

BASIC CHARACTERIZATION OF

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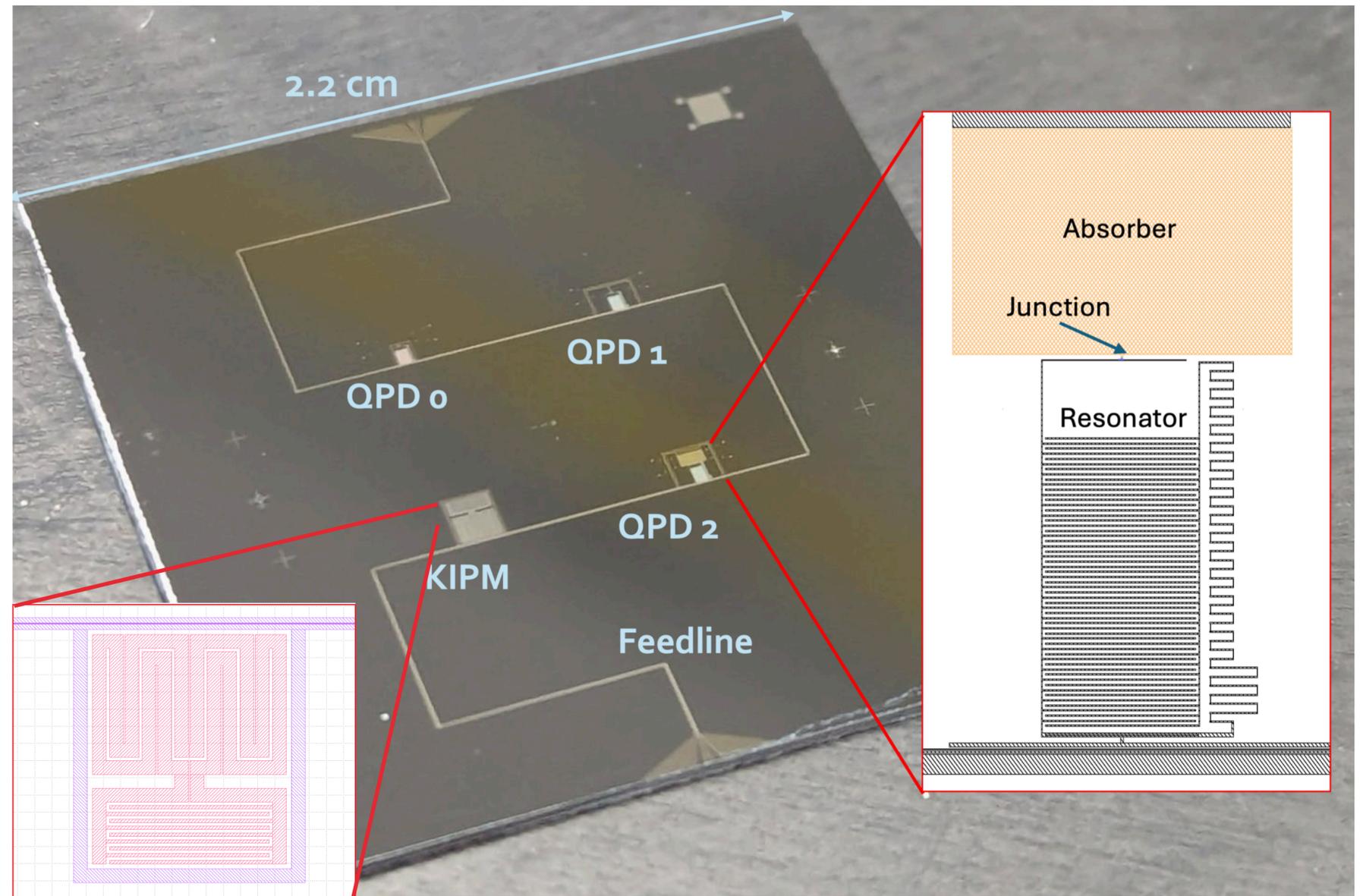
# QUANTUM PARITY DETECTOR

Lanqing Yuan (Washington University in St. Louis)

on behalf of Brandon J. Sandoval, Andrew D. Beyer, Andrew D. Beyer, Andrew D. Beyer, William D. Ho & Karthik Ramanathan

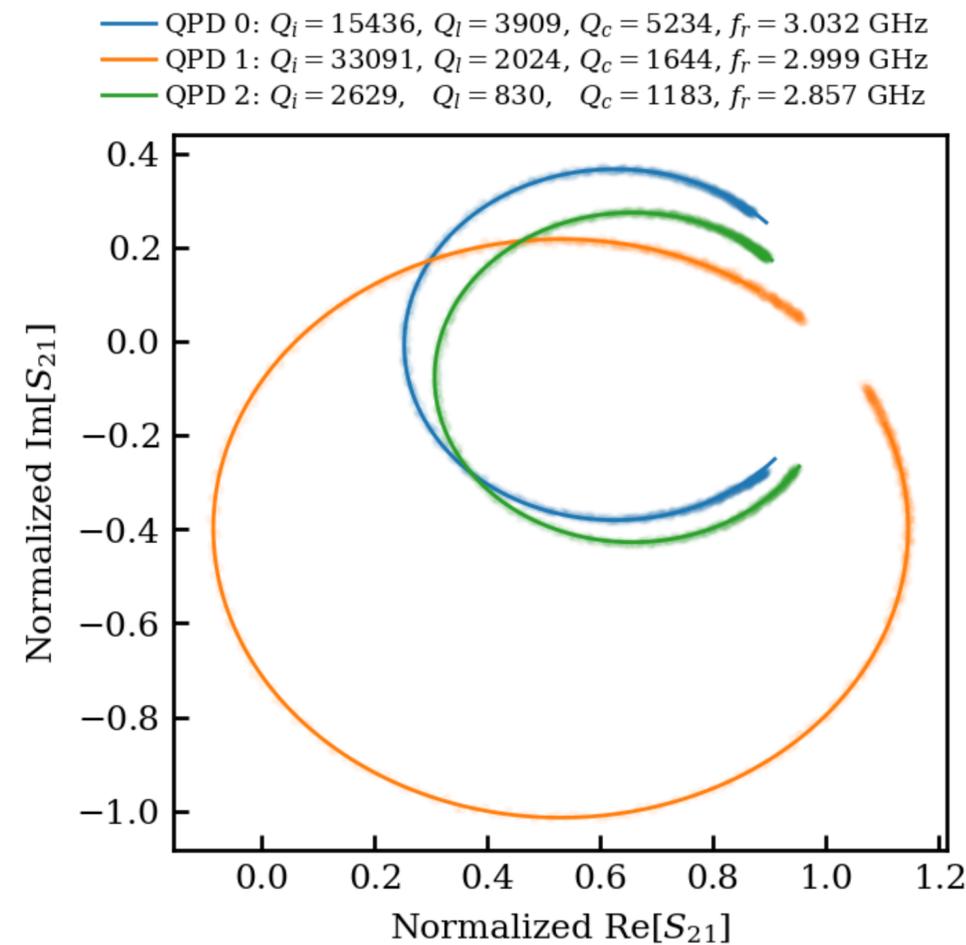
## DEVICE DESIGN

- ▶ Three QPDs with identical junctions but with absorber sizes spanning 1, 100 and 1000  $\mu\text{m}^3$  (QPD0, 1, 2).
- ▶ Each has an absorber, Josephson junction, island, and readout resonator.
- ▶ Bias voltage is applied to the feed line through a bias tee.
- ▶ One KIPM to co-calibrate QPDs (when there is calibration source available).

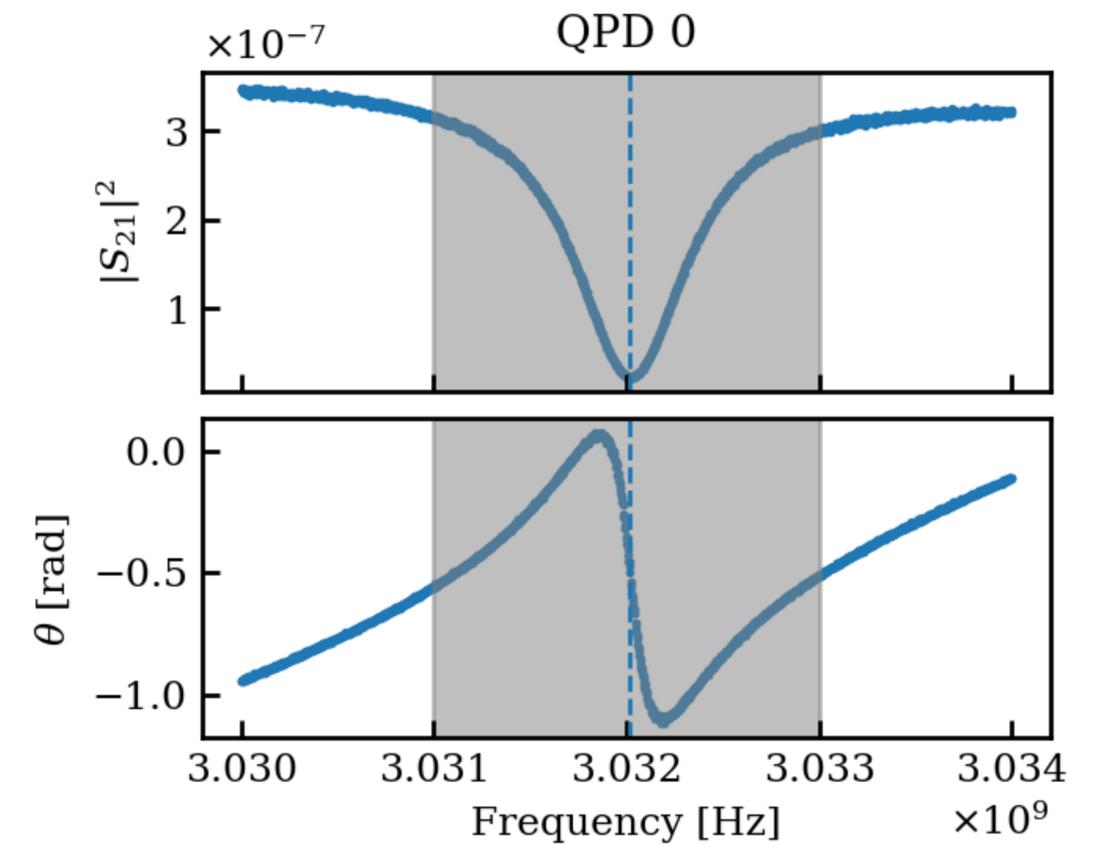


# BASIC RESONATOR PARAMETERS

- ▶ Saw all resonances in frequency sweep:
  - ▶ Measured using Presto-8;
  - ▶ Highly usable thanks to the Python interface.



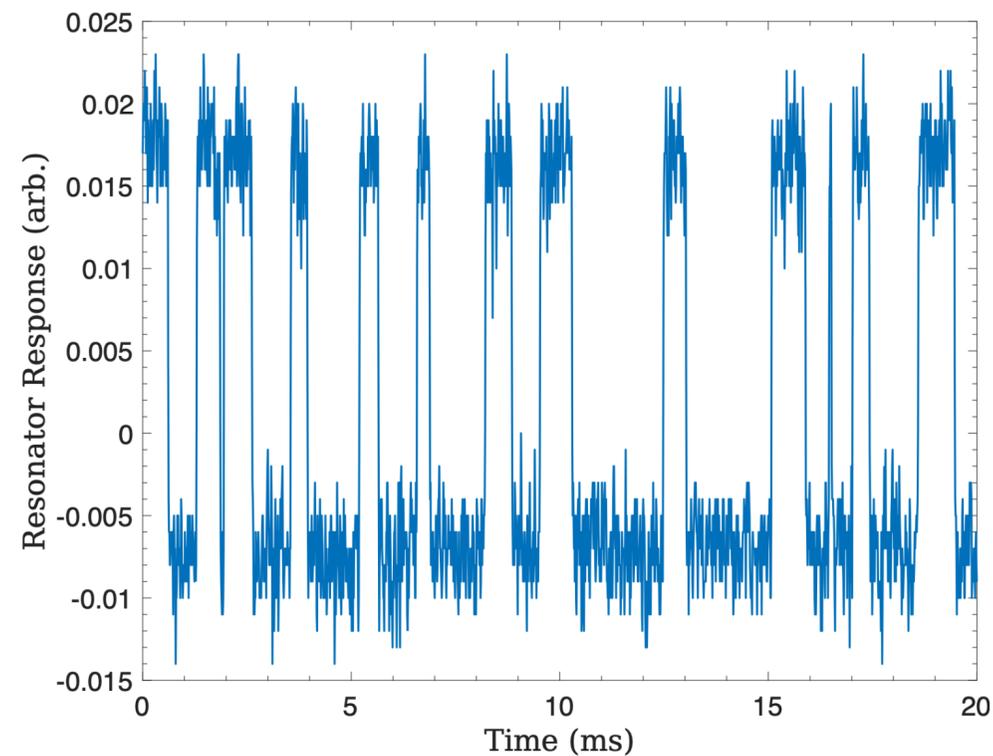
Sensor	$f_r$ (GHz)	$Q_i$	$Q_c$
KIPM	4.040	277000	12500
QPD0	3.032	34100	6720
QPD1	2.999	24300	2020
QPD2	2.857	2920	2600



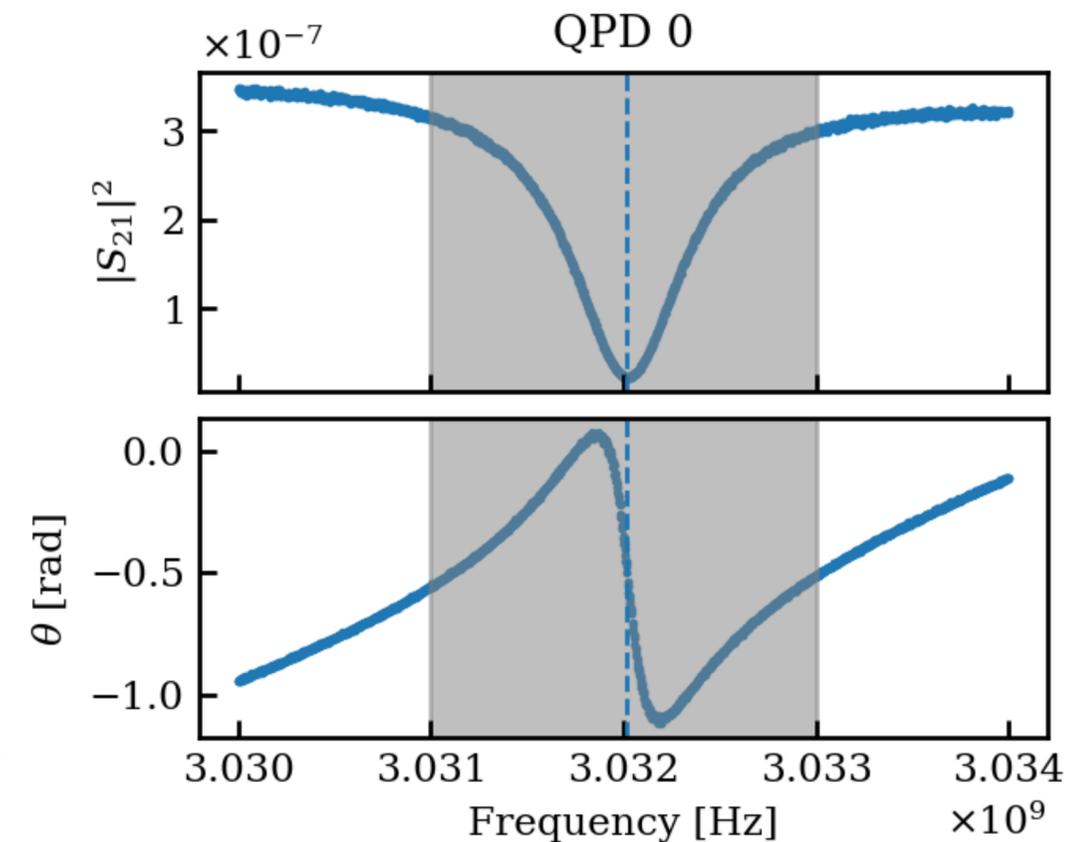
# OBSERVED PARITY FLIPPING SIGNALS

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- ▶ But only QPD0 (3.032 GHz) showed parity flipping signals.

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At constant  $n_g \approx 0.5$



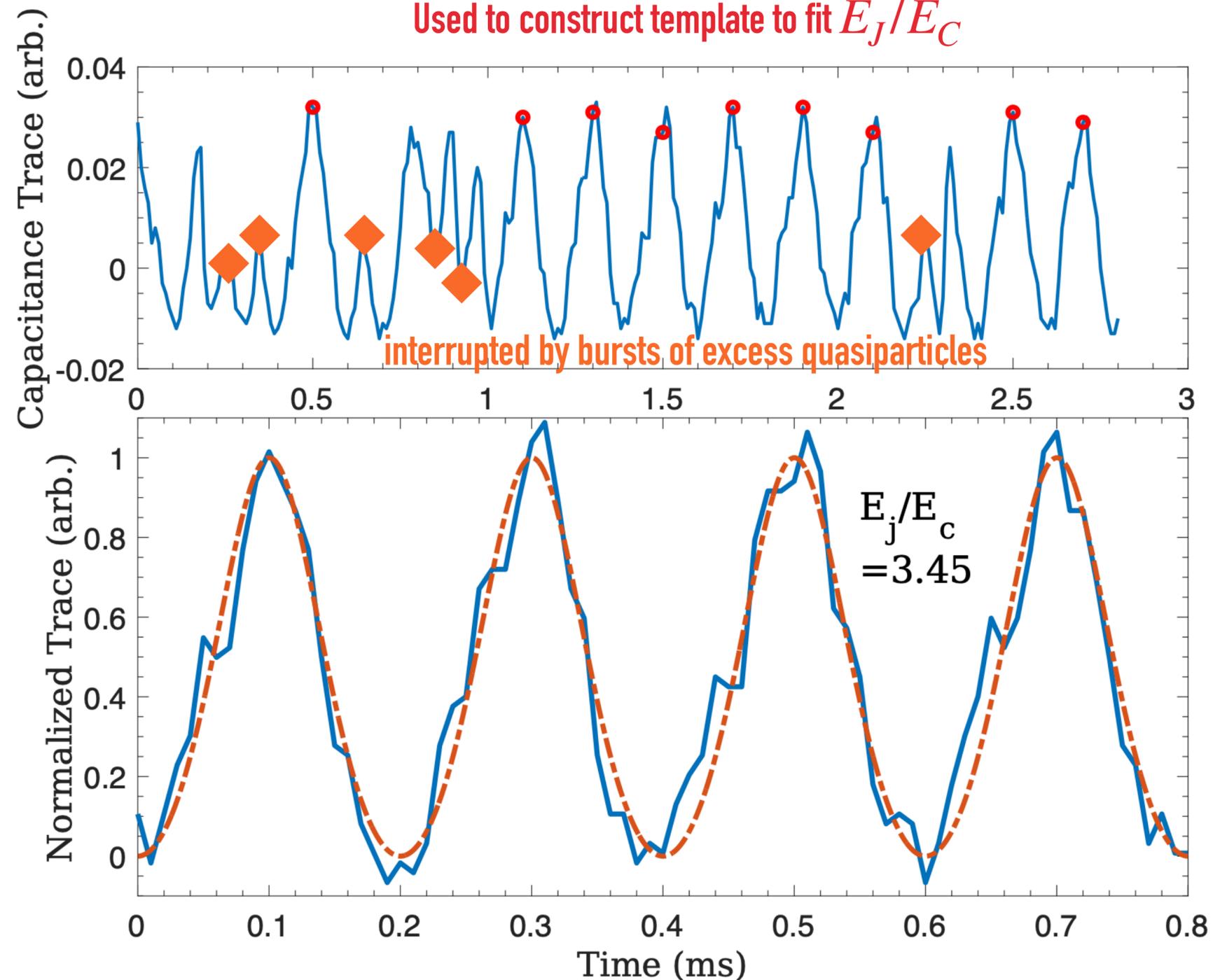
# OBSERVED PARITY FLIPPING SIGNALS

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  - ▶ Measured using Presto-8;
  - ▶ Highly usable thanks to the Python interface.
- ▶ But only QPD0 (3.032 GHz) showed parity flipping signals.
- ▶ Multiplex readout on the same line by using sawtooth DC bias generator at ~50 kHz
  - ▶ Can extract  $E_J/E_C$  from capacitance traces.

Phys. Rev. B 79, 144511

$$H_{\text{CPB}} = 4E_C \left( \hat{n} - n_g + \frac{P-1}{4} \right)^2 - E_J \cos \hat{\phi}$$

Used to construct template to fit  $E_J/E_C$





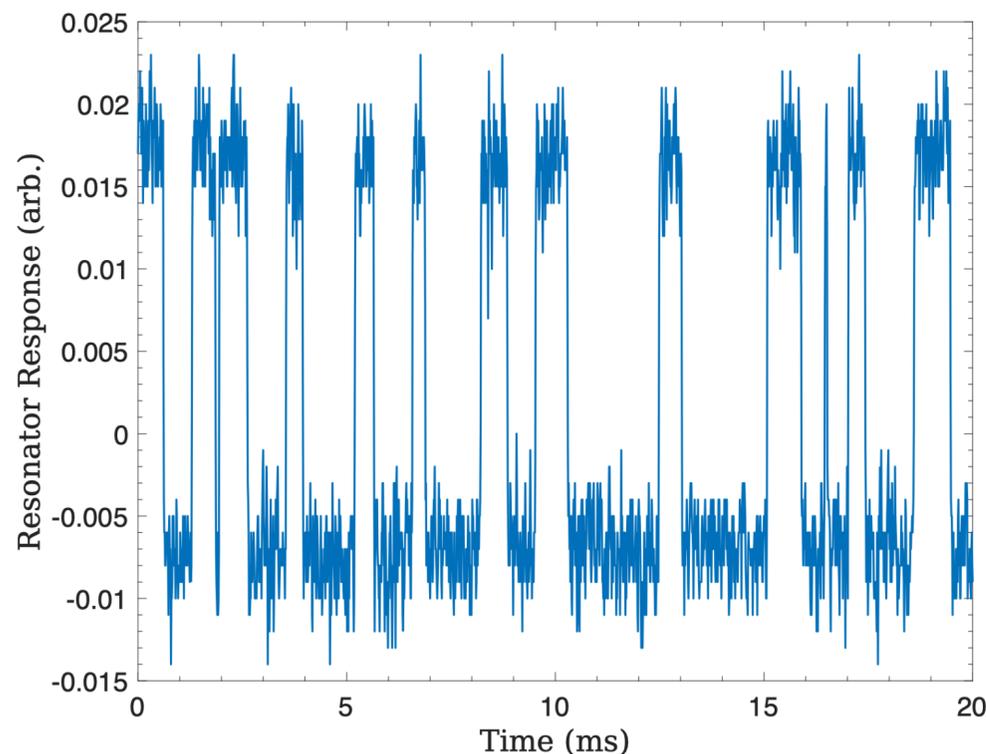
# PARITY FLIPPING RATE: NAIVE FITTING

- ▶ Principle of quiescent quasiparticle density measurement:

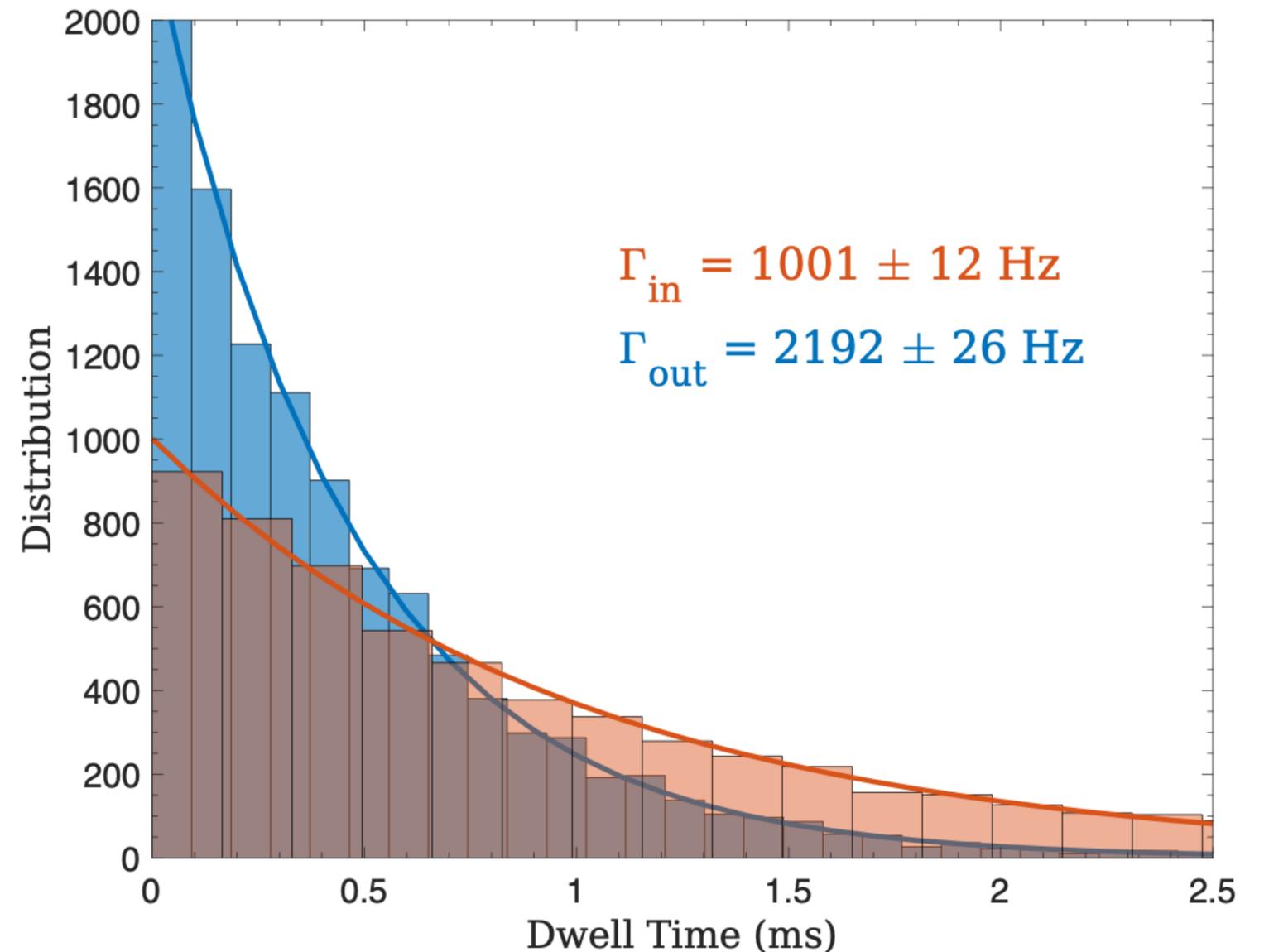
$$\Gamma_{in} = Kn_{qp}$$

- ▶ Measured flipping rate at constant bias voltage for QPD0.

- ▶ Educated guess: tunneling in (even->odd) is faster than tunneling out (odd->even) Phys. Rev. B 72, 014517



Did NOT observe double exponential in either state's dwell time in this run!



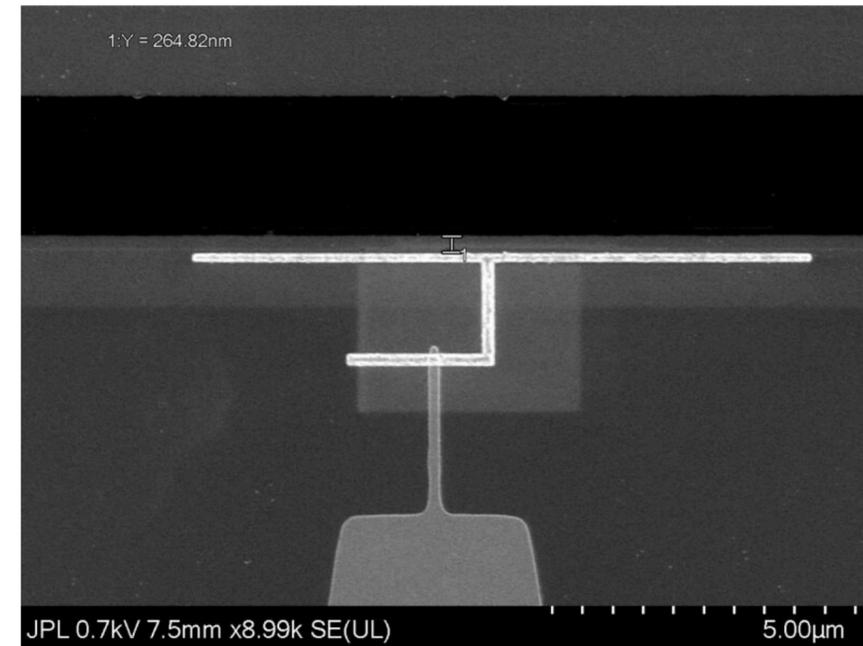
# INFERRING $K$ FROM JUNCTION CONDUCTANCE

- ▶ Principle of quiescent quasiparticle density measurement:  $\Gamma_{in} = Kn_{qp}$
- ▶ Assuming the absorber is not diffusion-limited and symmetric gap energy across the junction

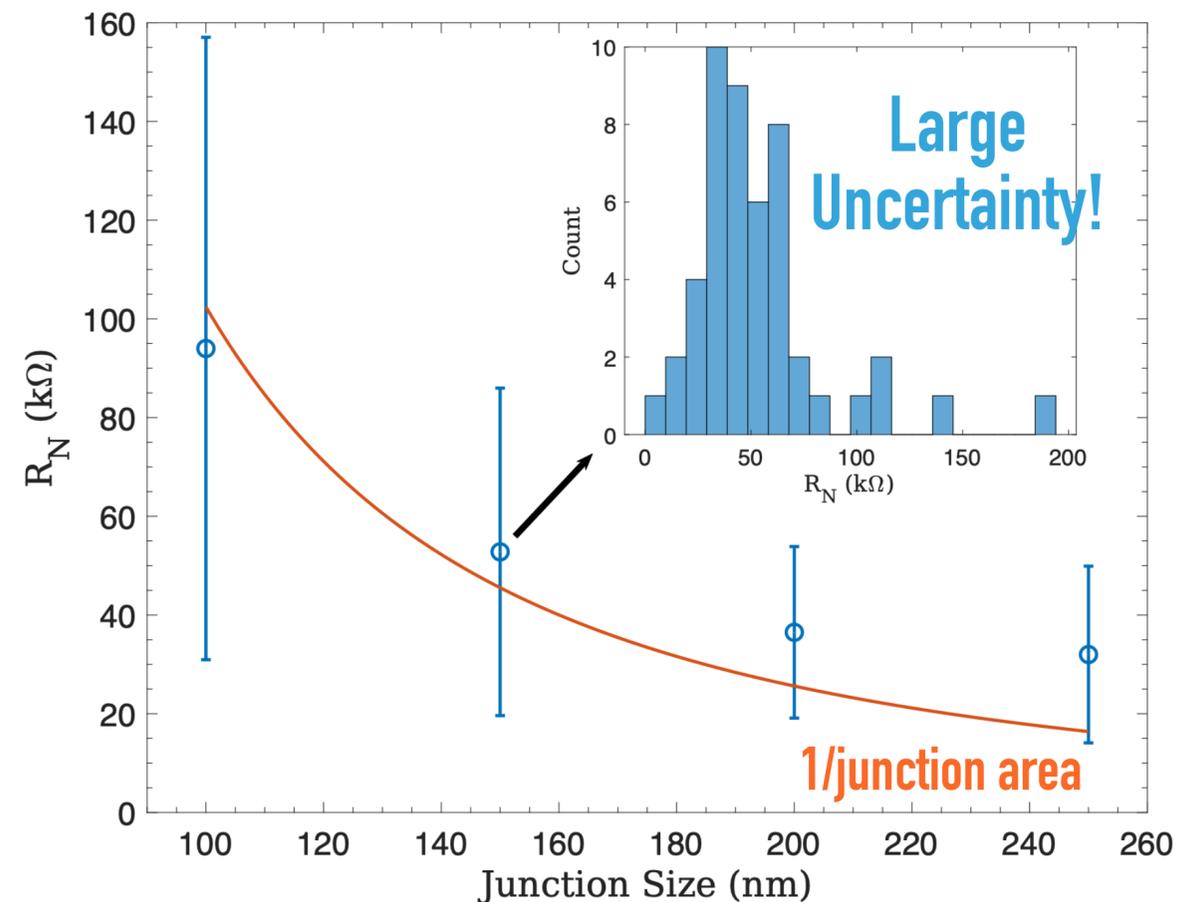
## Normal state junction conductance

$$K = \frac{G_N}{e^2} \frac{e^{\Delta/k_B T}}{N_0 \sqrt{2\pi\Delta k_B T}} \int_{\Delta}^{\infty} dE h(E) e^{-E/k_B T}$$

$$h(E) = \frac{E(E + \delta E) - \Delta^2}{\sqrt{((E + \delta E)^2 - \Delta^2) (E^2 - \Delta^2)}}$$

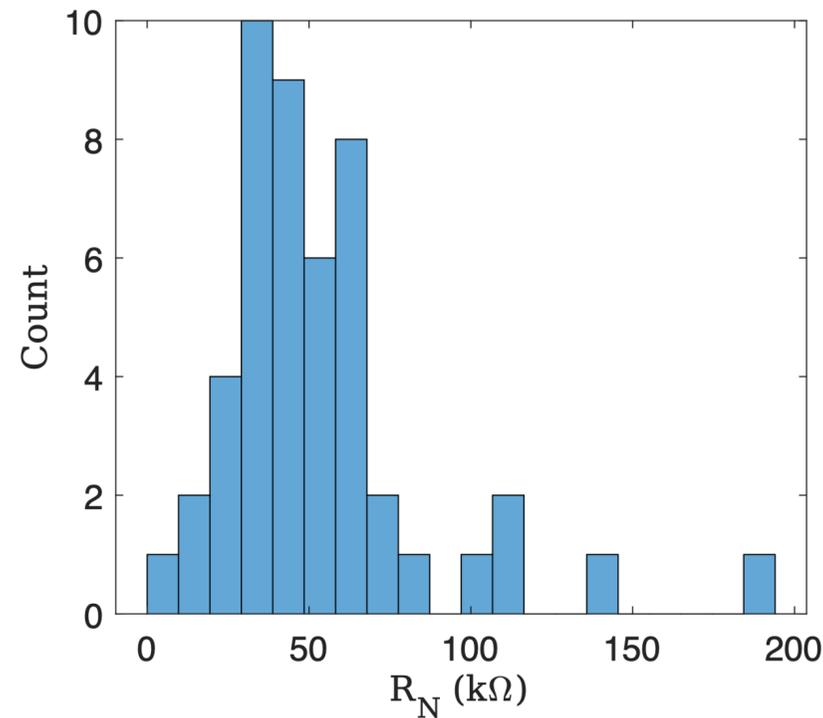


Constructed 50 test junctions of side lengths ranging from 100 nm to 250 nm



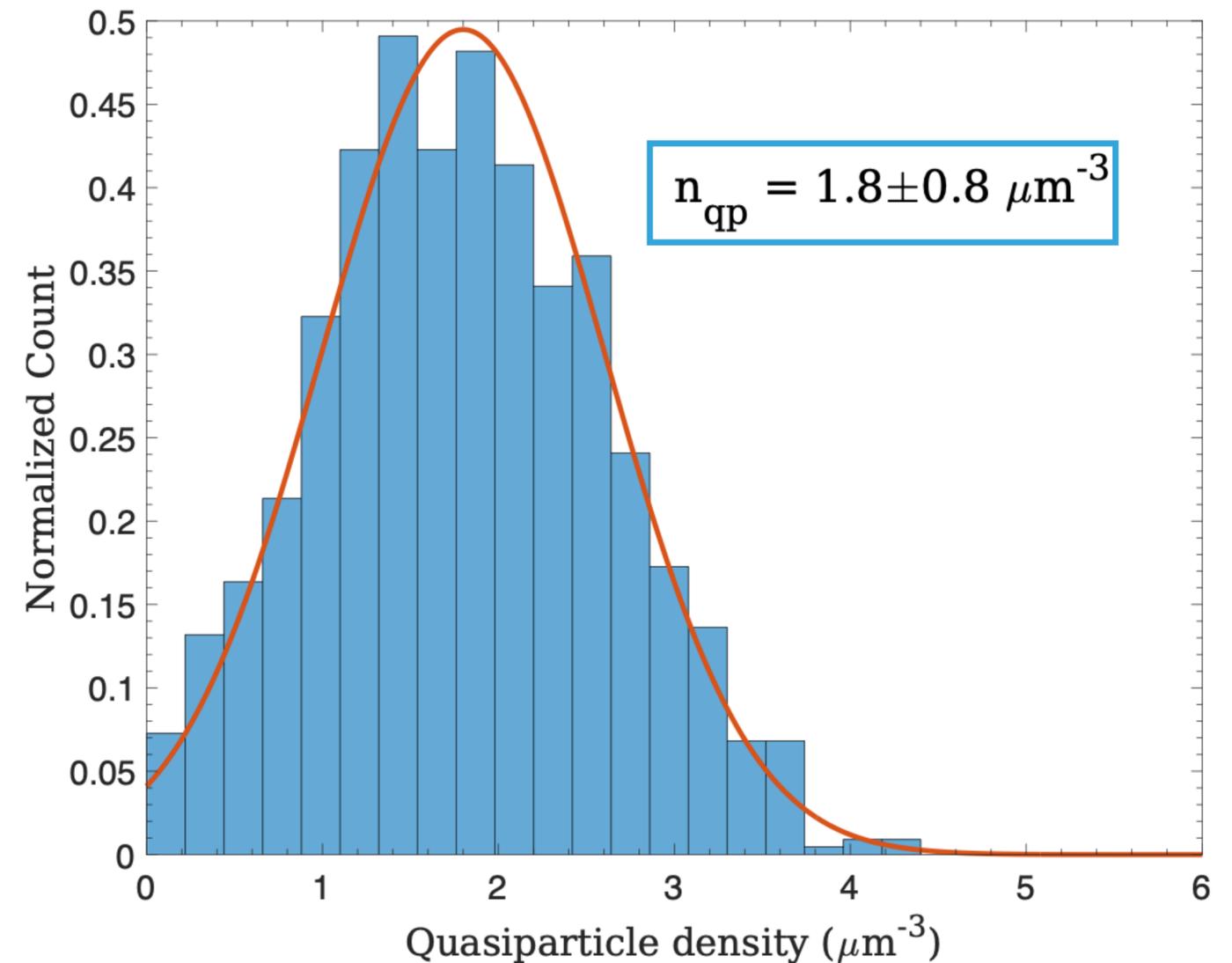
# INFERRING $n_{qp}$ FROM MEASURED $K$

- ▶ Principle of quiescent quasiparticle density measurement:  $\Gamma_{in} = Kn_{qp}$
- ▶ Embedding uncertainty in  $K$  by a Monte-Carlo approach



QPD design paper: need  $\ll 1\mu\text{m}^{-3}$

In line with literatures: Potentially due to parasitic IR radiation

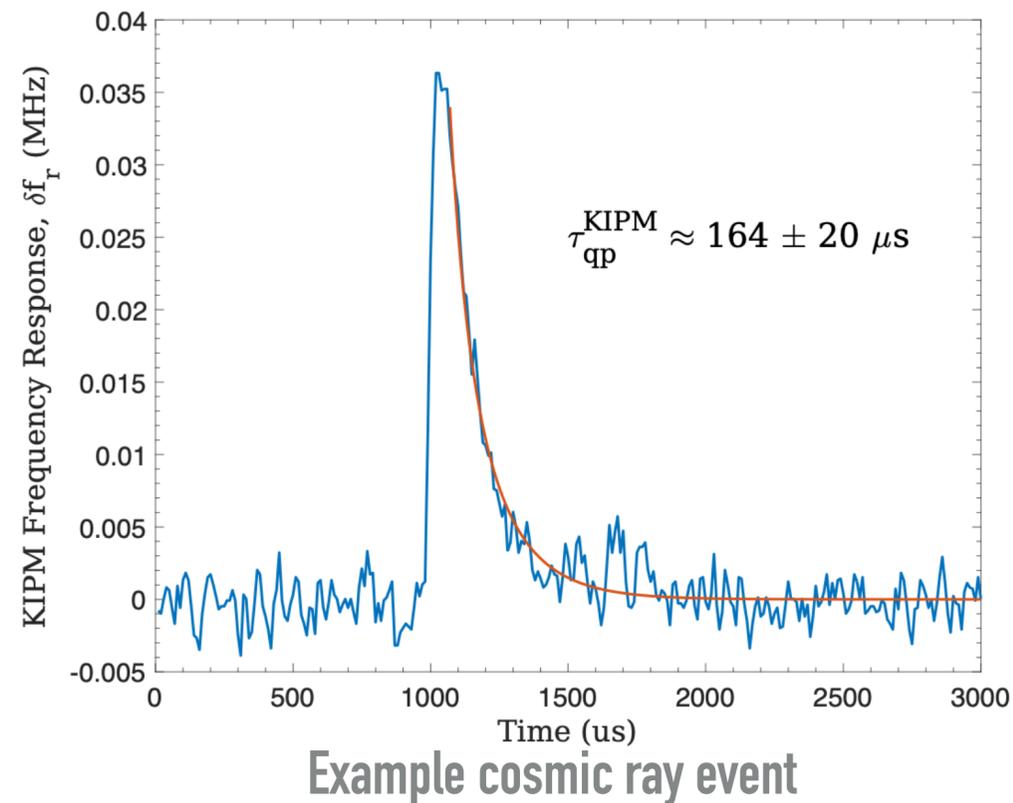


# SIDE NOTE: COMPARISON TO KIPM

- ▶ One can *roughly* infer quasiparticle density from intrinsic quasiparticle lifetime:

$$n_{qp}^{KIPM} = \frac{\tau_0 N_0 (k_B T_c)^3}{2\Delta^2 \tau_{qp}^{KIPM}} \approx 710 \mu\text{m}^{-3}$$

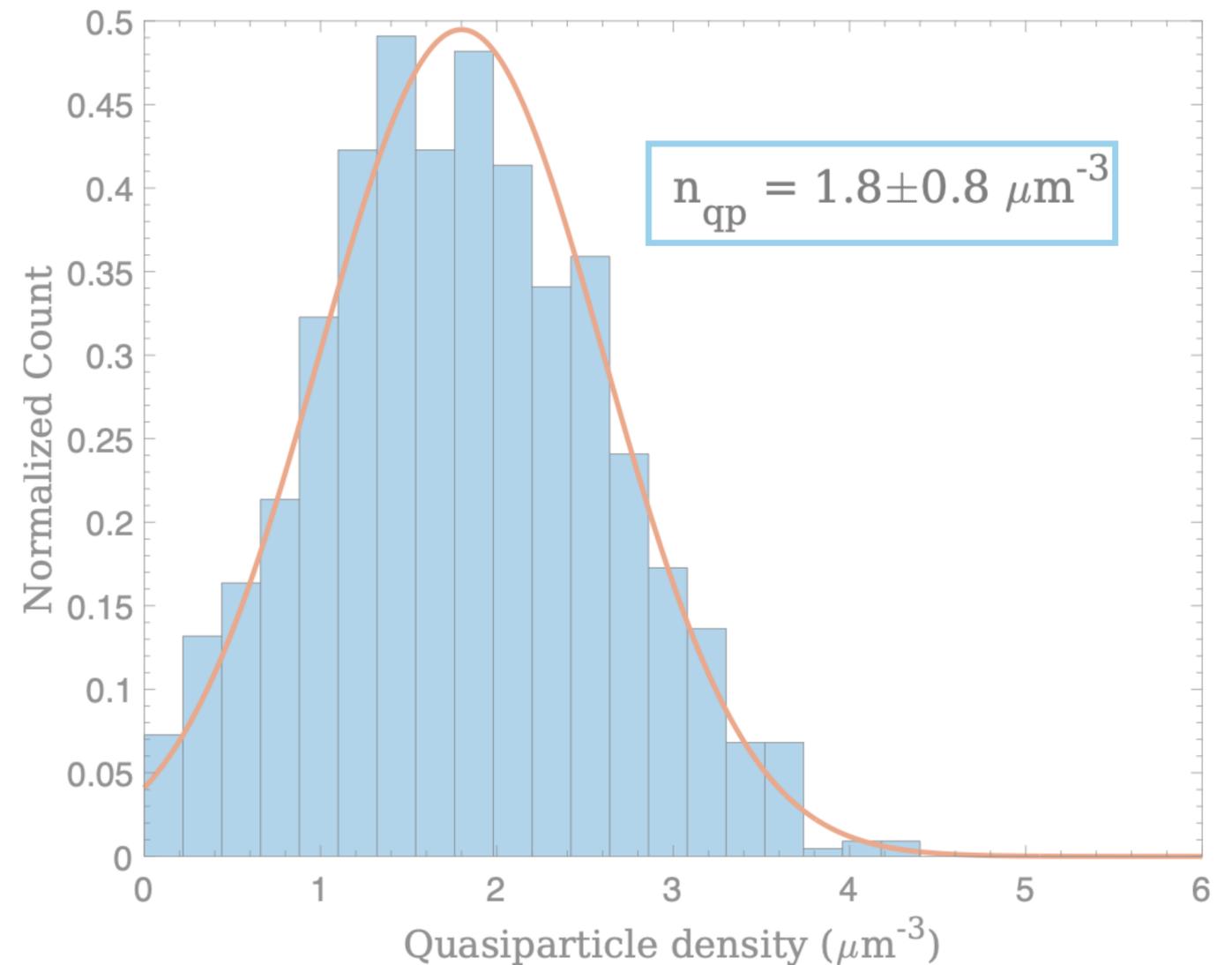
Phys. Rev. B 104, L180506



**Mismatch:  
Potentially due  
to readout  
power mismatch**

QPD design paper: need  $\ll 1 \mu\text{m}^{-3}$

In line with literatures: Potentially due to parasitic IR radiation



# COULD NOT REPRODUCE MEASUREMENTS AT WASHU

- ▶ Used similar fridge setup as JPL.
- ▶ Expected frequency shift:  $\sim 1$  MHz.
- ▶ Low-sweep: expect broadened resonant peak due to quasiparticle tunneling.

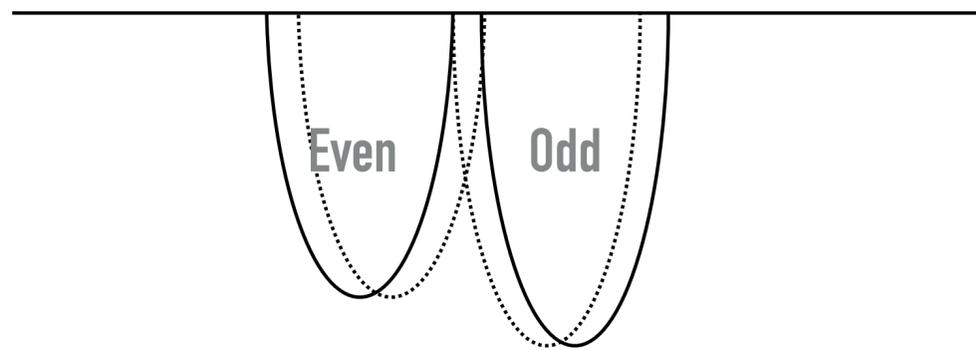
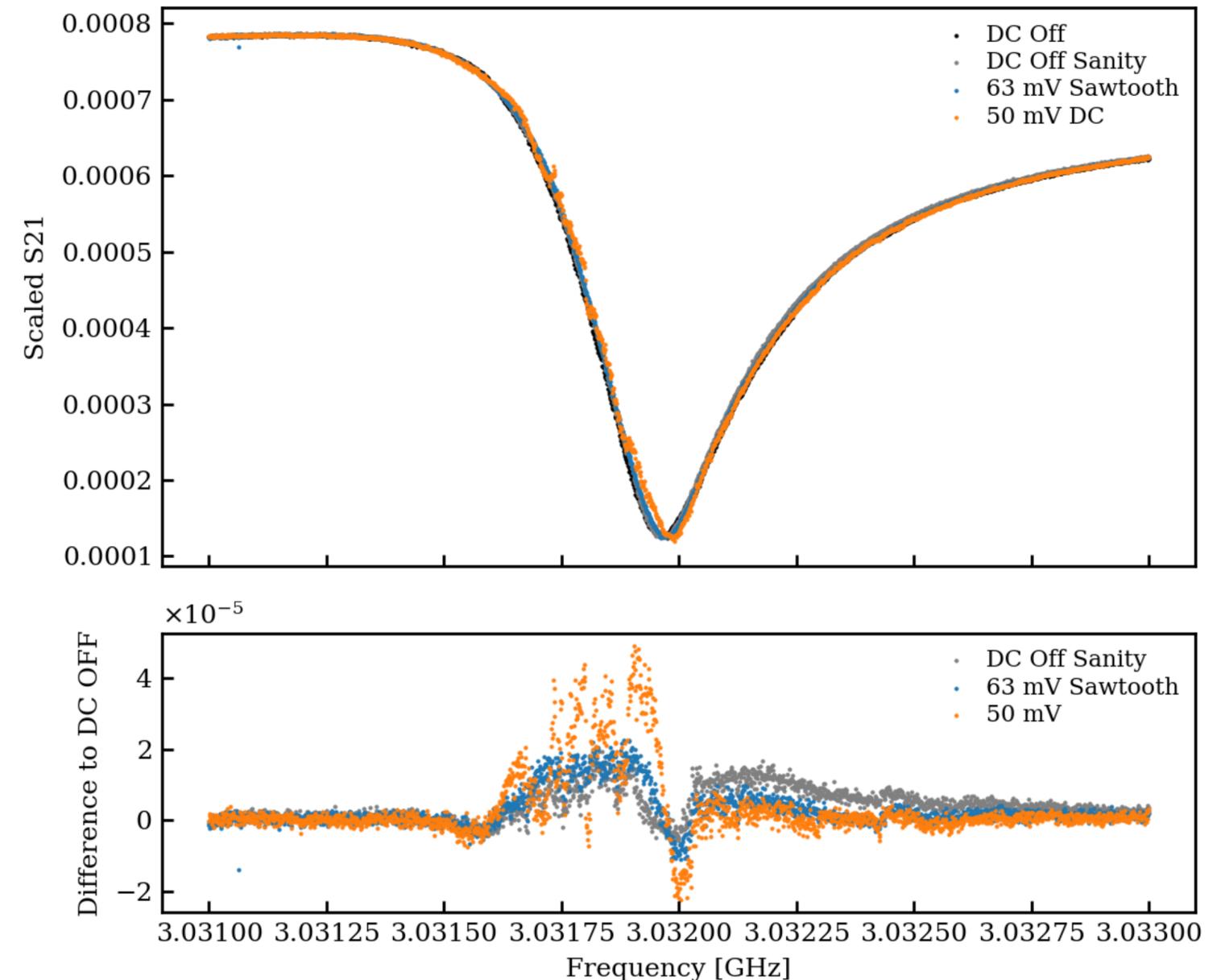
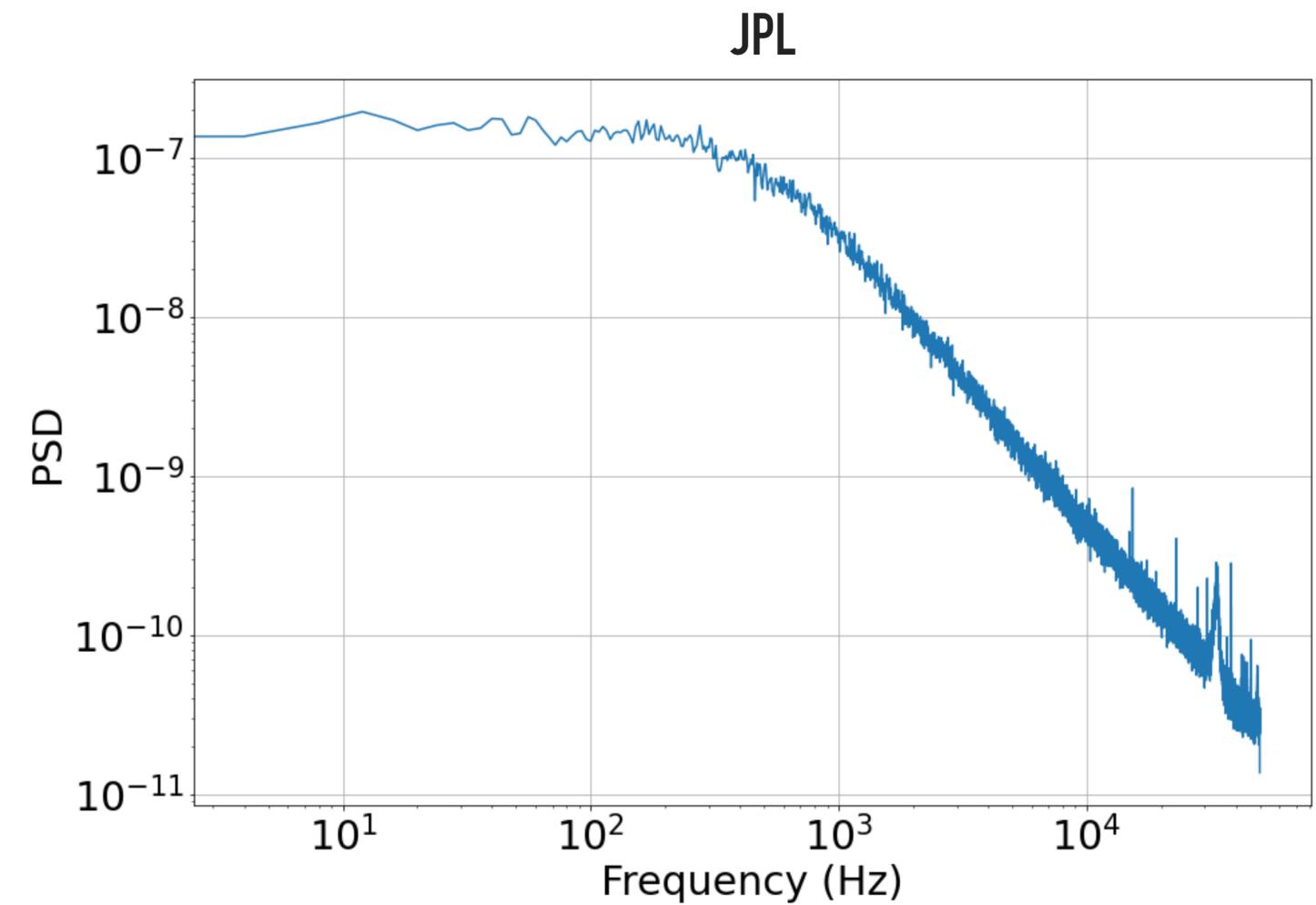
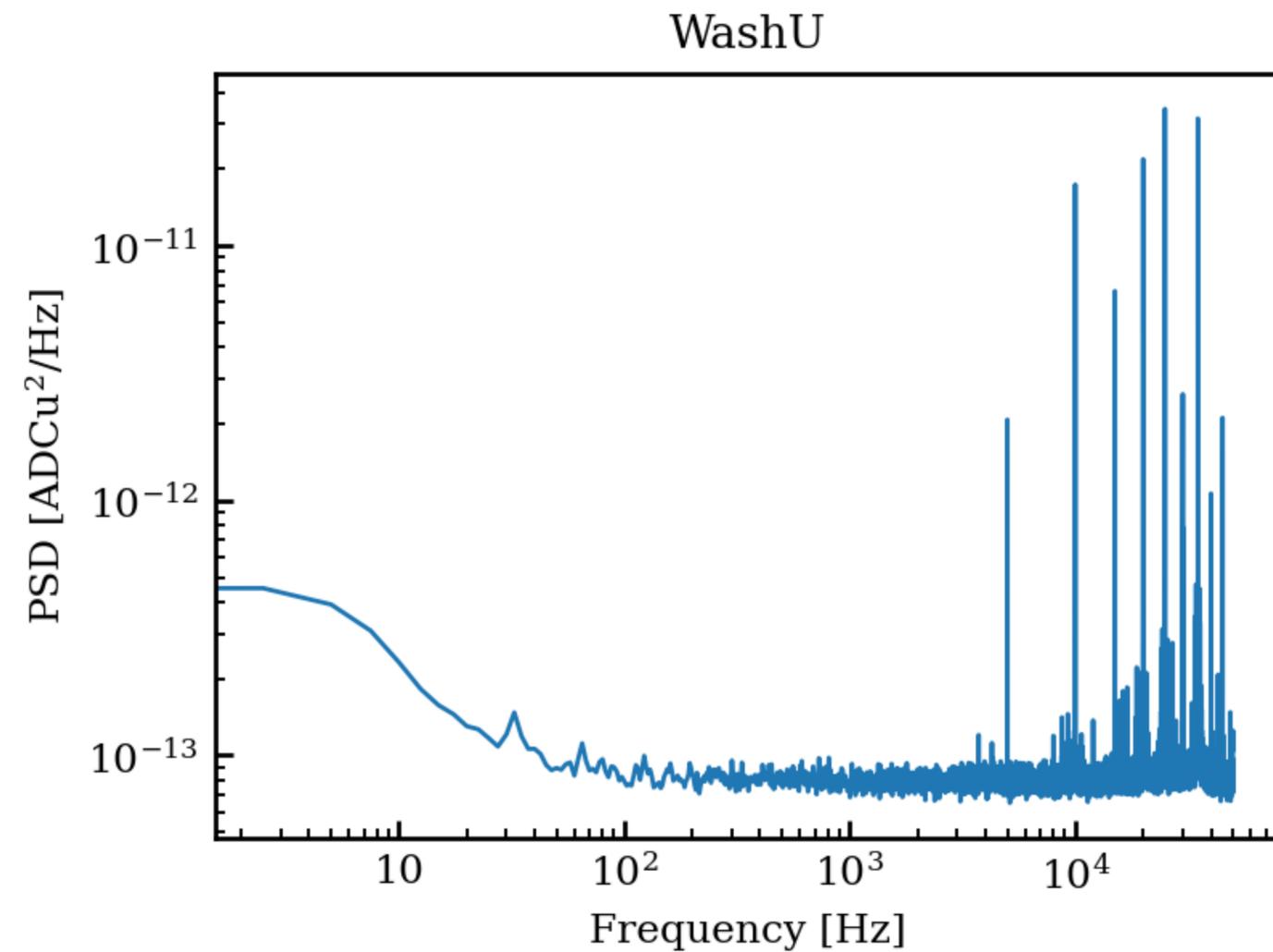


Illustration of slow sweep under different offset charge

The effect of DC is negligible compared to systematics!



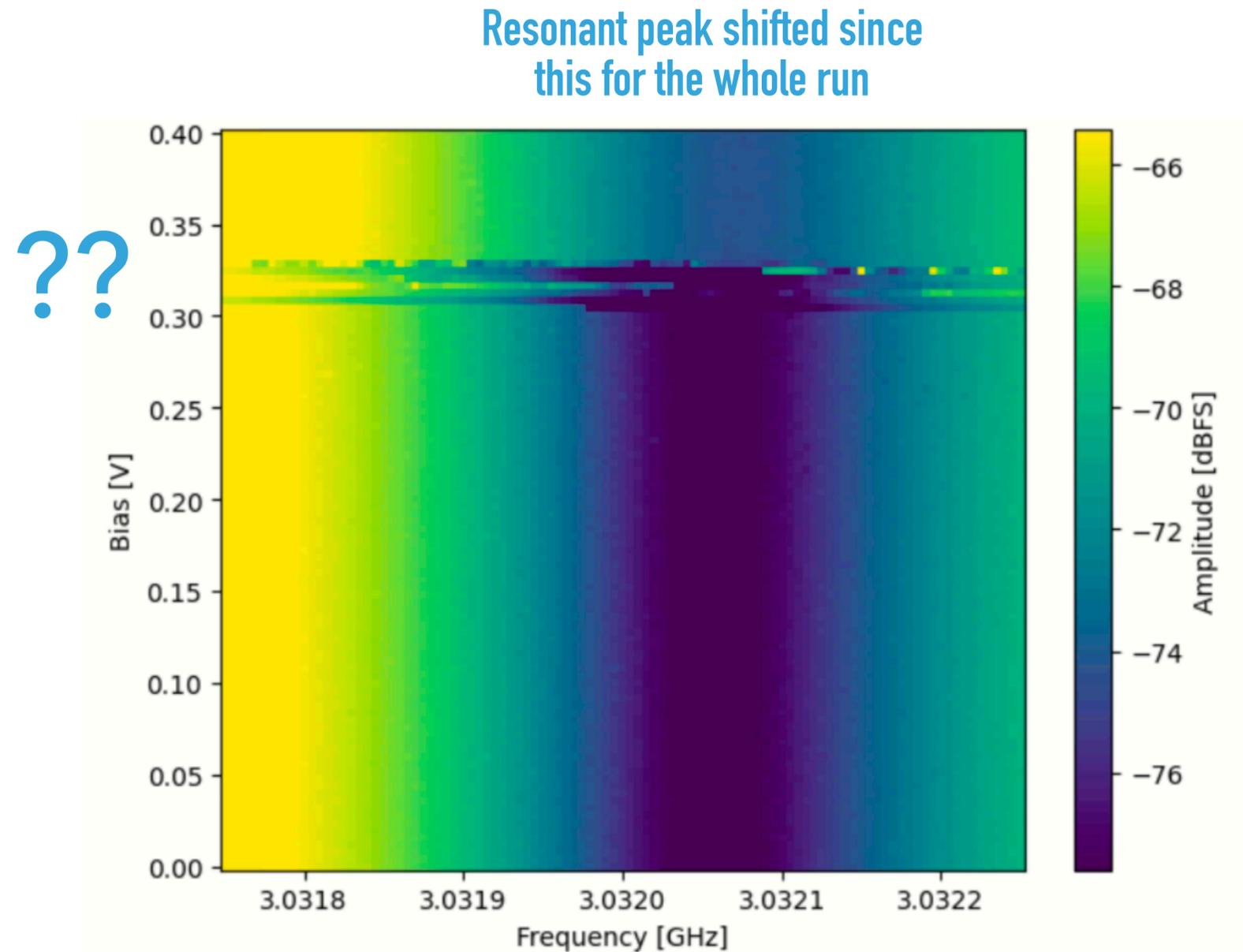
# COULD NOT REPRODUCE MEASUREMENTS AT WASHU



Caveat: Y axes may not be directly comparable...

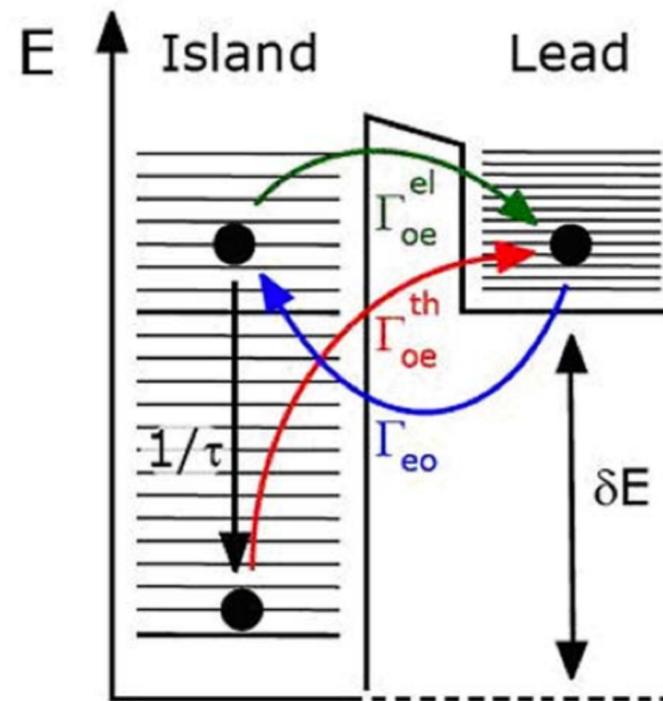
## HYPOTHESES FOR MISSING PARITY FLIPPING

- ▶ Elevated IR background or thermal noise background is saturating the qubit.
  - ▶ Will try to add another layer of shielding.
- ▶ Some accident breaks the qubit in early tests which shows weird behavior in DC bias sweep.

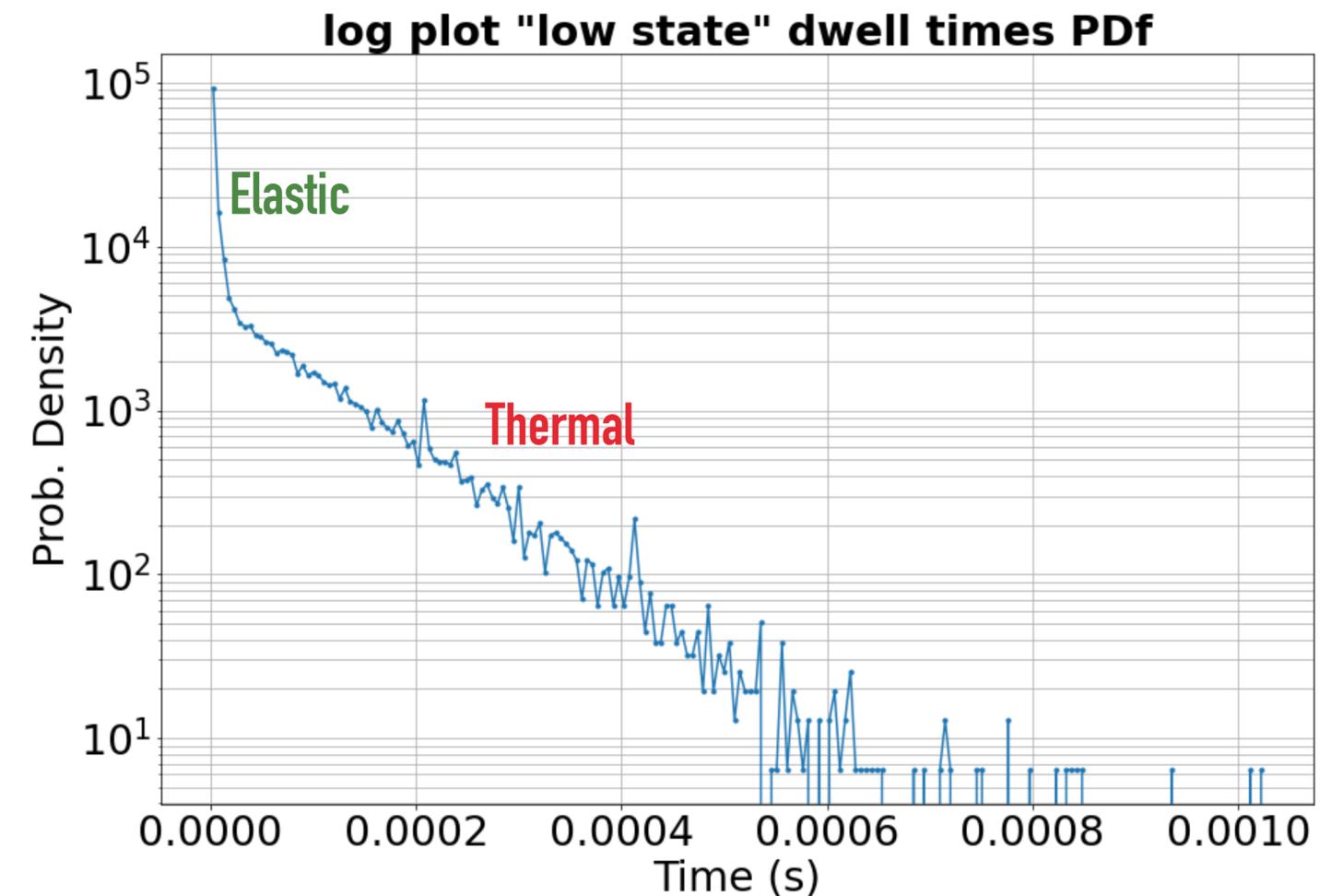


# DOUBLE EXPONENTIAL FITTING FOR ODD- $\rightarrow$ EVEN

- ▶ Expect two components in the process of tunneling out from island, when relaxation rate and tunneling rate are comparable:
  - ▶ **“Thermal”**: escape from the island via thermal excitation.
  - ▶ **“Elastic”**: elastically tunnel before relaxing to the bottom of the well.



Phys. Rev. B 78, 024503

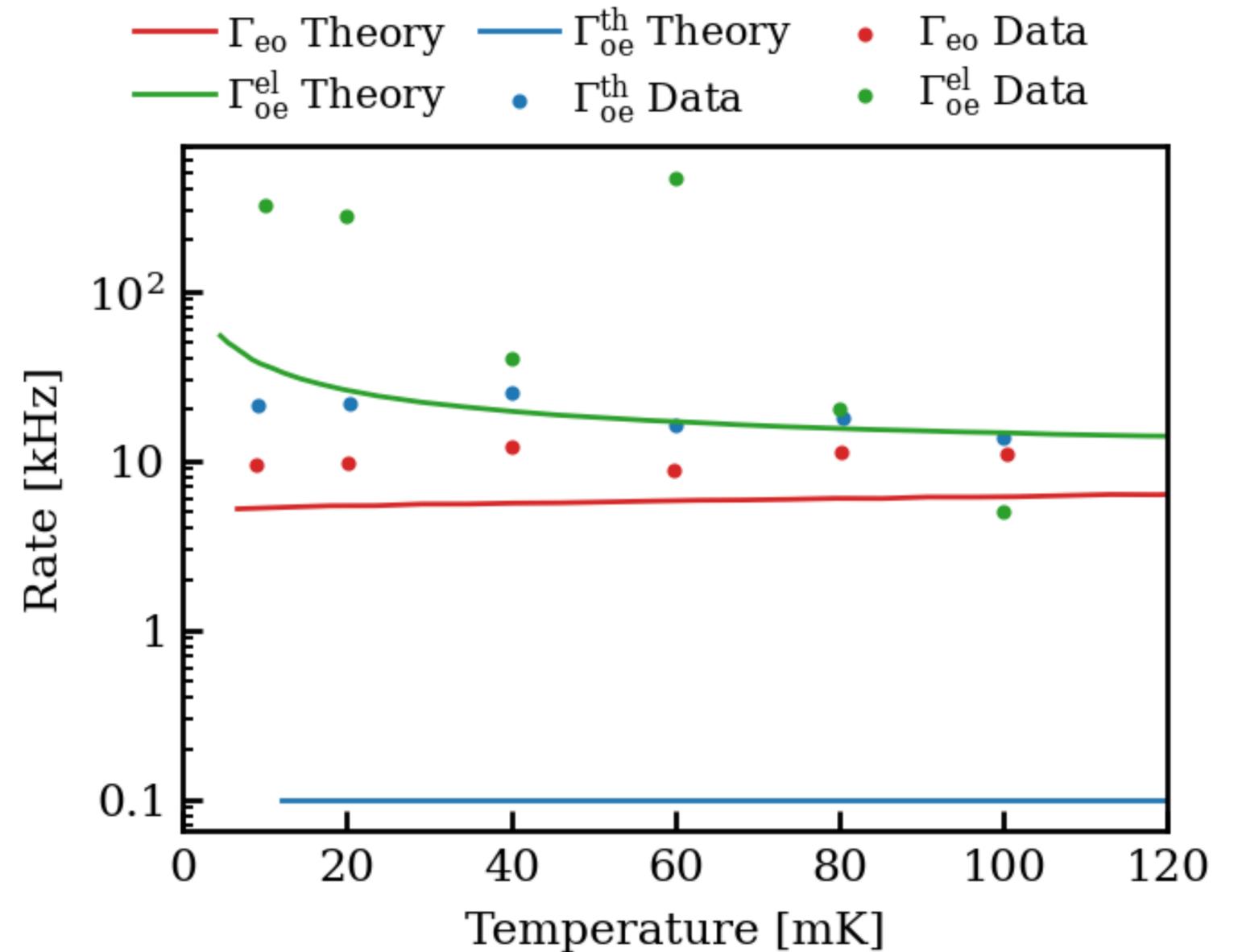


## OBSERVED ELEVATED TUNNELING RATE

- ▶ Theory based on kinetics of nonequilibrium quasiparticle tunneling predicts temperature dependencies of  $\Gamma_{oe}^{el}$ ,  $\Gamma_{oe}^{th}$  and  $\Gamma_{eo}$ .

Phys. Rev. B 78, 024503

- ▶ Observed elevated rate of parity switching potentially due to a red leak.



## SUMMARY

- ▶ Tested an initial AI based Quantum Parity Detector
  - ▶ Observed parity flipping signals, whose rate is ~in line with expectation.
  - ▶ Attempted to reproduce measurement at WashU.
  - ▶ Attempted to perform temperature sweep.