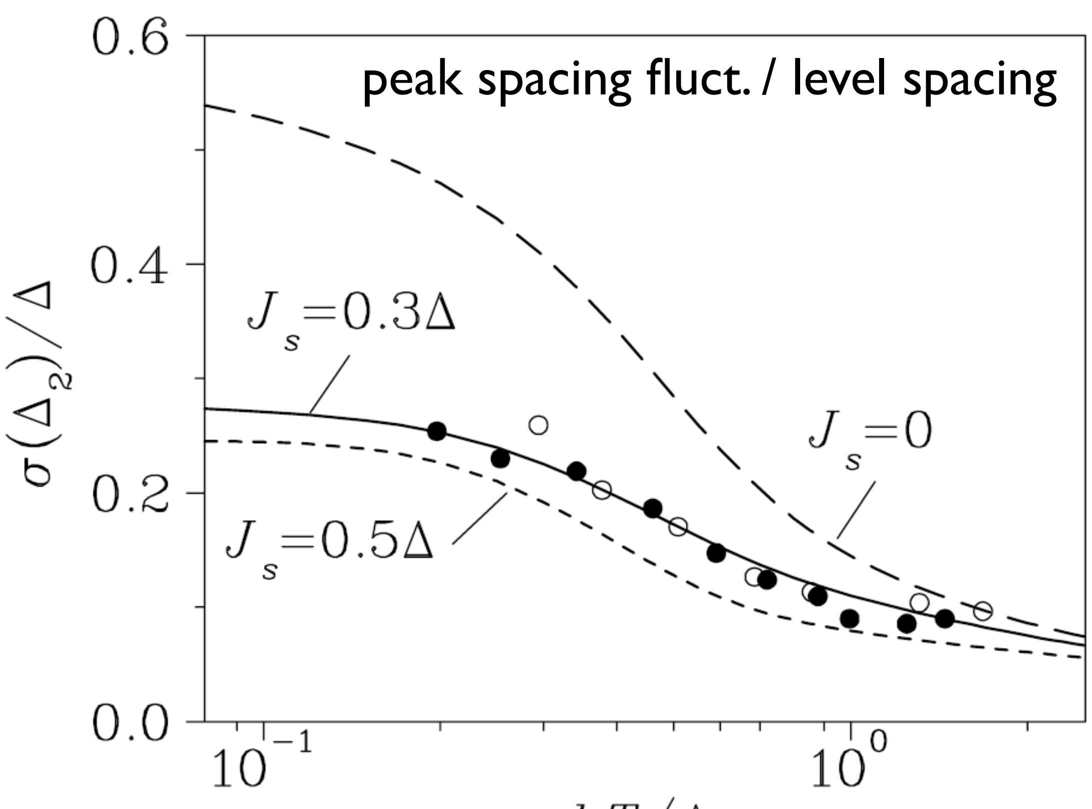


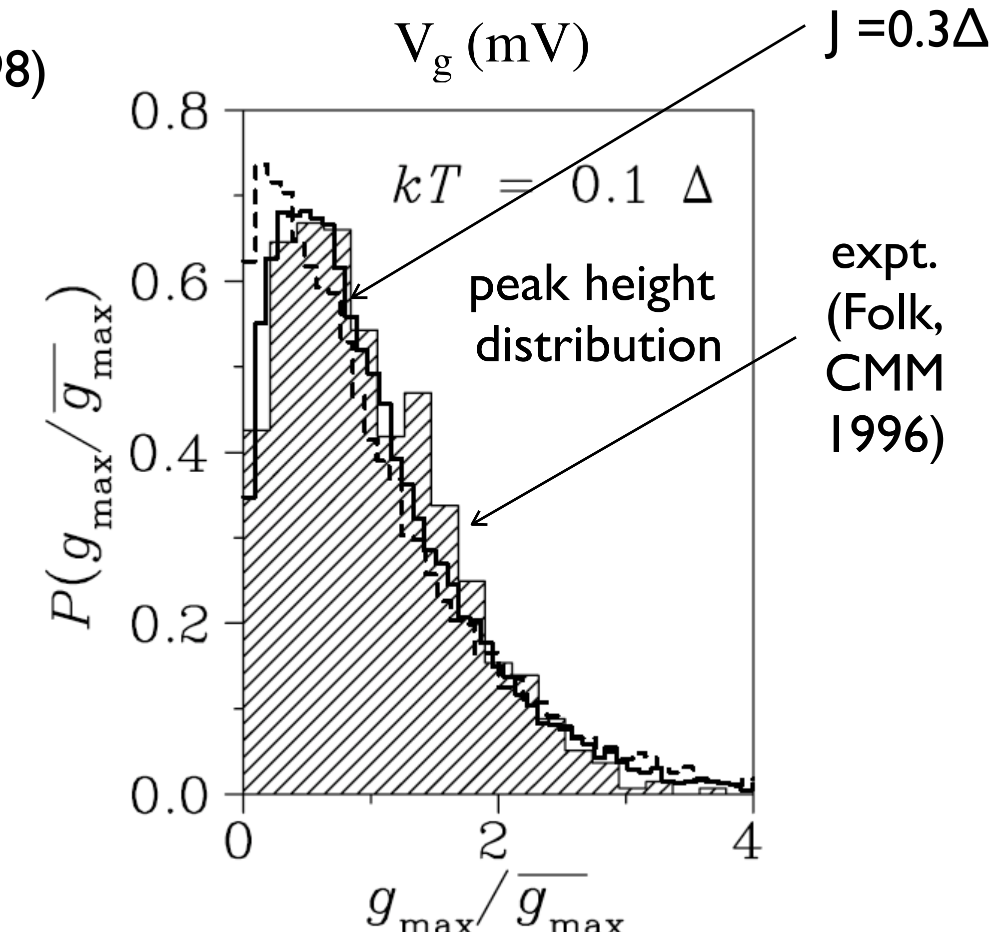
CB peak statistics and Exchange





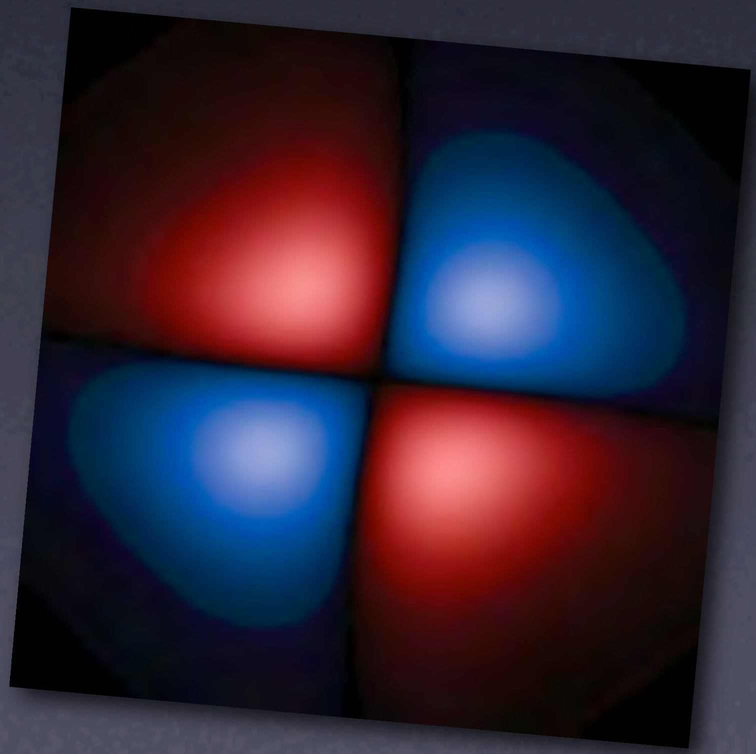
Patel, CMM (1998)

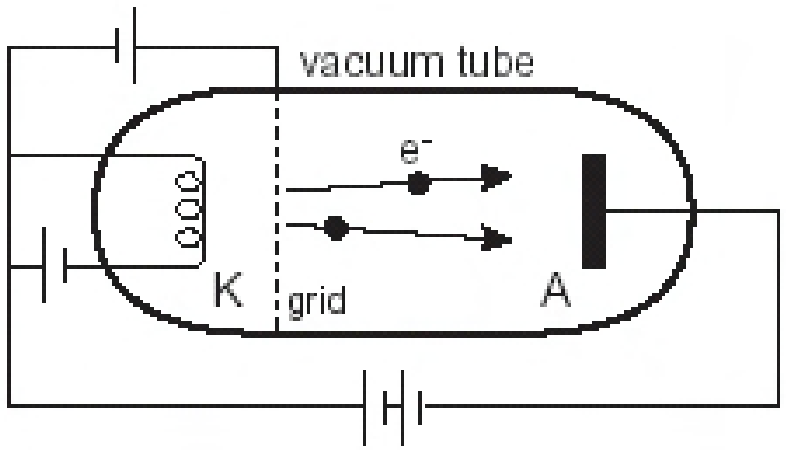




Analysis: Rupp, Alhassid (2003)

Shot noise and noise correlations





Shot noise:
Signature of discrete charges evident in tunneling processes

$$\langle(\Delta I)^2\rangle_\nu = 2e\langle I\rangle$$

W. Schottky, Ann. Phys. (Leipzig) 57, 541 (1918)

power spectral density of current fluctuations

$$S(f) = \langle \delta I(f)^2 \rangle / \Delta f$$

In thermal equilibrium, zero current flowing

$$S = 4kTG$$

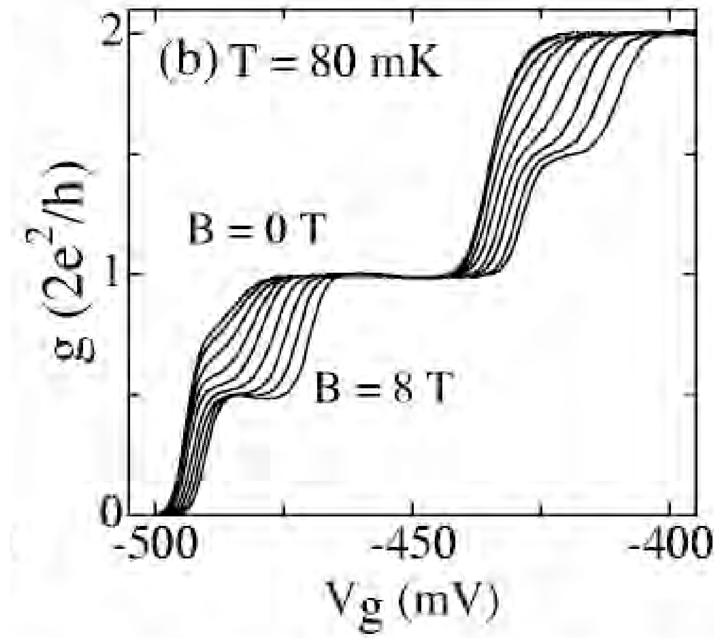
temperature conductance

Out of equilibrium (current flowing) at zero temperature

$$S_{\mathrm{Poisson}} = 2e\bar{I}$$

current and noise in terms of transmission (Landauer formula)

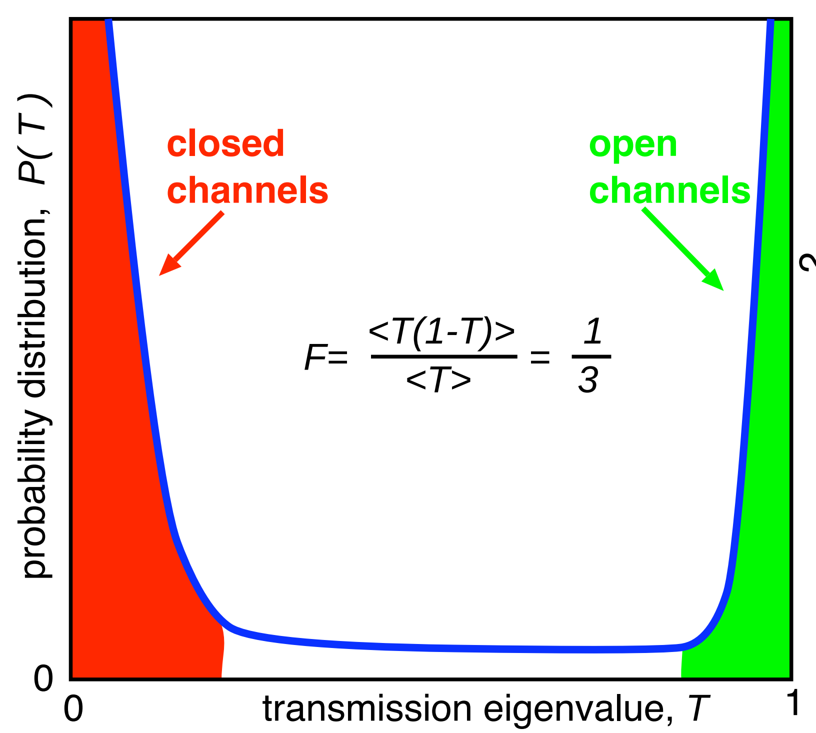
example 1: QPC

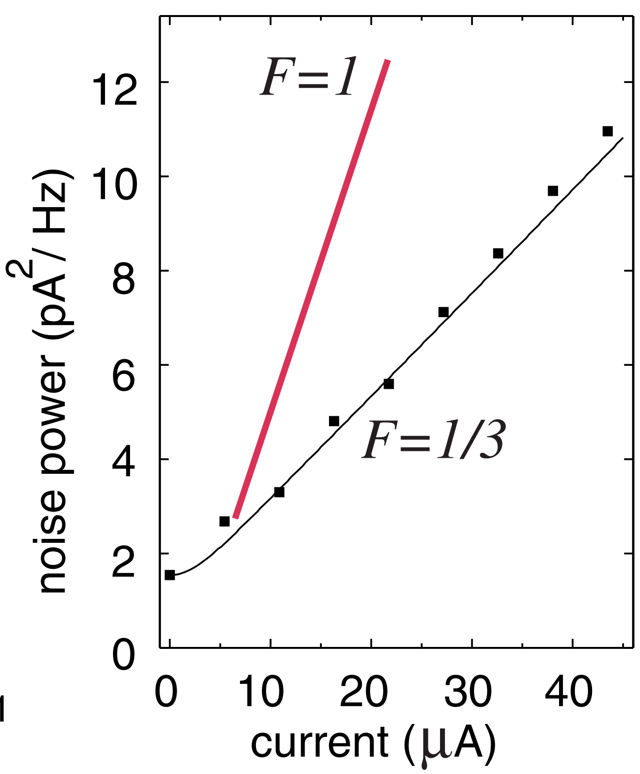


$$\bar{I} = \frac{2e^2}{h} V \sum_{n=1}^{N} T_n$$

$$S = 2e \frac{2e^2}{h} V \sum_{n=1}^{N} T_n (1 - T_n)$$

example 2: disordered metal wire





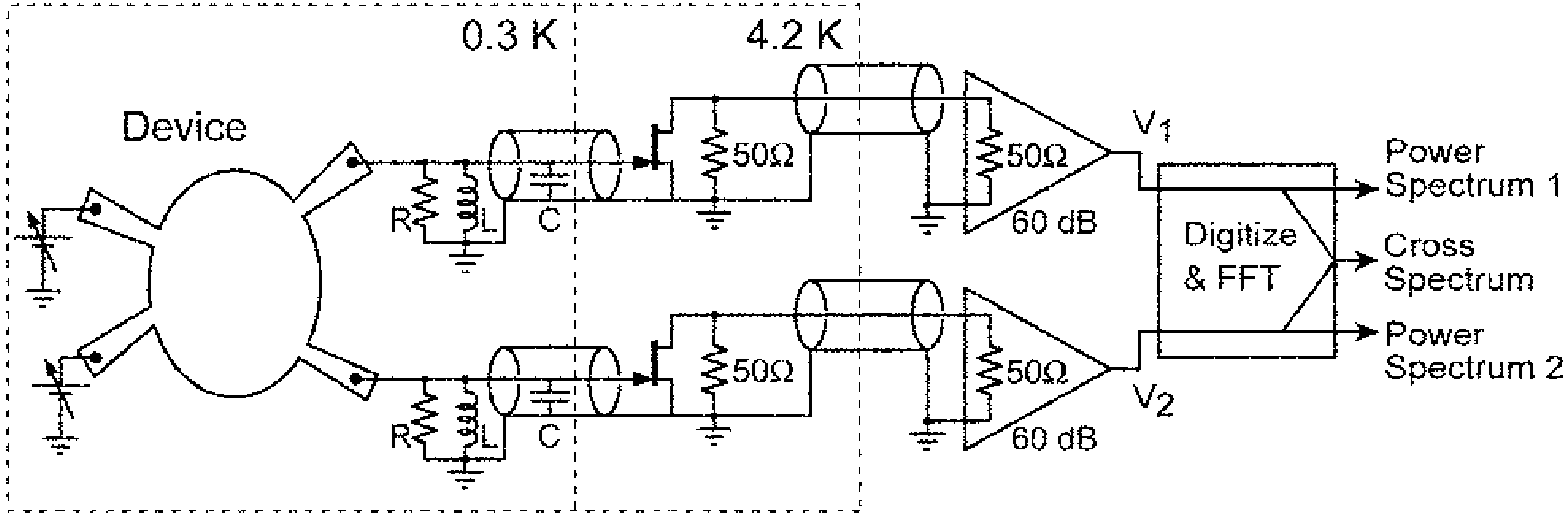
$$P(T) \propto T^{-1}(1-T)^{-1/2}$$

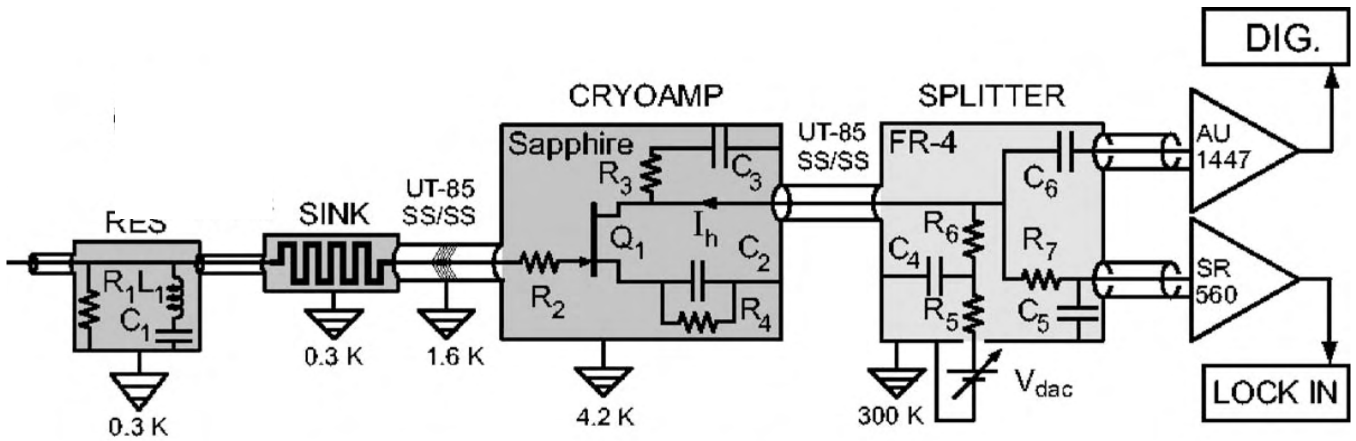
$$\int T^2 P(T) dT / \int T P(T) dT = 2/3$$

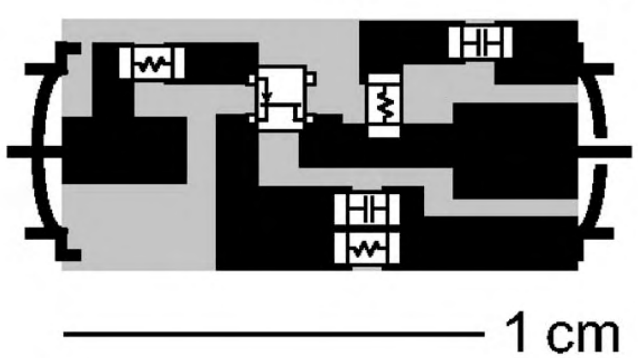
fano factor

$$F = \frac{\langle T(1-T) \rangle}{\langle T \rangle} = \frac{1}{3}$$

noise measurement circuitry

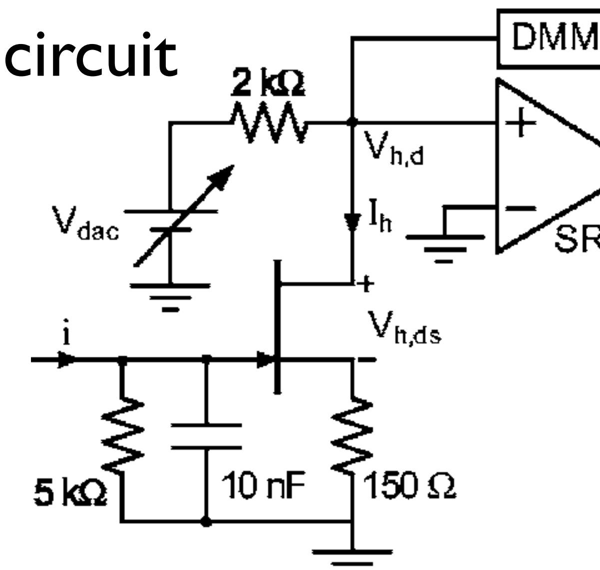




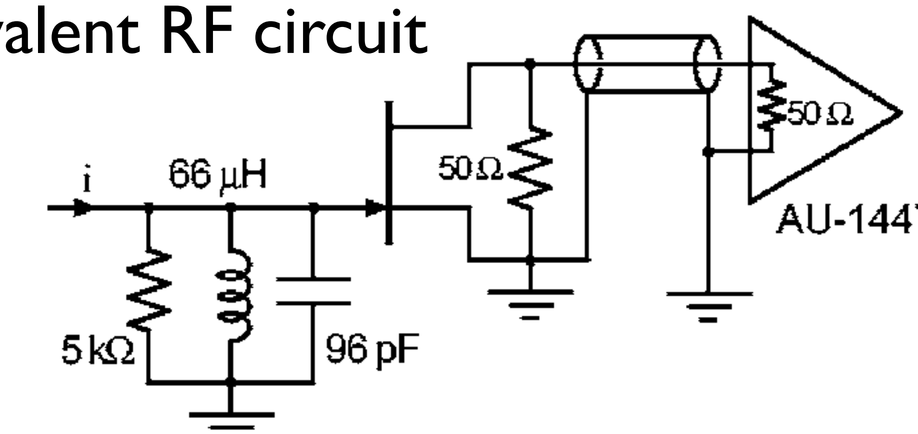


R_1	5 kΩ
R_2	10 Ω
R_3	50 Ω
R_4	150 Ω
R_5	1 kΩ
R_6	1 kΩ
R_7	10 kΩ
C_1	2x5 nF
C_2	15 nF
C_3	22 nF
C_4	2.2 nF
C_5	2.2 nF
C_6	22 nF
L_1	2x33 μH

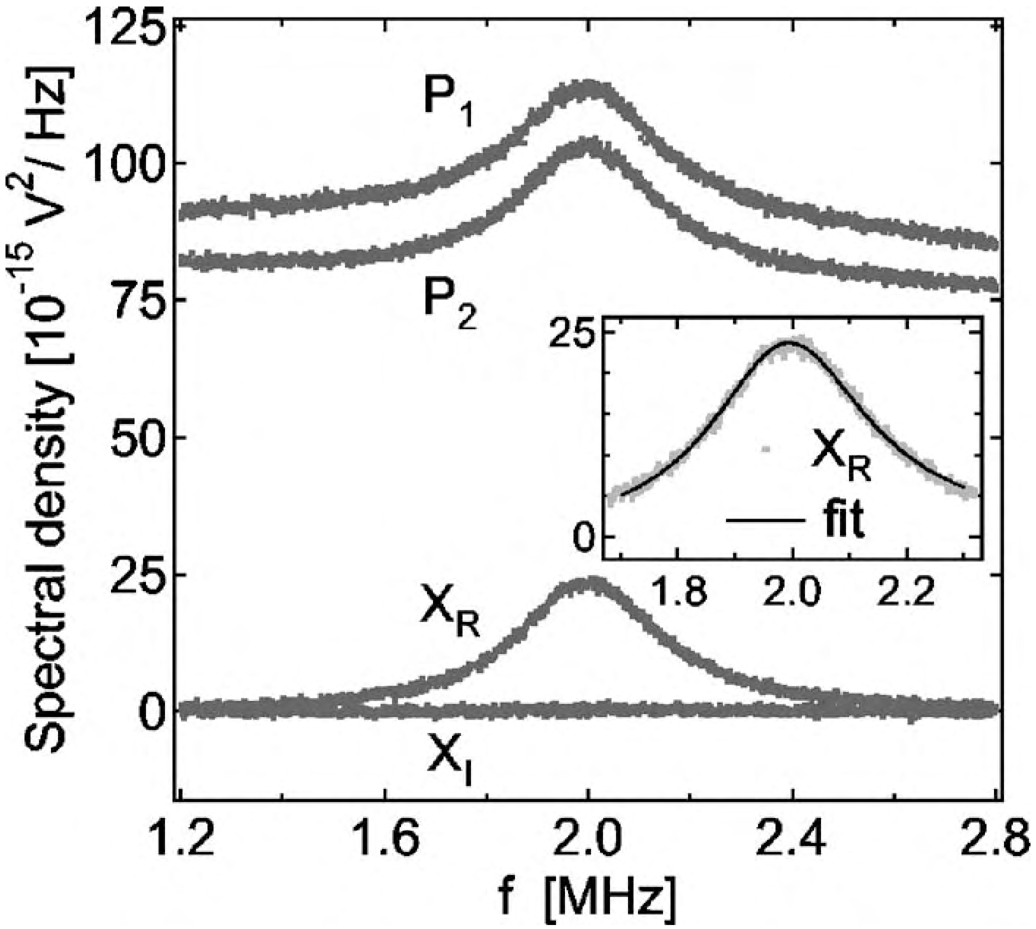
equivalent LF circuit



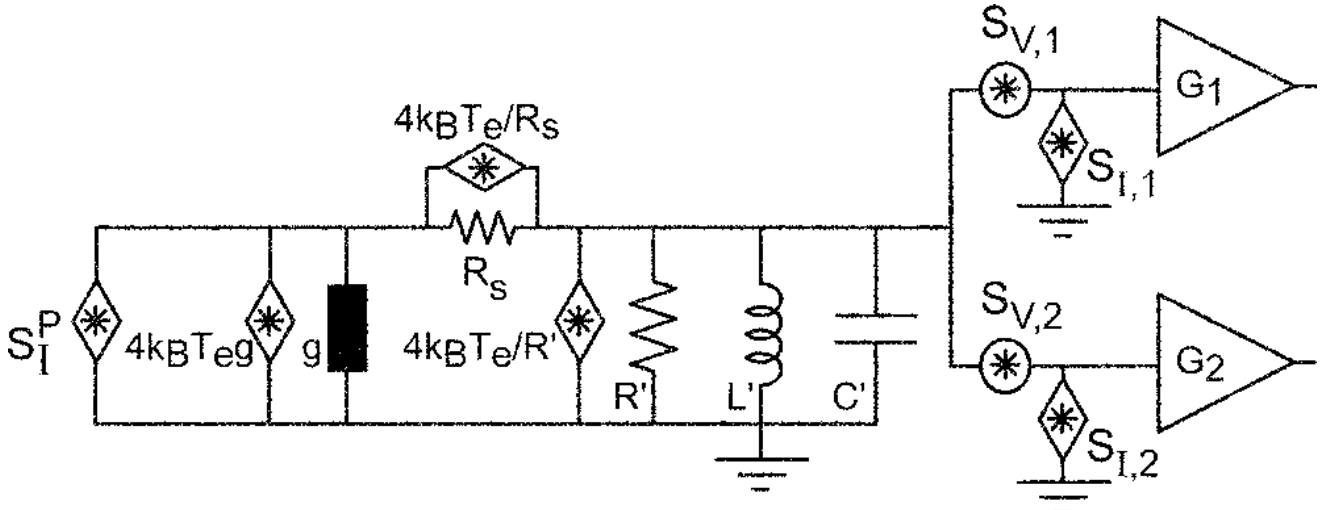
equivalent RF circuit

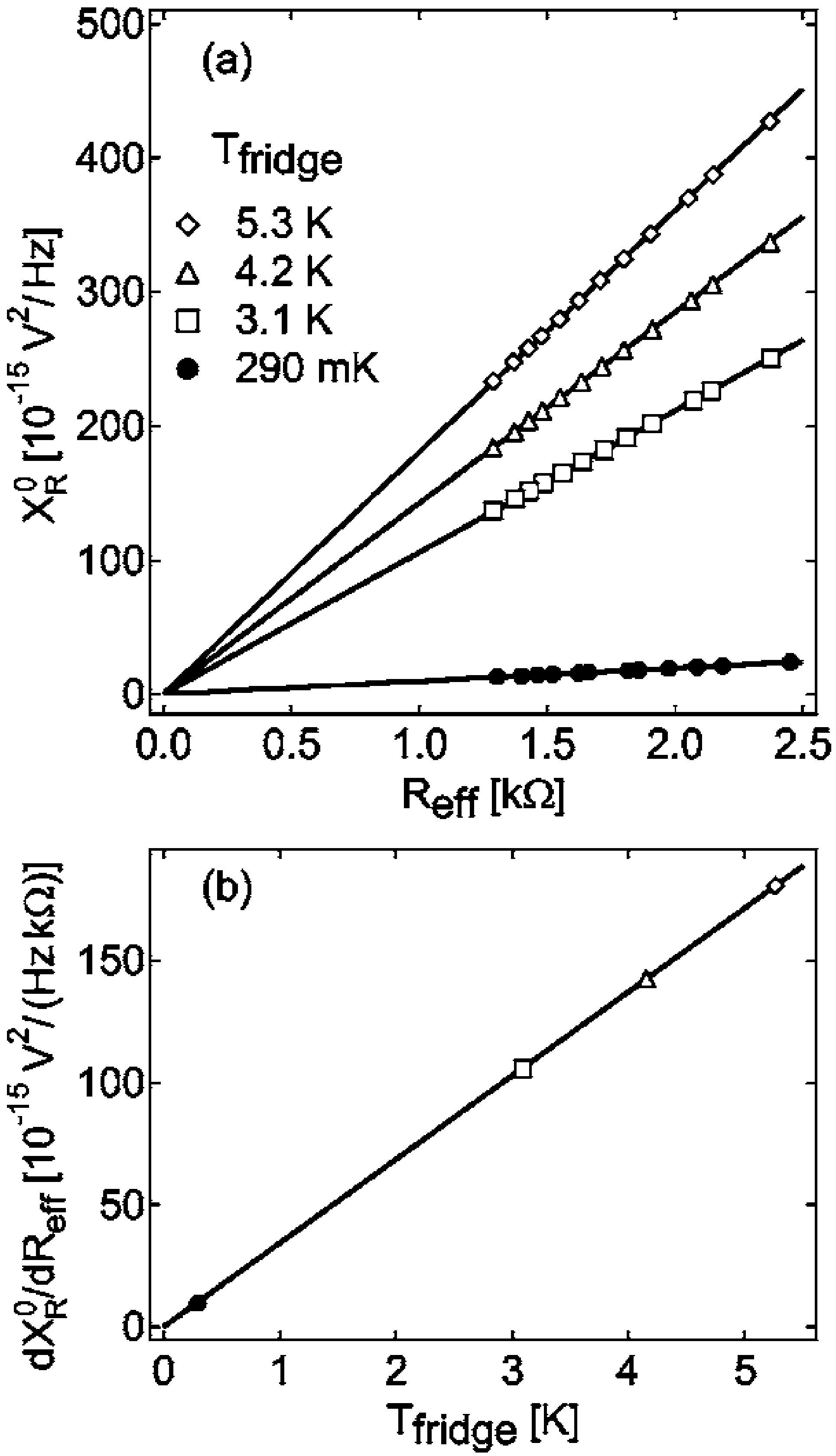


REVIEW OF SCIENTIFIC INSTRUMENTS **77**, 073906 (2006)

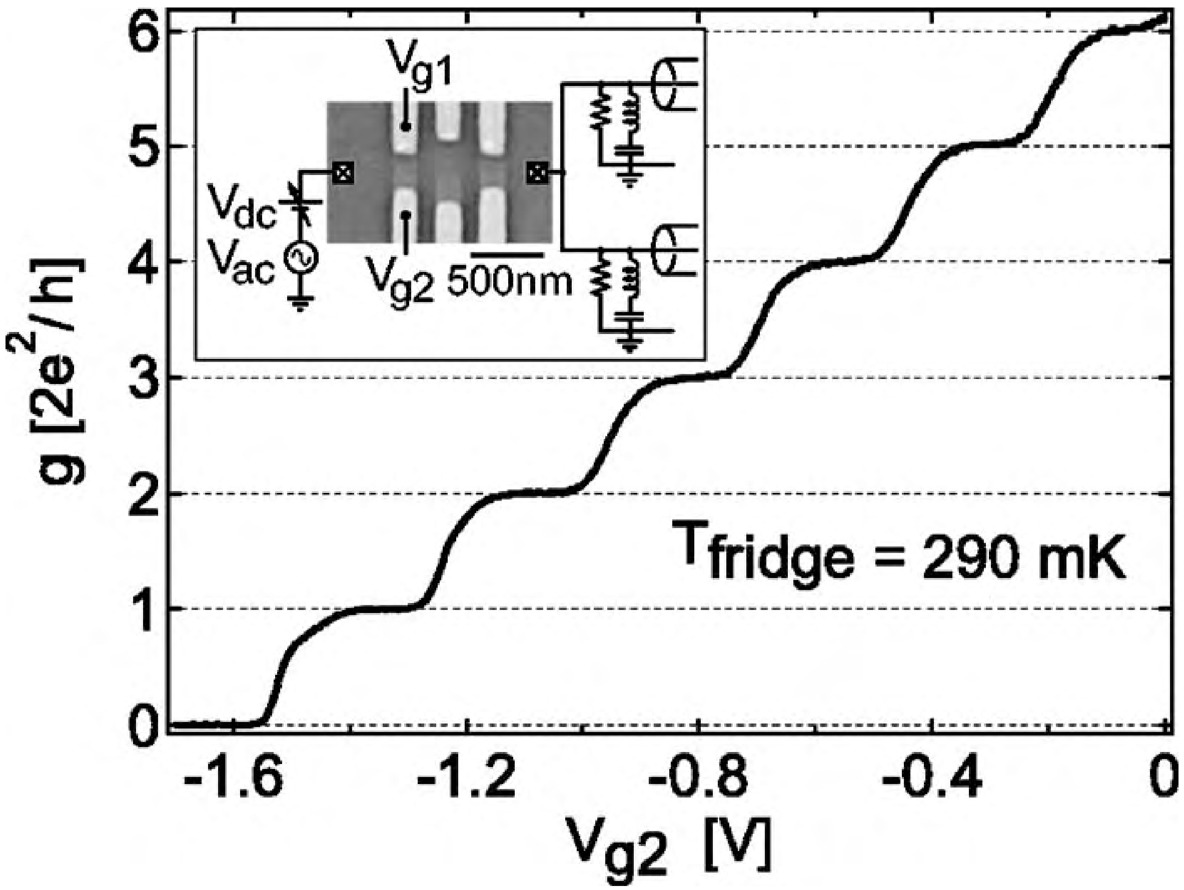


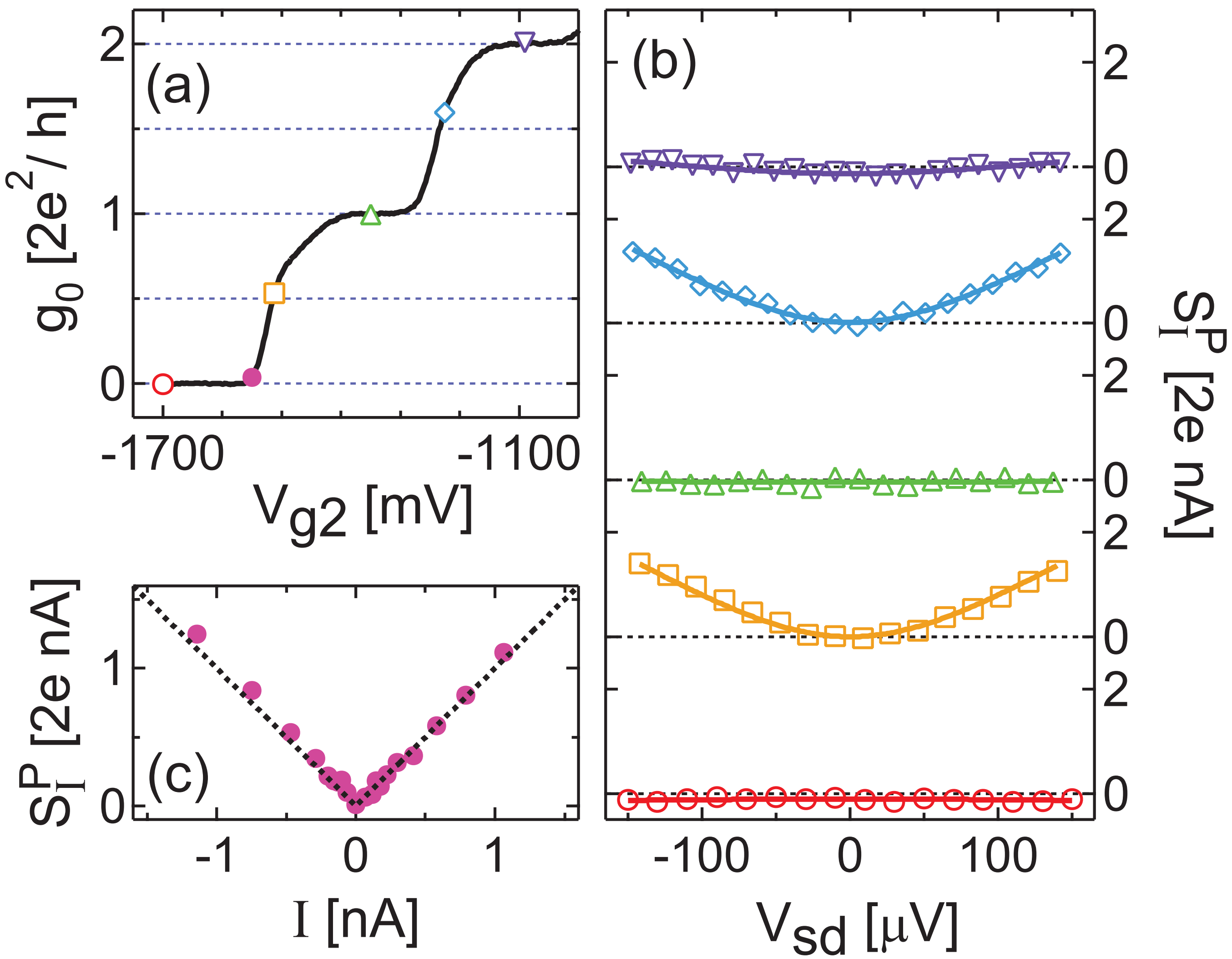
$$X_R(f) = \frac{X_R^0}{1 + (f^2 - f_o^2)^2/(f\Delta f_{3\text{dB}})^2}$$





$$X_R^0 = 4k_BT_eR_{\text{eff}}G_X^2$$





$$S_I^P(V_{\rm sd}) = 2\frac{2e^2}{h}\mathcal{N}\left[eV_{\rm sd}\coth\left(\frac{eV_{\rm sd}}{2k_B T_e}\right) - 2k_B T_e \right]$$

$$\textit{noise factor}\ \ \mathcal{N} = \tfrac{1}{2}\sum \tau_{n,\sigma}(1-\tau_{n,\sigma})$$

Shot-Noise Signatures of 0.7 Structure and Spin in a Quantum Point Contact

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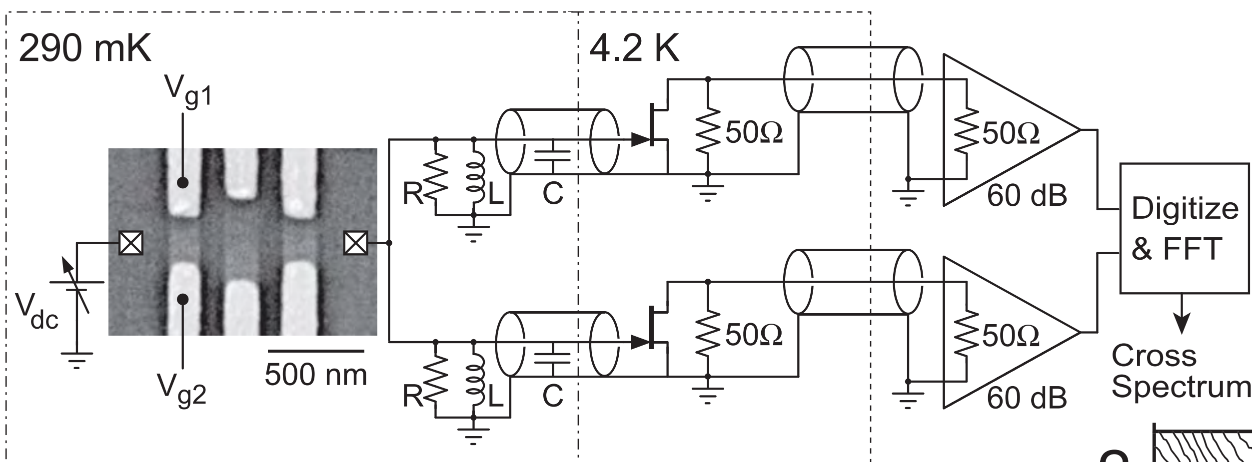
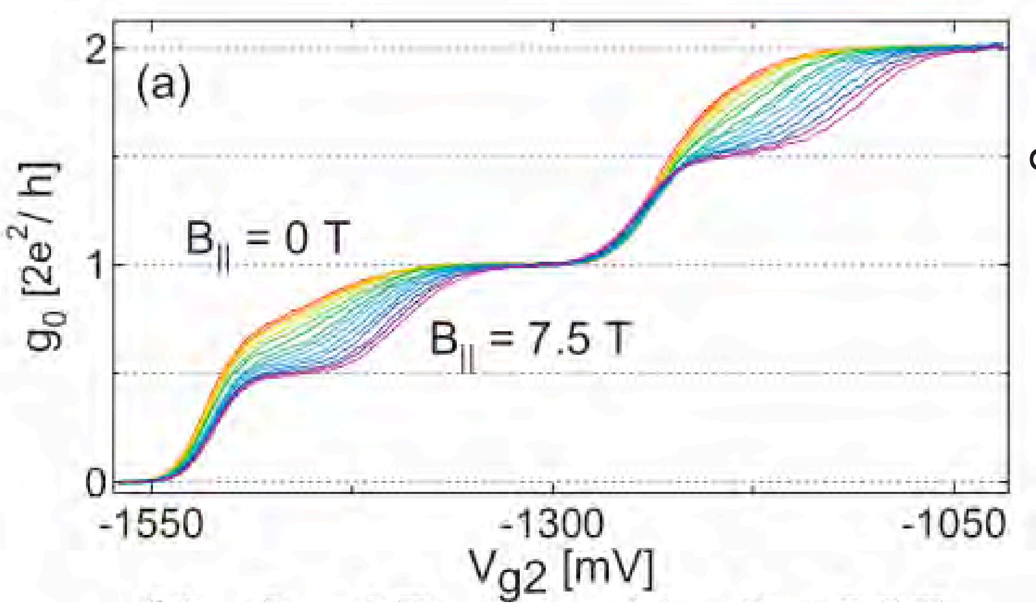
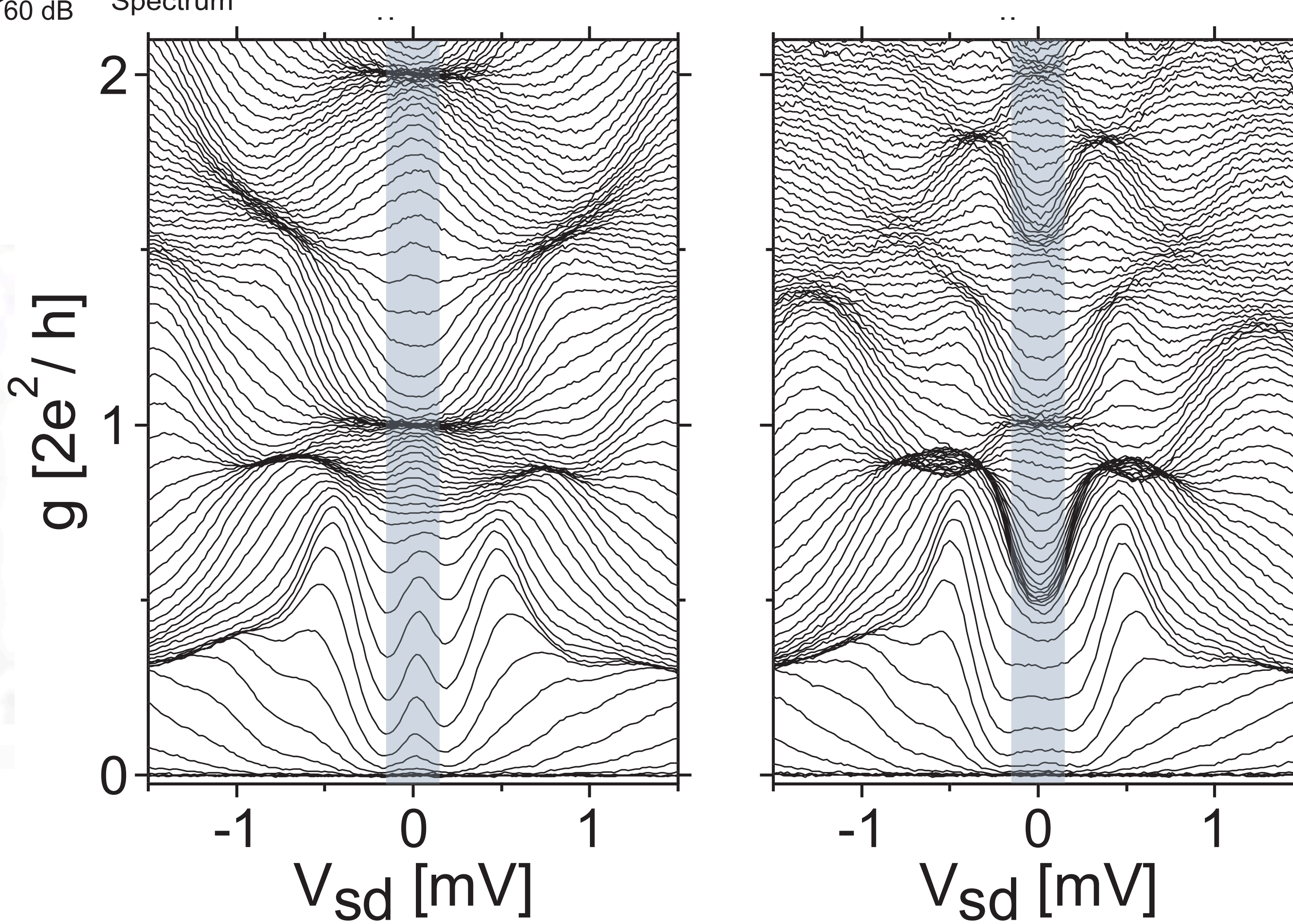
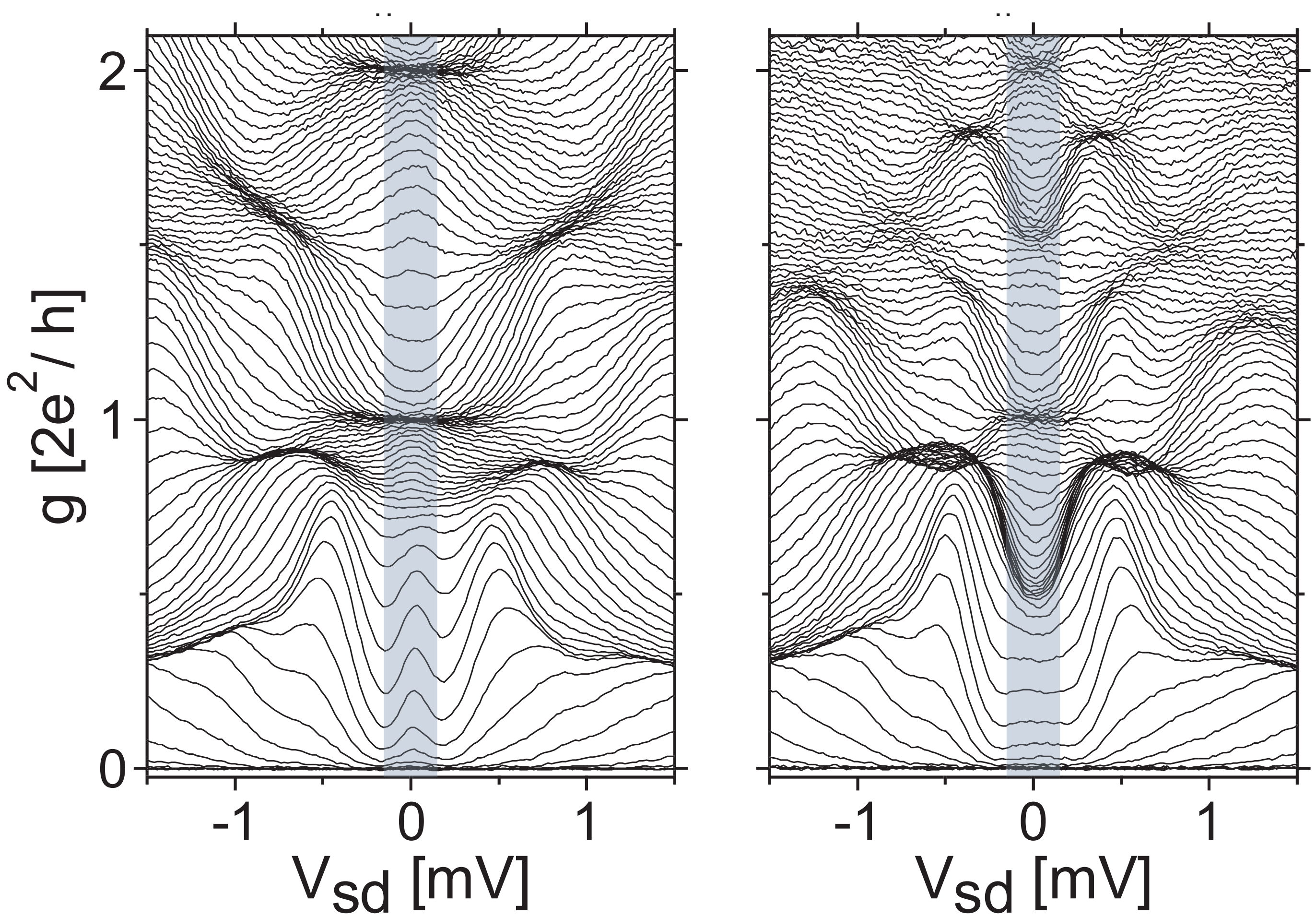
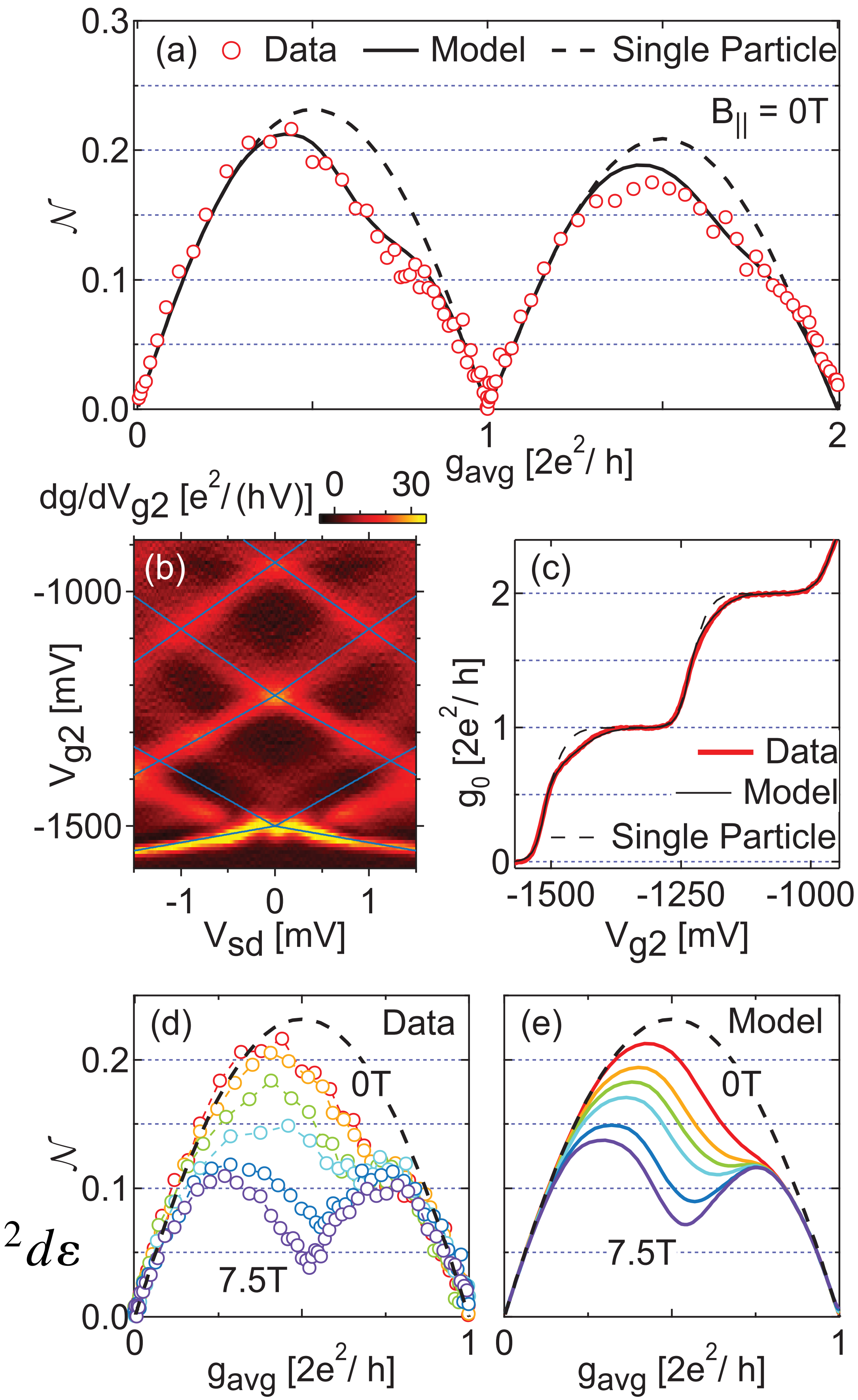
(Received 2 April 2006; published 21 July 2006)











$$S_I^P(V_{\rm sd}) = 2\,\frac{2e^2}{h}\,\mathcal{N}\left[\,eV_{\rm sd}\coth\!\left(\frac{eV_{\rm sd}}{2k_BT_e}\right) - 2k_BT_e\,\right]$$

$$S_I^P(V_{\rm sd}) = \frac{2e^2}{h}\int\sum_{n,\sigma}\tau_{n,\sigma}(\varepsilon)[1-\tau_{n,\sigma}(\varepsilon)](f_s - f_d)^2 d\varepsilon$$

Suppression of Shot Noise in Quantum Point Contacts in the "0.7 Regime"

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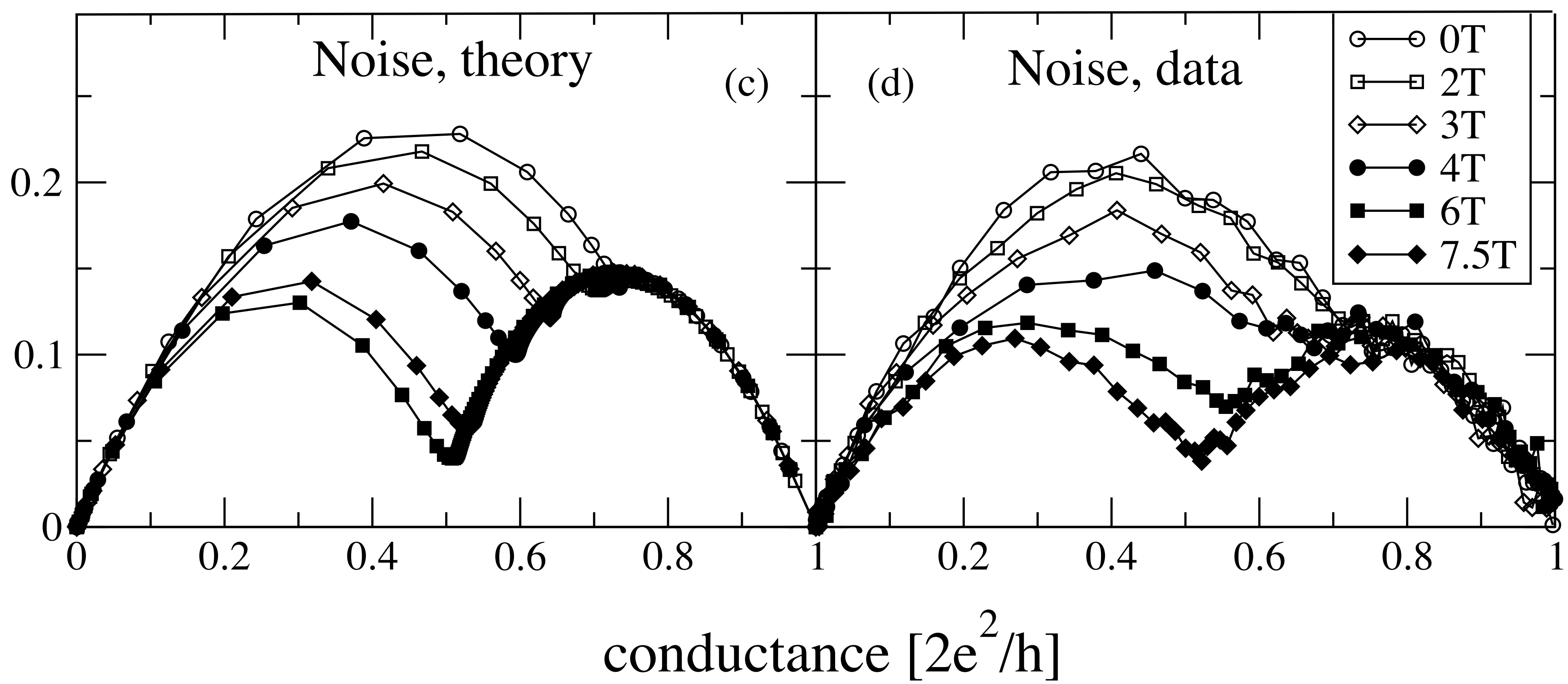

Tunable Noise Cross Correlations in a Double Quantum Dot

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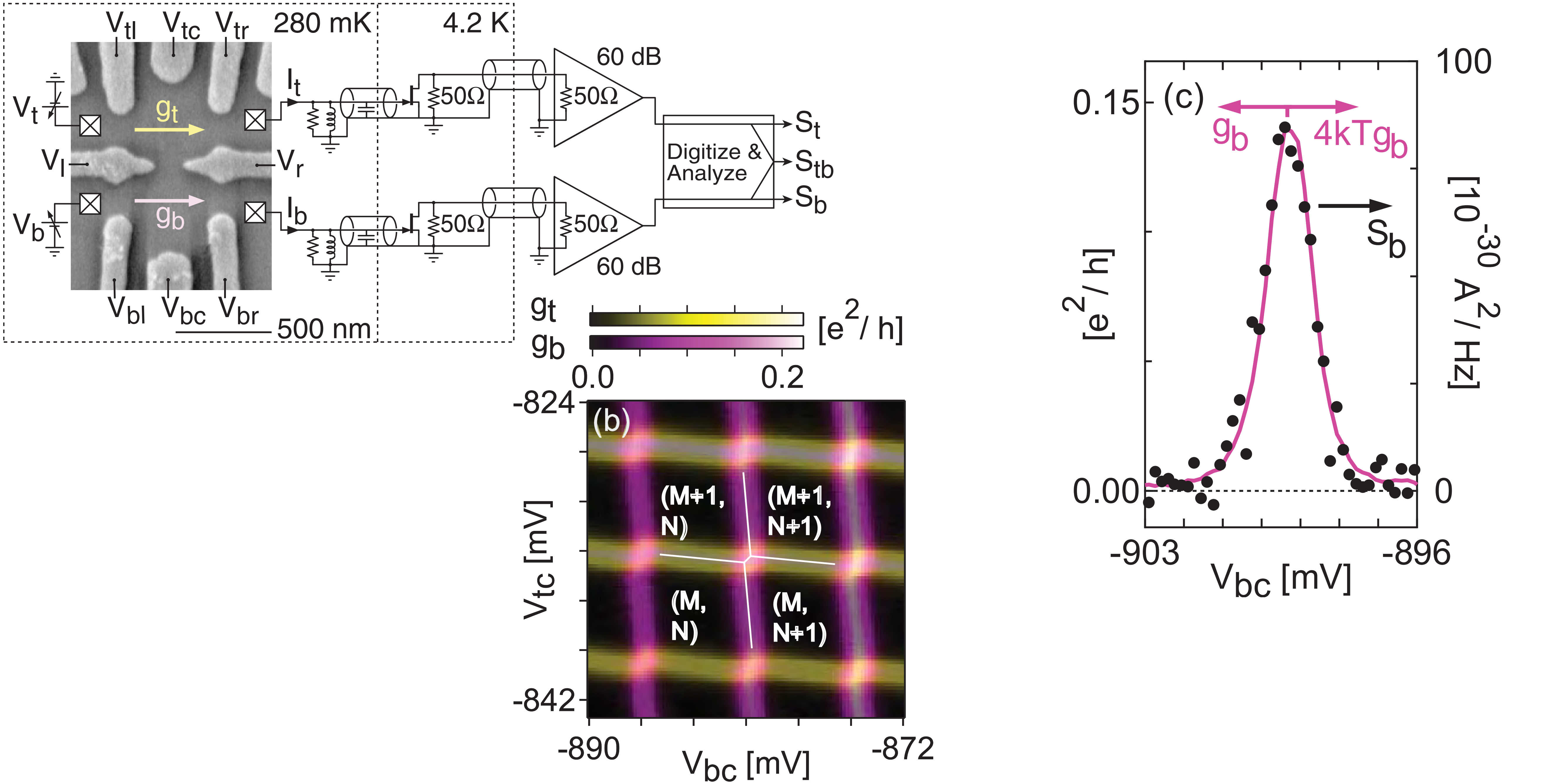
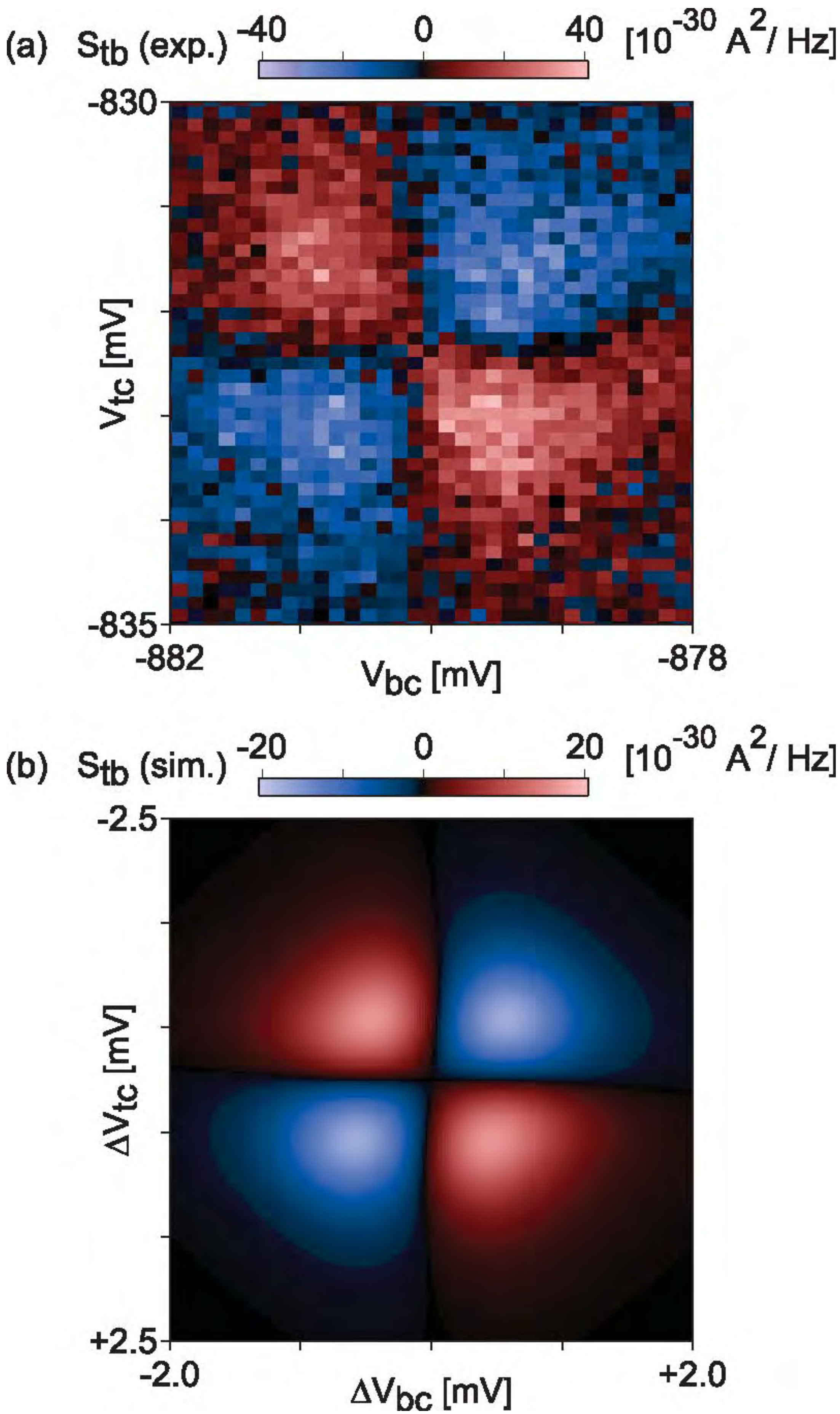
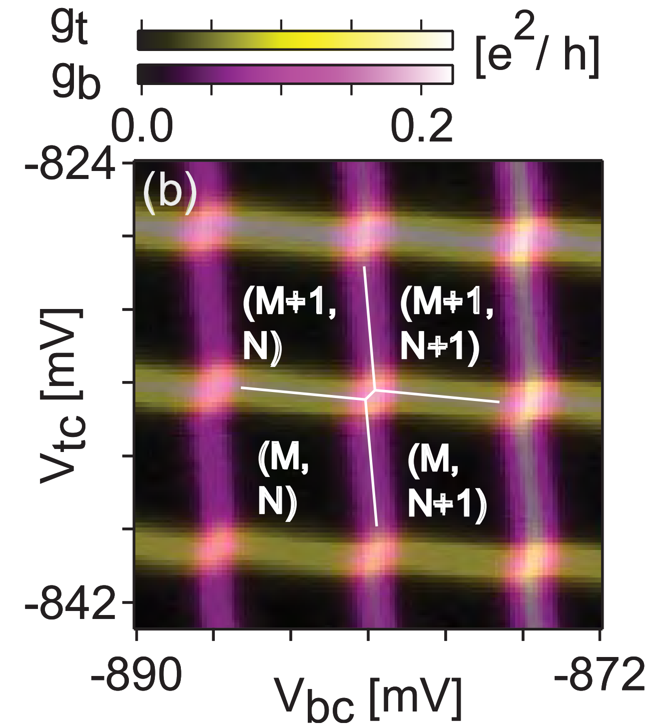
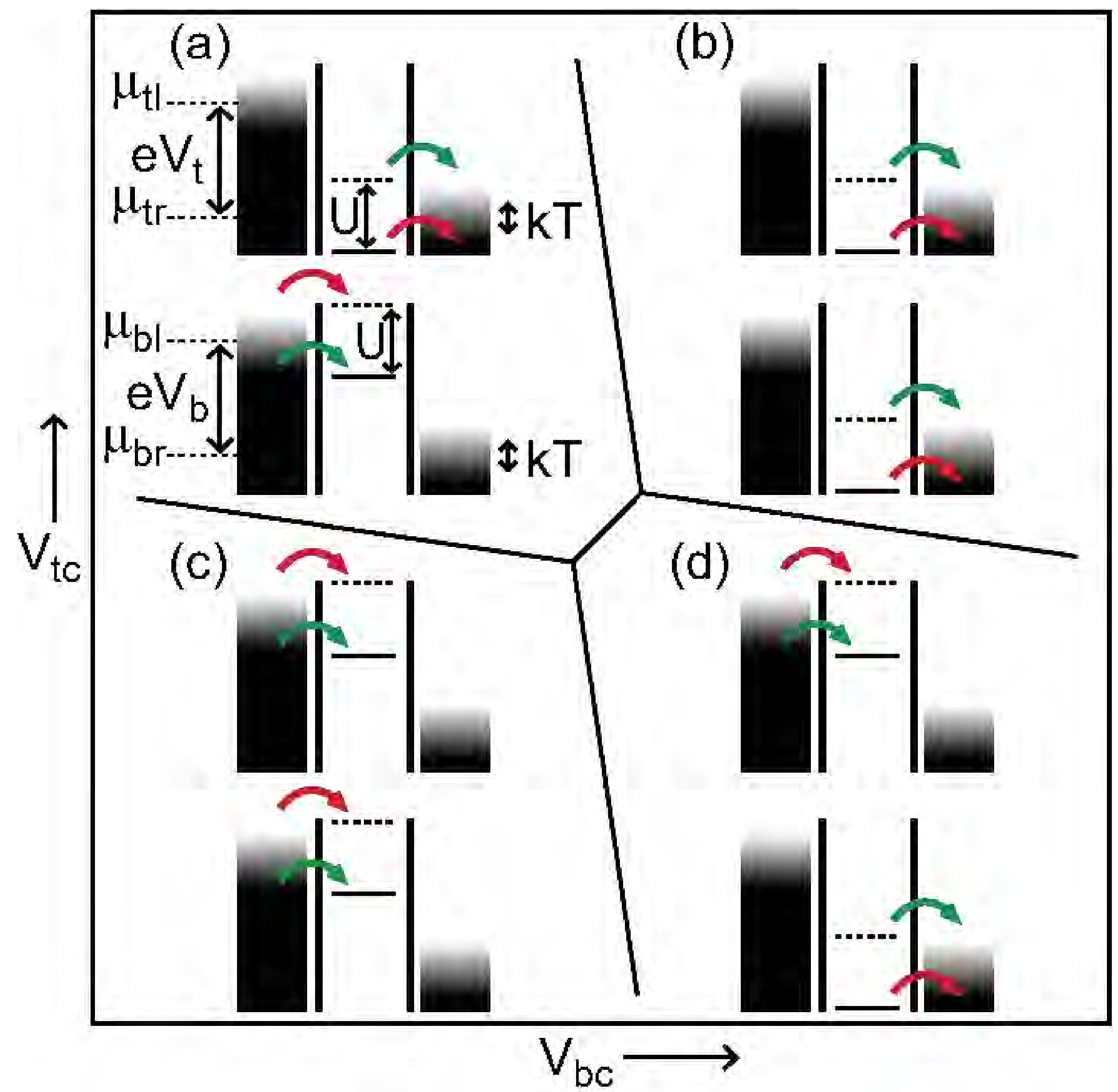
(Received 11 July 2006; published 29 January 2007)




(a) Stb (exp.)
-40 0 40 [10-30 A2/ Hz]
-830
-835
Vtc [mV]
-882
-878
Vbc [mV]
(b) Stb (sim.)
-20 0 20 [10-30 A2/ Hz]
-2.5
+2.5
ΔVtc [mV]
-2.0
+2.0
ΔVbc [mV]

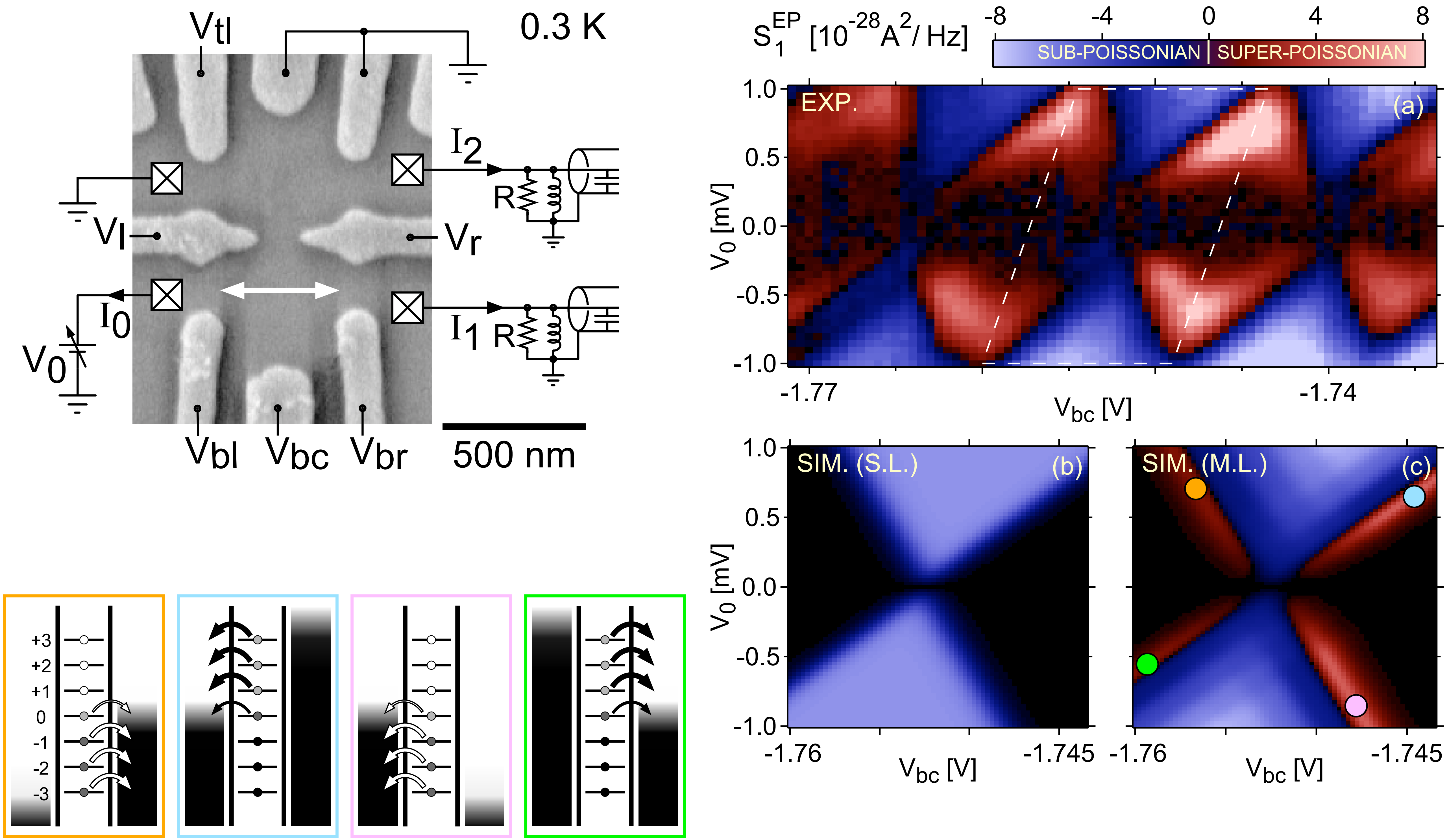

gt
gb
[e2/ h]
0.0
0.2
-824
-842
(b)
(M+1, N)
(M+1, N+1)
(M, N)
(M, N+1)
Vtc [mV]
-890
-872
Vbc [mV]


(a)
(b)
(c)
(d)
μtl
eVt
μtr
U
kT
μbl
U
eVb
μbr
kT
Vtc
Vbc

PRL 99, 036603 (2007) PHYSICAL REVIEW LETTERS week ending 20 JULY 2007

Noise Correlations in a Coulomb-Blockaded Quantum Dot

Yiming Zhang,[1] L. DiCarlo,[1] D. T. McClure,[1] M. Yamamoto,[2,3] S. Tarucha,[2,4] C. M. Marcus,[1]
M. P. Hanson,[5] and A. C. Gossard[5]



PRL **99,** 036603 (2007) PHYSICAL REVIEW LETTERS week ending 20 JULY 2007

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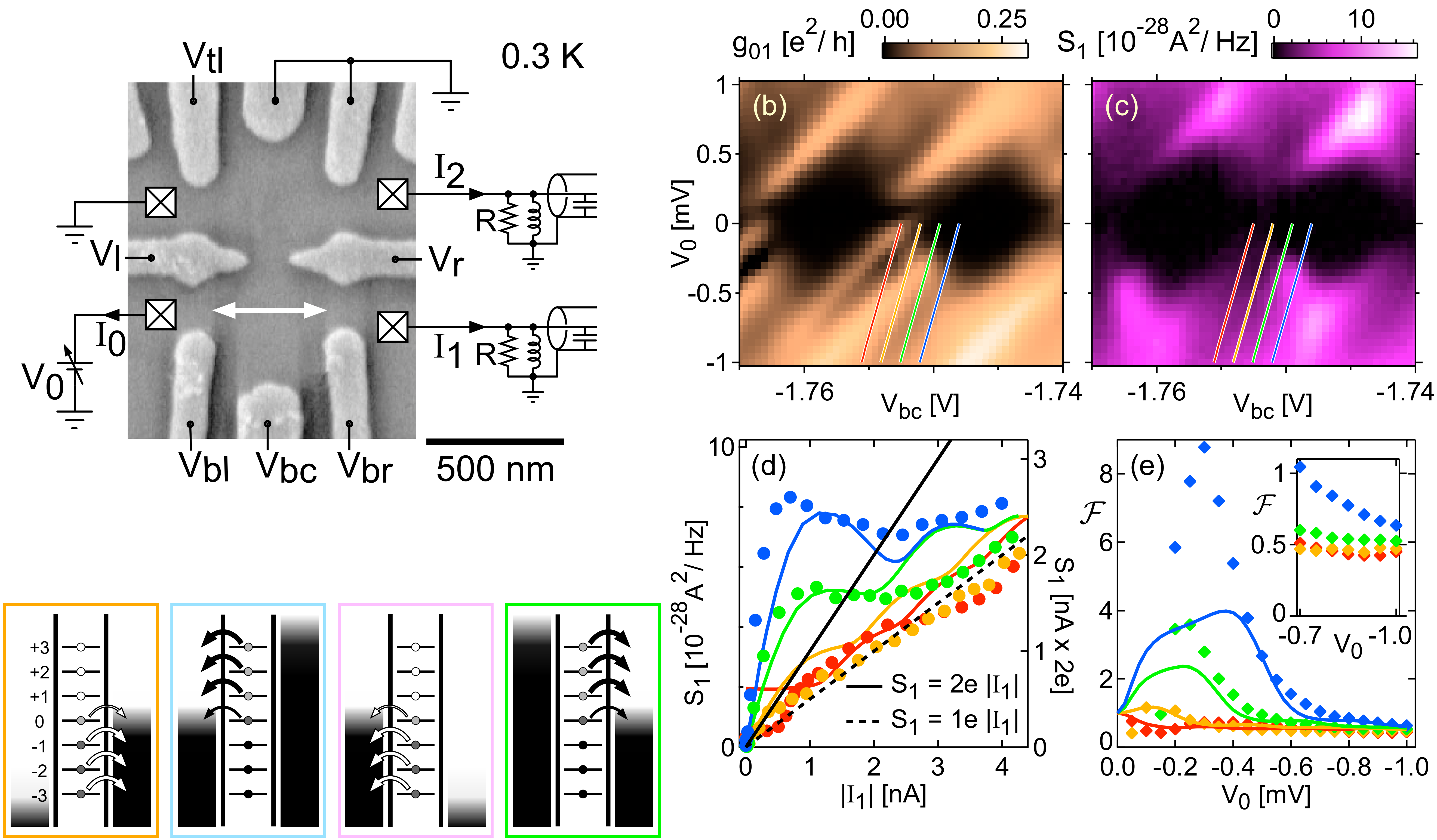

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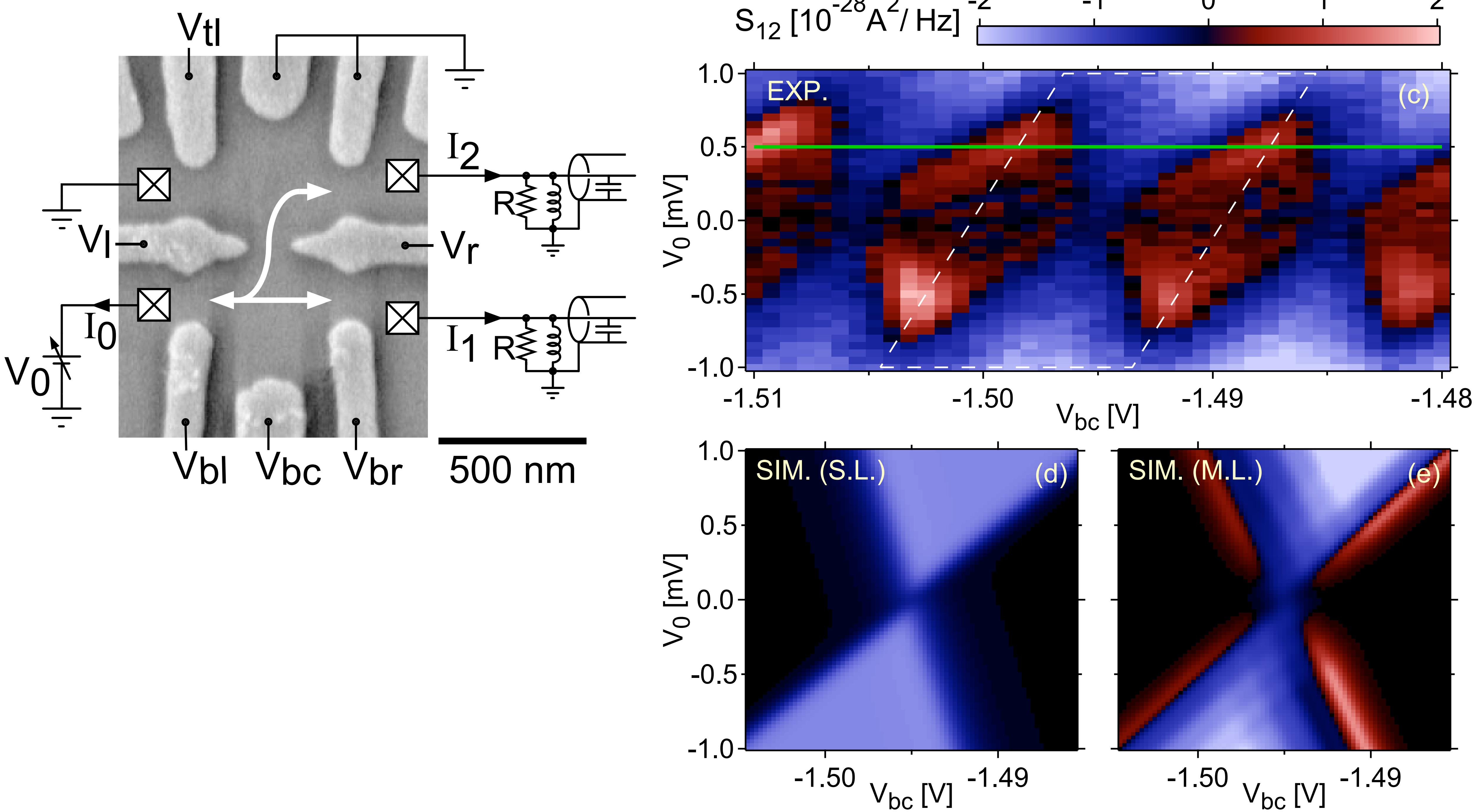

Noise Correlations in a Coulomb-Blockaded Quantum Dot

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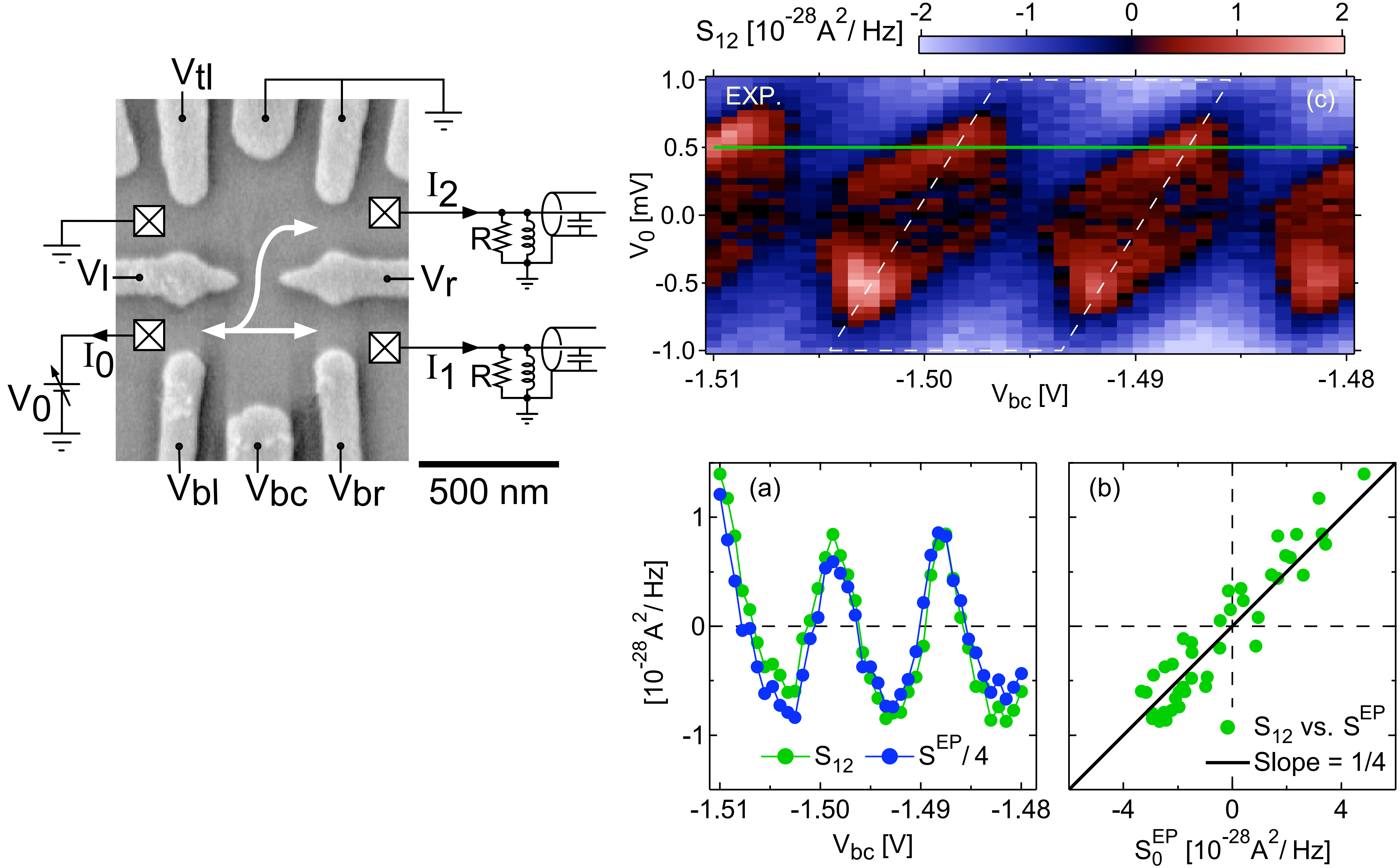
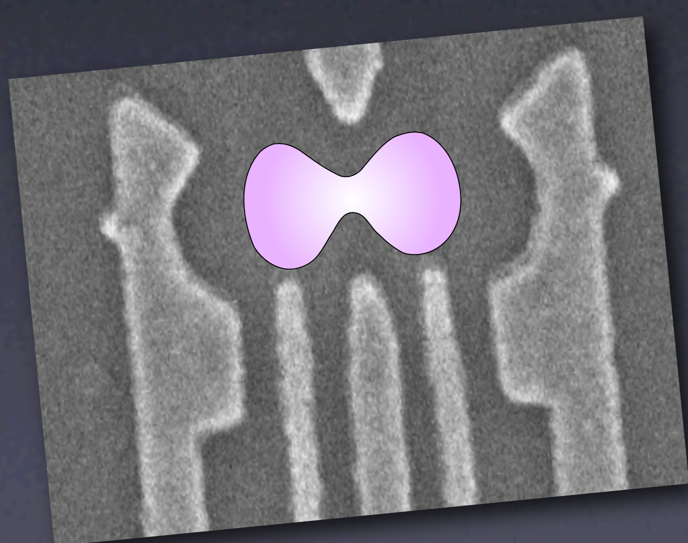
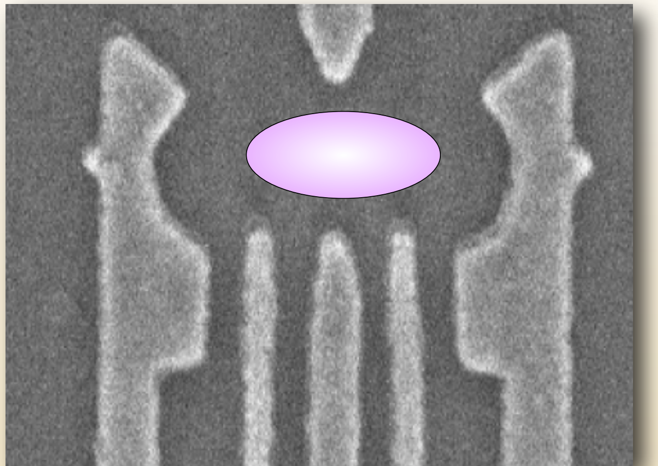


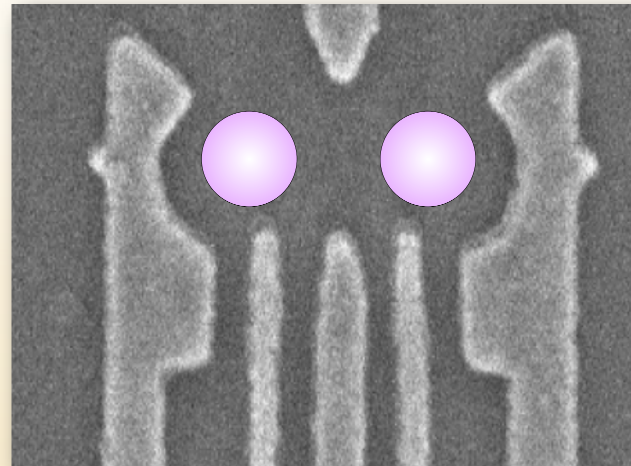
Double quantum dots



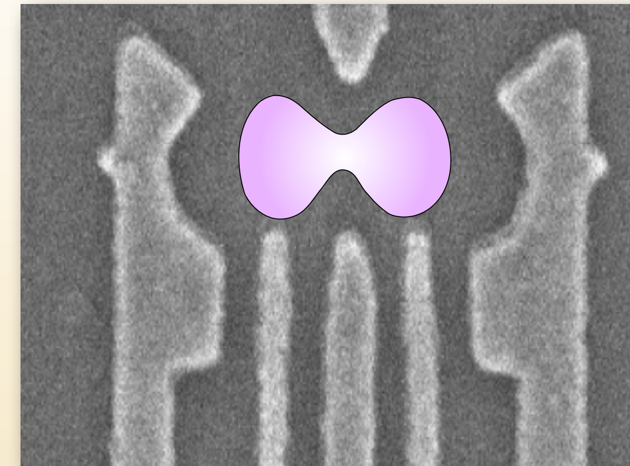
Double Dots



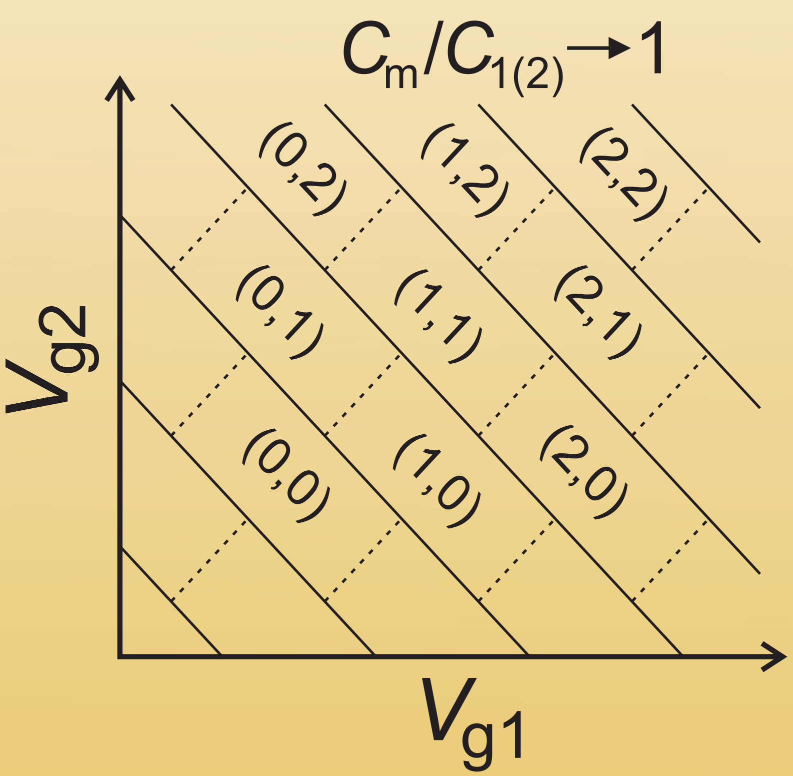
one big dot

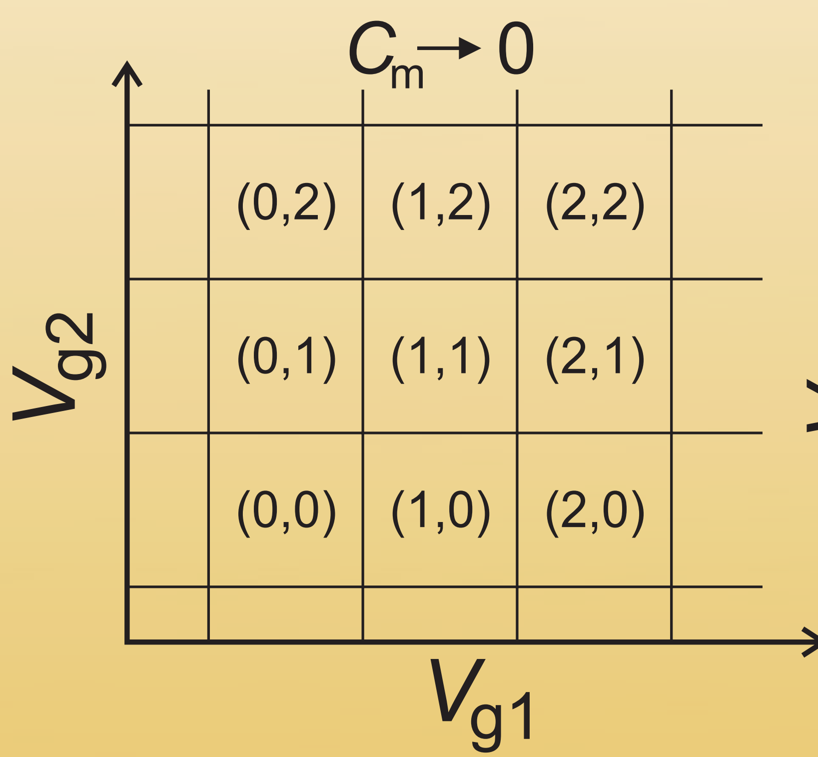


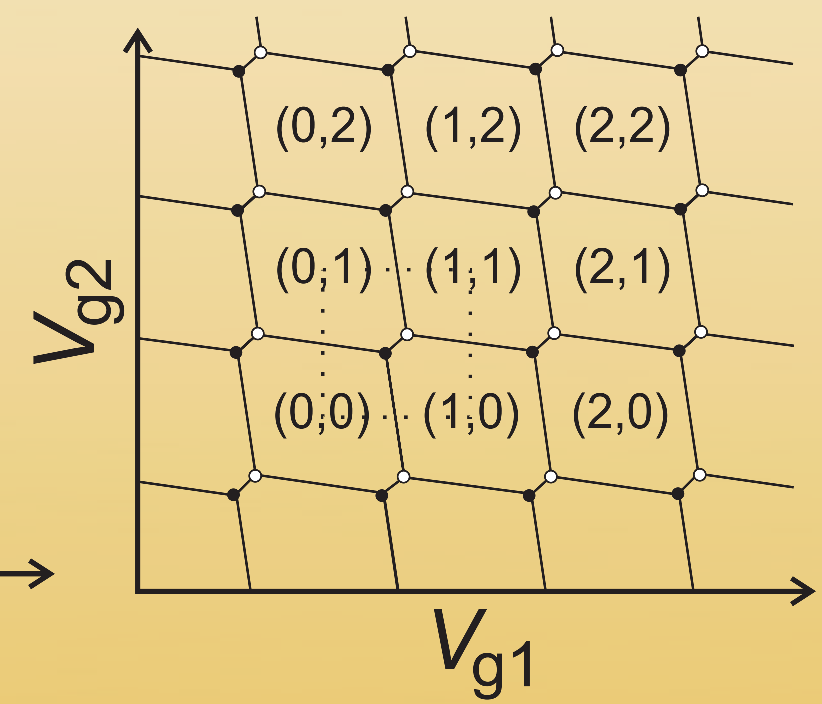
two independent dots



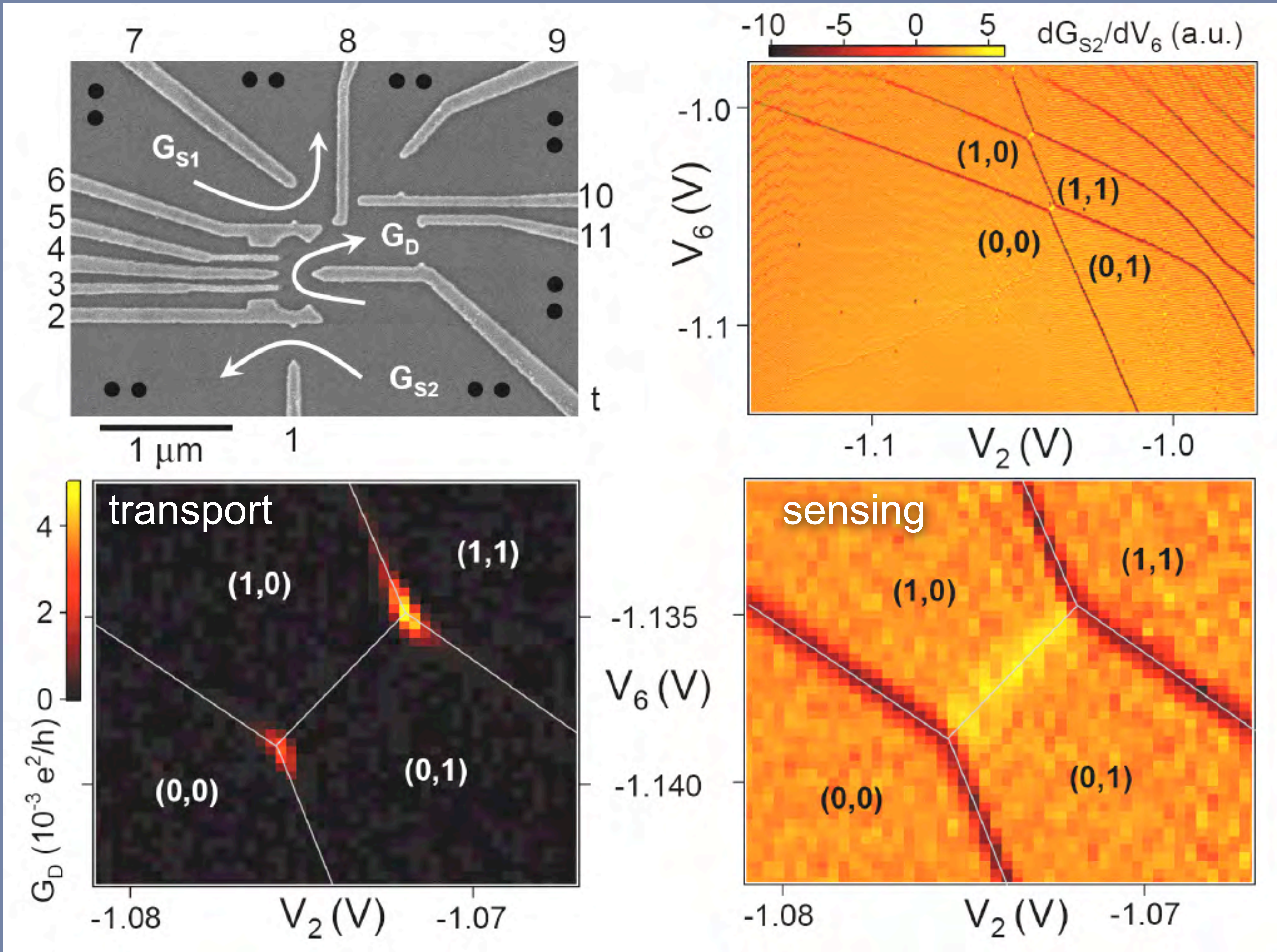
individual and mutual capacitances



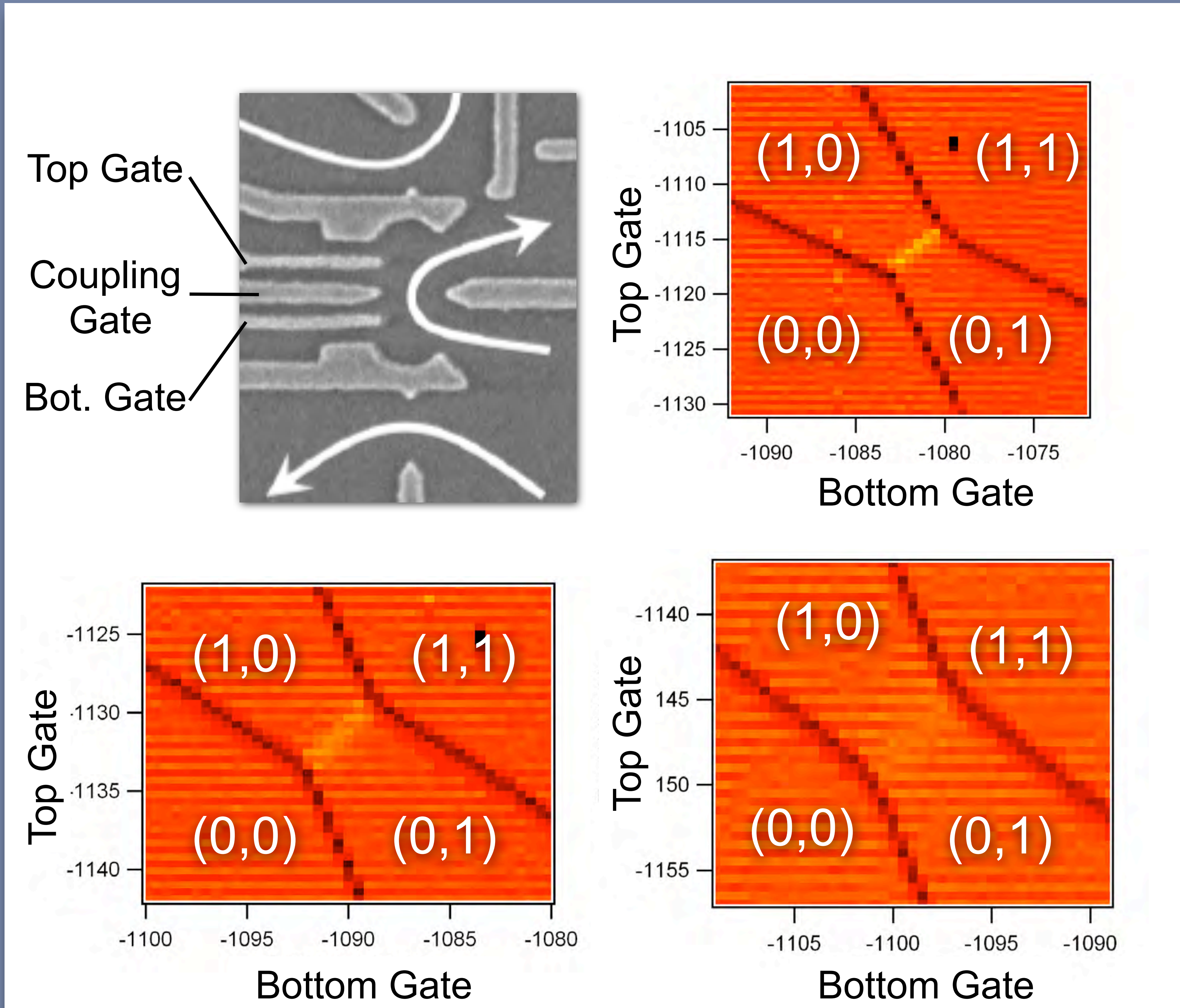




van der Wiel, et al.

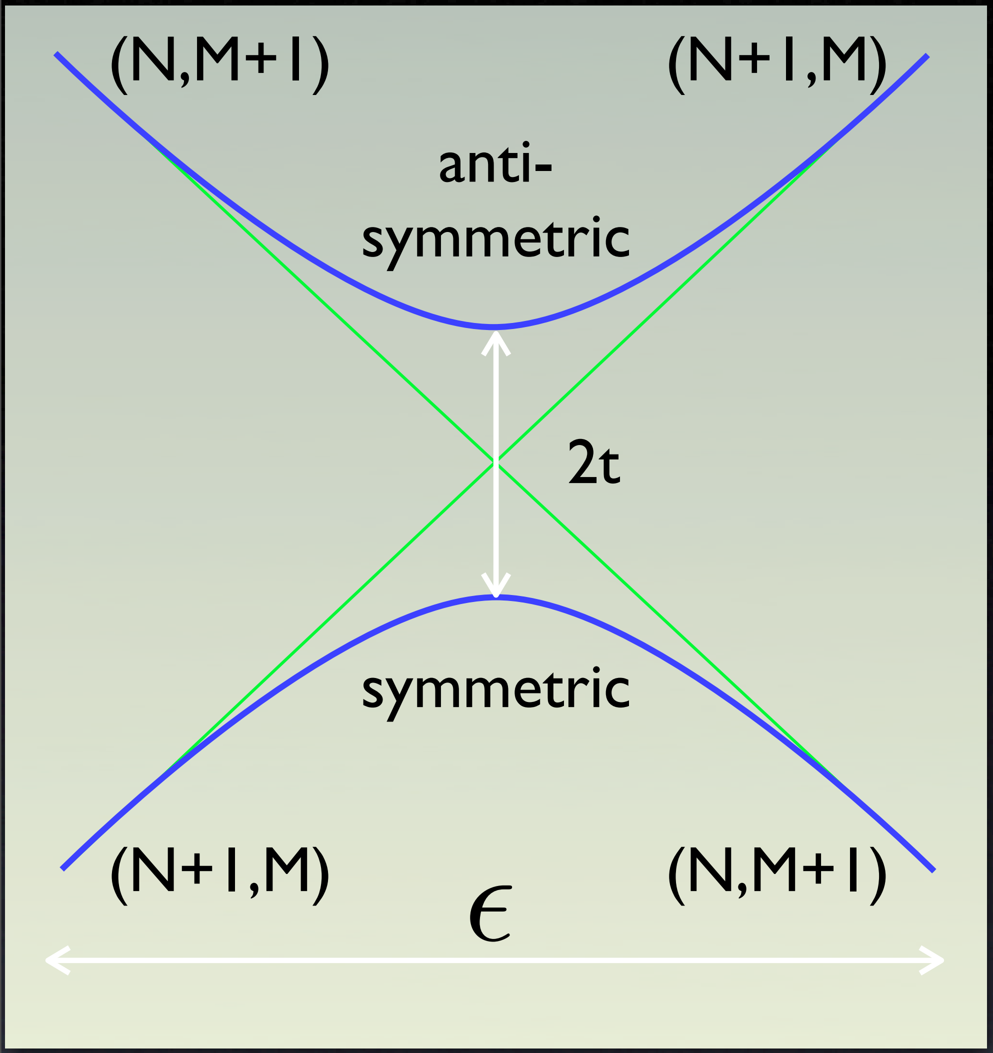

7
8
9
G_{S1}
G_D
G_{S2}
6
5
4
3
2
10
11
t
1
1 µm
-10 -5 0 5
dG_{S2}/dV_6 (a.u.)
-1.0
-1.1
V_6 (V)
(1,0)
(1,1)
(0,0)
(0,1)
-1.1
V_2 (V)
-1.0
transport
4
2
0
G_D (10^{-3} e^2/h)
(1,0)
(1,1)
(0,0)
(0,1)
-1.08
V_2 (V)
-1.07
-1.135
V_6 (V)
-1.140
sensing
(1,0)
(1,1)
(0,0)
(0,1)
-1.08
V_2 (V)
-1.07

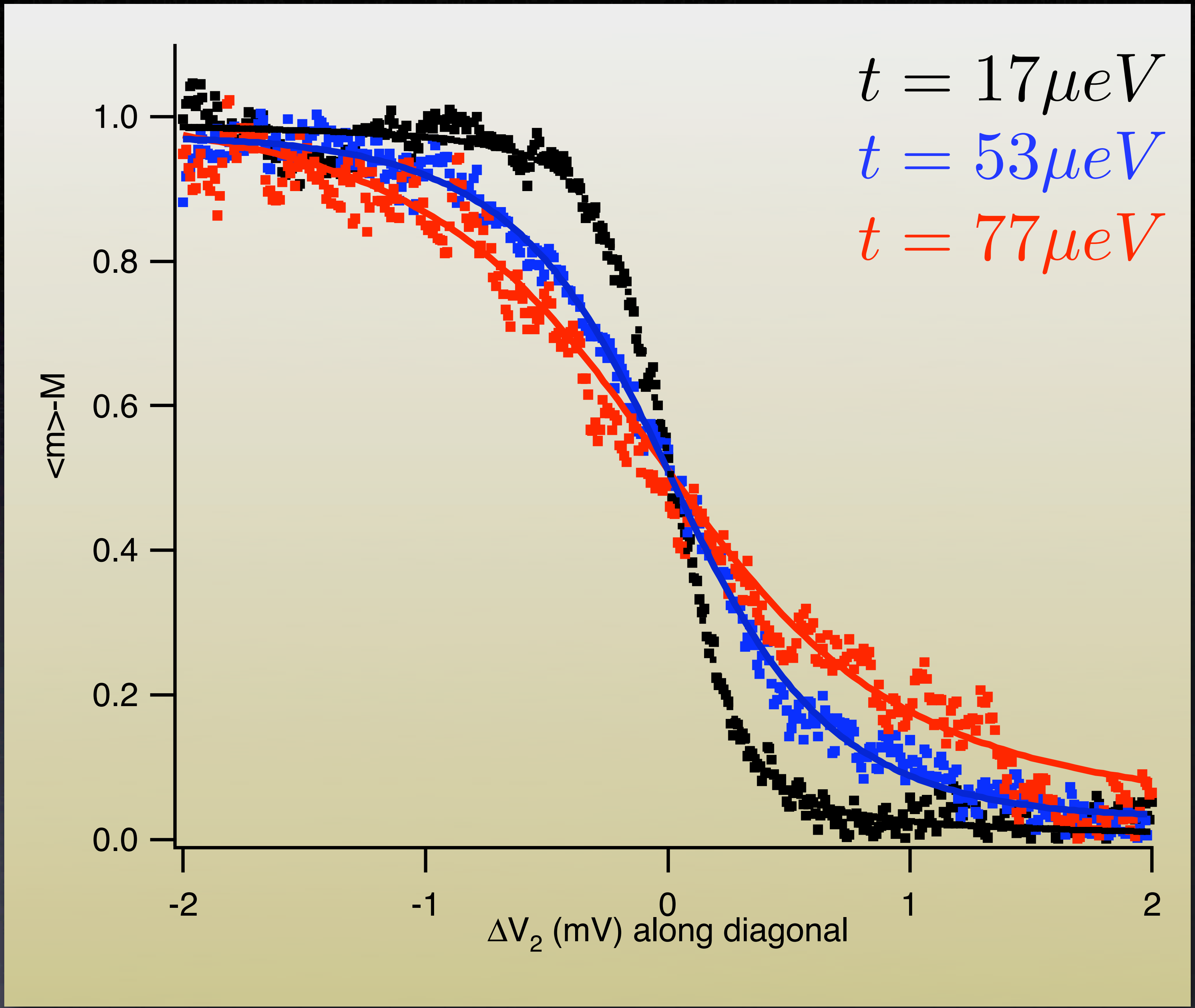
Controlled Interdot Tunneling

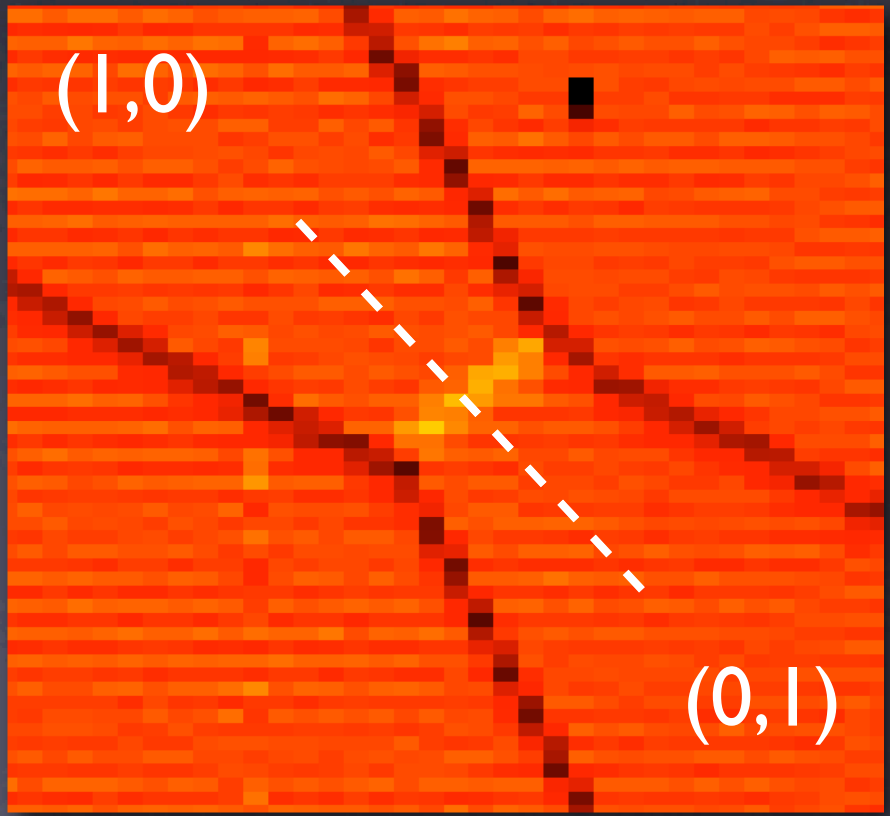


J. R. Petta, CMM (2004)

Charge-state readout using charge sensors





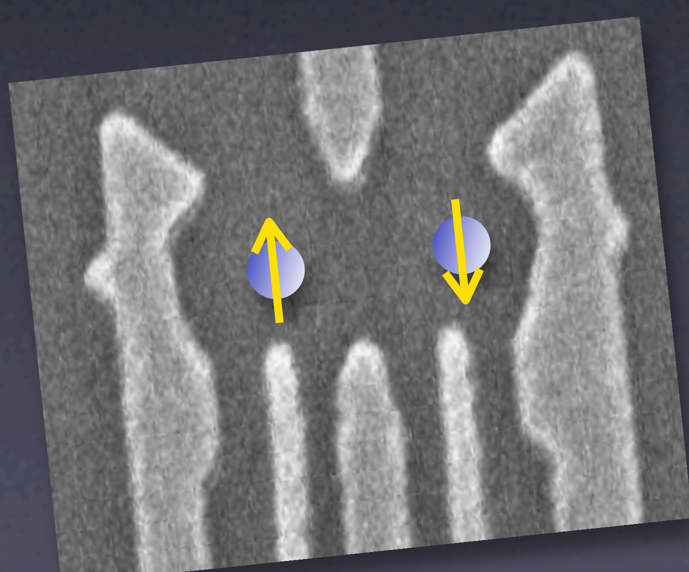


Theory

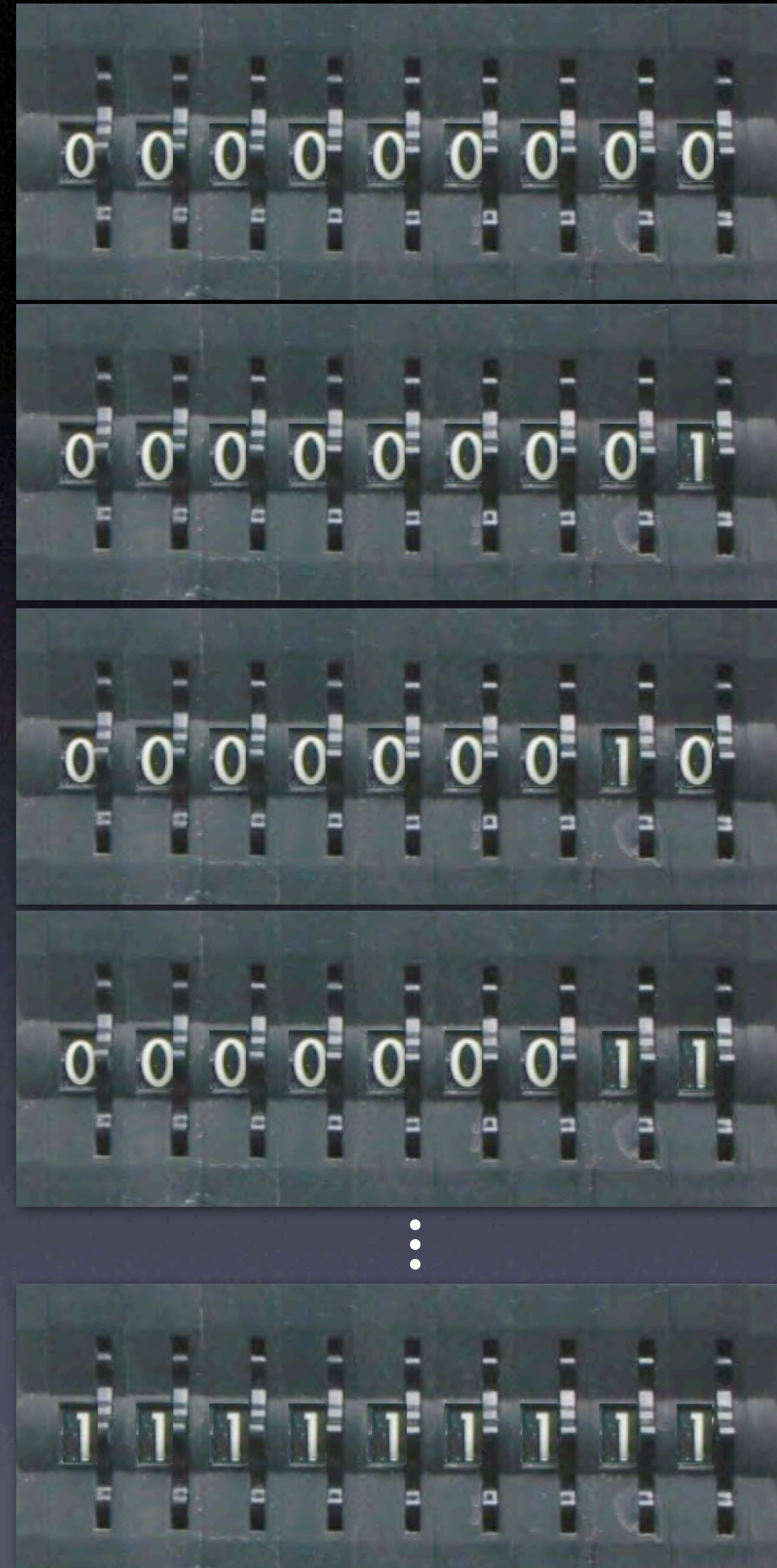
$$\delta g_{\mathrm{s,i}} = \delta g_i \frac{\epsilon}{\sqrt{\epsilon^2 + 4t^2}} \tanh\left(\frac{\sqrt{\epsilon^2 + 4t^2}}{2k_B T_e}\right) + \frac{\partial g_{\mathrm{s,i}}}{\partial \epsilon}\epsilon$$

L. DiCarlo, et al. Phys. Rev. Lett. 92, 226801 (2004);
J. R. Petta, et al. Phys. Rev. Lett. 93, 186802 (2004).

Spin Qubits

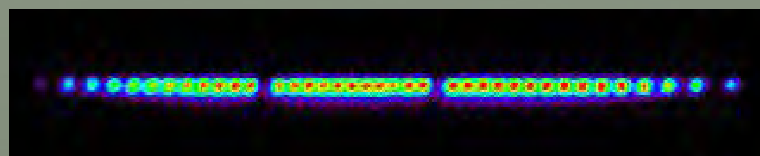


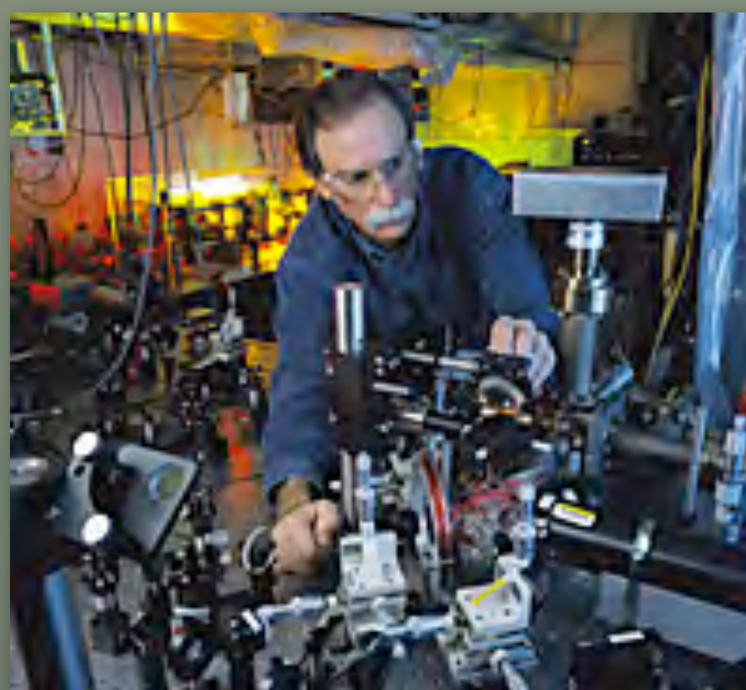
$$|\psi\rangle = \left\{ \right.$$



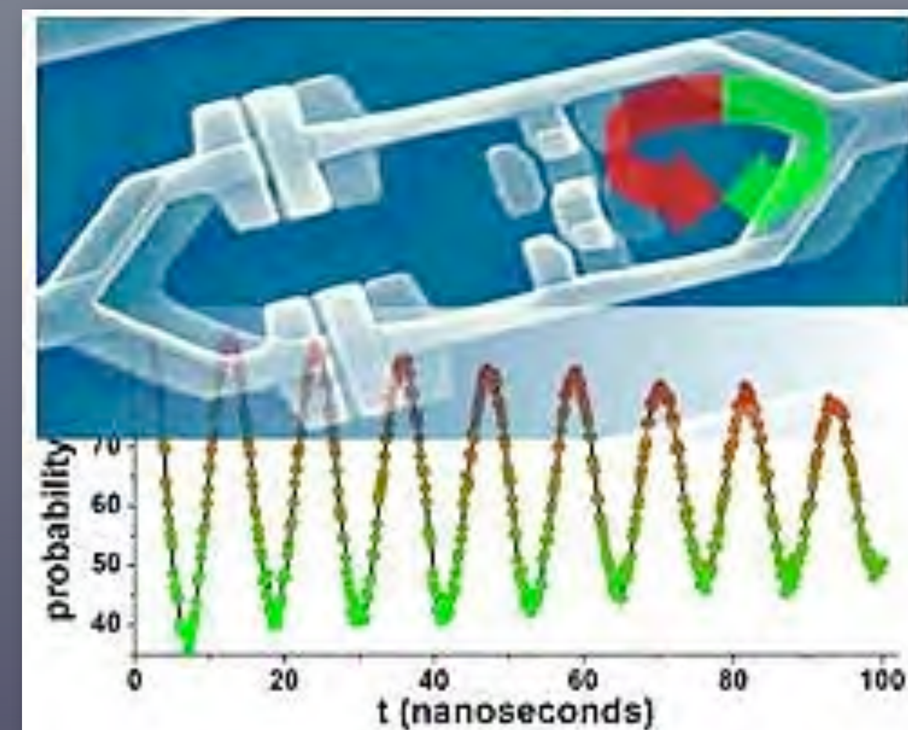
making controllable qubits

ion traps

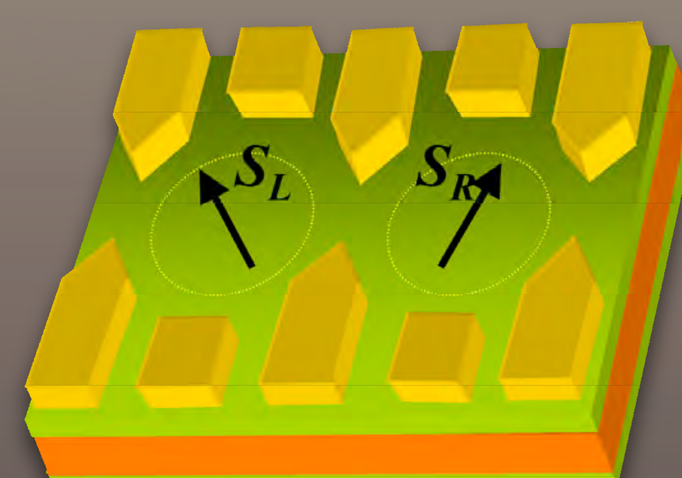




Josephson devices



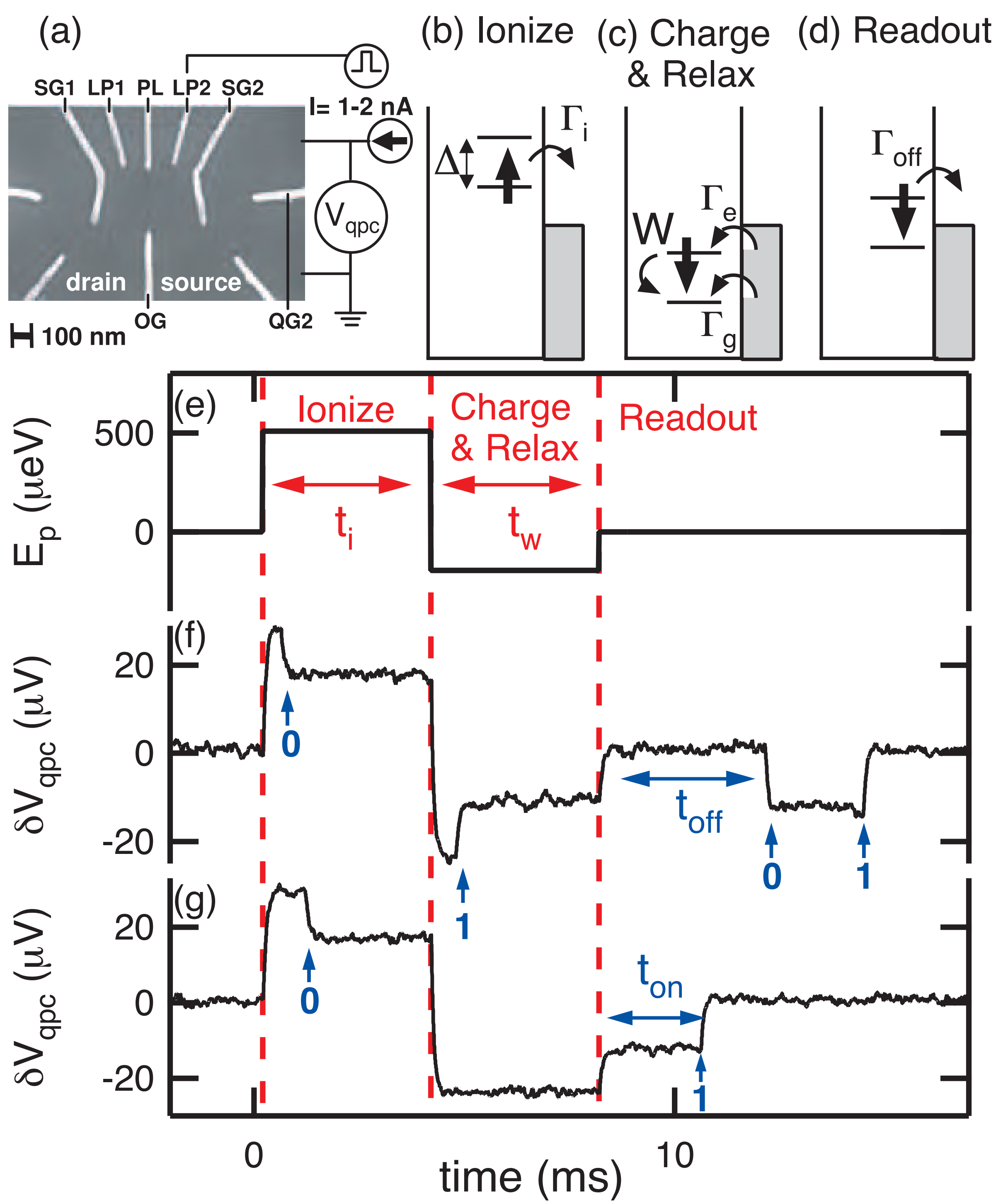
Electron Spins in Dots

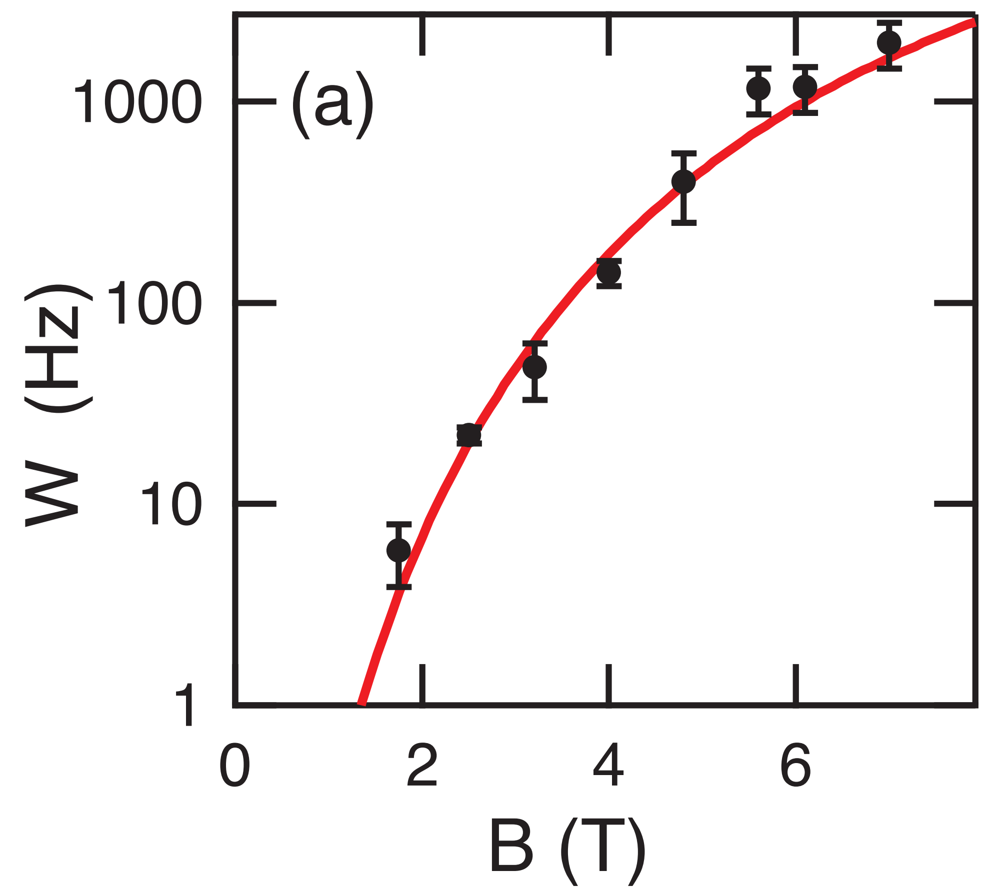


Measurements of the spin relaxation rate at low magnetic fields in a quantum dot

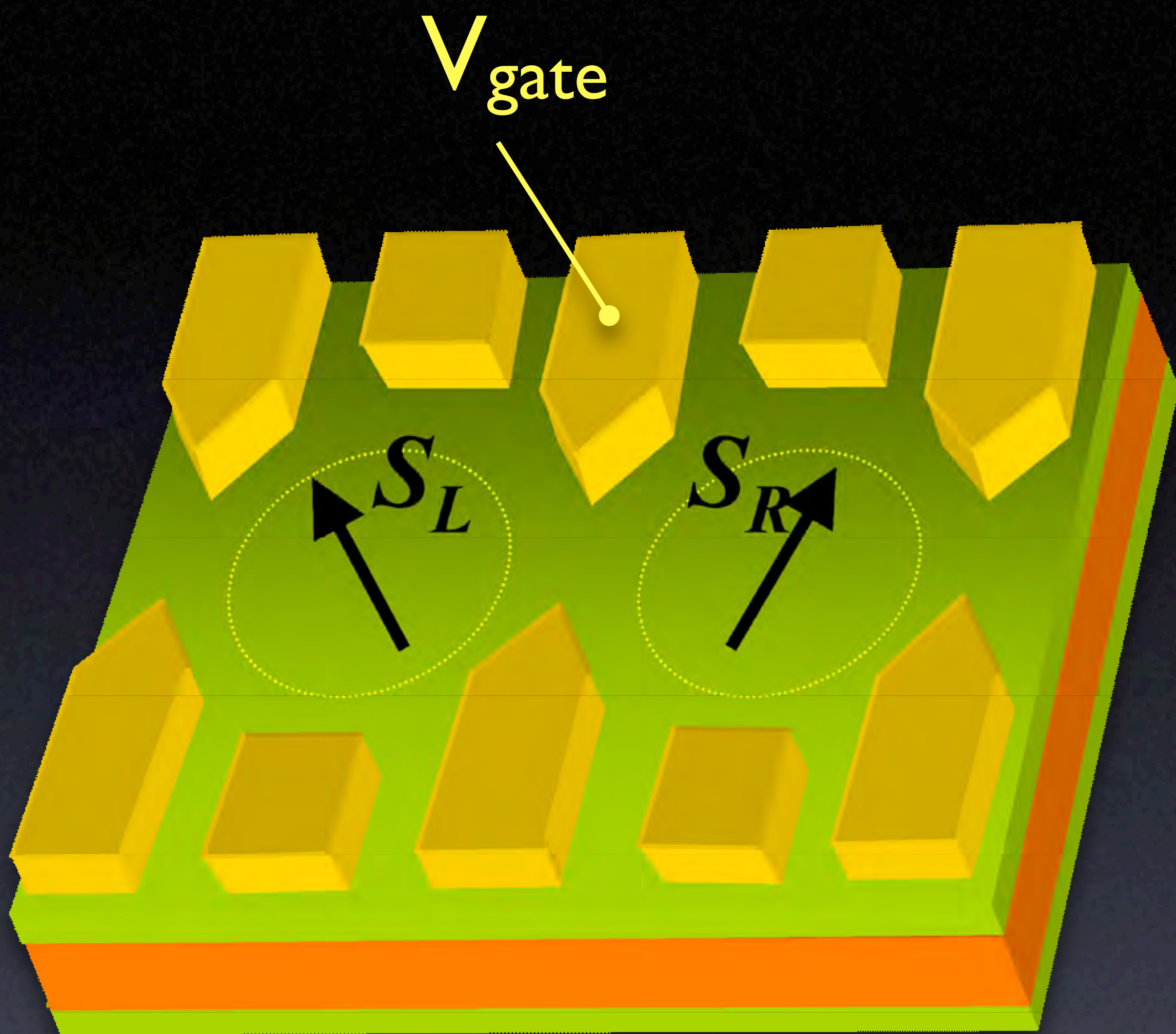
S. Amasha,[1,*] K. MacLean,[1] Iuliana Radu,[1] D. M. Zumbühl,[1,2] M. A. Kastner,[1] M. P. Hanson,[3] and A. C. Gossard[3]

[1]*Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*
[2]*Department of Physics and Astronomy, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland*
[3]*Materials Department, University of California, Santa Barbara 93106-5050*

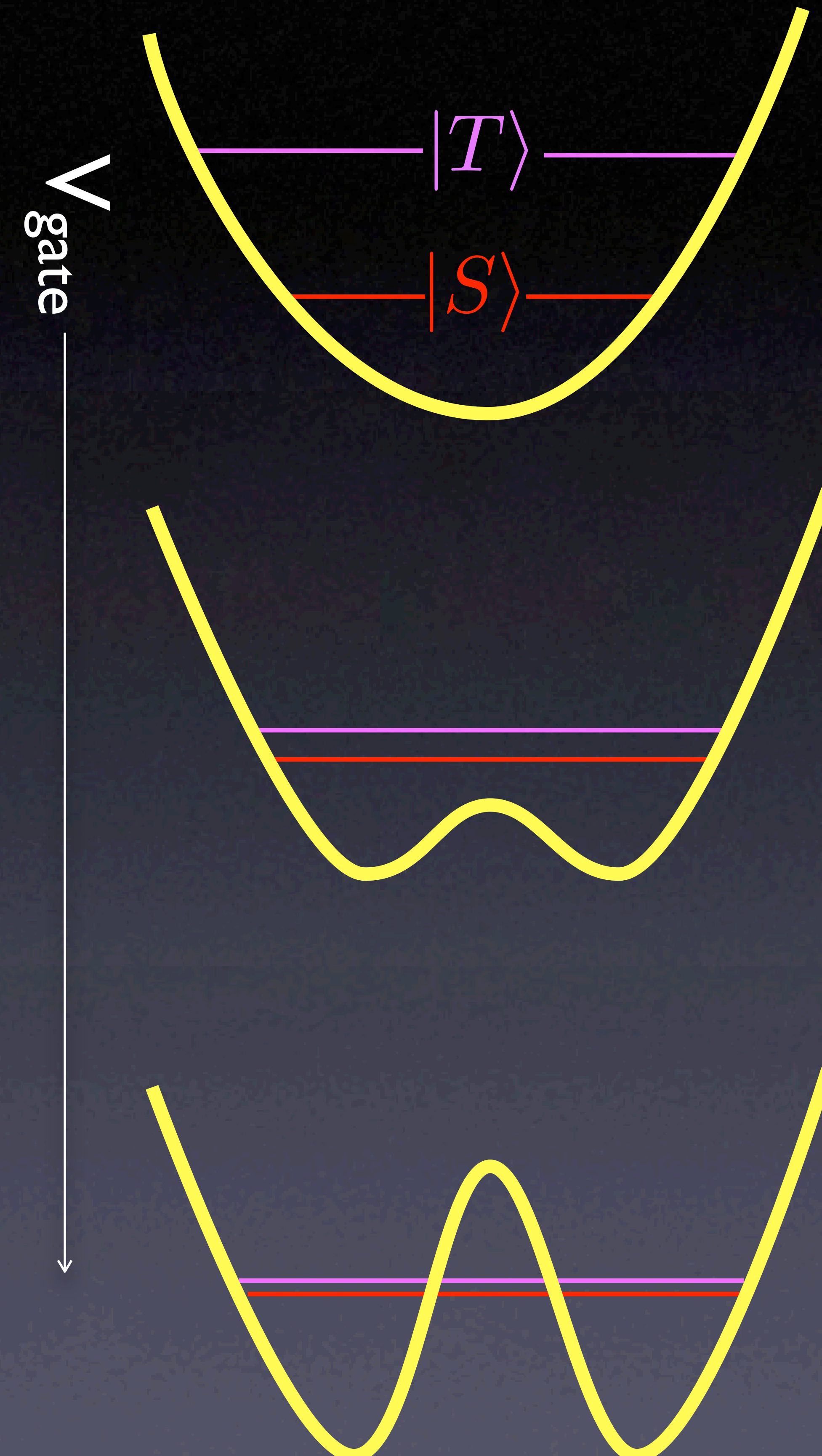




spin qubits



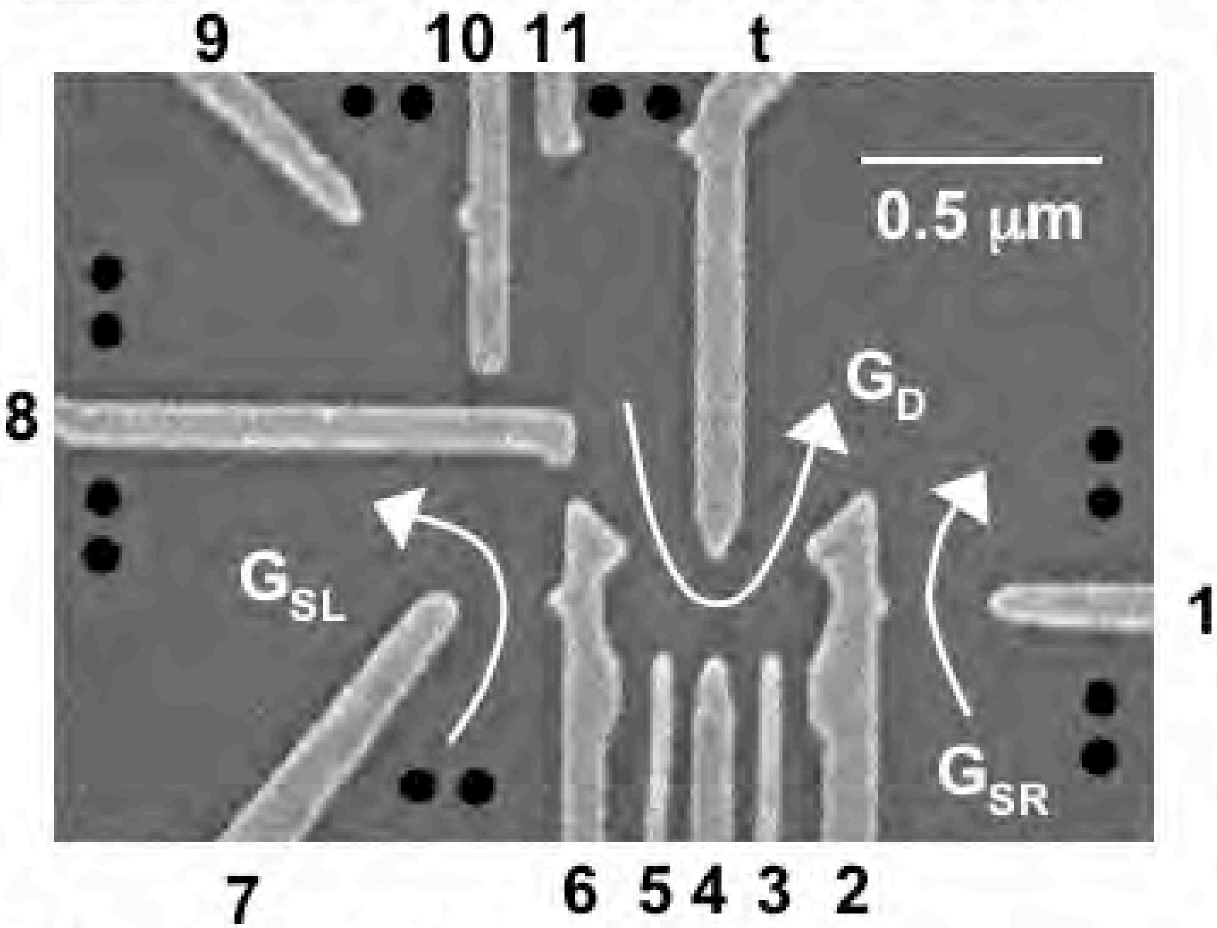
two-electron states

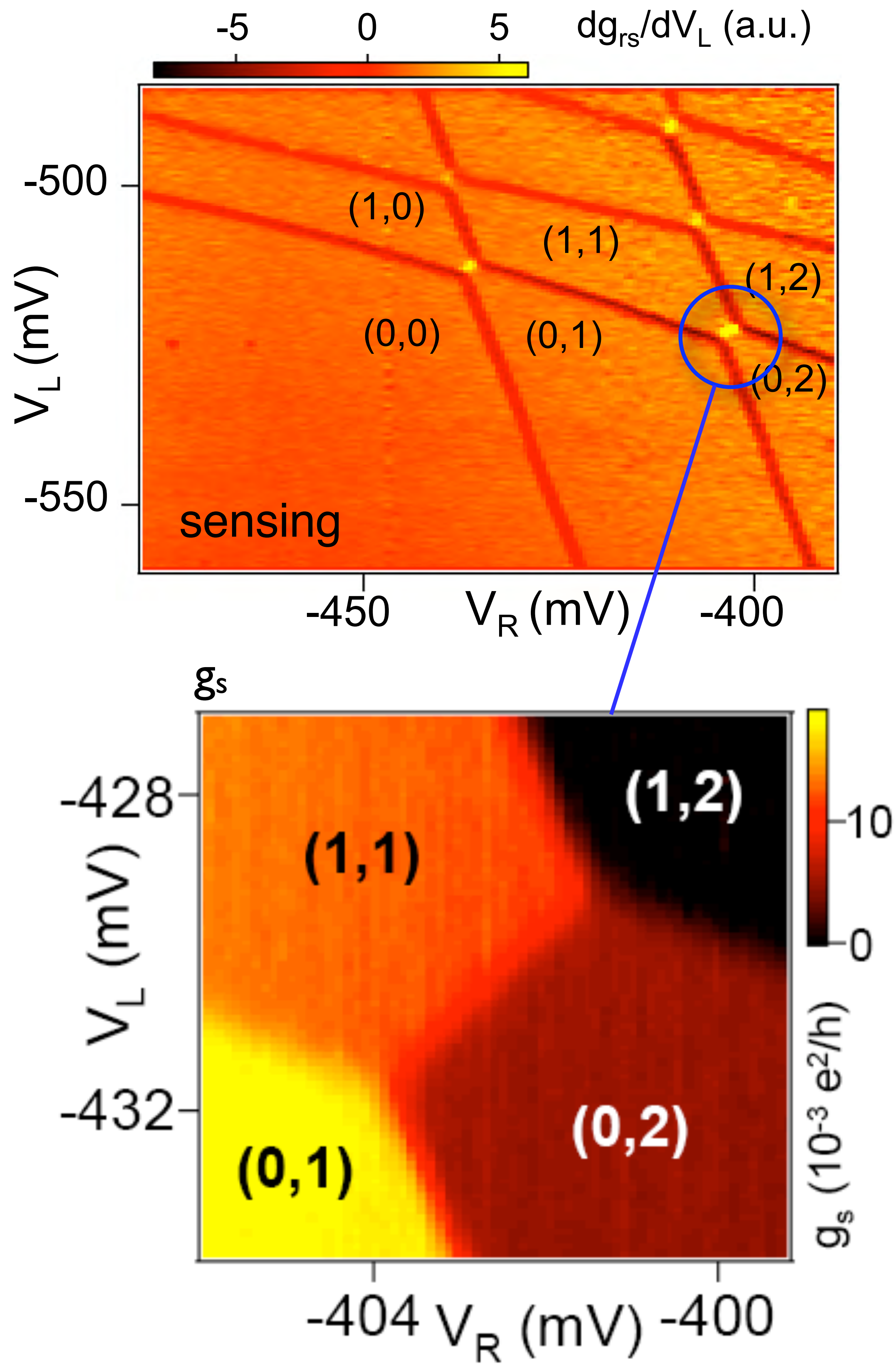


$$|S\rangle = |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$

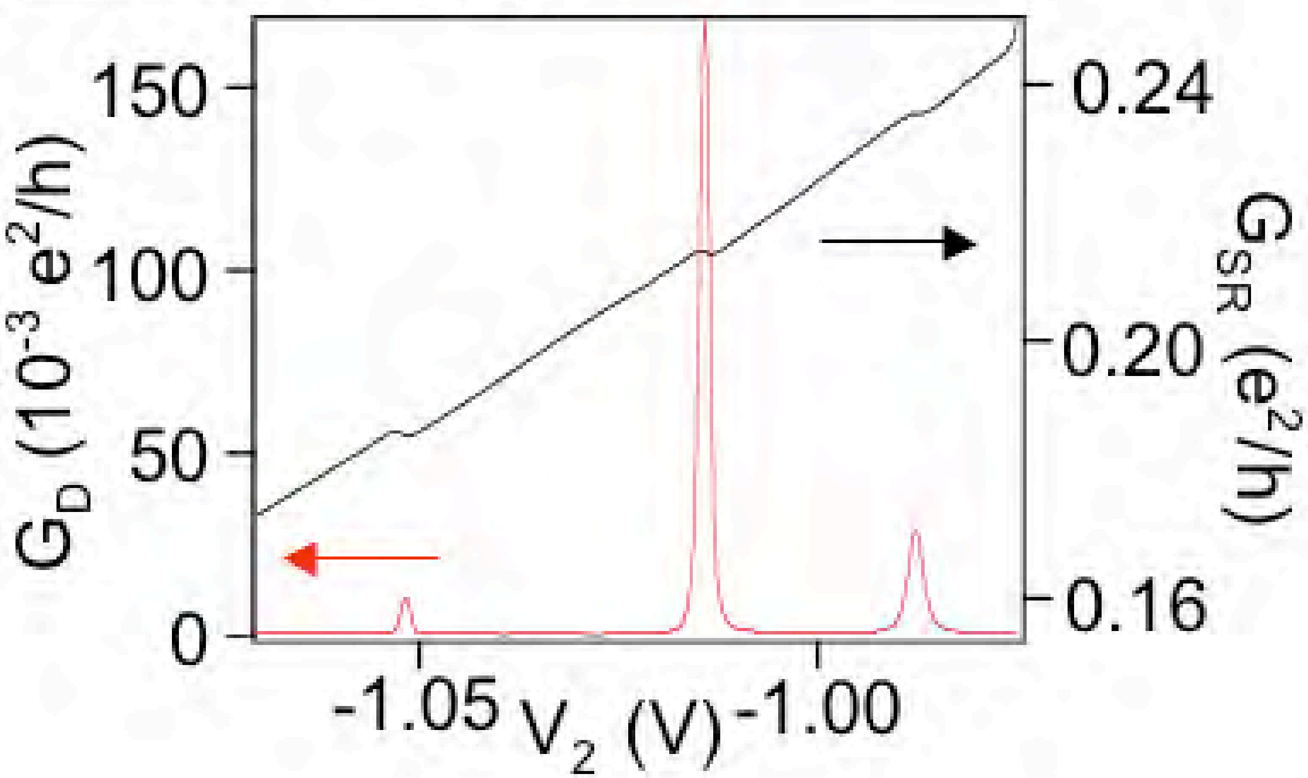
$$|T\rangle = |\uparrow\uparrow\rangle, |\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle, |\downarrow\downarrow\rangle$$

Charge transport in a double dot



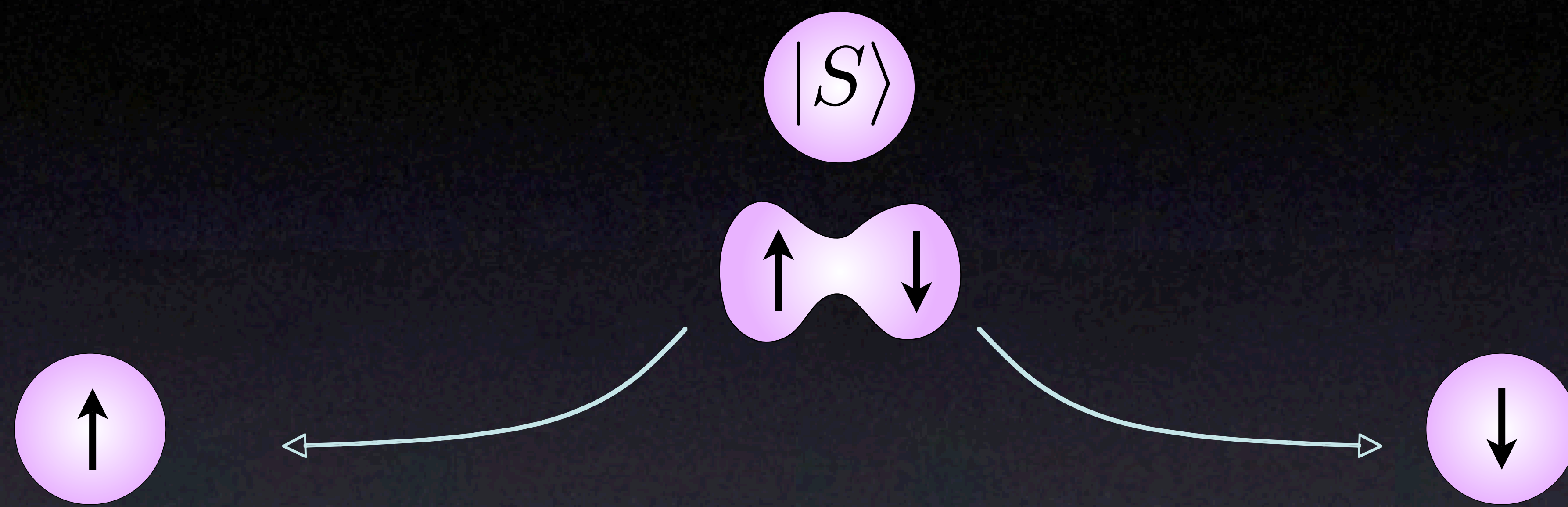


Charge sensing

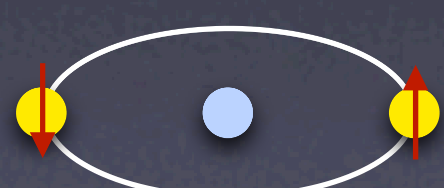


QPC sensing: Field *et al.*, PRL **70**, 1311 (1993)

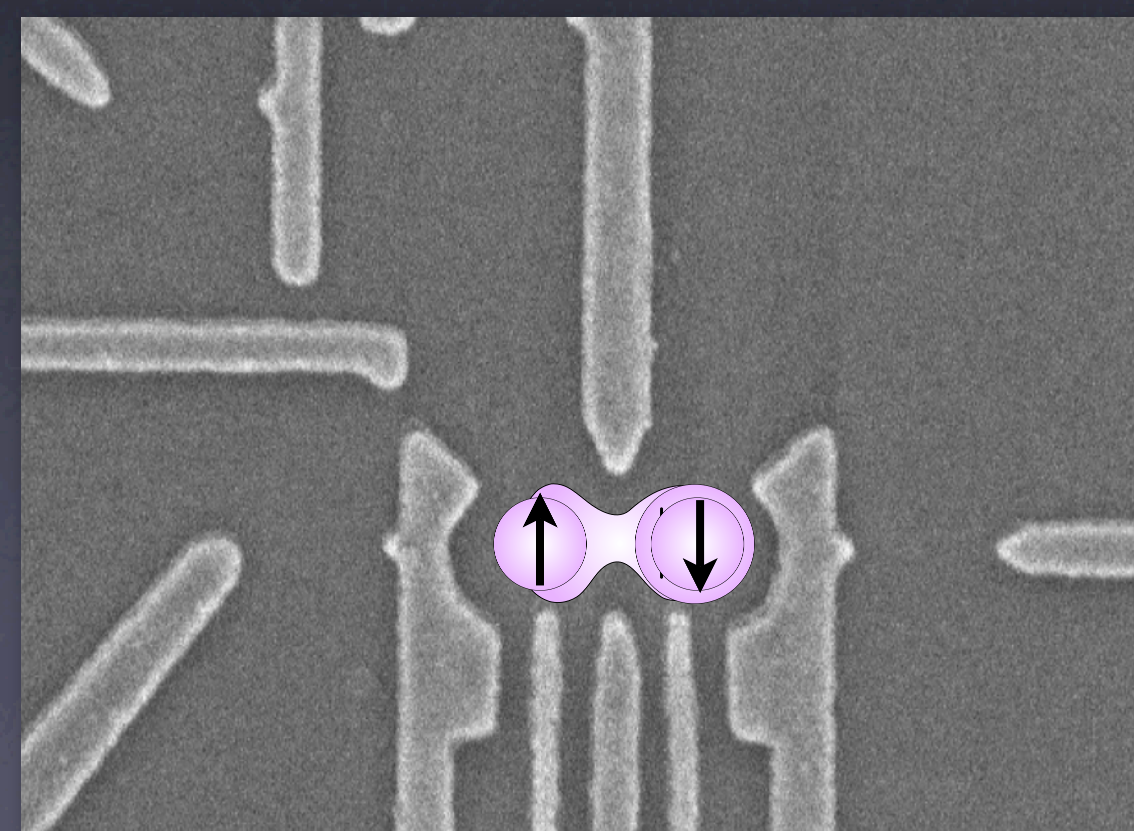
Artificial Helium Atom - Hydrogen Molecule:
An entanglement generator



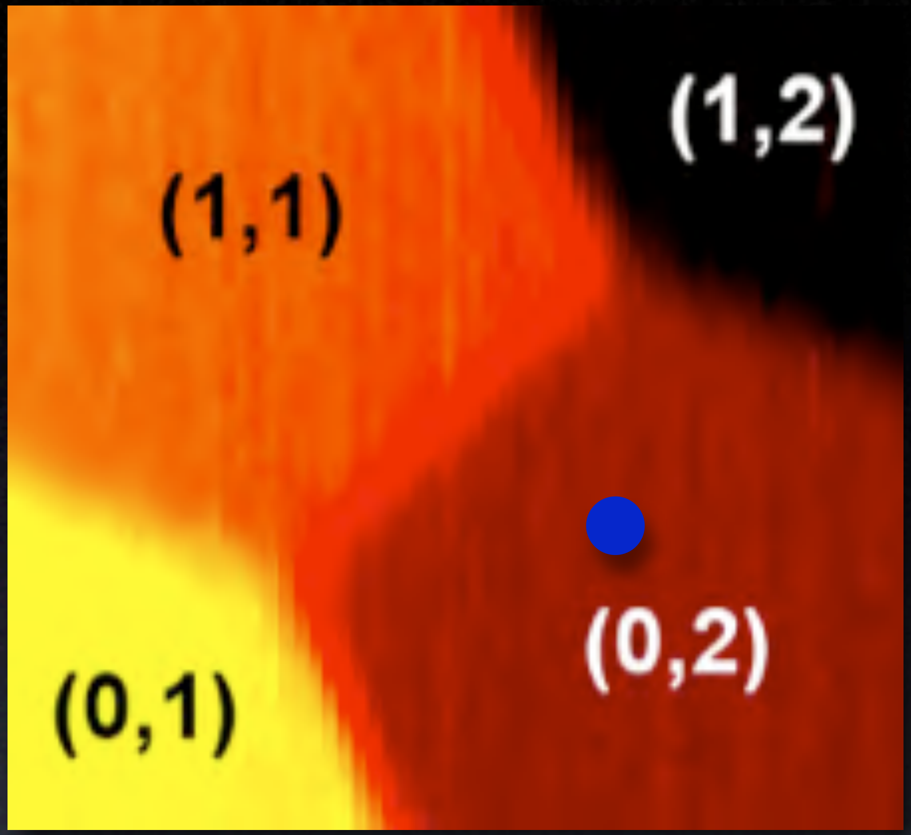
helium

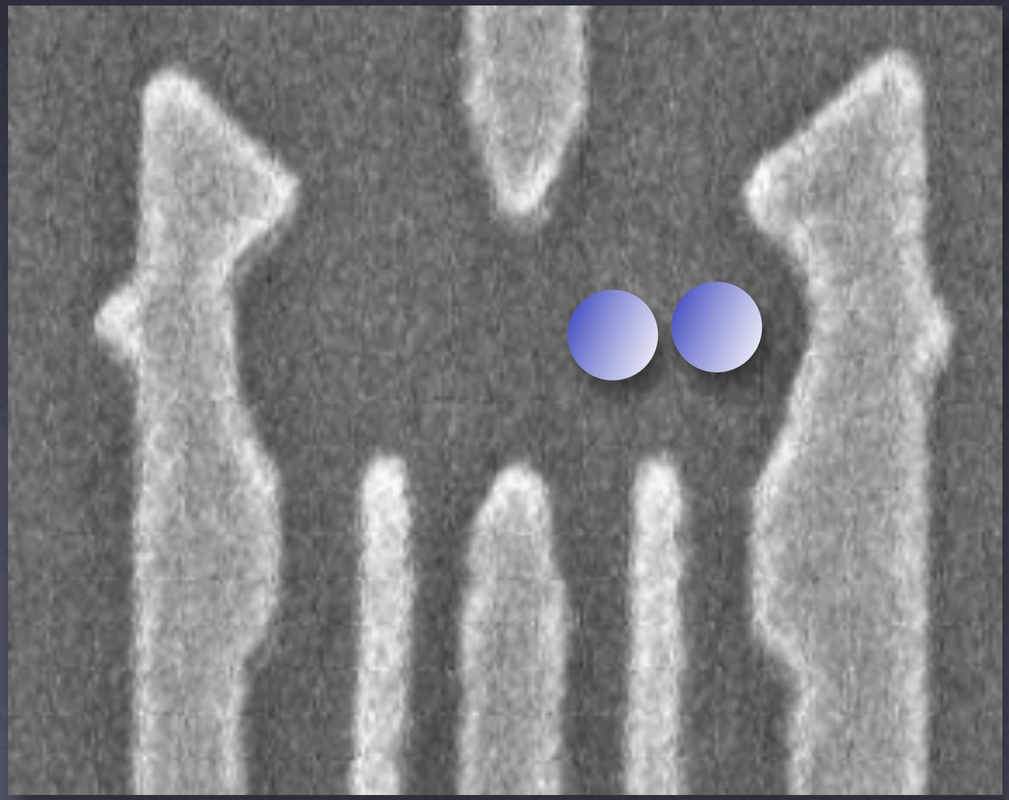


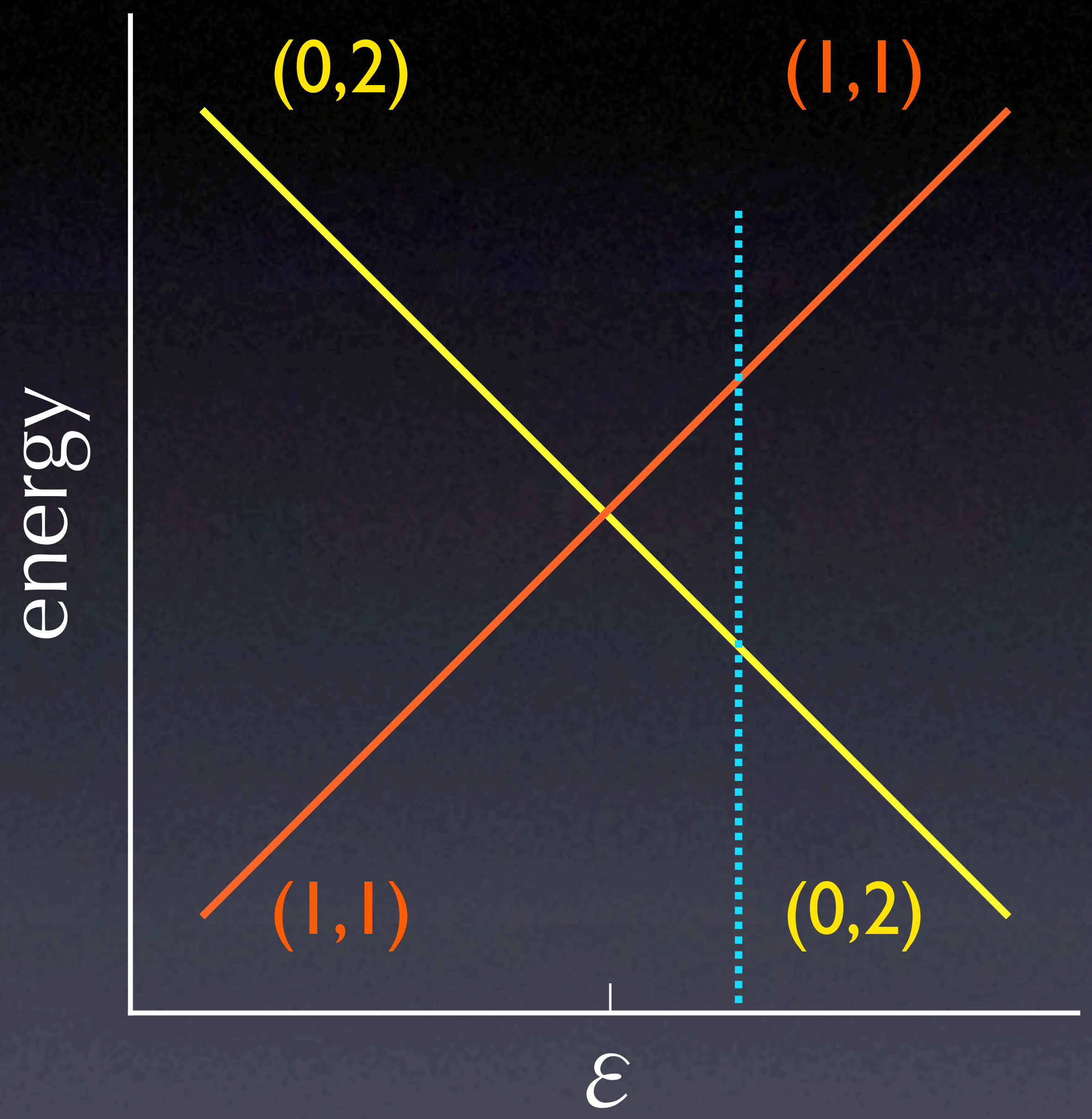
$$|S\rangle = |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$



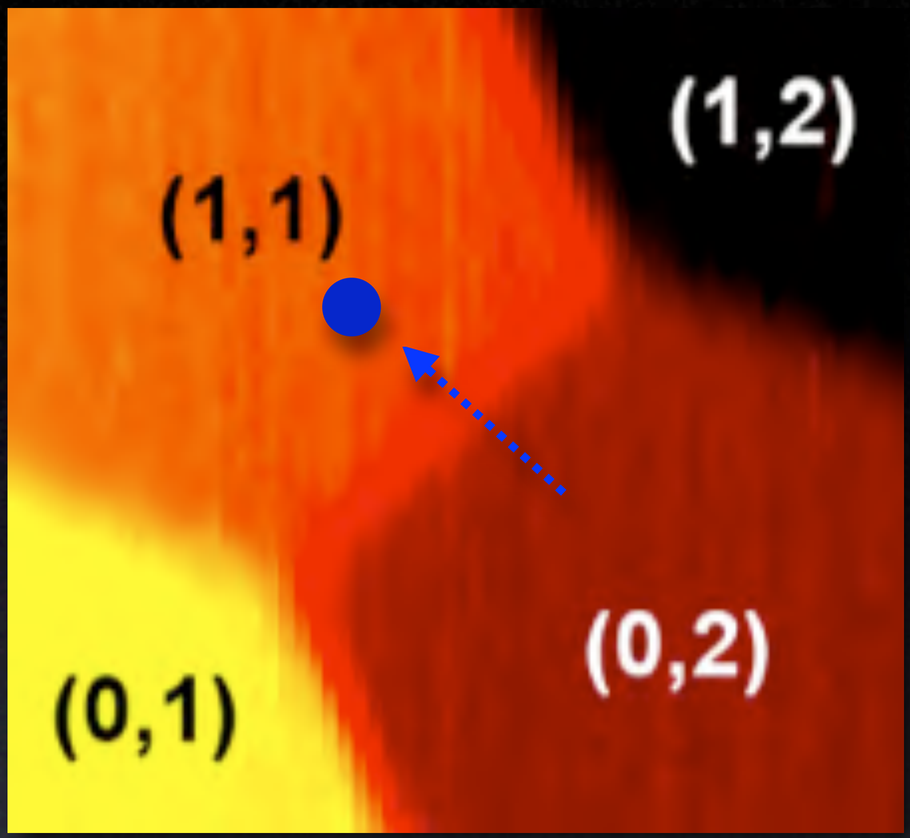
Measuring Entanglement Coherence Time

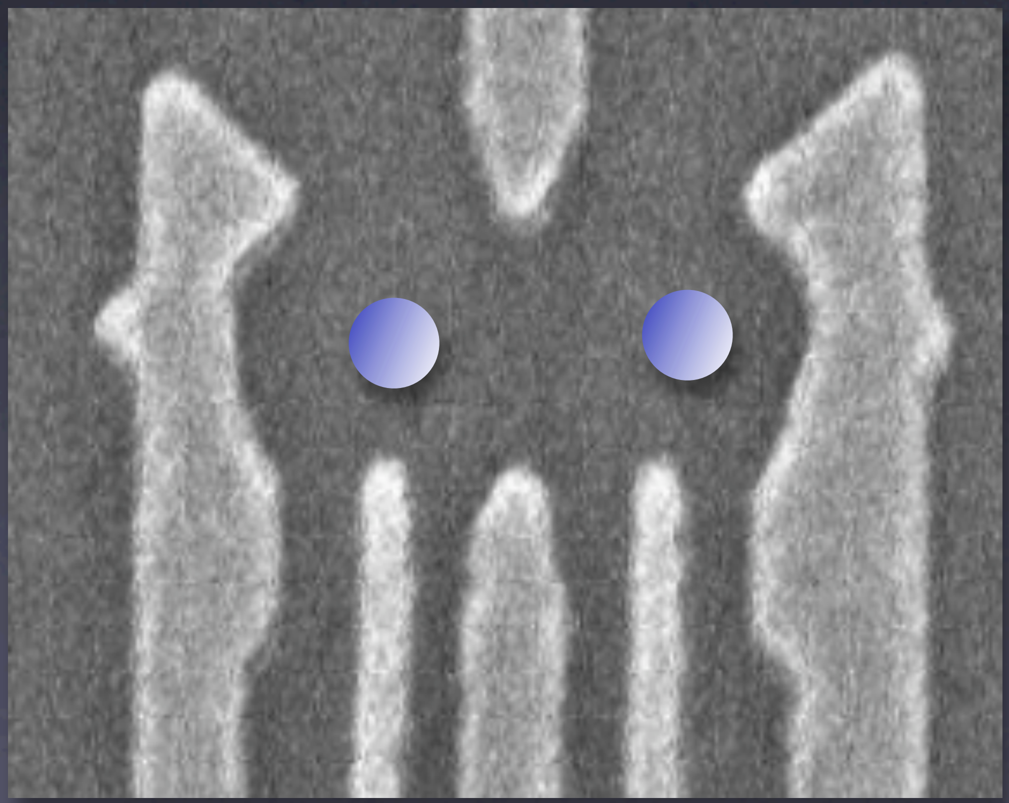


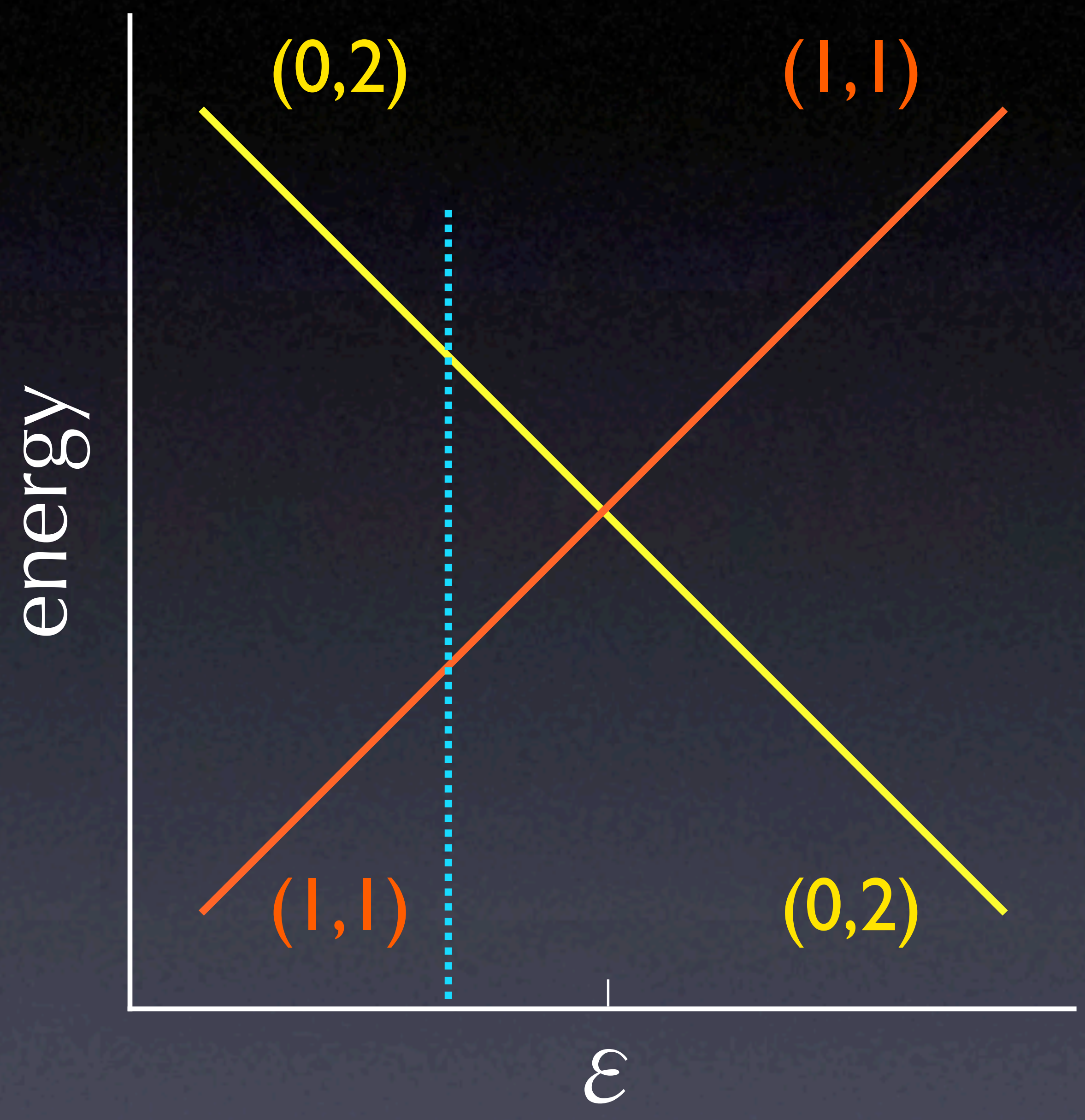




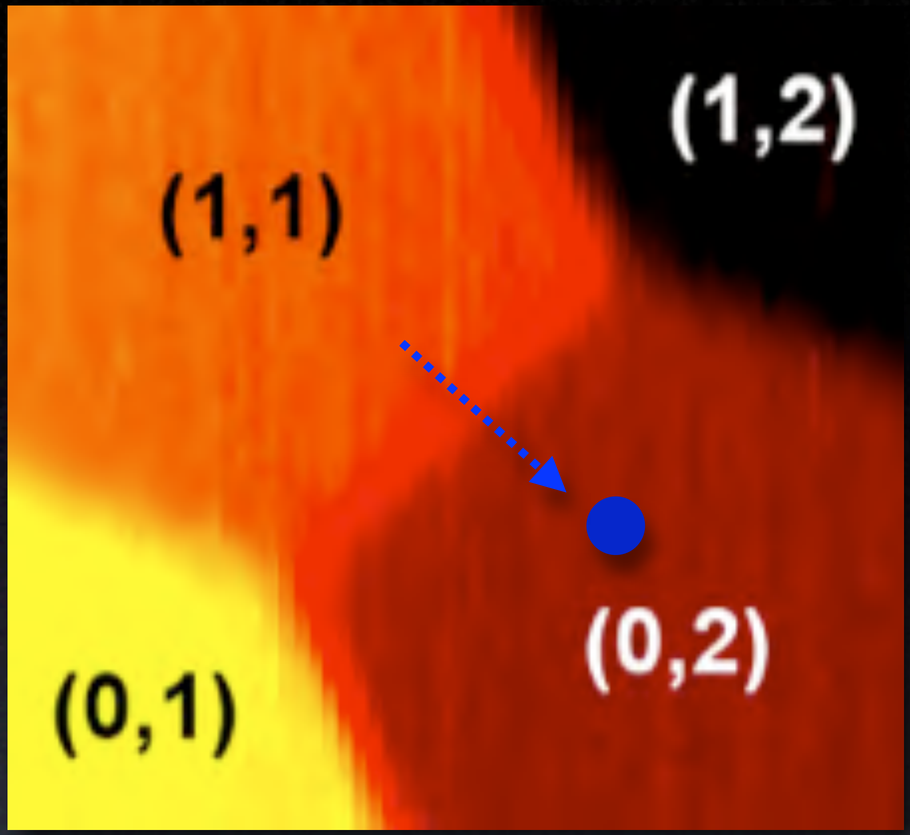
Measuring Entanglement Coherence Time

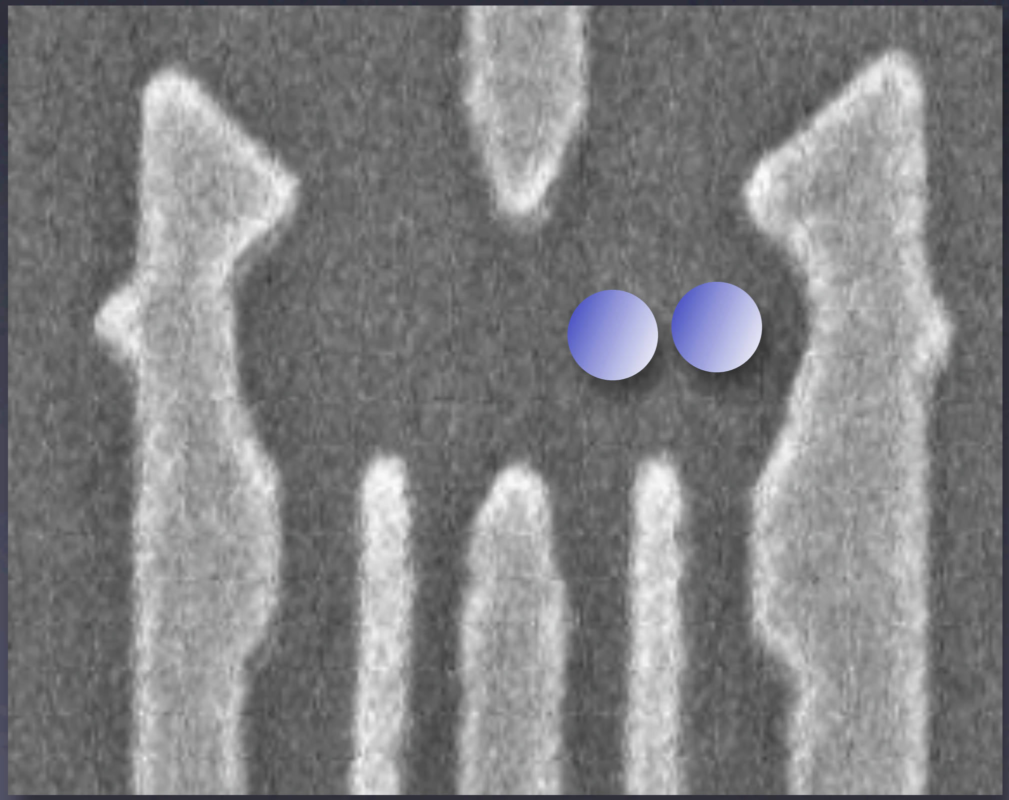


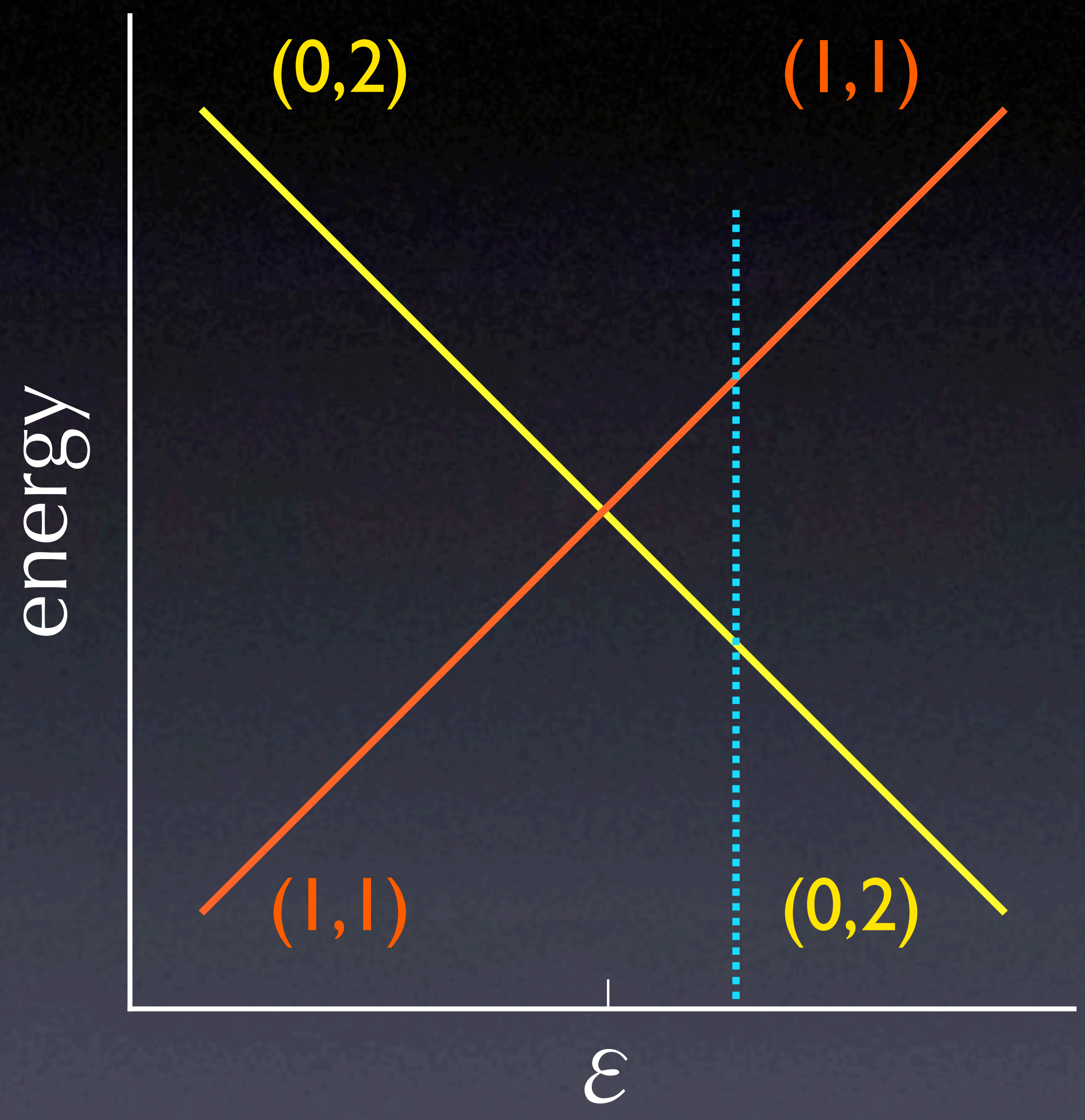




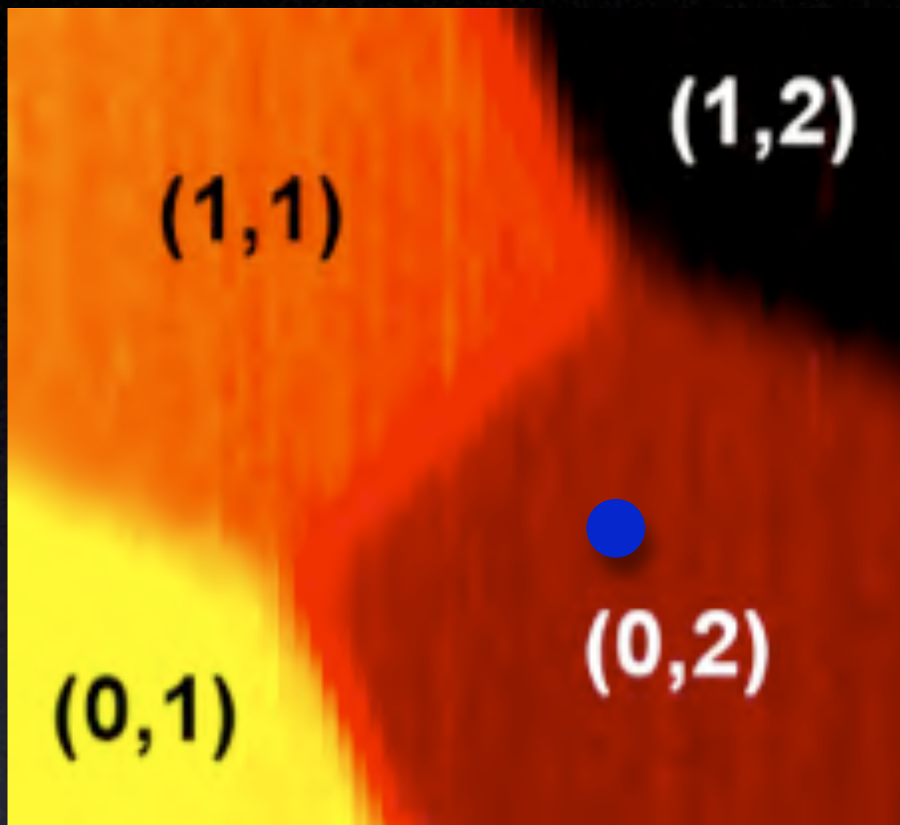
Measuring Entanglement Coherence Time

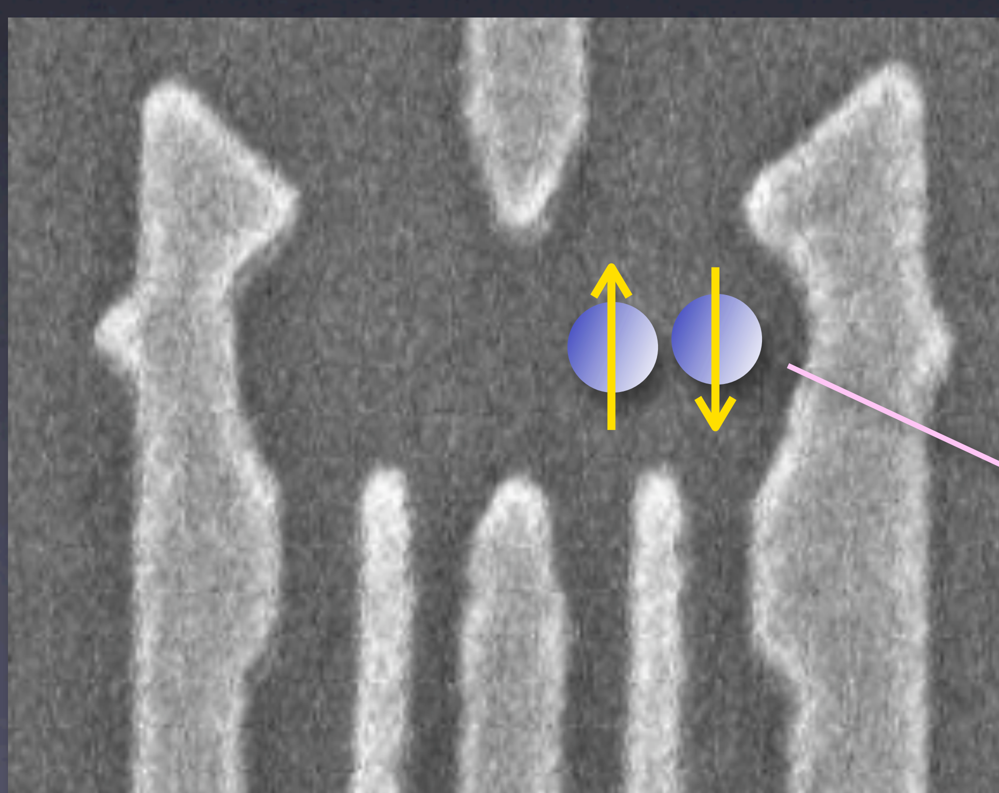


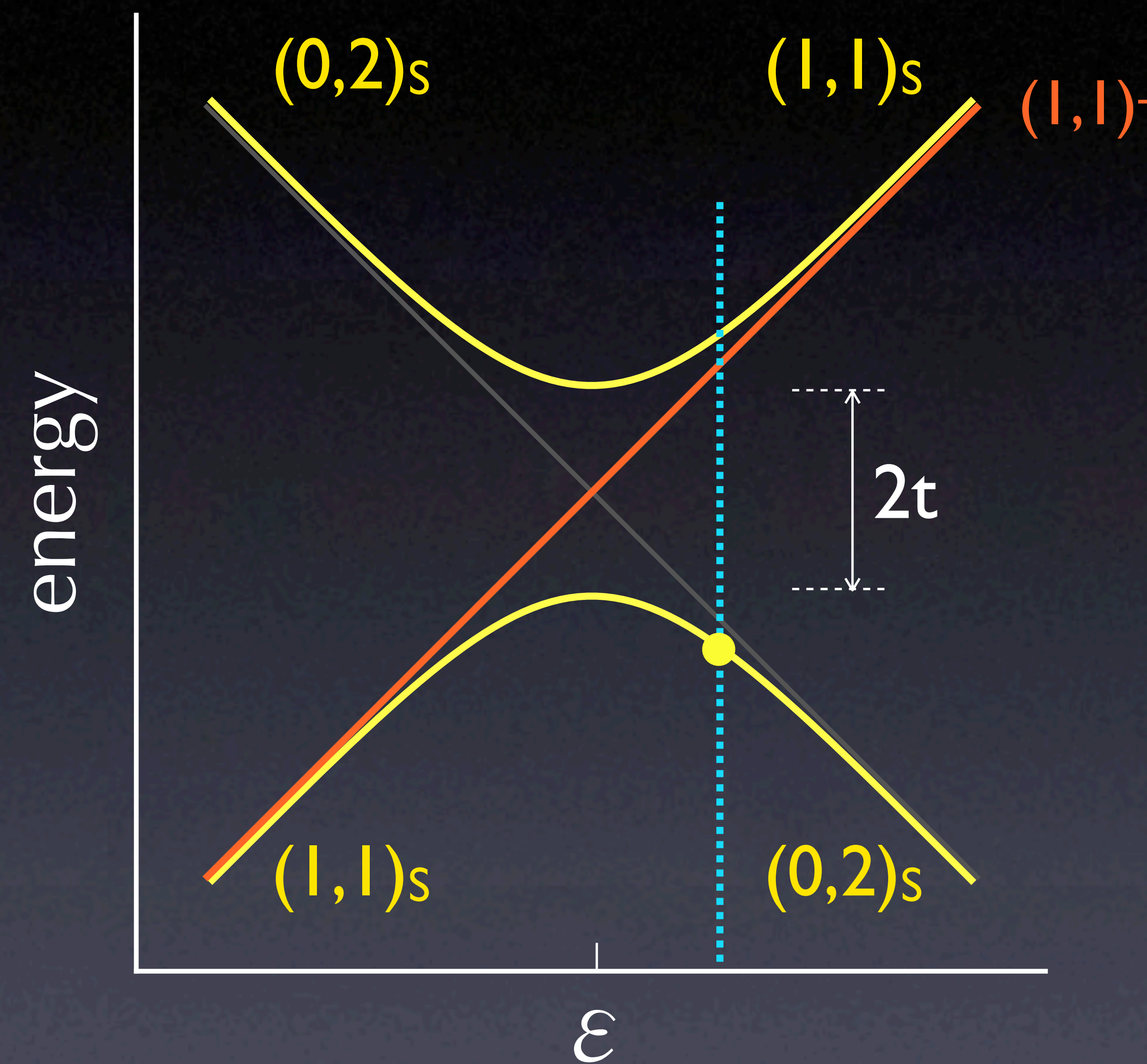




Measuring Entanglement Coherence Time

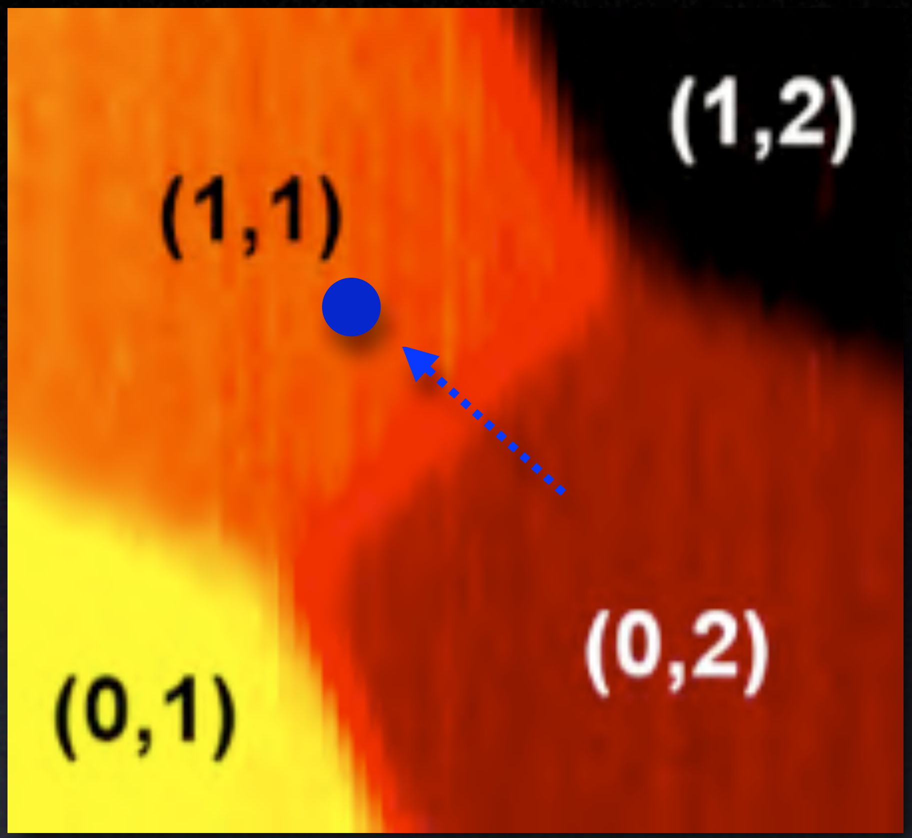


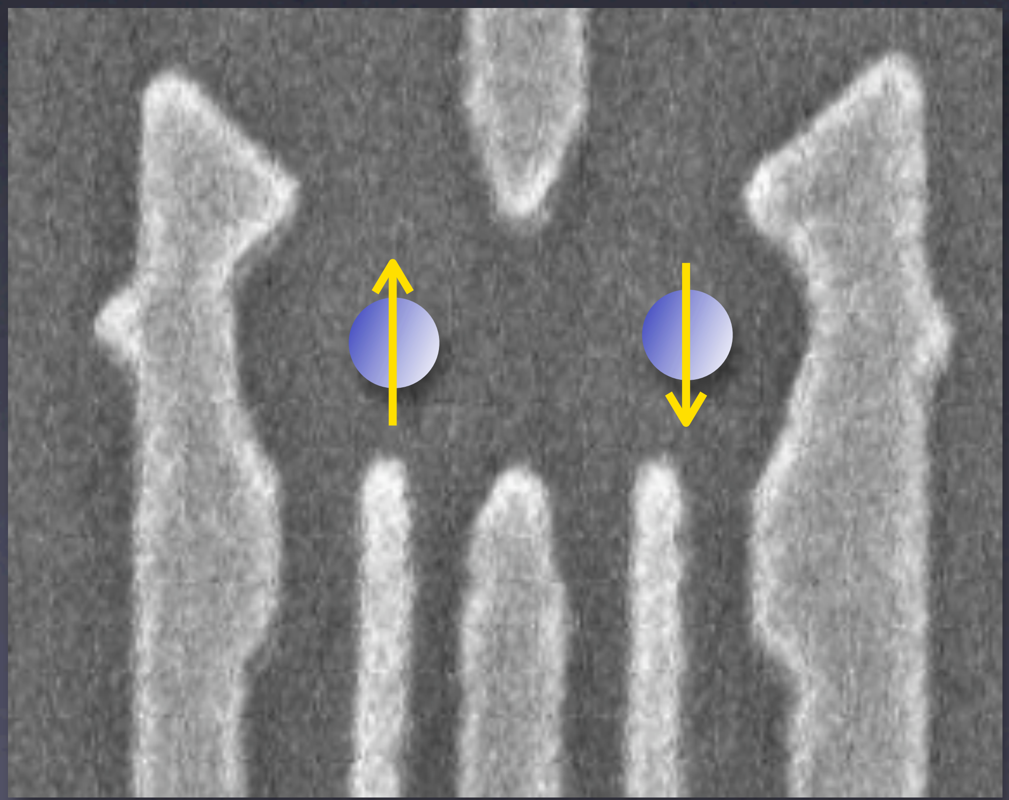


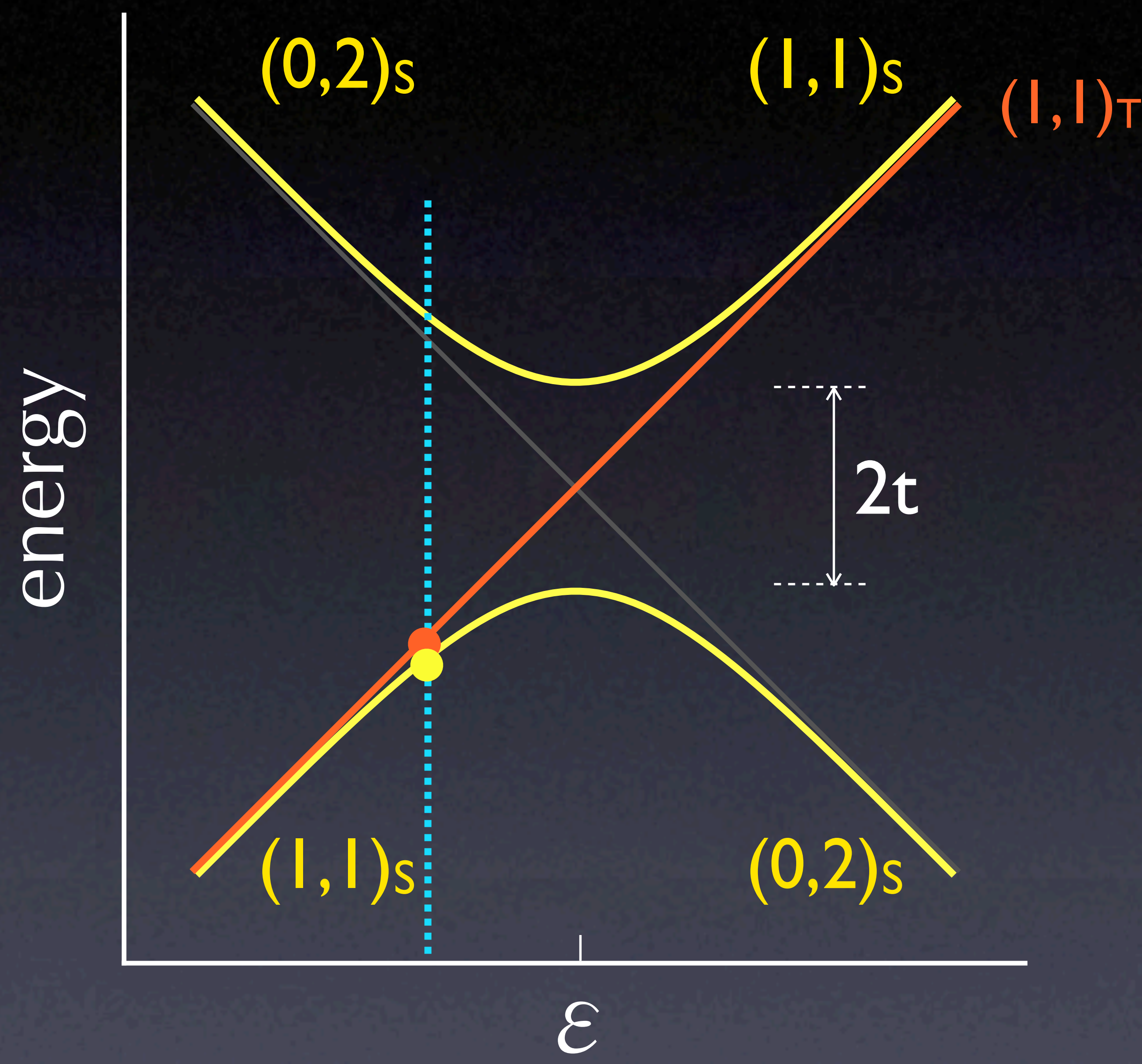


(0,2) triplets are unavailable
~ 4K above (0,2)S.

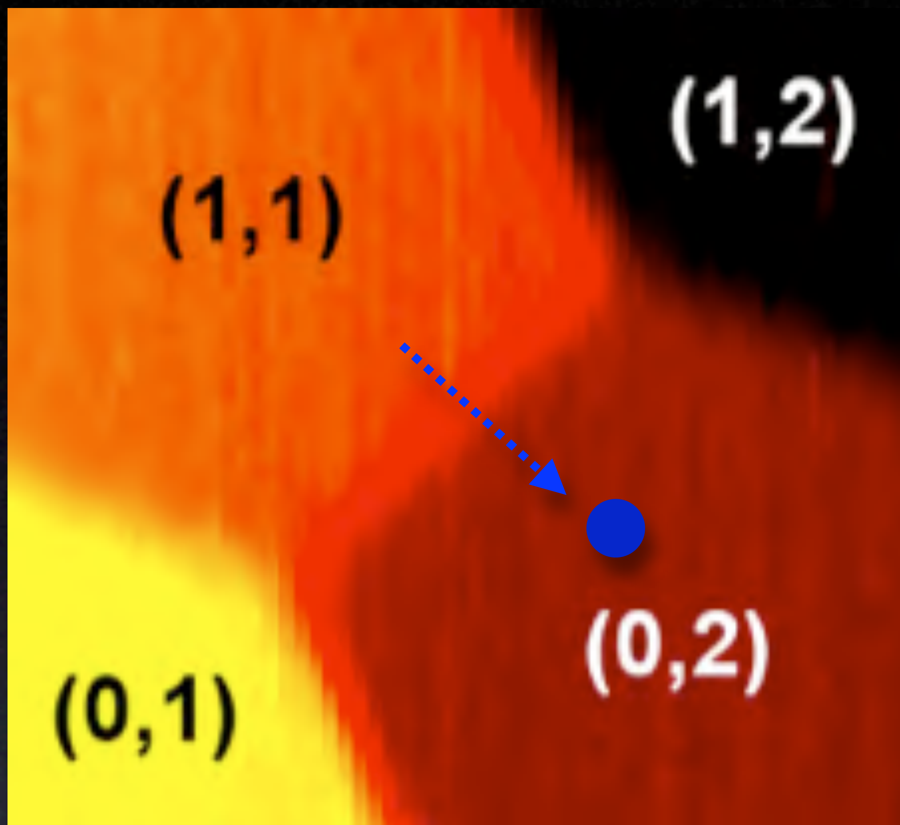
Measuring Entanglement Coherence Time

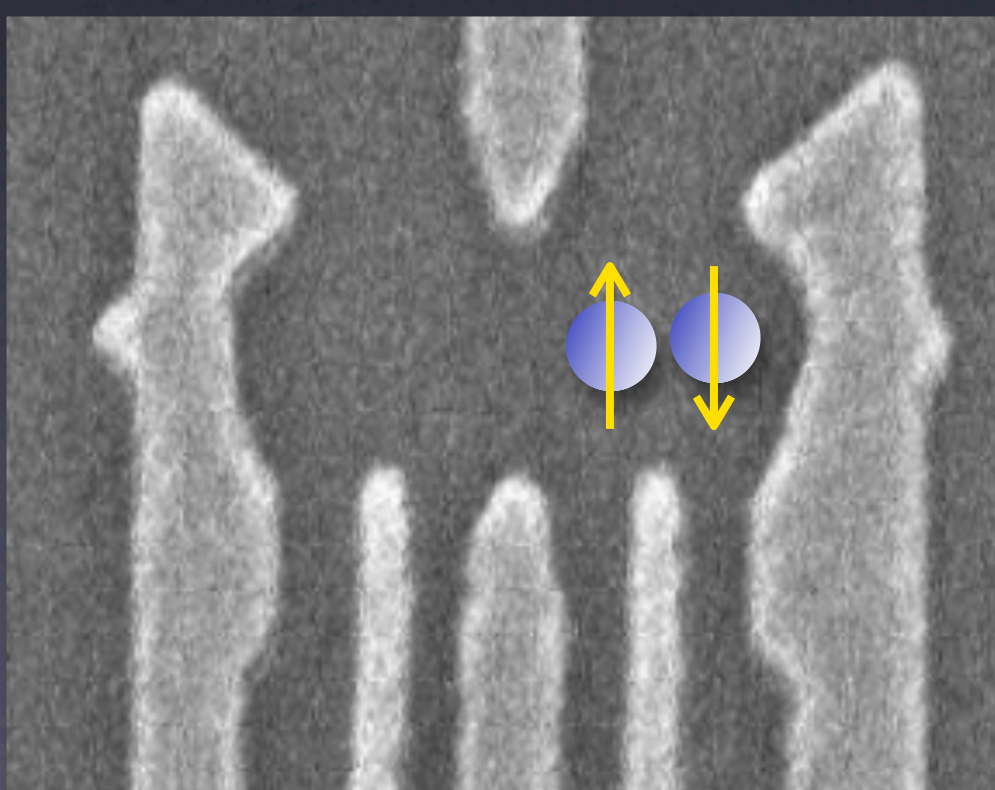


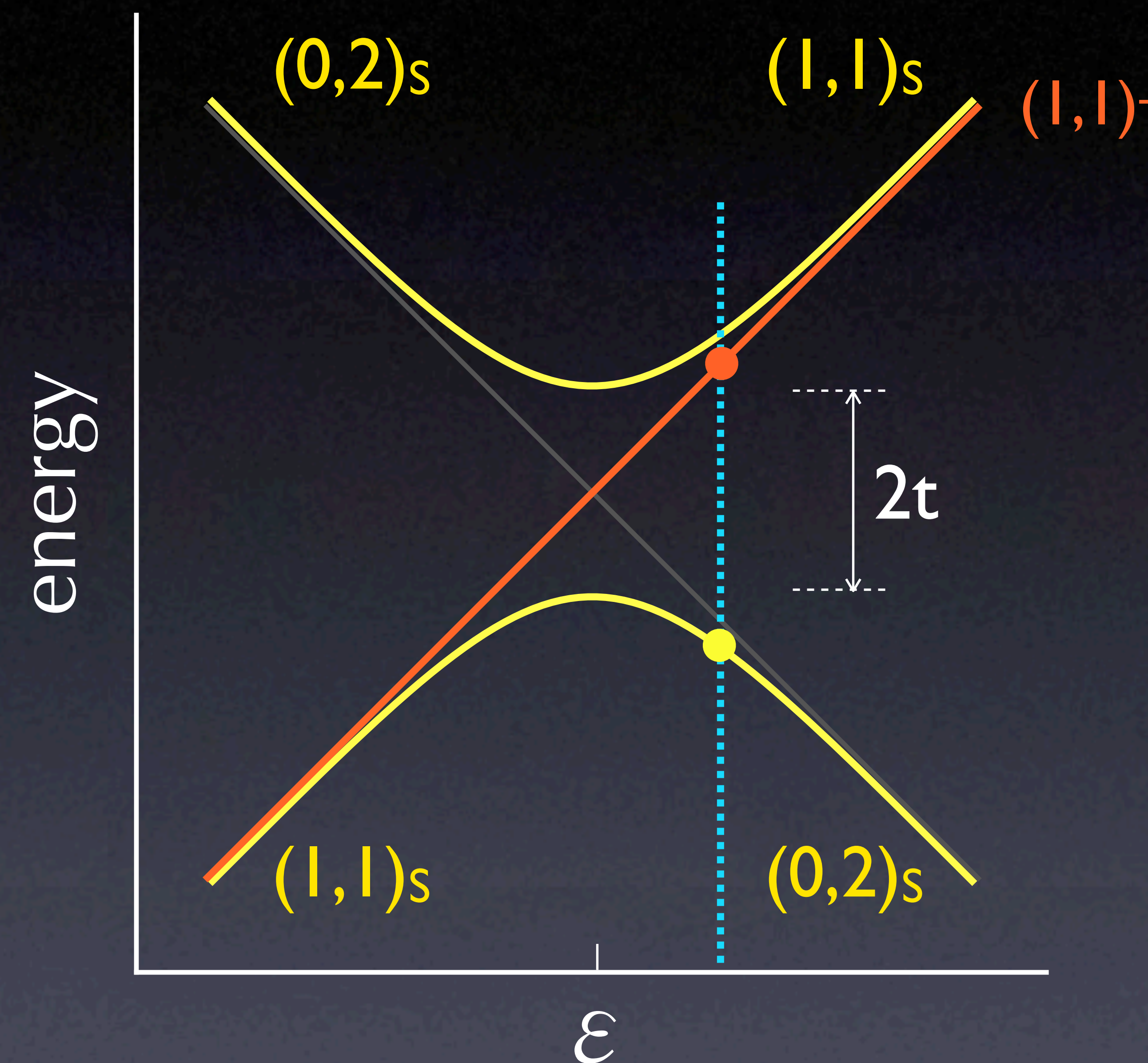




Measuring Entanglement Coherence Time

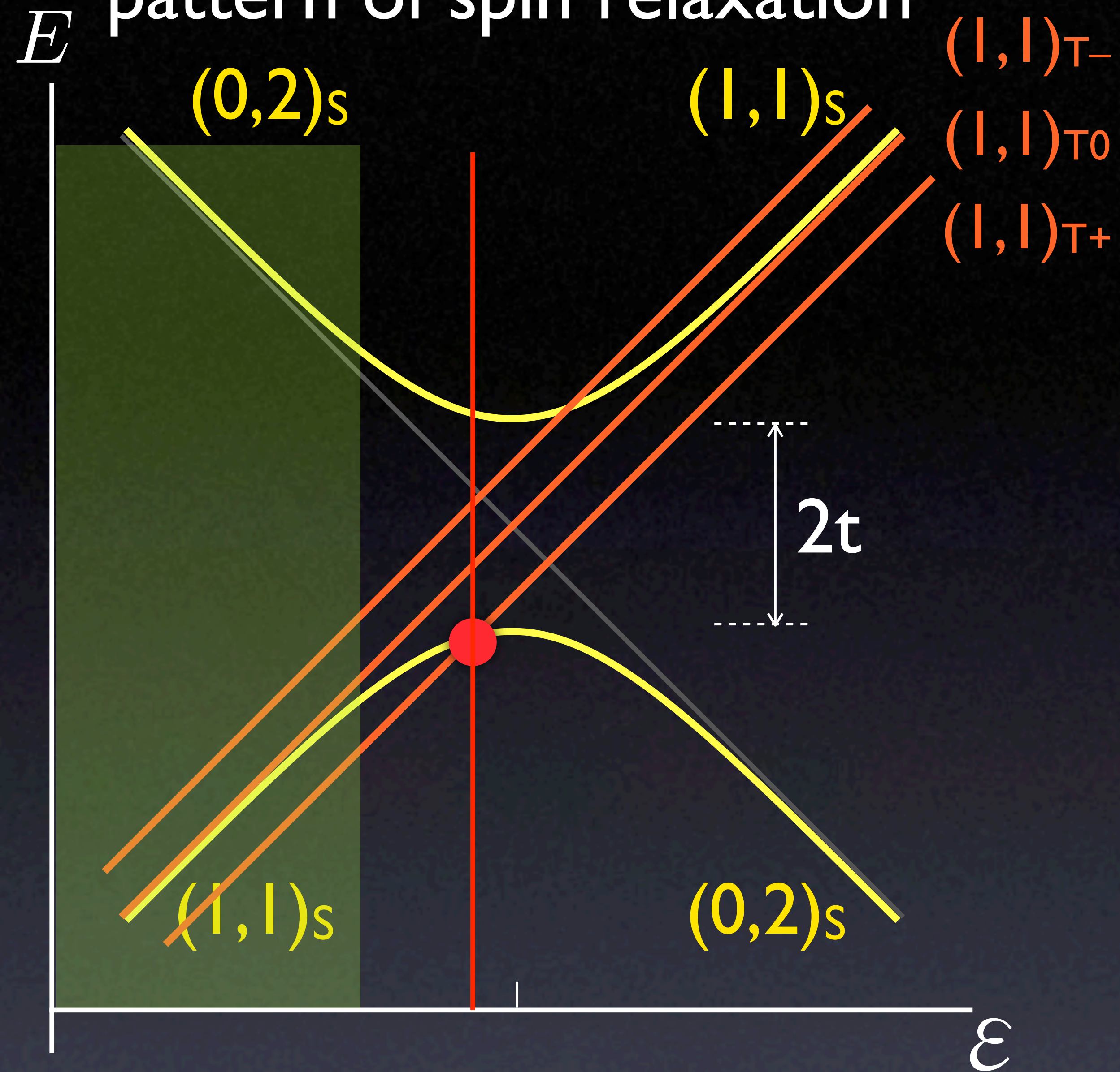






singlet-to-charge conversion

pattern of spin relaxation



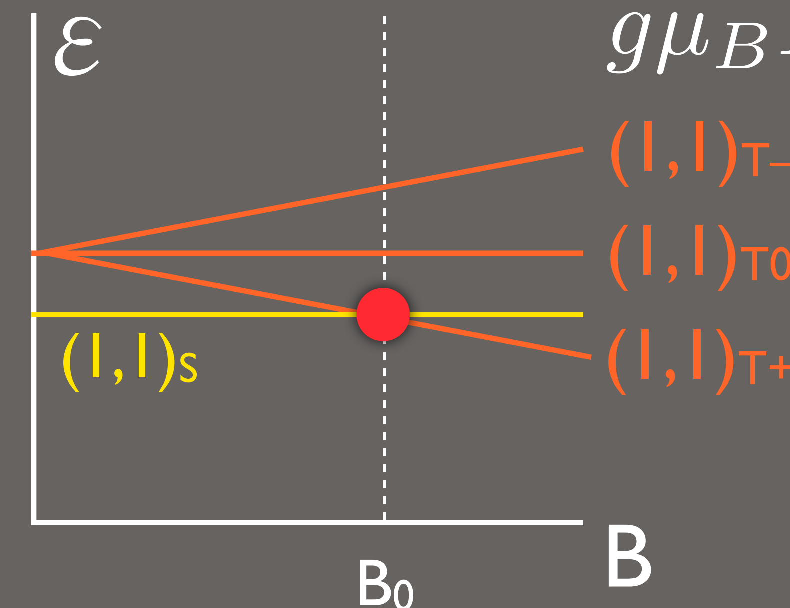
● S - T+ degeneracy

$$E_{(1,1)_S} = E_{(1,1)_{T+}} \quad \text{where}$$

$$E_{(1,1)_S} = -\sqrt{(\epsilon/2)^2 + t^2}\,,$$

$$E_{(1,1)_{T+}} = -\epsilon/2 - mg\mu_B B\,.$$

$$g\mu_B B_0 \approx t^2/|\epsilon|$$

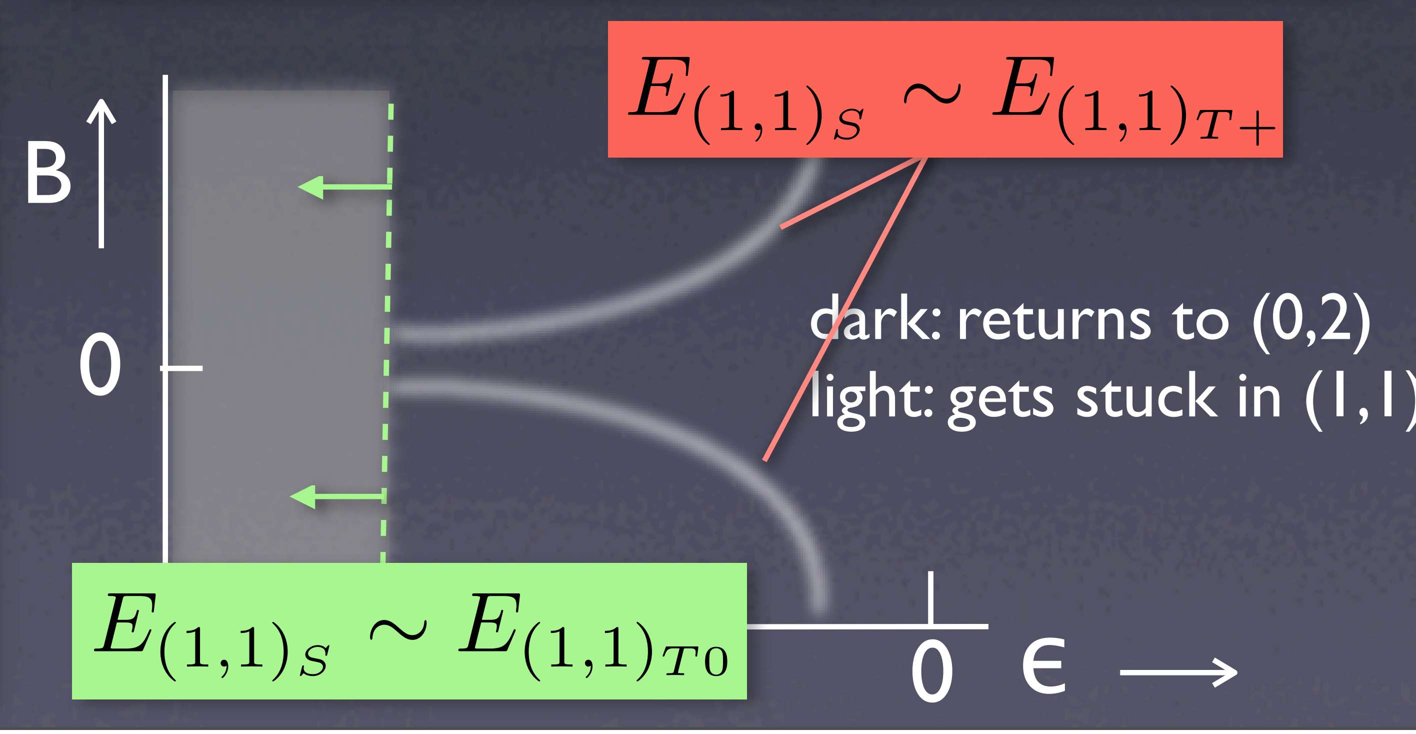


● S - T0 degeneracy

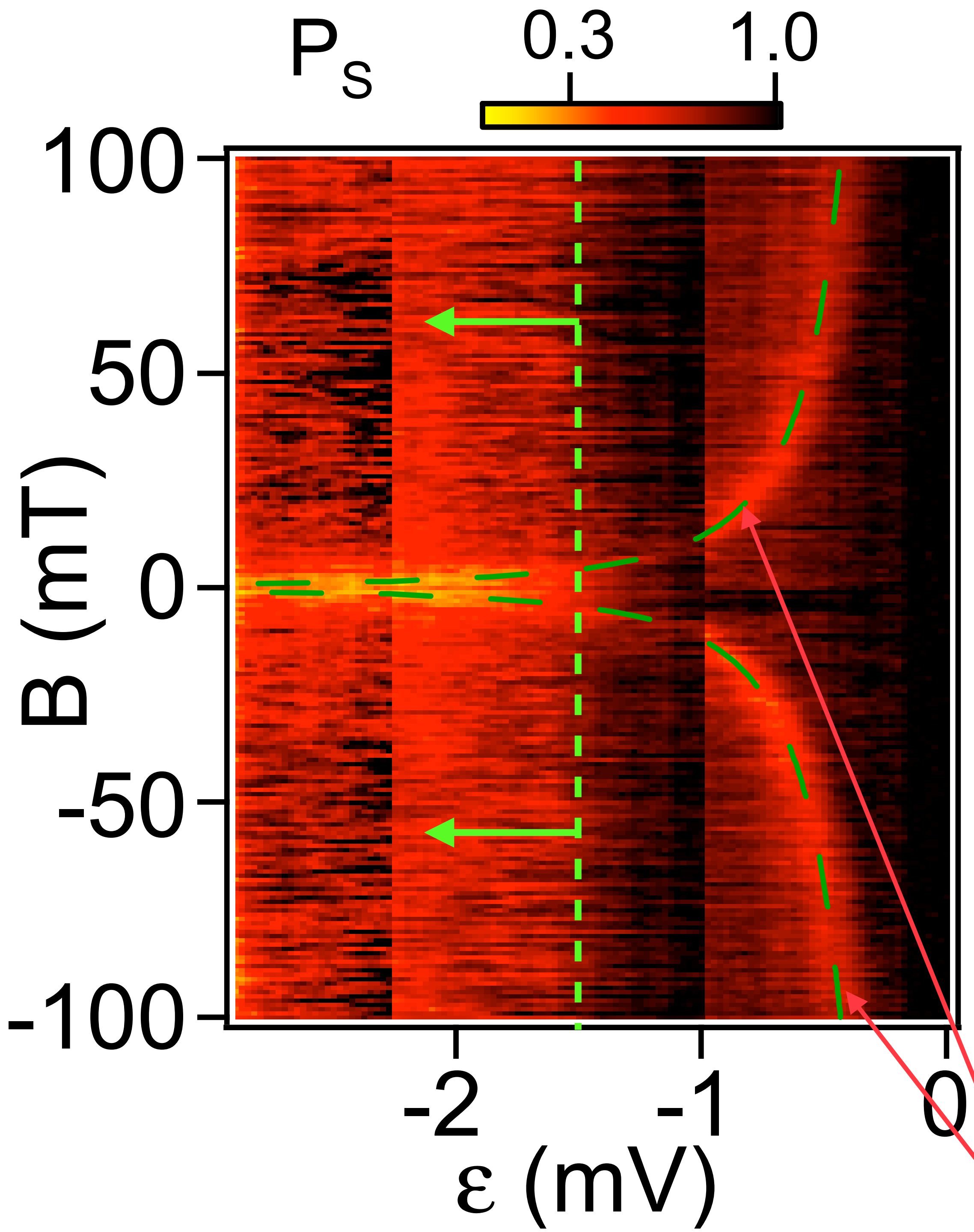
$$E_{(1,1)_S} \sim E_{(1,1)_{T0}}$$

at large ϵ

so that $t^2/|\epsilon| \approx g\mu_B B_{nuc.}$

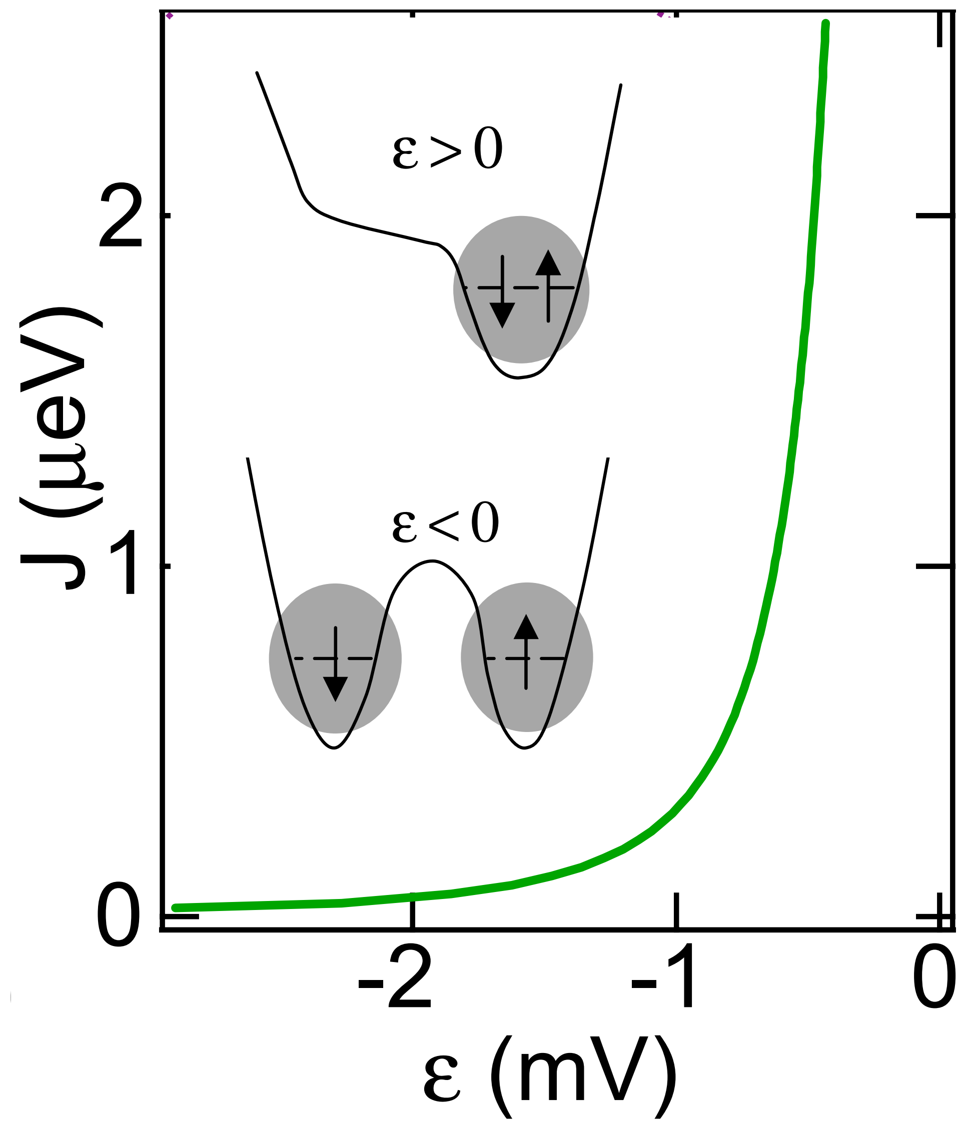


Probability for separated singlet to be in a found in a singlet state after 200 ns.



S - T₊ degeneracy occurs at

$$J(\epsilon) = g\mu_B B$$

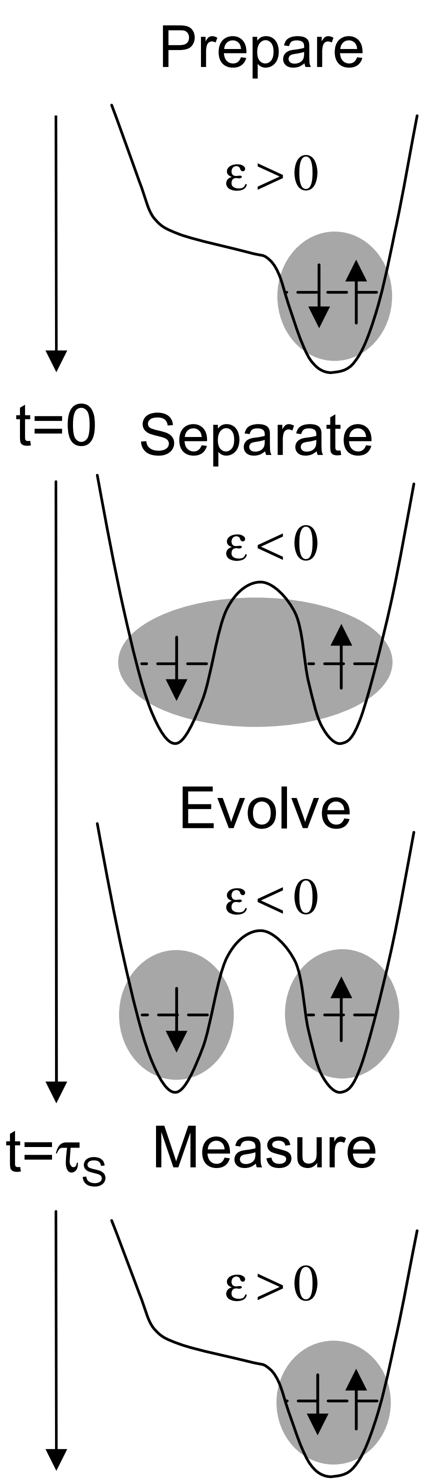


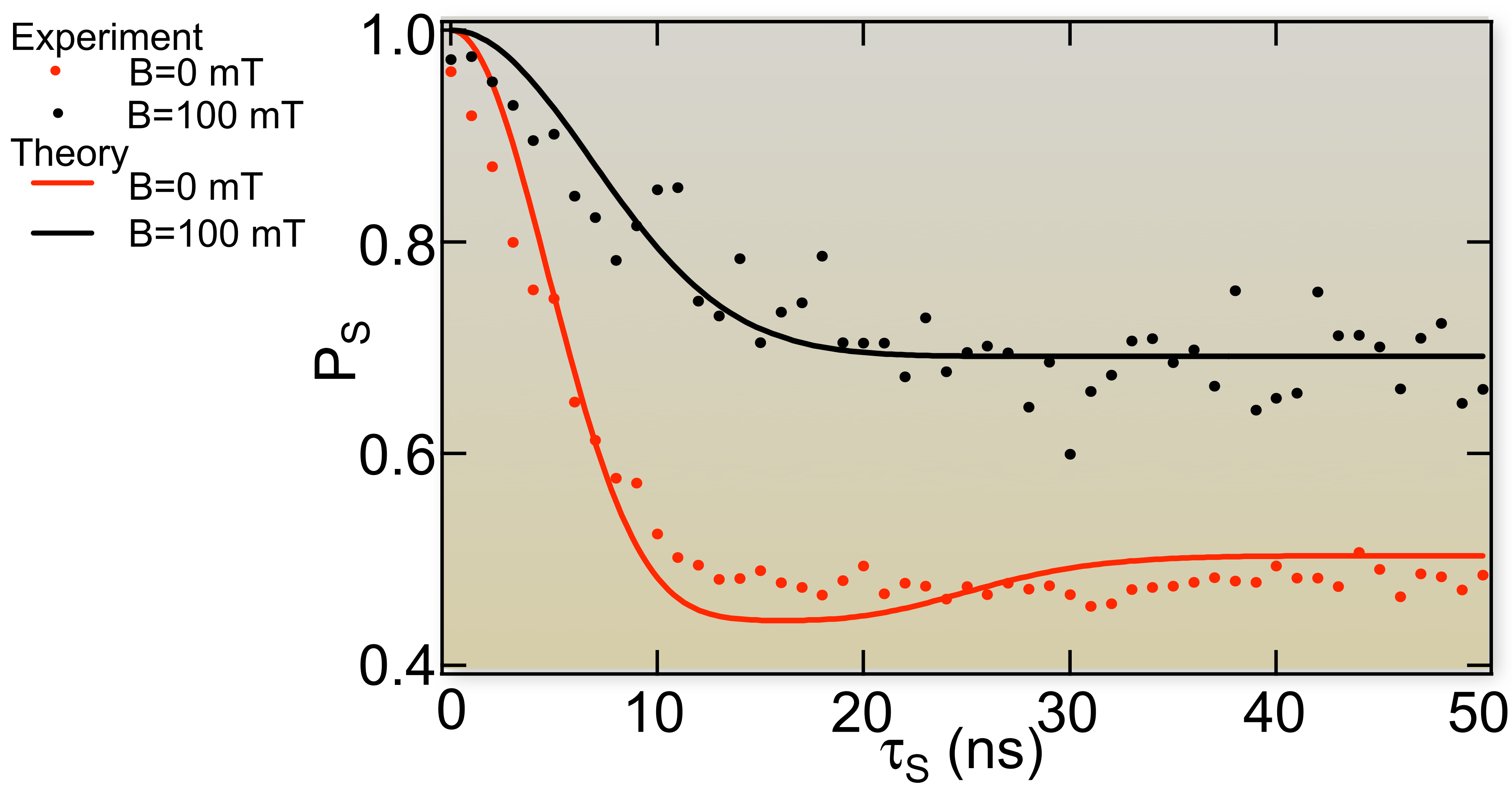
$E_{(1,1)_S} \sim E_{(1,1)_{T0}}$

$E_{(1,1)_S} \sim E_{(1,1)_{T+}}$

J. R. Petta, A. C. Johnson, J. Taylor, A. Yacoby, M.D. Lukin, M. Hanson, A. C. Gossard, CMM Science **309** 2180 (2005)

Measuring Spin Dephasing (T2*)

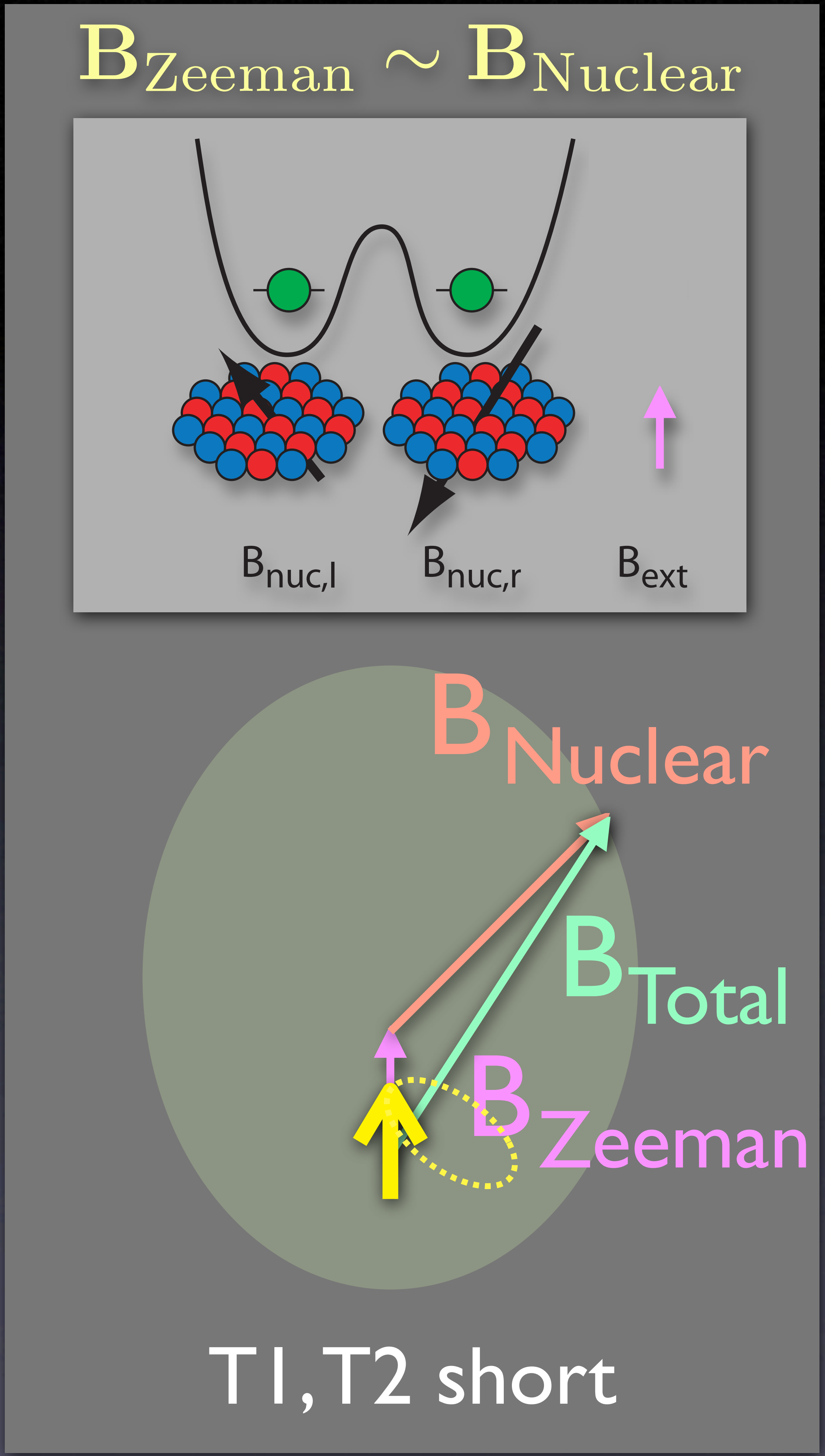




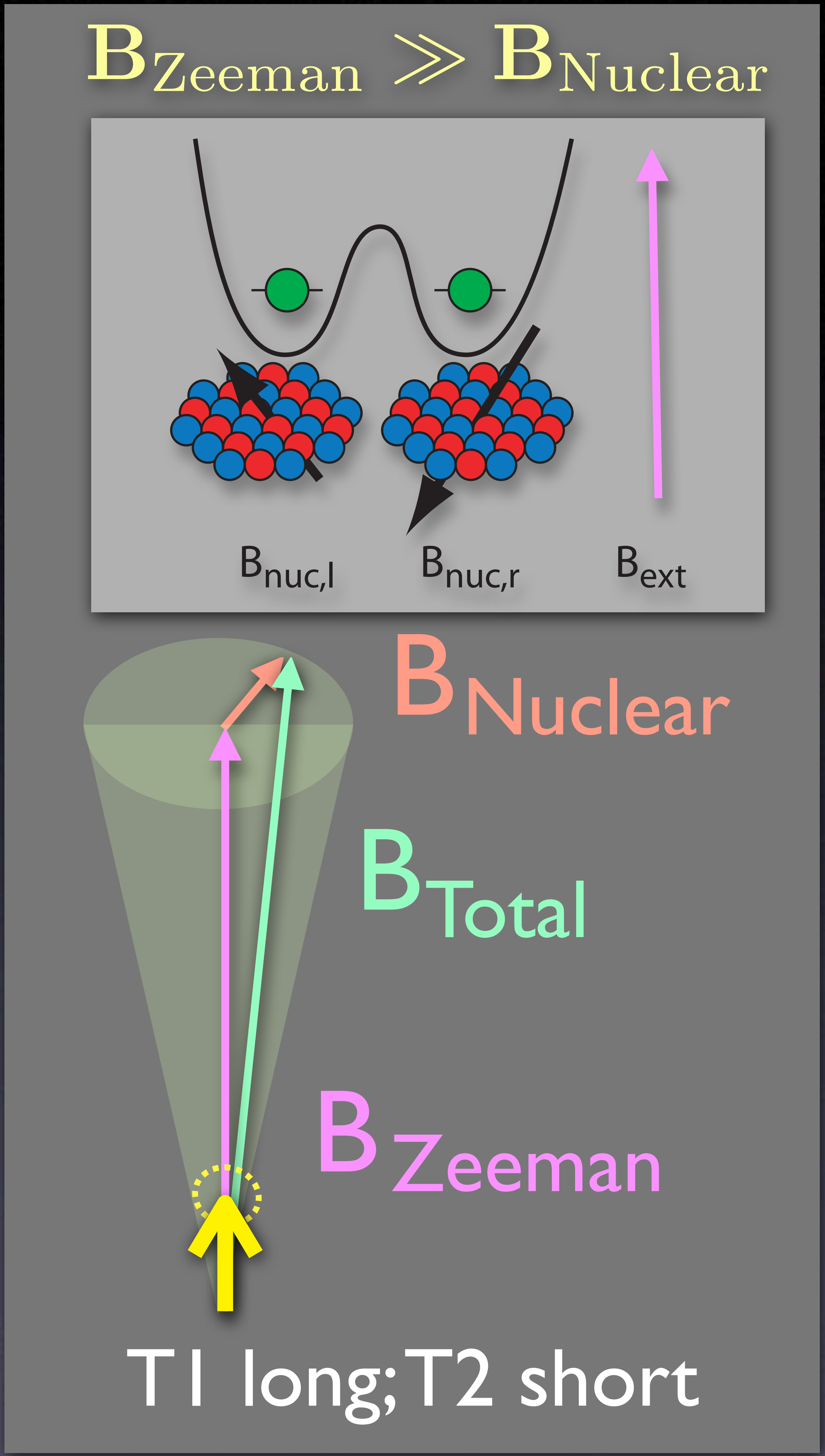
$$P_S(\tau_S) = 1 - \frac{C_1}{2}\left(1 - e^{-(\tau_S/T_2^*)^2}\right) \text{ for } B \gg B_{nuc}$$

$$P_S(\tau_S) = 1 - \frac{3}{4}C_2\left\{1 - \frac{1}{9}\left(1 - 2e^{-\frac{1}{2}(\tau_S/T_2^*)^2}\left\{(\tau_S/T_2^*)^2 - 1\right\}\right)^2\right\} \text{ for } B \ll B_{nuc}.$$

K. Schulten and P. G. Wolynes, J. Chem. Phys. **68** 3292 (1978); J. M. Taylor, *et al.* cond-mat/0602470 (2006).

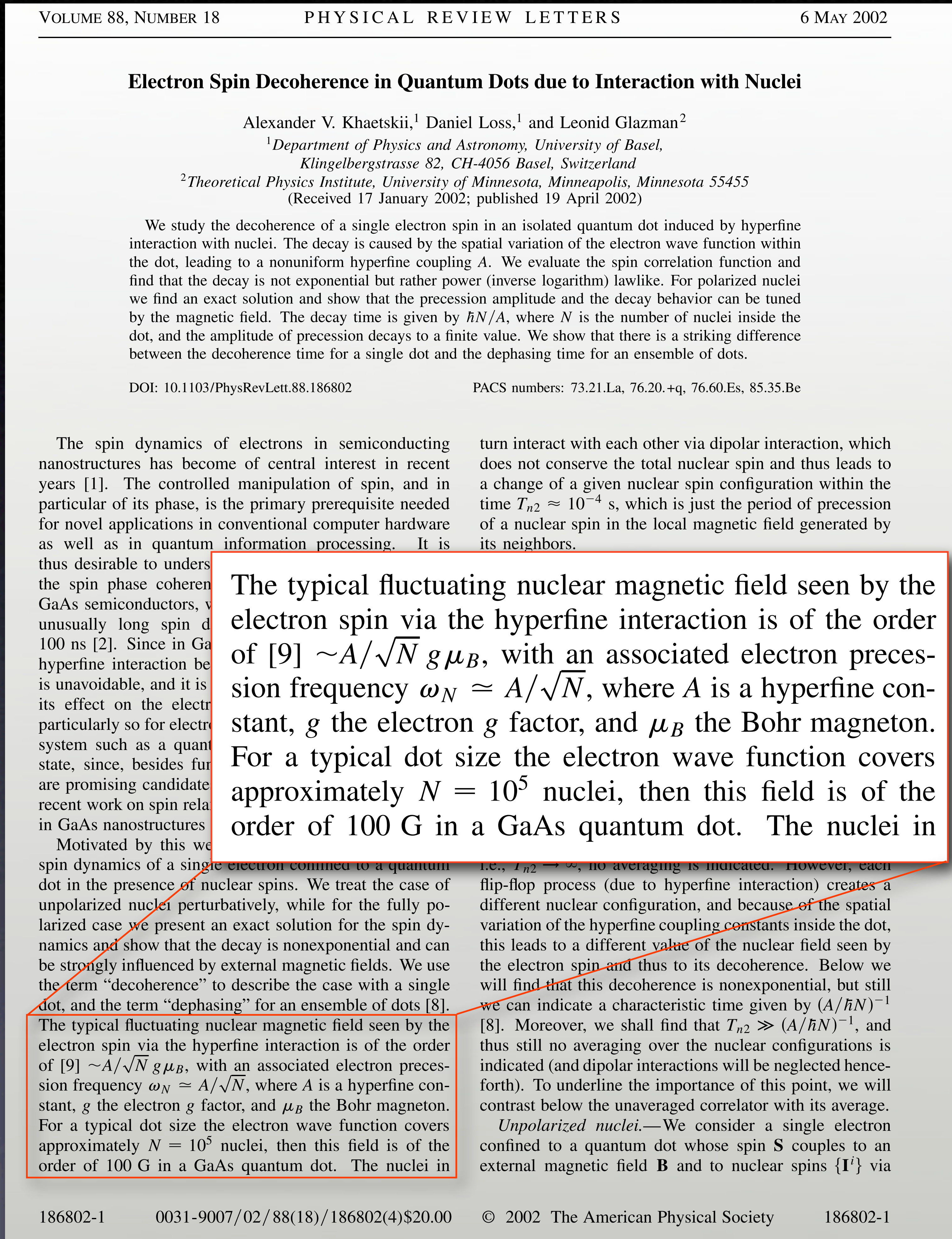


$B_{Zeeman} \sim B_{Nuclear}$
$B_{nuc,l}$
$B_{nuc,r}$
B_{ext}
$B_{Nuclear}$
B_{Total}
B_{Zeeman}
T1,T2 short



$B_{Zeeman} \gg B_{Nuclear}$
$B_{nuc,l}$
$B_{nuc,r}$
B_{ext}
$B_{Nuclear}$
B_{Total}
B_{Zeeman}
T1 long; T2 short

Nuclear coupling well understood



VOLUME 88, NUMBER 18 PHYSICAL REVIEW LETTERS 6 MAY 2002

Electron Spin Decoherence in Quantum Dots due to Interaction with Nuclei

Alexander V. Khaetskii,[1] Daniel Loss,[1] and Leonid Glazman[2]

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(Received 17 January 2002; published 19 April 2002)

We study the decoherence of a single electron spin in an isolated quantum dot induced by hyperfine interaction with nuclei. The decay is caused by the spatial variation of the electron wave function within the dot, leading to a nonuniform hyperfine coupling A. We evaluate the spin correlation function and find that the decay is not exponential but rather power (inverse logarithm) lawlike. For polarized nuclei we find an exact solution and show that the precession amplitude and the decay behavior can be tuned by the magnetic field. The decay time is given by $\hbar N/A$, where N is the number of nuclei inside the dot, and the amplitude of precession decays to a finite value. We show that there is a striking difference between the decoherence time for a single dot and the dephasing time for an ensemble of dots.

DOI: 10.1103/PhysRevLett.88.186802 PACS numbers: 73.21.La, 76.20.+q, 76.60.Es, 85.35.Be

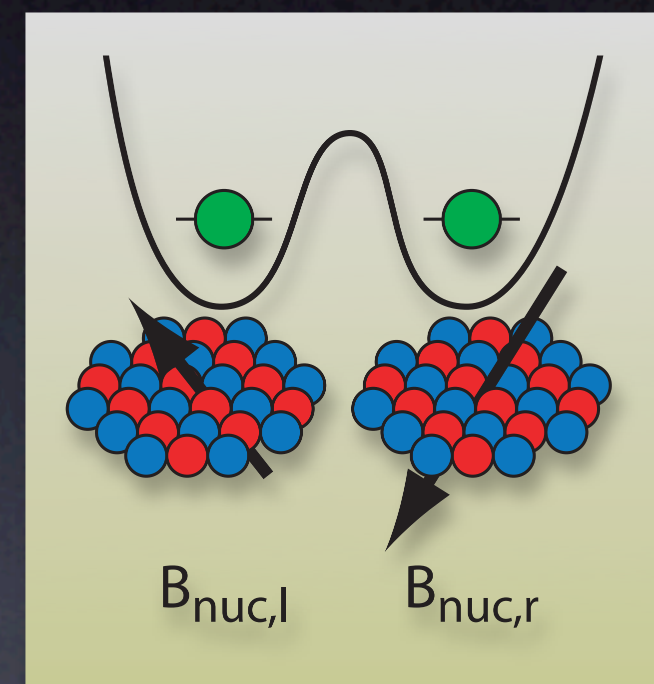
The spin dynamics of electrons in semiconducting nanostructures has become of central interest in recent years [1]. The controlled manipulation of spin, and in particular of its phase, is the primary prerequisite needed for novel applications in conventional computer hardware as well as in quantum information processing. It is
thus desirable to unders
the spin phase coheren
GaAs semiconductors, v
unusually long spin d
100 ns [2]. Since in Ga
hyperfine interaction be
is unavoidable, and it is
its effect on the electr
particularly so for electr
system such as a quant
state, since, besides fu
are promising candidate
recent work on spin rela
in GaAs nanostructures

Motivated by this we
spin dynamics of a single electron confined to a quantum dot in the presence of nuclear spins. We treat the case of unpolarized nuclei perturbatively, while for the fully polarized case we present an exact solution for the spin dynamics and show that the decay is nonexponential and can be strongly influenced by external magnetic fields. We use the term "decoherence" to describe the case with a single dot, and the term "dephasing" for an ensemble of dots [8]. The typical fluctuating nuclear magnetic field seen by the electron spin via the hyperfine interaction is of the order of [9] $\sim A/\sqrt{N}\, g\mu_B$, with an associated electron precession frequency $\omega_N \simeq A/\sqrt{N}$, where A is a hyperfine constant, g the electron g factor, and μ_B the Bohr magneton. For a typical dot size the electron wave function covers approximately $N = 10^5$ nuclei, then this field is of the order of 100 G in a GaAs quantum dot. The nuclei in turn interact with each other via dipolar interaction, which does not conserve the total nuclear spin and thus leads to a change of a given nuclear spin configuration within the time $T_{n2} \approx 10^{-4}$ s, which is just the period of precession of a nuclear spin in the local magnetic field generated by its neighbors.

i.e., $T_{n2} \to \infty$, no averaging is indicated. However, each flip-flop process (due to hyperfine interaction) creates a different nuclear configuration, and because of the spatial variation of the hyperfine coupling constants inside the dot, this leads to a different value of the nuclear field seen by the electron spin and thus to its decoherence. Below we will find that this decoherence is nonexponential, but still we can indicate a characteristic time given by $(A/\hbar N)^{-1}$ [8]. Moreover, we shall find that $T_{n2} \gg (A/\hbar N)^{-1}$, and thus still no averaging over the nuclear configurations is indicated (and dipolar interactions will be neglected henceforth). To underline the importance of this point, we will contrast below the unaveraged correlator with its average.

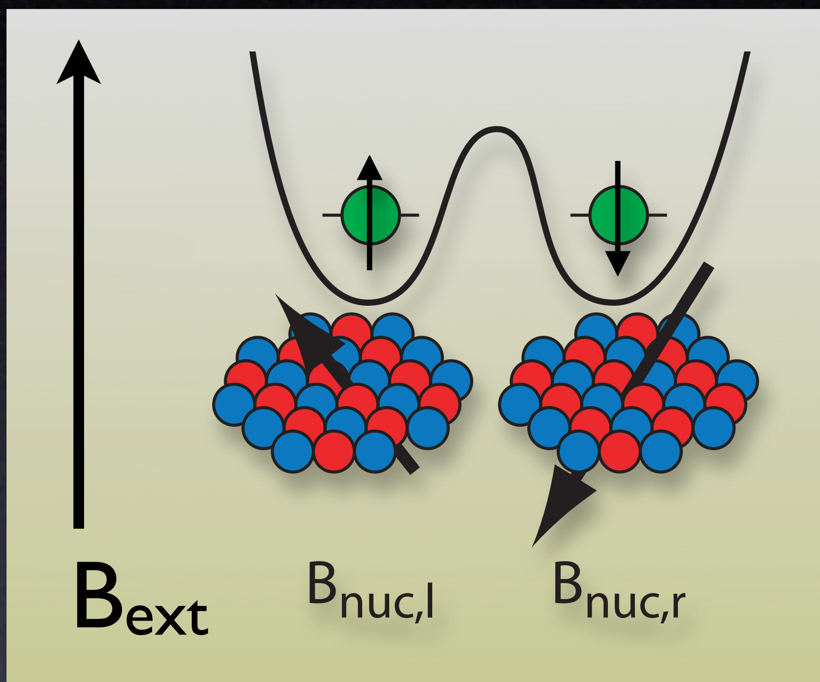
Unpolarized nuclei.—We consider a single electron confined to a quantum dot whose spin $\mathbf{S}$ couples to an external magnetic field $\mathbf{B}$ and to nuclear spins $\{\mathbf{I}^i\}$ via

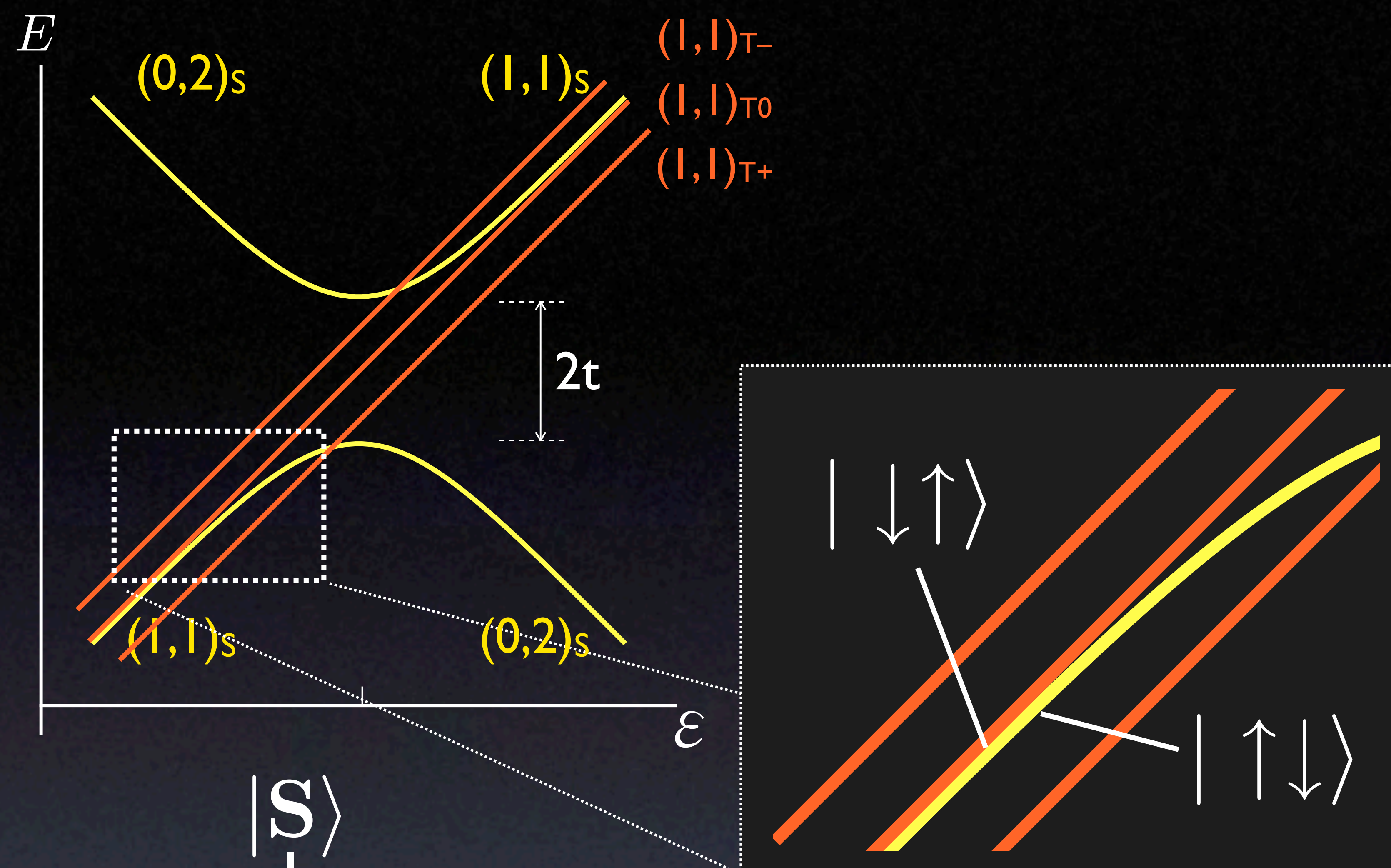
The typical fluctuating nuclear magnetic field seen by the electron spin via the hyperfine interaction is of the order of [9] $\sim A/\sqrt{N}\, g\mu_B$, with an associated electron precession frequency $\omega_N \simeq A/\sqrt{N}$, where A is a hyperfine constant, g the electron g factor, and μ_B the Bohr magneton. For a typical dot size the electron wave function covers approximately $N = 10^5$ nuclei, then this field is of the order of 100 G in a GaAs quantum dot. The nuclei in



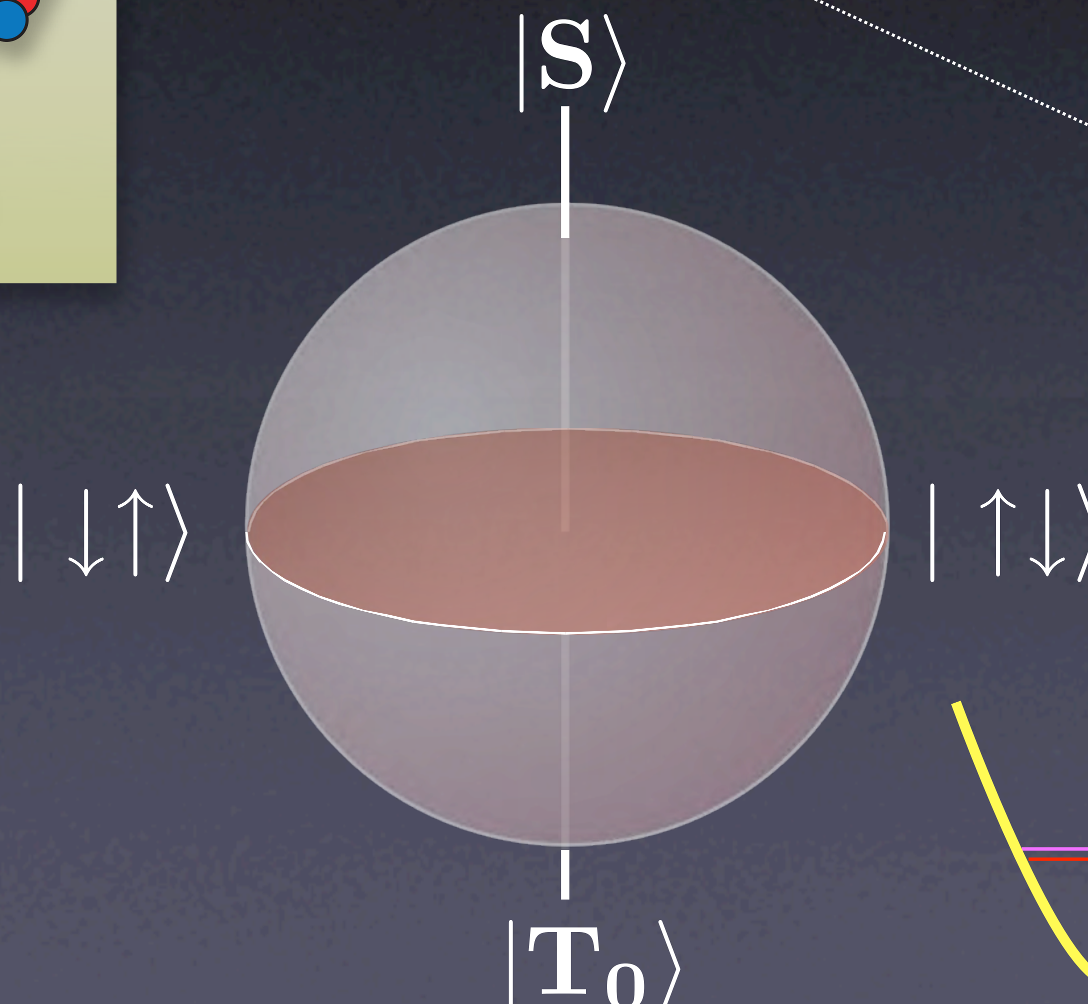
$$T2^* \sim \omega_N^{-1} \sim 10ns$$

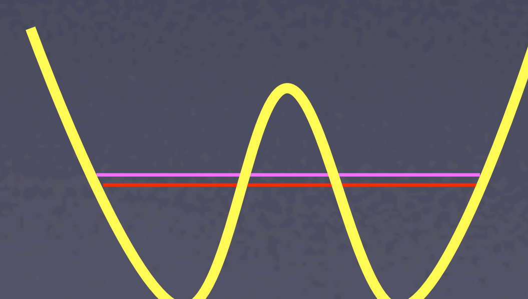
In the (1,1) S - T_0 subspace, the eigenstates of the nuclear fields are $|\uparrow\downarrow\rangle$ and $|\downarrow\uparrow\rangle$.



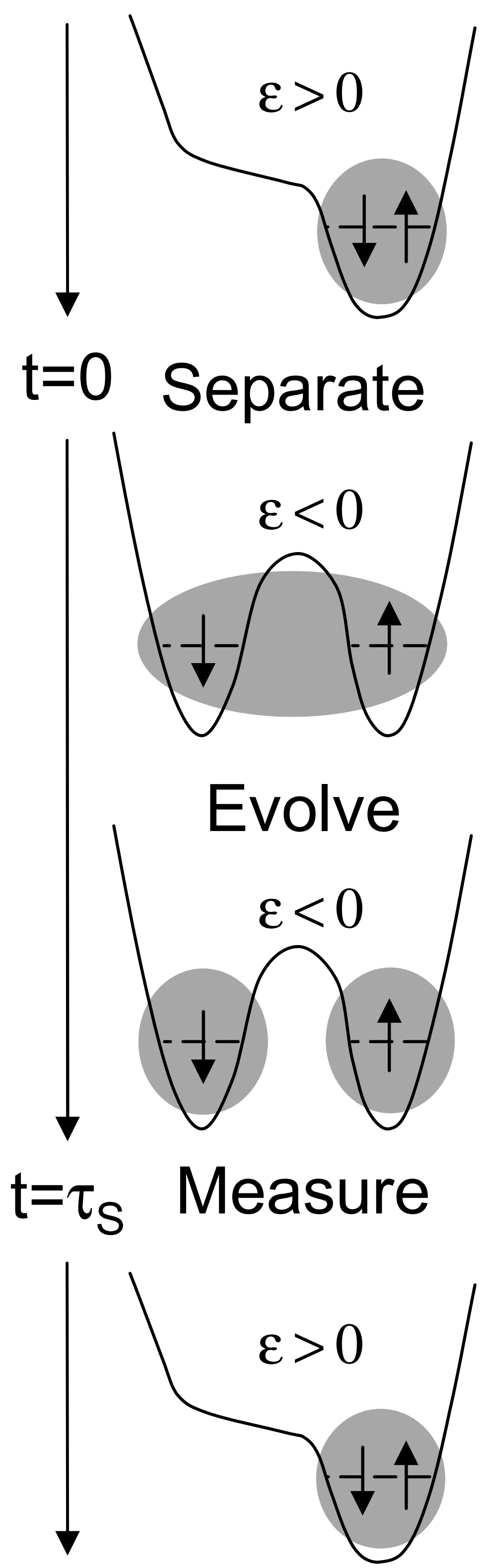


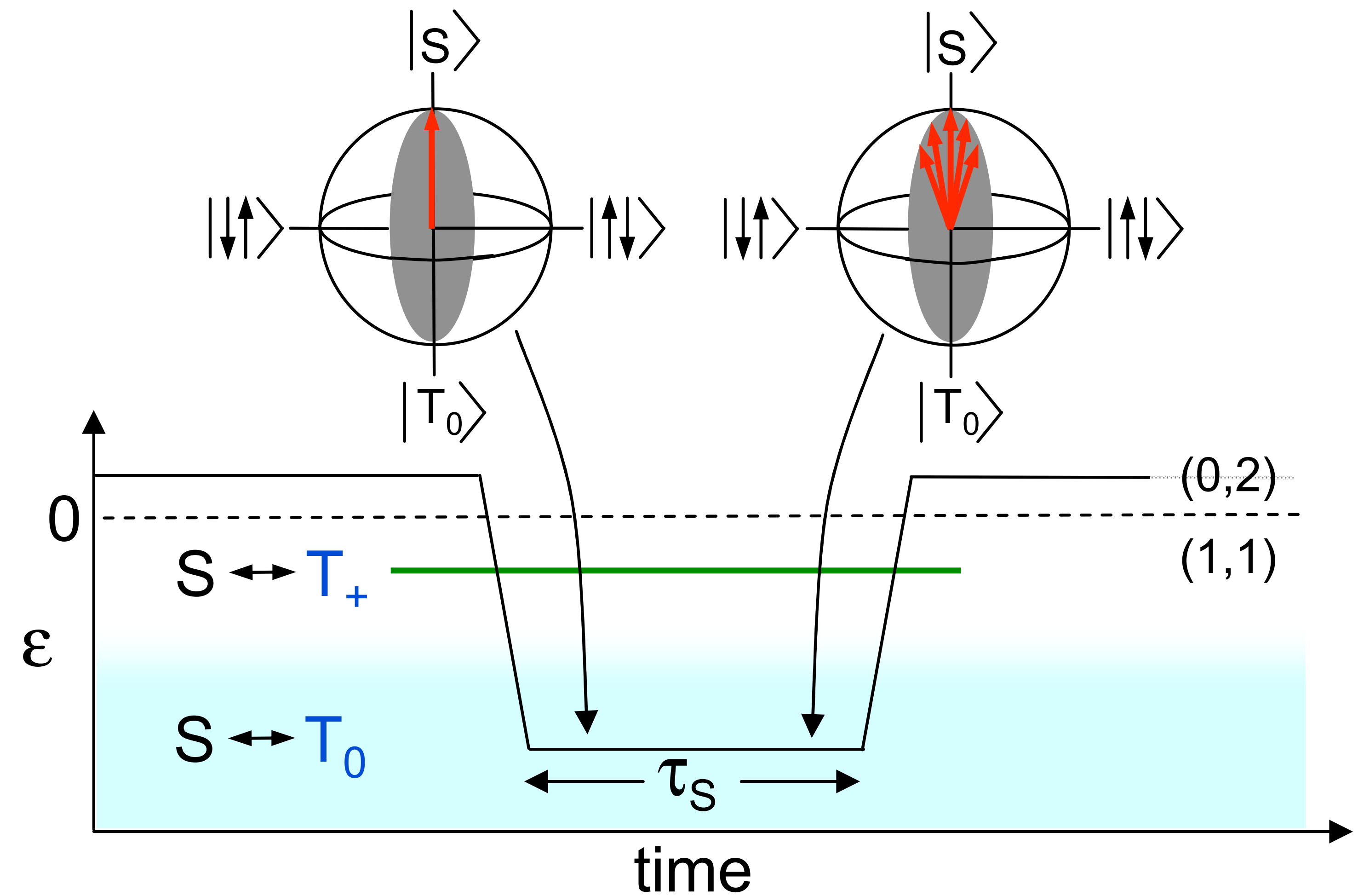
Bloch sphere in (1,1) S - T_0 subspace





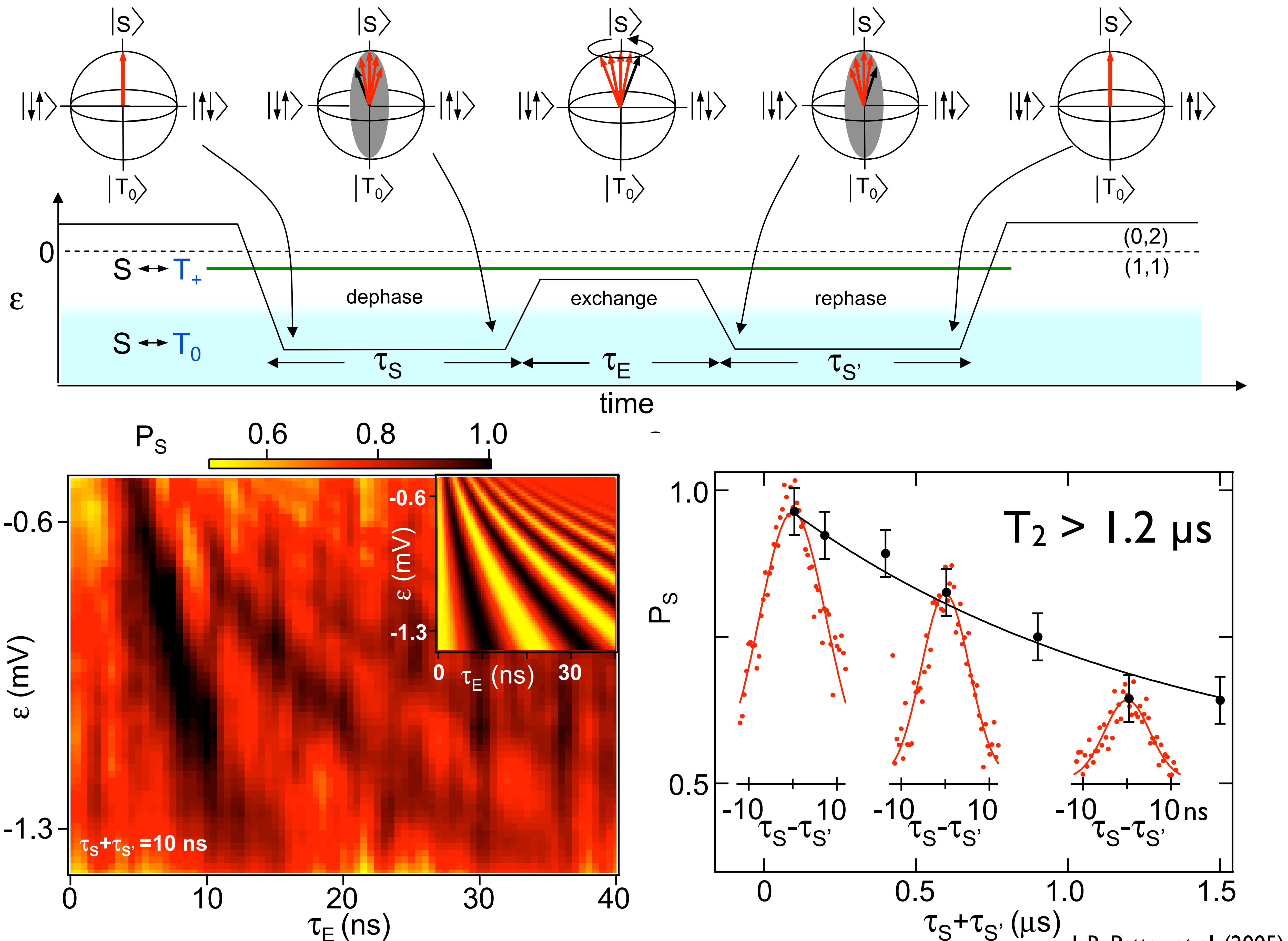
Probability for separated singlet to be found in a singlet after time τ_S





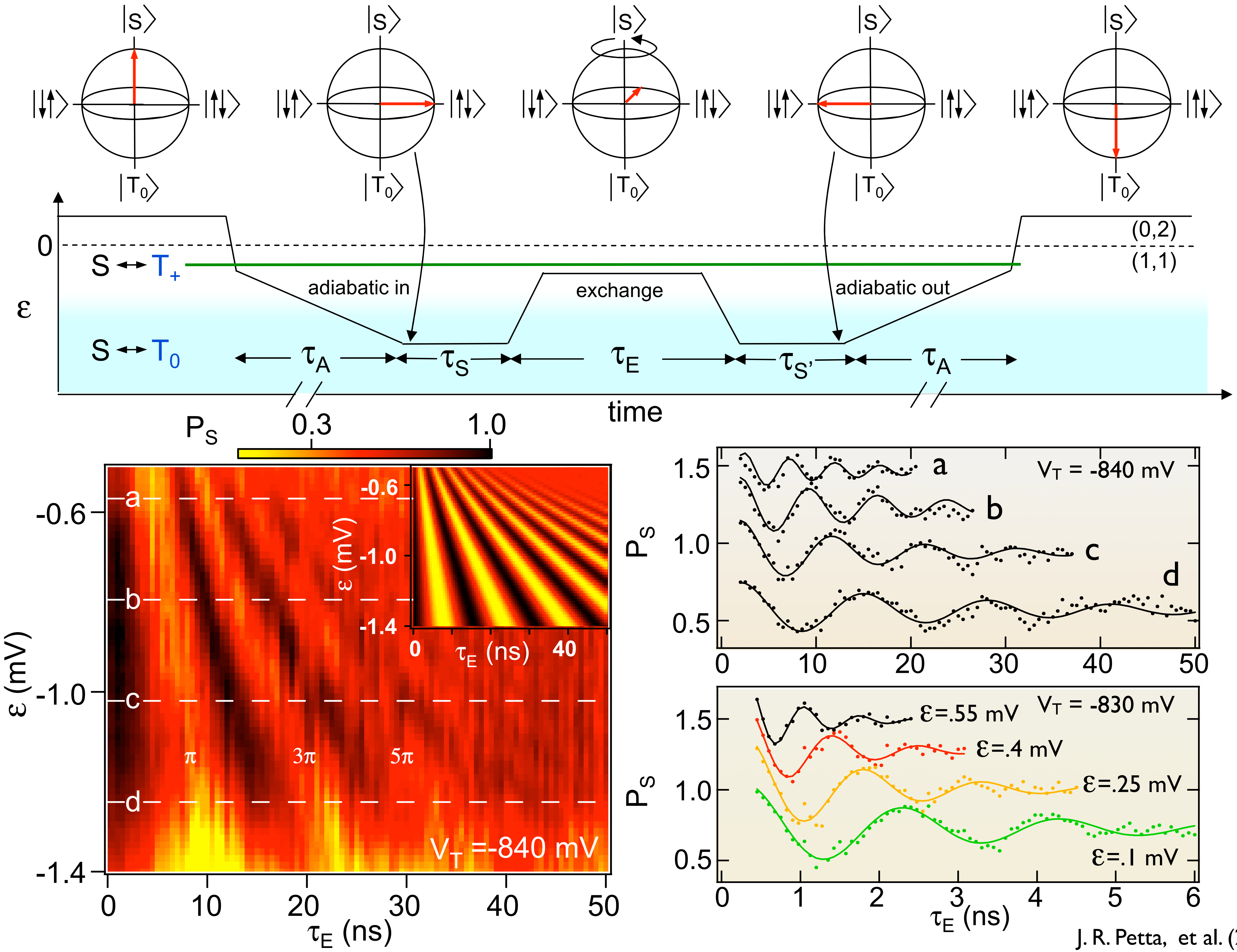
J. R. Petta, A. C. Johnson, J. Taylor, A. Yacoby, M.D. Lukin, M. Hanson, A. C. Gossard, CMM Science **309** 2180 (2005)

Hahn Echo in S - T_0 basis



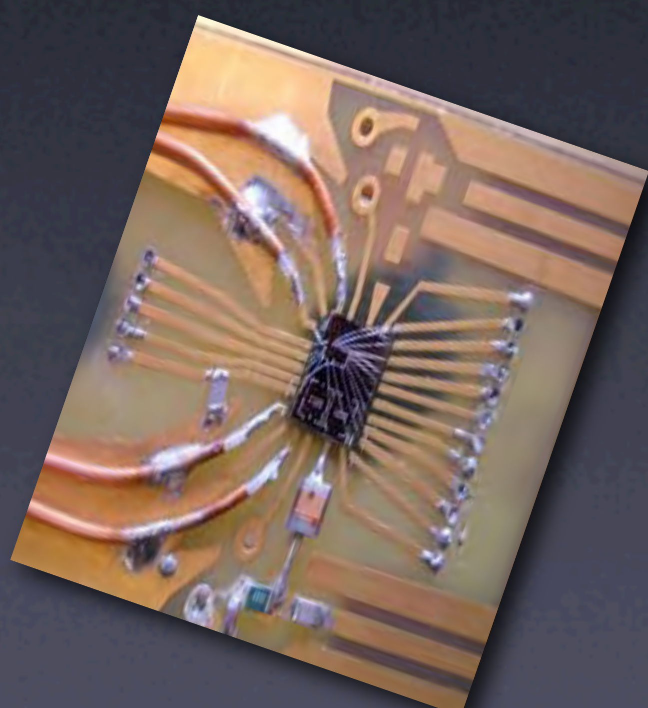
J. R. Petta, et al. (2005)

Exchange Control: Rabi oscillations between ↑↓ and ↓↑ states

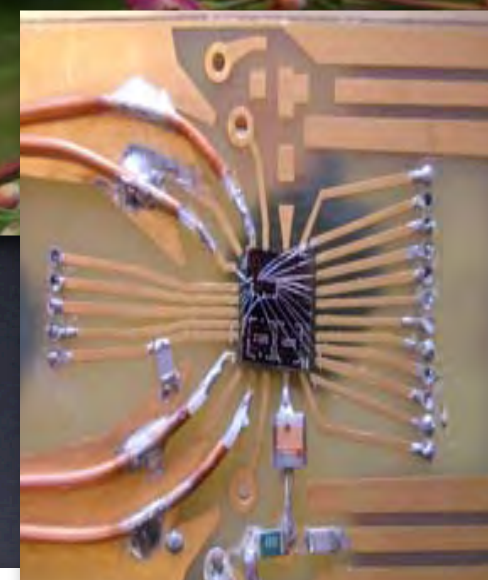


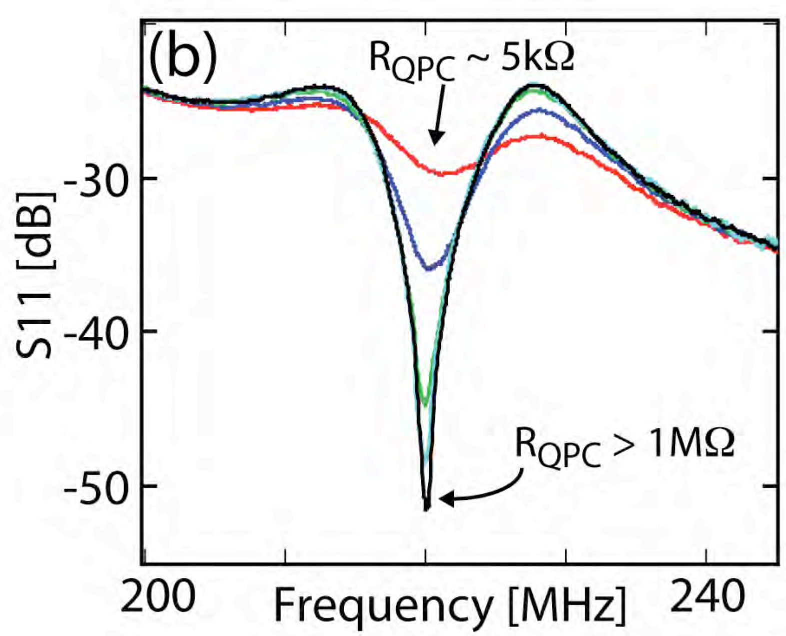
J. R. Petta, et al. (2005)

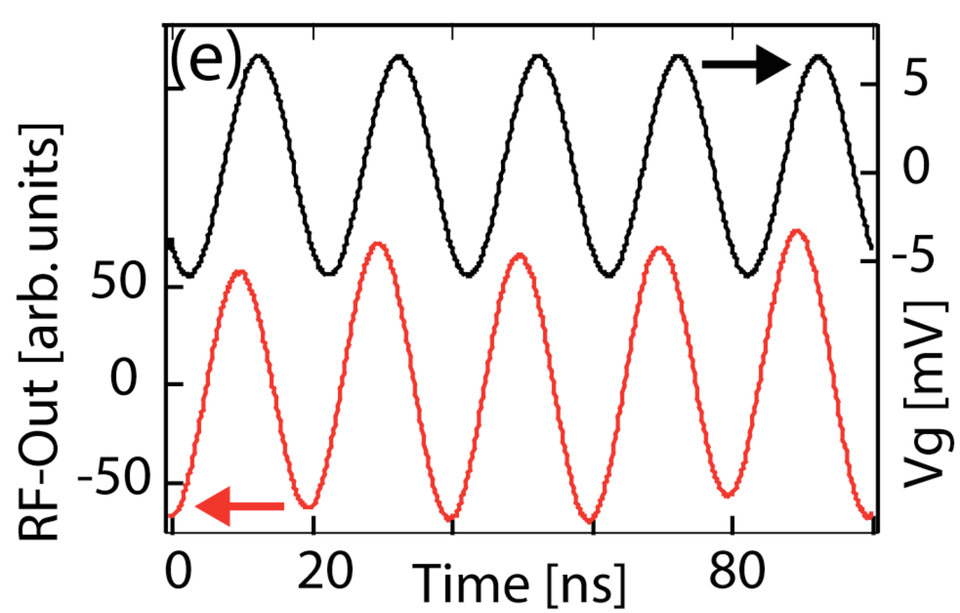
Measuring and using the nuclear environment

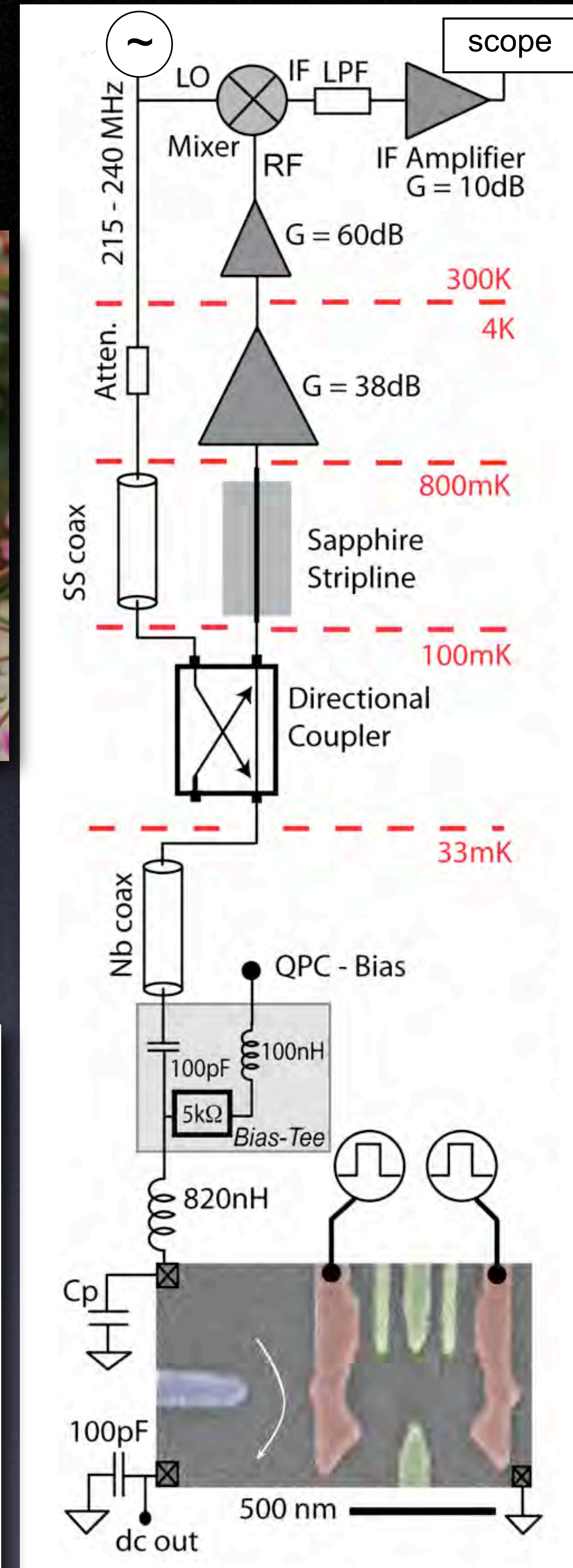


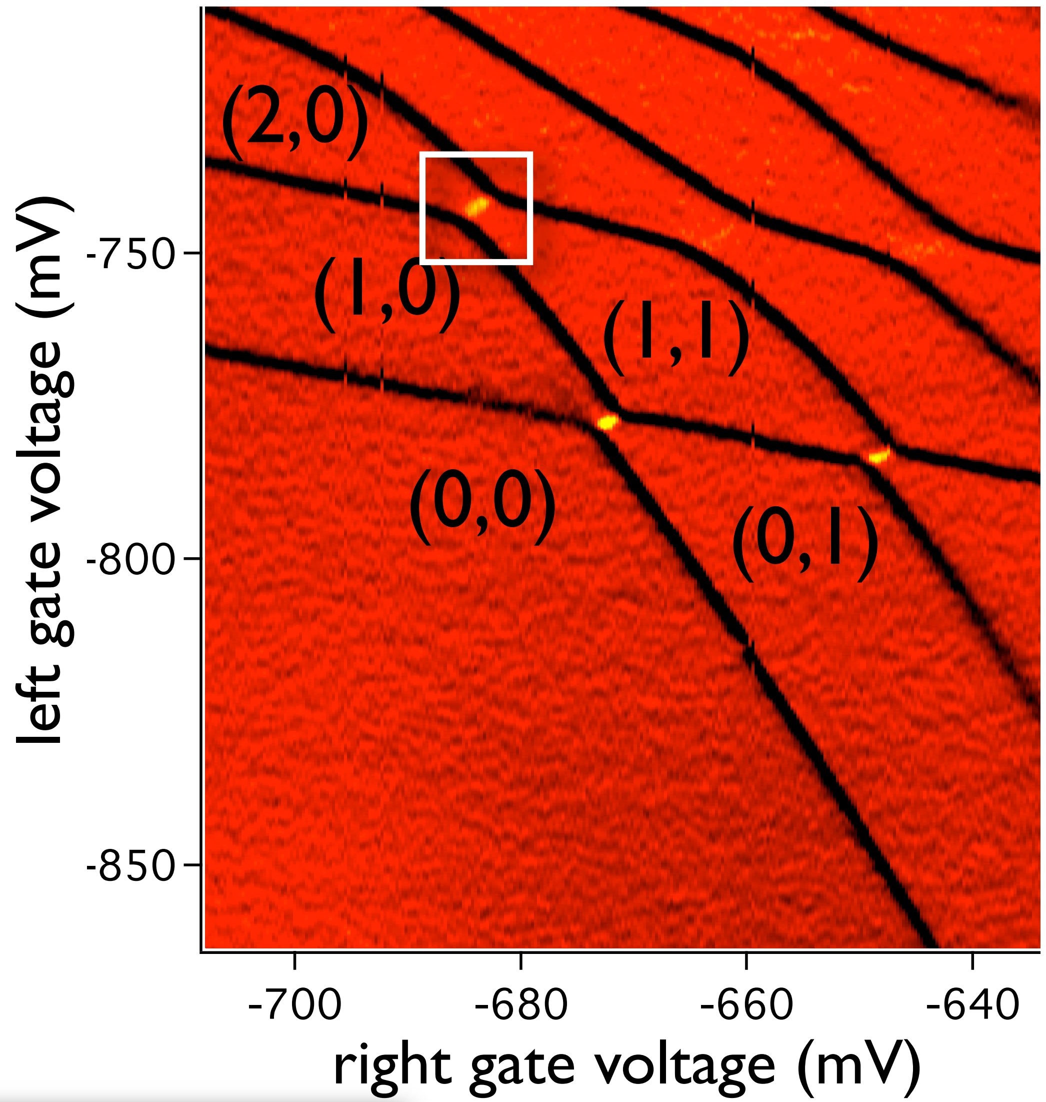
High-bandwidth QPC detection

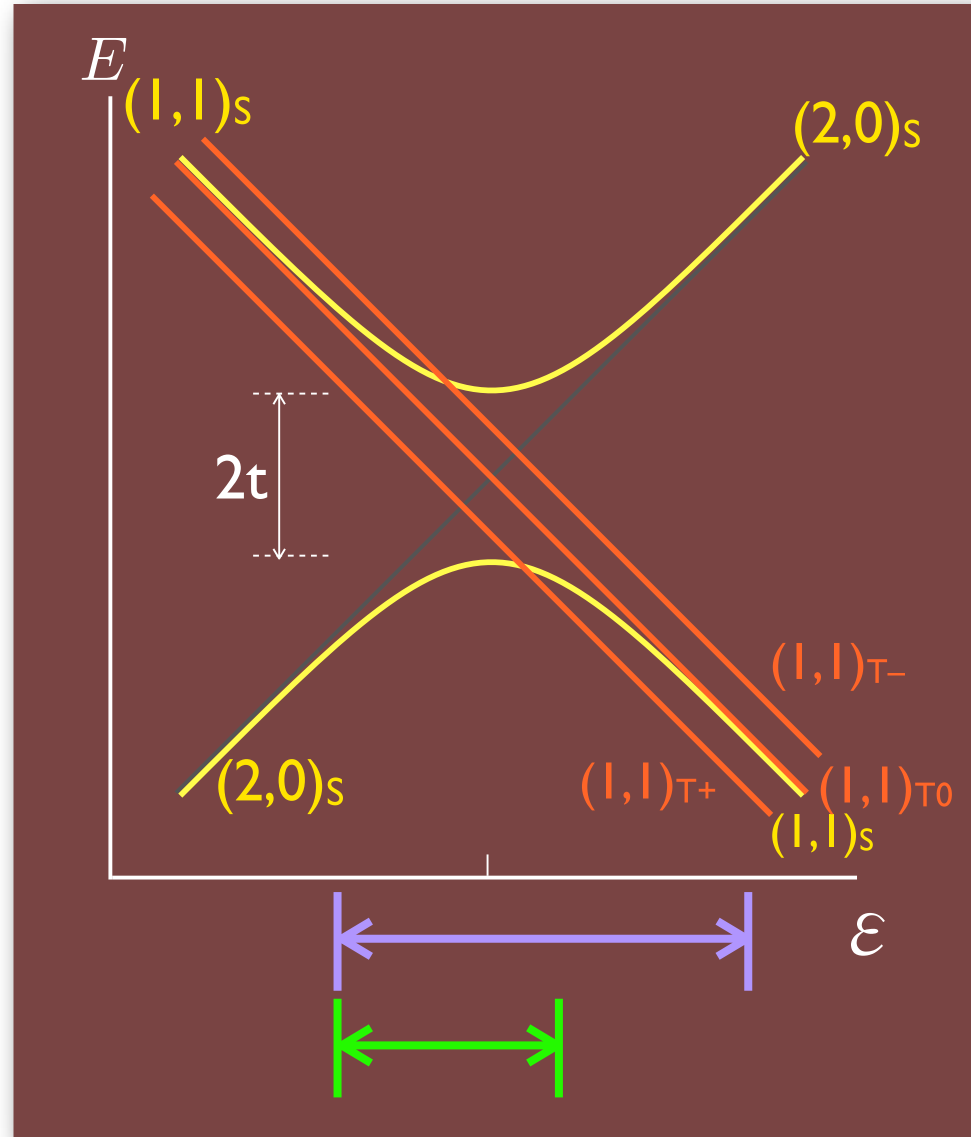


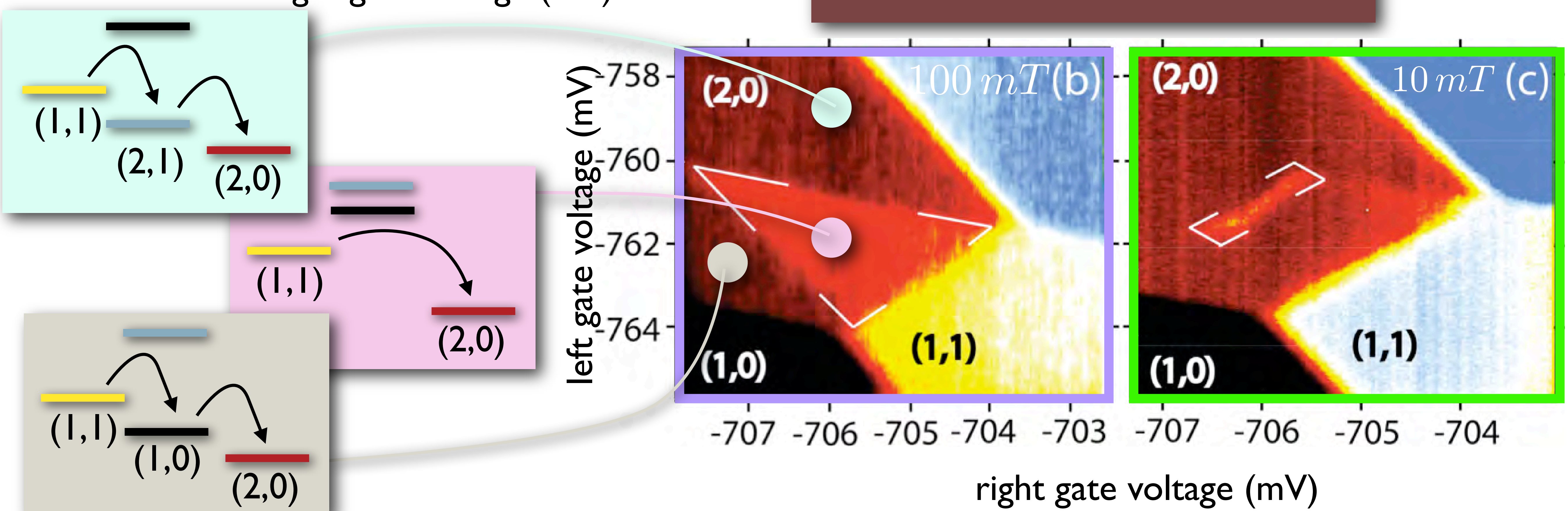




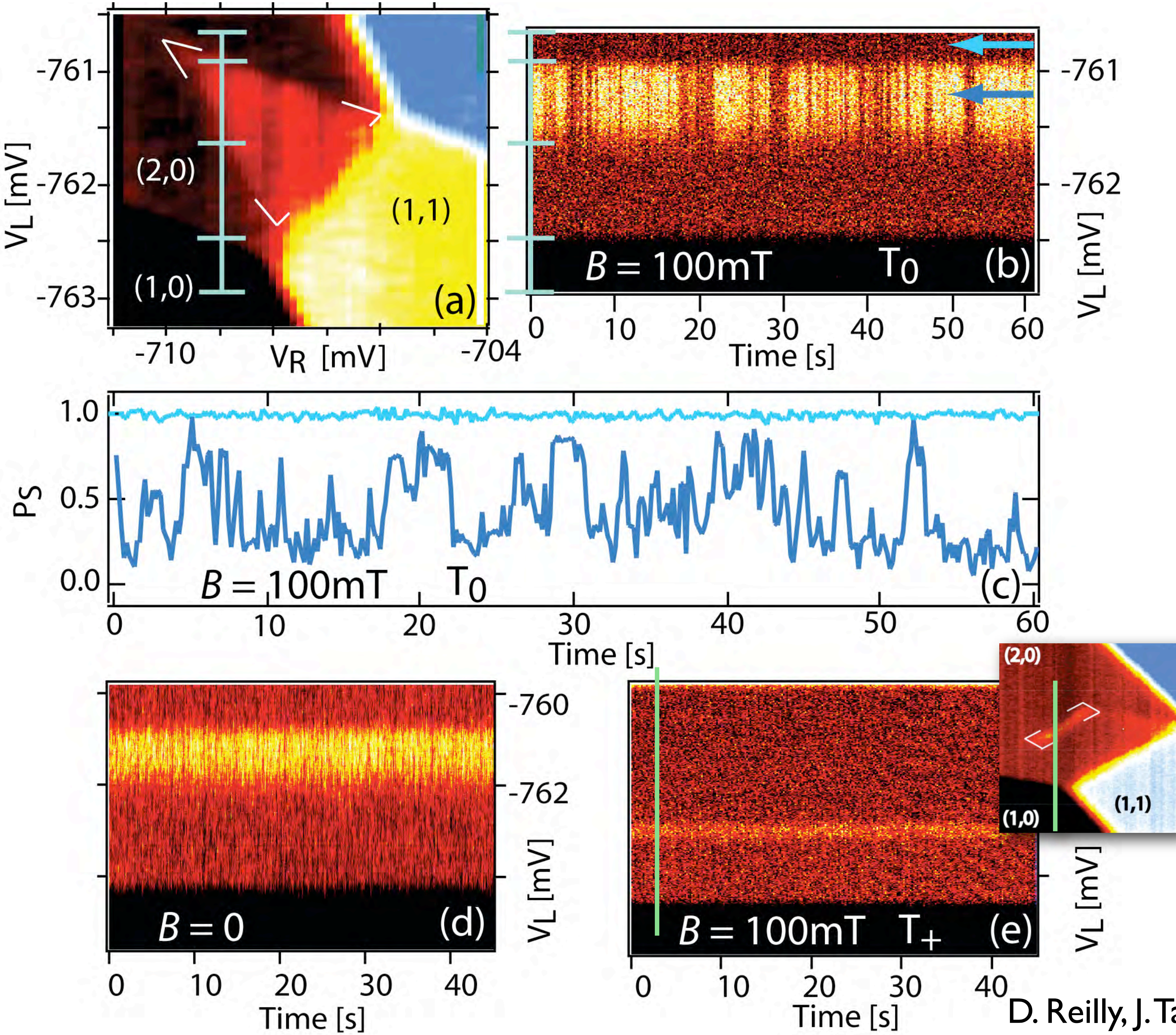



(2,0)
(1,0)
(1,1)
(0,0)
(0,1)
-750
-800
-850
left gate voltage (mV)
-700
-680
-660
-640
right gate voltage (mV)


E
(1,1)S
(2,0)S
2t
(1,1)T−
(2,0)S
(1,1)T+
(1,1)T0
(1,1)S
ε


(1,1)
(2,1)
(2,0)
(1,1)
(2,0)
(1,1)
(1,0)
(2,0)
-758
-760
-762
-764
left gate voltage (mV)
(2,0)
100 mT (b)
(1,0)
(1,1)
(2,0)
10 mT (c)
(1,1)
(1,0)
-707 -706 -705 -704 -703
-707 -706 -705 -704
right gate voltage (mV)

Time evolution of the singlet return probability



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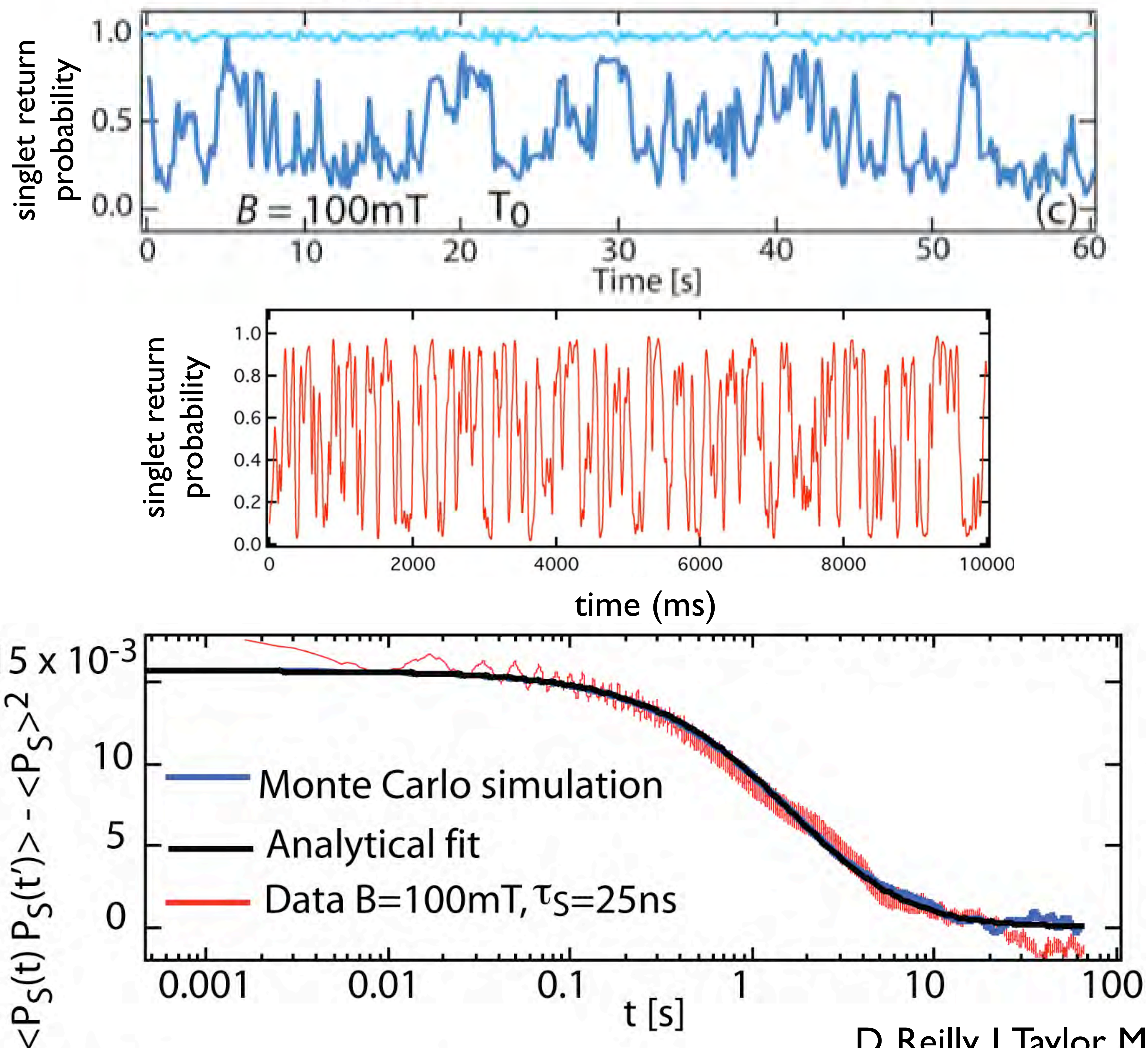
Comparing Experiment and Theory



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Relaxation, dephasing, and quantum control of electron spins in double quantum

J. M. Taylor,[1] J. R. Petta,[1] A. C. Johnson,[1] A. Yacoby,[2] and C. M. Marcus,[1] and M. D. Lukin[1]

[1] *Department of Physics, Harvard University, 17 Oxford St., Cambridge, MA 02138*

[2] *Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel*

(Dated: December 13, 2005)

upper frequency cut-off of nuclear dynamics

$$\gamma \sim B_{\mathrm{nuc}}^2 / B_{\mathrm{ext}} \sqrt{N}$$

$$B_{\mathrm{nuc}} = 3 \text{ mT}$$

$$B_{\mathrm{ext}} = 100 \text{ mT}$$

$$N \sim 10^6$$

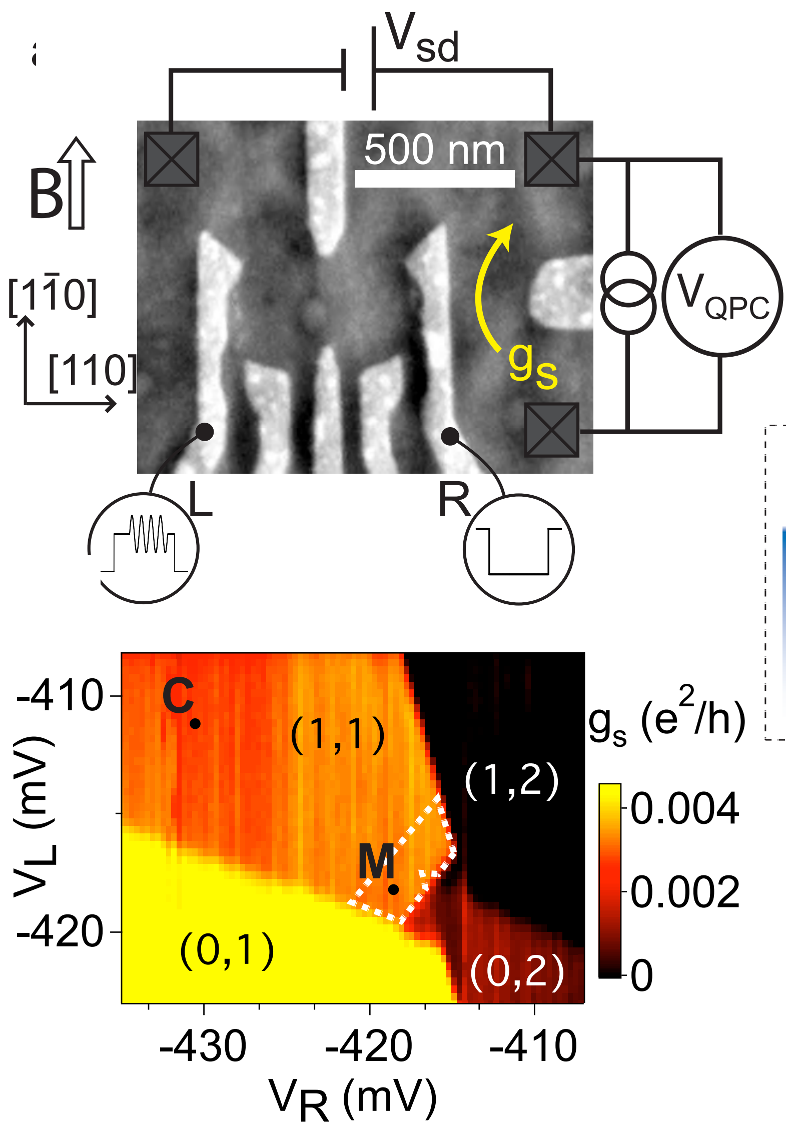
$$\gamma \sim 10^4 s^{-1}$$

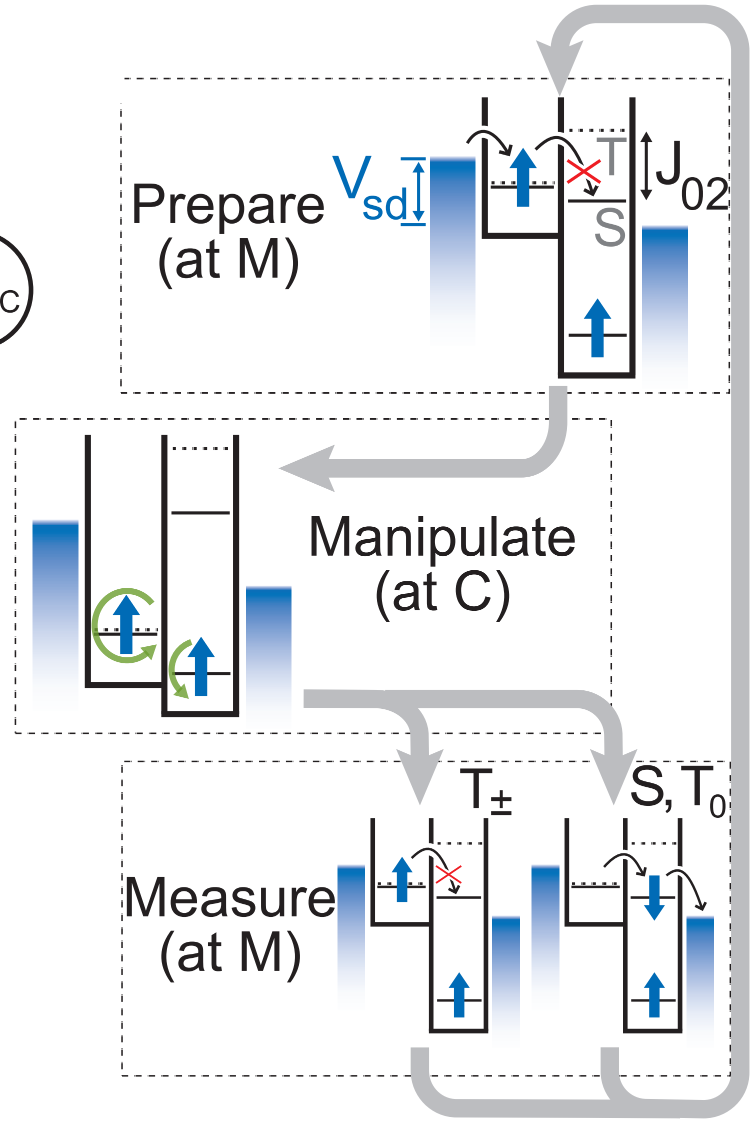
this sets the scale for spin-echo T2

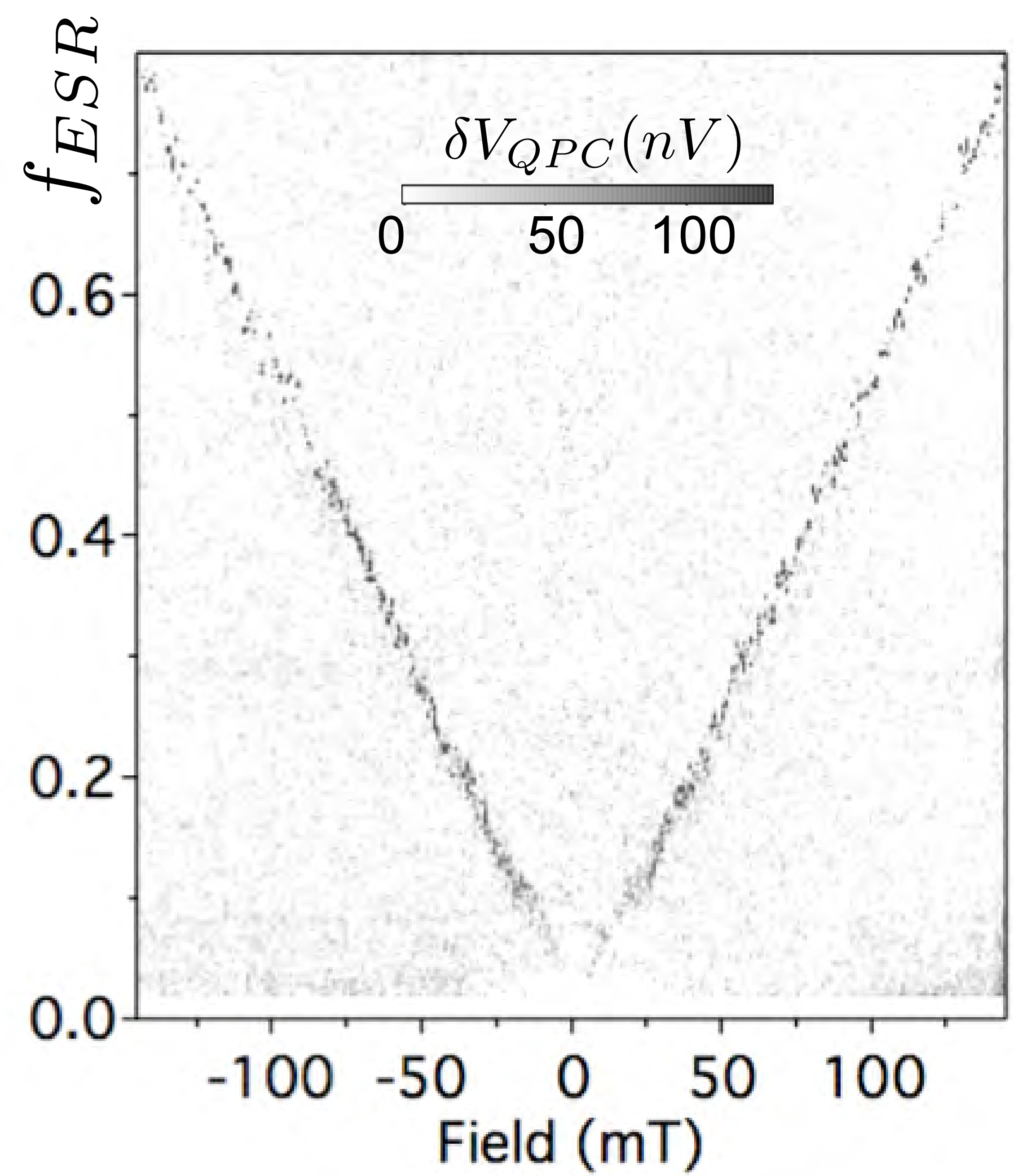
$$T_{2,SE} = 8^{1/4} \sqrt{T_2^* / \gamma} \sim 2\mu\mathrm{s}$$

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]







$$h f_{\mathrm{ESR}} = g \mu_B B_{tot}$$

$$g \sim 0.4$$

E. Laird, C. Barthel, E. Rashba Marcus Lab arXiv: 0707.05572 (2007)

Hyperfine-mediated gate-driven electron spin resonance

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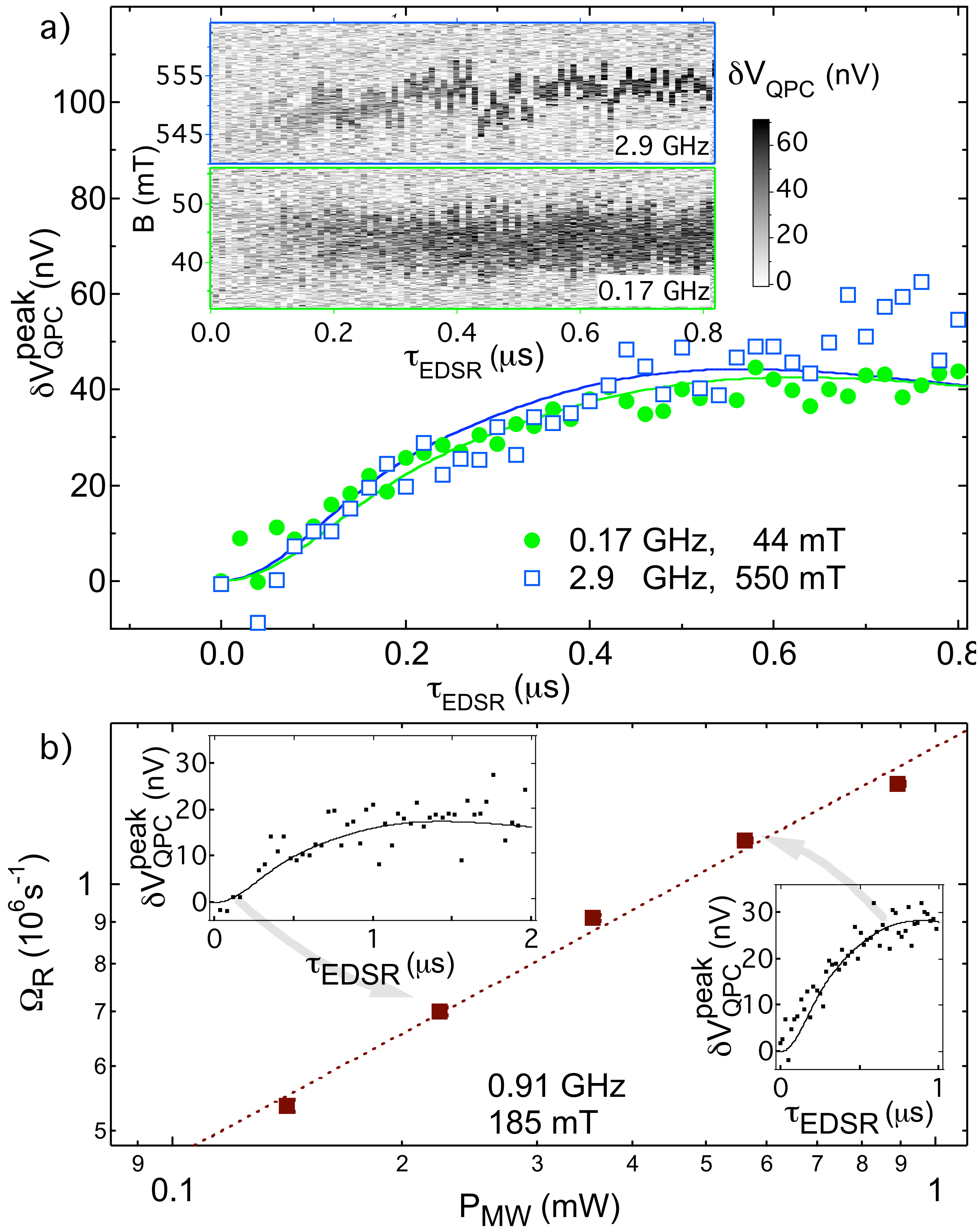


contact hyperfine coupling

$$H_{\rm hf}^U = A\Sigma_j \delta(\mathbf{r} + \mathbf{R}(t) - \mathbf{r}_j)(\mathbf{I}_j \cdot \mathbf{S})$$

mean field model

$$H_{\rm hf}^U(t) = \mathbf{J}(t)\cdot\boldsymbol{\sigma}$$

Larmor detuning

$$J_z = \frac{1}{2}A\sum_j \psi^2(\mathbf{r}_j) I_j^z$$

Spin flip

$$J_\pm(t) = \frac{eA}{m\omega_0^2}\sum_j \psi(\mathbf{r}_j)\tilde{\mathbf{E}}(t)\cdot\nabla\psi(\mathbf{r}_j) I_j^\pm$$

$$\Delta = \frac{A}{2\hbar}\sqrt{\frac{I(I+1)m\omega_0 n_0}{3\pi\hbar d}} \qquad \Omega_R = \frac{e\tilde{E}A}{\hbar^2\omega_0}\sqrt{\frac{I(I+1)n_0}{32\pi d}}$$

Simple assumptions

$$\rho(\omega_z) = \exp(-\omega_z^2/\Delta^2)/(\Delta\sqrt{\pi})$$

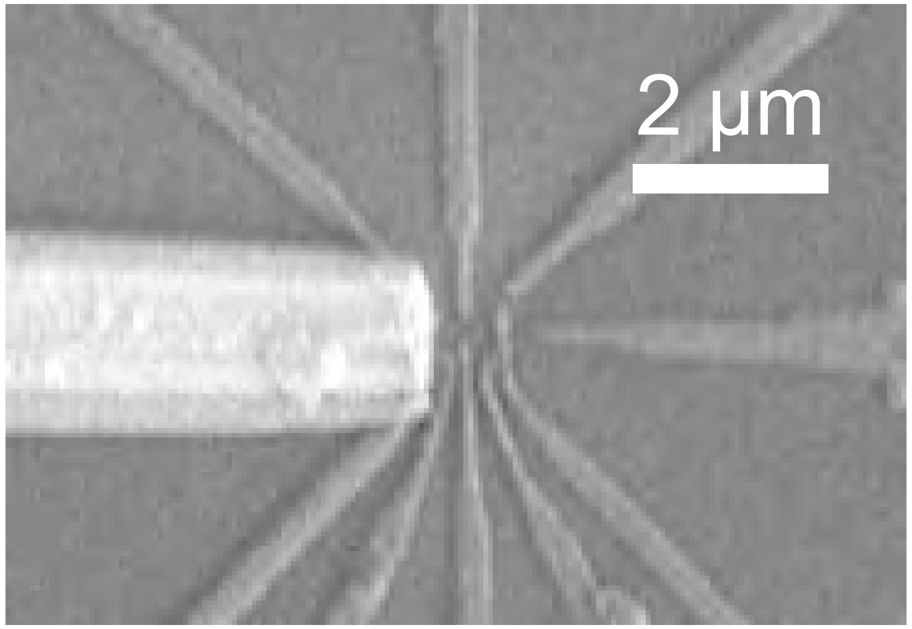
$$\rho(\Omega) = 2\Omega\exp(-\Omega^2/\Omega_R^2)/\Omega_R^2$$

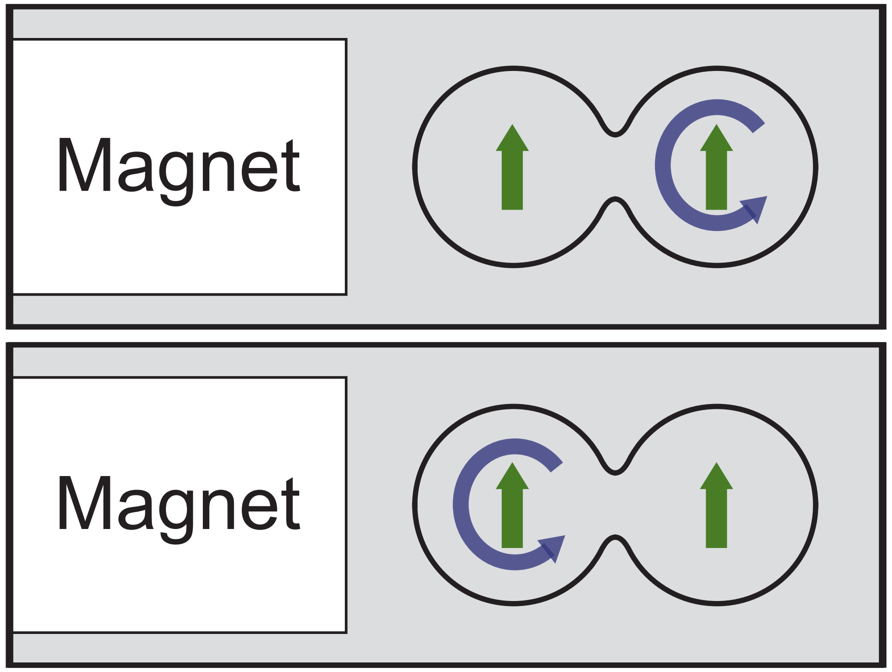
E. Laird, C. Barthel, E. Rashba Marcus Lab arXiv: 0707.05572 (2007)

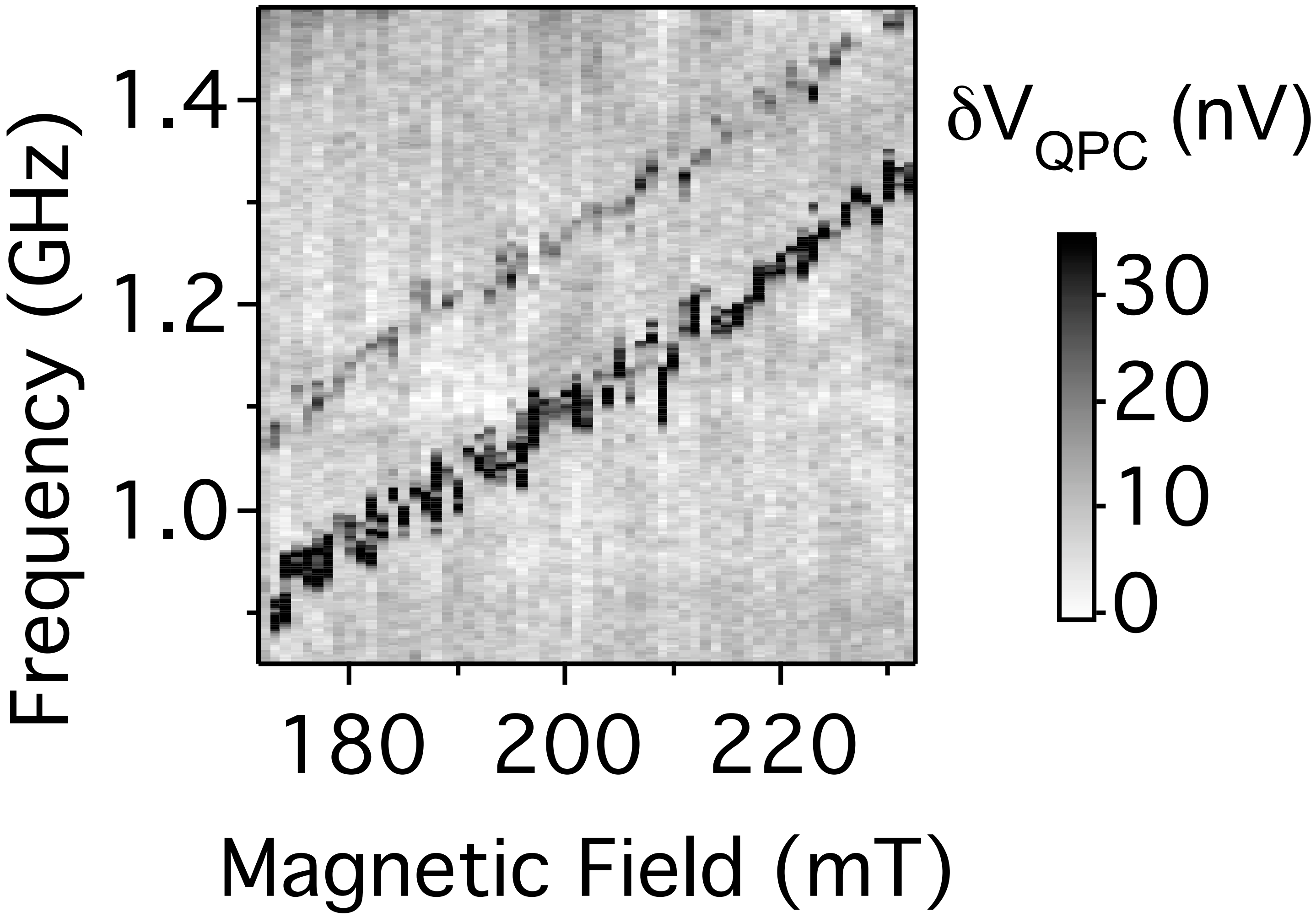
Hyperfine-mediated gate-driven electron spin resonance

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]

ESR Imaging: field gradient - frequency shift - spacial resolution



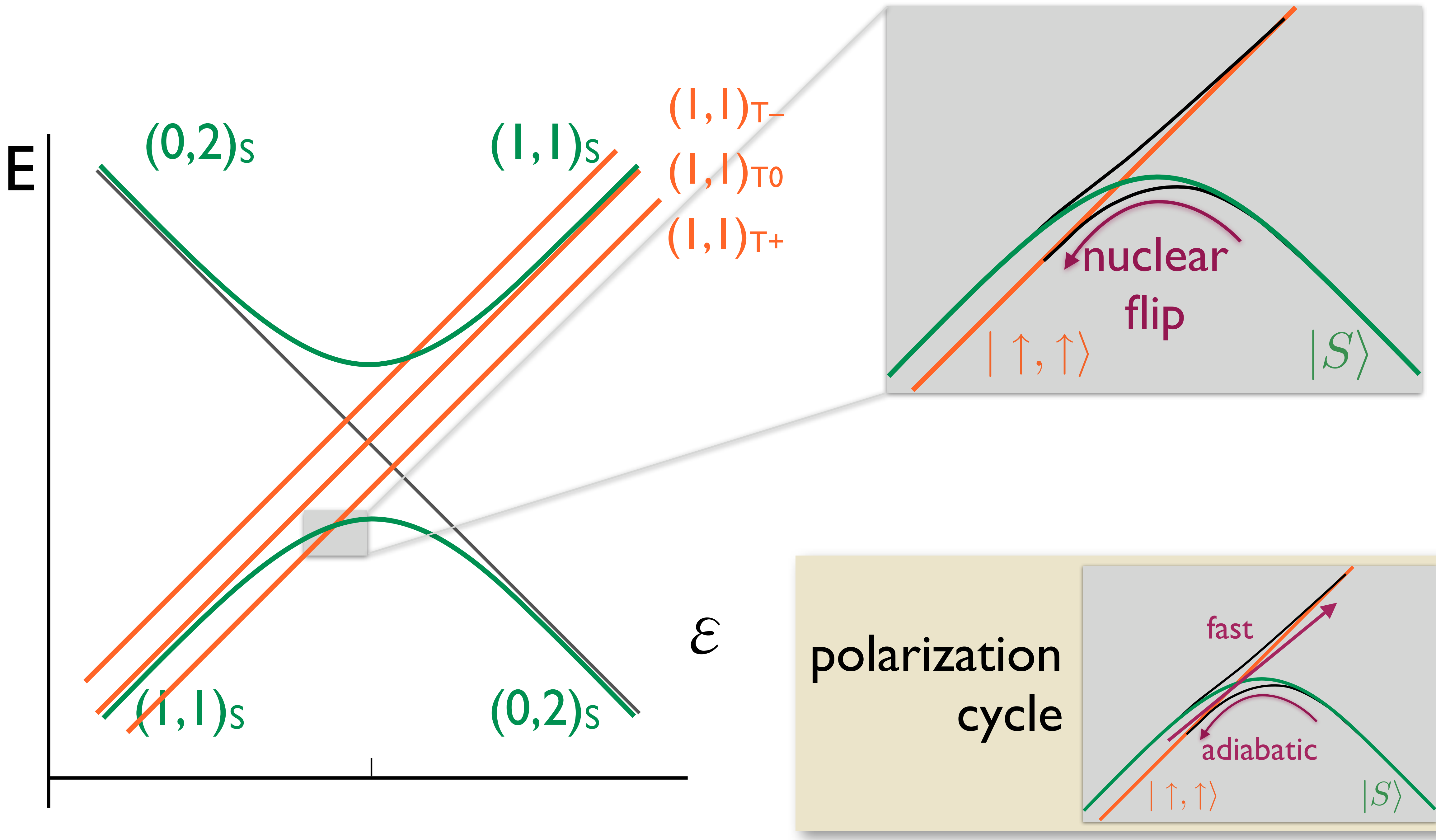




E. Laird, C. Barthel, E. Rashba Marcus Lab arXiv: 0707.05572 (2007)

Controlling the nuclear environment

Single-electron Dynamic Nuclear Polarization at the S - T+ anticrossing



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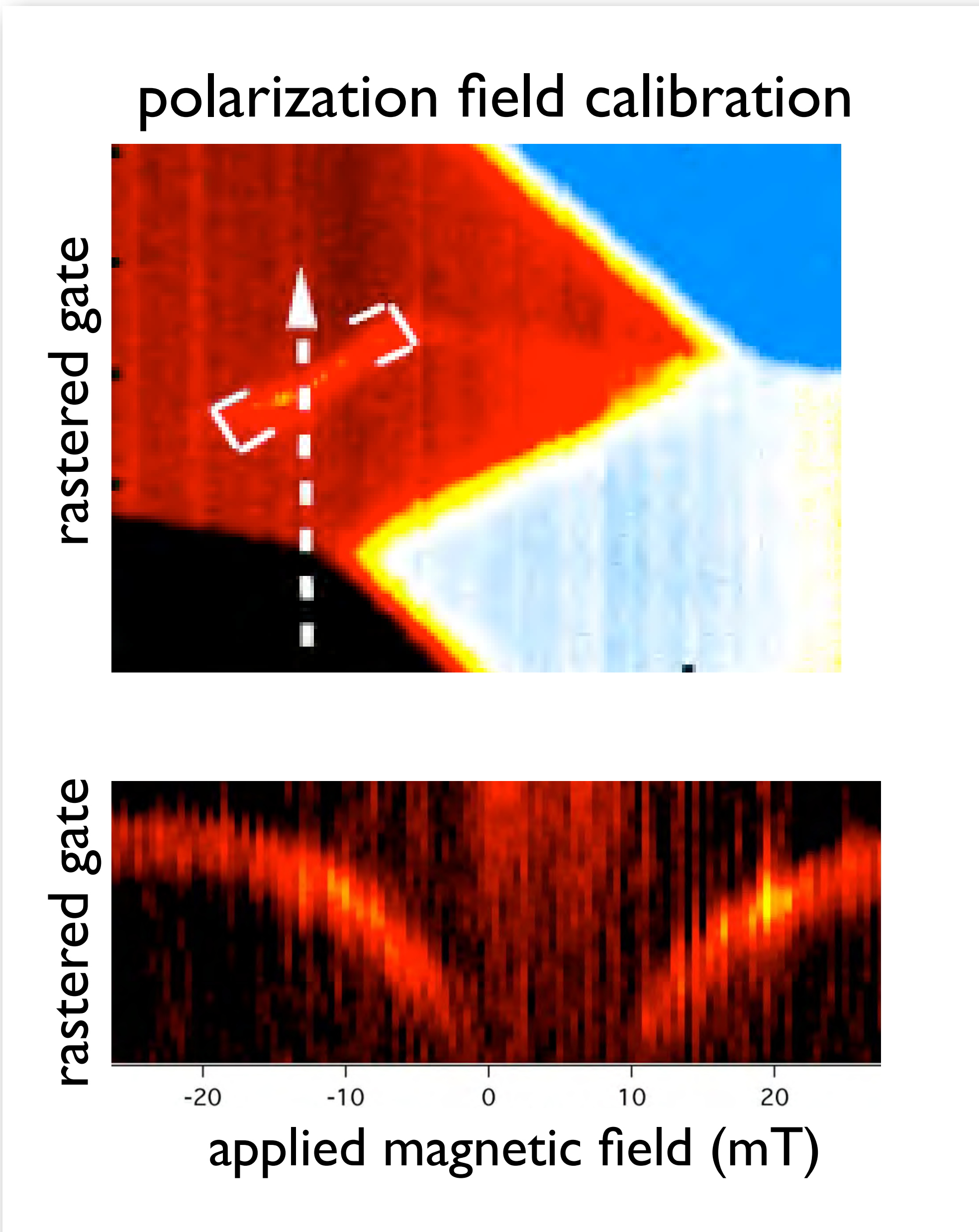
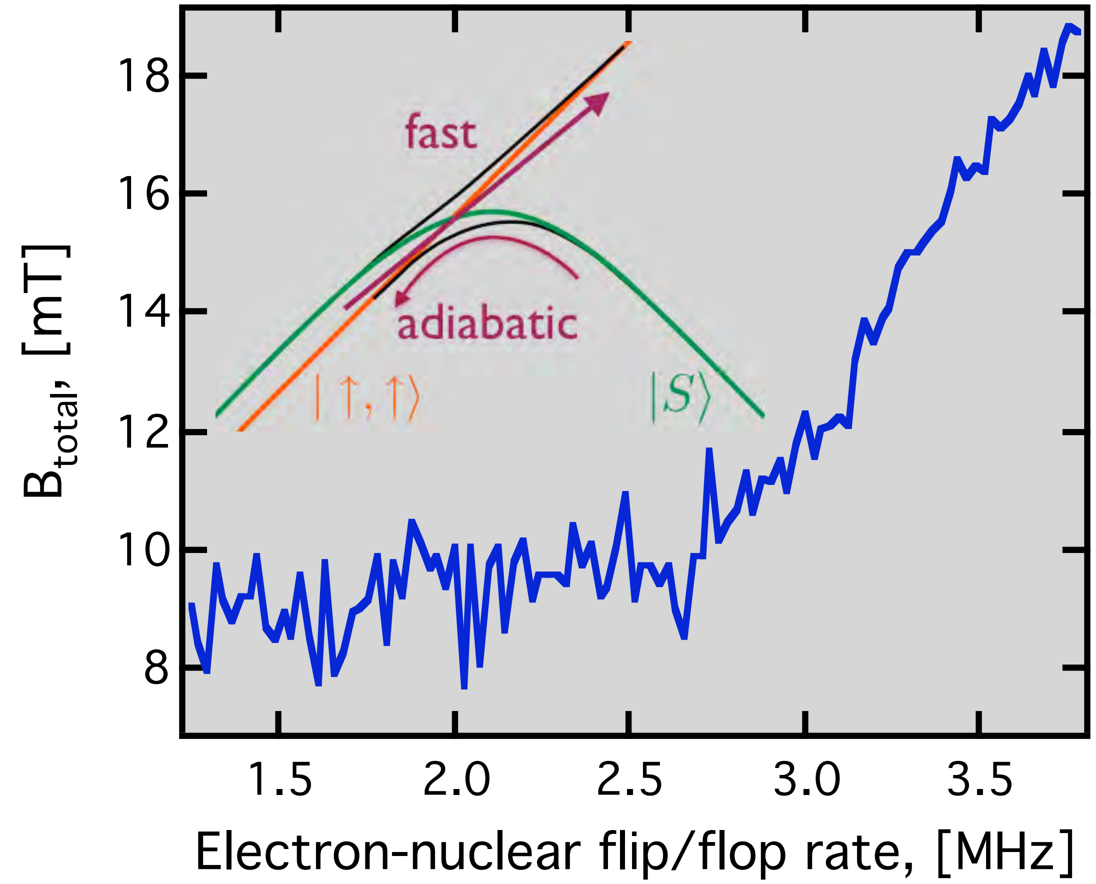
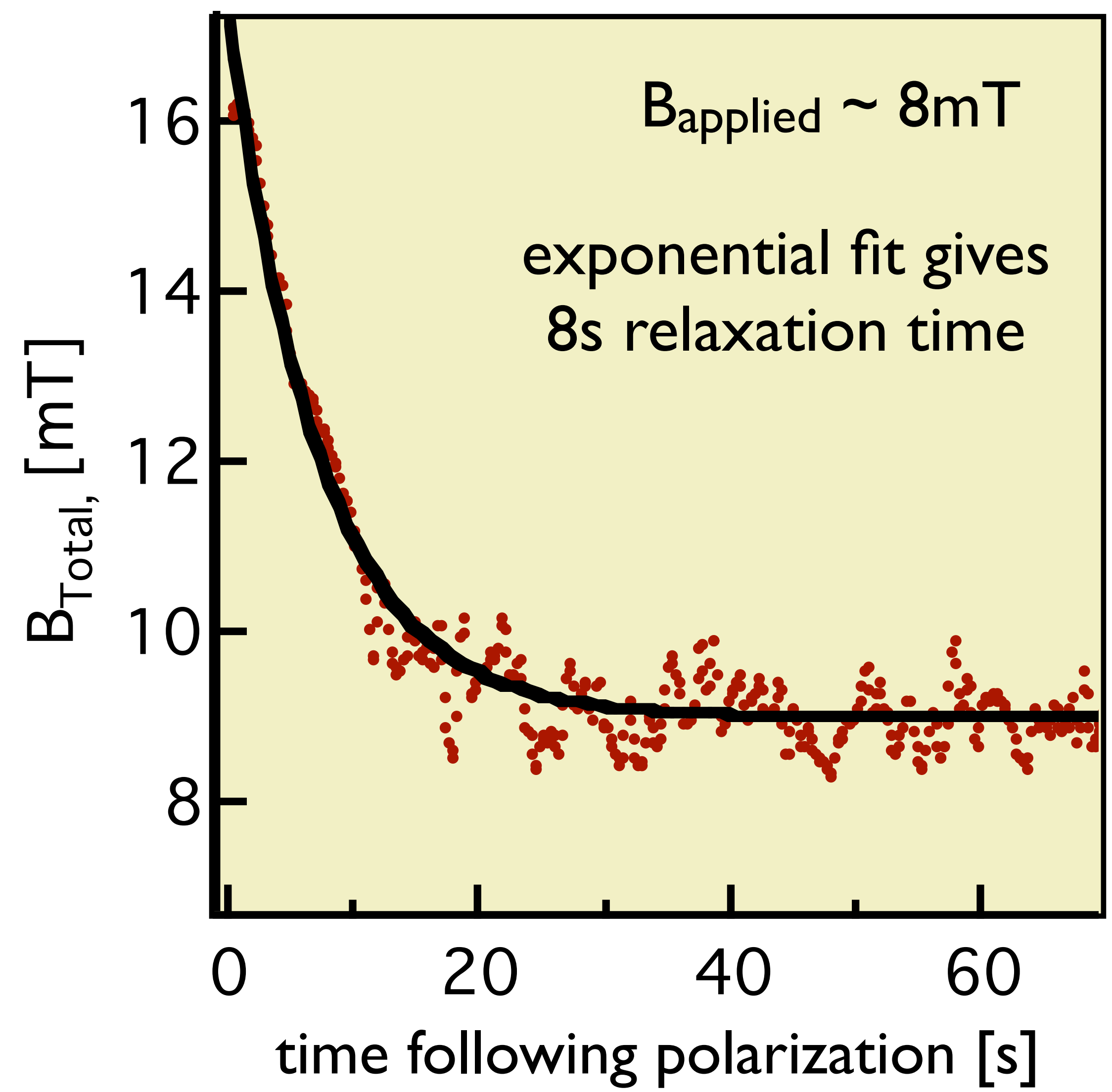
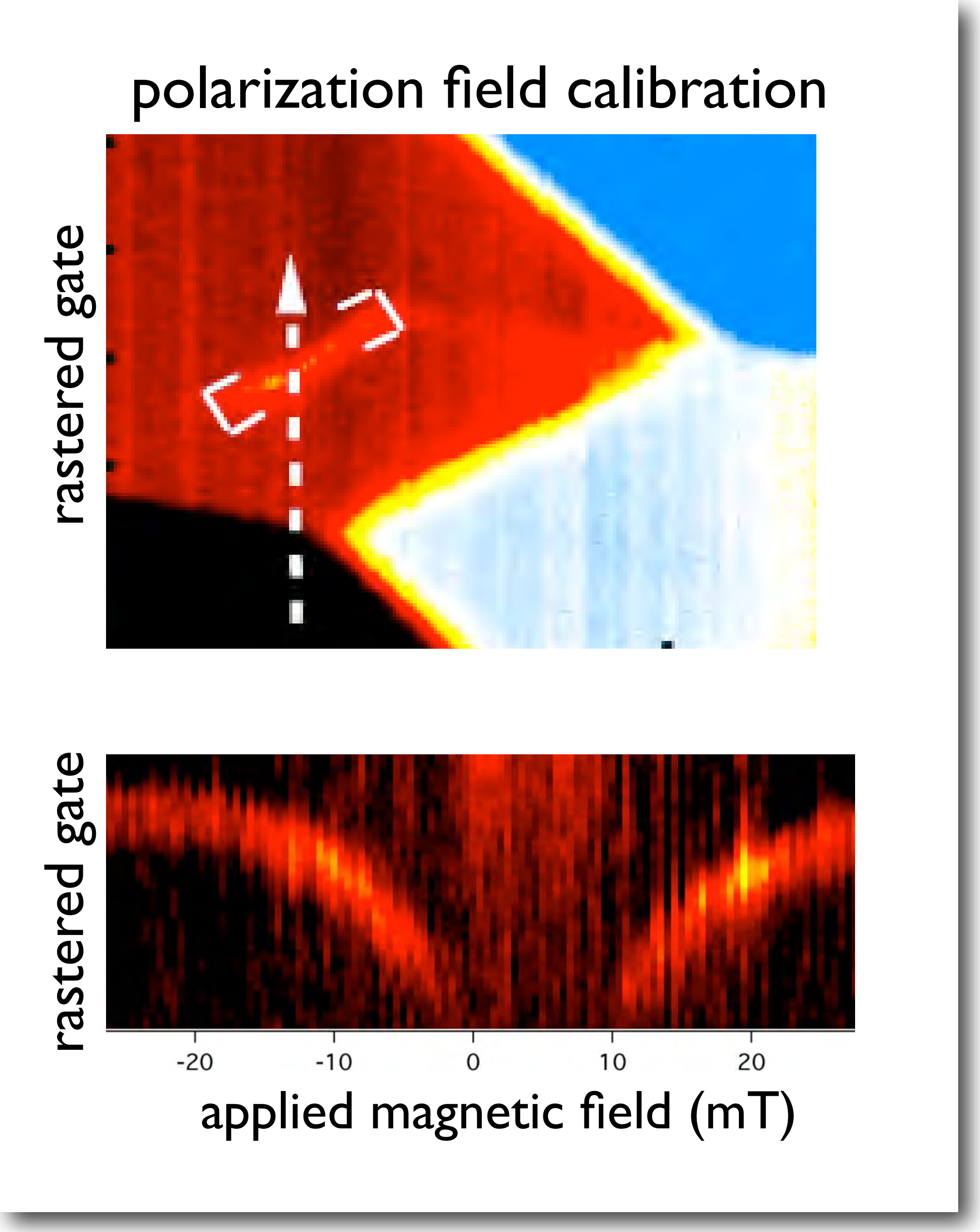
Single-electron Dynamic Nuclear Polarization

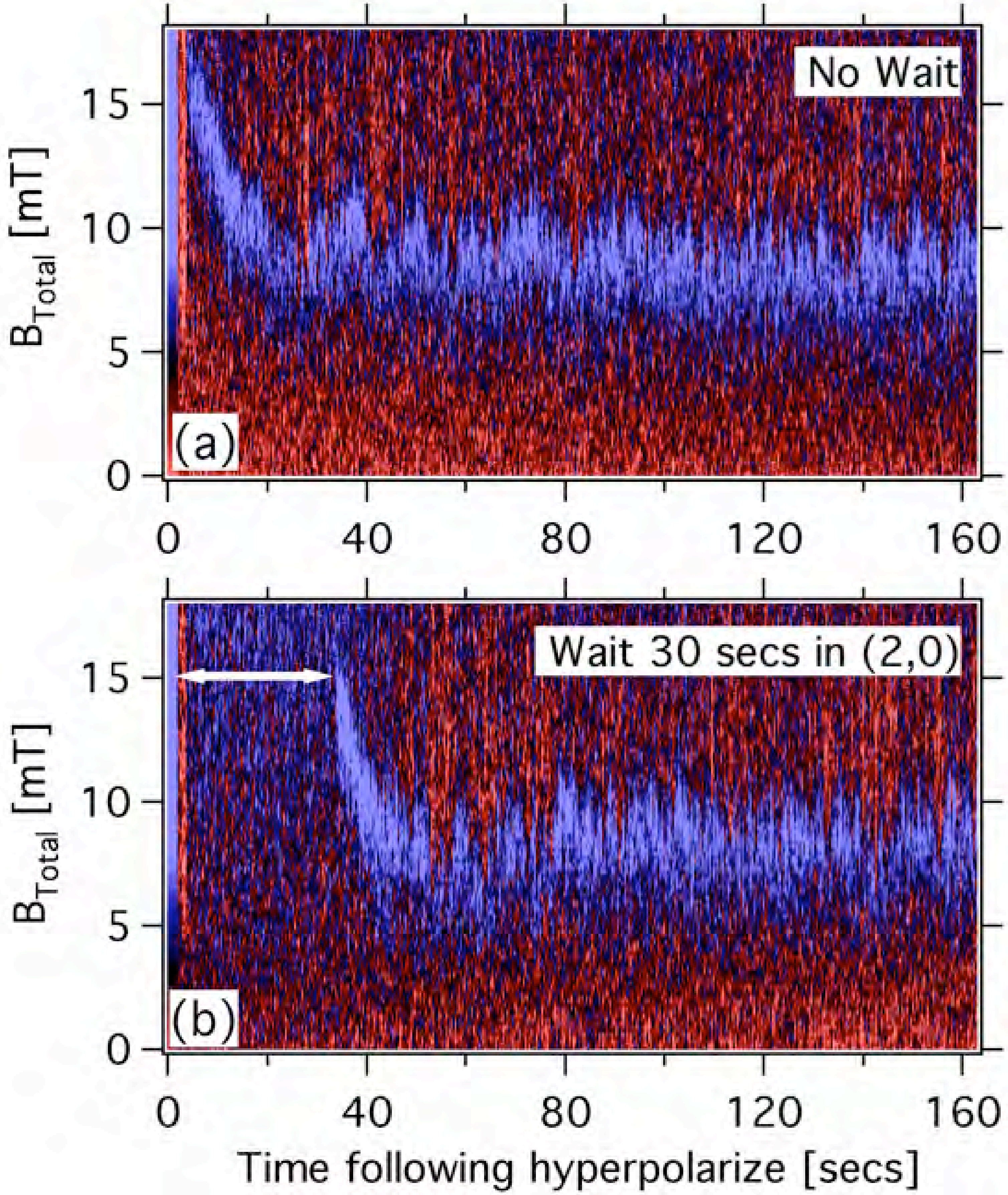




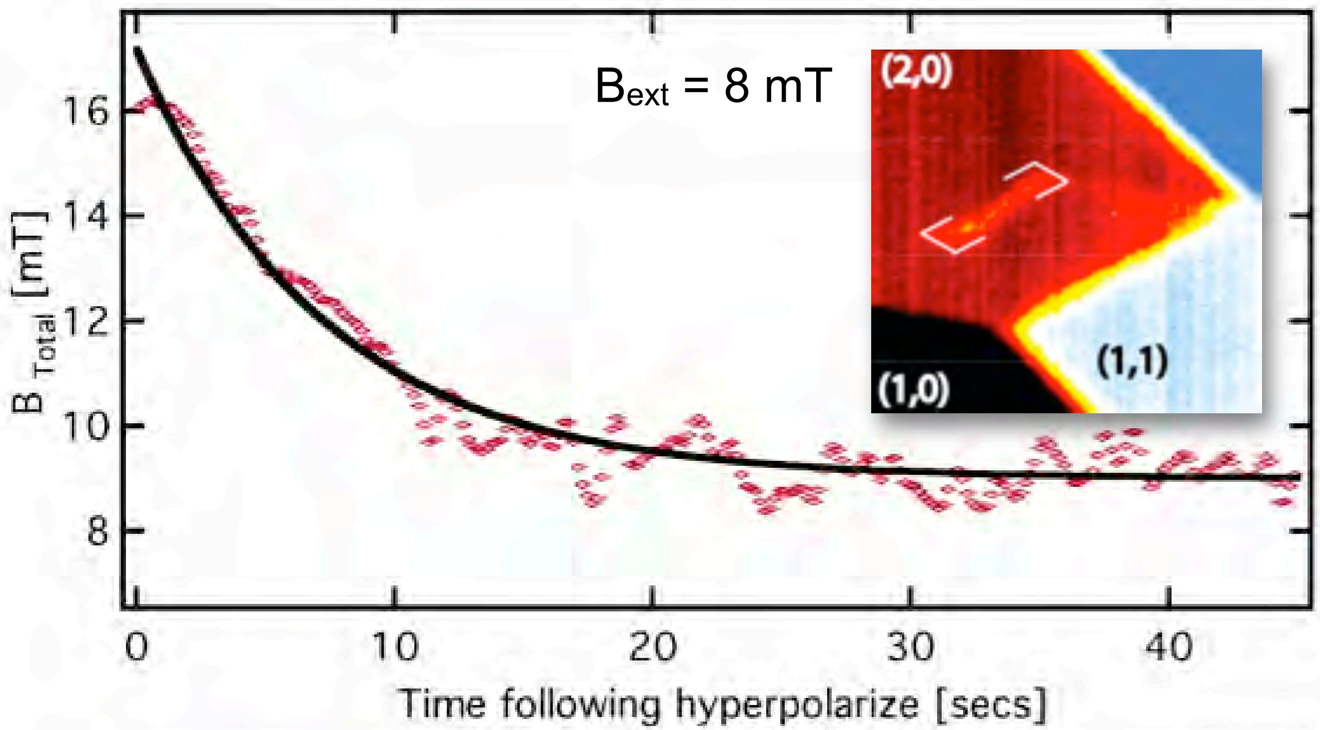


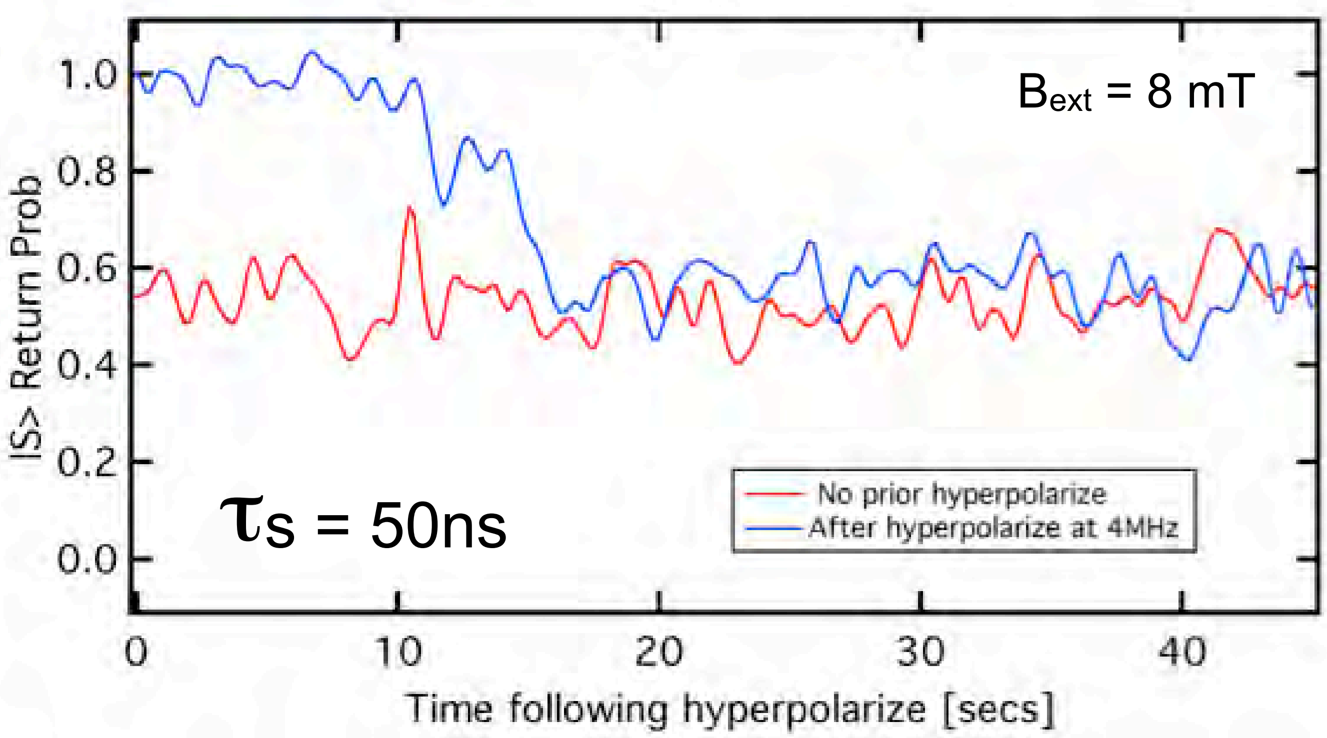
Single-electron Dynamic Nuclear Polarization

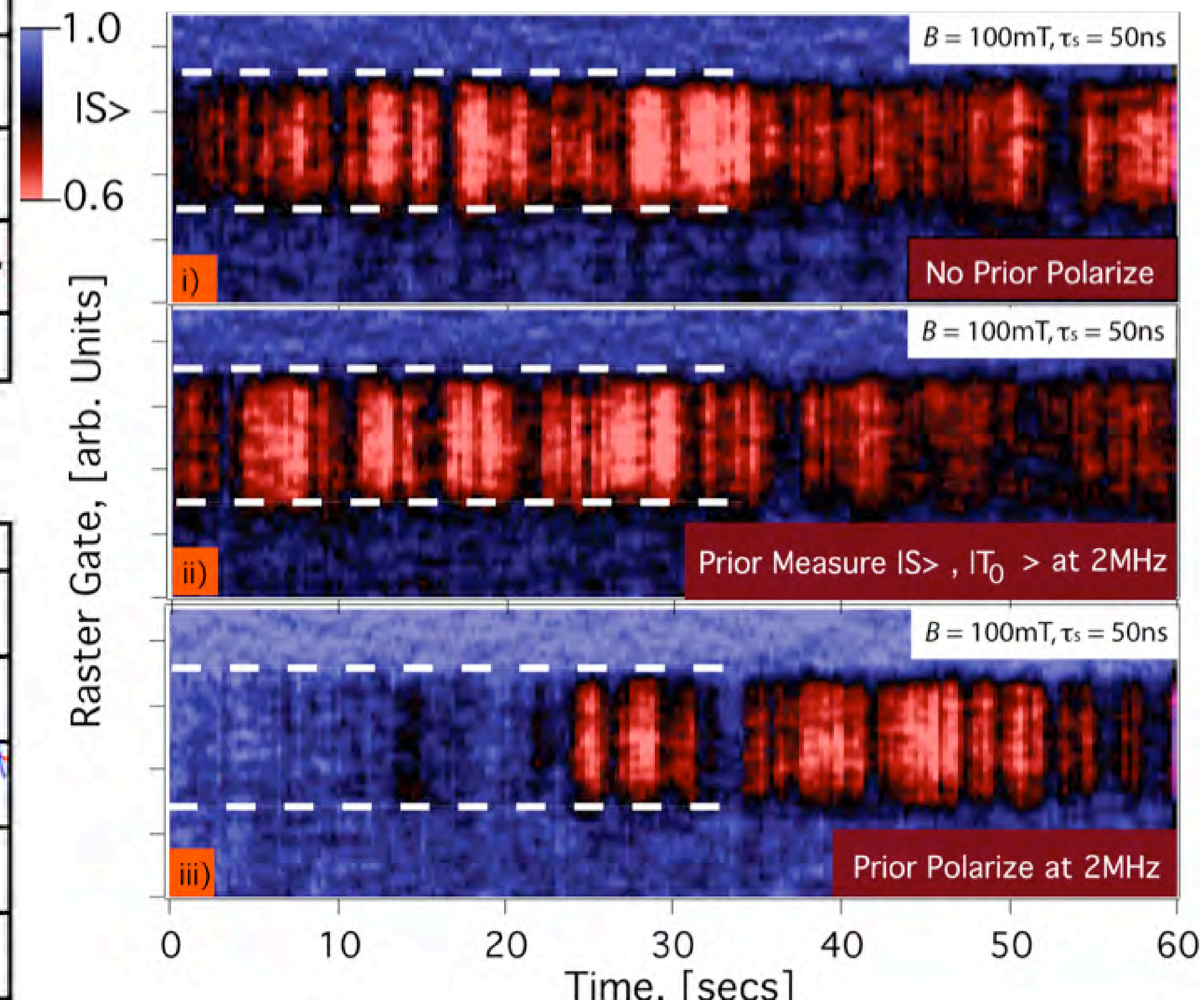




Single-Electron DNP cycle extends T2*







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Nuclear Zamboni

PHYSICAL REVIEW B **75**, 161301(R) (2007)

Dynamical nuclear spin polarization and the Zamboni effect in gated double quantum dots

Guy Ramon* and Xuedong Hu
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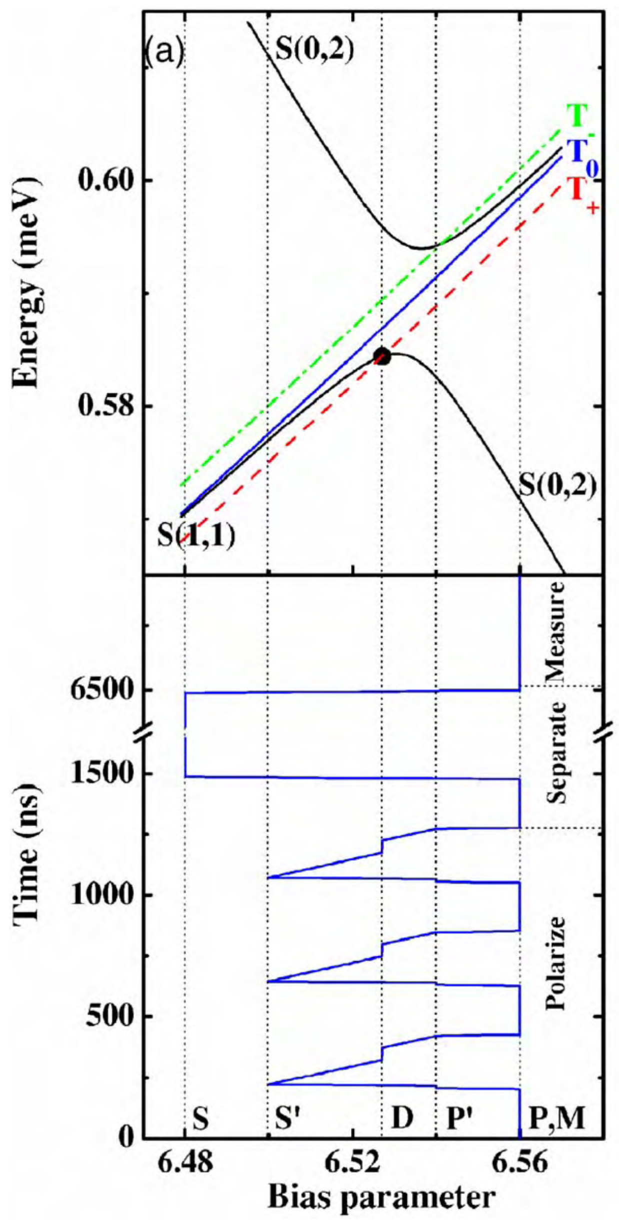
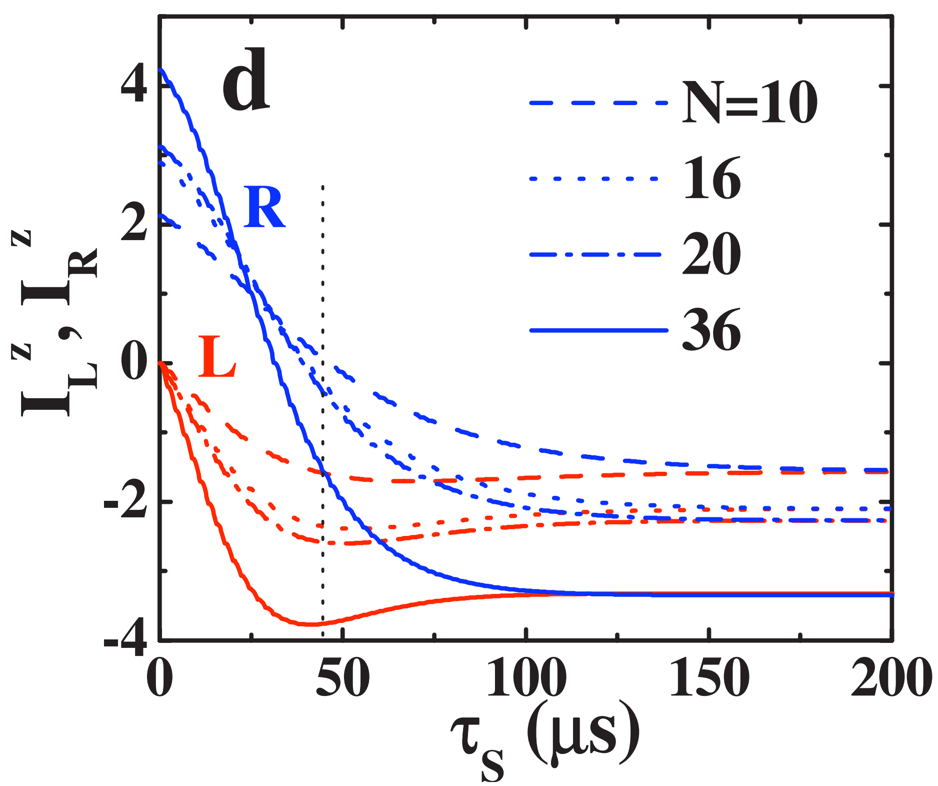
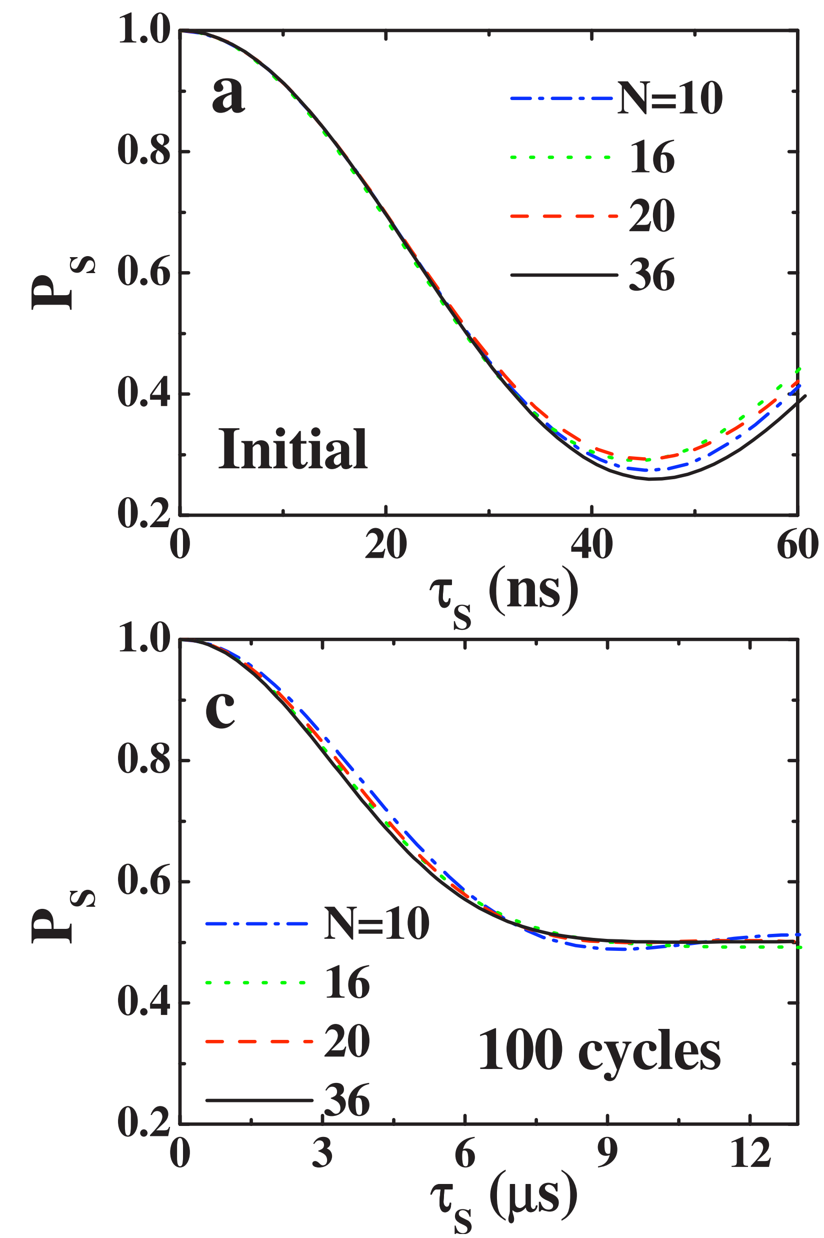
(Received 12 February 2007; published 5 April 2007)

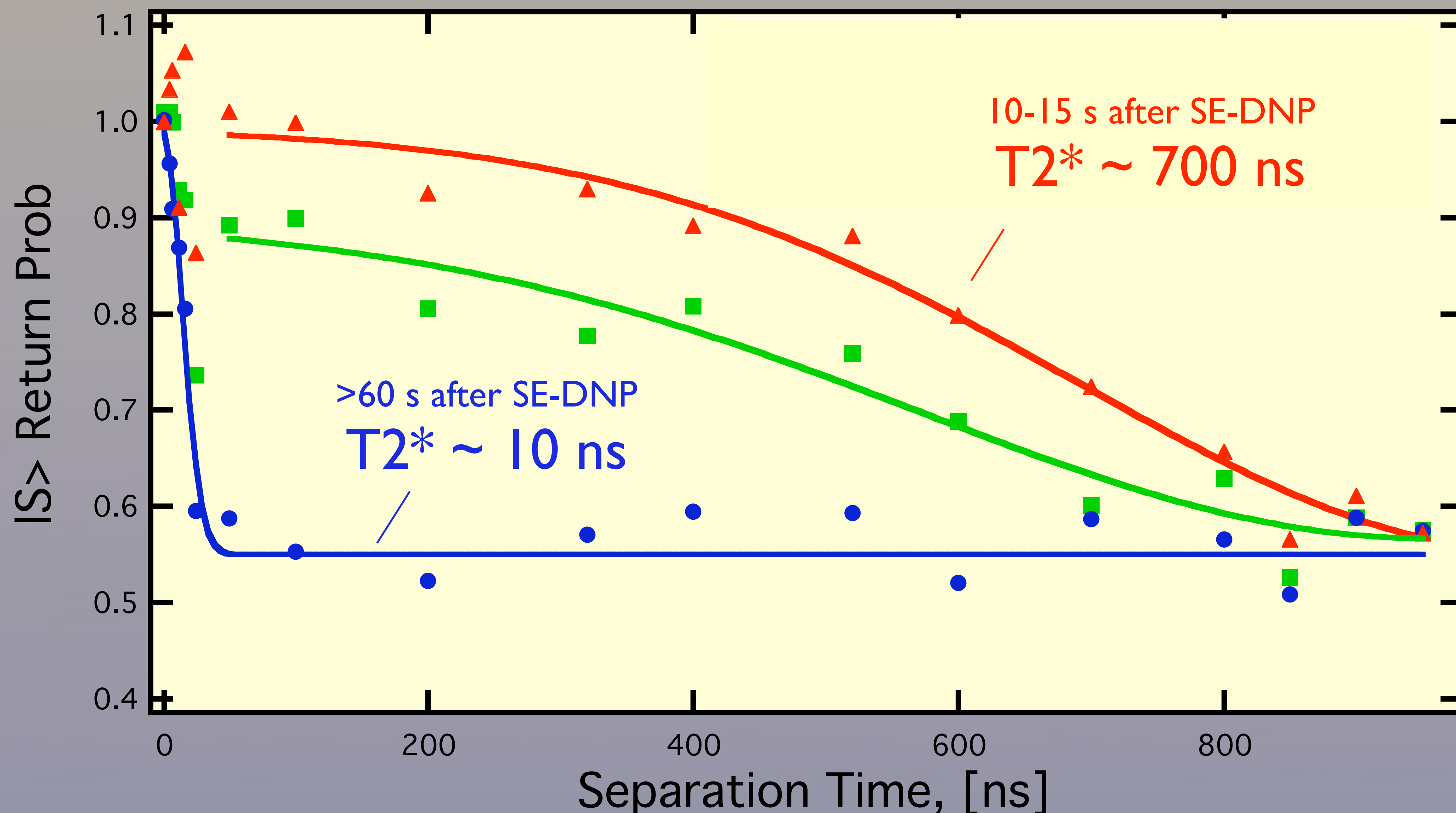
A dynamical nuclear polarization scheme is studied in gated double dots. We demonstrate that a small polarization (~0.5%) is sufficient to enhance the singlet decay time by two orders of magnitude. This enhancement is attributed to an equilibration process between the nuclear reservoirs in the two dots accompanied by reduced fluctuations in the Overhauser fields that are mediated by the electron-nuclear spin hyperfine interaction.





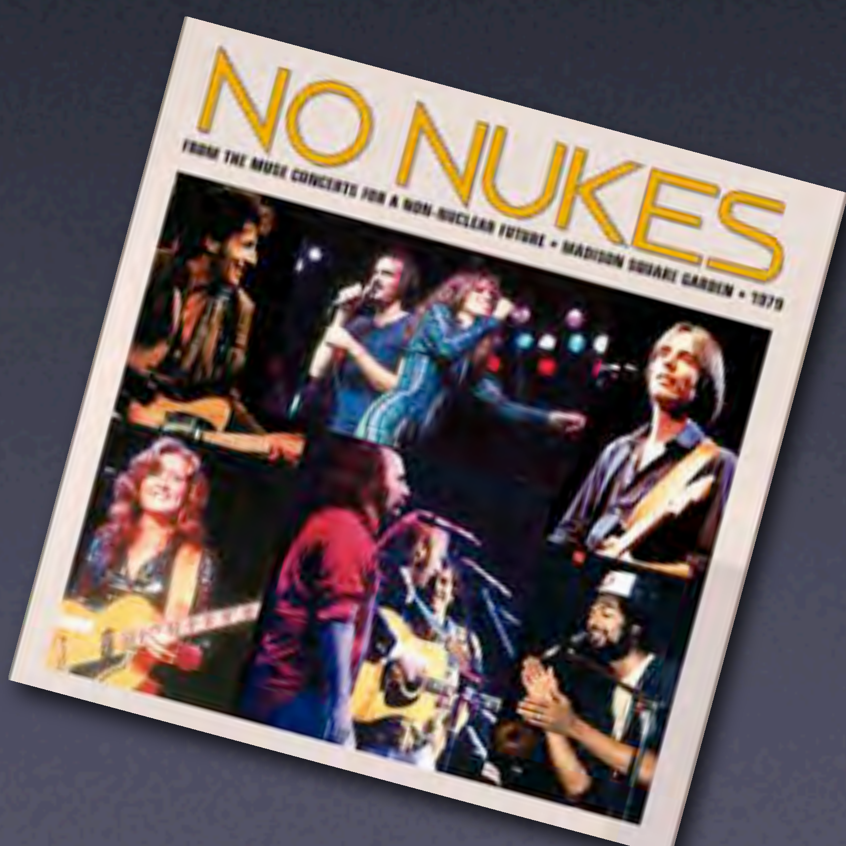


T2* extended by a factor of 70 with small SE-DNP polarization



not known what happens to T2

New materials to eliminate the nuclear environment



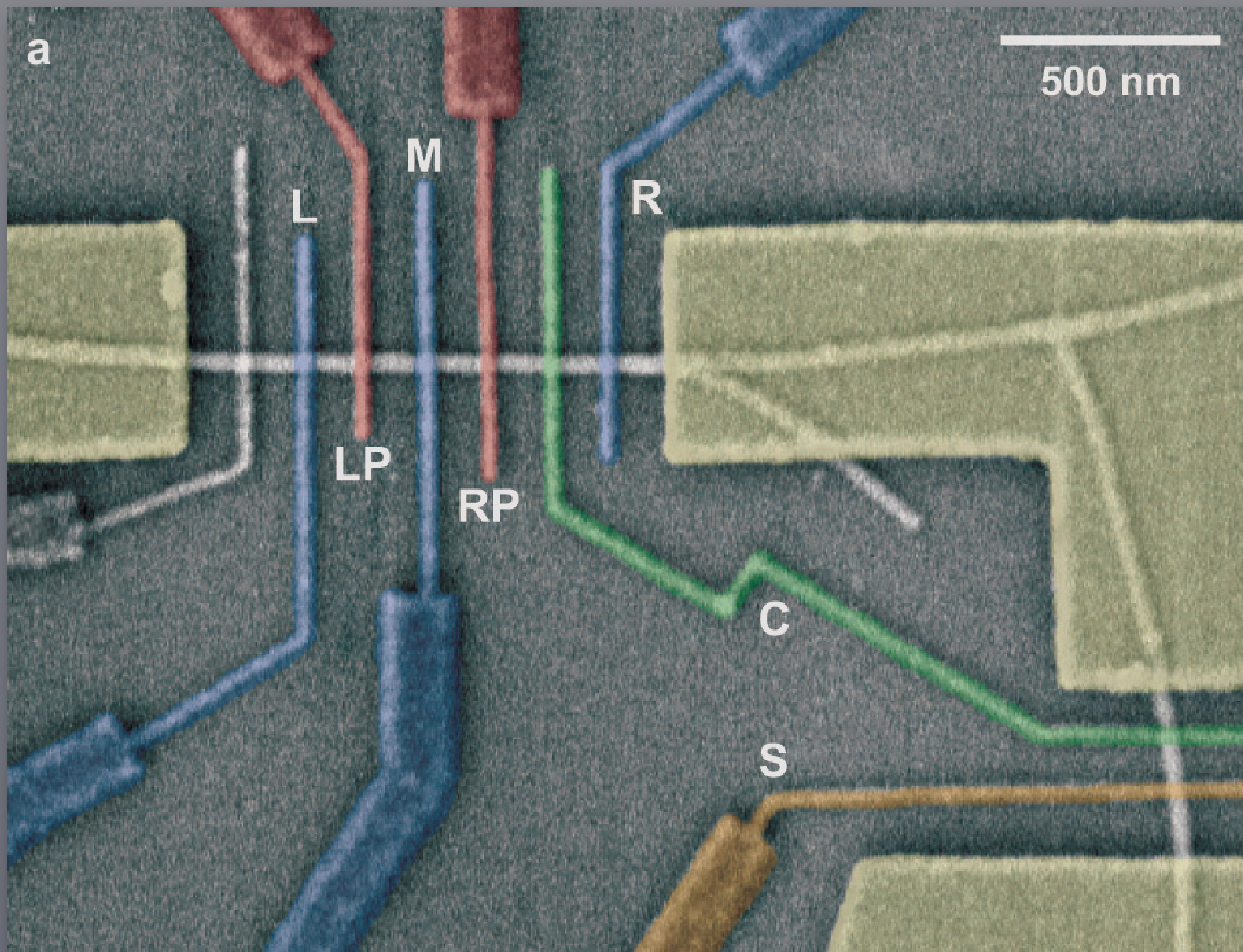
mostly zero nuclear spin isotopes

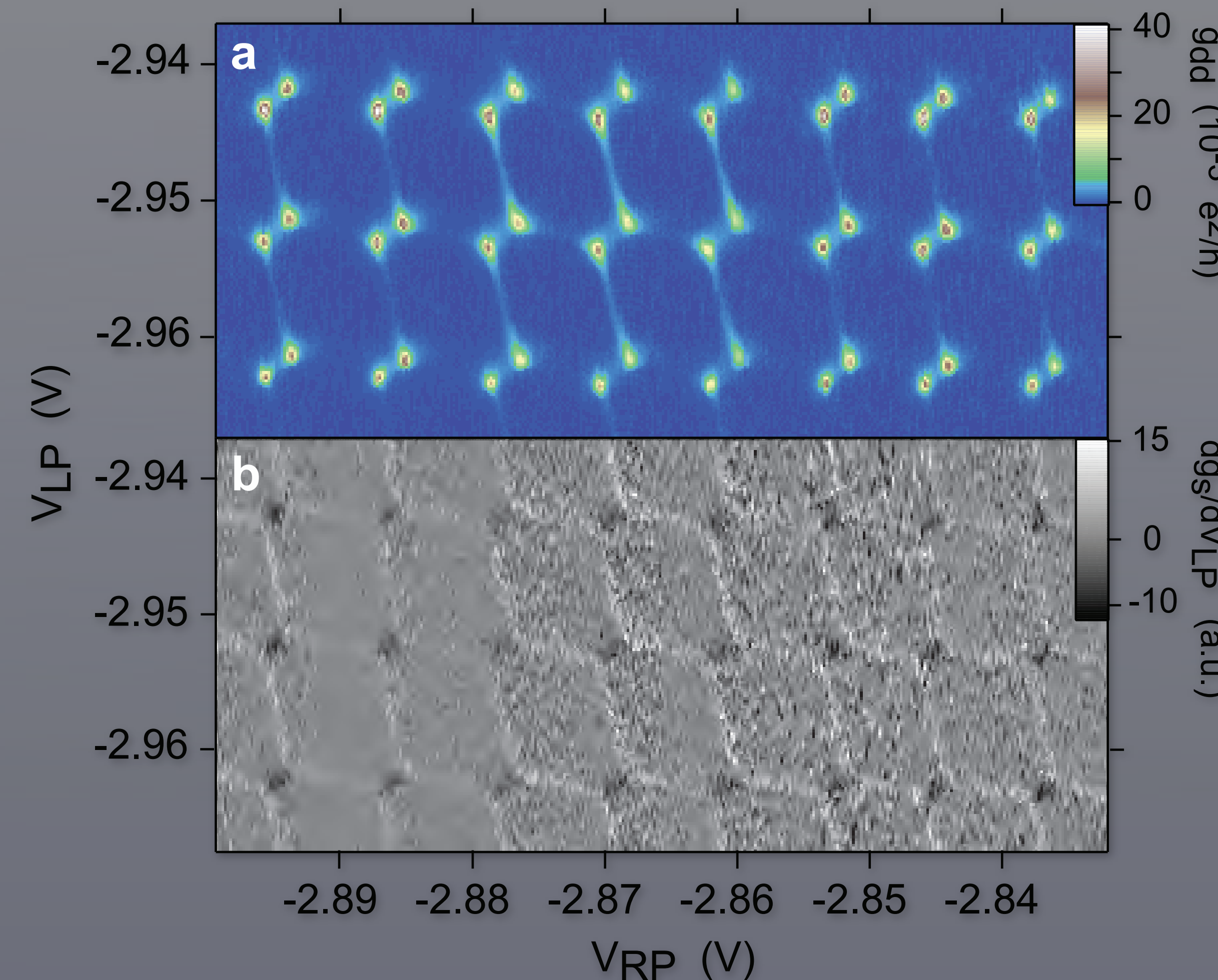
Isotope	Atomic mass (m_a/u)	Natural abundance (atom %)	Nuclear spin (I)
^{12}C	12.000000000*	98.93 (8)	0
^{13}C	13.003354826 (17)	1.07 (8)	$^1/_2$

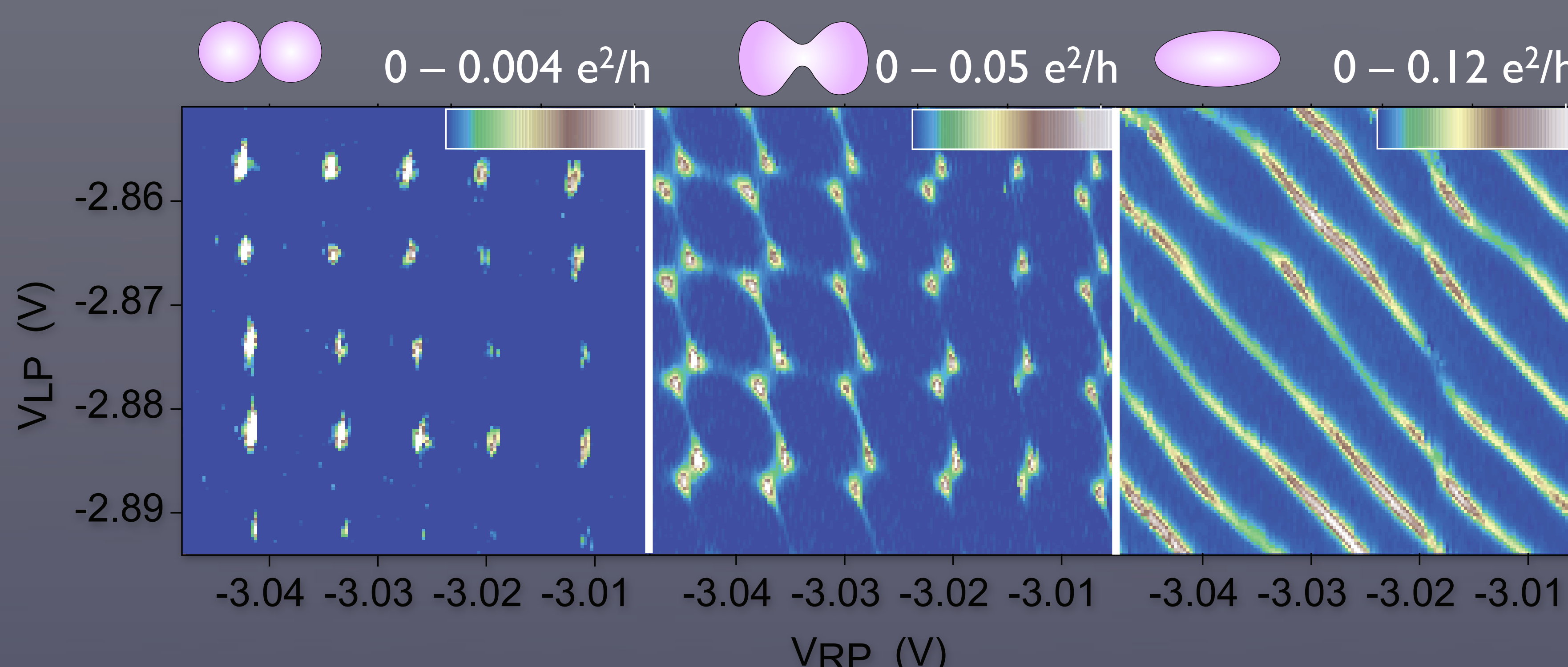
Isotope	Atomic mass (m_a/u)	Natural abundance (atom %)	Nuclear spin (I)
^{28}Si	27.9769271 (7)	92.2297 (7)	0
^{29}Si	28.9764949 (7)	4.6832 (5)	$^1/_2$
^{30}Si	29.9737707 (7)	3.0872 (5)	0

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

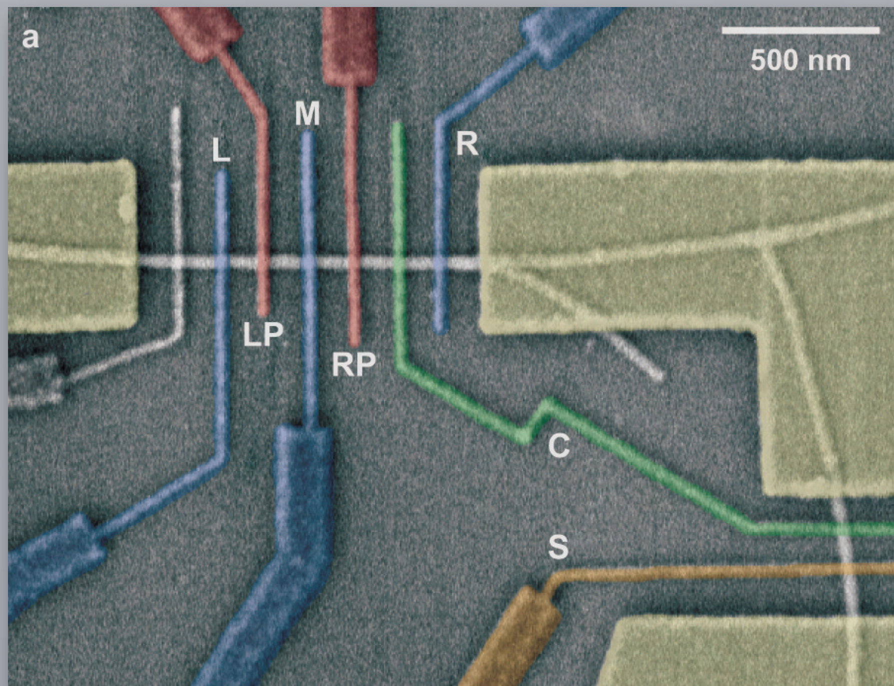
Si/Ge Nanowire with Integrated Charge Sensor

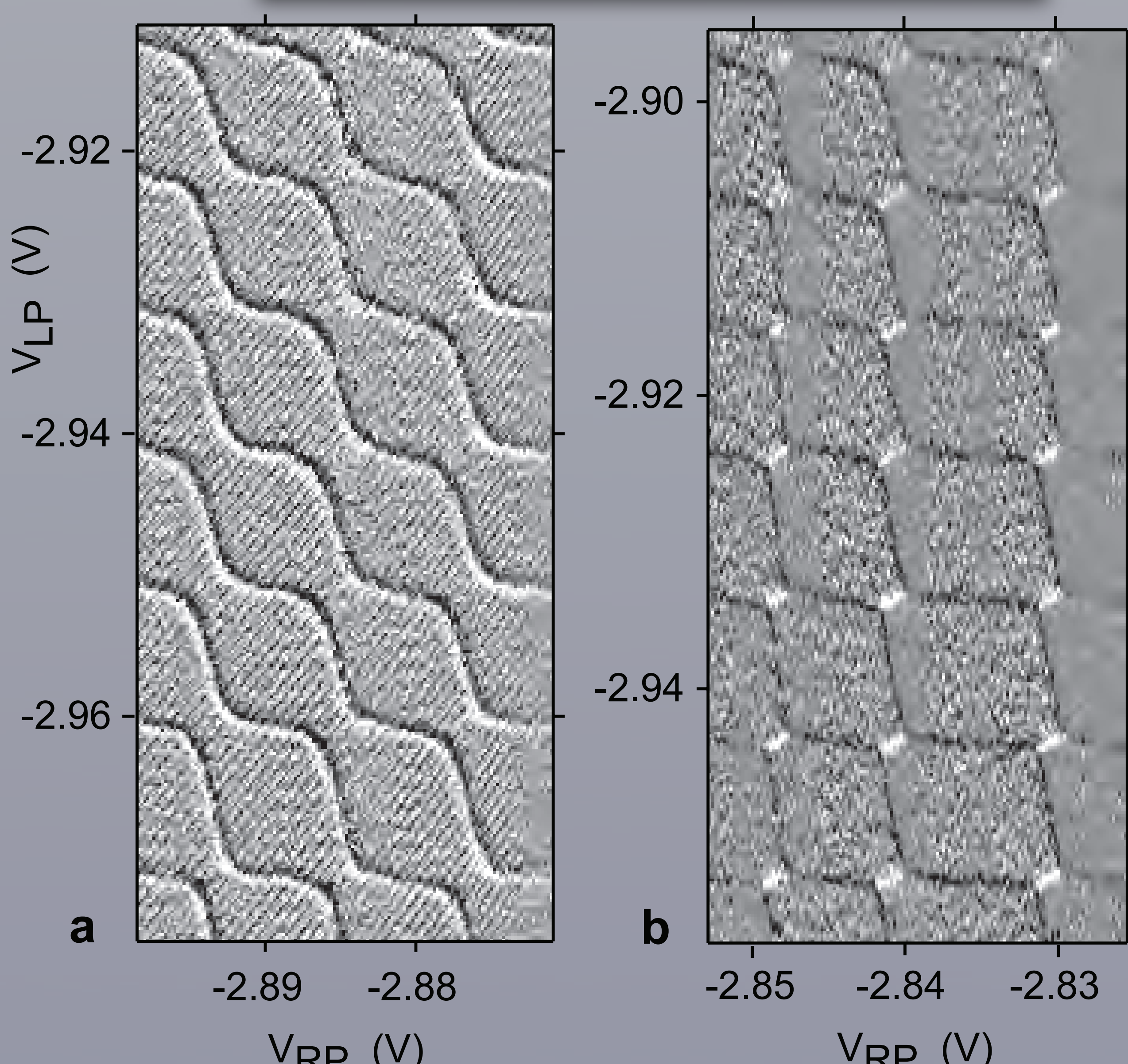


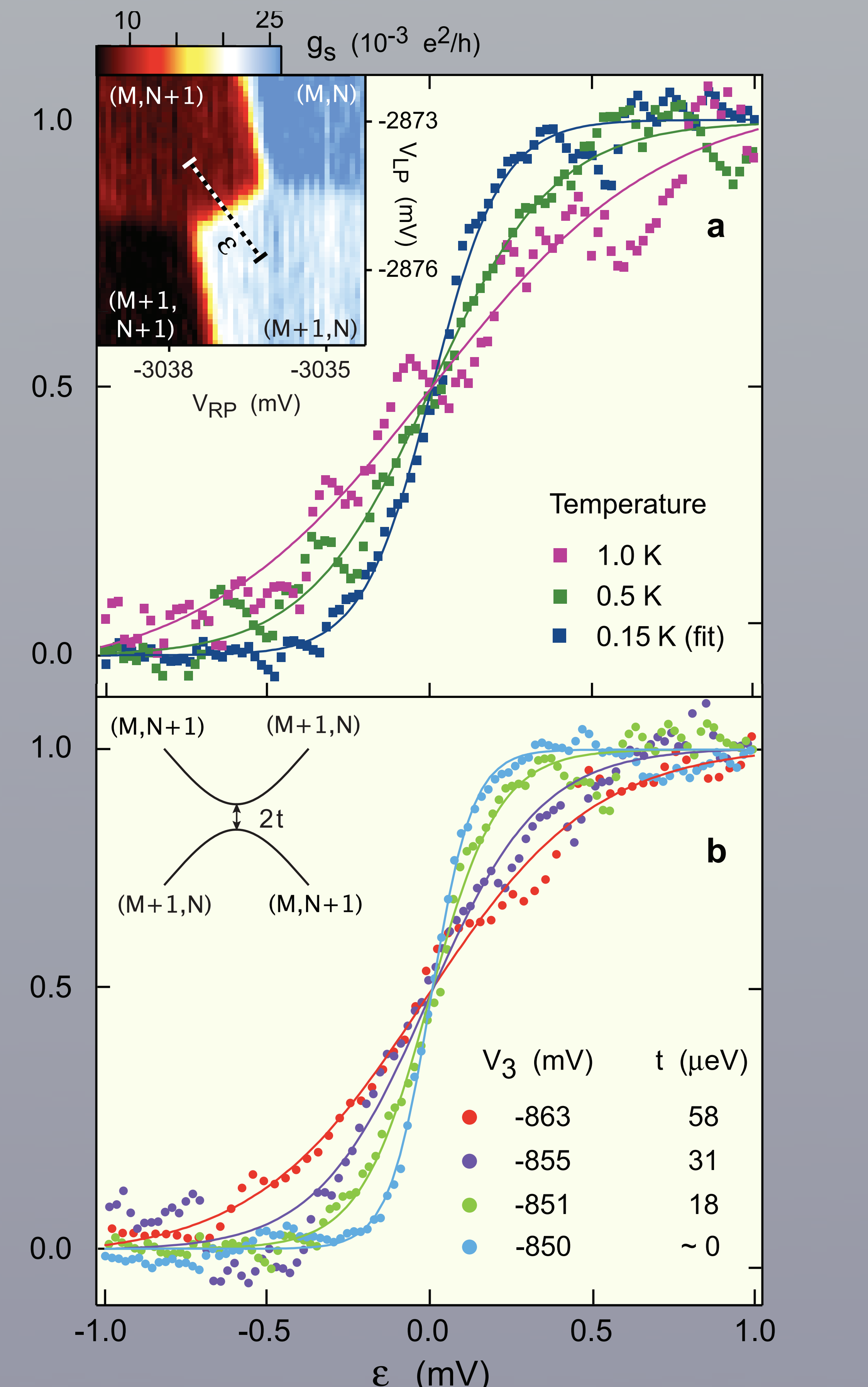




Si/Ge Nanowire with Integrated Charge Sensor







Nonequilibrium Singlet-Triplet Kondo Effect in Carbon Nanotubes

J. PAASKE[1*], A. ROSCH[2], P. WÖLFLE[3], N. MASON[4,5], C. M. MARCUS[5] AND J. NYGÅRD,[1]

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[5] Department of Physics, Harvard University, Cambridge MA 0213, USA
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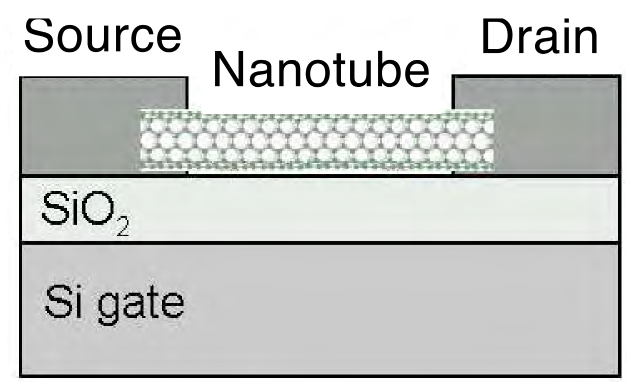
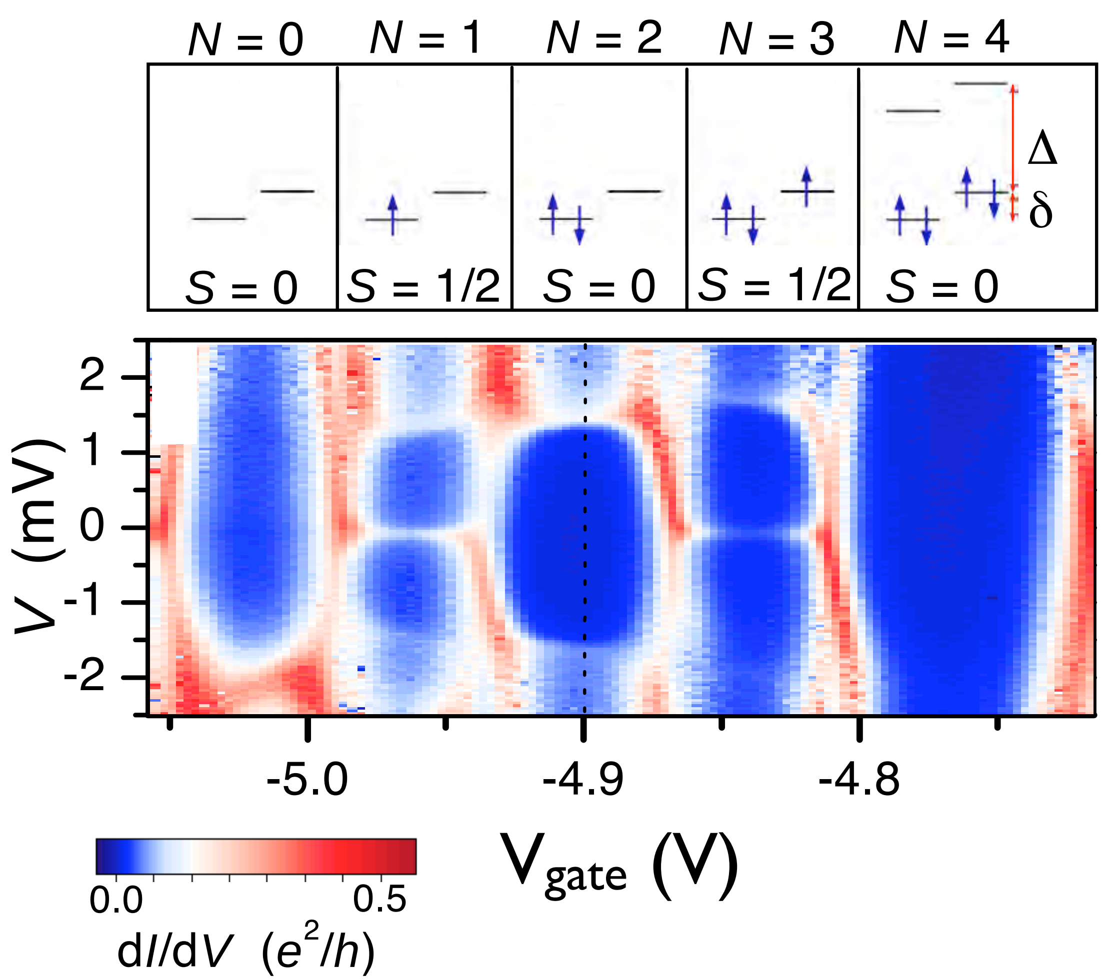
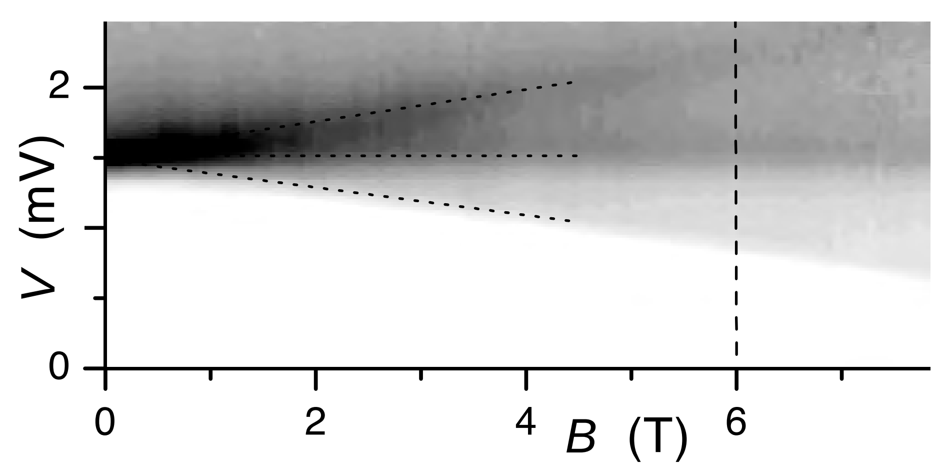






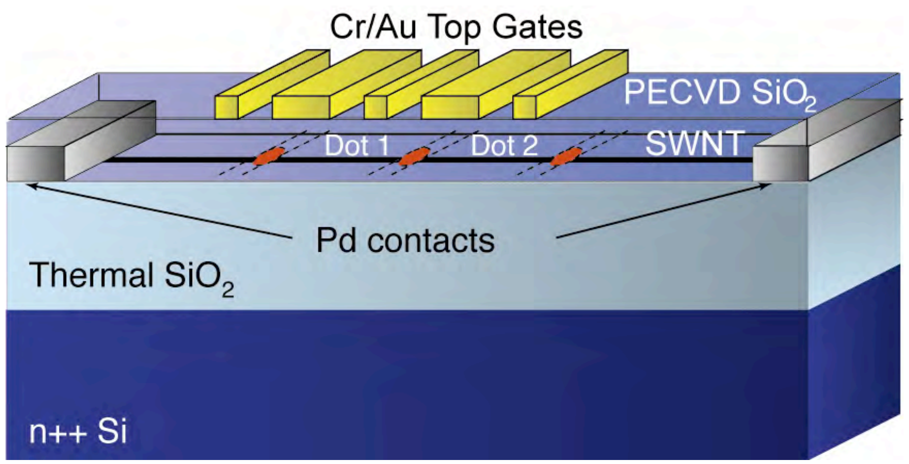
nature physics

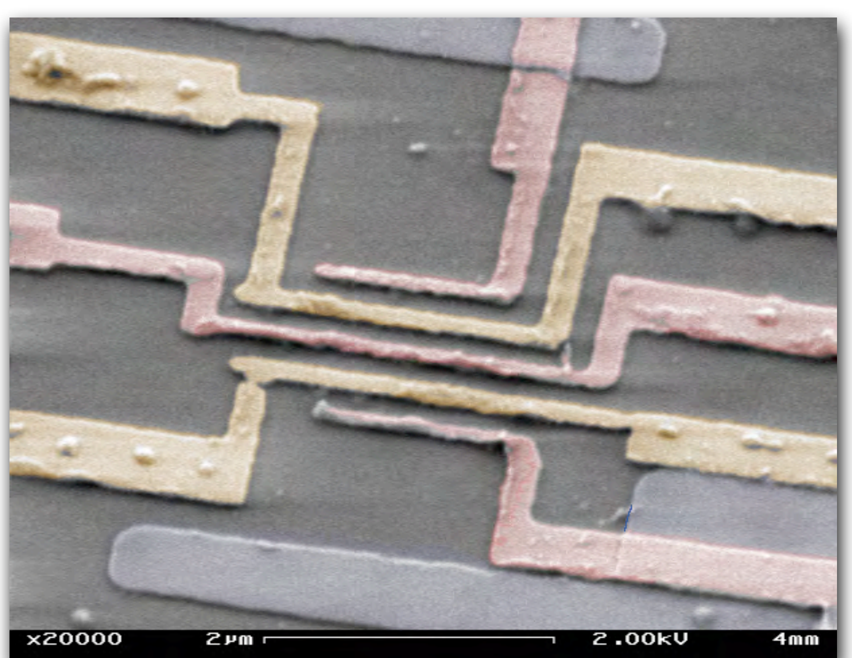
Gate-Defined Quantum Dots on Carbon Nanotubes

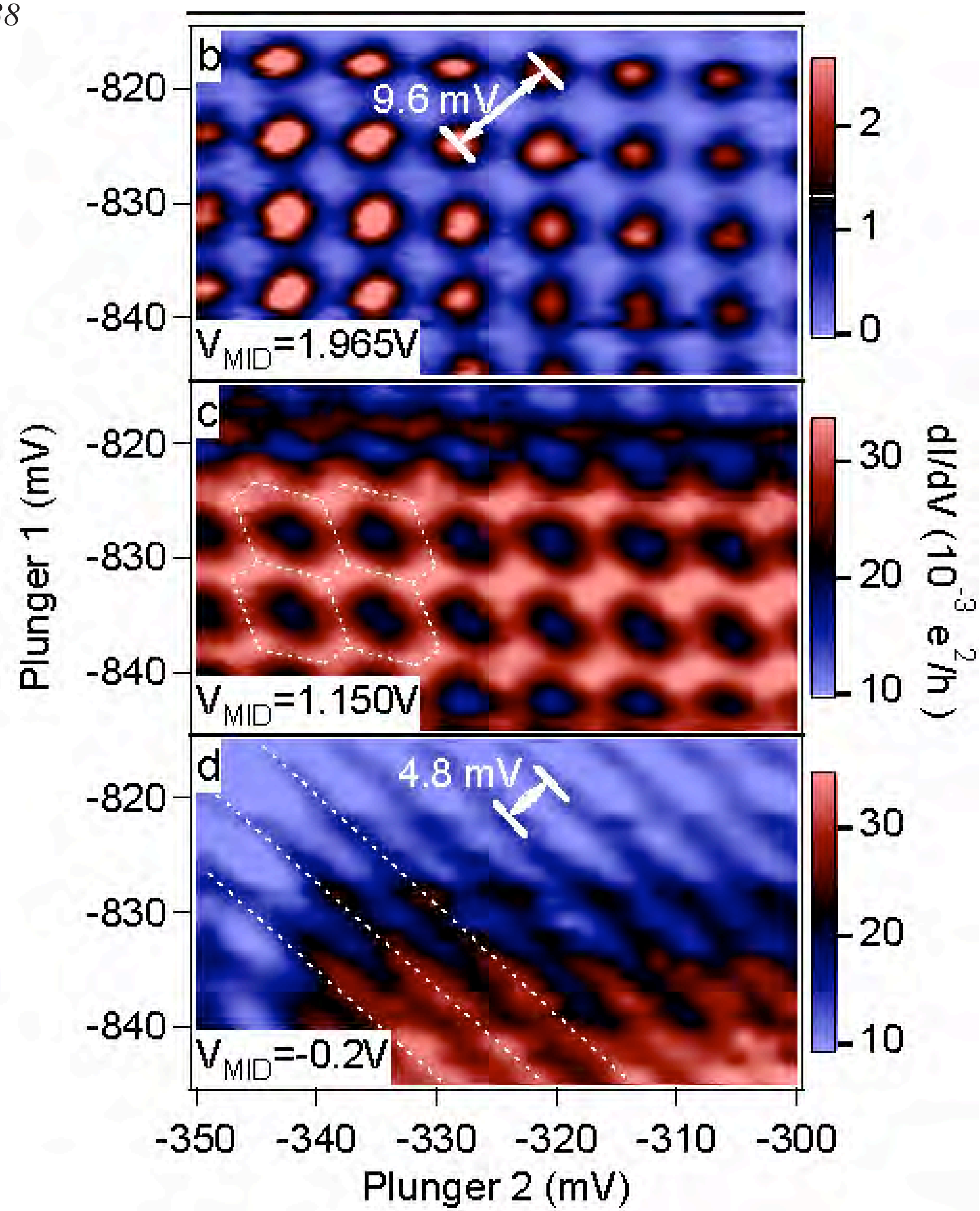
NANO LETTERS
2005
Vol. 5, No. 7
1267−1271

M. J. Biercuk, S. Garaj, N. Mason, J. M. Chow, and C. M. Marcus*

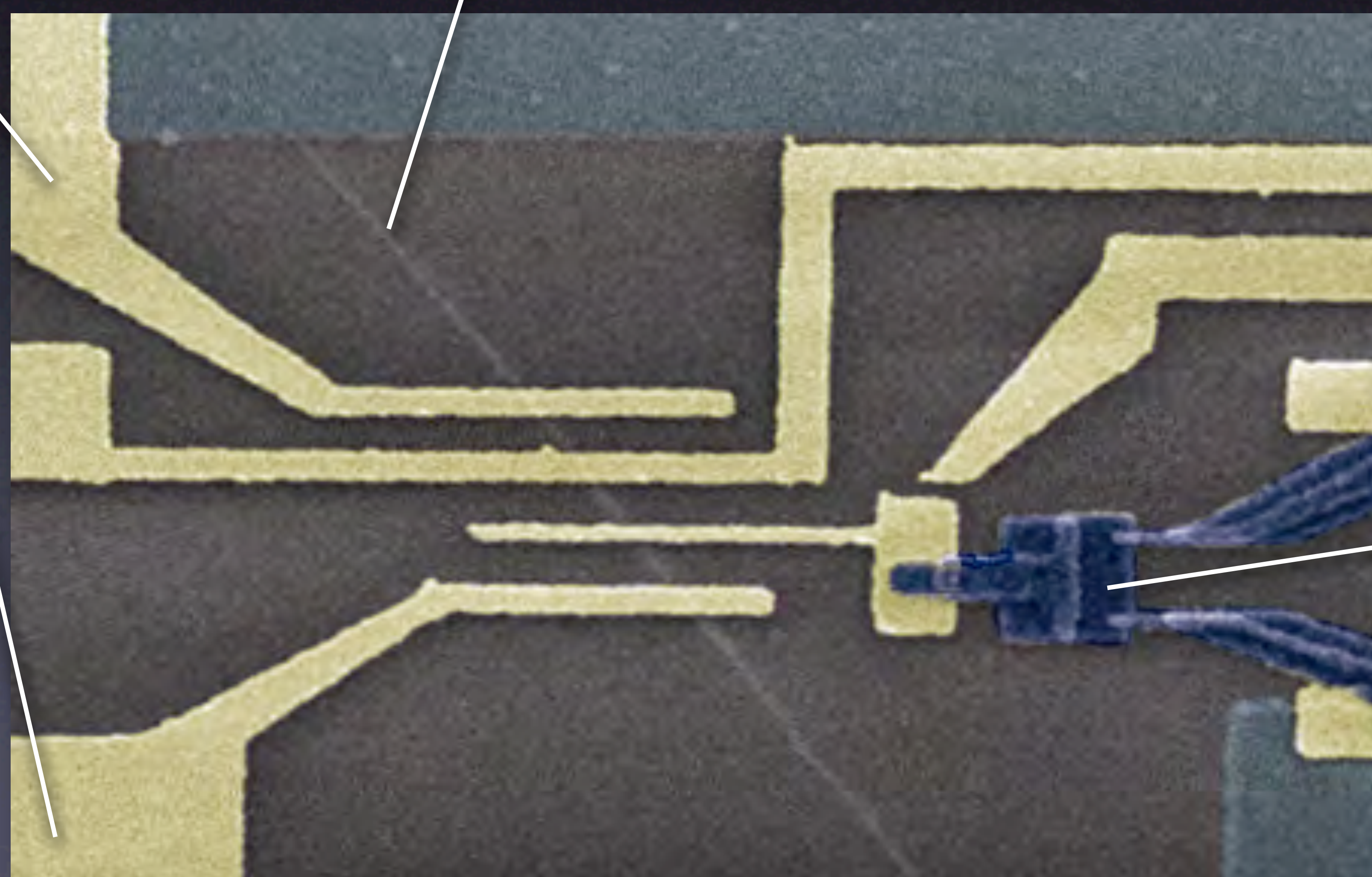
Department of Physics, Harvard University, Cambridge, Massachusetts 02138





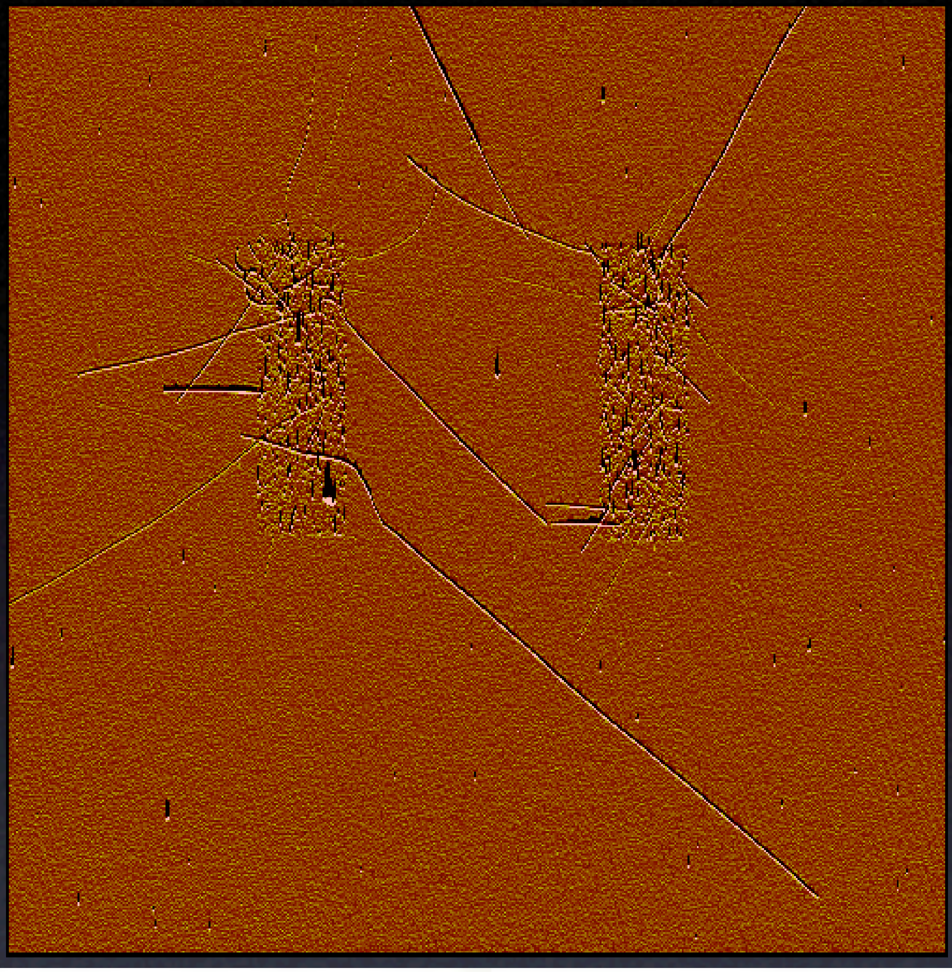


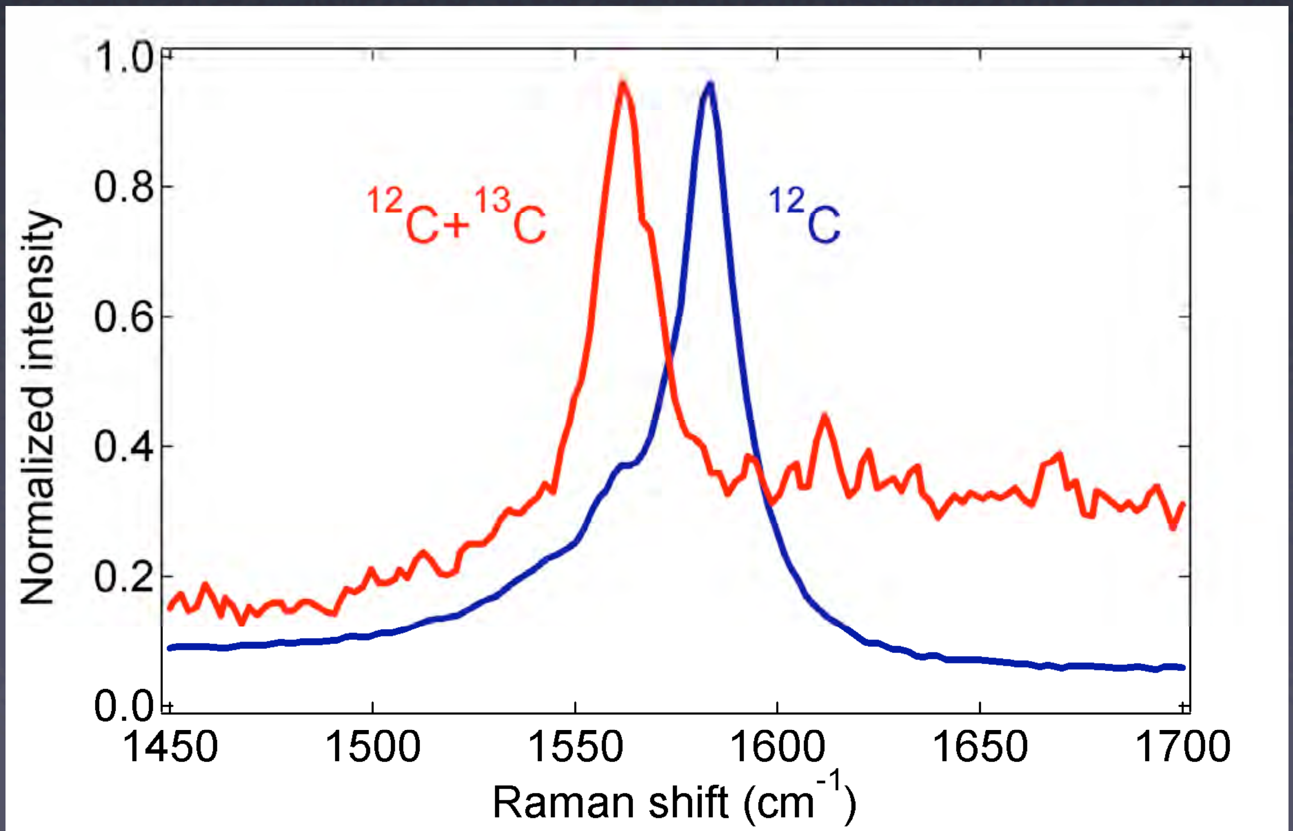
Nanotube-Based Single Electron Device with Fast Charge Sensor



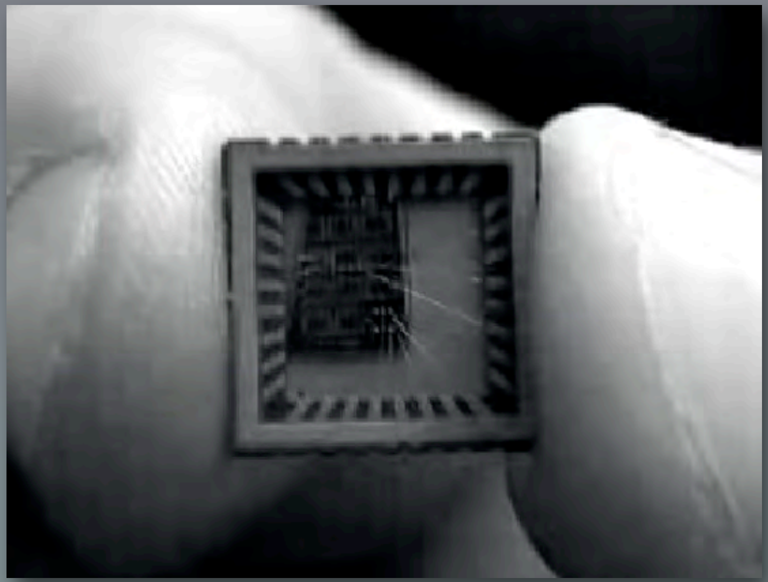
M. J. Biercuk, et al. [in collaboration with R. Clark, UNSW], Phys. Rev. B **73** 201402(R) 2006.

99% ^{13}C Methane feedstock
50% ^{12}C, 50% ^{13}C mixture

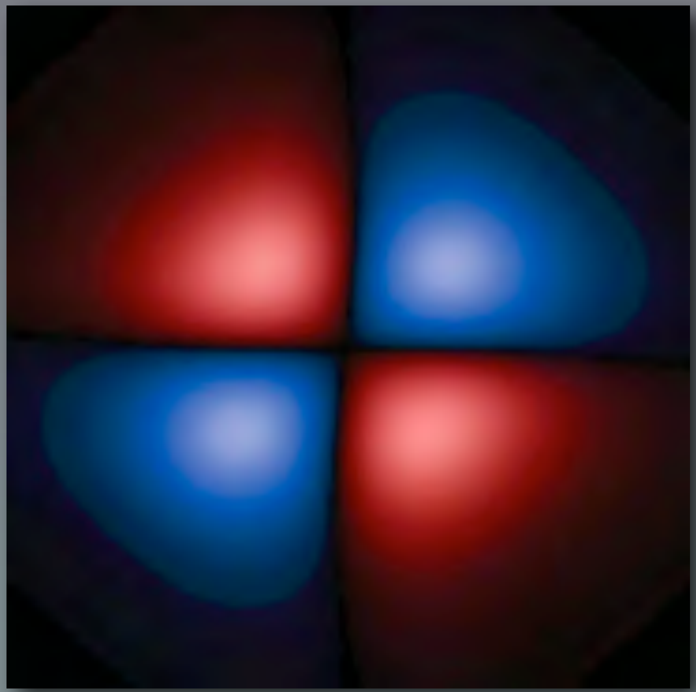




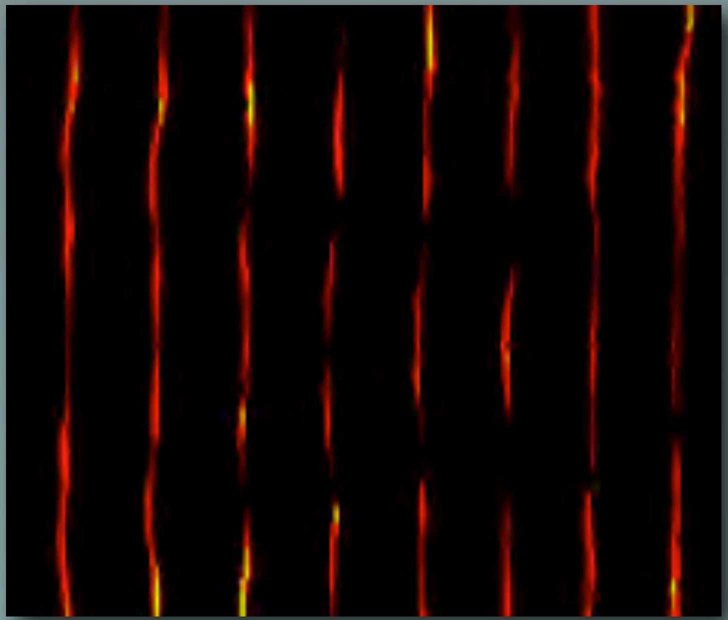
Summary



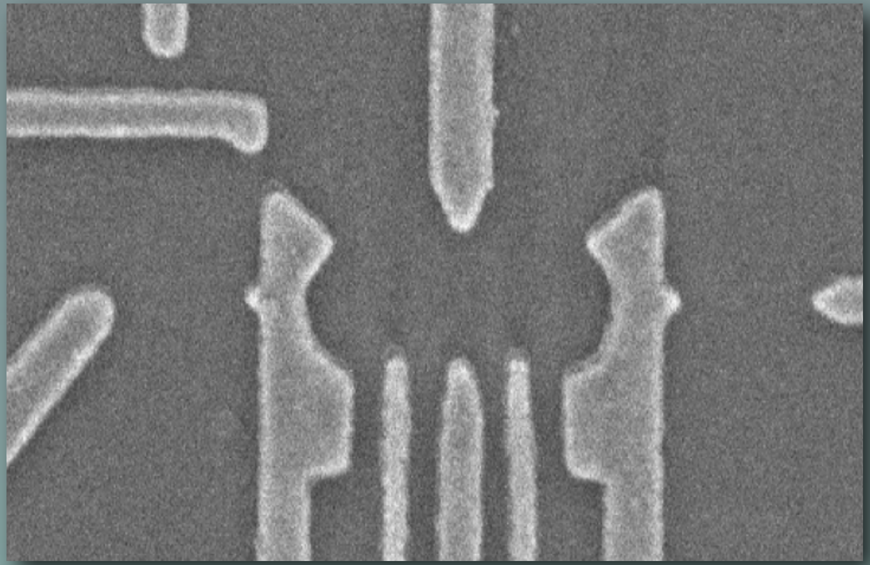
gate defined quantum dots



shot noise correlations

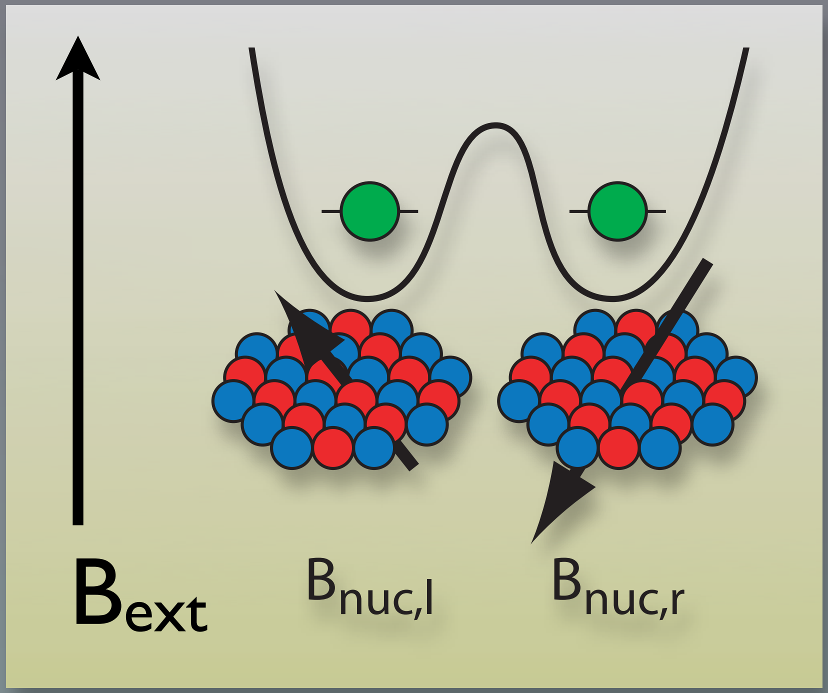


coherent Coulomb blockade

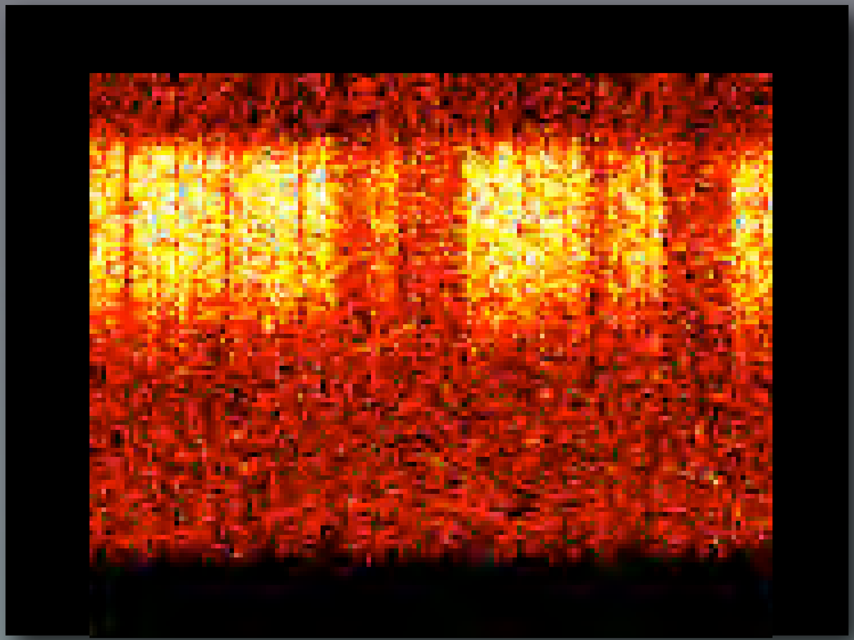


double dots

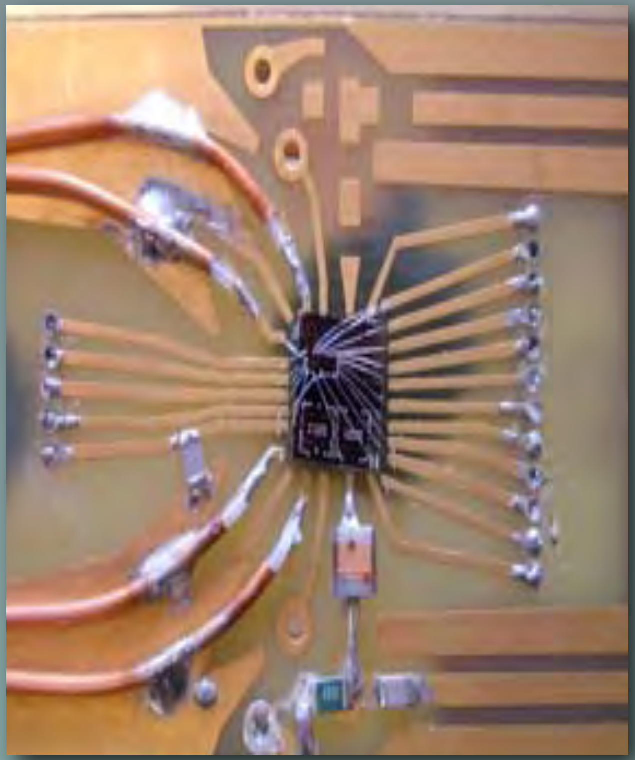
Summary



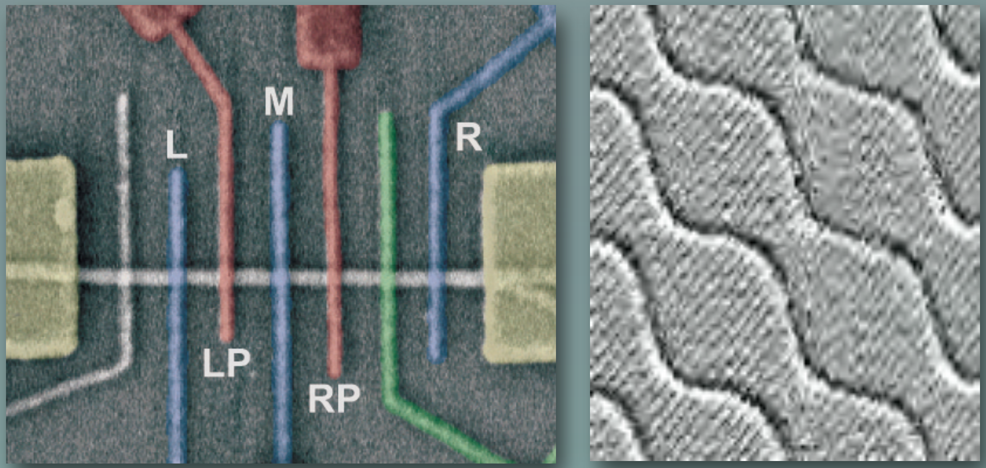
hyperfine coupling to spins



measuring nuclear fields



rf-QPC



nuclear spin 0 systems