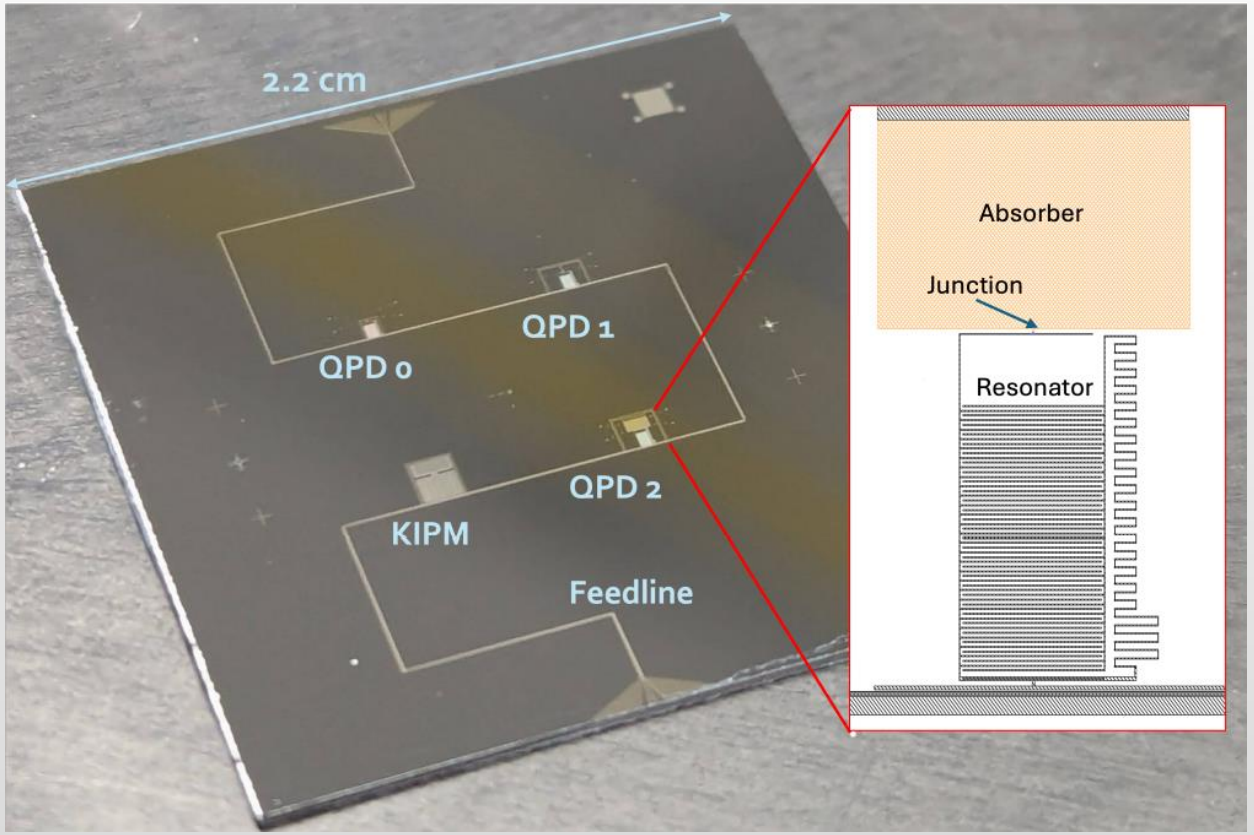
QPD Design

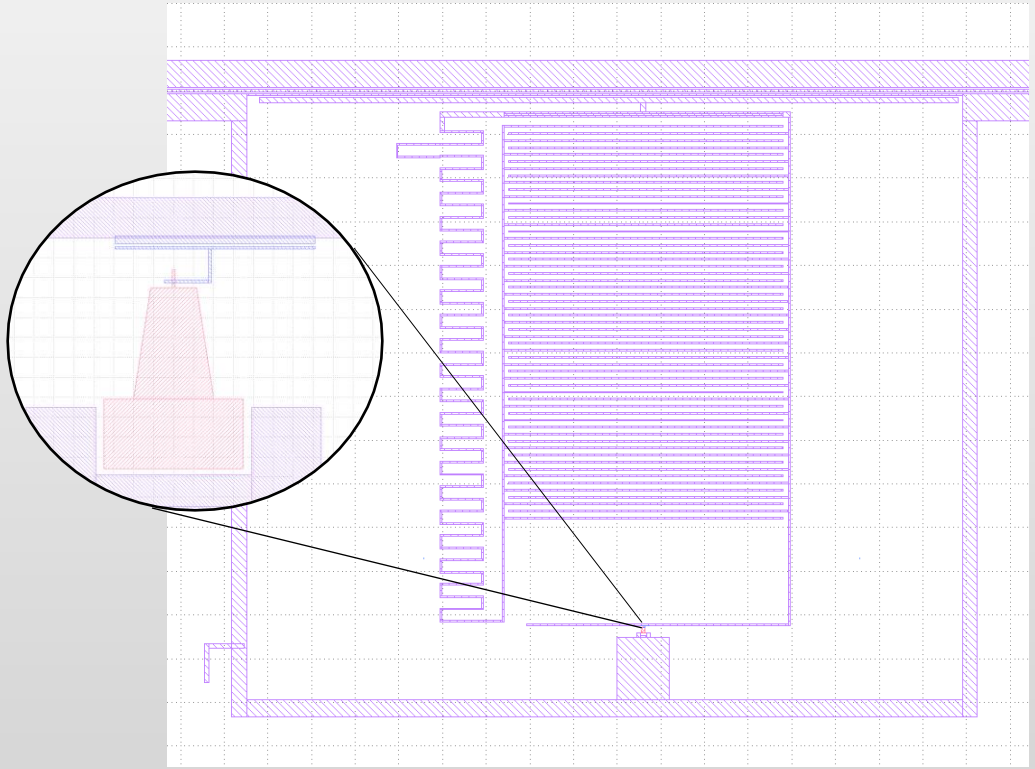
William Ho
on behalf of WashU group



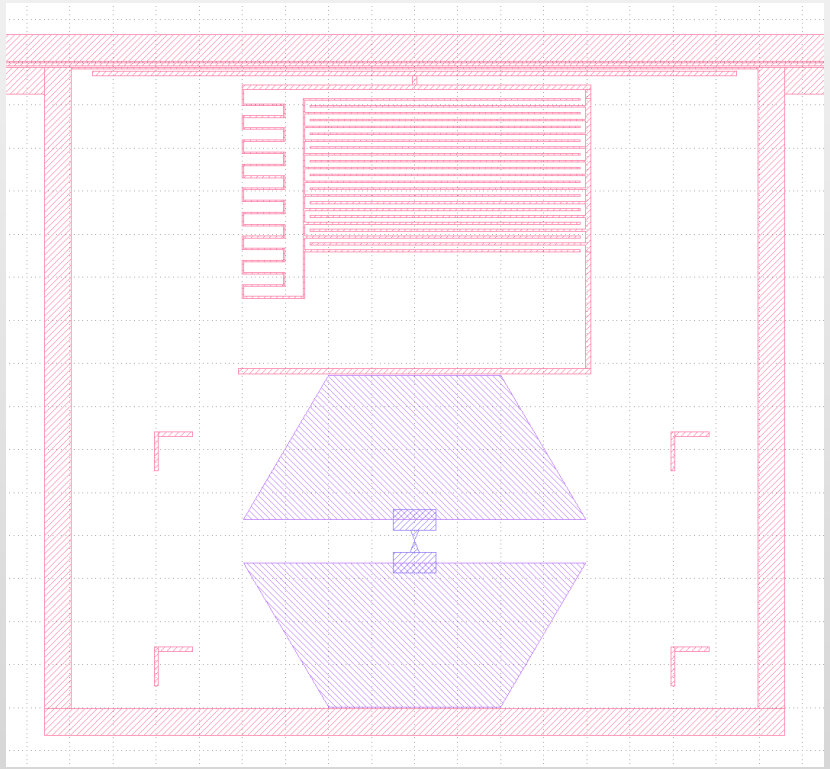
October 29, 2025

SONIQ
SENSING OF NEUTRINOS IN QUBITS

Two regimes for QPDs



Charge Qubit

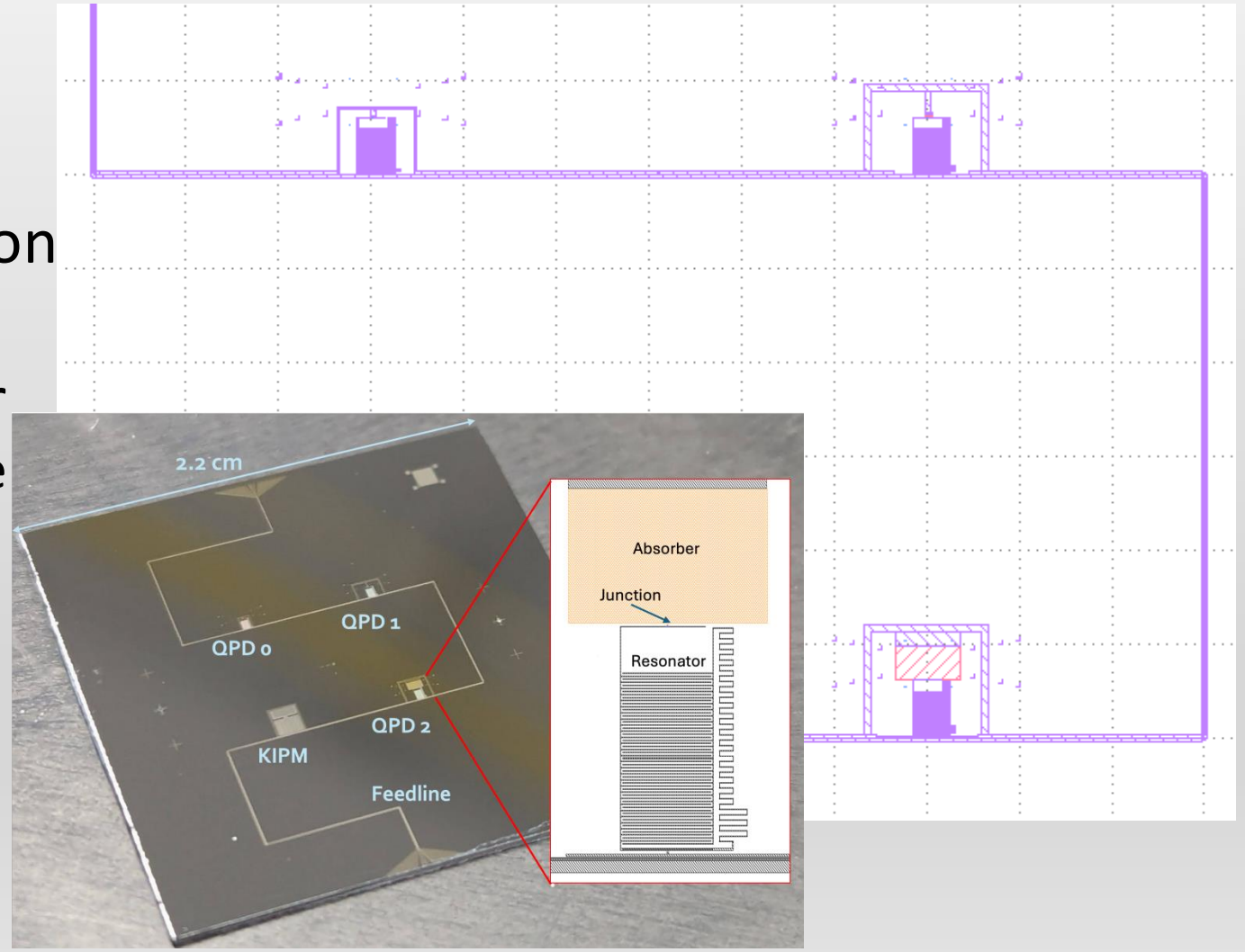


Transmon

Charge Qubit (Previous JPL Work)

"Milled Junction Design"

- Aluminum, 40 nm thick
- 150x150 nm Josephson Junction
  - Ion milling process
- KID device used as a co-sensor
  - Better understood performance



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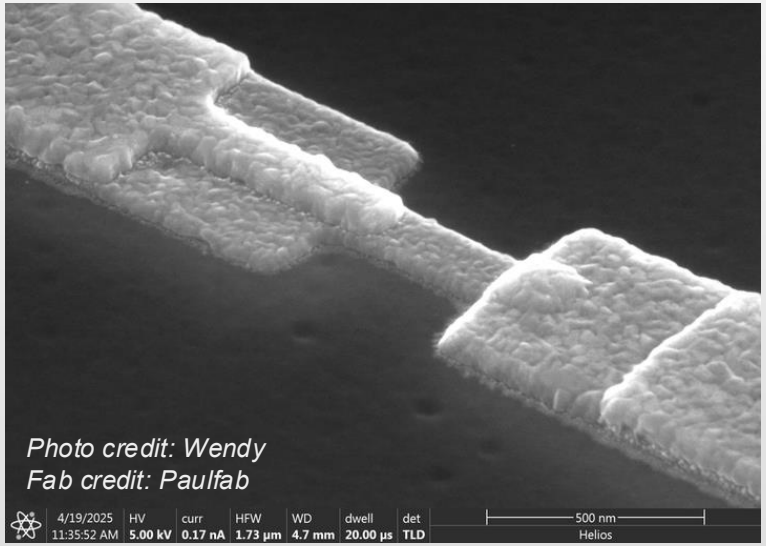

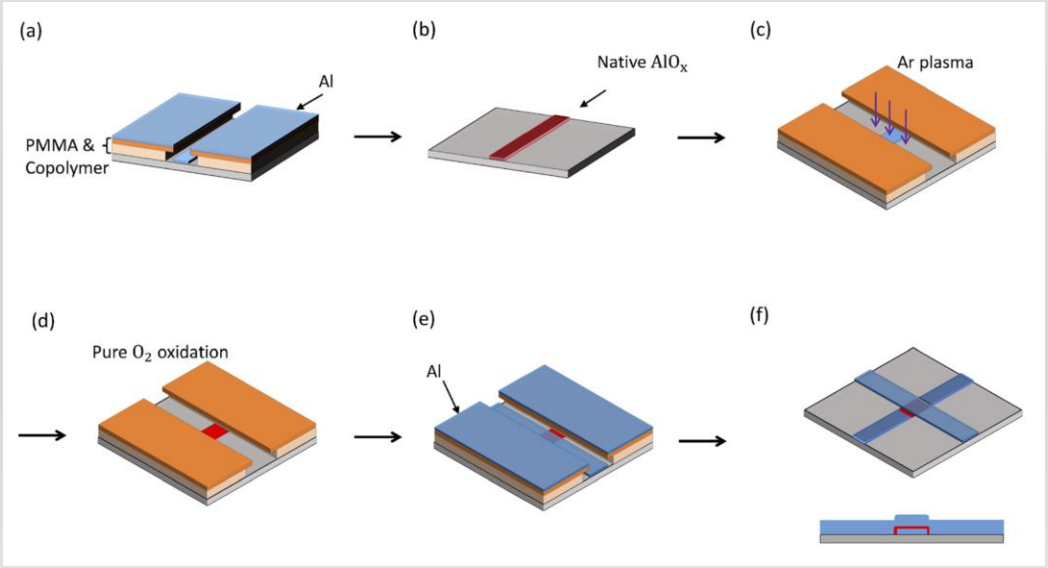

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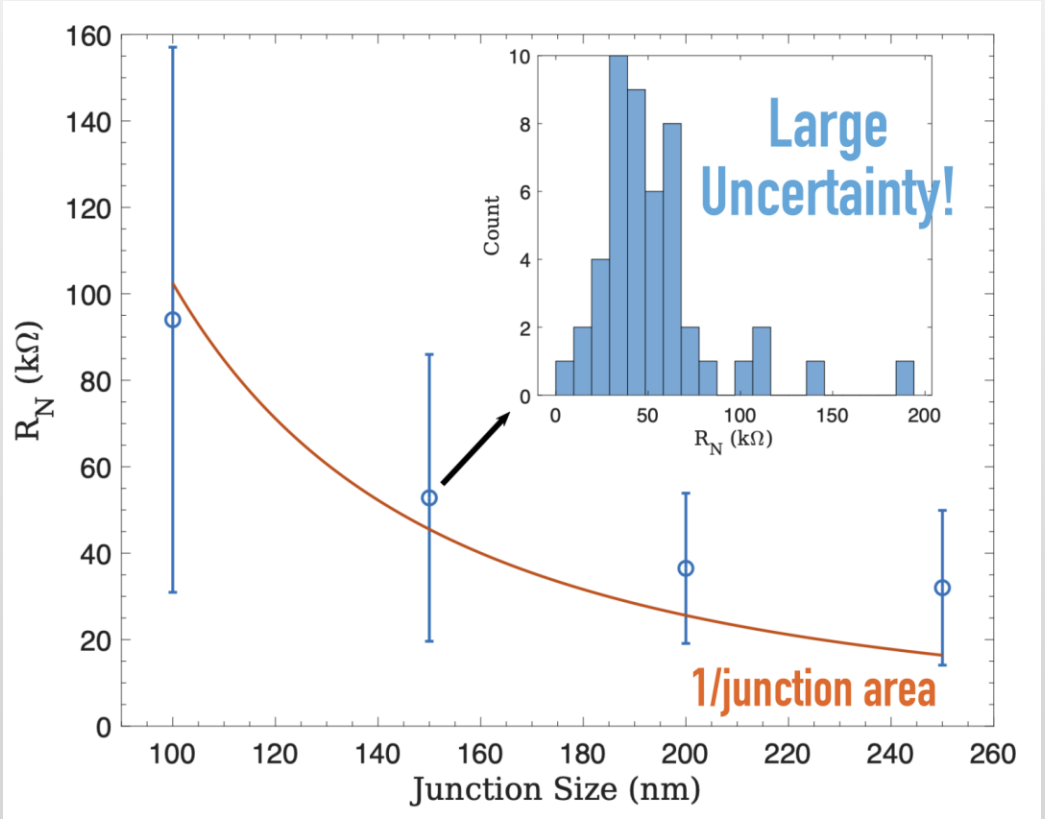

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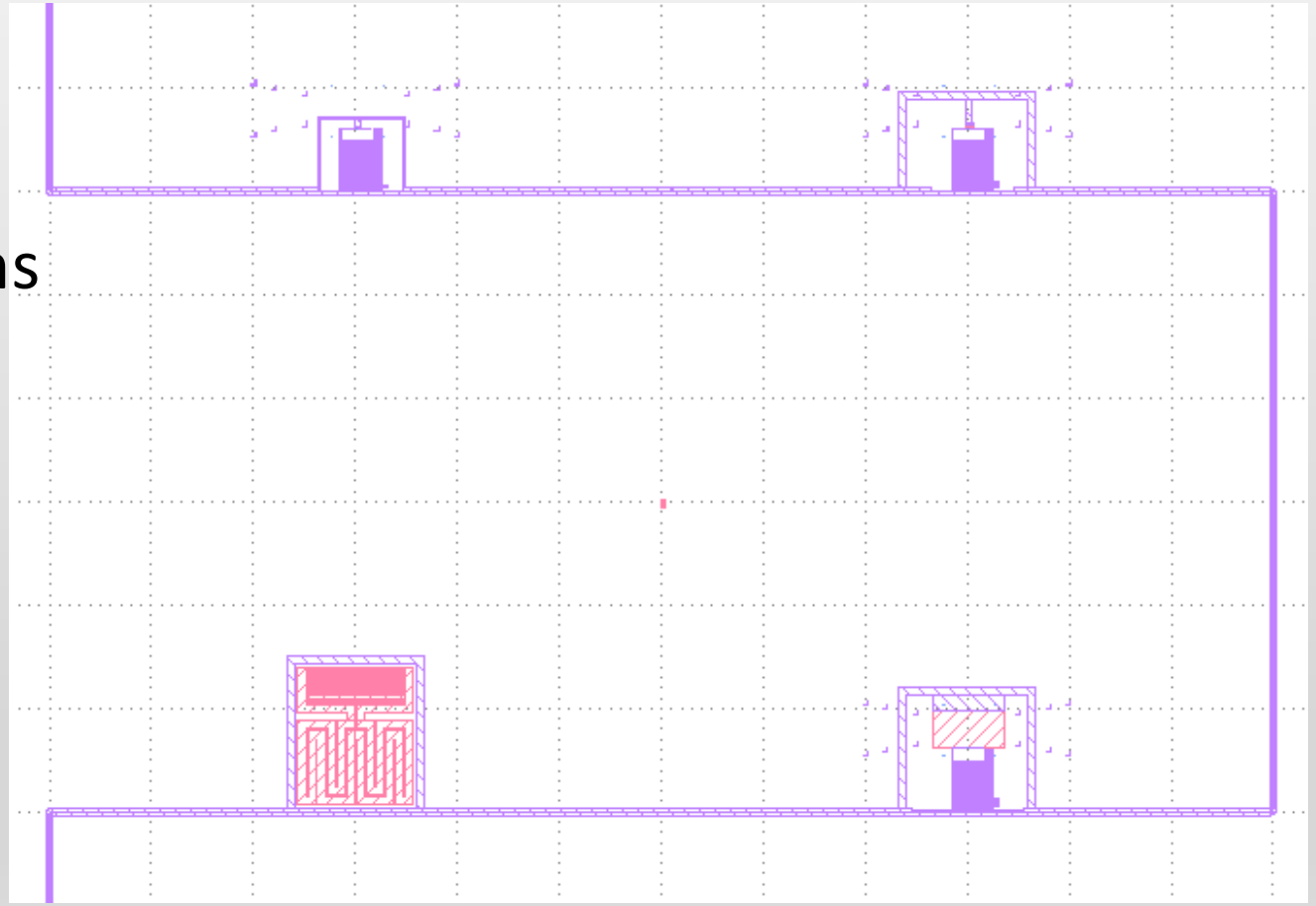
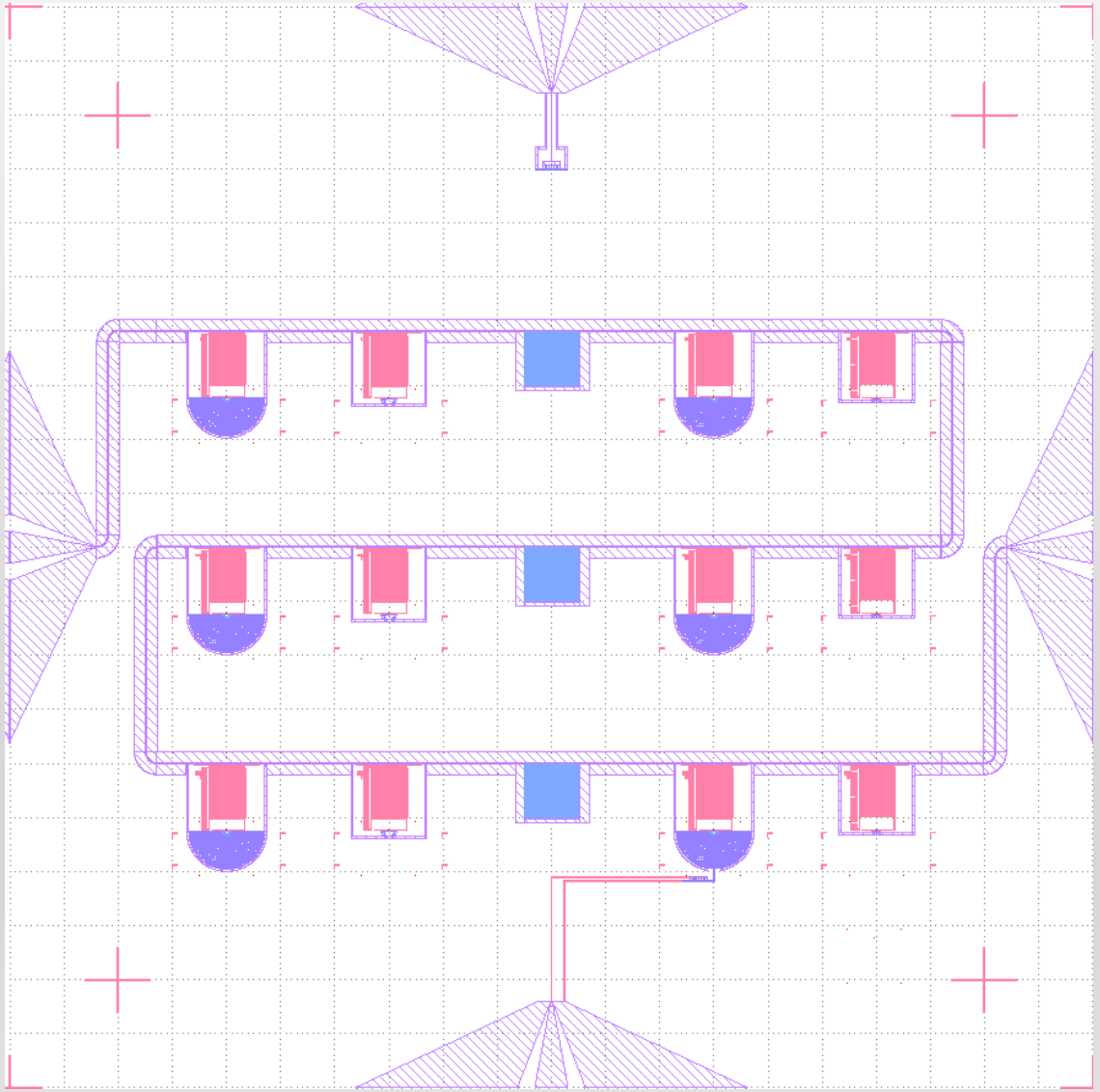
Want to build on this design

- More QP Trapping
- Low T_c Junctions



Charge Qubit (Current JPL Work)



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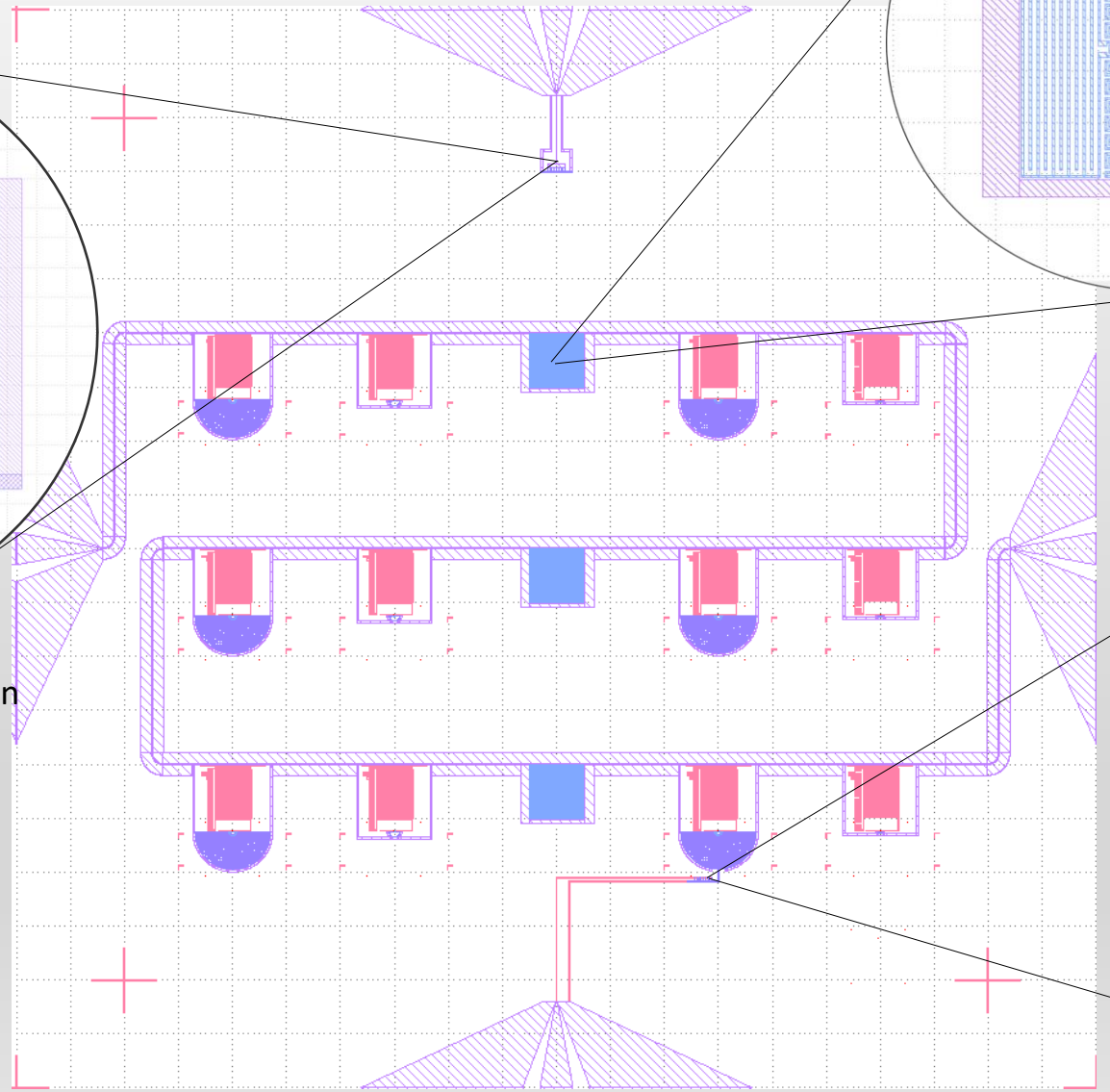
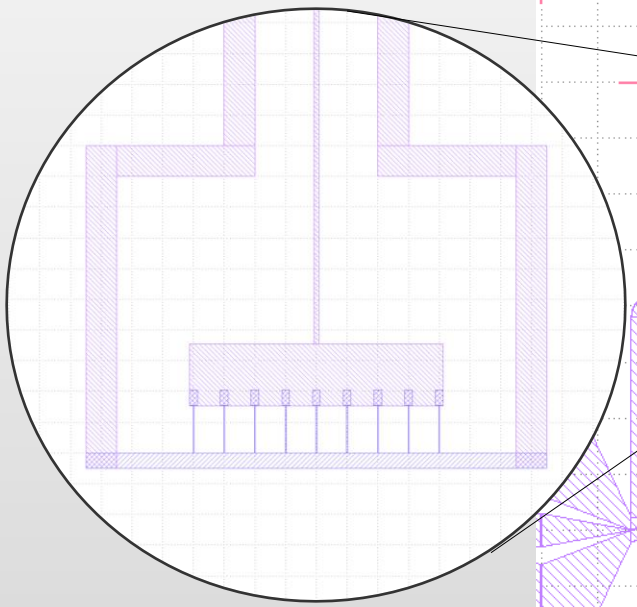
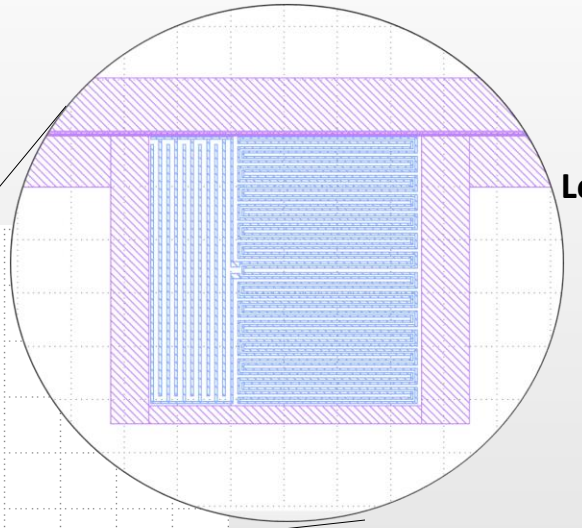


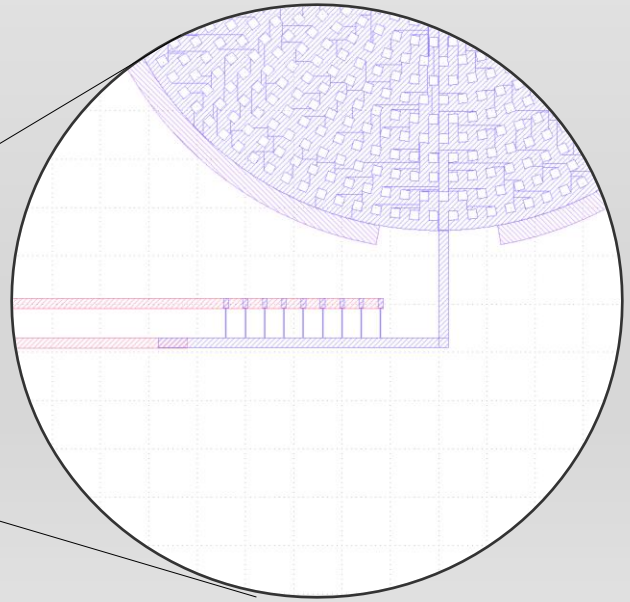


QP Injectors (JJ)
Measure Phonon Propagation



Low Volume Resonator
Measure Material Properties (τ_{qp})

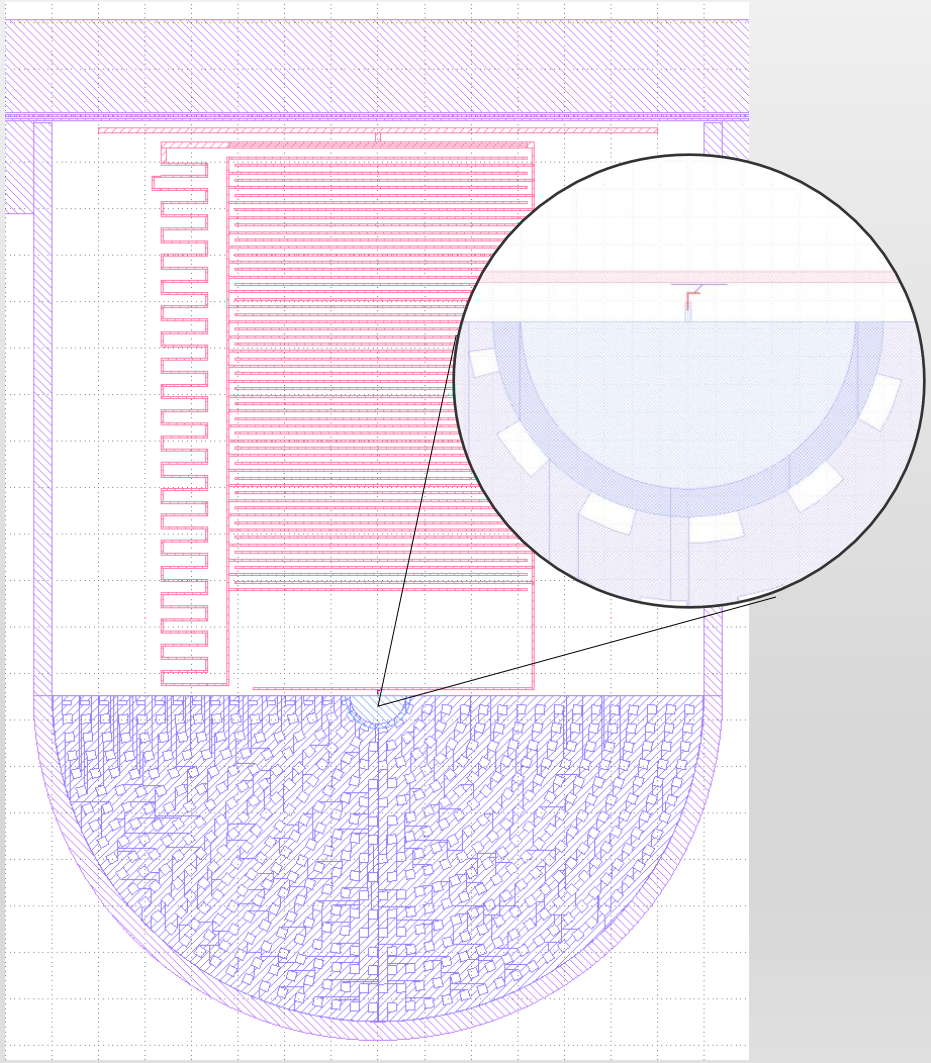
QP Injectors (JJ)
Measure QP Diffusion



Charge Qubit (Current JPL Work)

"QUSEN v1"

- QP Trap Design
  - Thin 40 nm Al (Nb for feedline) for now to validate architecture
- Flux trap holes in absorber
  - Reduce impact of stray magnetic fields



Low T_c Development

There are a lot of options for low Tc trap and junction. We are investigating a few, as a form of risk mitigation.

- Al/Ti/Au Tri-layer Stack
  - Preliminary results show T_c ~ 270 mK
  - Achieved using “proximitization”

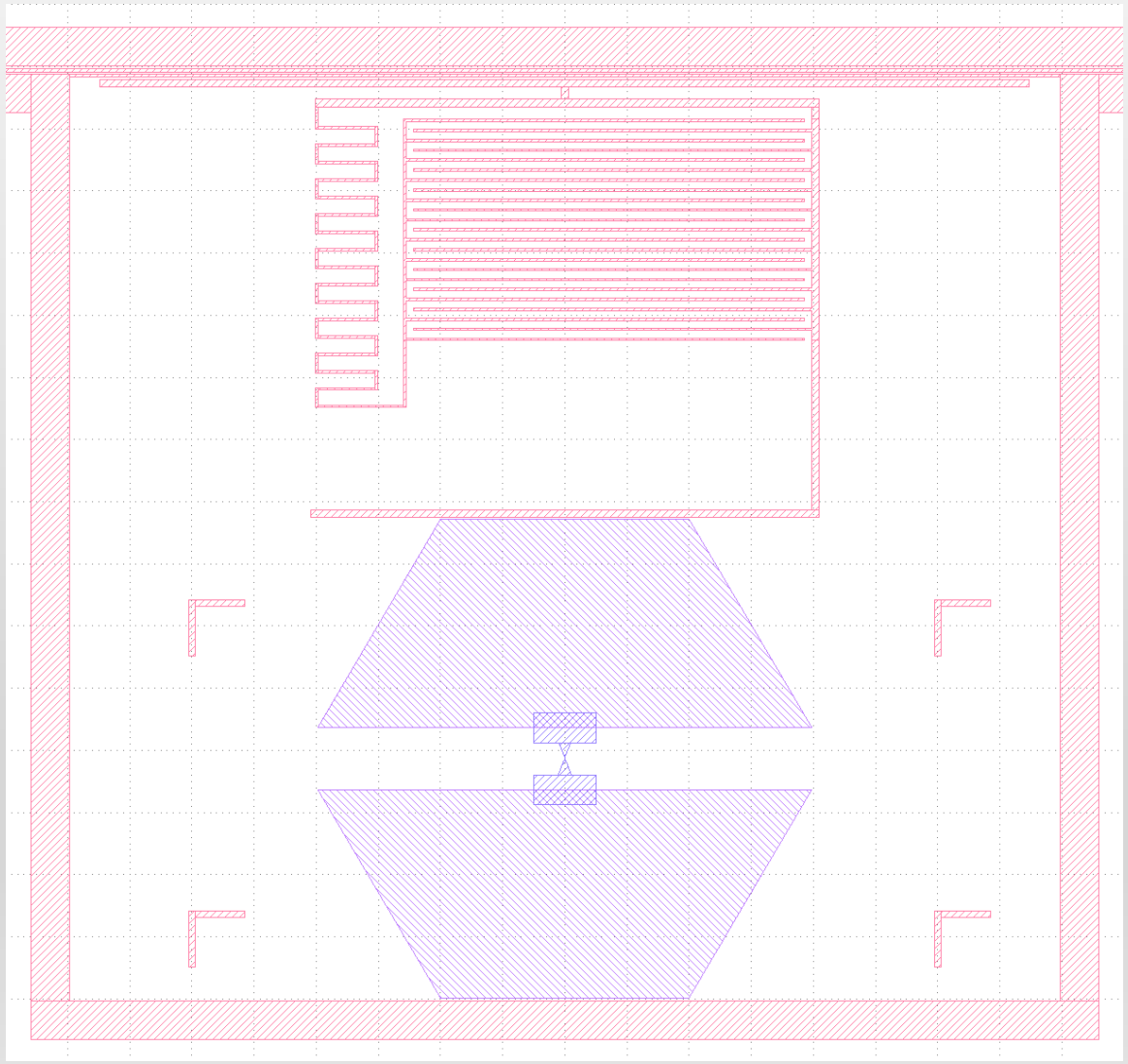
Low-volume Resonators were fabricated to further investigate this material stack

- **Goal:** Extract τ_{qp}
- Unfortunately, current ones show either a bad Q_i or high Q_c
- Work ongoing to investigate this

Other low T_c ideas: AlMn

- <1000 ppm should achieve T_c ~ 250 mK

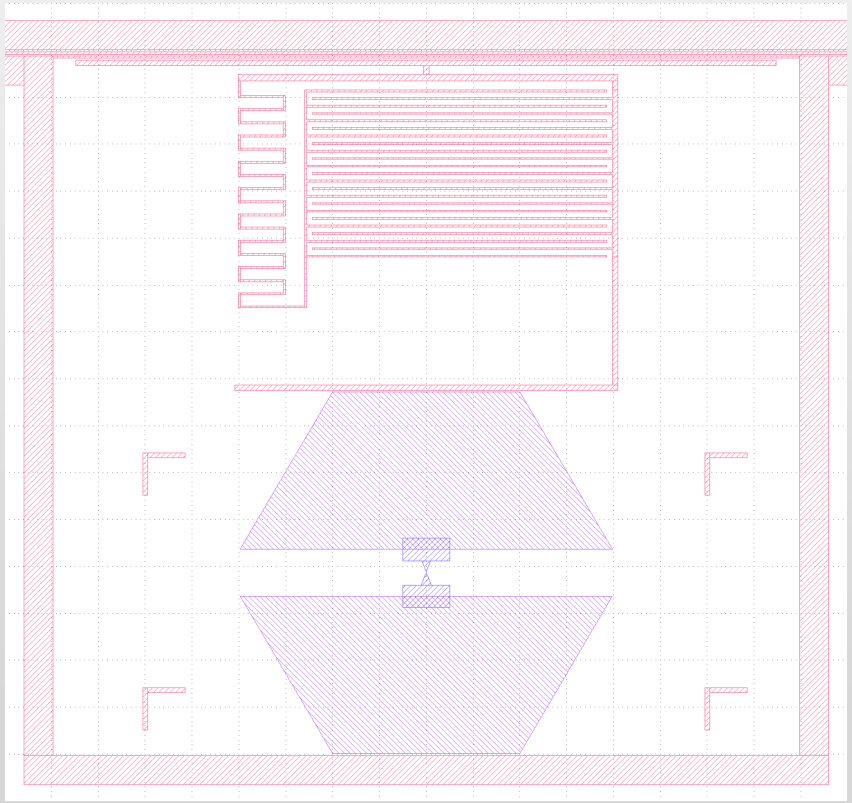
WashU OCS Transmon Design



WashU OCS Transmon Design

Compared to the charge qubit

+ Small E_c → no blockade effect
+ Resonator can be made quite small
- Signal will be O(100 kHz) vs O(1 MHz) for other approaches



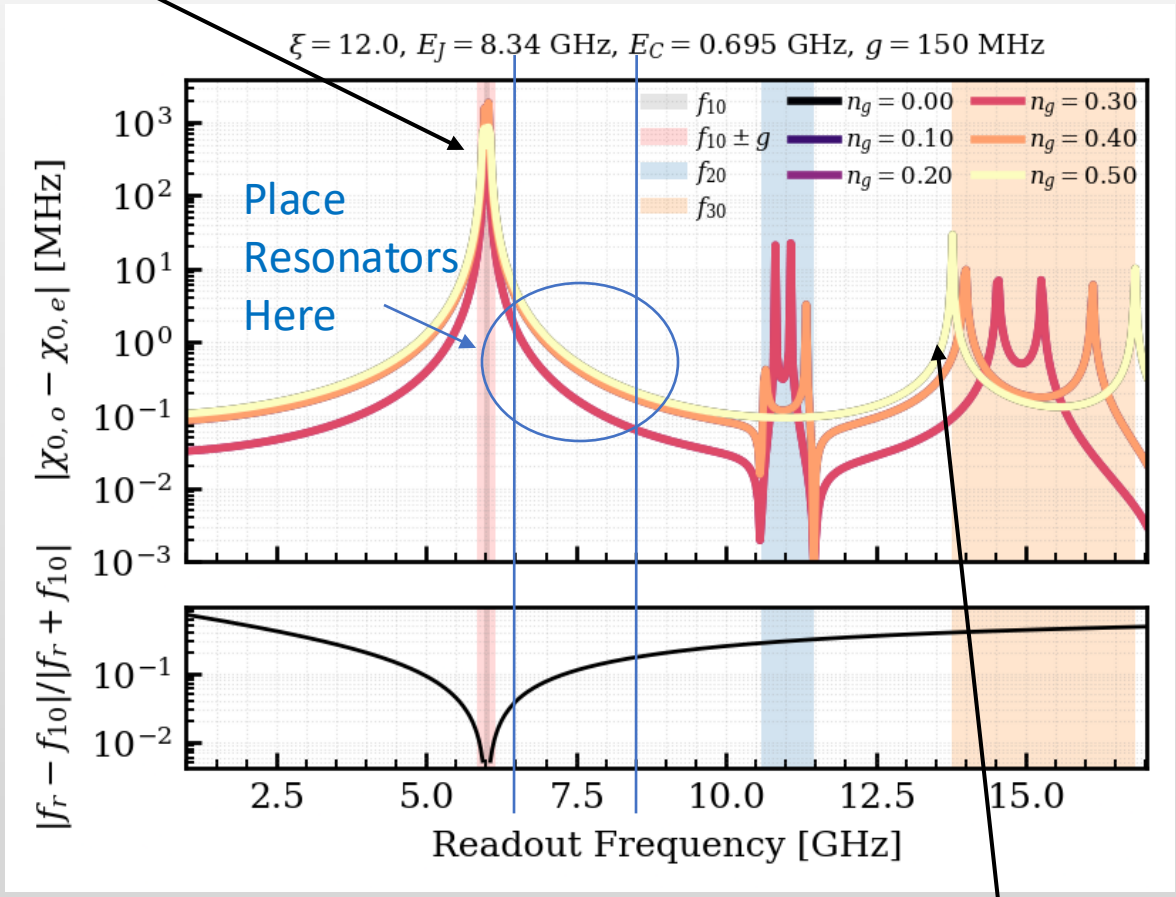
Readout Scheme

- Direct dispersive monitoring:

$$\chi_{i,p} = g^2 \sum_{j \neq i} \frac{2\omega_{ij}^{pp} \left| \langle j,p|\hat{n}|i,p\rangle \right|^2}{(\omega_{ij}^{pp})^2 - \omega_r^2},$$

- Note poles in above expression
  - ω_{ij} is transition frequency
  - ω_r is resonator
  - $|\langle j,p|i,p\rangle|$ are matrix elements for parity state p
  - g is resonator-qubit coupling
- Plot shows how resonator placement (x-axis) affects dispersive shift
  - <u>Can engineer ~7 GHz band where parity response is observable</u>

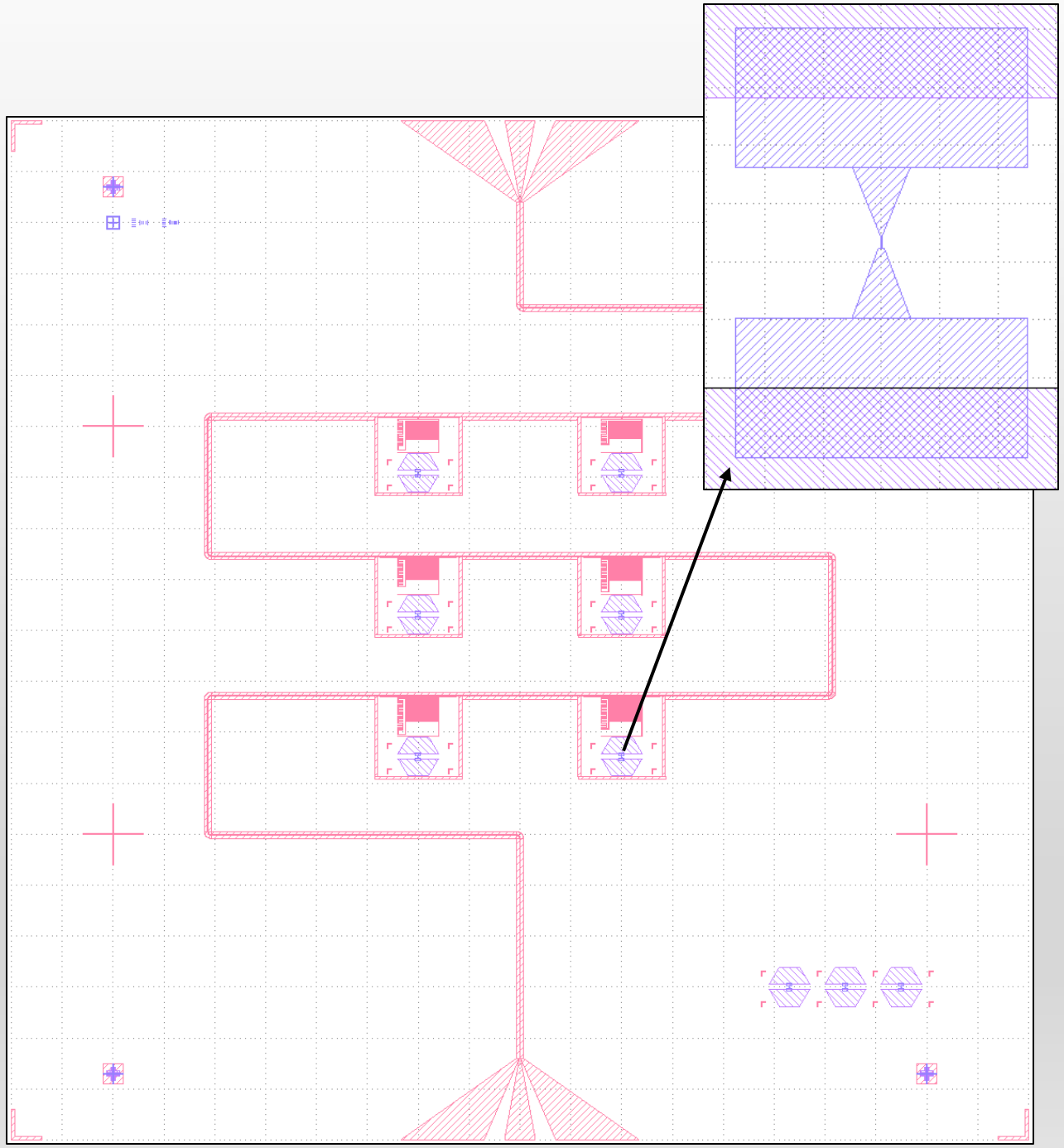
Qubit Frequency



Near third level of qubit state

OCS Transmon Design

- Results
  - HFSS Sims give qubit f_r ~ 5.55 GHz
  - Implies E_C ~ 0.695 GHz
  - Targeting a junction E_J = 8.34 GHz
  - E_J/E_C ~ 14.8
  - X_{shift} ~ 0.6-1.4 MHz
    - Sweeping 6.5-8 GHz resonators
- Like JPL design, first fab run will be thin Al qubits for now



Future Development Considerations

- Reduce resonator size even more
- Thicker absorbers
  - 600 nm Al
- Traps & Junctions to be made of low T_c material
  - Whatever ends up working: Al/Ti/Au, AlMn, Hf as demonstrated
- Could investigate direct charge lines if needed

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Open to Questions/Discussion