laboratoire pierre aigrain
électronique et photonique quantiques

Microwave cavity as a probe of Kondo effect

« *Electrical conductance from a frozen charge* »

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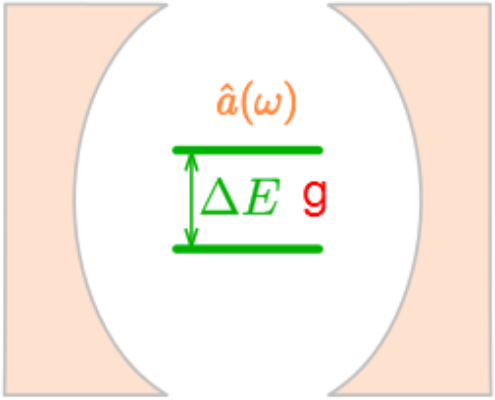
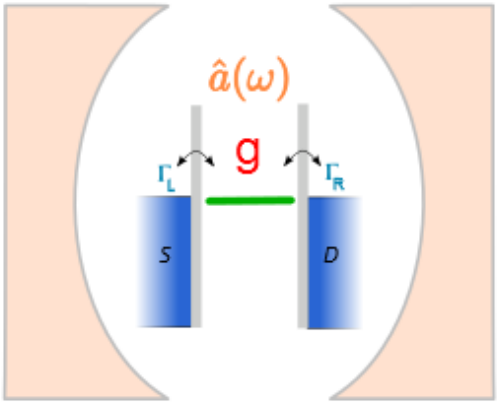
Theory : A. Cottet, B. Douçot, M.-S. Choi

Using tools of cavity Quantum ElectroDynamics

- **cQED + closed system**



- **cQED + open system**



J.-M. Raimond, M. Brune, and S. Haroche, RMP **73**, 565 (2001)
A. Wallraff et al. , Nature **431**, 162 (2004)
K. D. Petersson et al., Nature **490**, 380 (2012)
J.J. Viennot et al, Science **349**, 408, (2015)

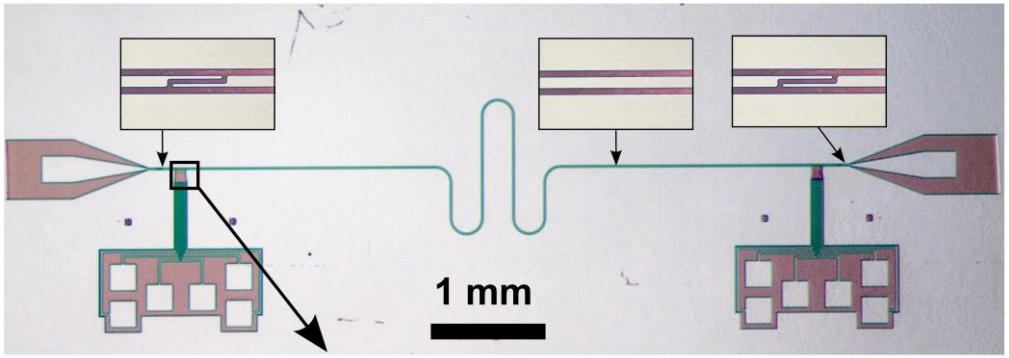
L.E. Bruhat, PRX, to be published

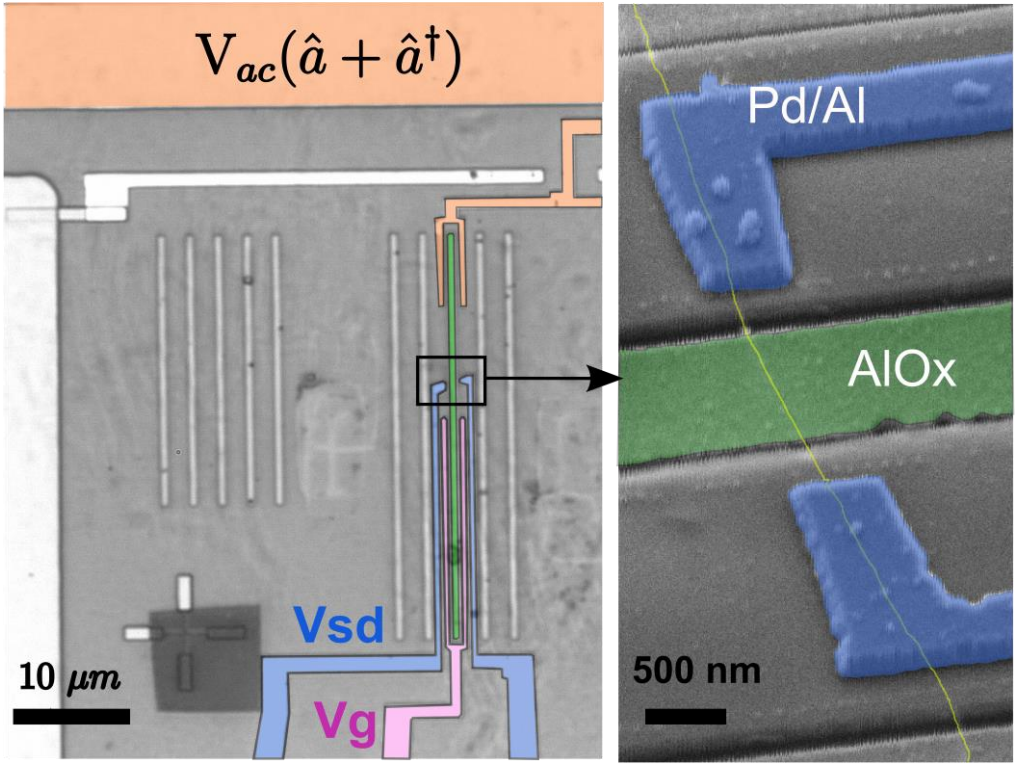
→ Simplest open system : the Anderson model

→ Anderson hamiltonian leads to a *quantum many body effect* : the Kondo effect

→ **What can we learn on the Kondo effect with a cQED architechture ?**

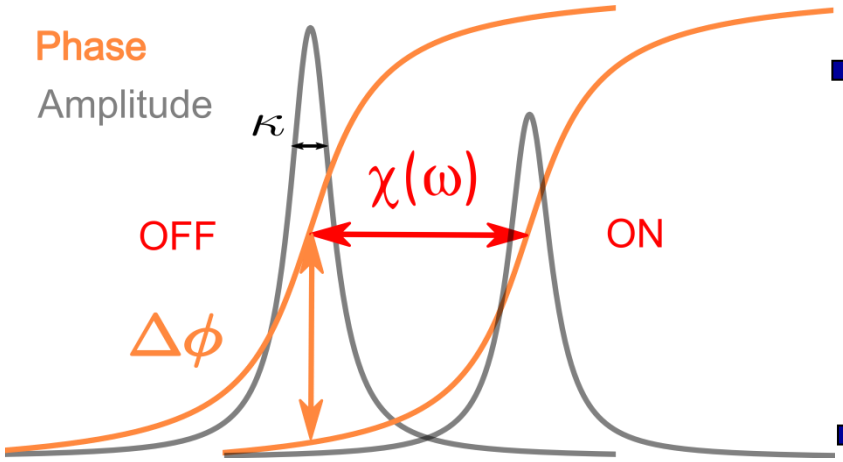
The experimental setup





- **Stamped single wall carbon nanotube quantum dot coupled to microwave photons**
- **Joint measurement of the conductance and the transmission of the cavity**

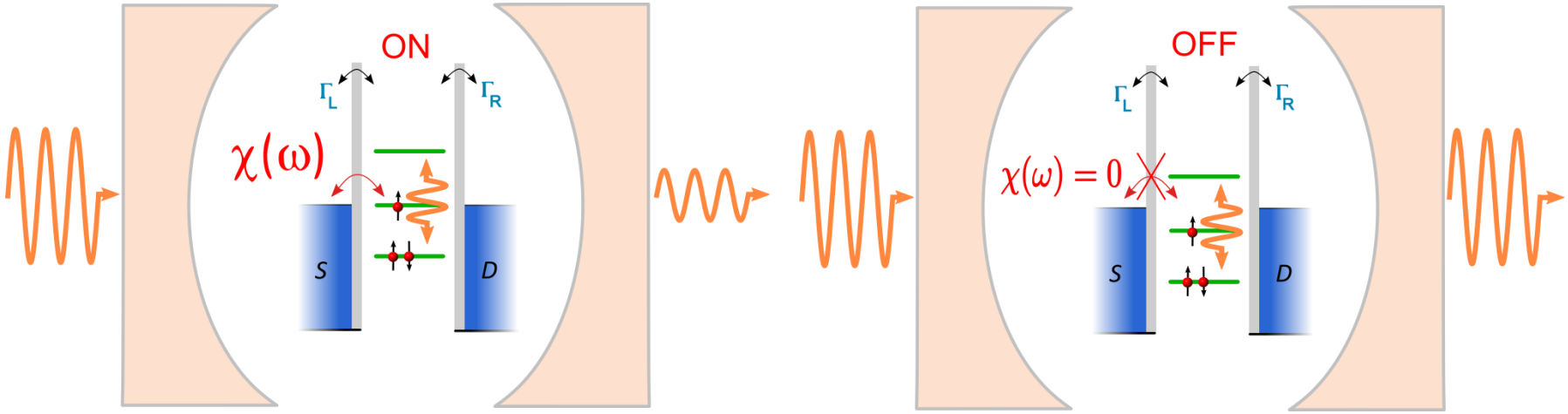
Charge susceptibility



The charge susceptibility of a QD connected to its leads shifts the transmission

$$T(\omega) = \frac{-i\,\kappa}{(\omega - \omega_{cav}) - i\,\kappa + g^2\chi(\omega)}$$

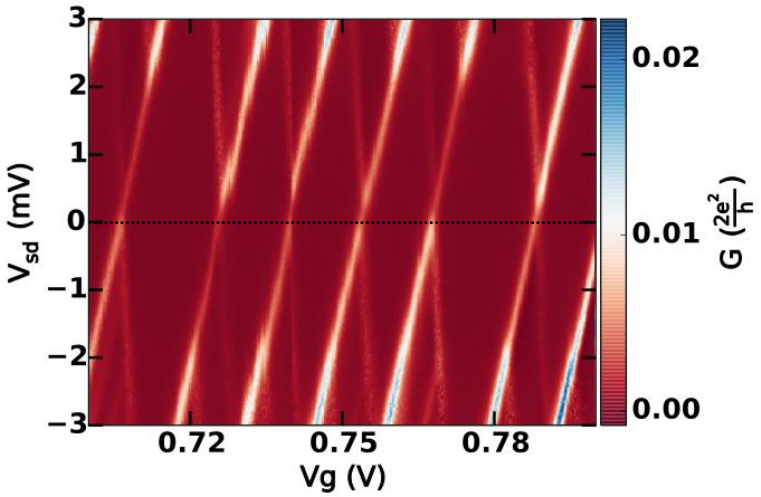
$$\Delta\phi \sim \frac{g^2}{\kappa} * \mathrm{Re}(\chi)$$

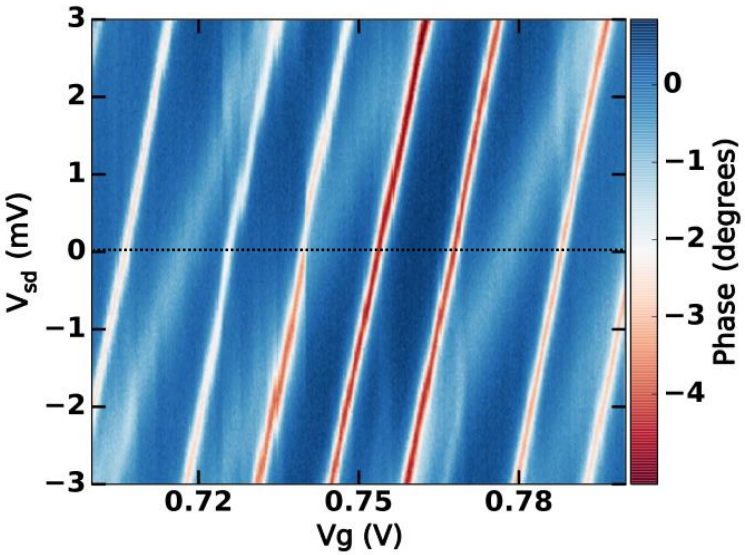


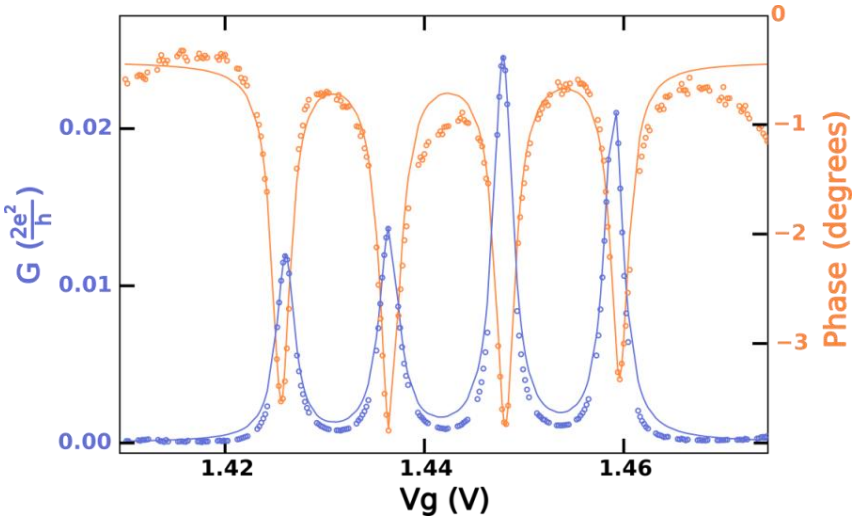
Microwave phase shift each time a charge level of the QD is resonant with ε_f

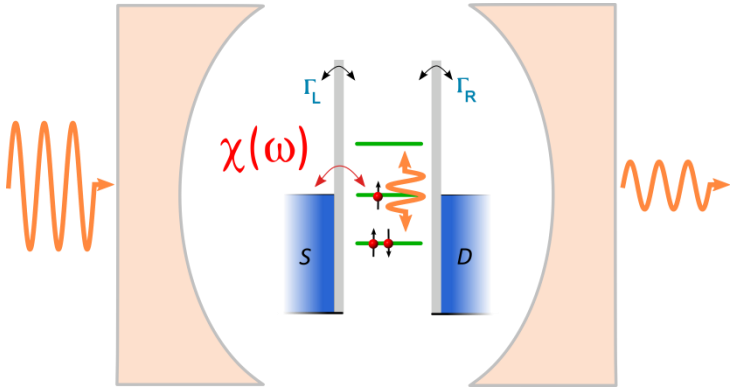
Electron-photon coupling calibration

- **Coulomb blockade regime** :
  U ~ 3meV and Γ ~ 0.7 meV







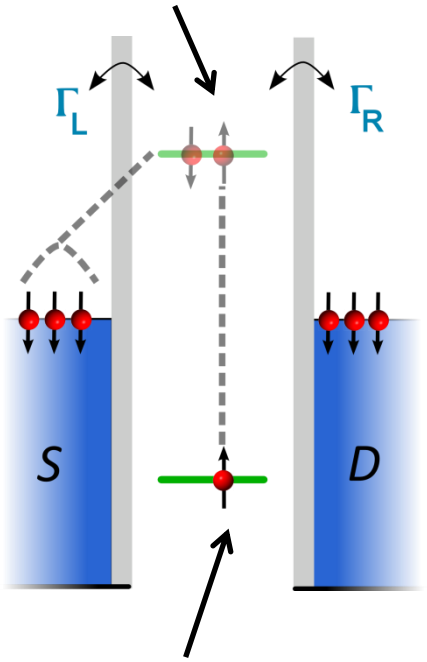


➡ Conductance peaks and phase dips are correlated

➡ **Calibration of electron-photon coupling**
g ~ 100 Mhz

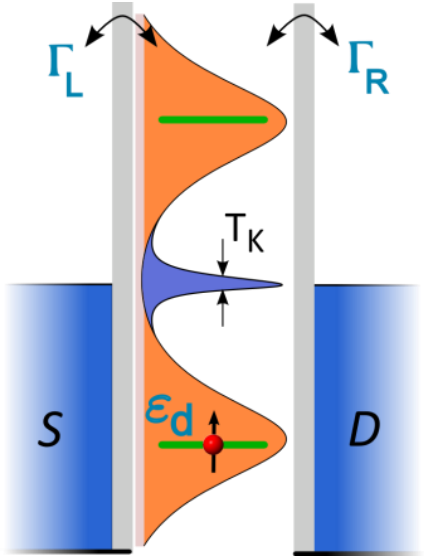
Kondo regime

- Virtual processes



Coherent screening

$T \ll T_K$



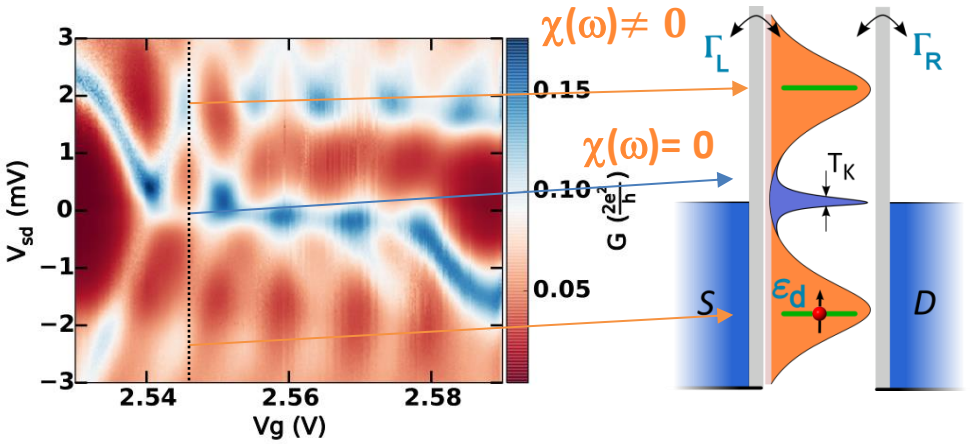
- Single occupied charge state

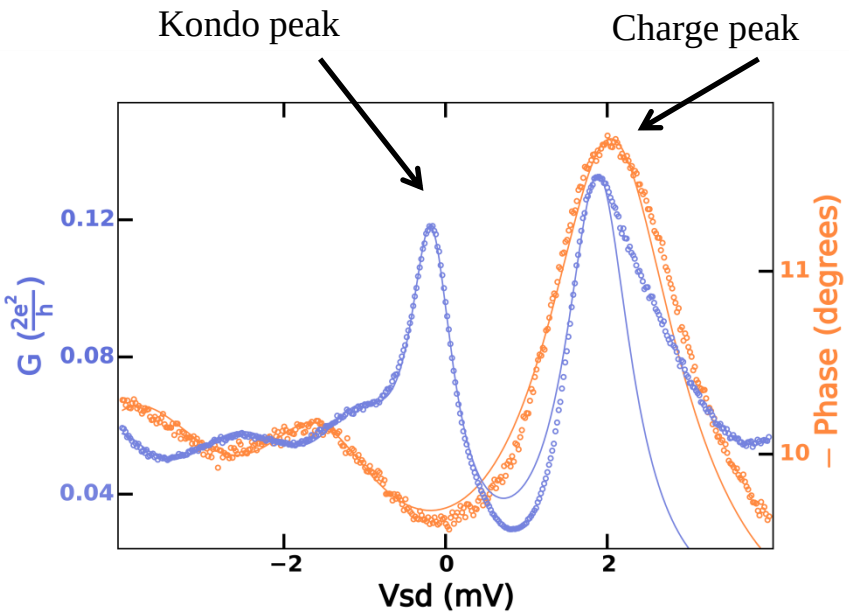
→ **Antiferromagnetic coupling** → **New resonance : Kondo states**

‘Transparent’ Kondo/AS resonance

- **Kondo regime :**

U ~ 2meV and Γ ~ 1 meV T = 300mK ≪ T_K = 6K





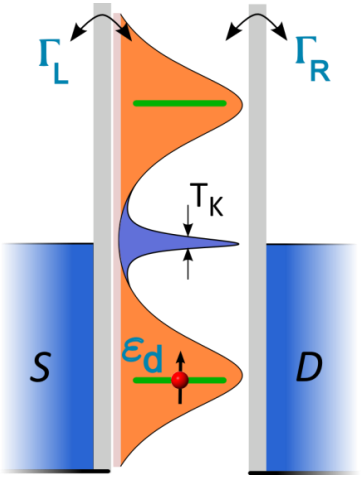
➡ Kondo resonance is ‘transparent’ to photons while charge peaks visible.

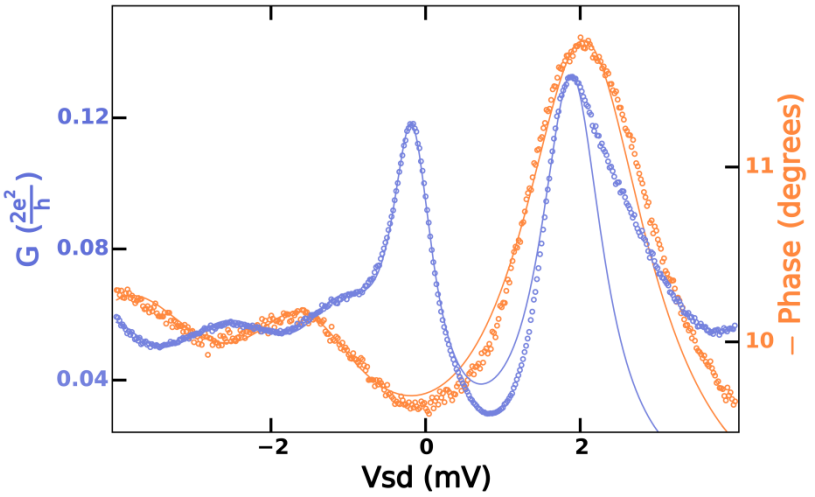
➡ **Charges transfert with a frozen charge dynamics in the dot.**

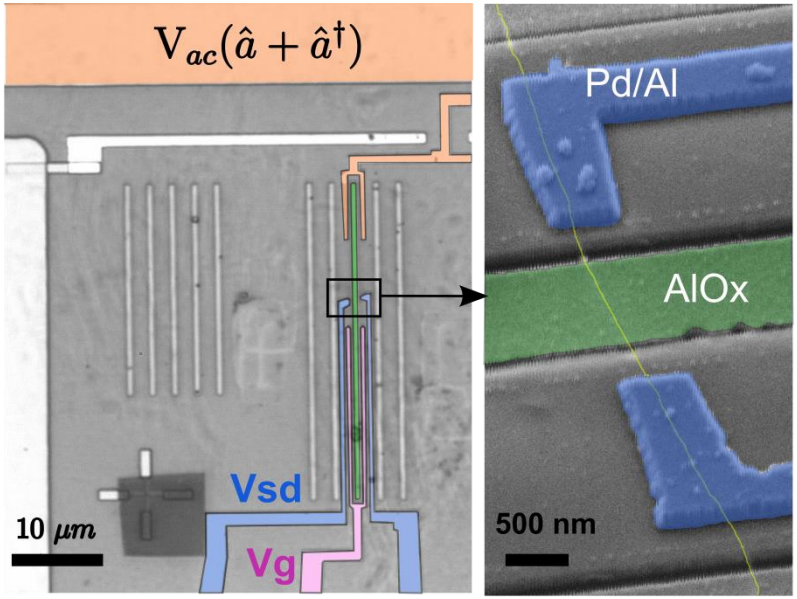
Conclusion

✓**cQED architecture can be used as a *sensitive and precise non-perturbative* probe to study condensed matter problems**

✓**Observation of zero charge dynamics of the Kondo cloud.**







Perspectives of this setup

- Quantum quench of Kondo cloud
- Quantum simulation of strongly correlated fermion-boson systems

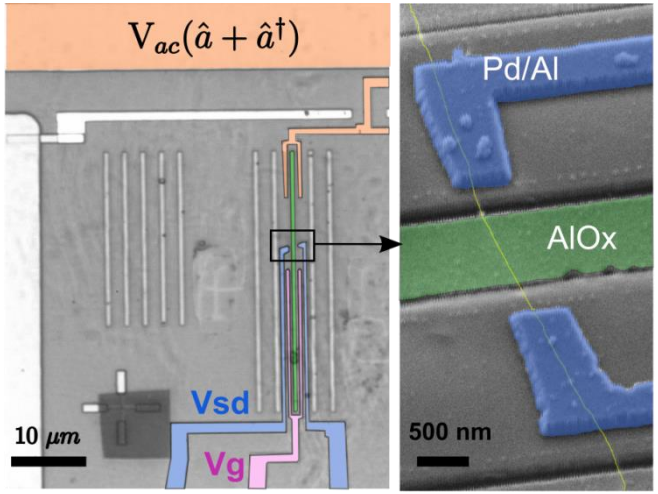
Perspectives

- **Majorana fermions in CNT**

➡ Superconducting electrodes + ferromagnetic bottom gates

R. Egger et al, PRB **85**, 235462 (2012)

✓ cQED architecture



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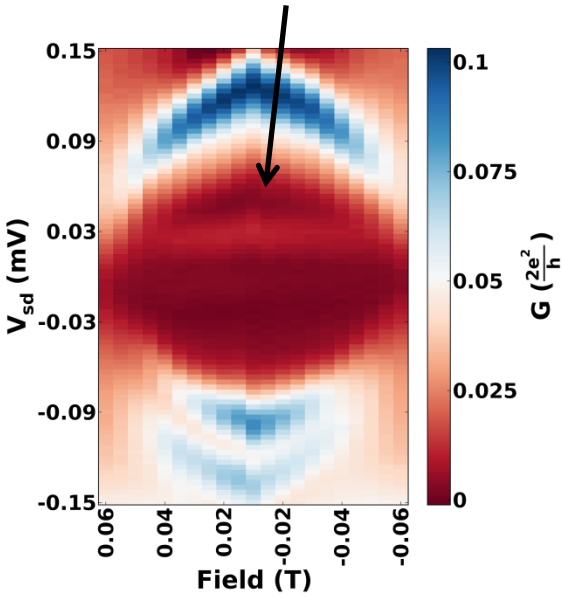
✓ Supgap states



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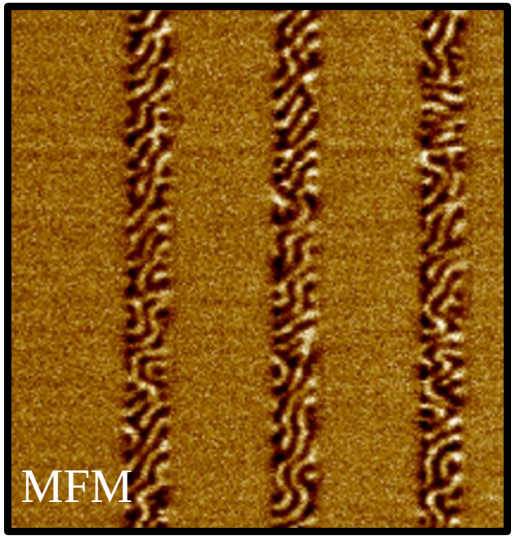
✓ Magnetic texture



- **Coupling them to the cavity**

➡ **Signature of the self adjoint property** $\gamma^\dagger = \gamma$

A. Cottet et al, PRB **88**, 195415 (2013)

Supplementary