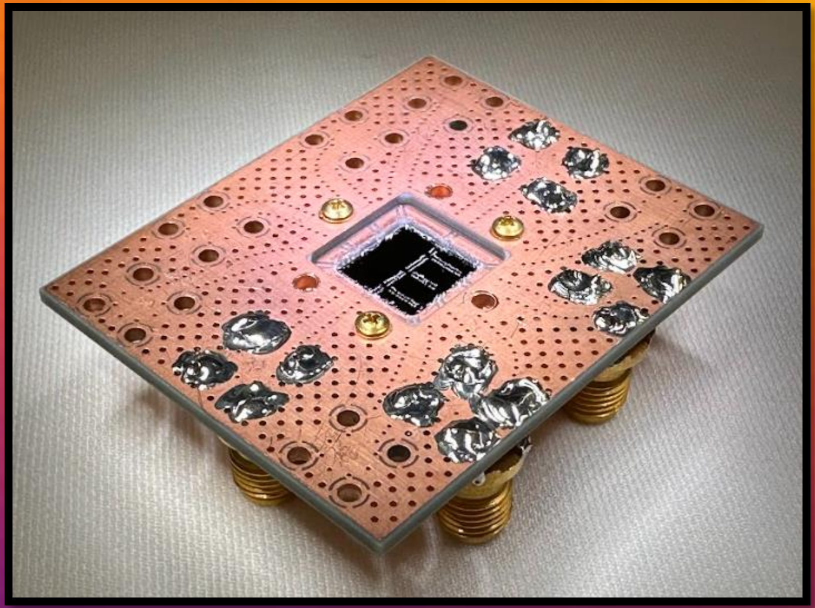
First Measurements of SQUAT Sensors

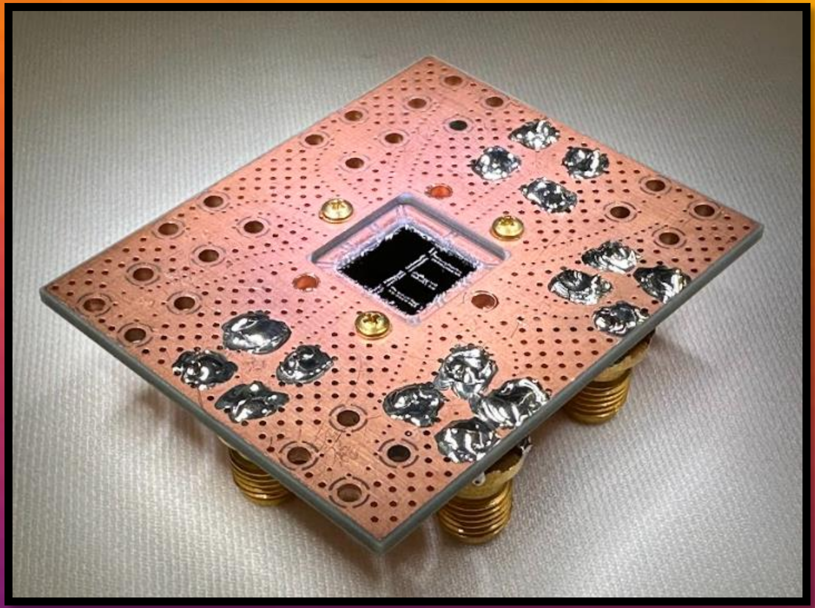


Chiara P. Salemi
Porat Postdoctoral Fellow, Stanford University and SLAC
→ Assistant Professor, UC Berkeley and LBNL
CPAD 2024

Fink, Salemi, Young, Schuster, Kurinsky *Phys.Rev.Applied* 2024
Magoon et al. *in prep* 2025

Superconducting Quasiparticle-Amplifying Transmon

First Measurements of SQUAT Sensors



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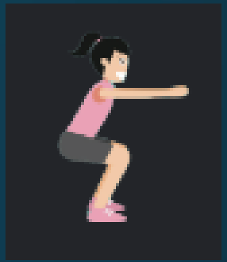
SQUAT team



Hannah Magoon

Sam Condon

+

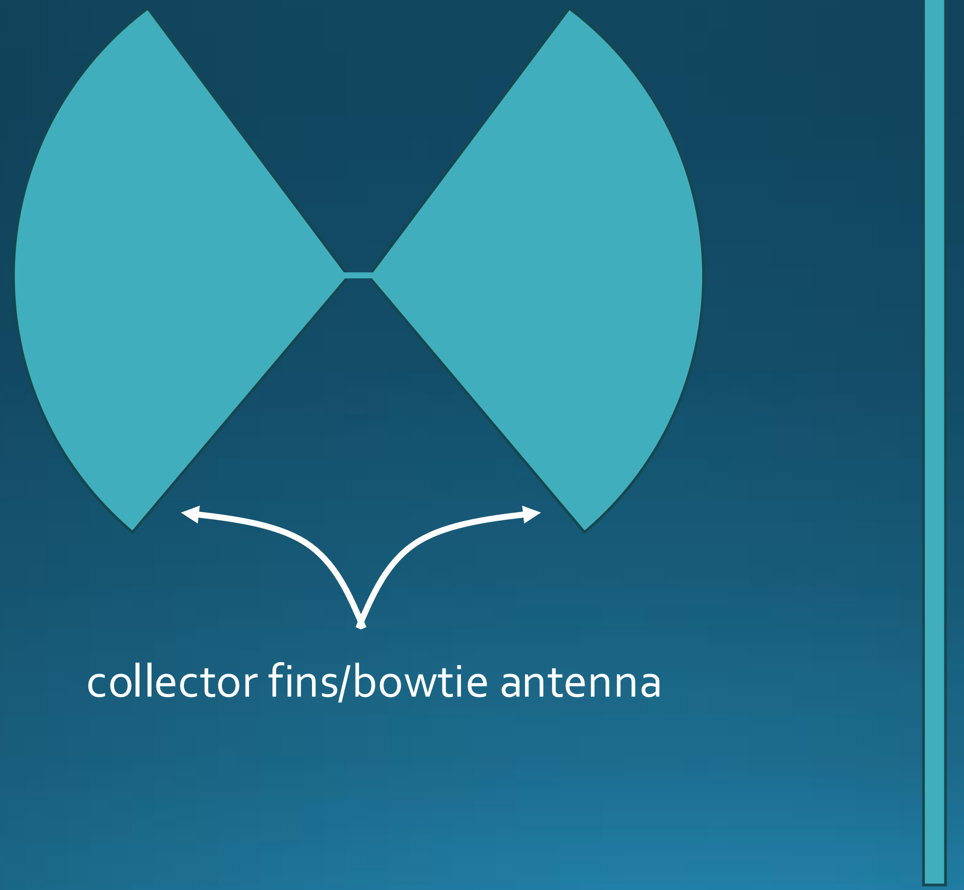
Jadyn Anczarski
Riley Carpenter
Caleb Fink
Shannon Harvey
Noah Kurinsky
Anthony Nuñez
Mihir Pendharkar
Tonya Peshel
Britton Plourde
Chiara Salemi
Dave Schuster
Aviv Simchony
Zoë Smith
Pam Stark
Noshin Tabassum

SQUAT concept

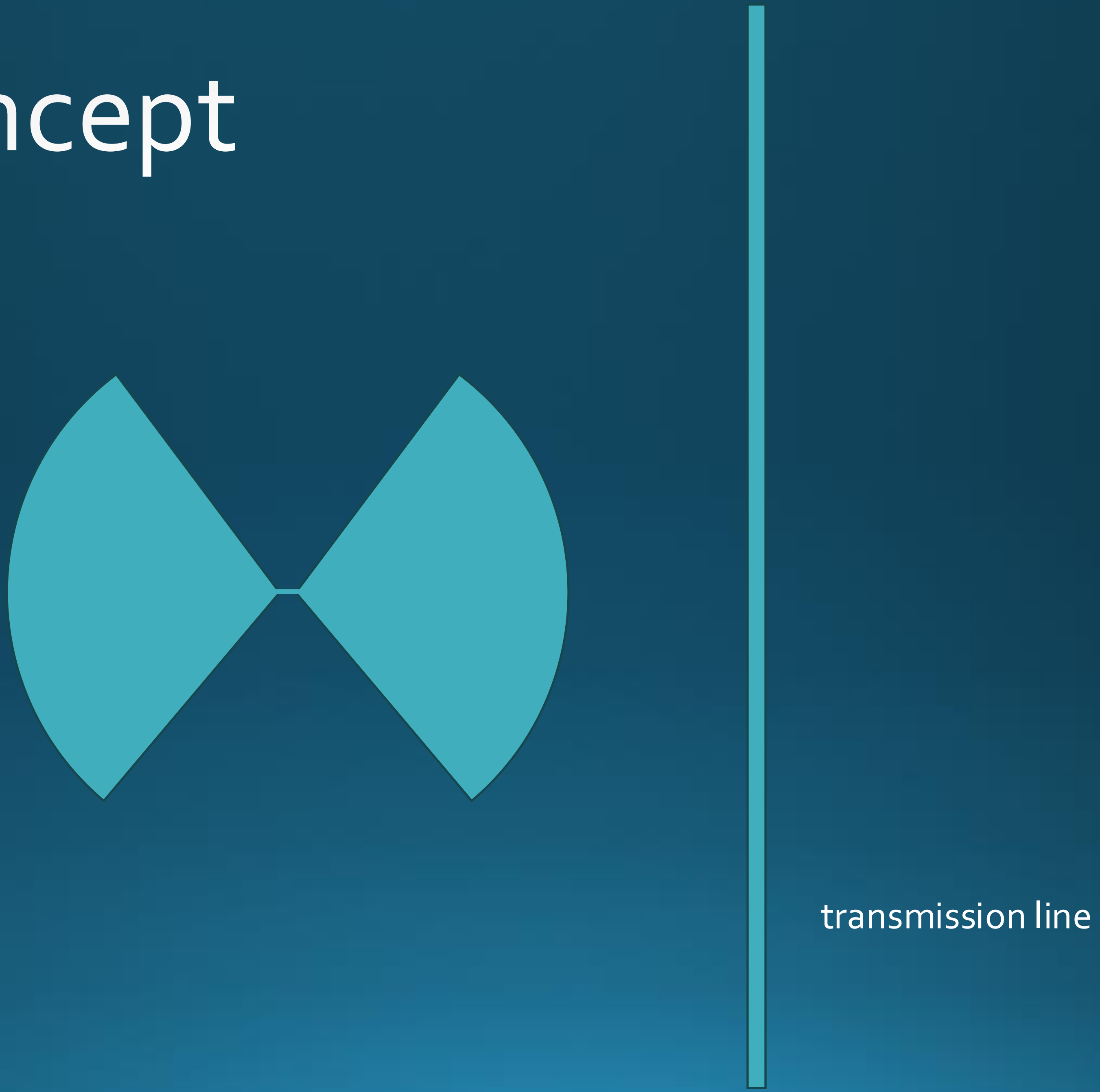
SQUAT concept

weakly charge
sensitive transmon

SQUAT concept

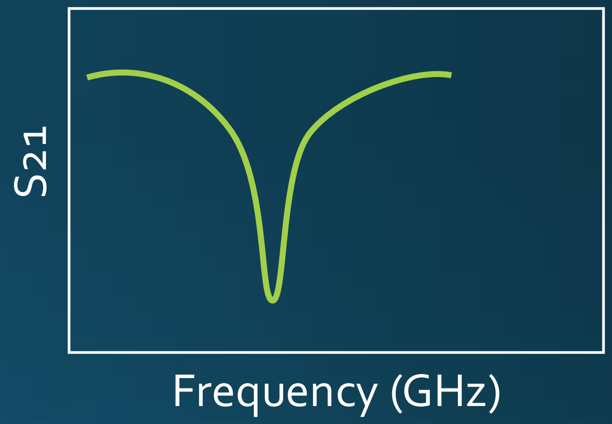


SQUAT concept



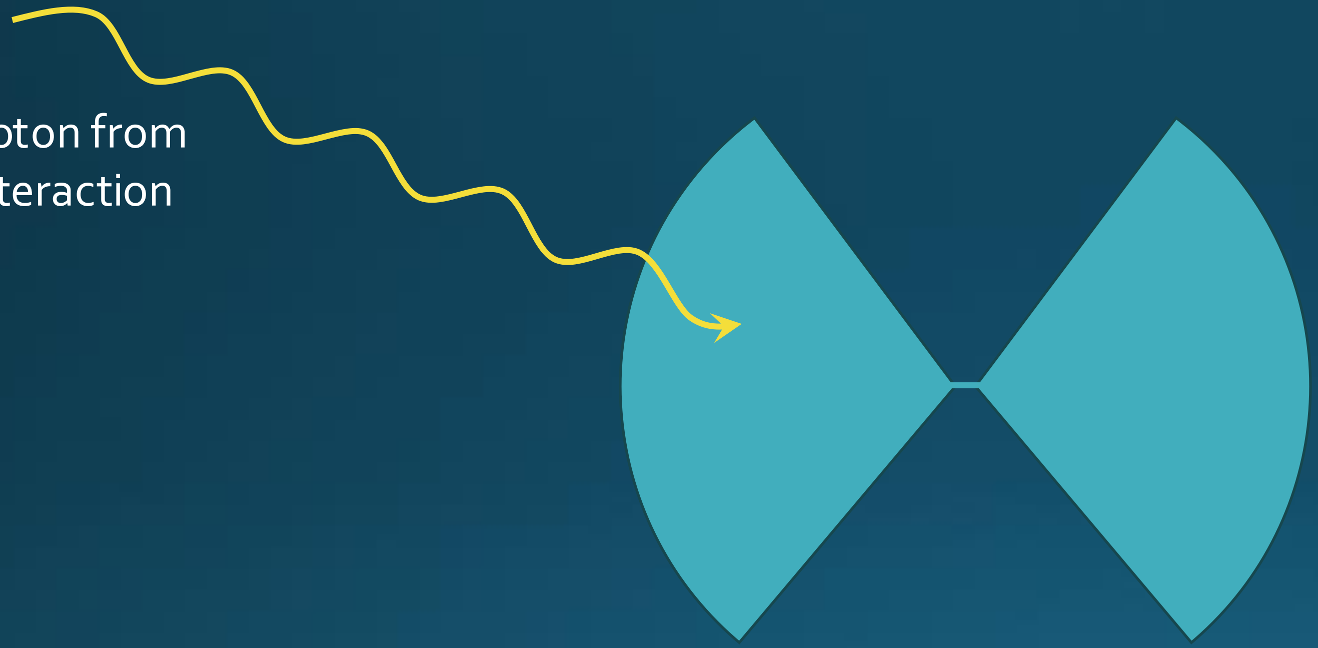
Signal pathway

(o) observe qubit resonance by injecting signals down a feedline that is coupled to the qubit



Signal pathway

(1) photon from
DM interaction



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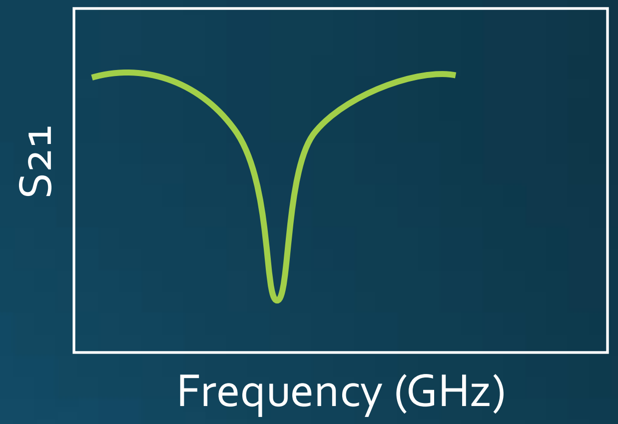

Signal pathway

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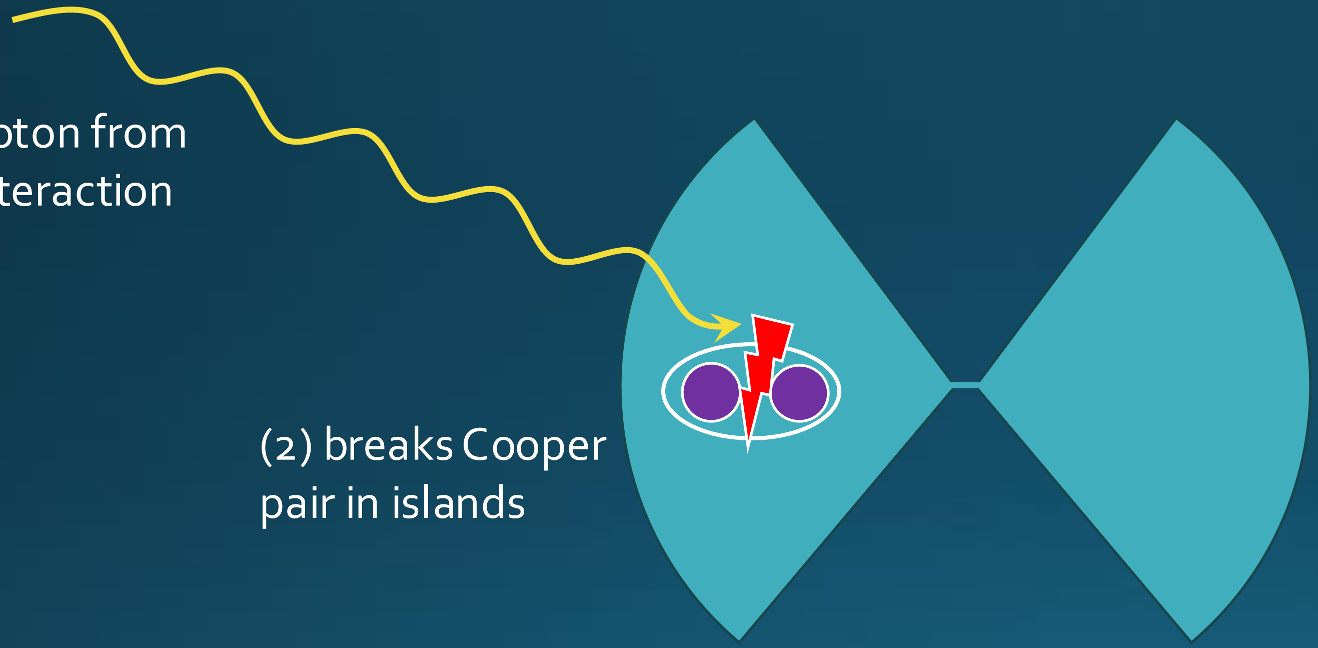
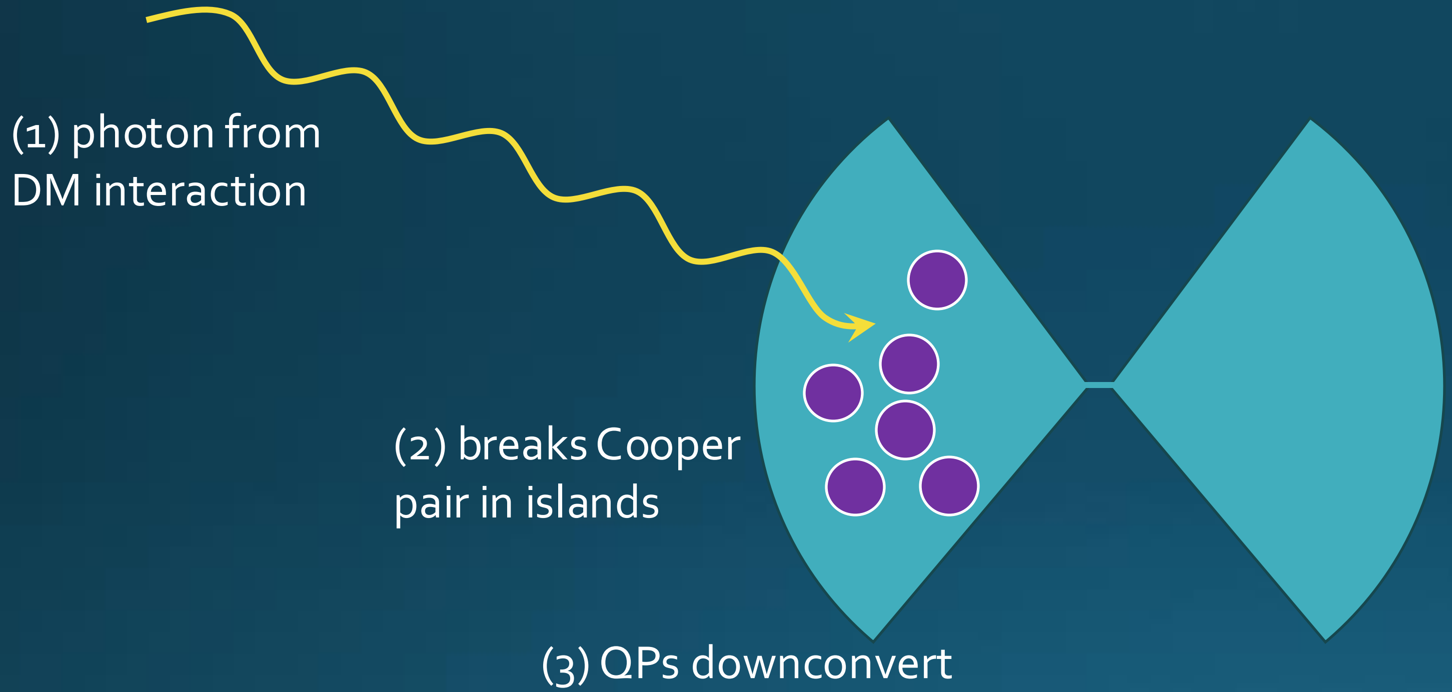


(2) breaks Cooper pair in islands

(0) observe qubit resonance by injecting signals down a feedline that is coupled to the qubit

Signal pathway



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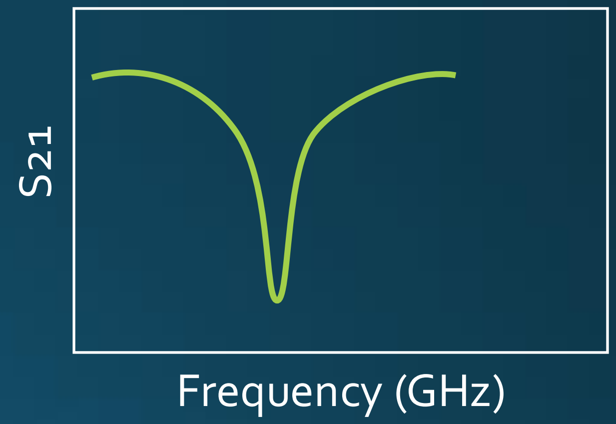
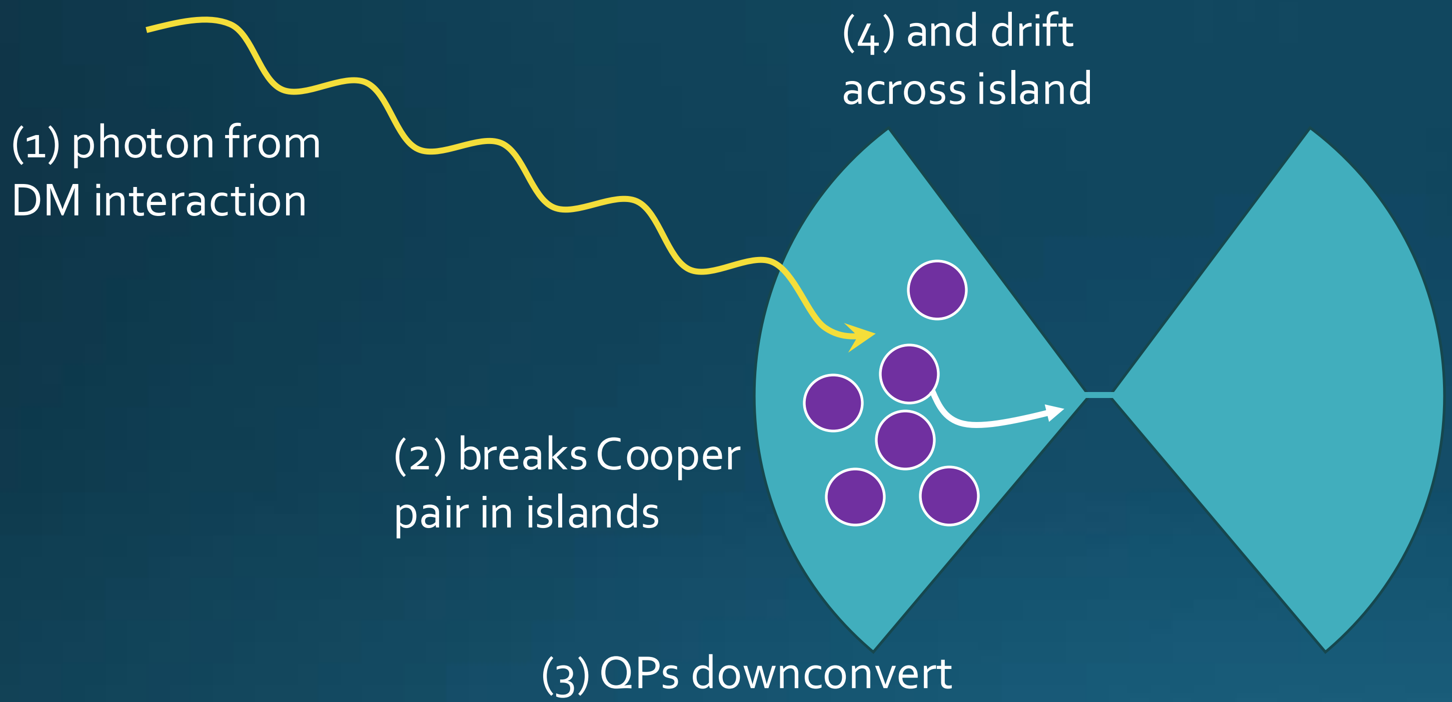


*QP = quasiparticle

Signal pathway



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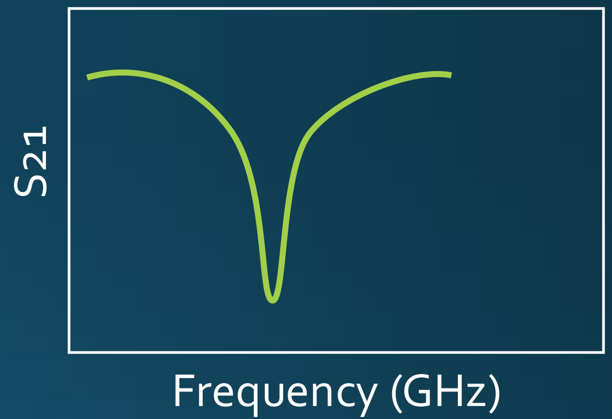

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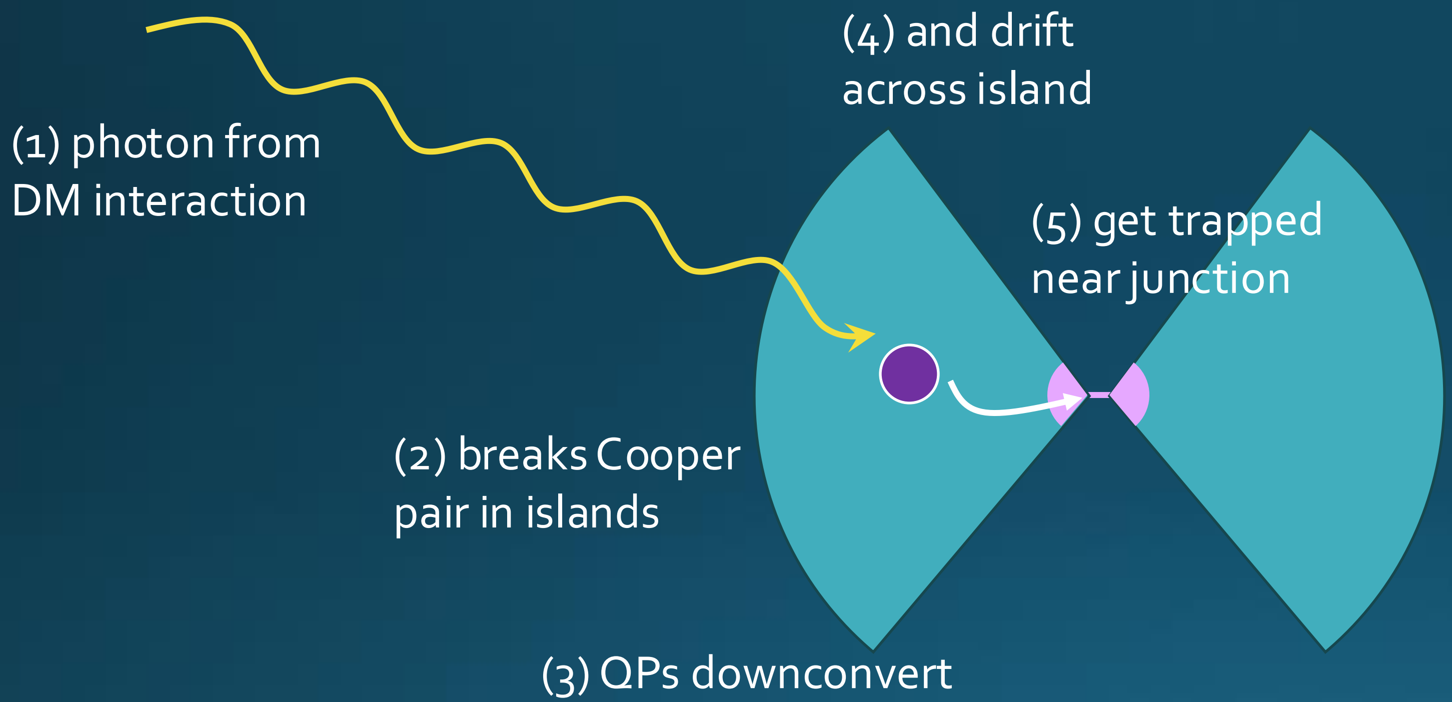

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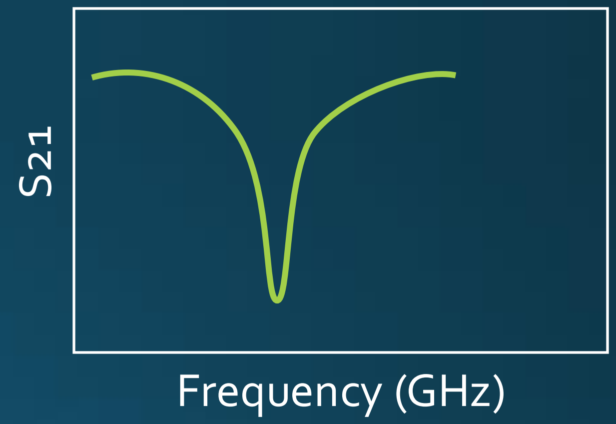

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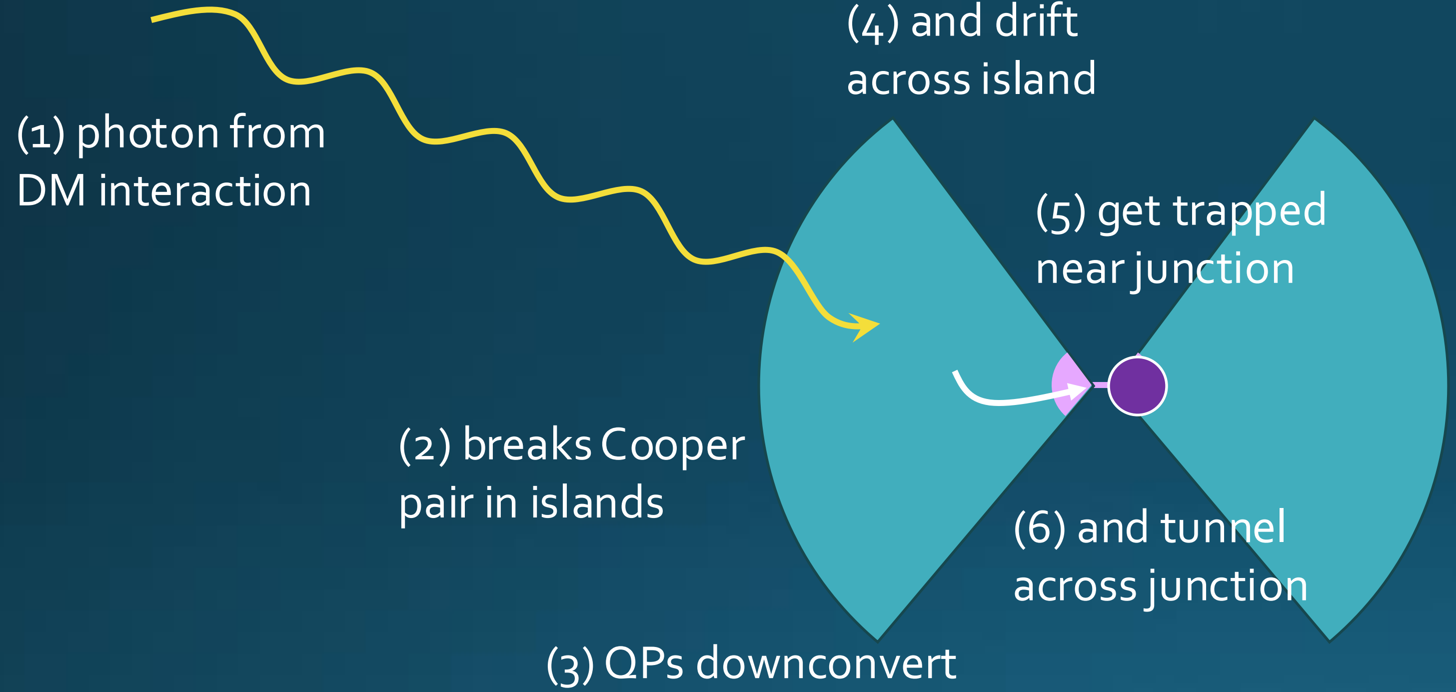

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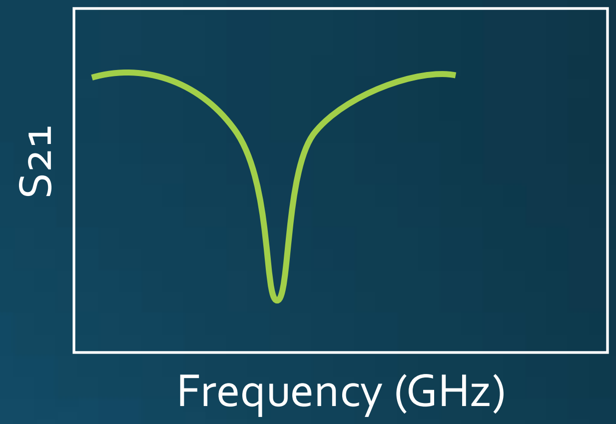

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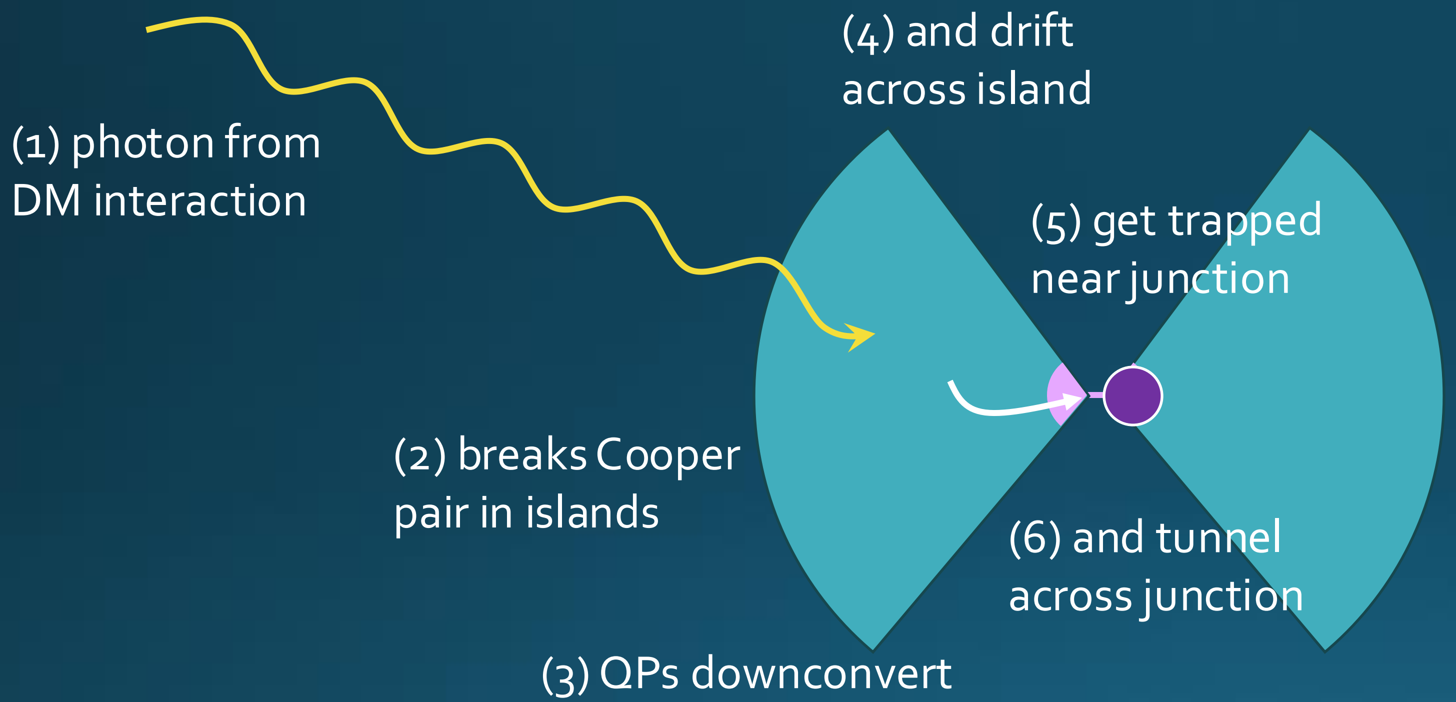

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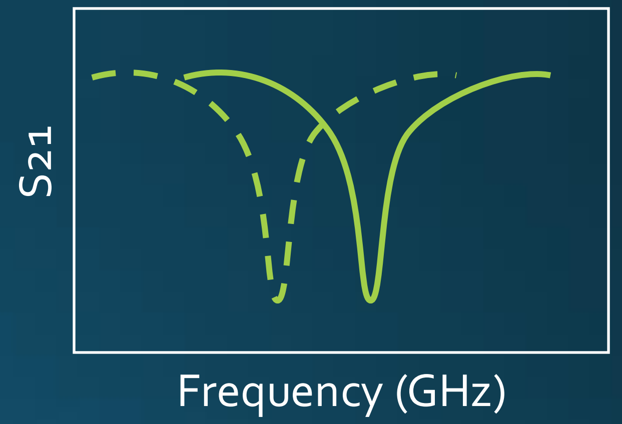


(7) resonance shifts as qubit parity swaps

*QP = quasiparticle

Signal pathway

(1) photon from DM interaction

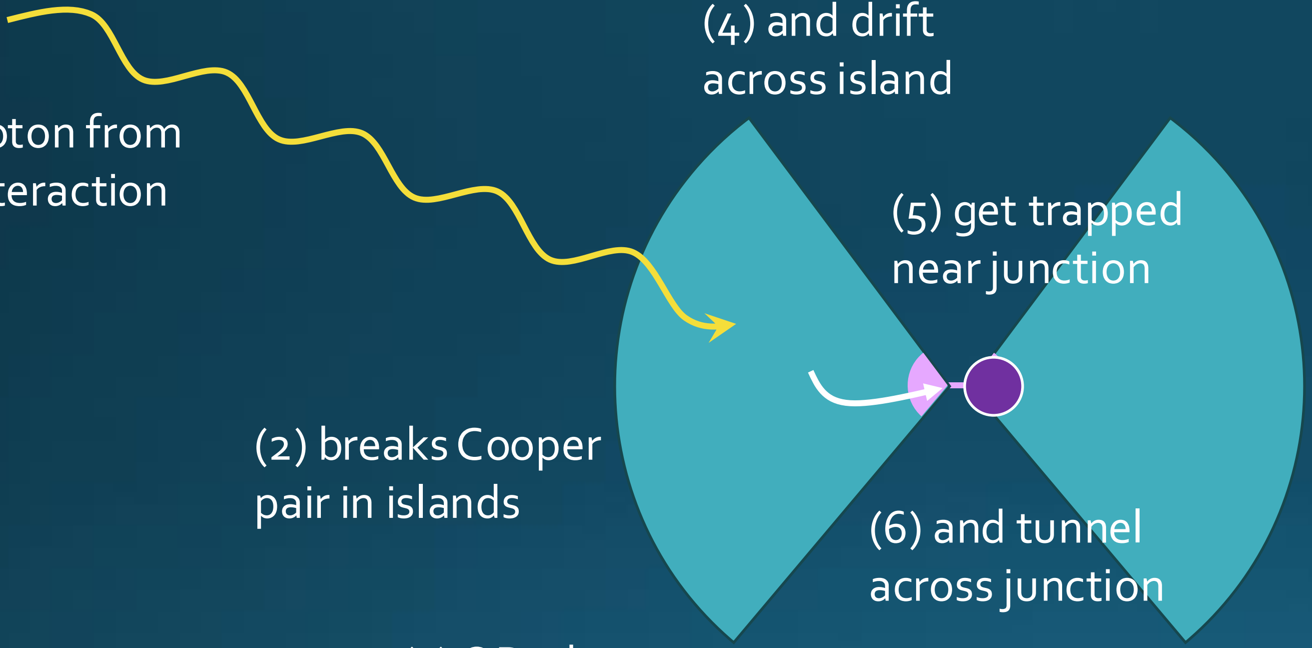
(2) breaks Cooper pair in islands

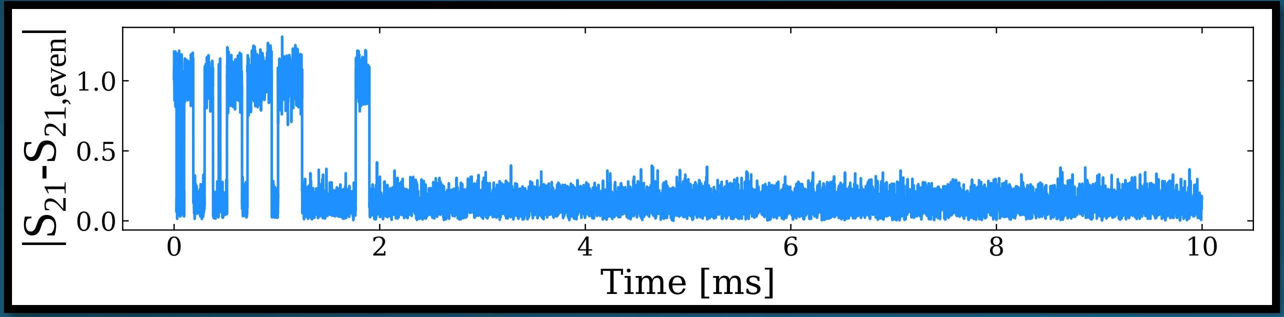
(3) QPs downconvert

(4) and drift across island

(5) get trapped near junction

(6) and tunnel across junction





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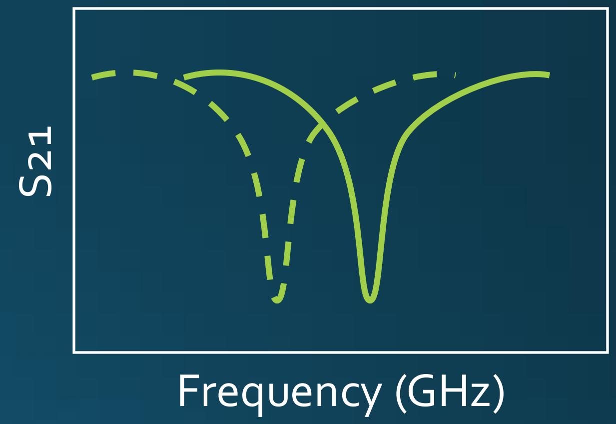
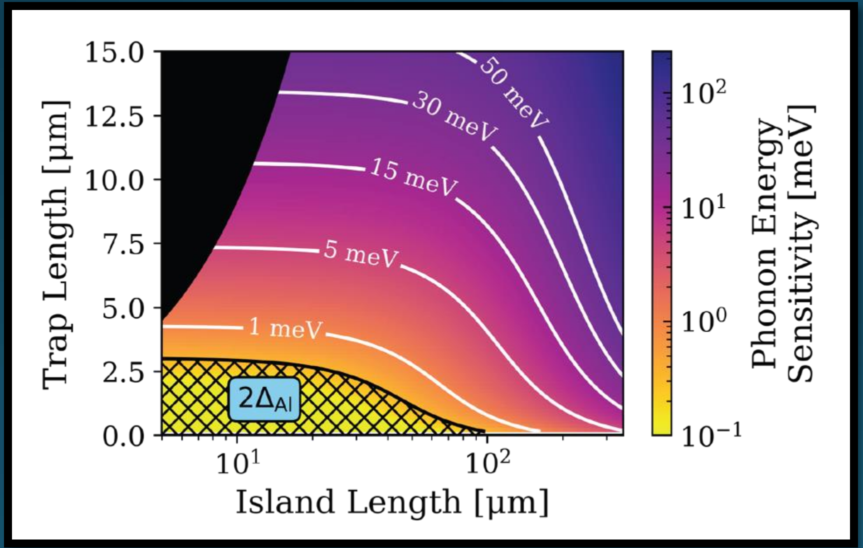


(7) resonance shifts as qubit parity swaps

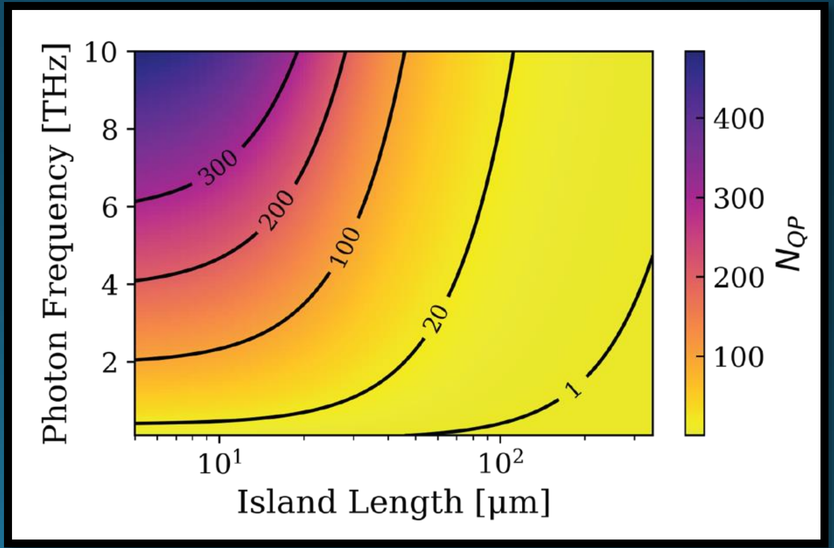
*QP = quasiparticle

Why SQUAT?

- Broadband (expect ~20% bandwidth from antenna)
- Energy resolving ~200GHz-10THz
- High efficiency (low passive area, multiplexing, tunnel amplification)

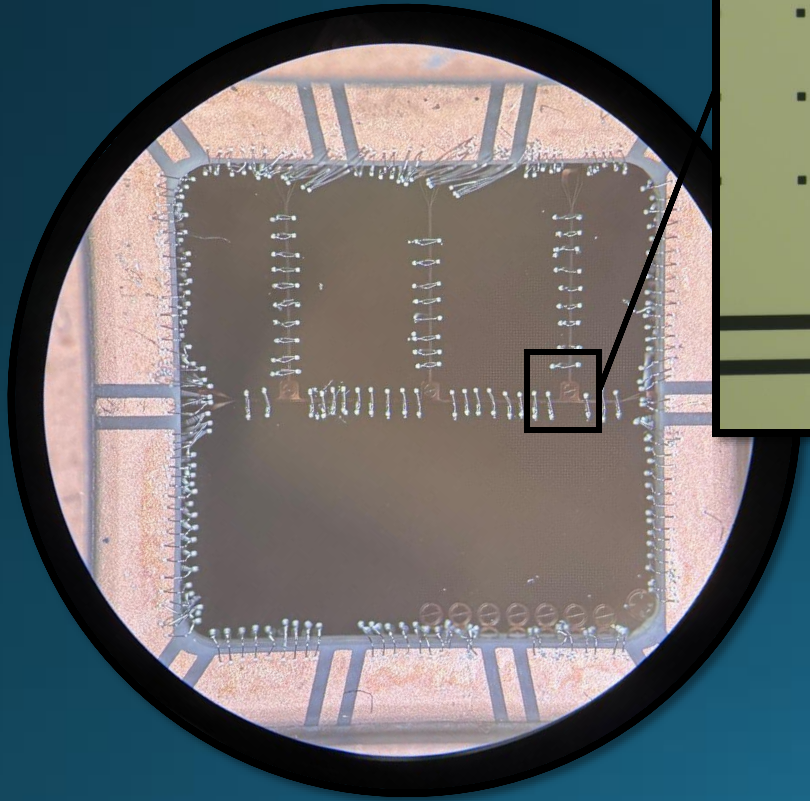


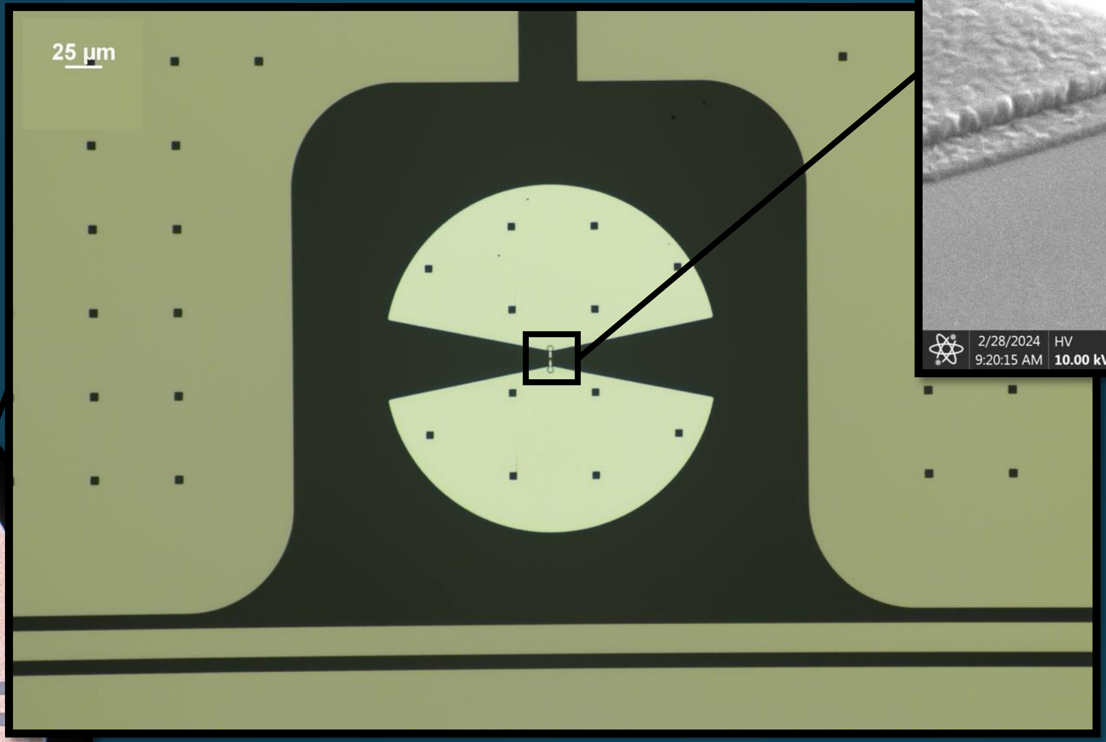
phonon energy sensitivity

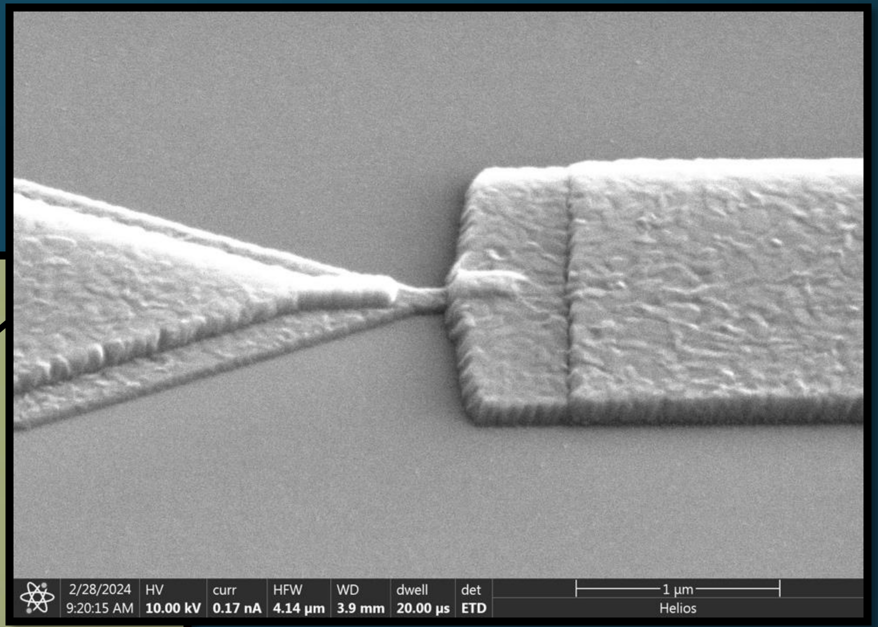


photon tunneling count

We have SQUATs

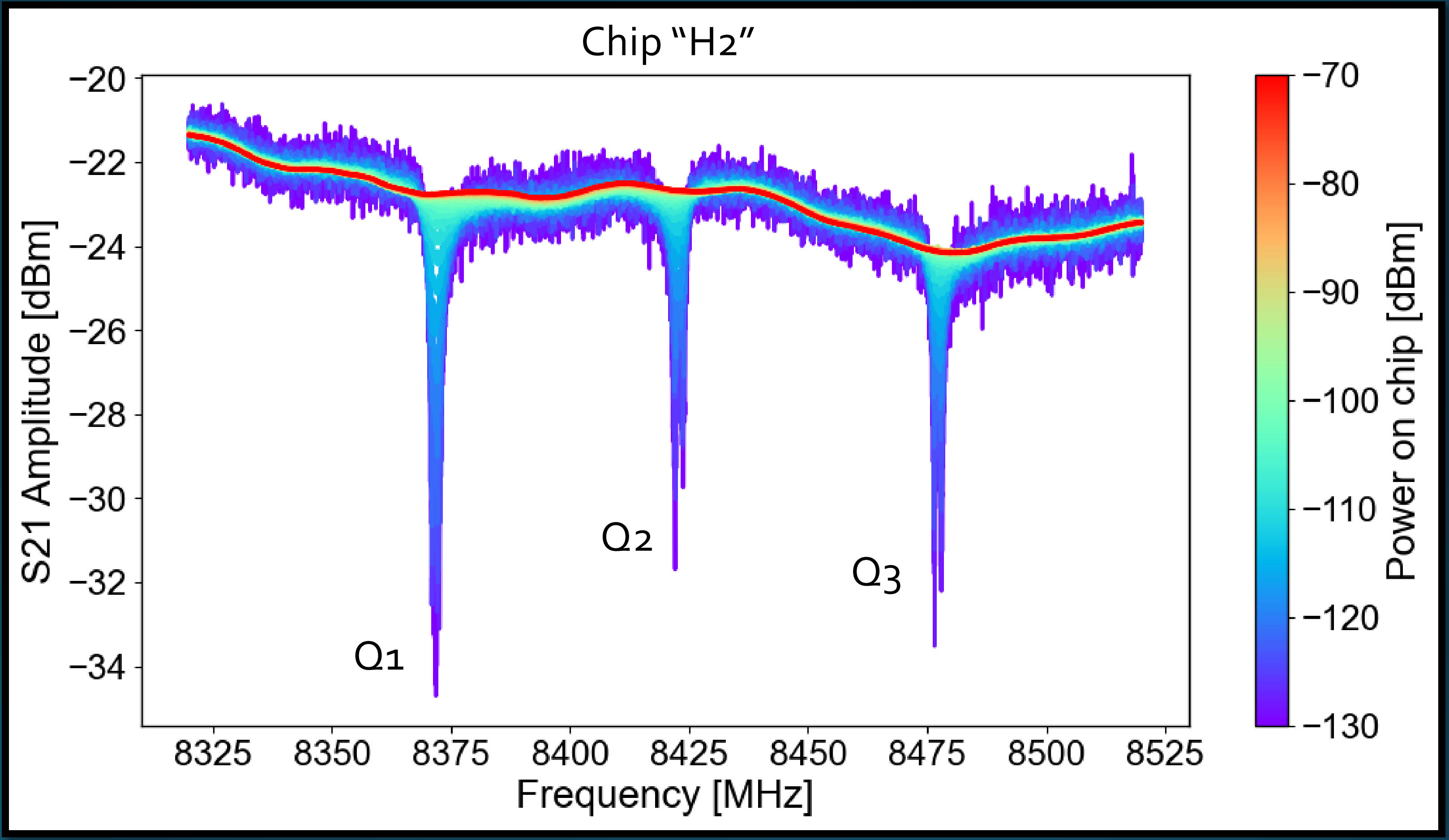




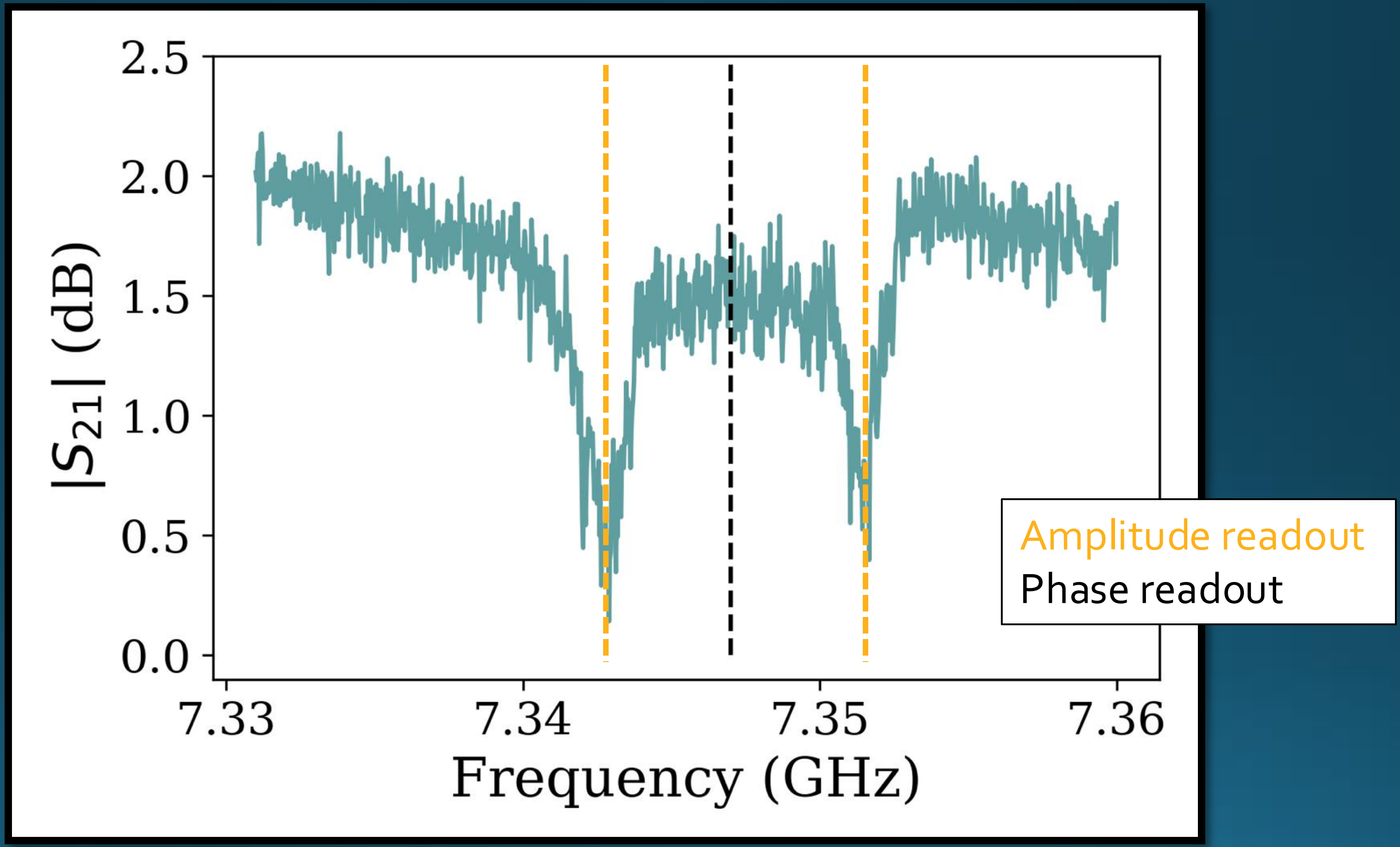


fabricated at Stanford Nanofabrication Facility (SNF) and Stanford Shared Nanofabrication Facility (SNSF)

Functioning qubits

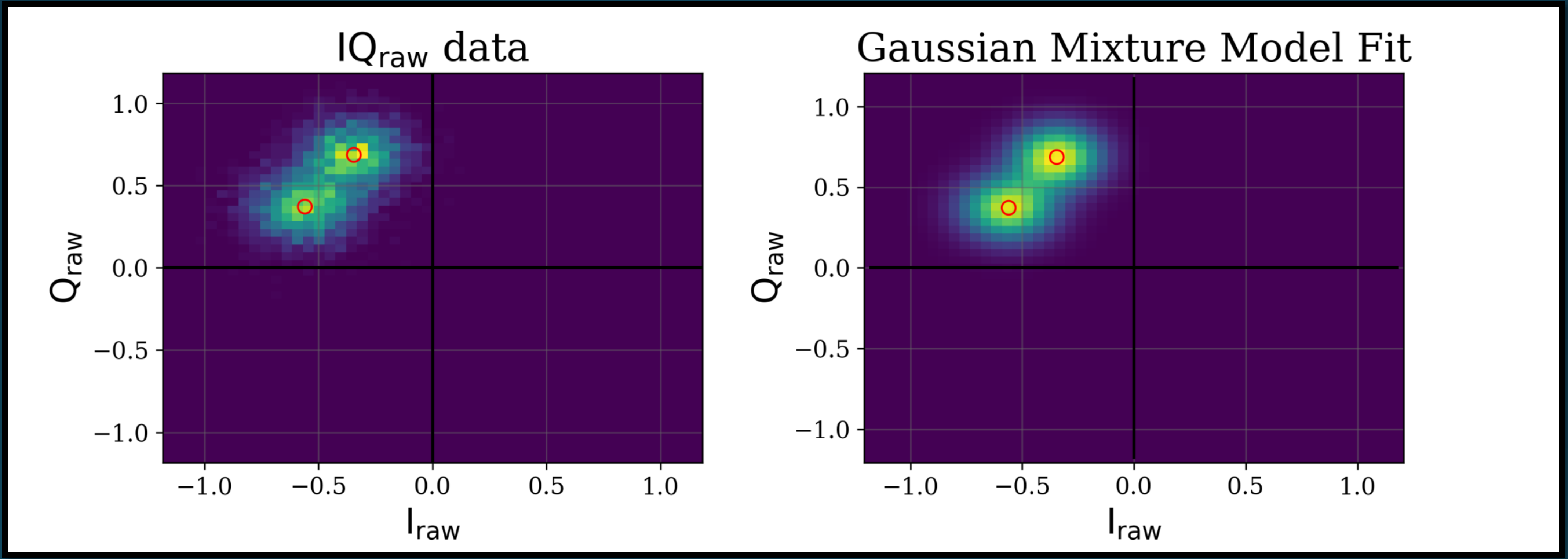


Phase or amplitude readout



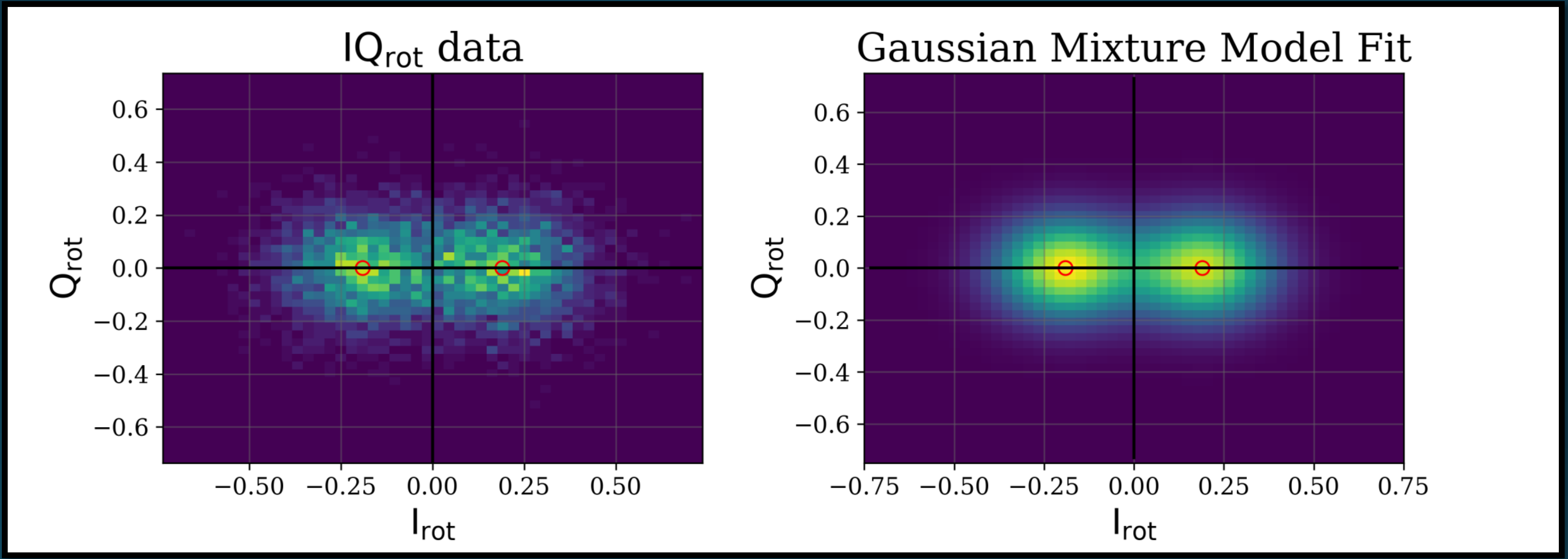
IQ streaming

Fit IQ data with 2-component Gaussian mixture

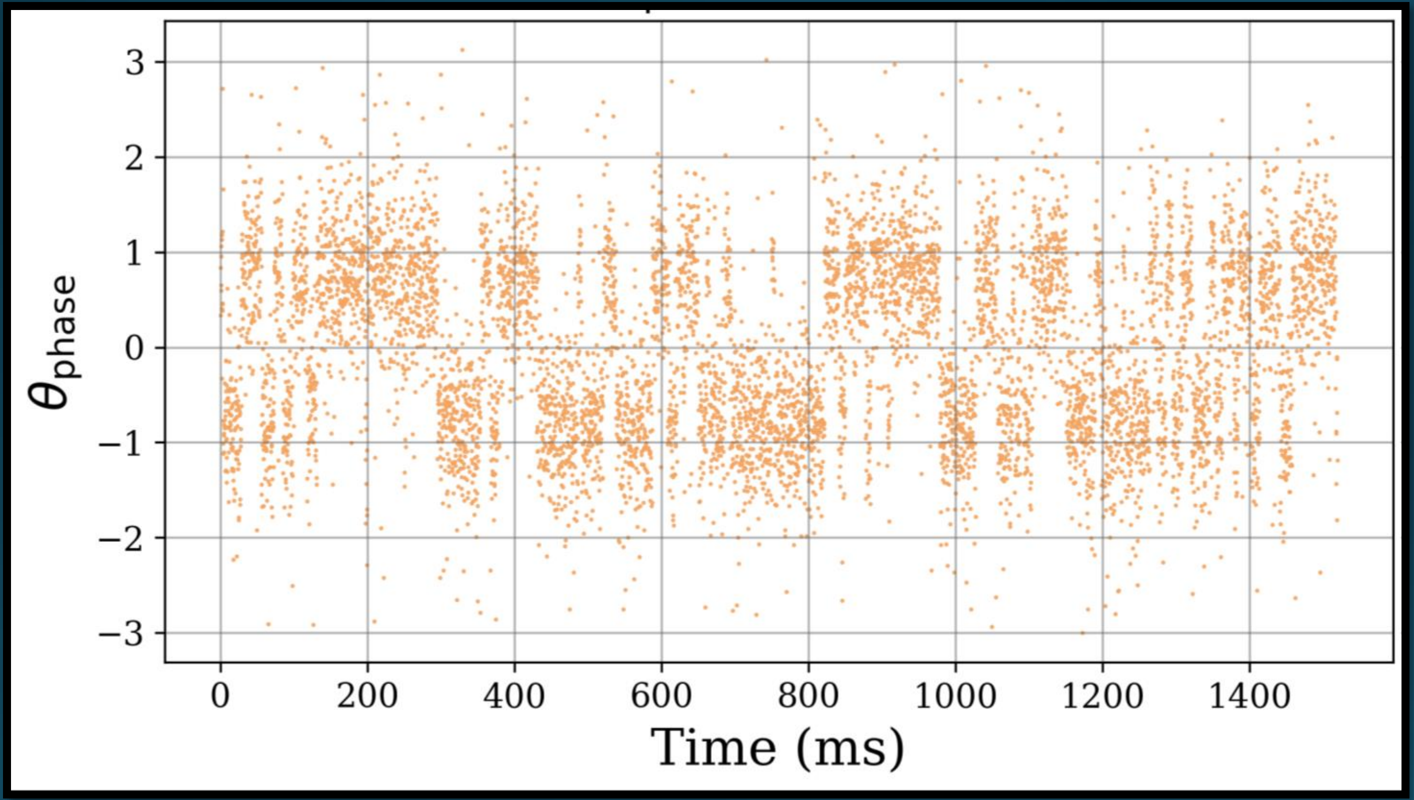


Parity state separation

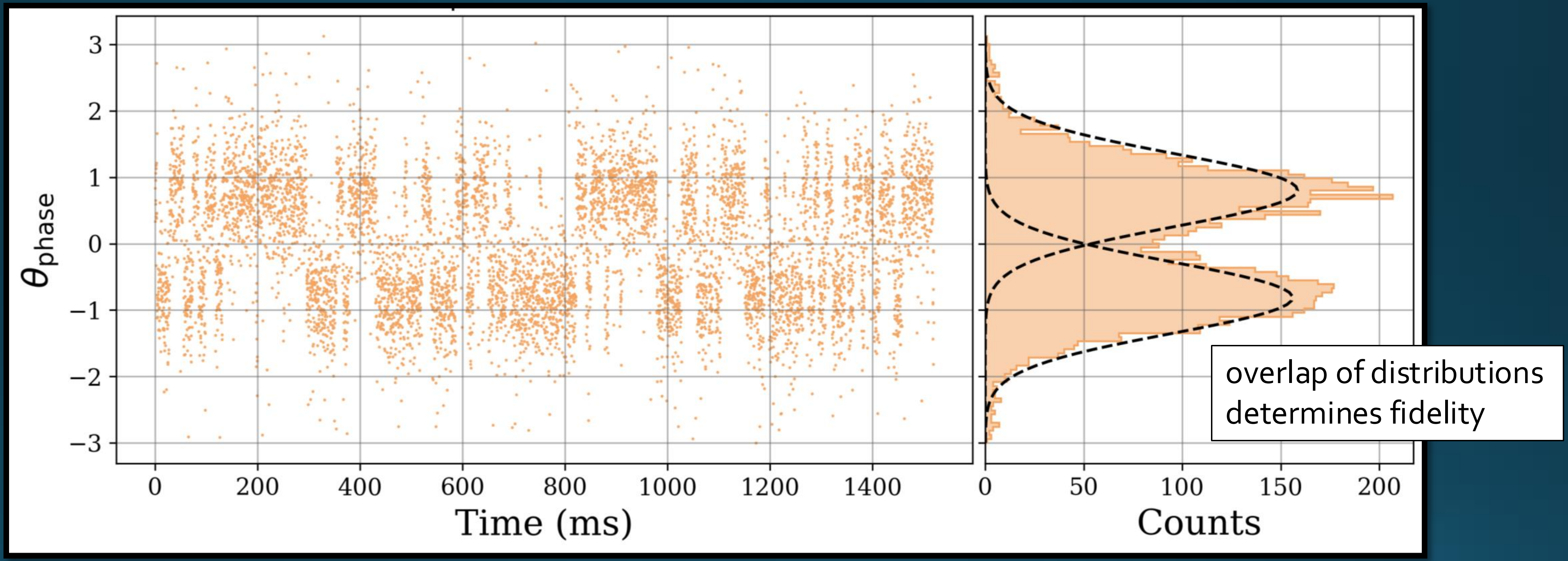
Rotate IQ data along maximum separation



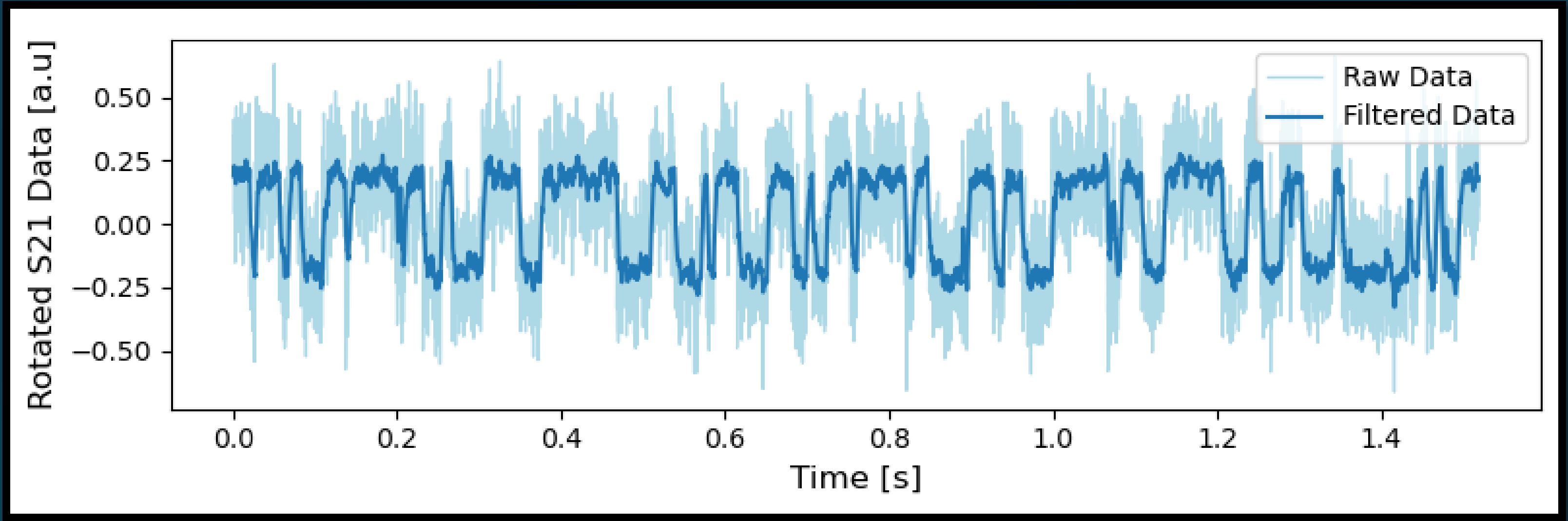
Parity state separation

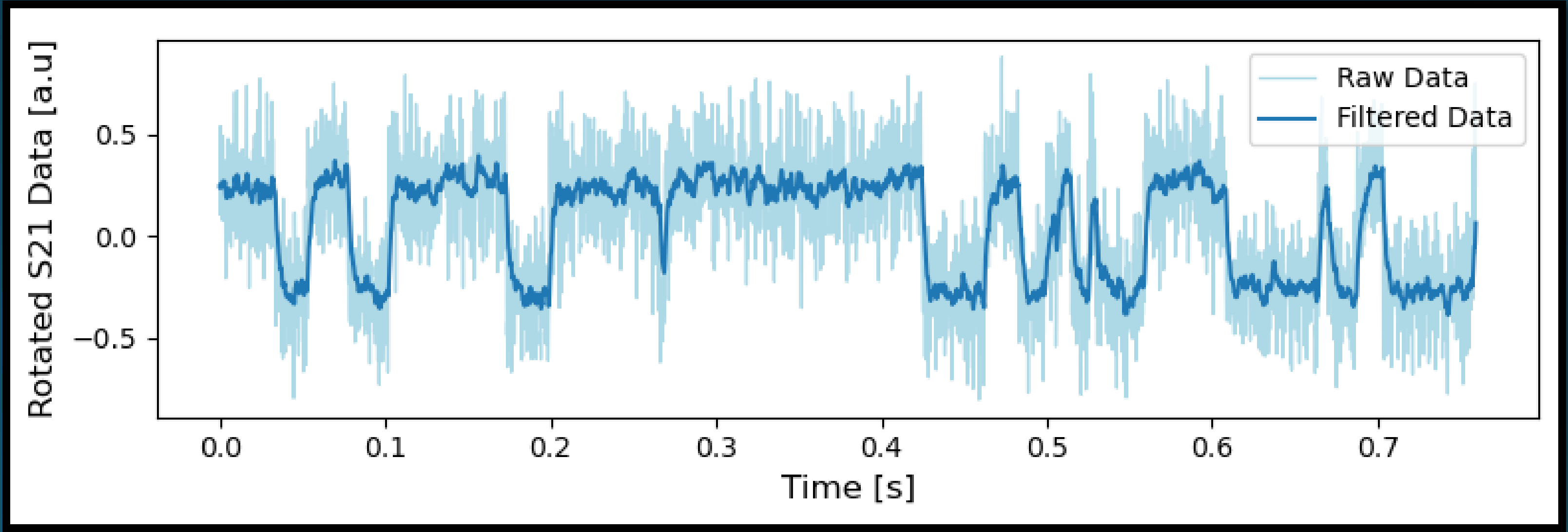


Parity state separation



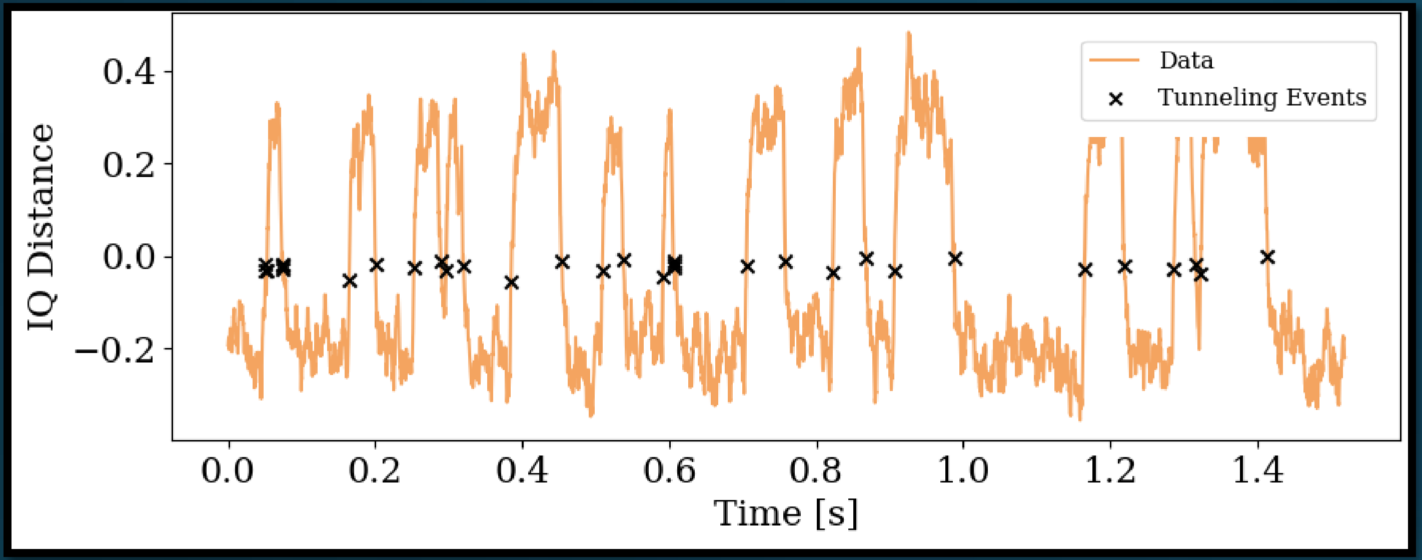
Some parity switching timestreams





Calculating switching rate, 2 ways

(1) count crossings in filtered data



Calculating switching rate, 2 ways

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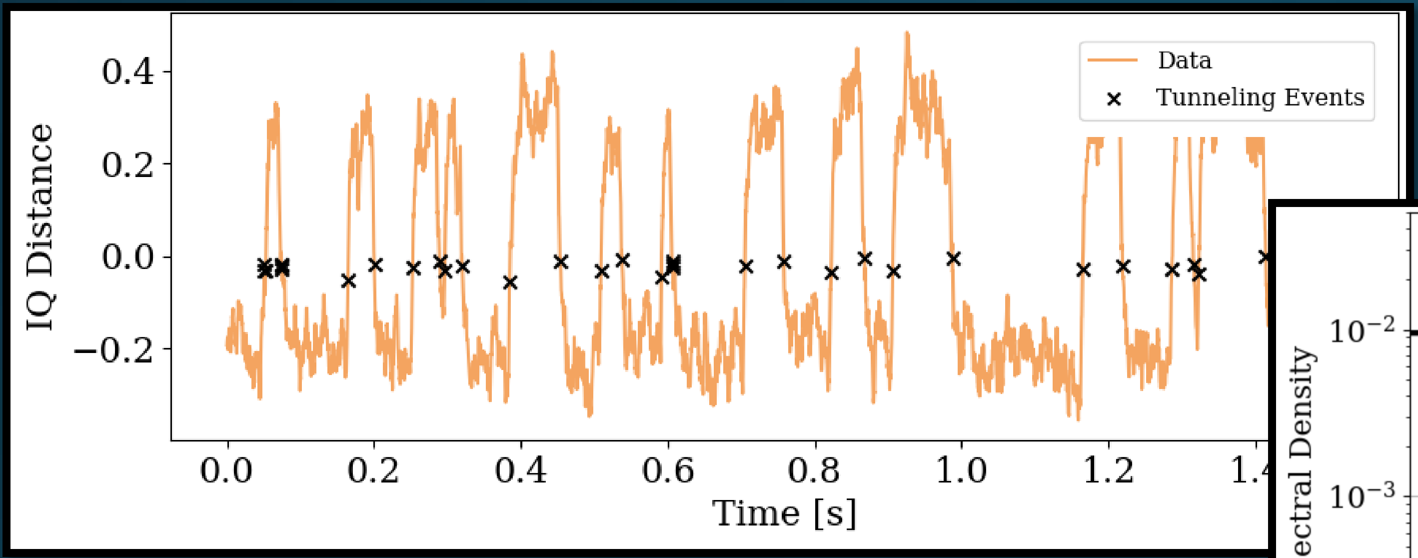
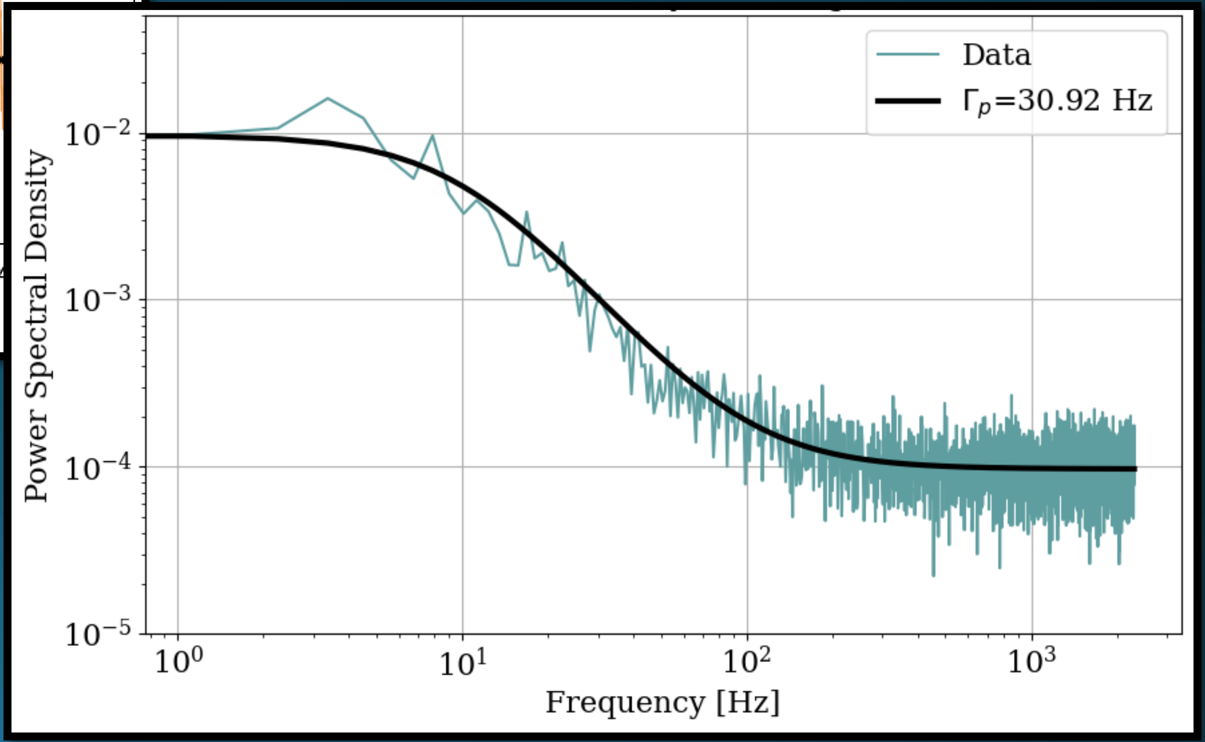


(2) fit PSD with Lorentzian (Ristè et al. 2013)



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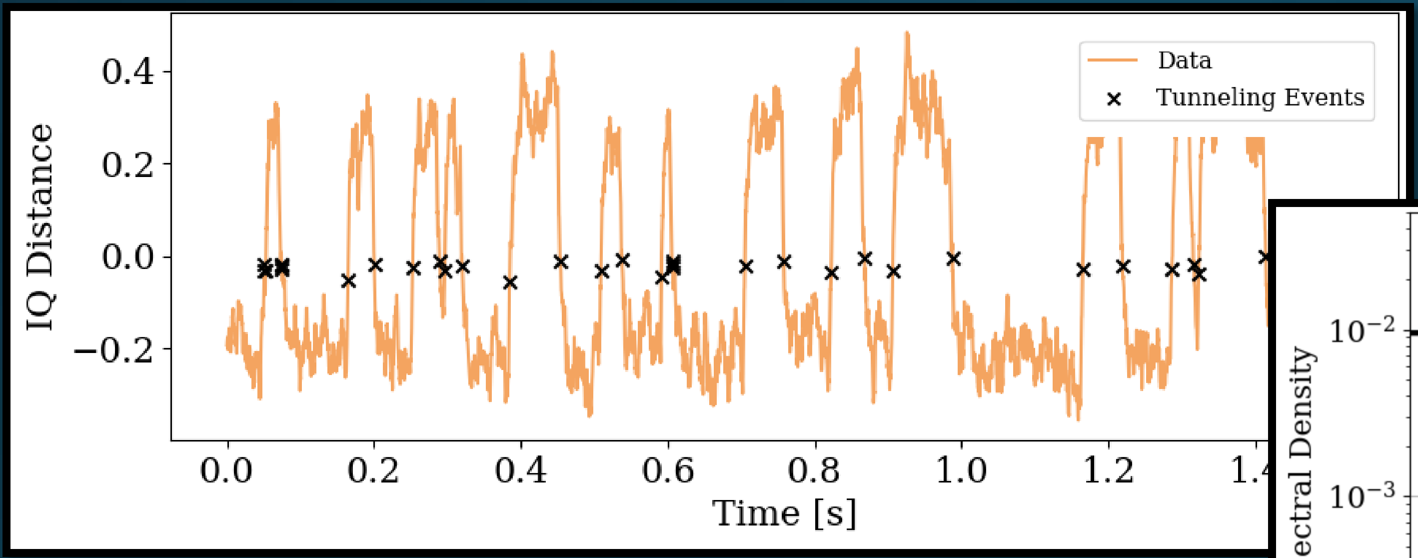

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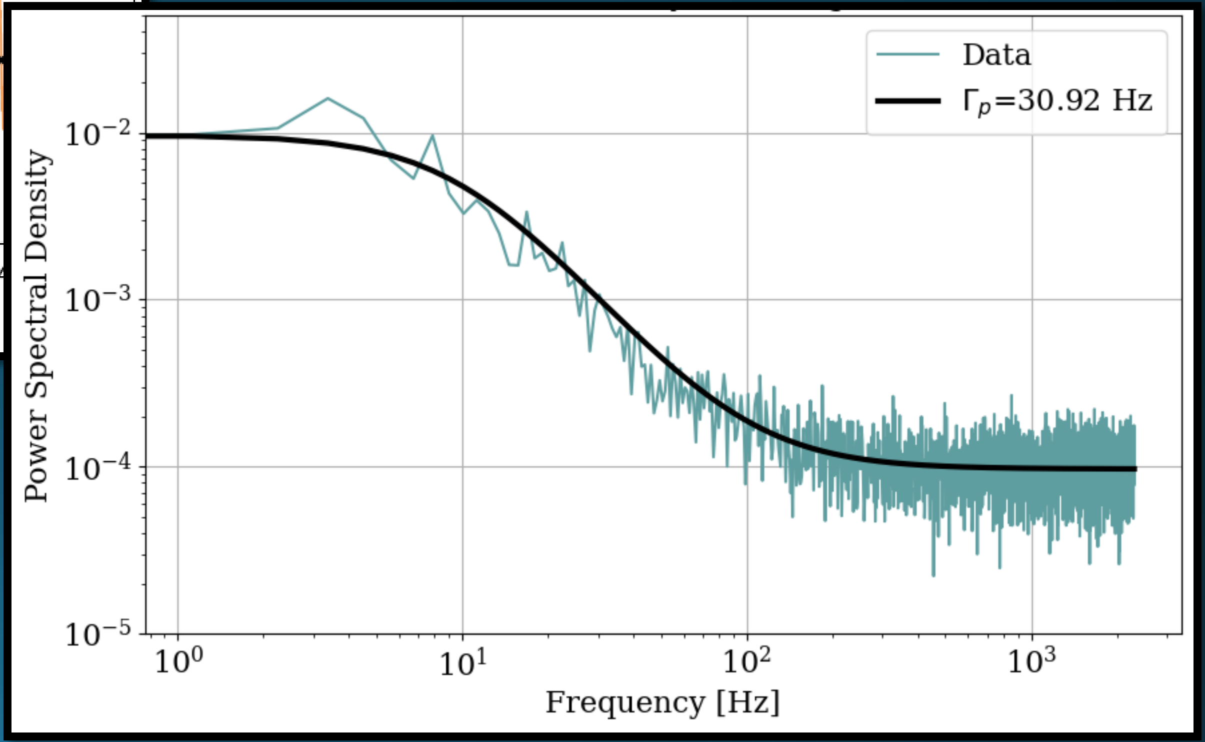
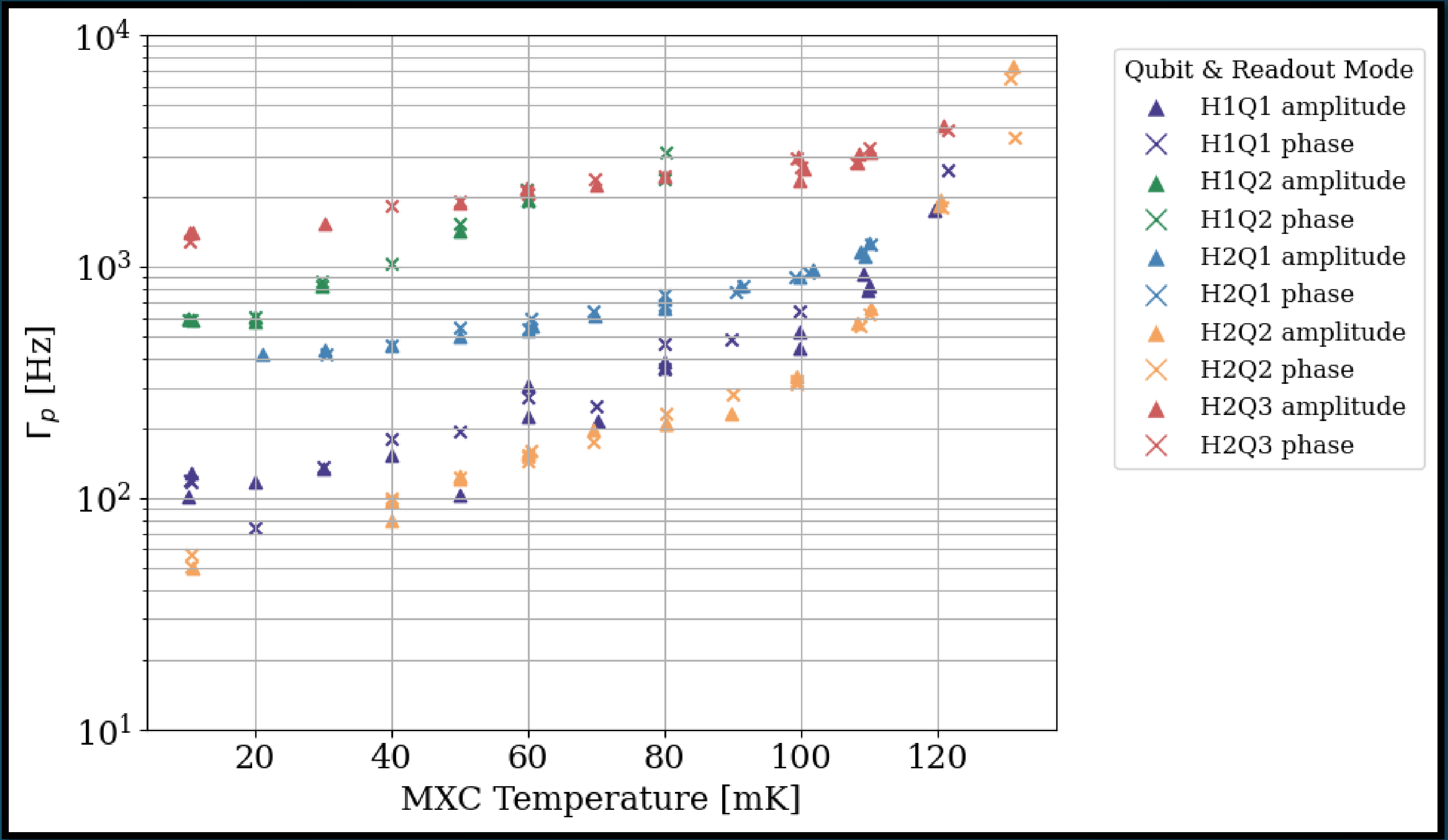


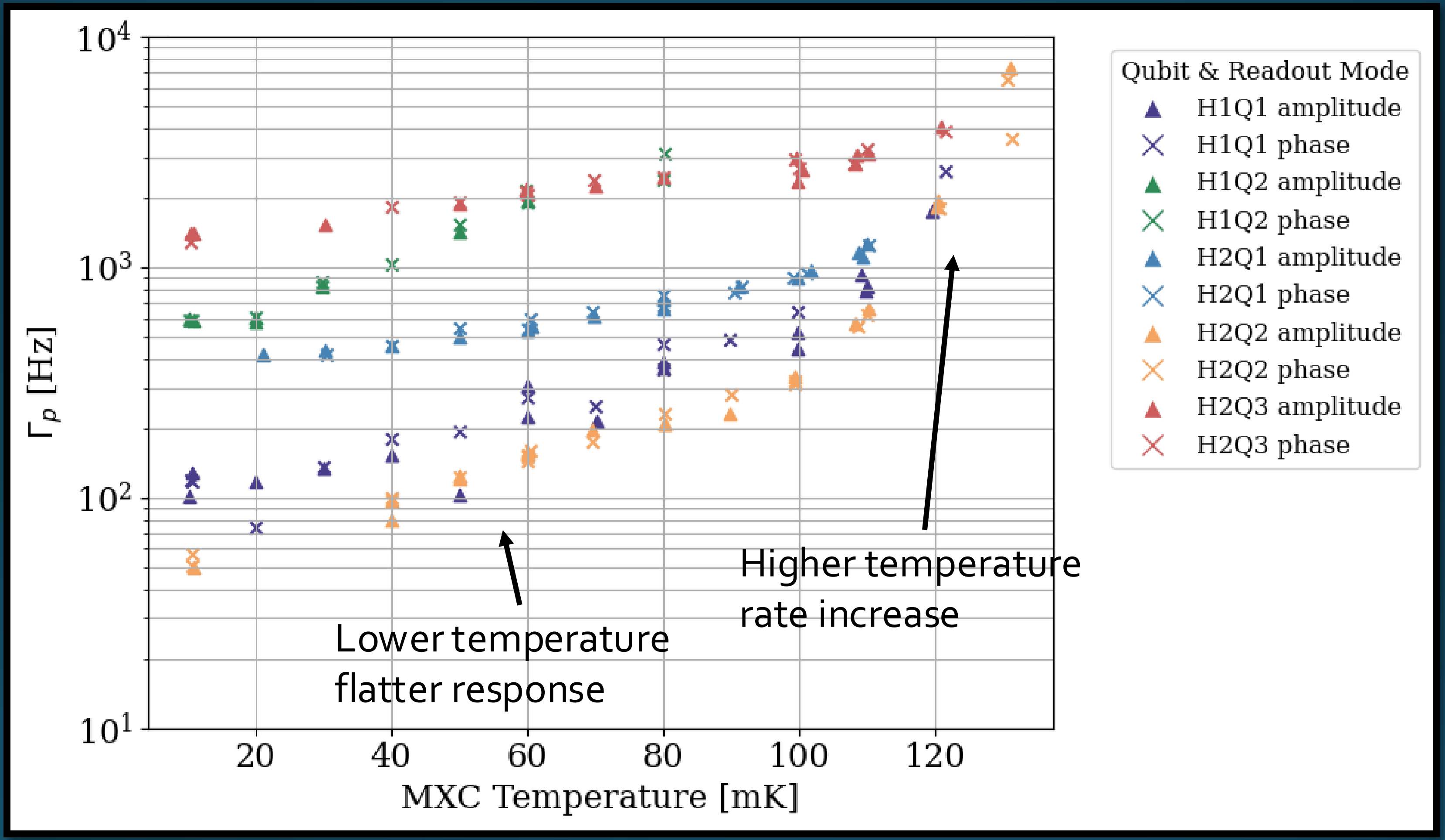
Lowest switching rate ~30 Hz!

Switching rate depends on temperature



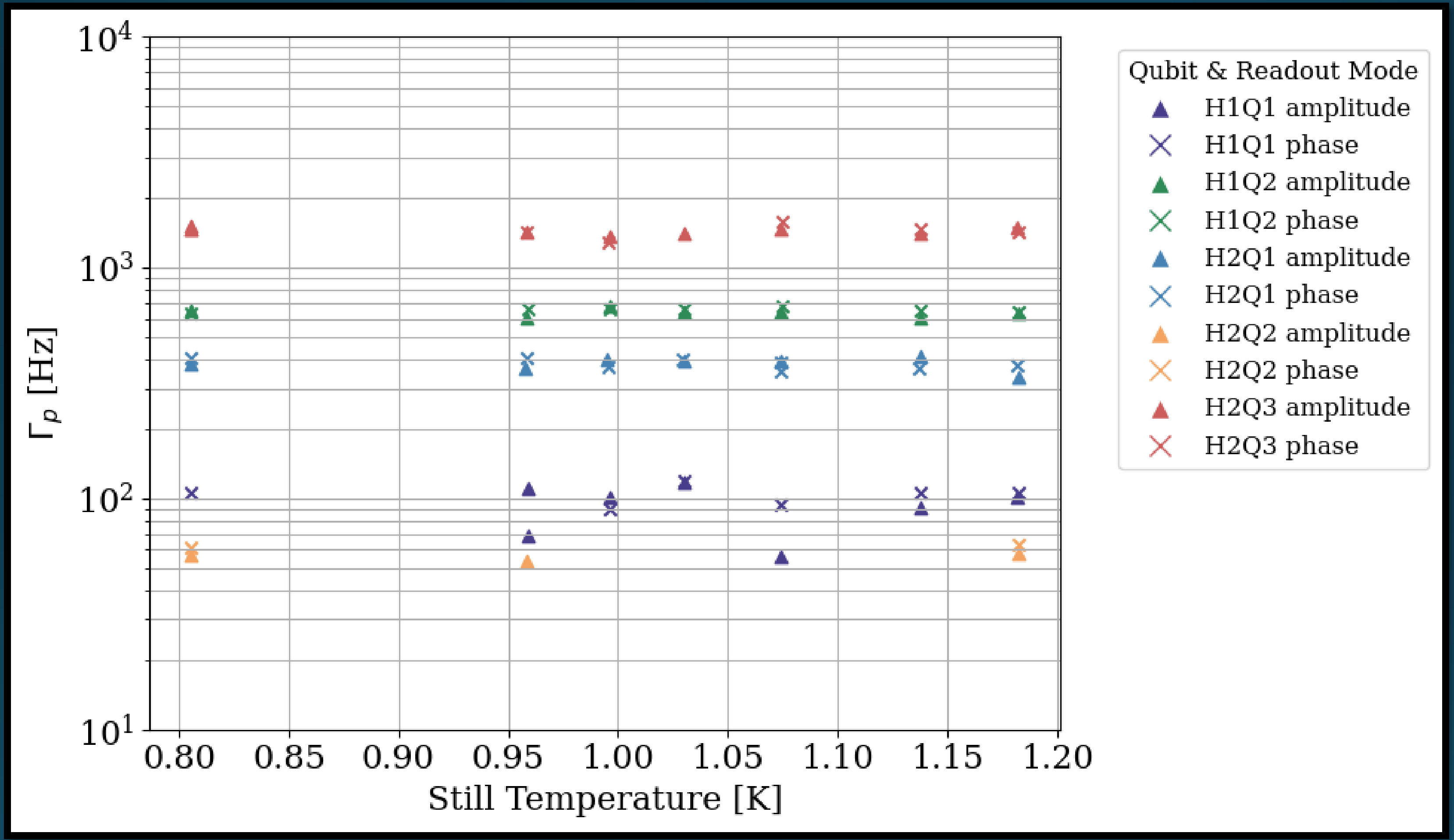
See also Connolly et al. 2024

Switching rate depends on temperature



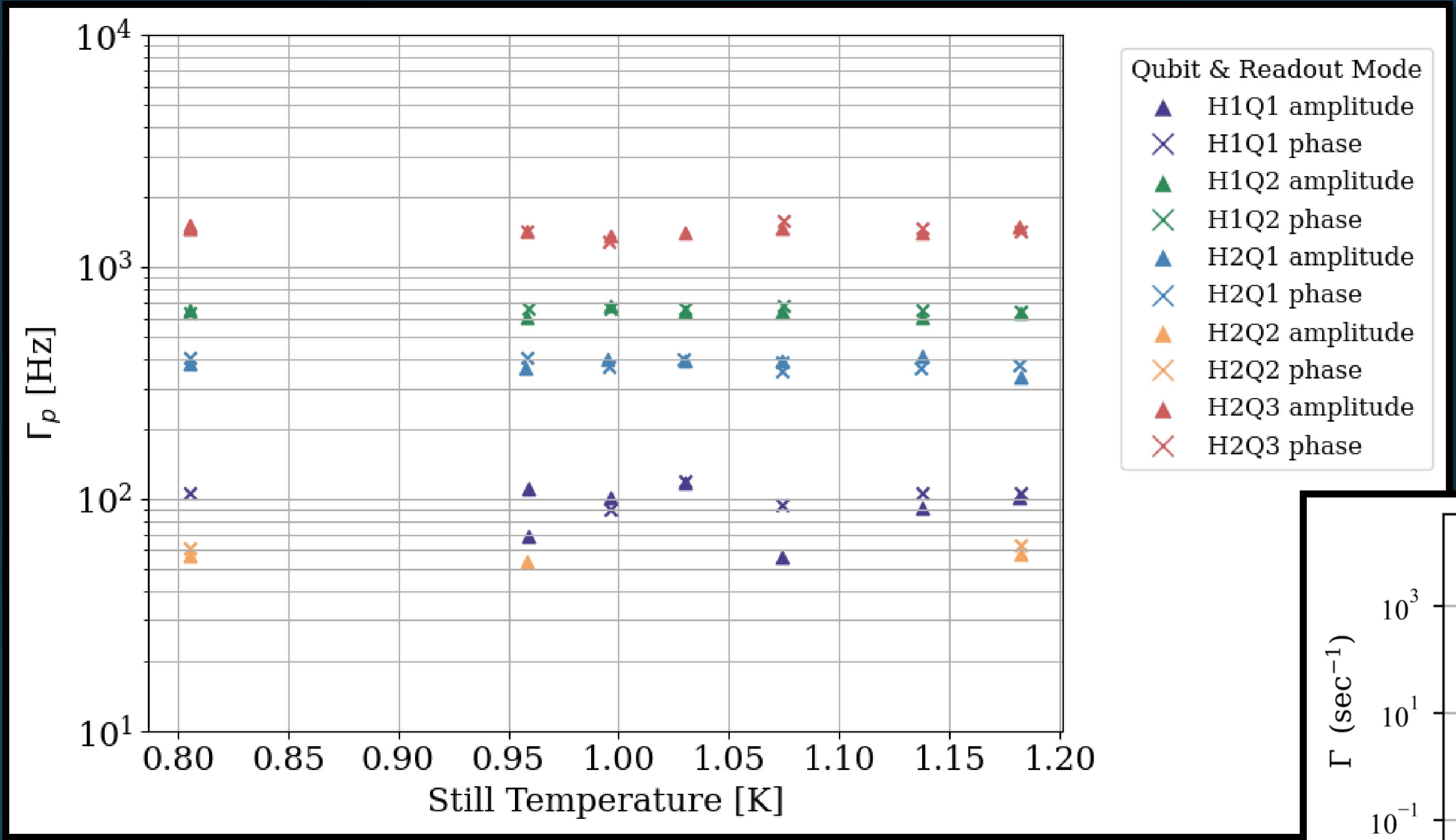
See also Connolly et al. 2024

Can IR leakage is subdominant

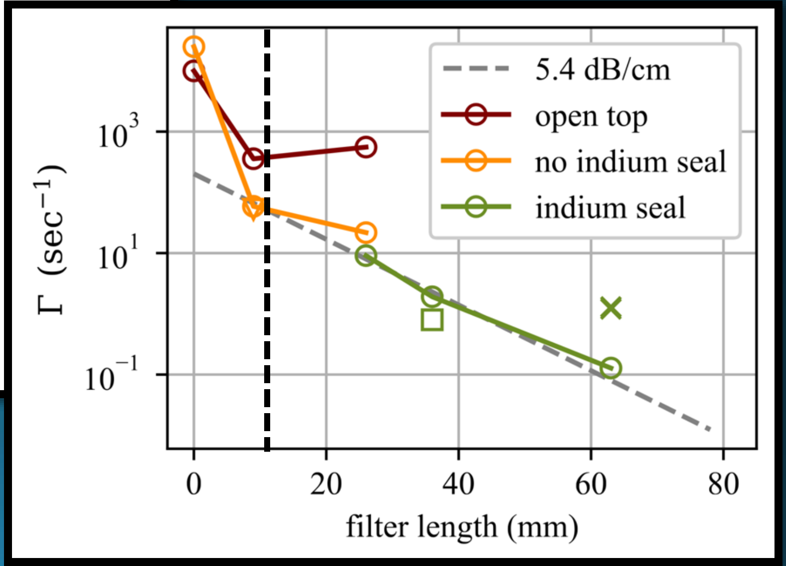


MXC temp = 20±0.3 mK

Can IR leakage is subdominant



Connolly et al. 2024



MXC temp = 20±0.3 mK

Summary

- SQUATs are promising sensors for axion and low-mass particle dark matter searches
- The first SQUAT devices demonstrate low parity switching rates
- Next steps are to demonstrate event detection and calibrate*
- Longer term: low T_c junctions for trapping, higher multiplexing, testing underground**

*see poster this evening by Tonya Peshel! **see talk Friday by Grace Bratrud!

BREAD COLLABORATION

Pete Barry, Clarence Chang, Juliang Li, *Argonne National Laboratory*

Jesse Liu, *University of Cambridge*

Kristin Dona, Gabe Hoshino, Alex Lapuente, David Miller, Max Olberding, *University of Chicago*

Daniel Bowring, Gustavo I Cancelo, Claudio Chavez, Aaron Chou, Mohamed Hassan, Stefan Knirck, Samantha Lewis, Matthew Malaker, Cristian Pena, Andrew Sonnenschein, Leonardo Stefanazzi, Christina Wang Kevin Zvonarek, *Fermilab*

Rakshya Khatiwada, *Fermilab and Illinois Institute of Technology*

Gianpaolo Carosi, *Lawrence Livermore National Laboratory*

Karl Berggren, Dip Joti Paul, Tony (Xu) Zhou, *Massachusetts Institute of Technology*

Omid Noroozian, *NASA Goddard Space Flight Center*

Sae Woo Nam, *National Institute of Standards and Technology*

Huma Jafree, *Randolph-Macon College*

Noah Kurinsky, Chiara Salemi, *SLAC*

SLAC NATIONAL ACCELERATOR LABORATORY

DM QiS

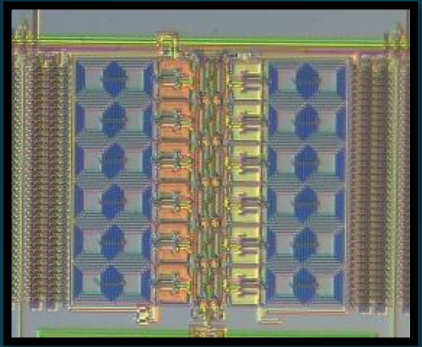
SLAC mK FACILITY EST. 2020

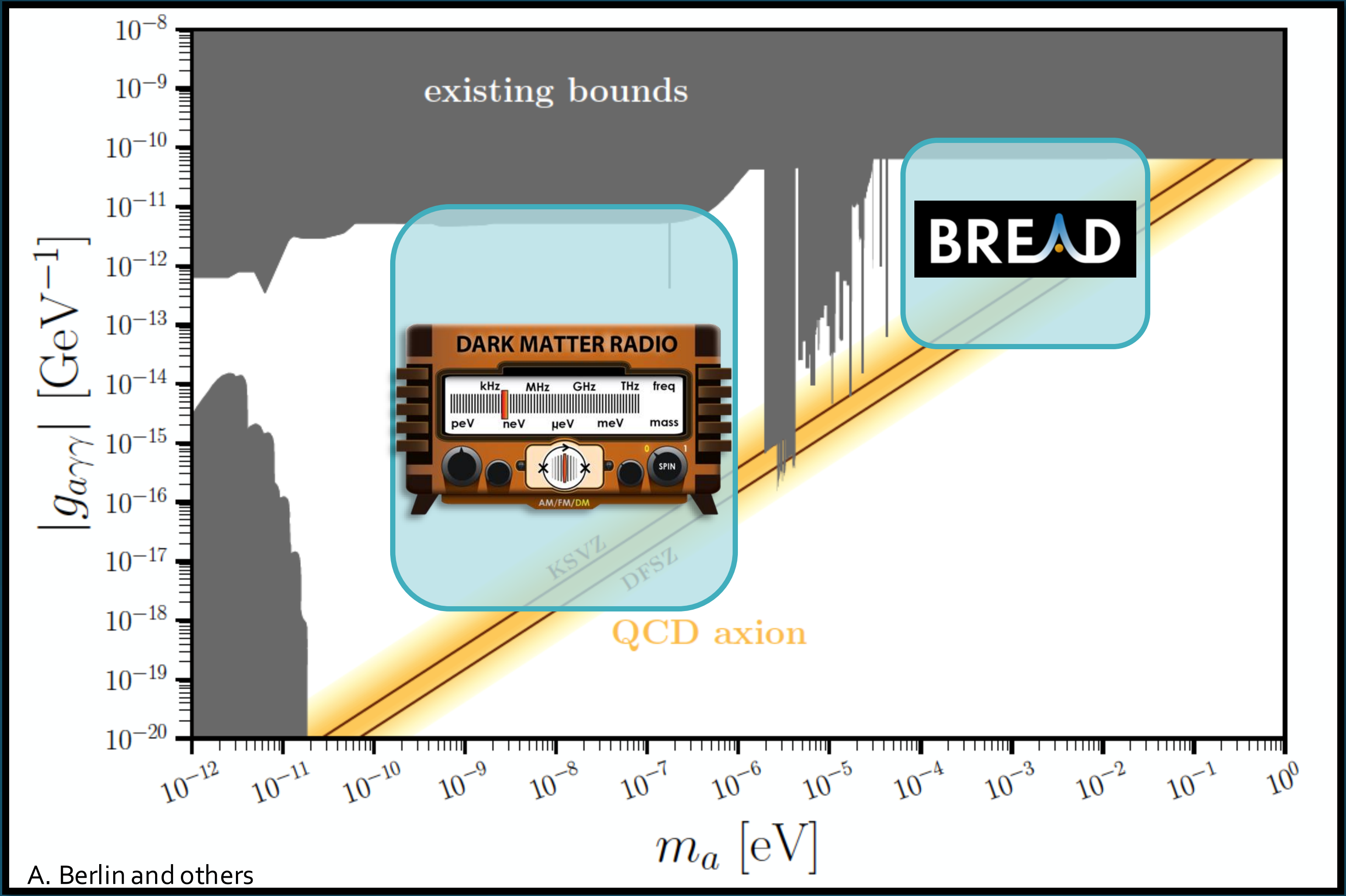
THE UNIVERSITY OF CALIFORNIA BERKELEY LET THERE BE LIGHT 1868

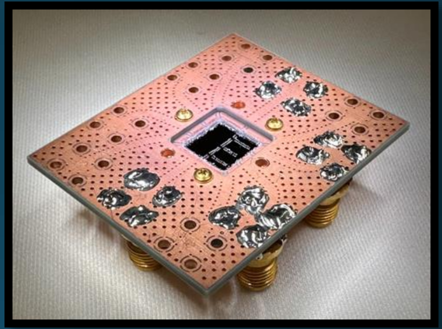
BERKELEY LAB

Join the group!

salemi@berkeley.edu

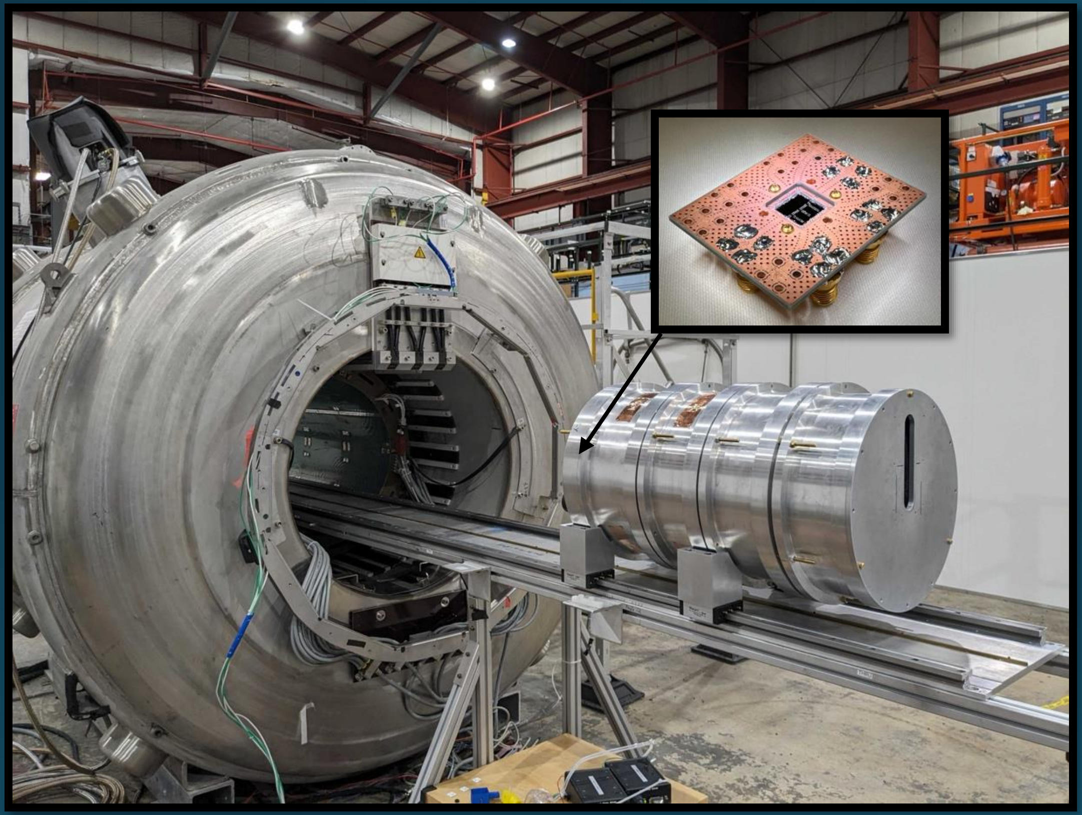




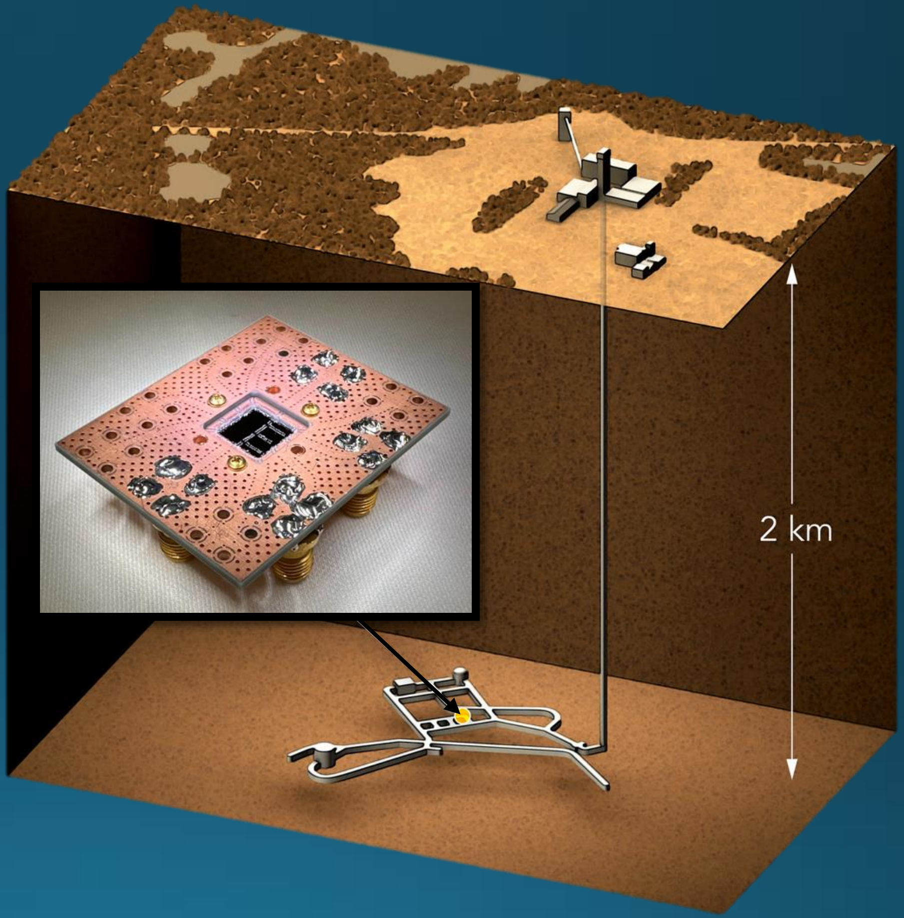


Backup slides

Goal: low-mass dark matter detection

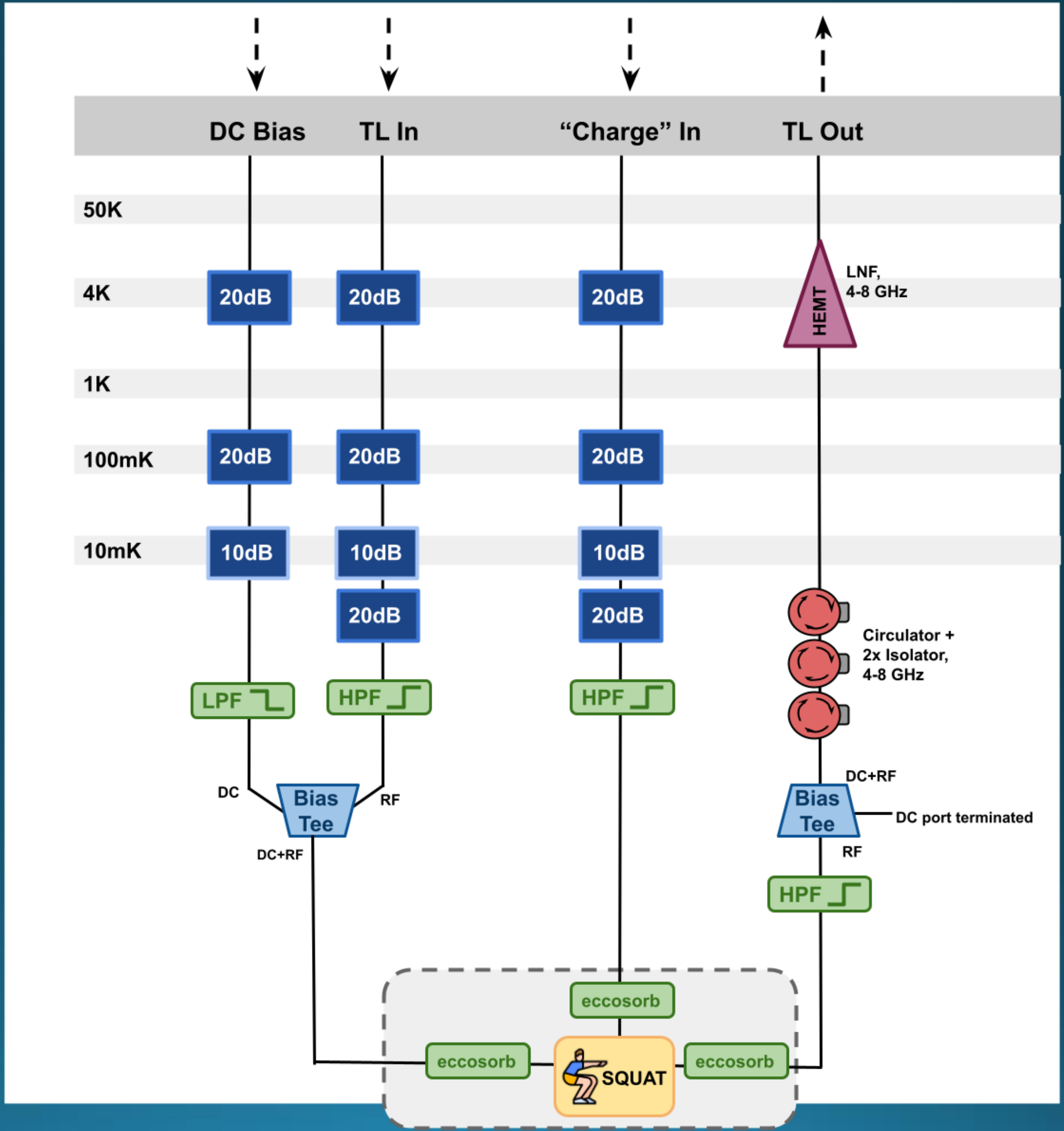


THz photons for wave DM detection



meV phonons for particle DM detection

Wiring

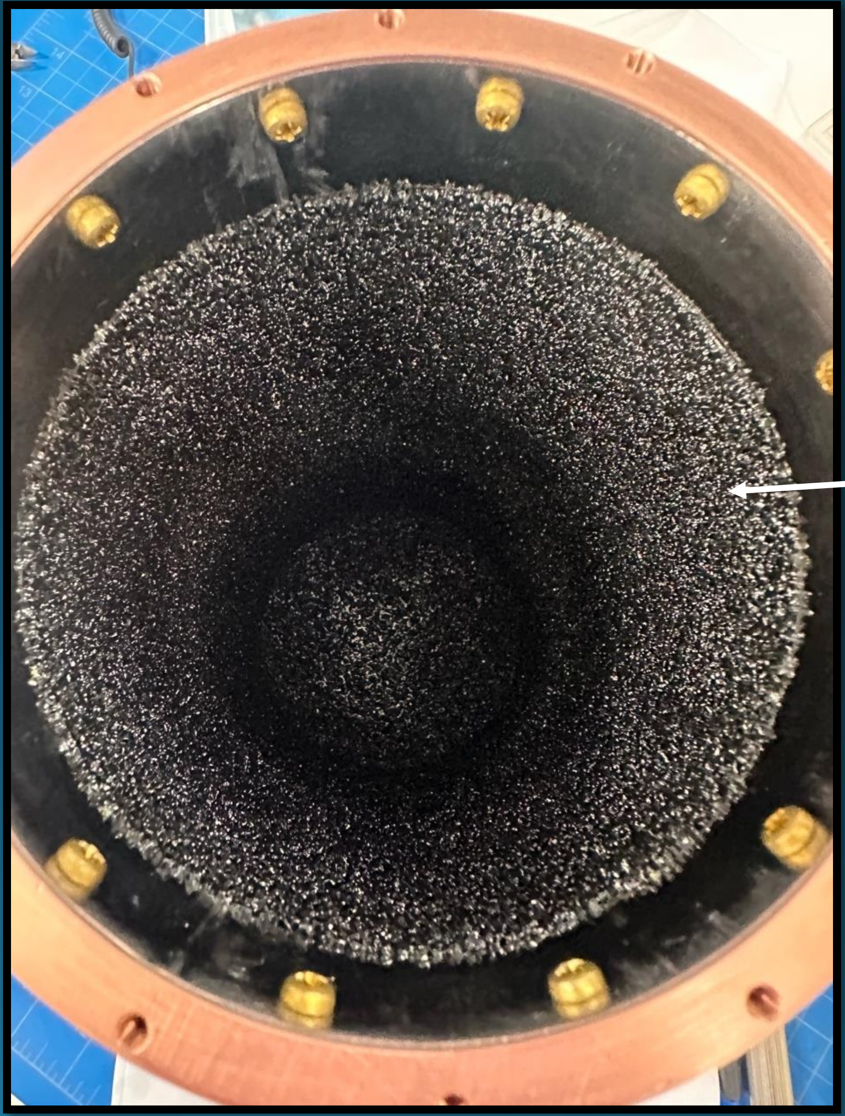


DC Bias
TL In
"Charge" In
TL Out
50K
4K
1K
100mK
10mK
20dB
10dB
LNF,
4-8 GHz
HEMT
Circulator +
2x Isolator,
4-8 GHz
LPF
HPF
DC
RF
DC+RF
Bias
Tee
DC port terminated
eccosorb
SQUAT

Reducing dark rate

12mm eccosorb filters

stub filter
(design following Pyle group, Berkeley)



IR black coating
(courtesy of Plourde group, Syracuse/Wisconsin)

We can tune charge dispersion