

Low temperature operation

Single electron charging energy

$$E_C = e^2/C, (C=8\epsilon_r\epsilon_0 R, \text{ disk})$$

$$R = 10 \text{ nm} \quad E_C = 30 \text{ meV}$$

$$R = 100 \text{ nm} \quad E_C = 3 \text{ meV}$$

Thermal energy

$$T = 300 \text{ K} \quad k_B T \sim 26 \text{ meV}$$

$$T = 4.2 \text{ K} \quad k_B T \sim 0.35 \text{ meV}$$

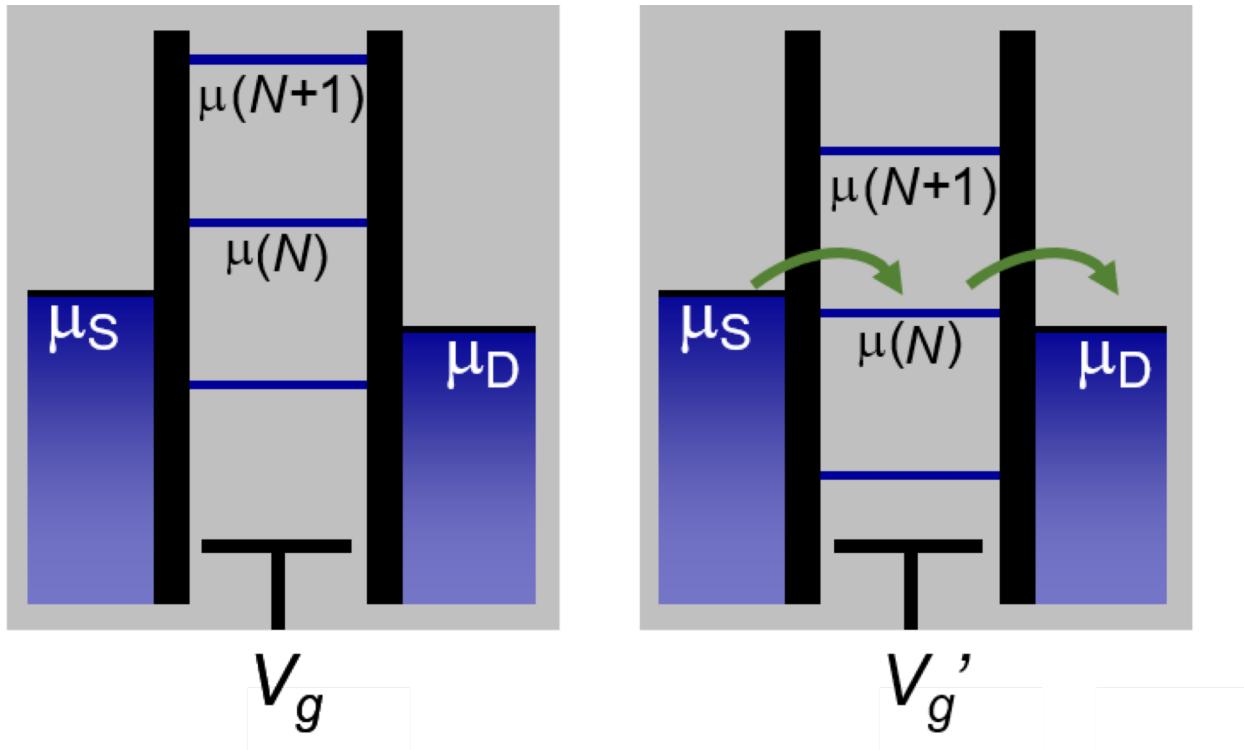
$$T = 30 \text{ mK} \quad k_B T \sim 2.6 \text{ ueV}$$

Operation is at low temperatures



Dilution refrigerators reach temperatures below 10mK

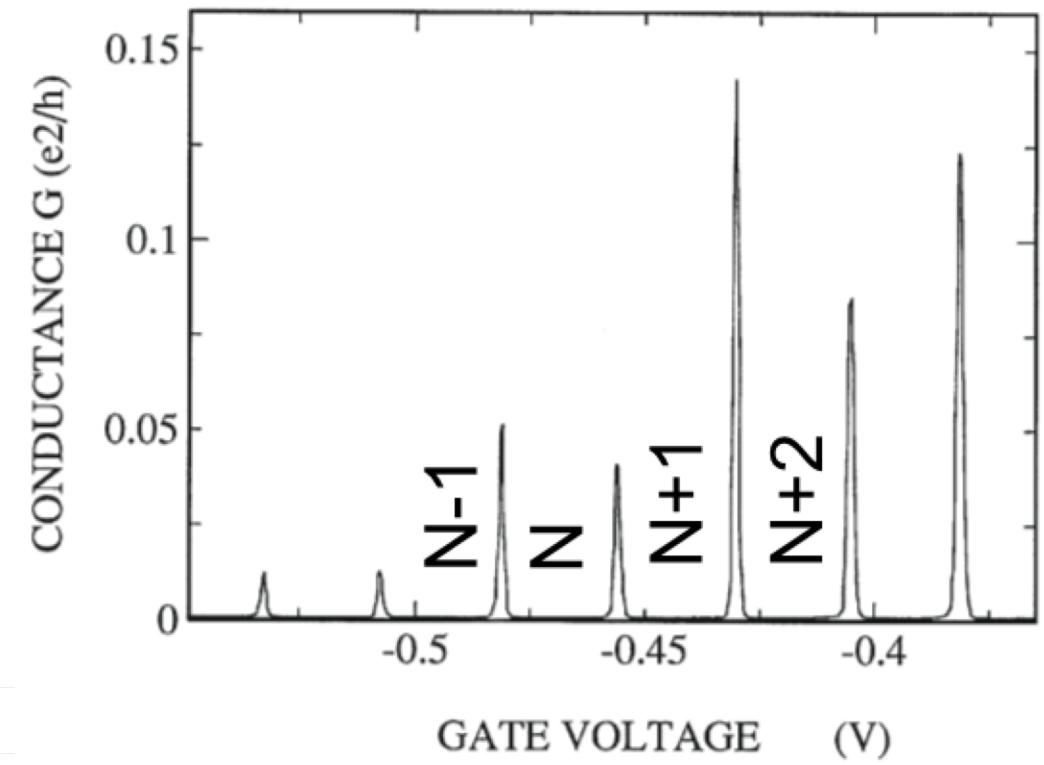
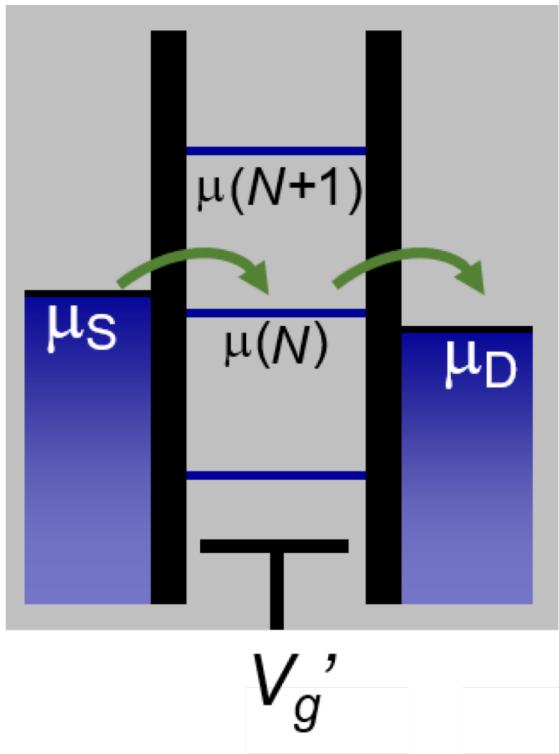
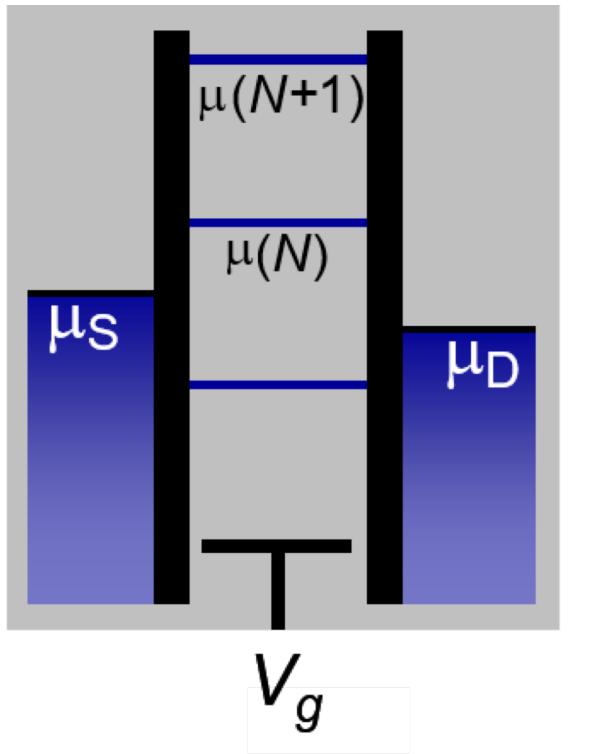
Quantum dots



- Energy an electron needs to have in order to enter the dot.

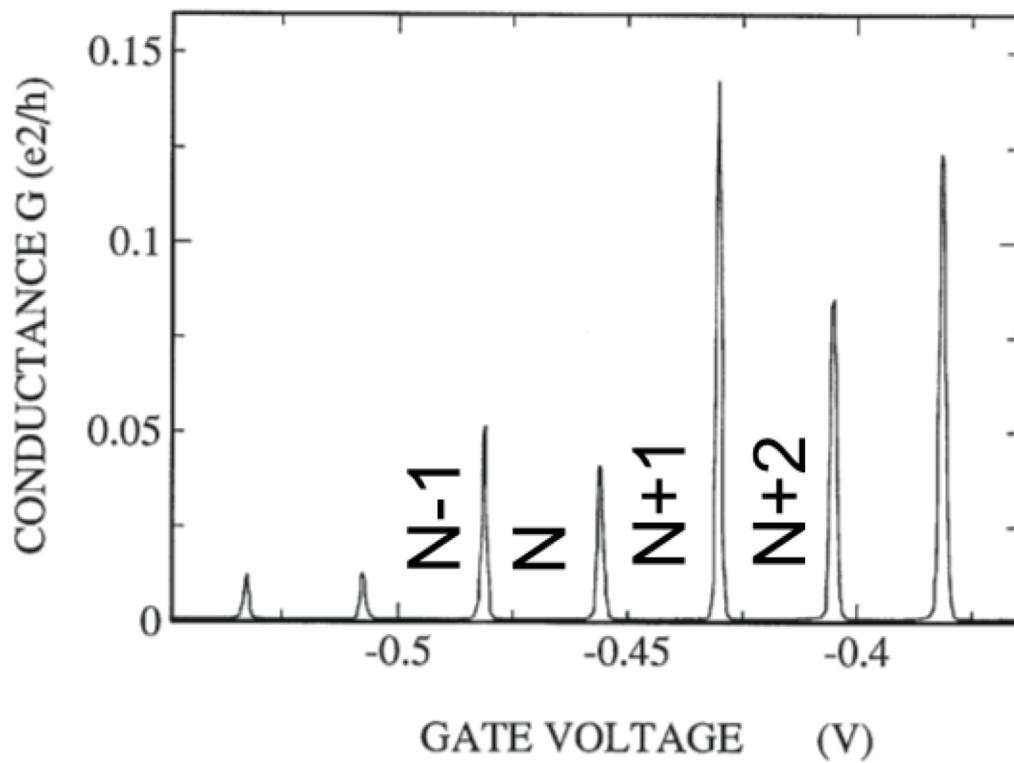
$$m(n) = \mu(N) - \mu(N - 1)$$

Quantum dots

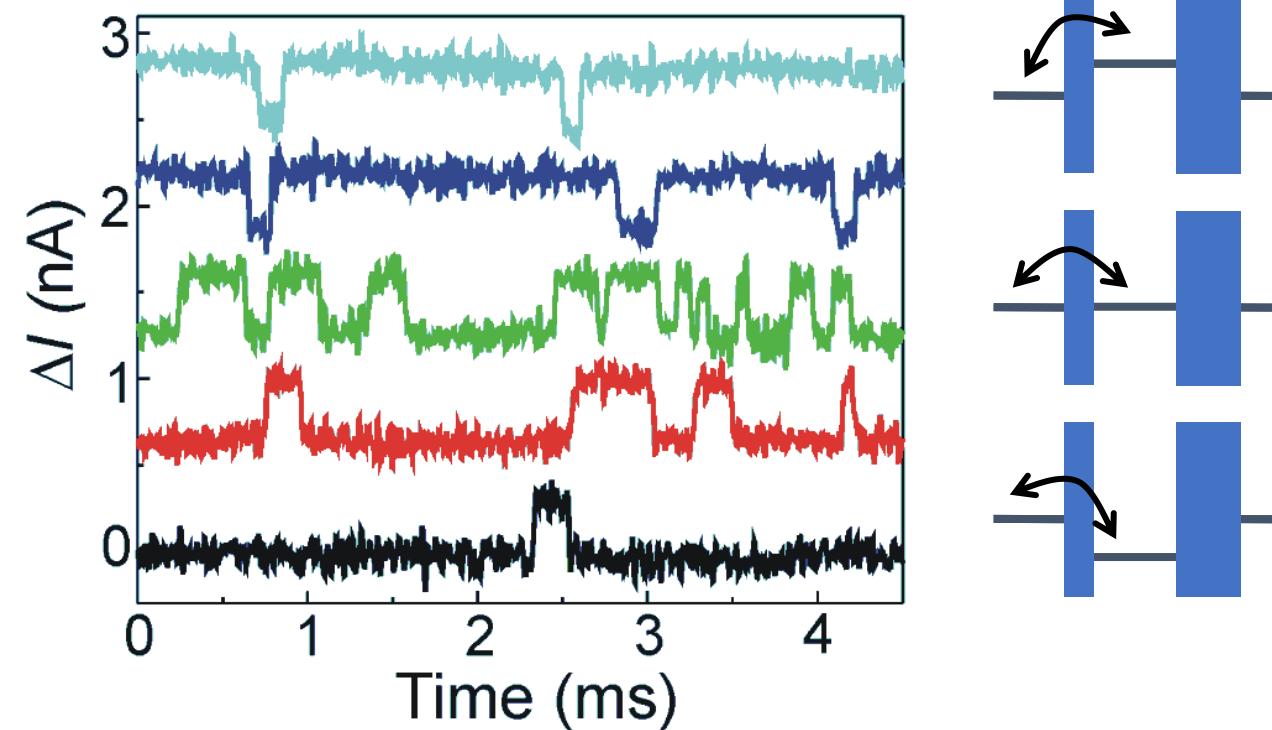


Charge sensing

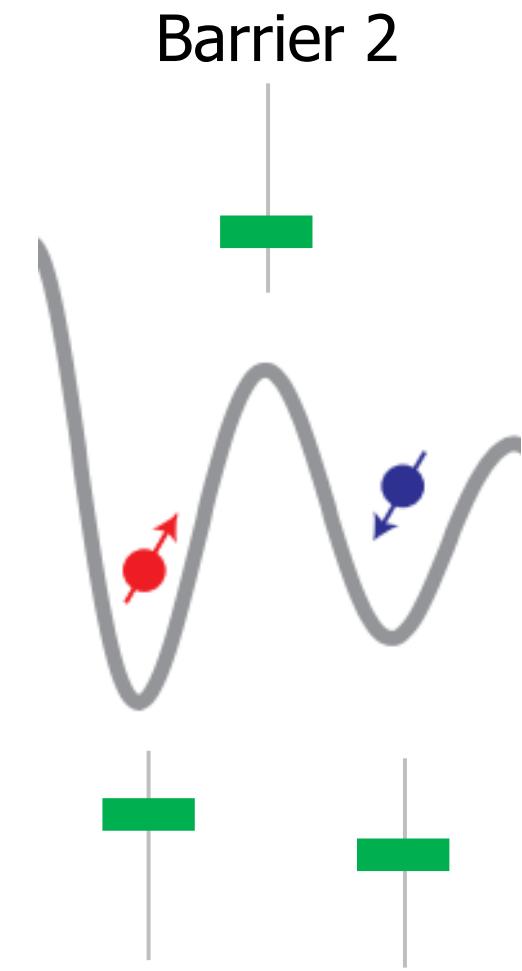
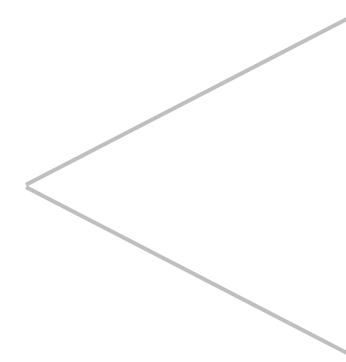
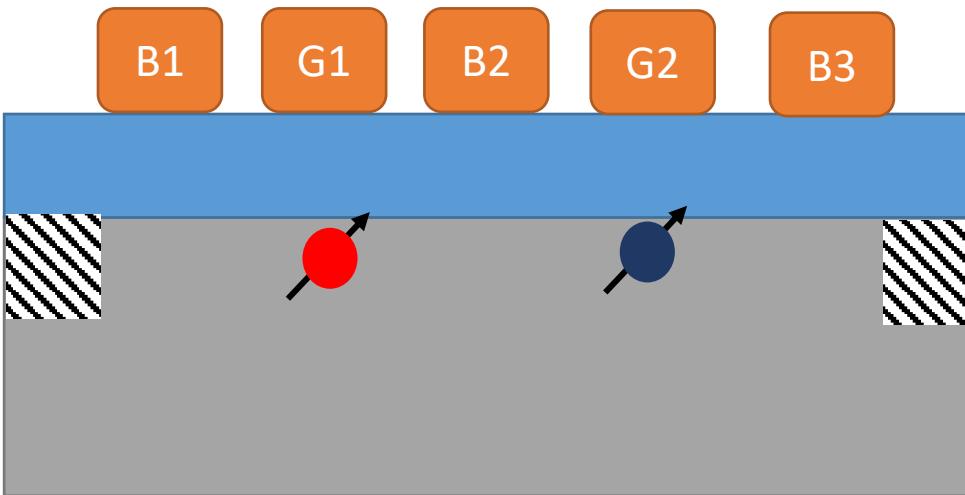
- A quantum dot can also be a very sensitive electrometer.



- See single electrons jump on/off in real time.

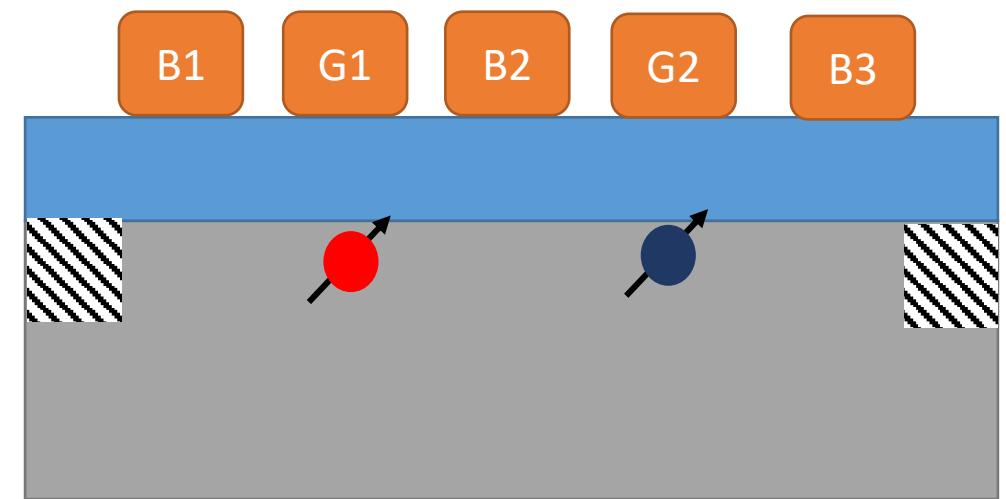
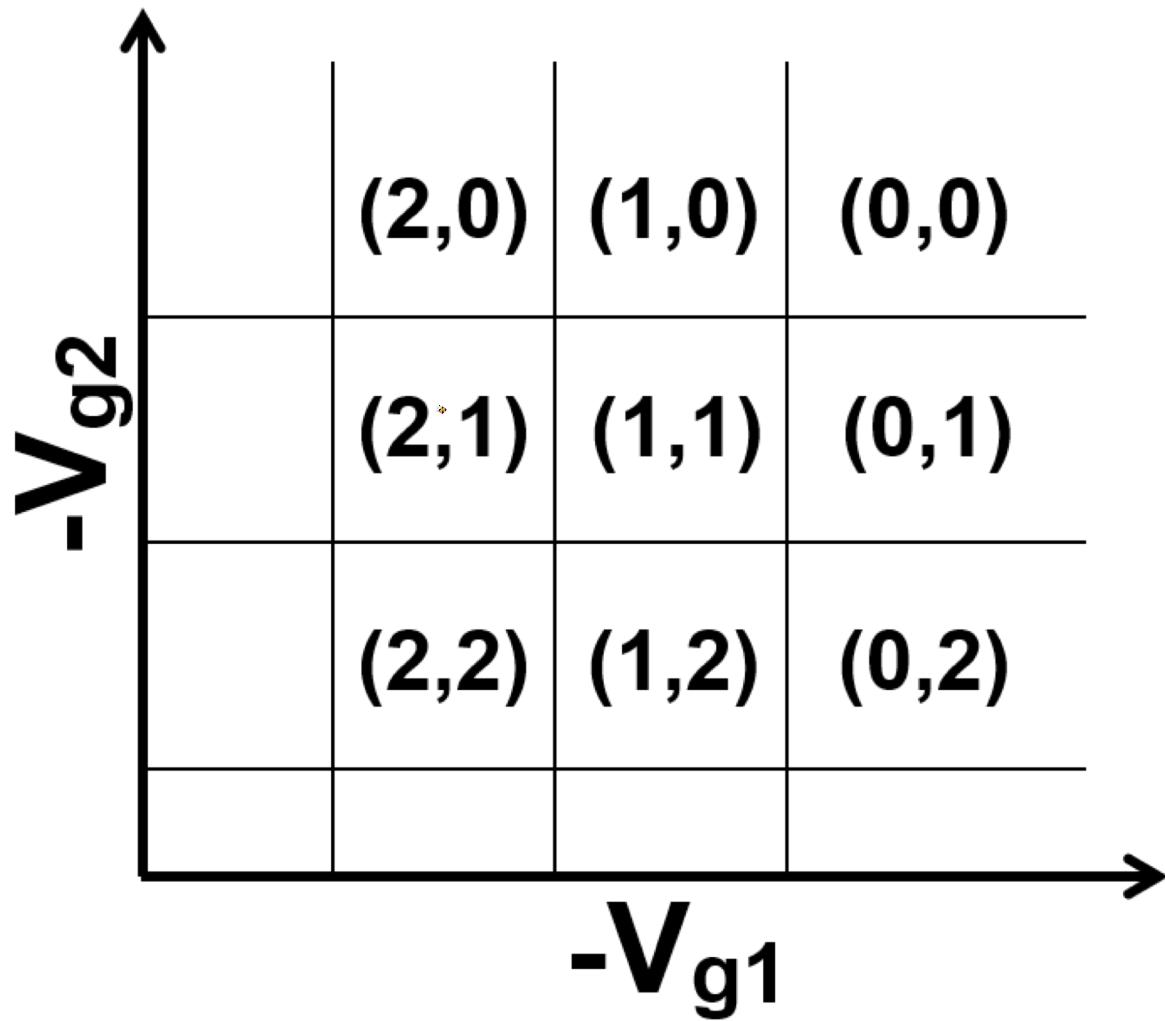


Quantum dot system

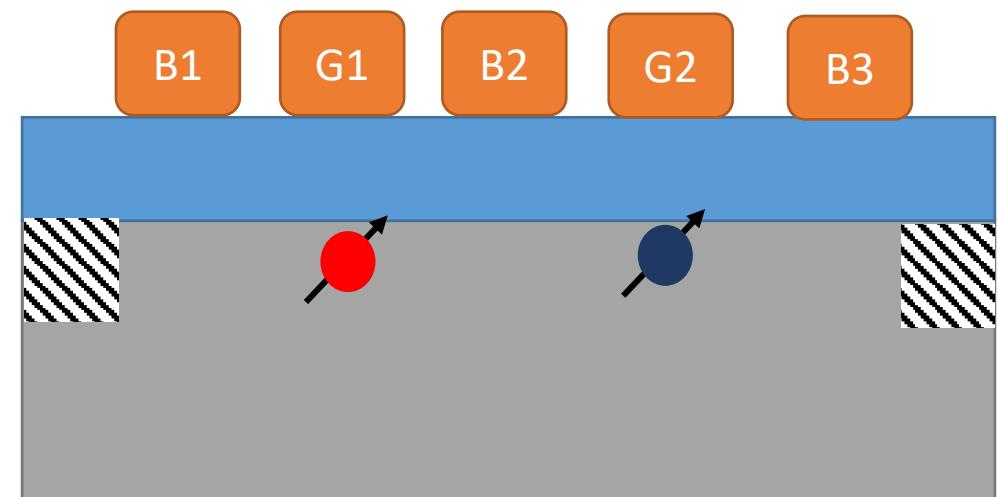
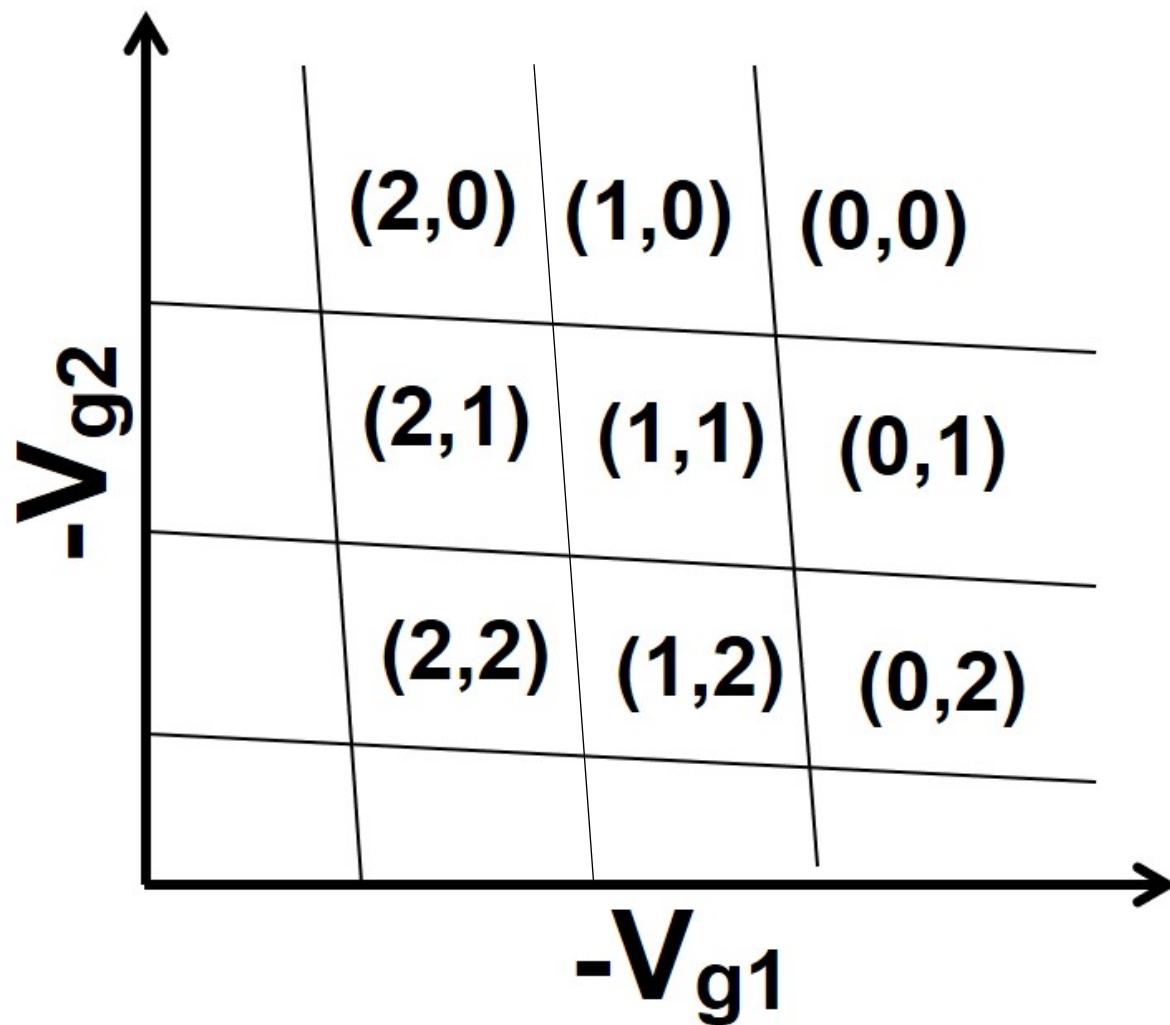


Barrier 2
Gate 1 Gate 2

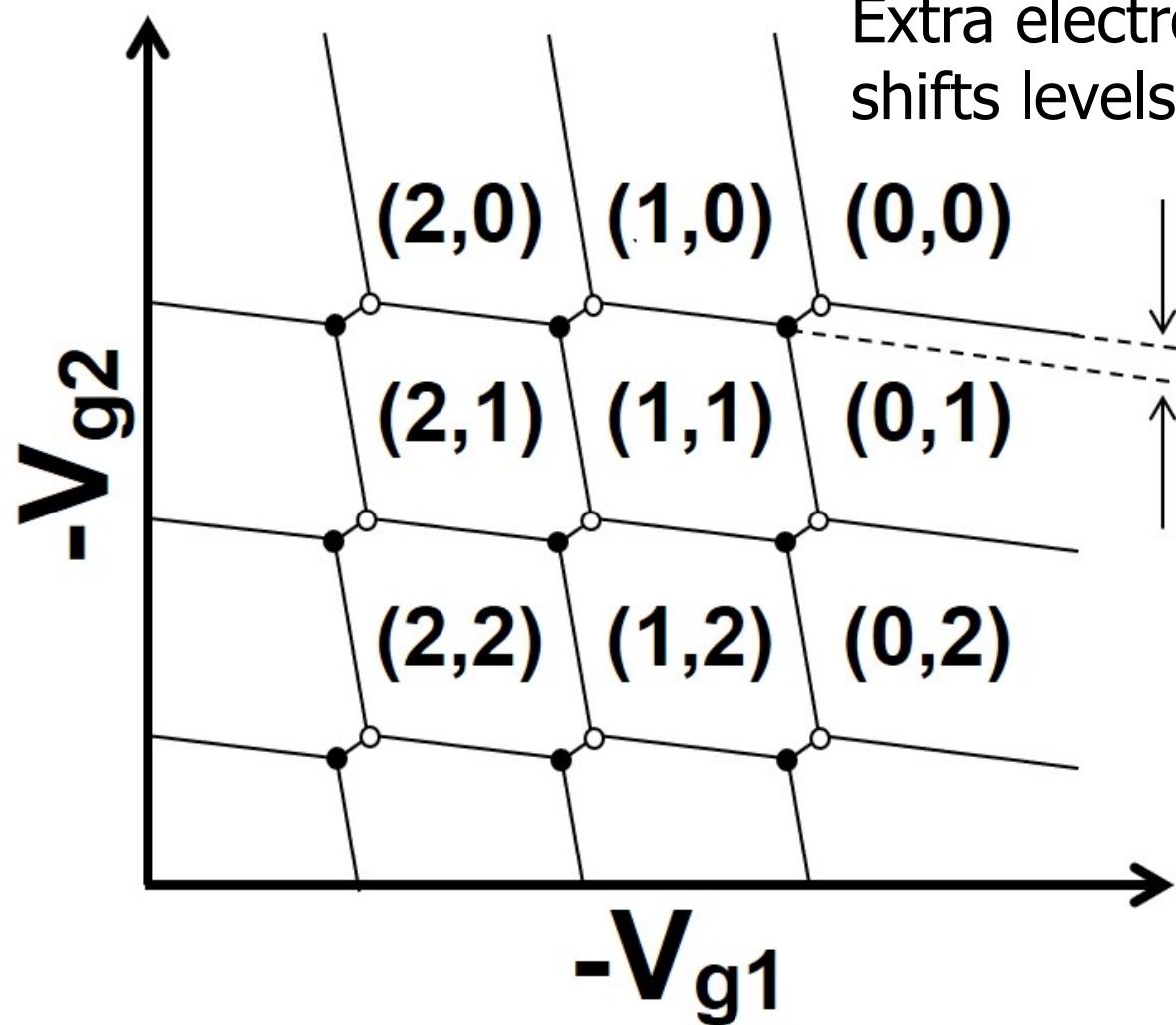
Two coupled quantum dots



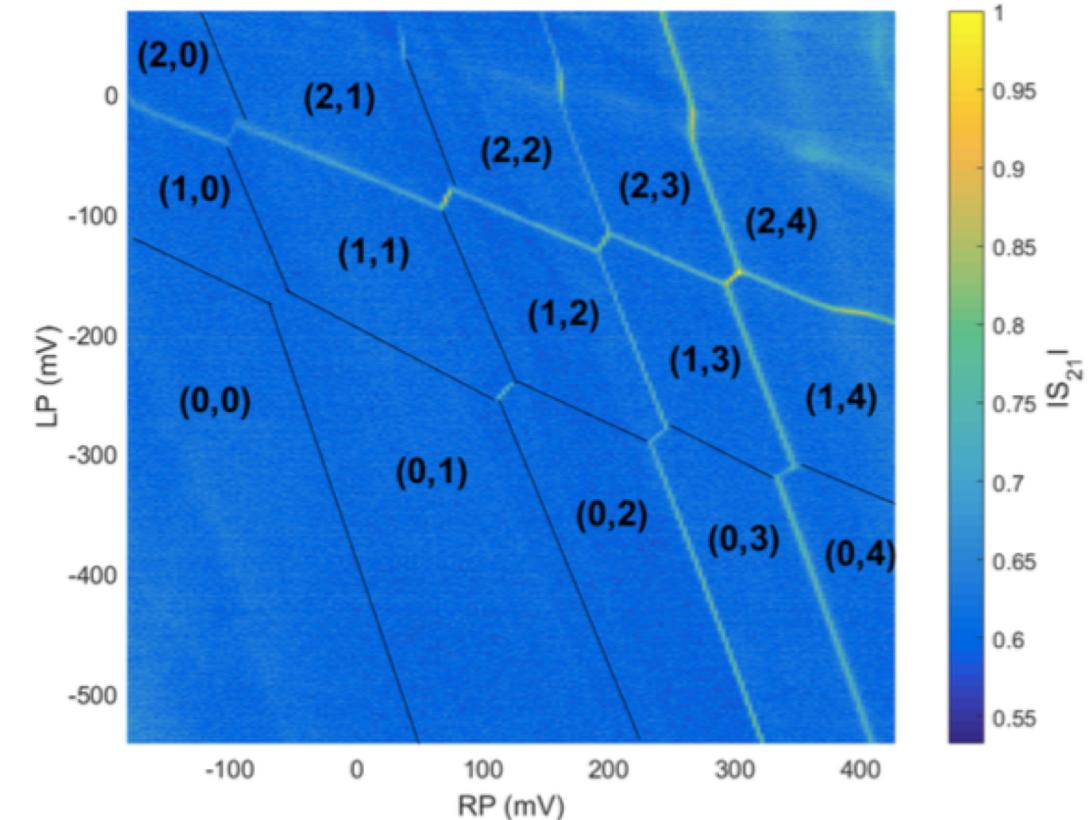
Two coupled quantum dots



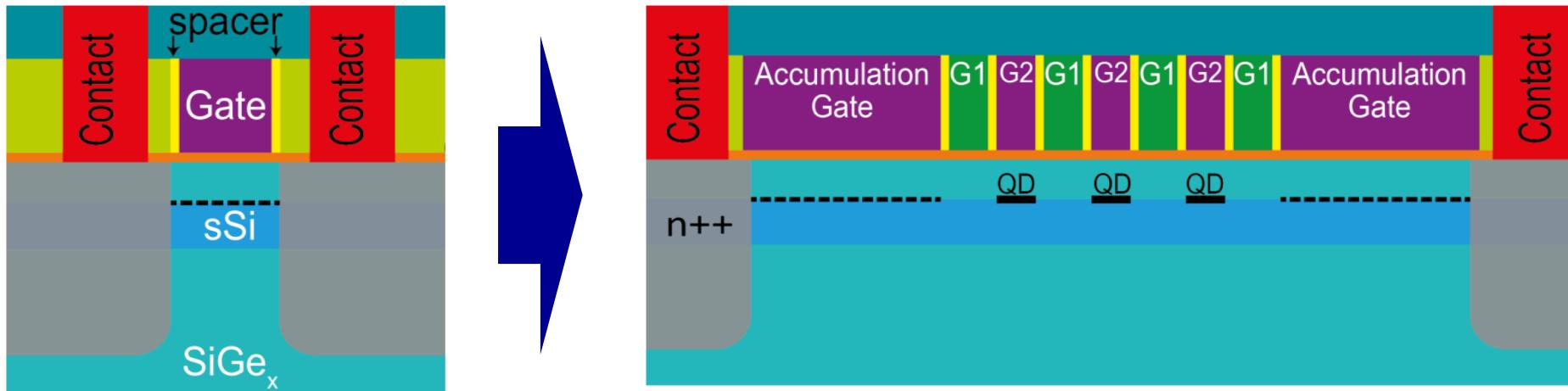
Two coupled quantum dots



Extra electron in one dot
shifts levels of other dot



From transistors to many quantum dots



Industrial involvement





A quantum integrated circuit

