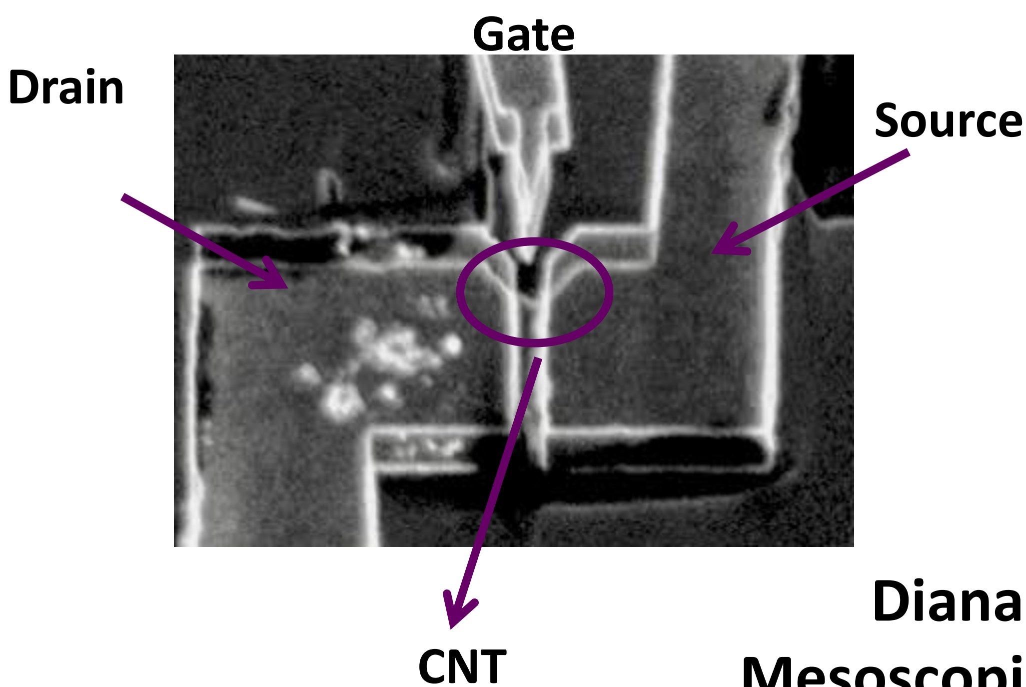
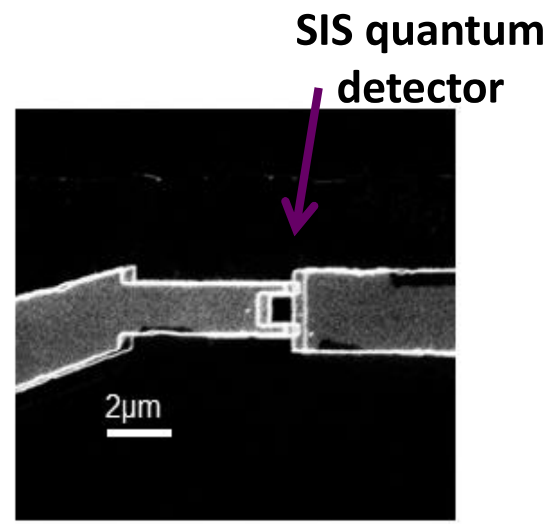
Collapse of the AC Josephson emission of Carbon nanotube in the Kondo regime





Diana WATFA
Mesoscopic physics group

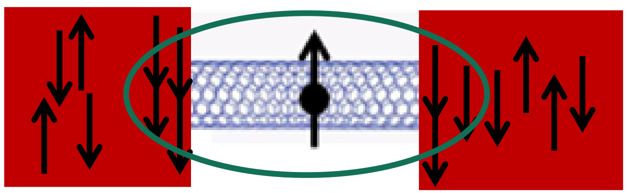
Introduction

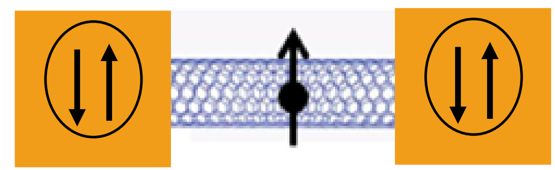
- **goal :**

Kondo effect in the normal state

Superconducting proximity effect

Investigate the competition





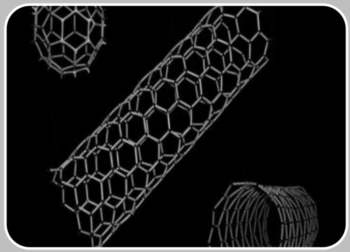
Screening of dot's Spin

Supercurrent due to electron pair tunneling

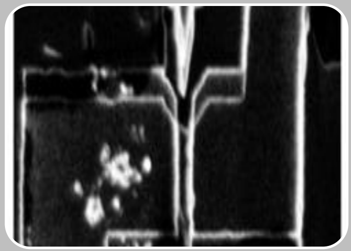
Competition in DC properties (supercurrent, current-phase relation) ✓

Dynamics of this competition at high frequency? Measuring the AC Josephson emission

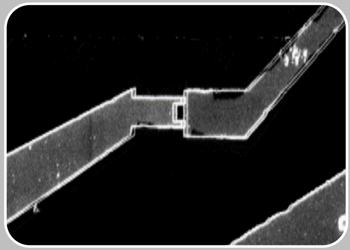
Outline



CNT quantum dot



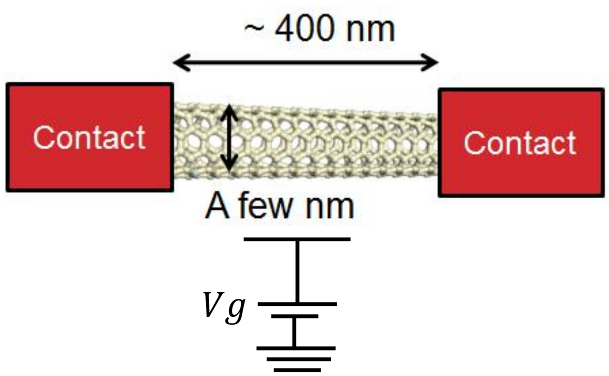
The Kondo effect and superconductivity



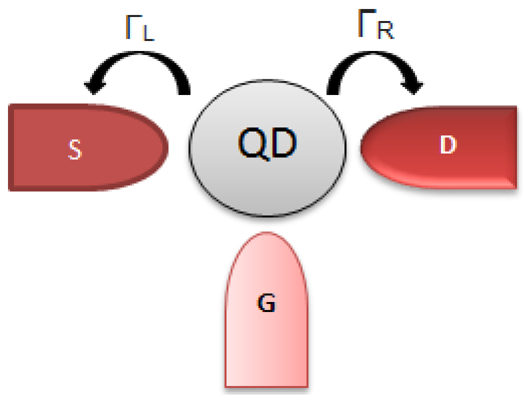
Collapse of the AC Josephson emission

Carbon Nanotube Quantum Dot

T=50mK



k_BT<<ΔE, U



Gate voltage is applies to control number of electrons

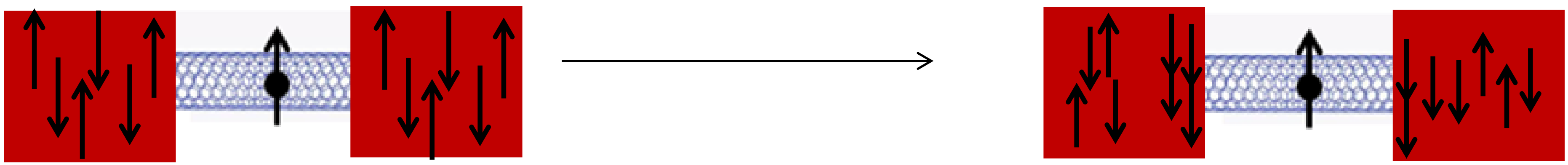
U: Charging energy
Γ: **Coupling constant**

$$\Gamma \approx U$$

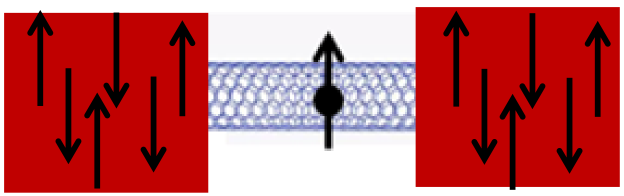
Intermediate regime

Kondo effect in a quantum dot

Kondo screening of the dots impurity.

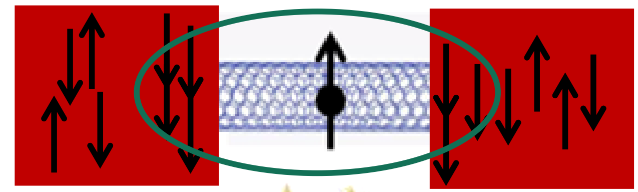


Kondo effect in a quantum dot



Kondo effect for $T < T_K$

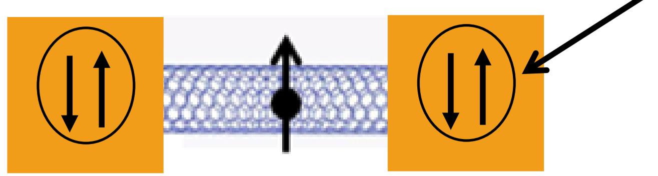
Kondo screening of the dots impurity.



Kondo effect in a quantum dot

- Superconducting electrodes

  Δ: superconducting gap

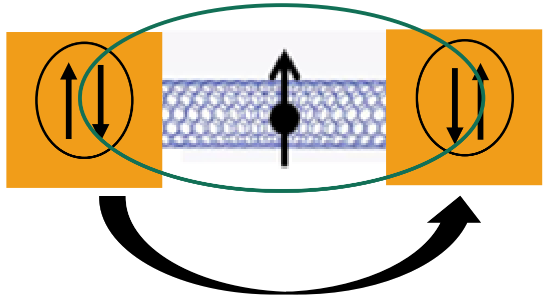


would the Kondo screening survive the superconducting proximity effect??

Coexistence of the Kondo effect with superconductivity?

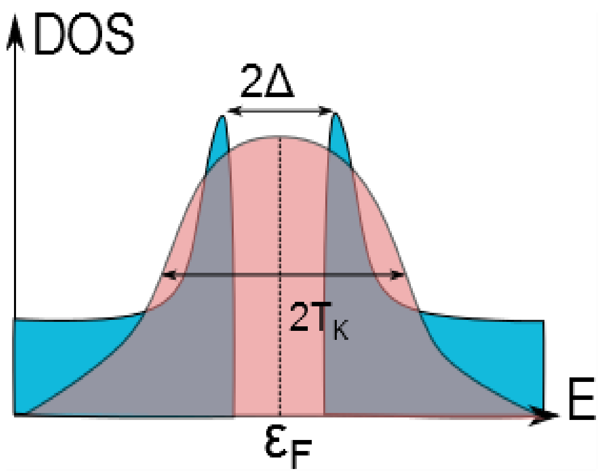
❖competition of strong electron correlations with a proximity effect

$$k_B T_k \gg \Delta$$

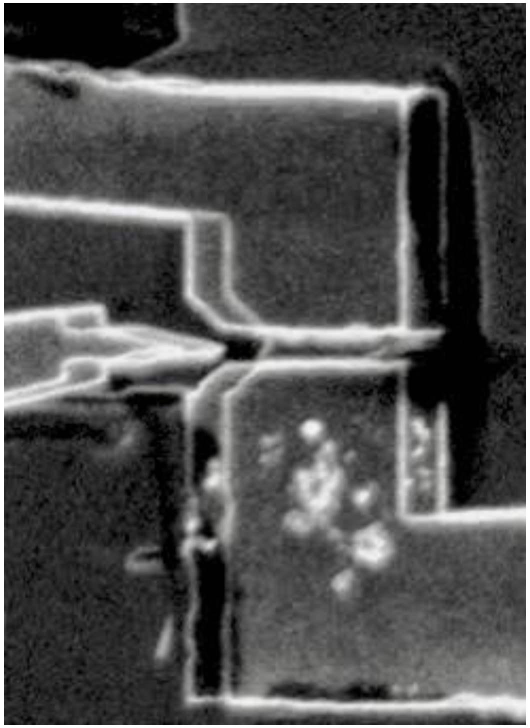


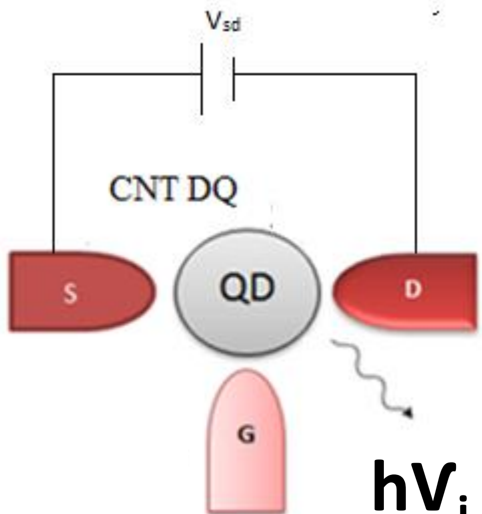
Supercurrent flow

- Kondo screening of the dot's spin



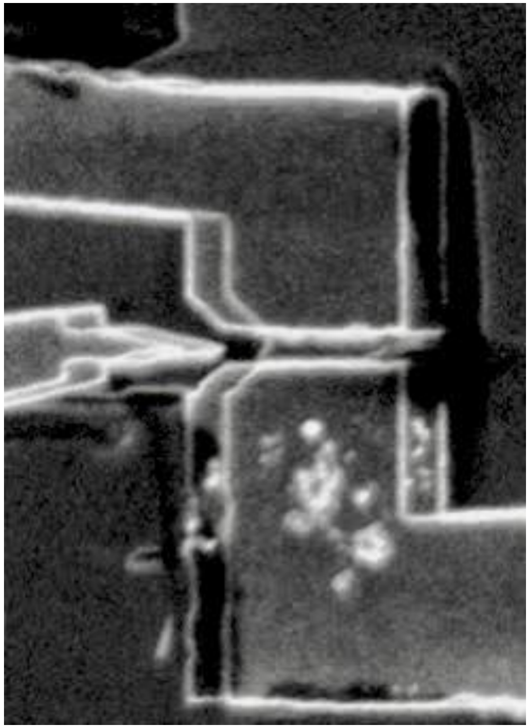
AC Josephson emission in CNT QD

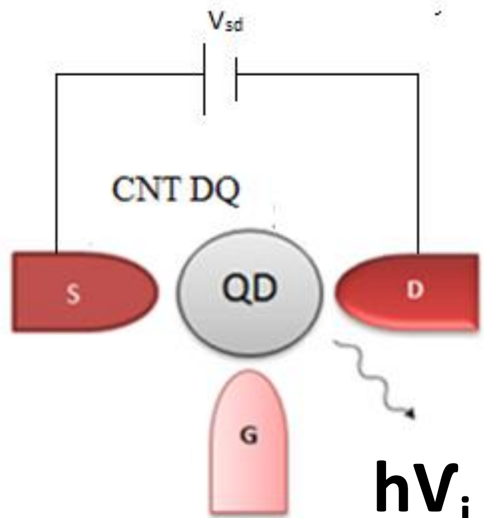




$$hV_j = 2eV$$

AC Josephson emission in CNT QD





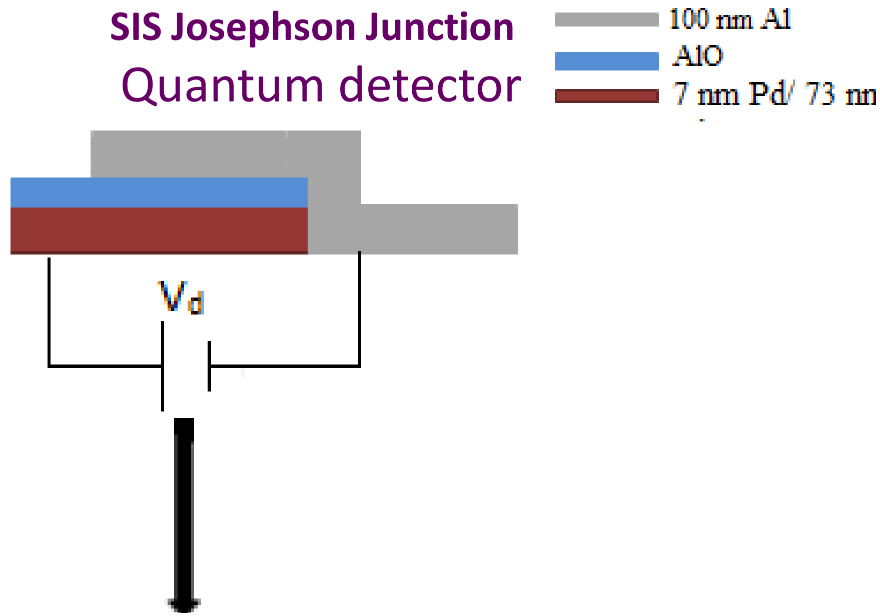
$hV_j = 2eV$

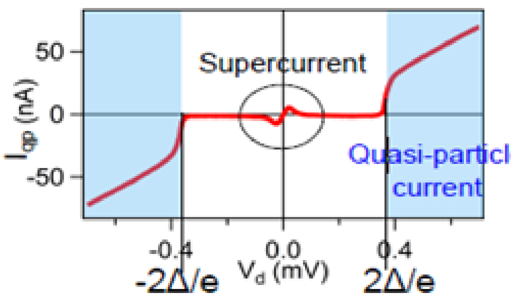
Supercurrent is small ≈ nA ,
how to detect the AC emission??

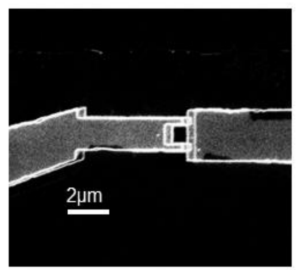
SIS junction noise as quantum detector

SIS Josephson Junction

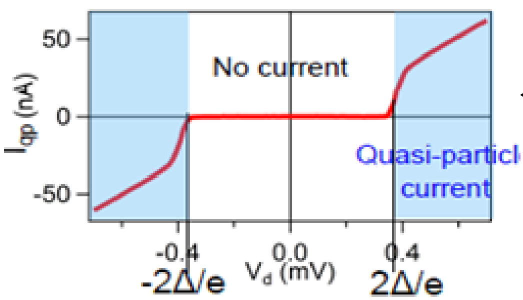
Quantum detector



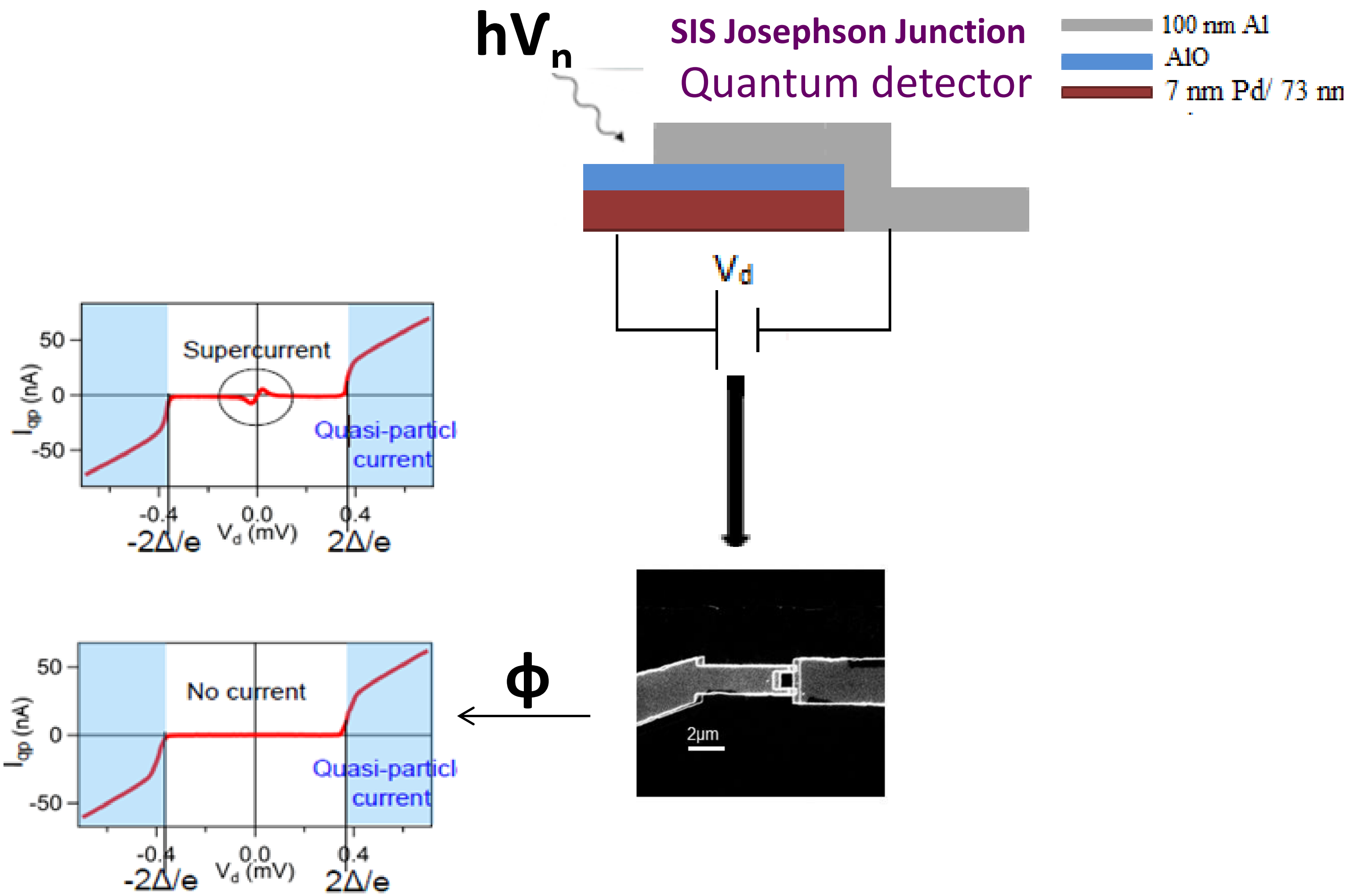




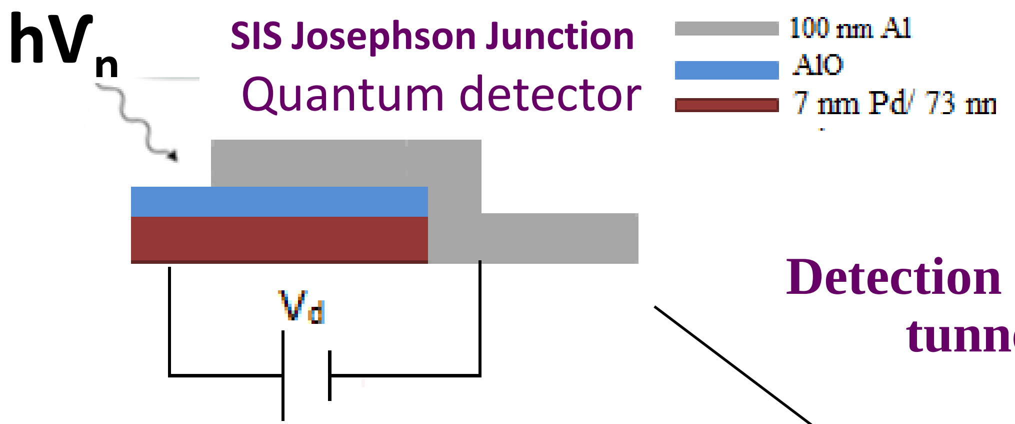
Φ

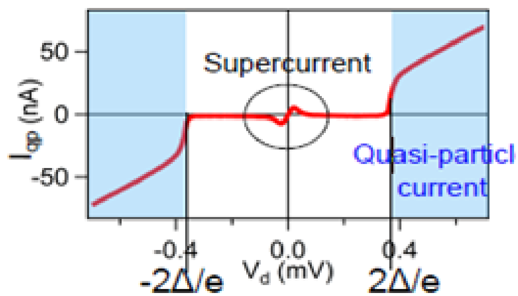


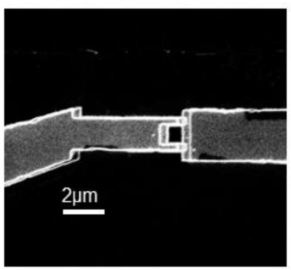
SIS junction noise as quantum detector

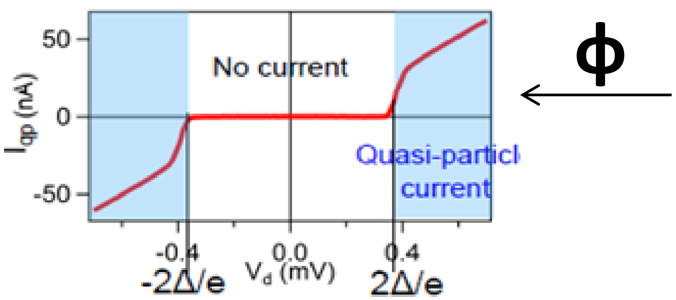


SIS junction noise as quantum detector

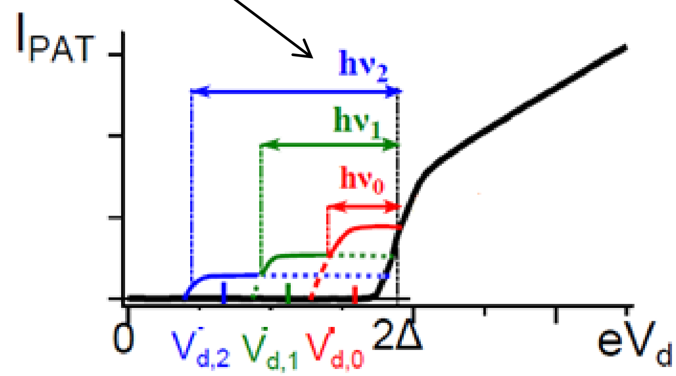






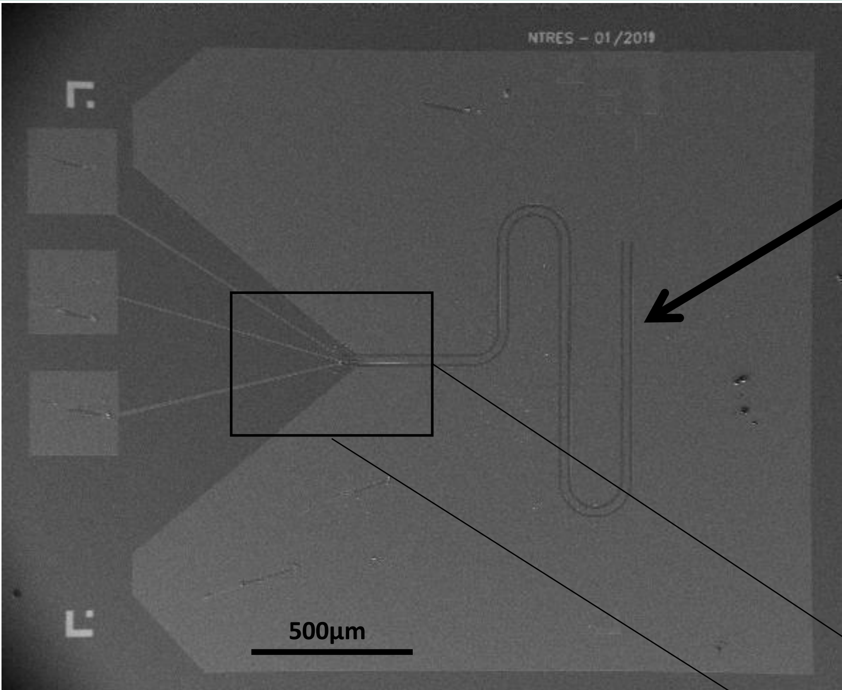


Detection of photon-assisted tunneling current



→ Modification of the I(V) characteristic

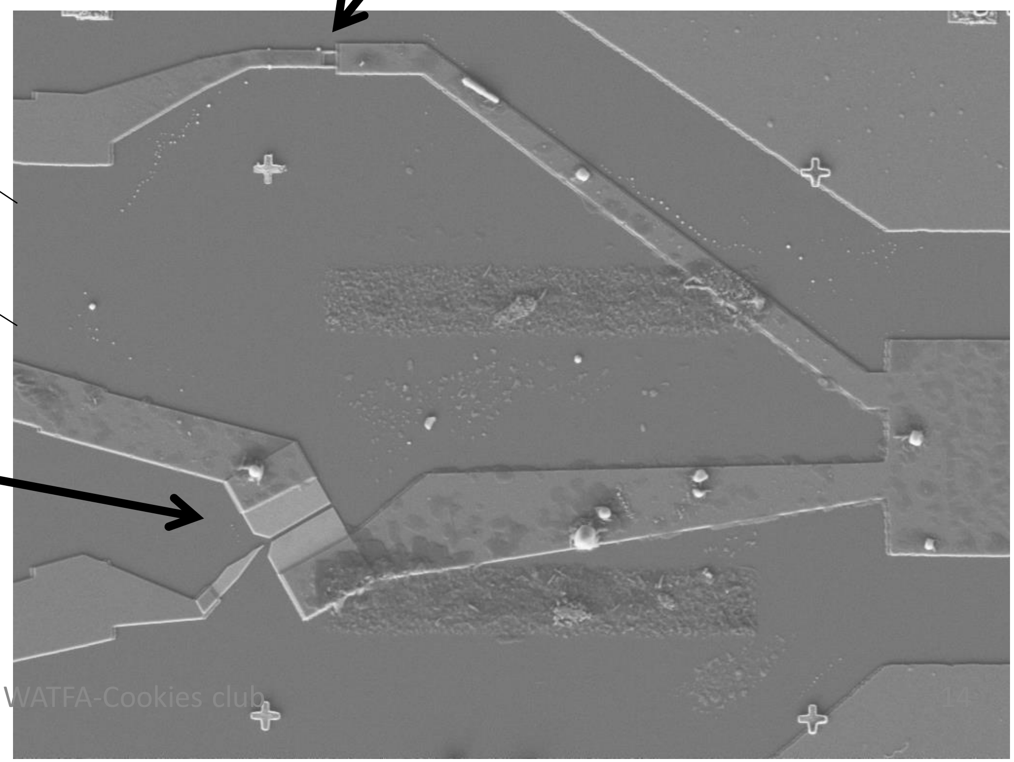
Detection setup for the AC emission at low temperature

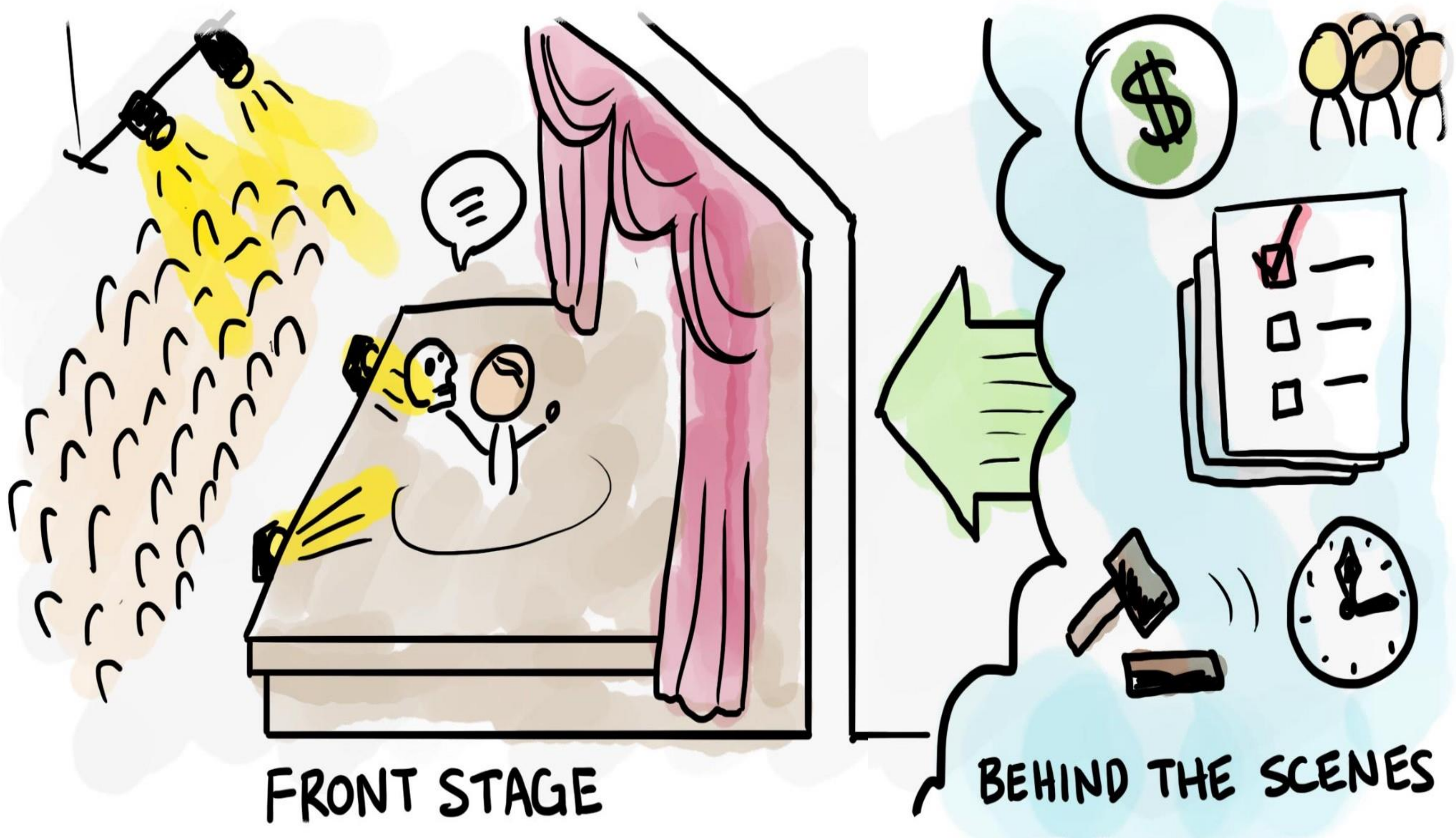


Coplanar waveguide resonator

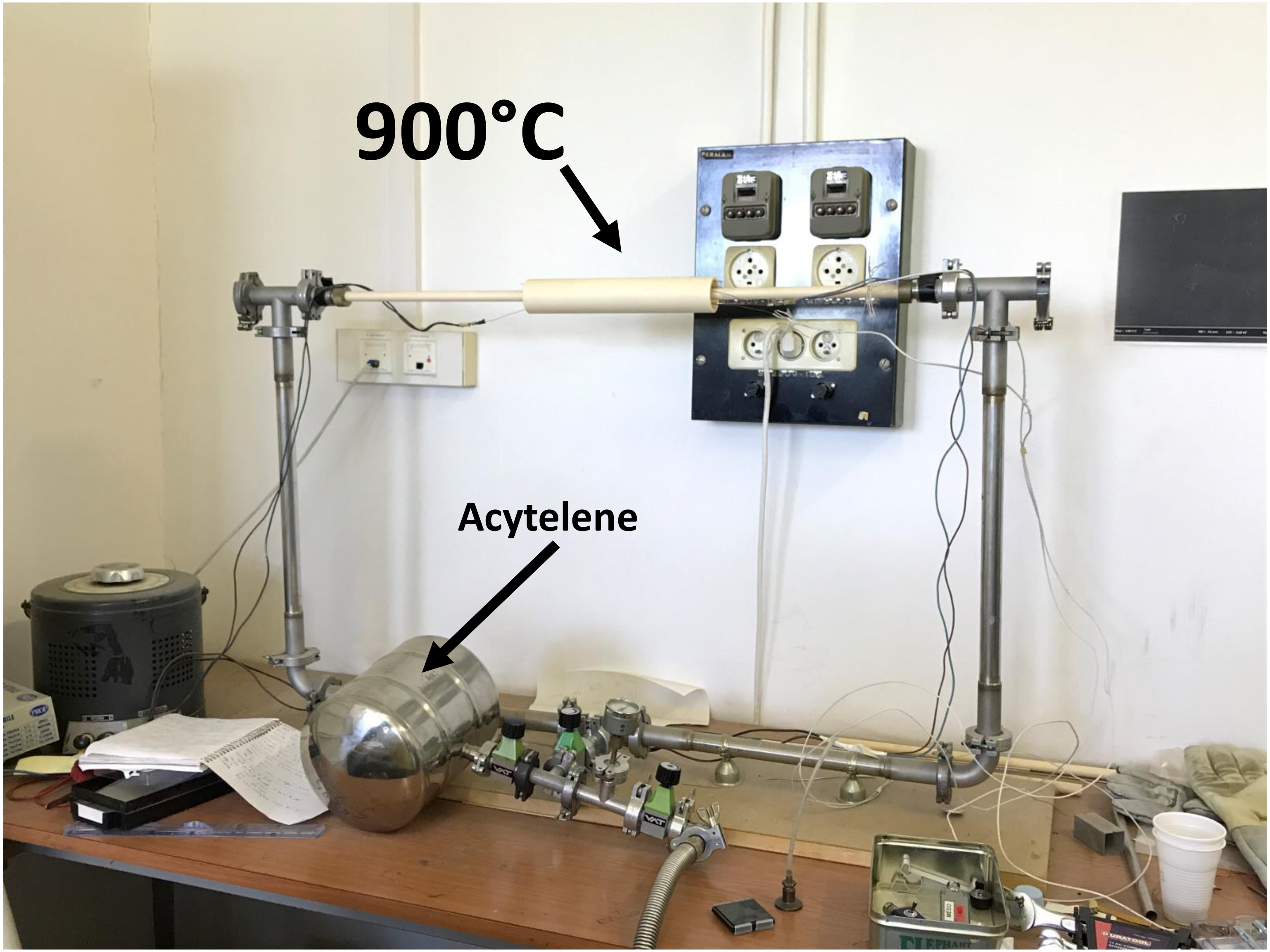
SIS Josephson Junction

CNT Josephson Junction

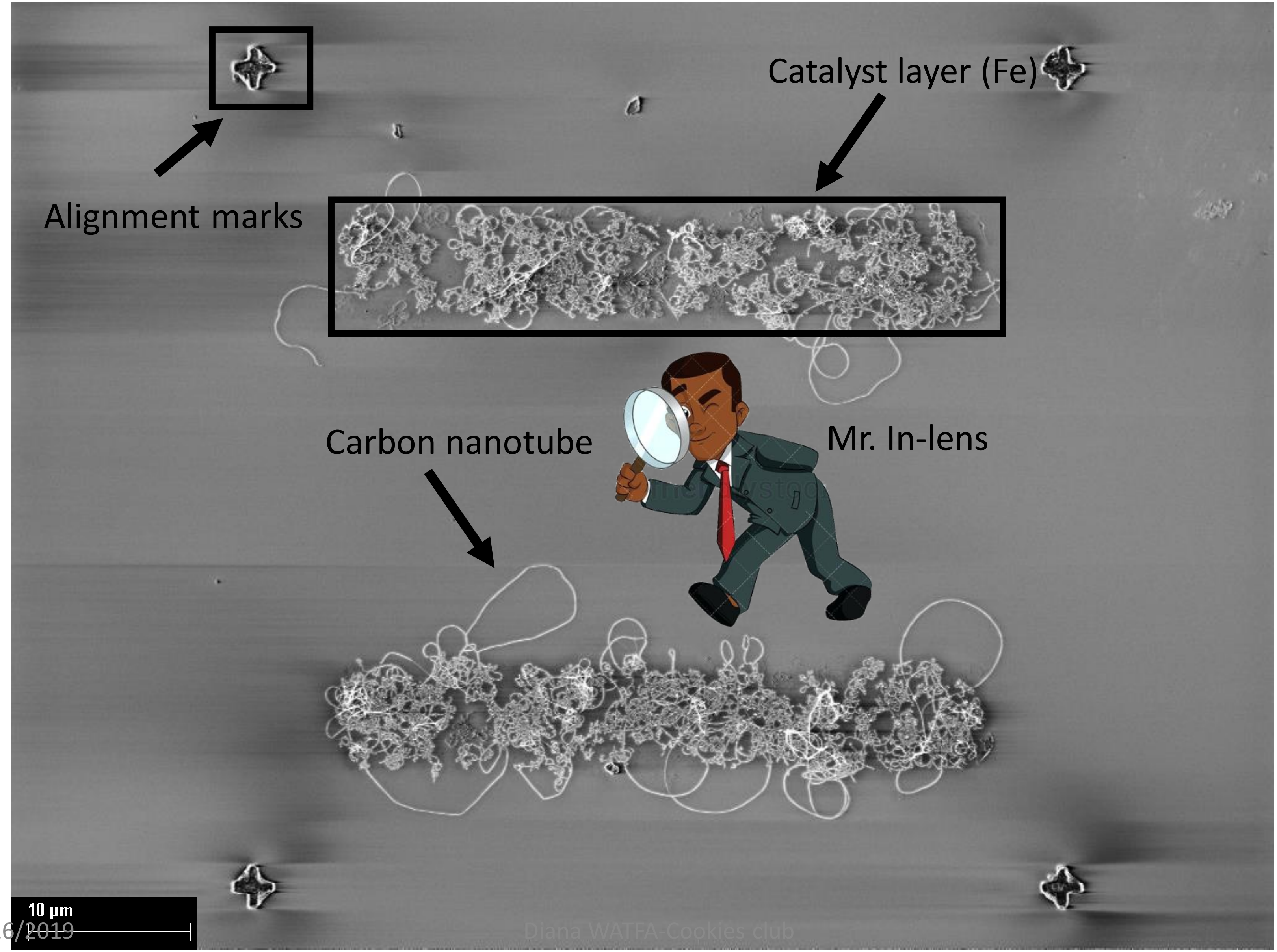



FRONT STAGE
BEHIND THE SCENES

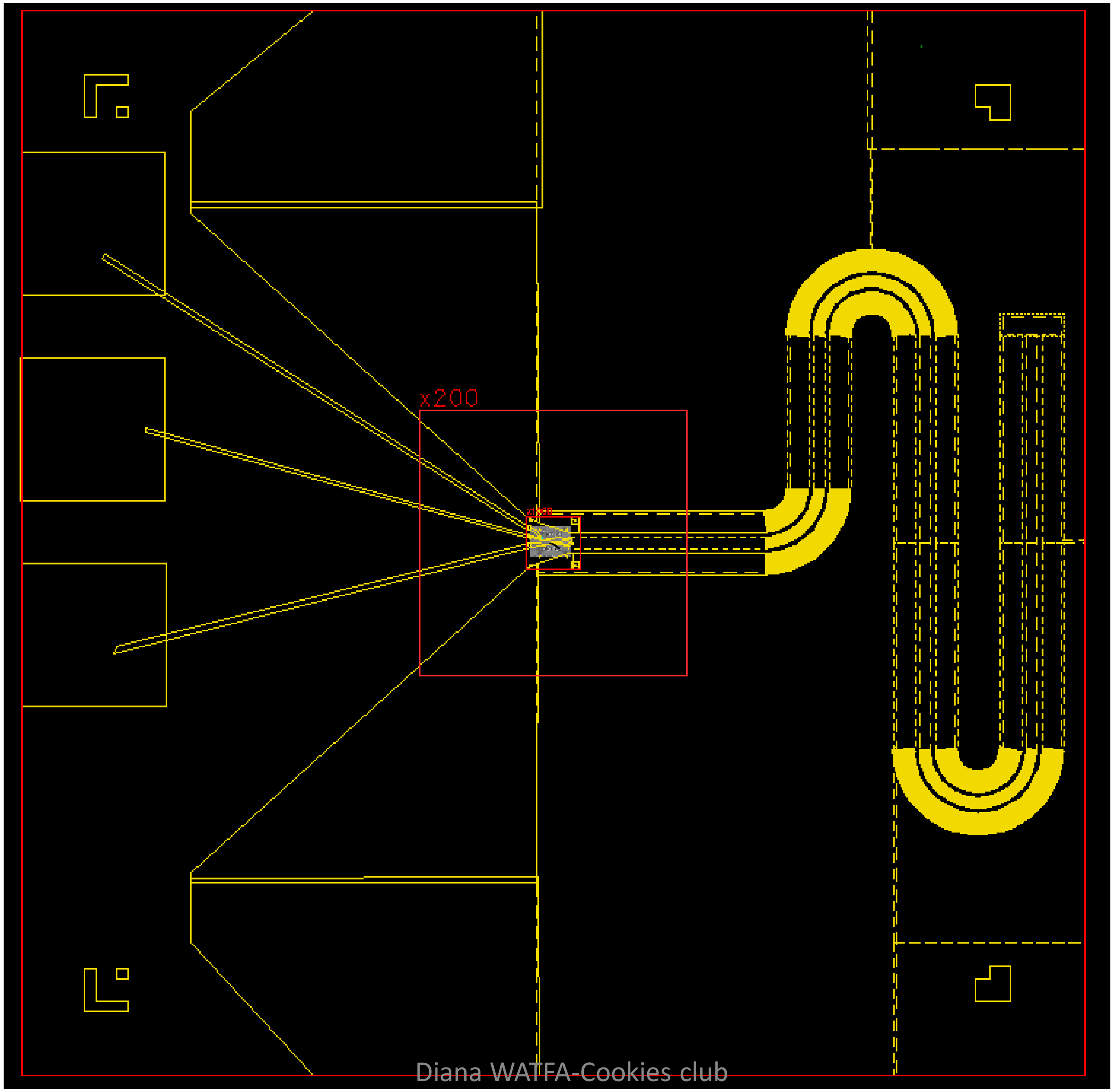
Growing the CNT by chemical vapor deposition (CVD)



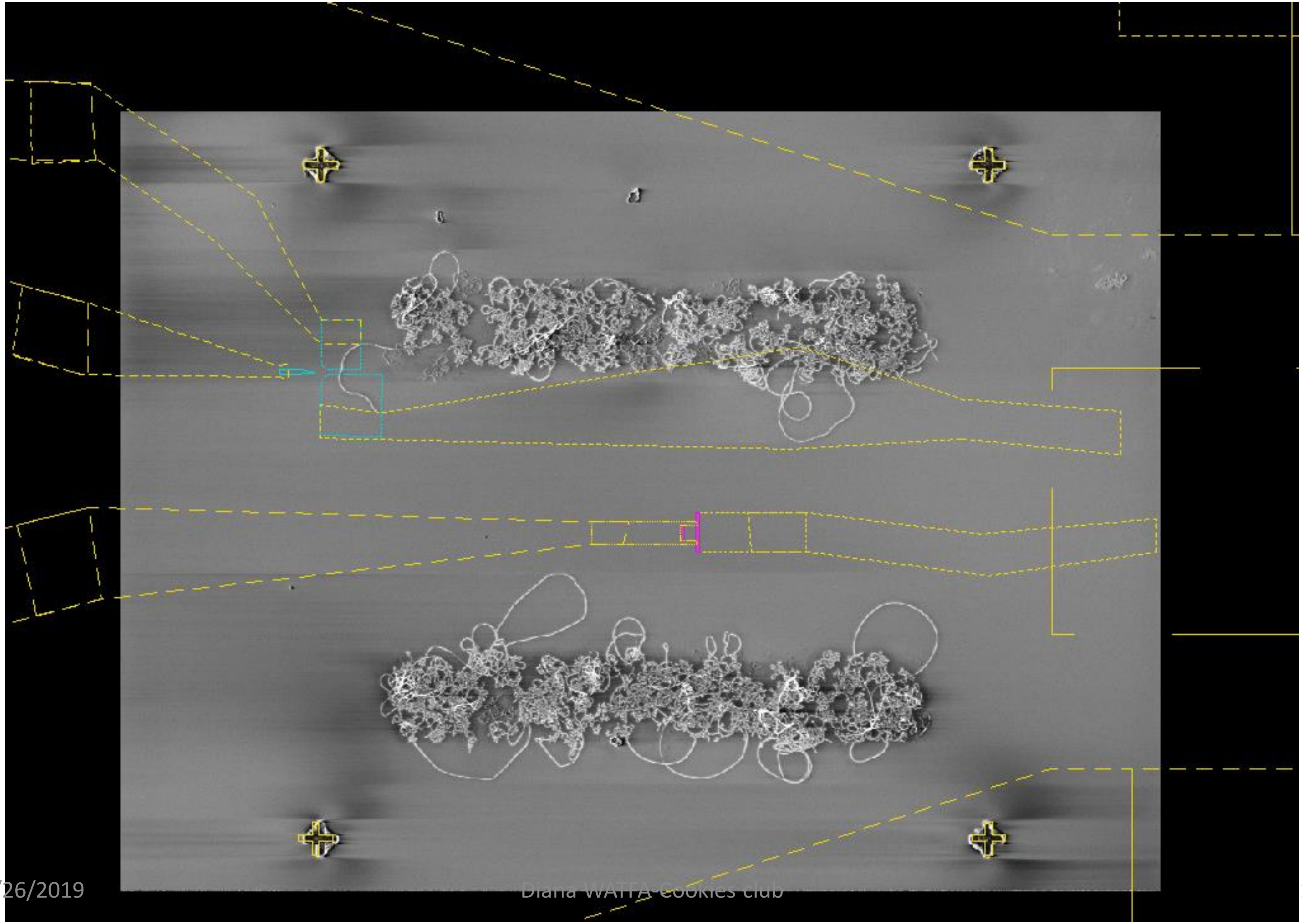
SEM image of the CNT sample



Preparing the design using Designcad



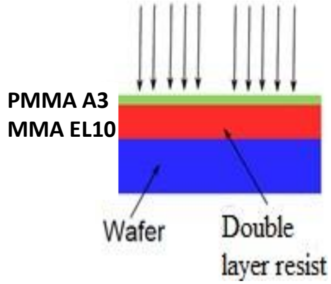
Preparing the design using Design cad



Sample fabrication

Spin-coating of resist

e^- accelerated at 30 kV

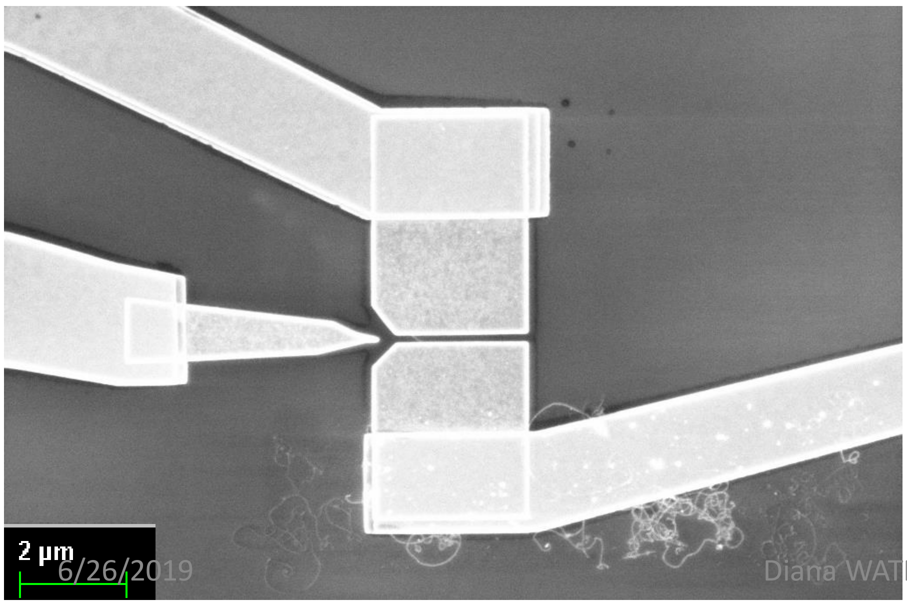


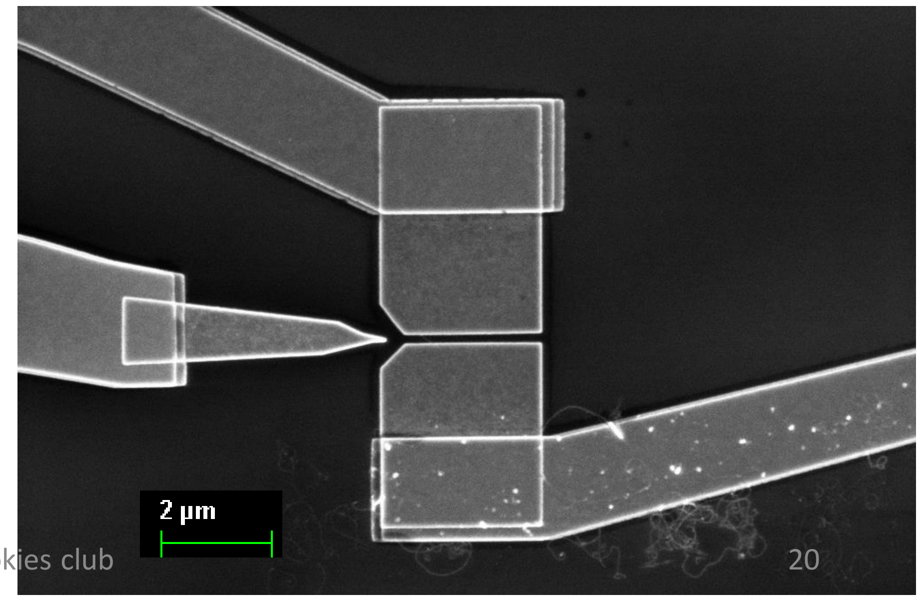
E-Beam lithography with SEM

MIBK development

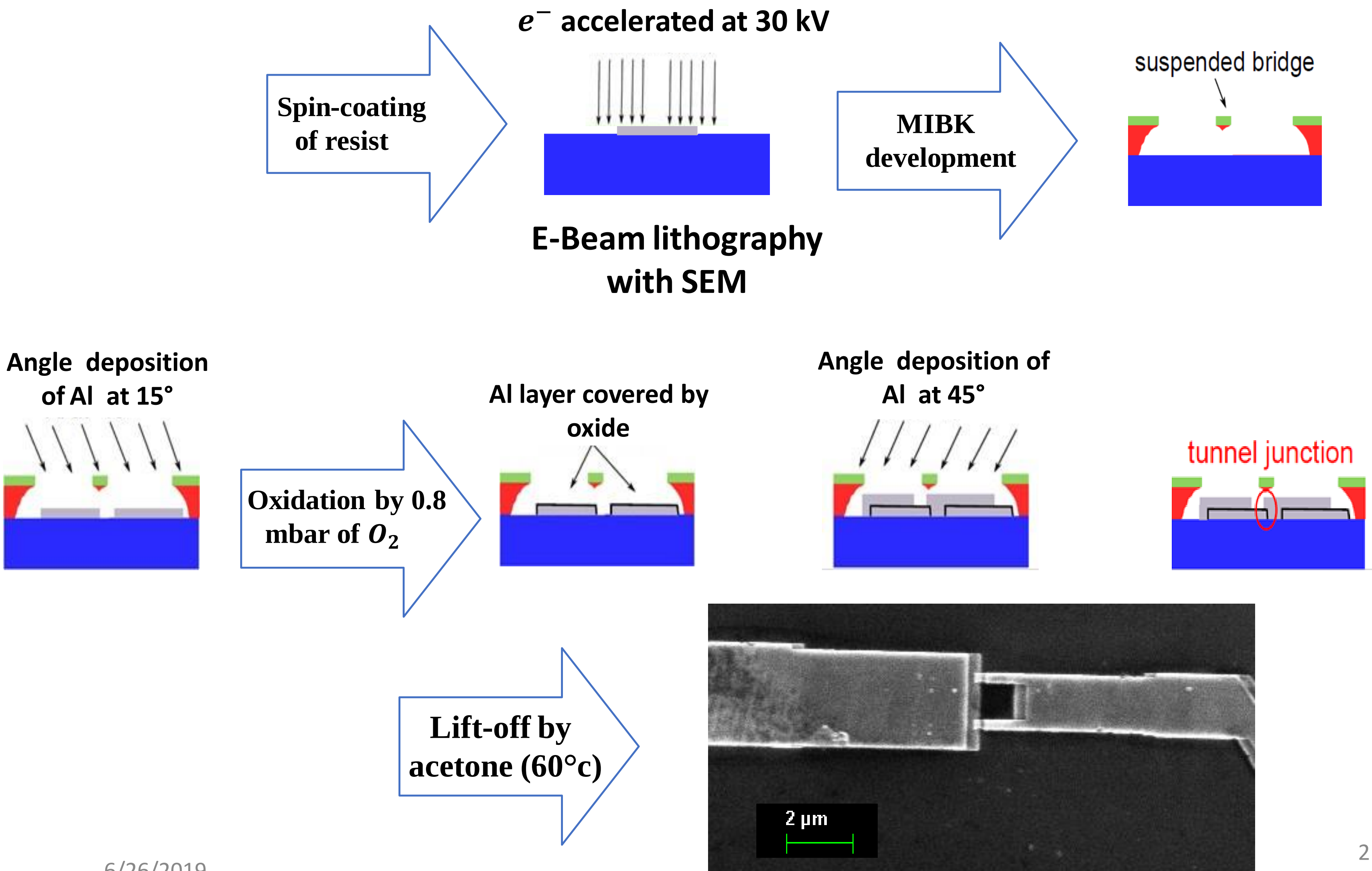
Electron beam evaporation of Pd/Al

Lift-off by acetone (60°c)





Experimental techniques



Low Temperature Measurment

If R_{CNT} and $R_{JJ} \leq 80\ \Omega K$

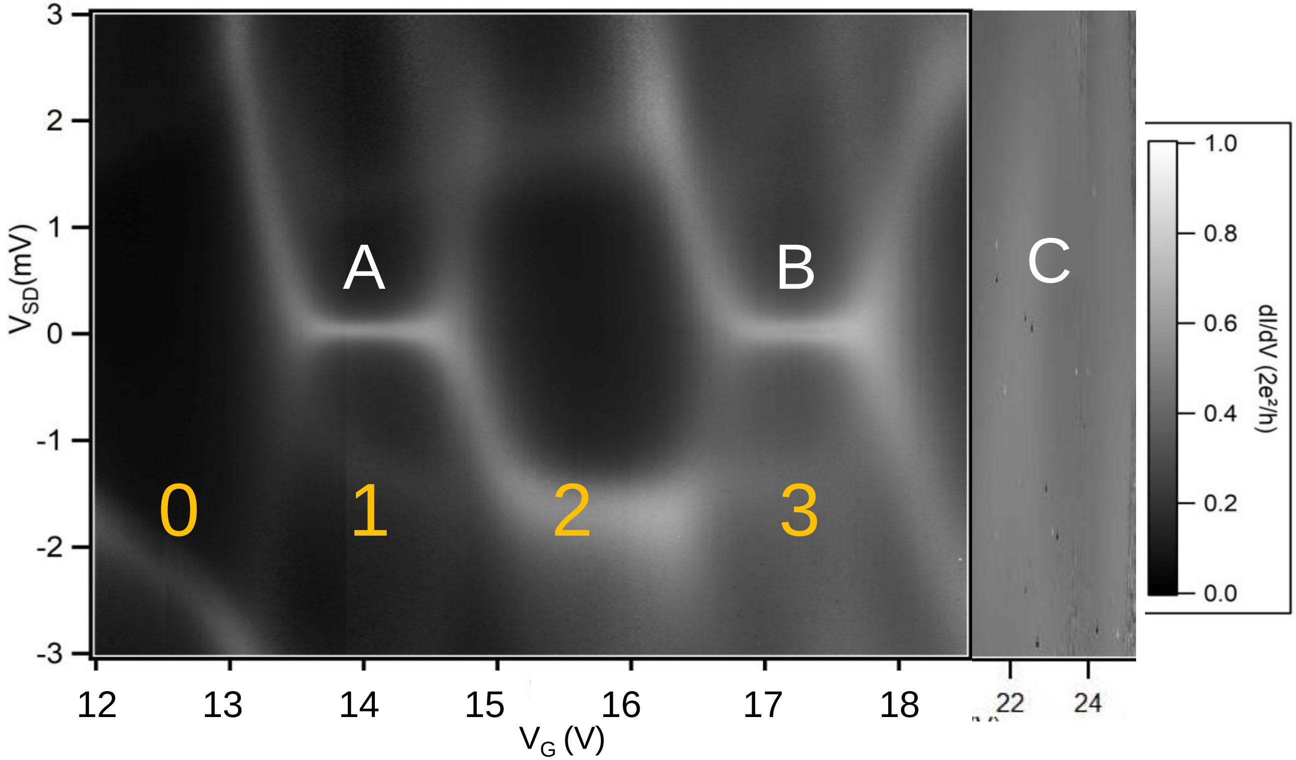
Connecting the sample to the fridge by Al-Si wires

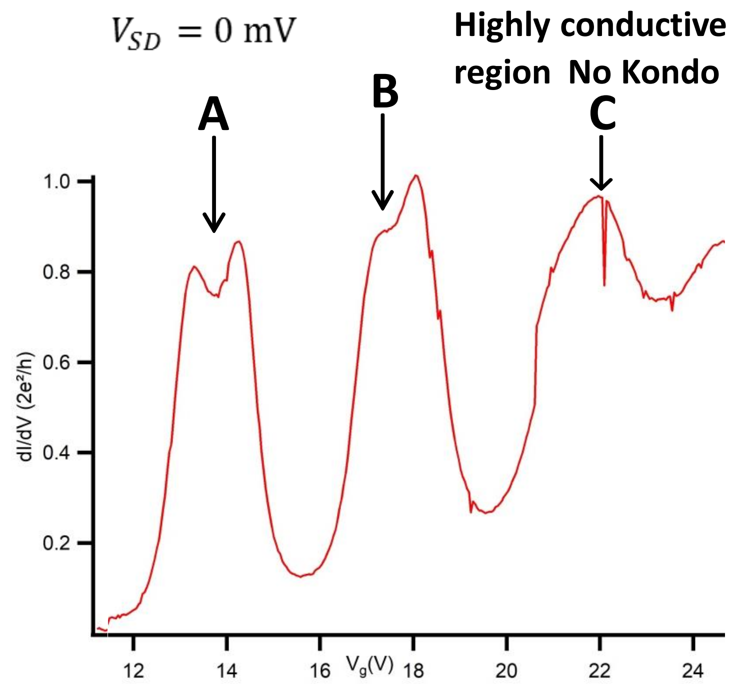
- Cryogenic cooling

Dilution fridge cooled down to T=50mK by mixture of He_3/He_4


GAME OVER
Don't give up now, Mario...
Hope is still underway...
Do you want to try again?
YES or NO

Normal state of the CNT quantum dot

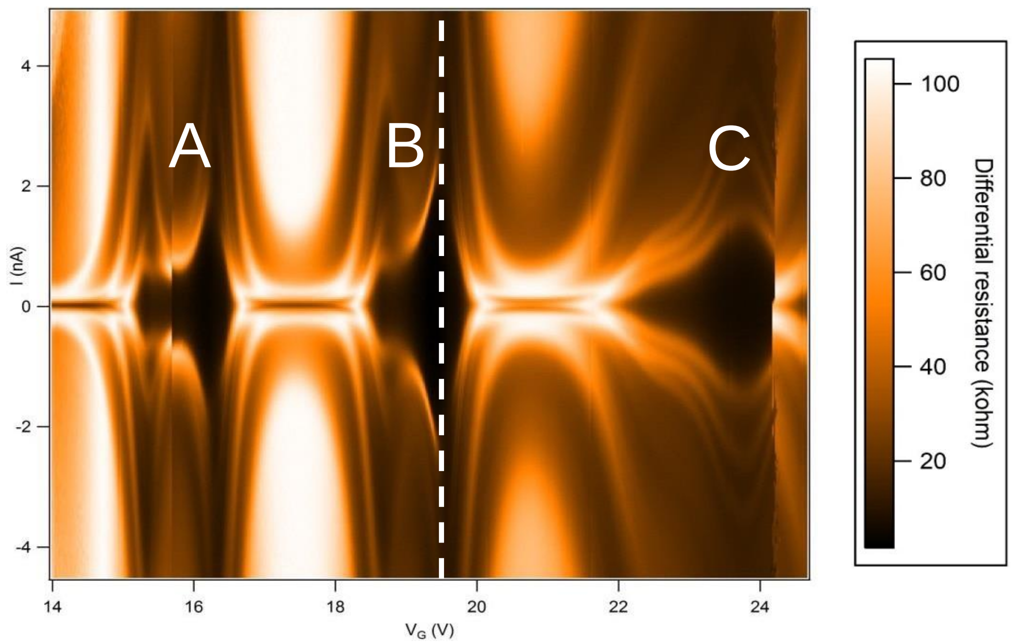




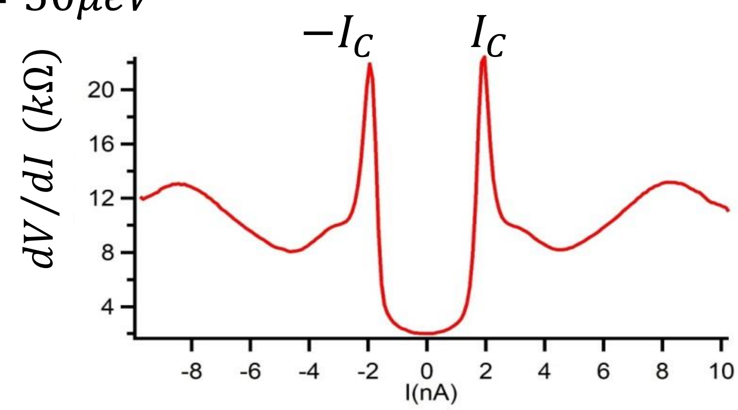
Kondo Ridge A : $T_K = 1.1K, U = 3.9meV, \Gamma = 1.2meV\ , a = \frac{\Gamma_L}{\Gamma_R} = 3.3$

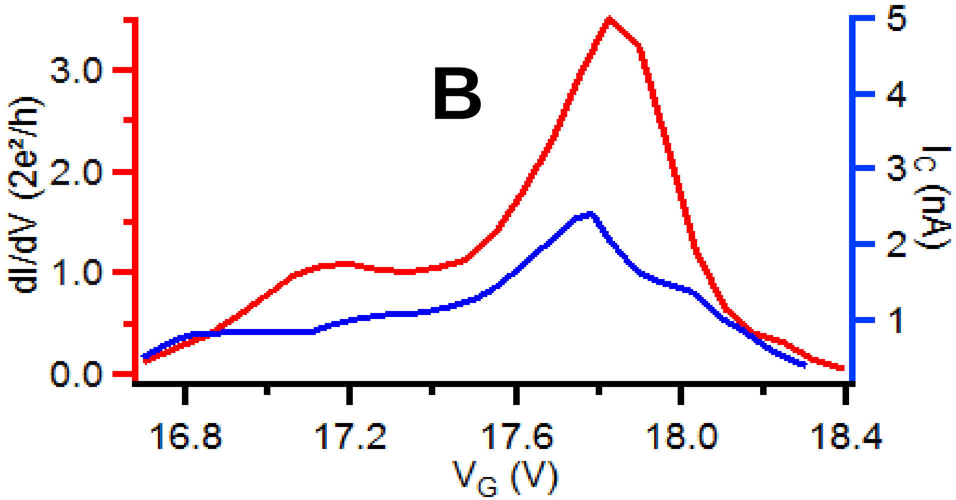
Kondo Ridge B : $T_K = 1.7K, U = 3.7meV, \Gamma = 1.4meV, a = \frac{\Gamma_L}{\Gamma_R} = 2.5$

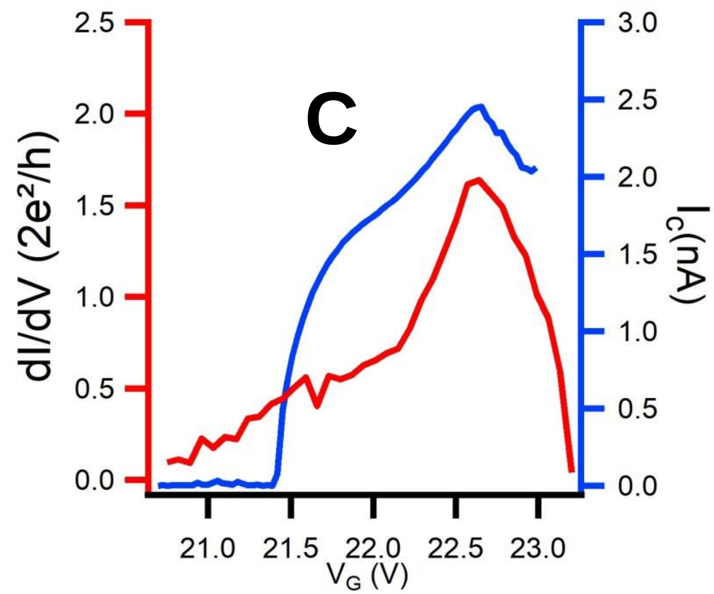
Switching current of the CNT Josephson junction



$\Delta = 50\mu eV$

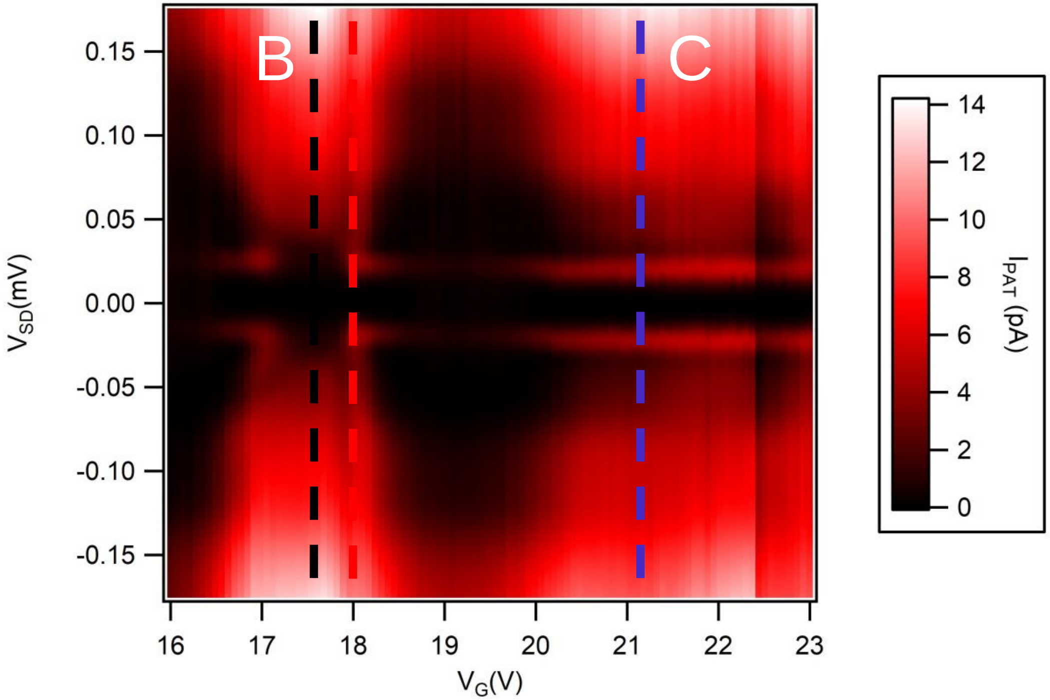


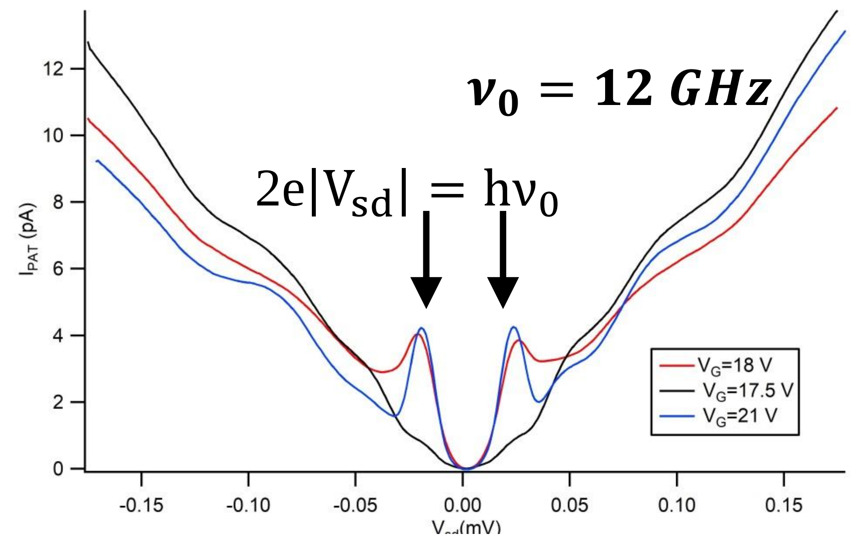


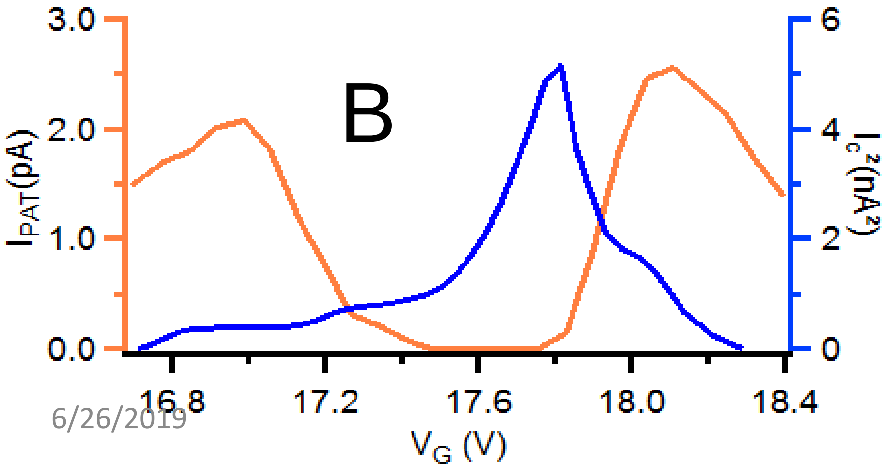


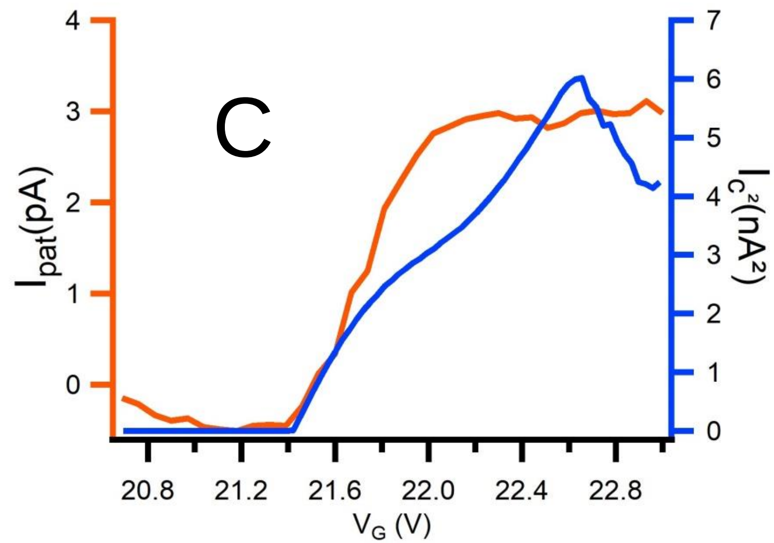
Collapse of the AC Josephson emission!!

Photo assisted tunneling current of the detector: $I_{PAT}\ \alpha\ AC\ josephson\ emission$



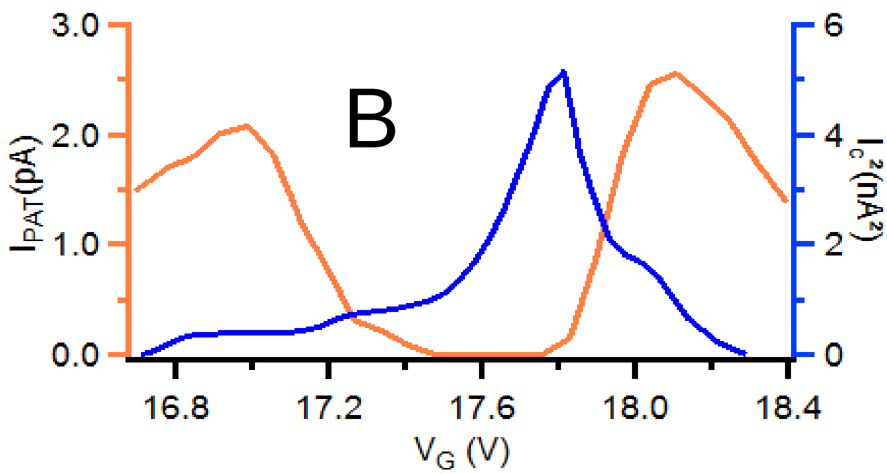


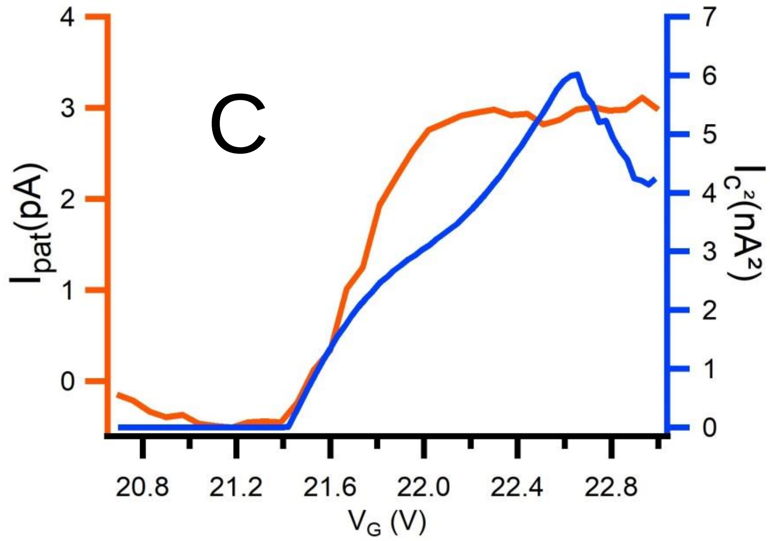




Collapse of the AC Josephson emission

Photo assisted tunneling current of the detector: $I_{PAT}\ \alpha\ AC\ josephson\ emission$





Strong reduction of the PAT current in the center of the Kondo Ridge B

↓

Collapse of the AC Josephson emission in the Kondo region

Interpretation

Kondo effect or Landau-Zener transition?

- **Collapse of AC Josephson emission in Kondo region only!!** **Kondo physics!**

For $\nu = 12$ Ghz

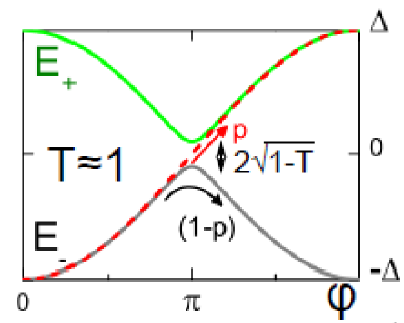
$\frac{h\nu}{k_B T_K} = 0.52$ and 0.34 for Kondo ridge A and B

Frequency cut-off of the Kondo effect ?

Cut-off seen in noise experiment : Delagrange *et al.* PRB (2018).

- **Landau-Zener transition:**

High T, the ABS are to close ⟶ transition to excited level,



AC relation $\propto \sin\left(\frac{2eV}{\hbar}t\right)$

Landau-Zener $\propto \sin\left(\frac{4eV}{\hbar}t\right)$

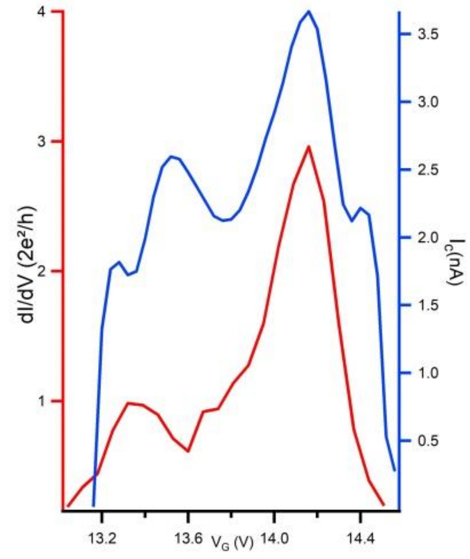
} No 4π periodic AC Josephson effect

$P_{Z/A}=0.17$
$P_{Z/B}=0.28$

Calculating the ABS spectrum of the QD

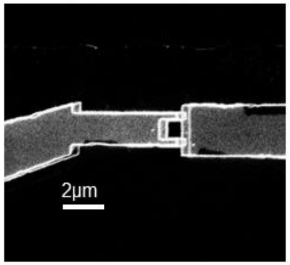
Conclusion

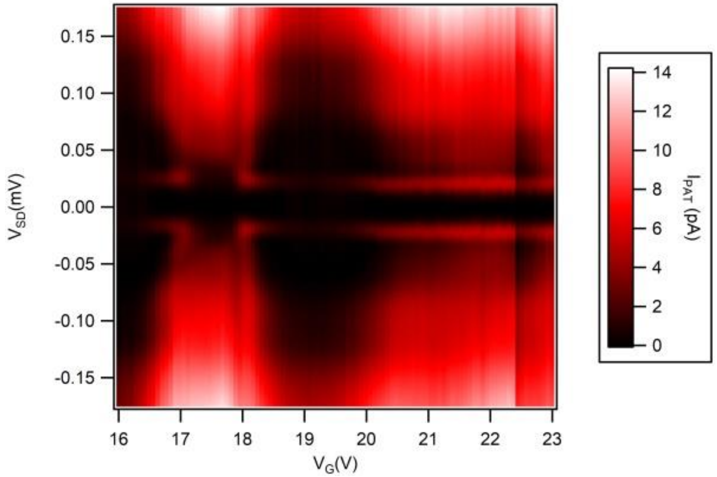
- Competition between Kondo and Superconducting proximity effect :
  the two effect cooperate: DC supercurrent is enhanced



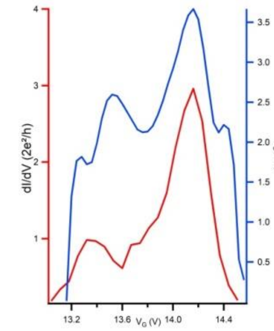
- Dynamics of this competition by detecting AC Josephson effect

Using on chip Quantum detector.



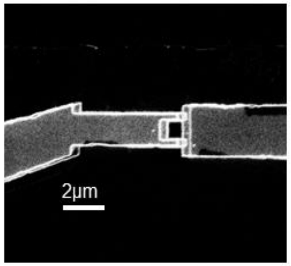


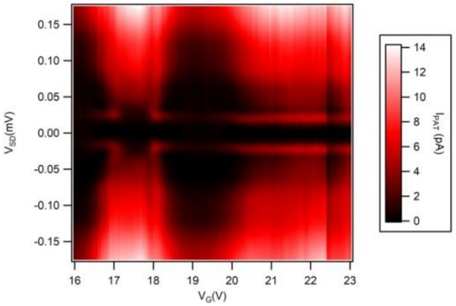
Conclusion



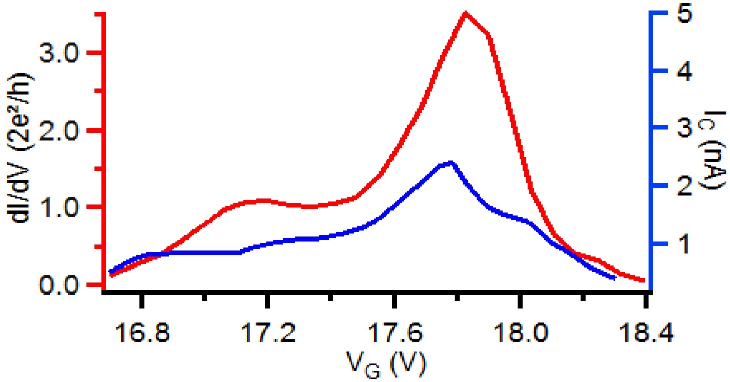
- Competition between Kondo and Superconducting proximity effect : the two effect cooperate: DC supercurrent is enhanced
- Dynamics of this competition by detecting AC Josephson effect

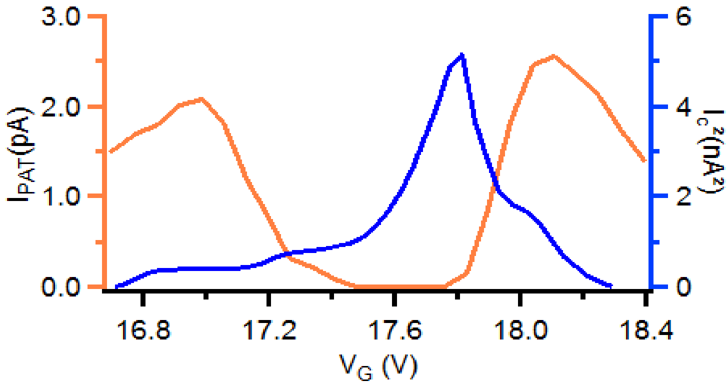
Using on chip Quantum detector.





- **Collapse of the Josephson emission in the Kondo regime**





Thank you for your attention