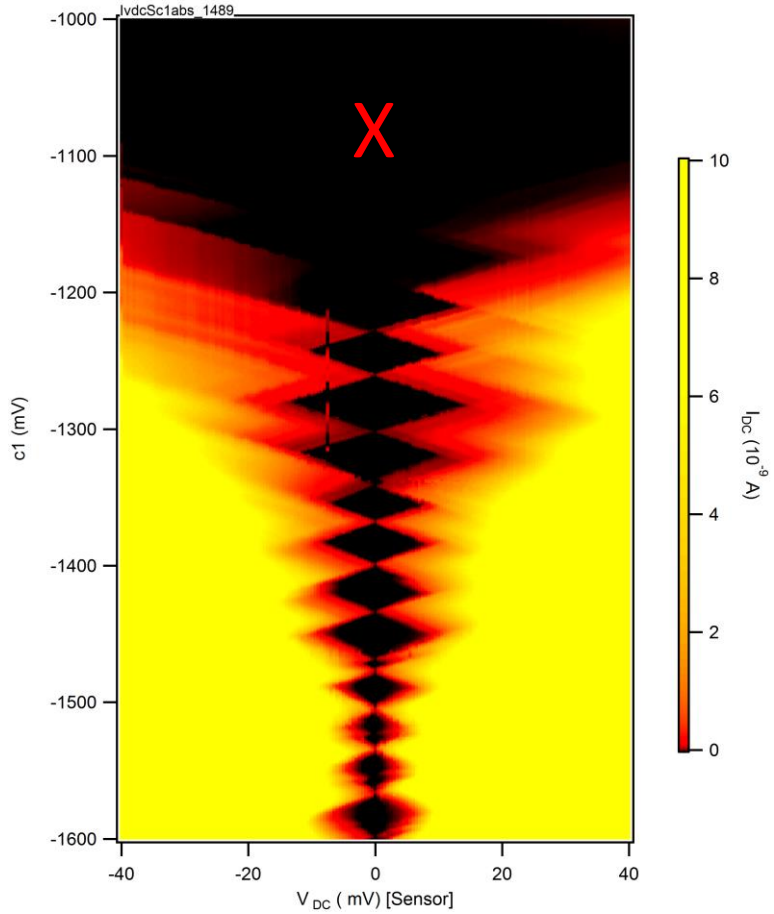
Charge Sensing

Simon Geyer – 02.04.2020

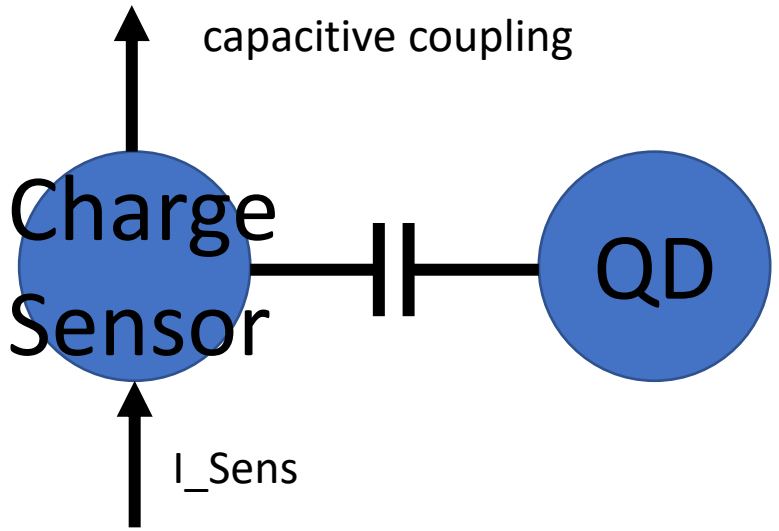
Problem: Measure QD at last electron/hole

- reducing number of electrons/holes reduces tunnel rate
- Is this the last hole or is the transport current just too small to measure?



Solution: Charge Sensing

- Measures change of charge
- sensitive to electrostatic changes (high dI_Sens/dV)
- different types:
  - Quantum point contact (QPC)
  - Single-electron transistor (SET)
  - Sensing QD



Charge Sensing with QPC

PHYSICAL REVIEW B **67**, 161308(R) (2003)

Few-electron quantum dot circuit with integrated charge read out

J. M. Elzerman,[1] R. Hanson,[1] J. S. Greidanus,[1] L. H. Willems van Beveren,[1] S. De Franceschi,[1] L. M. K. Vandersypen,[1]
S. Tarucha,[2,3] and L. P. Kouwenhoven[1]
[1]*Department of NanoScience and ERATO Mesoscopic Correlation Project, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands*
[2]*NTT Basic Research Laboratories, Atsugi-shi, Kanagawa 243-0129, Japan*
[3]*ERATO Mesoscopic Correlation Project, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan*
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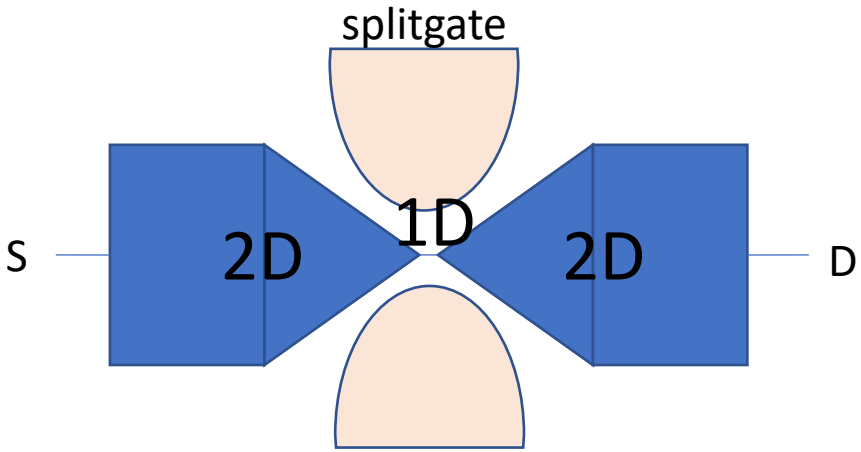
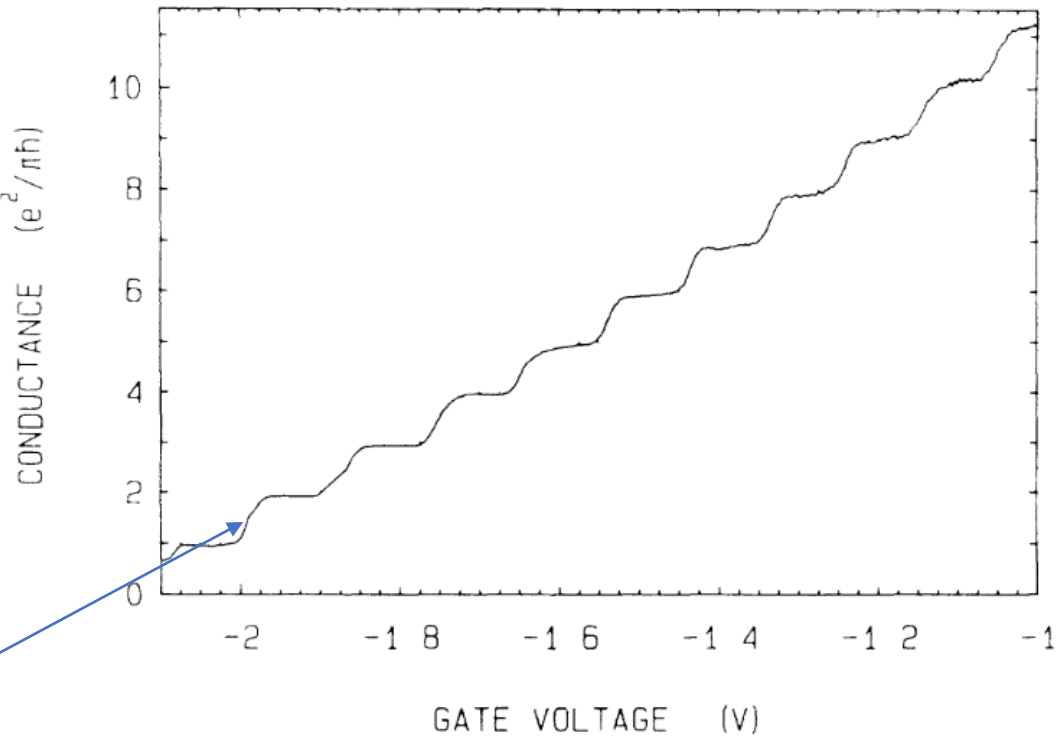
Dutch

QPC





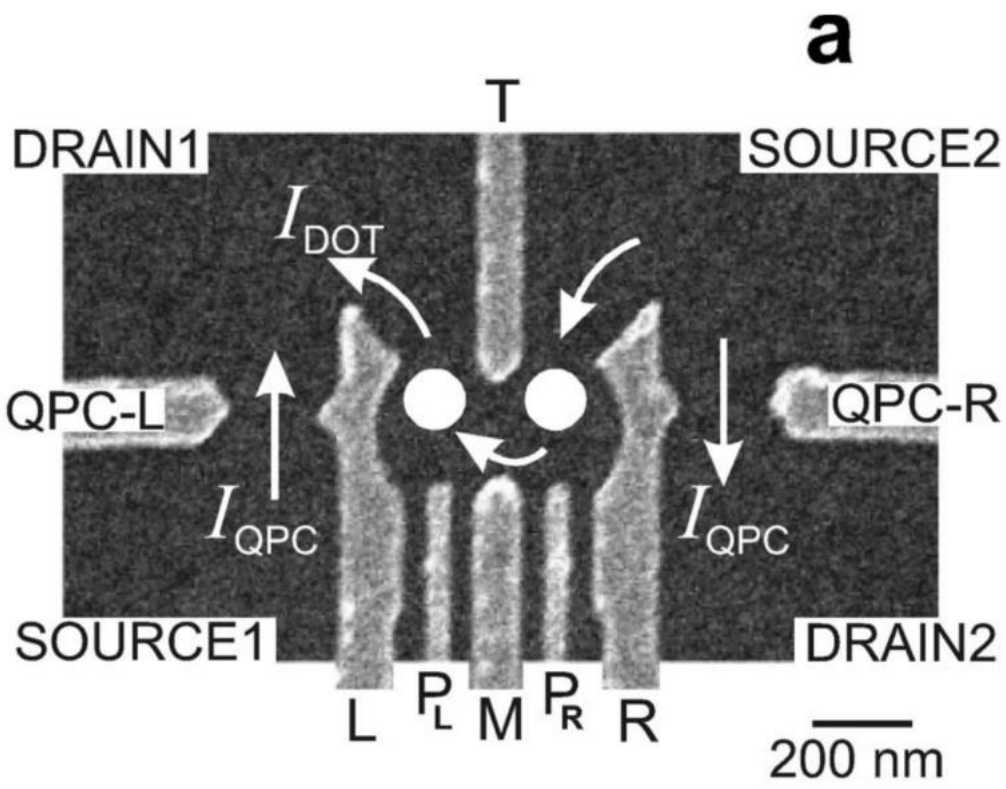
- 1D confinement -> quantized conduction ($2e^2/h$)
- high dI/dV at steps

B. J. van Wees, Phys. Rev. Lett. 60, 848 (1988)

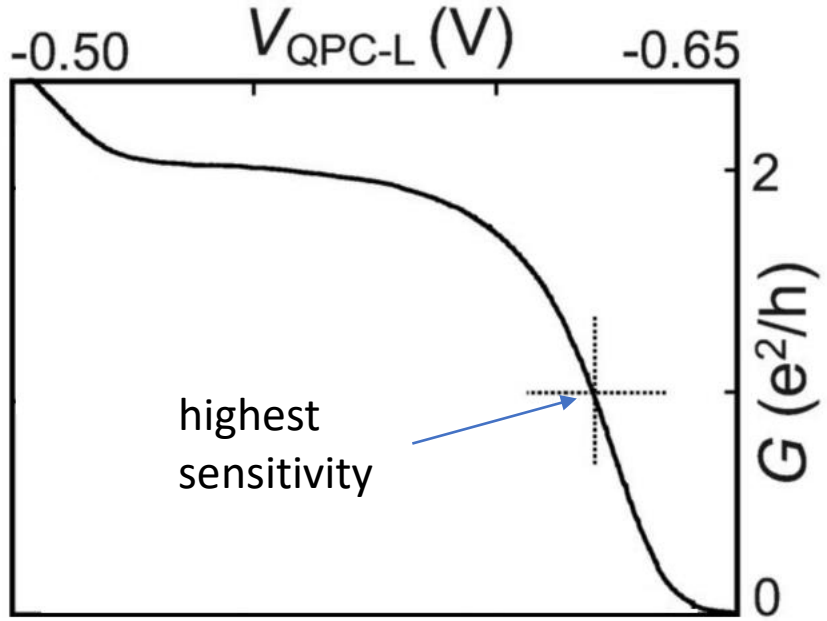
also Dutch

Device

- Double dot with 2 adjacent QPCs (now only used as single dot)

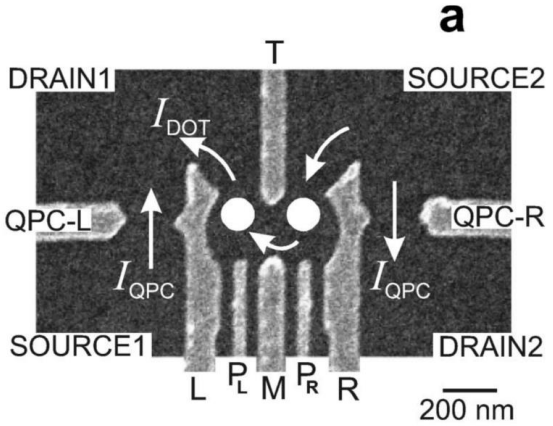


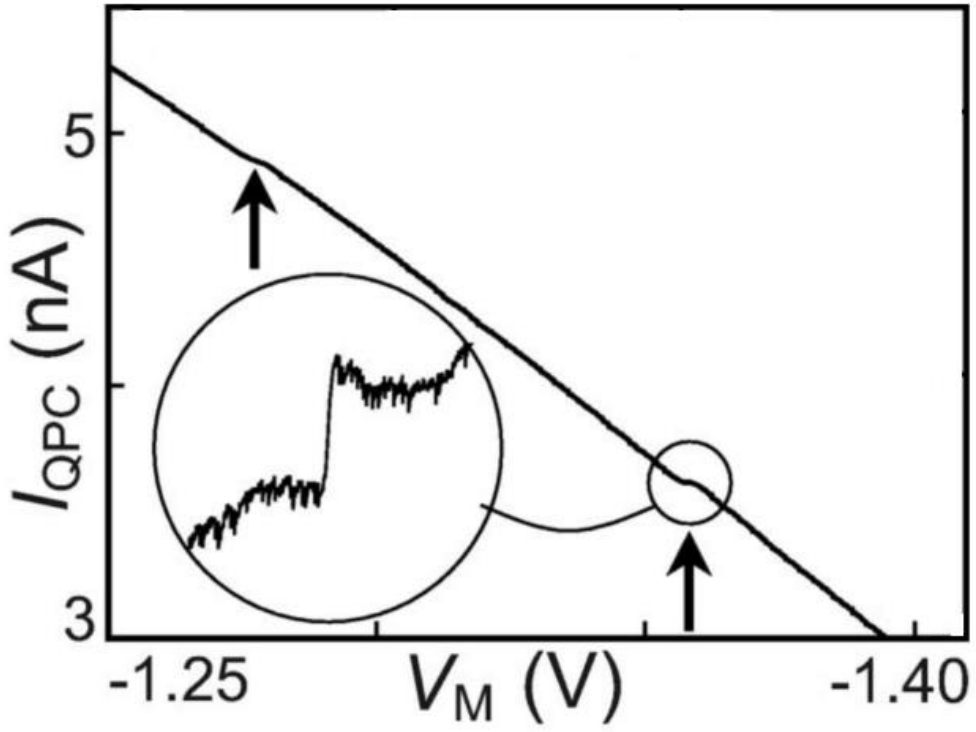
- Left QPC quantized conduction steps



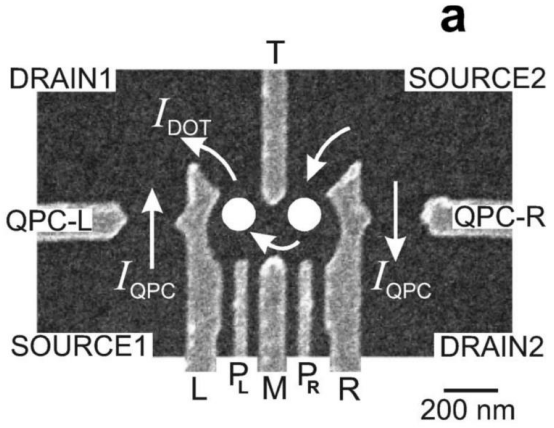
Charge Sensing

- I_QPC increases linear, kink occurs when electron is loaded to QD
- For inset: subtract linear background -> sudden jump in I_QPC when dot changes occupancy number
- Sensitivity ~0.1e

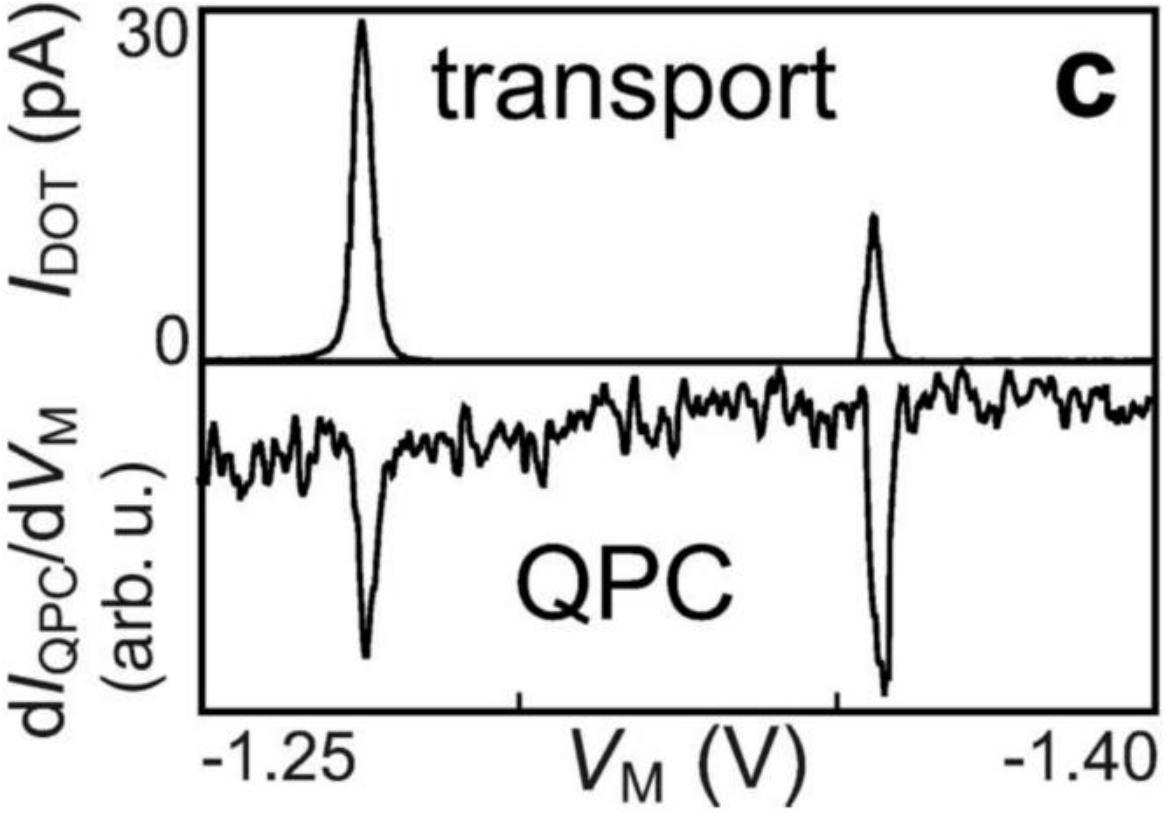




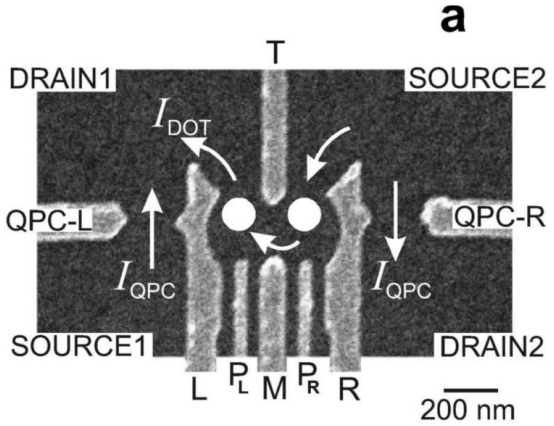
Comparing Transport/Charge Sensing



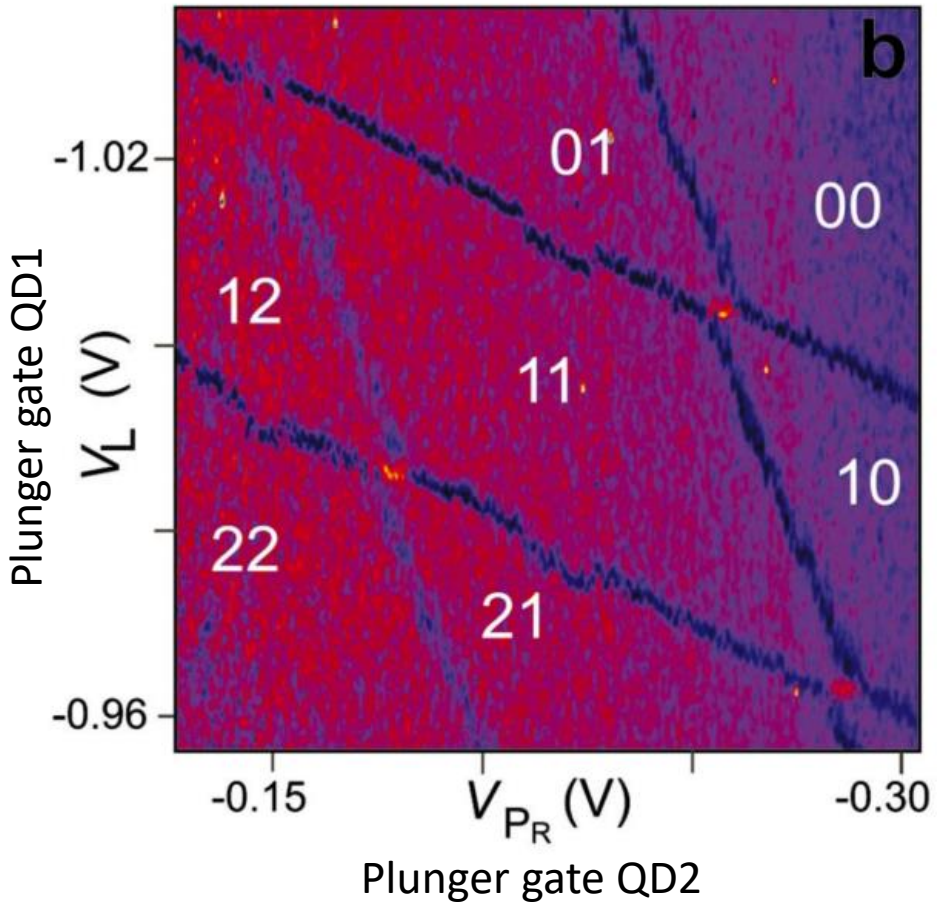
- Coulomb oscillations in transport coincide with dips in dI_QPC/dV_M
- QPC can measure charge state transistions in QD
- works even when barriers of the QD are very opaque (no transport current measureable)

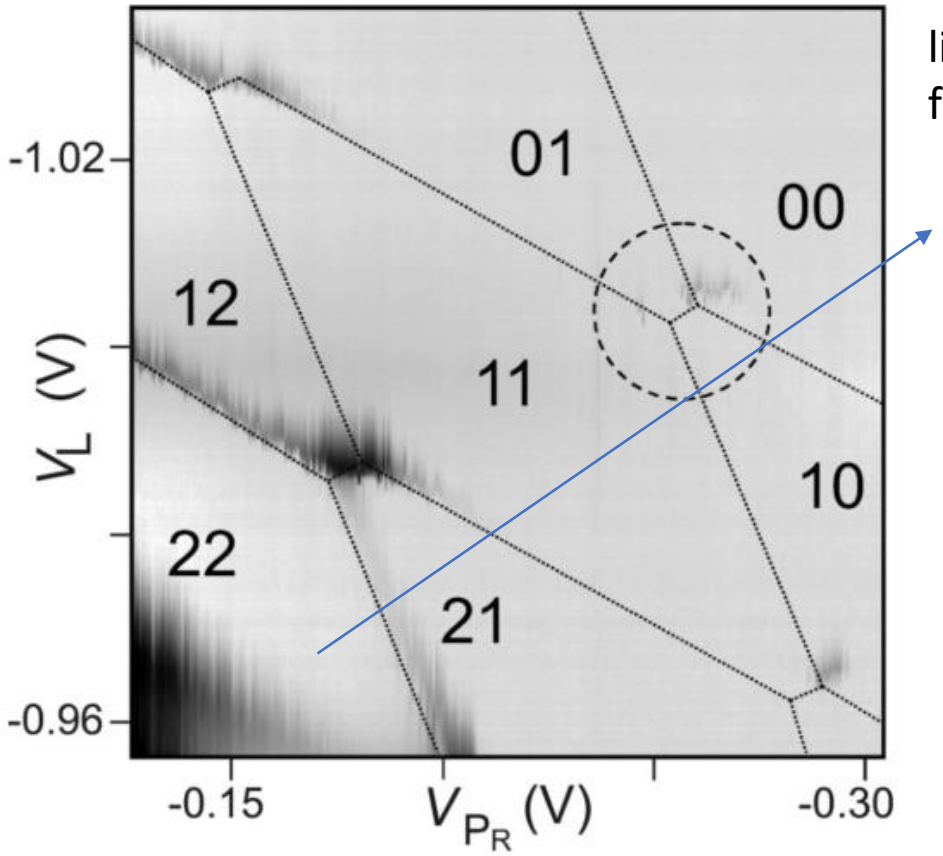


Comparing Charge Sensing/Transport



- In DQD:

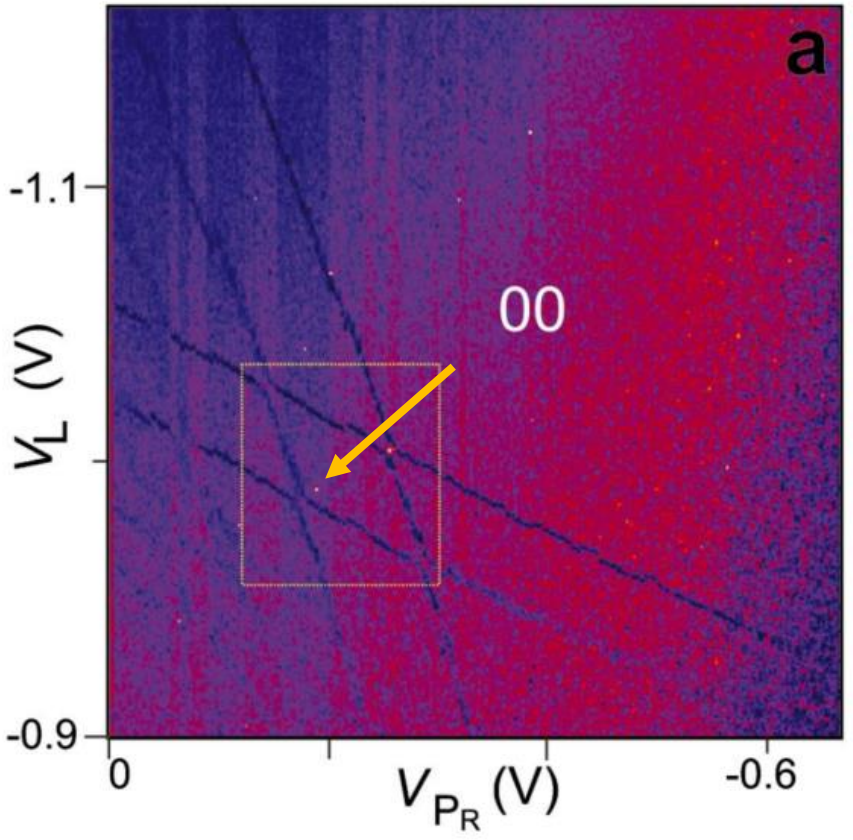




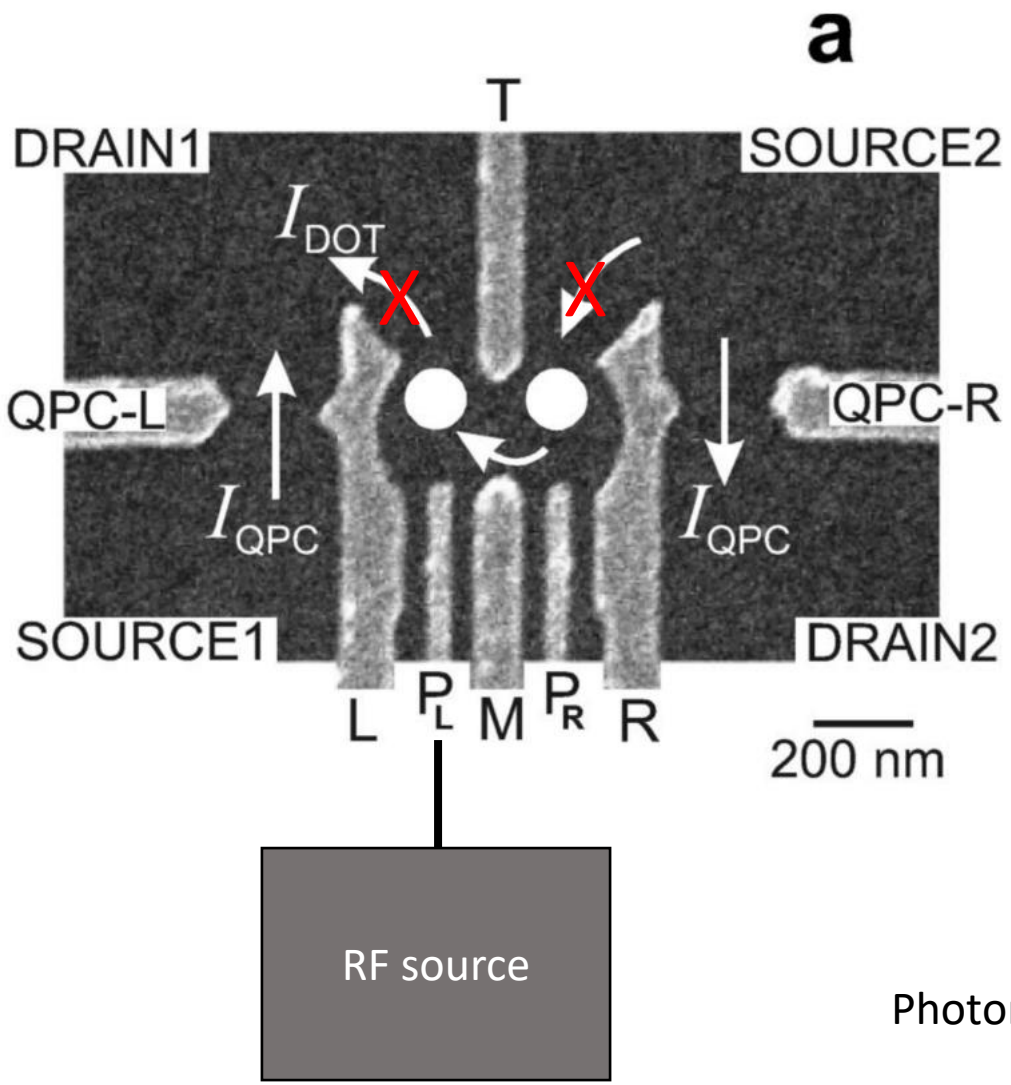
lines get more faint for less e

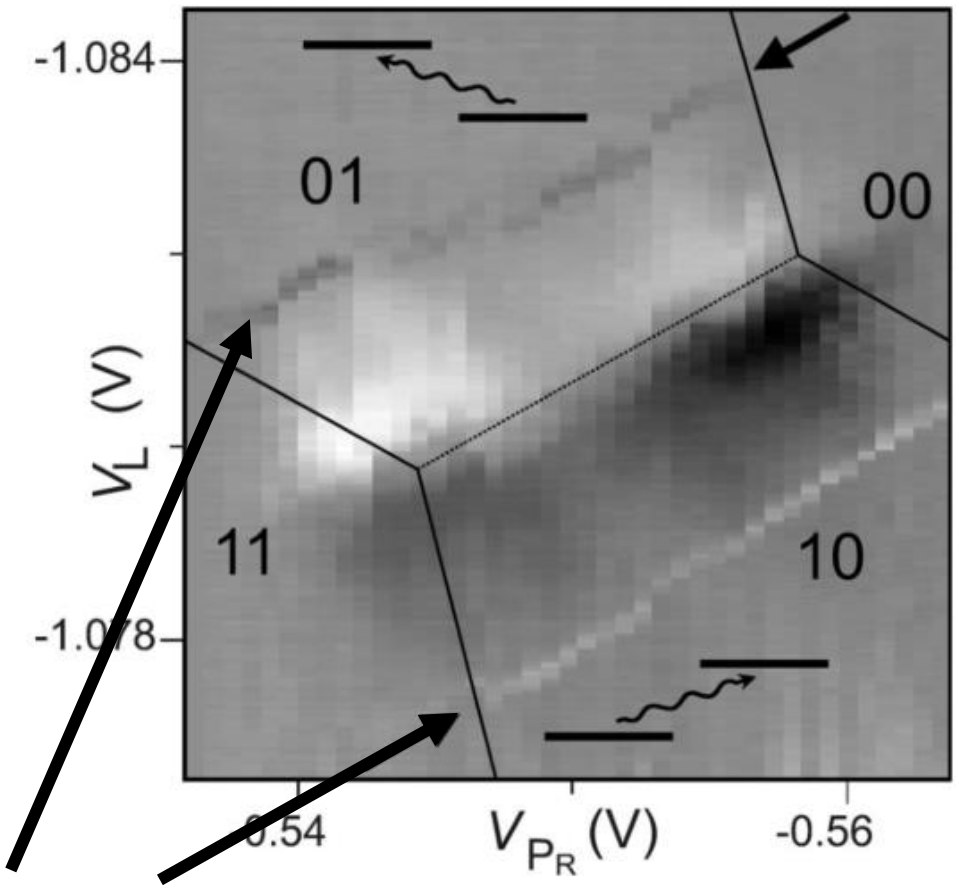
Measure absolute Charge in QD

- Empty QD, then count



Only with Charge Sensing: Inter-dot transitions





Photon-assisted transistion

Detecting single electrons

- So far: we measured averages of many transitions
- Now: measuring a single electron tunnelling event

Nature **423**, 422–425(2003)

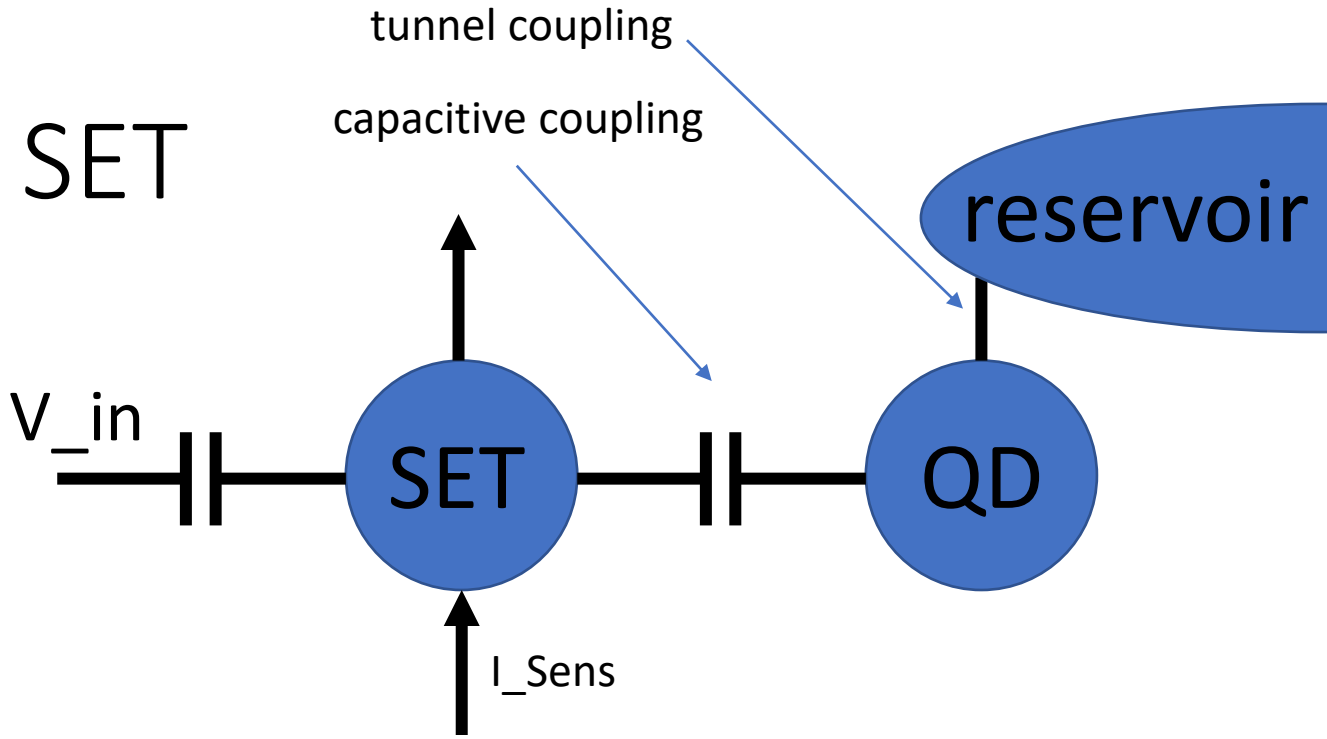
Real-time detection of electron tunnelling in a quantum dot

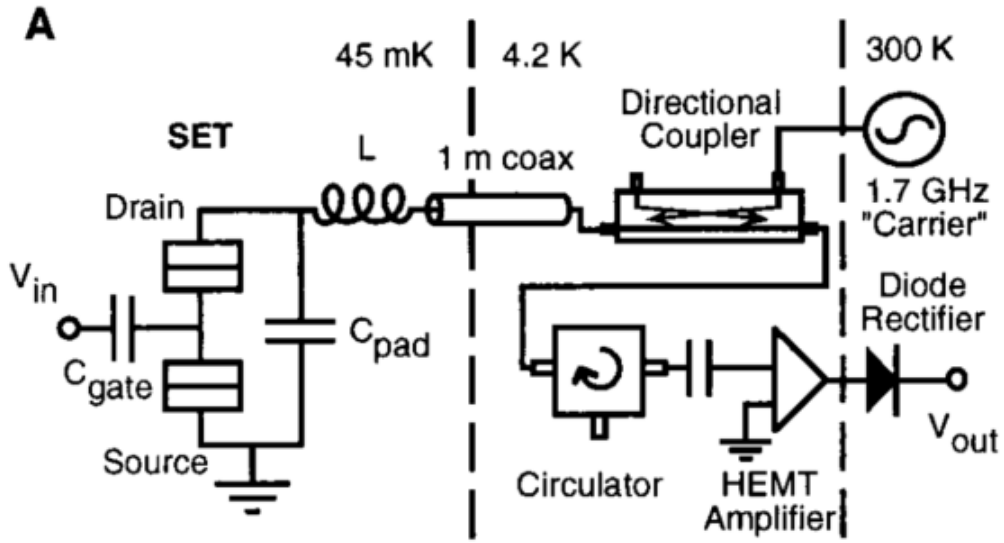
Wei Lu*†, Zhongqing Ji*, Loren Pfeiffer‡, K. W. West‡ & A. J. Rimberg*§

Not Dutch

Charge Sensing with a SET

- basic idea similar to QPC: tune SET in high dI/dV regime
- here: more complex RF read-out at 1GHz
- Amplitude of reflected RF signal is sensitive to dR/dV of SET



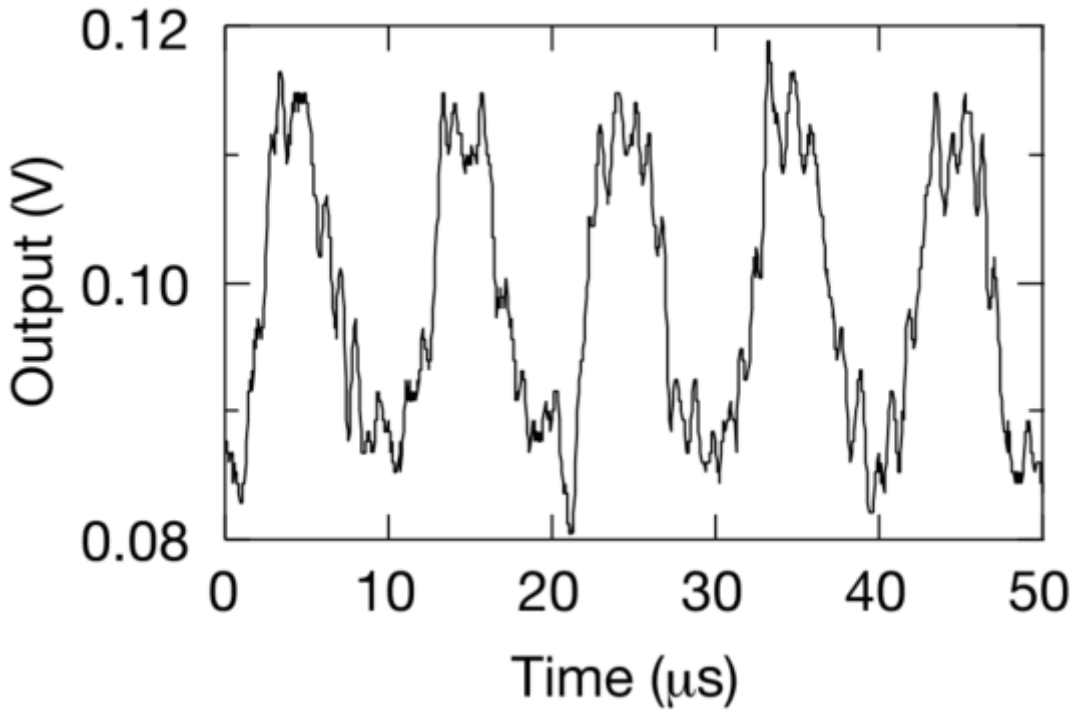


R. J. Schoelkopf et al., Science **280** 5367 (1998)

Testing SET Charge Sensing

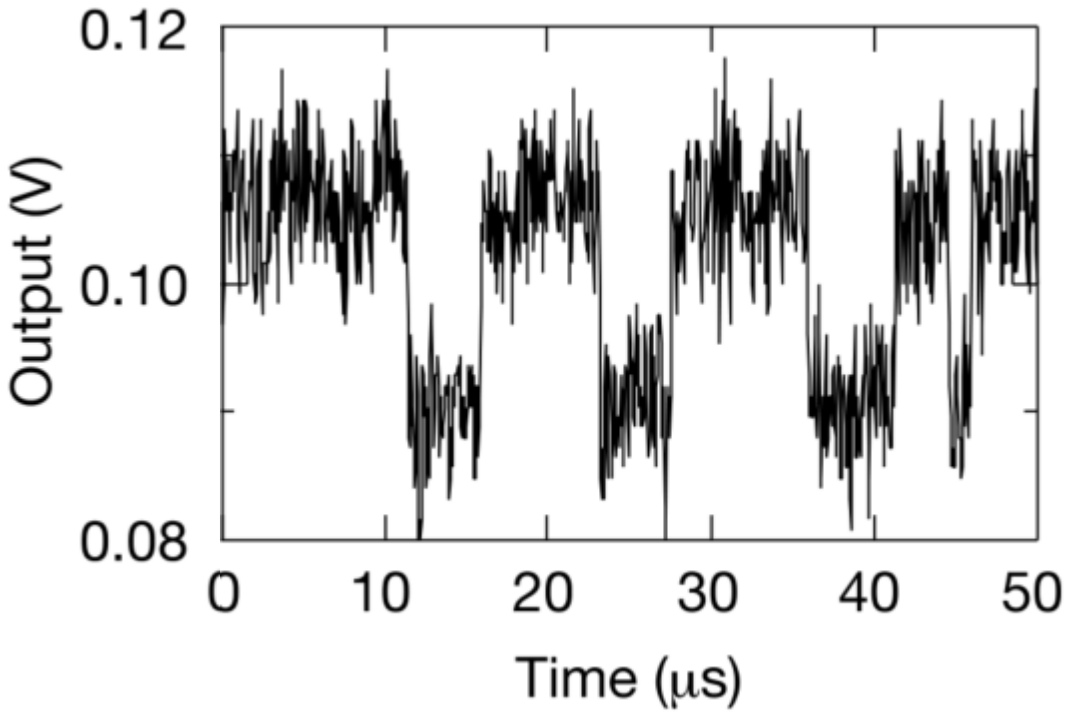
- deplete QD
- modulate Q_SET with 100kHz signal
- ΔQ_SET ~ 0.1e

- -> RF readout works



SET Charge Sensing with QD

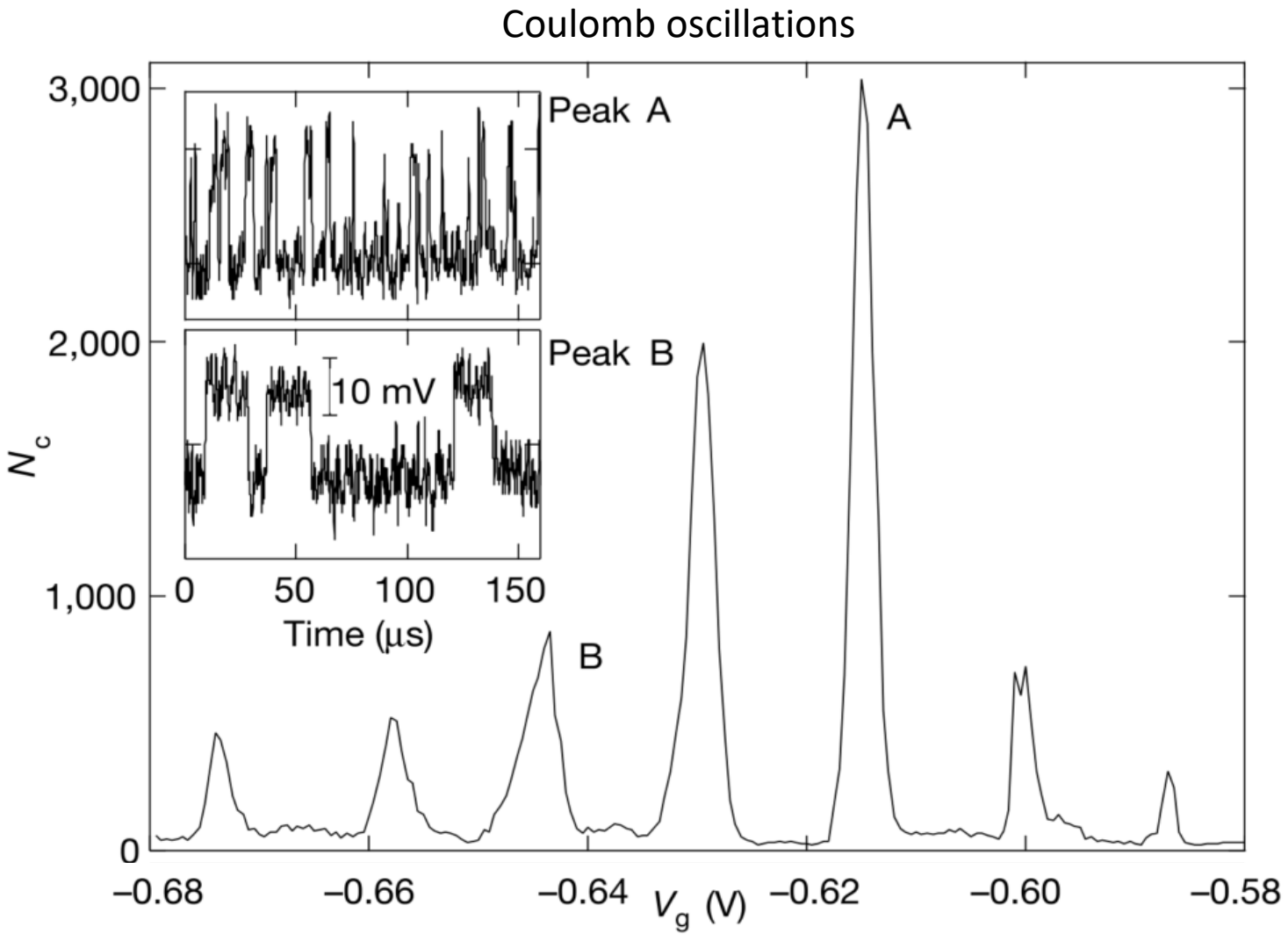
- now with QD close to transition from N to N+1 electrons
- random telegraph noise (RTS) is induced by QD occupancy:
  - lower level: N electrons
  - upper level: N+1 electrons
- -> we can see single tunnelling events



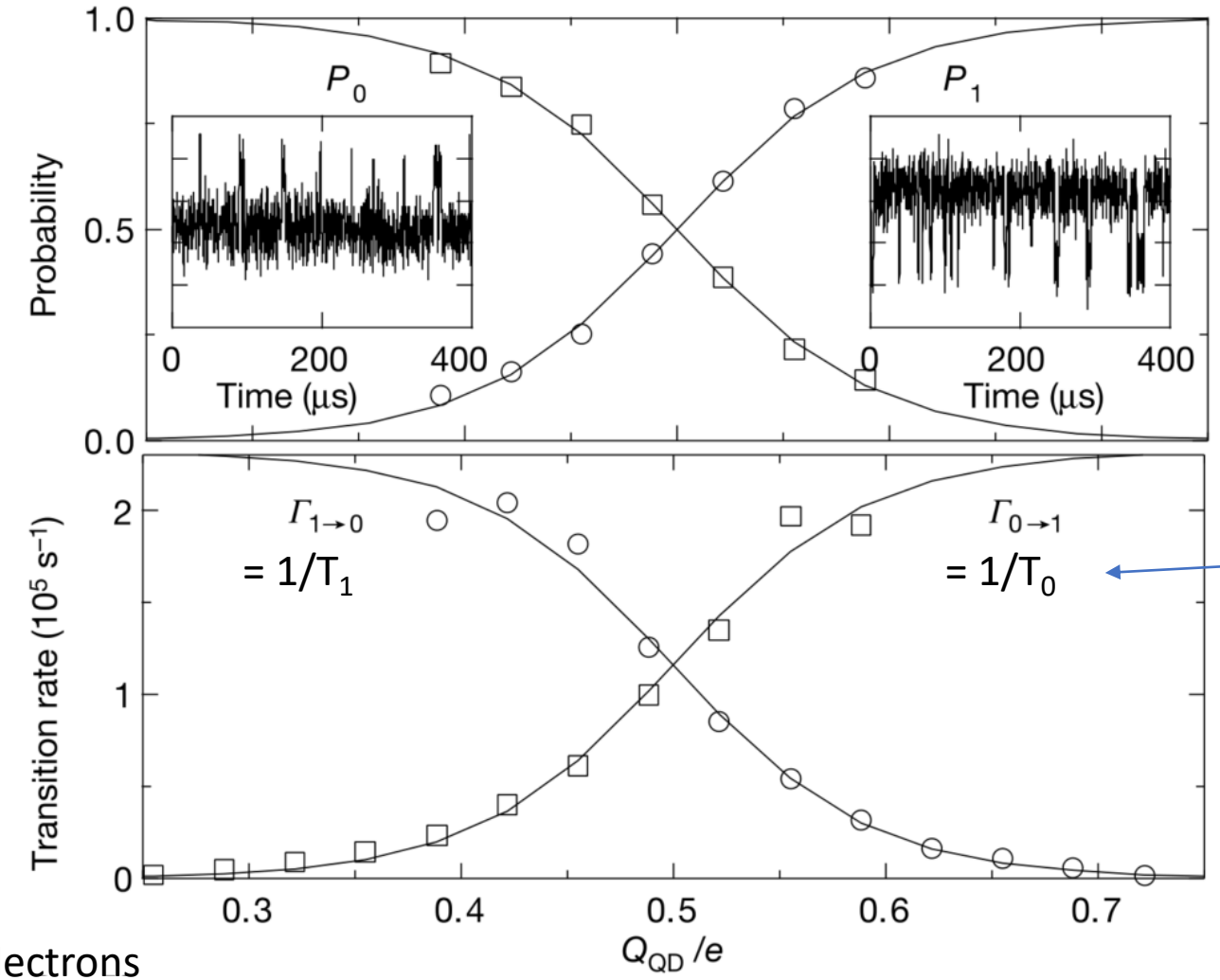
Analysis of RTS

- NC = # transitions
- If QD level is aligned with reservoir -> high NC

- -> Coulomb oscillations are visible



Probing Charge Degeneracy Point



Average time for staying in state N

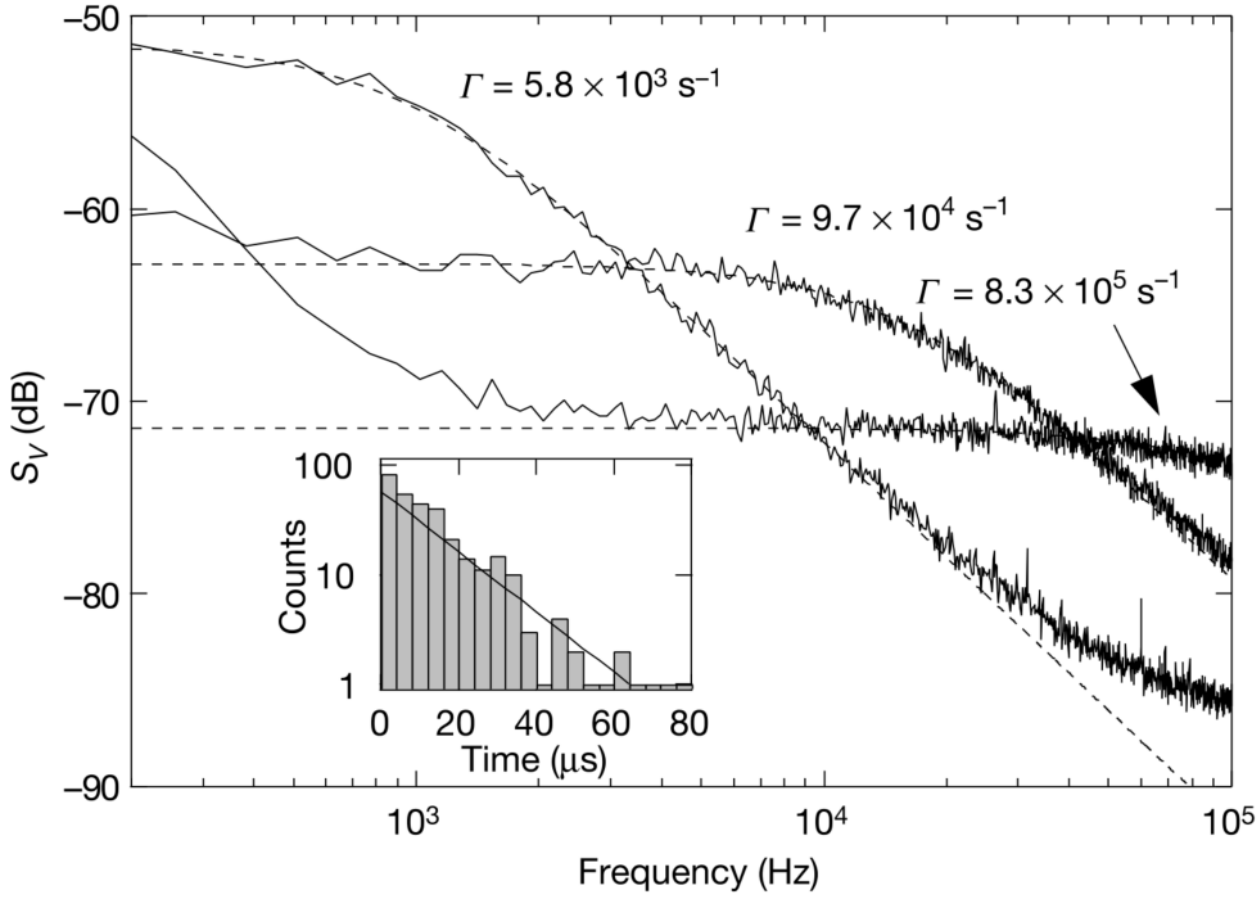
N electrons

N+1 electrons

Total Tunnelling Rate

- Tunnel coupling $\Gamma = \Gamma_0 + \Gamma_1$
- Lorentzian power spectrum

$$S_V \propto \frac{1}{\Gamma^2 + (2\pi f)^2}$$



Summary

- charge sensor reads charge transitions in adjacent QD
- sensitiv, fast, strong signal for low current
- QDs which are not connected to reservoirs can be measured
- a single electron tunnelling process can be resolved
  -> towards single shot spin read out