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ARTICLES
https://doi.org/10.1038/s41565-020-00816-w

nature nanotechnology

Coherent control of individual electron spins in a two-dimensional quantum dot array

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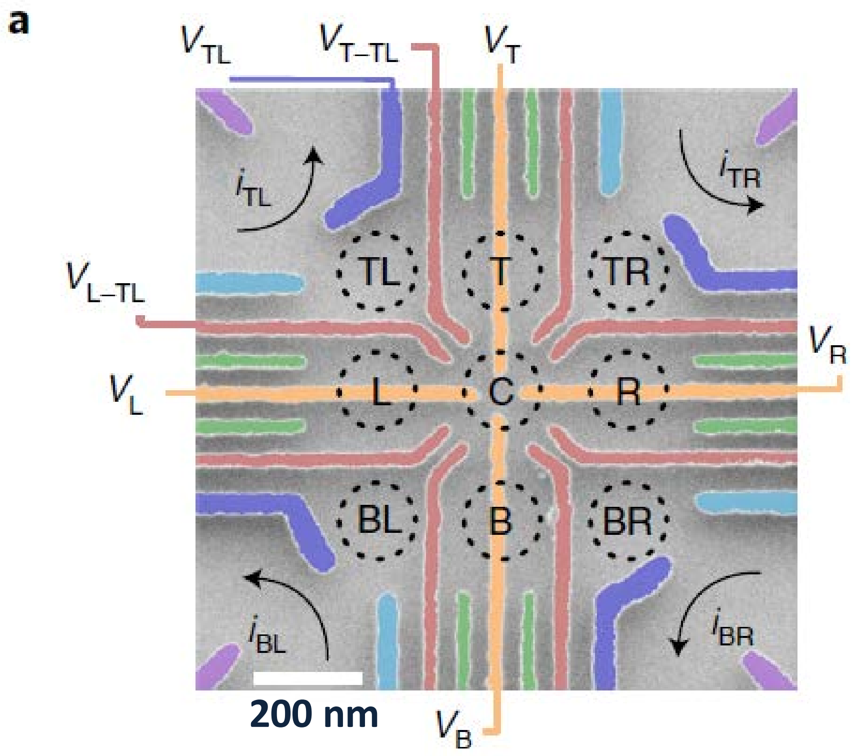
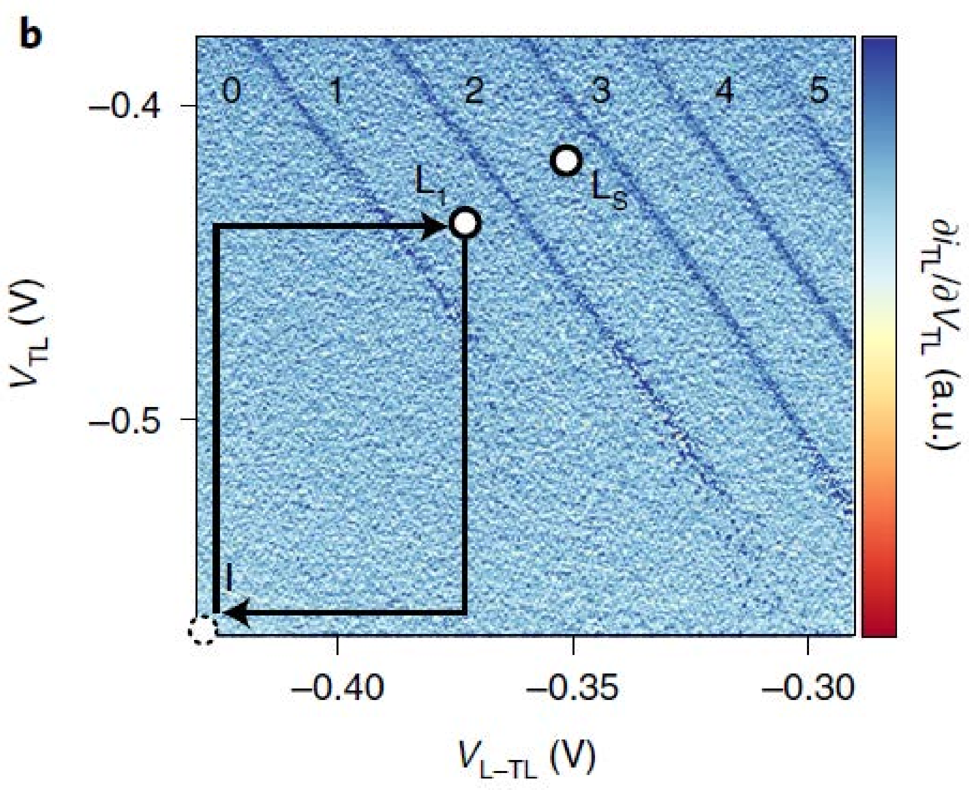
26.04.2021

Device architecture



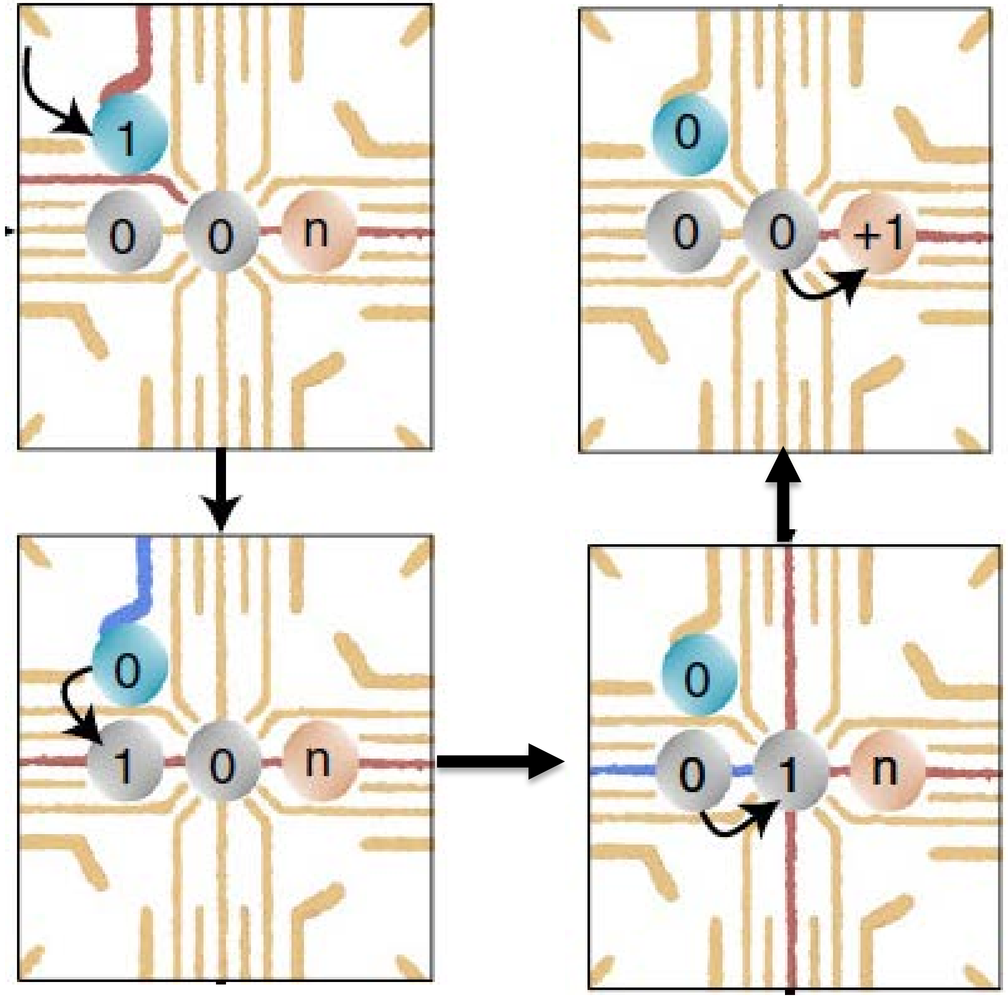
- (Homemade) Dilution refrigerator: T ~ 60 mK
- Static out-of-plane magnetic field
- 9 dots:
  - GaAs/AlGaAs heterostructure
  - 28 Gates: light blue and red ones are plungers
    other gates are used as barriers/tunnel
  - 4 Quantum Point Contact (in the edges)

Loading sequence (up to 2 electrons)



- Load electron to TL dot (standard single dot charge stability diagram):
  - L_1: 1 electron
  - L_S: singlet state
  - I: isolate the QD from the reservoir or perform readout
- Loading fidelity decreases with the number of electron n

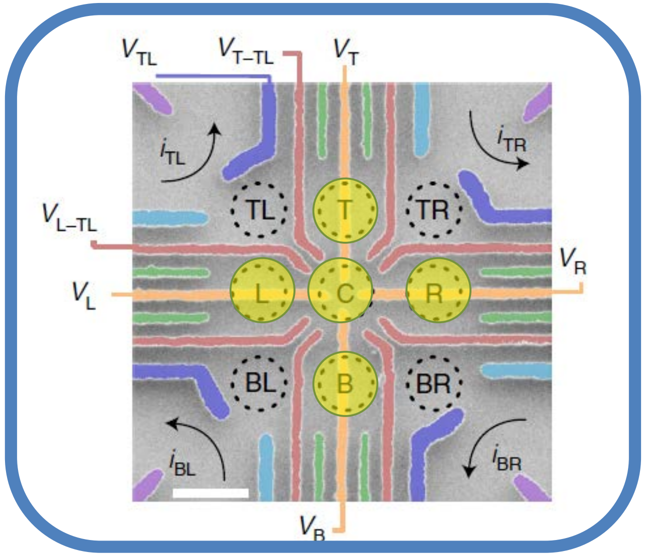
Loading sequence (more than 2 electrons)



Single-electron charge config. in the array of 9 dots

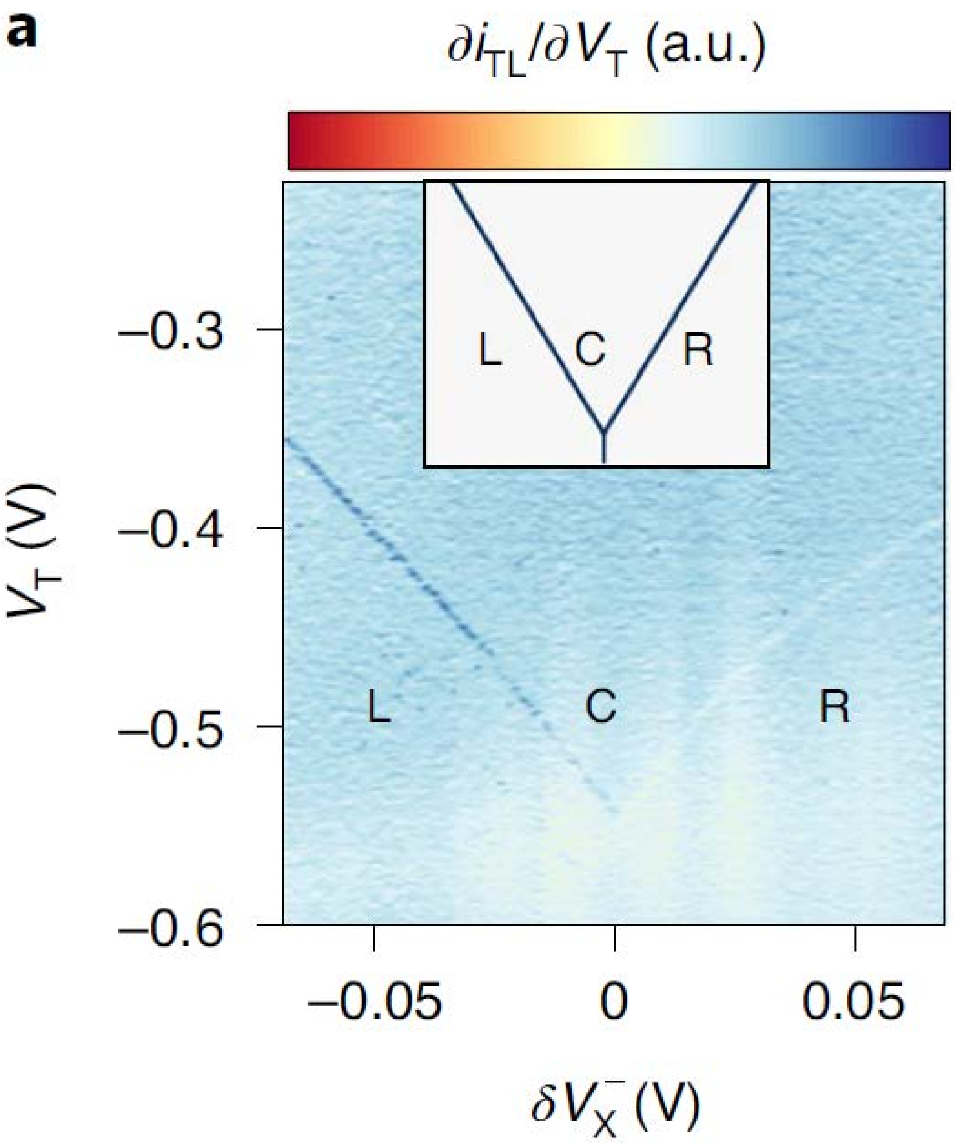
Virtual gates are define such as:

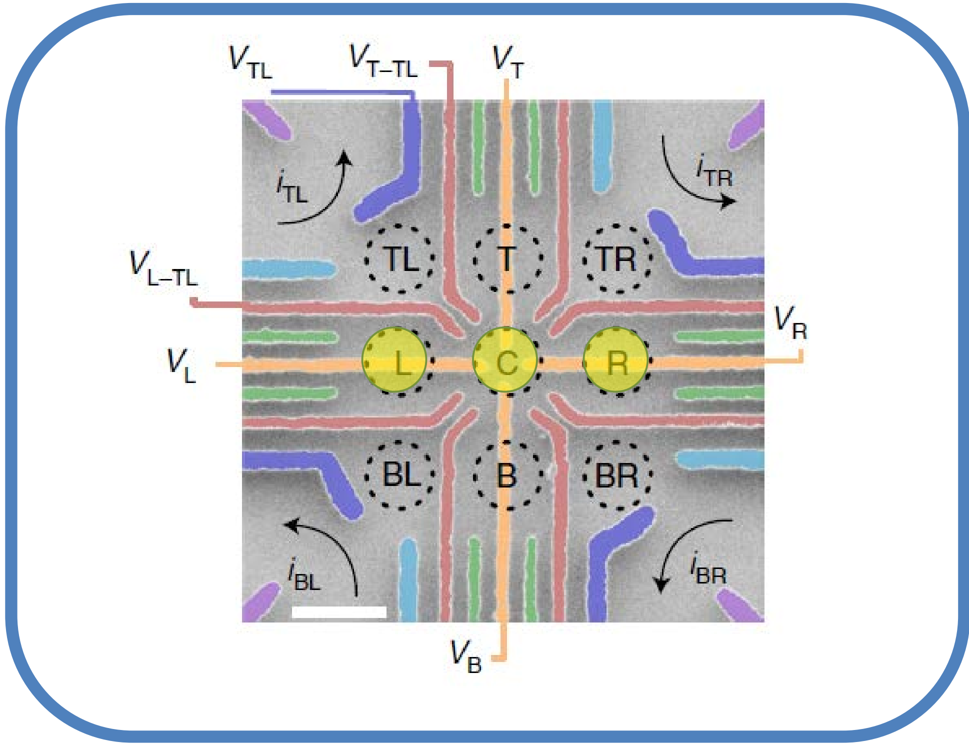
$$\begin{bmatrix} \delta V_X^+ \\ \delta V_X^- \\ \delta V_Y^+ \\ \delta V_Y^- \end{bmatrix} = \begin{bmatrix} C_L^L/C_R^R & 1 & 0 & 0 \\ -C_L^L/C_R^R & 1 & 0 & 0 \\ 0 & 0 & C_B^B/C_T^T & 1 \\ 0 & 0 & -C_B^B/C_T^T & 1 \end{bmatrix} \begin{bmatrix} \delta V_L \\ \delta V_R \\ \delta V_B \\ \delta V_T \end{bmatrix}$$



- Goal is to mimic electric dipole behavior
- But another way to see it: Gates+ shift the energy level of the dots simultaneously
  Gates- move the electron from one side to the other

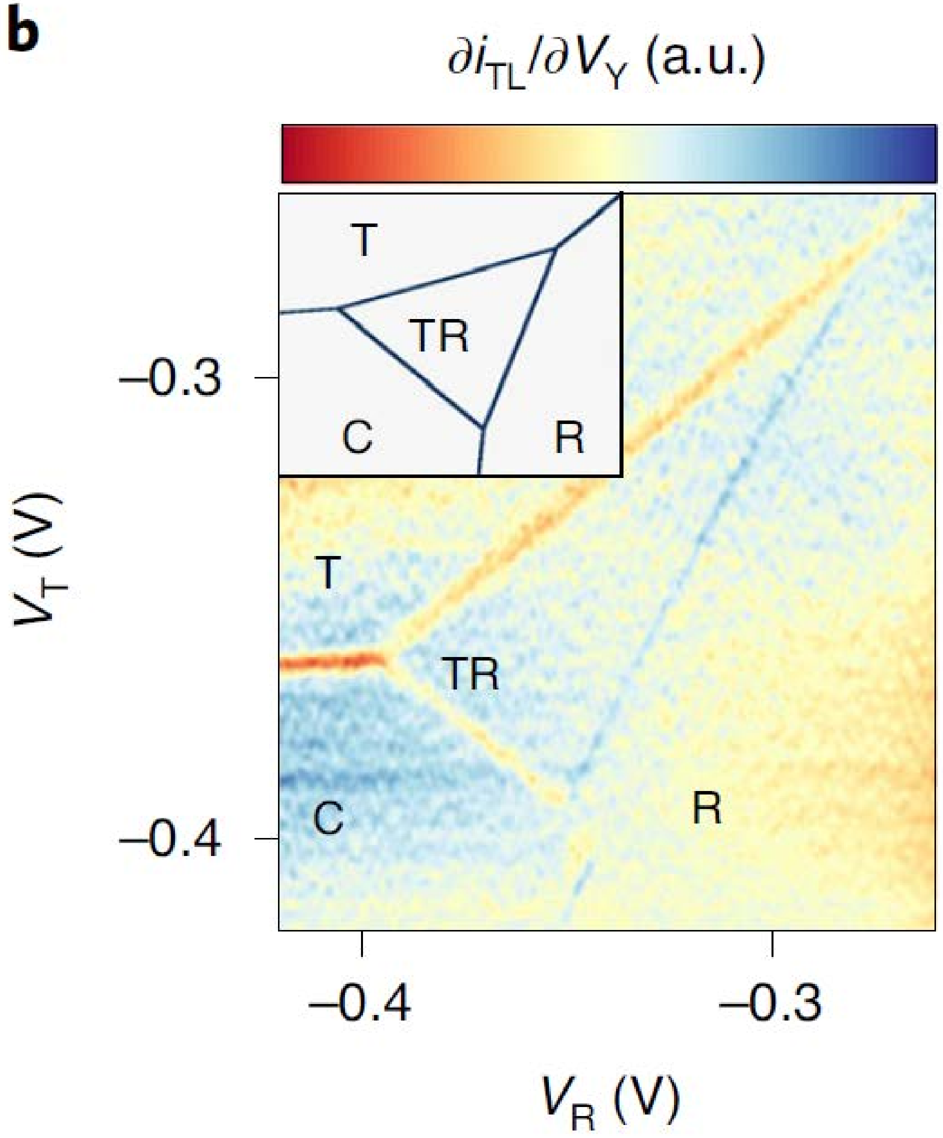
Single-electron charge config. in the array of 9 dots

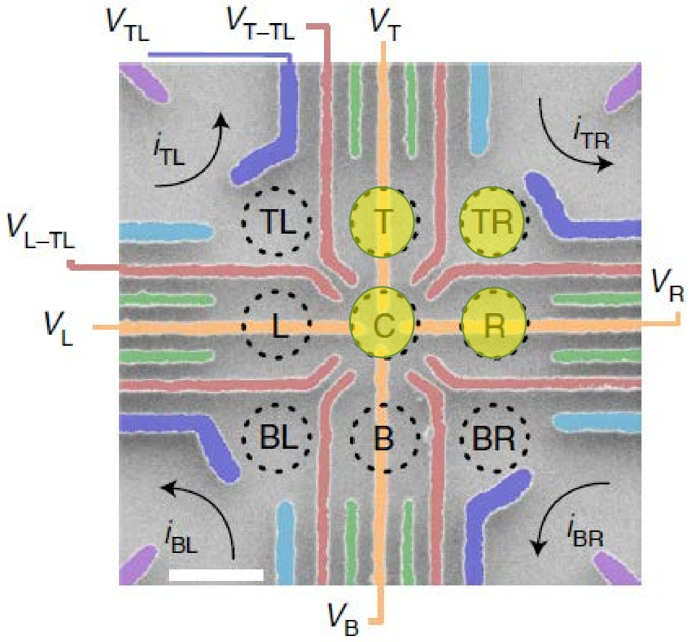




Inset: simulation using a constant interaction model

Single-electron charge config. in the array of 9 dots





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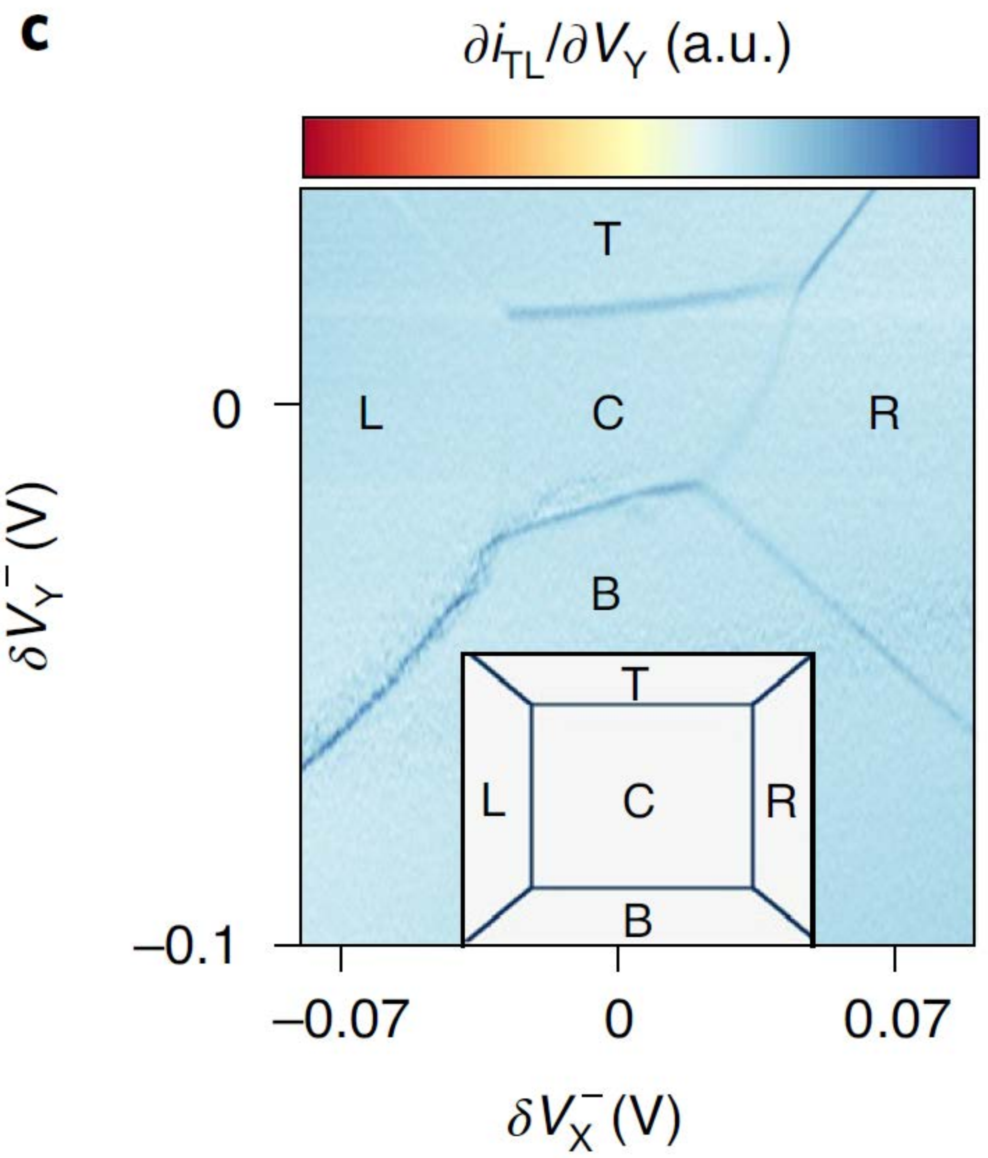

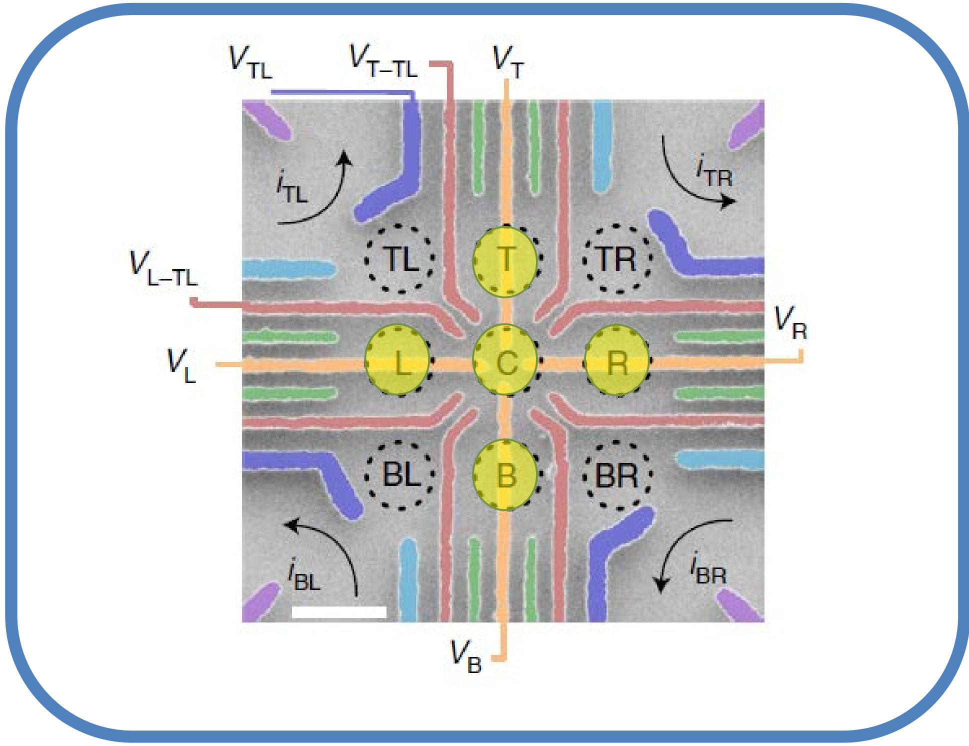

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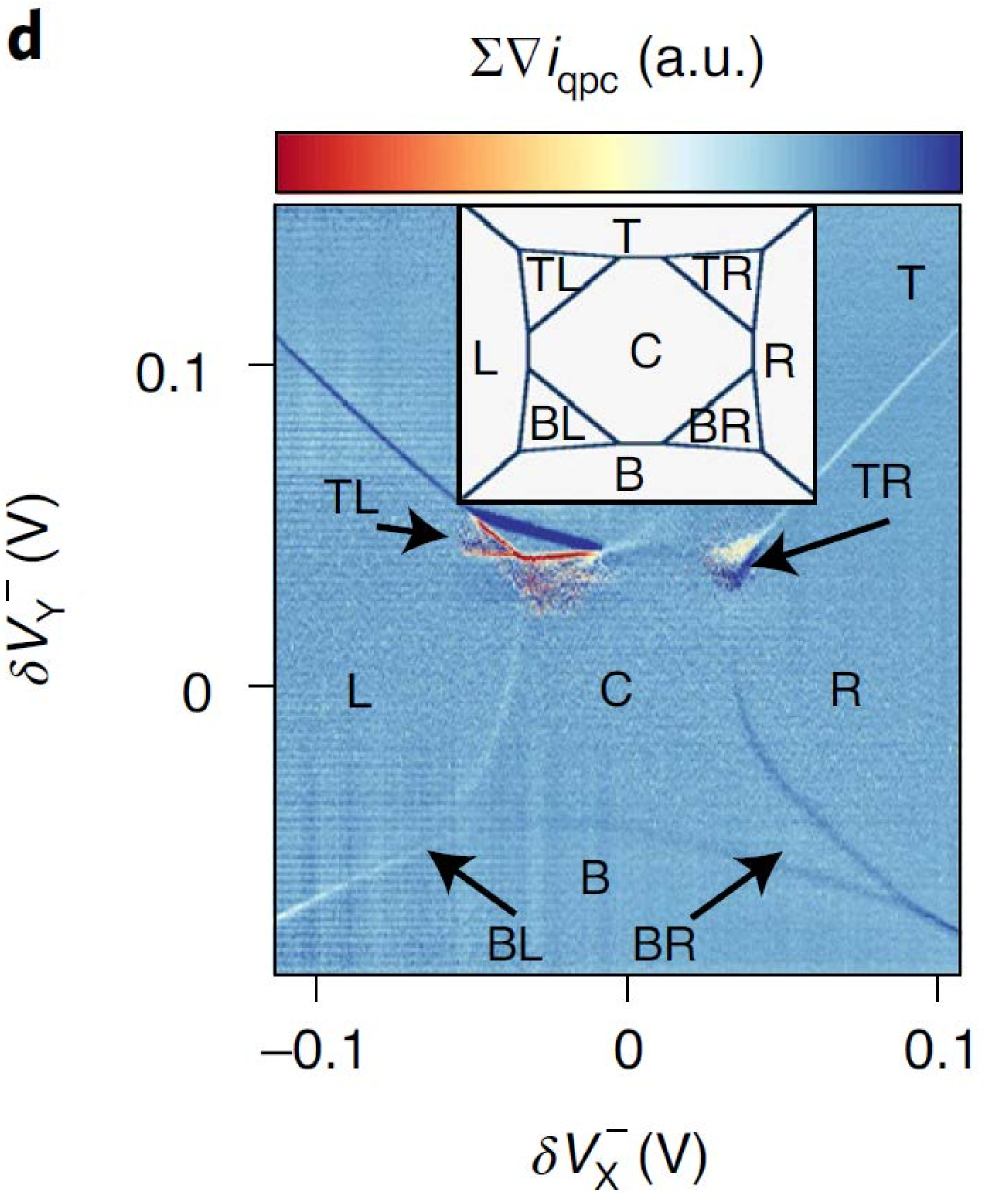

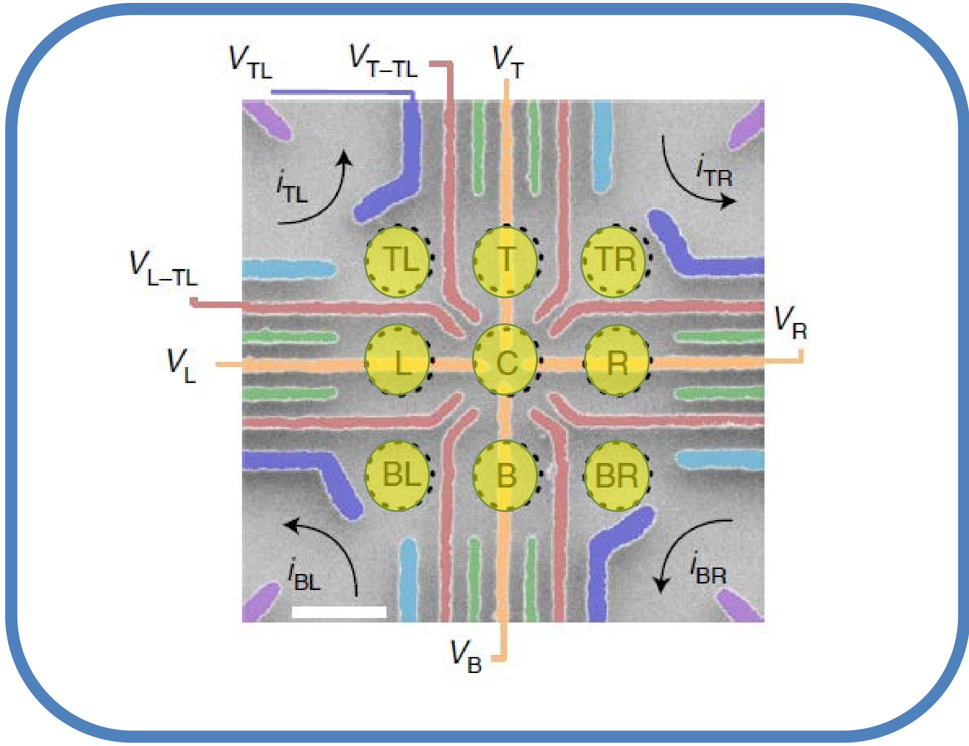

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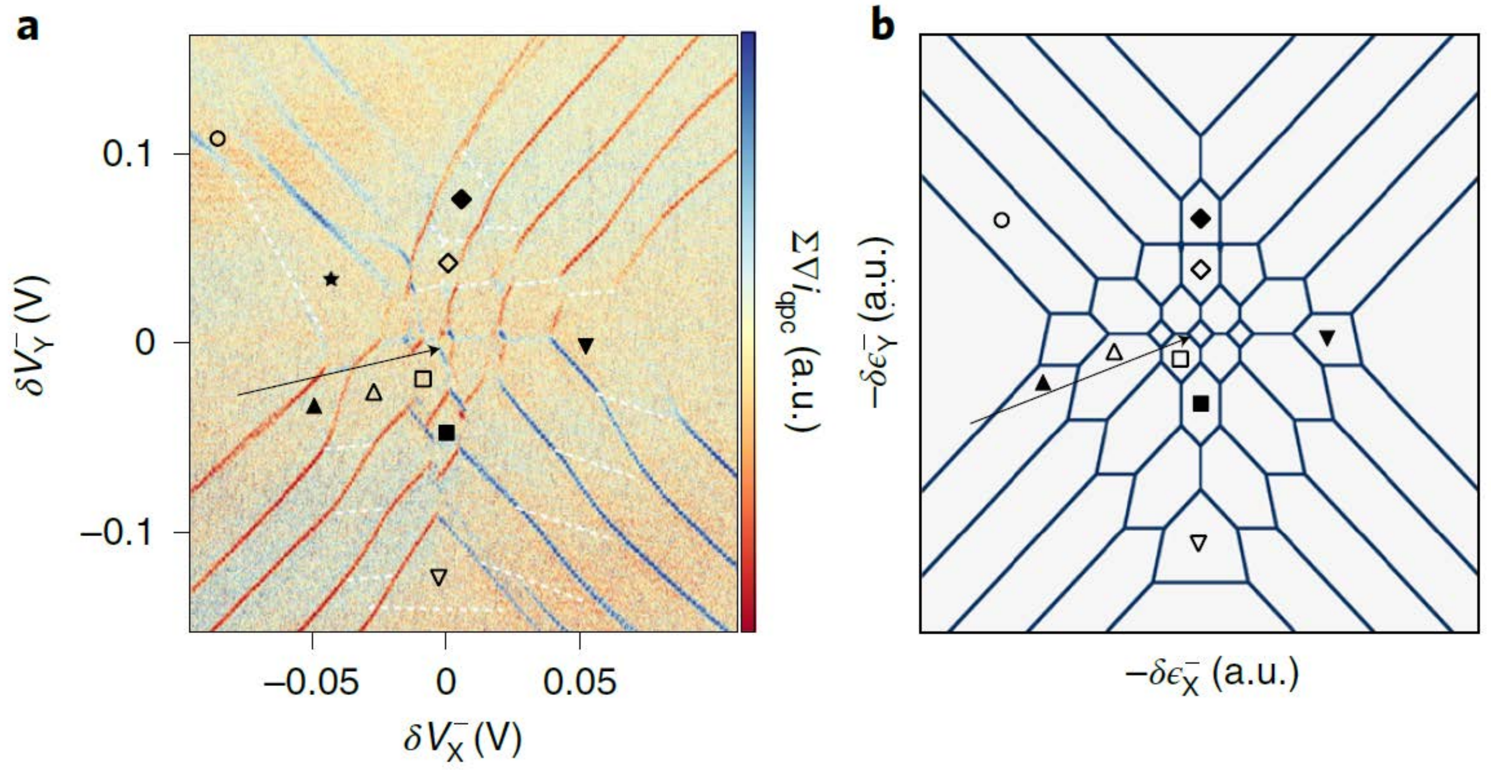
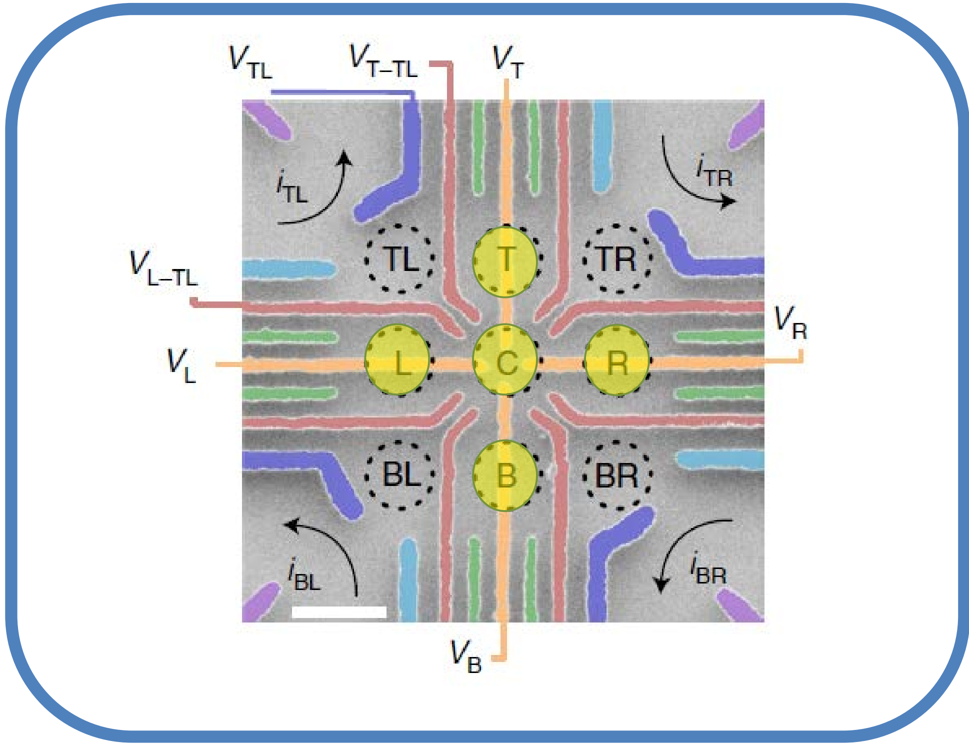
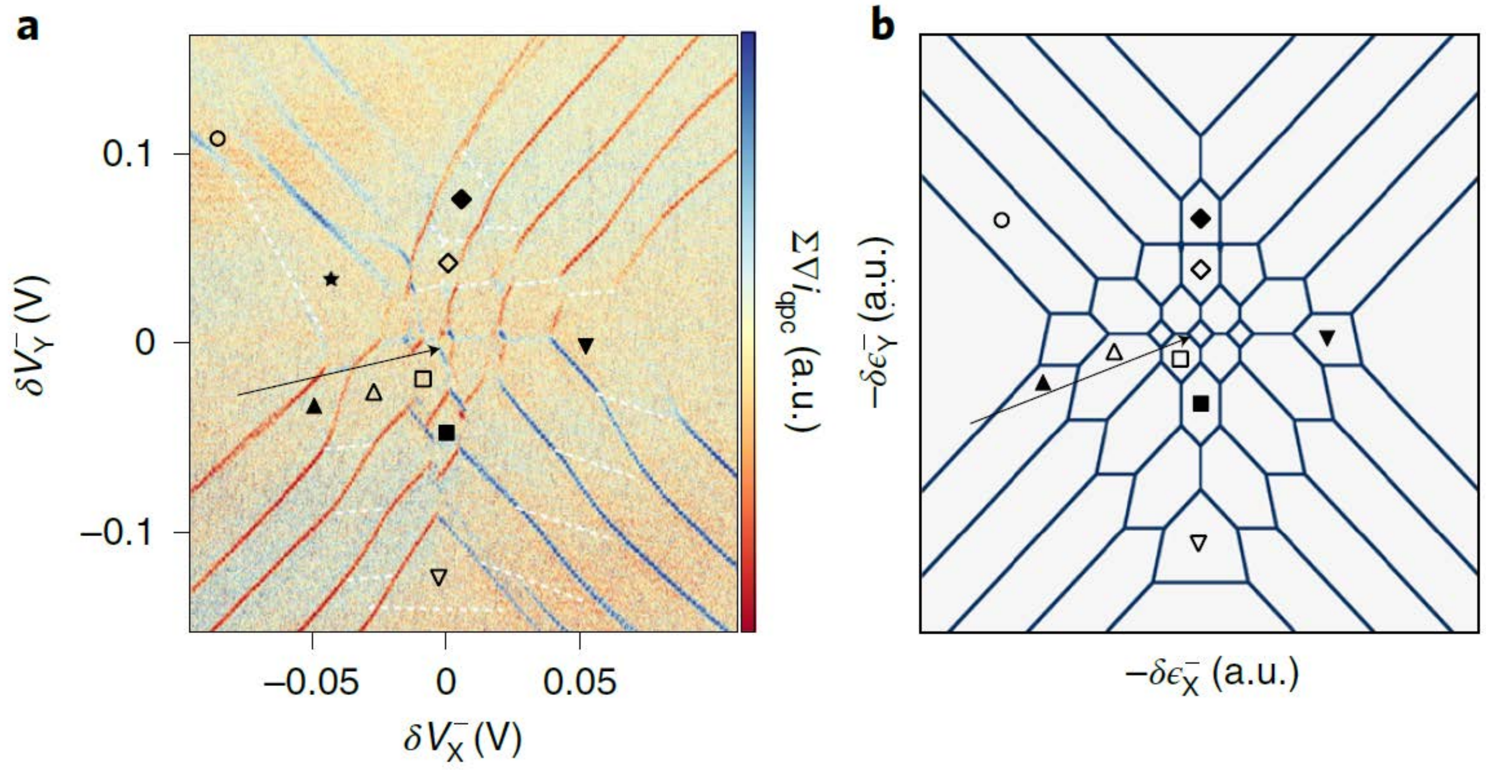
Multiple electrons charge configuration

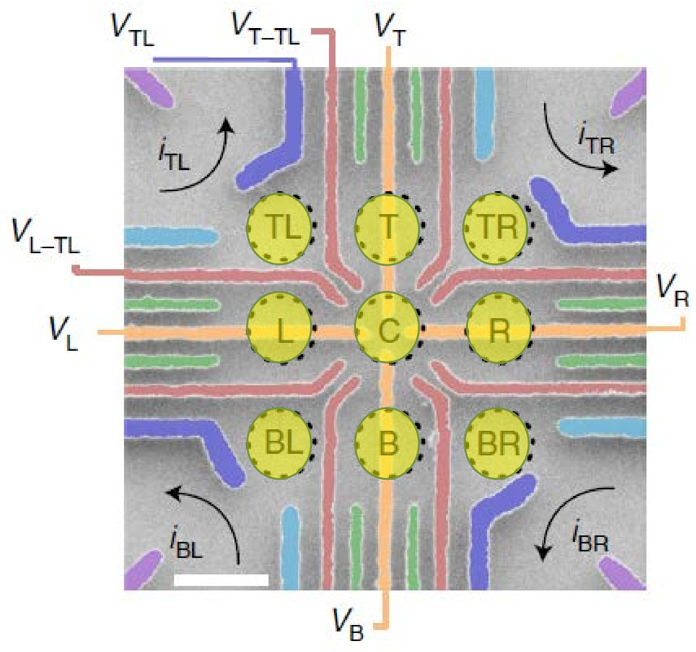




1. Load 5 electrons
2. Record a stability diagram varying $\delta V^-_{X;Y}$
3. Identify (1, 1, 1, 1, 1): highest symmetry point

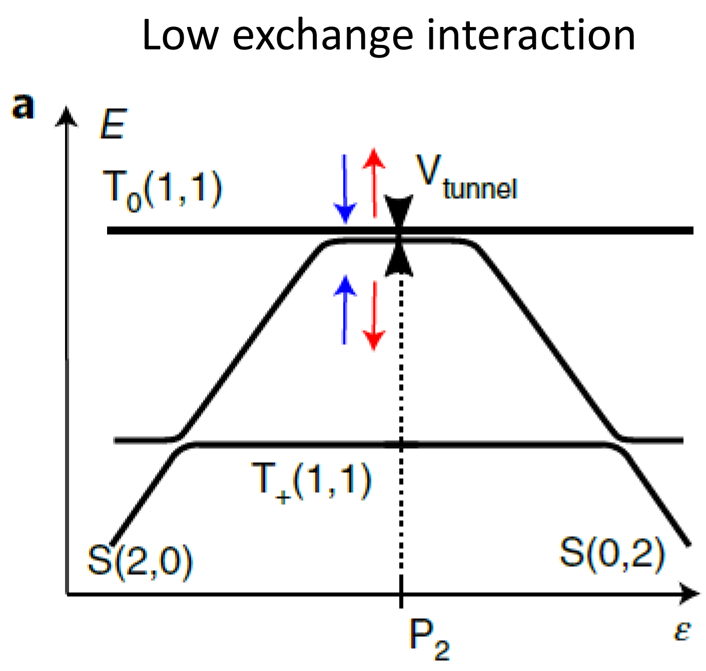
Multiple electrons charge configuration

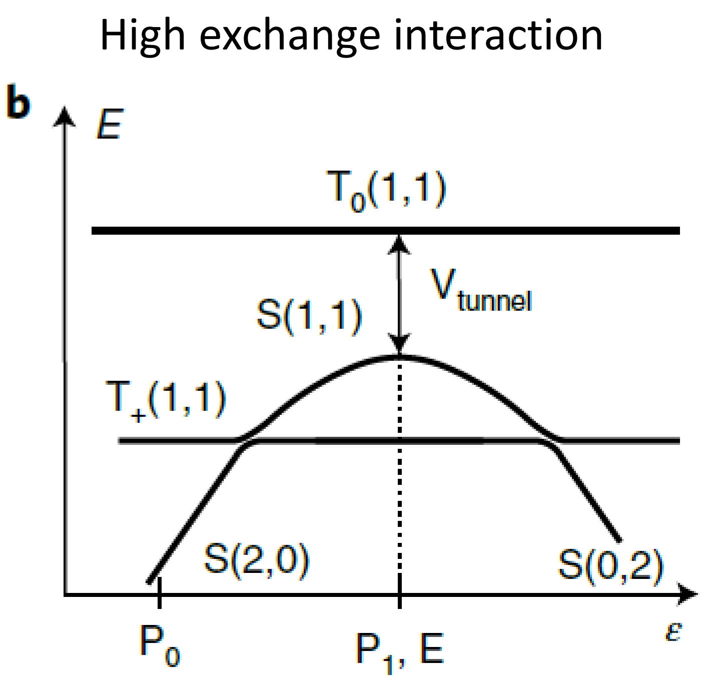


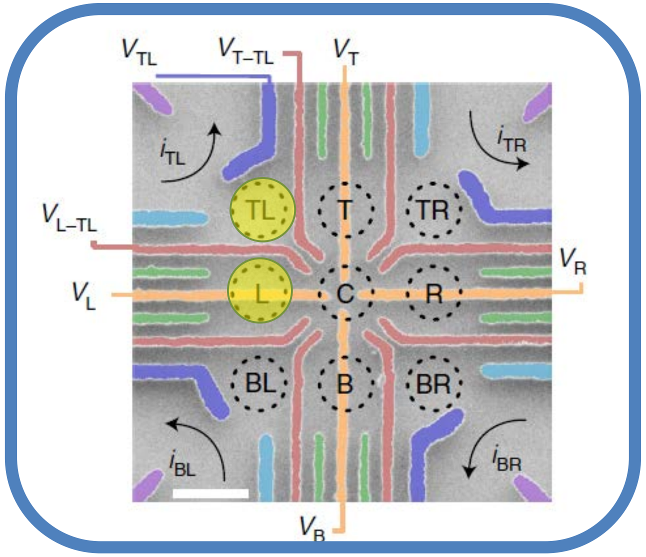


1. Load 5 electrons
2. Record a stability diagram varying $\delta V^-_{X;Y}$
3. Identify (1, 1, 1, 1, 1): highest symmetry point
4. Load 4 more electrons in the corners

2 Spins manipulations: energy diagrams

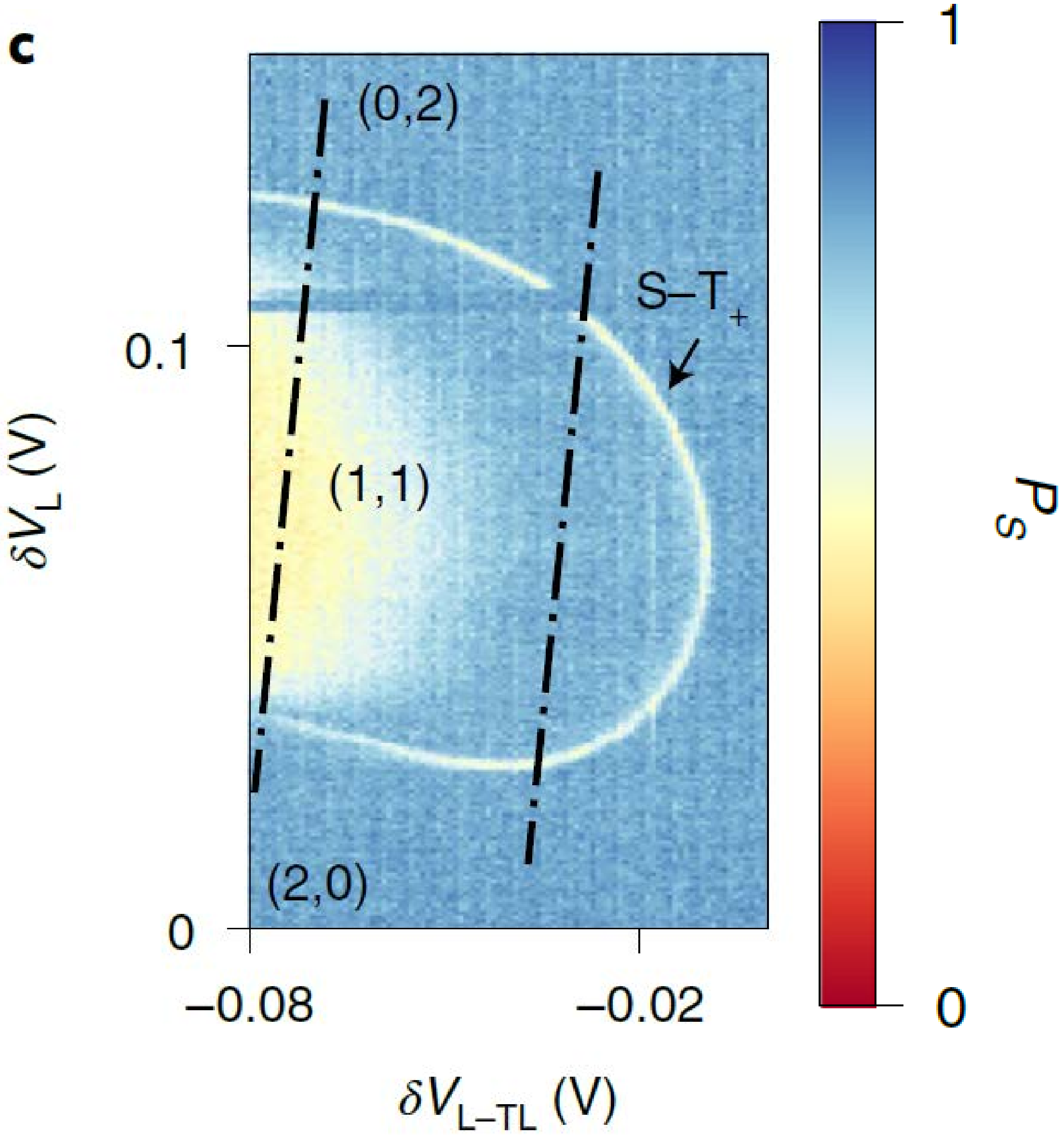






- When the 2 electrons are in the same dot, the singlet state is the ground state
- Otherwise, the ground state is the triplet T_+
- At P2, we get a mixture of $T_0(1,1)$ and S(1,1)

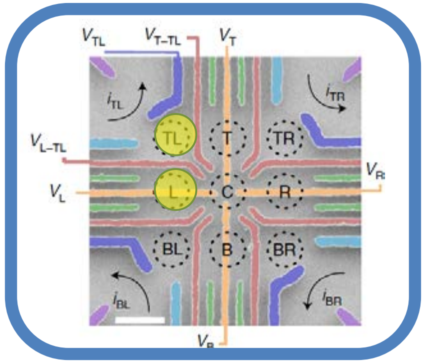
2 Spins manipulations: Spin mixing map



Method:

- Start with a singlet in TL
- Pulse in a given gate configuration
- Read the state
- Repeat this 1000 time to get P_S

The spin mixing area (white/yellow) correspond to weakly tunnel coupled dots (or to S(2,0) and T_+(1,1) mixing)



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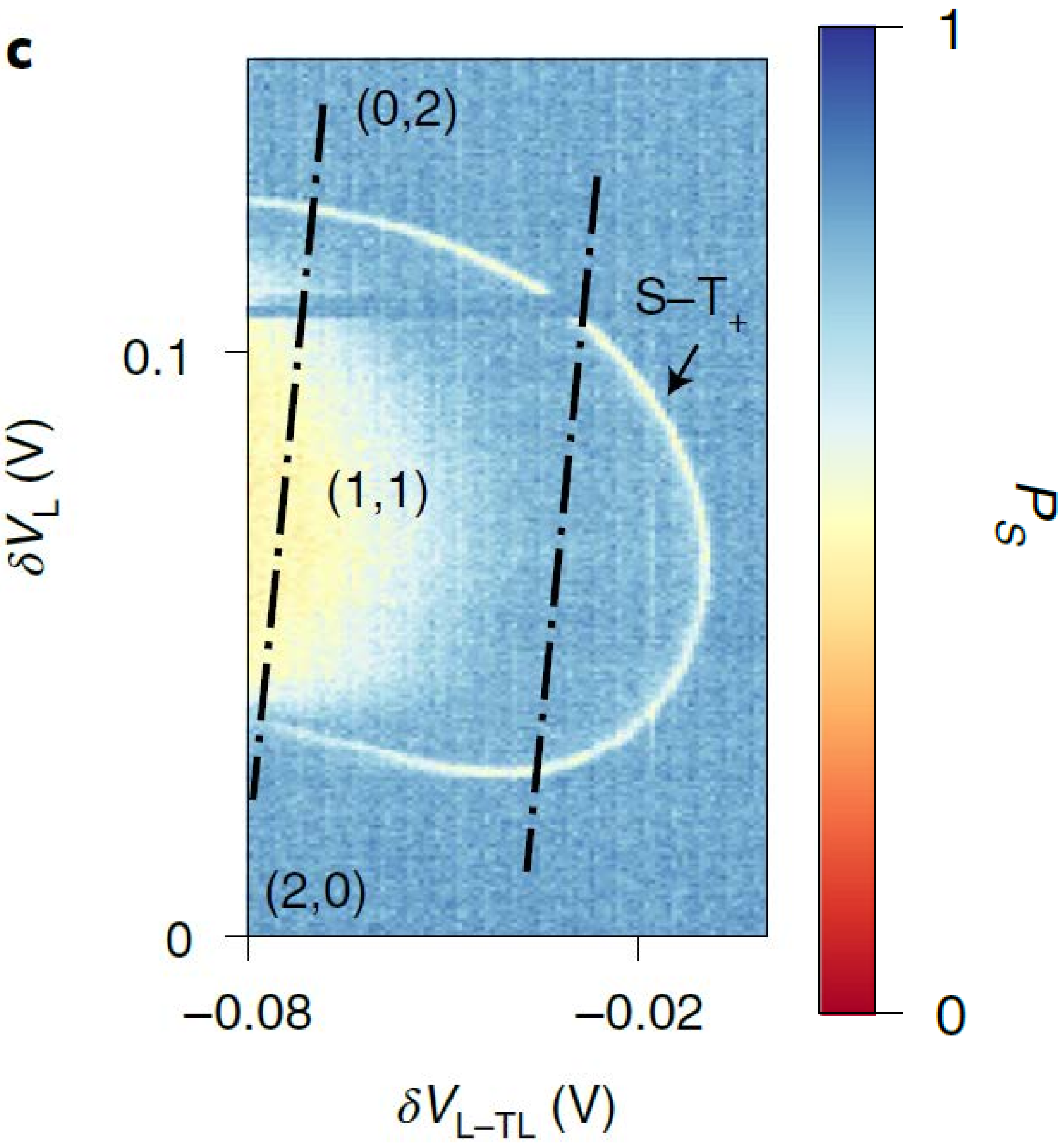

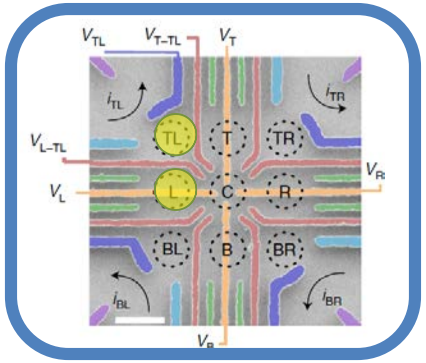

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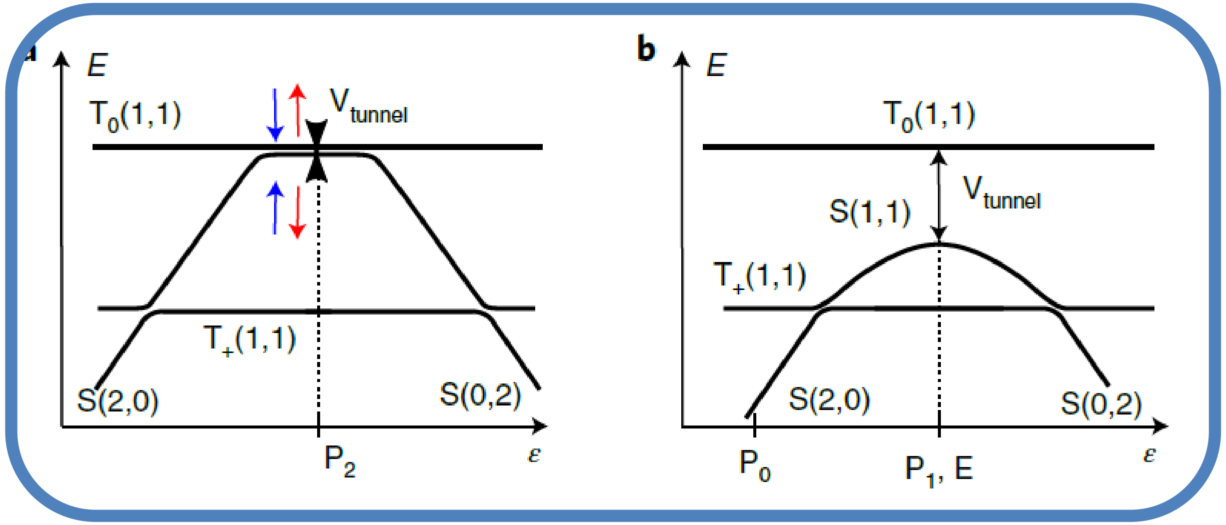

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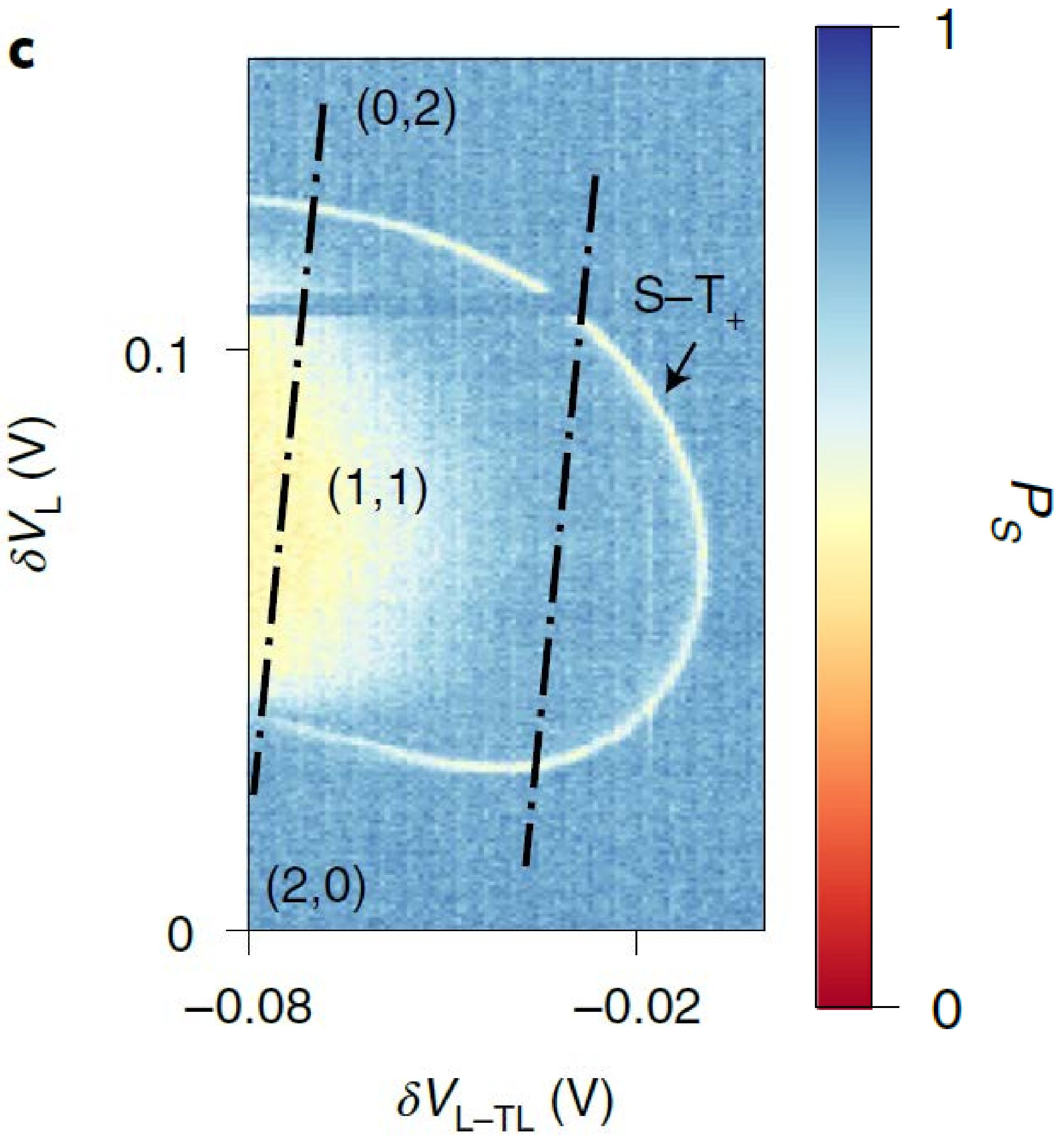

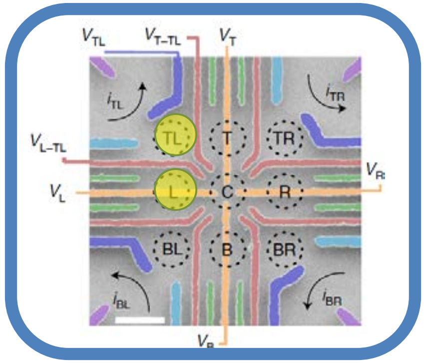

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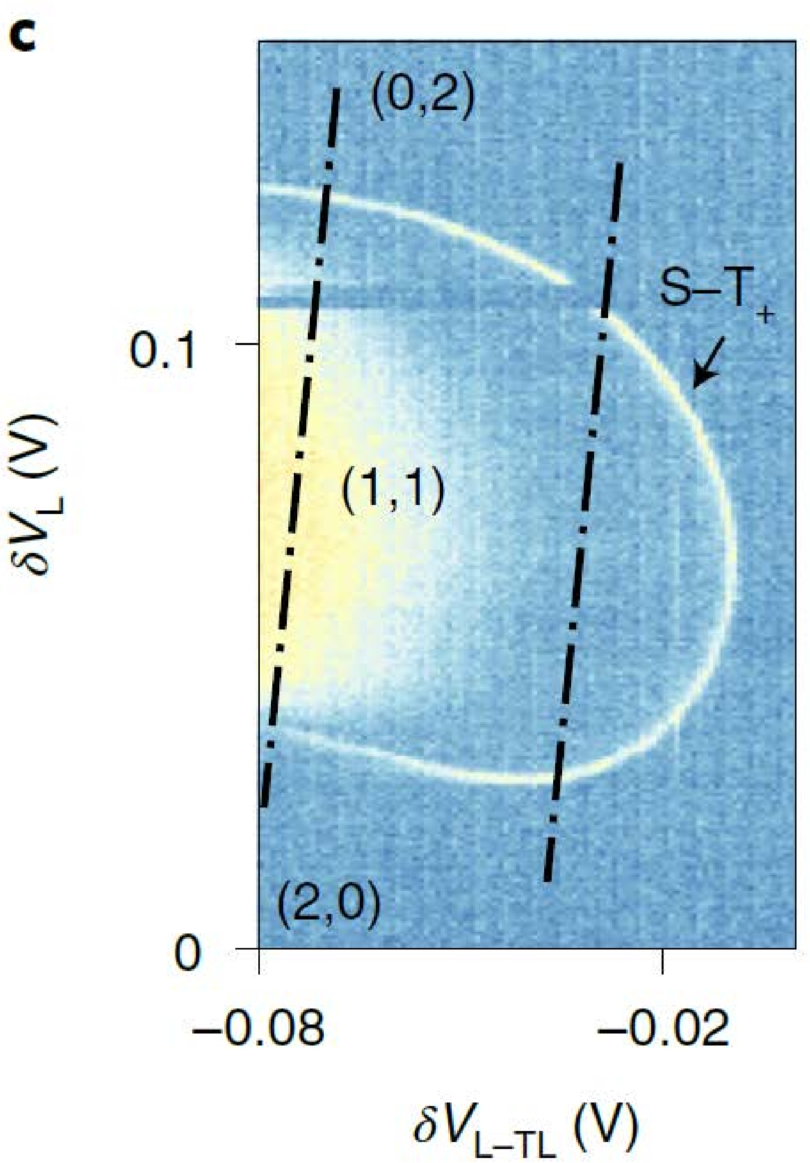
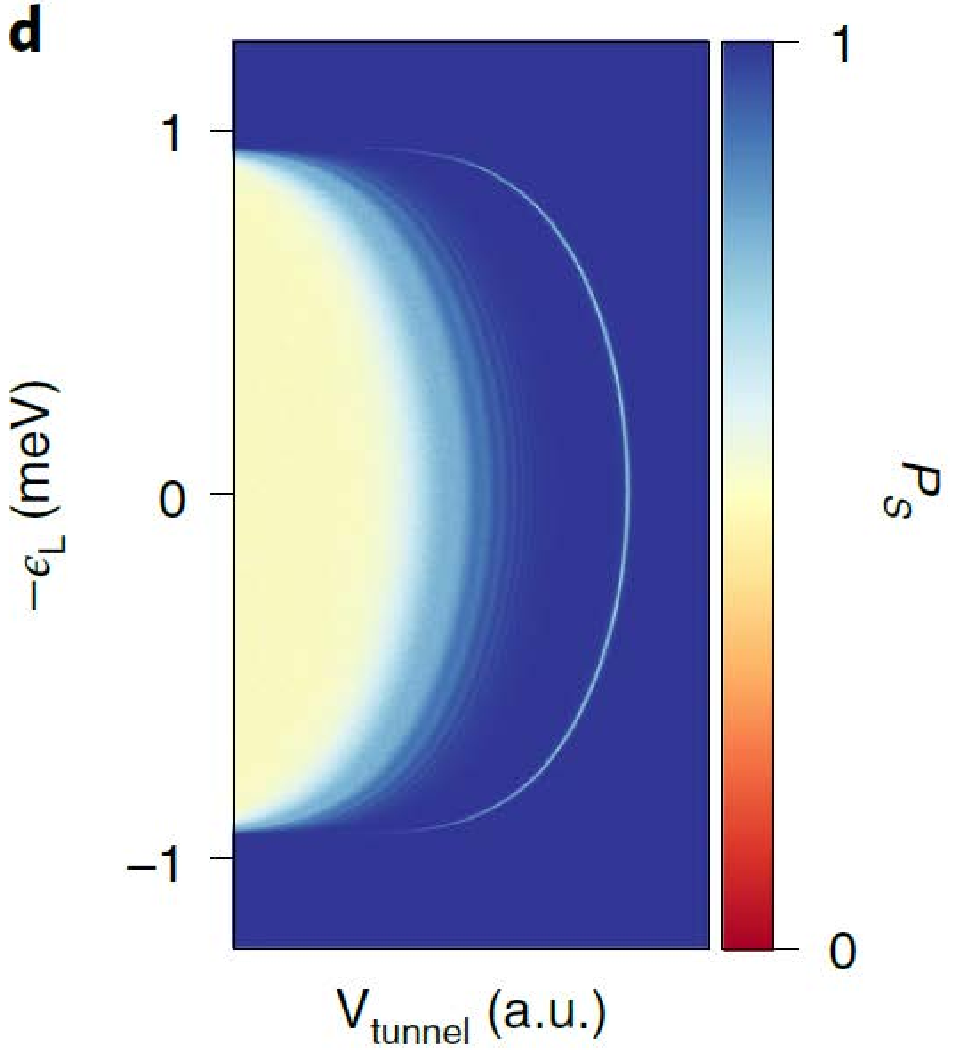
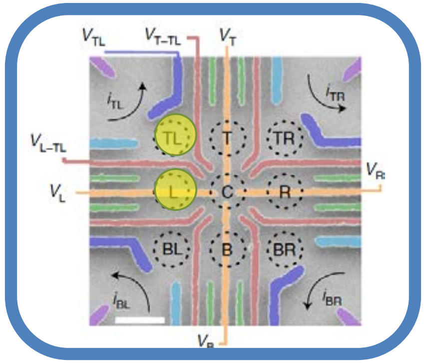
=> Possible to tune the coupling of 2 dots inside the array (i.e. go from a decoupled regime to high exchange one and oppositely)

2 Spins manipulations: Spin mixing map







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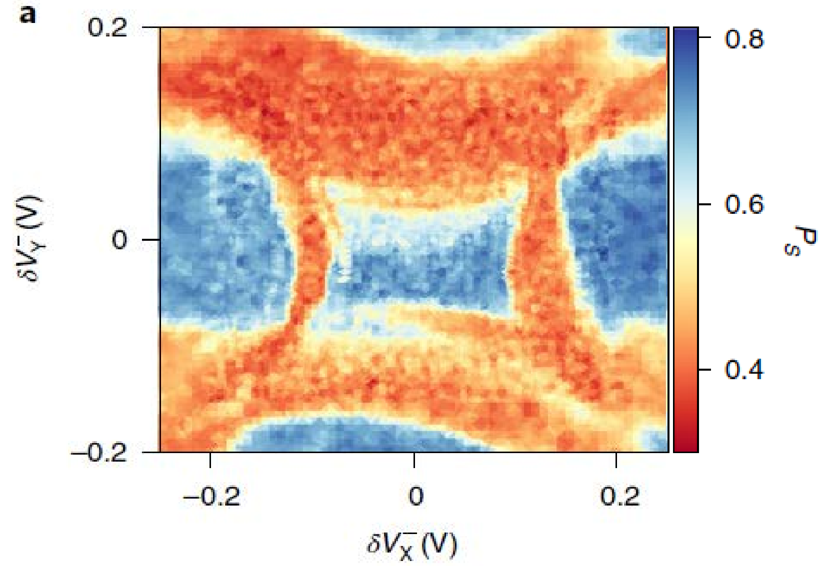
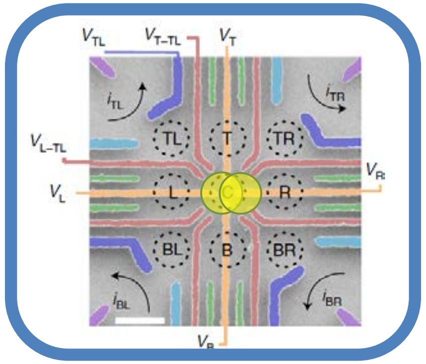
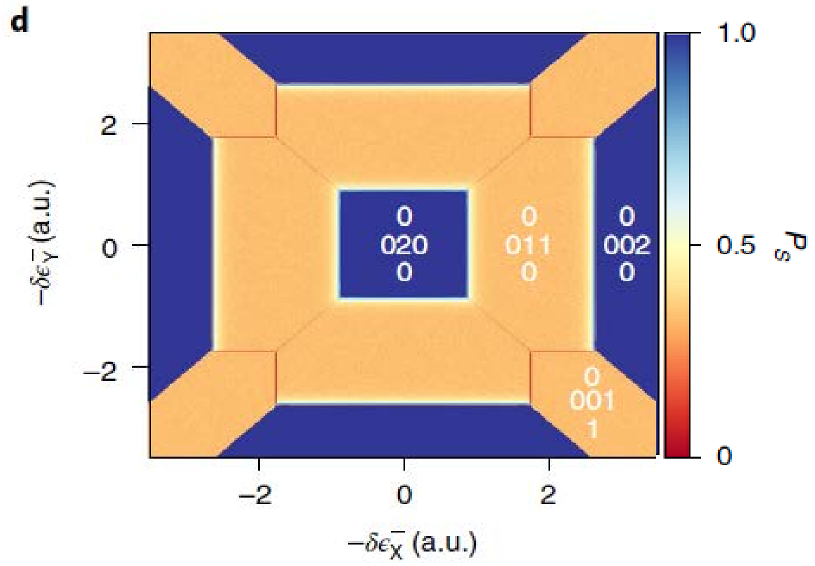


Method:

- Start with a singlet in TL
- Move it to C
- Pulse in a given gate configuration (50 ns)
- Read the state
- Repeat this 150 time to get P_S





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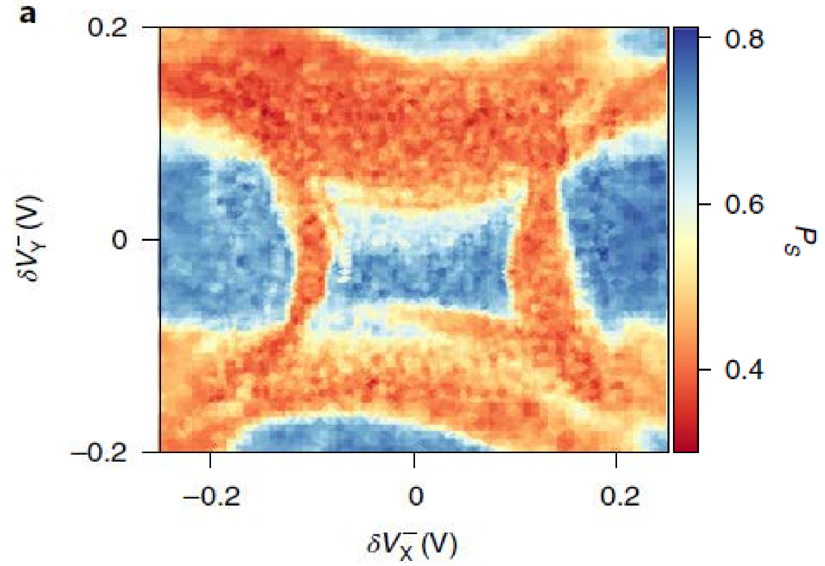

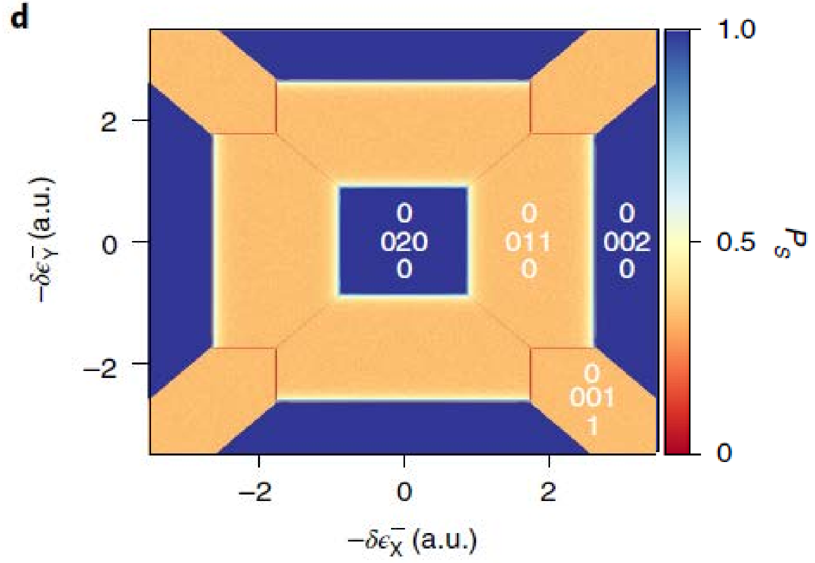

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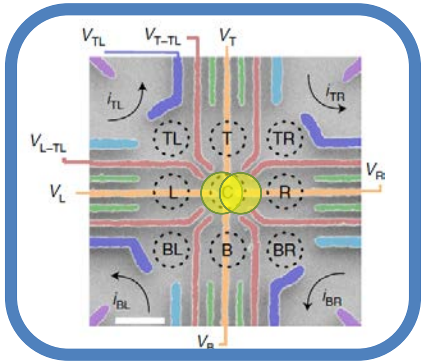
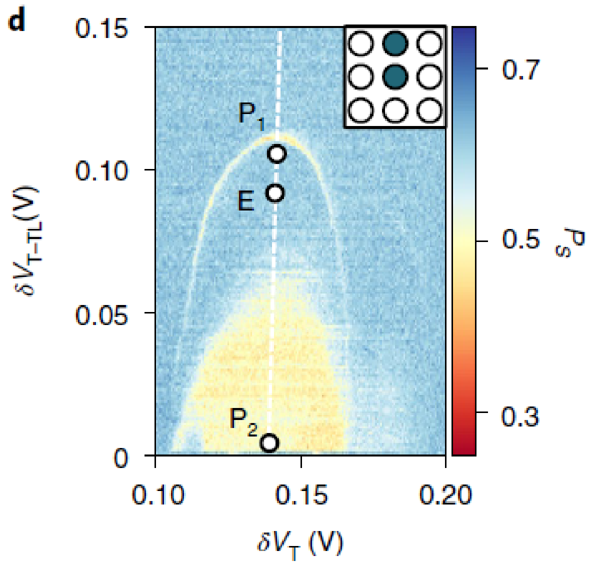
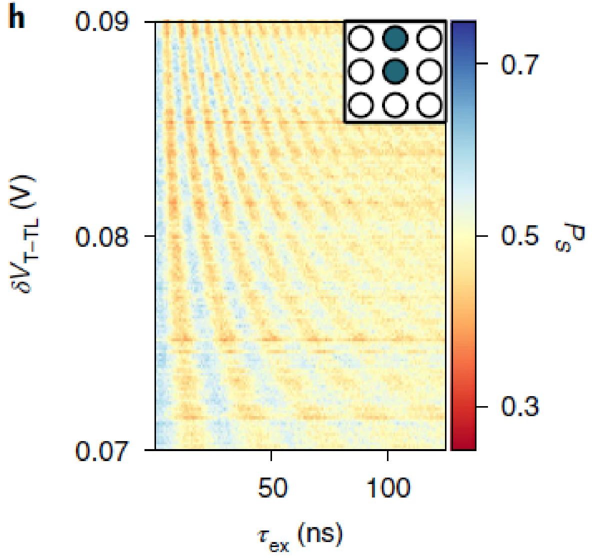


The high P_S probability area (blue) correspond to transfer the 2 electrons in another dot, preserving the singlet state.
The mixing area (red) are where the electrons are split in 2 dots (and we have a mixture of S(1,1) and T_0(1,1)

=> Possible to coherently displace spins

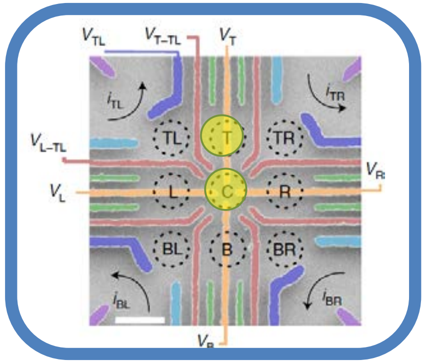
Coherent exchange oscillations





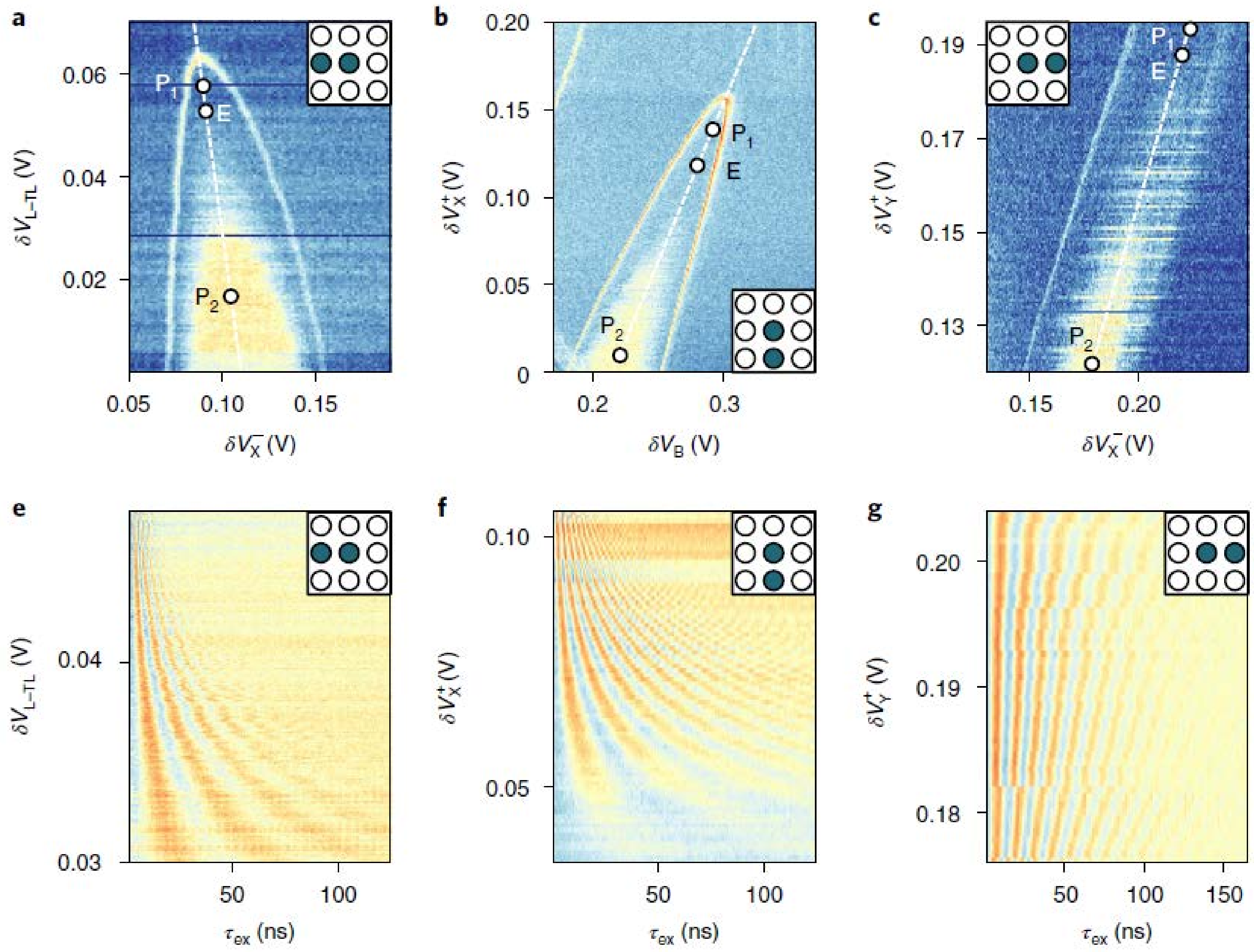
- Similarly do a spin map corresponding to T and C.
- Apply a poltage pulse sequence to pulse the tunnel barrier interaction in order to perform coherent exchange oscillations*

=> Coherent time of 100 ns



*See Bertrand, B. et al. Quantum manipulation of two-electron spin states in isolated double quantum dots. *Phys. Rev. Lett.* **115**, 096801 (2015).

Coherent exchange oscillations



Conclusion

Summary of results:

- Loading and displacement of a single electron in the QD array
- Loading and (simple) displacement of up to 9 electrons
- 2 electron spin readout from any QD
- Local coherent spin oscillation between 2 dots of the array

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- Loading and displacement of a single electron in the QD array
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- 2 electron spin readout from any QD
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My personal opinion:
- Pragmatic approach to start to work on QD array
- But difficult to scale up

Thanks

Thank you for your attention!

2 Spins manipulations: Spin mixing maps