Superconducting qubits

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FiQCI short course

4th June 2024

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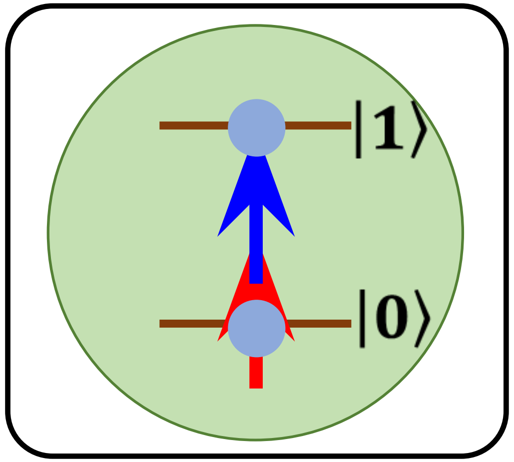
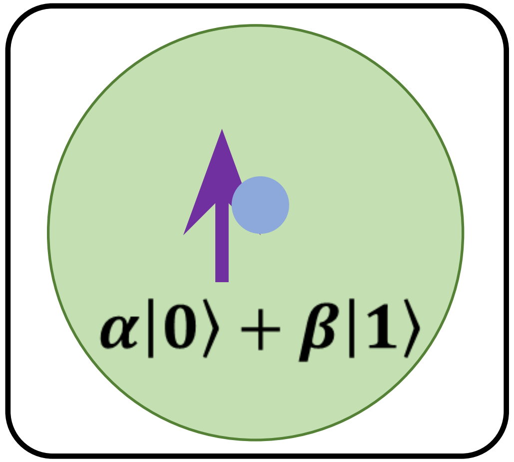
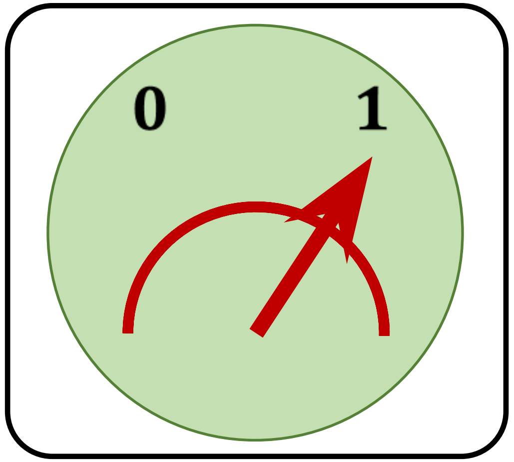
Quantum computer: Requirements



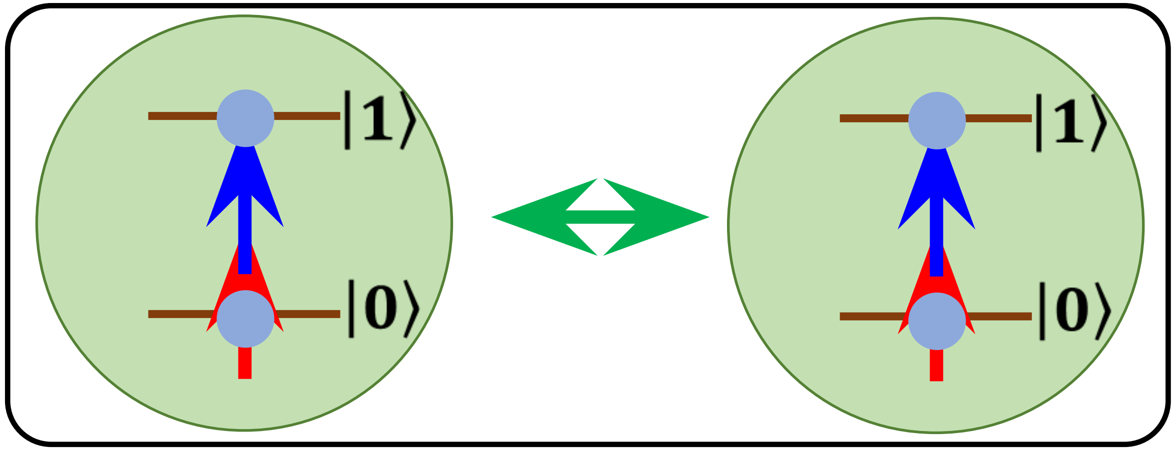
Two level quantum system



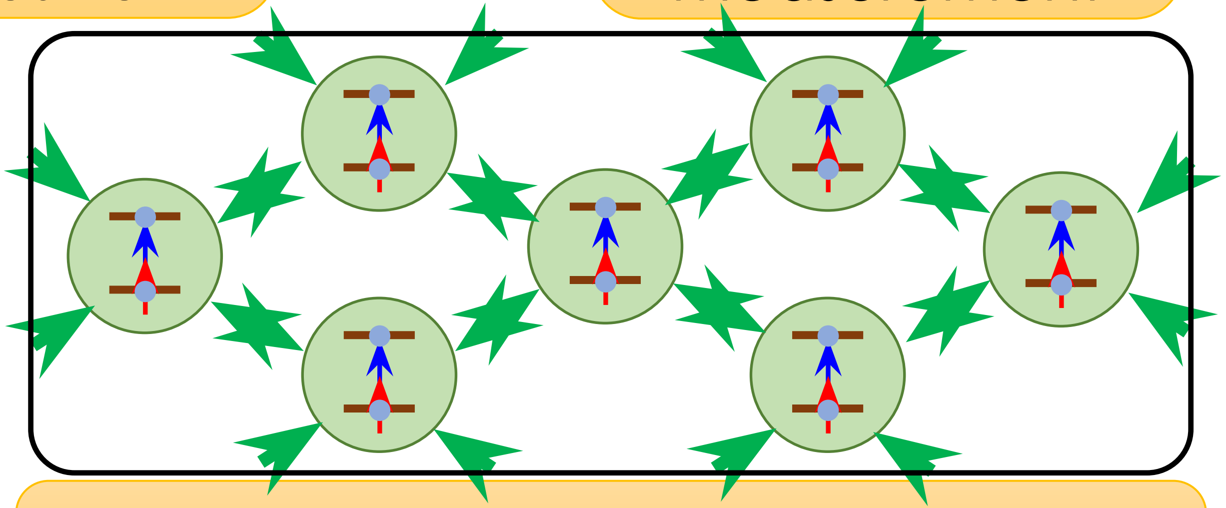
Arbitrary superposition



State measurement

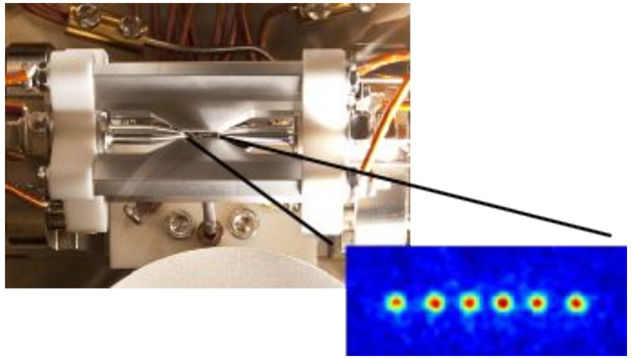


Multi-qubit interaction



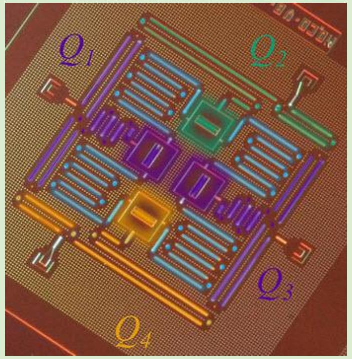
Scalable architecture

Quantum computer: Implementations



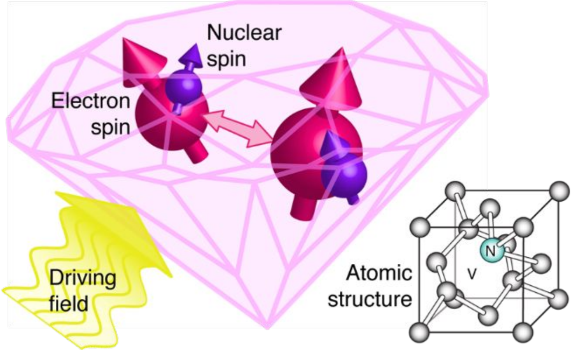
IQOQI, Blatt’s group

Ion traps



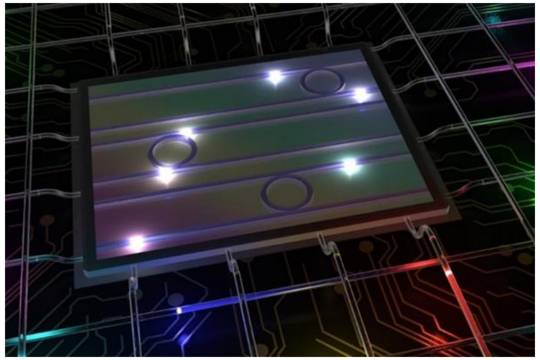
IBM

Superconducting circuits



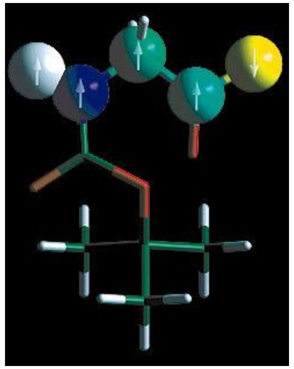
aps.org

NV centers in diamond



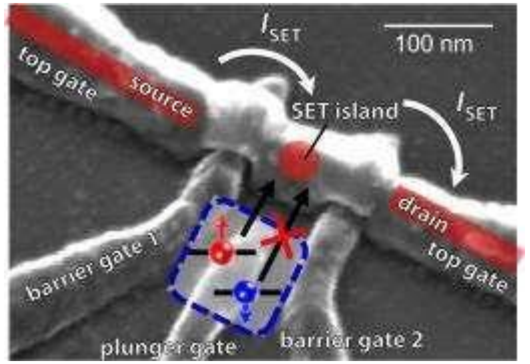
Cosmos magazine

Photonic crystals



Chemie.tu

NMR



phys.org

Quantum dot

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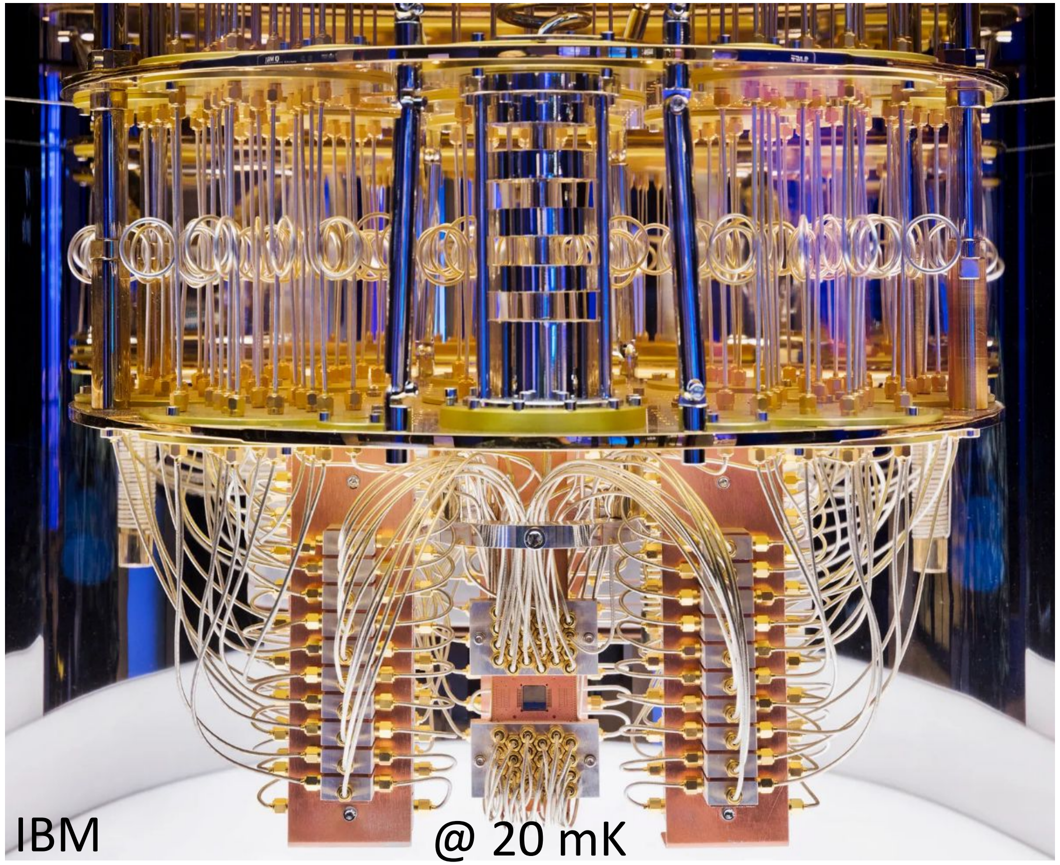
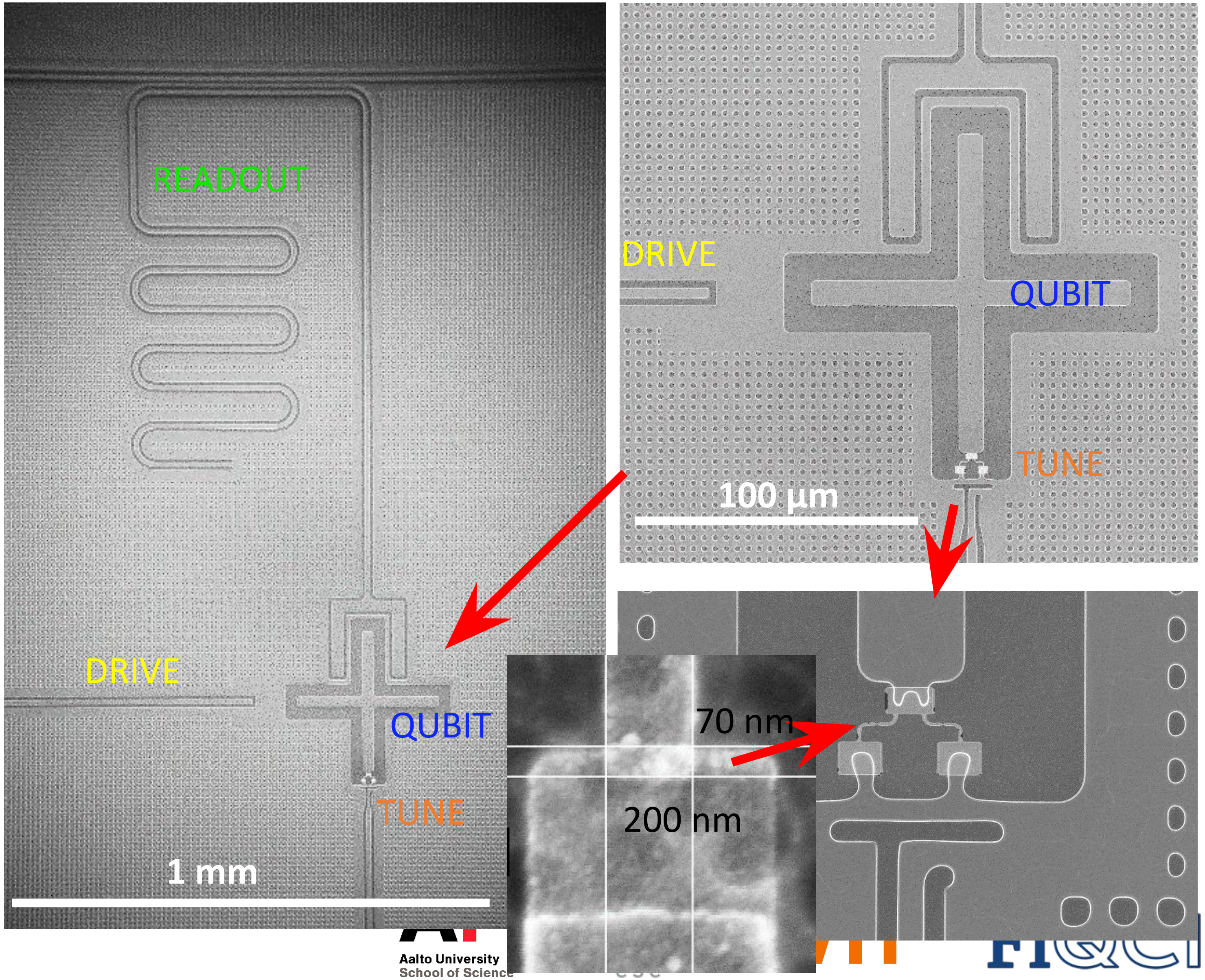
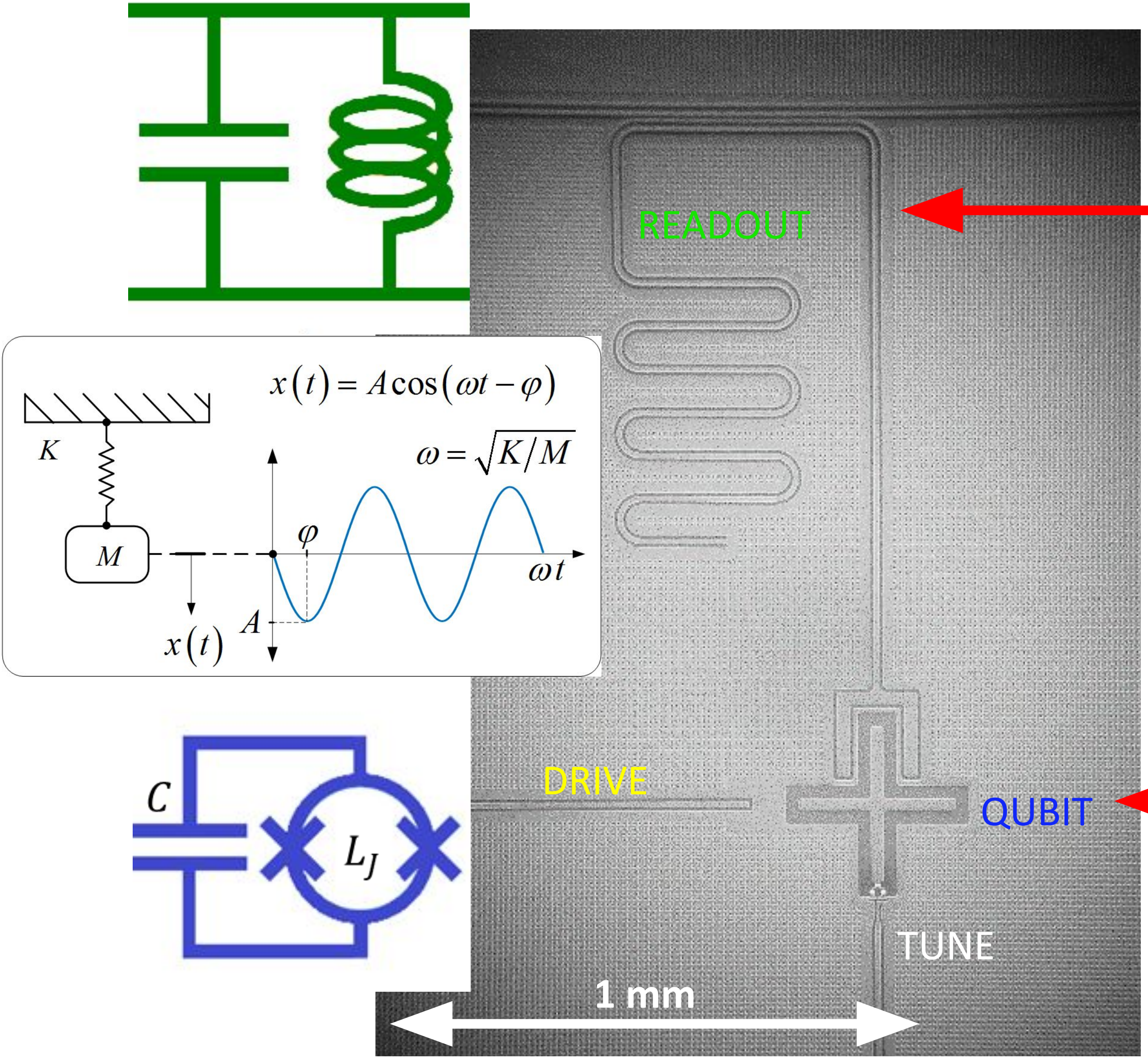
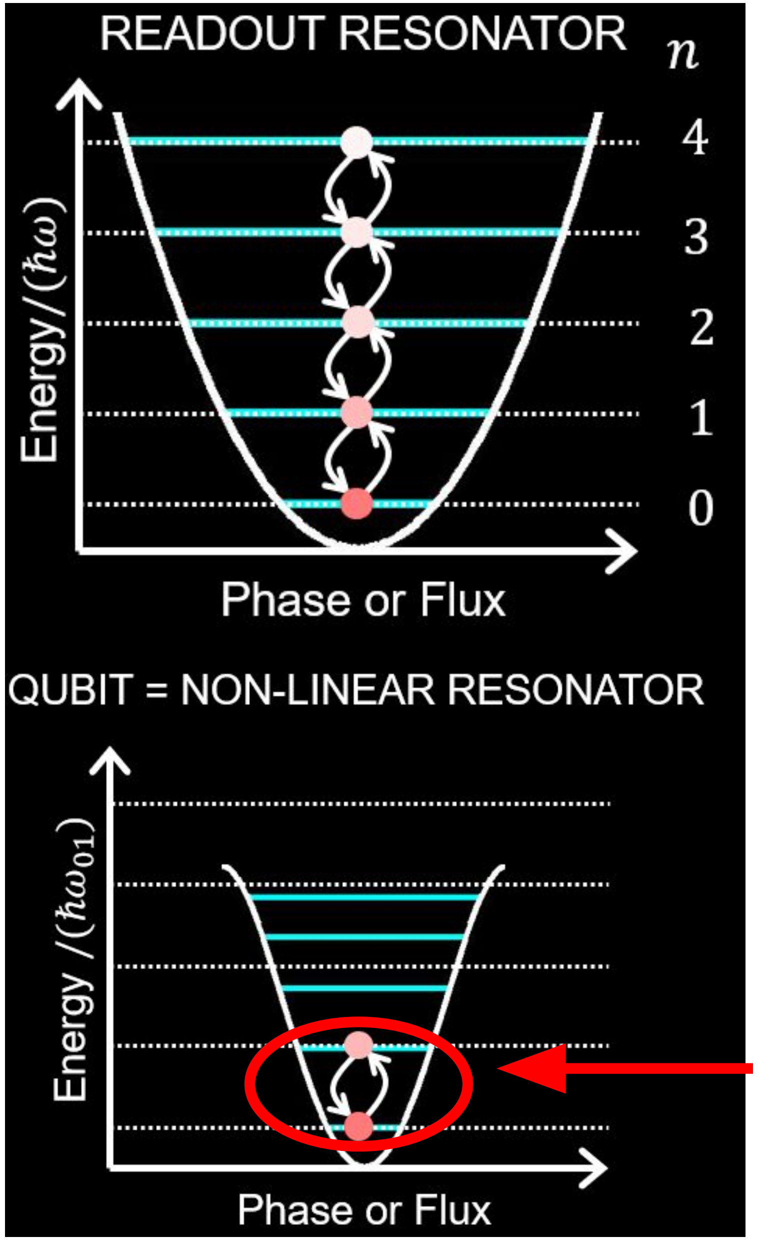
Superconducting qubit & readout





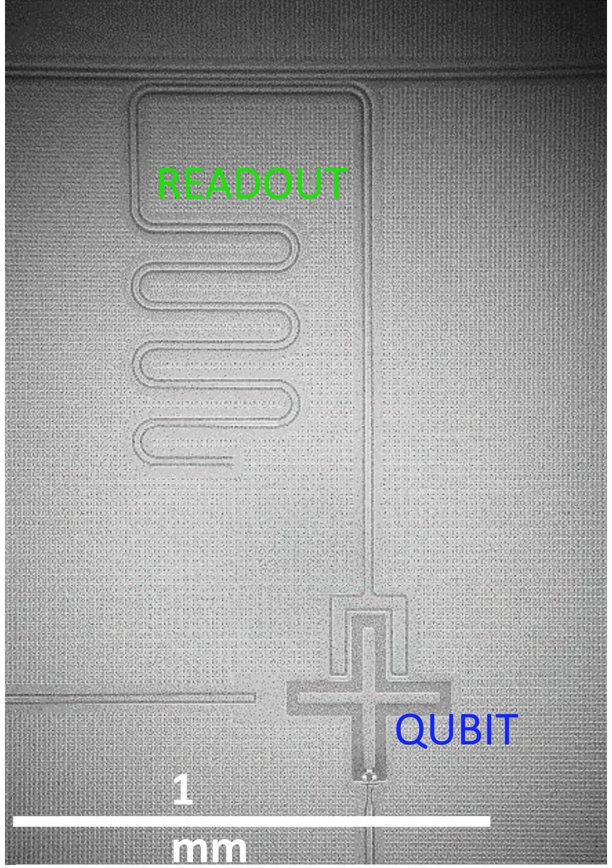
Superconducting qubit & readout





THIS IS THE
PHYSICAL QUBIT

Qubit readout

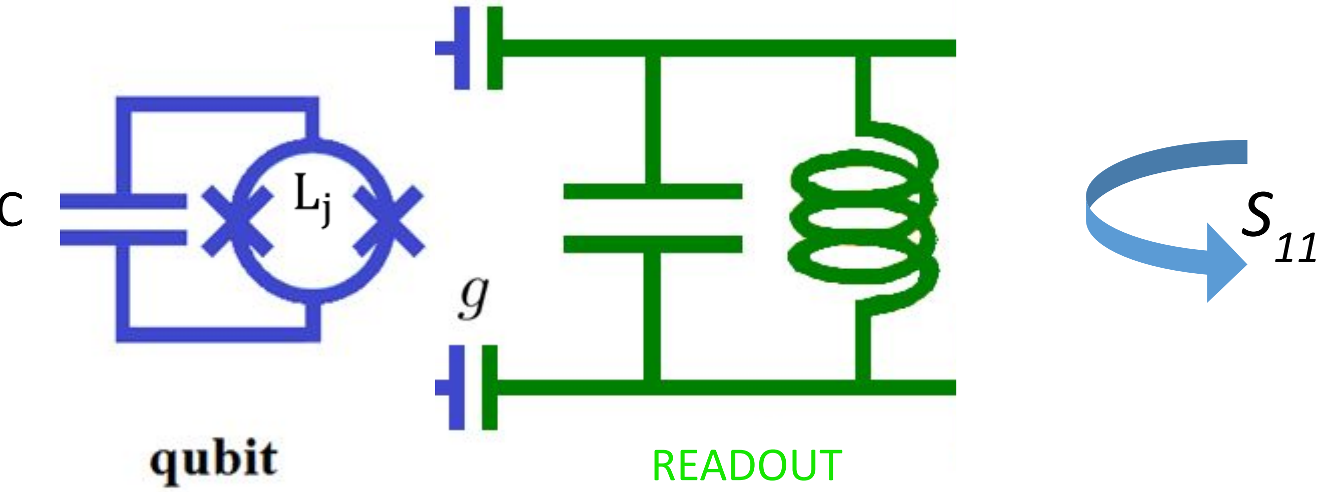


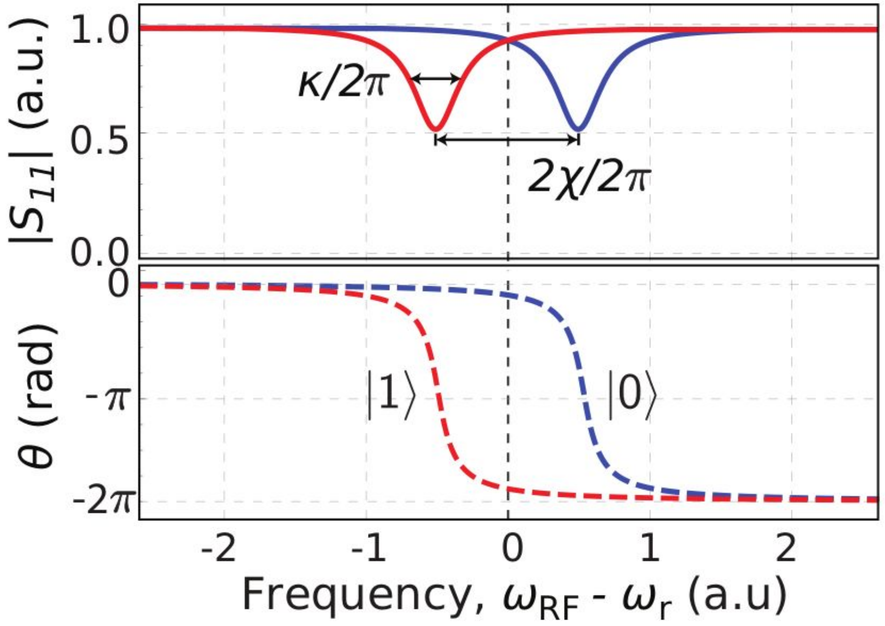
Jaynes-Cummings Hamiltonian

$$\mathcal{H}/_{\hbar} = -\frac{1}{2}\omega_{01}\hat{\sigma}_z + \omega_r\left(a_r^\dagger a_r + \frac{1}{2}\right) + g(\sigma^+ a_r + \sigma^- a_r^\dagger)$$

In dispersive regime ($g \ll |\omega_r - \omega_{01}|$)

$$\mathcal{H}/_{\hbar} = -\frac{1}{2}\omega_{01}\hat{\sigma}_z + (\omega_r - \chi\hat{\sigma}_z)\left(a_r^\dagger a_r + \frac{1}{2}\right)$$





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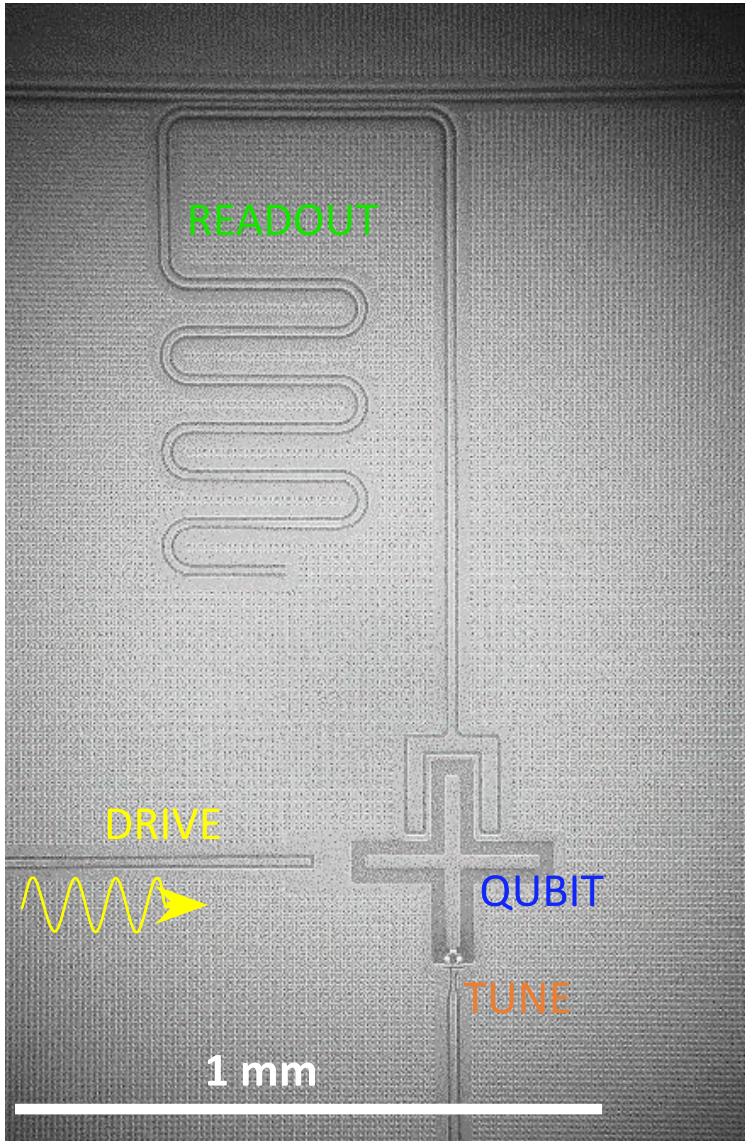
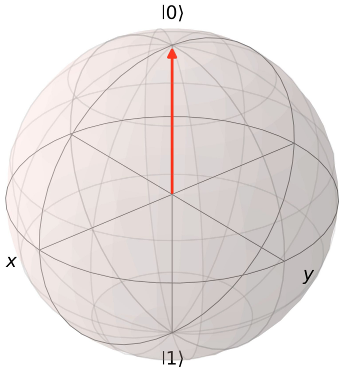
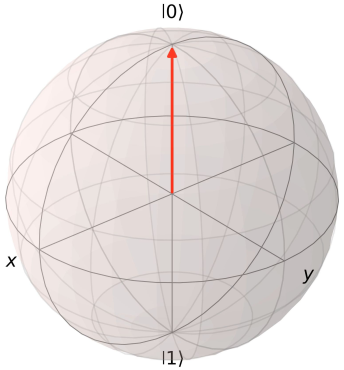
Single qubit gate

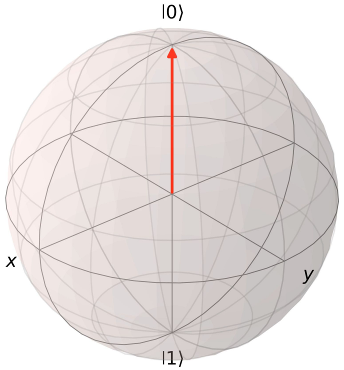




$c_0|0\rangle + c_1|1\rangle$

Rabi





Y

X

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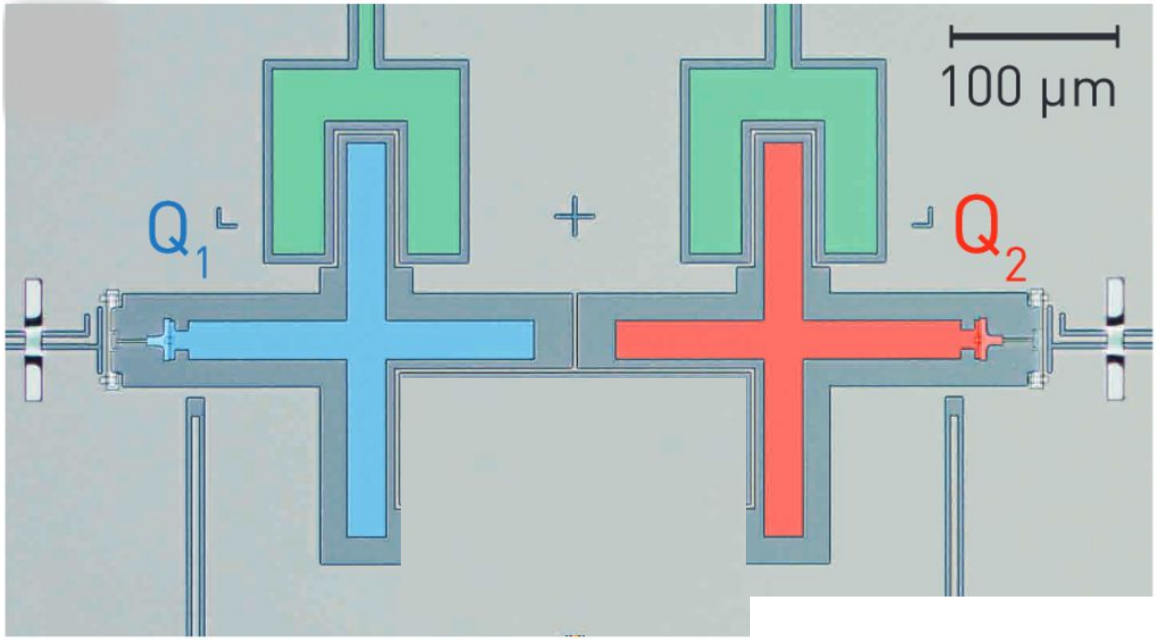
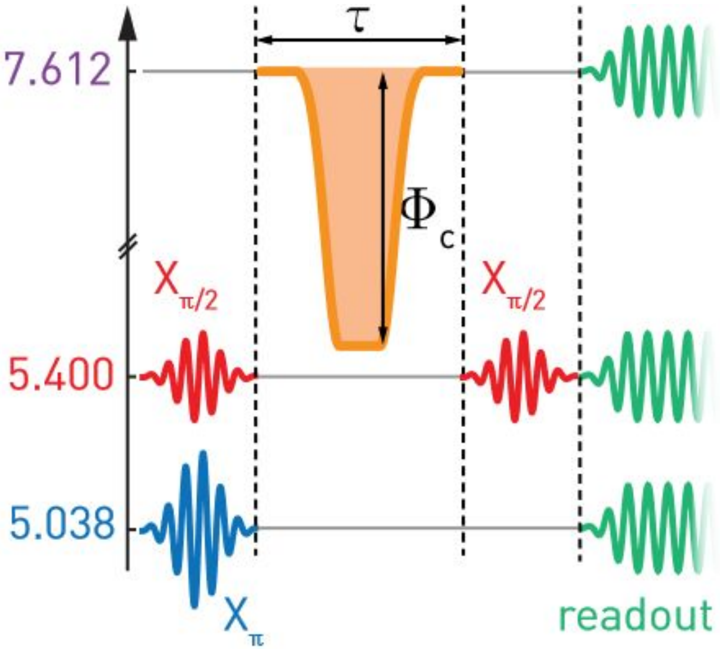
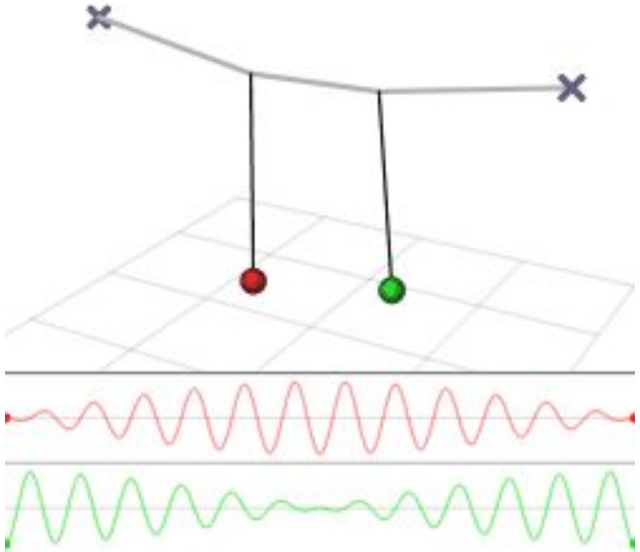
Two-qubit gate



PRL 125, 240502 (2020)





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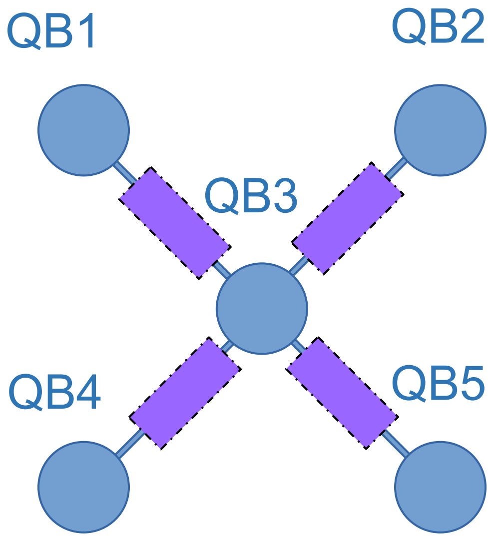
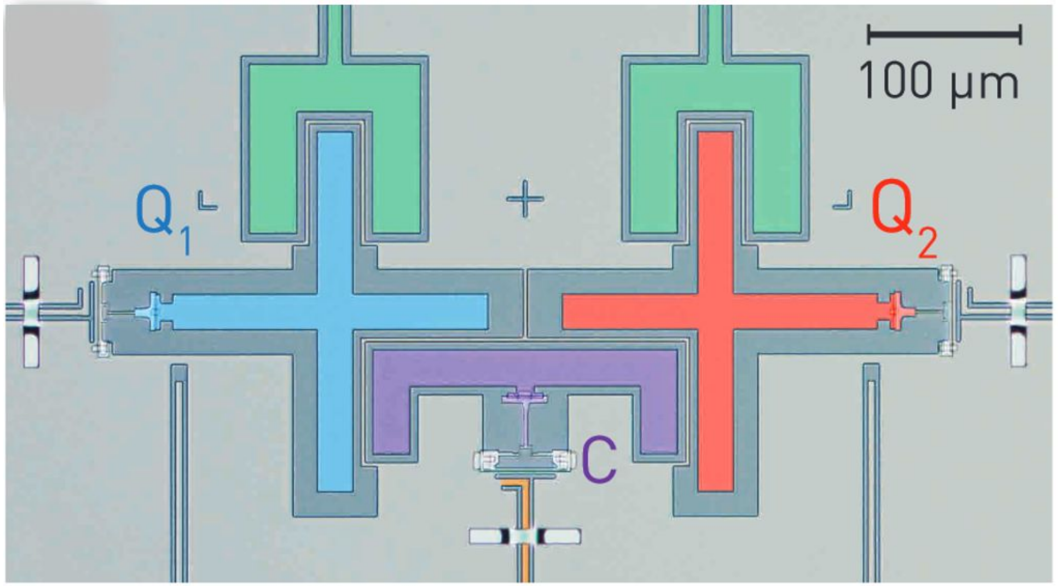
Helmi-5 overview

- Star topology
  - 5 qubits
  - 4 couplers
- Native gates:
  - 1QB- R_x, R_y, R_z
  - 2QB- CZ



Picture: IQM



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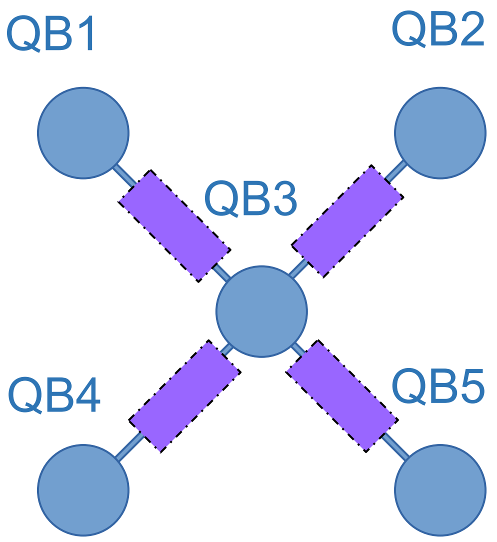
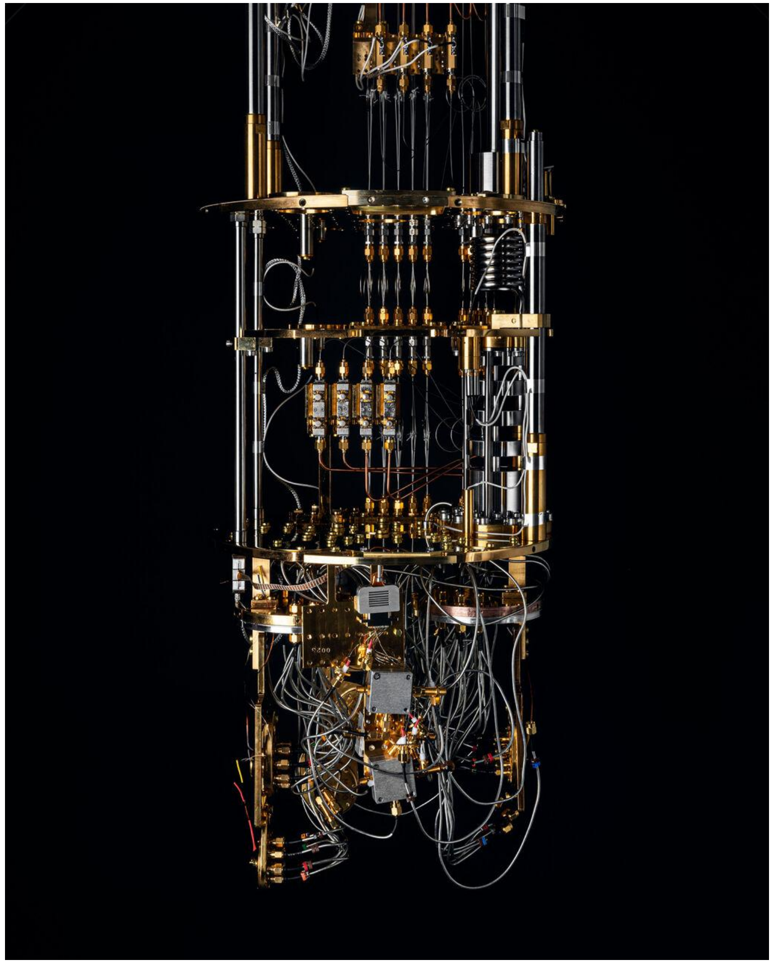
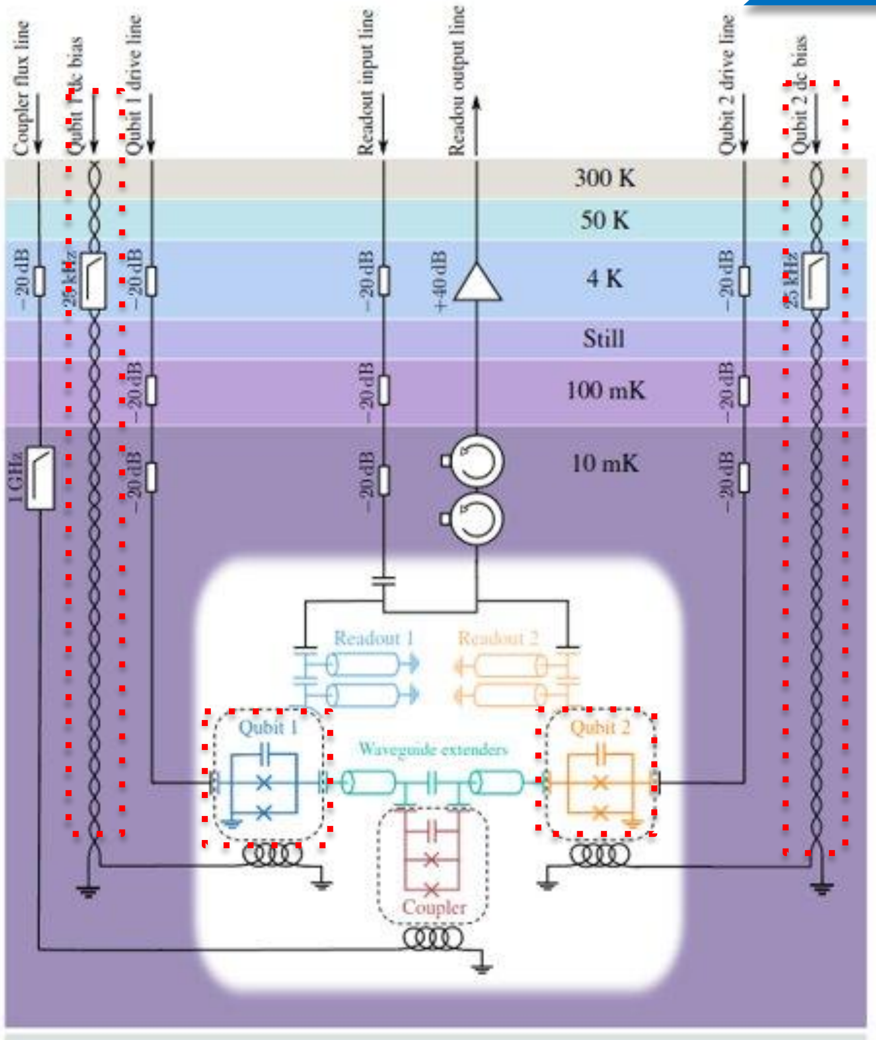
Helmi



Picture: IQM





Fabian Marxer *et al.* PRX Quantum 4, 010314

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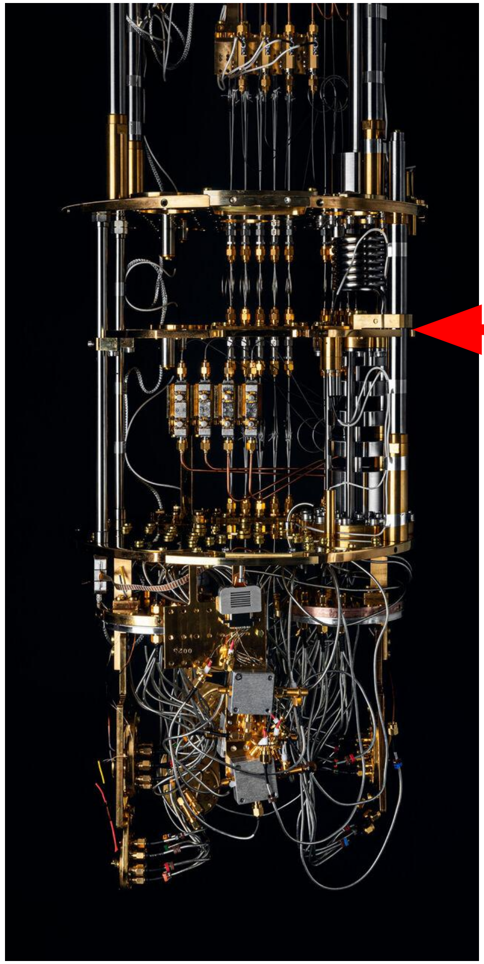
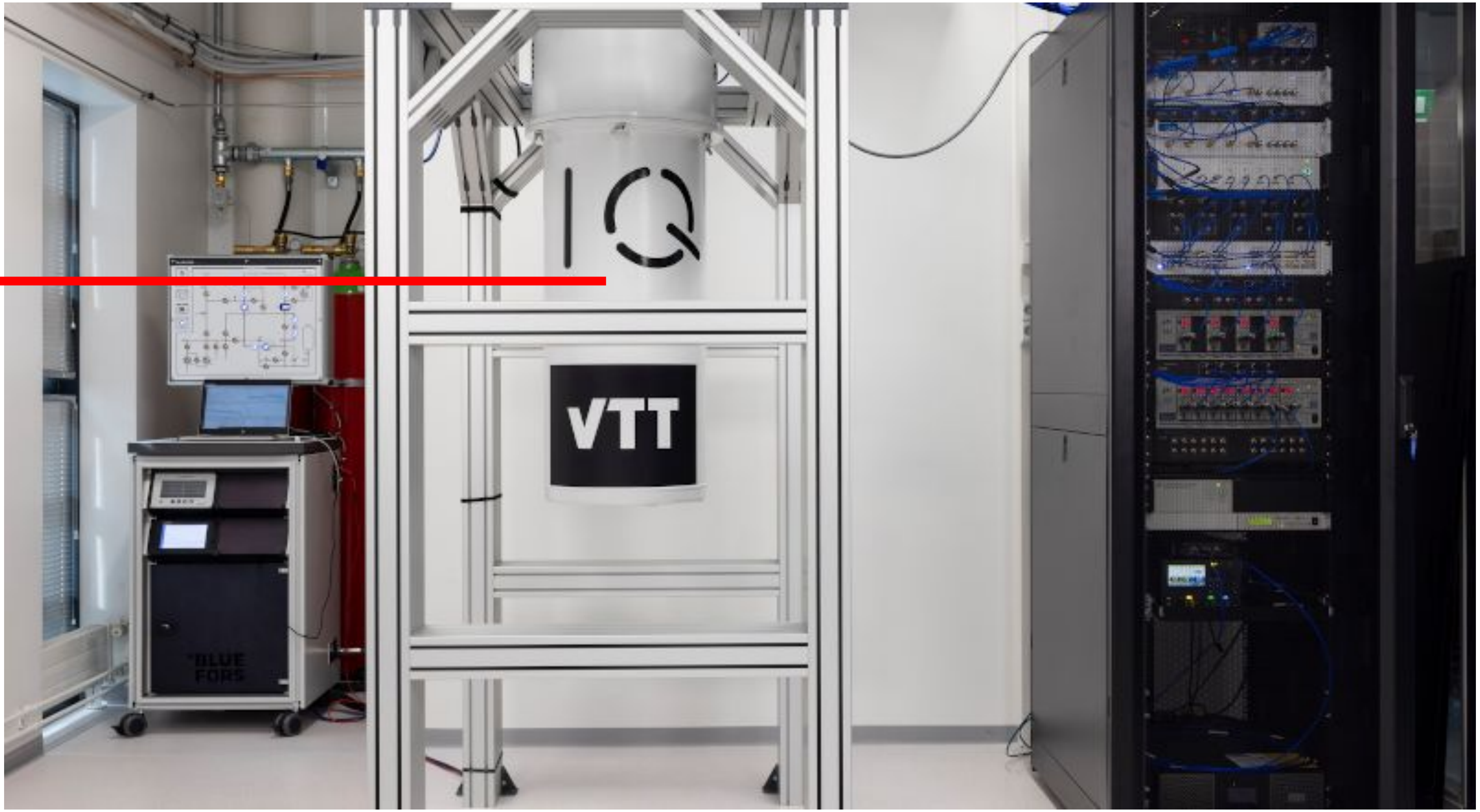
Helmi





Picture: VTT

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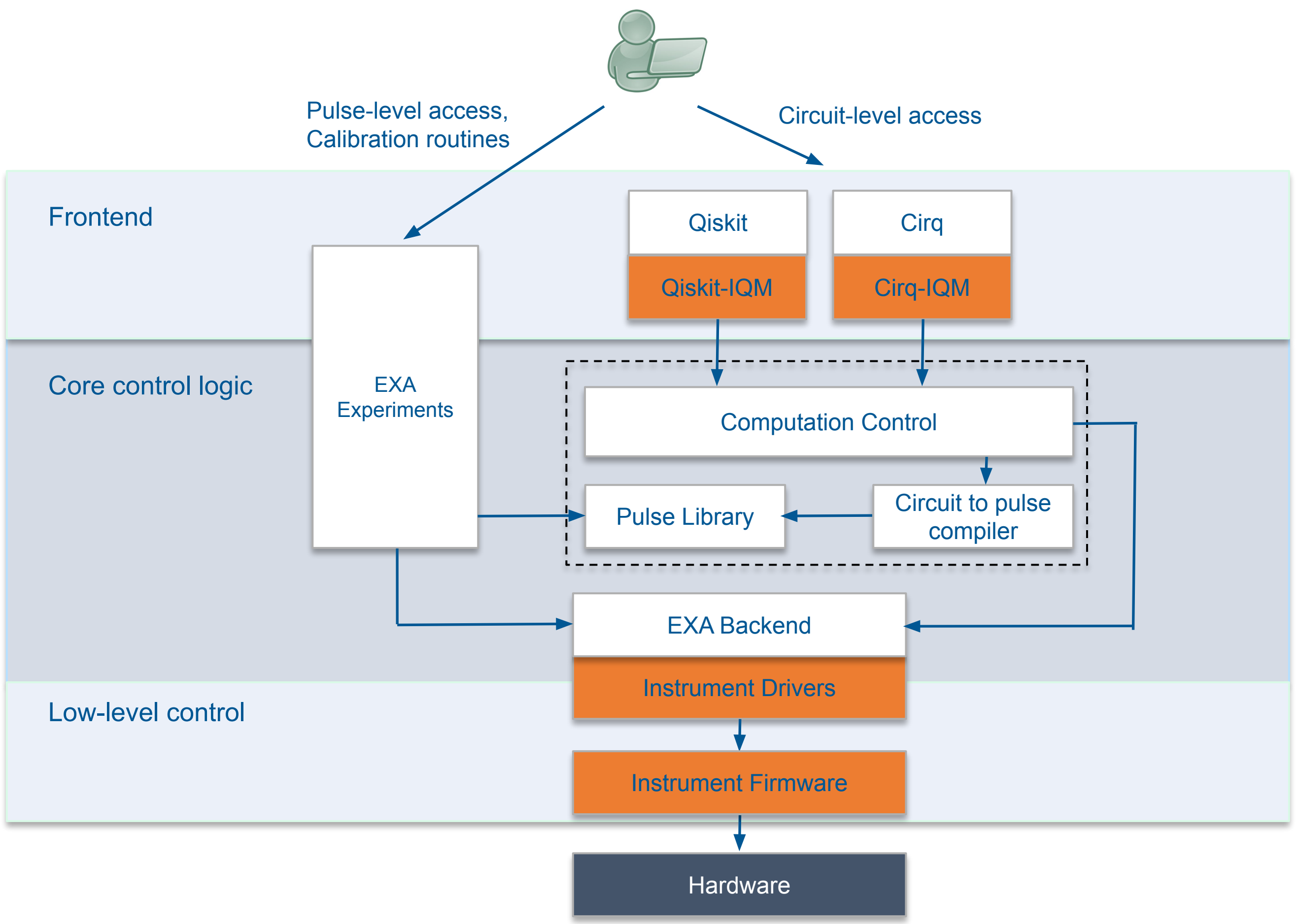
Helmi Architecture



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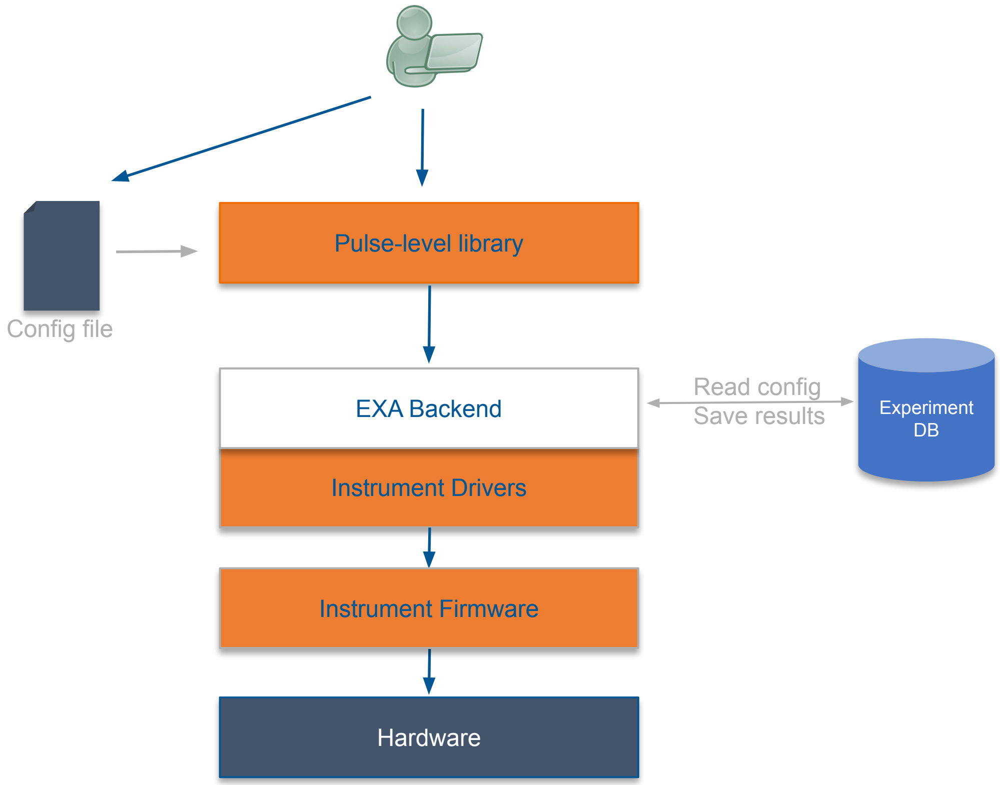
Pulse-level access

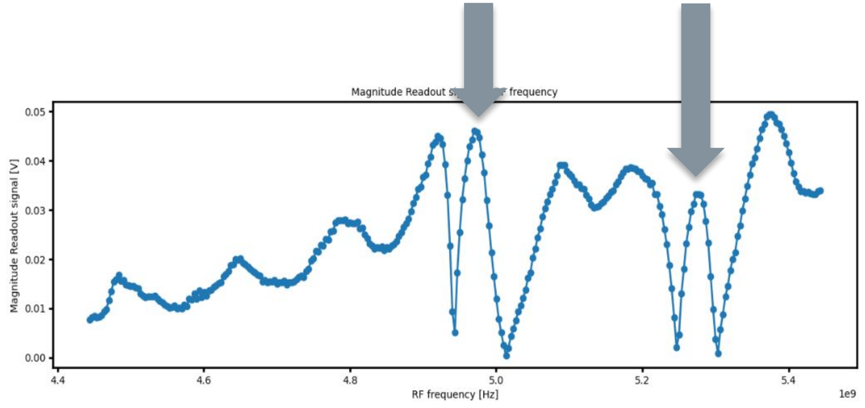
- Comparable to Qiskit Pulse [1]
- Python library with pre-defined experiments (e.g. Rabi, T1, ...)
- Instrument / experiment configuration file needed

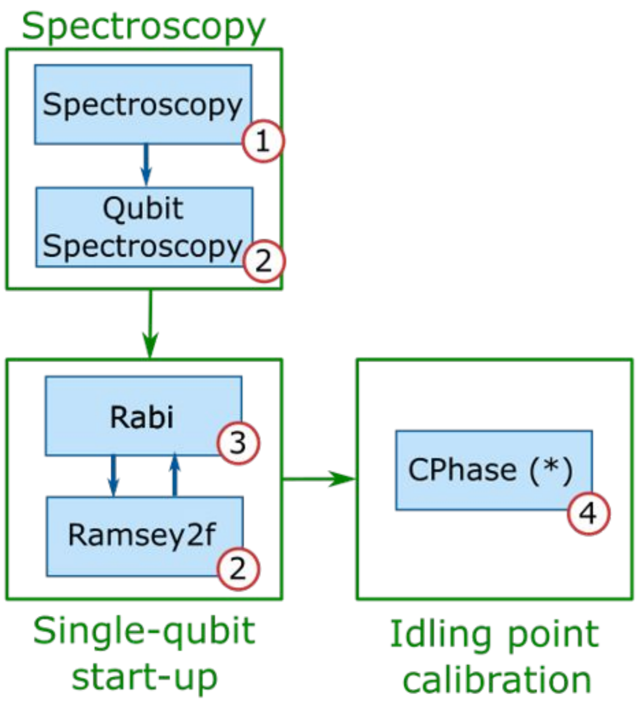


[1] https://qiskit.org/textbook/ch-quantum-hardware/calibrating-qubits-pulse.html

Calibration

- Find RO frequency Resonator spectroscopy
- Qubit drive frequency Qubit spectroscopy, Ramsey
- Pulse parameters Rabi Oscillation
- CZ gate CPhase





Observations
1. Readout frequency
2. Drive frequency
3. Pi pulse amplitude (I)
4. Coupler idling flux bias

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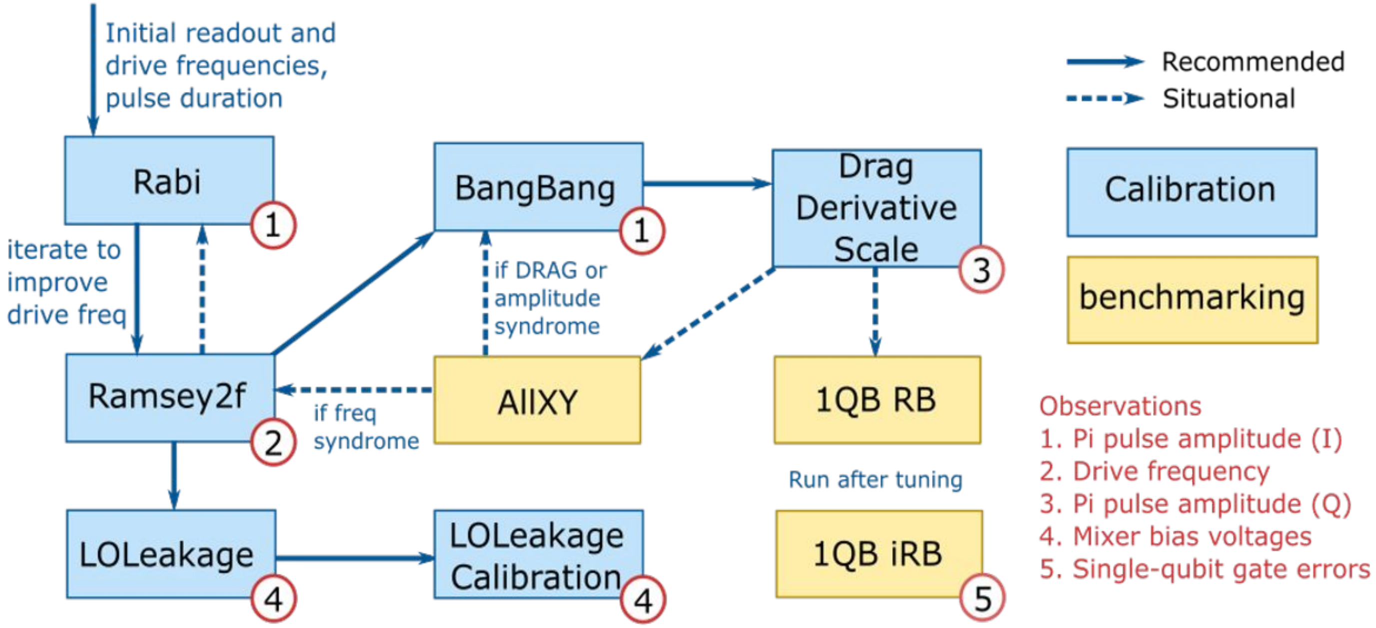
Extensive Calibration

- Ensure that Helmi is working properly
- Avoid drifts in qubit or RO frequency
- Short set of routines for calibration and benchmarking



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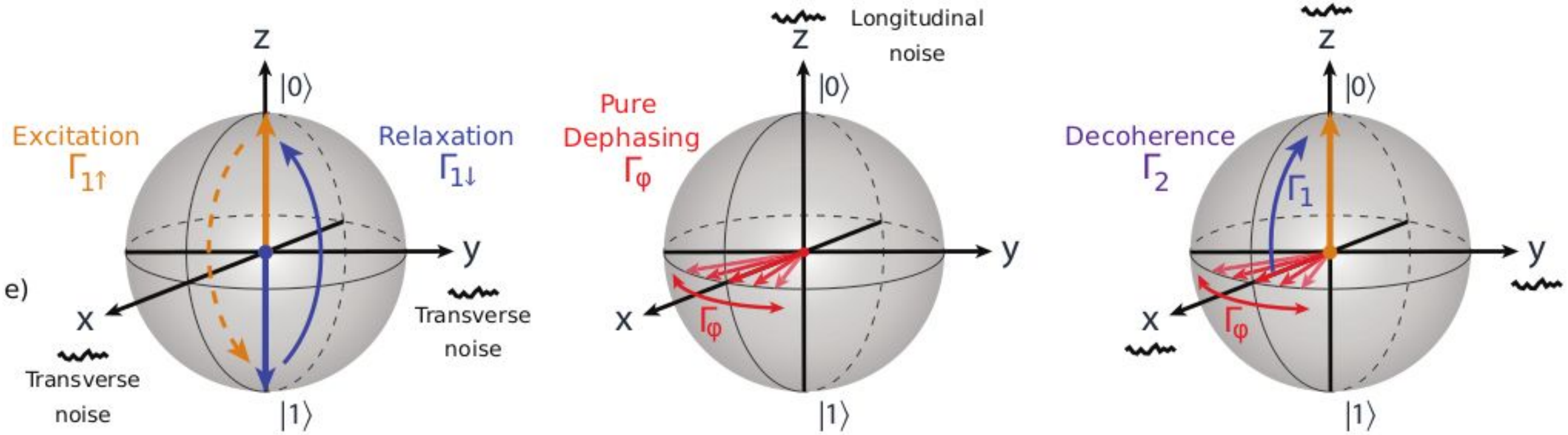
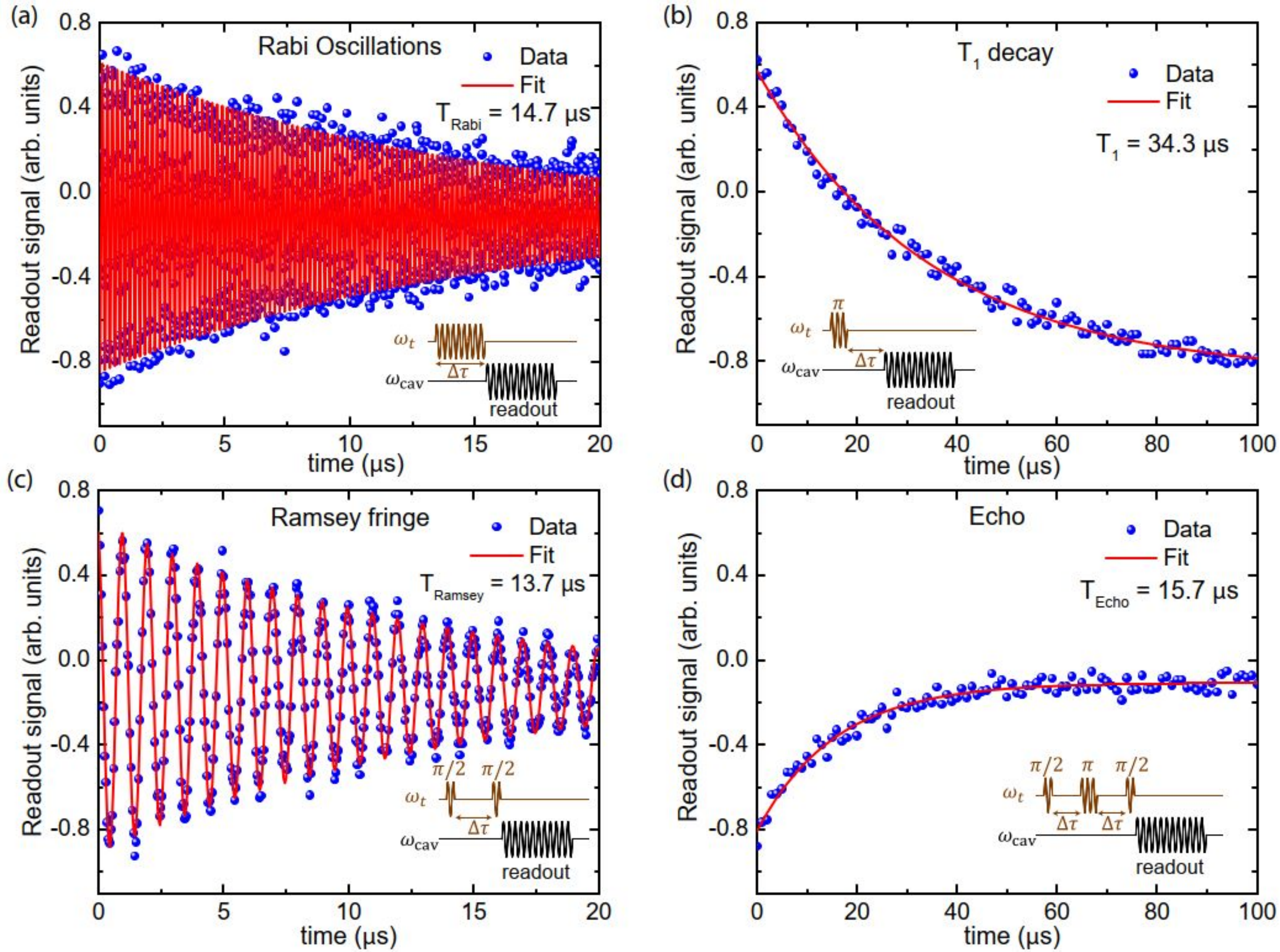
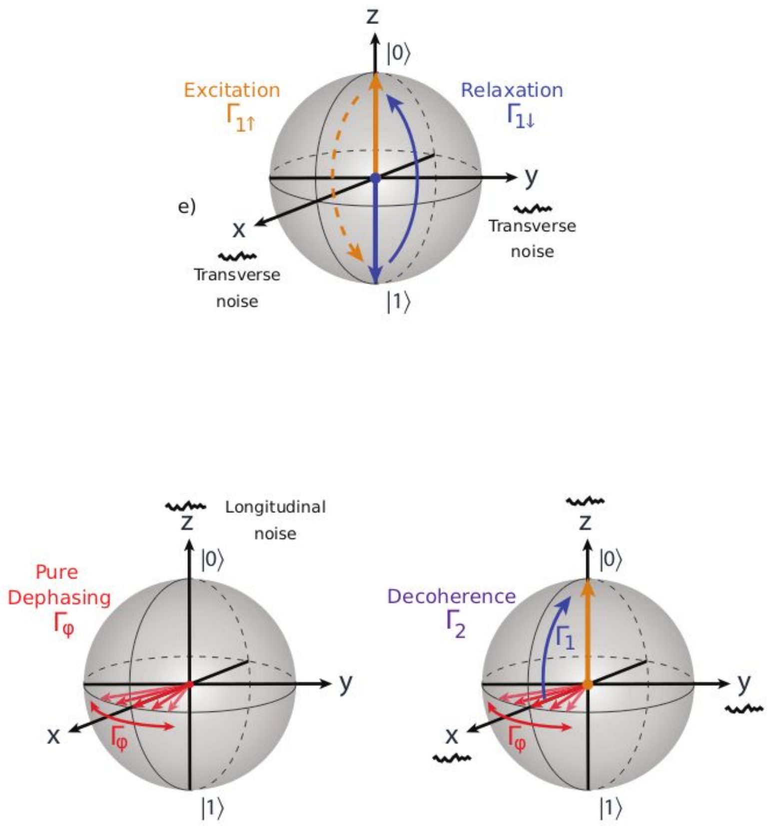
Noise in QC

- NISQ-era of Quantum Computing
  - Noisy-Intermediate-Scale Quantum
- QCs are prone to systematic errors that affecting the qubits
- Coupling to environment introduces decoherence
- Other sources:
  - Leakage, Crosstalk, ...

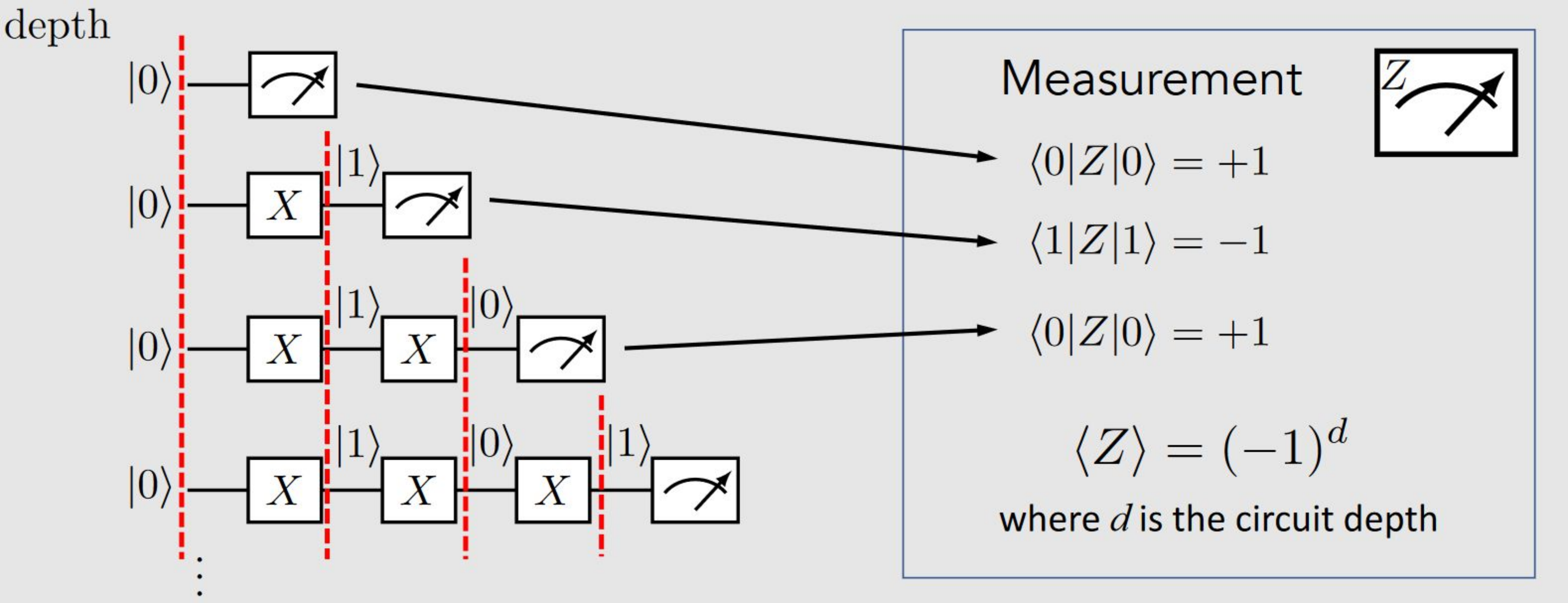


Coherence characterisation

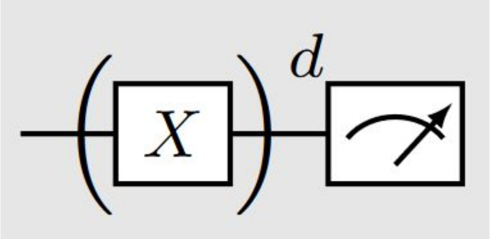


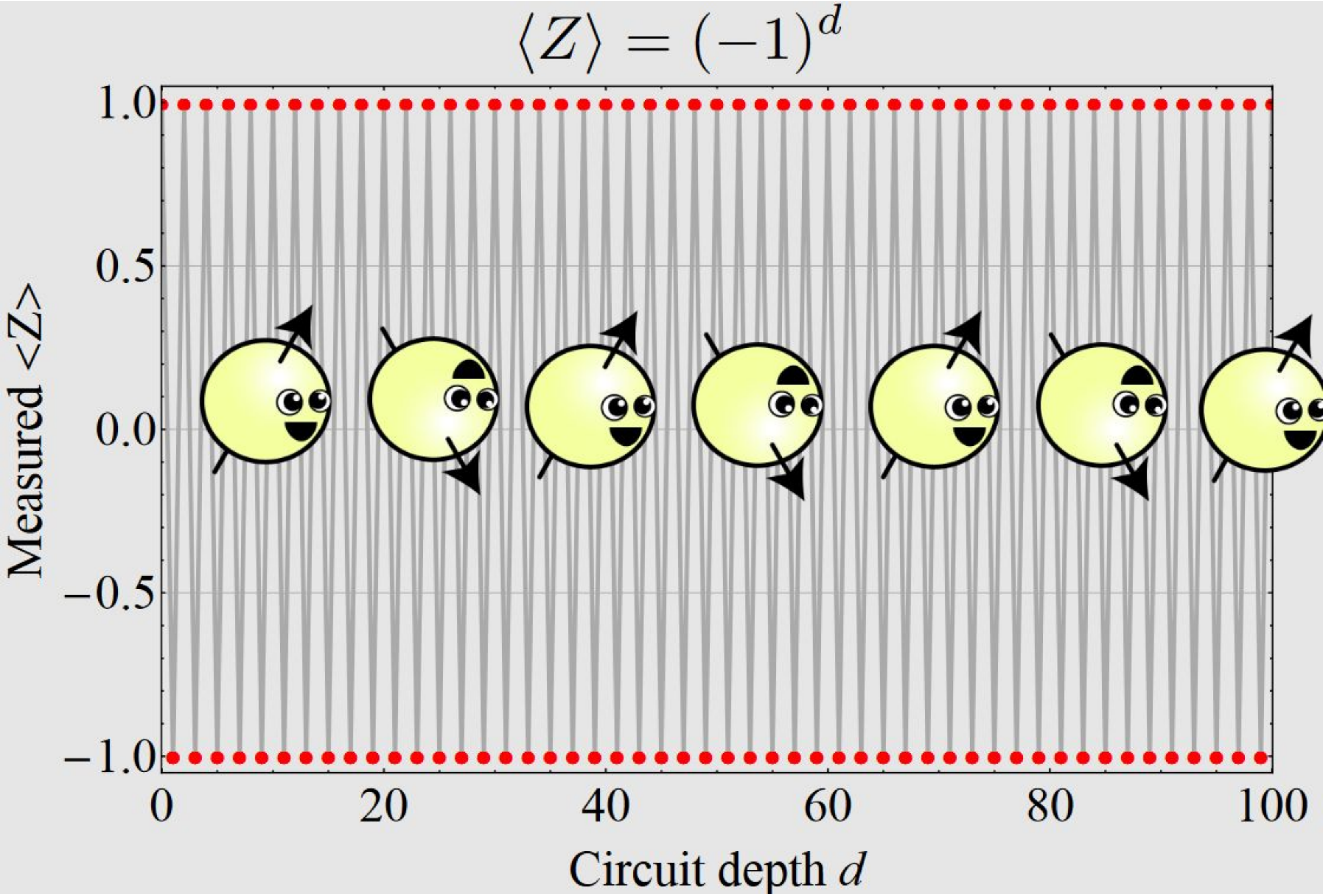


Noise characterisation



Noise characterisation





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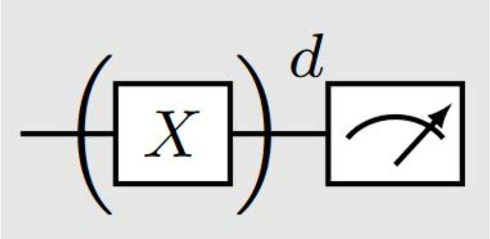
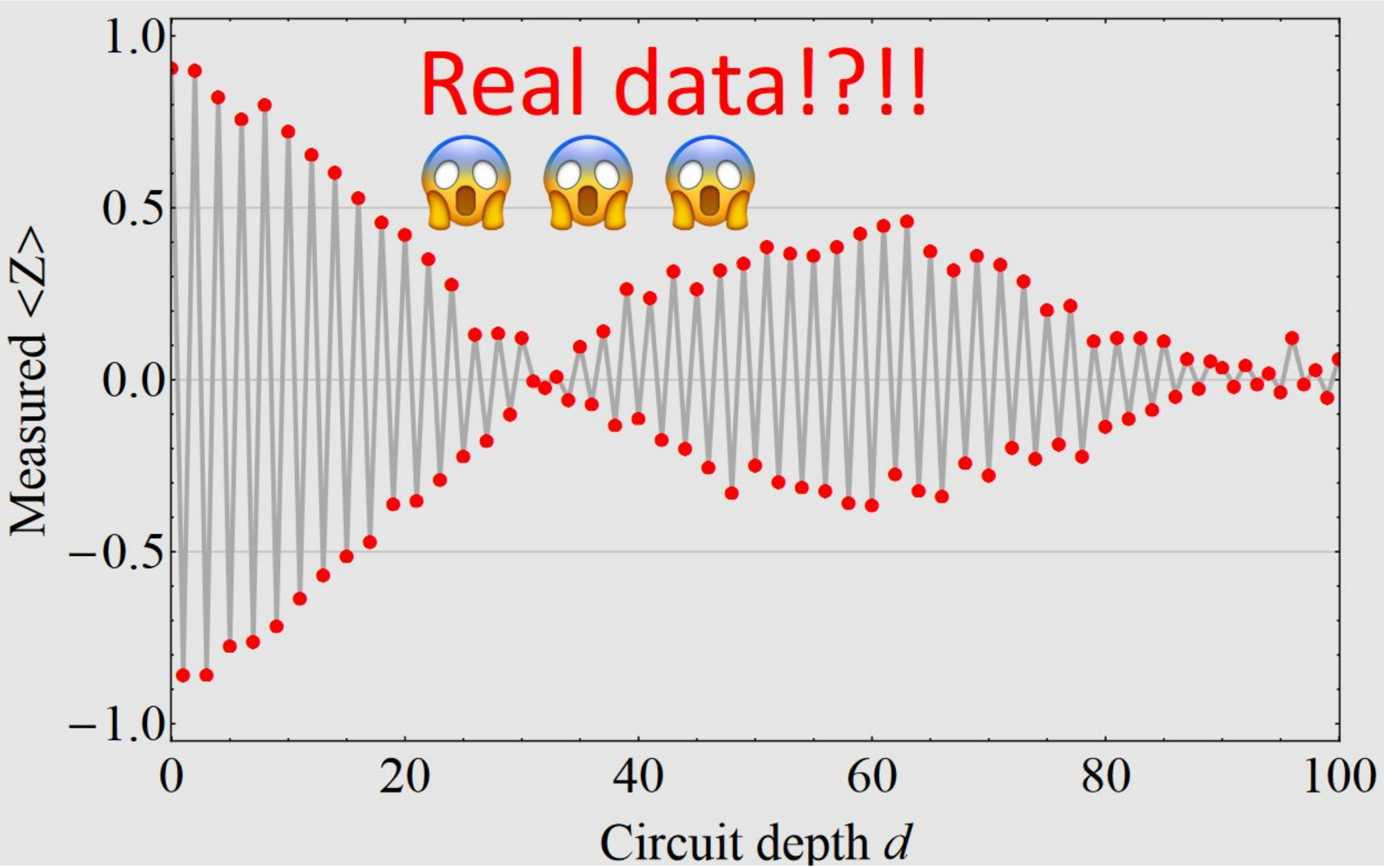
Noise characterisation





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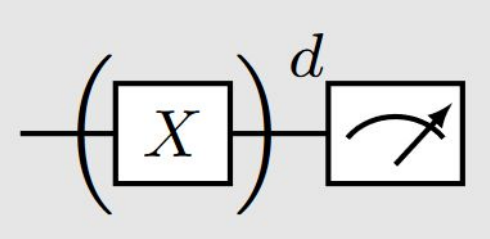
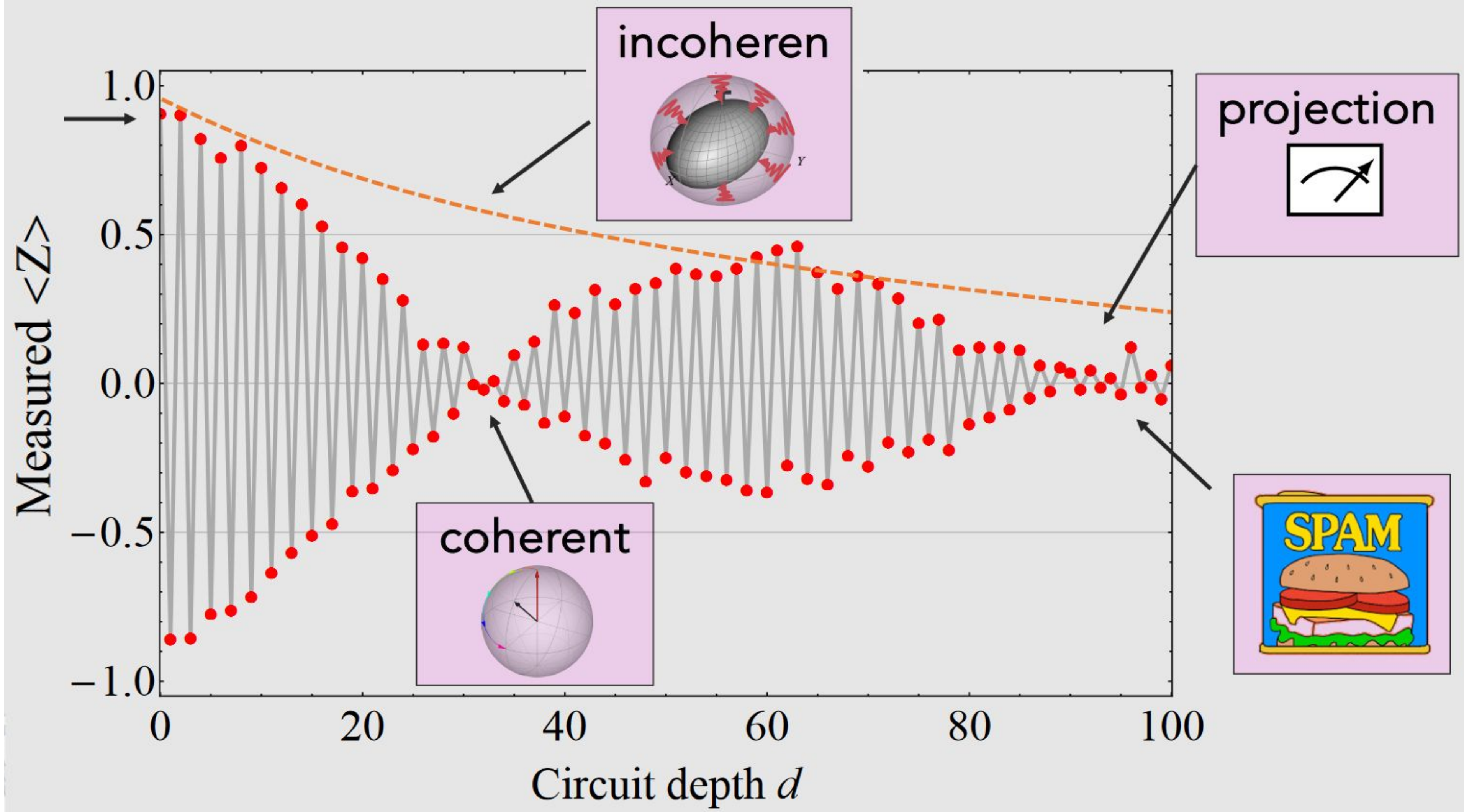
Noise characterisation





THANK YOU

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