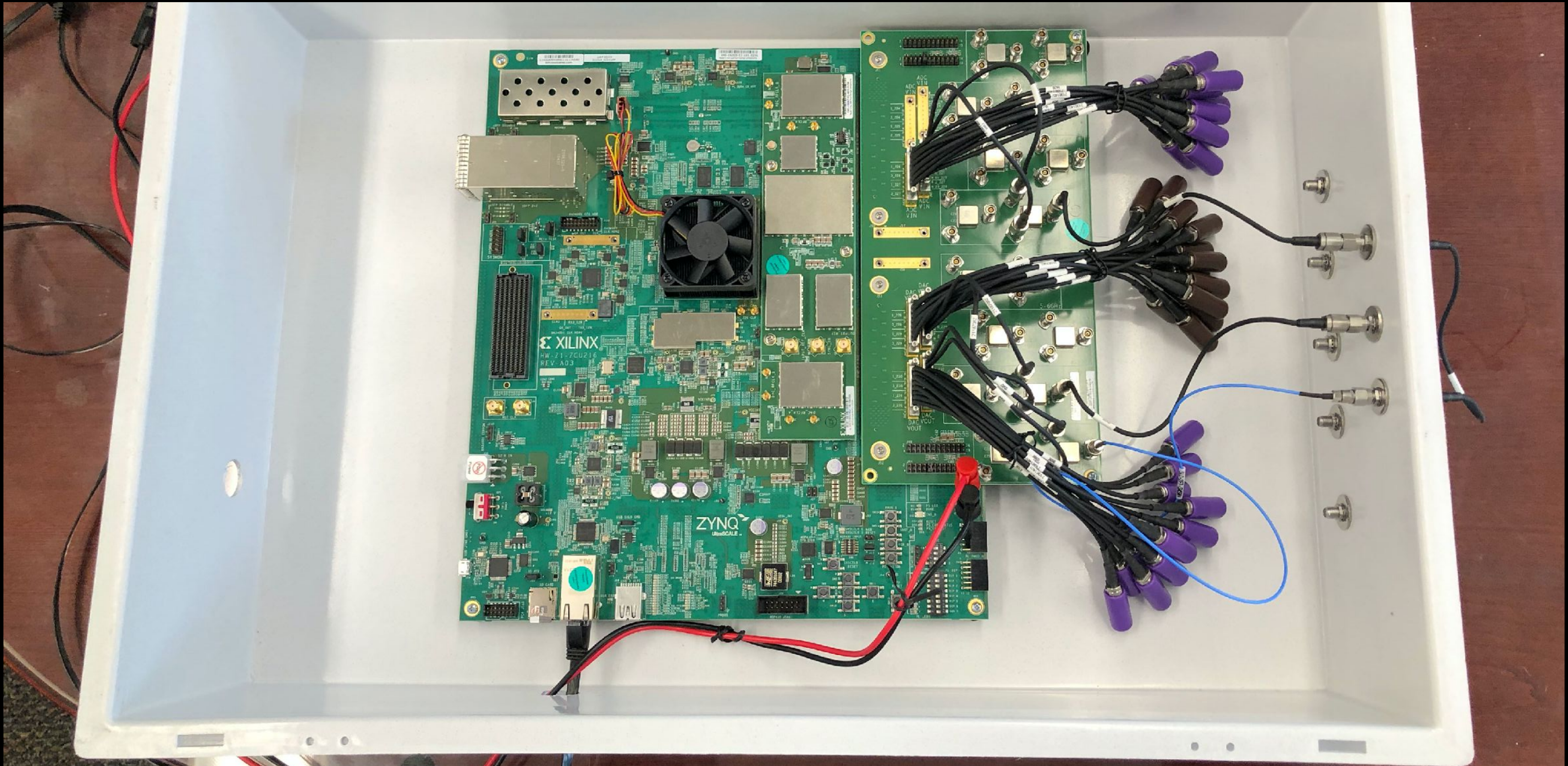
# *Progress deploying the QICK qubit controller on superconducting qubit systems in the Houck lab*



# The Houck lab's contributions to QICK

- Founding members of the collaboration
- Developed new Xilinx dev boards for QICK (ZCU216)
- Beta-testers of new QICK boards and firmwares
  - Multiplexed readout
  - Multi-qubit systems
- Developed library of qubit measurement scripts
- Wrote the first scientific paper to use the QICK
- Contributing two-qubit gate/randomized benchmarking expertise to the QICK team

# QICK at the 2023 APS March Meeting: Houck lab at Princeton

Projects that mainly use the QICK:

- Monday
  - A75.00008 : Experimental demonstration of the treatment of time-dependent flux in circuit QED devices
- Tuesday
  - F75.00006 : Experimental Investigation of a Protected Qubit Subspace Within a Fluxonium Molecule
  - F75.00010 : Improving T1 in dielectric-loss-limited fluxonium qubits
- Thursday
  - S67.00004 : Engineering Flat-Band Lattices with Superconducting Circuits
  - S75.00011 : Novel wideband Purcell filters for circuit QED

Projects that sometimes use the QICK:

- Q75.00001 : Understanding Material Systems for Superconducting Qubits
- Q75.00004 : Optimizing Designs and Materials for Transmon Qubits
- Z75.00007/8 : Progress on a tunable coupler architecture for parametric gates between far-detuned fixed-frequency transmon qubits

APS March Meeting

March 5–10, 2023 | Las Vegas, Nevada

March 20–22, 2023 | Virtual

# Control priorities in the Houck lab

- Automated tune-up of qubit systems
    - Multi-qubit systems
        - S67.00004 : Engineering Flat-Band Lattices with Superconducting Circuits
        - Z75.00007/8 : Progress on a tunable coupler architecture for parametric gates between far-detuned fixed-frequency transmon qubits
    - Systematic coherence studies
        - F75.00010 : Improving T1 in dielectric-loss-limited fluxonium qubits
    - Establish control over new qubits
        - F75.00006 : Experimental Investigation of a Protected Qubit Subspace Within a Fluxonium Molecule

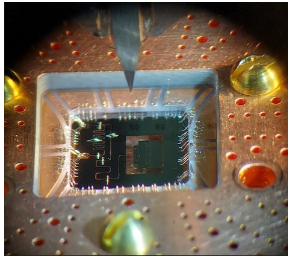
- Highly-multiplexed readout (emulating a VNA, measuring many resonators in parallel)
    - Q75.00001 : Understanding Material Systems for Superconducting Qubits
    - S67.00004 : Engineering Flat-Band Lattices with Superconducting Circuits

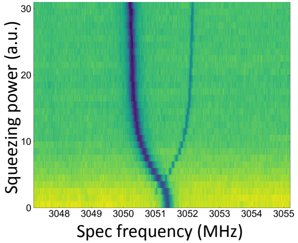
- Compensated fast flux pulses for fluxonium, tunable transmons, etc.
    - A75.00008 : Experimental demonstration of the treatment of time-dependent flux in circuit QED devices
    - S67.00004 : Engineering Flat-Band Lattices with Superconducting Circuits

- Efficient, low-latency two-qubit randomized benchmarking
    - Collaboration with Schuster lab two-qubit team
    - Z75.00007/8 : Progress on a tunable coupler architecture for parametric gates between far-detuned fixed-frequency transmon qubits

HOUCK LAB

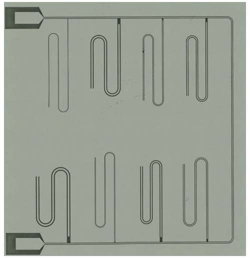
## 2D tantalum Kerr-Cat qubit

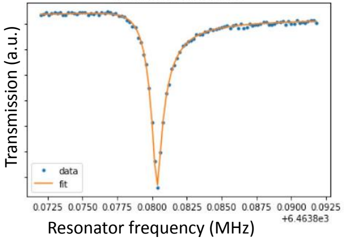





Phase-coherent squeezing drive for noise-biased cat states

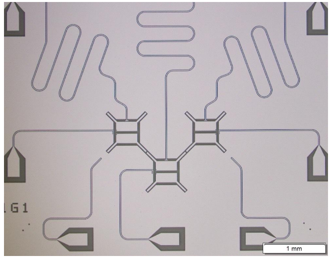
## High-Q tantalum resonators

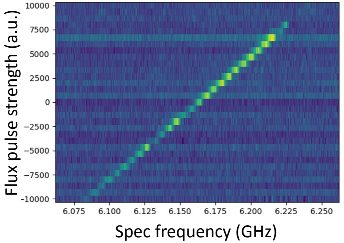





MUX'd readout
Fitted Qs > 15 million

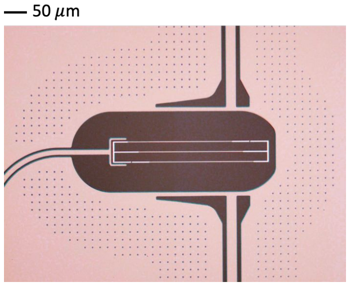
## Tunable transmon lattice for quantum simulation

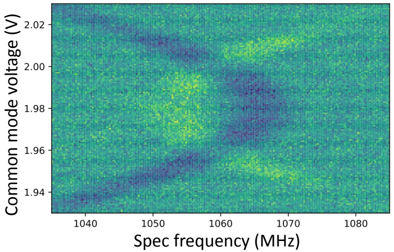



Fast flux pulses to simulate flat band state dynamics

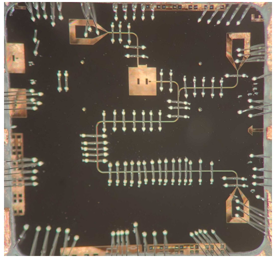
## Fluxonium molecule

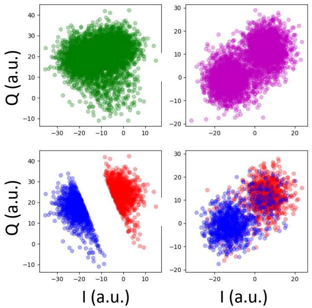



Sensitivity to qubit levels that are protected from noise

## Active control of fluxonium

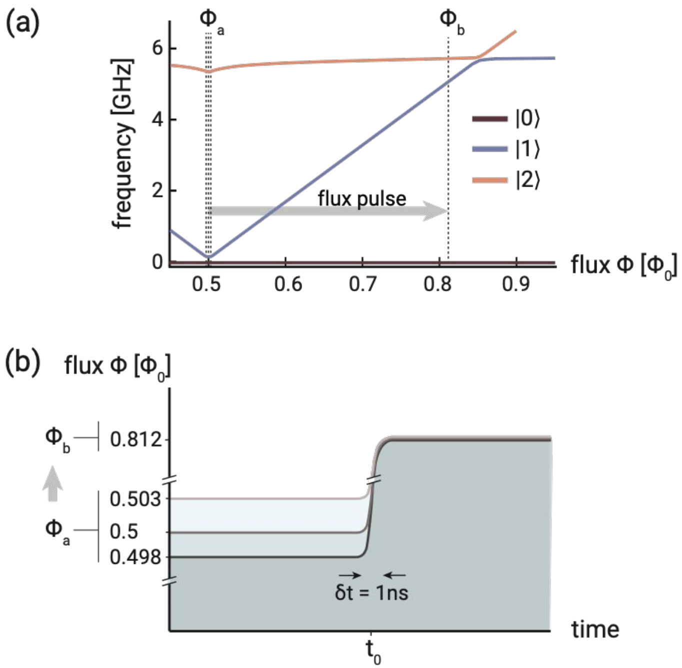


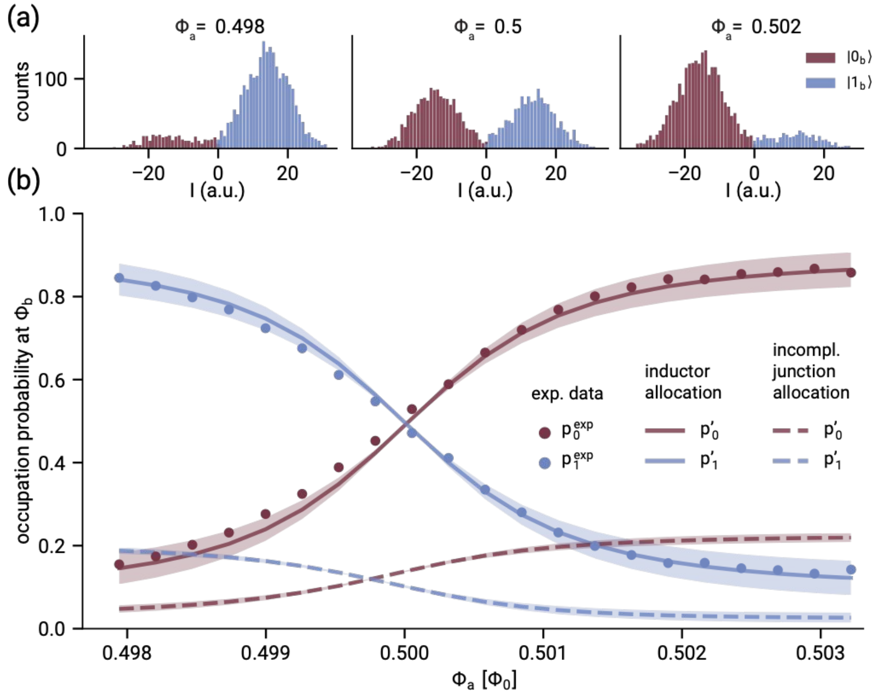



Optimal readout
Post-selection

# Experimental validation of circuit quantization in the presence of time-dependent flux

- The first-ever scientific paper to use the QICK
- Active control of fluxonium: fast flux pulses, postselection, single shot readout > 90% fidelity



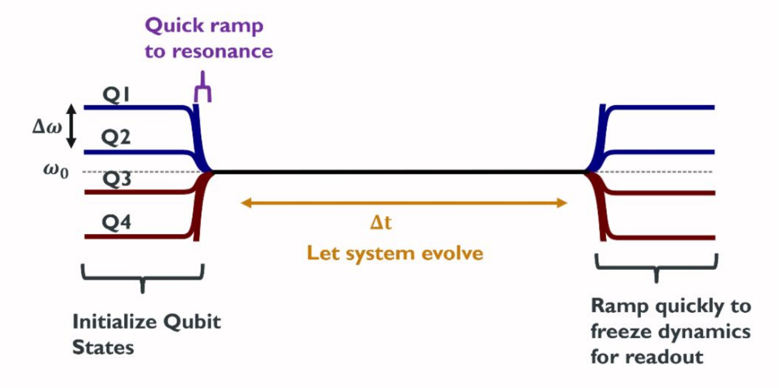



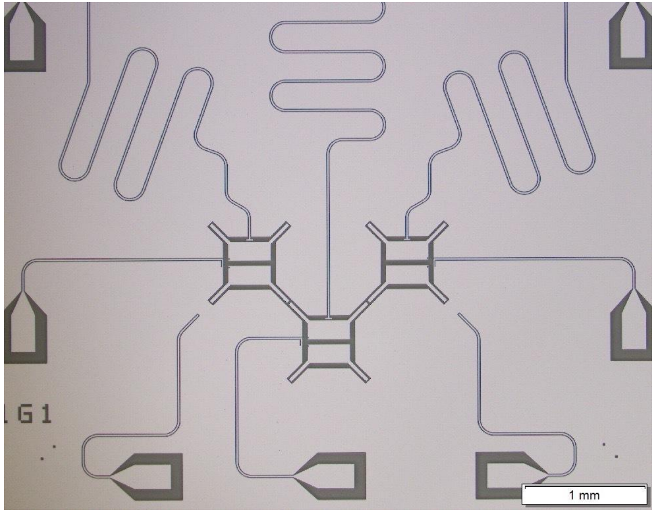

Houck Lab

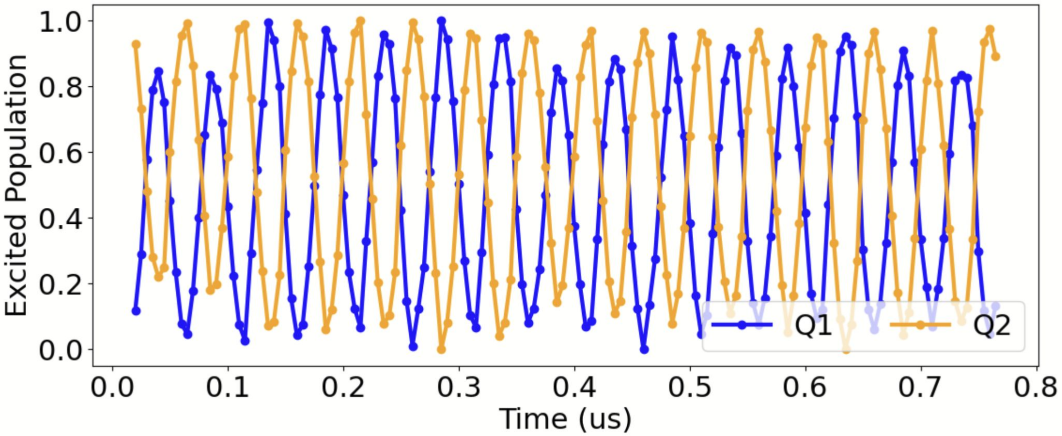
J. Bryon et al., arXiv:2208.03738

# 3 Qubit Time Evolution (quantum simulation, preliminary data)

- Single unit cell of a lattice with a flat-band
- Time-domain measurements using flux-tunable transmons
- Swapping dynamics associated with system quench
- Controls and multiplexed readout using QICK



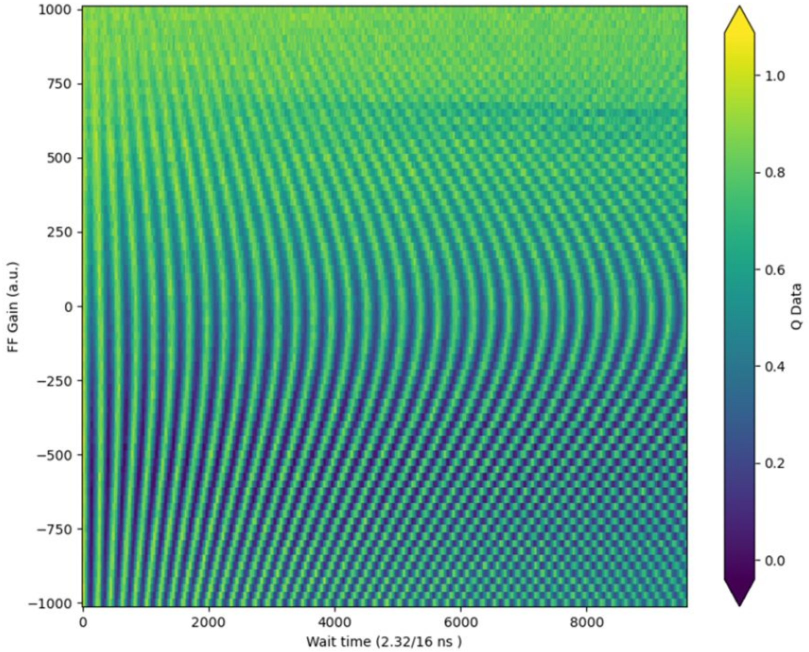

J. Martinez, C. Chiu et al. (preliminary)

HOUCK LAB

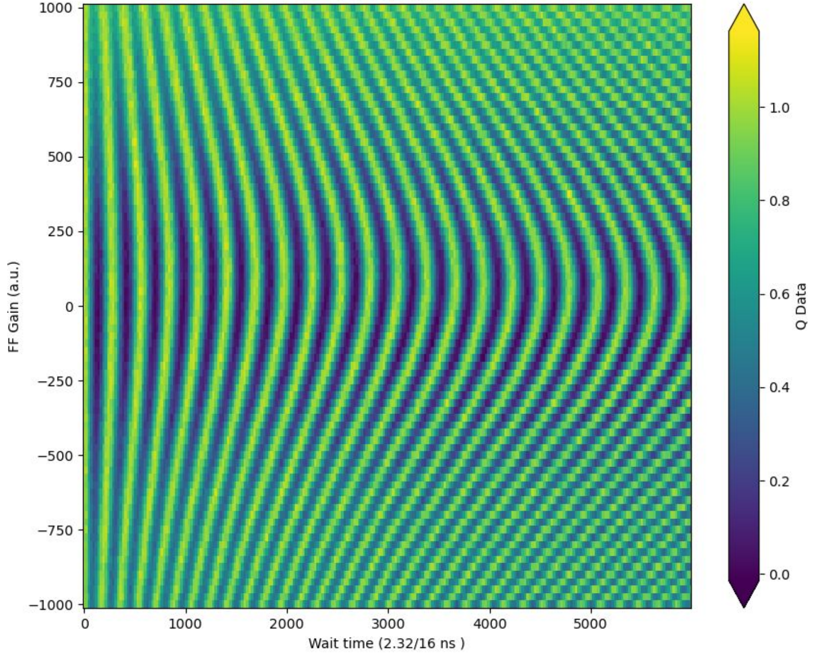
# 3 Qubit Time Evolution (quantum simulation, preliminary data)

- Fast-flux step pulses are used to quench the system
- High time-resolution of QICK allows for custom pulses to compensate for fridge line distortions

Uncompensated




Compensated

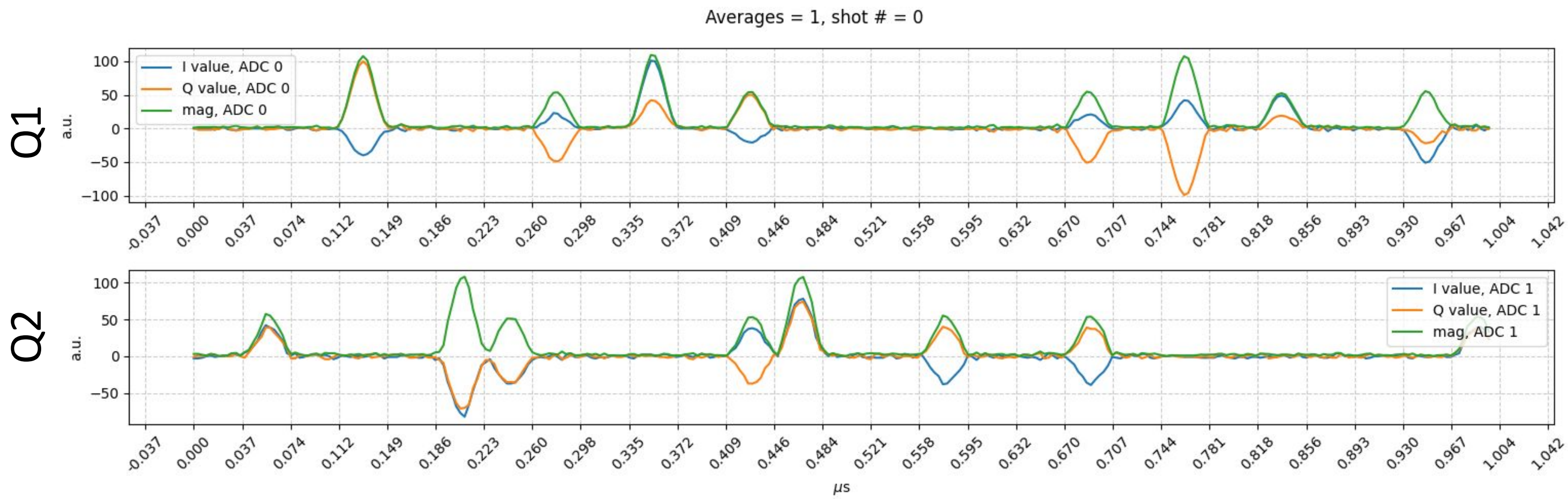



HOUCK LAB

J. Martinez, C. Chiu et al. (preliminary)

# Two-qubit RB with the QICK (Houck and Schuster lab collaboration) demo sequence

[{'Q1': 'Z', 'Q2': 'X/2', 'C': 'I'}, {'Q1': 'I', 'Q2': 'Z', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'X', 'Q2': 'I', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': '-Z/2', 'Q2': 'X', 'C': 'I'}, {'Q1': '-Z/2', 'Q2': 'X/2', 'C': 'I'}, {'Q1': 'X/2', 'Q2': 'I', 'C': 'I'}, {'Q1': '-Z/2', 'Q2': 'I', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'X', 'Q2': 'I', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': '-Z/2', 'Q2': '-Z/2', 'C': 'I'}, {'Q1': 'X/2', 'Q2': 'X/2', 'C': 'I'}, {'Q1': 'Z', 'Q2': '-Z/2', 'C': 'I'}, {'Q1': '-Z/2', 'Q2': 'X', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'I', 'Q2': '-Z/2', 'C': 'I'}, {'Q1': 'Z', 'Q2': 'X/2', 'C': 'I'}, {'Q1': 'I', 'Q2': 'Z', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'I', 'Q2': '-Z/2', 'C': 'I'}, {'Q1': '-Z/2', 'Q2': '-Z/2', 'C': 'I'}, {'Q1': 'X/2', 'Q2': 'X/2', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'X', 'Q2': 'I', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': '-Z/2', 'Q2': 'Z', 'C': 'I'}, {'Q1': 'X/2', 'Q2': 'I', 'C': 'I'}, {'Q1': 'Z', 'Q2': 'I', 'C': 'I'}, {'Q1': 'I', 'Q2': '-Z/2', 'C': 'I'}, {'Q1': 'I', 'Q2': 'Z/2', 'C': 'I'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'I', 'Q2': 'I', 'C': 'sqrtiSWAP'}, {'Q1': 'X/2', 'Q2': '-Z/2', 'C': 'I'}, {'Q1': 'Z/2', 'Q2': 'I', 'C': 'I'}, {'Q1': '-Z/2', 'Q2': 'X/2', 'C': 'I'}, … ]





C. Guinn, S. Sussman (Houck)
C. Ding, H. Zhang (Schuster)

# Status of QICK in the Houck lab

- Automated tune-up of qubit systems
  - Consolidating a lab-wide QICK qubit measurement library
  - Moving towards fully automated tune-up for faster sample turnaround

- Highly-multiplexed readout (emulating a VNA, measuring many resonators in parallel)
  - Goal is for this to become significantly faster and more reliable than using a VNA for multiplexed resonator chips
  - Working on establishing better overall SNR even at extremely low drive powers

- Compensated fast flux pulses for fluxonium, tunable transmons, etc.
  - Will develop more general code for this after experimentation on the 3-qubit lattice

- Efficient, low-latency two-qubit randomized benchmarking
  - Continuing collaboration with Schuster lab two-qubit team

Thank you for listening!