Google AI Quantum

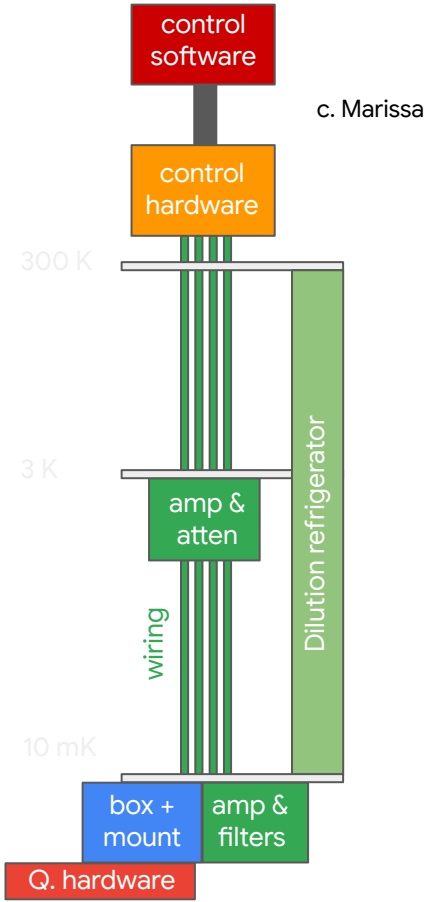
Quantum Hardware

Cirq Bootcamp 5/14/2019

Eric Ostby

Outline

1. Systems engineering
2. High quality qubits
3. Control and readout
4. Scaling



Building a Real Quantum Computer

- For one device, qubits have
  - Coherence
  - Coupling
  - Measurement
  - Low errors

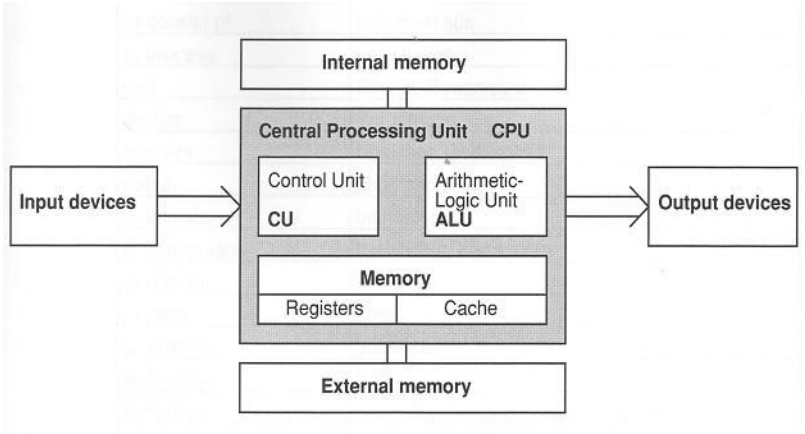
these are competing requirements

- Good control <u>each</u> qubit
- Room for control circuitry
- Reprogrammable (single and two-qubit gates)
- Flexible architecture
- Scalable

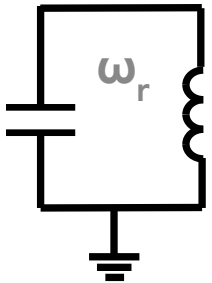
Systems vs. Control:

Can’t copy quantum information

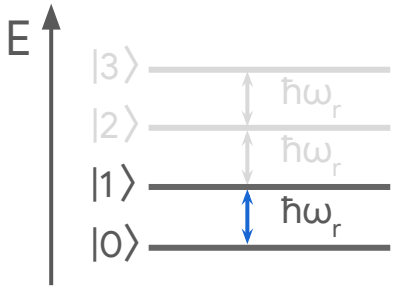
Hard to separate into sub-functions



Quantum harmonic oscillator



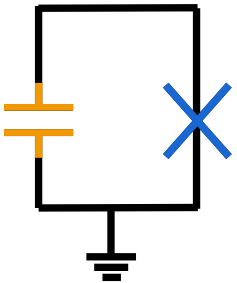
Quantum mechanics: **energy is quantized**, oscillator stores n photons (of energy $\hbar\omega_r$)

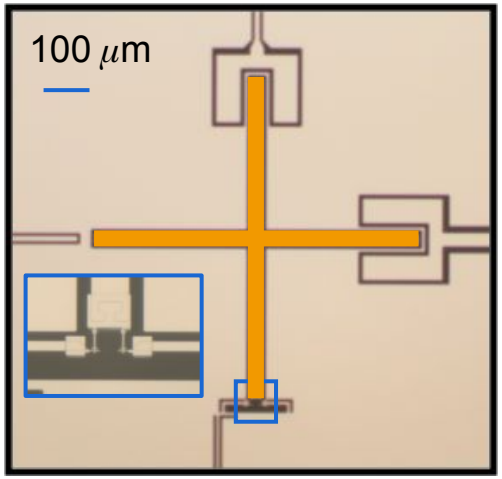


Quantum state is encoded in the energy level of an (electric circuit) oscillator

Transmon Qubit

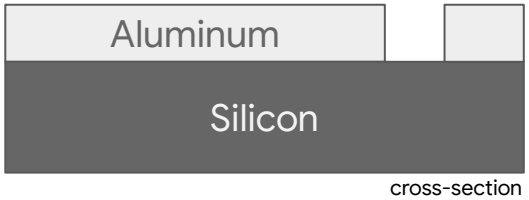
GHz microwave oscillator





How do we make our qubits?

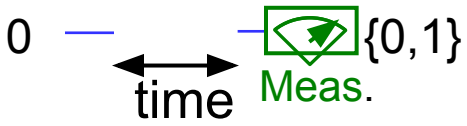
- Cleanroom facilities
- Aluminum on silicon

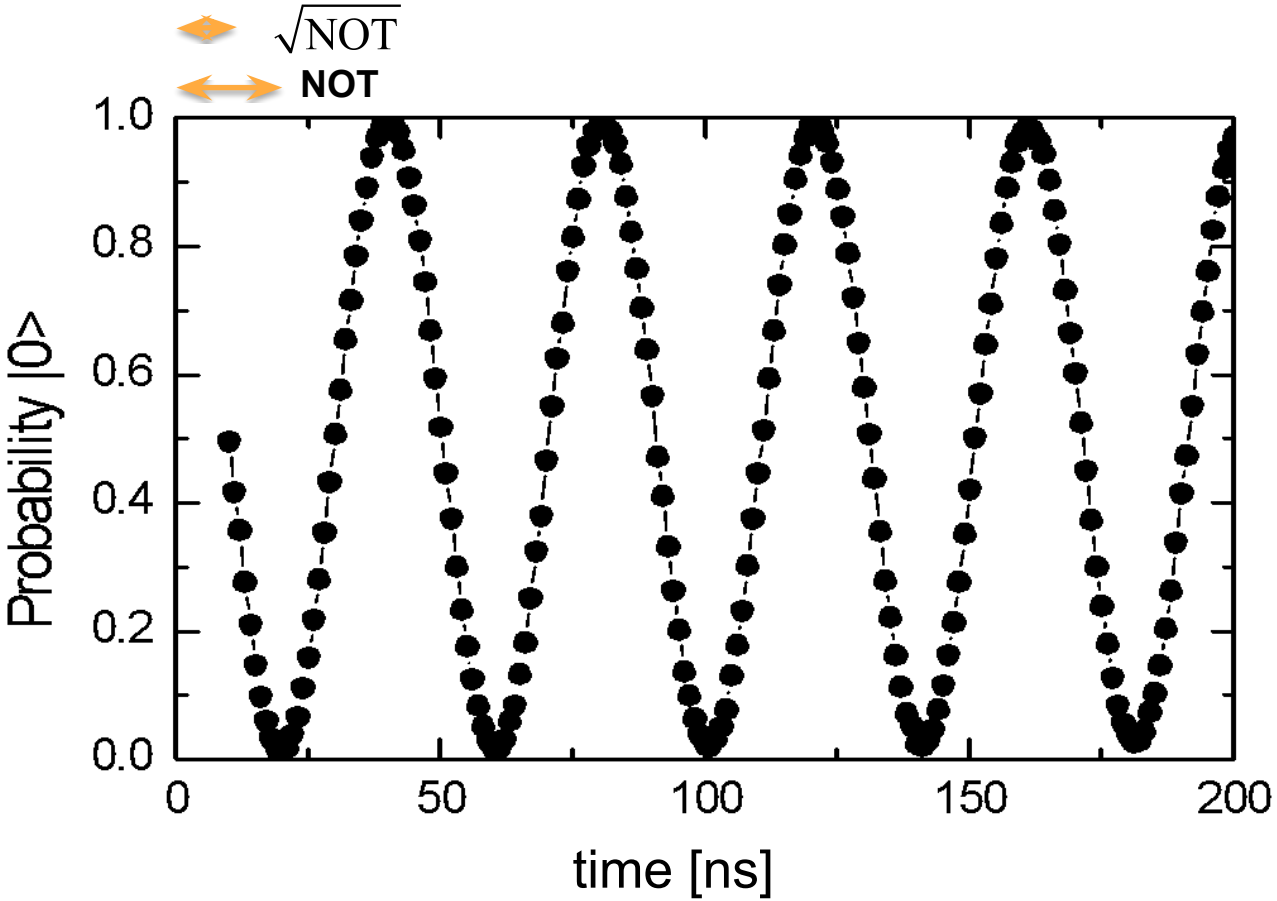


cross-section

Large, easier to fabricate and control

Qubit Operation





Custom Electronics

Utility

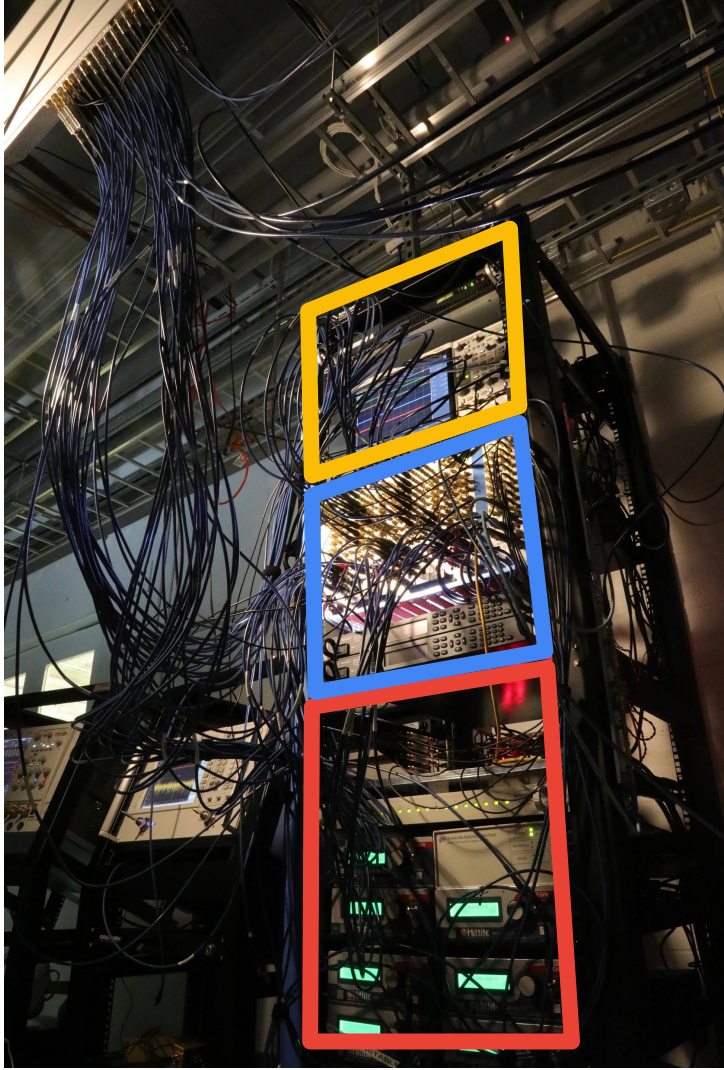
- Oscilloscope
- Power
- Server computer

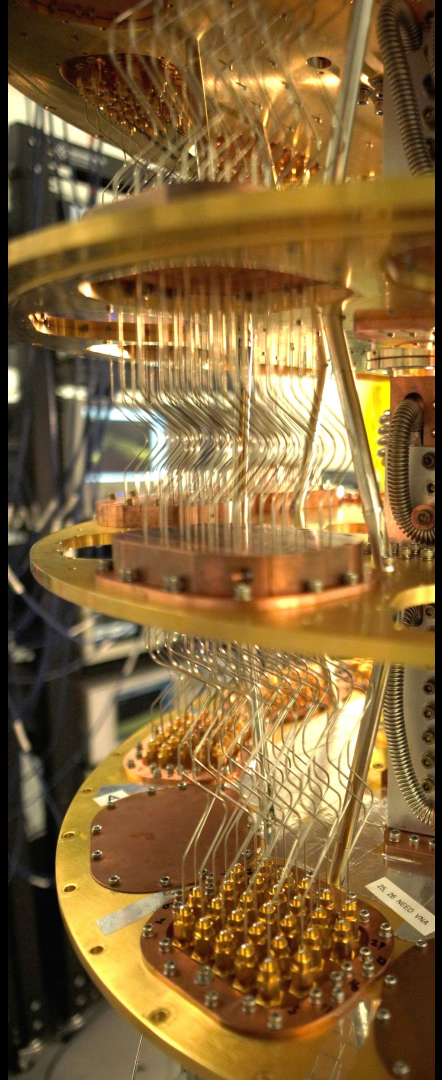
Control

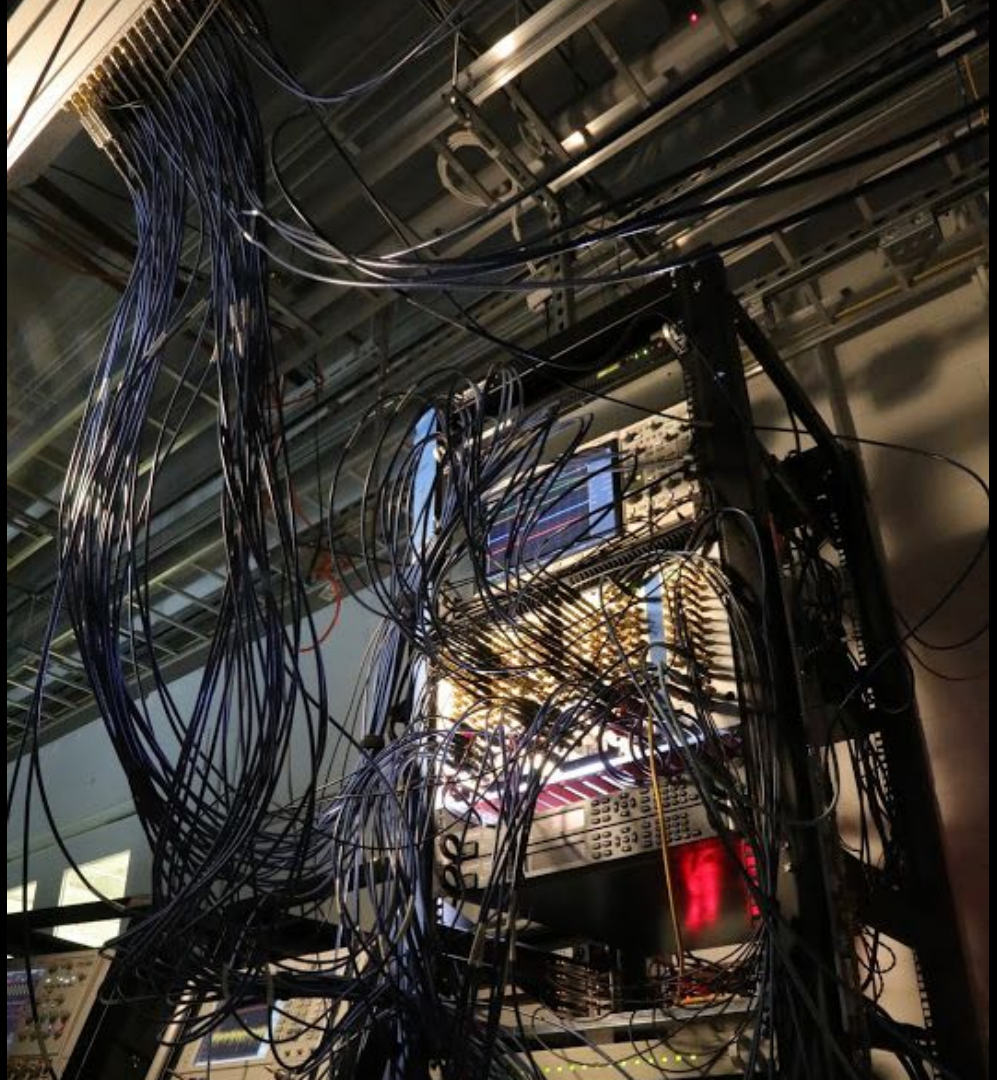
- Tuning control, microwave control, readout input, for 24 qubits

Legacy

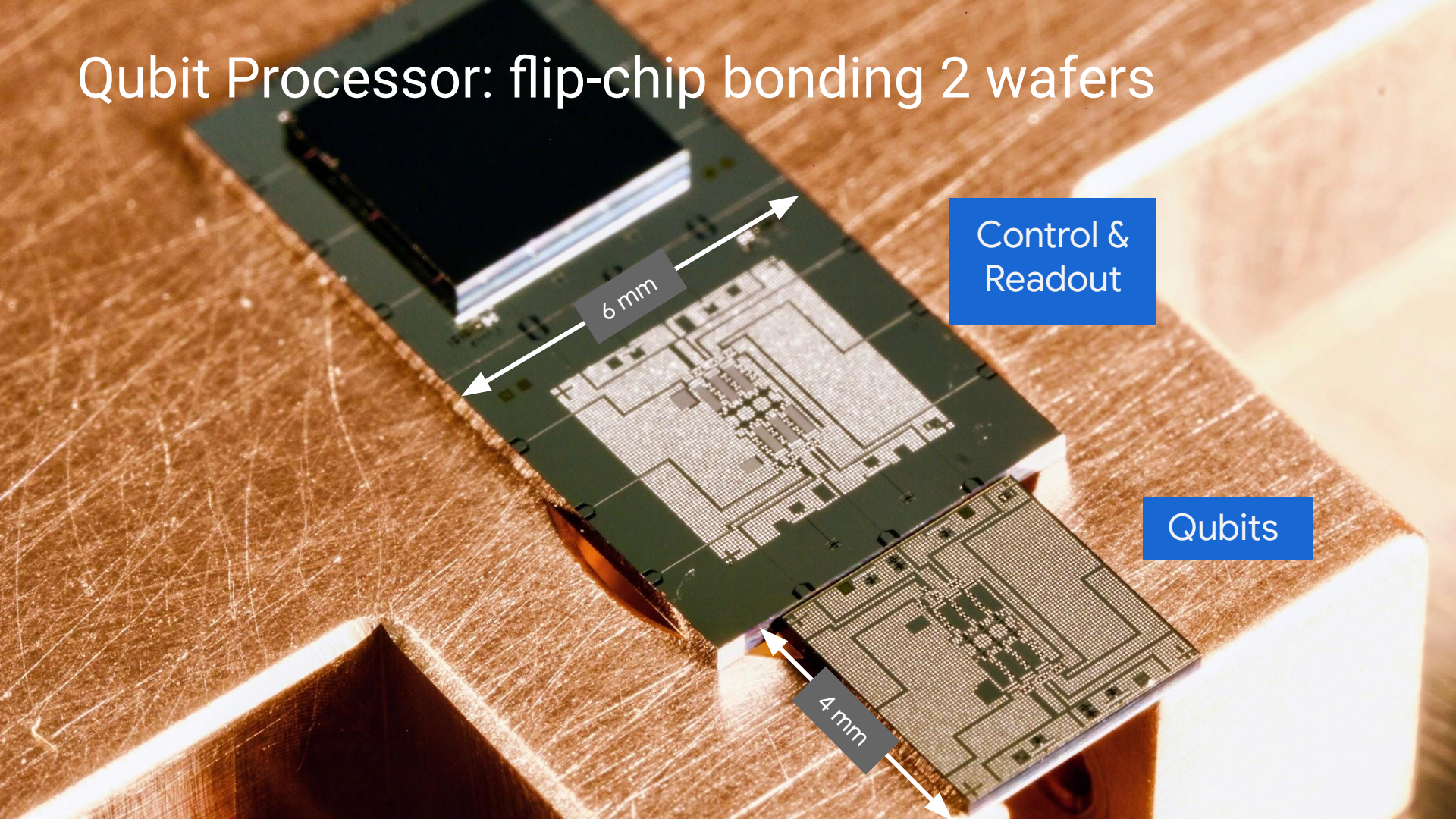
- Analog-Digital converter
- Microwave sources
- Clock

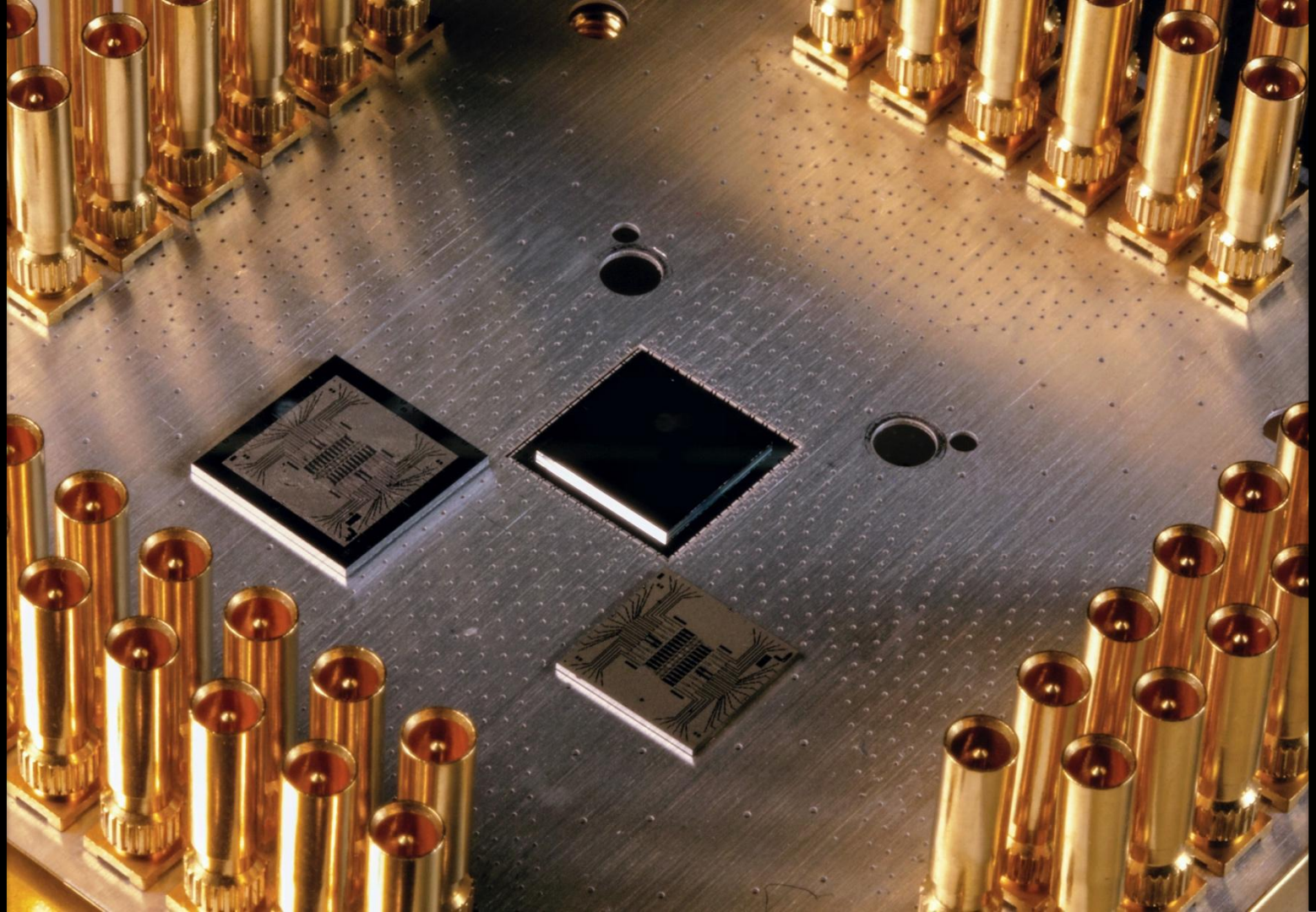






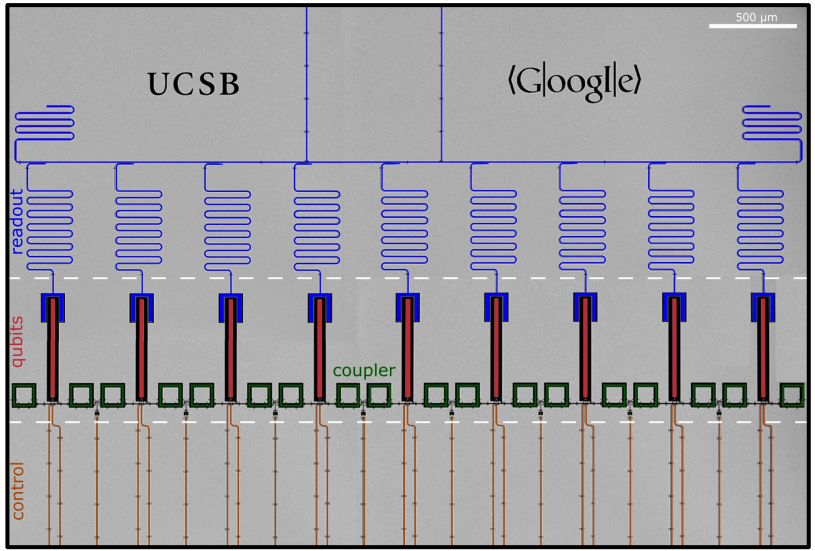
Qubit Processor: flip-chip bonding 2 wafers



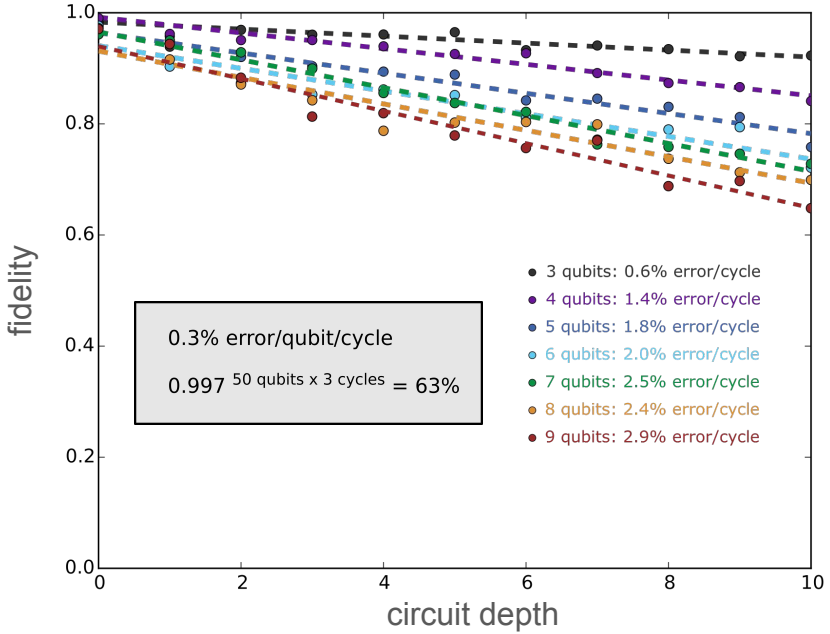


9-qubit demonstration with low errors

9 qubit device



benchmarking data

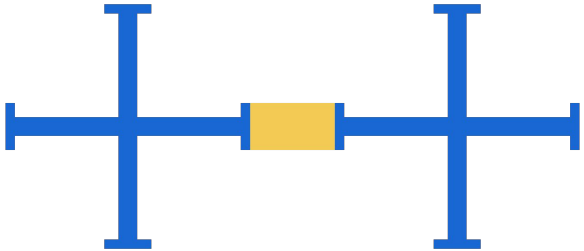


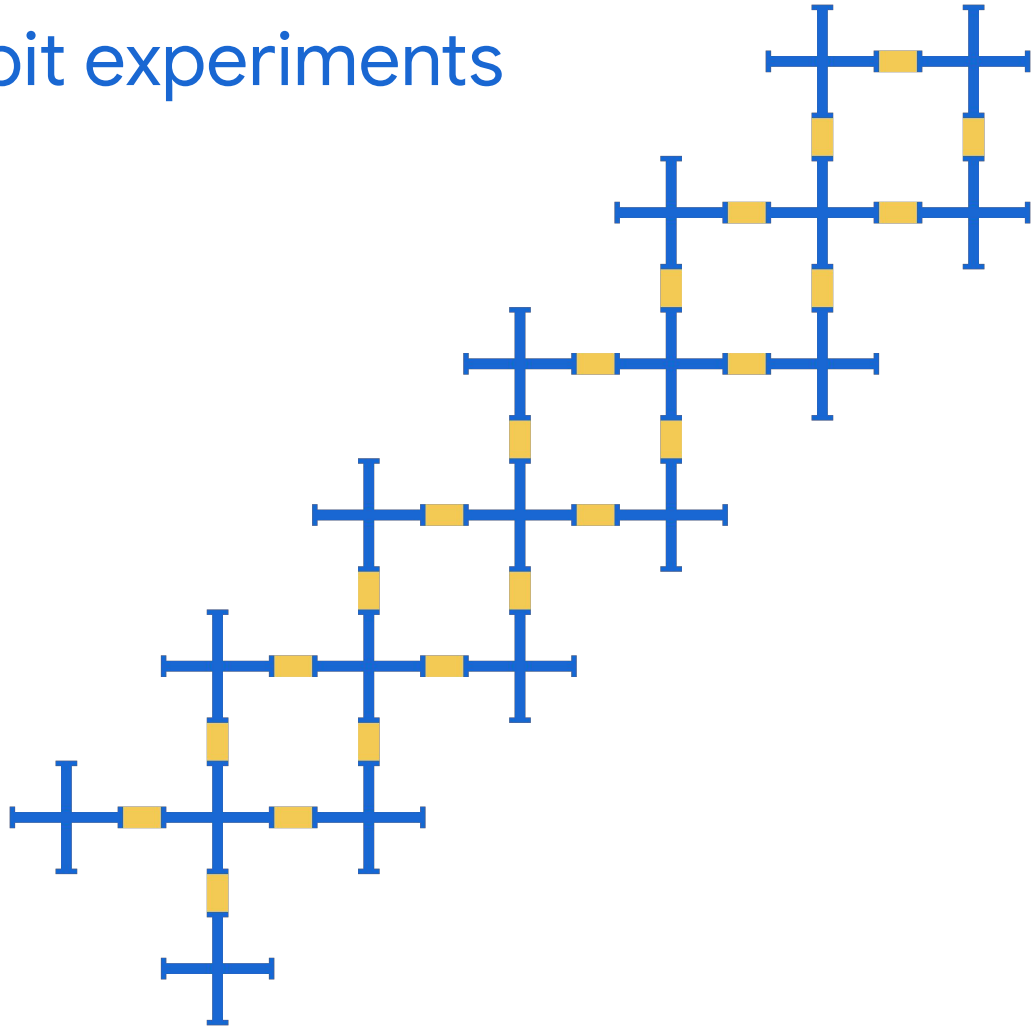
Google AI Quantum

A blueprint for demonstrating quantum supremacy, Neill et al, Science (2018)

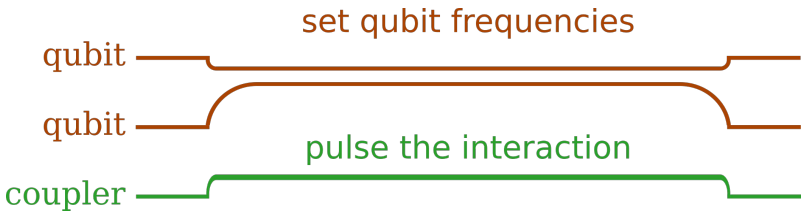
Tunable Coupler: 18 qubit experiments

Tileable 2D design
with tunable coupling





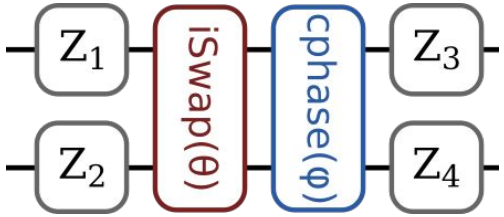
2-qubit gates

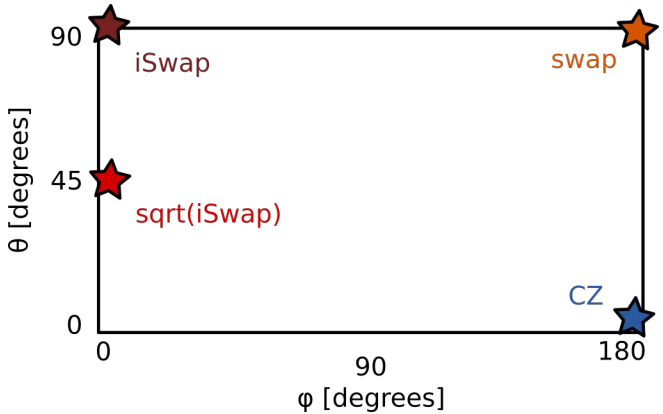


$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{i\alpha}\cos\theta & e^{i\beta}\sin\theta & 0 \\ 0 & e^{i\gamma}\sin\theta & e^{i\delta}\cos\theta & 0 \\ 0 & 0 & 0 & e^{i\varphi} \end{pmatrix}$$

00 01 10 11

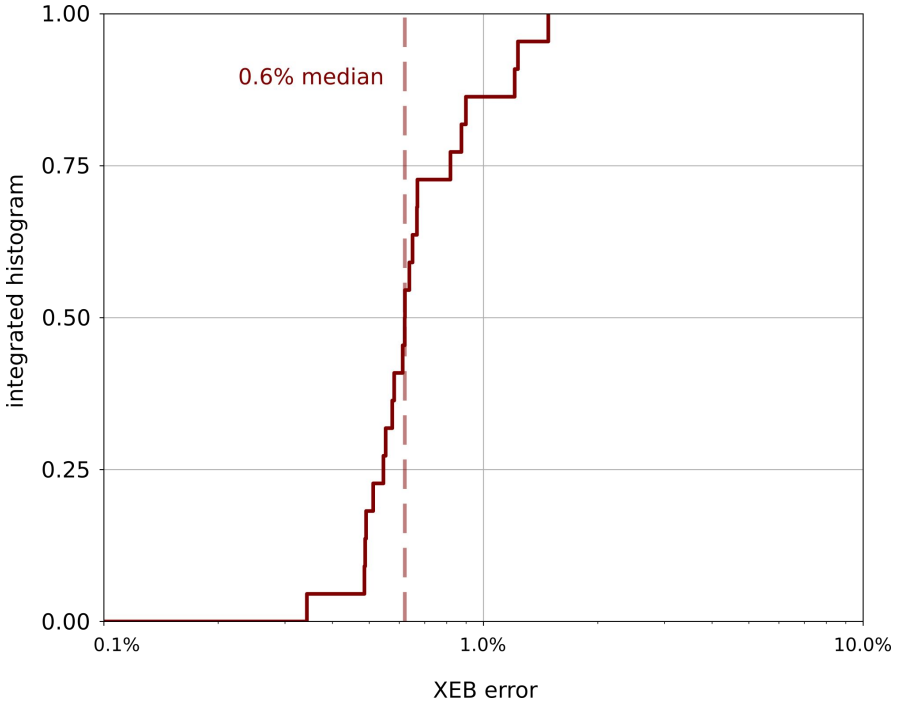
Model for arbitrary photon-conserving gate

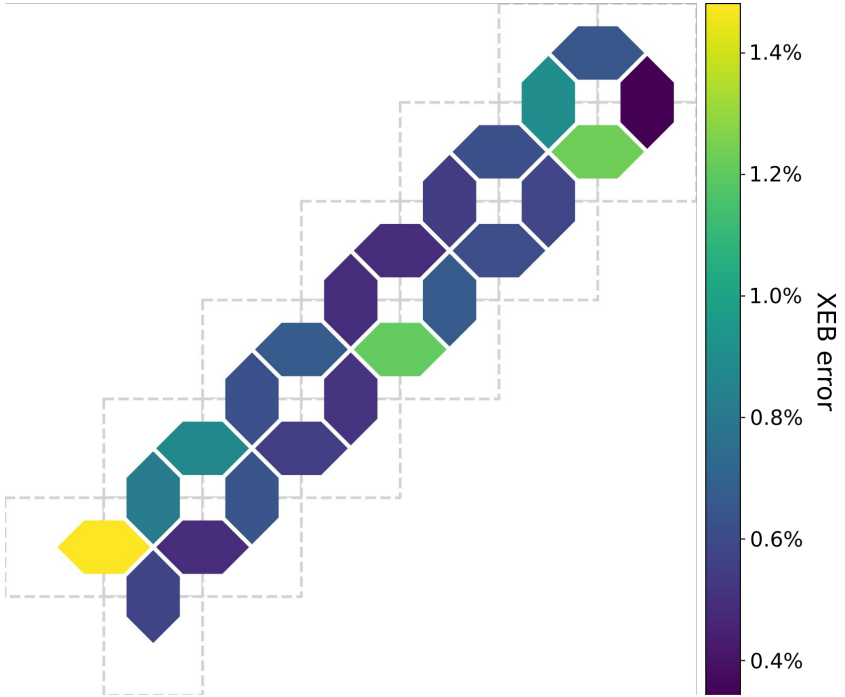




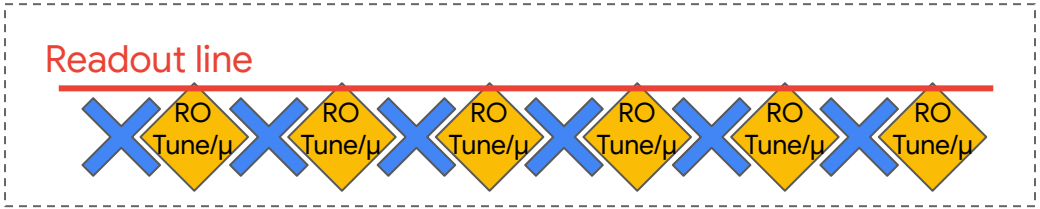
High fidelity control for all angles, see B42.8 (today @ 11:15)

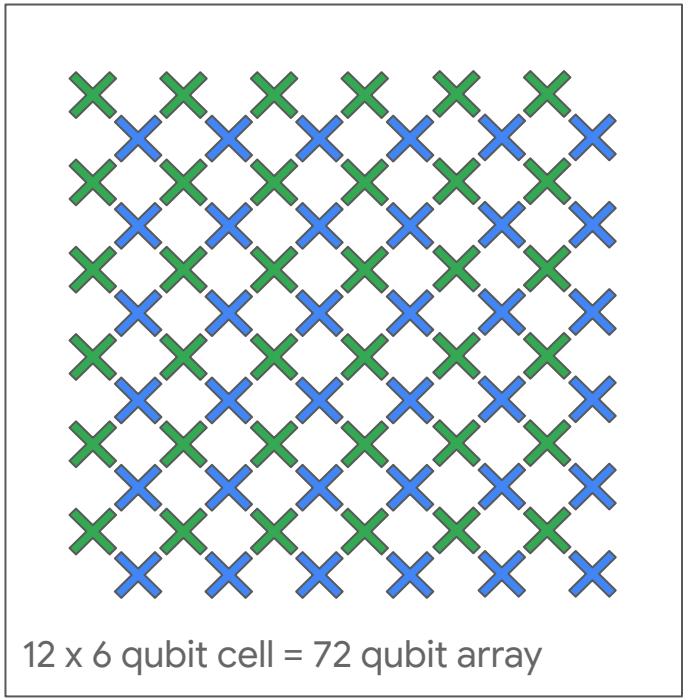
Distribution of XEB errors across the chip





Bristlecone: Our first 2D array



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Bristlecone


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