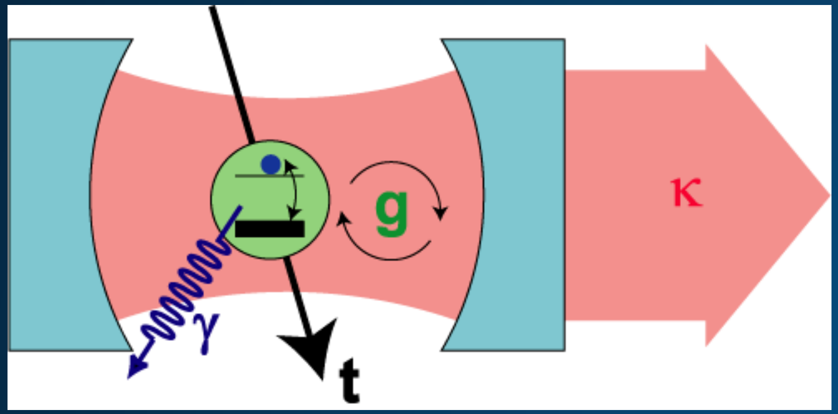
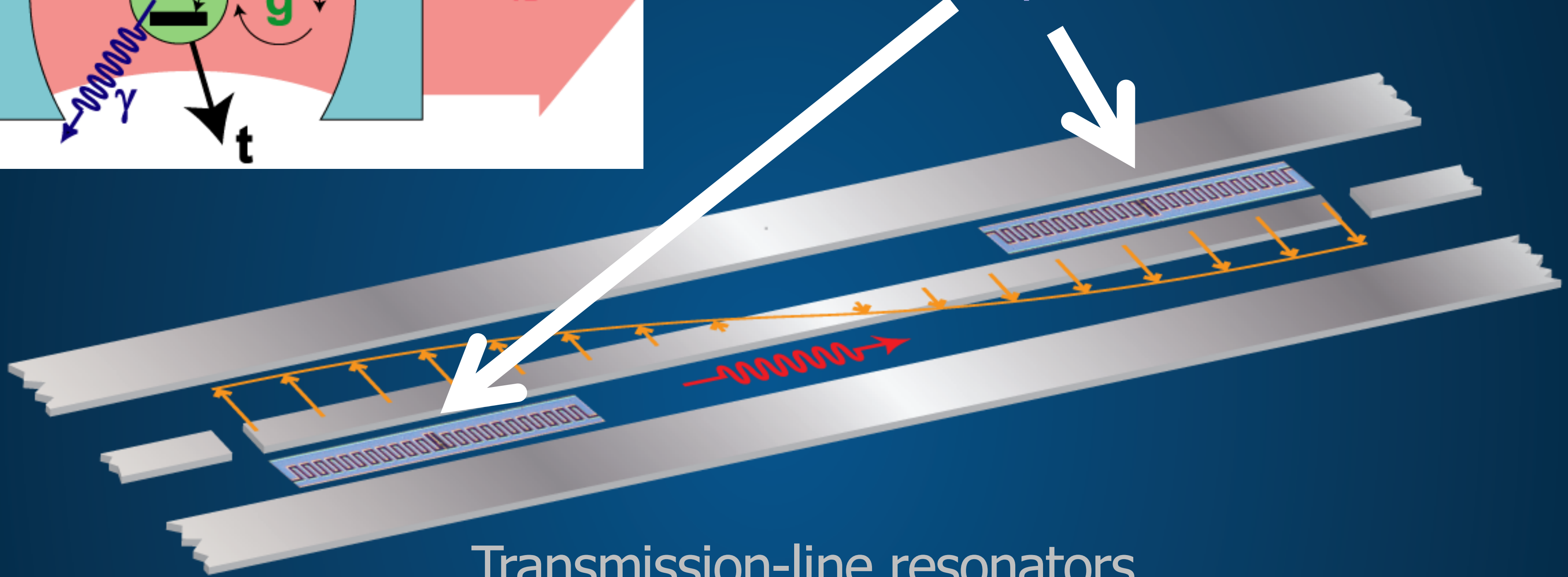
Leonardo DiCarlo

Superconducting quantum circuits: Circuit QED

Circuit QED: Cavity QED with wires



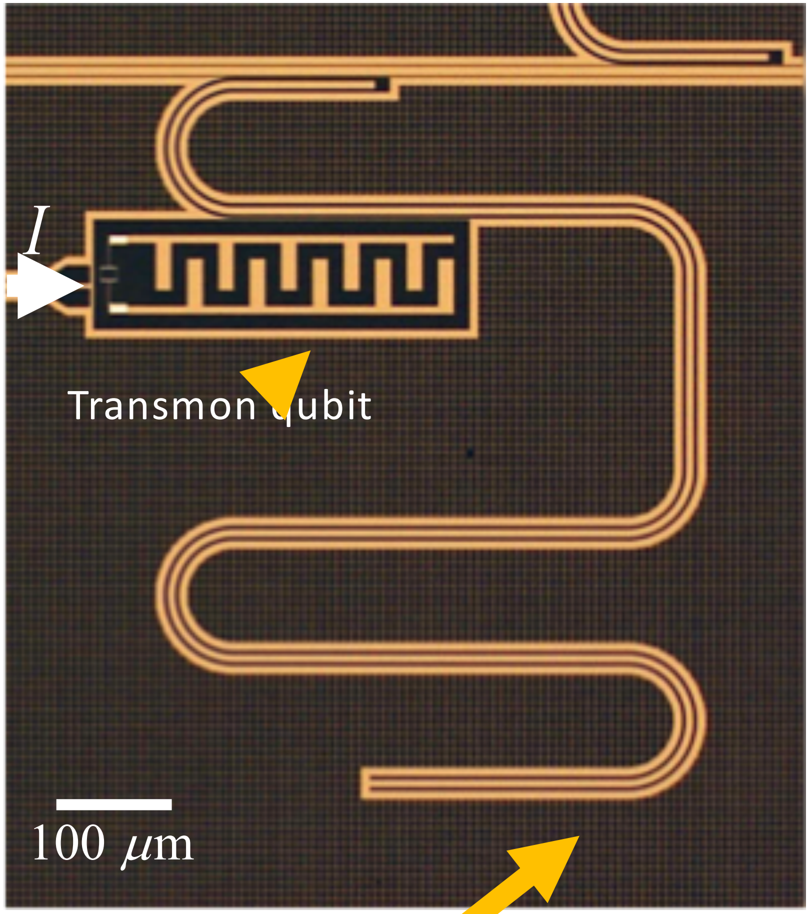


Transmission-line resonators

- mediate interaction between qubits
- allow qubit readout

Blais *et al.*, Phys. Rev. A (2004)

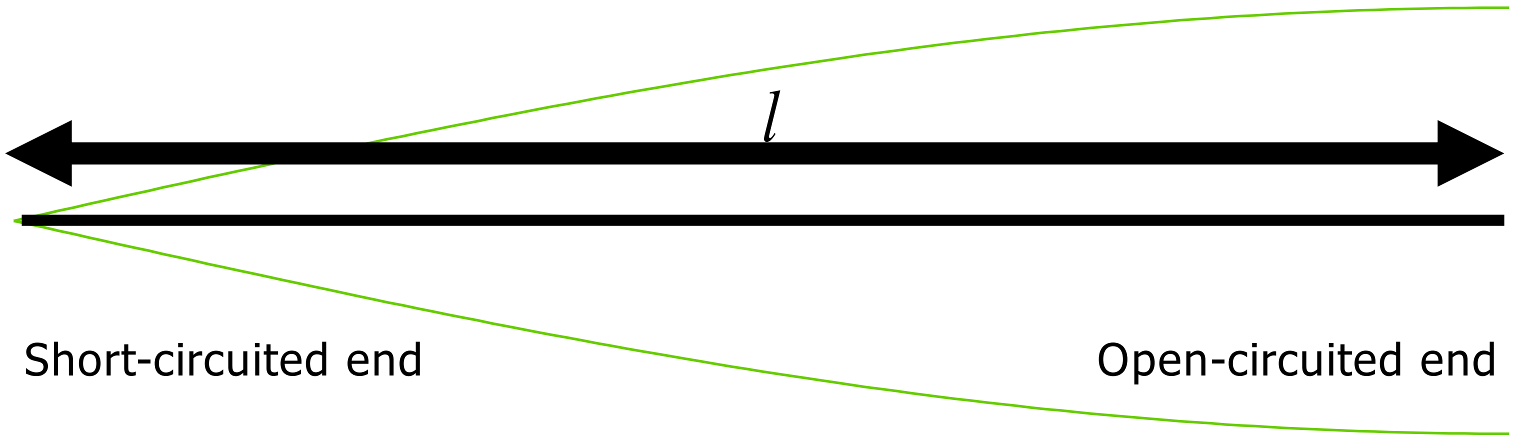
Qubit-resonator interaction



Transmission-line resonator

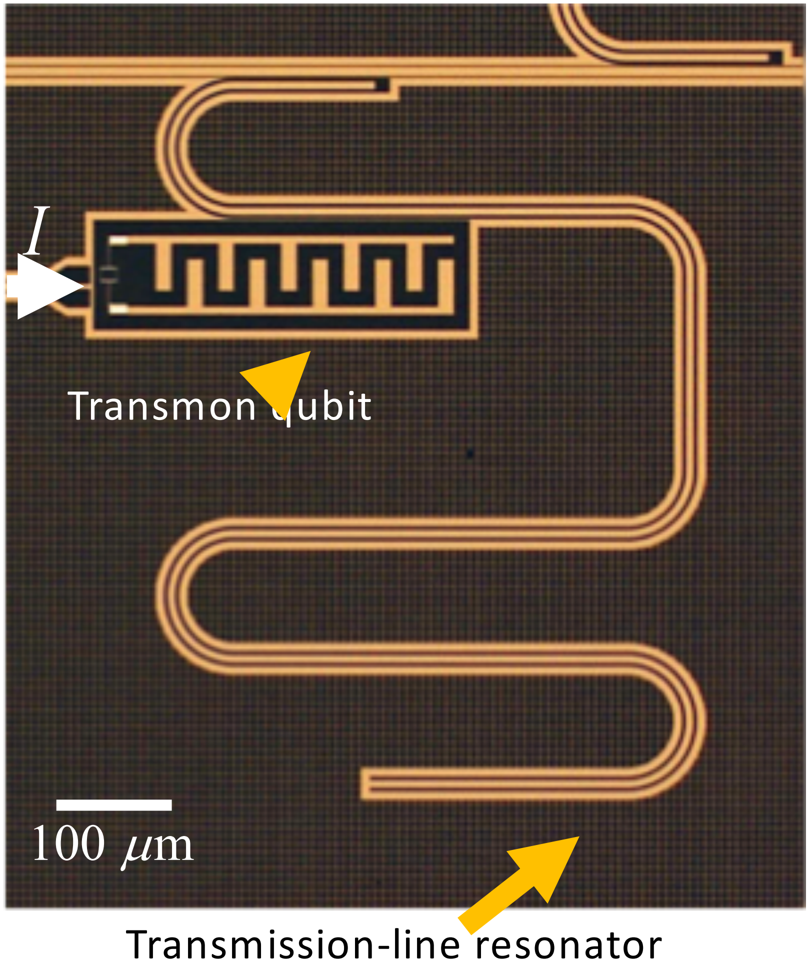
Resonator modes (usually we focus on fundamental) are set by

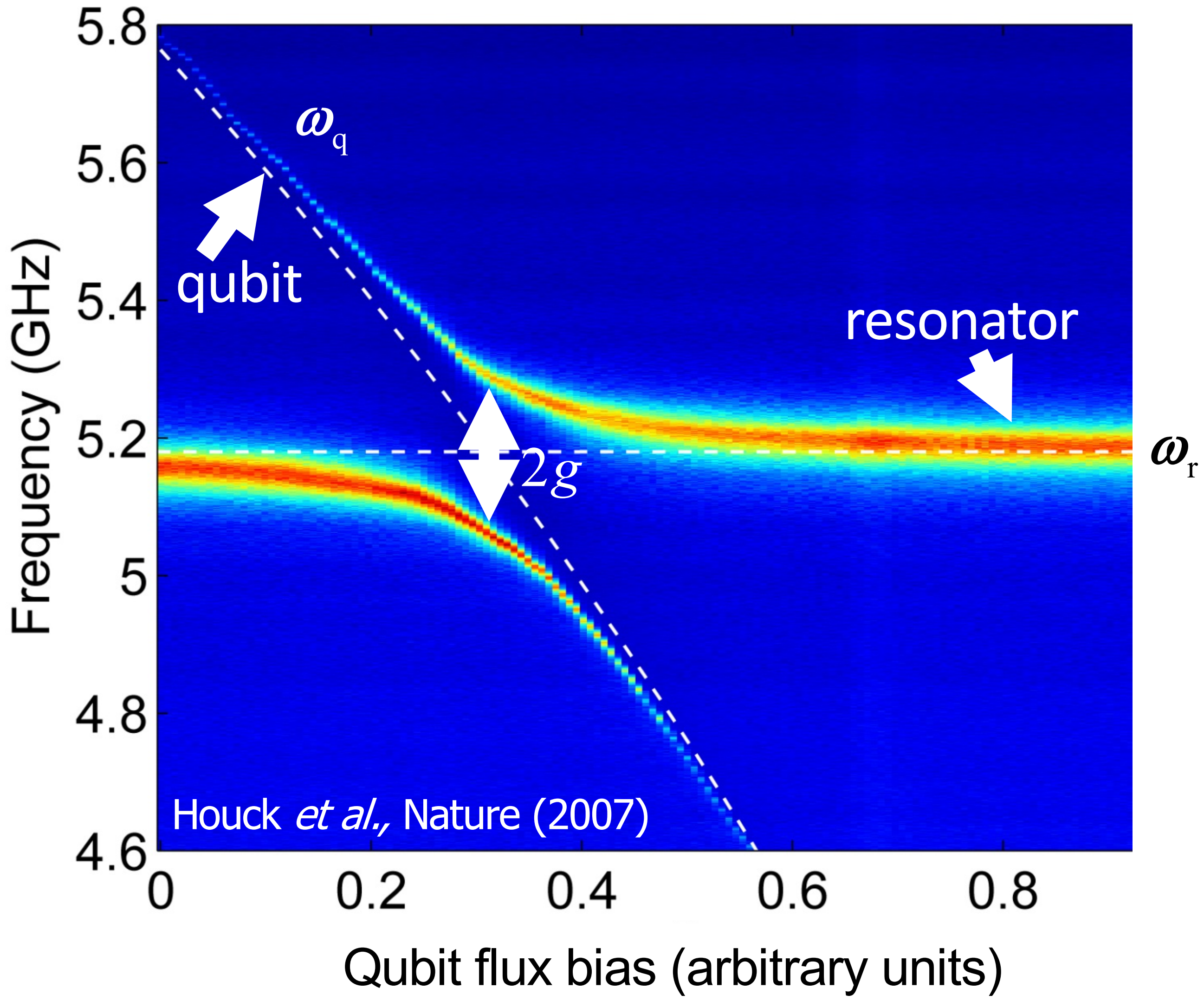
the total resonator length l
the end terminations (short or open circuit)
the phase velocity (slower than speed of light in vacuum by factor 2-3)



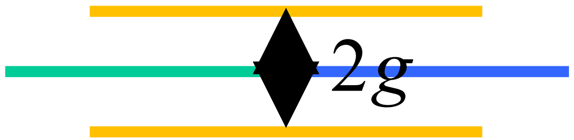
The coupling between qubit and resonator is typically capacitive

Qubit-resonator interaction

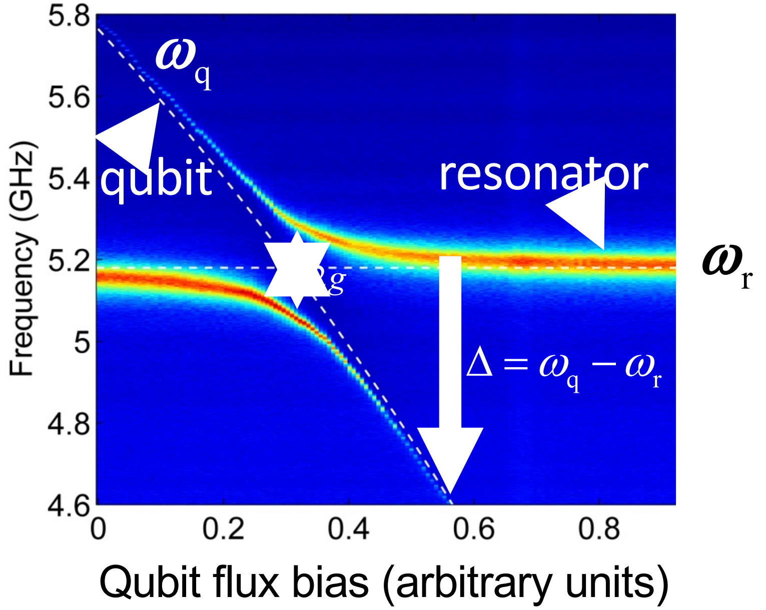


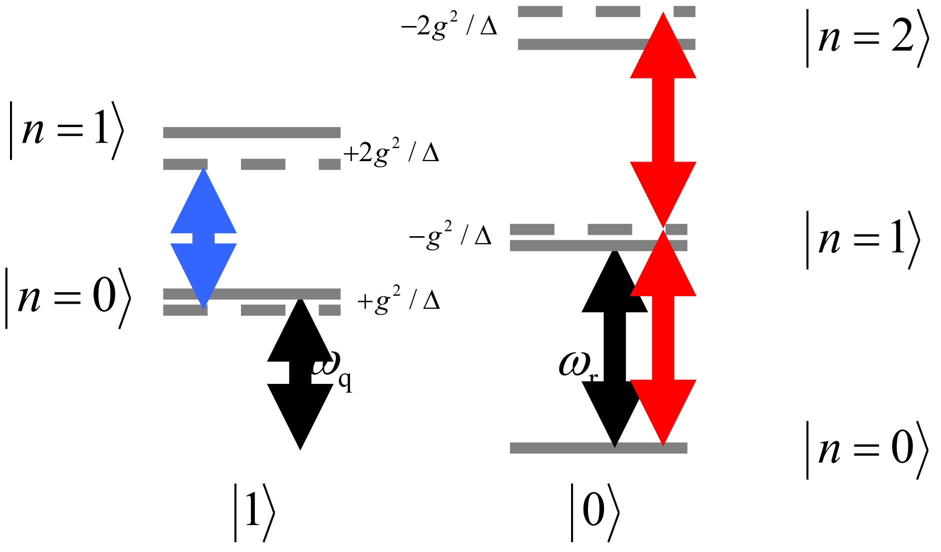


$$\hat{H}_{\text{int}} = \hbar g\left(a_r \hat{\sigma}_+ + a_r^\dagger \hat{\sigma}_-\right)$$ Jaynes-Cummings interaction



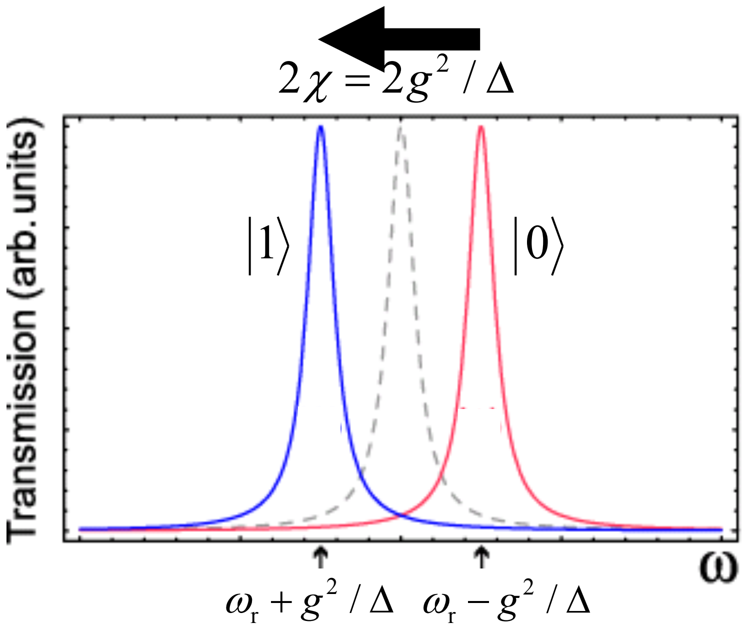
Dispersive regime





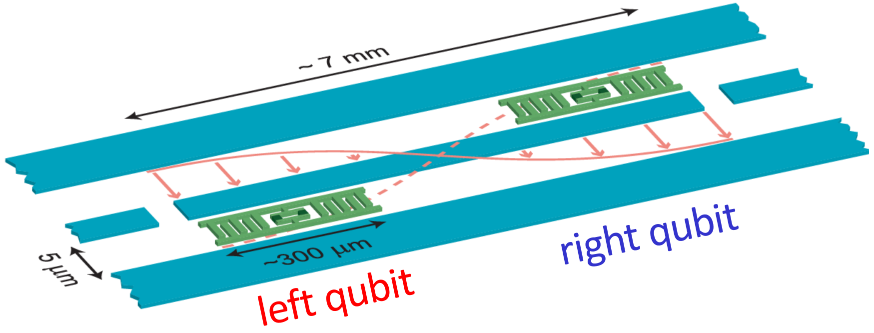
Photon ladder

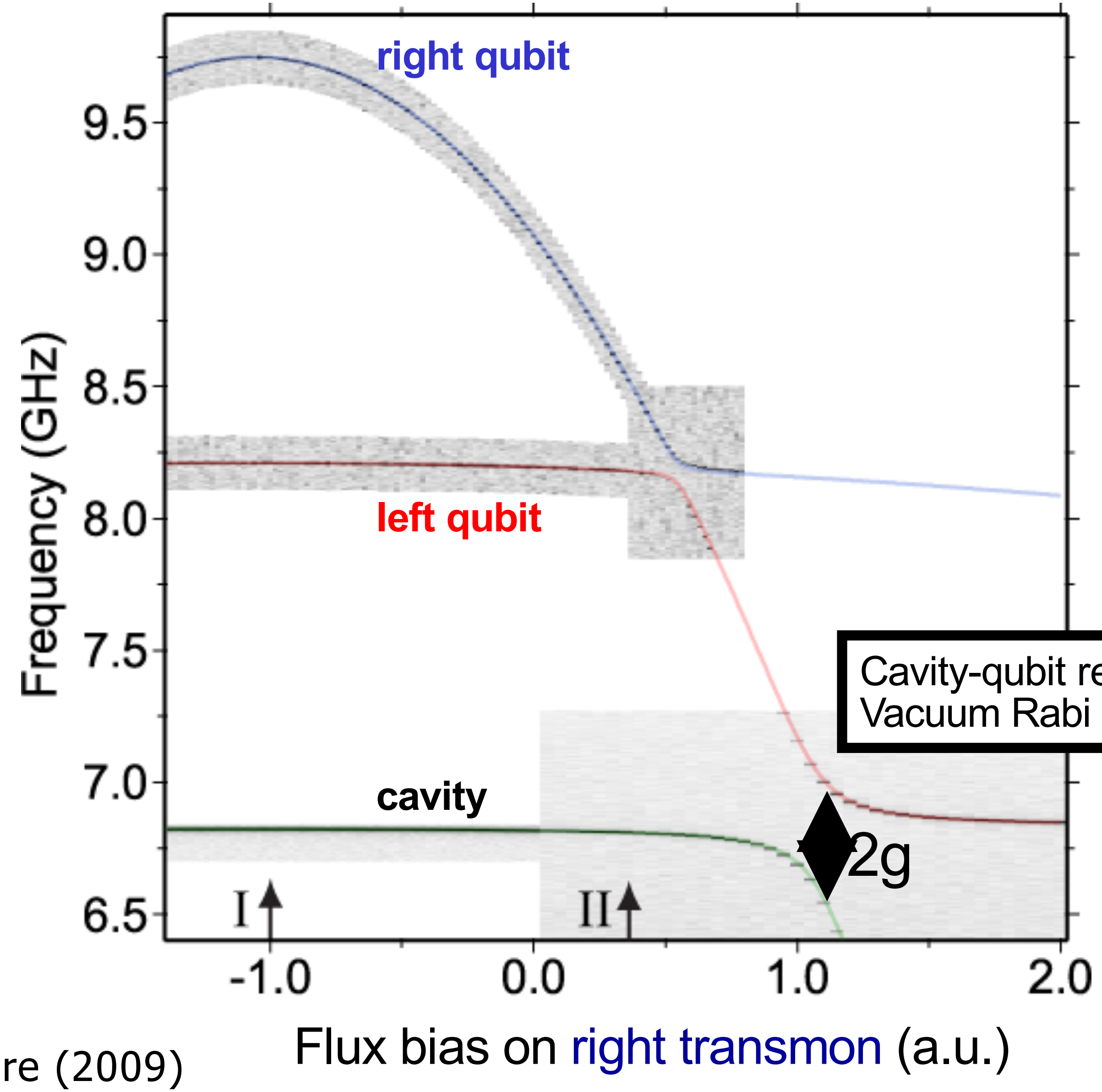
Dispersive regime: $|\Delta| = |\omega_q - \omega_r| >> g$



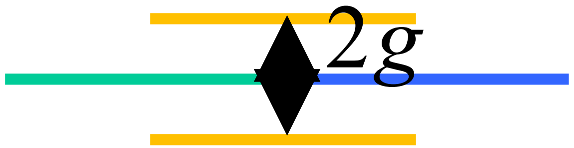
$$\hat{H}_{int} = -\hbar\chi\hat{\sigma}_Z a_r^\dagger a_r$$

Dispersive qubit-qubit interactions



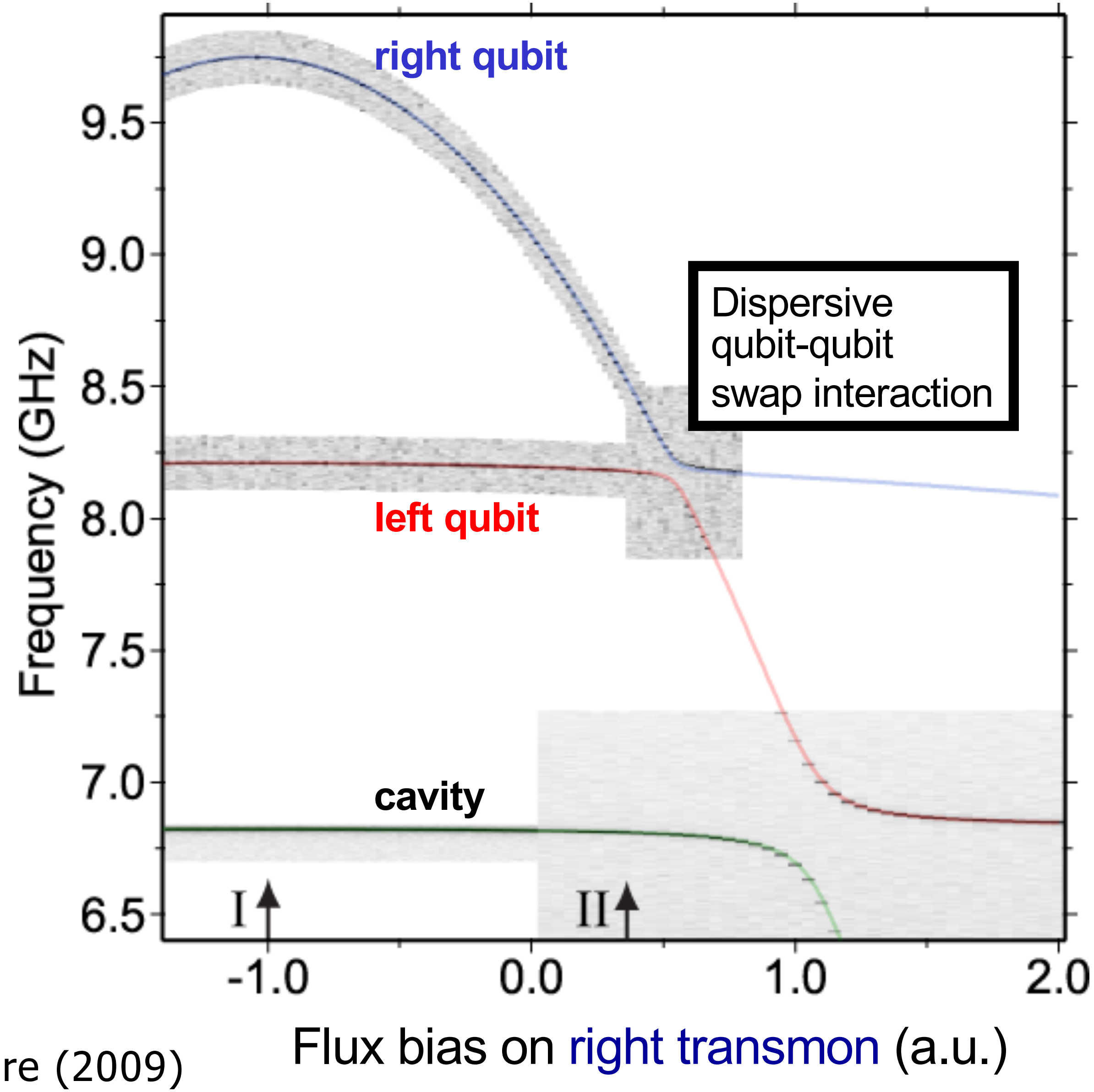


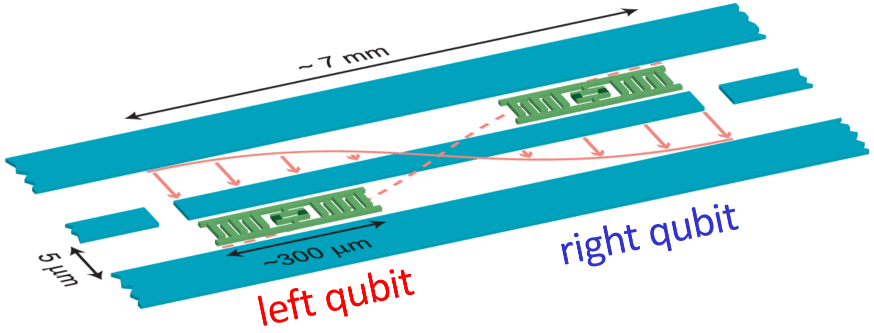
Cavity-qubit resonant interaction
Vacuum Rabi splitting

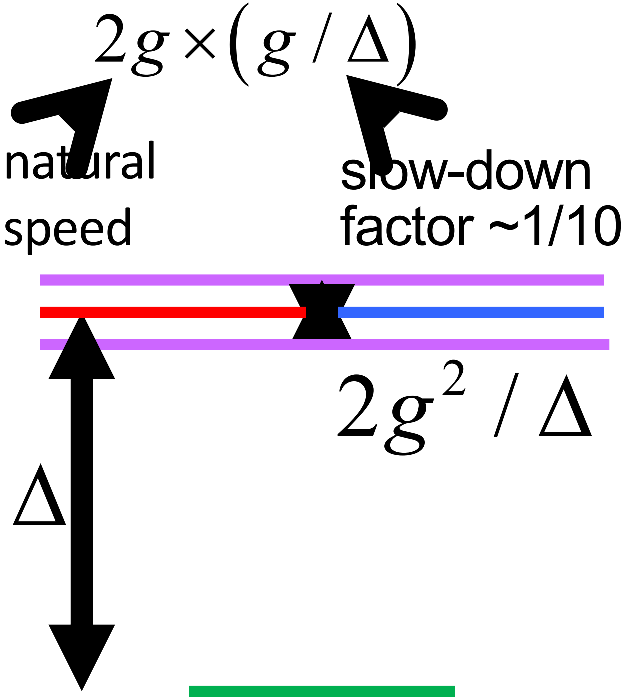


DiCarlo *et al.*, Nature (2009)

Dispersive qubit-qubit interactions

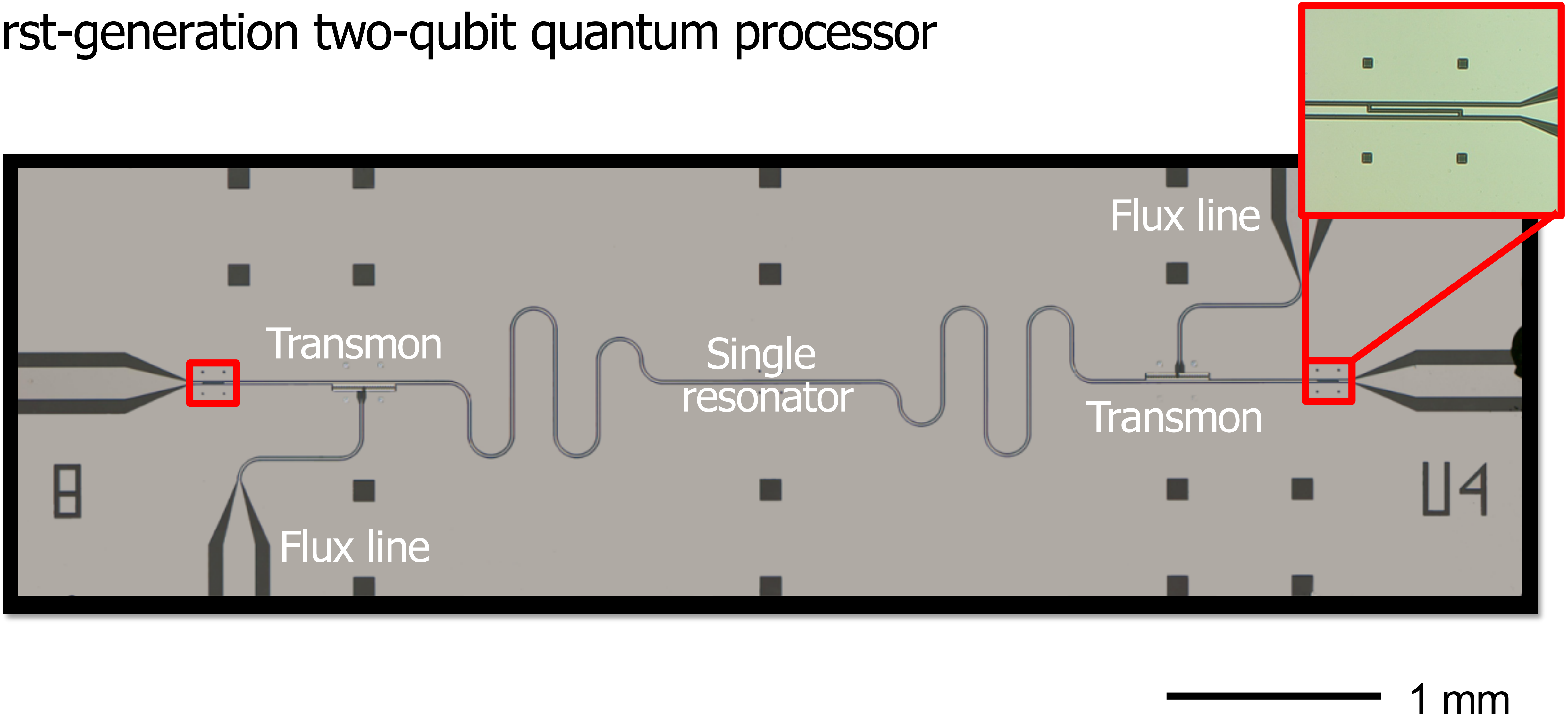






DiCarlo *et al.*, Nature (2009)

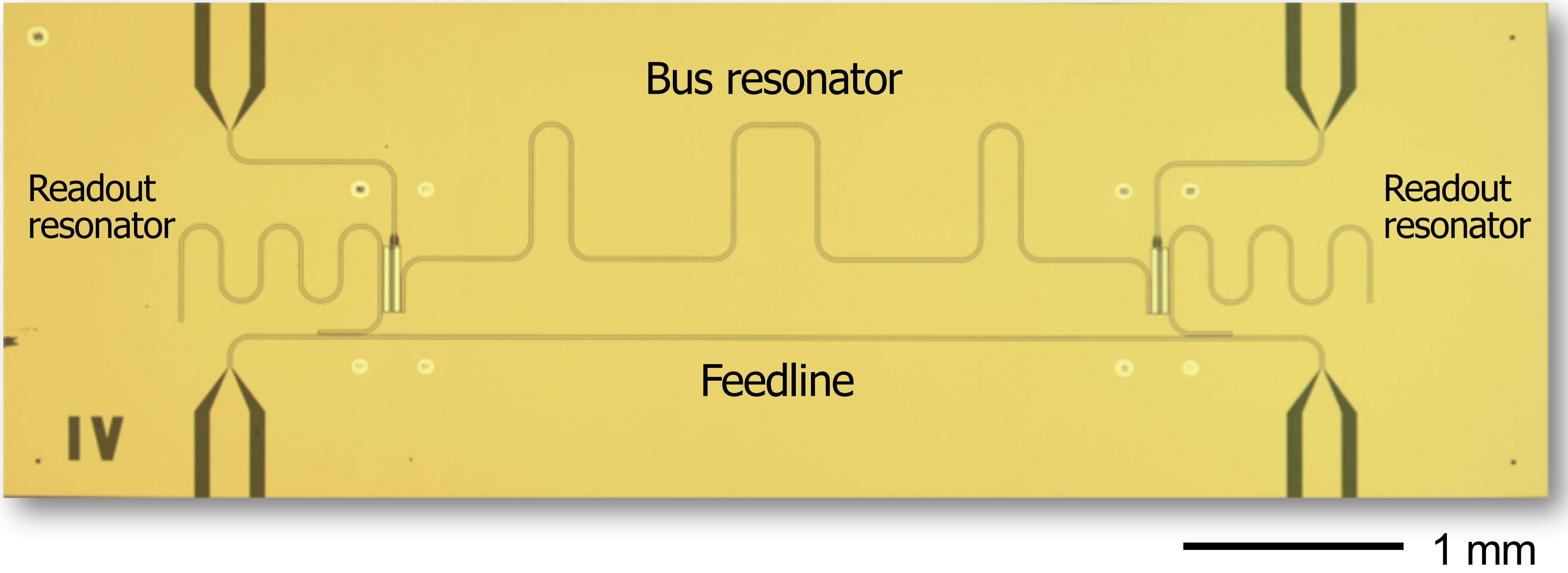
First-generation two-qubit quantum processor



One resonator for both qubit-qubit coupling and for readout

DiCarlo *et al.*, Nature (2009)

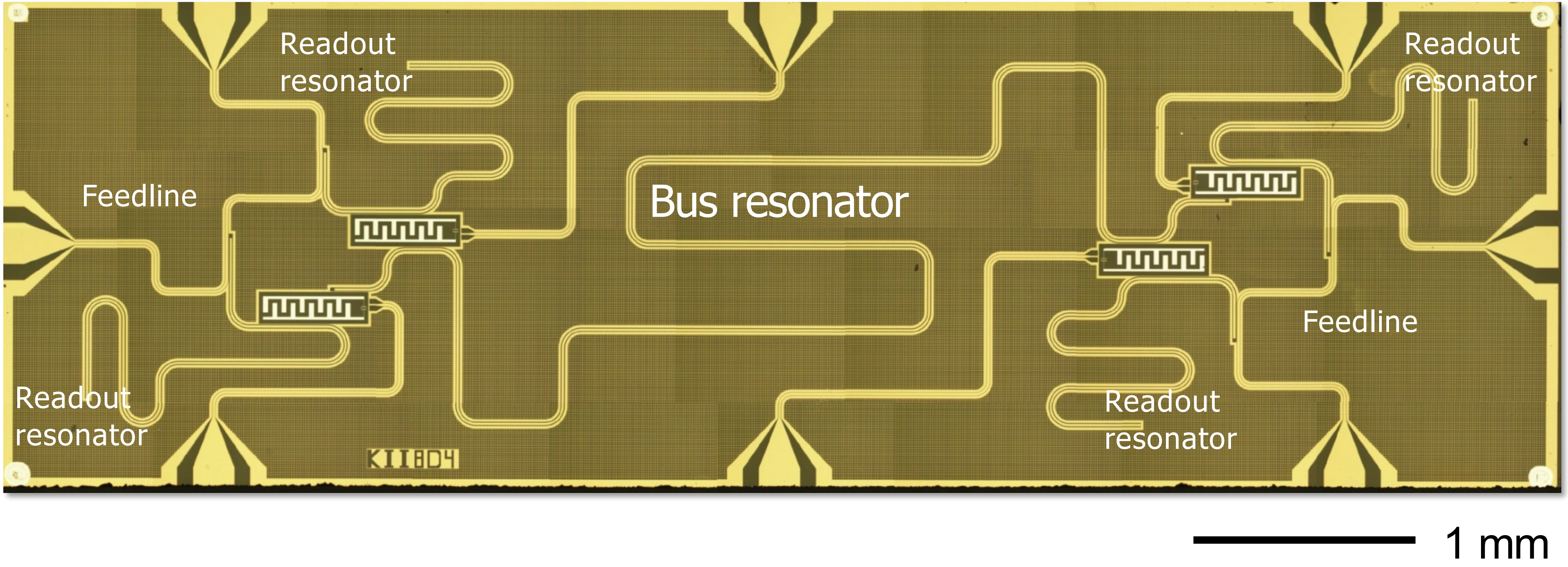
Second-generation two-qubit processor



Different resonators for qubit-qubit coupling and for readout of each qubit

Groen *et al.*, Phys. Rev. Lett. (2013)

Second-generation four-qubit processor

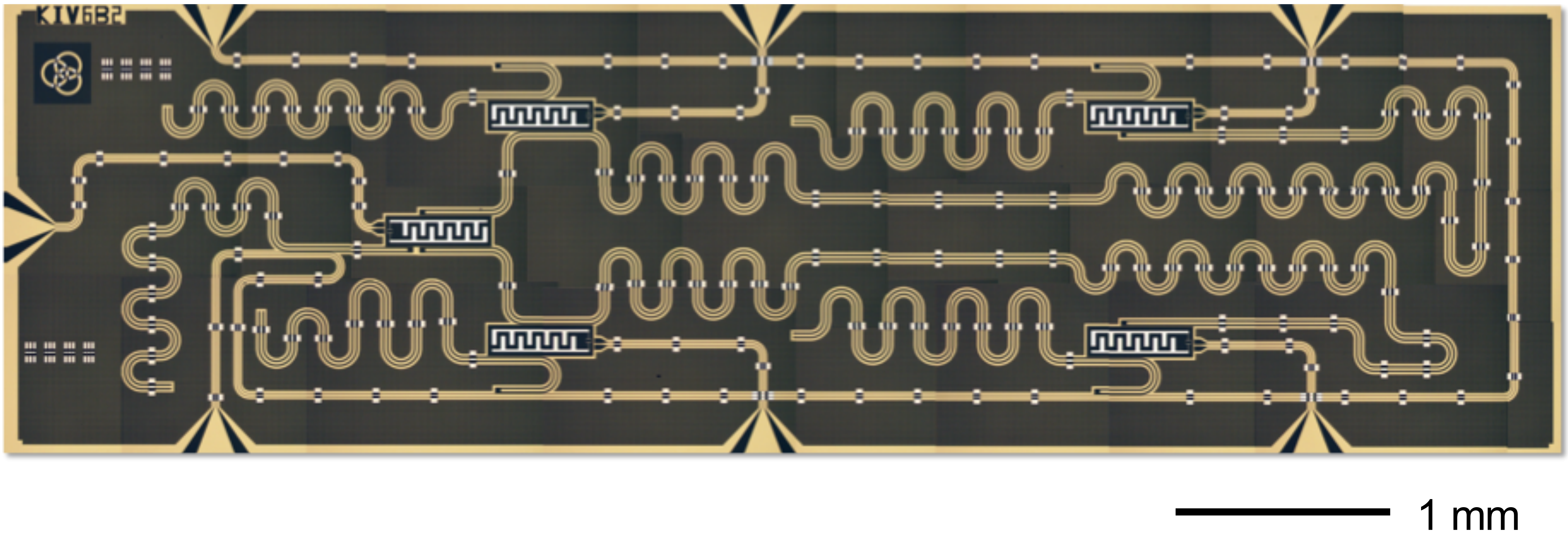


Different resonators for qubit-qubit coupling and for readout of each qubit

Saira *et al.*, Phys. Rev. Lett. (2014)

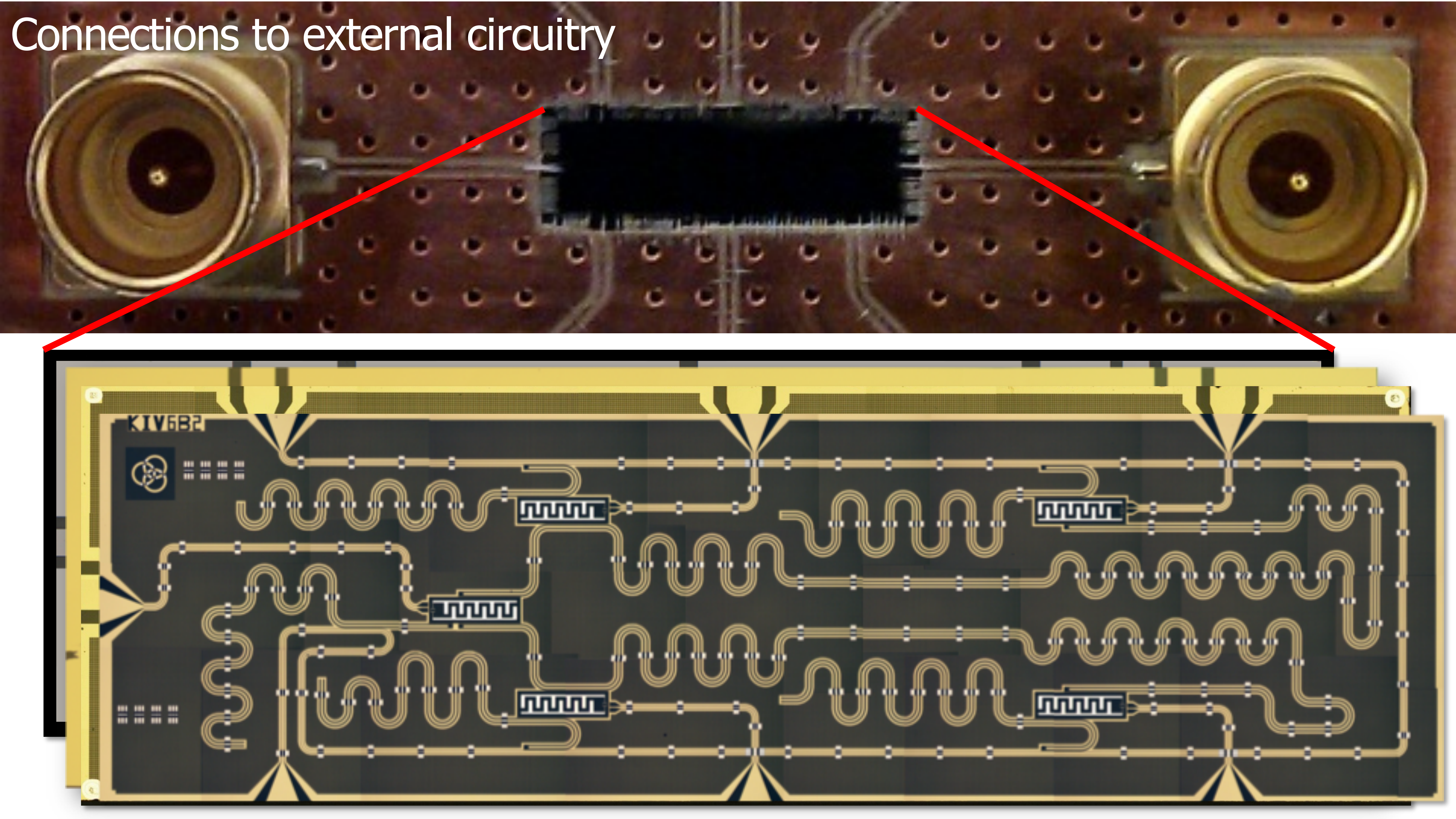
Second-generation five-qubit processor

Challenge: identify the readout resonators and bus resonators



Different resonators for qubit-qubit coupling and for readout of each qubit

Riste *et al.*, Nature Communications (2015)


Connections to external circuitry
KIV6B2