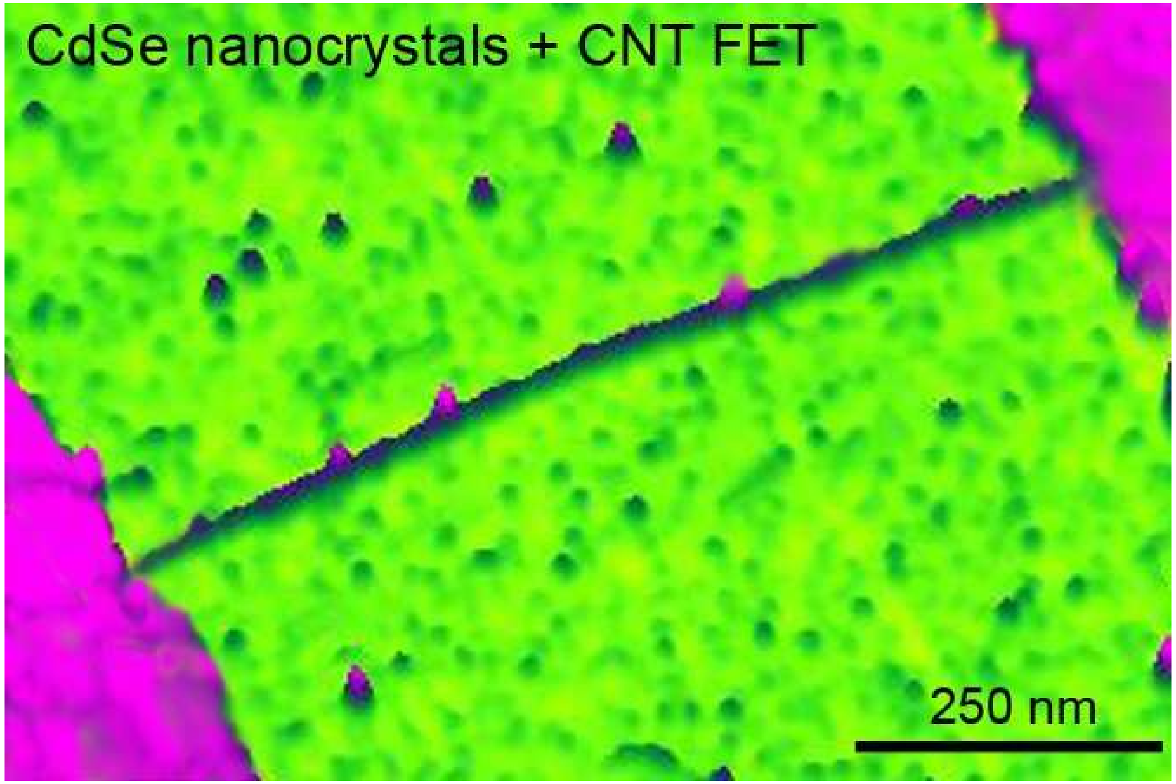
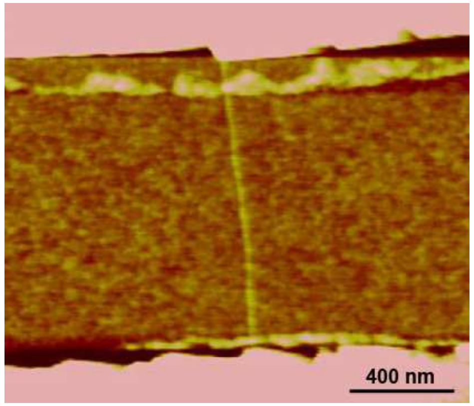
Electron counting spectroscopy of CdSe nanocrystals using Nanotube Transistor

***M. Zdrojek*, M. J. Esplandiu, A. Barreiro and A. Bachtold**
CIN2, (CSIC-ICN) Barcelona, Spain

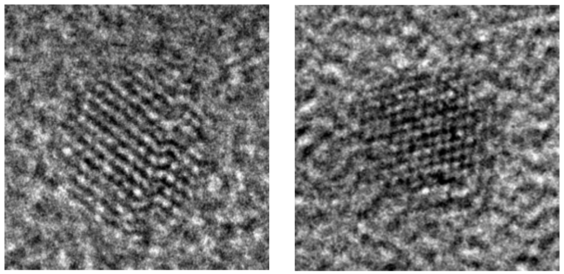


Experimental evidence of confinment energy fluctuation in chaotic CdSe quantum dots

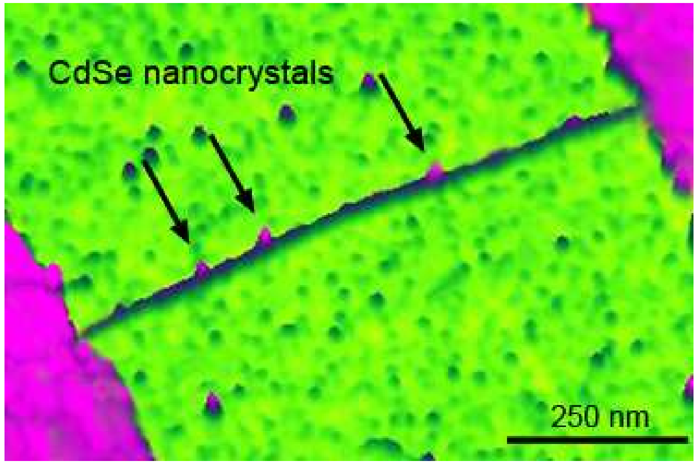
The device



SWNT+ Cr/Au electrods

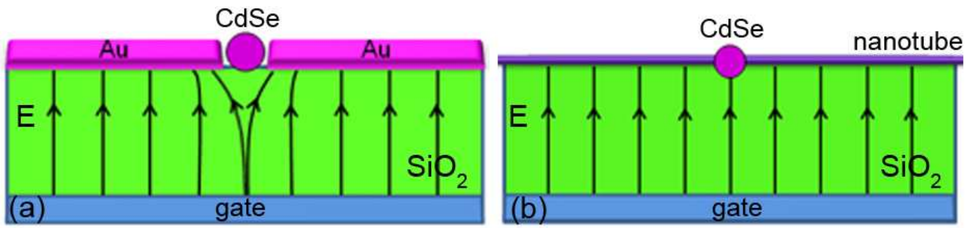


CdSe particles

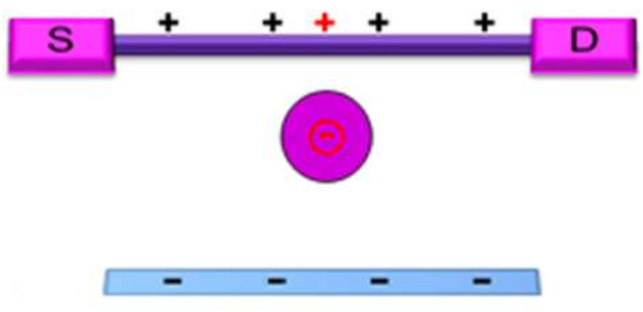


Only one electrode - a carbon nanotube

Only one CdSe dot per device is active



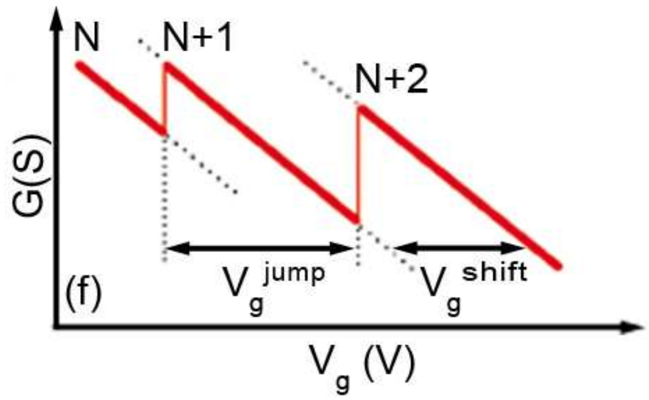
Electron detection scheme



Electron counting spectroscopy

The nanotube has two roles:

- **electron reservoir**
- **it detects the transfer of single electrons onto the CdSe particle**

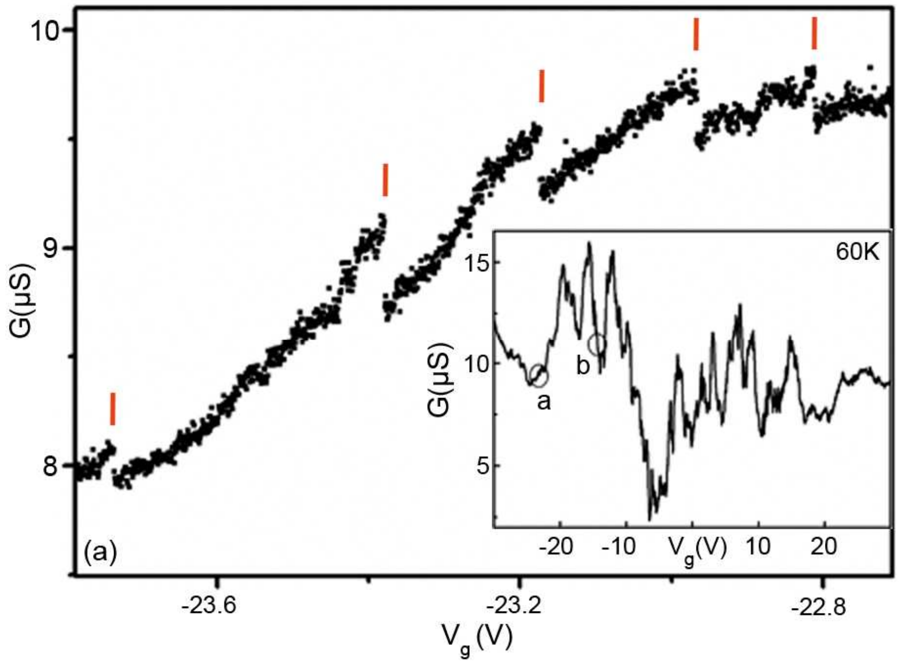


One electron transfer corresponds to one shift of the tube conductance

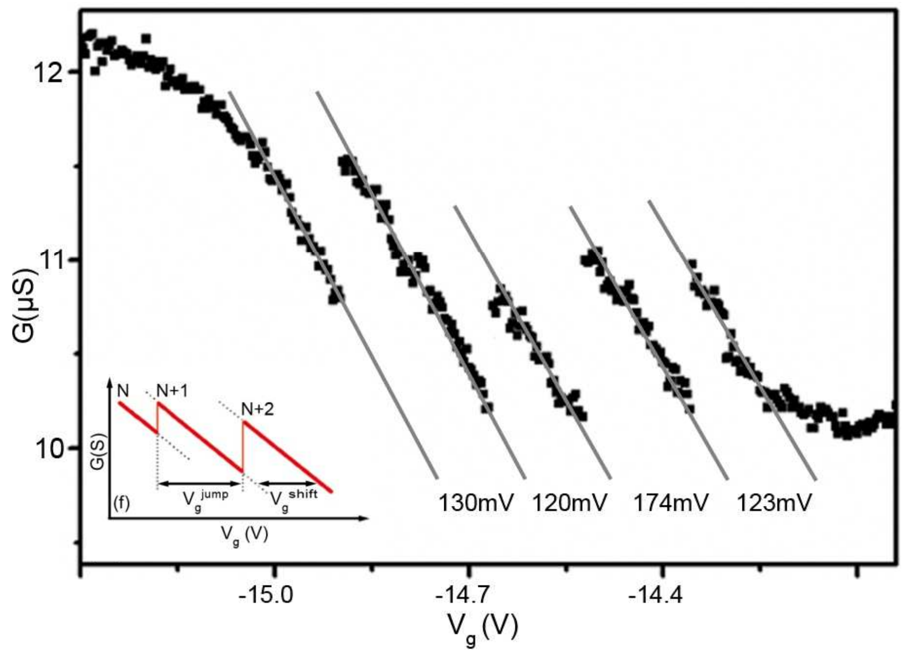
$$\Rightarrow \quad V_g^{shift} \sim E_{ad}$$

Energy to add one electron to the system

The experiment – electron transfers



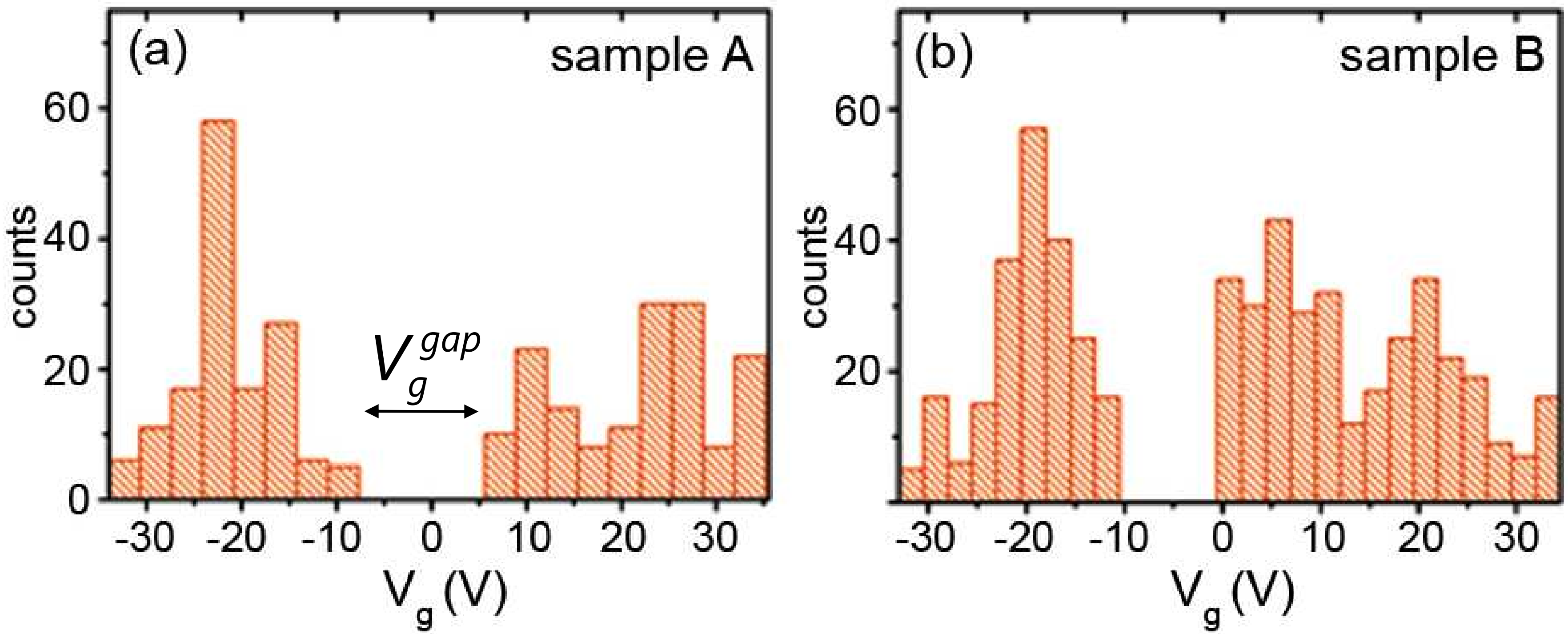
Parallel shifts in the tube conductance



We can put ~ 200 electrons (!) onto the 5nm CdSe dot

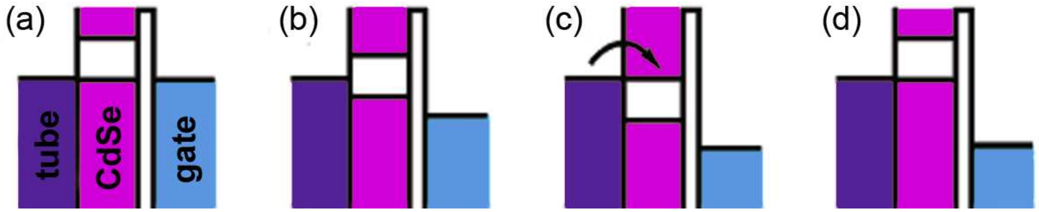
Shifts not equal ⇒ fluctuation of the addition energy

Electron counts vs. the gate voltage



The gate voltage gap ⇒ energy gap of the semiconducting CdSe dot

Energy levels of the dot vs. the gate voltage



$\Rightarrow$ $V_g^{shift} = \alpha E_{ad}$

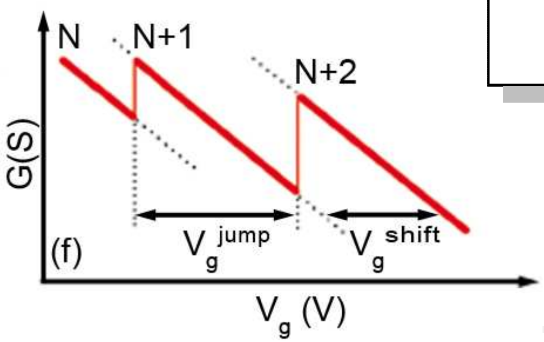
Energy to add one electron to the system

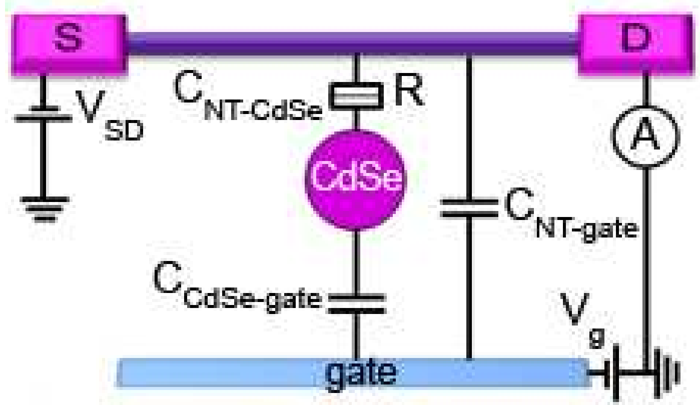
Addition energy related with the gate voltage

$$eV_g^{shift} = \frac{C_{CdSe-NT}}{C_{NT-gate} + C_{CdSe-gate}} E_{ad}$$

$$e\Delta V_g^{jump} = \frac{C_{CdSe-NT}}{C_{CdSe-gate}} E_{ad}$$

$$\Delta V_g^{gap} = \frac{C_{CdSe-NT}}{C_{CdSe-gate}} E_g$$



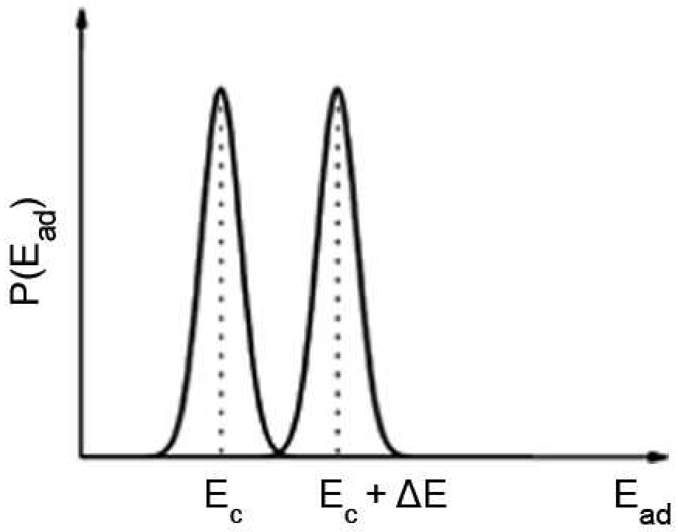


$\alpha \sim 0.22$

Energy level distribution - models

Constant Interaction model

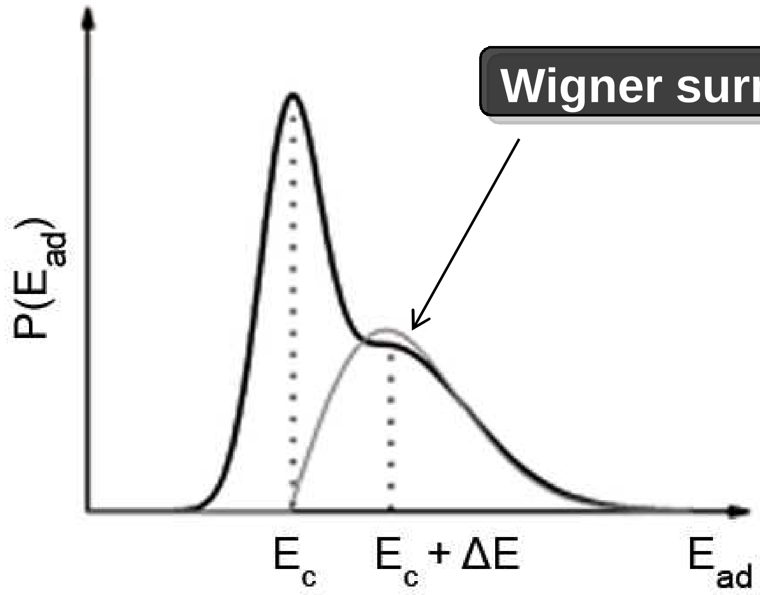
$$E_{ad}^{i} = \begin{cases} E_C & i = odd \\ E_C + \Delta E & i = even \end{cases}$$



Quantum confinement ⇒ RMT

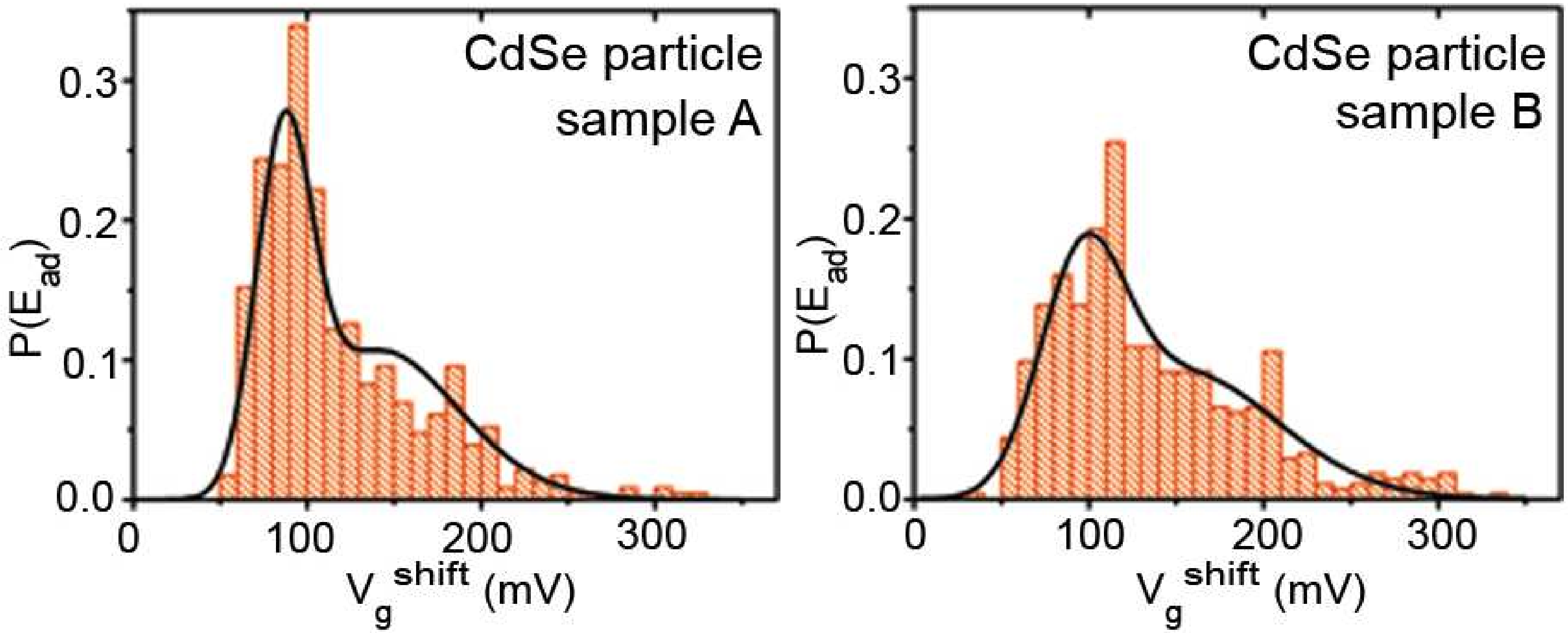
Chaotic behaviour of the level spacing

Wigner surmise



$$P(E_{ad}) = \frac{1}{2}[\delta(s) + \frac{\pi}{2}(s\exp(-\frac{\pi}{4}s^2))] \qquad s = \frac{E_{ad} - E_c}{< \Delta E >}$$

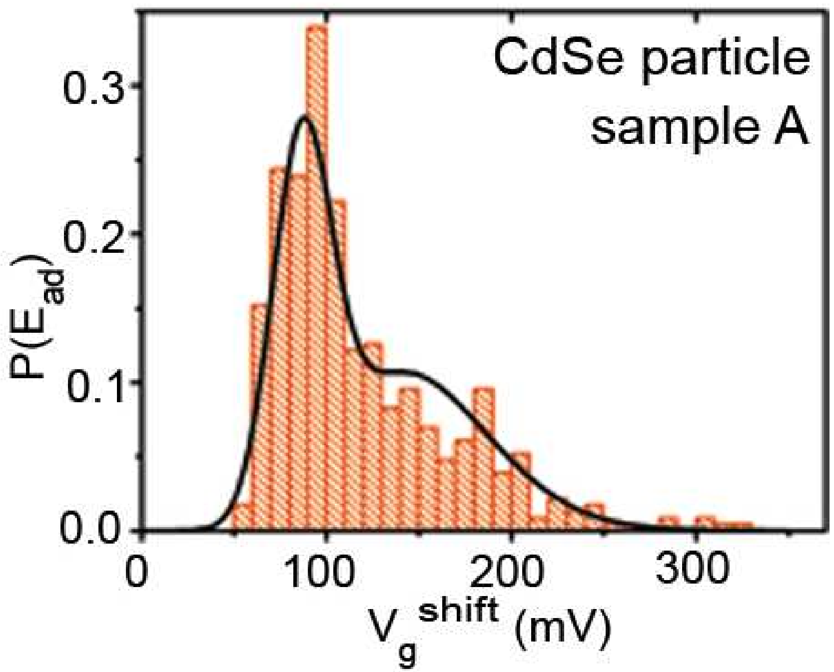
Distribution of the energy levels in the dot

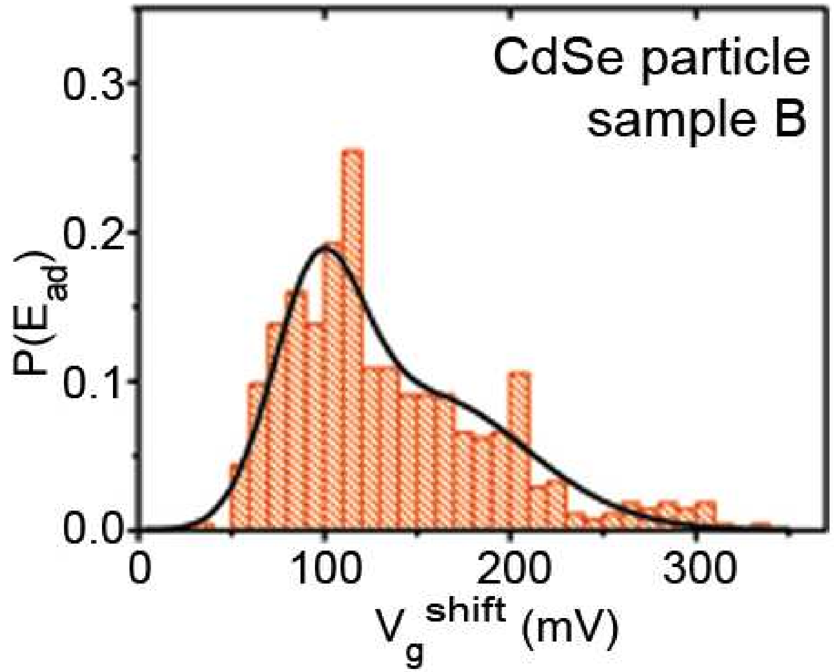


Bimodal distribution of addition energy ⇒ chaotic behaviour

Experimental evidence of confinement energy fluctuations

Distribution of the energy levels in the dot





$E_c \approx 23{,}2\ mV$

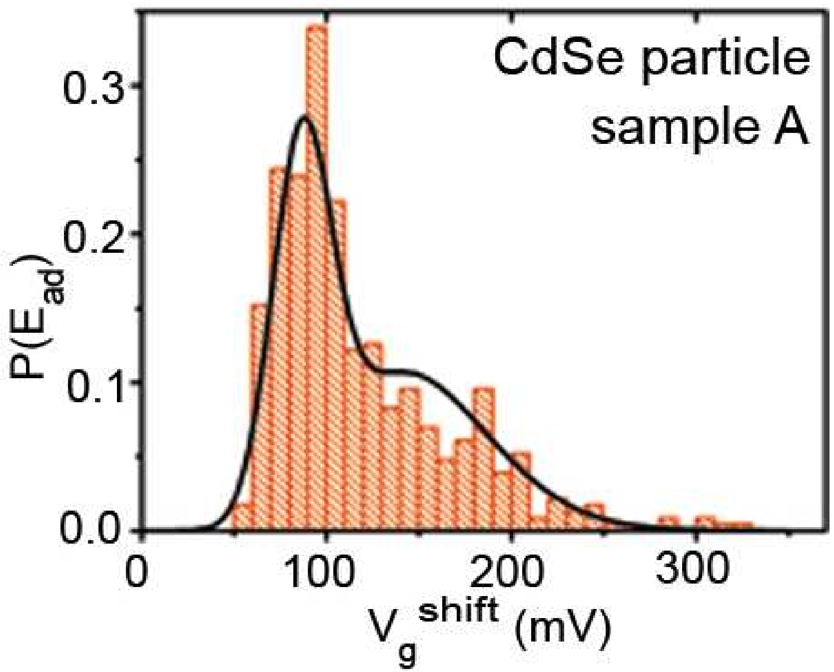
$\Delta E \approx 18{,}3\ mV$

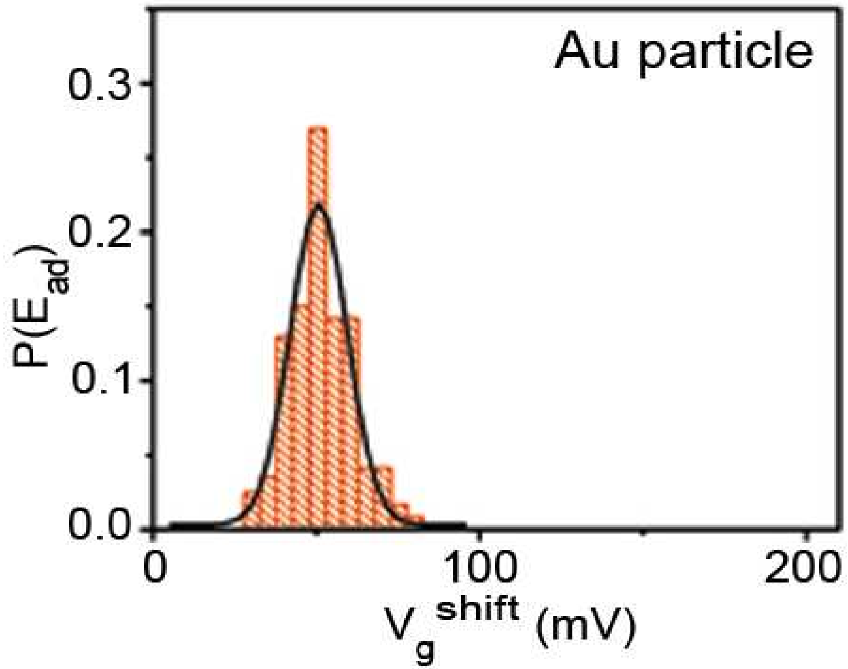
$E_c \approx 19{,}2\ mV$

$\Delta E \approx 15\ mV$

Device parameter α included

Distribution of the energy levels in the dot





In Au particle - only charging energy!

Summary

Electron counting spectroscopy for quantum dots that allows to:

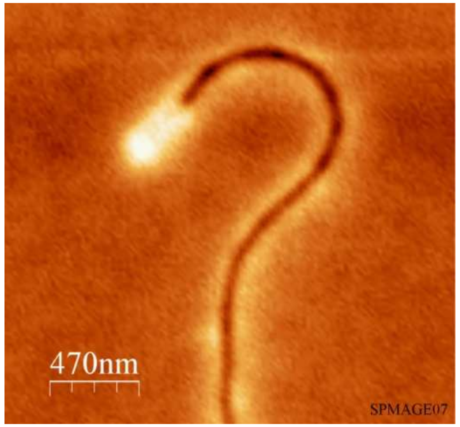
- put large number of electron on the dot
- observe the energy gap of individual semiconducting quantum dots
- study the statistical aspects of the spectral properties

People

Quantum NanoElectronics Group

Adrian Bachtold
Maria Jose Esplandiu
Benjamin Lassagne
Joel Moser
Mariusz Zdrojek
Amelia Barreiro
Daniel Garcia
Marianna Śledzińska

Thank you for your attention



literature

Jalaberd et al., PRL 1992
Sivan et al., PRL 1996
McEuen et al., Nature 1997
Blanter et al., PRL 1997
Patel et al., PRL 1998
Vallejos et al., PRL 1998
Huibers et al., PRL 1998
Berkovits, PRL 1998
Simmel et al.,. PRL 1999
Banin et al., Nature 1999
Luscher et al., PRL 2001
Boehm et al., PRB 2005
Jdira et al., PRB 2006
Geim et al., Science 2008

Probing energy spectrum of quantum dots