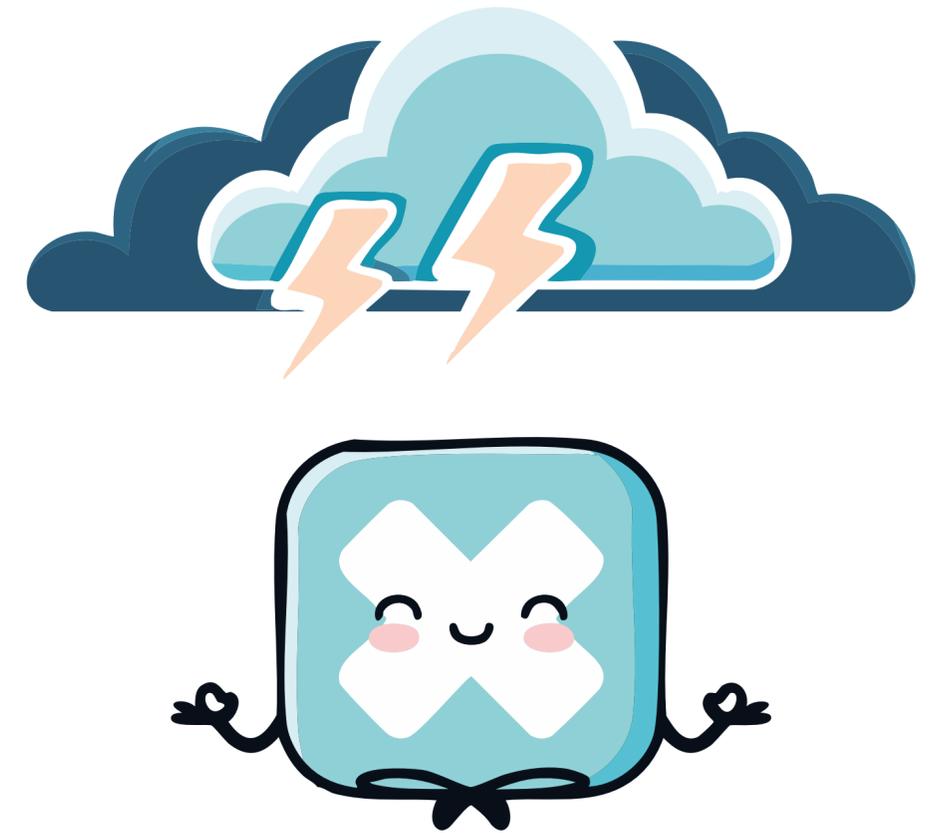
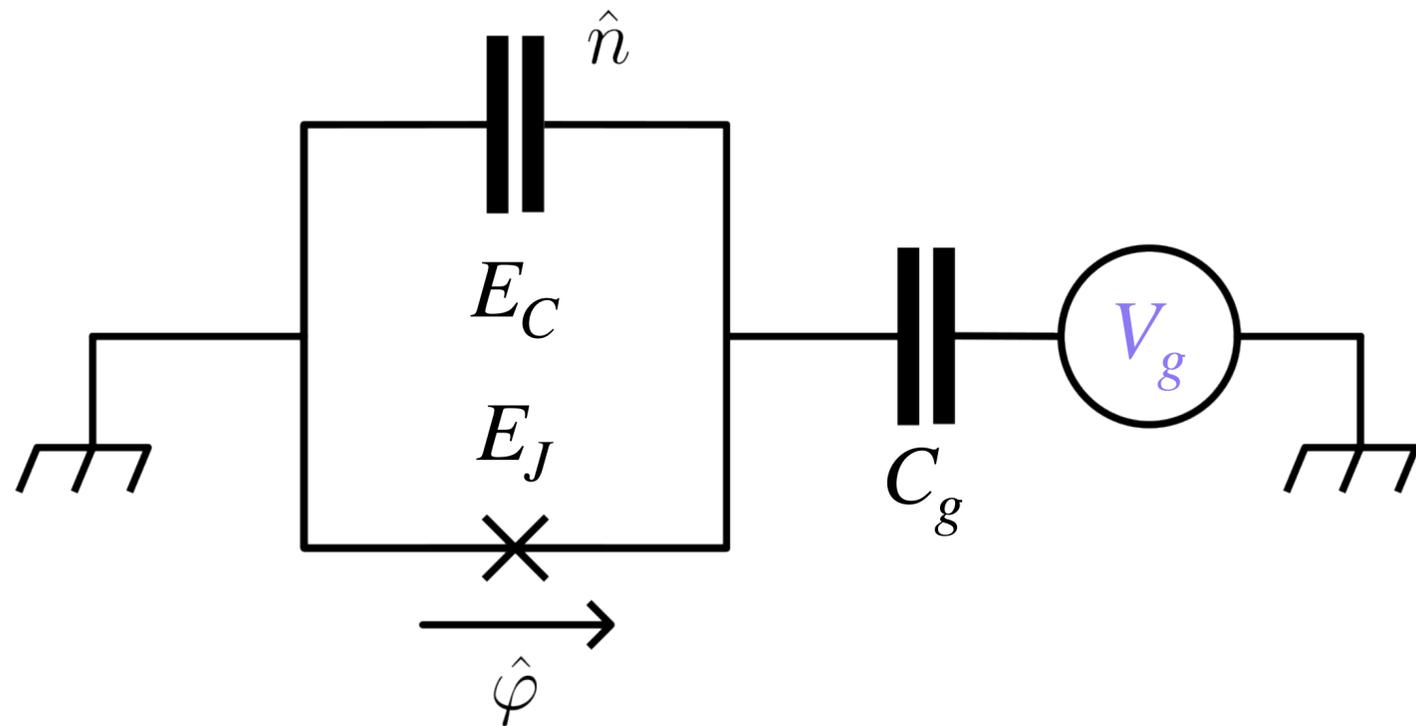


Absence Of Charge Drifts in a Cooper Pair Box



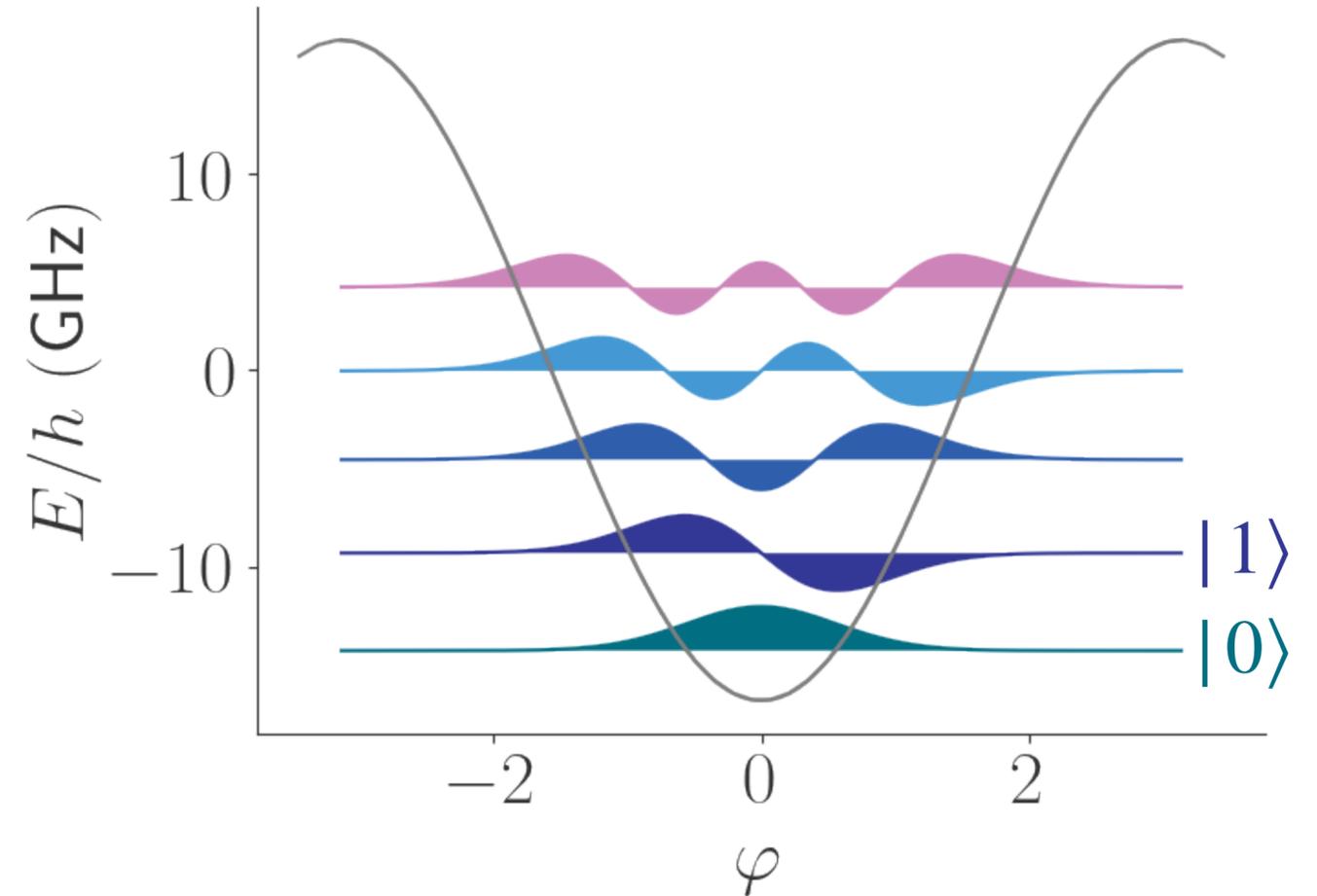
Adria Rospars, ENS de Lyon

The Cooper Pair Box



$$\hat{H} = 4E_C(\hat{n} - n_g)^2 - E_J \cos \hat{\varphi}$$

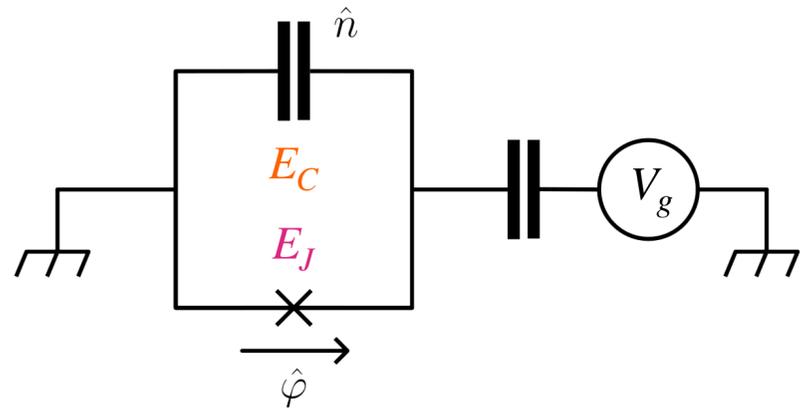
$$n_g = \frac{C_g V_g}{2e}$$



$$E_J/\hbar = 16.83 \text{ GHz}$$

$$E_C/\hbar = 199.7 \text{ MHz}$$

From the Cooper Pair Box to the Transmon



$$E_J/E_C = 3$$

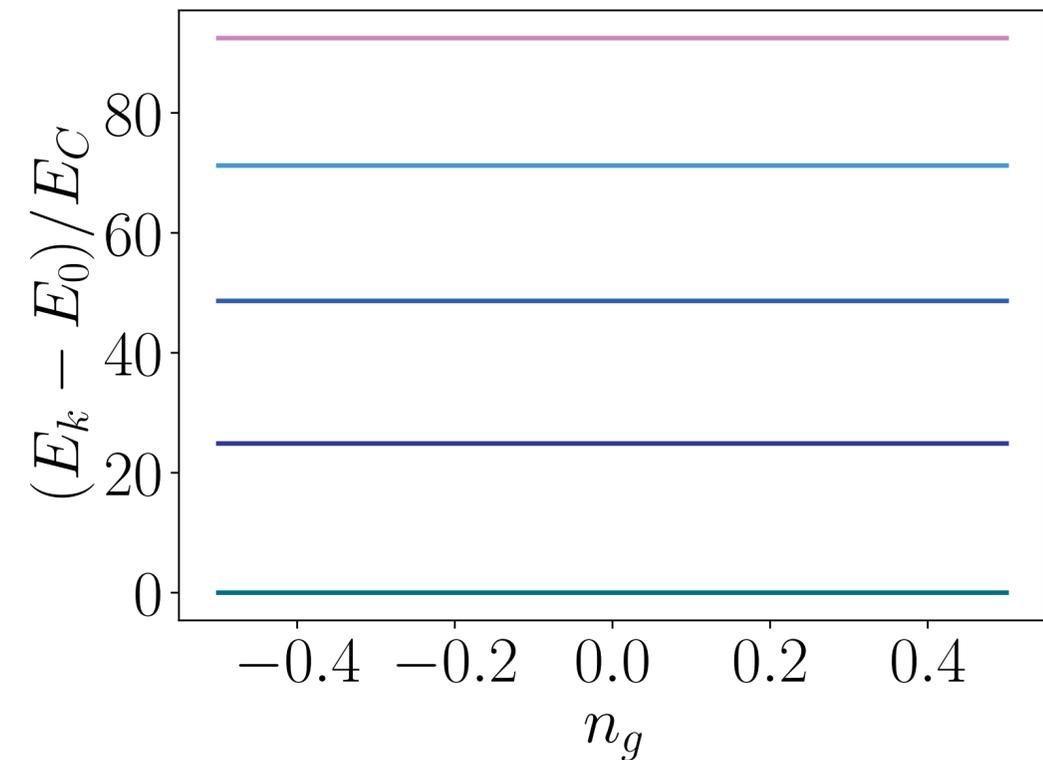
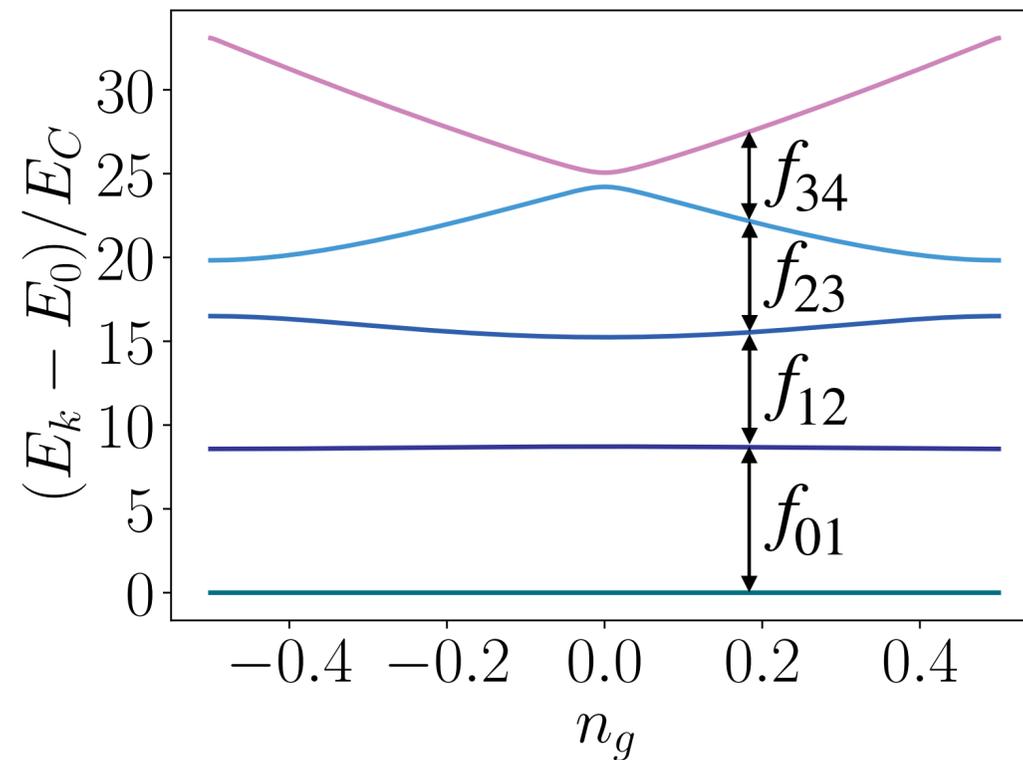
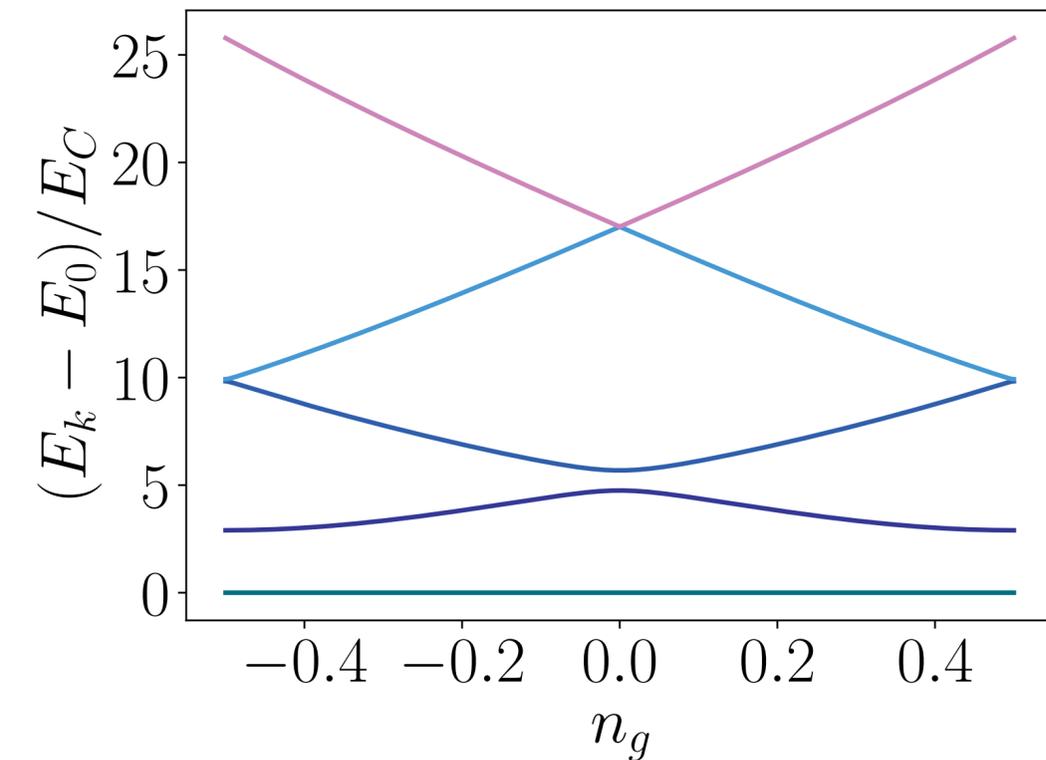
$$\Gamma_2^{\text{charge noise}} \propto \left| \frac{df_{01}}{dn_g} \right|$$

$$E_J/E_C = 12$$

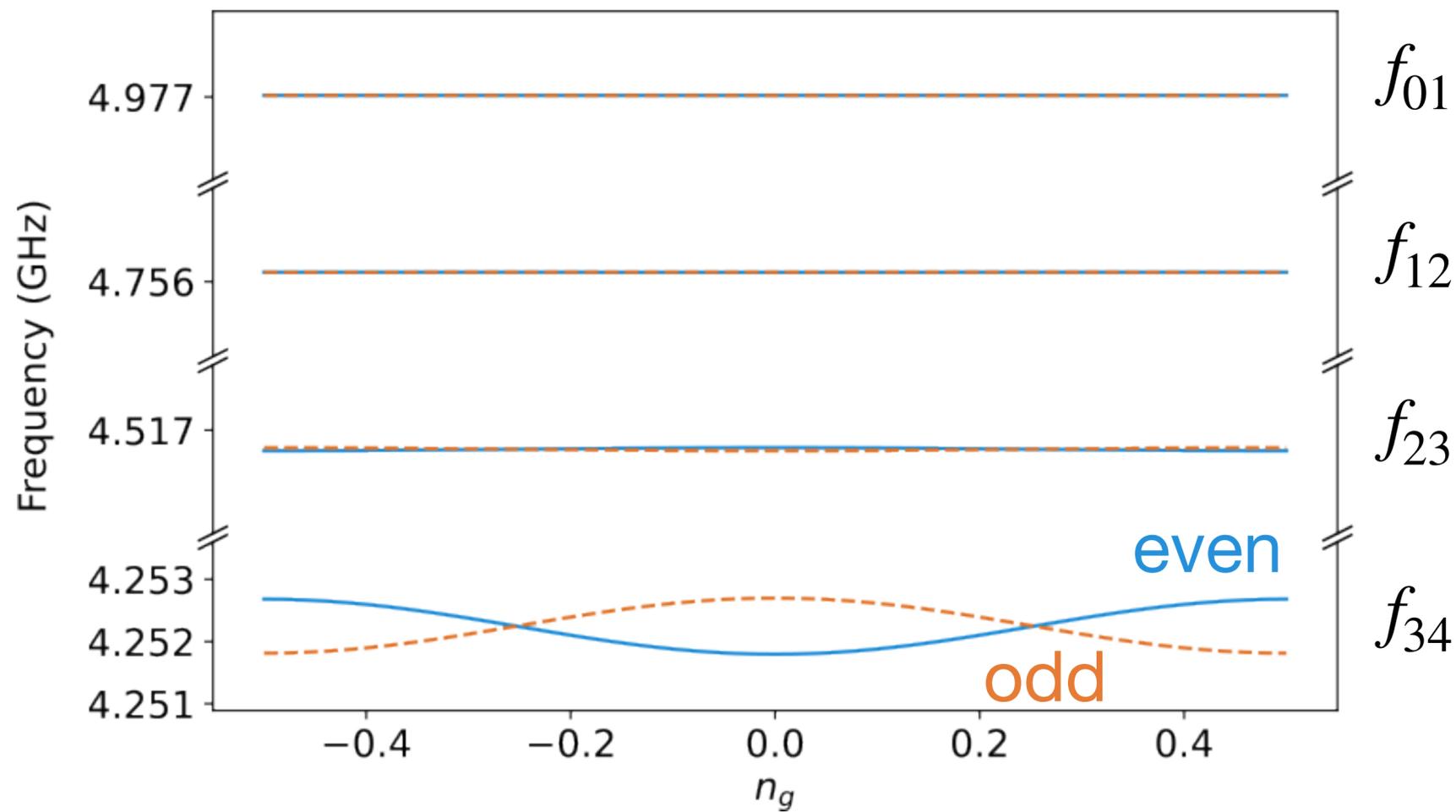
transmon

[J. Koch et al., PRA 2007]

$$E_J/E_C = 84$$



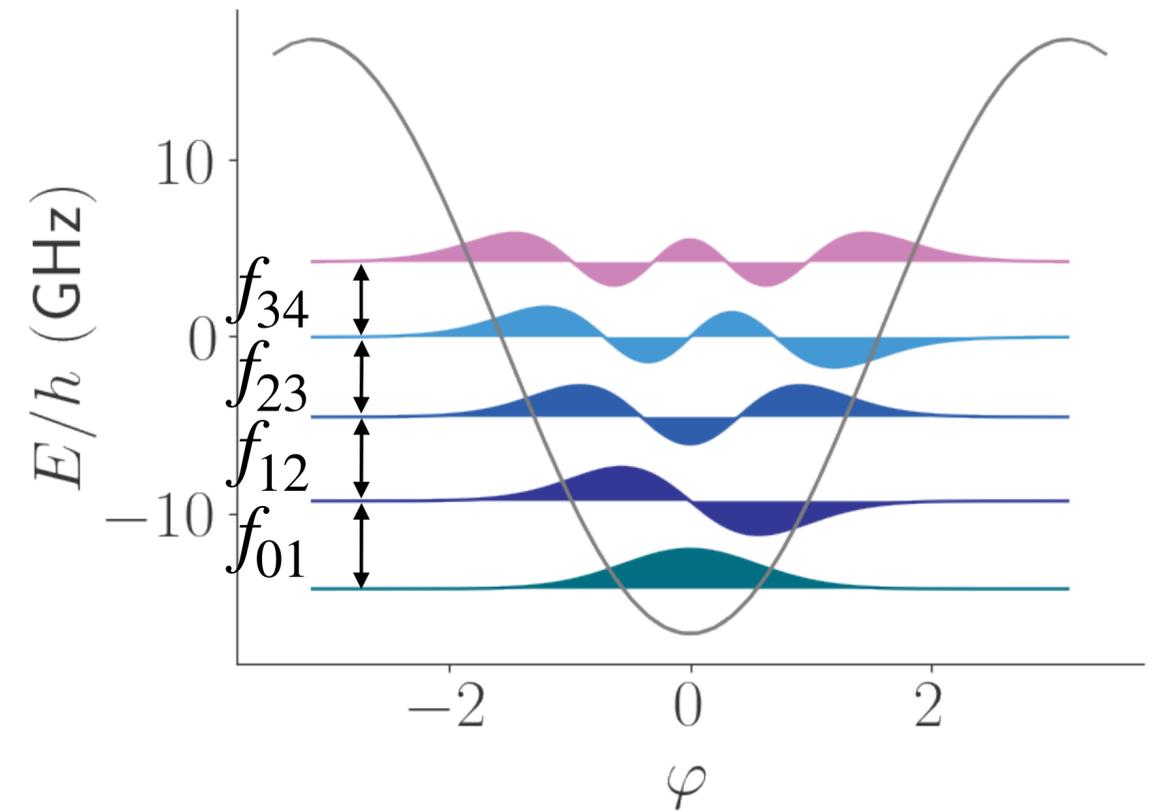
Frequency Dispersion



$$E_J/\hbar = 16.83 \text{ GHz}$$

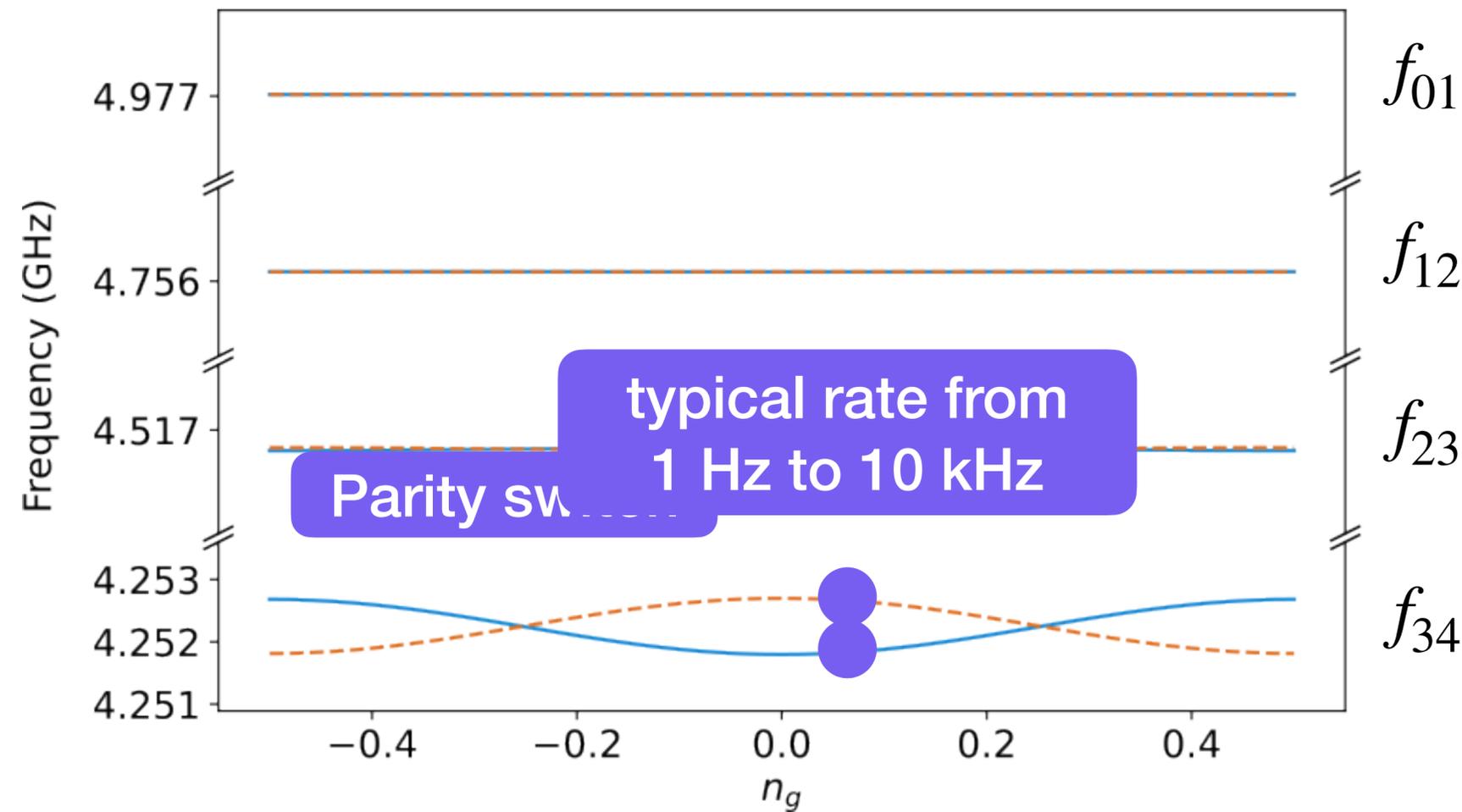
$$E_C/\hbar = 199.7 \text{ MHz}$$

$$E_J/E_C = 84$$



$$f_{34} = \bar{f}_{34} \pm \frac{\Delta f_{34}}{2} \cos(2\pi n_g)$$

Parity Switching



f_{01}

f_{12}

f_{23}

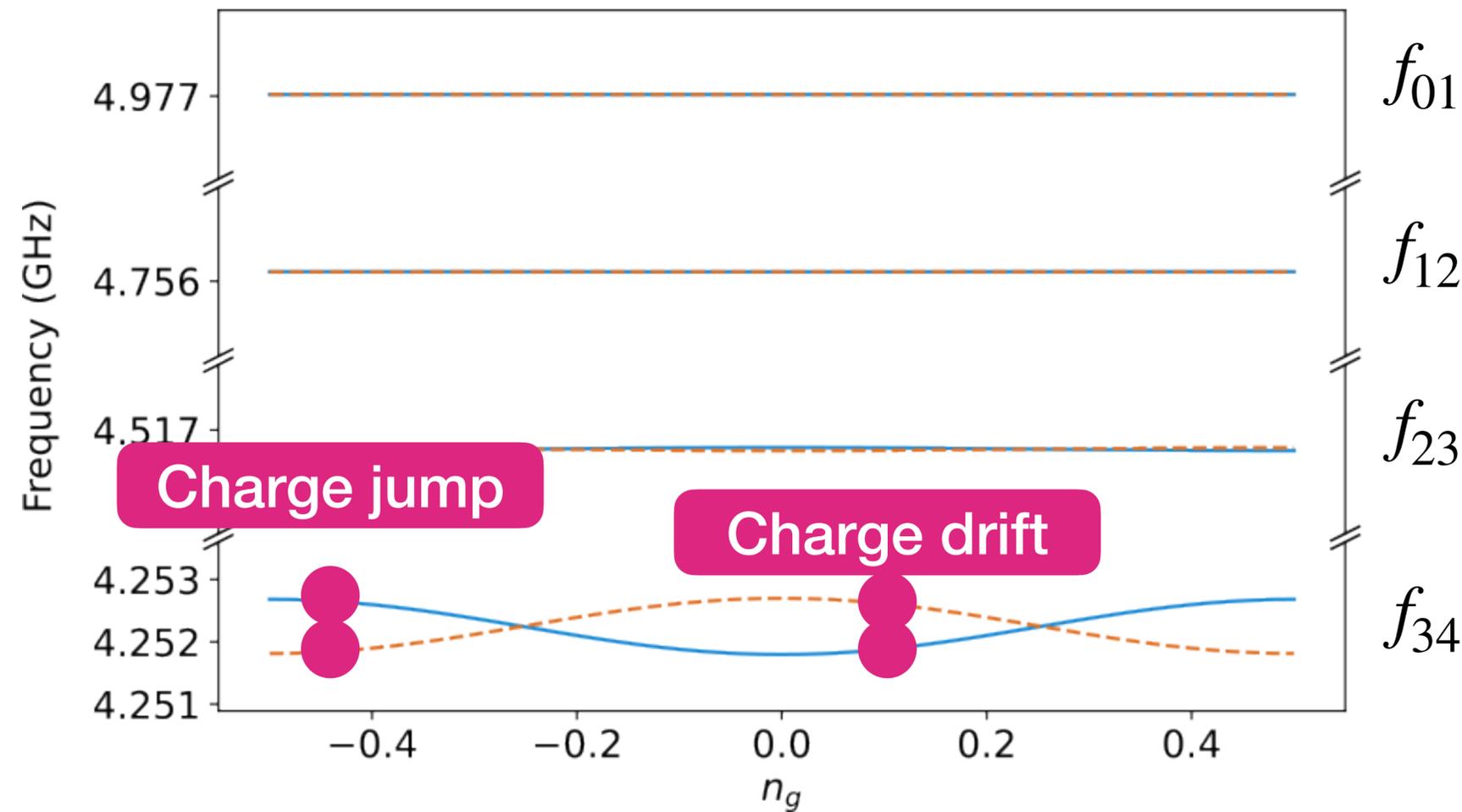
$$f_{34} = \bar{f}_{34} \pm \frac{\Delta f_{34}}{2} \cos(2\pi n_g)$$

$$E_J/\hbar = 16.83 \text{ GHz}$$

$$E_C/\hbar = 199.7 \text{ MHz}$$

$$E_J/E_C = 84$$

Charge Drifts and Jumps



f_{01}

f_{12}

f_{23}

$$f_{34} = \bar{f}_{34} \pm \frac{\Delta f_{34}}{2} \cos(2\pi n_g)$$

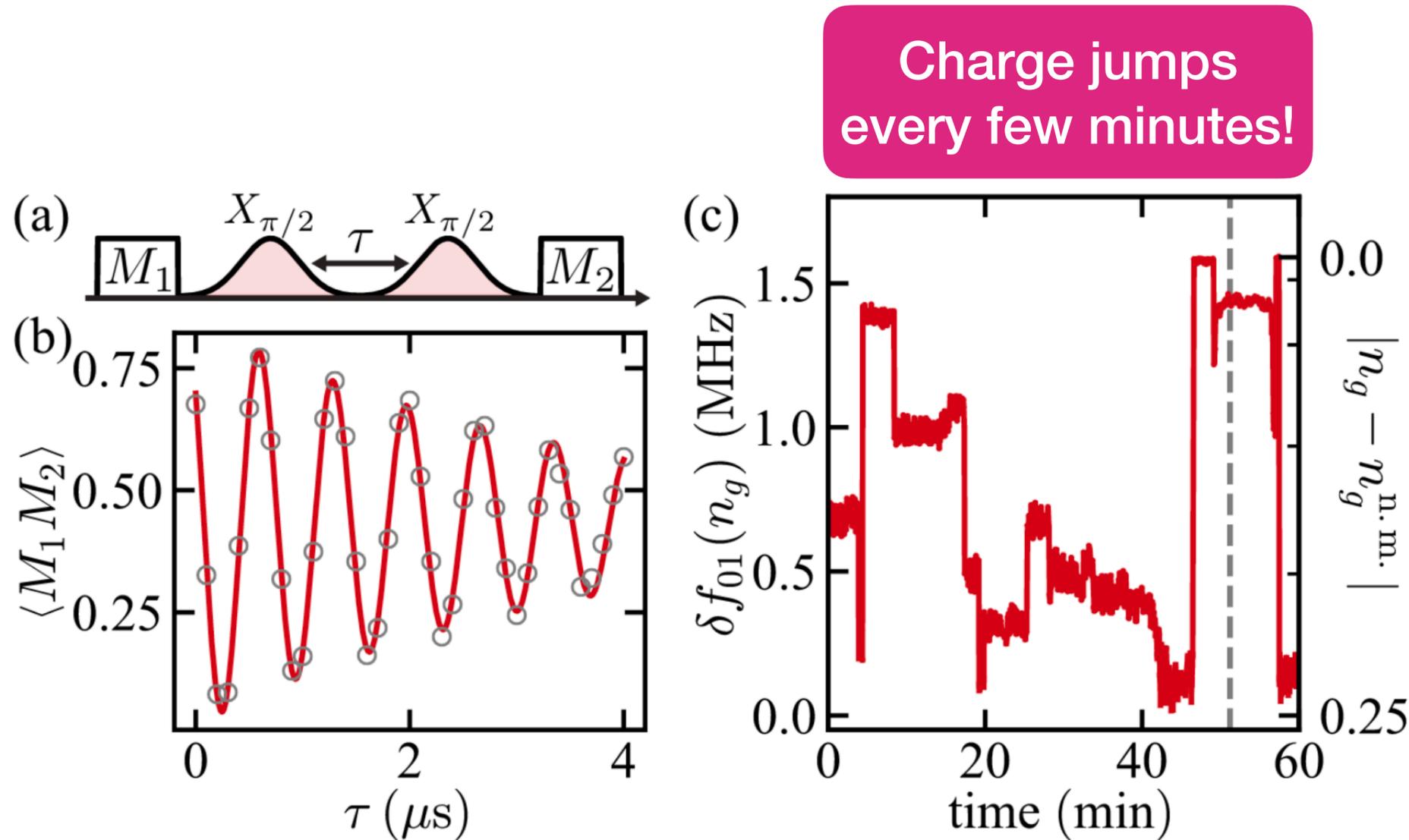
$$E_J/\hbar = 16.83 \text{ GHz}$$

$$E_C/\hbar = 199.7 \text{ MHz}$$

$$E_J/E_C = 84$$

Charge Jumps Observed By Other Experiments

[Serniak et al, PRL (2018)]

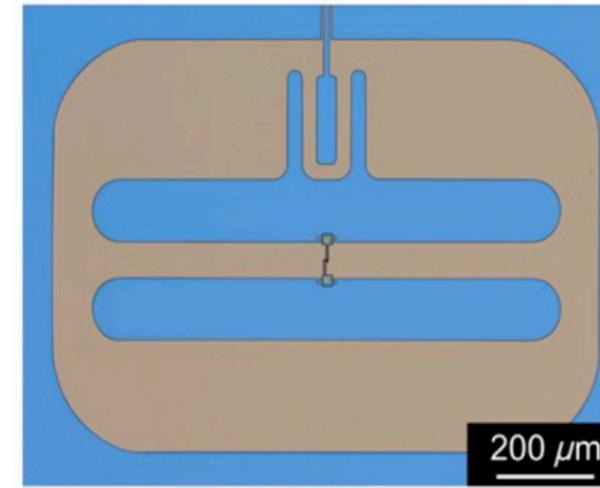
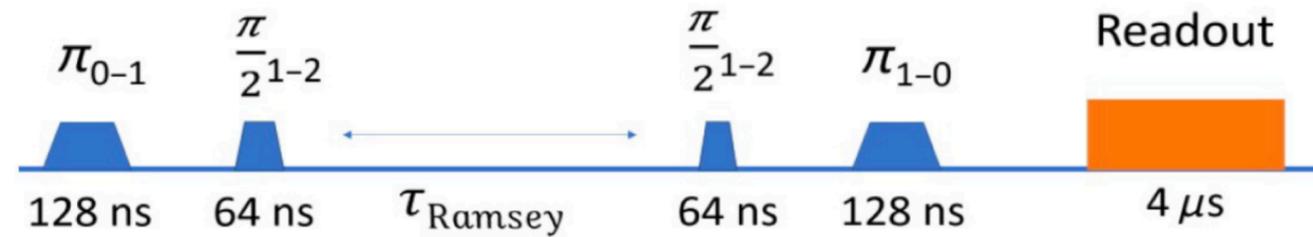


$$f_{01} = \bar{f}_{01} \pm \delta f_{01}$$

E_J/E_C	23
f_{01} (GHz)	4.4
Island(s)	2
Substrate	Sapphire
Metal	Aluminum

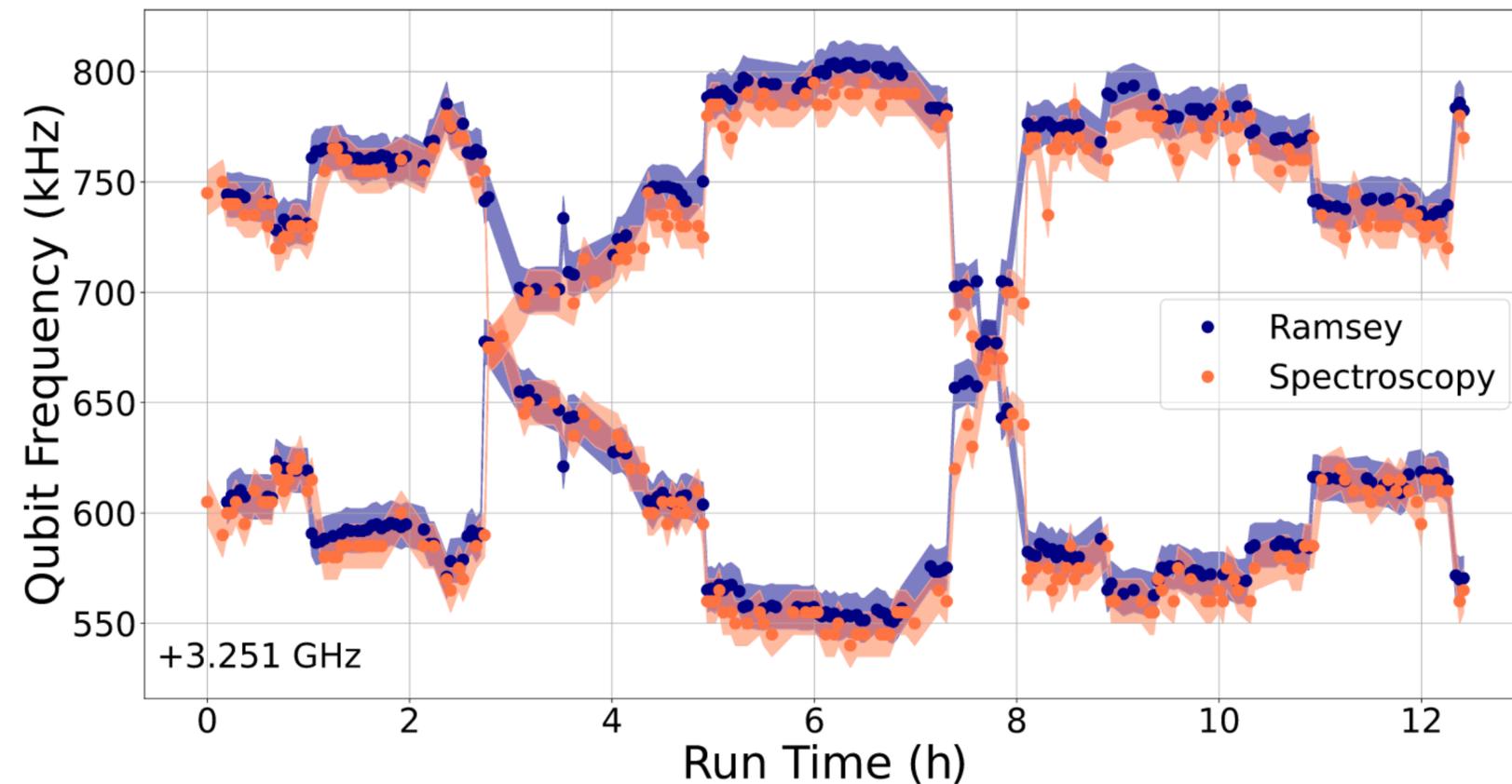
Charge Jumps Observed By Other Experiments

[Tennant et al, PRX Quantum (2022)]



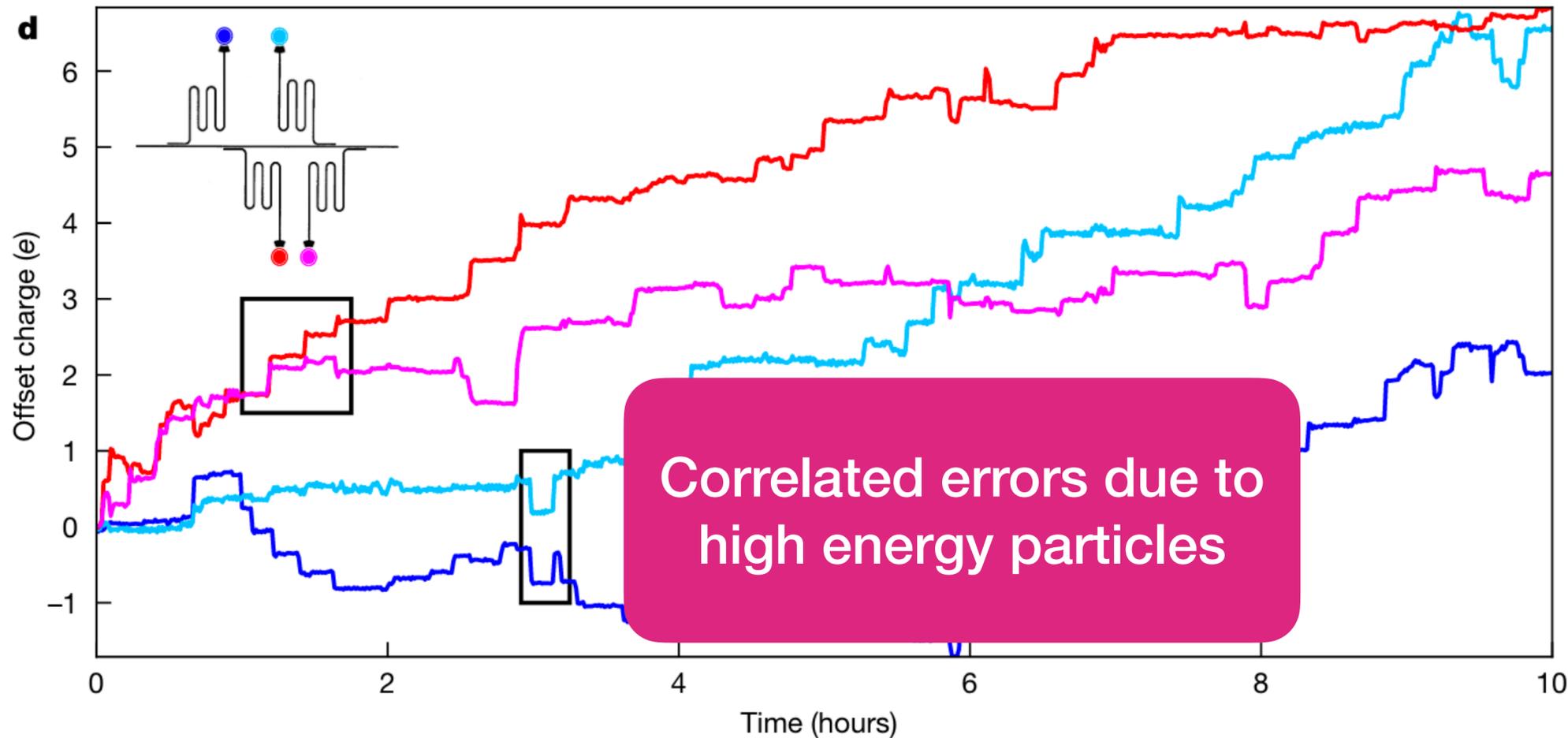
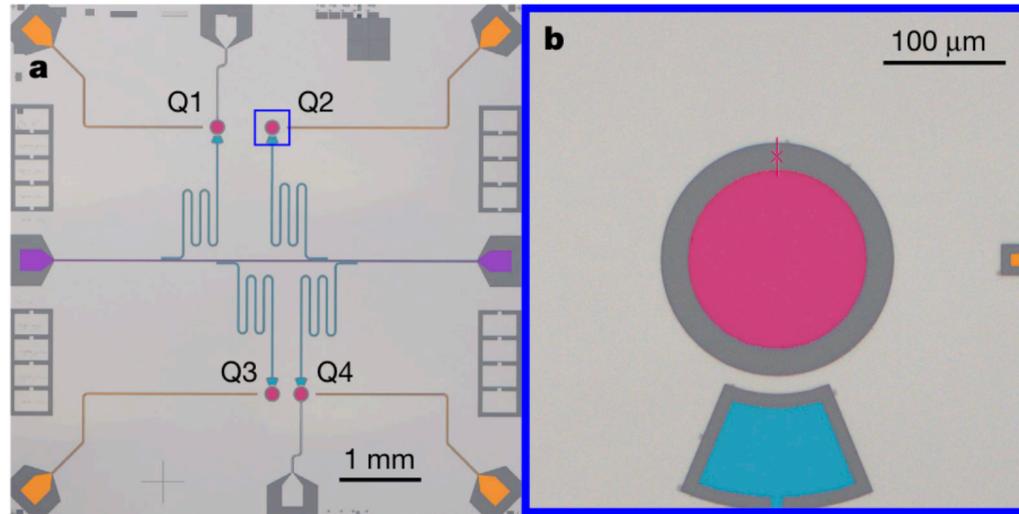
E_J/E_C	50
f_{01} (GHz)	3.5
Island(s)	2
Substrate	Sapphire
Metal	Tantalum

Charge jumps every few hours!



Charge Jumps Observed By Other Experiments

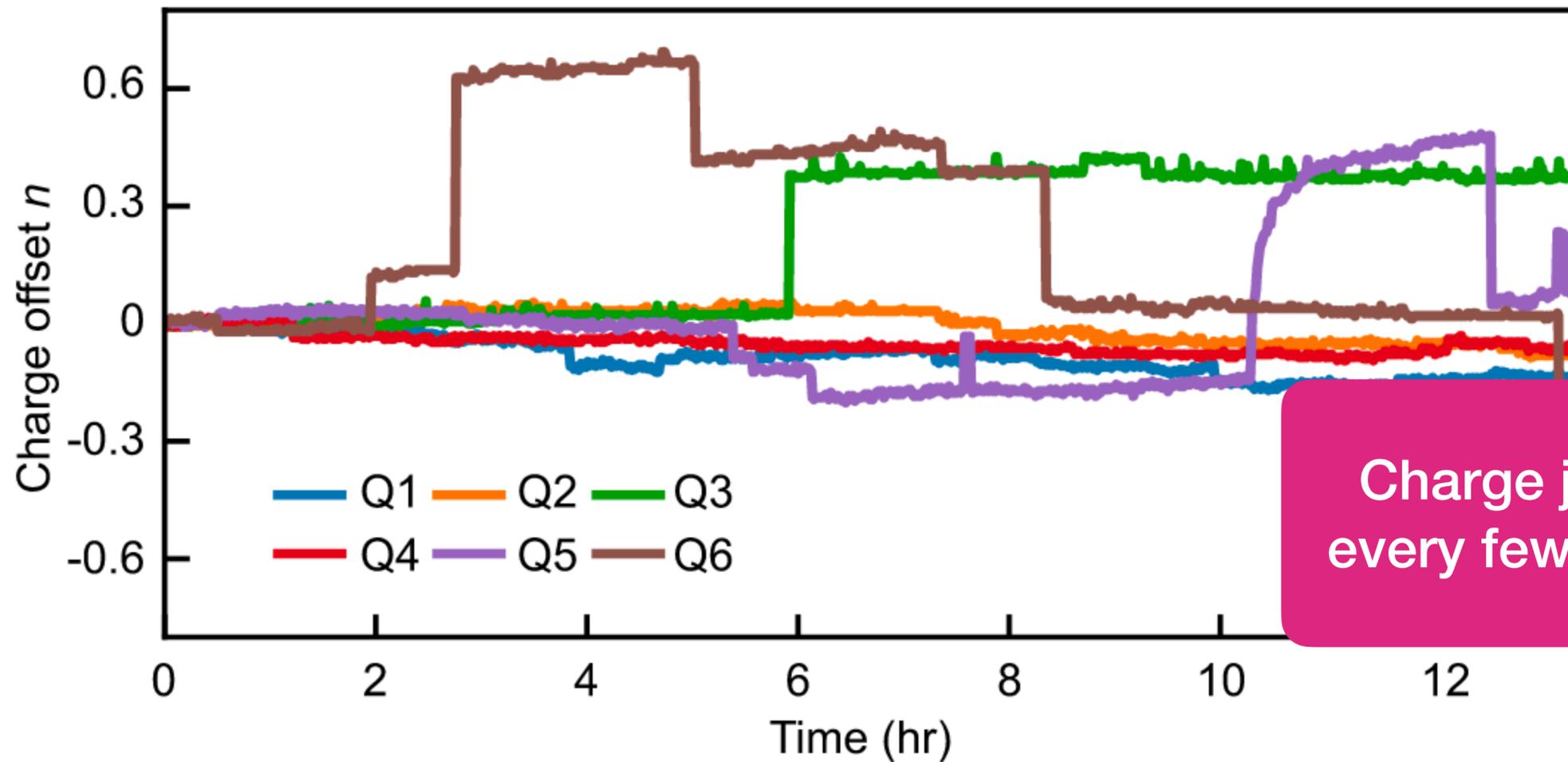
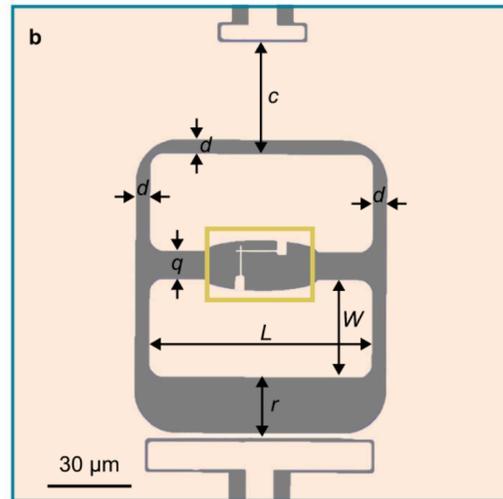
[Willen et al, Nature (2021)]



E_J/E_C	24
f_{01} (GHz)	4.4
Island(s)	1
Substrate	Silicon
Metal	Niobium

Charge Jumps Observed By Other Experiments

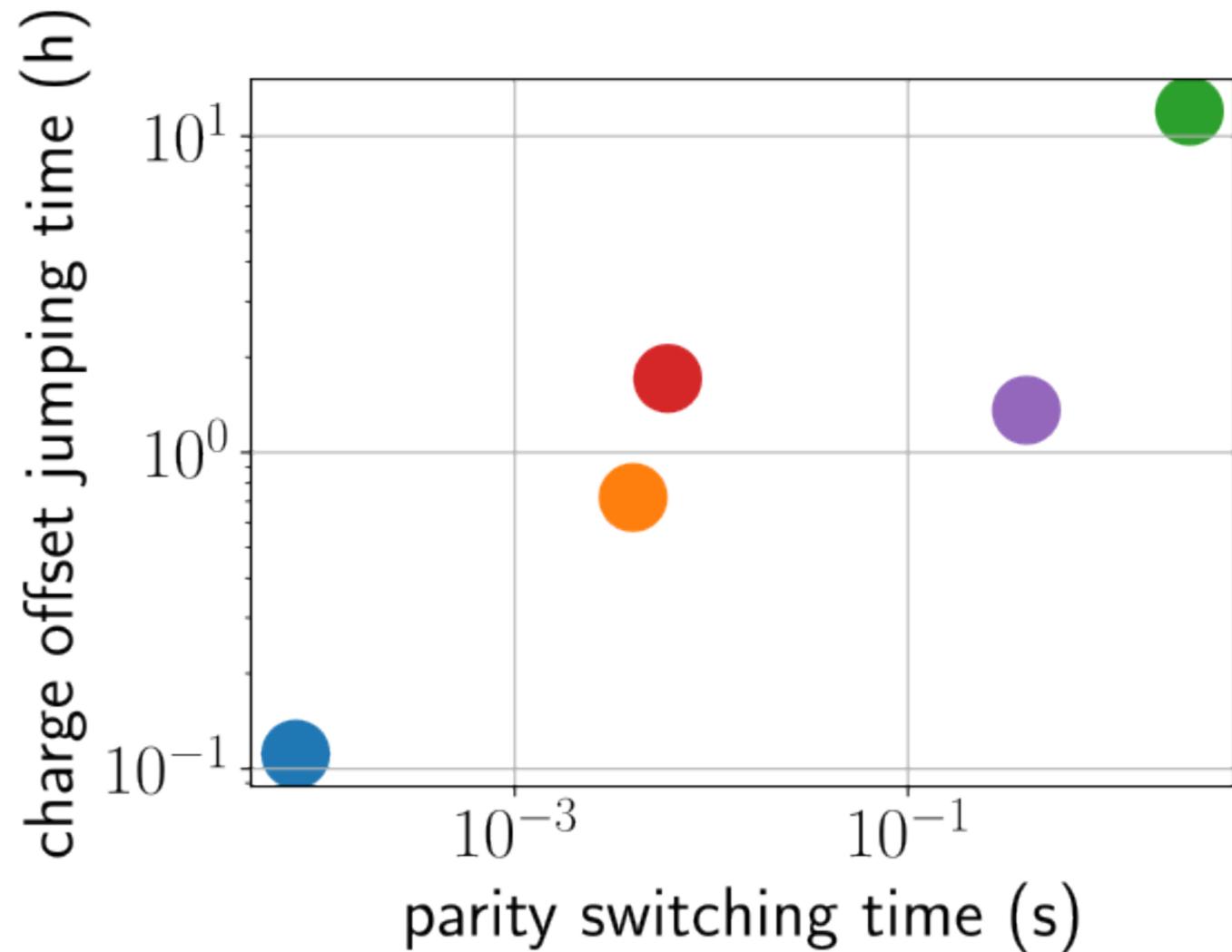
[Pan et al, Nat Comm. (2022)]



Charge jumps every few hours!

E_J/E_C	~ 3
f_{01} (GHz)	various
Island(s)	2
Substrate	Sapphire
Metal	Aluminum

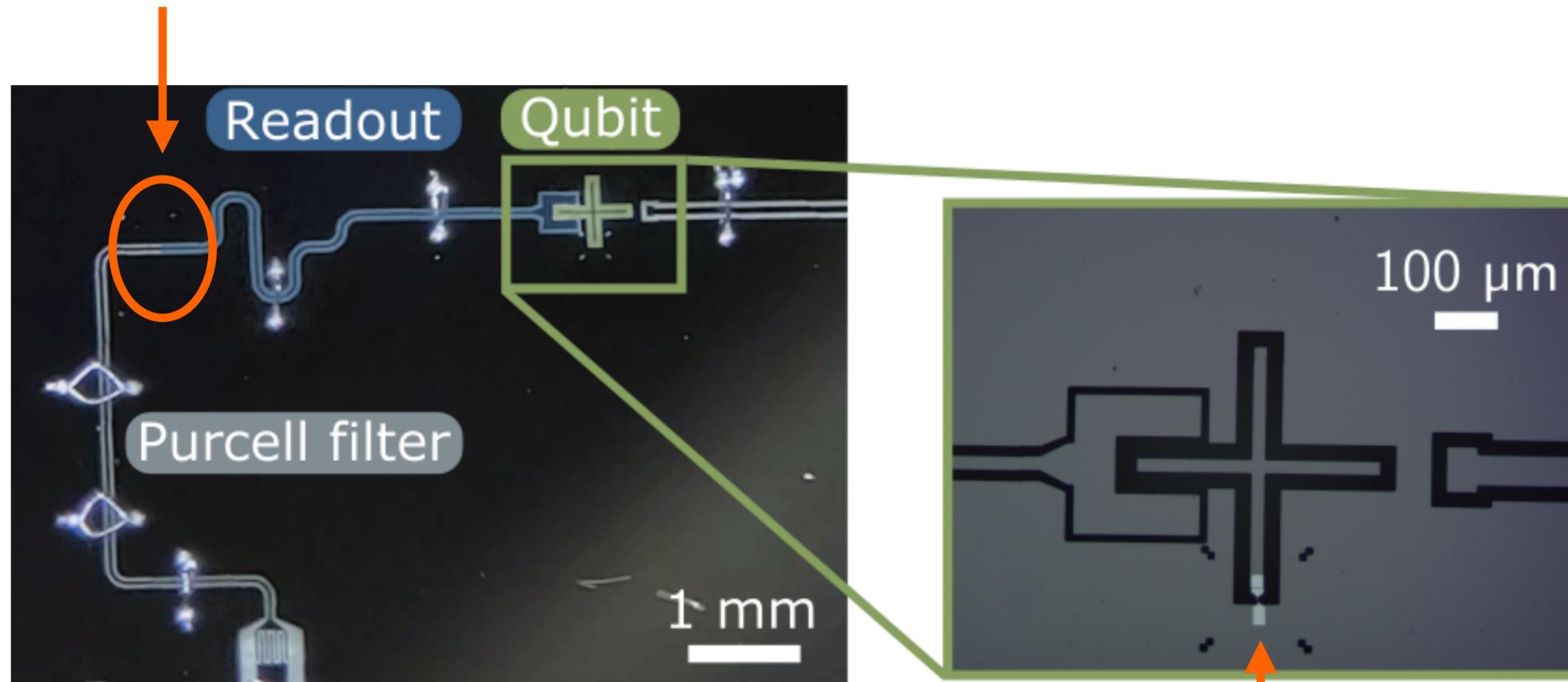
Charge Jumps and Switching Time



- [Serniak et al, PRL (2018)]
- [Christensen et al, PRL (2019)]
- [Pan et al, Nat Comm. (2022)]
- [Tennant et al, PRX Quantum (2022)]
- [Amin et al, arXiv:2404.01277]

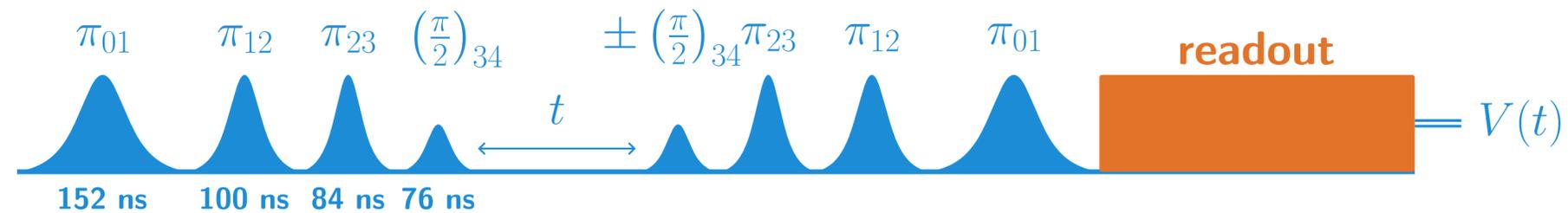
Our Device

DC connection to ground



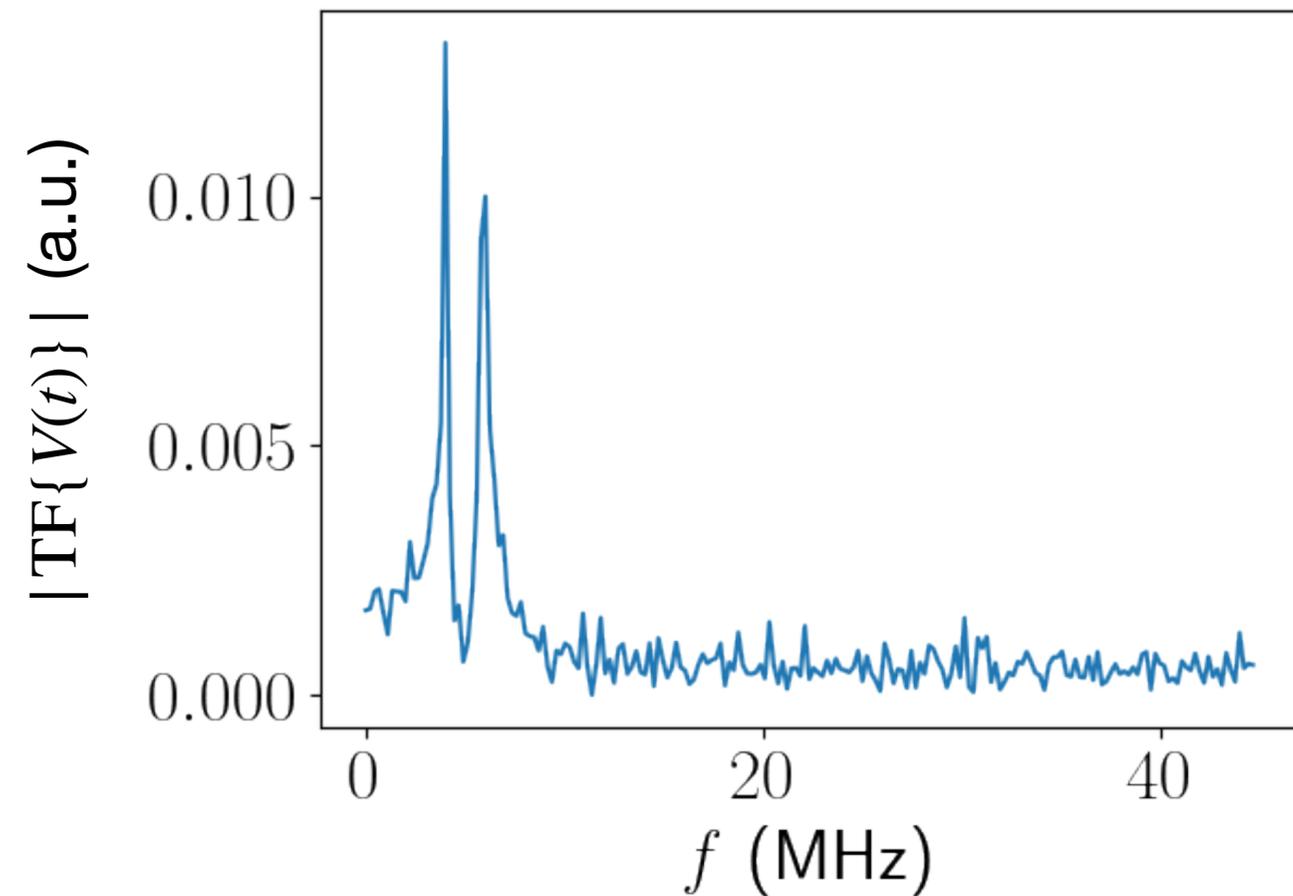
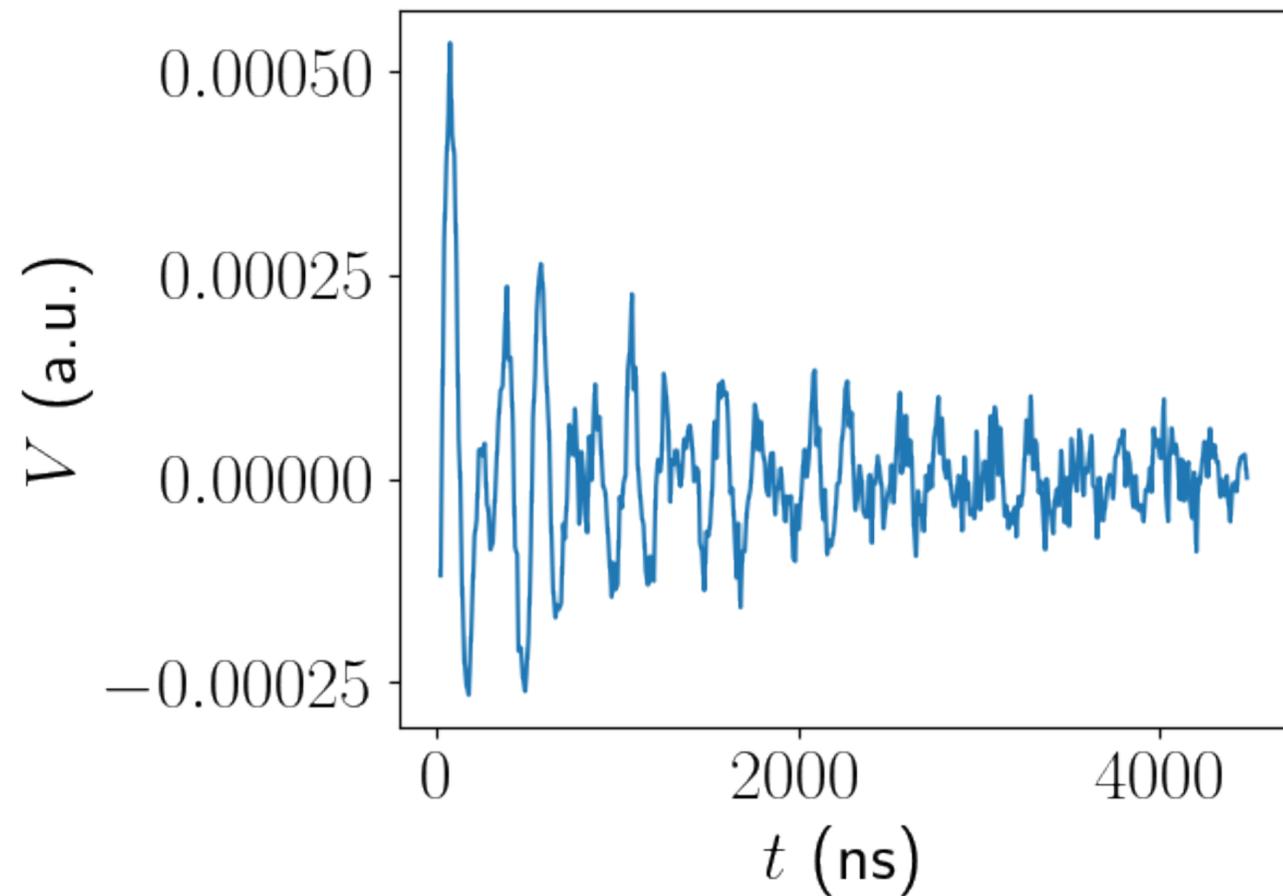
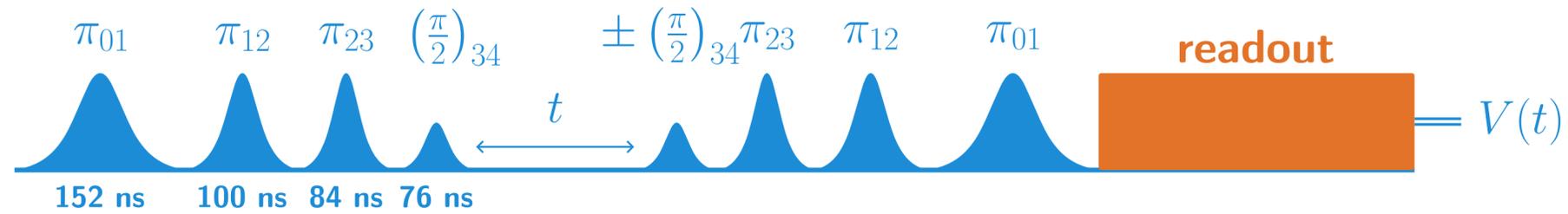
E_J/E_C	84
f_{01} (GHz)	5.0
Island(s)	1
Substrate	Sapphire
Metal	Tantalum

Measurement Protocol

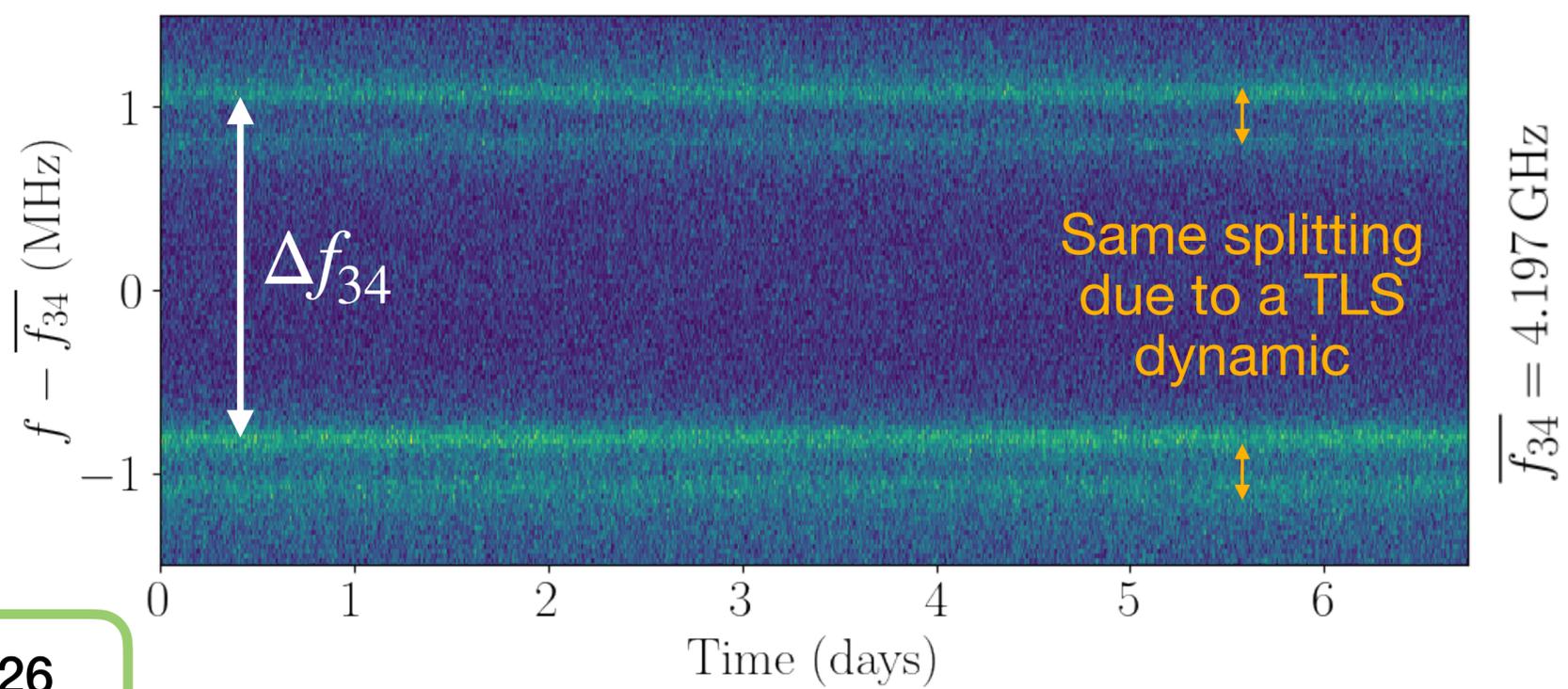
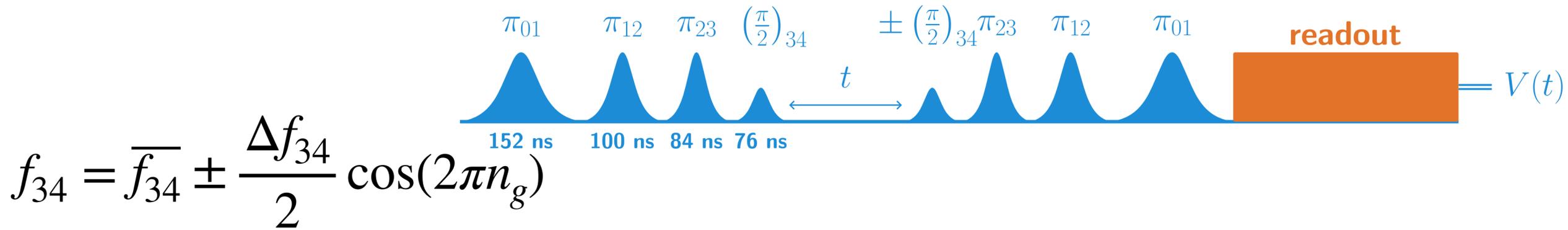


1. Prepare the state $\frac{|3\rangle + |4\rangle}{\sqrt{2}}$
2. Do Ramsey oscillations between states $|3\rangle$ and $|4\rangle$
3. Measure in the $\{|0\rangle, |4\rangle\}$ basis

$|3\rangle - |4\rangle$ Ramsey Spectroscopy



Absence of Charge Drift

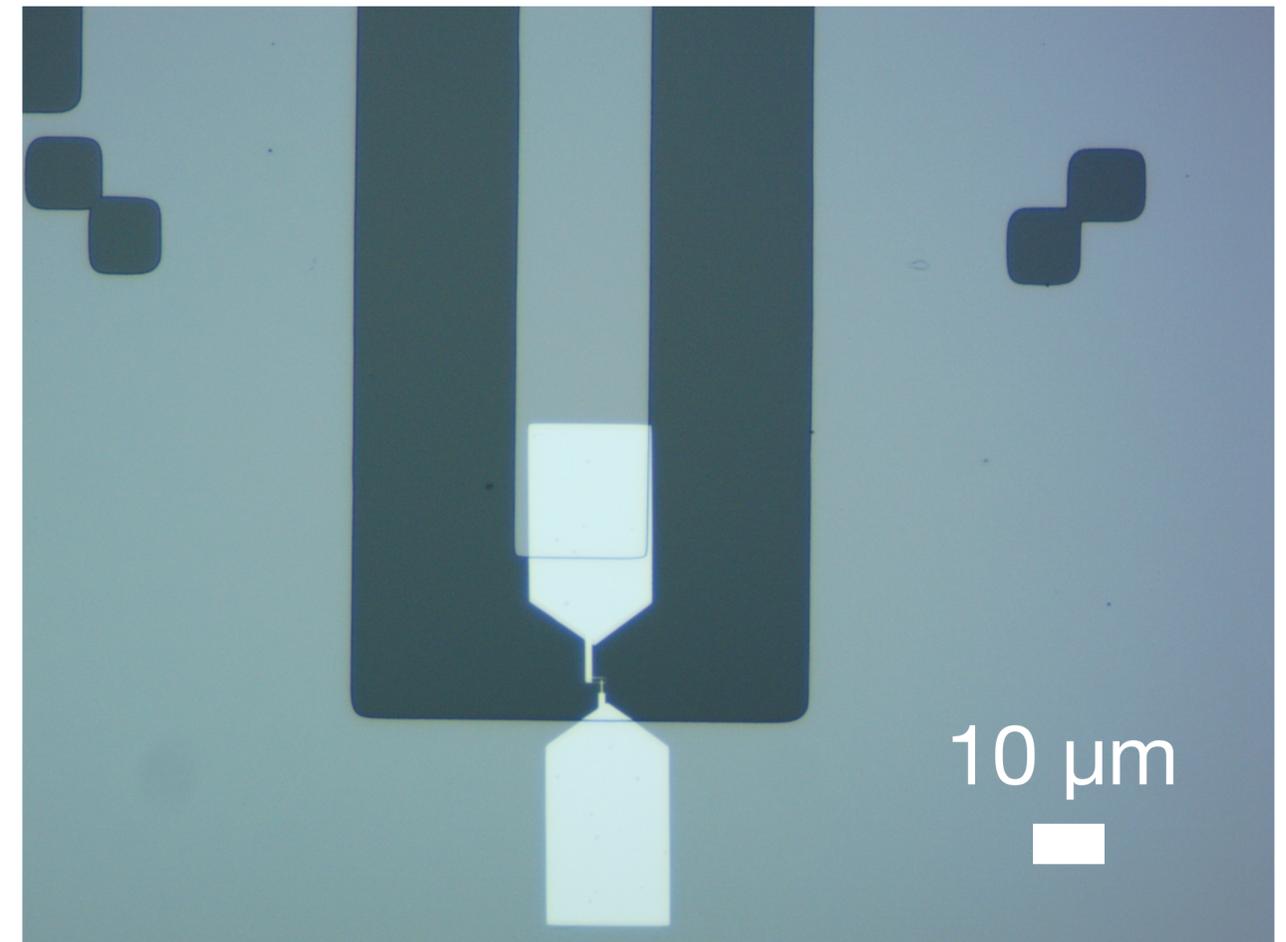
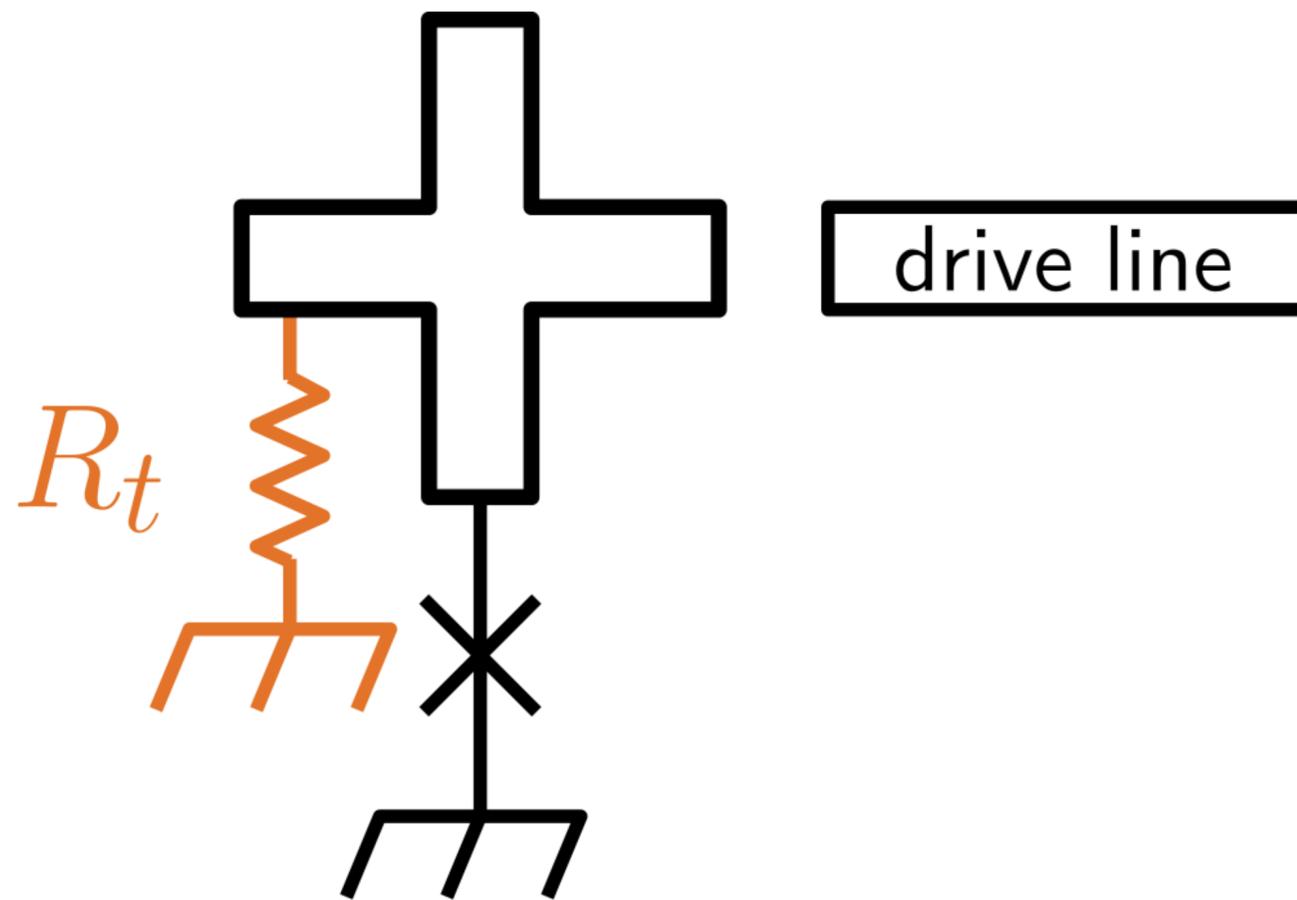


Run 26
10/05/24

No charge drift over a week!

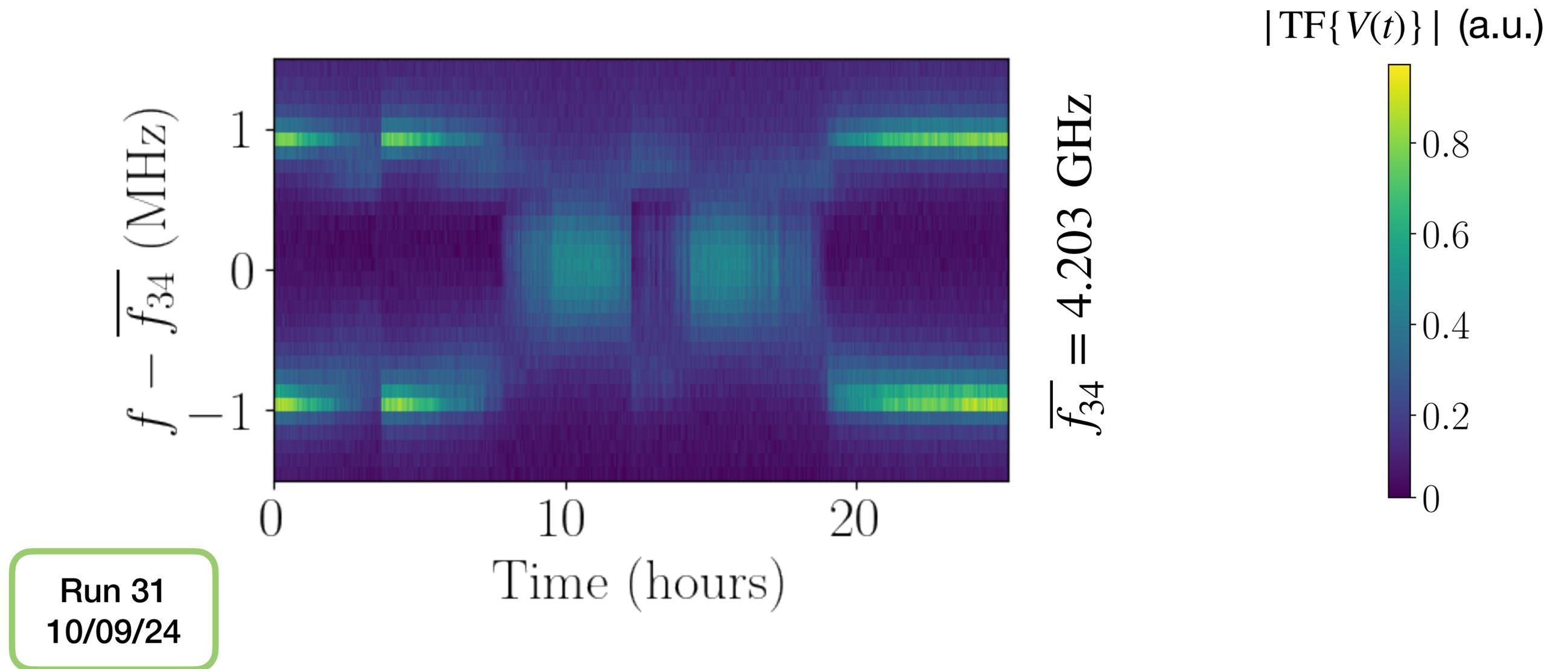
Same splitting → same charge offset over a month, including a warmup!

First Investigations



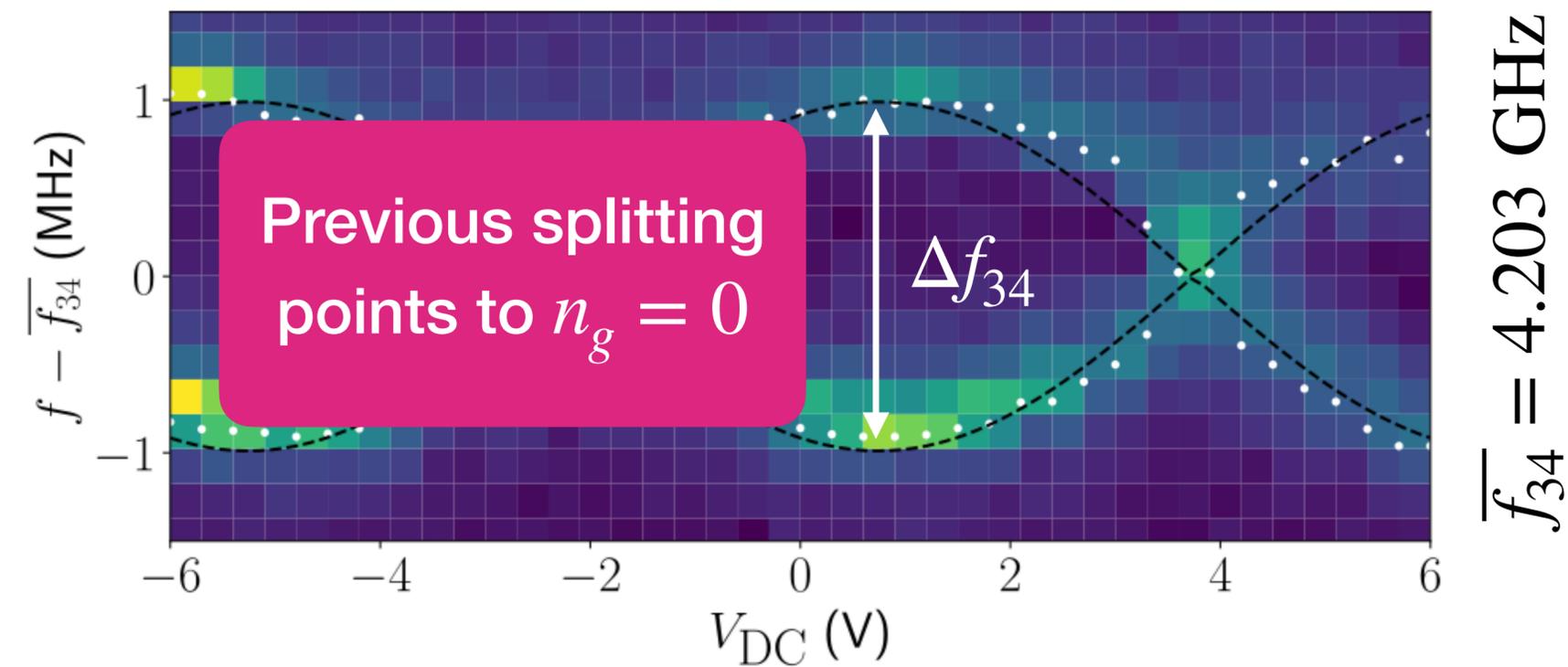
Observation with an optical microscope
→ everything looks as expected

Presence of Charge Drifts Since Then



Tuning the Charge Offset

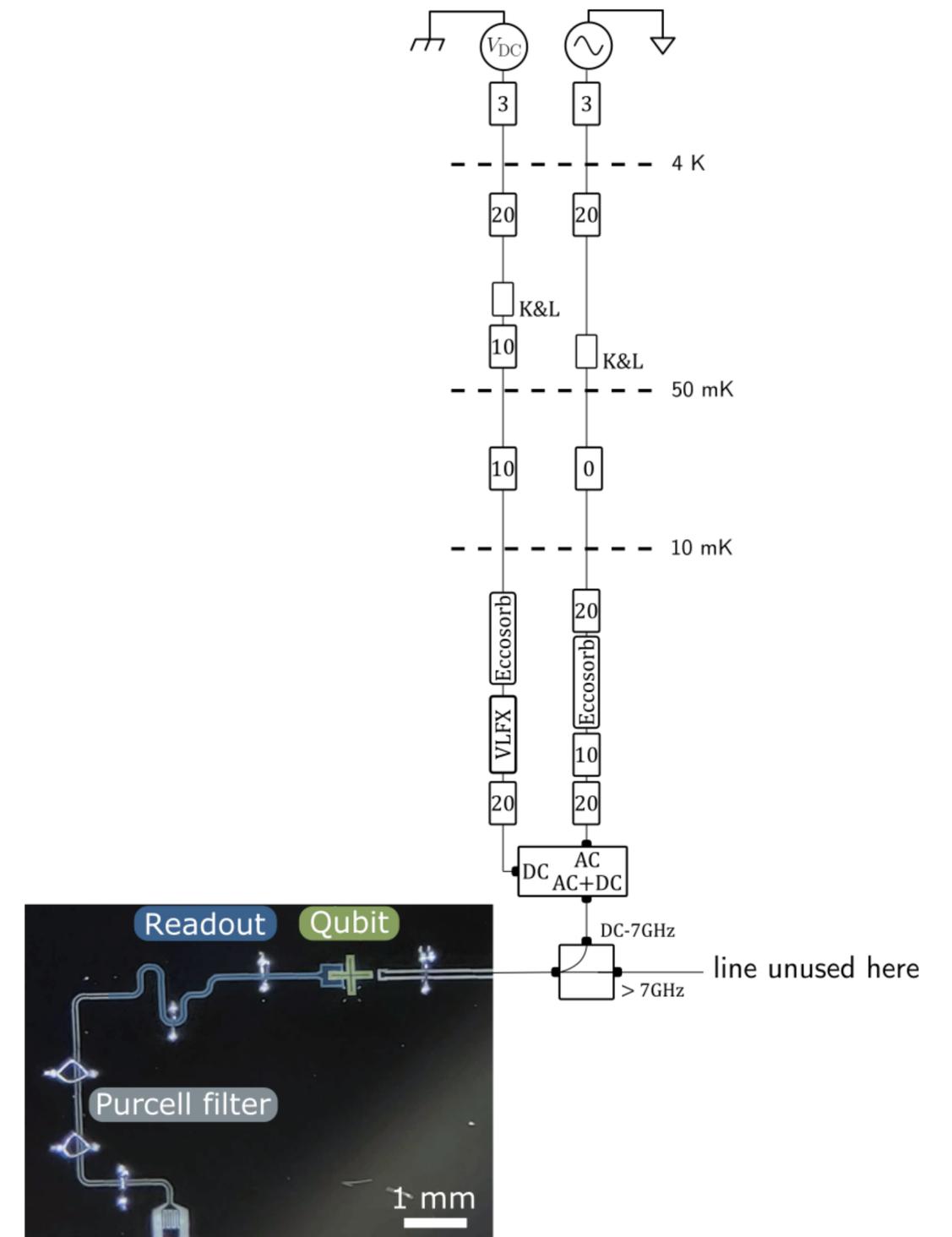
$$f_{34}^{\pm} = \bar{f}_{34} \pm \frac{\Delta f_{34}}{2} \cos(2\pi n_g)$$



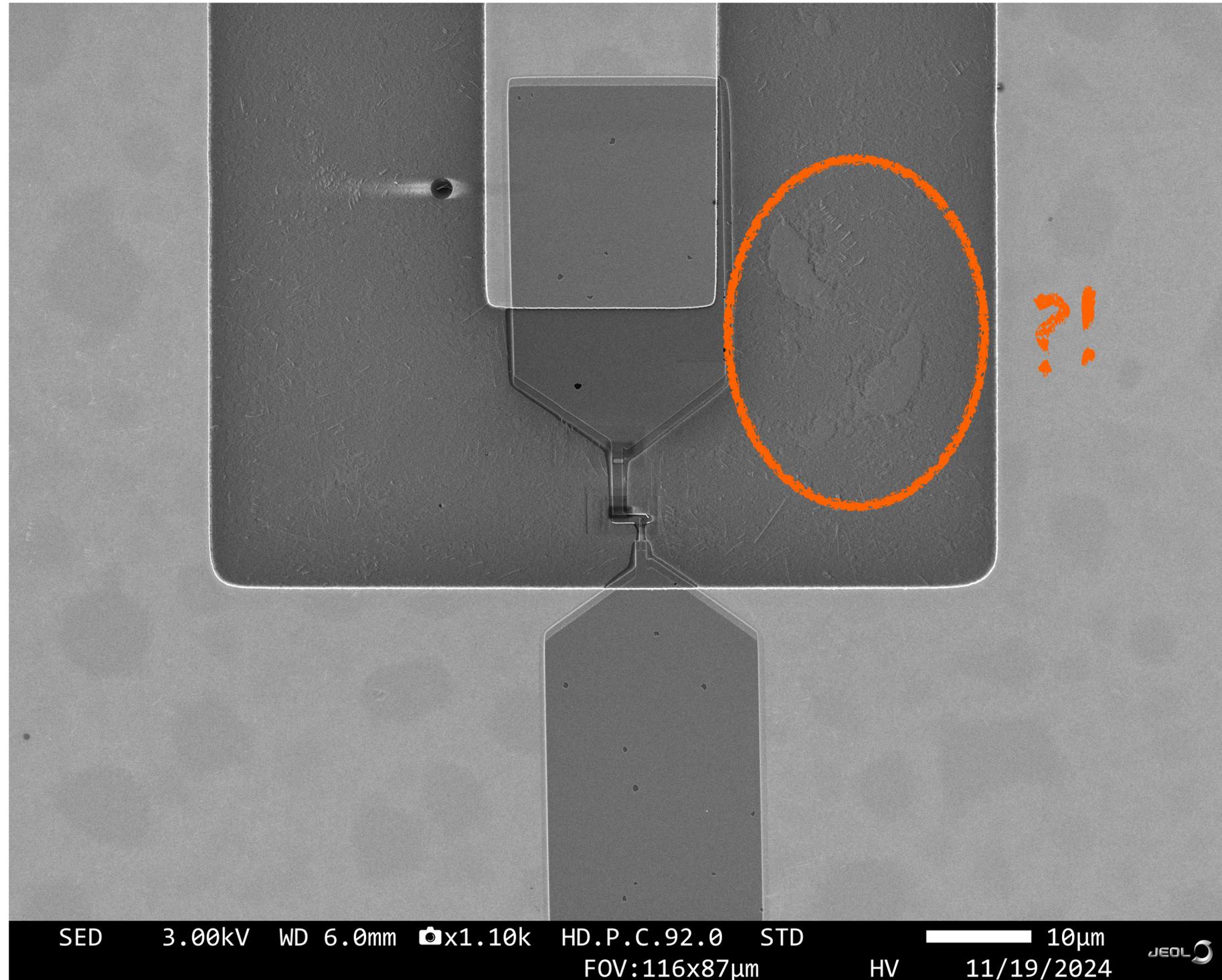
Run 30
30/08/24

$$\Delta f_{34} = 2 \text{ MHz}$$

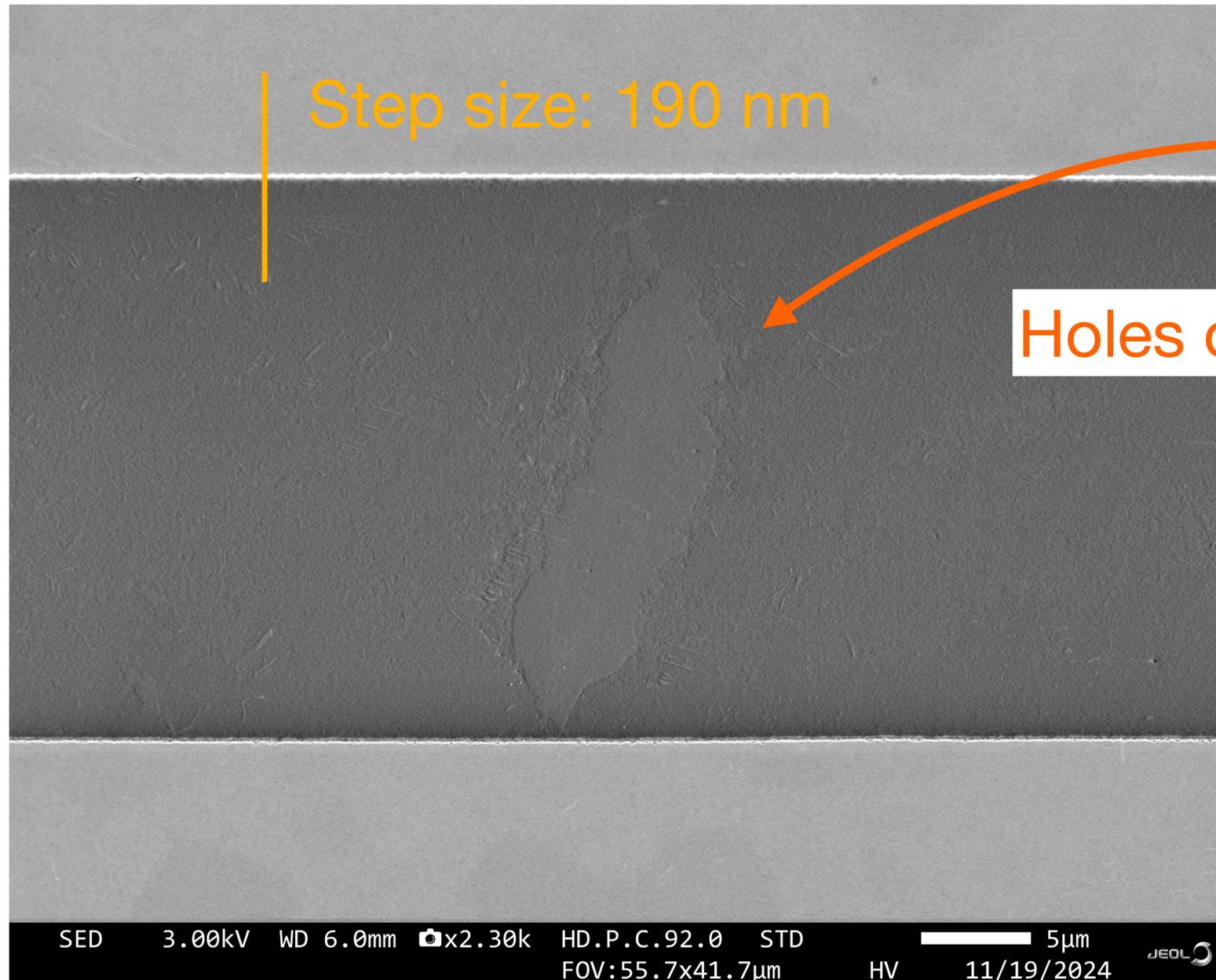
$$n_g = \frac{V_{\text{DC}}}{12 \text{ V}} + n_g^0$$



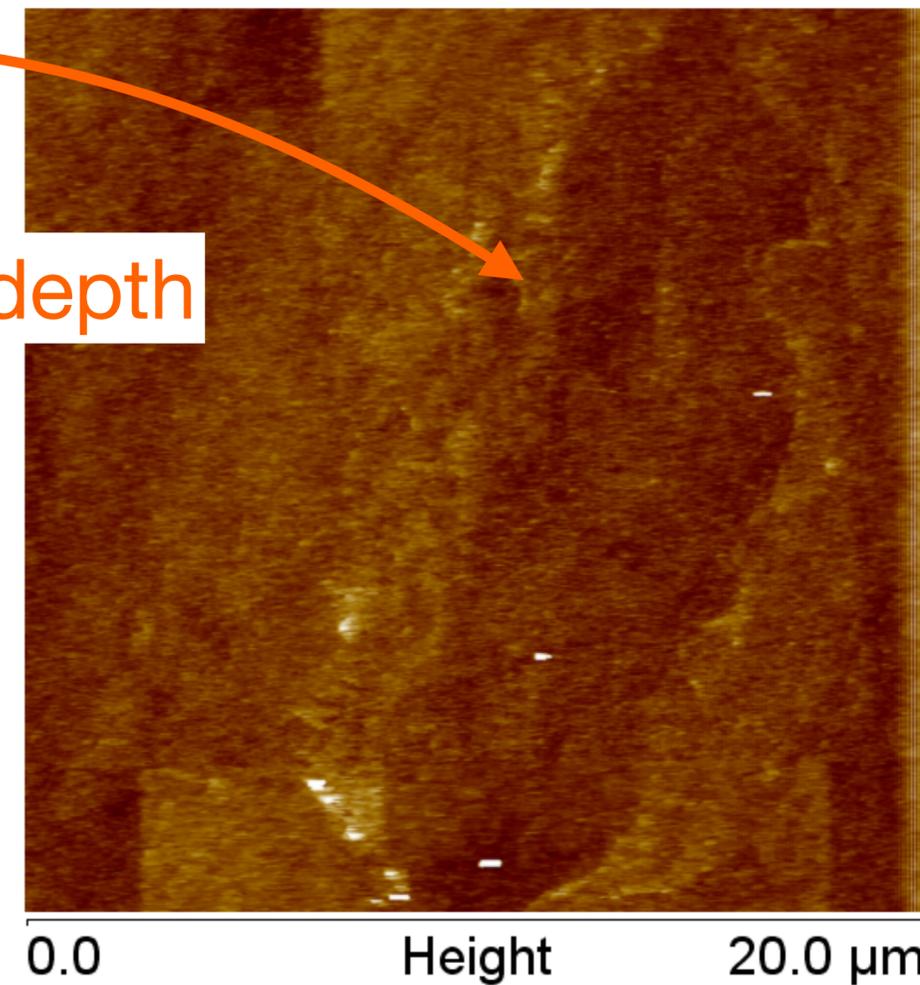
Inspection of the Device With SEM



Surface Analysis

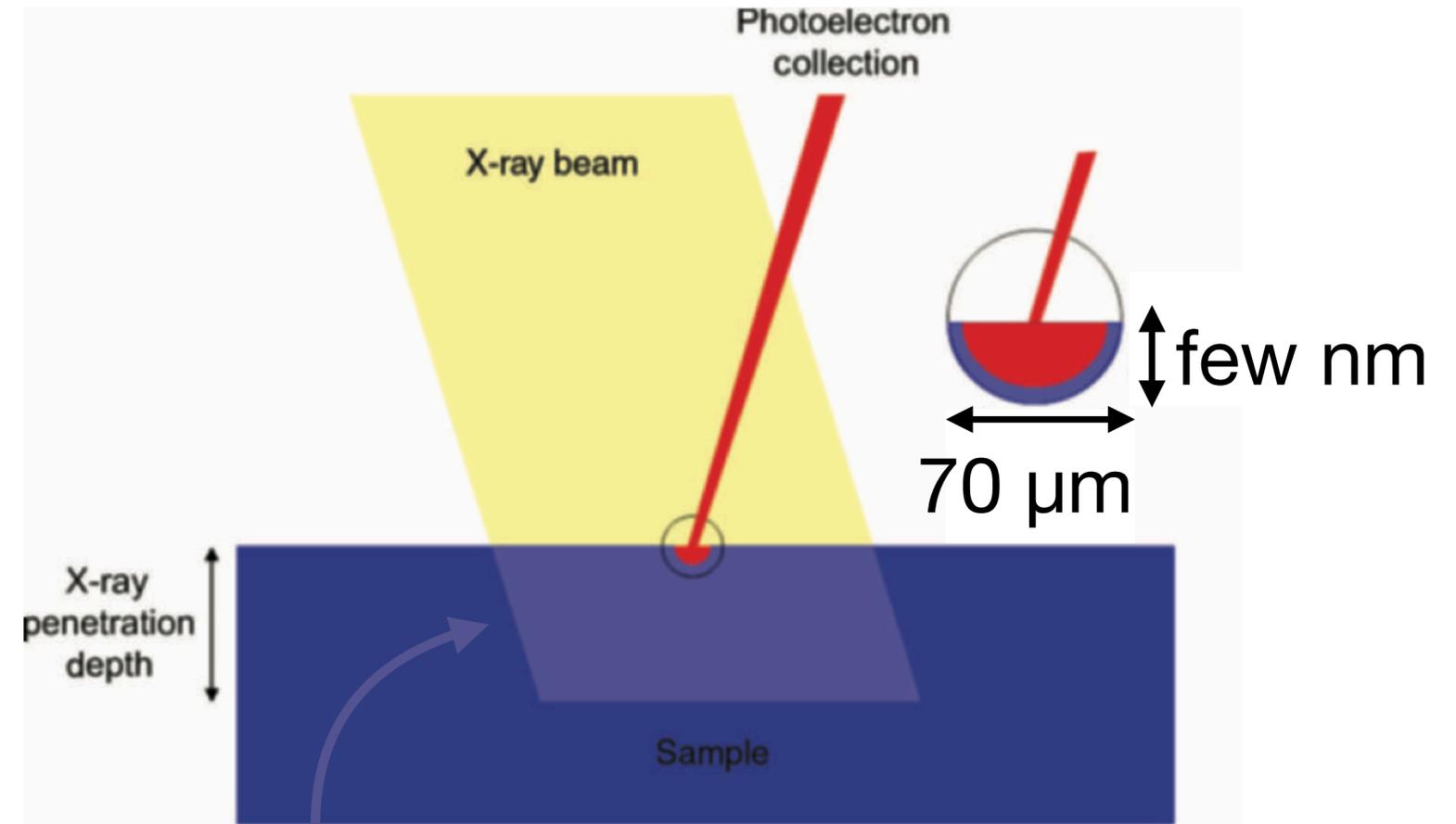
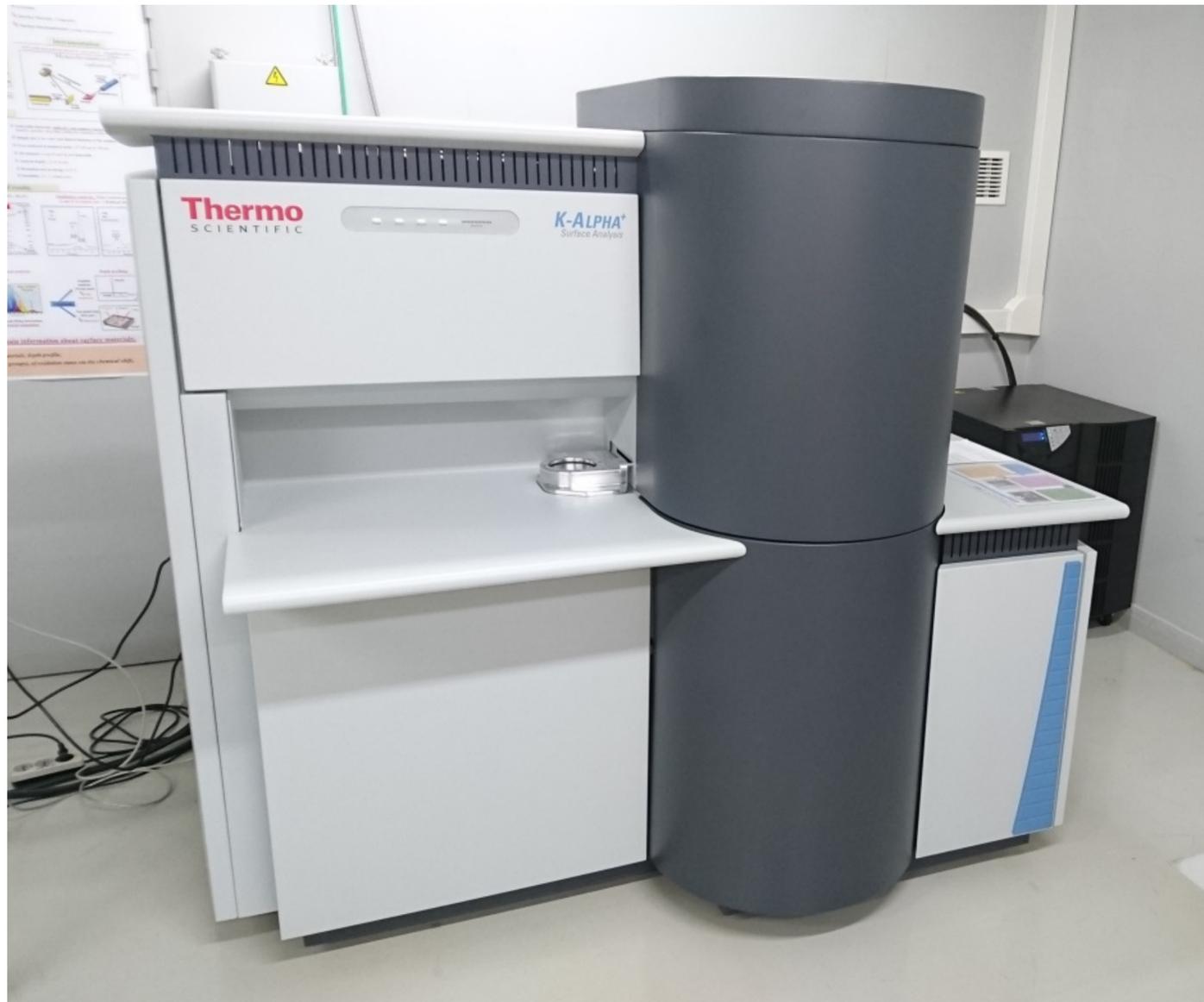


Holes of nm depth



AFM Image done by Cendrine Moskalenko @LPENSL 20

X-Ray Photoelectron Spectroscopy (XPS)

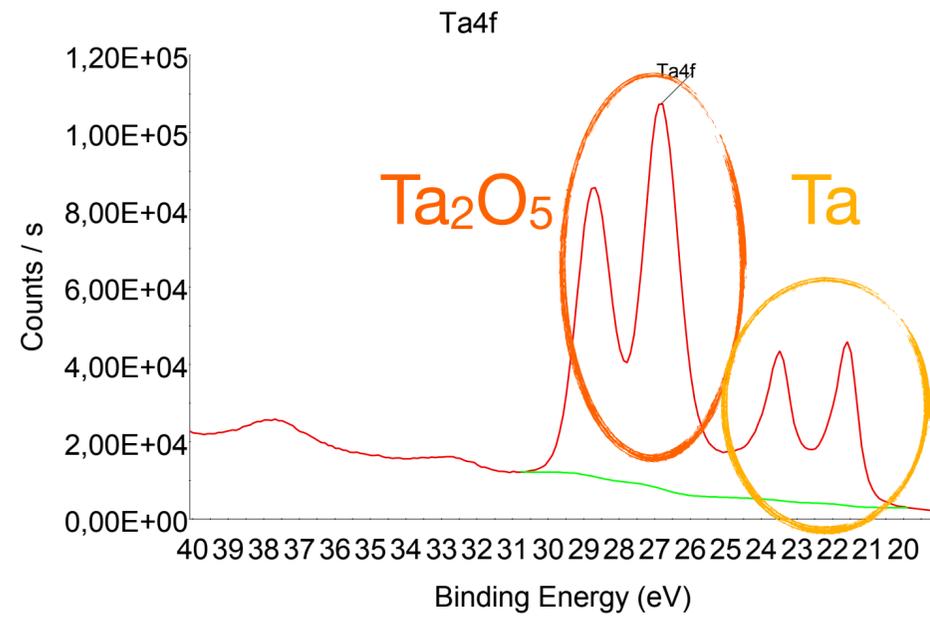


Contribution to the background

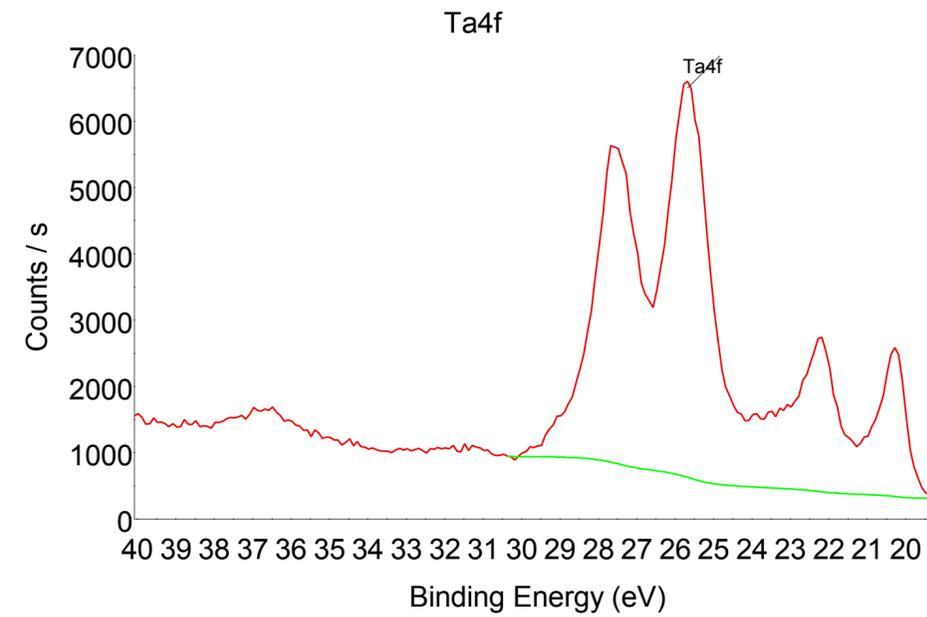
[Lee & Flynn, Handbook of Applied Solid State Spectroscopy, Ch.11 (2006)]

Surface Analysis

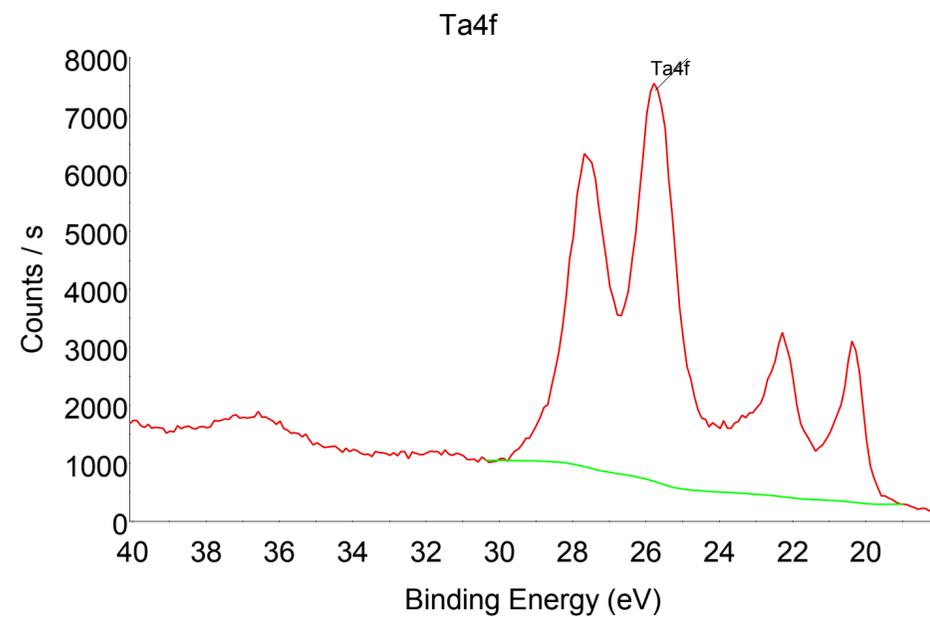
Zone 1 (ground plane)



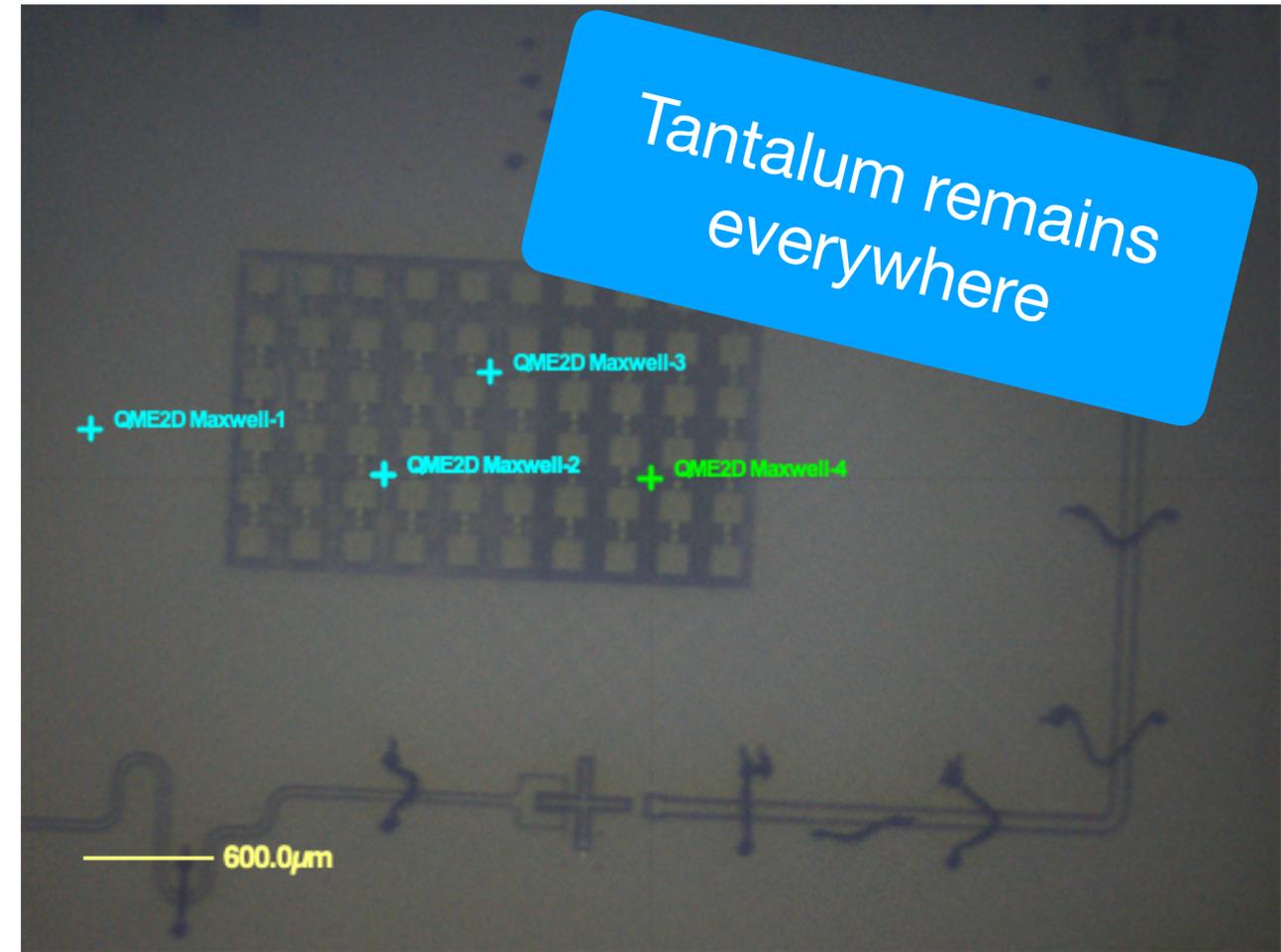
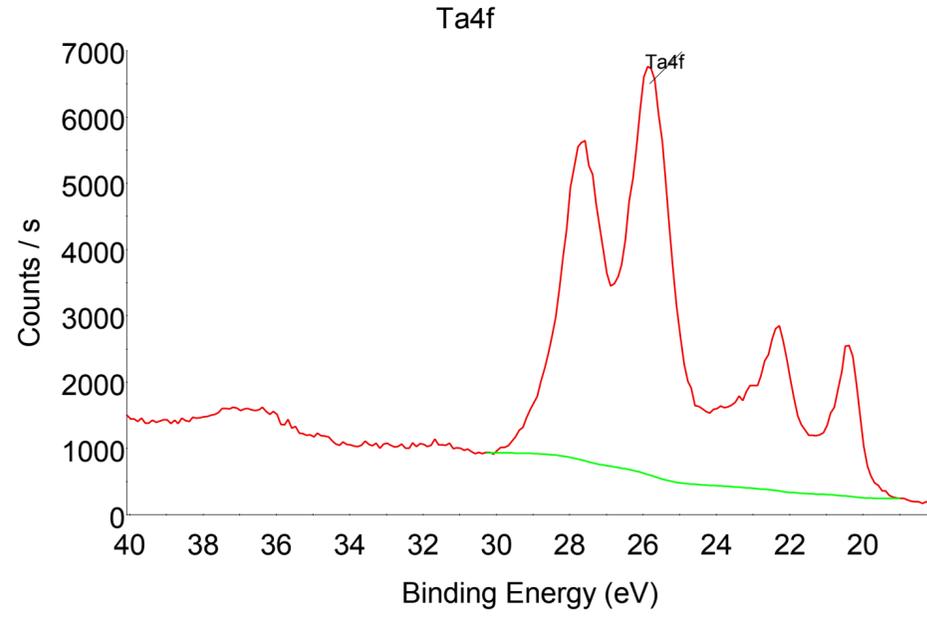
Zone 2 (no metal)



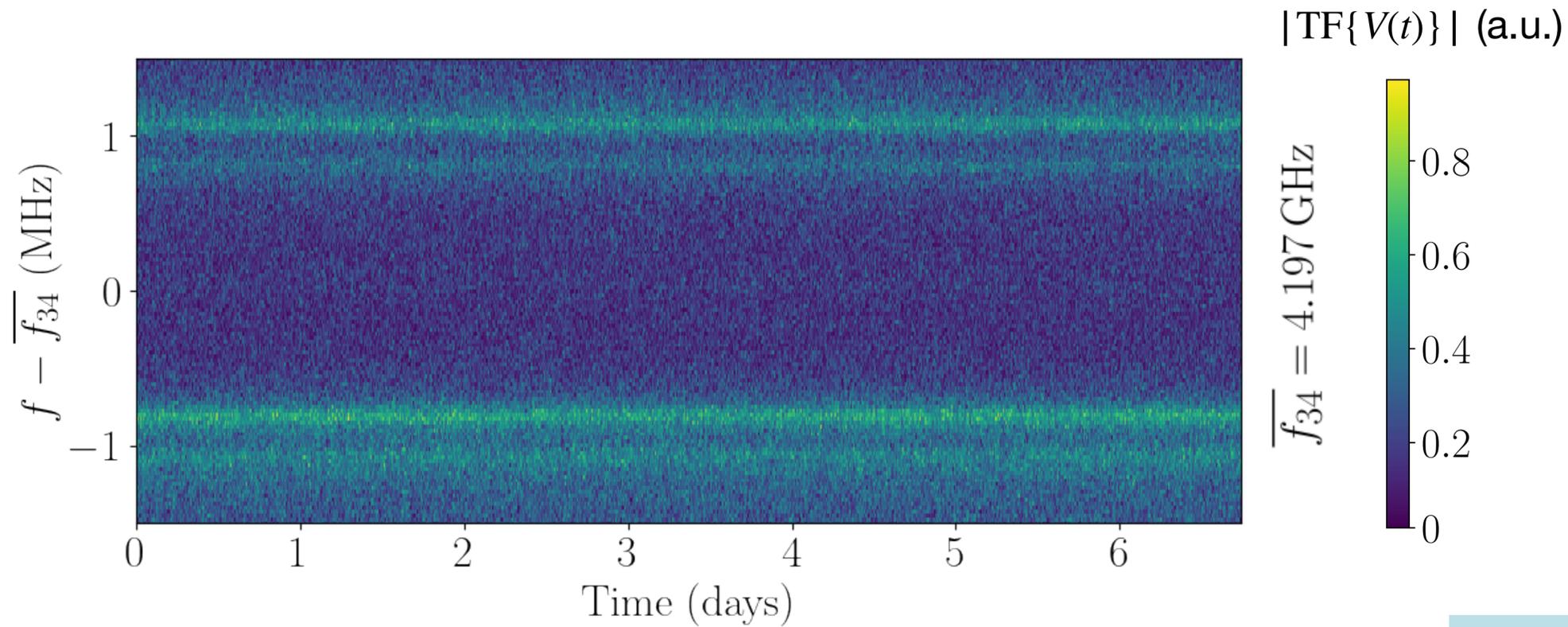
Zone 3 (no metal)



Zone 4 (no metal)



Conclusion



Charge offset $n_g=0$ observed **over a month**

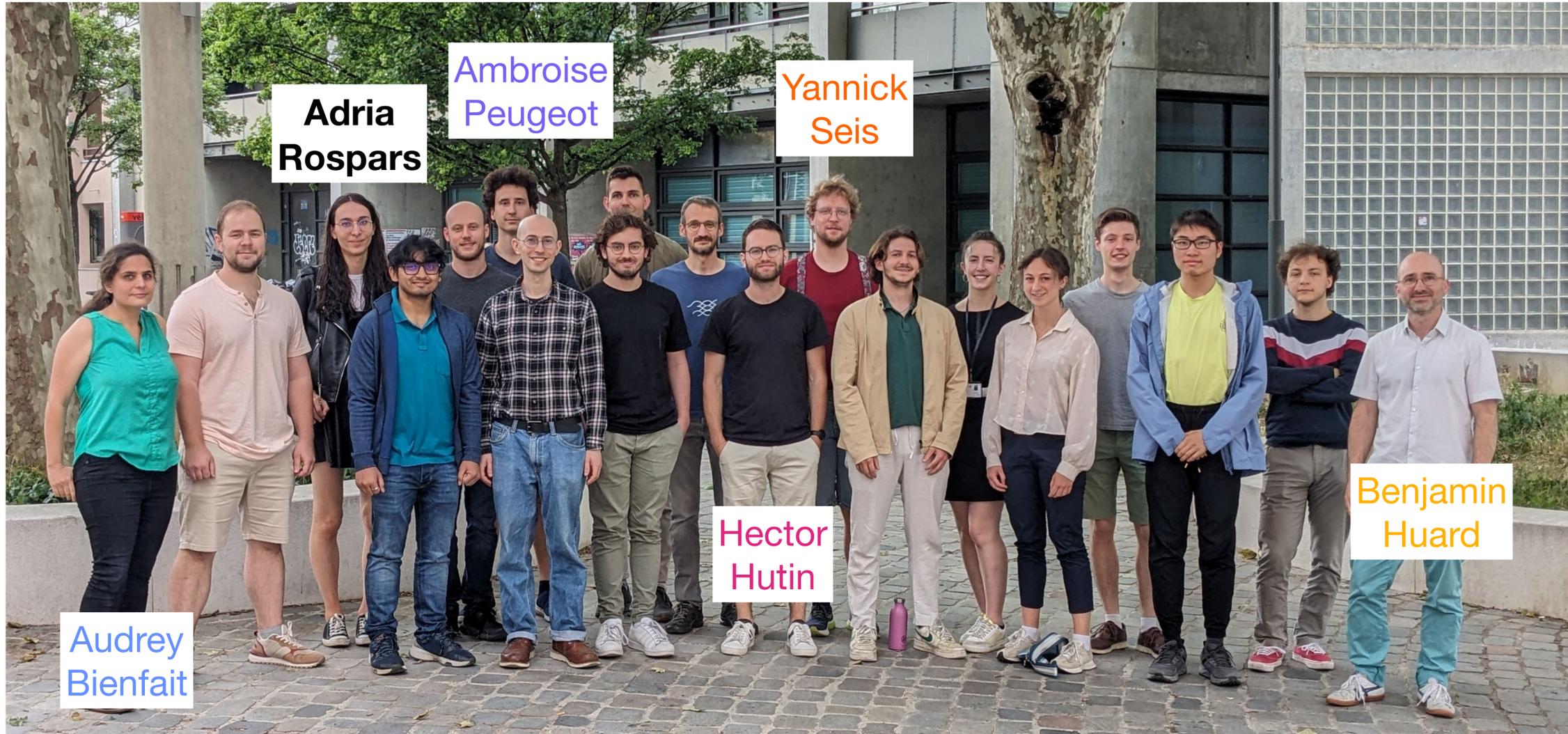
Tantalum film (few nm thick) may provide a resistive/inductive path to ground

XPS reveals that standard **Ta etching is incomplete on sapphire**

Perspective

Try to reproduce it in a controllable manner

Thank you



Rémy Dassonneville



Réouven Assouly

Romain Cazaly



Cristobal Lledo



Alexandre Blais