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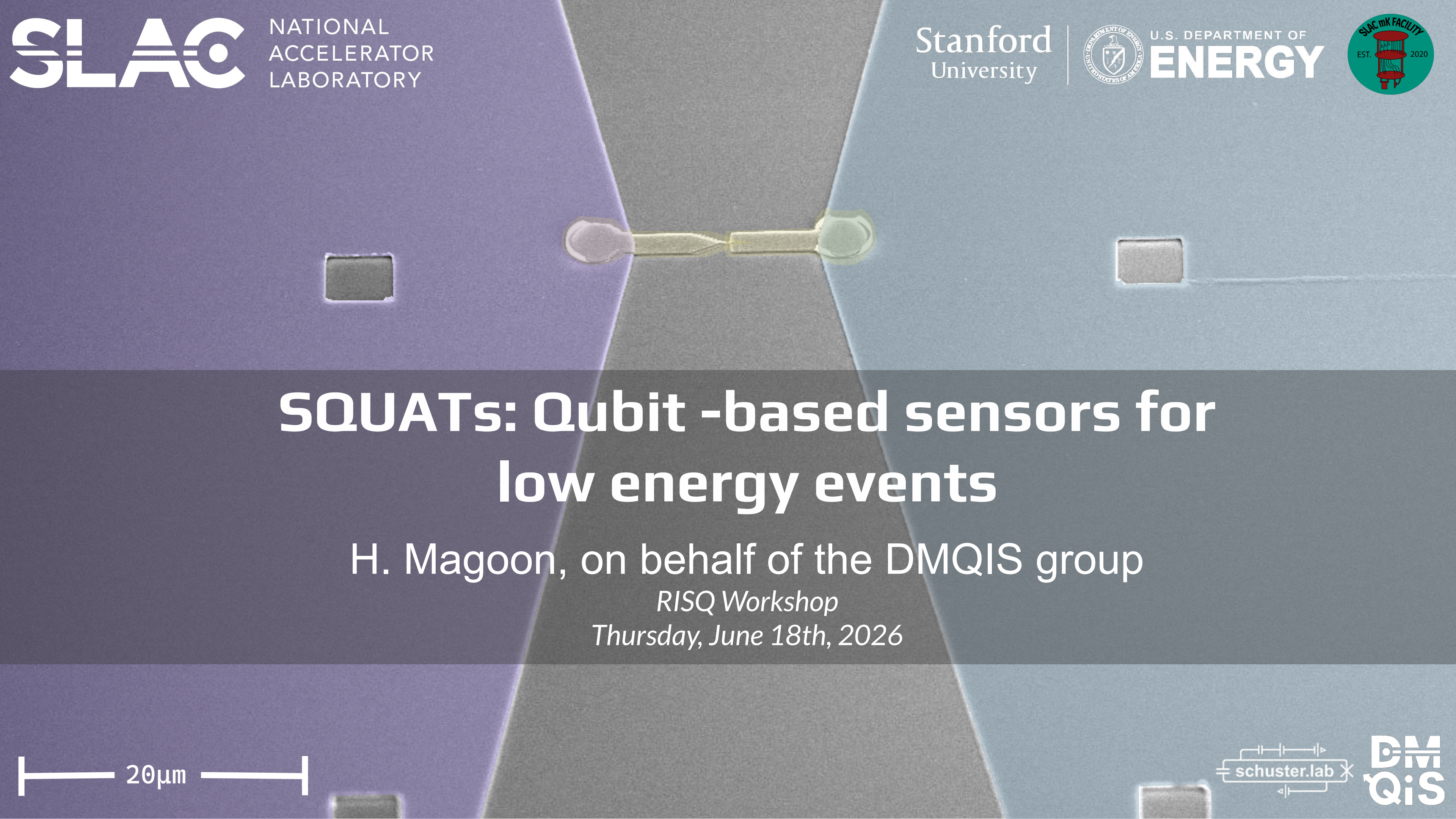


SQUATs: Qubit -based sensors for low energy events

H. Magoon, on behalf of the DMQIS group

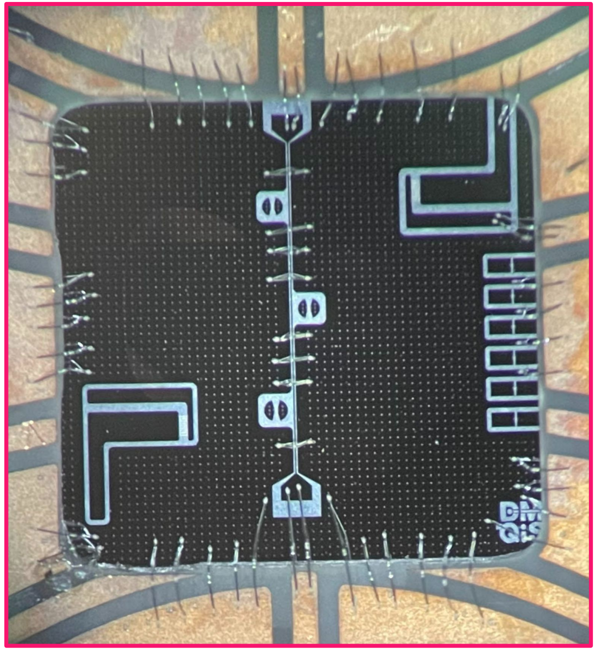
RISQ Workshop

Thursday, June 18th, 2026

schuster.lab

DMQIS

Superconducting Quasiparticle-Amplifying Transmon (SQUAT)



Design Paper

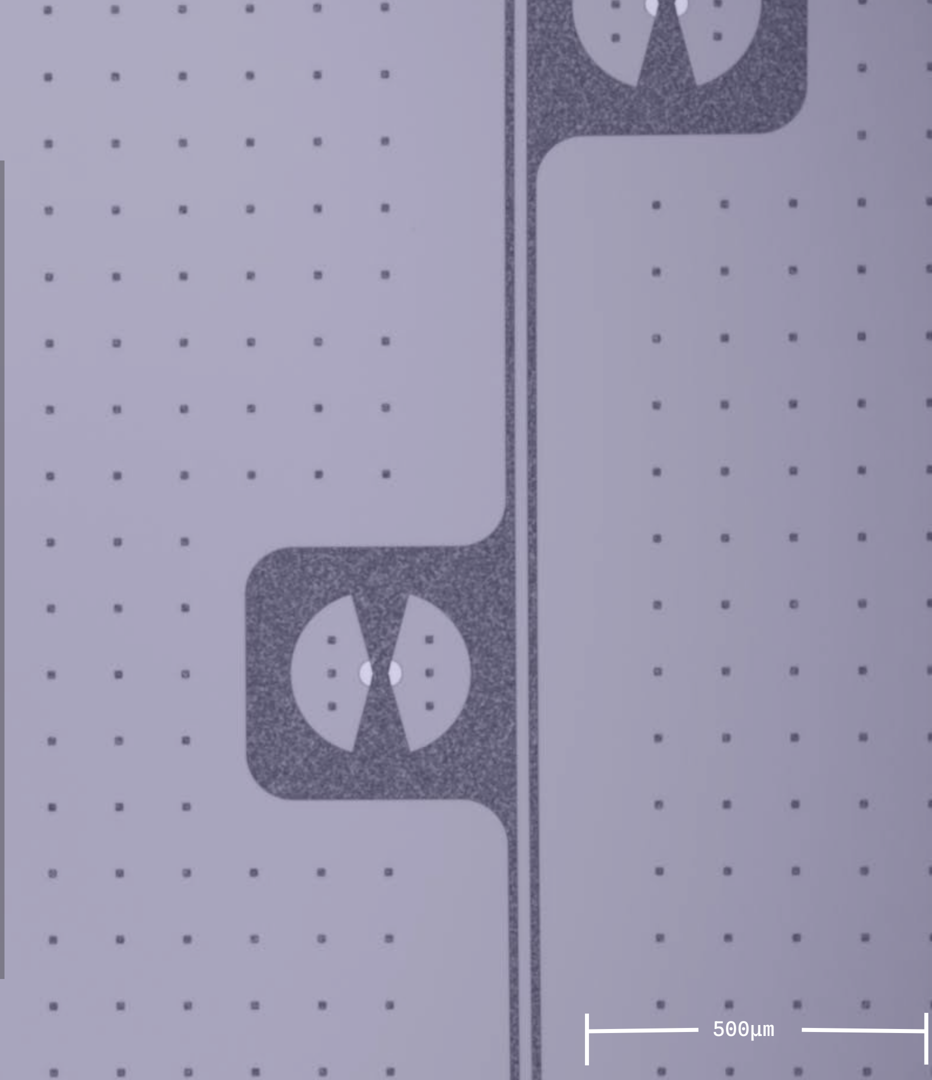
"The Superconducting Quasiparticle-Amplifying Transmon: A Qubit-Based Sensor for meV Scale Phonons and Single THz Photons",
C.W. Fink, C.P. Salemi et al., [arXiv:2310.01345v2]

Characterization Paper

"A First Demonstration of the SQUAT Detector Architecture: Direct Measurement of Resonator-Free Charge-Sensitive Transmons",
H.Magoon, T.Aralis et al., [arXiv:2601.16261]

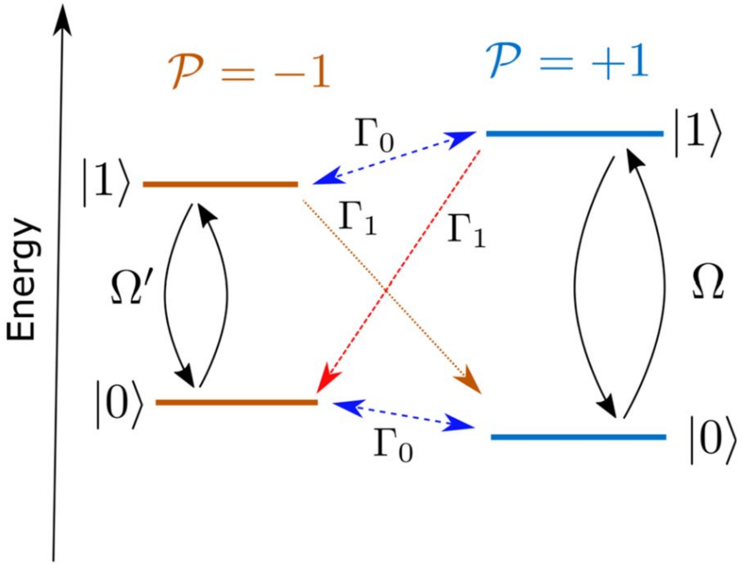
Outline

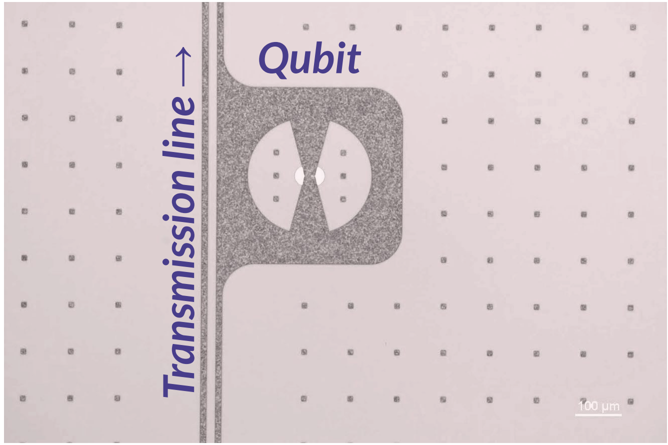
1. SQUATs Working Principle
2. SQUAT Characterization
3. Tunneling Rate Studies
4. Ongoing Work
5. Conclusion & Thank you!



Parity Measurement Procedure

The SQUAT is a charge sensitive transmon directly coupled to a feedline, allowing for parity state tracking with a single CW readout tone





[Amin 2024, arxiv:2404.01277]

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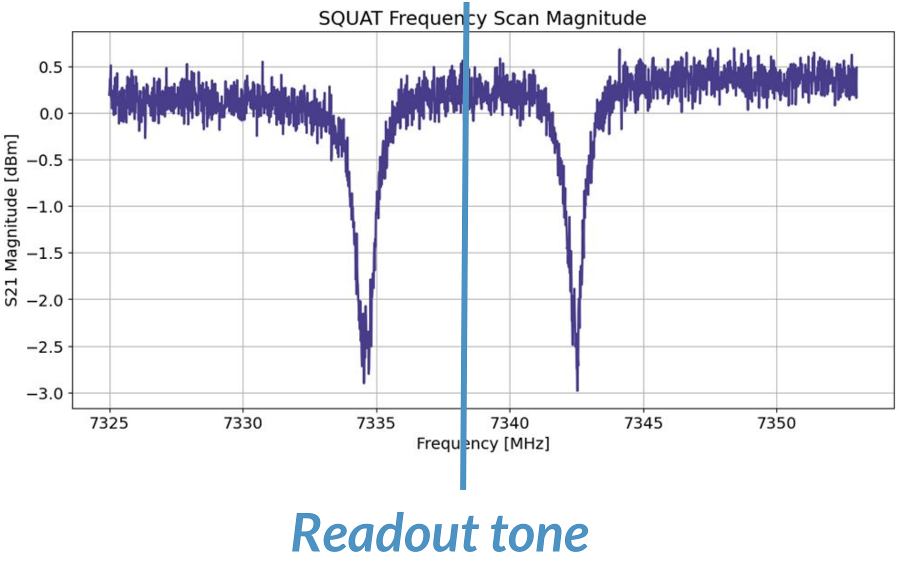

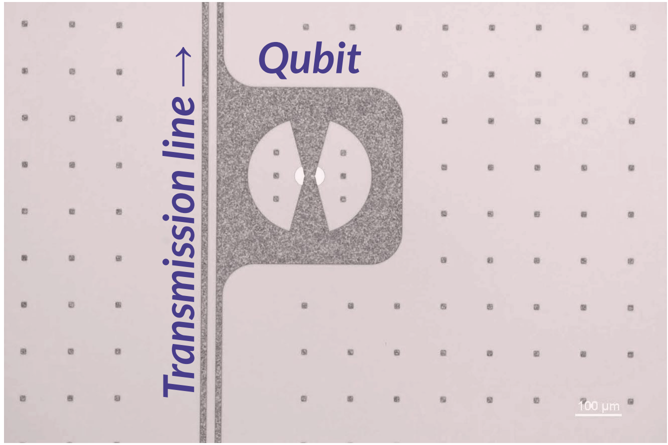

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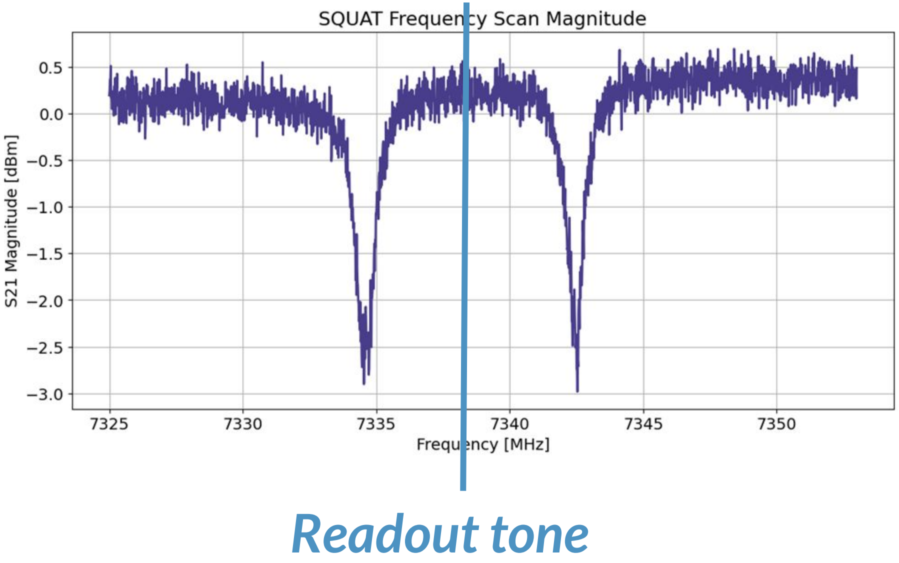

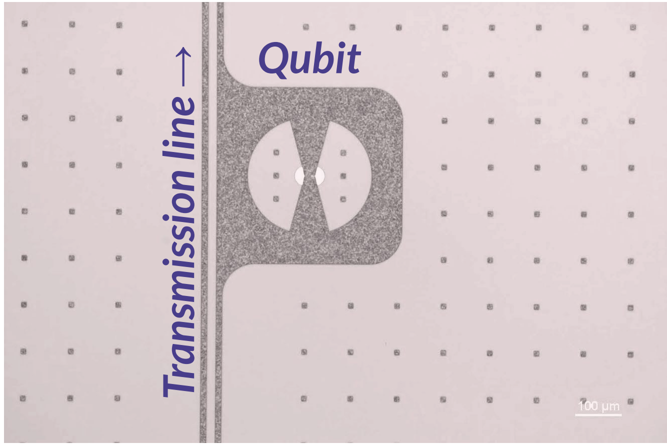

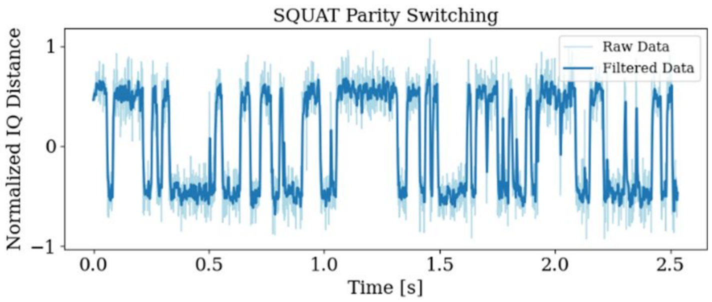

Plotting transmission of readout tone as a function of time shows tunneling events between parity states

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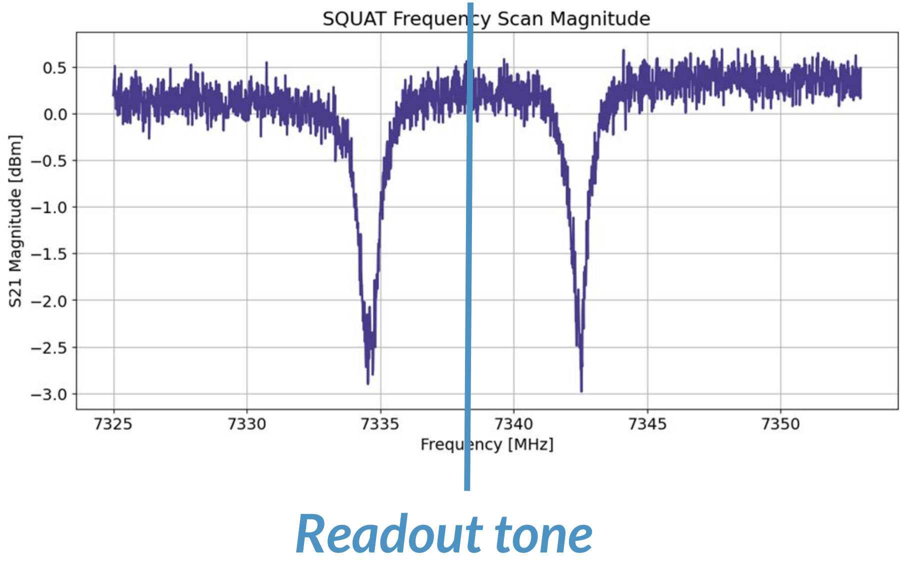

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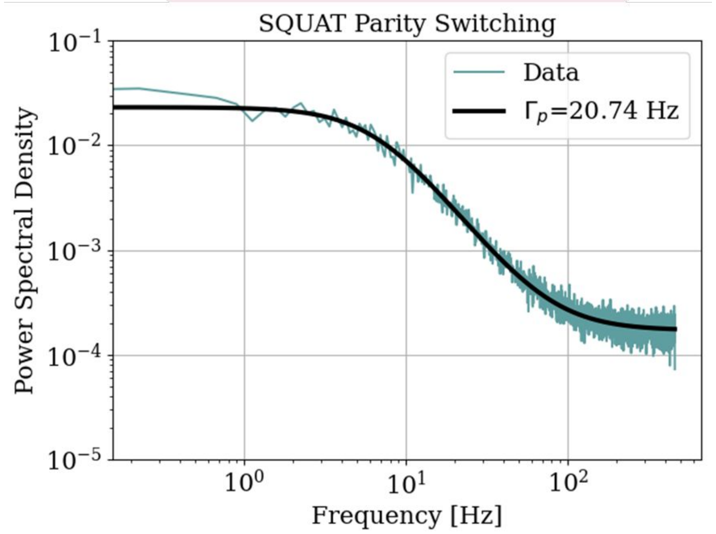
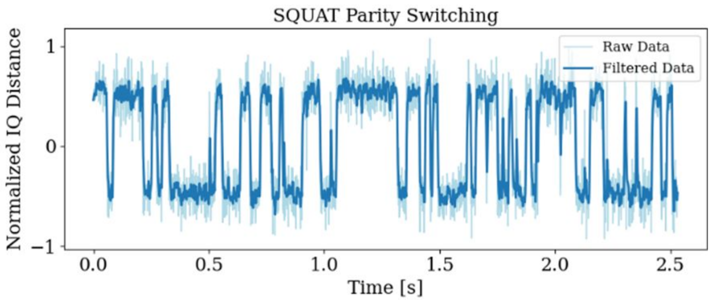
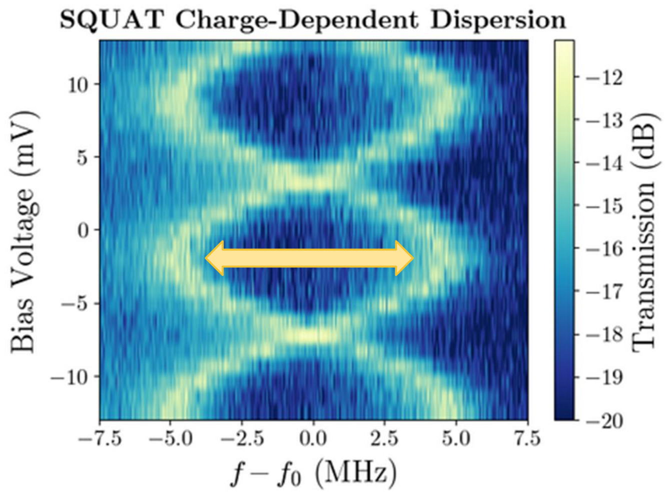
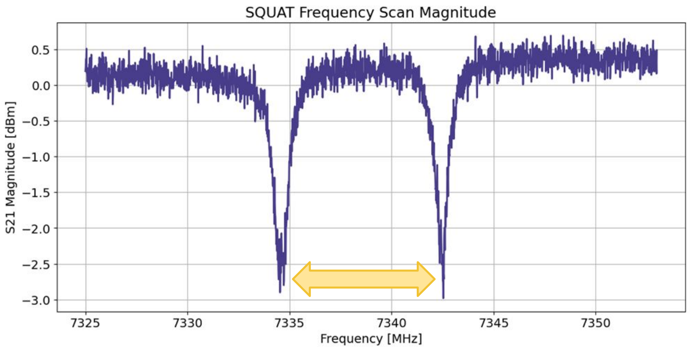




Weak Charge Sensitivity





Weakly charge sensitive transmon:

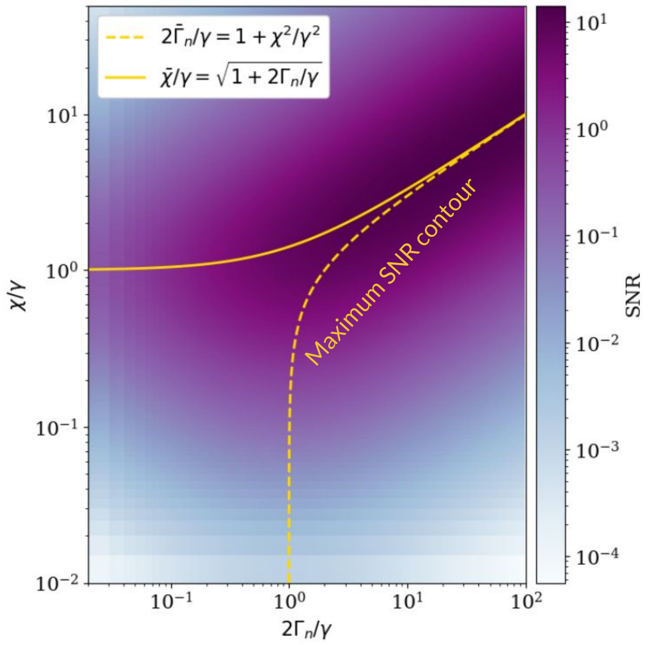
$$\hat{H}_{\mathrm{CPB}} = 4E_C \left(\hat{n} - n_g + \frac{P-1}{4}\right)^2 - E_J \cos\hat{\varphi}$$

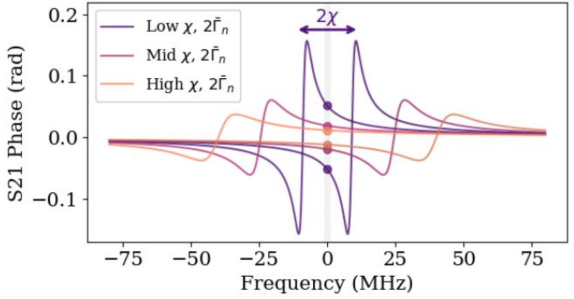
First transition energy varies with capacitor offset charge. Single QP tunneling events change the charge parity (P), causing a measurable shift in qubit resonance frequency.

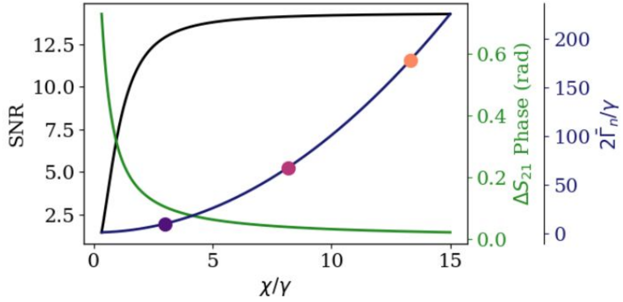
We typically aim for typically Ej/Ec ~15-20, with a maximum parity state dispersion of ~10MHz

Parity Measurement Fidelity Optimization

Direct feedline coupling makes it is easy to measure tunneling rate of devices with a wide range of dispersions, with the understanding that higher dispersions require higher readout tone power







Plots show expected relations, not actual data

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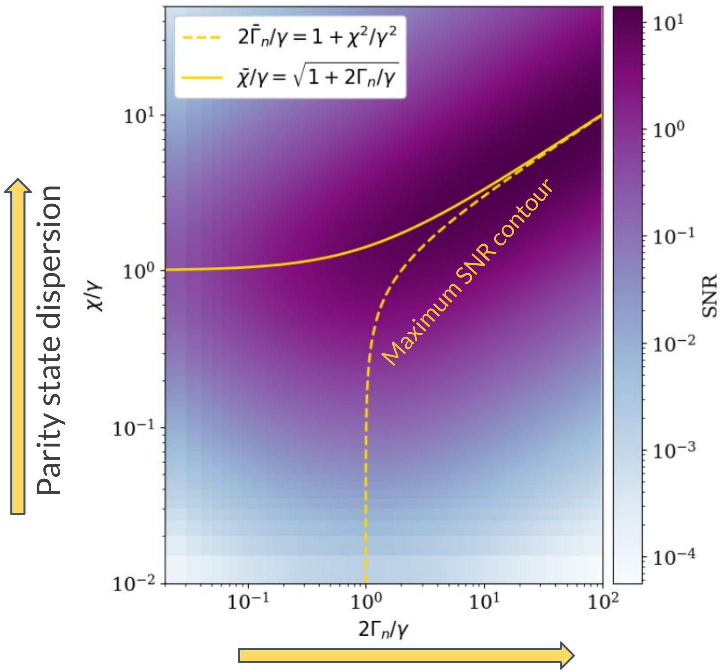
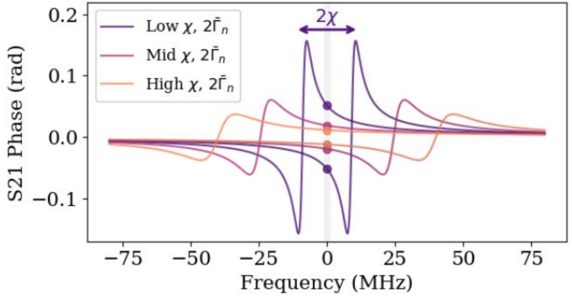
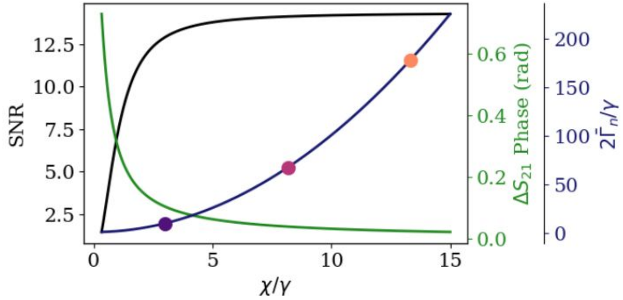


(in units of normalized photon interrogation rate)

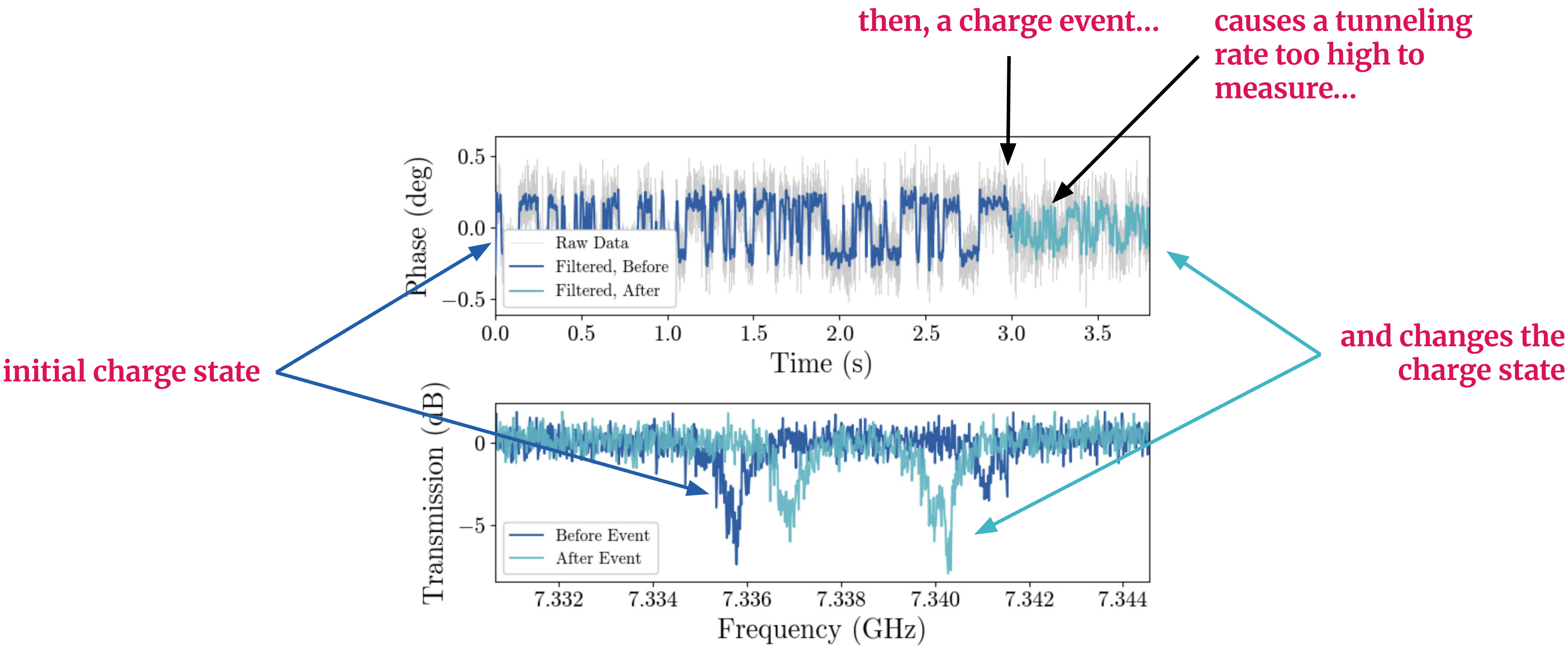




Plots show expected relations, not actual data

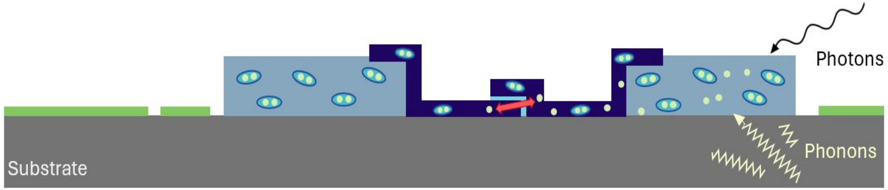
Prototype Characterization

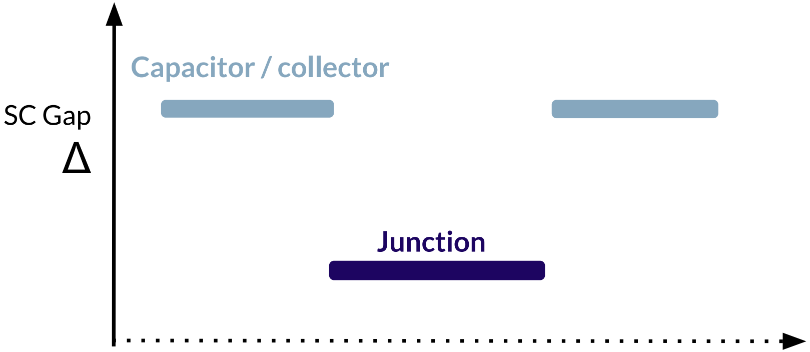
Thus, a change in charge dispersion is visible in the time domain as a change in readout fidelity:

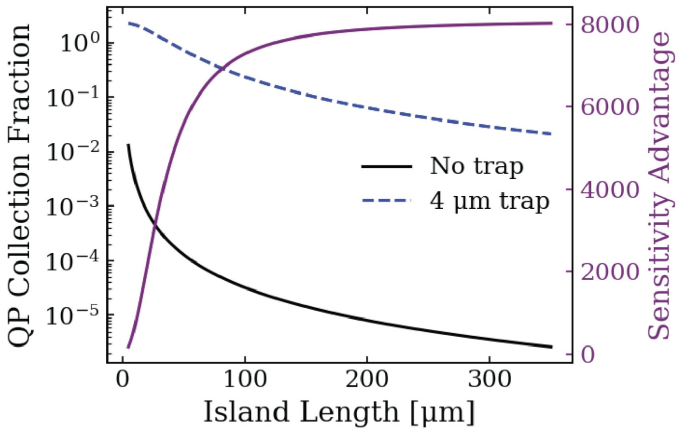


Sensing Architecture

Following the QET architecture, we can use gap-engineering to trap excess QPs in the junction region, enhancing the tunneling signal and increasing detector sensitivity







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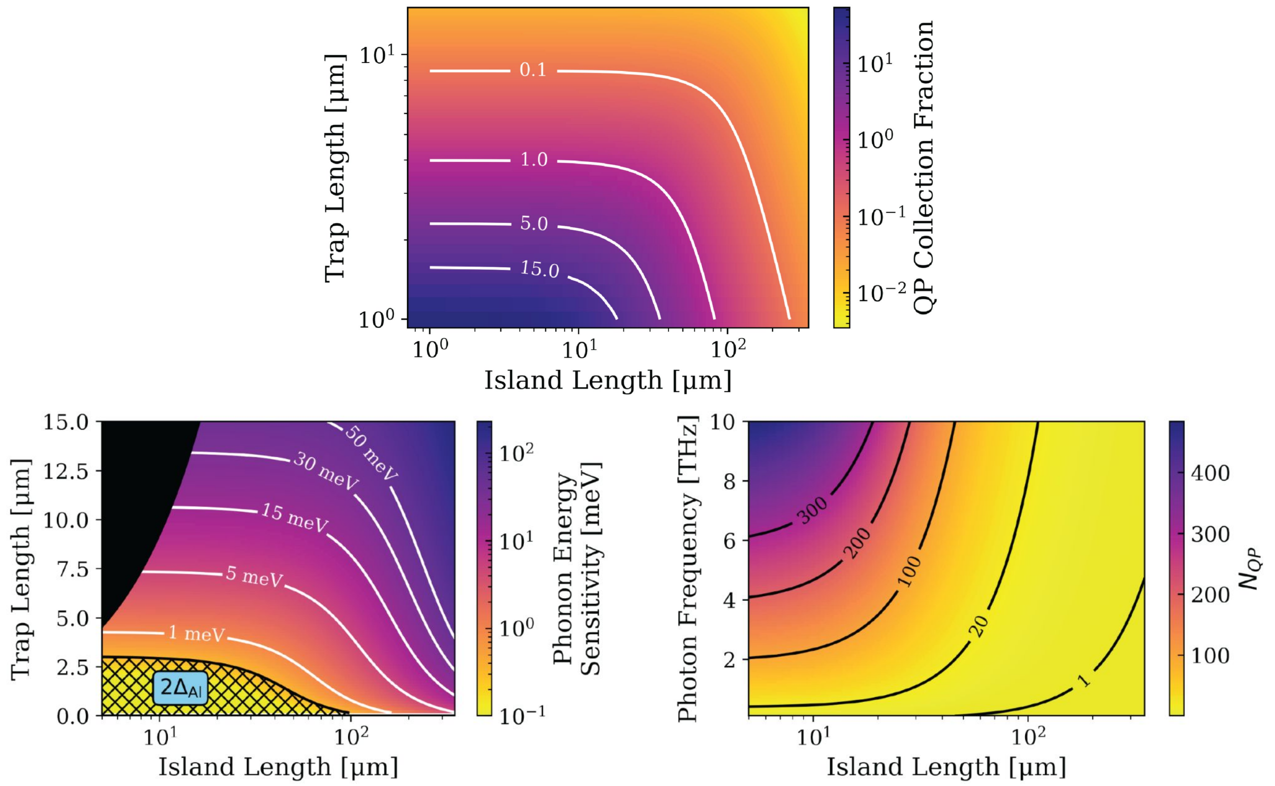
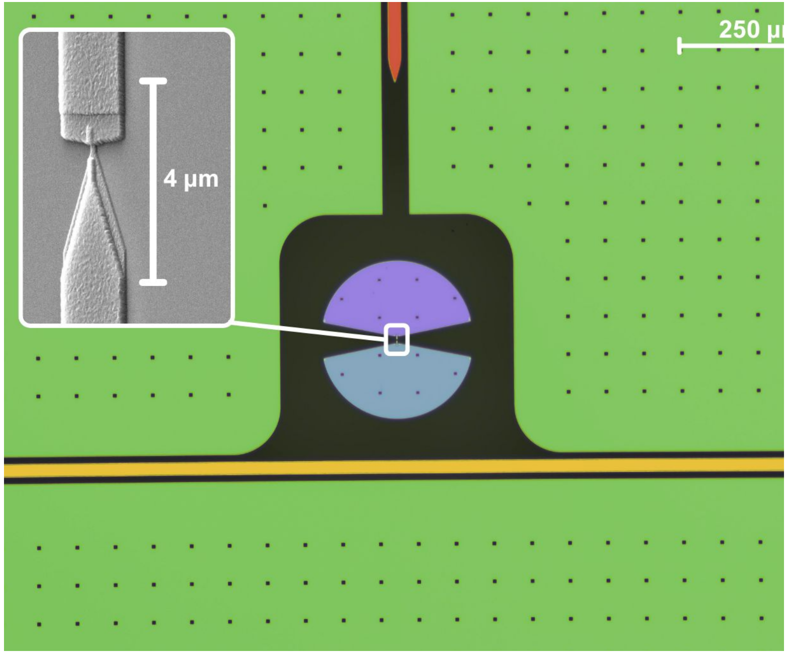
SQUAT Sensitivity Goals

Simulated sensitivity advantage (assuming Al fins and Tc~100mK junctions):



Design Considerations

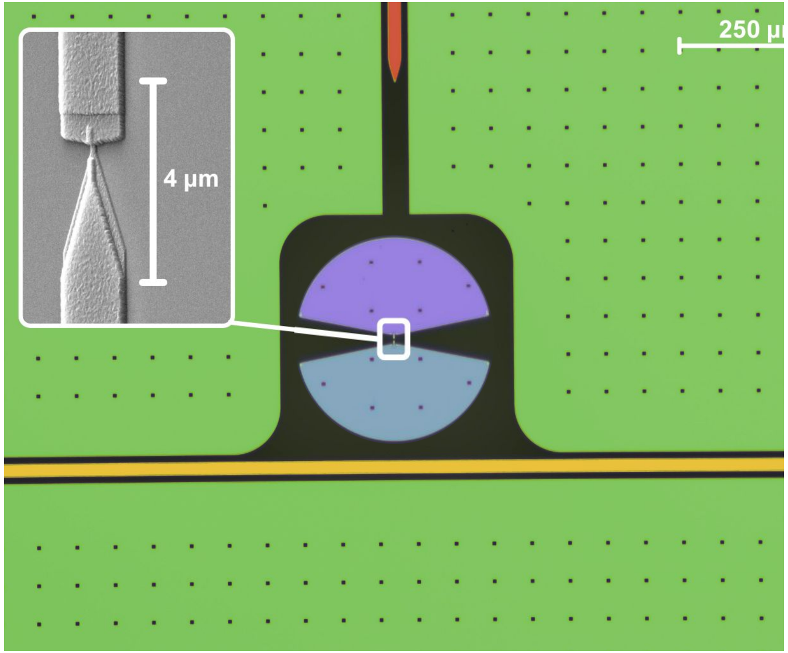
SQUATs can be designed to maximize phonon sensitivity…



Design Considerations

SQUATs can be designed to maximize phonon sensitivity…

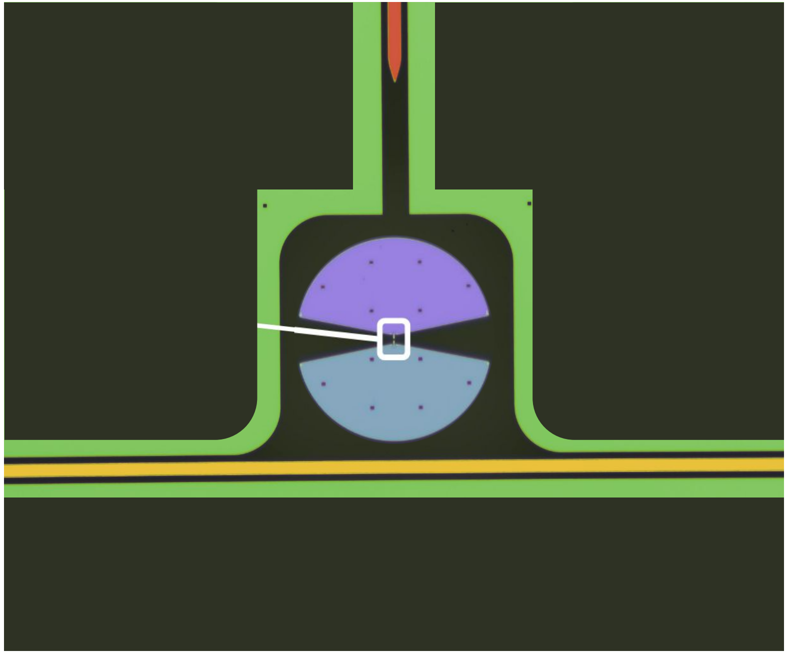
- Using large fins to improve phonon collection



Design Considerations

SQUATs can be designed to maximize phonon sensitivity…

- Using large fins to improve phonon collection
- Minimizing the ground plane to reduce phonon loss



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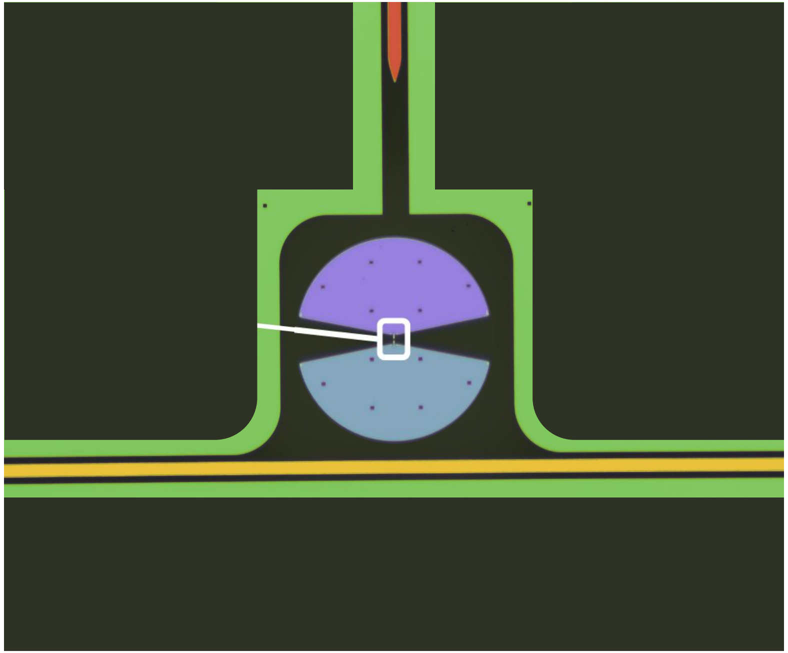
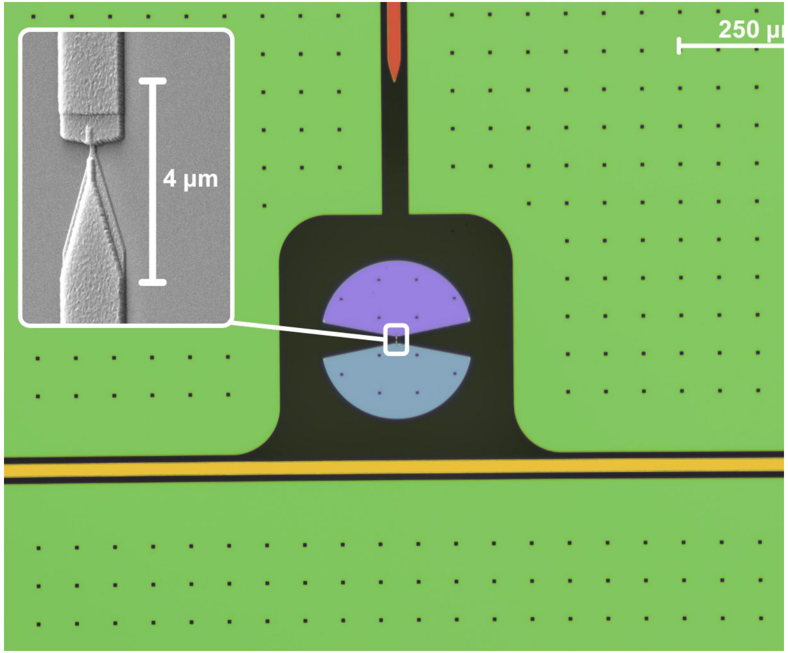


Or to direct absorption of *photons*



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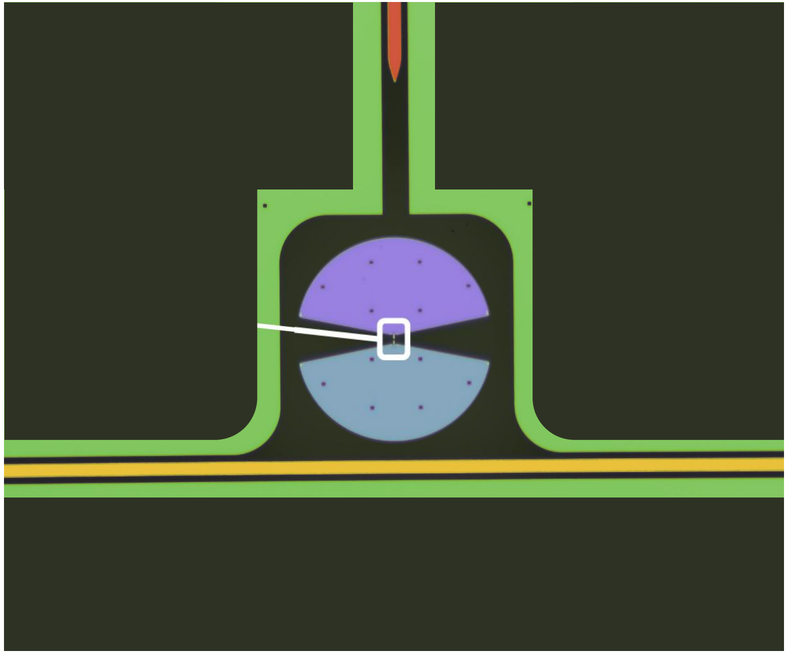
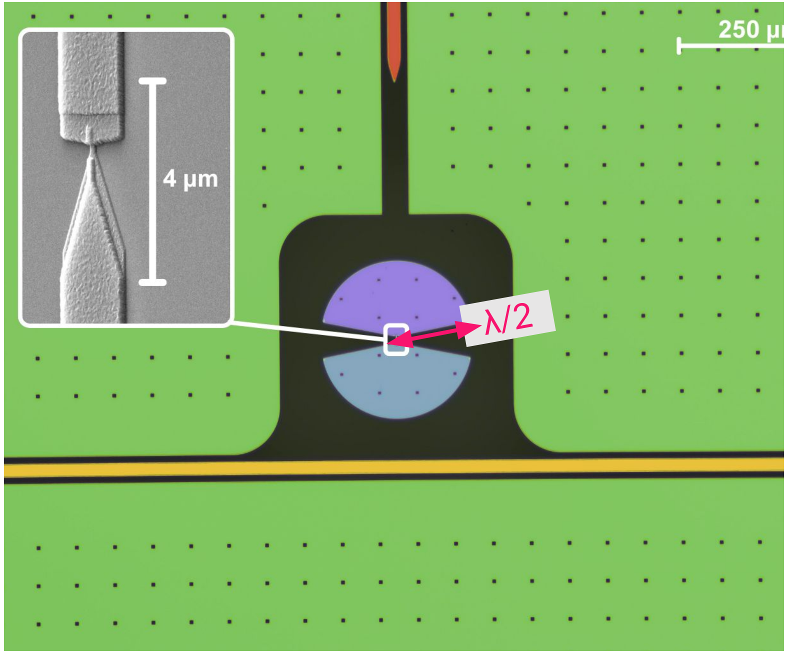
Or to direct absorption of *photons*

- By designing fins to operate as antennas





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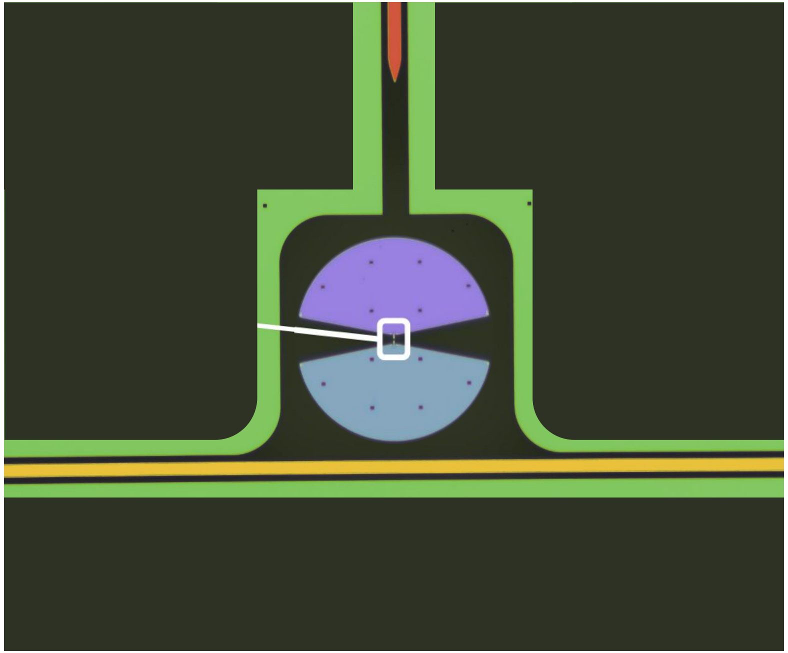
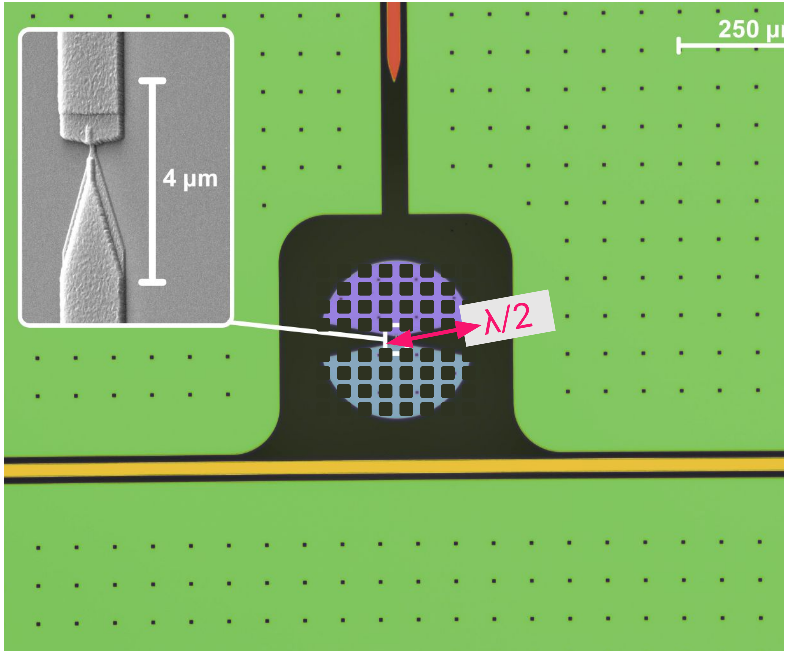
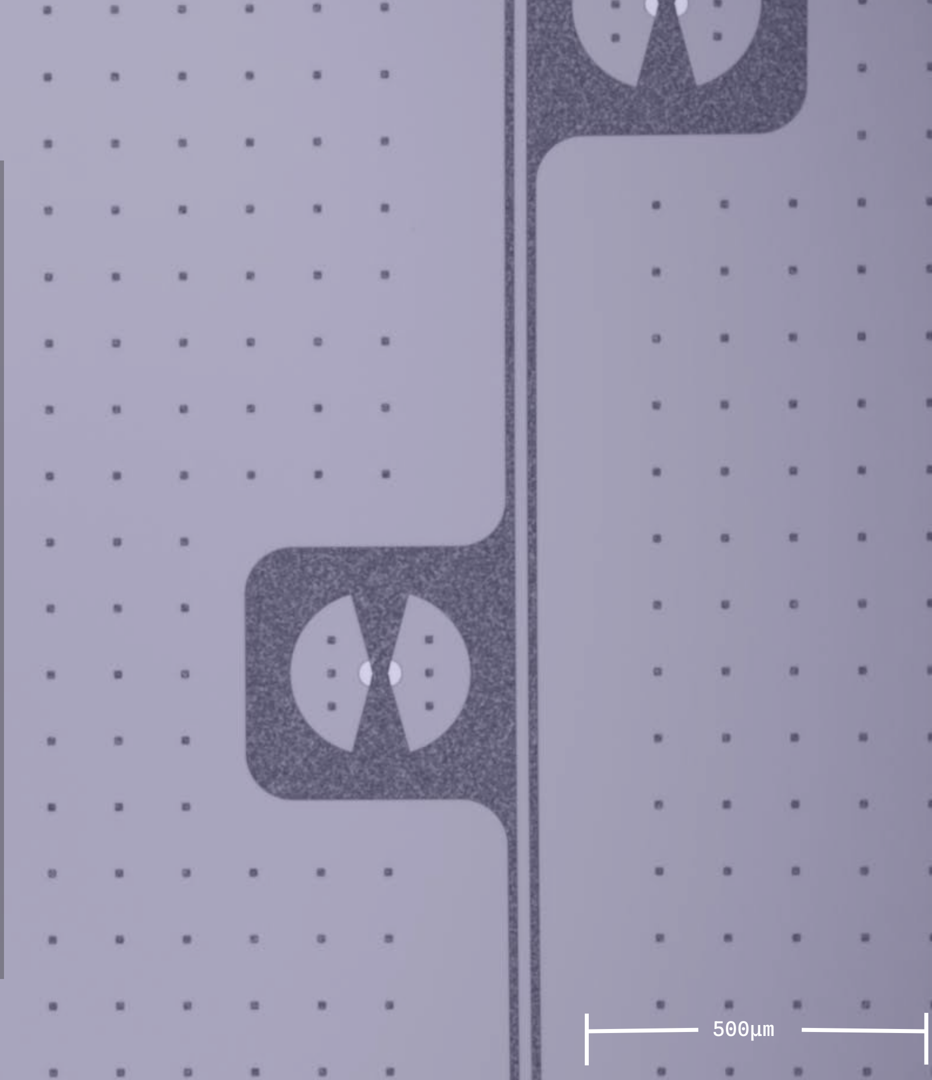


Or to direct absorption of *photons*

- By designing fins to operate as antennas
- Using a mesh to reduce phonon sensitivity

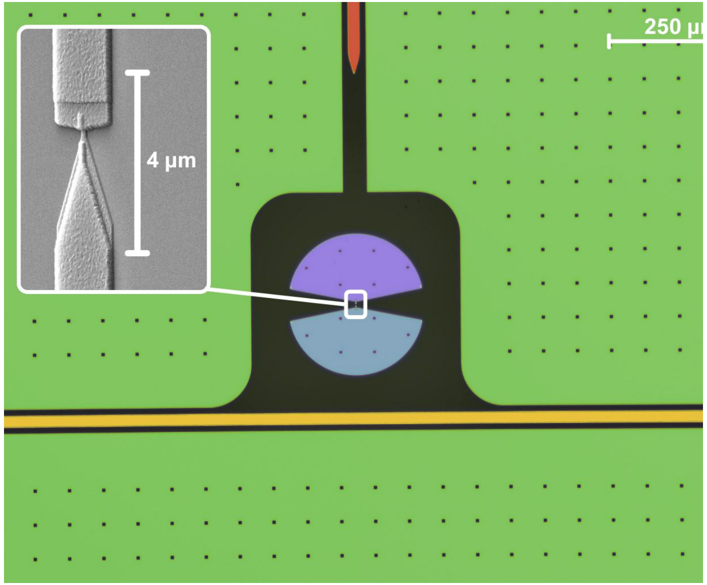


Outline



SQUAT Readout Dynamics

$$H = H_{\mathrm{qubit}} + H_{\mathrm{TL}} + H_{\mathrm{int}}$$



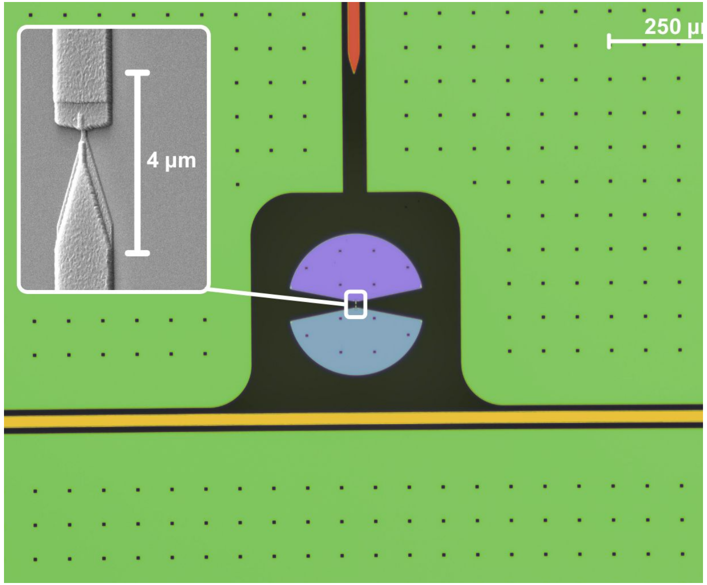
Interaction with SQUAT is ***direct***, rather than dispersive

SQUAT Readout Dynamics

$$H = H_{\text{qubit}} + H_{\text{TL}} + H_{\text{int}}$$

$$H_{\text{qubit}} = \frac{\omega_0}{2}\sigma_z$$

$$H_{\text{TL}} = \int_{-\infty}^{\infty} d\omega \; \omega b_\omega^\dagger b_\omega$$



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SQUAT Readout Dynamics

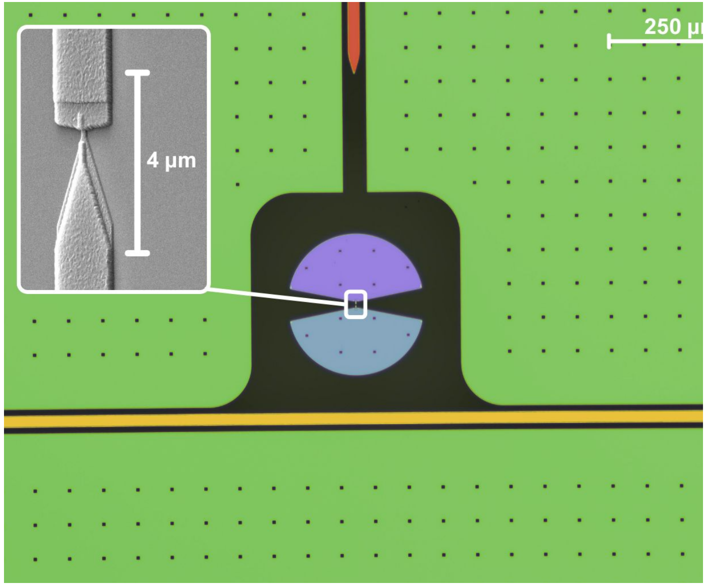
$$H = H_{\text{qubit}} + H_{\text{TL}} + H_{\text{int}}$$

$$H_{\text{int}} = \int_{-\infty}^{\infty} d\omega \; g(\omega) \; (b_\omega^\dagger \sigma_- + b_\omega \sigma_+)$$

Integral over all possible mode frequencies

Coupling strength

Exchange of photon between qubit and transmission line



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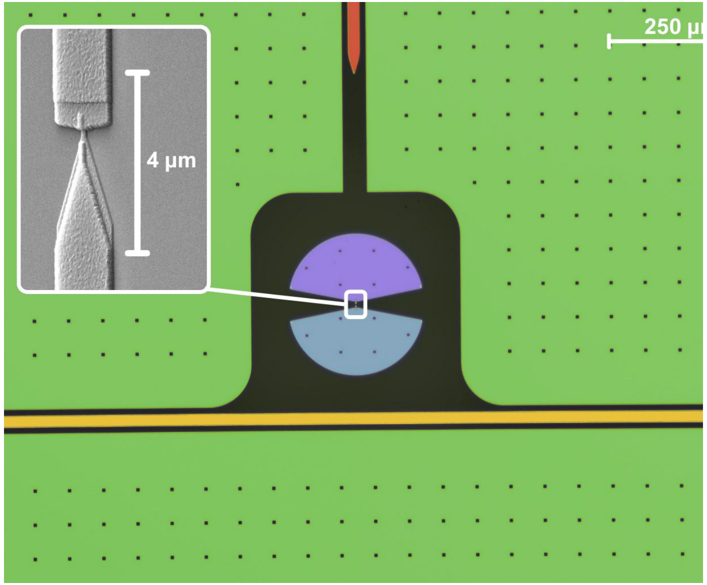
SQUAT Readout Dynamics

$$H = H_{\text{qubit}} + H_{\text{TL}} + H_{\text{int}}$$

Input output relations give qubit emission signal measured via coherent transmission signal:

$$\alpha_{out}^{L,R}(t) = \alpha_{in}^{R,L}(t) - i\frac{\Gamma_c}{2g}\sigma_-$$

Output = input modified by photon coupling to the transmission line (rate = Γ_c)



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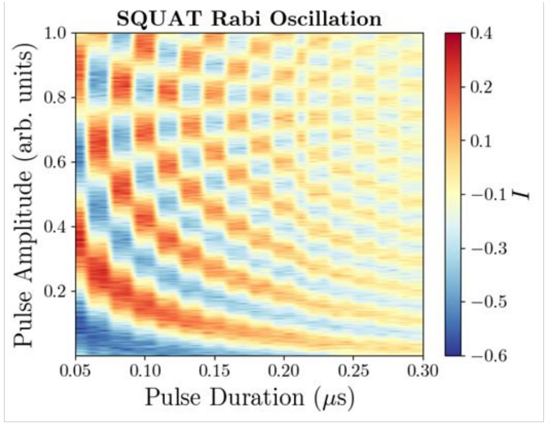
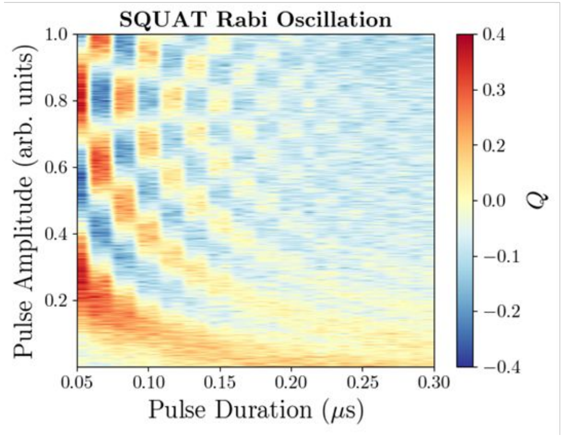
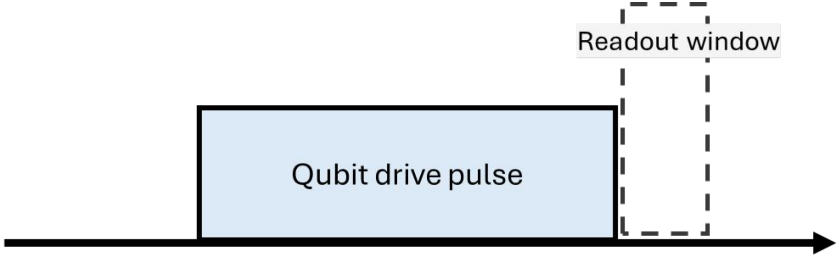
Pulsed Measurements

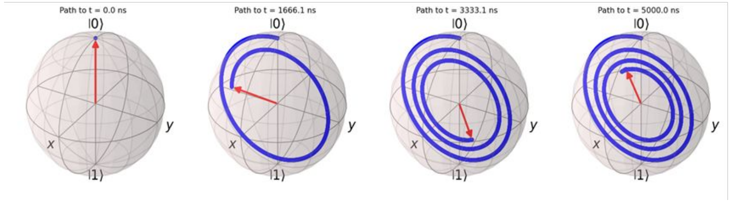




We can use short control pulses to set the qubit's state

As pulses become longer, we drive the qubit into a mixed state





SQUAT Readout Dynamics

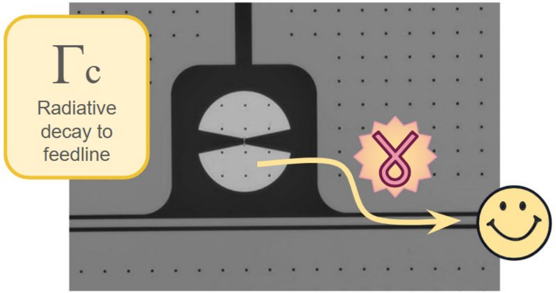
Master Equation (from Qubit's perspective)

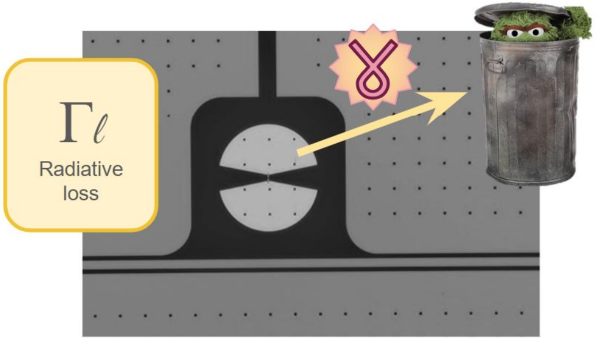
$$\frac{d}{dt}\rho(t) = -i\,[H_{\text{eff}}, \rho] + \Gamma_r \mathcal{D}[\sigma_-]\rho + \frac{\Gamma_\phi}{2}\mathcal{D}[\sigma_z]\rho$$

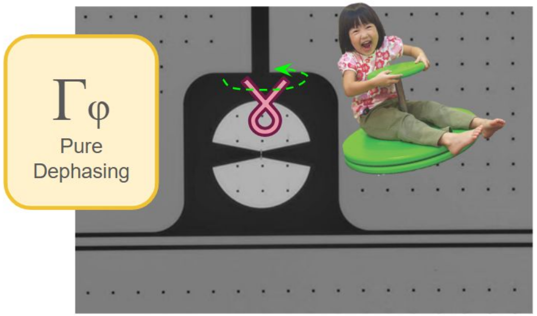
$$\Gamma_r = \Gamma_c + \Gamma_l$$

Radiative Losses (both to feedline coupling and to pure loss channels)

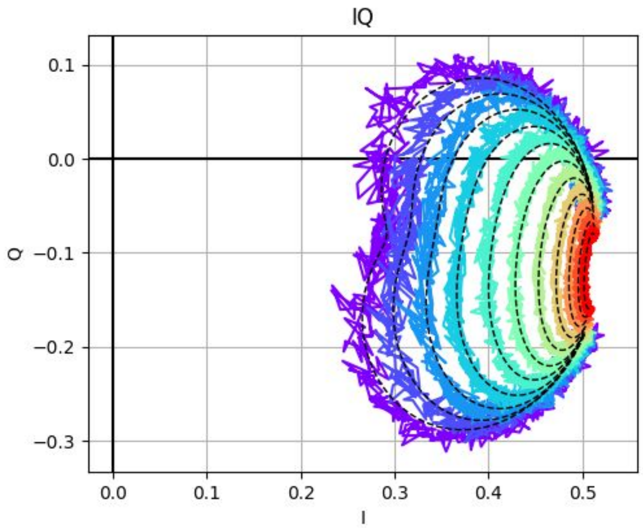
Pure Dephasing

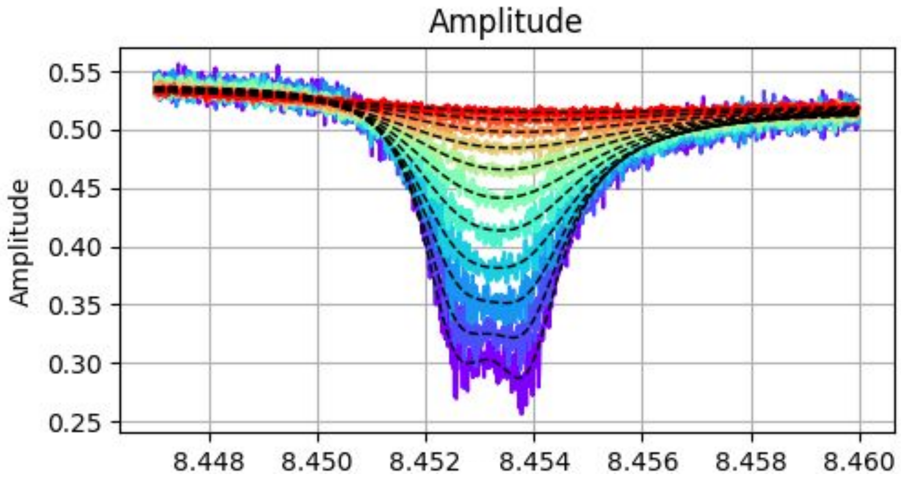






Steady-State Response & Resonance Fits



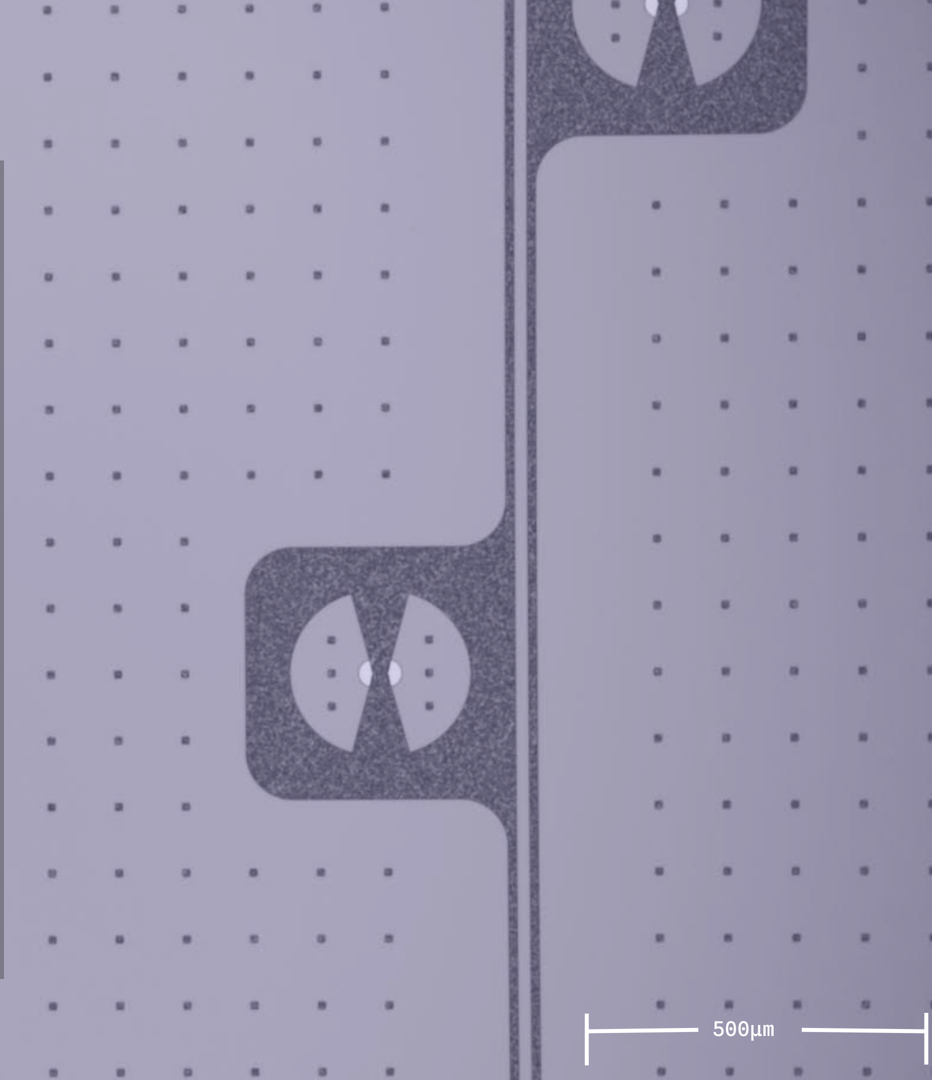


Resonance fit for directly coupled qubit:

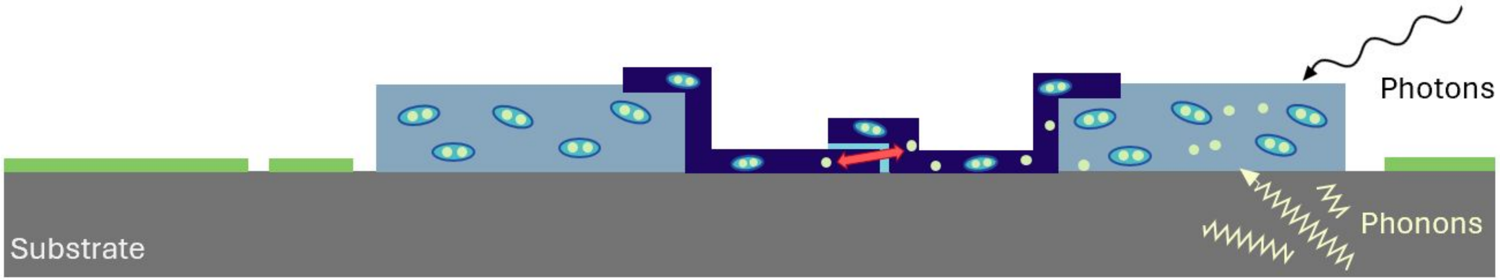
$$S_{21}(f) = 1 - \frac{\Gamma_c}{2\gamma} \frac{1 - i\frac{2\pi\delta f}{\gamma}}{1 + \left(\frac{2\pi\delta f}{\gamma}\right)^2 + \frac{2\Gamma_n}{\gamma}}$$

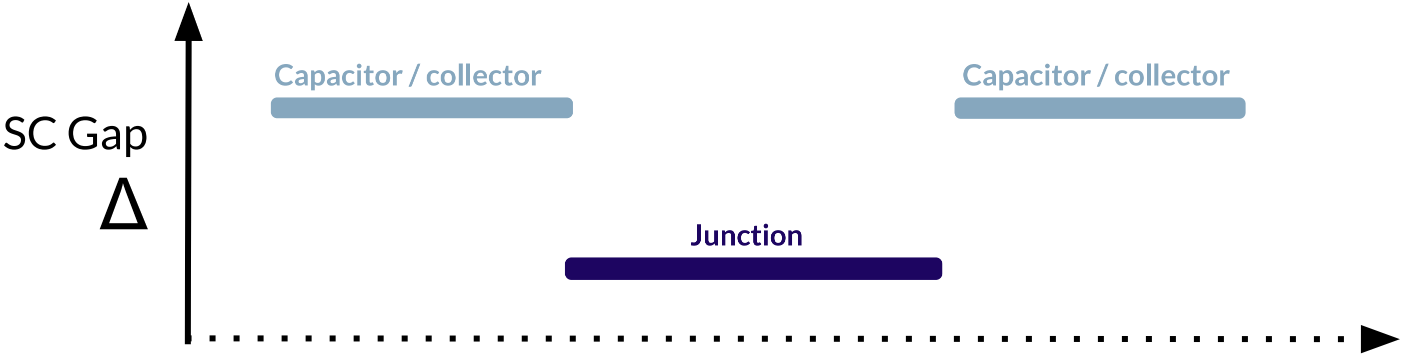
T1 = 100 ns
T2 = 200 ns
$\Omega/2\pi$ = 1 → 6 MHz

Outline



Another knob to turn: Gap difference across junction leads





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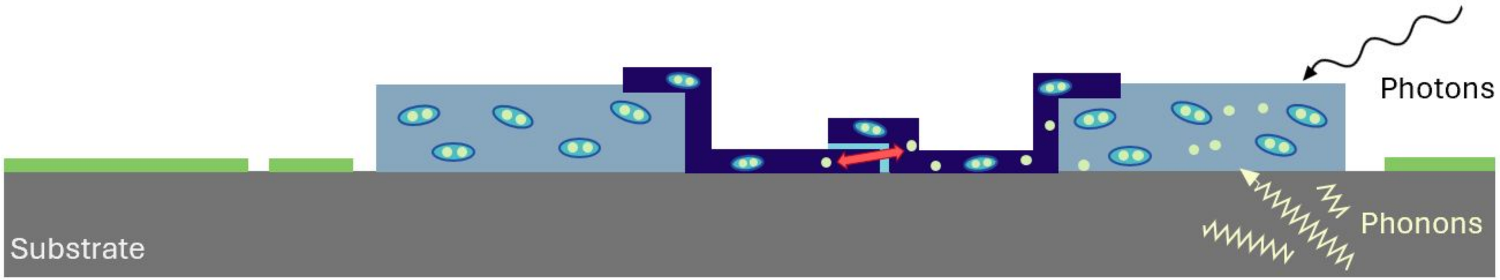
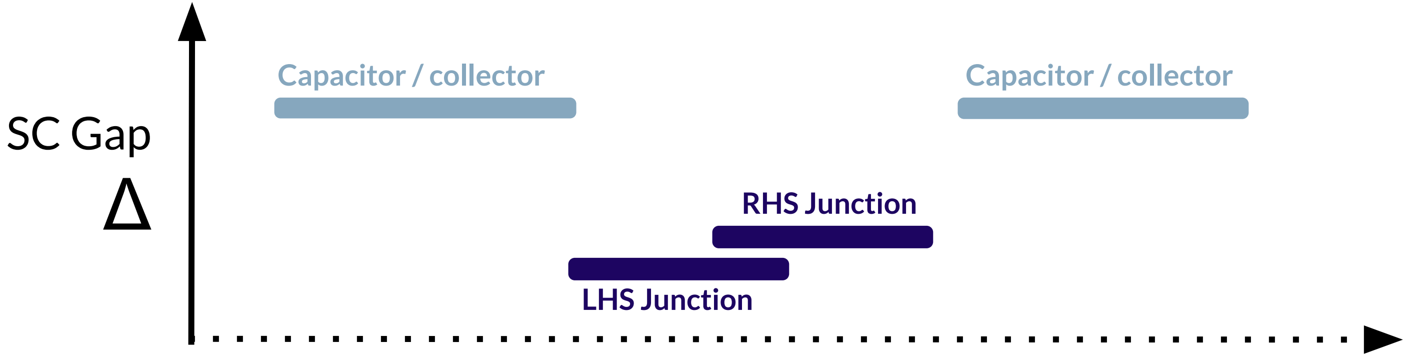
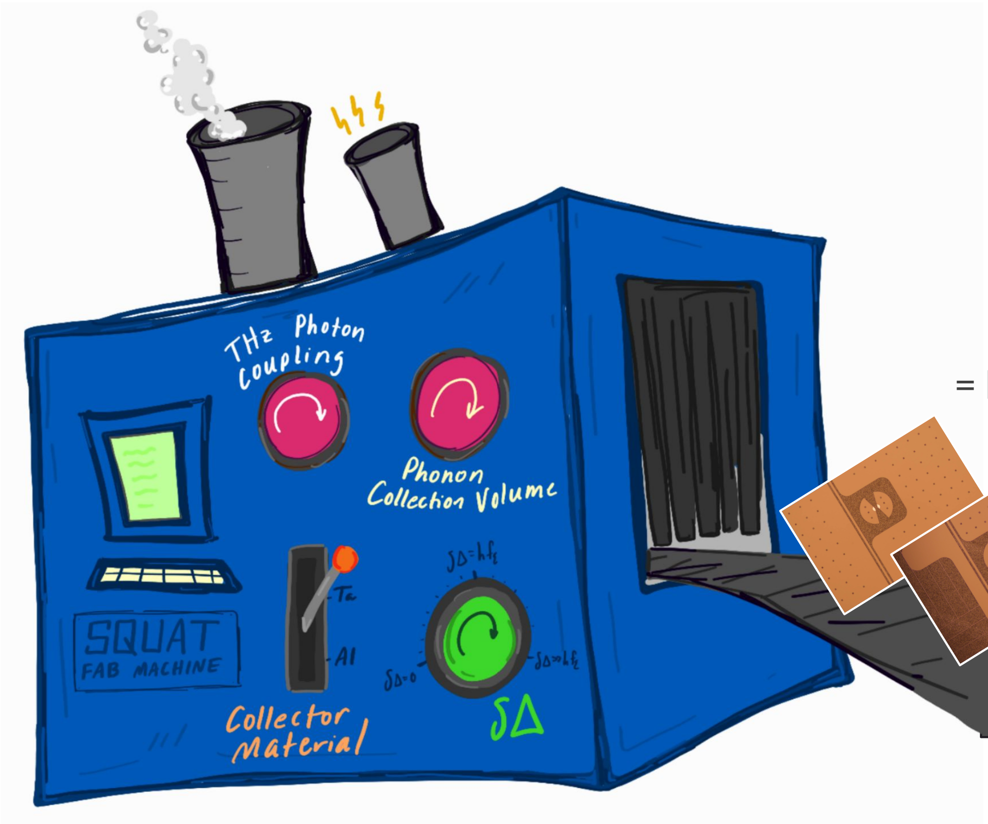
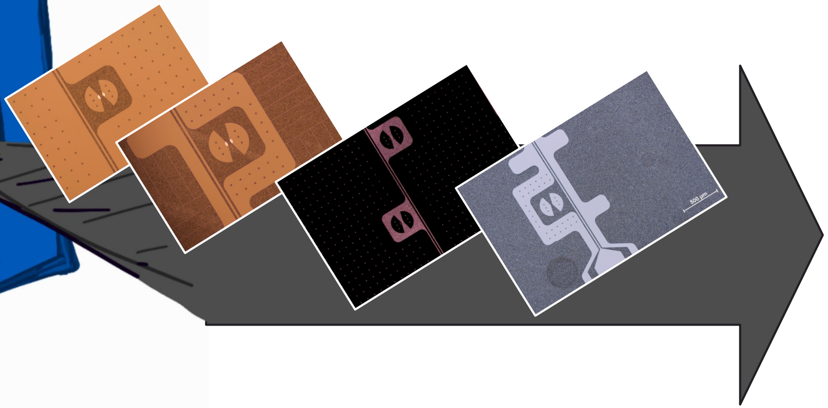


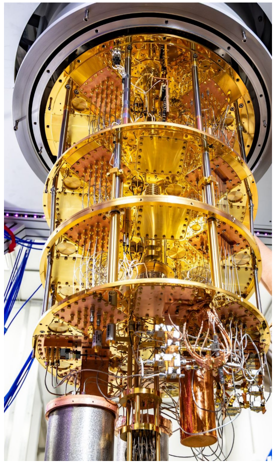


Let’s get fabbing?



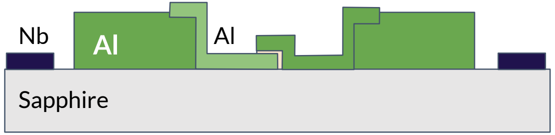
= Lots of parameter space to test!



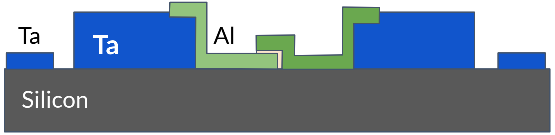


Introducing some devices:

Device: “H2”
Absorber: Al
Junction: Al
$0<\delta\Delta<hf_q$

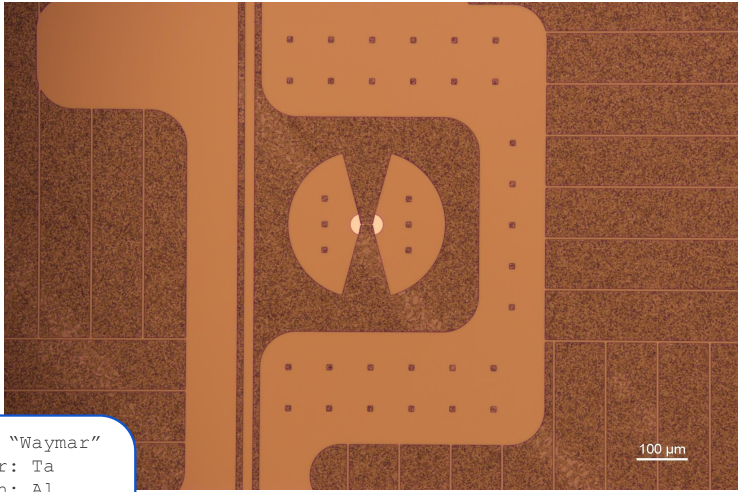


Device: “Waymar”
Absorber: Ta
Junction: Al
$0<\delta\Delta<hf_q$

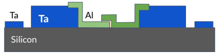


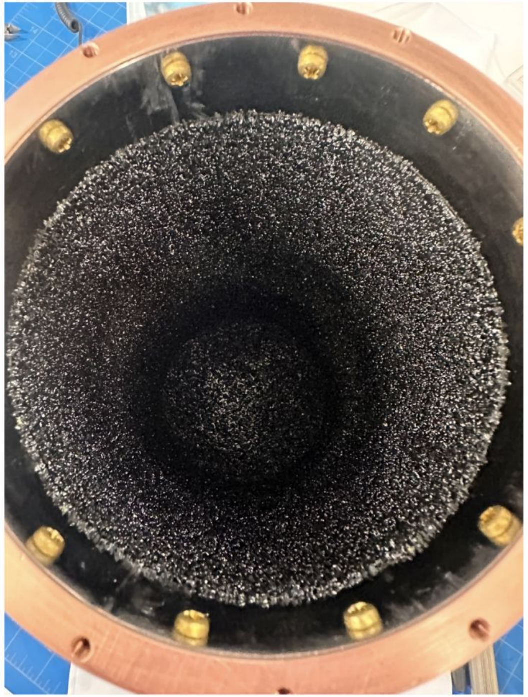
Device Mounting Scheme

Mount in IR-coated shielding with stub filter lid design:



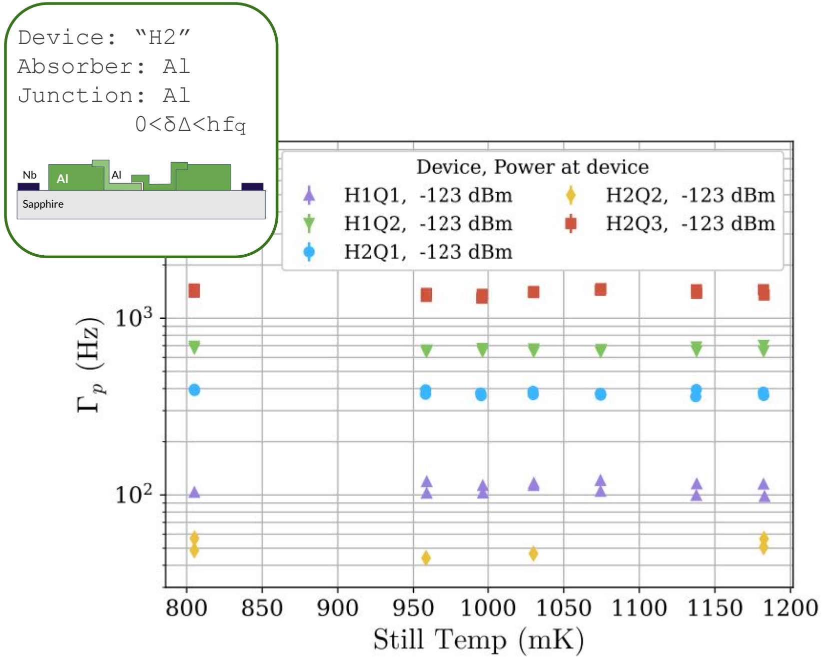
Device: "Waymar"
Absorber: Ta
Junction: Al
$0<\delta\Delta<hf_q$

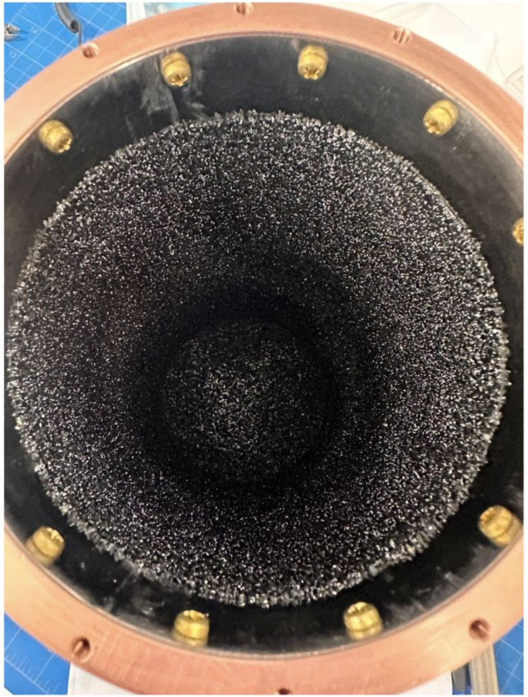




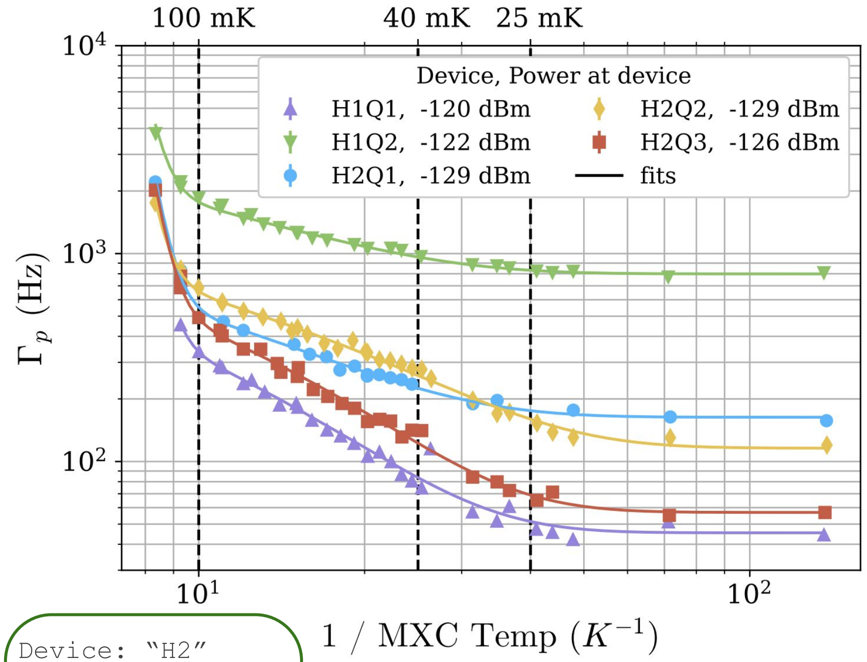
Device Mounting Scheme

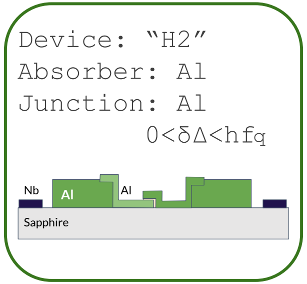
Mount in IR-coated shielding with stub filter lid design:





Temperature Characterization



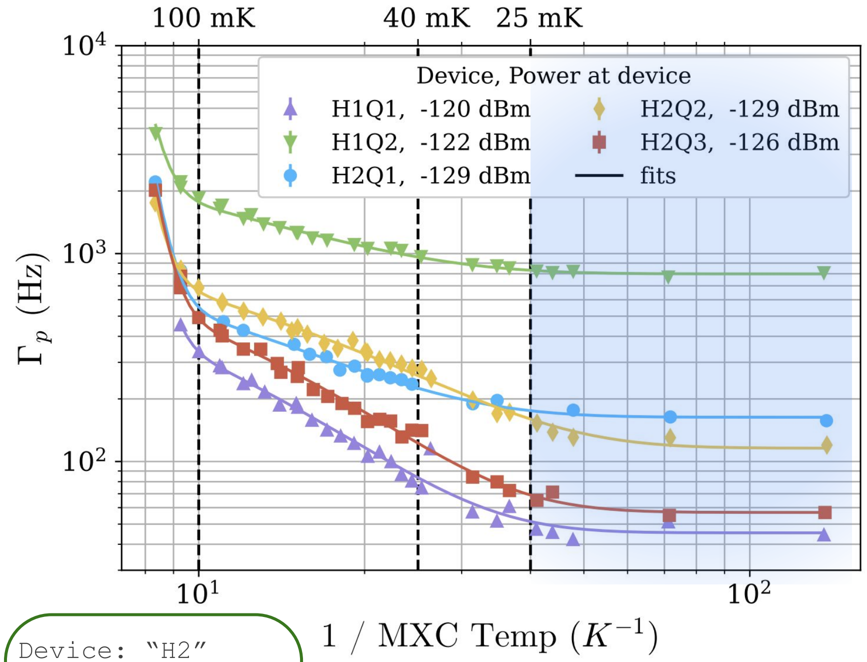


Following the temperature scan model developed by Yale group, detailed in:

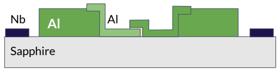
[Nho 2026, arxiv:2505.08104]

[Connolly 2024, arxiv:2302.12330]

Temperature Characterization



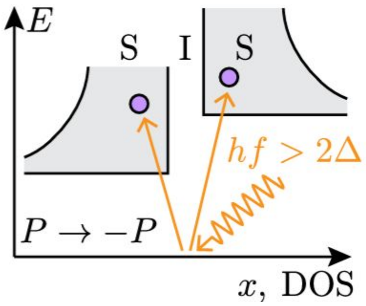
Device: "H2"
Absorber: Al
Junction: Al
$0<\delta\Delta<hf_q$



Following tunneling rate models nicely outlined in recent Yale group papers:

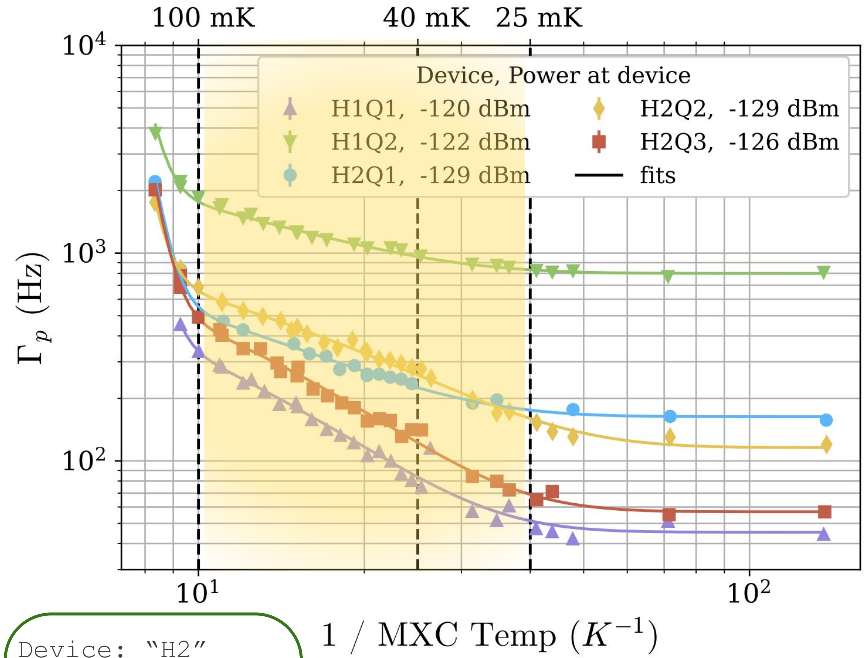
Low Temp Regime

Ground state tunneling rate saturates to a constant value. Excited state does not. Attributed to temperature-independent photon assisted backgrounds

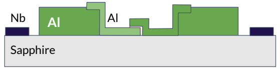


Γ_{other}

Temperature Characterization



Device: "H2"
Absorber: Al
Junction: Al
0<δΔ<hfq



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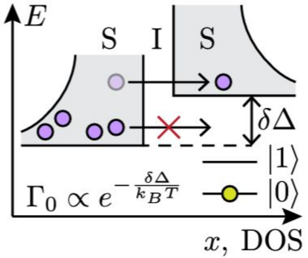
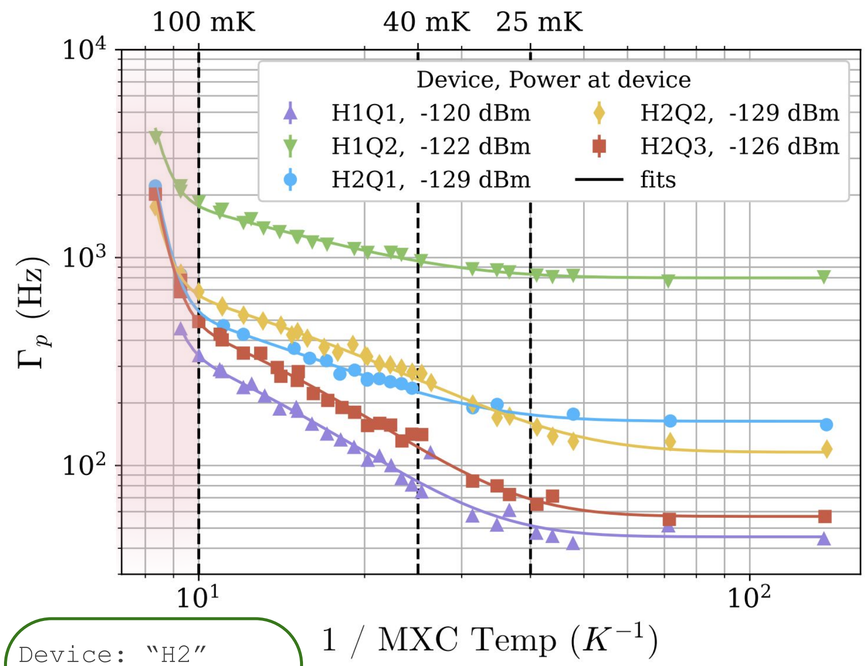
Intermed. Temp Regime

Thermal activation of residual QP population

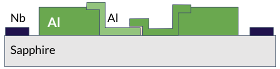


$$\Gamma_0 \propto e^{-\frac{\delta\Delta}{k_B T}}$$

Temperature Characterization



Device: "H2"
Absorber: Al
Junction: Al
0<δΔ<hf$_q$



Following tunneling rate models nicely outlined in recent Yale group papers:

Low Temp Regime

Ground state tunneling rate saturates to a constant value. Excited state does not. Attributed to temperature-independent photon assisted backgrounds

Intermed. Temp Regime

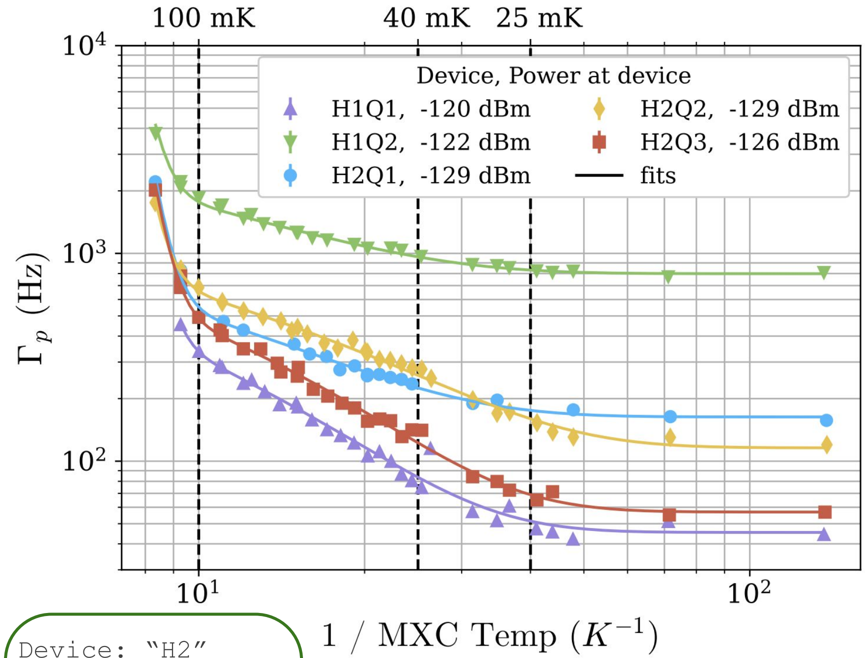
Thermal activation of residual QP population

High Temp Regime

Thermal creation of QPs exceeds the residual x_qp

$$x_{\rm qp} = x_{\rm qp}^{\rm res} + \sqrt{\frac{2\pi k_B T}{\Delta}} \exp\left(-\frac{\Delta}{k_B T}\right)$$

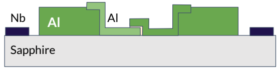
Temperature Characterization



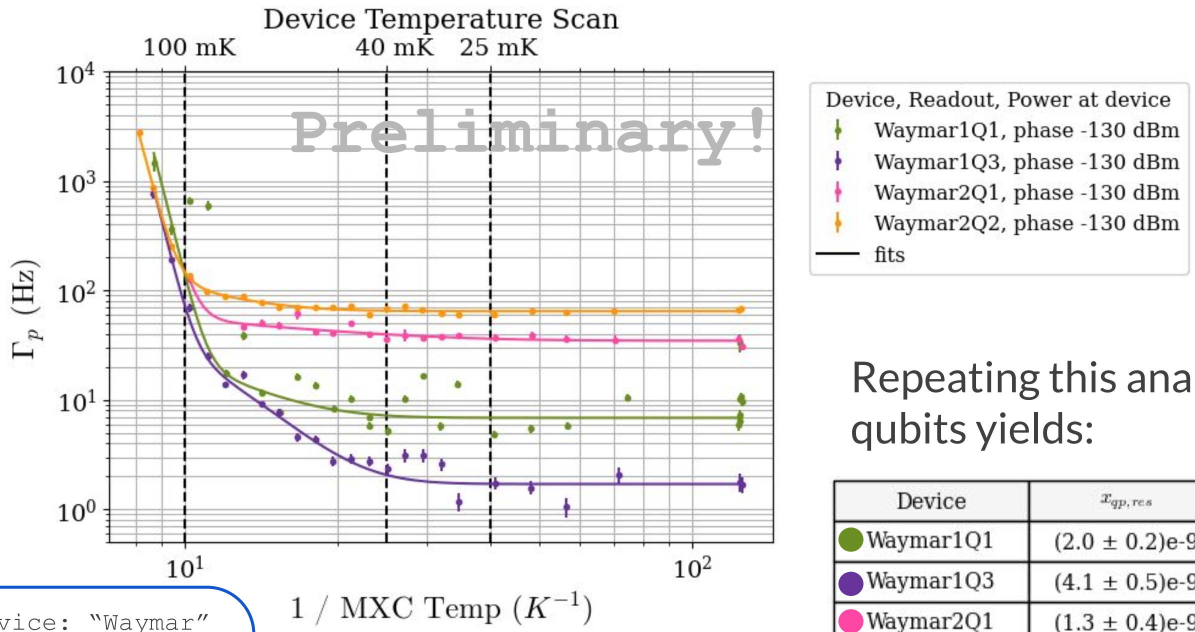
Fit results give us x_{qp}, T_c, $\delta\Delta$ ....

Device	x_{qp}^{ne} ($\times 10^{-8}$)	$\delta\Delta$ (GHz)	T_c (K)	Γ_{other} (Hz)
H1Q1	1.84 ± 0.05	2.49 ± 0.05	1.126 ± 0.009	45.4 ± 0.8
H1Q2	4.6 ± 0.2	2.2 ± 0.1	1.082 ± 0.005	799 ± 8
H2Q1	1.65 ± 0.10	2.2 ± 0.1	1.102 ± 0.004	163 ± 2
H2Q2	2.11 ± 0.04	1.57 ± 0.03	1.146 ± 0.003	116 ± 2
H2Q3	1.89 ± 0.04	2.29 ± 0.04	1.107 ± 0.002	56.9 ± 1.0

Device: "H2"
Absorber: Al
Junction: Al
$0<\delta\Delta<hf_q$



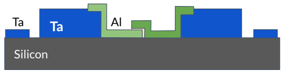
Temperature Characterization



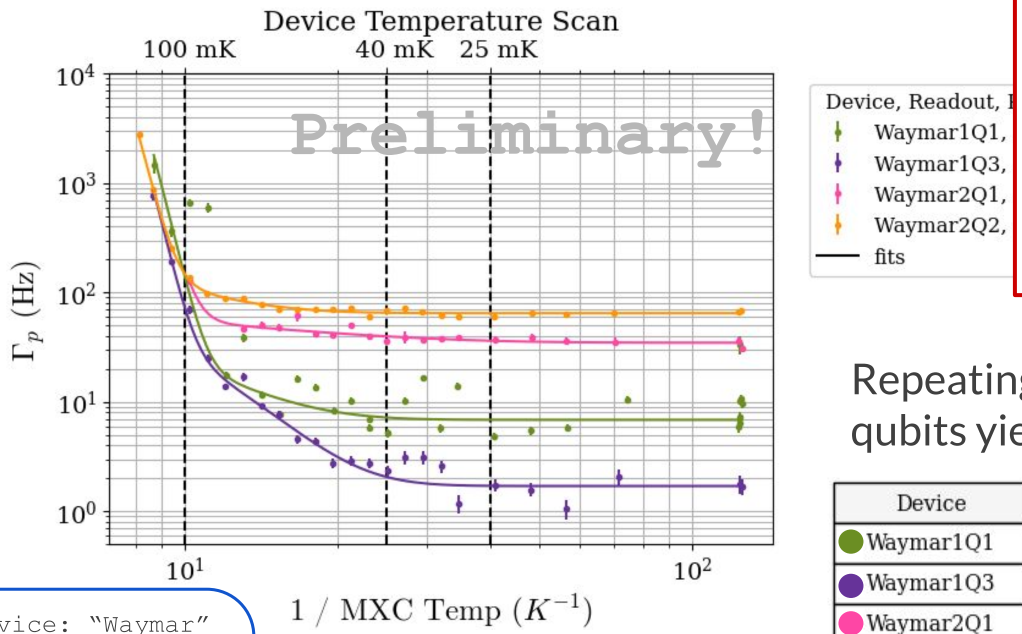
Repeating this analysis for the newer Tantalum qubits yields:

Device	$x_{qp,res}$	$\delta\Delta$ [GHz]	T_c [K]	Γ_{other} [Hz]
Waymar1Q1	(2.0 ± 0.2)e-9	5.1 ± 0.6	0.994 ± 0.007	6.9 ± 0.1
Waymar1Q3	(4.1 ± 0.5)e-9	5.5 ± 0.4	1.030 ± 0.004	1.71 ± 0.09
Waymar2Q1	(1.3 ± 0.4)e-9	1.6 ± 0.6	1.04 ± 0.01	35 ± 1
Waymar2Q2	(5 ± 3)e-9	6.2 ± 0.1	1.06 ± 0.03	64.7 ± 0.6

Device: "Waymar"
Absorber: Ta
Junction: Al
$0<\delta\Delta<hf_q$



Temperature Characterization



Why lower residual x_qp?

- Ta T_c is higher -> base temp is a lower relatively
- Ta diffusion length < aluminum
- Ta ground plane more lossy than Nb
- Si vs Sapphire phonon propagation
- Something else?

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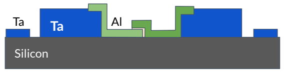


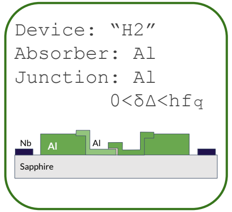
SQUATs Pulse Tube Sensitivity

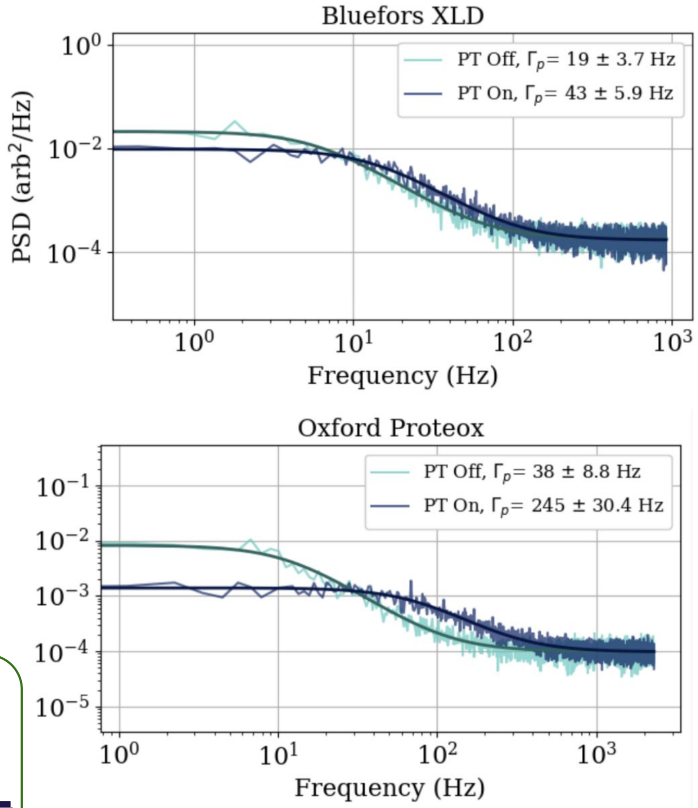
Prototypes demonstrate an interesting sensitivity to pulse tube vibrations:

- Vibrational noise appears in our data as a steady-state increase in tunneling rate

Given our existing model, one could imagine PT noise manifesting as:

1. Increased x_qp
2. Increased QP bath temp T_{eff}
3. Increased Γ_{other}

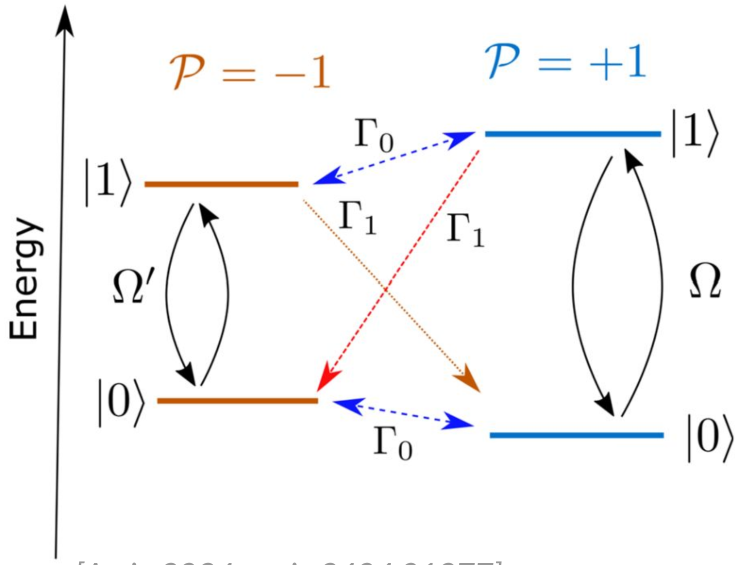


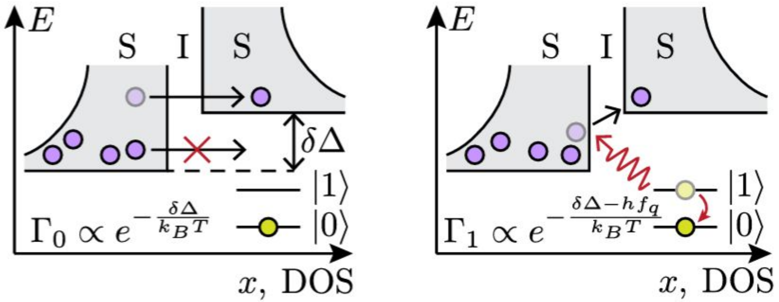


De-excitation Assisted Tunneling

Let's remember that the quasiparticle tunneling rate can be enhanced with qubit de-excitation assisted processes:

$$\Gamma_p(1/T) = (1 - P_1)\Gamma_0 + P_1\Gamma_1 + \Gamma_{\text{other}}$$





[Amin 2024, arxiv:2404.01277]

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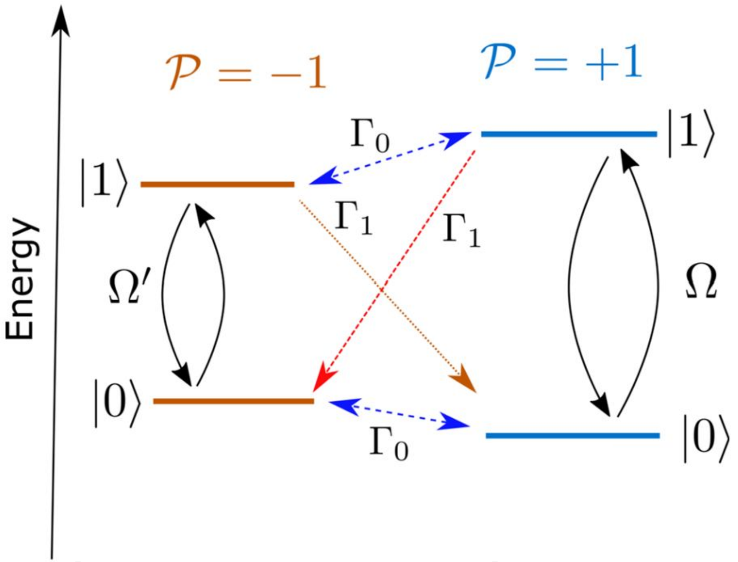
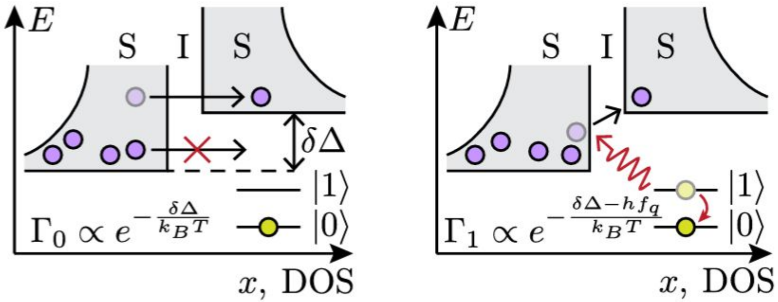
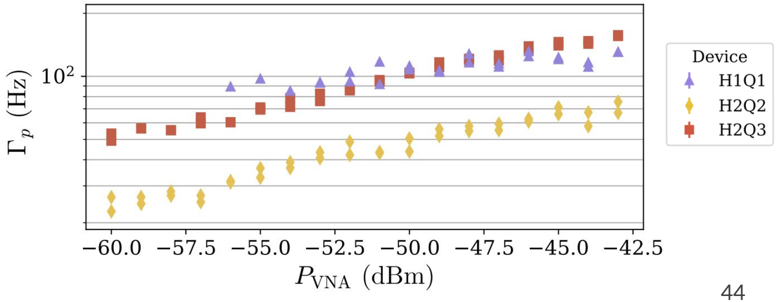


[Amin 2024, arxiv:2404.01277]



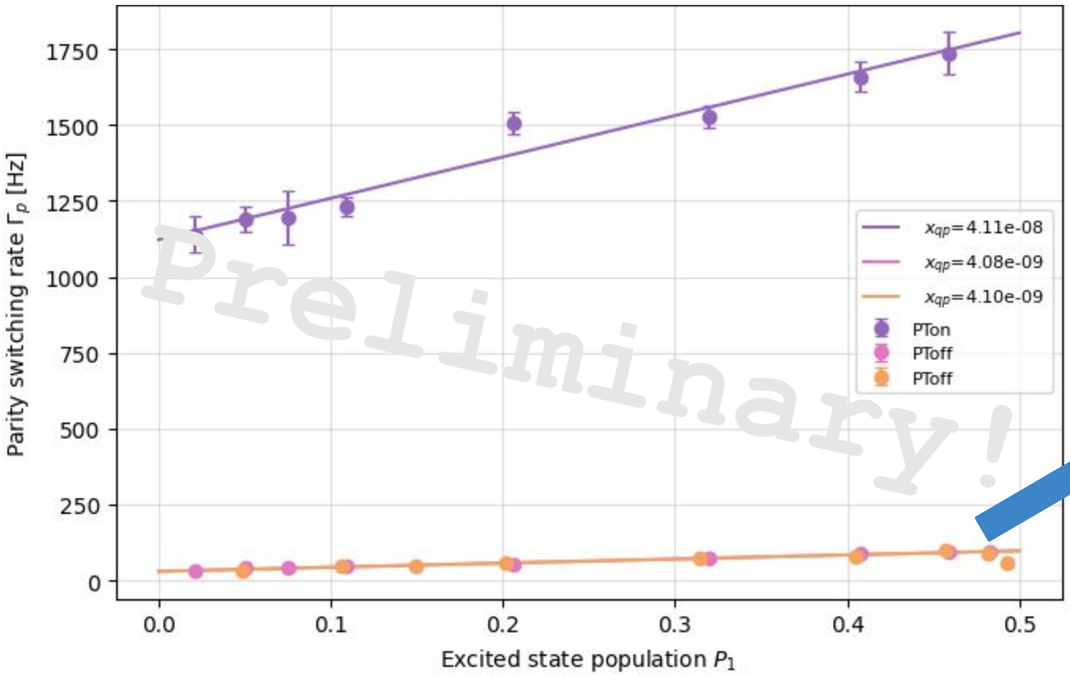


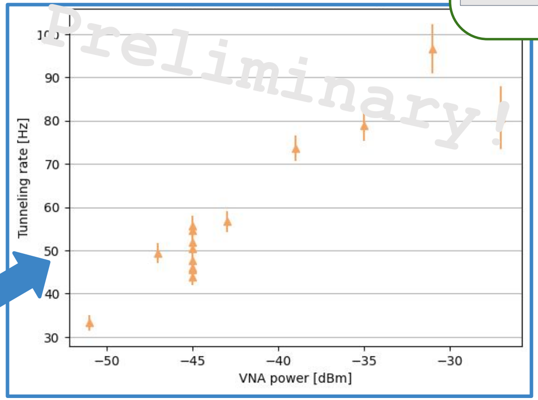
De-excitation Assisted Tunneling

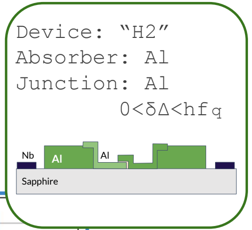
Tunneling rate vs readout power trend provides a handle to understand the pulse tube effect!

- Slope is given by x_qp and □Δ
- Y-intercept is given by Γ_{other} and T_{eff}

If we assume □Δ to be unchanged by PT noise, we can extract a change in ambient QP density:







(PT off datasets show the linear trend when axes are properly scaled...)

Okay… how can we distinguish between “Γ_{other}” and “T_{eff}”?

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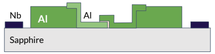
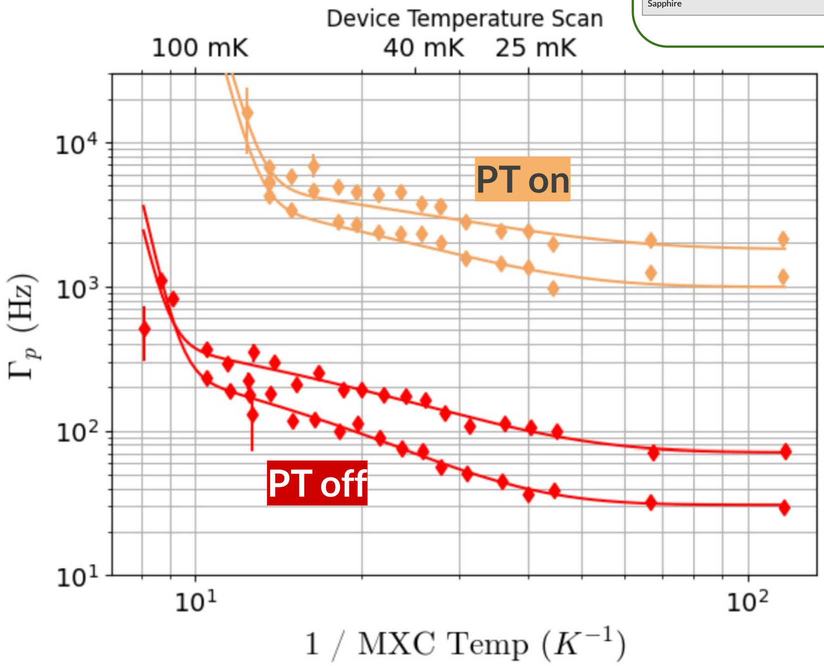
Device: "H2"
Absorber: Al
Junction: Al
0<δΔ<hfq



Temperature scan!



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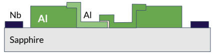
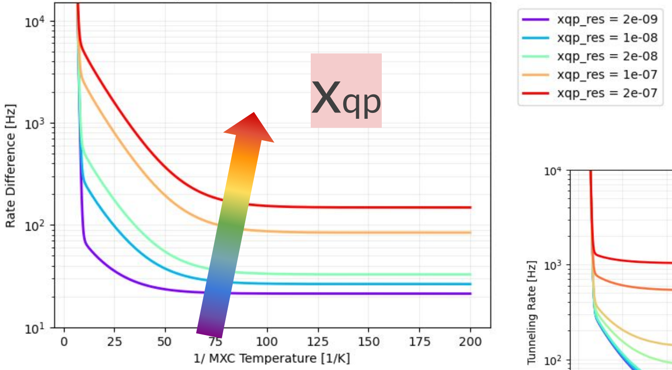
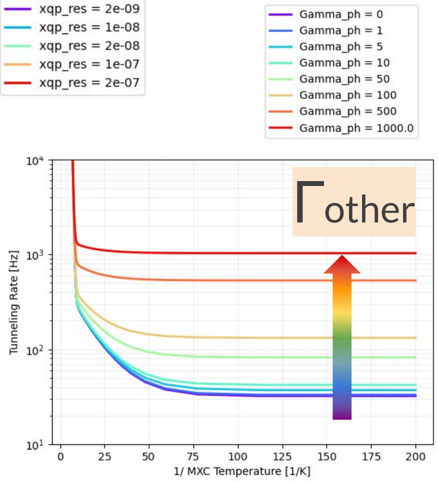
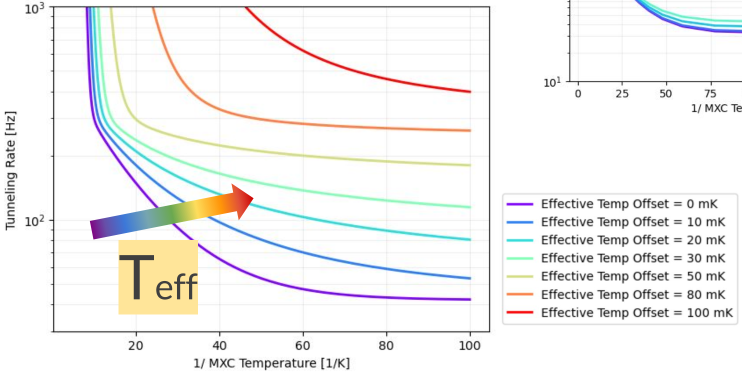


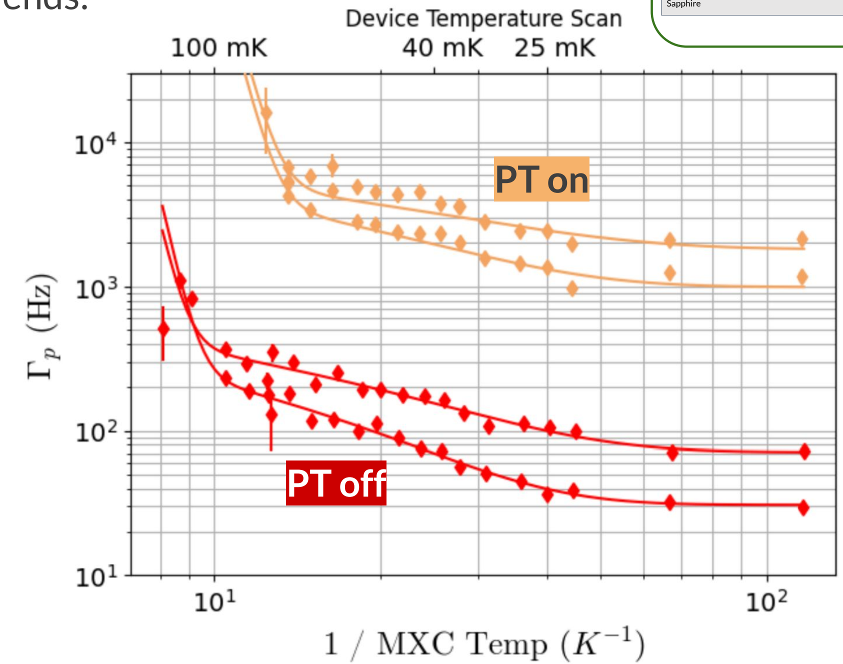
Not showing fit results yet!
but if you want to orient yourself, here are some expected trends:

Rate difference vs Temperature for Various PT Effective Temps P1=0.02







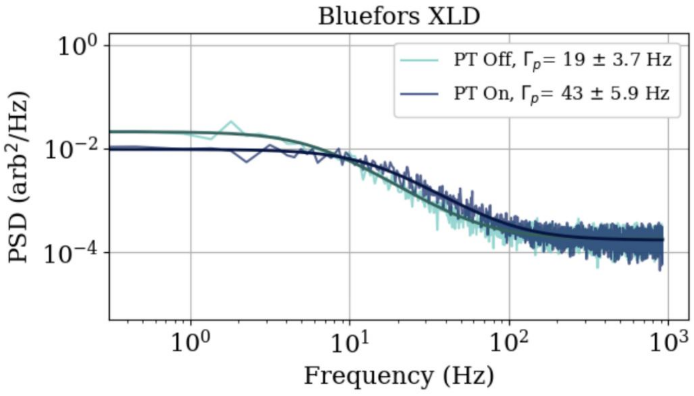


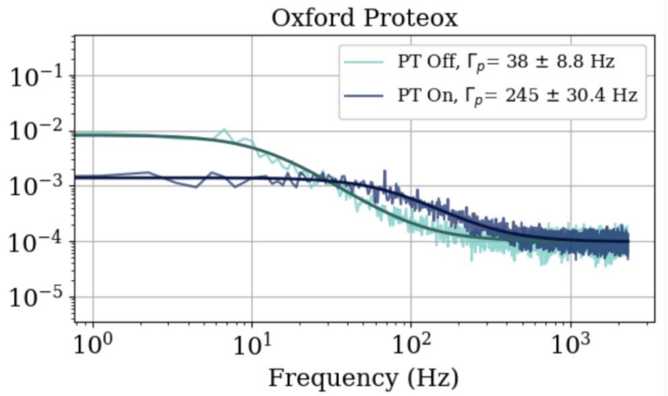
SQUATs Pulse Tube Sensitivity

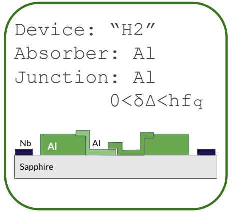
So circling back to these plots….

I think this analysis points towards $\Delta\Gamma_p$ not being the best figure of merit to compare PT on/off between fridges & devices. Instead, maybe we should look towards Δx_{qp} and/or effective QP bath temperature

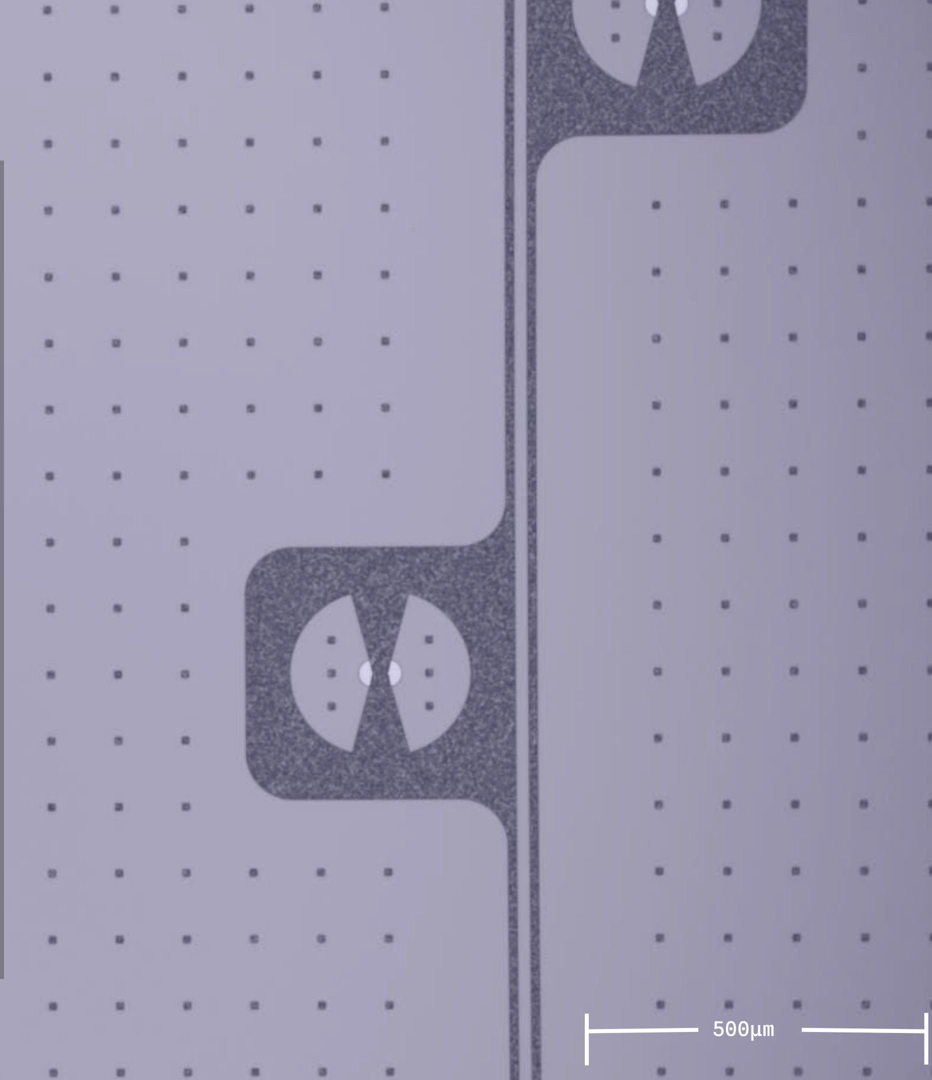
Furthermore, (at least in this dataset/mounting setup) we should consider that the effective temperature of the QP bath may have some offset from the fridge temperature





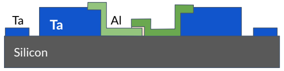


Outline

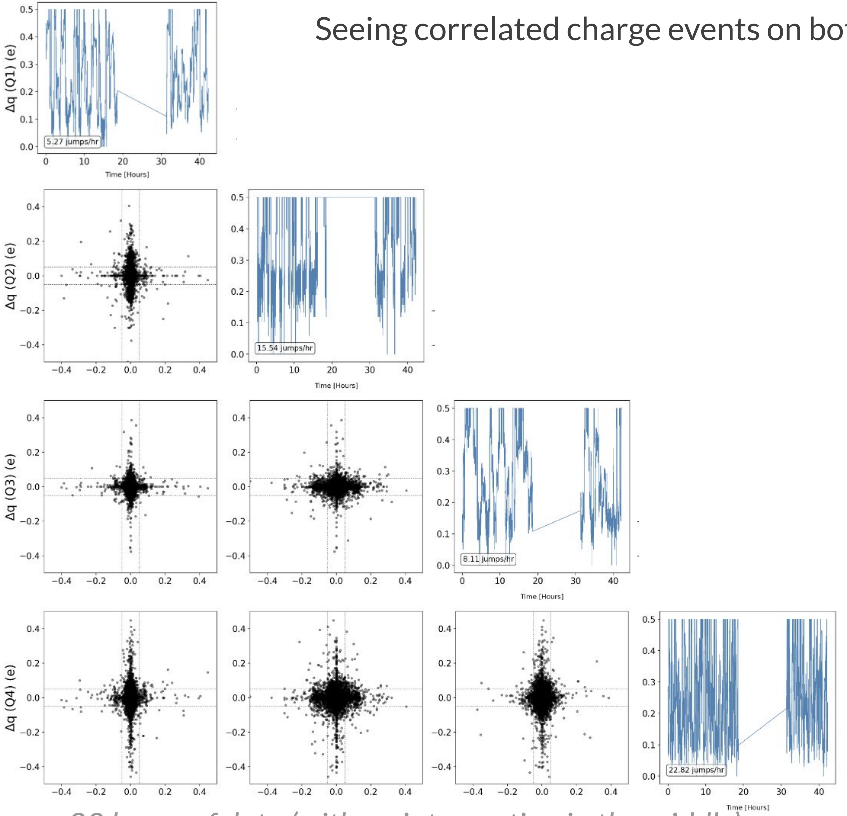


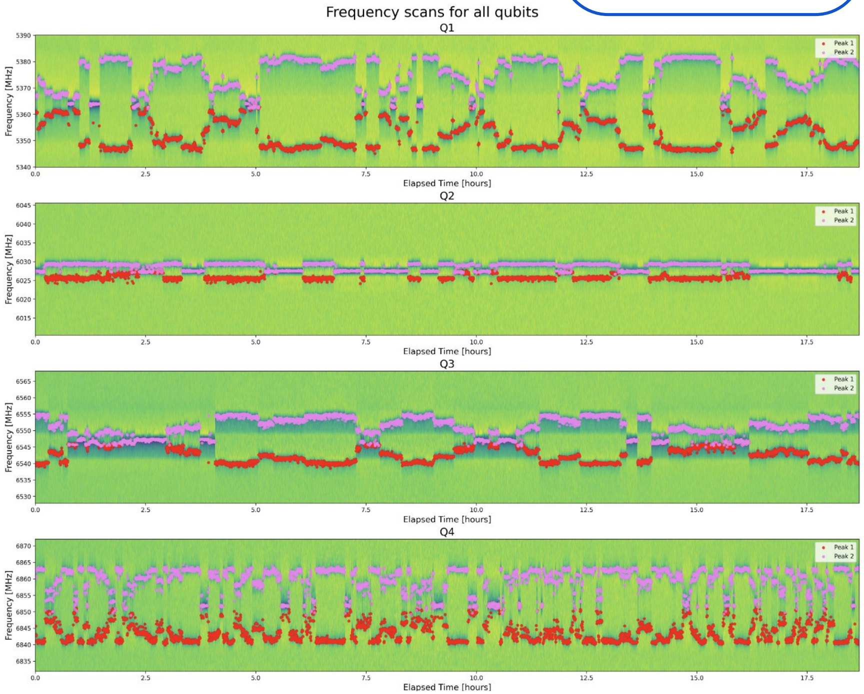
Charge Event Studies

Device: “Waymar”
Absorber: Ta
Junction: Al
$0<\delta\Delta<hf_q$



Seeing correlated charge events on both Si and Sapphire substrate devices



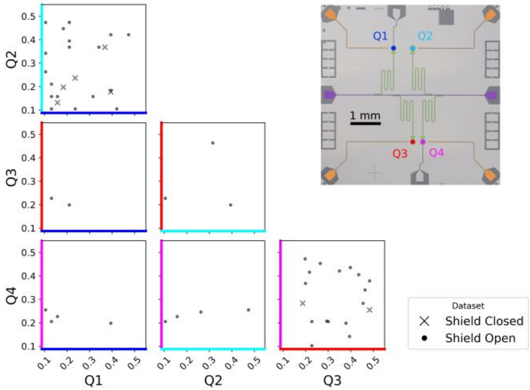


~20 hours of data (with an interruption in the middle)

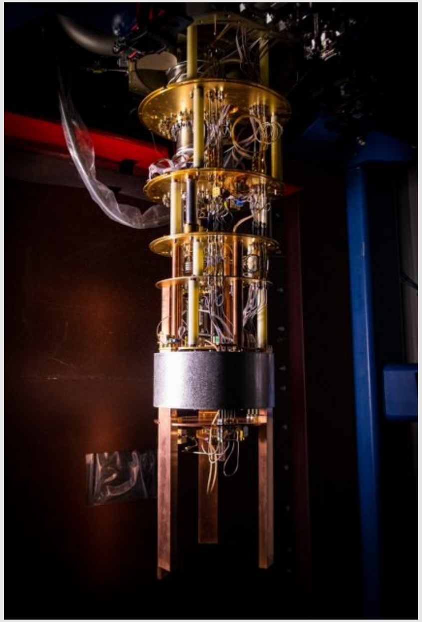
Underground SQUAT Measurements

First Measurement of Correlated Charge Noise in Superconducting Qubits at an Underground Facility

G. Bratrud[2,1], S. Lewis[3,1], K. Anyang[4,1], A. Colón Cesaní[2], T. Dyson[5,6,7], H. Magoon[1,5,6,7,8], D. Sabhari[2], G. Spahn[9,1], G. Wagner[1], R. Gualtieri[2], N.A. Kurinsky[1,6,7], R. Linehan[1], R. McDermott[9], S. Sussman[1], D.J. Temples[1], S. Uemura[1], C. Bathurst[10], G. Cancelo[1], R. Chen[2], A. Chou[1], I. Hernandez[4,1], M. Hollister[1], L. Hsu[1], C. James[1], K. Kennard[2], R. Khatiwada[4,1], P. Lukens[1], V. Novati[*2], N. Raha[2], S. Ray[2], R. Ren[†2], A. Rodriguez[2], B. Schmidt[‡2], K. Stifter[1,6,7], J. Yu[4], D. Baxter[1,2], E. Figueroa-Feliciano[2,1], and D. Bowring [§1]



- Underground facilities allow for lower background rates, as observed in OCS transmons (**arxiv:2405.04642**)
- SQUAT payload installed and measurements coming soon!
- With the help of radioactive sources, we plan to better characterize the SQUAT correlated charge and parity response



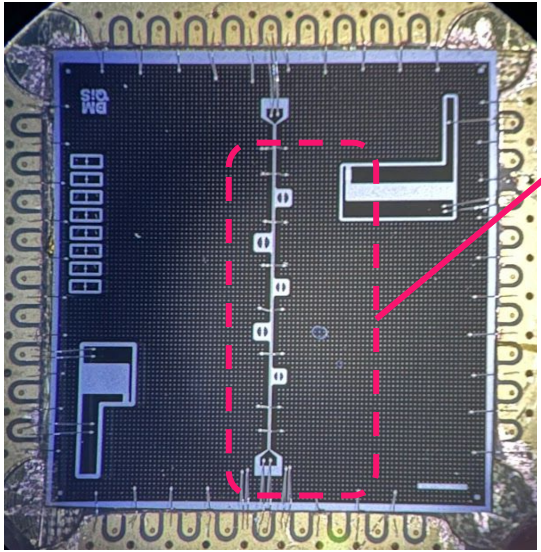
NEXUS & QUIET Underground Cryogenic Facilities at Fermilab

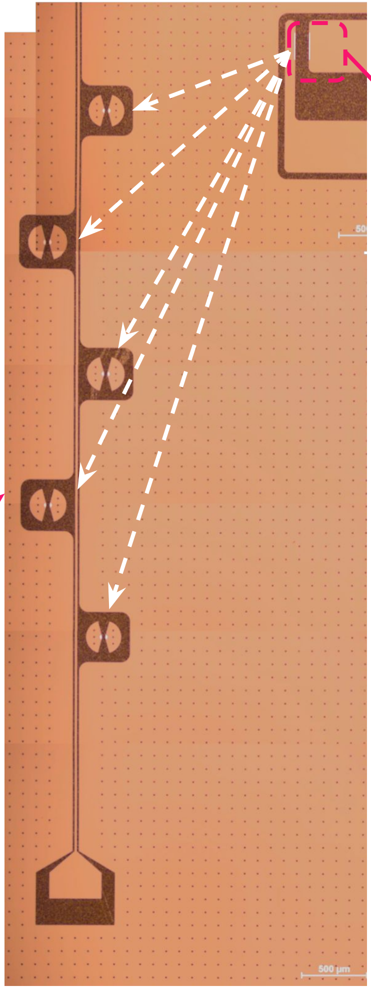
Enectalí Figueroa-Feliciano *(Northwestern PI))*
Daniel Baxter *(Northwestern/FNAL PI)*
Grace Bratrud *(Northwestern grad student)*

Phonon Injectors

Future studies on Si:

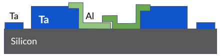
- Phonon-collection studies…
- using phonon injectors on the device surface
- Validate/compare pulse shapes with optical photon (backside illumination) study





Josephson junctions:
A DC current produces quasiparticles that release phonon energy into the substrate upon recombination

Device: "Waymar"
Absorber: Ta
Junction: Al
$0<\delta\Delta<hf_q$

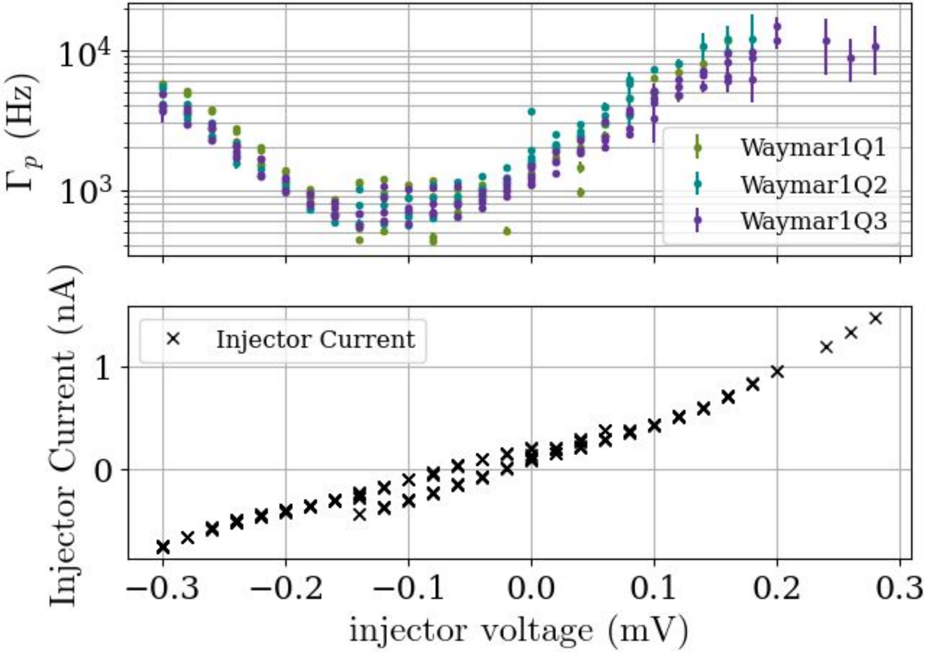


Phonon Injectors

Future studies on Si:

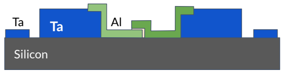
- Phonon-collection studies…
- using <u>phonon injectors</u> on the device surface
- Validate/compare pulse shapes with optical photon (backside illumination) study

Initial phonon injector measurements show a change in Γ_p with change in DC current through phonon injector



Note that minimum tunneling rate misalignment with 0V bias input (along with increased noise at this point) indicate noisy DC biasing conditions

Device: "Waymar"
Absorber: Ta
Junction: Al
$0 < \delta\Delta < hf_q$



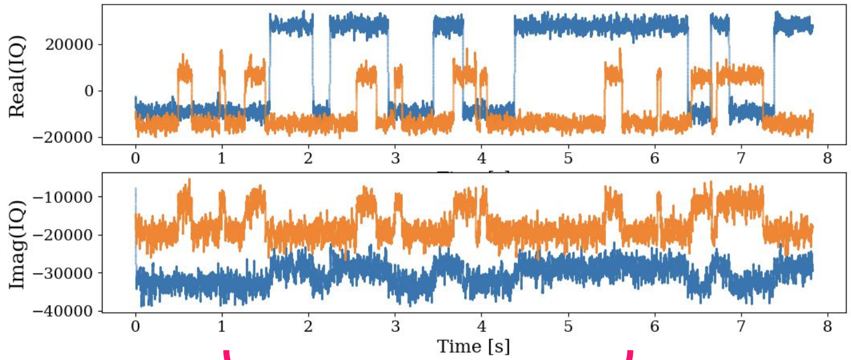
LED characterization with cryogenic MEMS mirrors

mirrorcle
TECHNOLOGIES, INC.

Correlated Parity Streaming

Future studies on Si:

- Phonon events should also be correlated between SQUATs
- Use multi-tone streaming to study such events and establish a trigger for DM-event searches



2x SQUAT readout (w/o phonon events)

Readout with RFSoC (ZCU 208) SmuRF

Alex Droster
DMQIS postdoc
KIPAC fellow

Shawn Henderson
Staff Scientist,
SMURF Extraordinaire

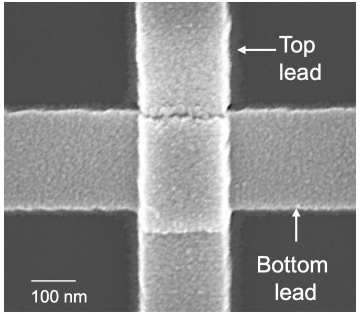
Jenny Smith
Staff Engineer,
Firmware Hero

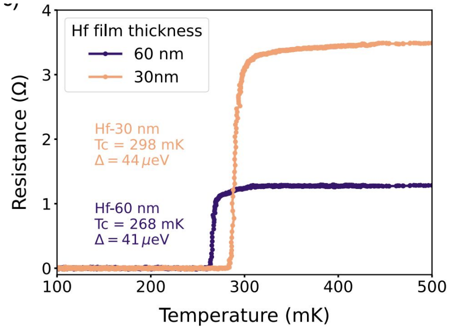
Low-Tc Junction Development

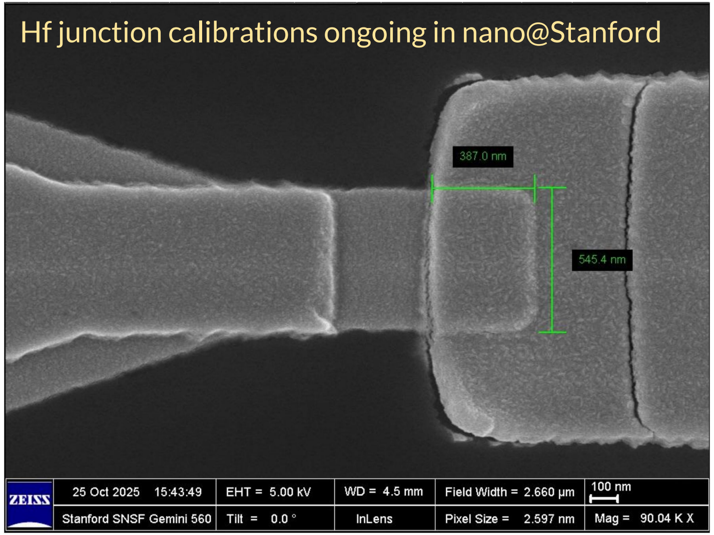
- Low Tc junctions allow gap-engineered QP trapping, improving device sensitivity
- Hf (Δ≈0.017 meV) Junctions shown viable

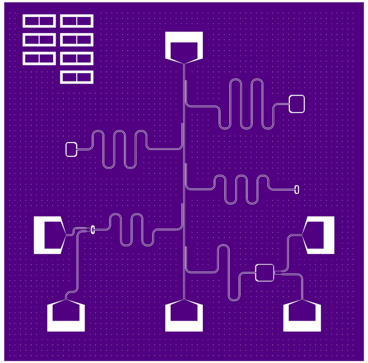
Low-Gap Hf–HfO_x–Hf Josephson Junctions for meV-Scale Particle Detection

Y. Balaji[1], M. Surendran[1], X. Li[2], A. Kemelbay[1], A. Gashi[1], C. Salemi[2,3], A. Suzuki[2], S. Aloni[1], A. Tynes Hammack[1], and A. Schwartzberg[1]
[1]*Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley, CA-94720, USA*
[2]*Physics Division, Lawrence Berkeley National Laboratory, Berkeley, CA-94720, USA and*
[3]*Department of Physics, University of California Berkeley, Berkeley, CA-94720, USA*
(Dated: November 11, 2025)









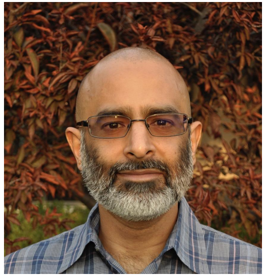
Transmon qubit designed to benchmark coherence & critical current density

Riley Carpenter
DMQIS/Schuster lab grad student

SoniQ Collaboration *(Sensing of Neutrinos In Qubits)*

WashU Caltech DMQiS SLAC THE UNIVERSITY of WISCONSIN MADISON THE UNIVERSITY OF CALIFORNIA BERKELEY 1868 JPL Jet Propulsion Laboratory California Institute of Technology

Karthik Ramanathan



Sunil Golwala

Noah Kurinsky

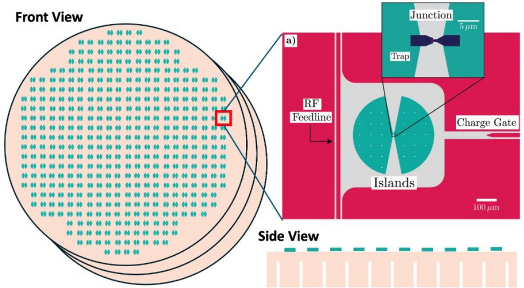
Britton Plourde

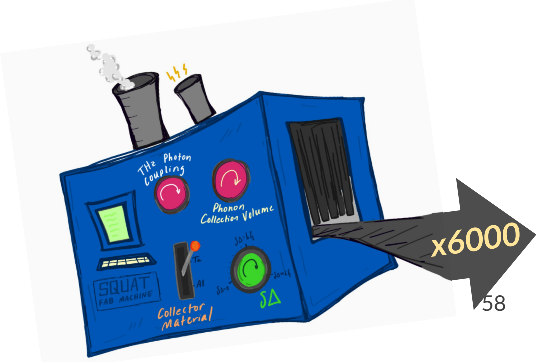
Chiara Salemi

Pierre Echternach

Final Deliverable

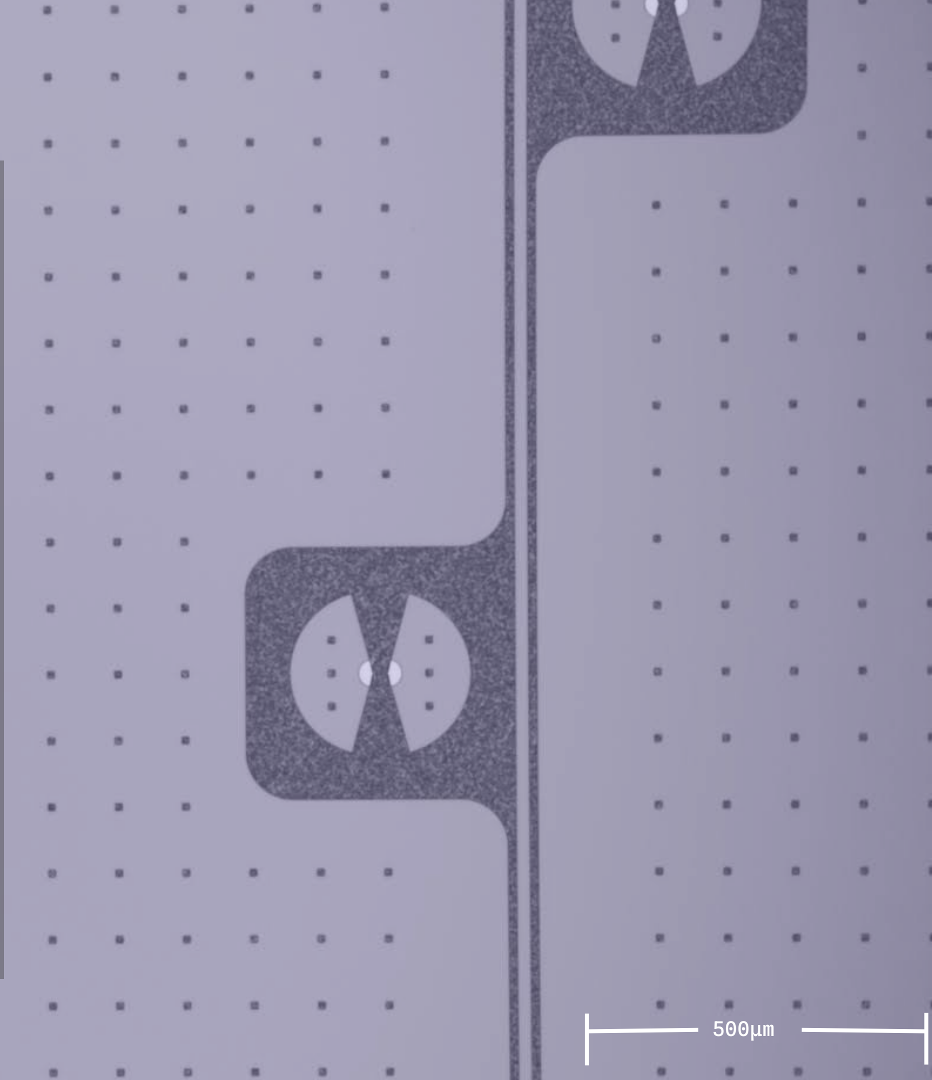
- 14x Ge wafers
- 4” by 2 mm thick
- Voxelized into 1x1 mm smaller segments
- ~6400 qubits per wafer



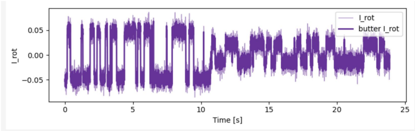


Outline

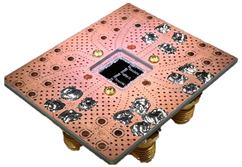
1. SQUATs Working Principle
2. SQUAT Characterization
3. Tunneling Rate Studies
4. Ongoing Work
5. Conclusion & Thank you!



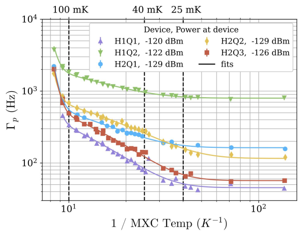
Conclusion



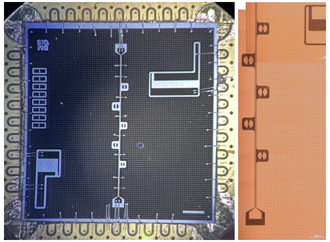
The SQUAT architecture enables straightforward measurement of QP tunneling, enabling measurement of photon and/or phonon events



First designs are already fabricated and characterized



With existing analysis frameworks, parity tunneling dynamics enable characterization of QP environment



Next-gen SQUATs on Si for calibration and improved sensitivity currently being studied at SLAC

- Beginning pulse characterization of phonon-based events
- Position-dependent studies

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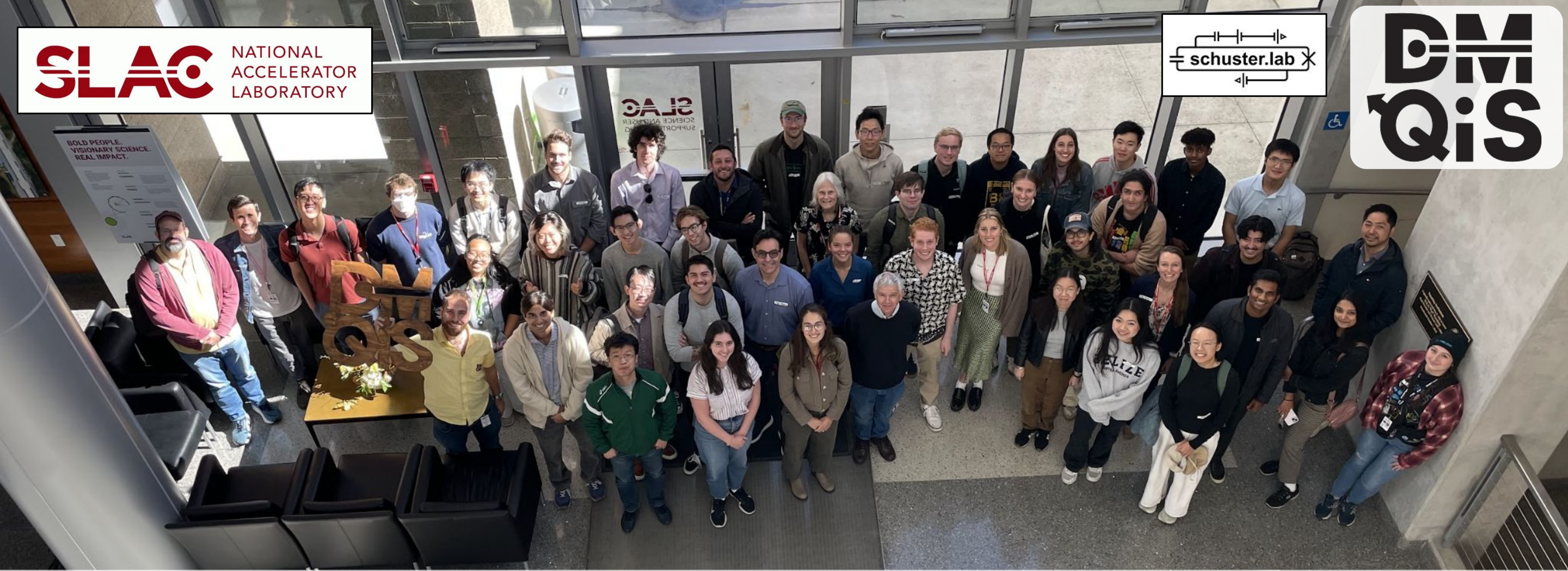
schuster.lab

DMQiS



Faculty/Staff

Noah Kurinsky (SLAC)

Shannon Harvey (SLAC)

David Schuster (Stanford)

Shawn Henderson (SLAC)

Jenny Smith (SLAC Engineer)

Sidney Stevens (SLAC Engineer)

Betty Young (SCU)

Postdocs

Taylor Aralis (SLAC)

Alex Droster (SLAC)

Aditi Pradeep (SLAC)

Students

Hannah Magoon (SLAC/Stanford)

Riley Carpenter (SLAC/Stanford)

Zach Gillis (SLAC/Stanford)

Taj Dyson (SLAC/Stanford)

Aviv Simchony (SLAC/Stanford)

Holden Kowitt (undergrad)

Emily Scott (undergrad)

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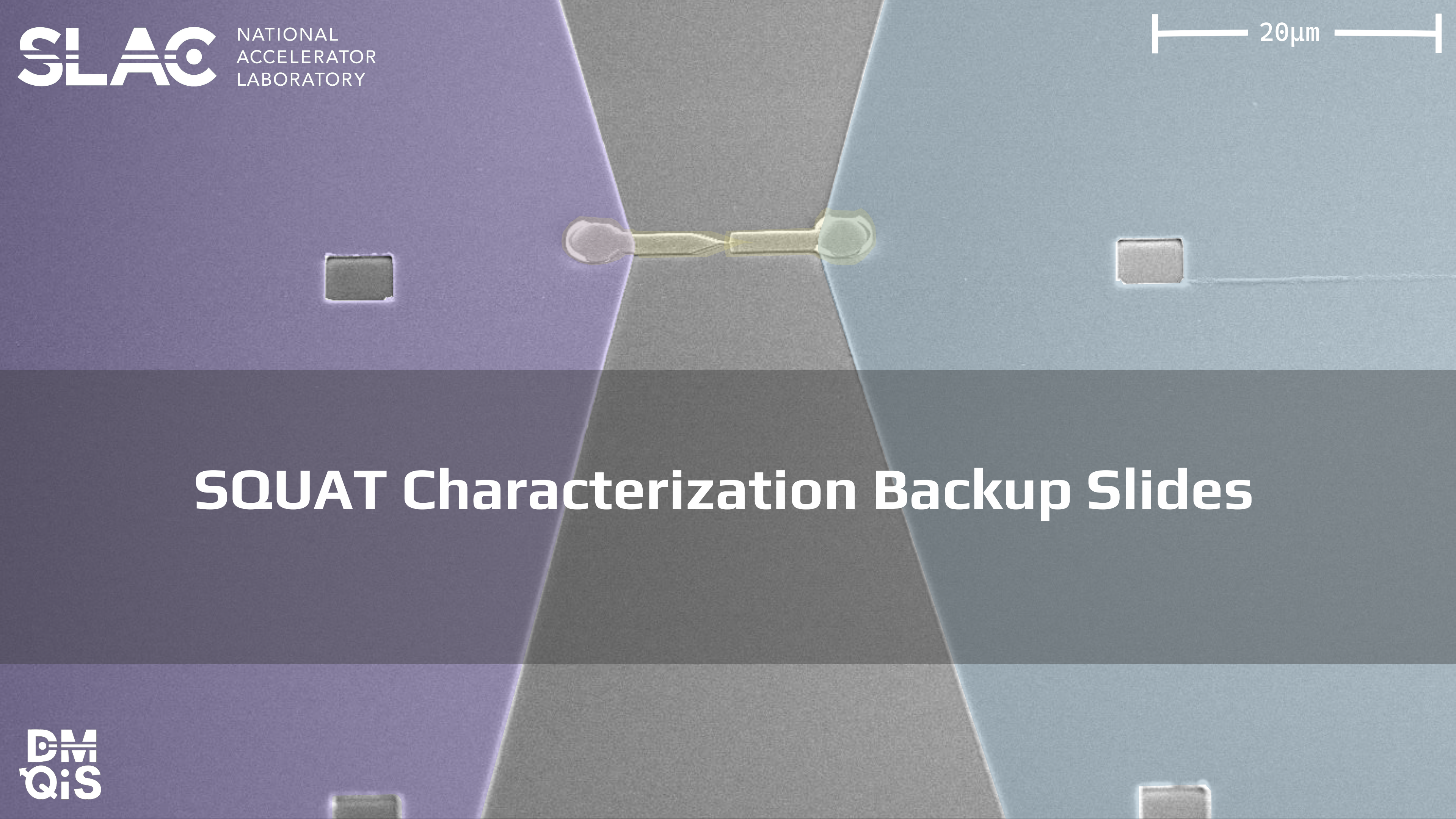
SQUAT Characterization Backup Slides



DMQiS

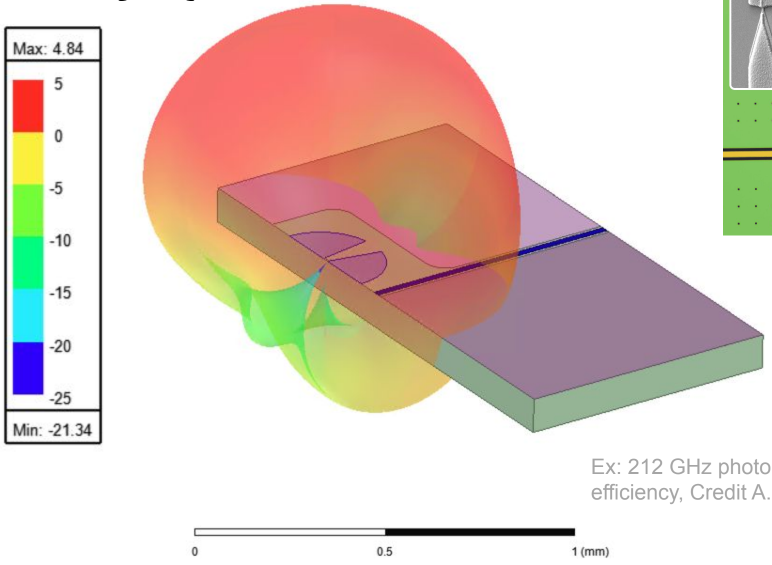
Next-Gen SQUATs

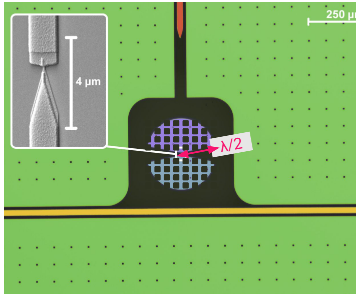
Alex Droster
DMQIS postdoc
(KIPAC fellow)

Future studies on Si:

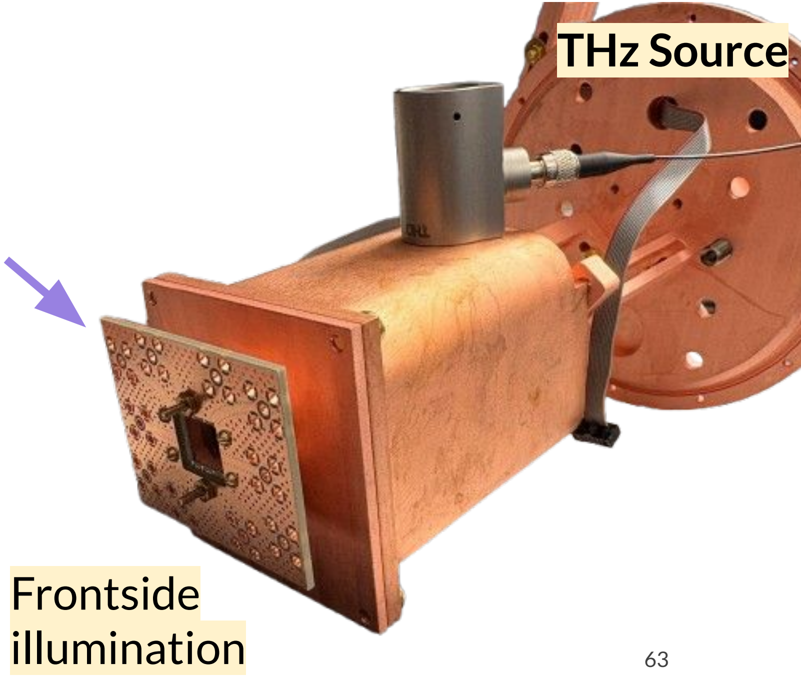
- Use MEMS with front-side illumination to study SQUAT antenna coupling
- Validate simulations and improve designs

Gain [dBi]



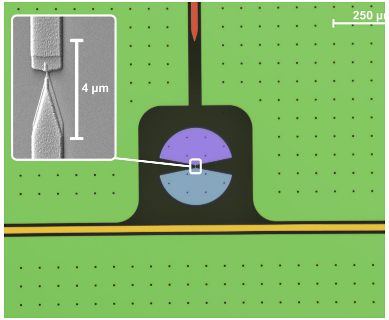


Ex: 212 GHz photon coupling efficiency, Credit A. Droster



SQUAT Readout Dynamics

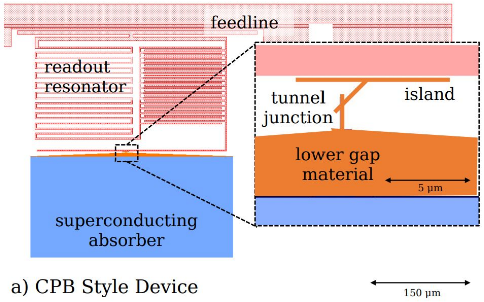
SQUATs are directly coupled to the feedline… why??



SQUATs

Advantages of direct coupling

- Enables single-tone readout of qubit parity state (no Ramsey sequences needed!)
- Simplified design
- Less dead metal per detector pixel
- Overcoupling to feedline reduces impacts of TLSs (useful for novel low-Tc junctions)



a) CPB Style Device

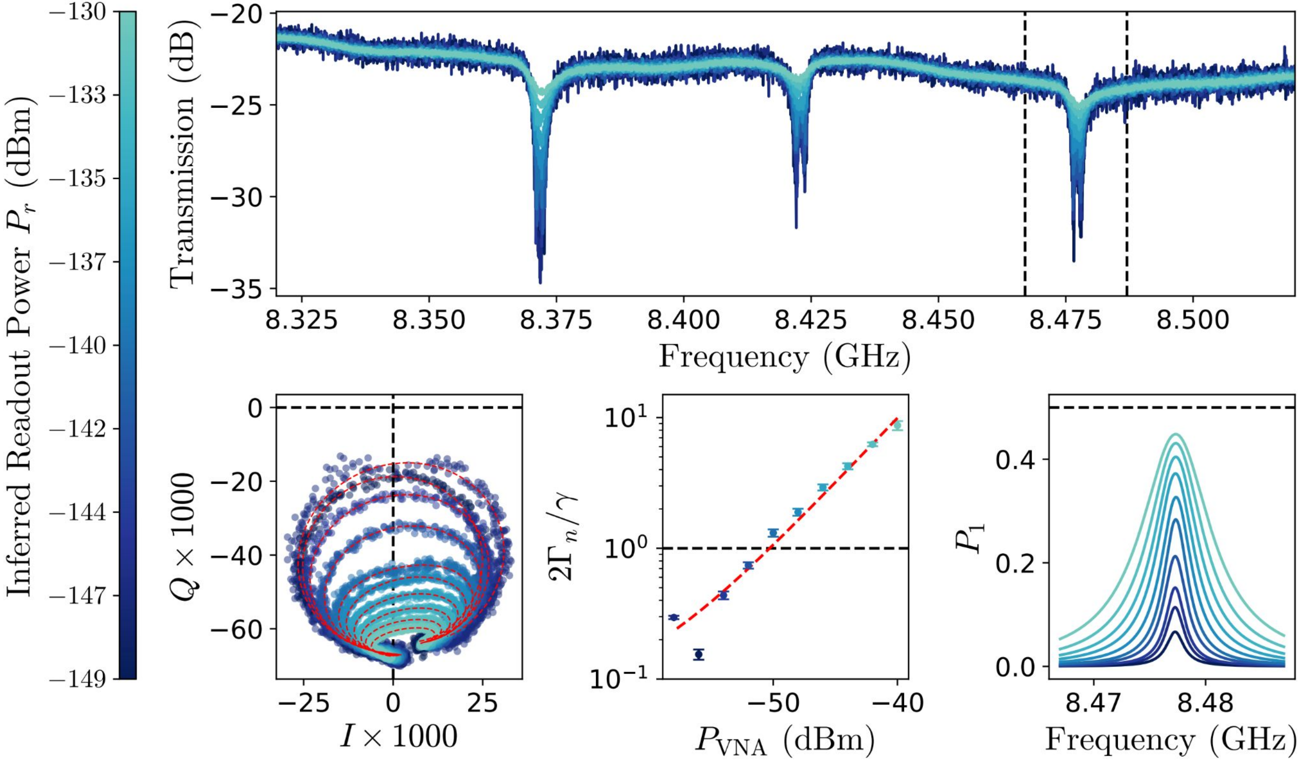
arXiv: 2405.17192

QPDs + OCS Transmons:

Advantages of dispersive coupling:

- Single-tone CW readout if your coupling is clever
- Easier to tightly pack devices with predictable frequencies when multiplexing
- Can enable higher readout powers

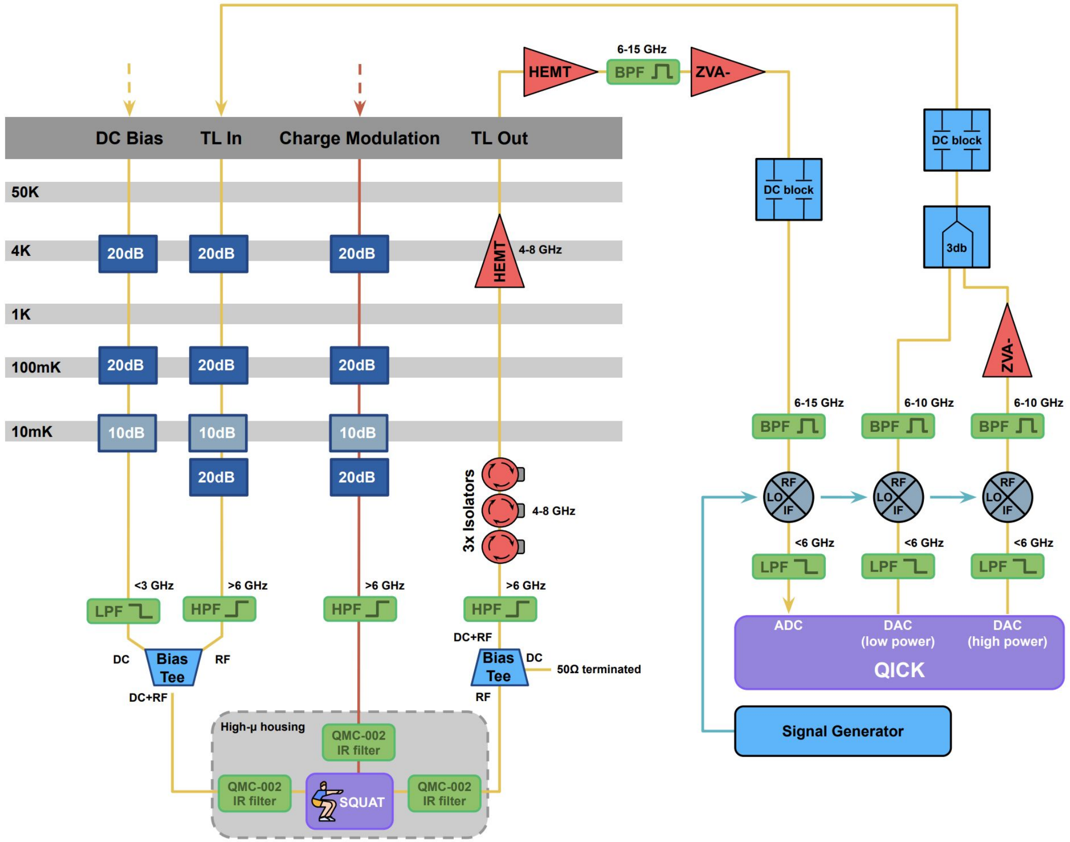
Brandon Sandoval
Caltech Grad Student, Visiting DMQIS via SCGSR



Inferred Readout Power P_r (dBm)
−130
−133
−135
−137
−140
−142
−144
−147
−149
Transmission (dB)
−20
−25
−30
−35
8.325
8.350
8.375
8.400
8.425
8.450
8.475
8.500
Frequency (GHz)
$Q \times 1000$
0
−20
−40
−60
−25
0
25
$I \times 1000$
$2\Gamma_n/\gamma$
10^1
10^0
10^{-1}
−50
−40
P_{VNA} (dBm)
P_1
0.4
0.2
0.0
8.47
8.48
Frequency (GHz)

Device	f_0 (GHz)	$2\chi_0$ (MHz)	E_J/h (GHz)	E_C/h (MHz)	γ (MHz) $\rightarrow T_2$ (ns)	Γ_r (MHz) $\rightarrow T_1$ (ns)	Γ_c (MHz)	T_2^* (ns)	T_1 (ns)
H1Q1	7.35	9.46	12.8	626	3.670 ± 0.003 $\rightarrow$ *266.5 ± 0.2*	6.35 ± 0.06 $\rightarrow$ *156 ± 1*	6.301 ± 0.004	291 ± 18	210 ± 8
H1Q2	8.18	3.10	15.7	622	5.564 ± 0.002 $\rightarrow$ *179.54 ± 0.08*	11.106 ± 0.005 $\rightarrow$ *90.00 ± 0.04*	11.140 ± 0.004	143 ± 5	98 ± 3
H2Q1	8.37	1.92	16.6	615	10.01 ± 0.09 $\rightarrow$ *98.8 ± 0.9*	19.3 ± 0.1 $\rightarrow$ *51 ± 3*	18.8 ± 0.1	116 ± 2	81 ± 2
H2Q2	8.42	2.11	16.7	618	4.80 ± 0.03 $\rightarrow$ *207 ± 1*	9.60 ± 0.06 $\rightarrow$ *103.7 ± 0.7*	9.61 ± 0.06	106 ± 5	103 ± 9
H2Q3	8.47	1.57	17.2	606	5.6 ± 0.1 $\rightarrow$ *174 ± 4*	10.7 ± 0.7 $\rightarrow$ *93 ± 6*	10.4 ± 0.2	85 ± 3	104 ± 4

SQUAT Device	l_{gap} (μm)	l_{fin} (μm)	f_0 (GHz)	χ (MHz)	E_J/h (GHz)	L_J (nH)	E_C/h (MHz)	C_Σ (fF)	Q_c	T_1 (ns)
A	16	110	9.31	13.27	16.3	10	780	35.0	1200	130
B	13	111.5	9.11	9.77	16.3	10	745	36.7	1300	140
C	10	113	8.84	6.47	16.3	10	698	39.1	1400	160


DC Bias
TL In
Charge Modulation
TL Out
50K
4K
1K
100mK
10mK
20dB
10dB
HEMT
4-8 GHz
6-15 GHz
BPF
ZVA-
DC block
3db
3x Isolators
<3 GHz
>6 GHz
LPF
HPF
DC
RF
DC+RF
Bias Tee
50Ω terminated
High-μ housing
QMC-002 IR filter
SQUAT
6-10 GHz
RF
LO
IF
<6 GHz
ADC
DAC (low power)
DAC (high power)
QICK
Signal Generator

TLS Sensitivity vs T1 Sim

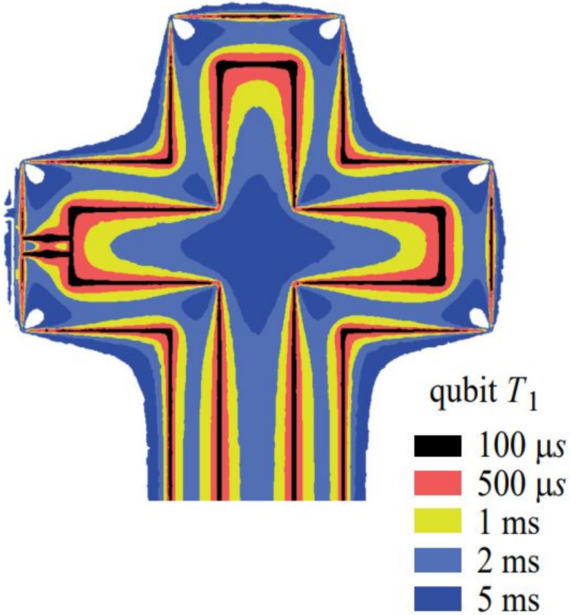


Fig. S4. The region where TLS interact sufficiently strongly to be detected in TLS spectroscopy depends on the T_1 time of the qubit, as indicated by the different colors. The plot was made with an Ansys HFFS simulation of the qubit's AC electric field strength, assuming a TLS coherence time of 100ns, a TLS dipole moment of 1 eÅ, and a detection factor of $\kappa = 0.1$.

arXiv:2511.05365

Mapping the positions of Two-Level-Systems on the surface of a superconducting transmon qubit

Jürgen Lisenfeld,[1,*)] Alexander K. Händel,[1] Etienne Daum,[1] Benedikt Berlitz,[1] Alexander Bilmes,[1,2] and Alexey V. Ustinov[1]
[1)] *Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany*
[2)] *Google Research, Mountain View, CA, USA*

(Dated: 4 March 2026)

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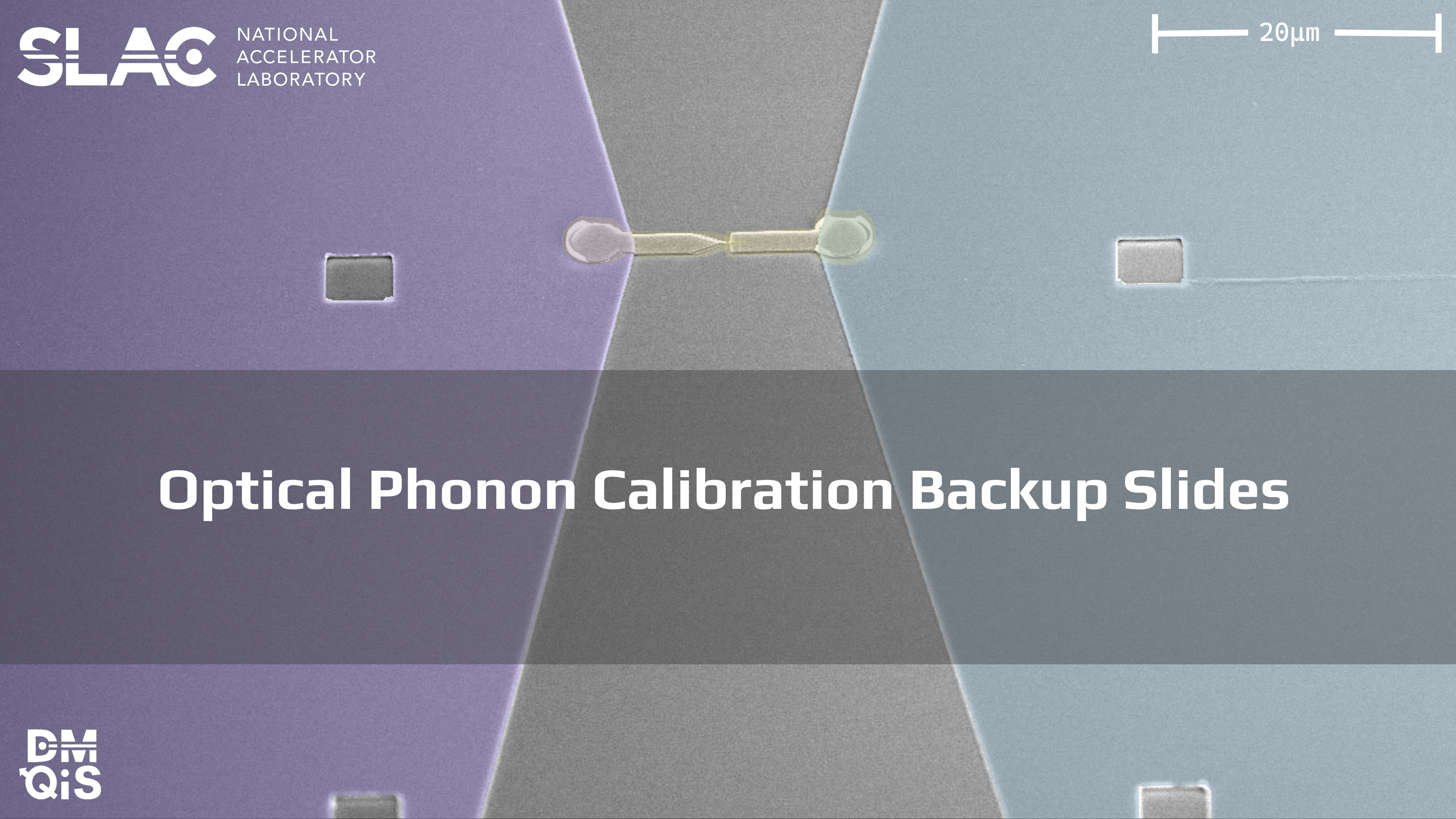
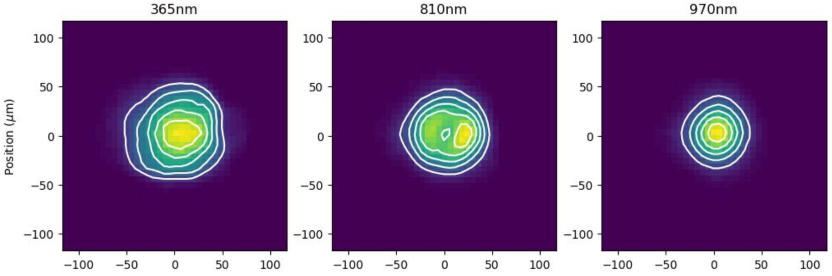


Optical Phonon Calibration Backup Slides

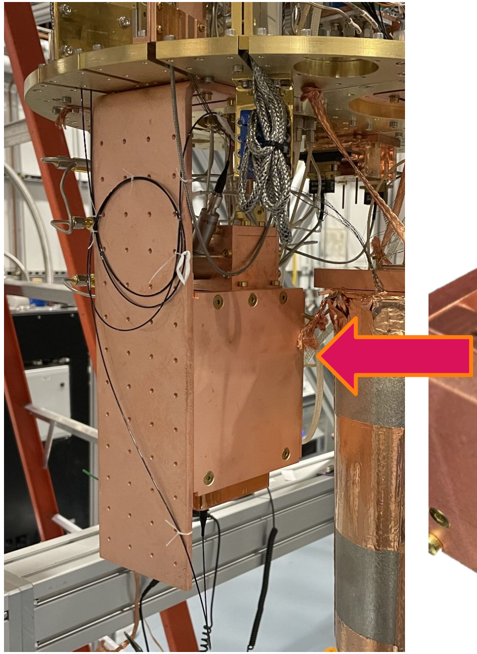
DM QiS

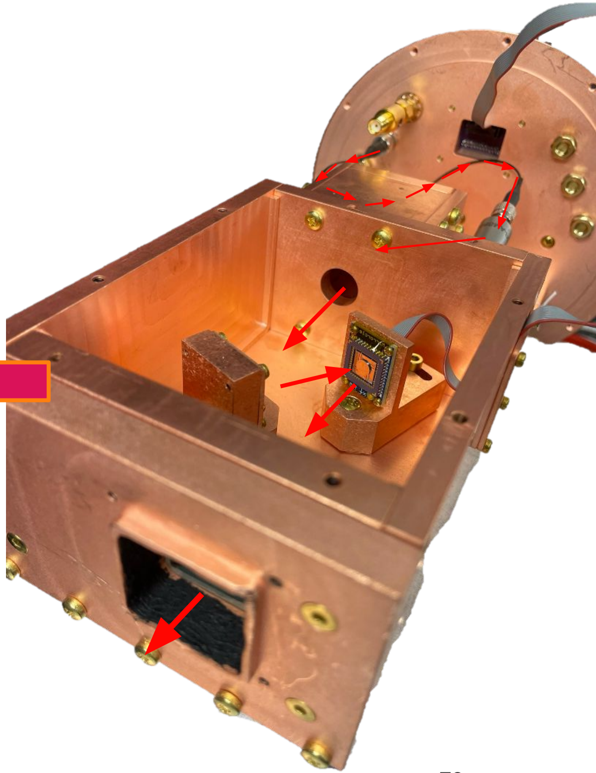
MEMS-based Optical Beam Steering

Characterized warm and cold



Wavelength (nm)	Spot Size [μm] CCD 300K	Spot Size [μm] Fiber 300K	Spot Size [μm] Fiber 10 mK	Pulse Width [μs] 300K	Pulse Width [μs] 10 mK
365	98.6			7.86	4.58
385	95.1			8.36	4.45
530	92.9			7.01	4.39
625	90.9	115.7		7.71	4.29
660	89.8	99.7	96.9	6.67	4.53
740	84.2			7.16	4.41
810	86.2			5.23	4.27
940	-			5.41	-
970	73.5			6.14	-





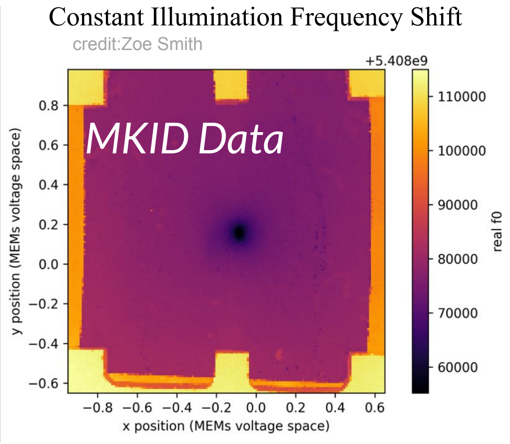
spot size < 100 μm

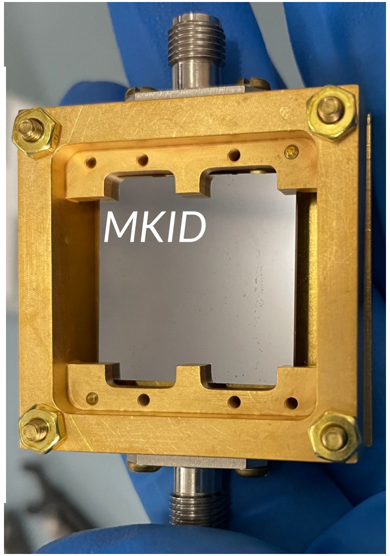
scan speed > 20 m/s

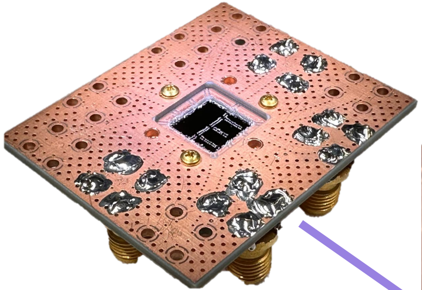
Next-Gen SQUATs

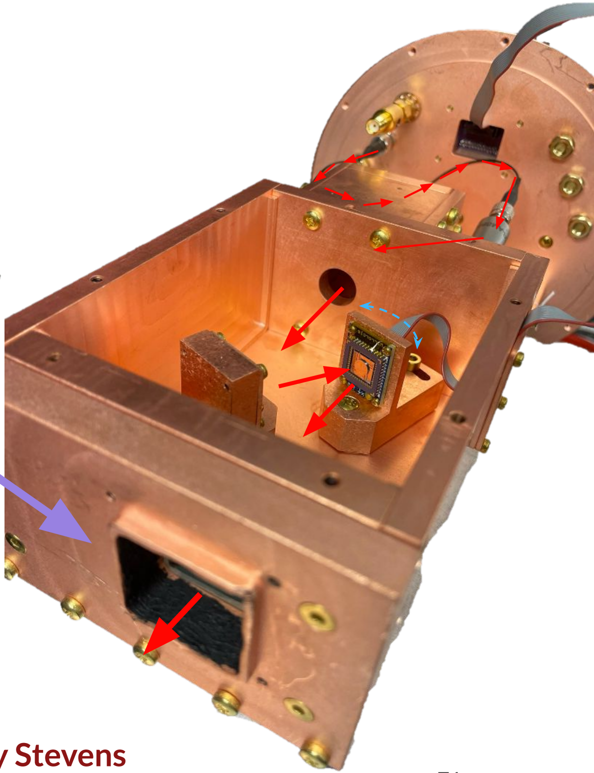
Future studies on Si:

- Phonon-collection studies...
- using the **MEMS cryogenic calibration system**









Zoë Smith
DMQIS grad student

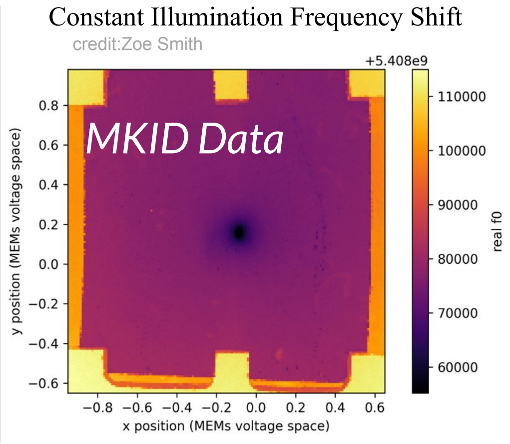
Sidney Stevens
Staff Mechanical Engineer

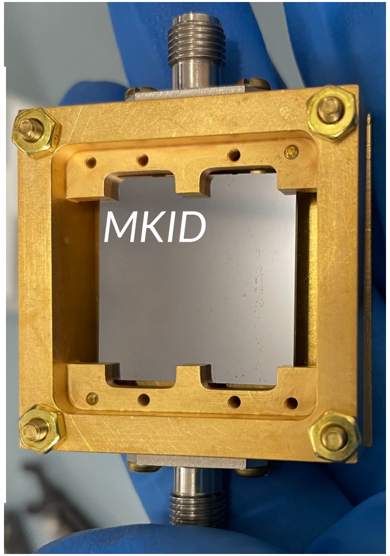
Next-Gen SQUATs

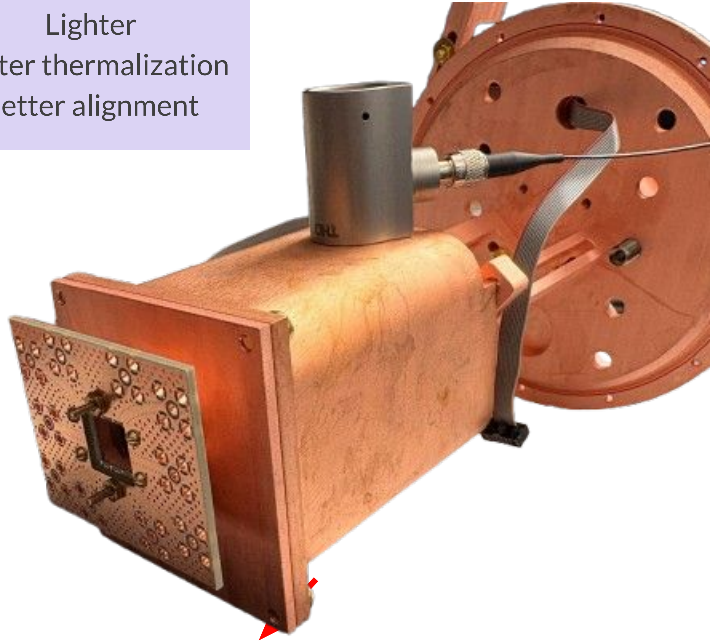
Future studies on Si:

- Phonon-collection studies…
- using the **MEMS cryogenic calibration system**

v3!
Lighter
Better thermalization
Better alignment



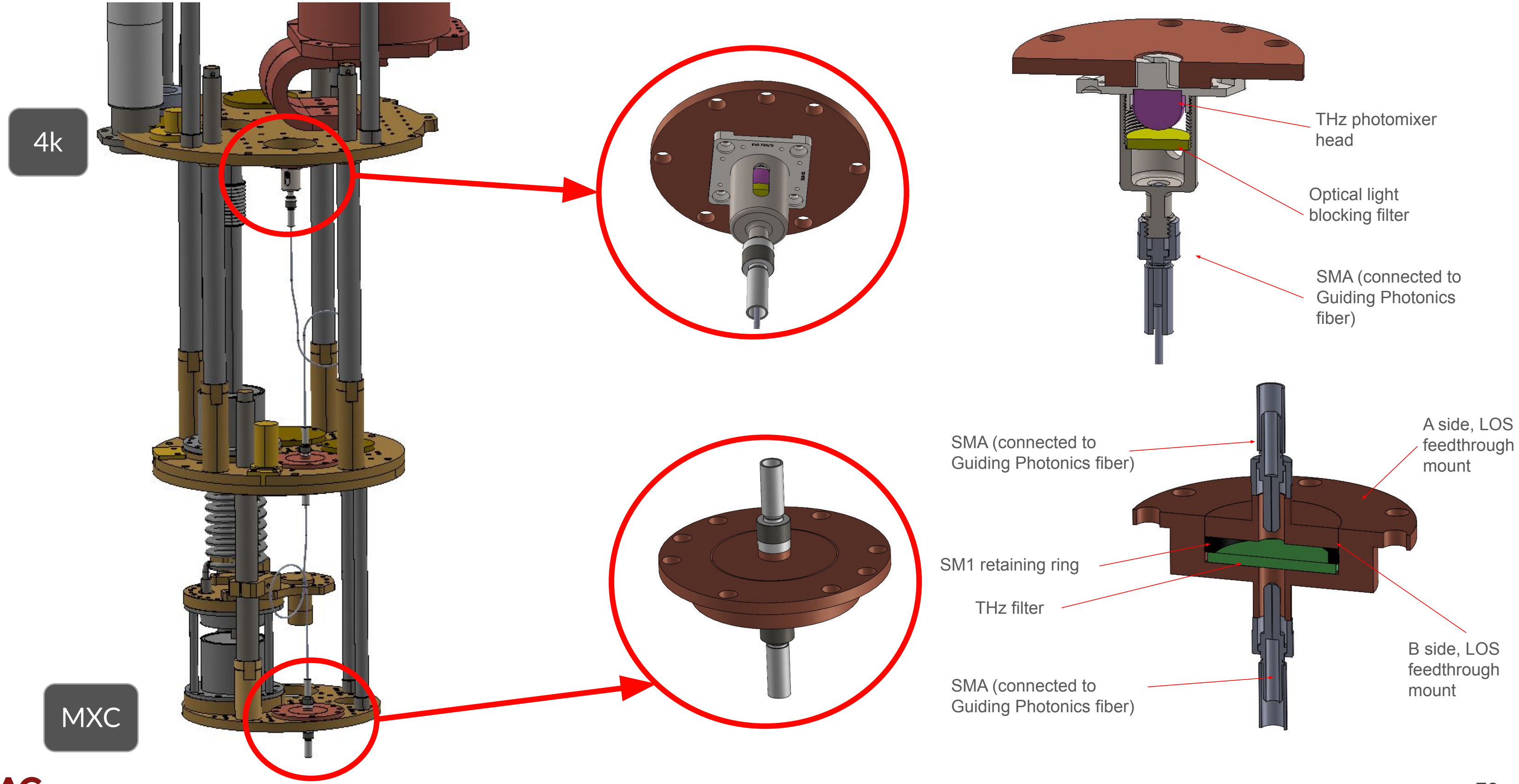




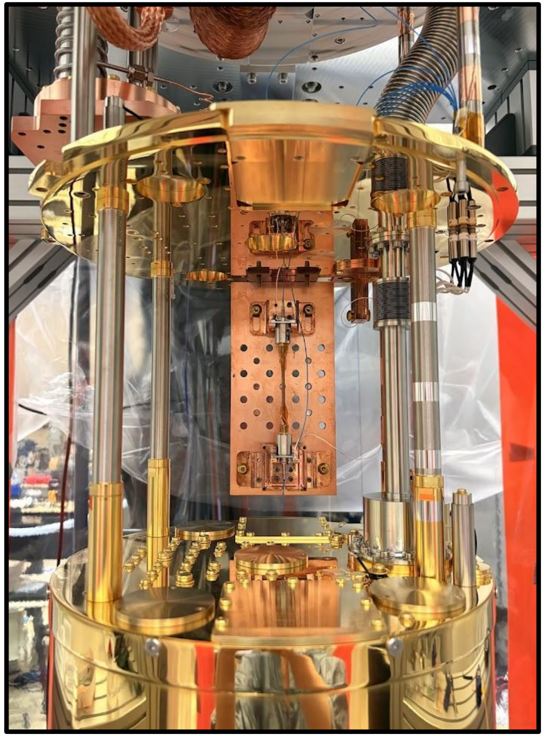
Zoë Smith
DMQIS grad student

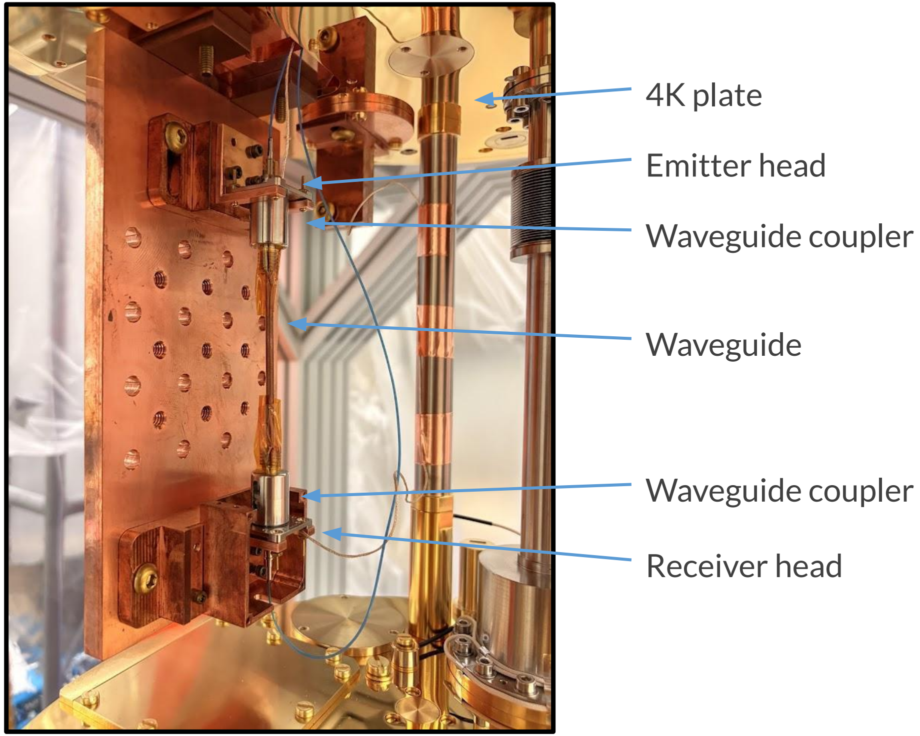
Sidney Stevens
Staff Mechanical Engineer

THz Calibration Source: Waveguide Mechanical Design



Photomixer at 4K





Emily Perry, Brennan Coffey