Double-dot quantum ratchet driven by an independent quantum point contact

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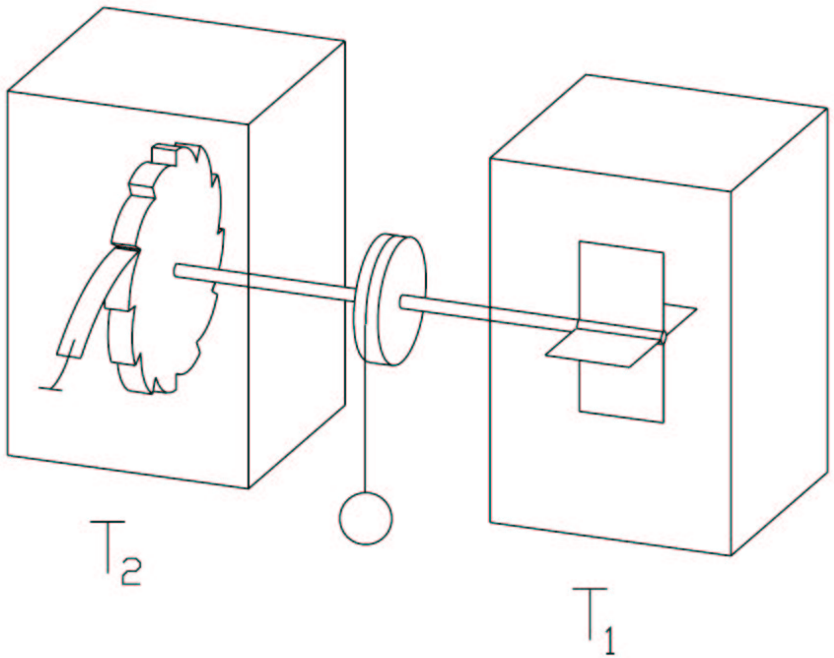
Classical “ratchet and a powl”

Spatial asymmetry is not enough for directed motion, if thermal equilibrum is preserved

Smoluchowski (1912)

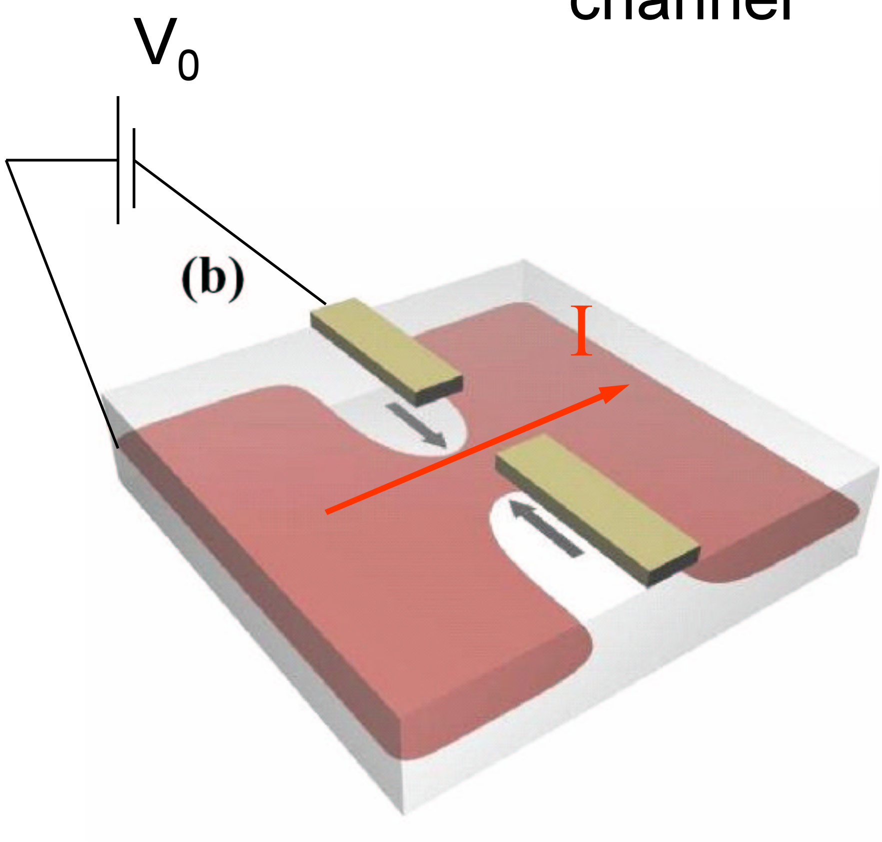


At $T_1 \neq T_2$ the direction of motion depends upon the sign of asymmetry

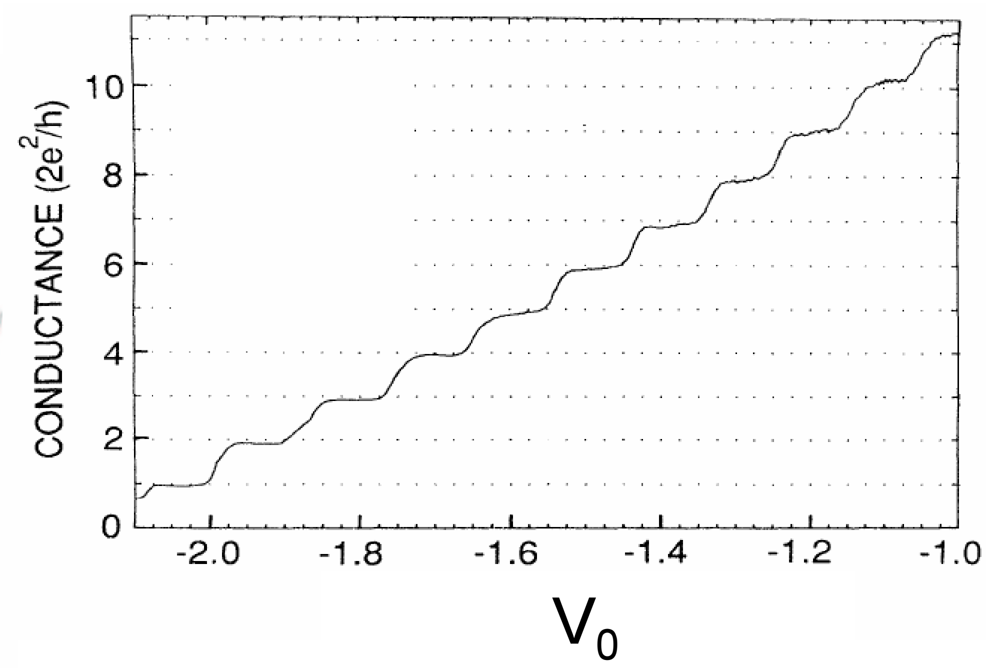
Feynman (1960)

Intro. Lateral nanostructures. Quantum point contact

Gates' electric field allows to tune the transverse energy quantization inside a 1D channel

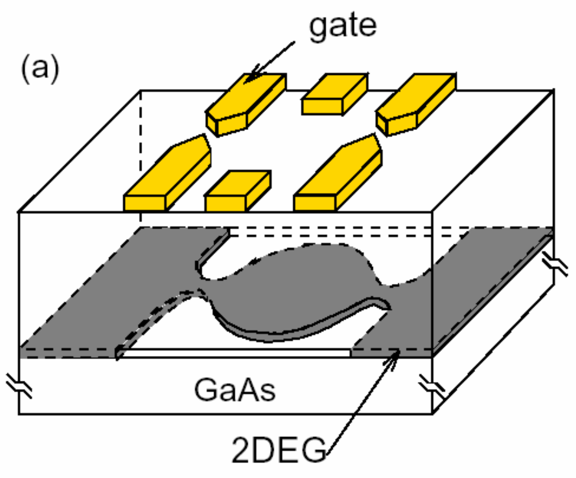


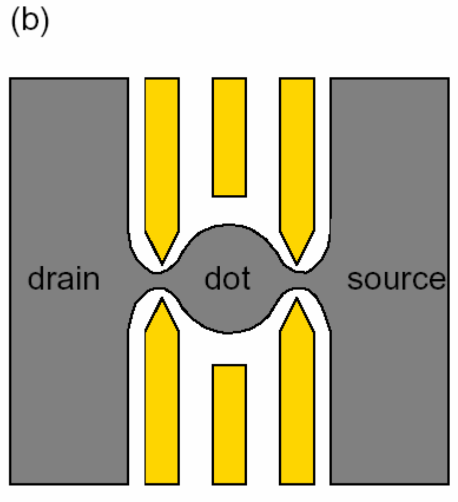
QPC Conductance quantization

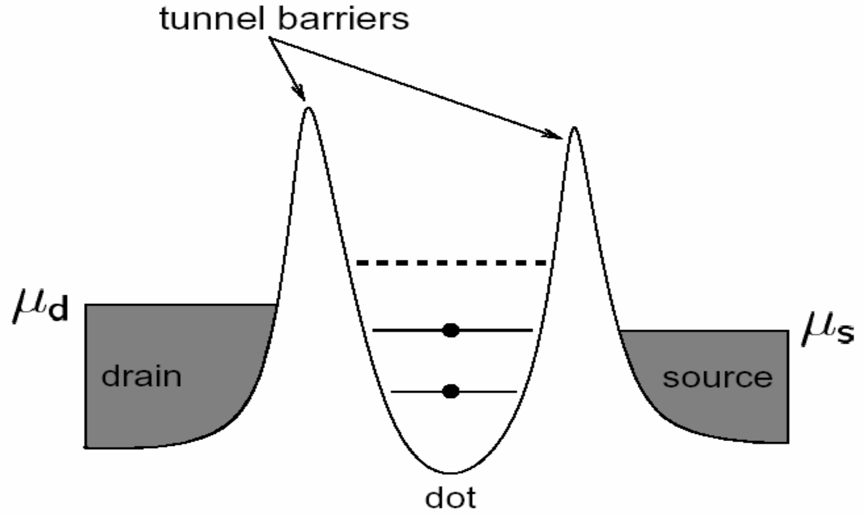


van Wees et al. and Wharam et al. (1988)

Intro. Quantum dot (QD)





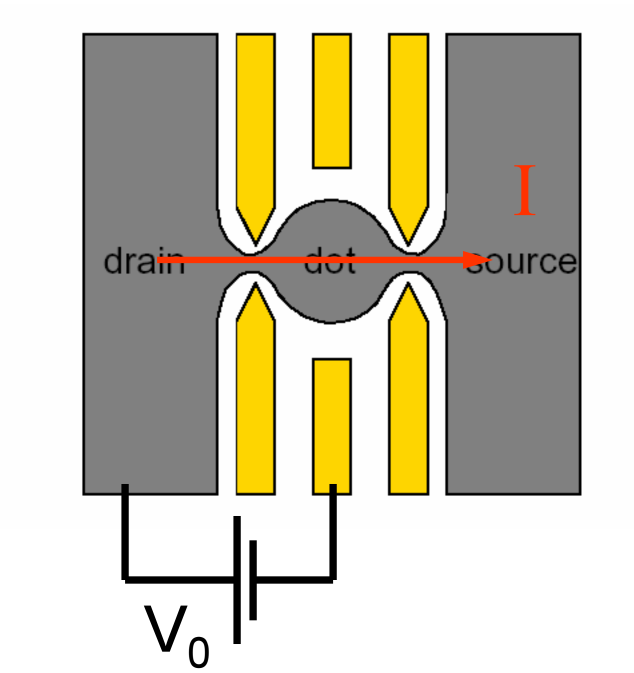


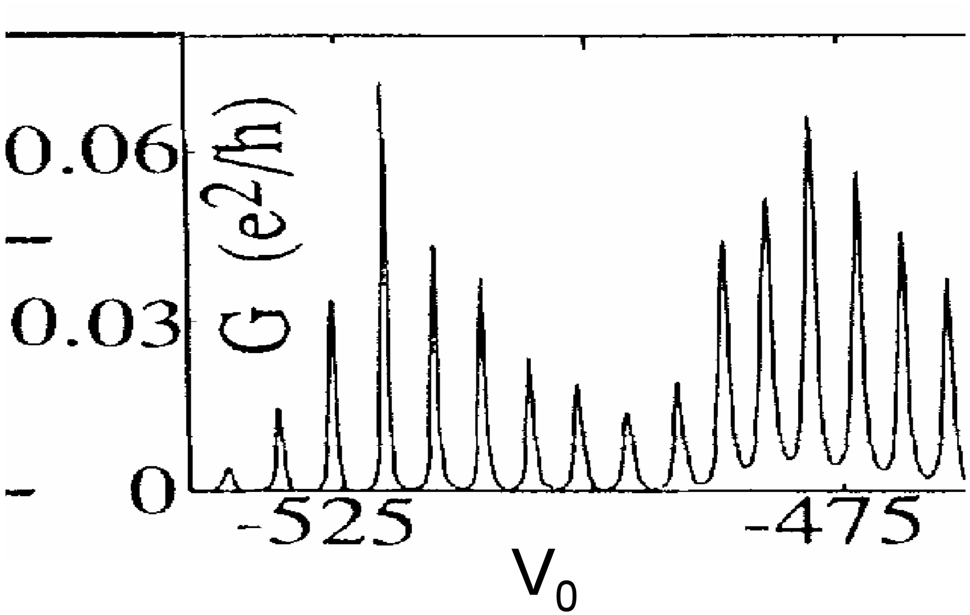
Charge quantization on an almost isolated island

Intro. Quantum dot (QD)

Coulomb Blockade

Fluctuations of electron number on a QD is impossible at low temperature, because of the Coulomb interaction. QD is isolating.





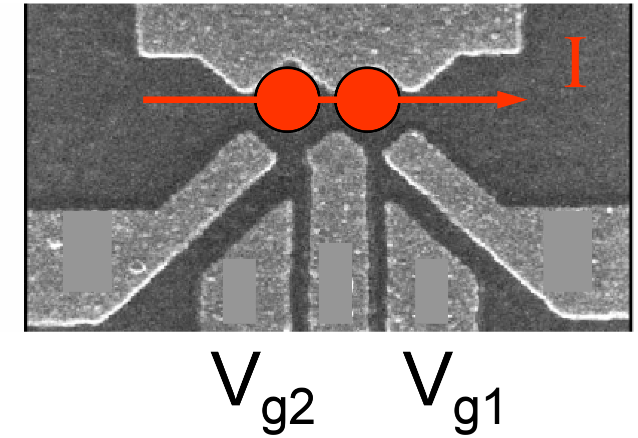
Conductance oscillations

lifting a blockade:

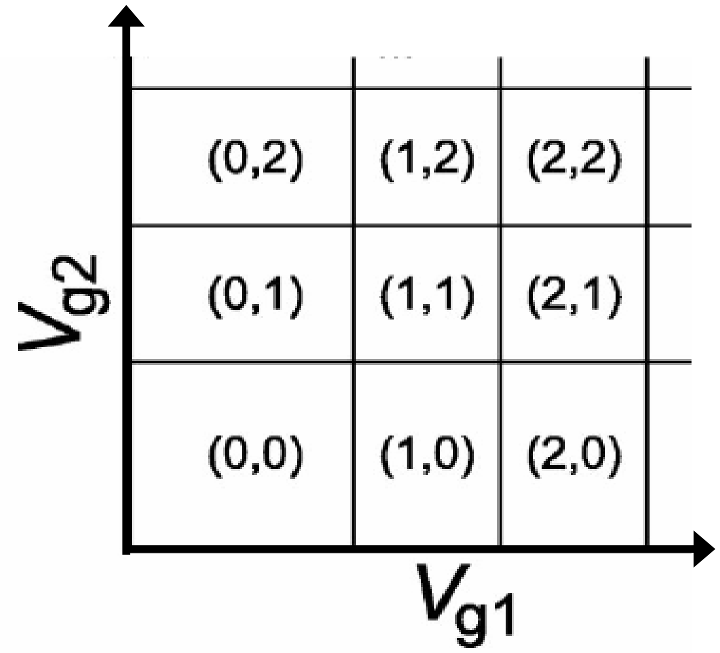
$E(N+1)-E(N)=\mu$

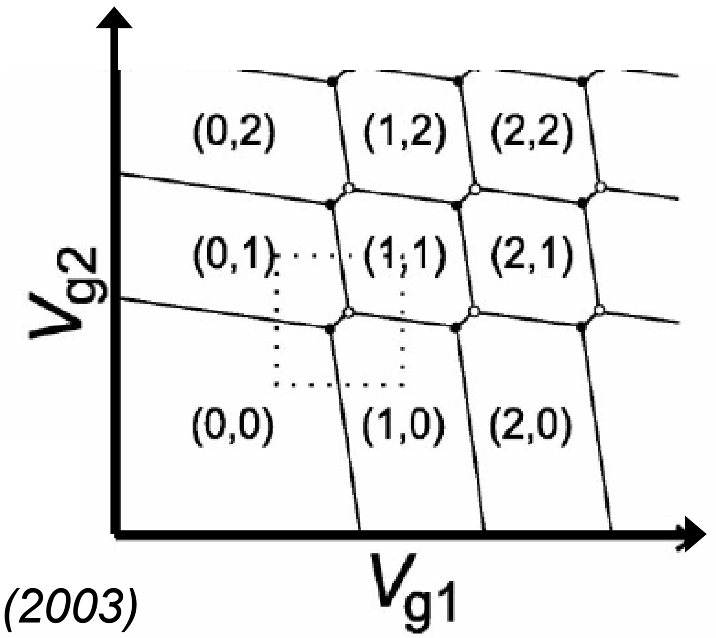
Shechter (198?)

Intro. Double Quantum Dot



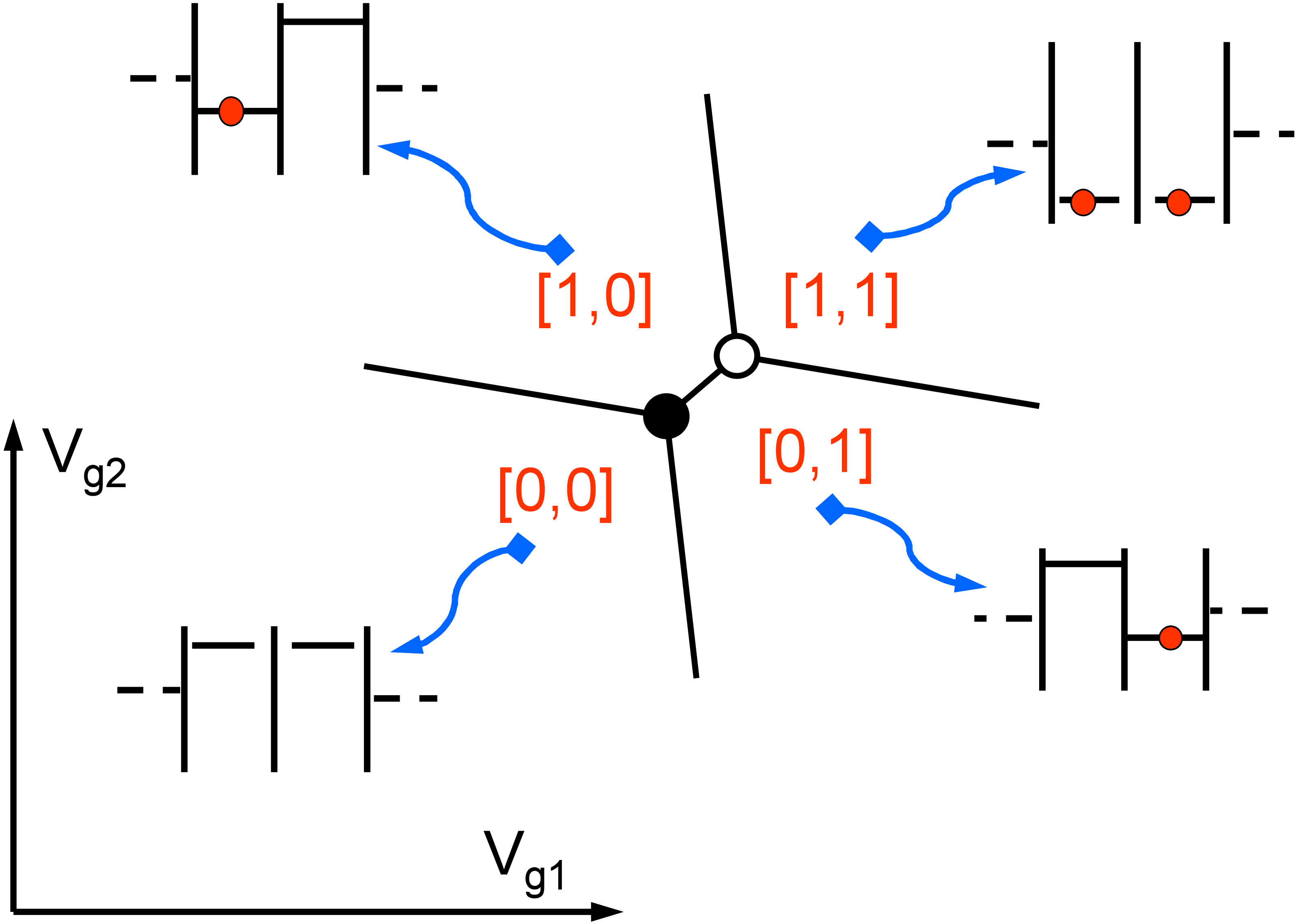
For current to flow the Coulomb blockade should be lifted in both serially coupled QD's





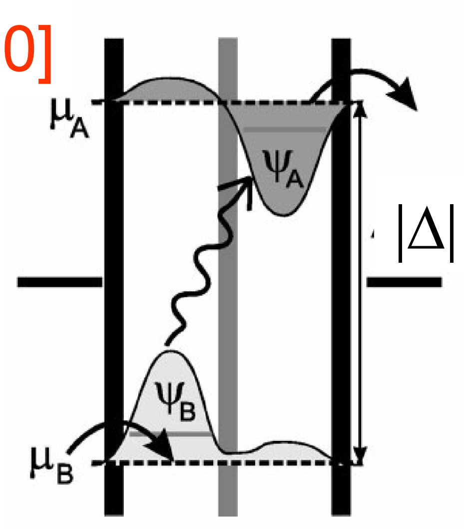
van der Wiel et al. (2003)

Intro. Double Quantum Dot



Intro. Photon-assisted tunnelling in DQD

[1,0]

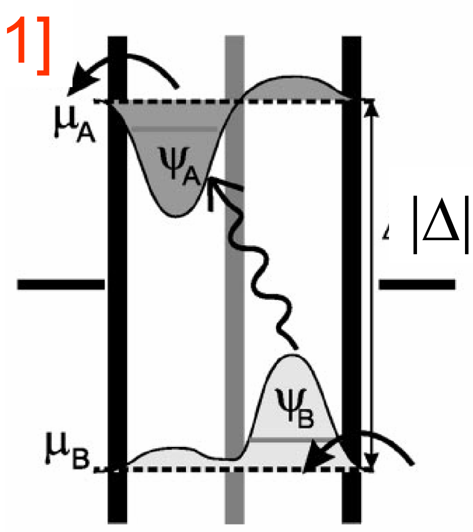


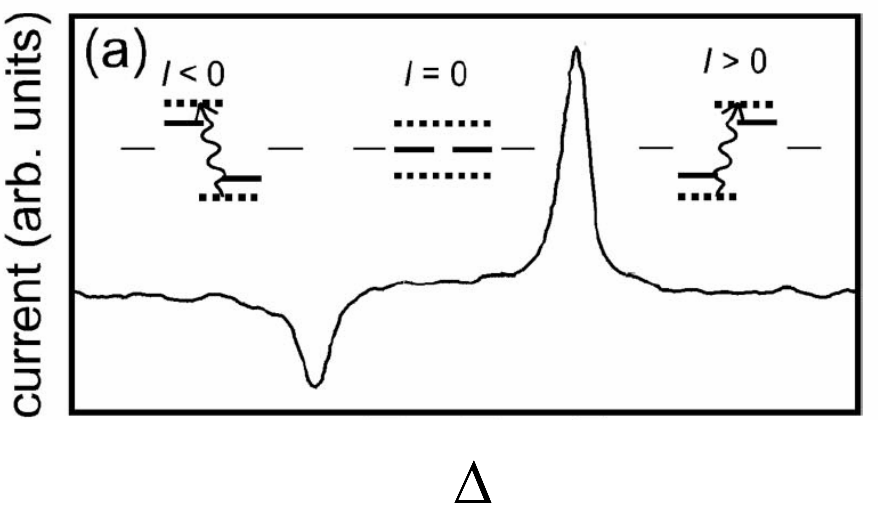
Inelastic transitions between the states localized in different dots give rise to a current in DQD, in the absence of potential difference between the leads.

Resonant microwave photon absorption: $h\nu=\Delta$

van der Wiel et al. (2003)

[0,1]





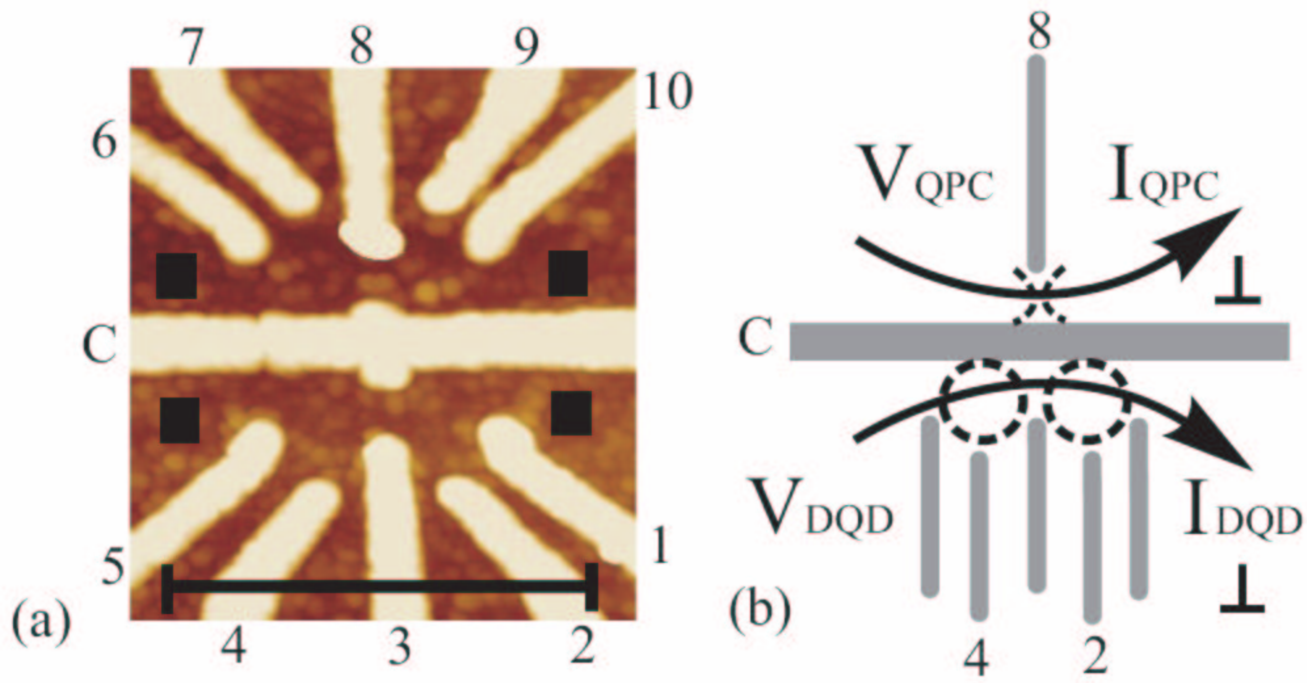
Experiment. Nanostructure

GaAs/AlGaAs heterostructure

2D layer - 90 nm benief the surface

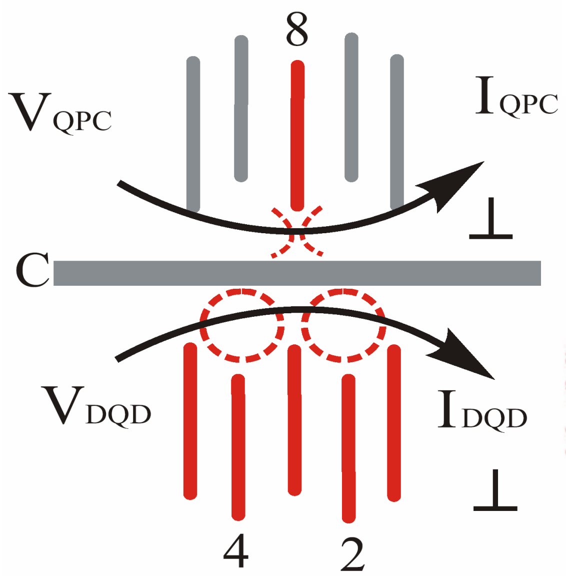
$N_S = 2.8x10^{11}\ cm^{-2}$

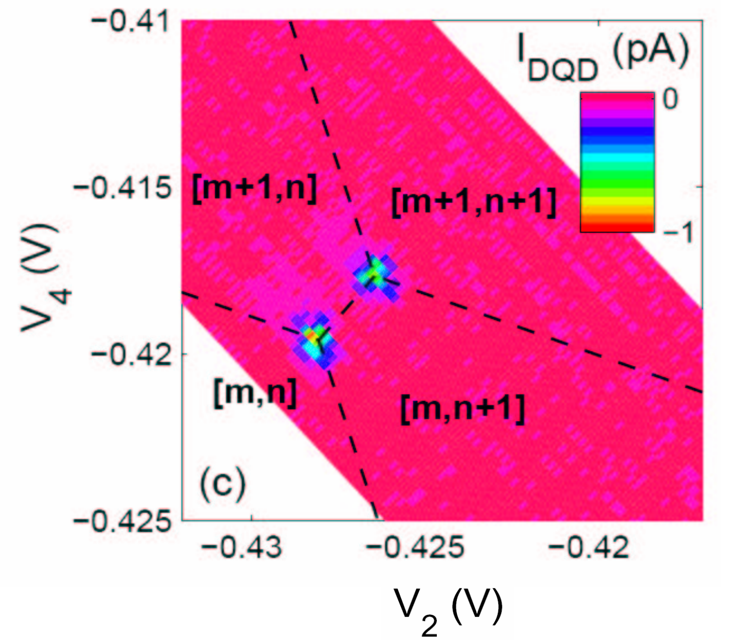
$\mu = 1.4x10^6\ cm^2/Vs$

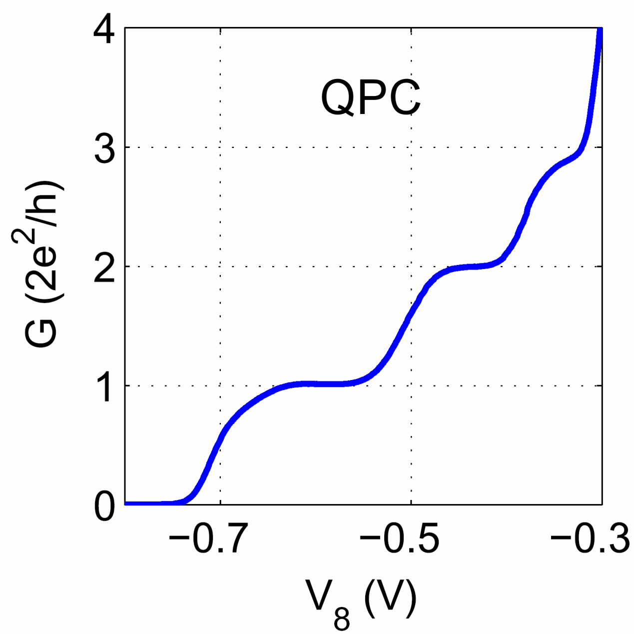


- Metallic gates (e-beam lytho)
- 2 independent electric circuits
- dc measurement
- $T_{el} < 150$ mK

Experiment. Characterization.



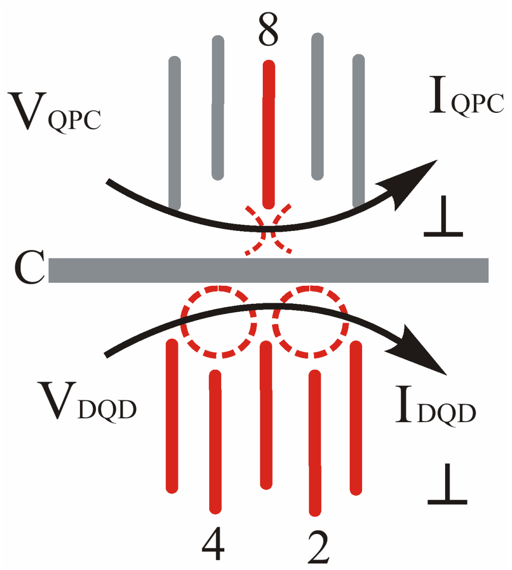




- QDs: Coulomb energy $E_C \approx 1.5$ meV
- DQD: $t_0 \approx 0.1$ μeV; $\Gamma_R, \Gamma_L \approx 40$ μeV

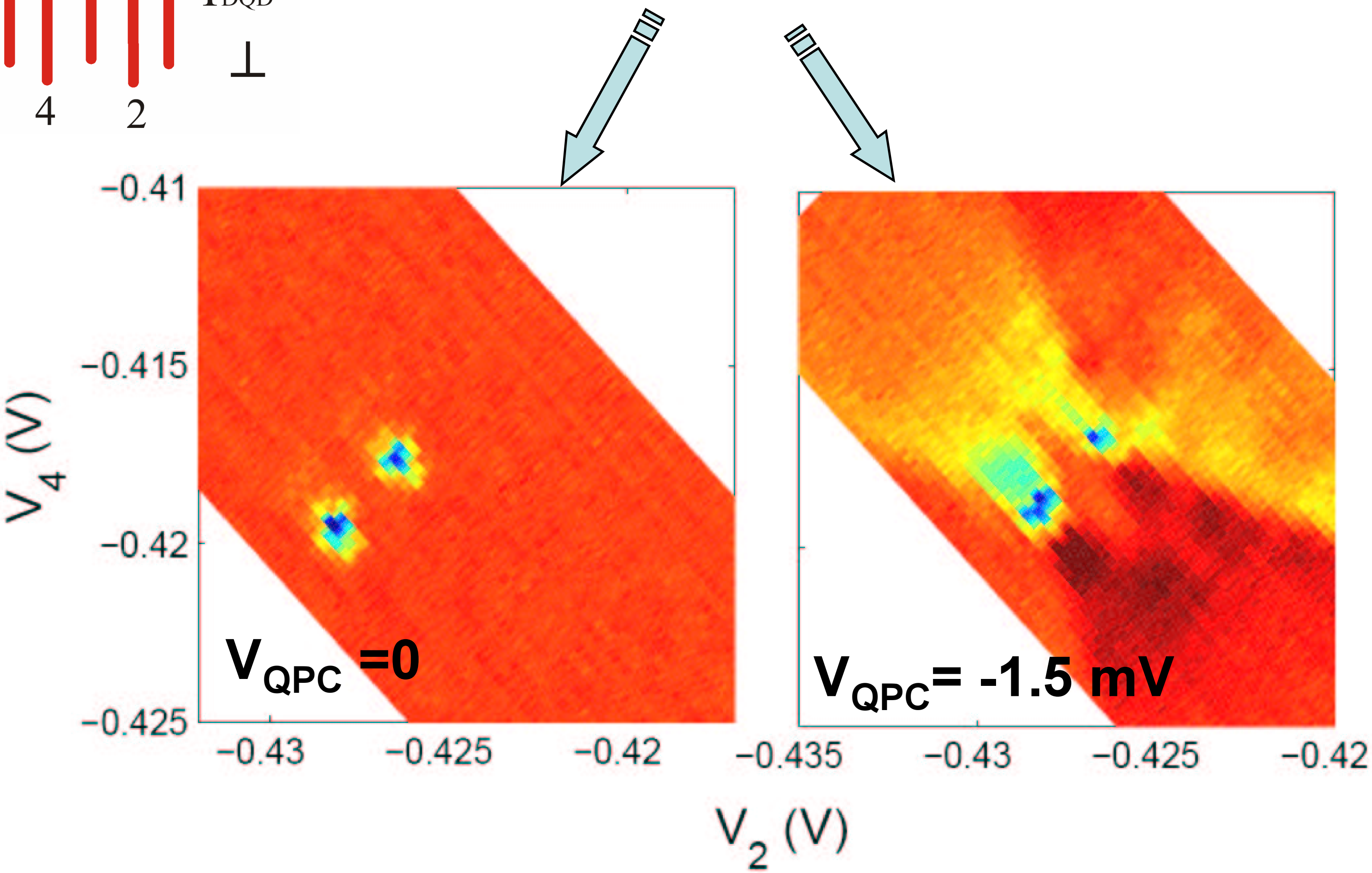
- QPC: subband splitting ≈ 4 meV

1D channel onset width ≈ 1 meV

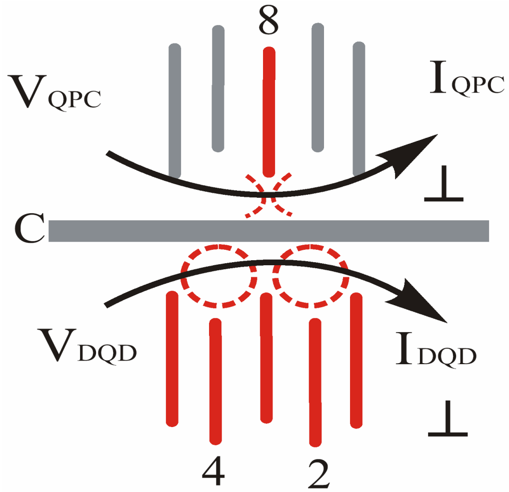


Experiment. Dynamic interaction QPC ↔ DQD

I_{DQD} measured at V_{DQD}= -20 μV

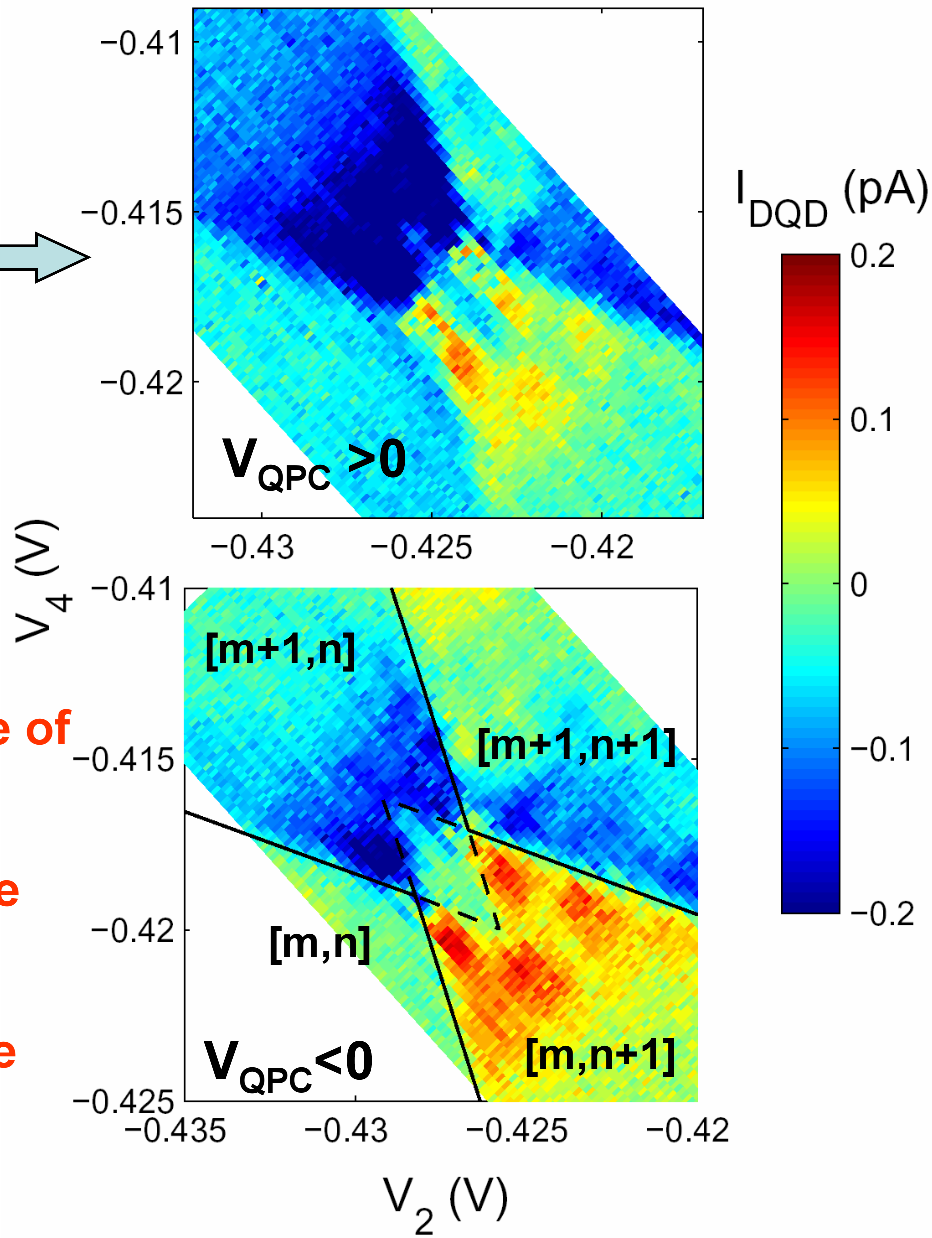


Experiment. Dynamic interaction QPC ↔ DQD



I_{DQD} measured

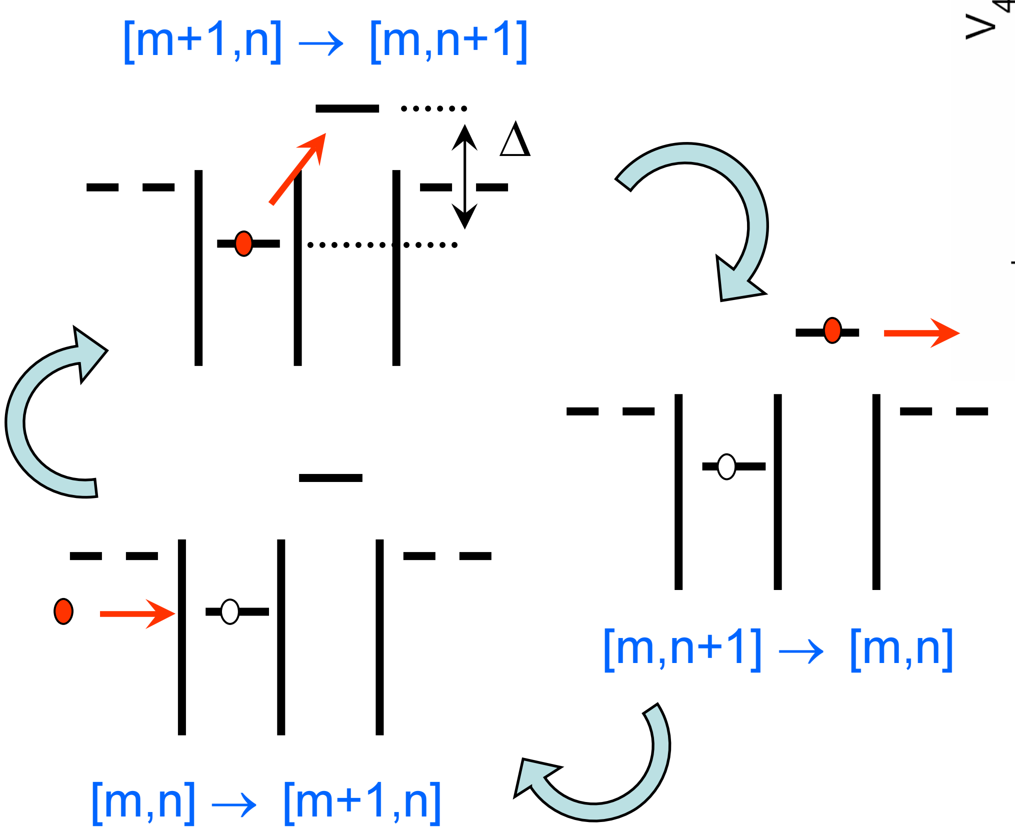
$V_{DQD} \approx 0\ \mu V$
$V_{QPC} = +/\_\ 1.45\ mV$
$G_{QPC} \approx e^2/h$

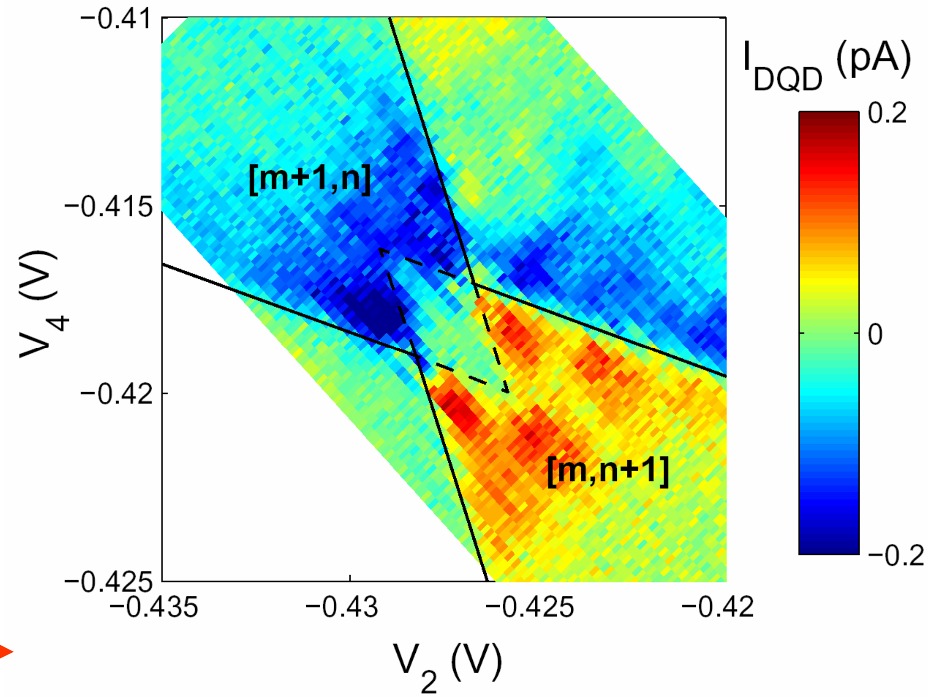


- Current through the DQD in the absence of bias
- Current in the Coulomb blockade regime
- Current direction is determined by the ground state charge configuration of the DQD

Experiment. Inelastic tunnelling?

Current sign is explained by inelastic interdot tunnelling



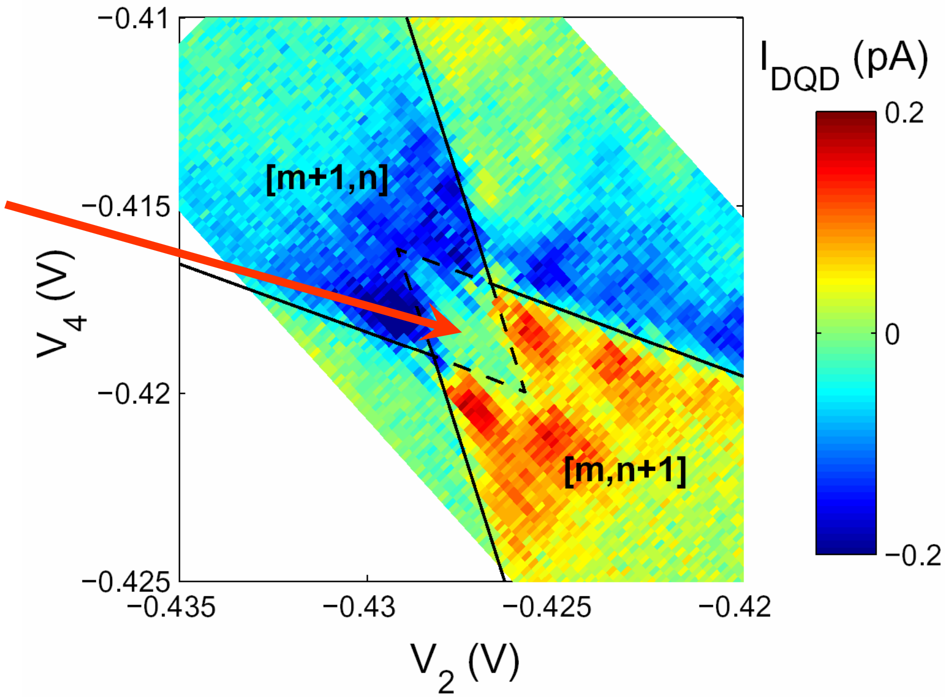


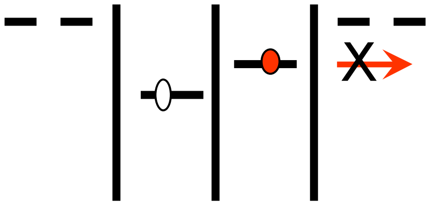
Similar to PAT

van der Wiel et al. (2003)

Experiment. Inelastic tunnelling!

Observed suppression of current between triple points

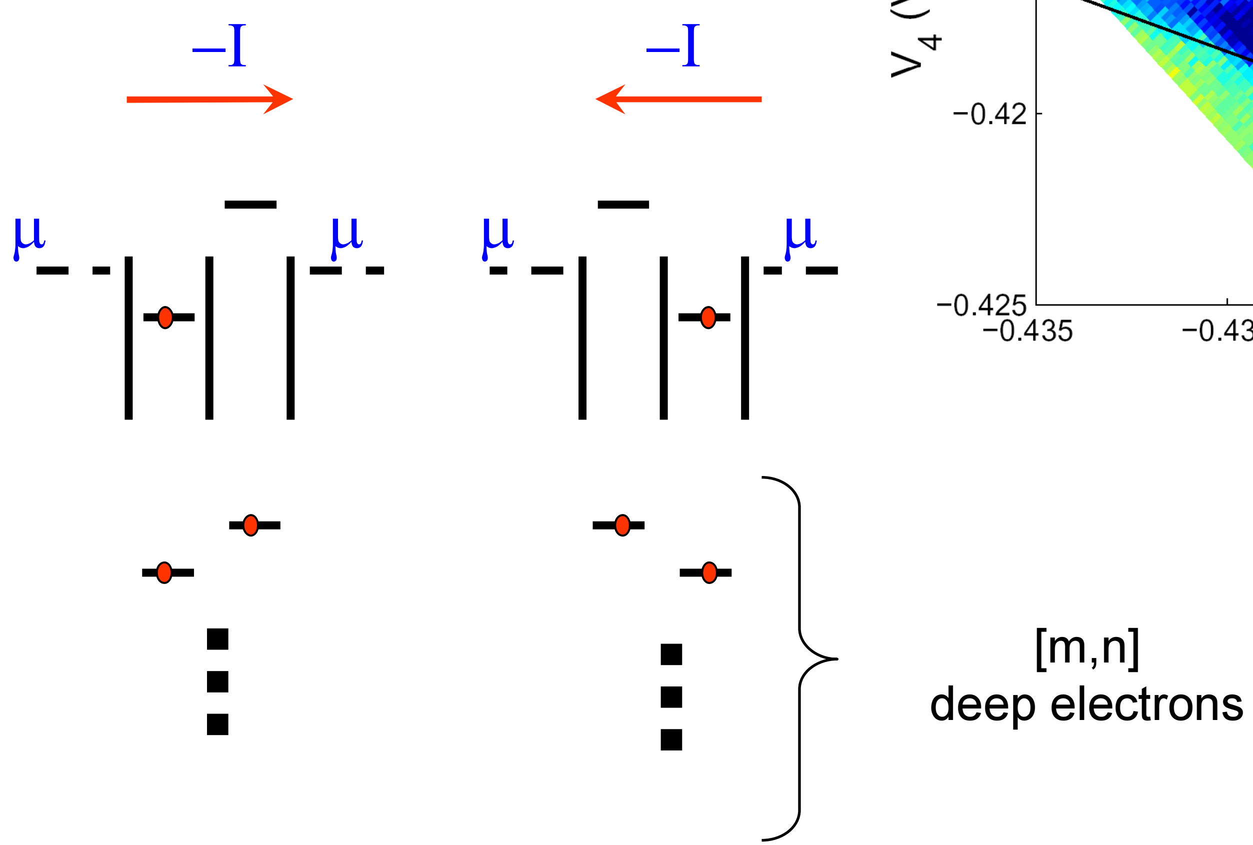


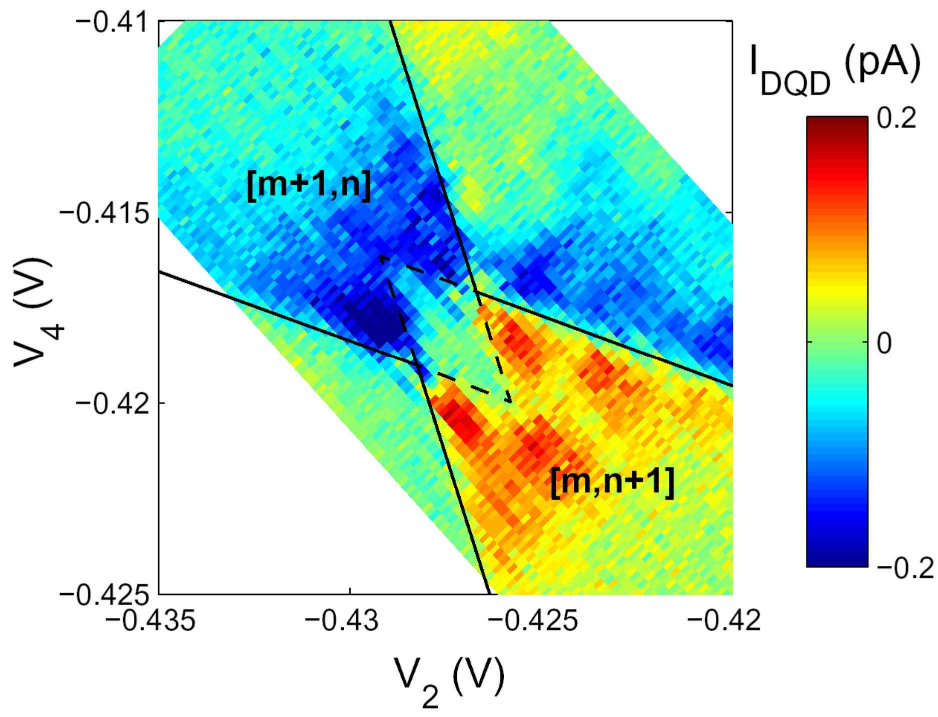


Inside the diamond the excited electron doesn’t have enough energy to leave into the Fermi sea

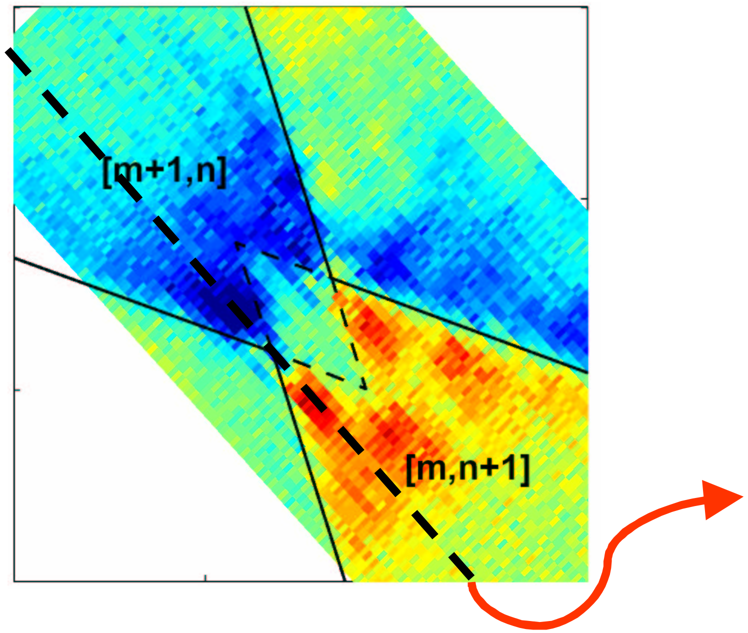
DQD analogous to a Quantum Ratchet

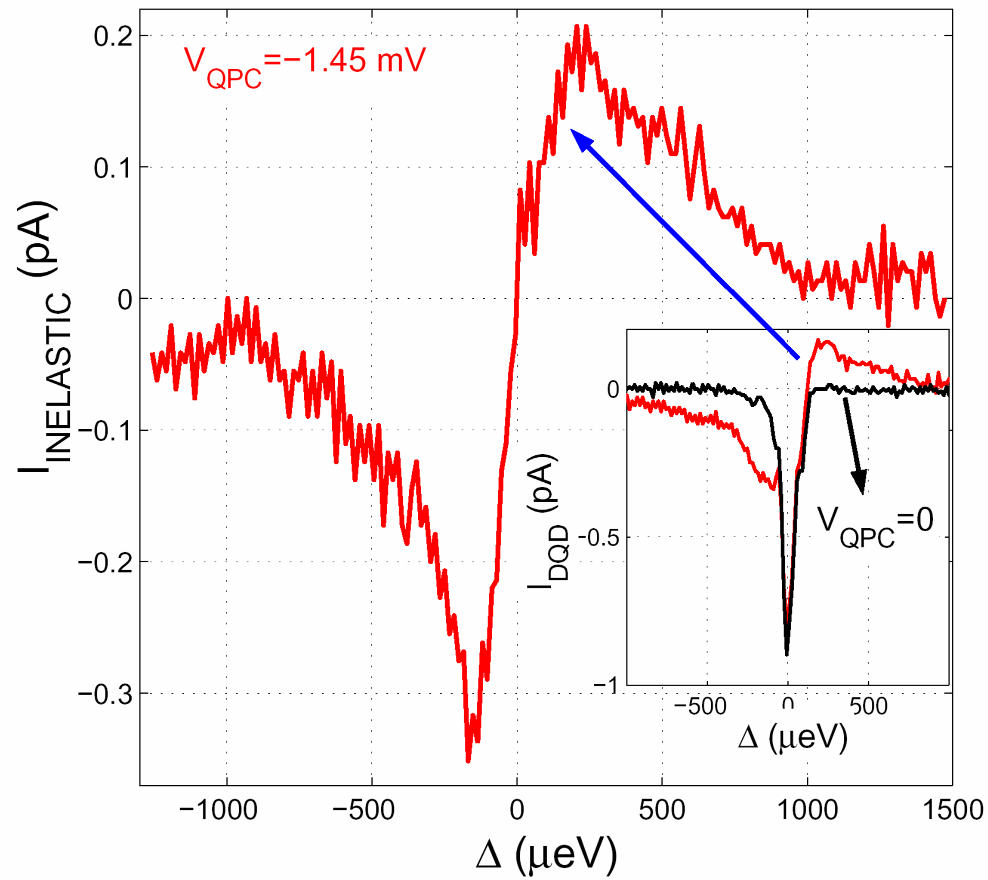
Internal asymmetry of the DQD determines the direction of current





Experiment. Excitation spectroscopy.

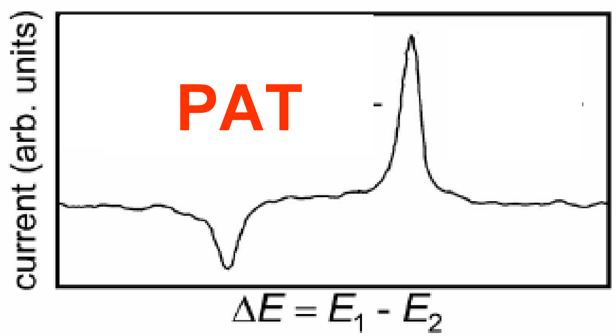




DQD is a tunable spectrometer

$|\Delta|=h\nu$

Fujisawa et al. '98

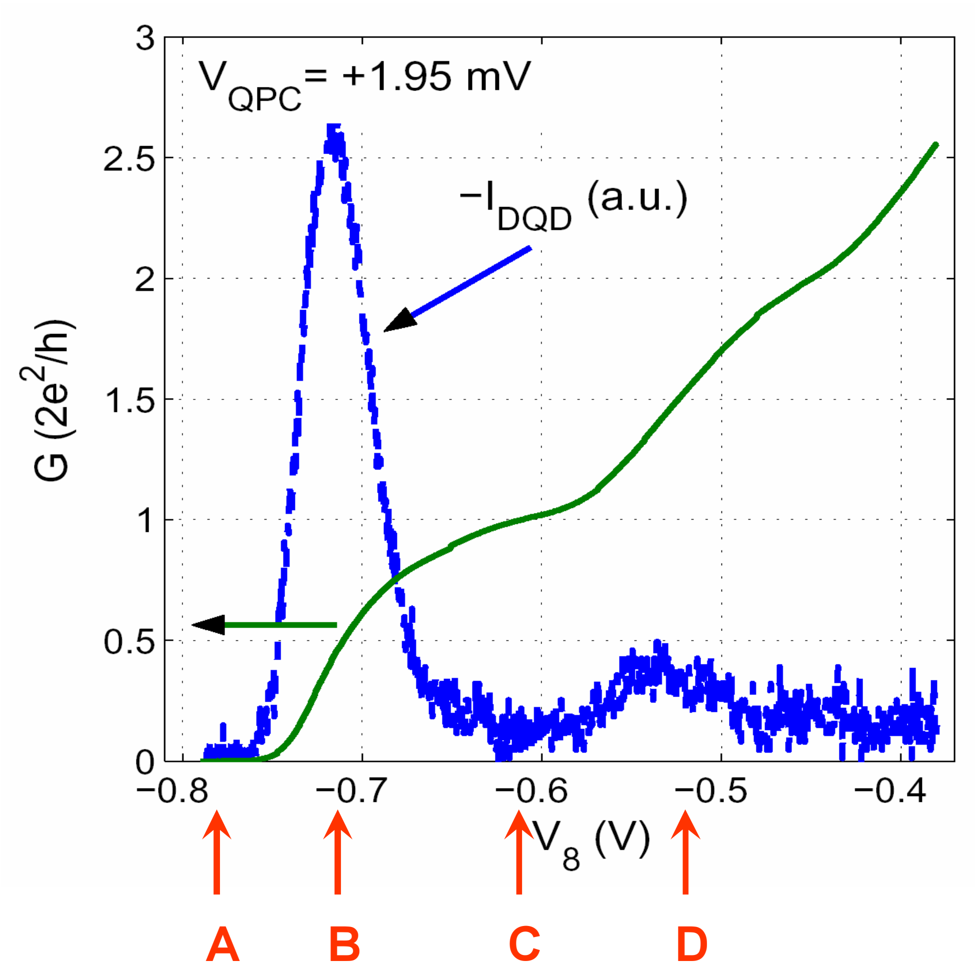


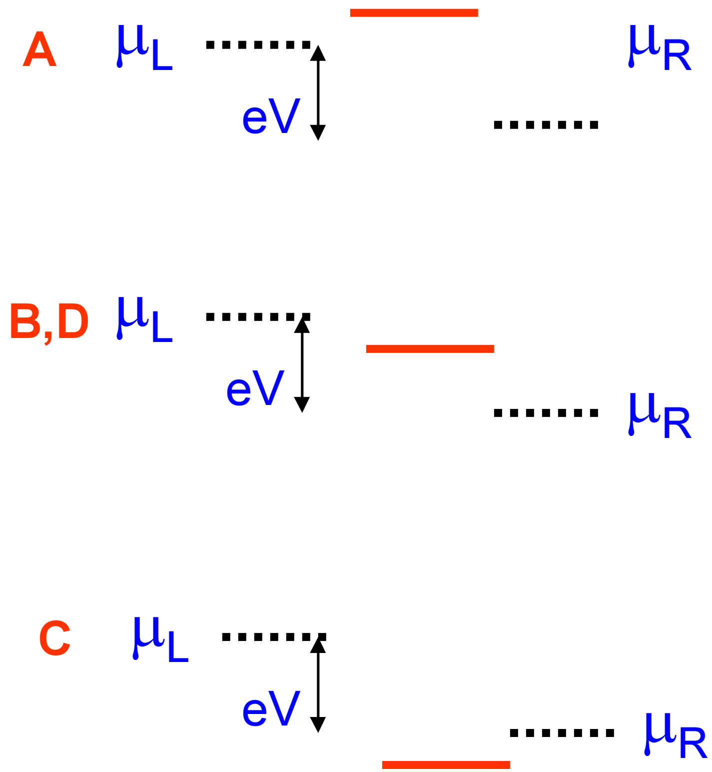
van der Wiel et al. (2003)

Wideband excitation (250 GHz) in sharp contrast to PAT

Experiment. Dependence on the QPC transmission

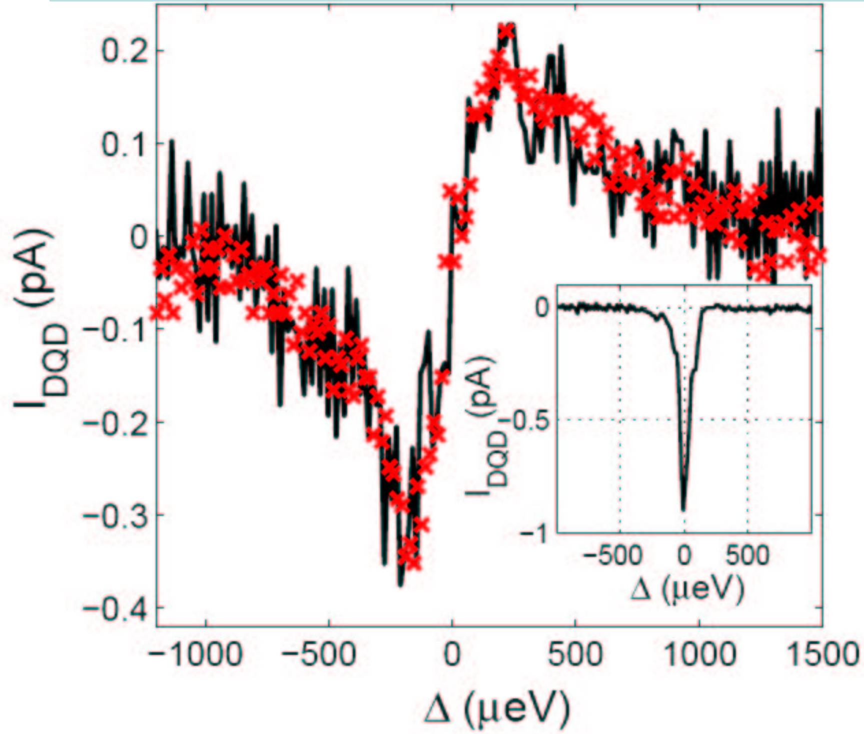
Not a Joule heating drives the ratchet!

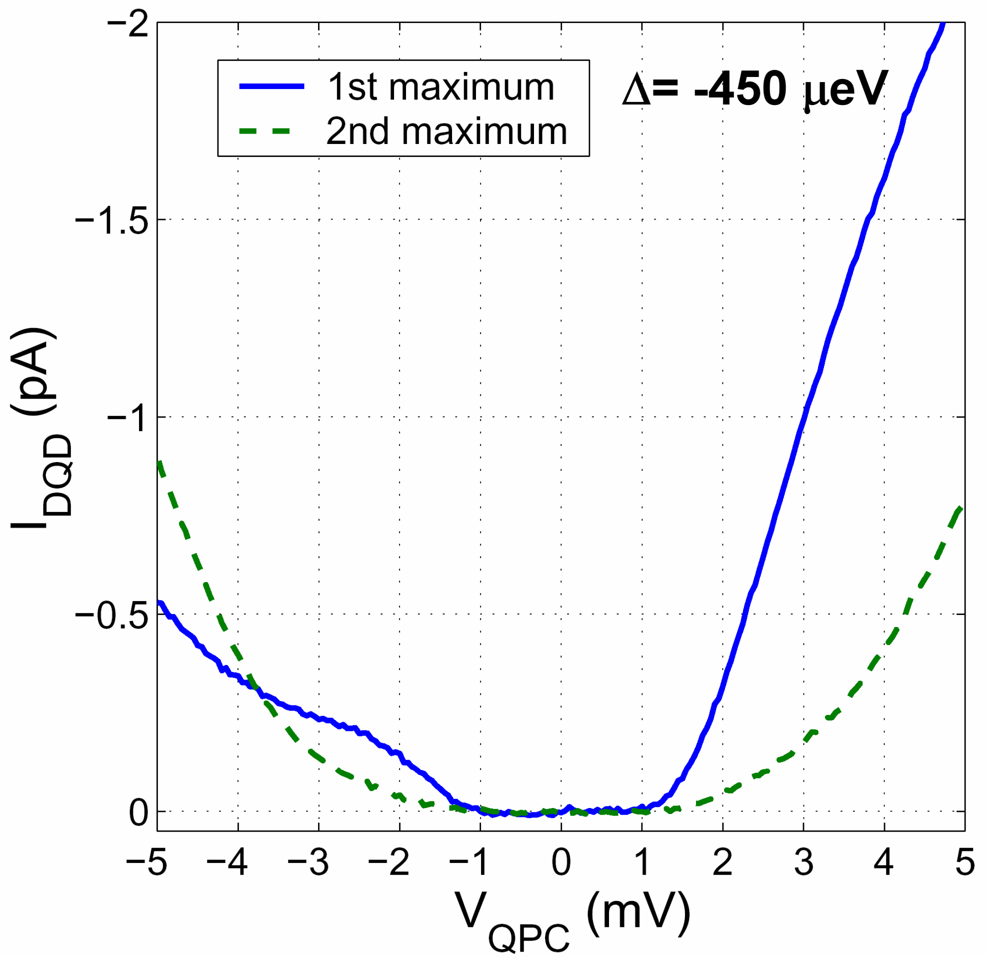




Experiment. Dependence on the QPC bias voltage

- Direction of the DQD current is independent of the QPC bias
- No effect at low bias V_{QPC}<1 mV
- Onset bias independent of Δ





QPC: ratchet excitation mechanism

Maximal effect next to the bottom of 1D subbands of QPC, i.e. at T≠1 (R≠0)

Occupation number fluctuations are important!

- HF voltage-fluctuations on a QPC caused by shot noise?

$V_{ONSET}=|V_{QPC}|-|\Delta|/e$ – No energy-(frequency-) dependence of the threshold observed!

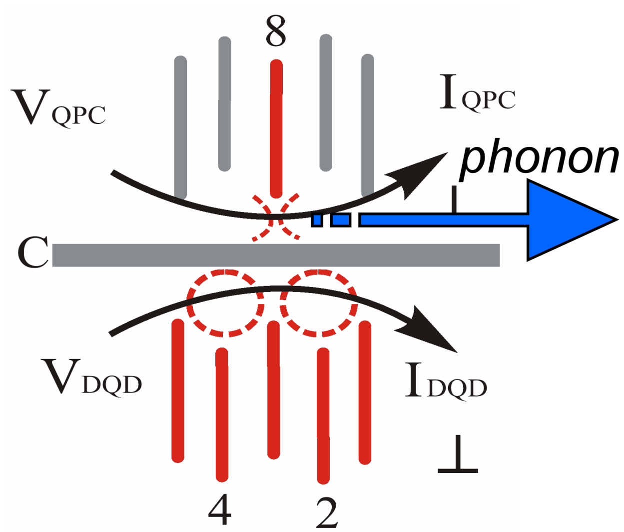
Blanter and Büttiker '00

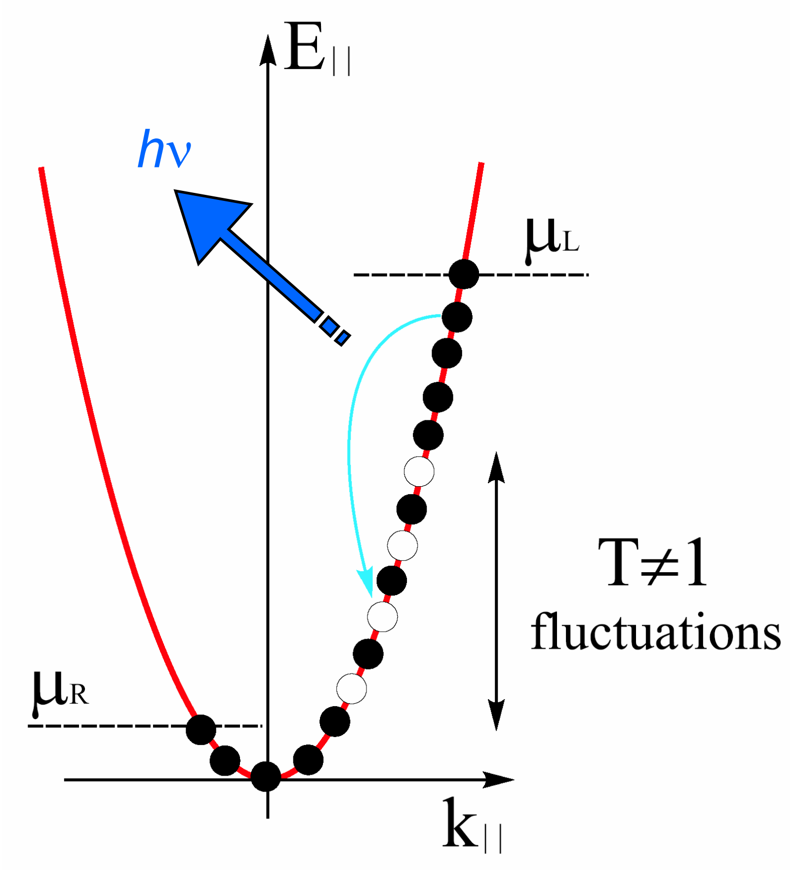
- Relaxation of electrons inside a 1D channel?

Occupation number fluctuations could increase the relaxation rate inside a 1D channel

Acoustic phonons?

Only a qualitative understanding of threshold-like emission is possible





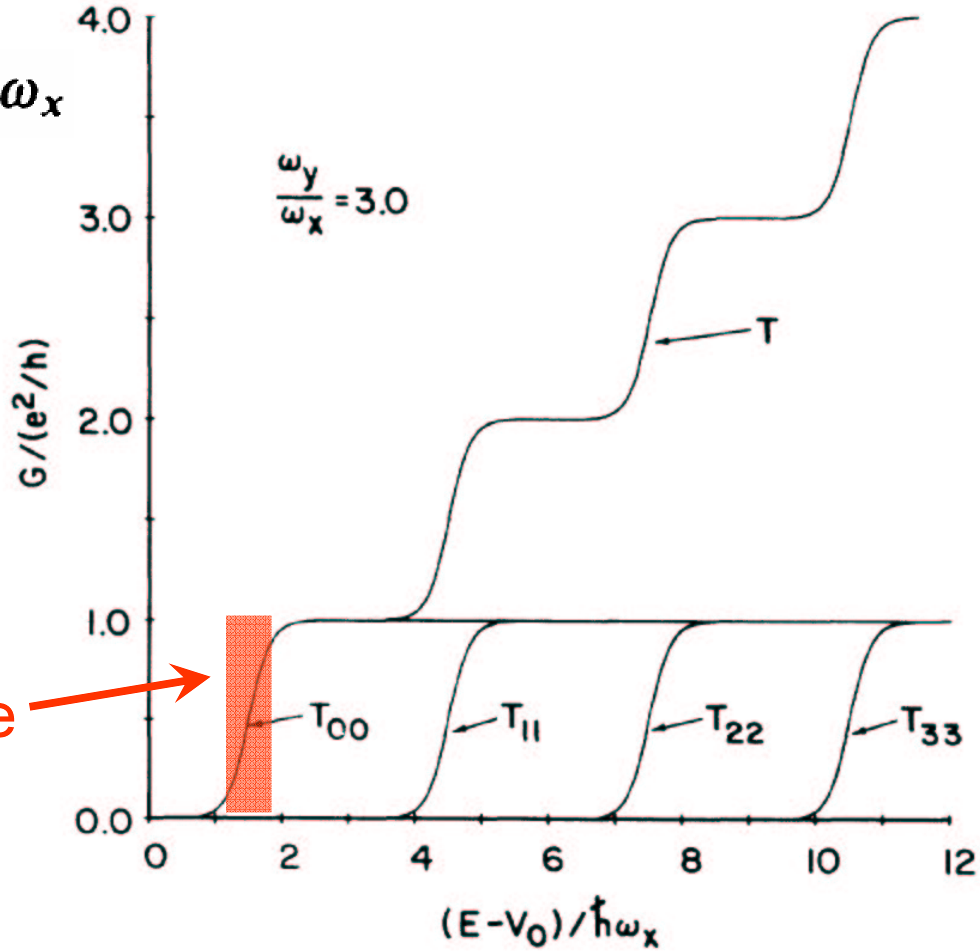
Alternatively: Photons? 1D plasmons?

Wide energy-window for fluctuations

$$\varepsilon_n = 2[E - \hbar\omega_y(n+\tfrac{1}{2}) - V_0]/\hbar\omega_x$$

$$T_{mn} = \delta_{mn}\frac{1}{1+e^{-\pi\varepsilon_n}}$$

Our QPC:
1D channel onset ≈ 1 meV wide



J. N. L. Connor, Mol. Phys. **15**, 37 (1968); W. H. Miller, J. Chem. Phys. **48**, 1651 (1968).

Concluding

- **Novel dynamic interaction phenomenon between the QPC and DQD**
- **Resonant energy absorption makes the DQD equivalent to a nonadiabatic quantum ratchet**
- **Occupation number fluctuations in the QPC channel are responsible for ratchet energization**

Coauthors

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Stefan Ludwig

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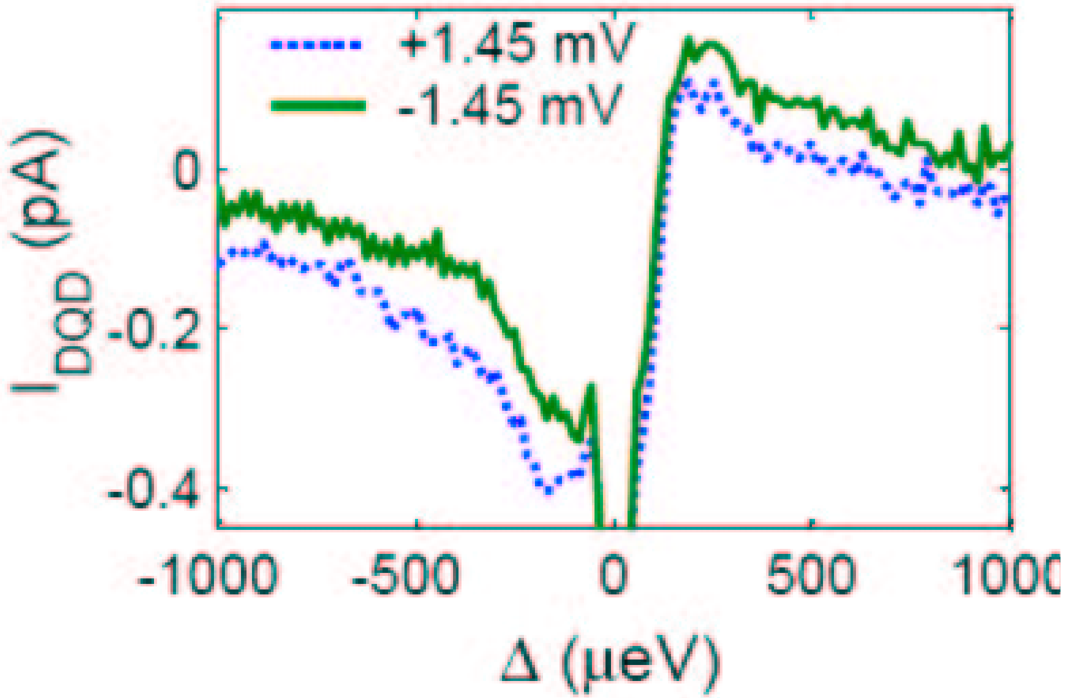
▸http://www.humboldt-foundation.de

Non-ratchet phenomenon observed

- No Δ dependence
- ‚Anti-drag' direction



- Acoustoelectric pumping?

  Levinson et al. '00

- Nongaussian electromagnetic fluctuations?

Non-ratchet phenomenon observed

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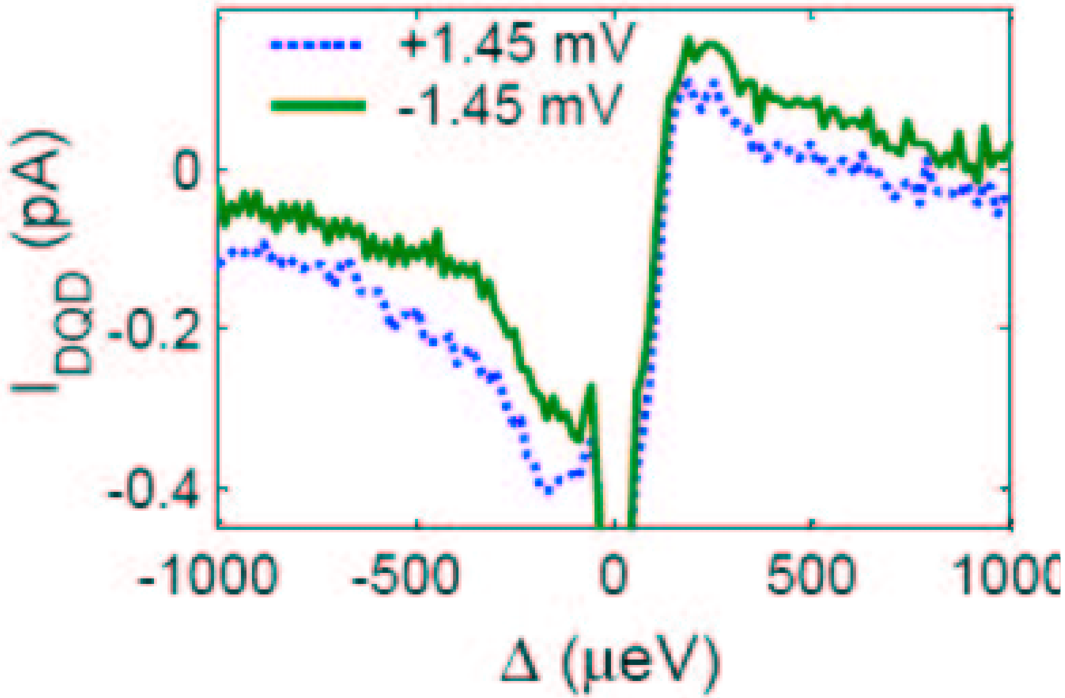

- Acoustoelectric pumping?

Levinson et al. ’00

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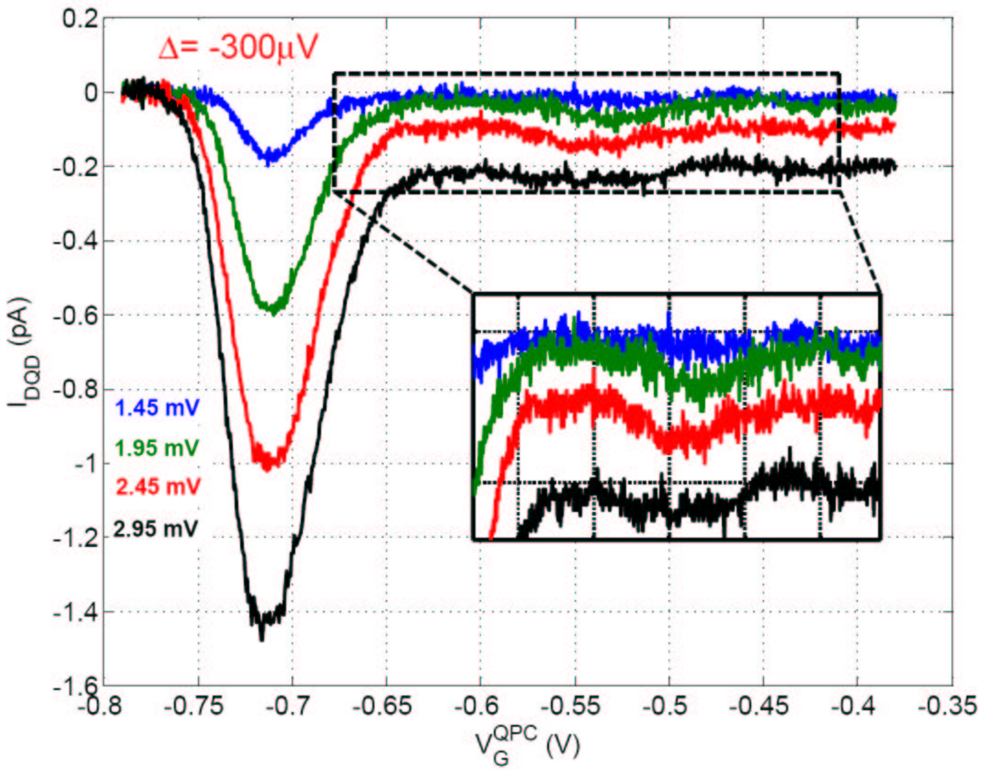
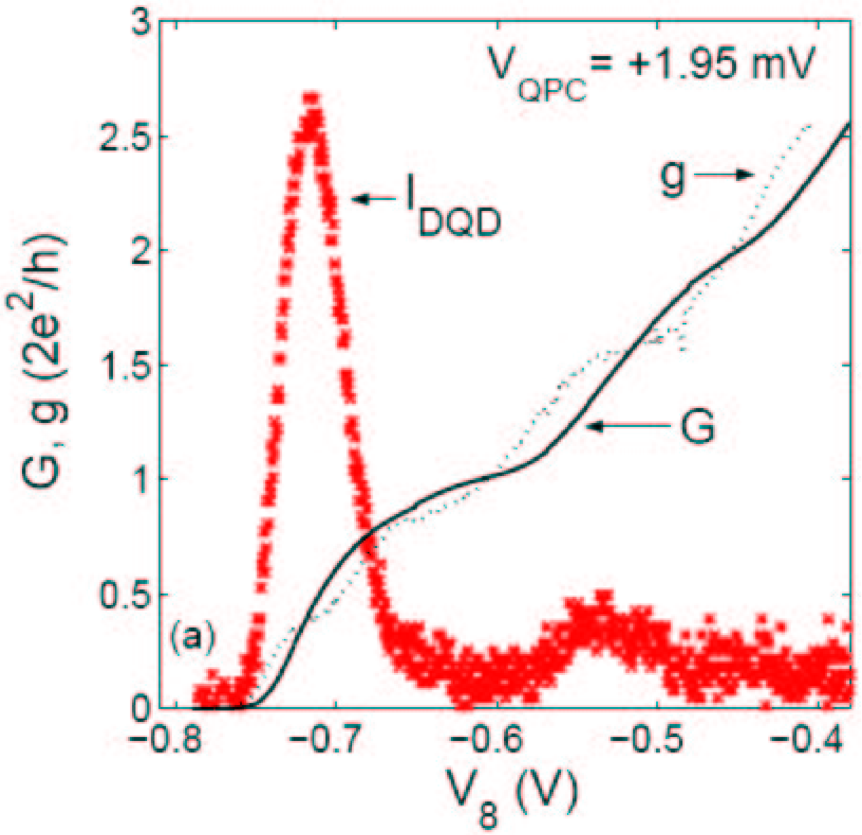
Current in the double dot as a function of QPC transmission.

Δ= -450 μeV





Observed about all the triple points