Transport through Quantum Rings and Dots

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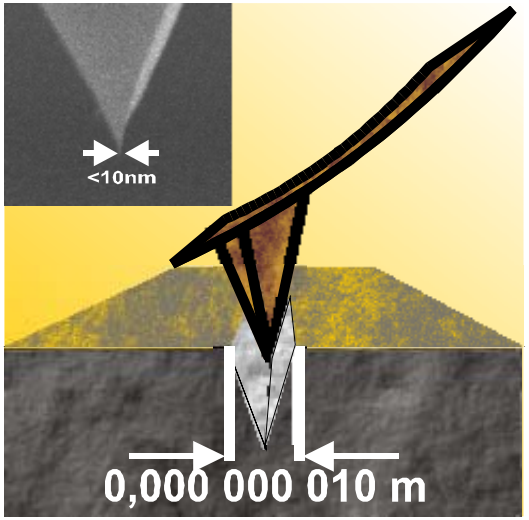
Germany

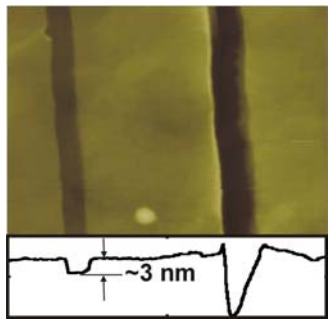
Overview

- **Direct writing with an atomic force microscope (AFM)**
- **Transport through a quantum ring: Aharonov-Bohm effect**
- **Coulomb blockade, Kondo, fractional Aharonov-Bohm effect, Fano effect**
- **more quantum-dot physics**

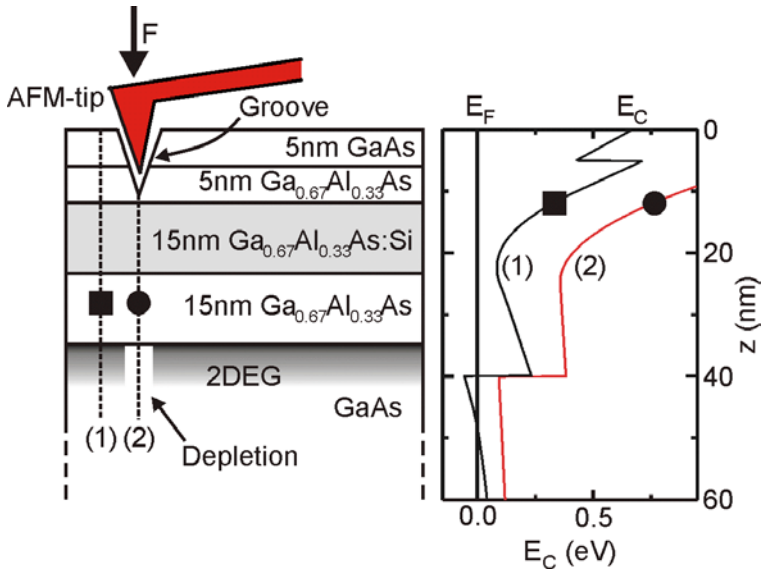
Surface Modification with an AFM

- **nanomachining**





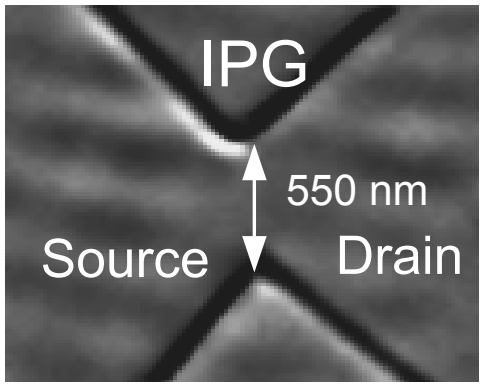
application:
GaAs/AlGaAs heterostruktur

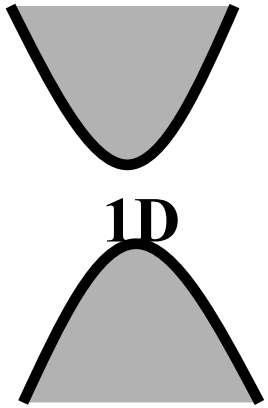


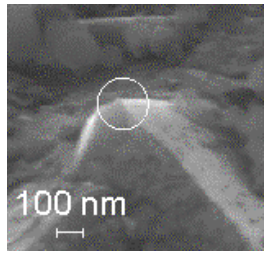
Appl. Phys. Lett.
75, 1107 (1999)

Nanomachining of a Point Contact

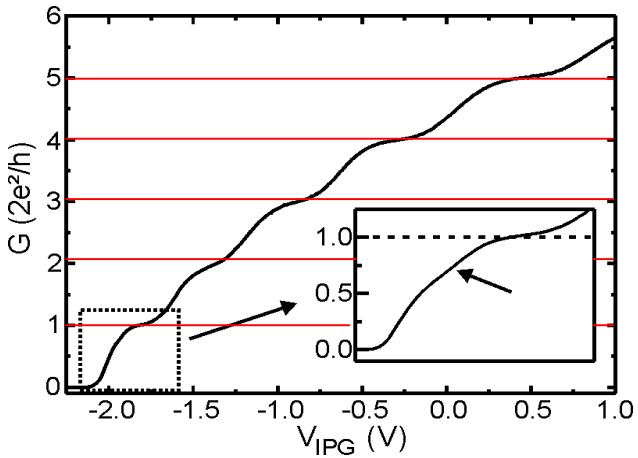
(with diamond tip!)

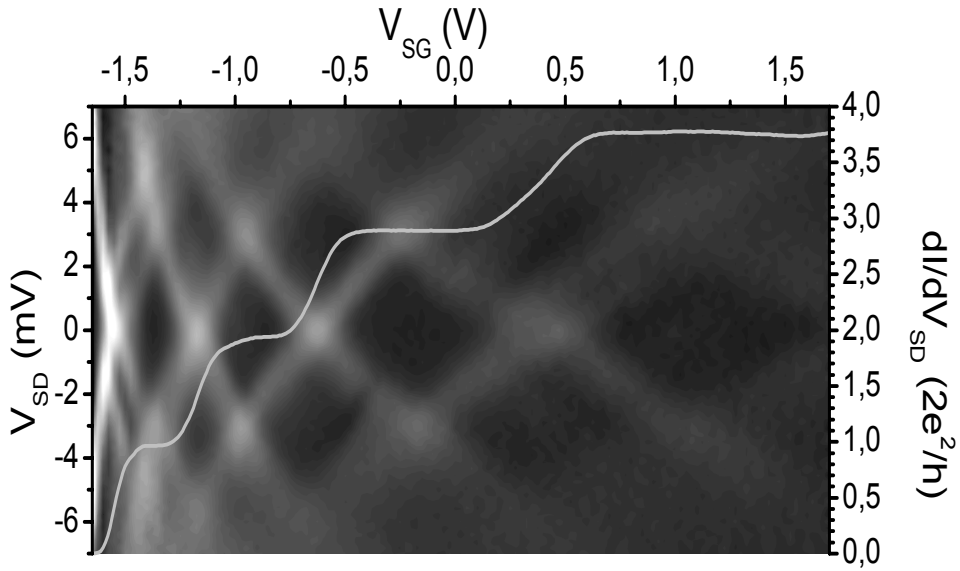




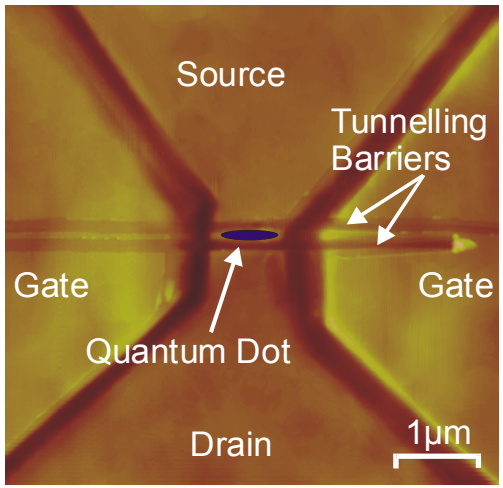


Appl. Phys. Lett. 81, 2023 (2002)





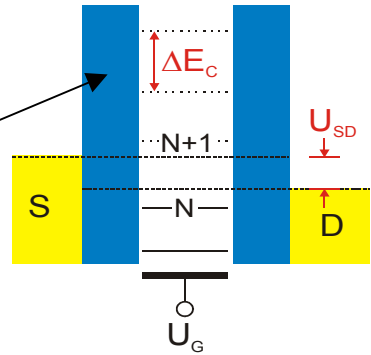
Nanomachining of a 0d System



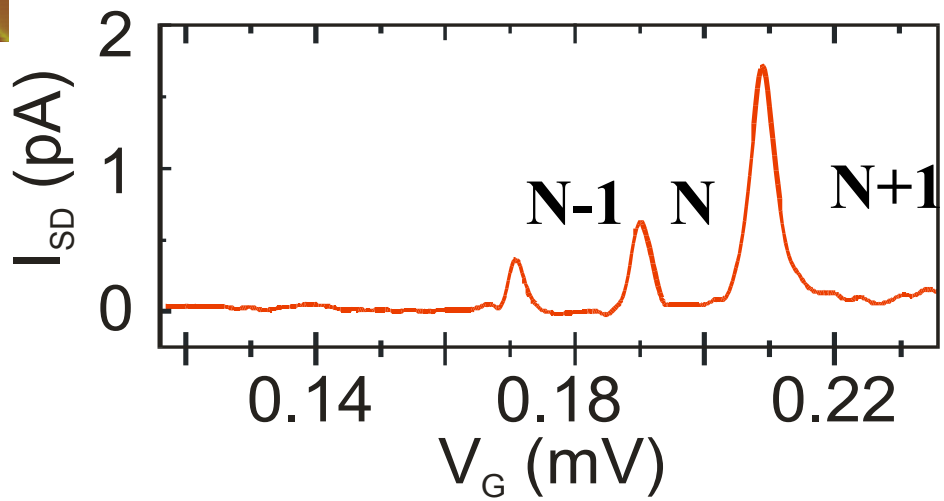
Appl. Phys. Lett. 1999

single-electron transistor

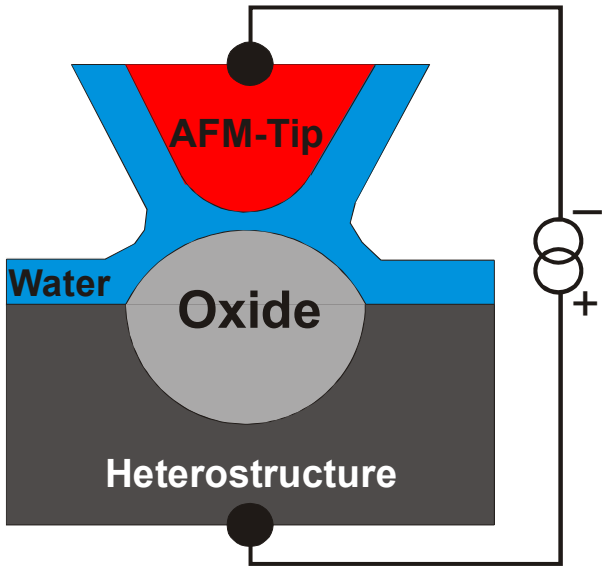
Coulomb blockade

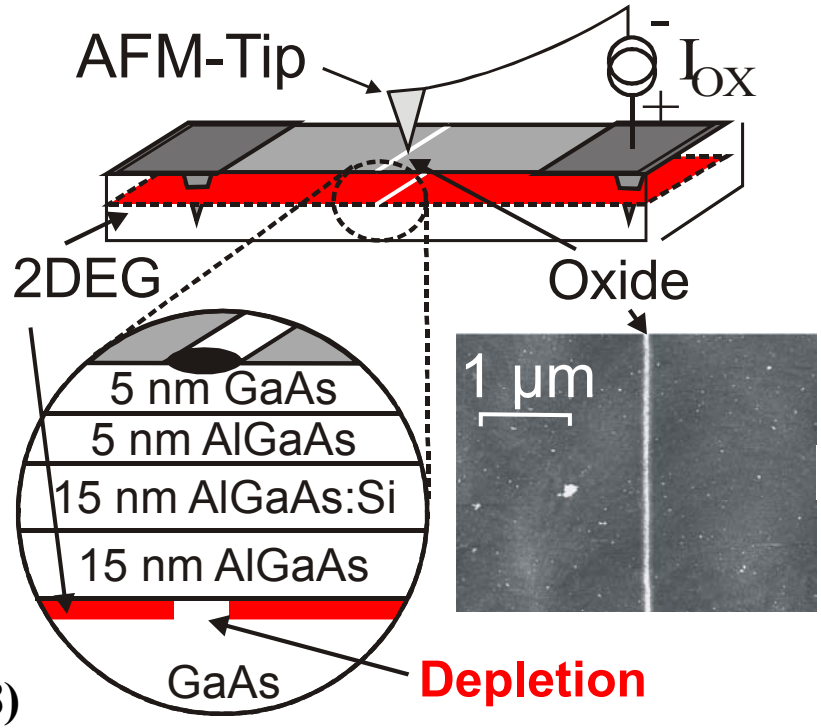


$$\Delta E_c = \frac{e^2}{C}$$

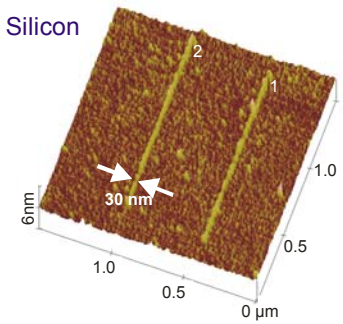


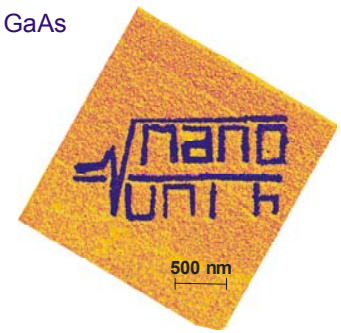
Local Oxidation





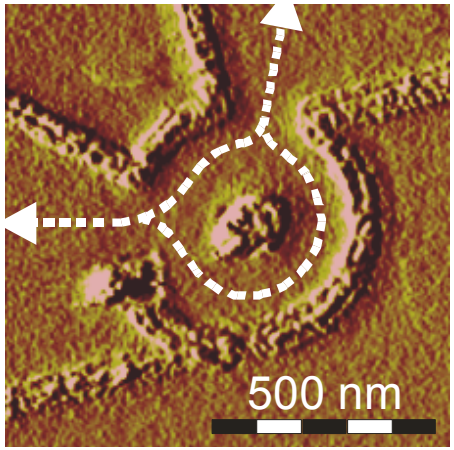
Ishii, Matsumoto (1995), Held et al. (1998)





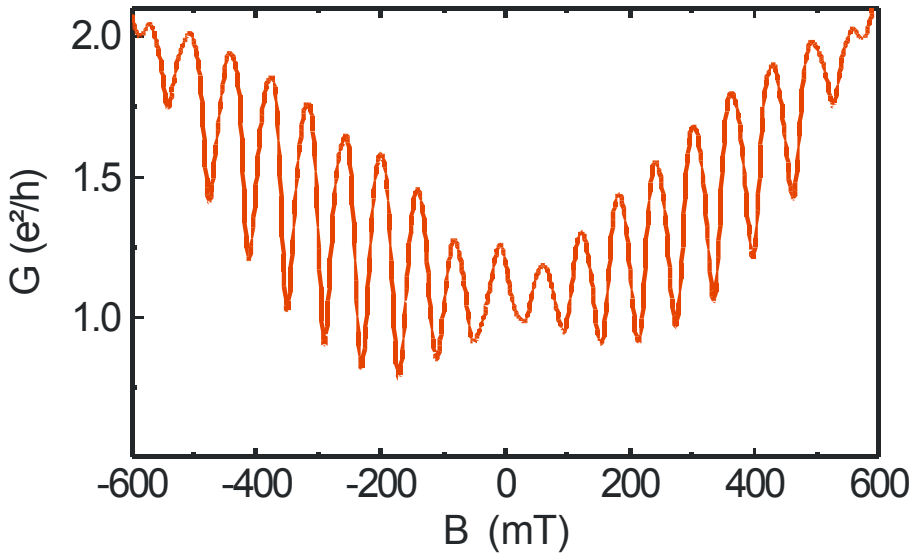
Appl. Phys. Lett. 76,457 (2000)

A Quantum Ring

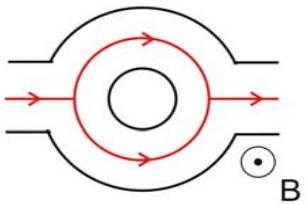


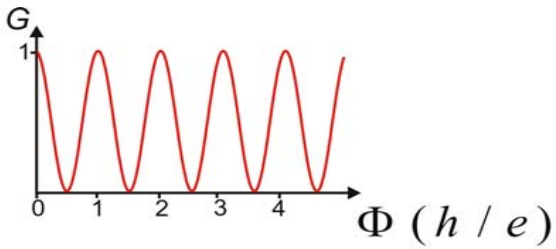
Semicond. Sci. Techn. 2002

see also Fuhrer et al. Nature 2001



Aharonov-Bohm effect



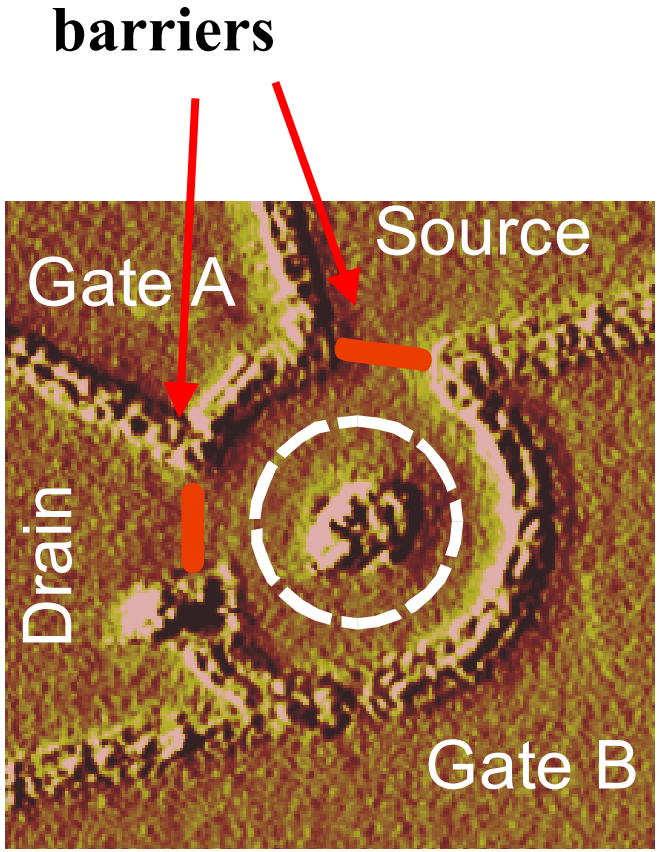


Periodicity 58mT: R=150nm

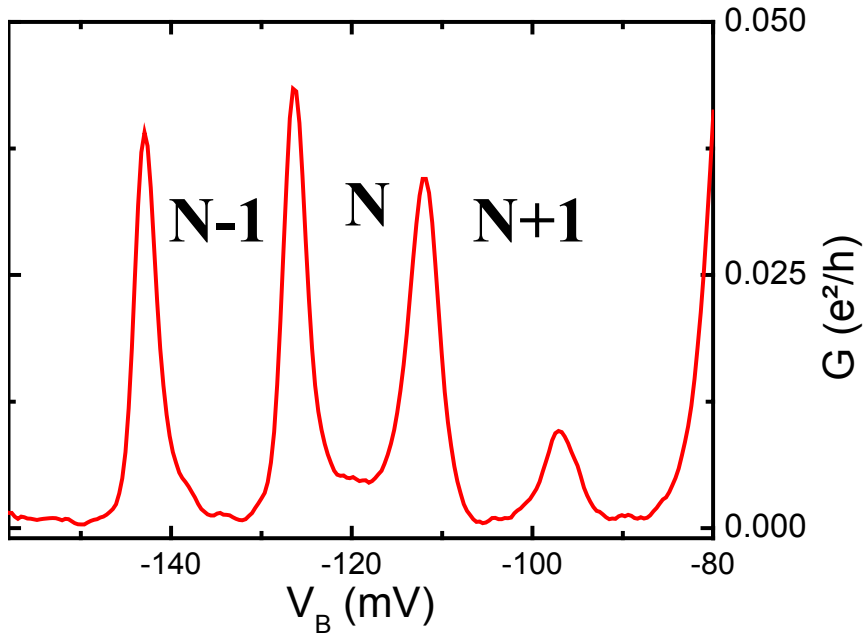
up to 50% modulation of the conductance

one 1d channel transmitted

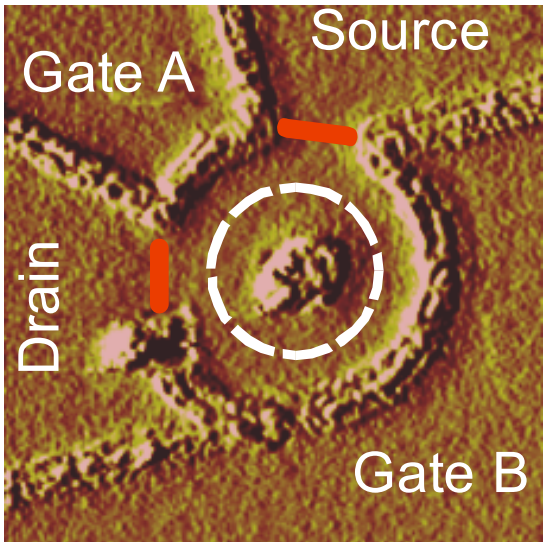
Tunable Quantum Ring

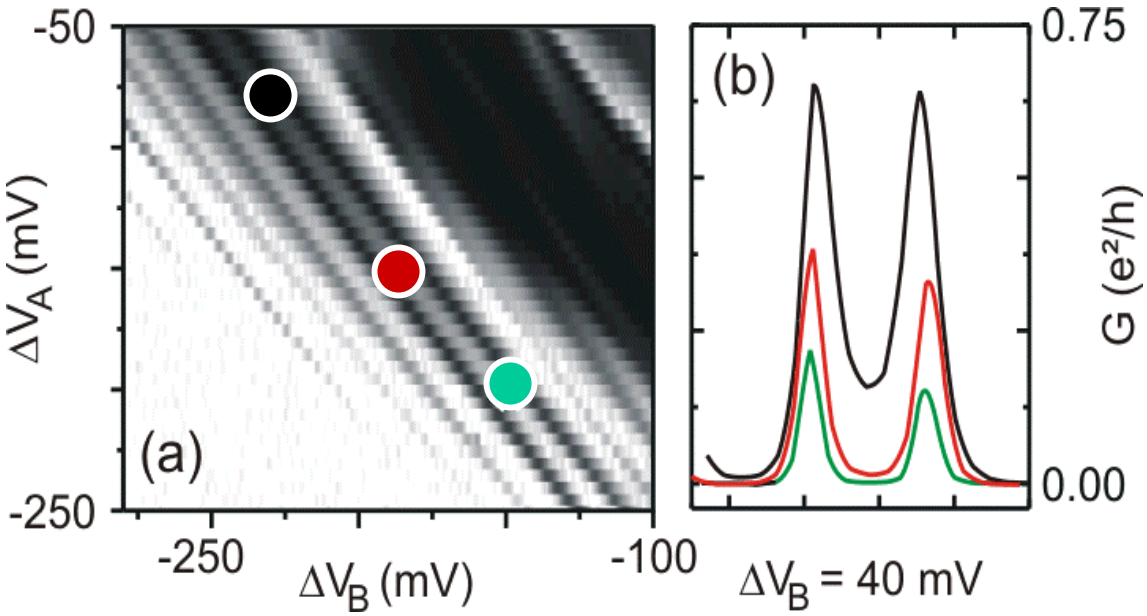


Coulomb blockade and single-electron tunneling



Quantum Ring as Quantum Dot: Variation of Coupling

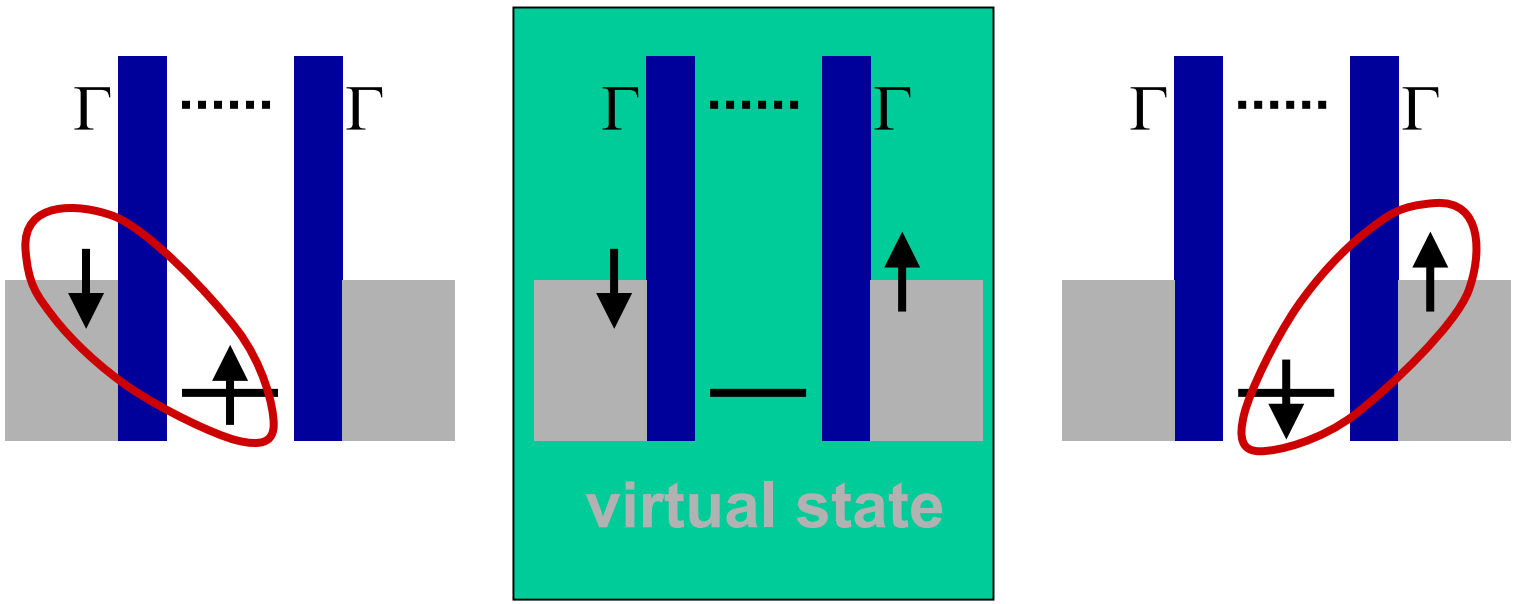




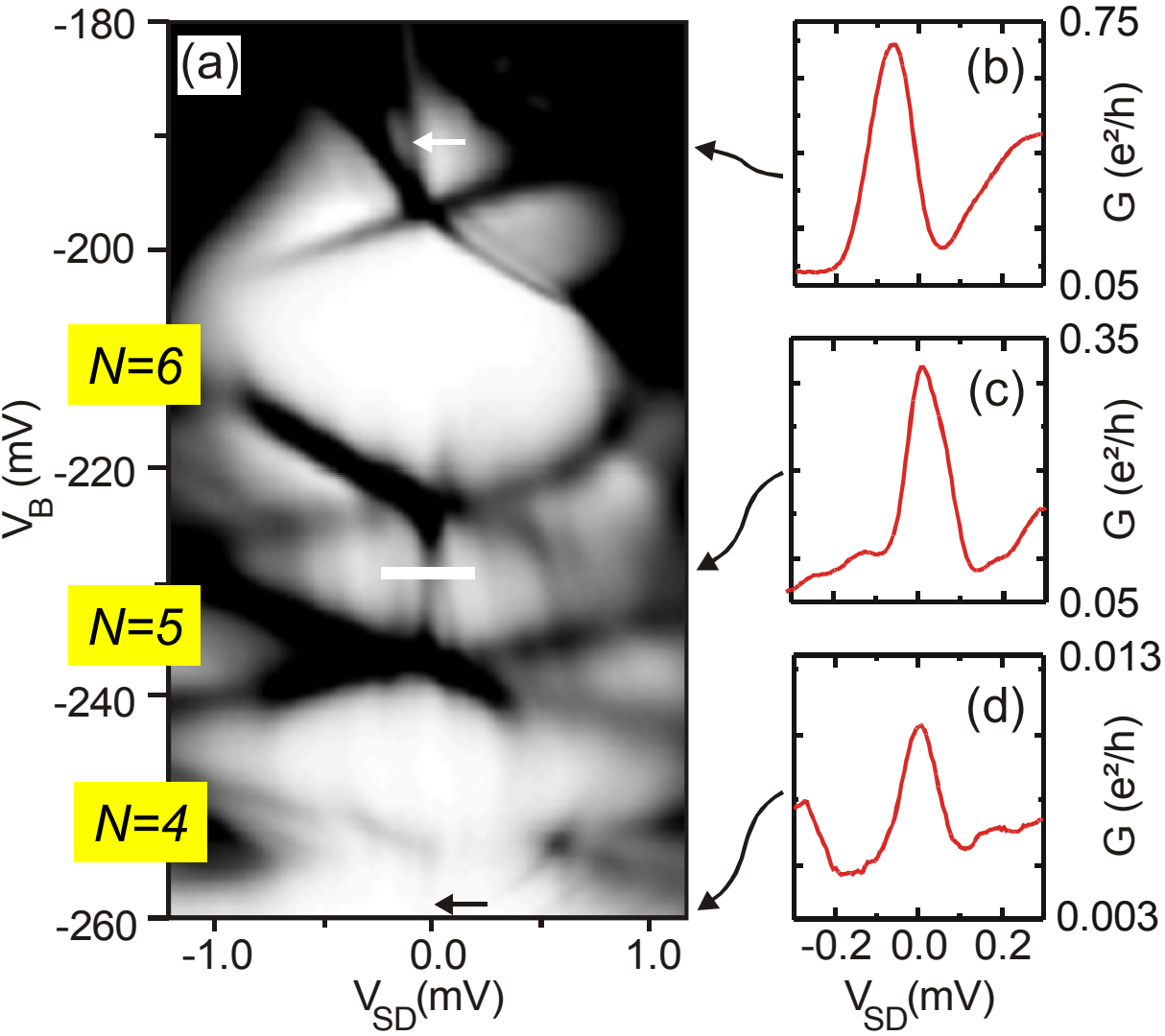
variation of conductance in the Coulomb-blockade regime

Kondo Effect

- quantum dot in a degenerate state
- formation of a spin singlet with the states in the lead
- increased conduction in the Coulomb-blockade regime



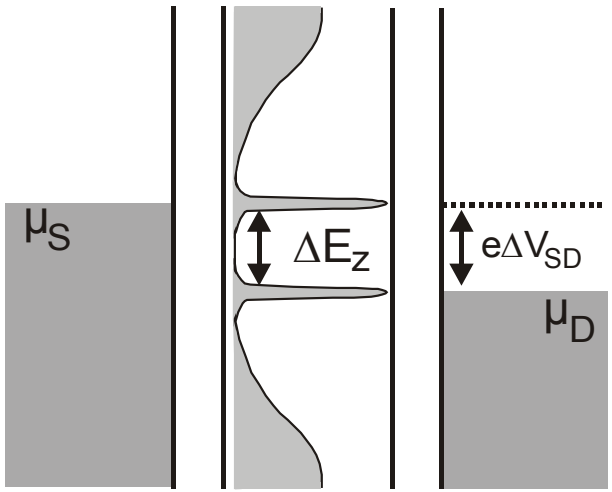
Influence of Number of Electrons

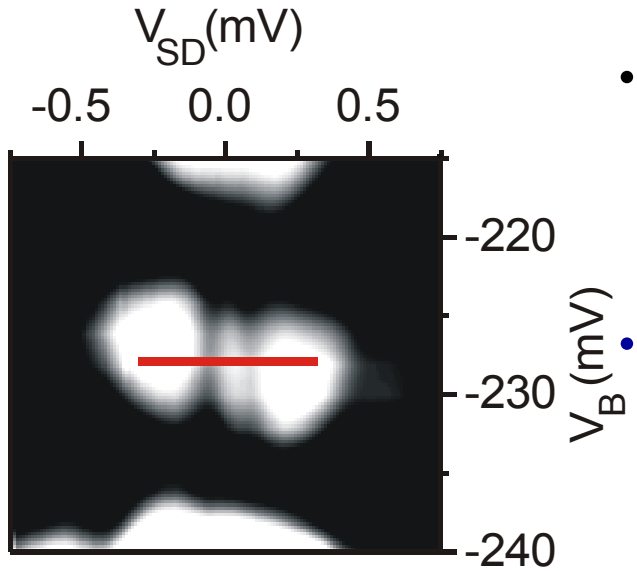


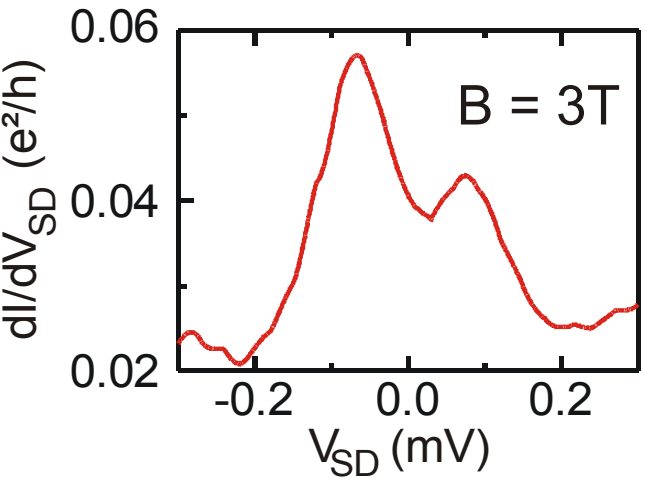
- **zero-bias anomaly**
- **spin-1/2 Kondo effect (for odd number of electrons)**

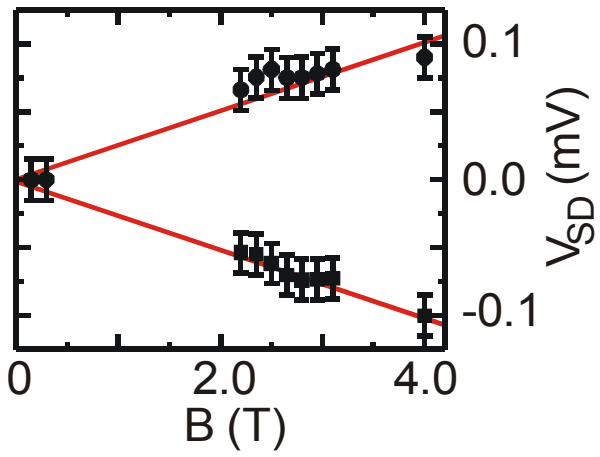
Keyser *et al.*, cond-mat/0206262

Splitting with Magnetic Field









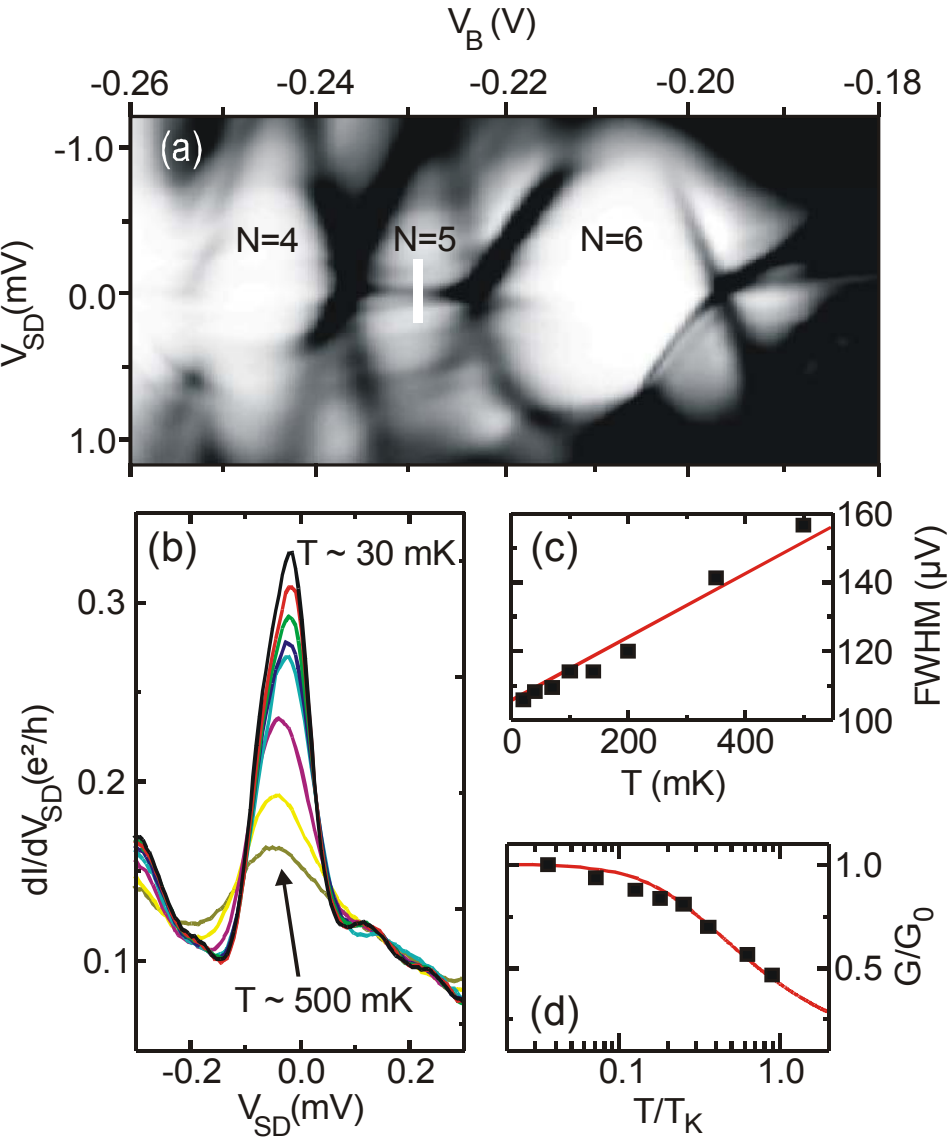
- **Kondo resonance splits with applied magnetic field *B***
- **Observed splitting fits for spin 1/2**

$$eV_{SD} = \pm g_{GaAs}\mu_B B$$

$$g_{GaAs} = -0.44$$

- **For *B* < 2 T no spin splitting observed**
- **Probably caused by high T_K**

Temperature Dependence



- **zero-bias peak**
- **vanishes for increasing temperature**
- **splits in a magnetic field**
- **empirical fit**

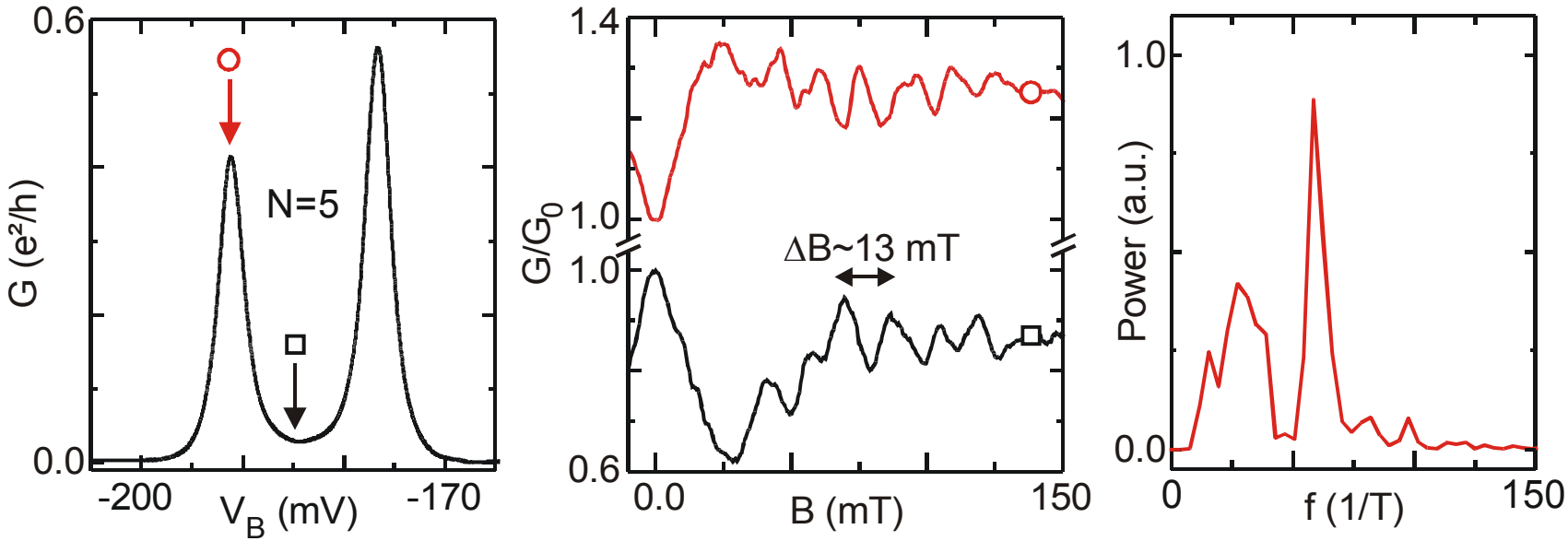
$$G(T) = G_0 \left(\frac{T_K'^2}{T^2 + T_K'^2} \right)^s$$

Goldhaber-Gordon **PRL81** (1998)

- $T_K \sim 600$ mK

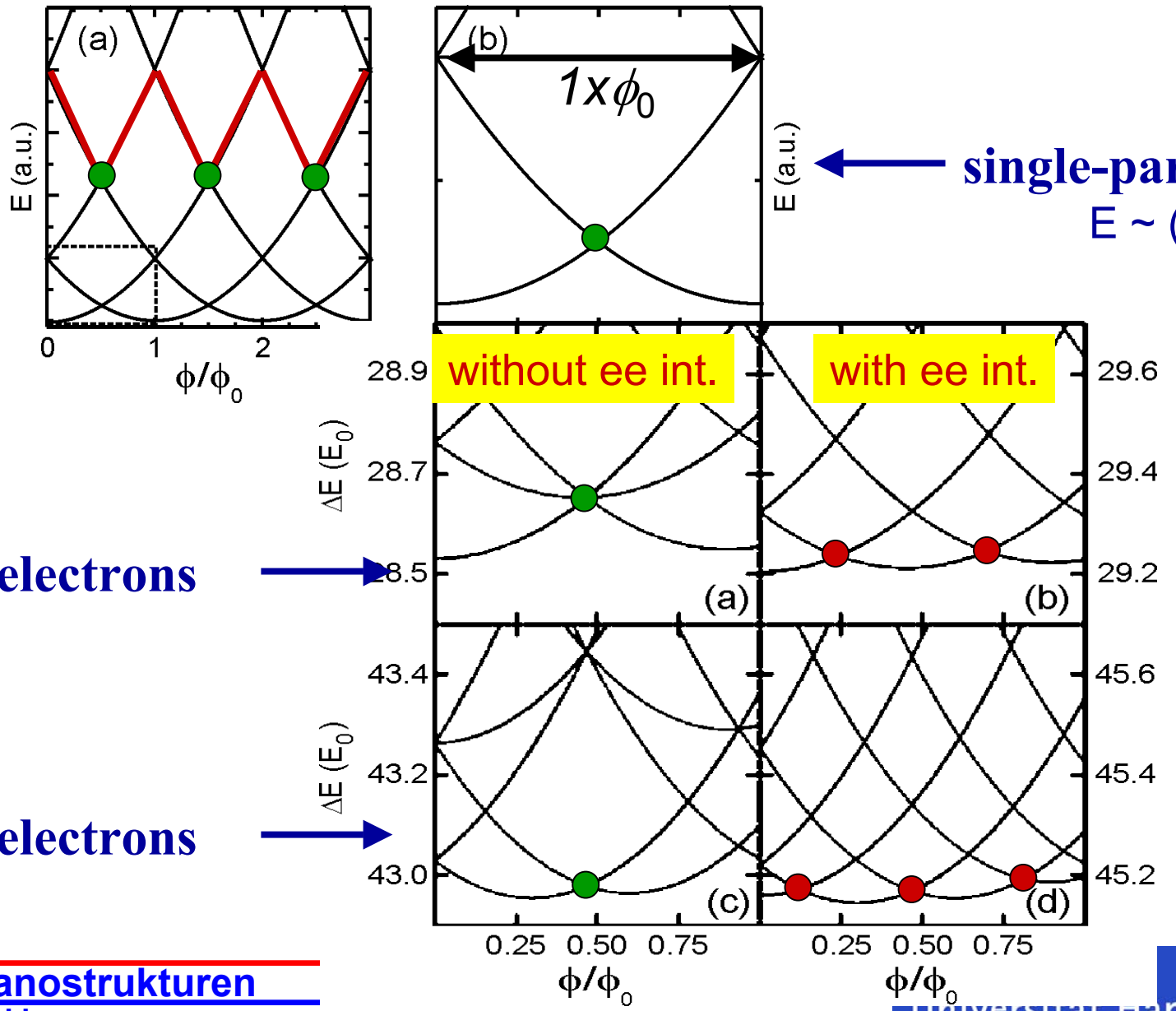
cond-mat/0206262

Influence of a Weak Magnetic Field



- **oscillations with** $\Delta B \sim 13$ mT
- **Aharonov-Bohm periodicity:** $\Delta B = 58$ mT

Ground States of a Quantum Ring



single-particle levels:
$E \sim (l + m)^2$

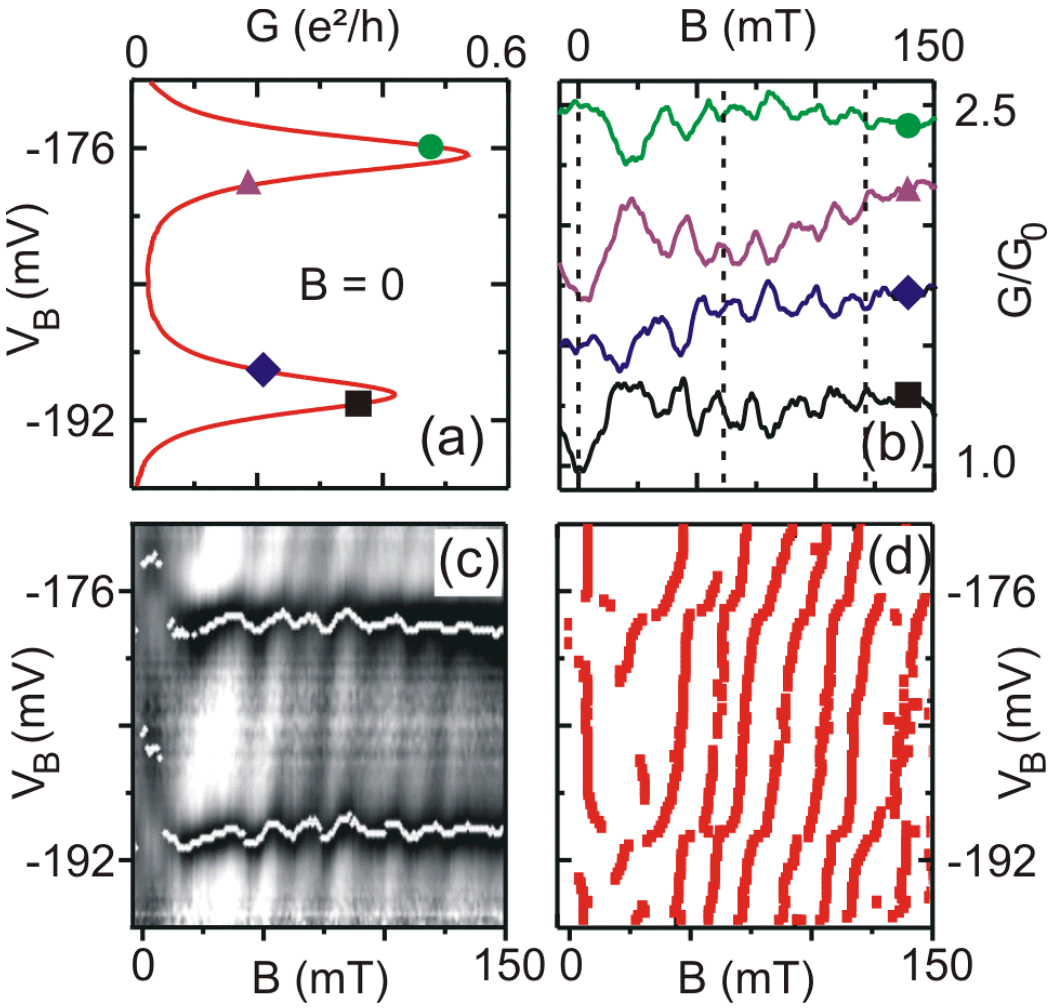
N=2 electrons

N=3 electrons

$\Delta B \sim 1/N$

Niemelä *et al.*,
EPL36 (1996)

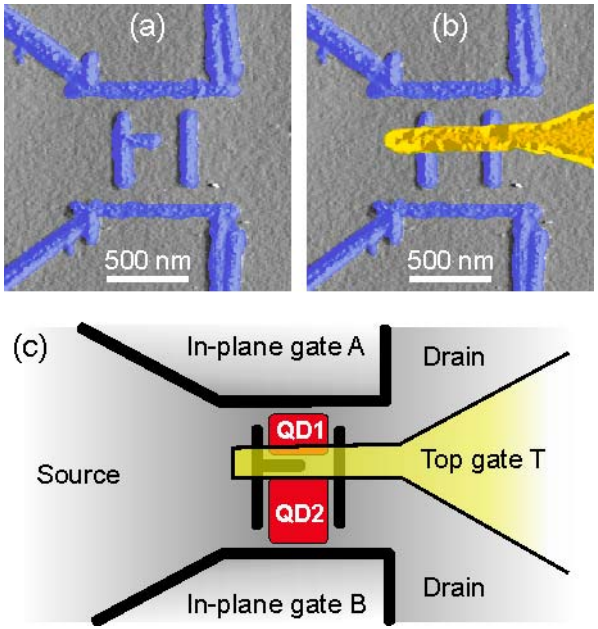
Fractional Aharonov-Bohm Effect



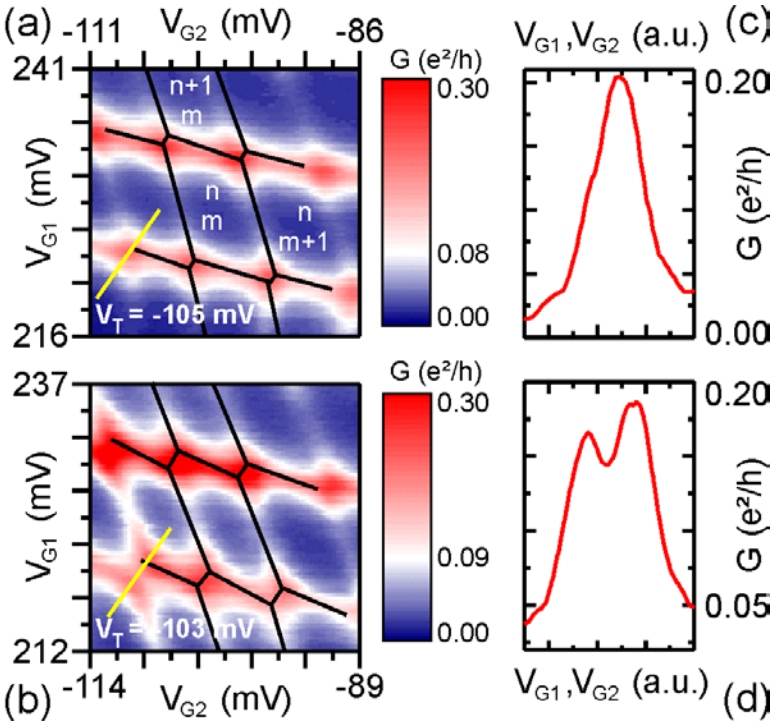
- **Kondo effect: oscillations visible in the Coulomb-blockade regime**
- **phase jumps at the resonances**

Combination of AFM and E-Beam

coupled quantum dots

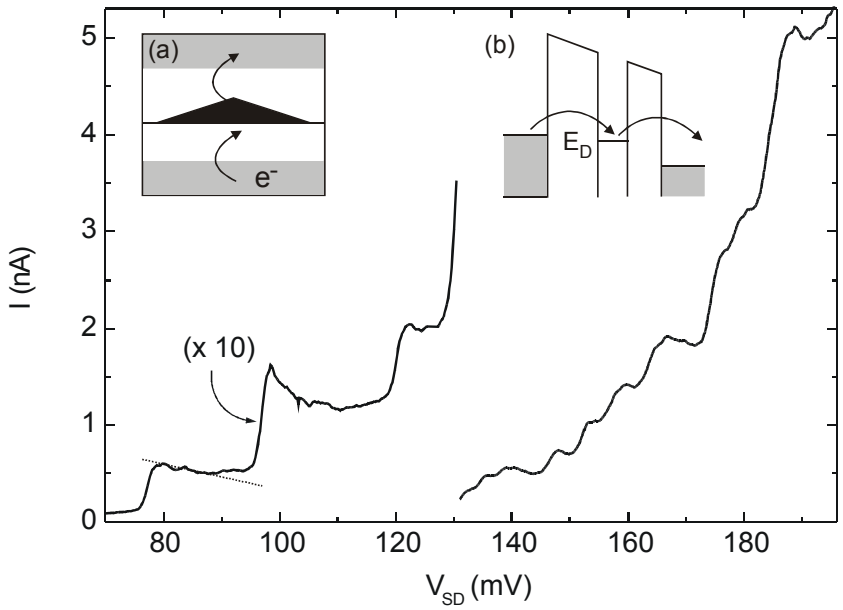


Phys. Rev. Lett. 80, 4032 (1998)
Phys. Rev. Lett. 81, 689 (1998)



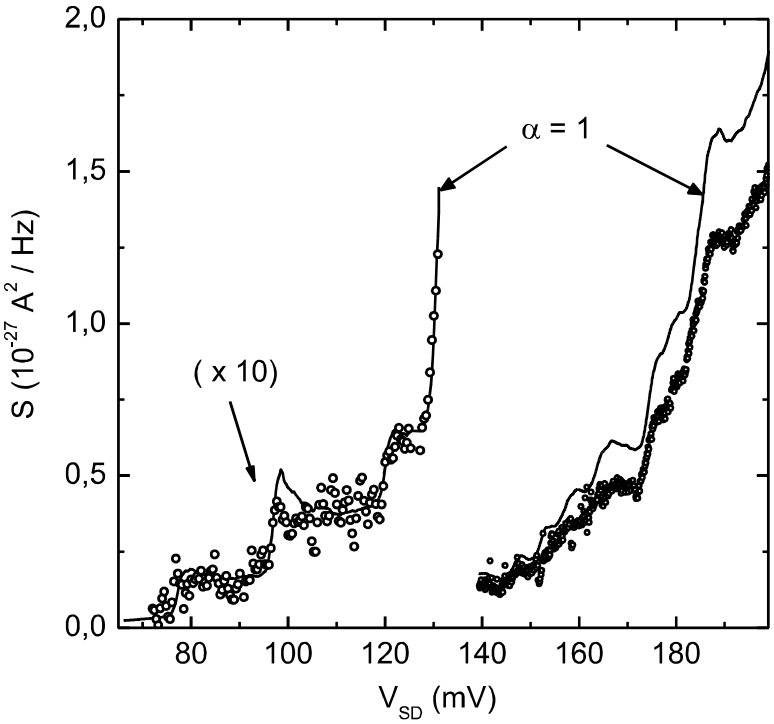
tunability

Noise measurements on InAs quantum dots



Phys. Rev. B 66, 161303R (2002)

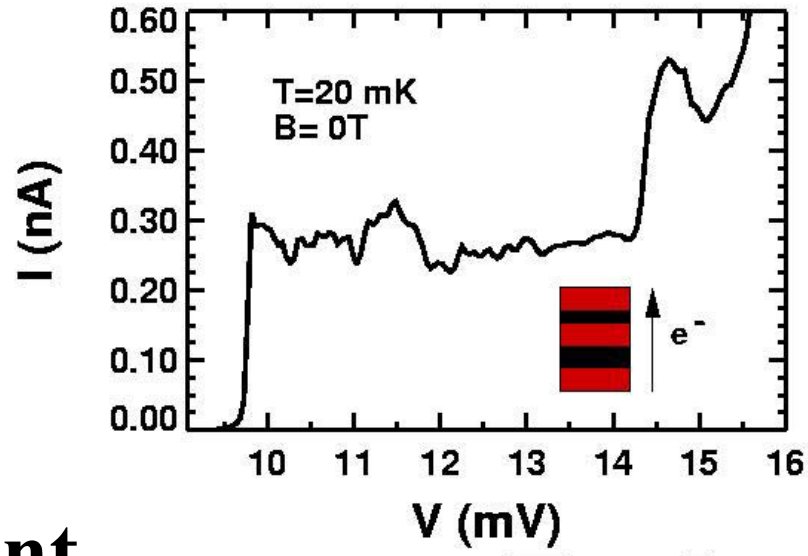
shot noise:



Poster F. Hohls

Quantum Dot as Spectrometer

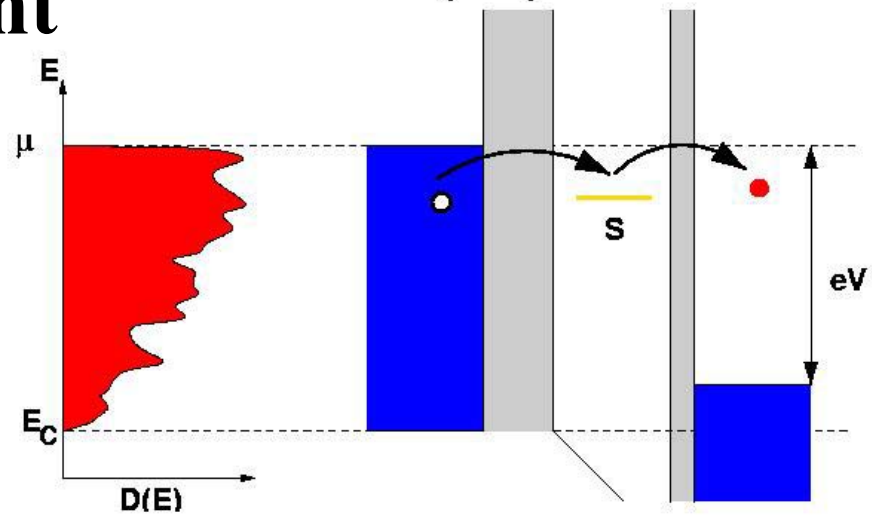
quantum dot:
extension of
lowest state:10nm



local spectrometer
of emitter states

fluctuations in the current

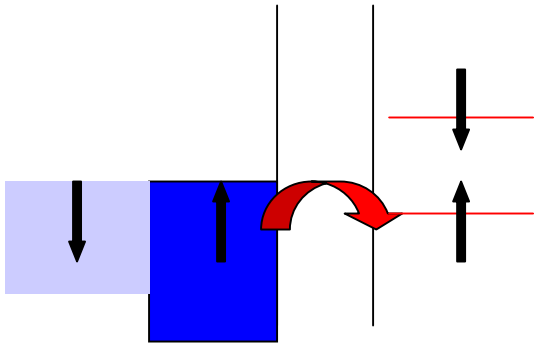
fluctuations of
local density of states



Europhys. Lett. 36, 61 (1996)
Phys. Rev. Lett. 78, 1540 (1997)
Phys. Rev. Lett. 86, 276 (2001)
Europhys. Lett. 54, 495 (2001)
Phys. Rev. B 2002

Spin-Resolved Tunneling through Quantum Dots

spin-resolved spectroscopy of the local density of states

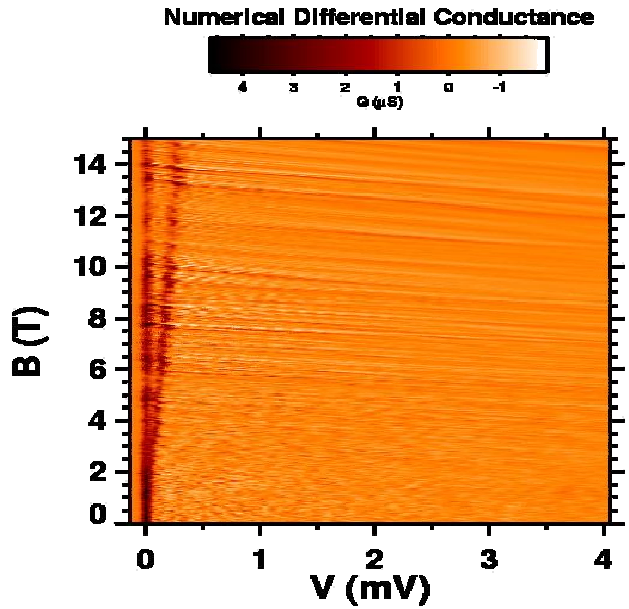


$g = 0.14$

Europhys. Lett. 54, 495 (2001)

Zeeman energy

$$\Delta = g\mu_B B$$



spin-polarized current

Summary

- **nanotechnology with AFM**
- **quantum rings:**
  Aharonov-Bohm effect,
  Kondo effect,
  Fano effect,
  fractional Aharonov-Bohm effect
- **quantum dots**