oxford ionics

All-Electronic Control for Scalable, High-Fidelity Ion-Qubits

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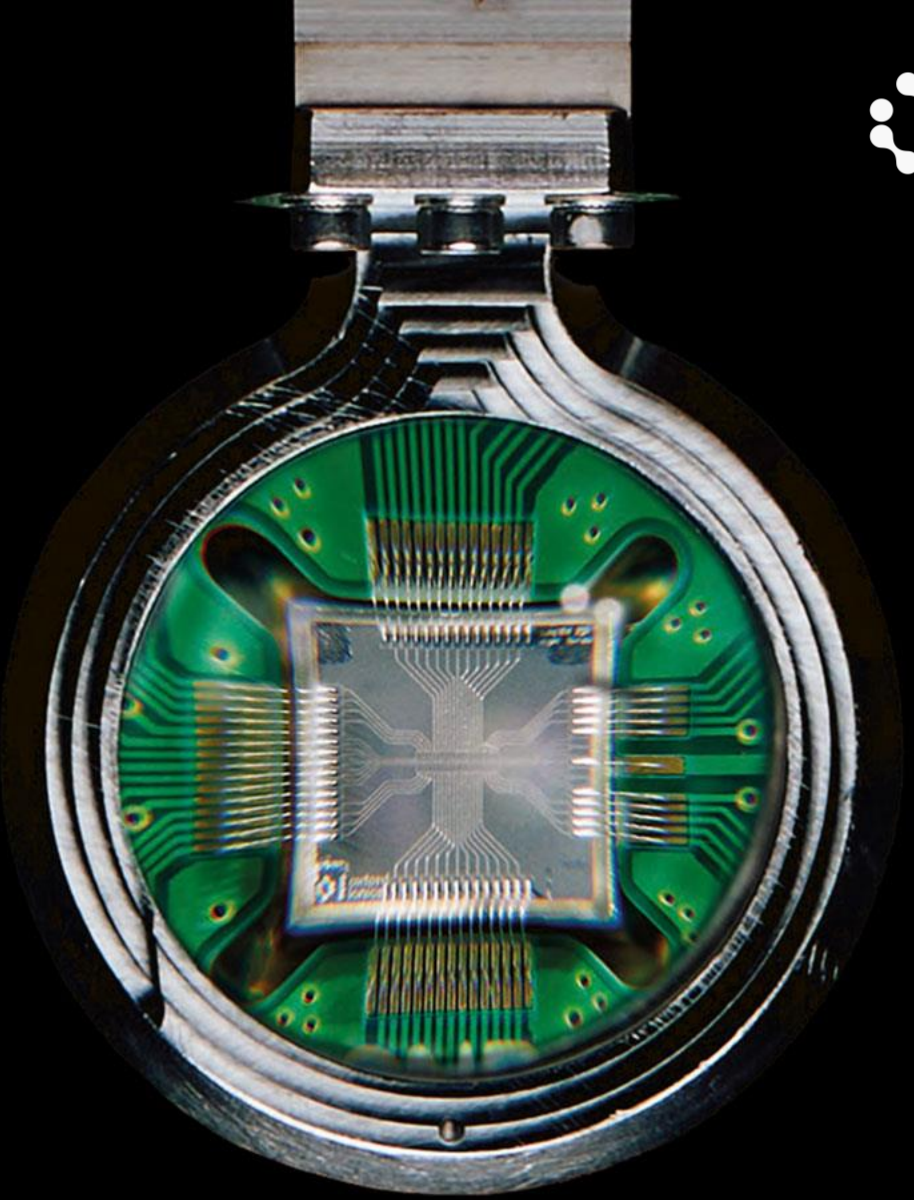
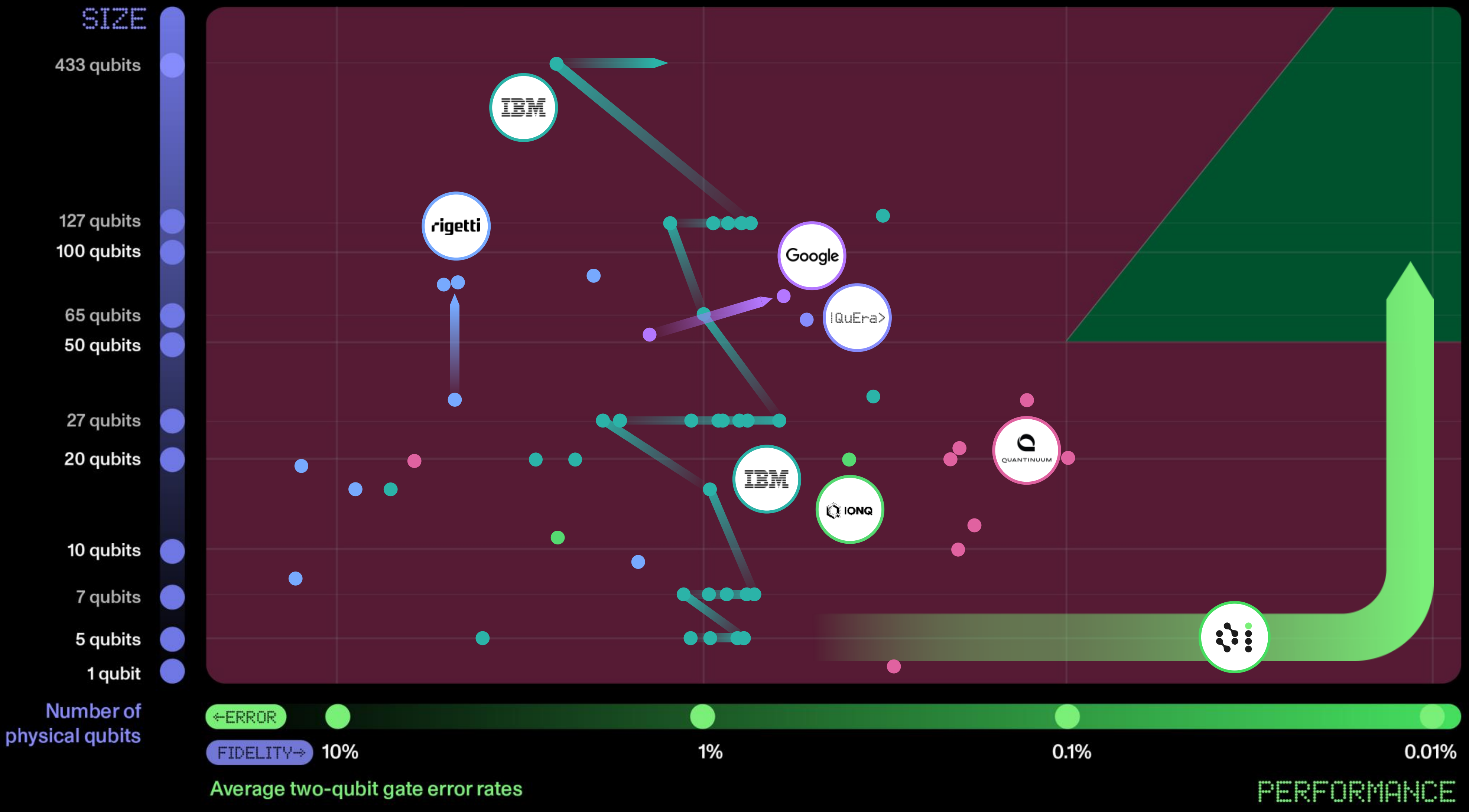
8 JULY 2024

Innsbruck, Austria



Quantum Computing: Two key ingredients



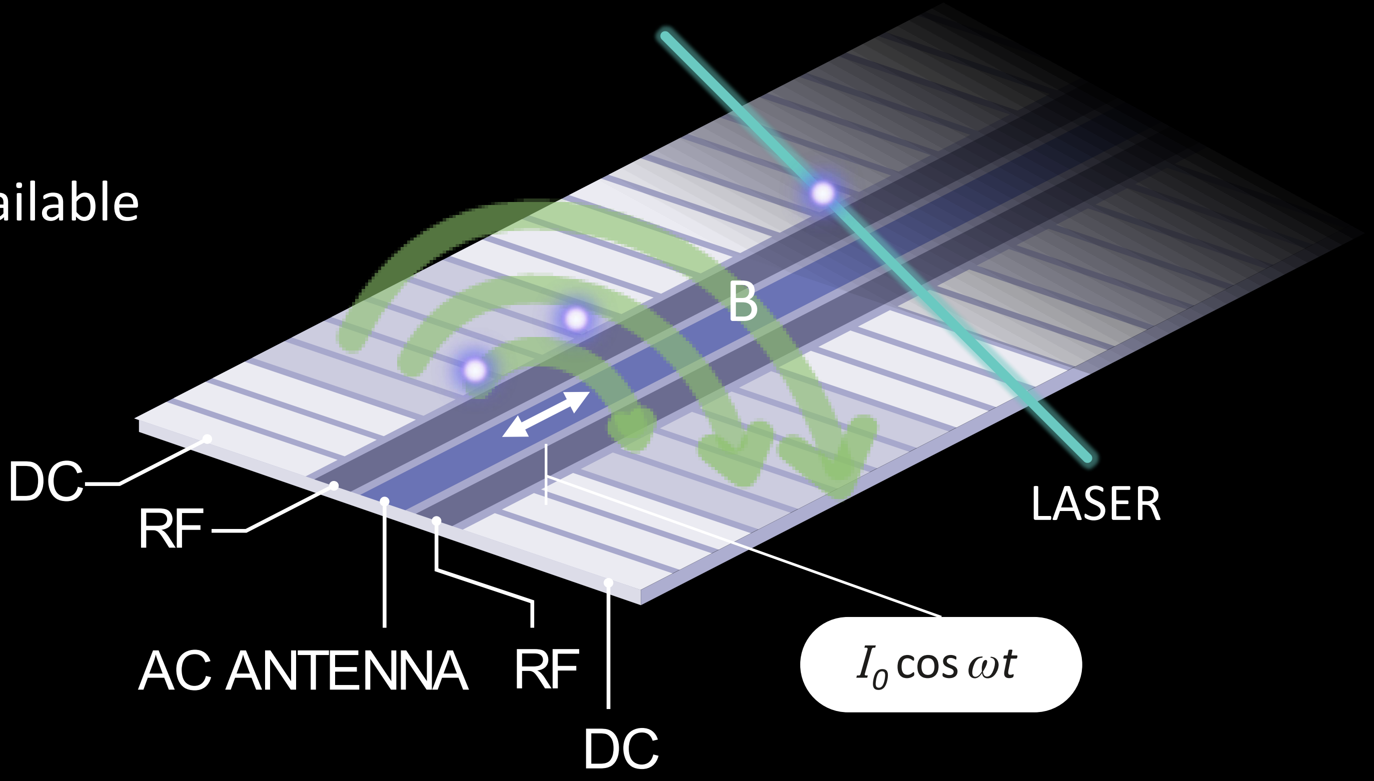
Why All-Electronic Control?

Great quantum-logic performance

- Ions are great qubits
- No photon scattering errors
- Stable, low noise sources readily available

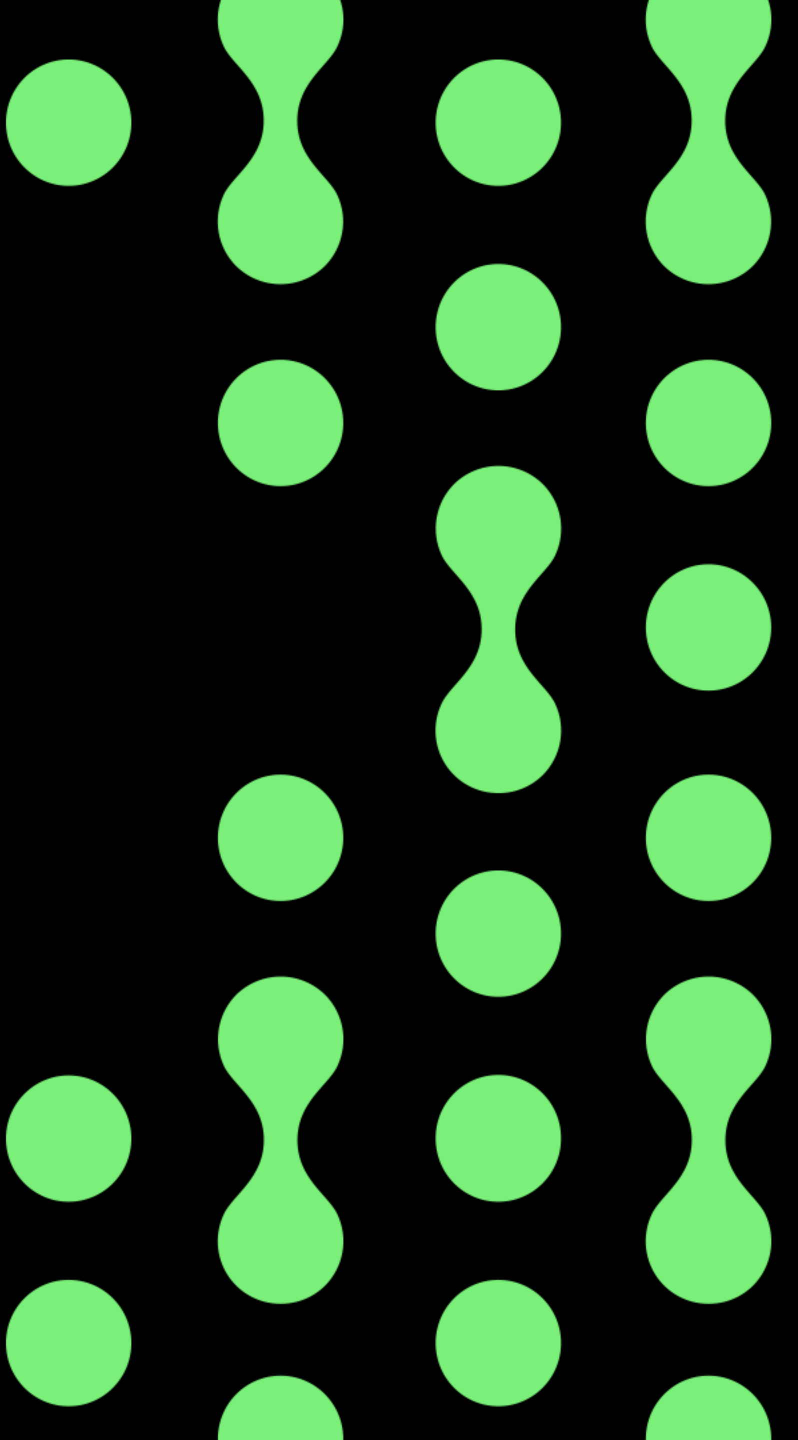
Scaling to many qubits

- Easily integrated into trap
- Well established gates
- Global parallel control



A crash course of our electronic control

1-qubit logic gates, addressing,
and 2-qubit logic gates



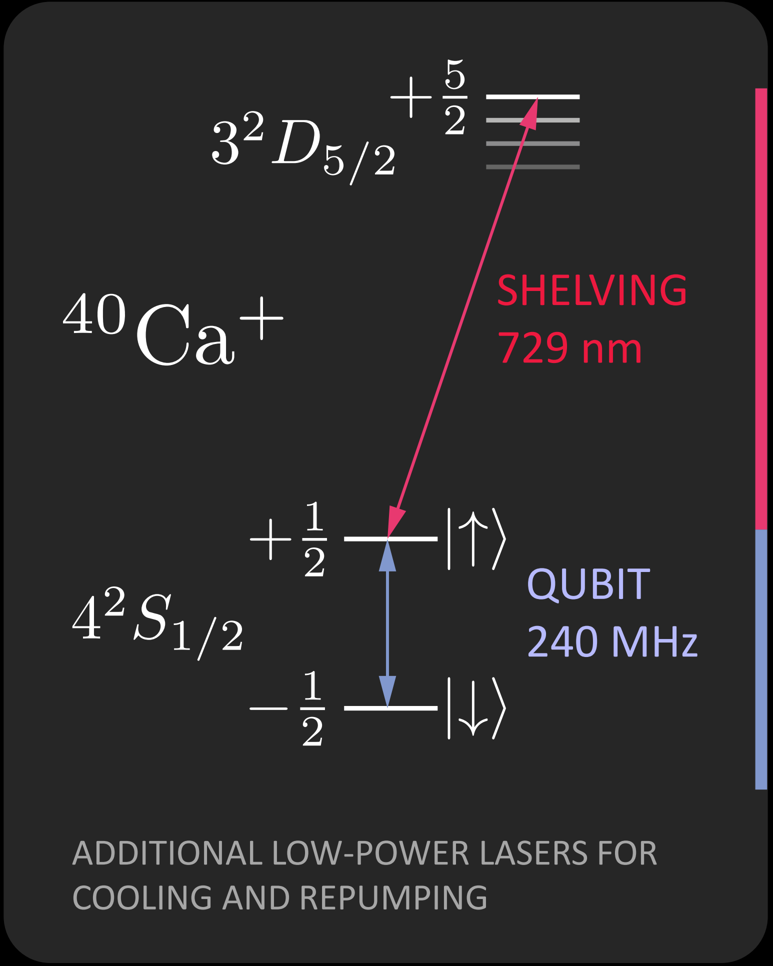
Our system

Near-field microwaves

- Trap integrated antenna
  High field gradient (>100 T/m per A)
- Control signals near qubit frequency

Cryogenic traps

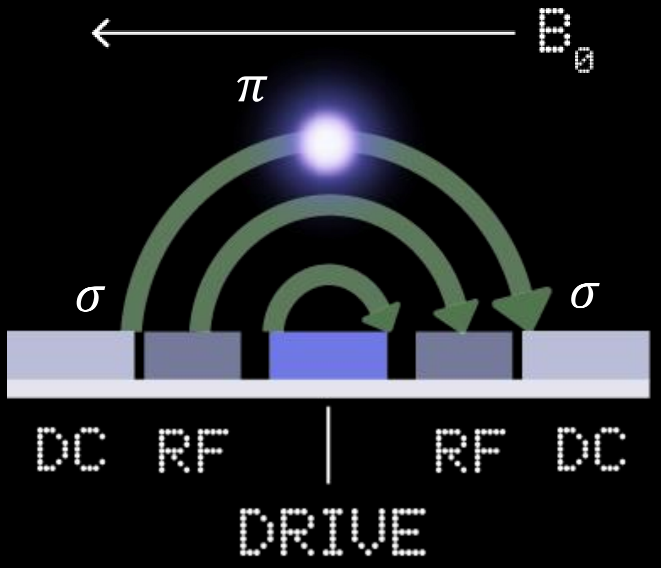
- Very low heating rates
  (~ 1 quanta / s in radial com modes)
- Reduced resistance
  Larger current for given input power

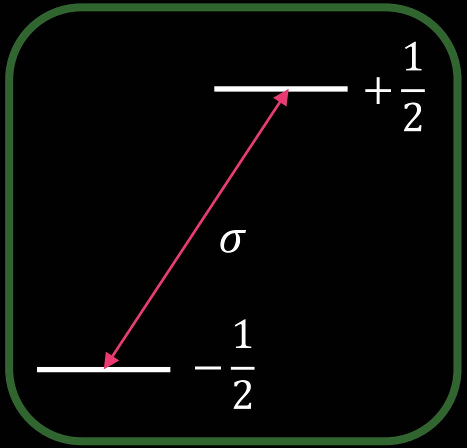


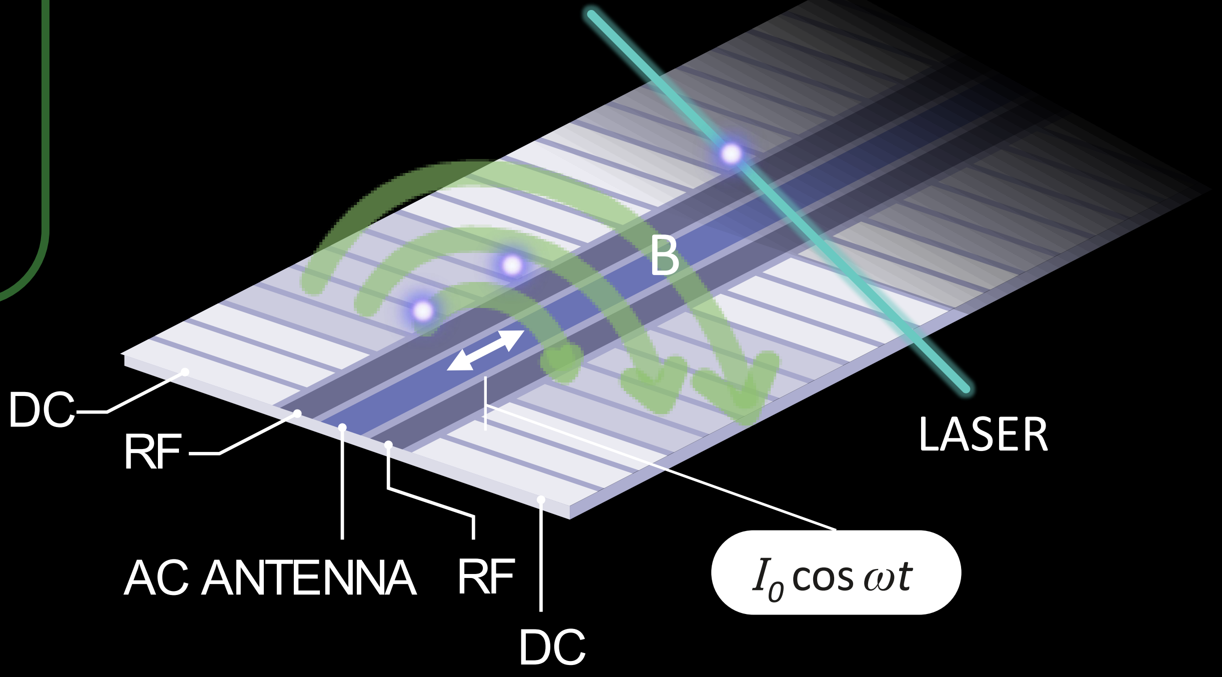
ADDITIONAL LOW-POWER LASERS FOR COOLING AND REPUMPING

Road to selective operations

Partial nulling in the near field

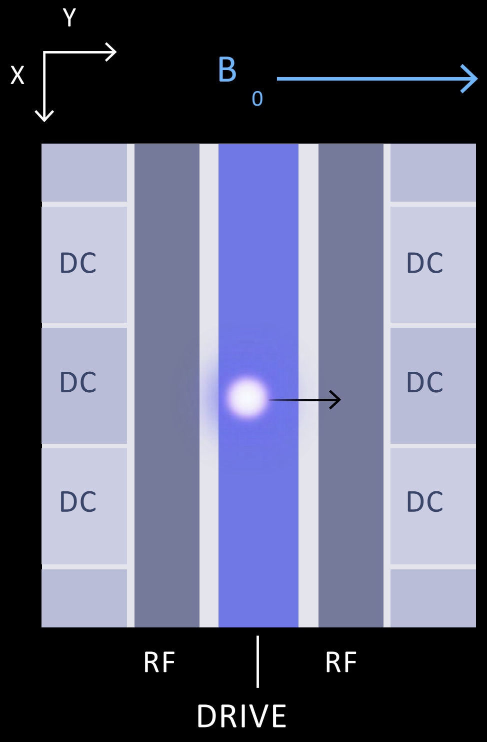


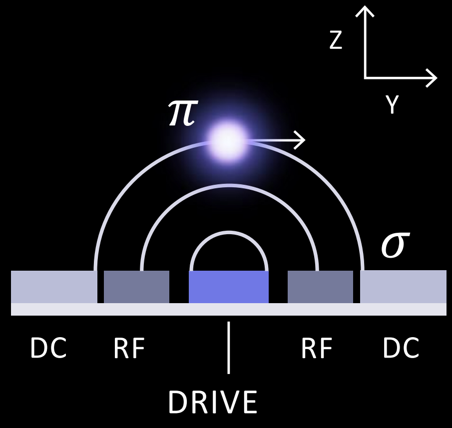


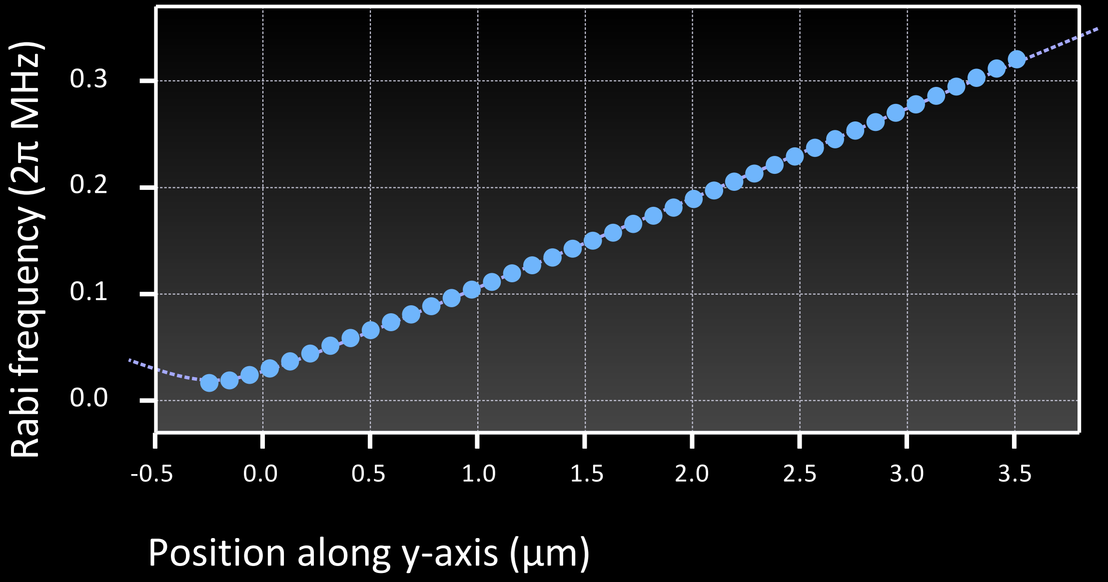


Position dependent Rabi-frequency

Controlling 1-Qubit rotations through DC electrodes

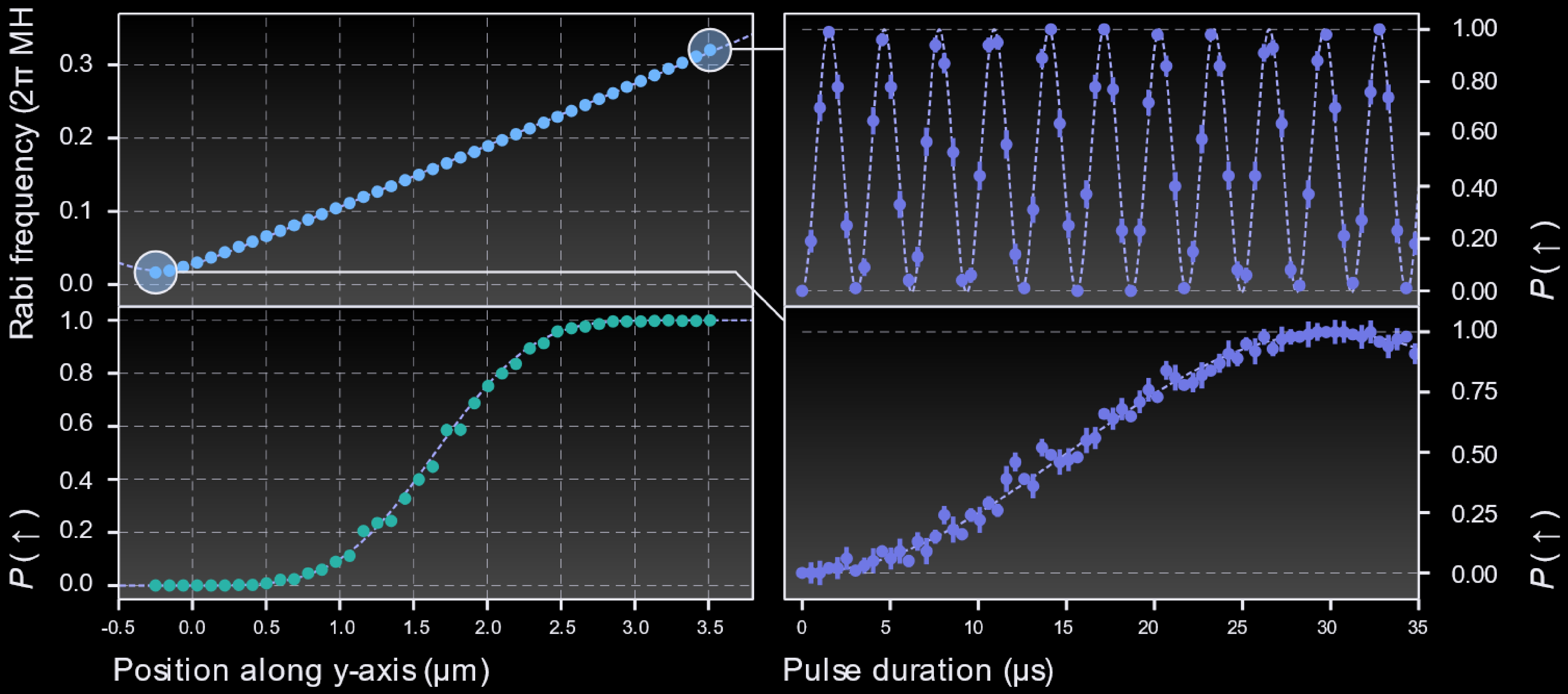






Selective 1Q logic operations

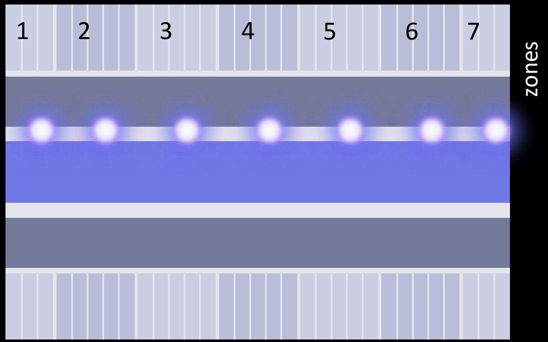
Addressing logic operations



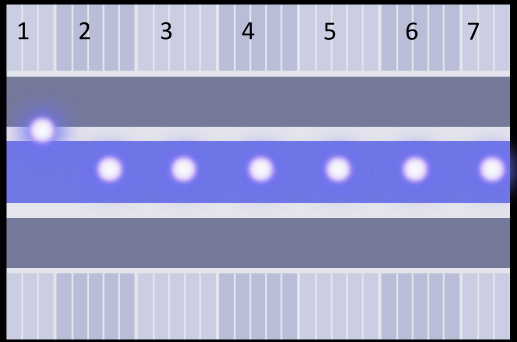
Measured 1Q logic performance

Running 1QRB in 7 zones

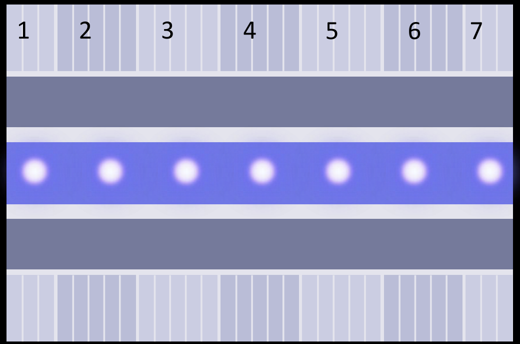
7 ACTIVE, 0 HIDDEN



1 ACTIVE, 6 HIDDEN



0 ACTIVE, 7 HIDDEN

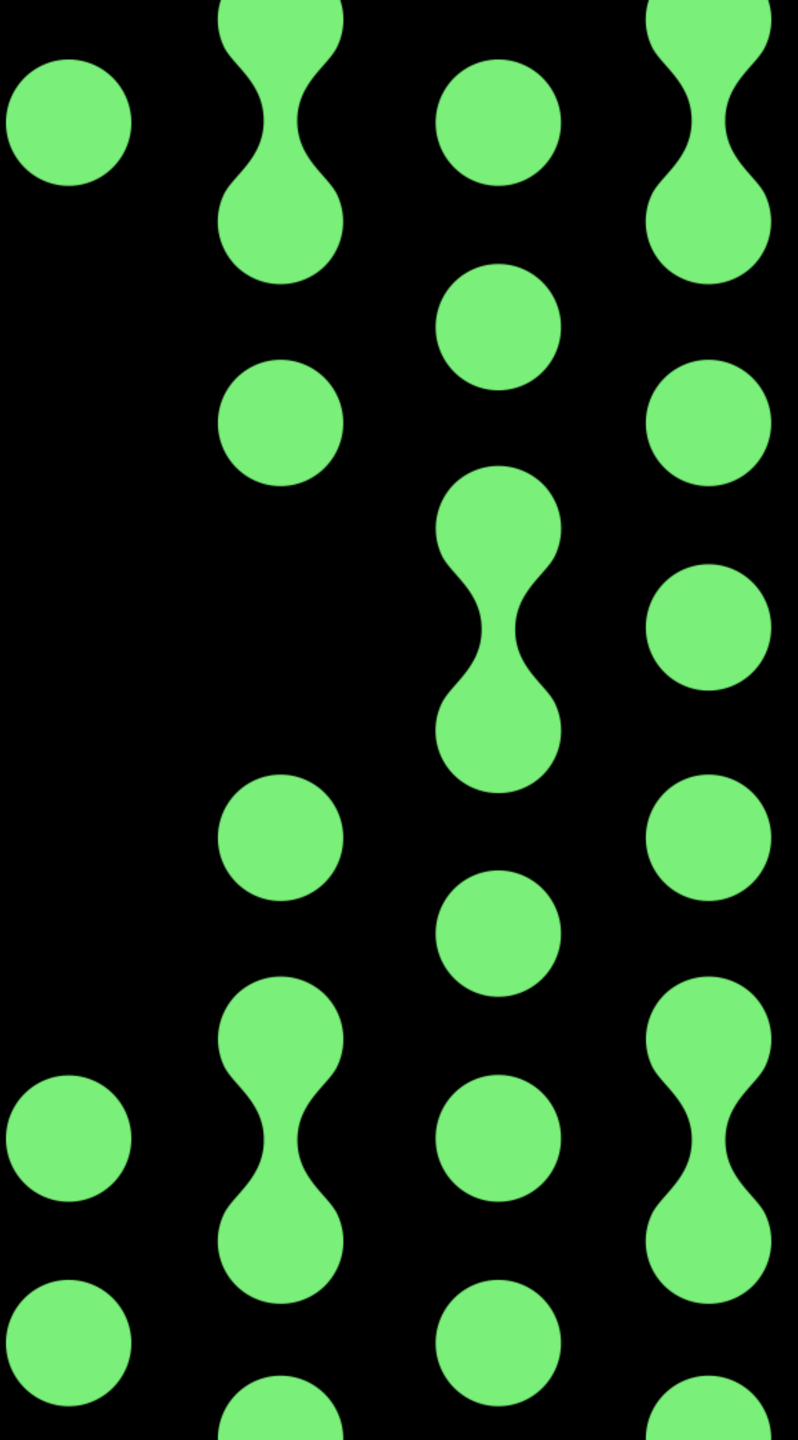


$P_{\text{Clifford}} \geq 99.999\%$

$P_{\text{cross-talk}} \leq 0.0003\%$

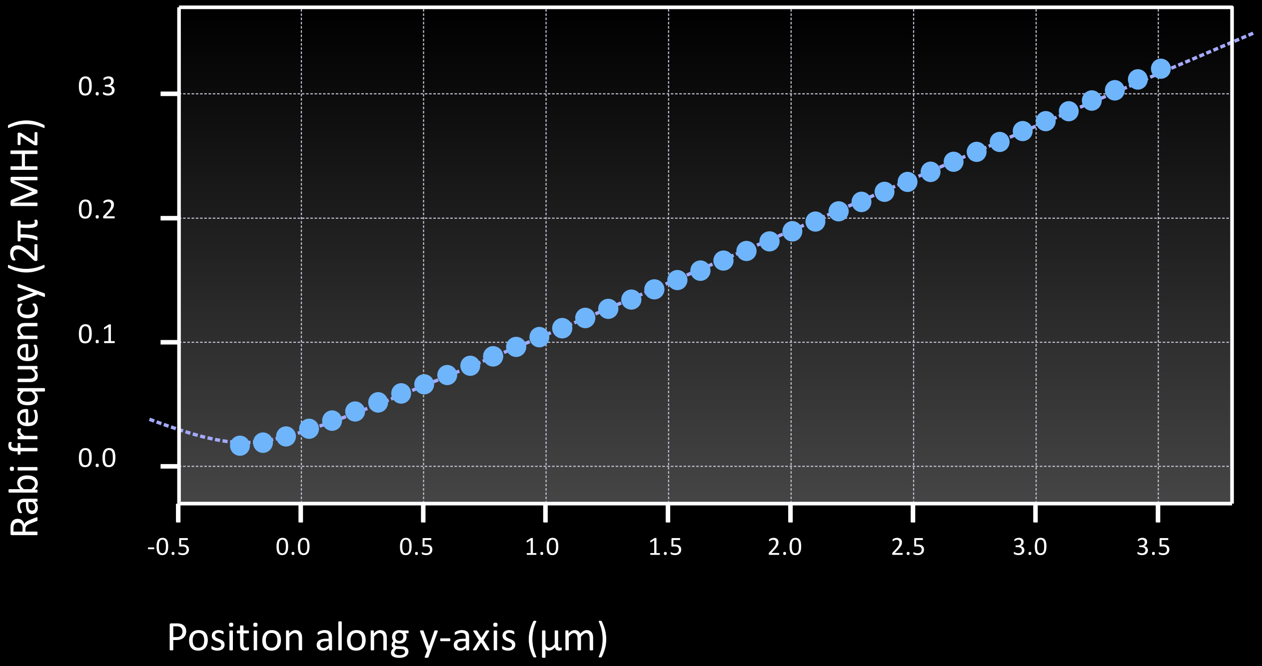
We can parallelise & address individual qubits…

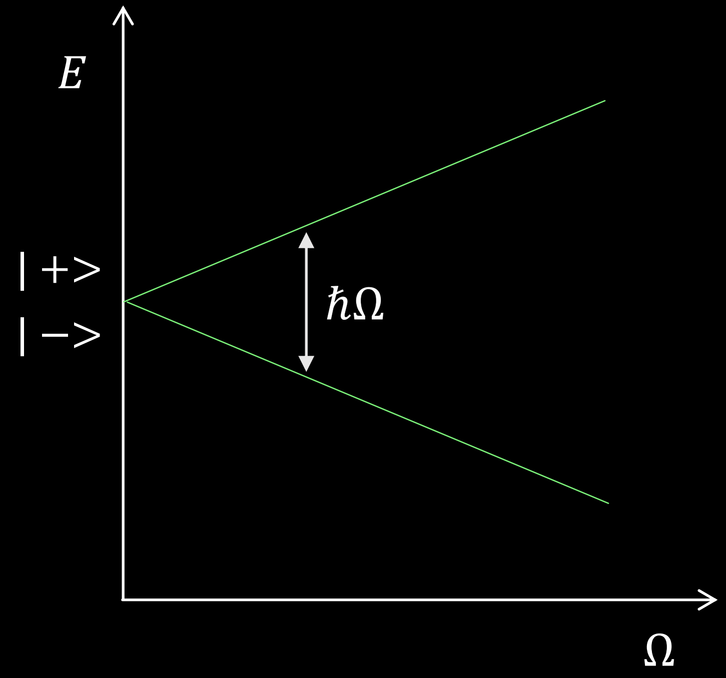
But we also need two-qubit gates!



How do we do two-qubit gates

Near field microwave & spin dependent forces



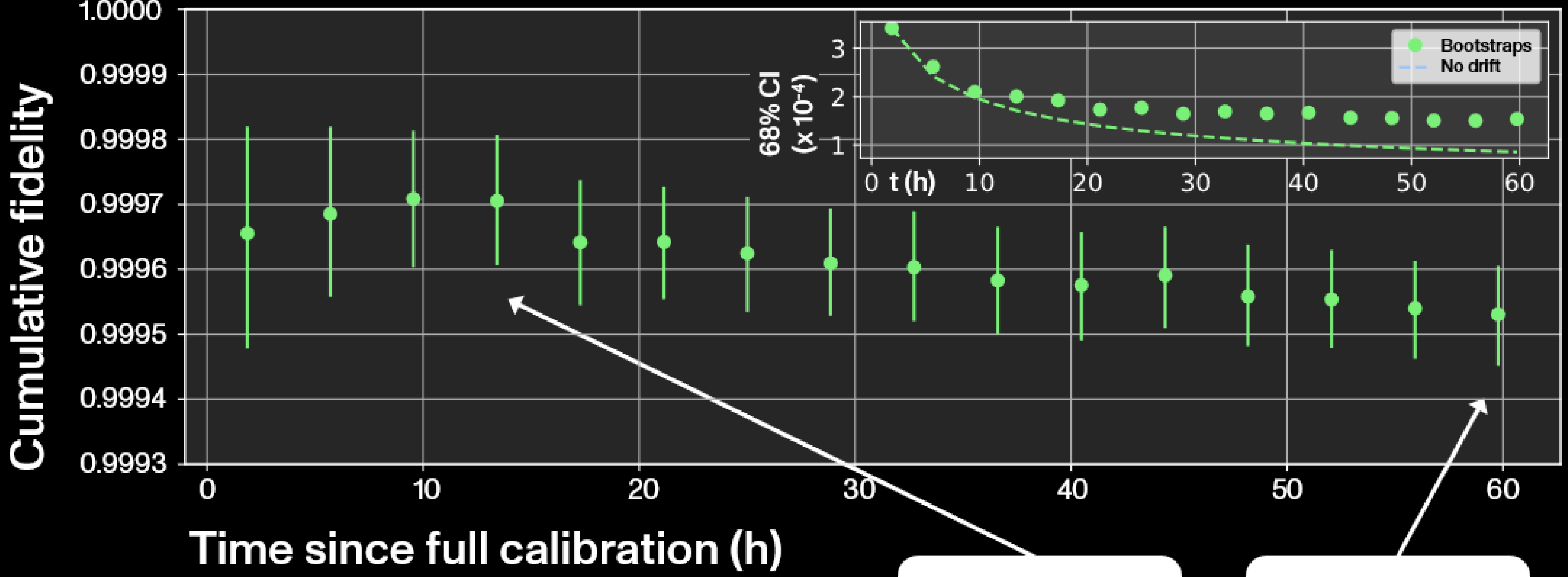


SEE E.G.

C. Ospelkaus et al., Phys. Rev. Lett. 101, 090502 (2008)

99.97% Fidelity

The best Bell-state ever measured?

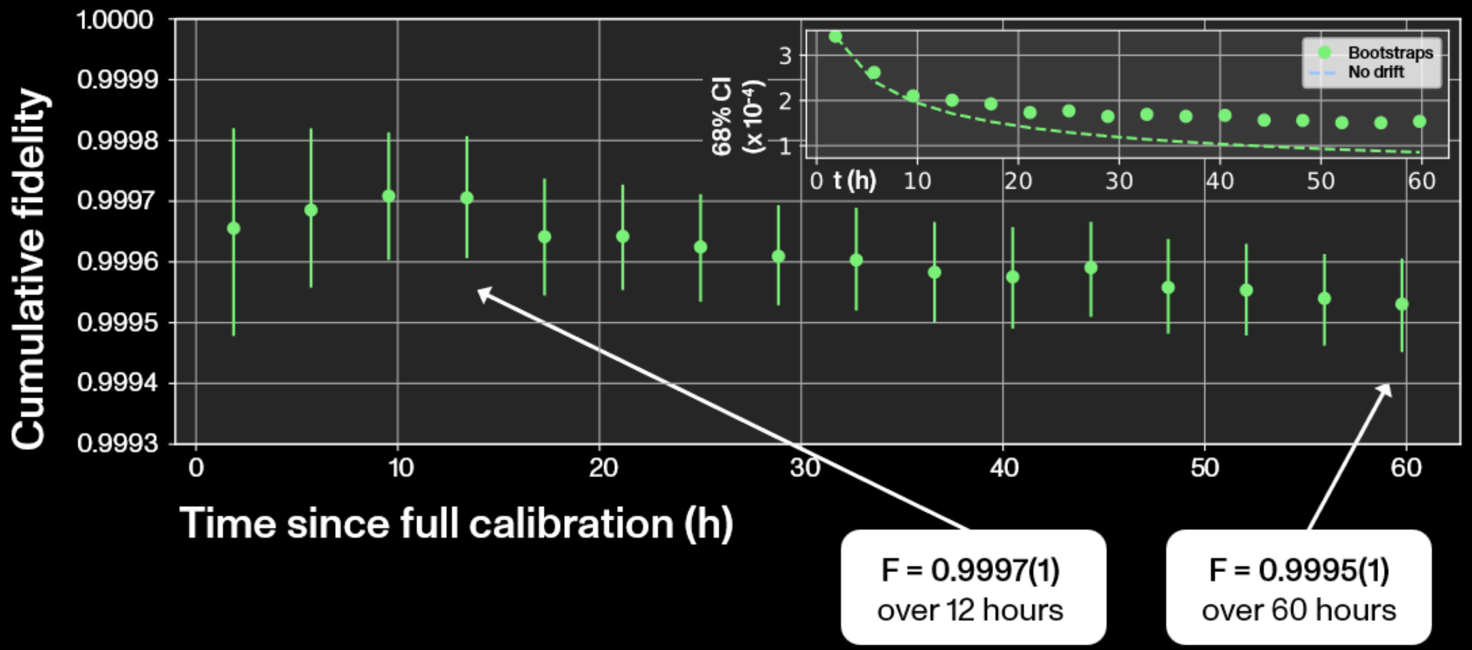


F = 0.9997(1)
over 12 hours

F = 0.9995(1)
over 60 hours

99.97% Fidelity

The best Bell-state ever measured?



F = 0.9997(1)
over 12 hours

F = 0.9995(1)
over 60 hours

- Limited by qubit frequency instability
- No fundamental limitations at the 10^{-4} level
- Ongoing work to measure fidelity via randomised benchmarking

So we have world class logic operations…

But does it scale to truly large devices?

Unit Cells in a QCCD

Global parallel control

Challenge of unit cell in QCCD architecture

- Power consumption
- Footprint
- IO count

Challenging per unit cell logic control

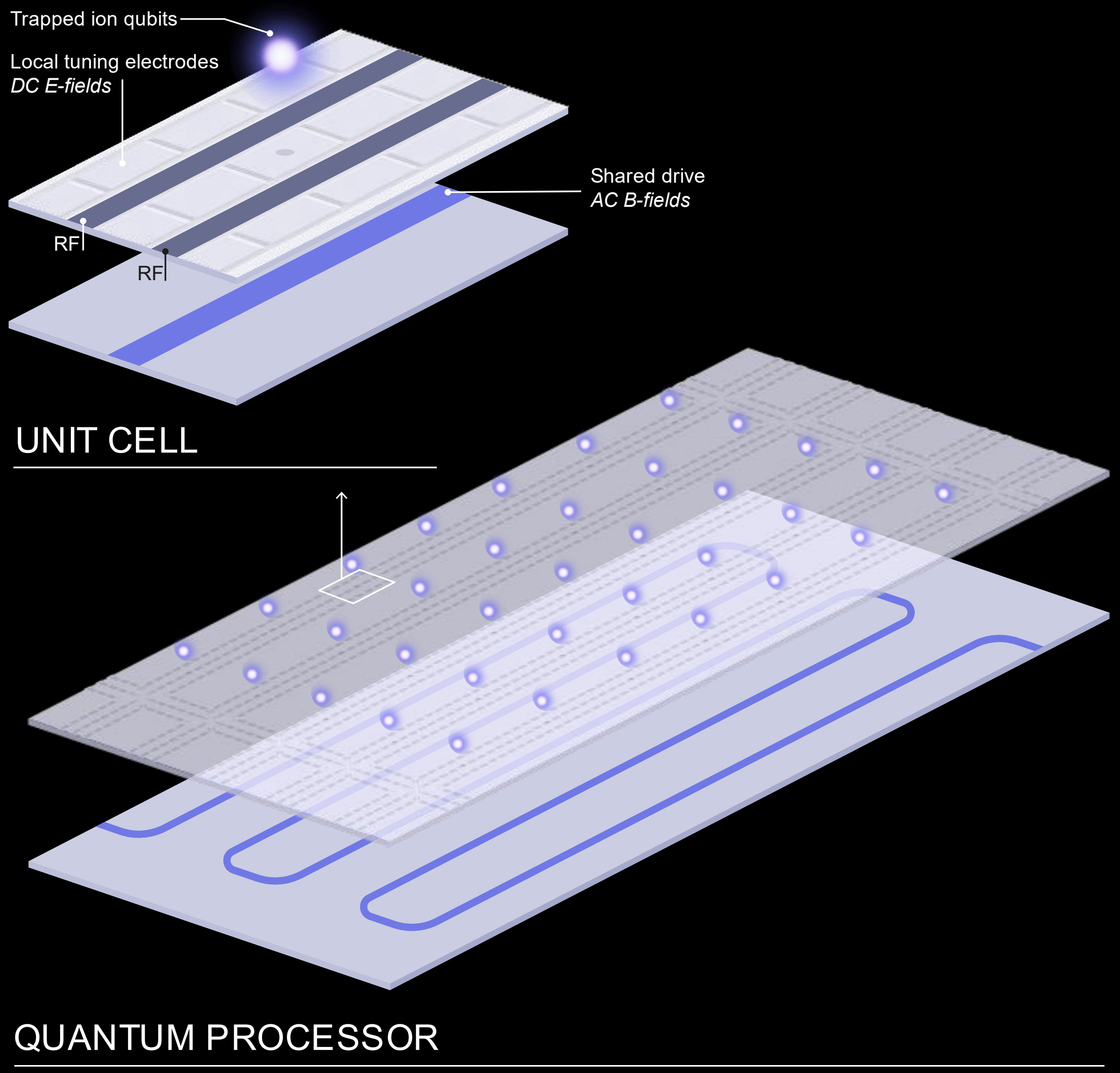
- No per-cell Modulator footprints (optical or microwave)

Challenge of scaling slow-down

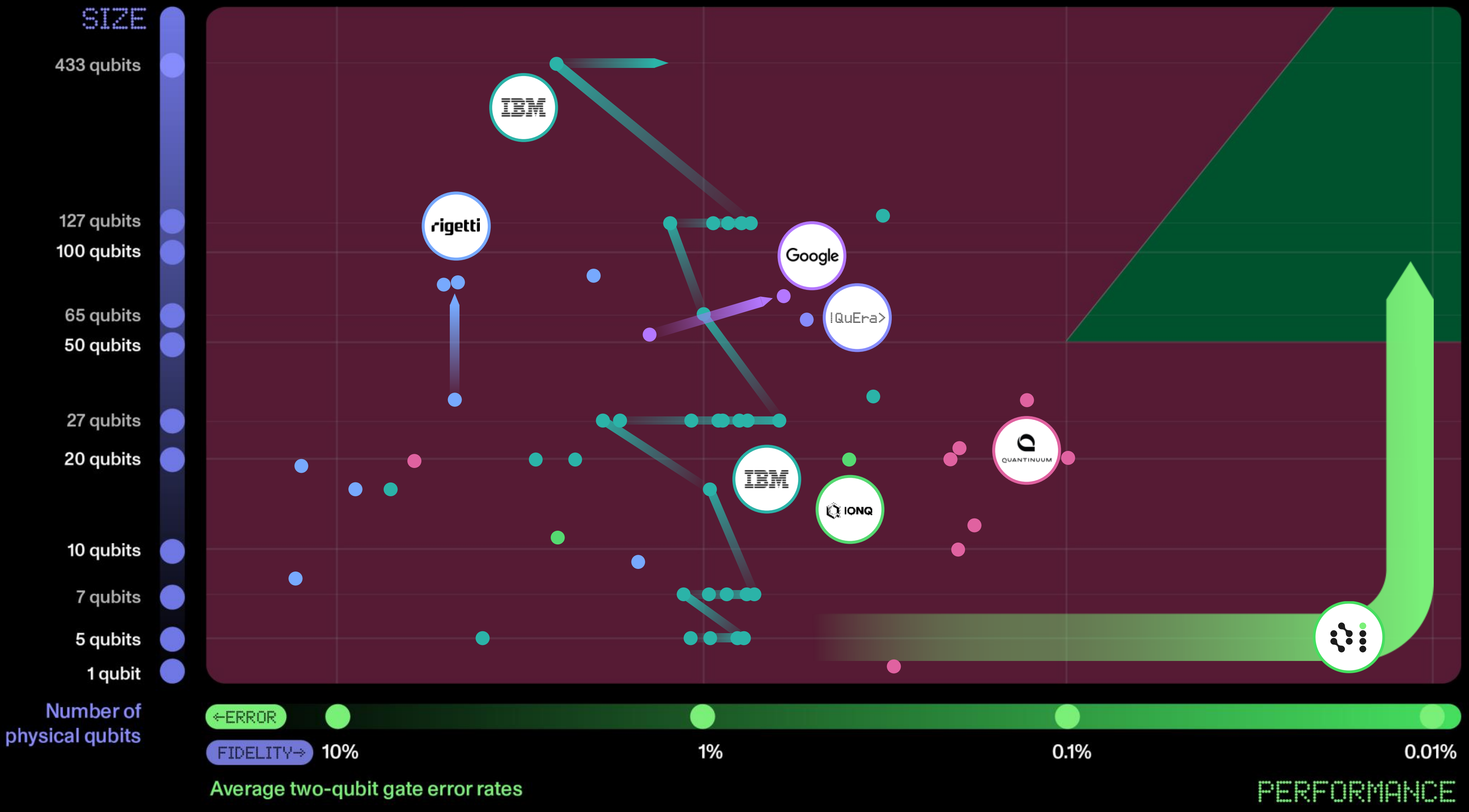
- No need to serialise gates on different ions

Challenge of power consumption

- Few high current sources/integrated modulators

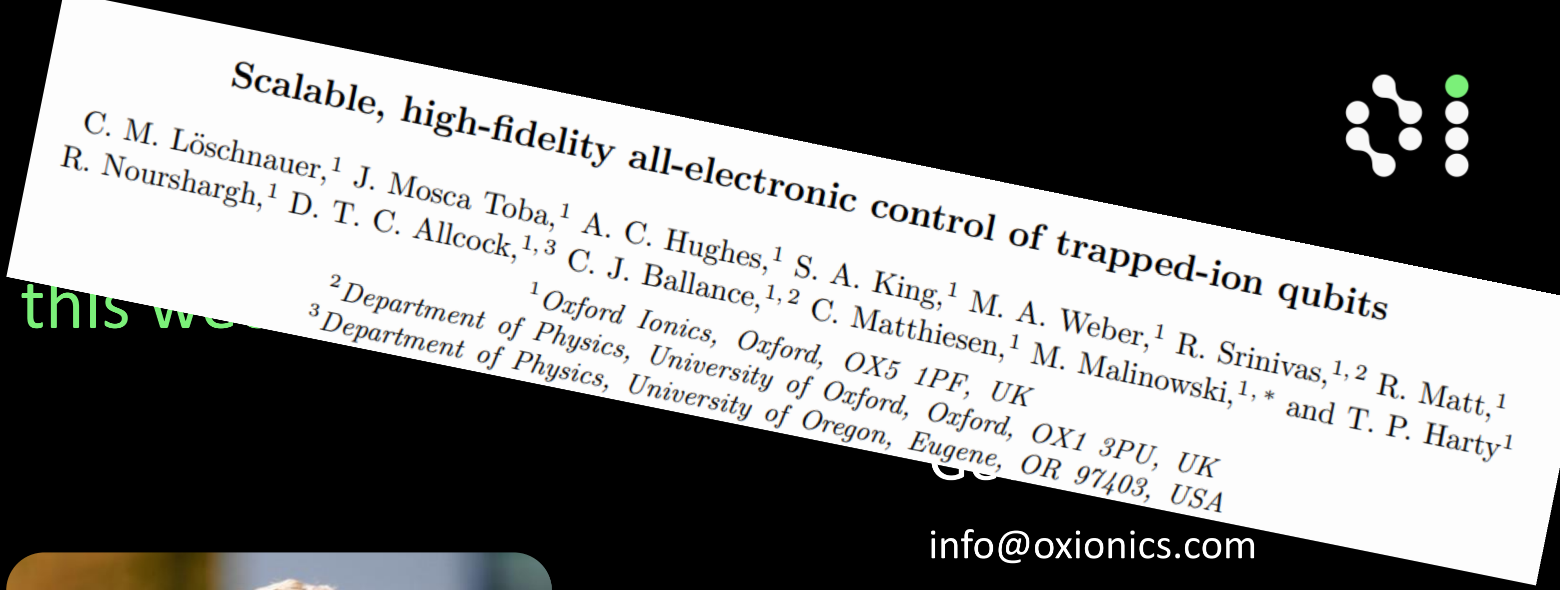


Quantum Computing: Two key ingredients



Thanks for listening

Where can you find the team this we



Scalable, high-fidelity all-electronic control of trapped-ion qubits

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Grab us for a chat:

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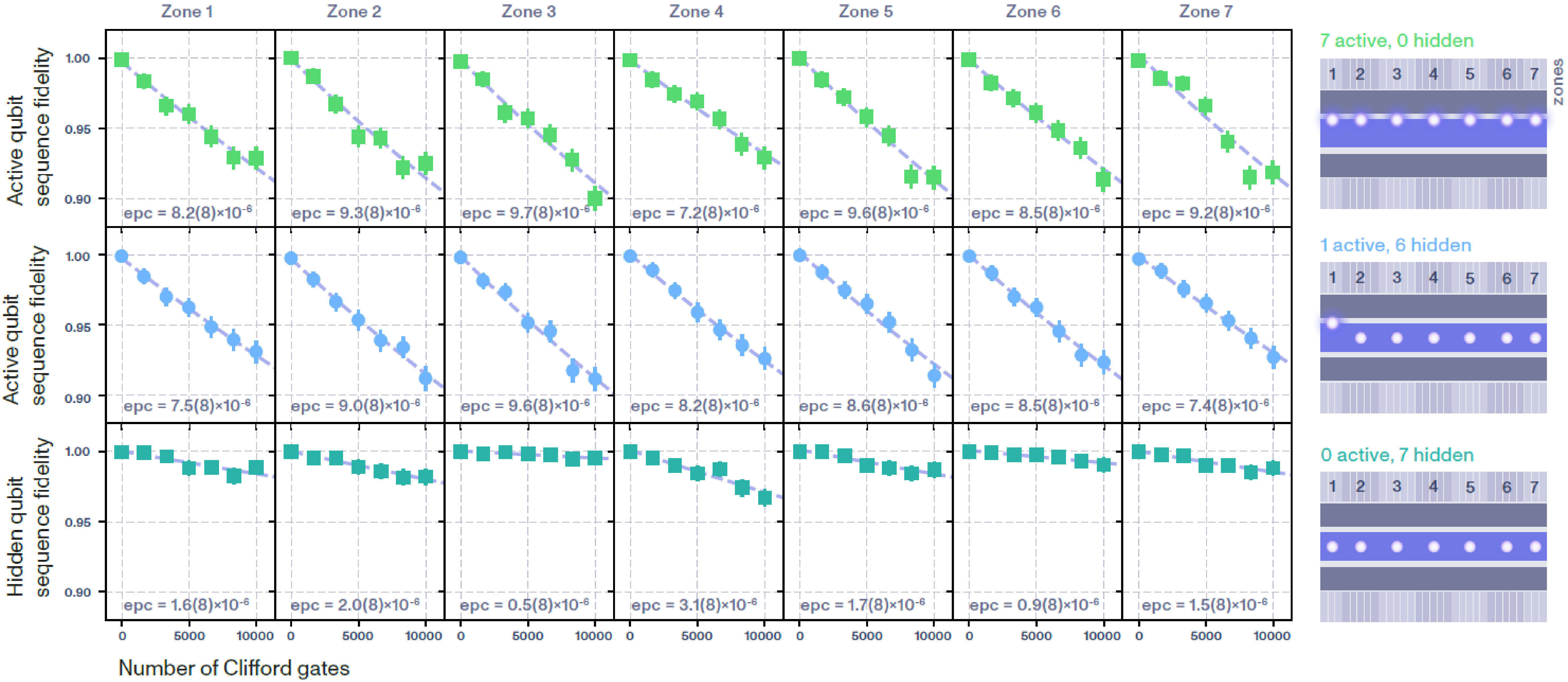
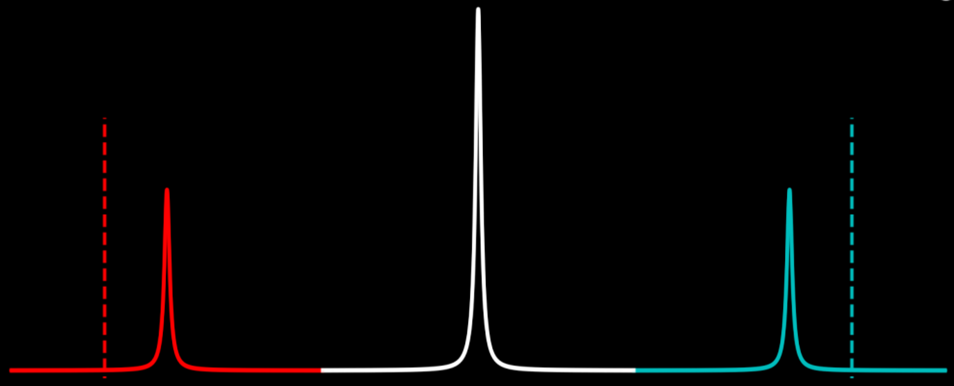
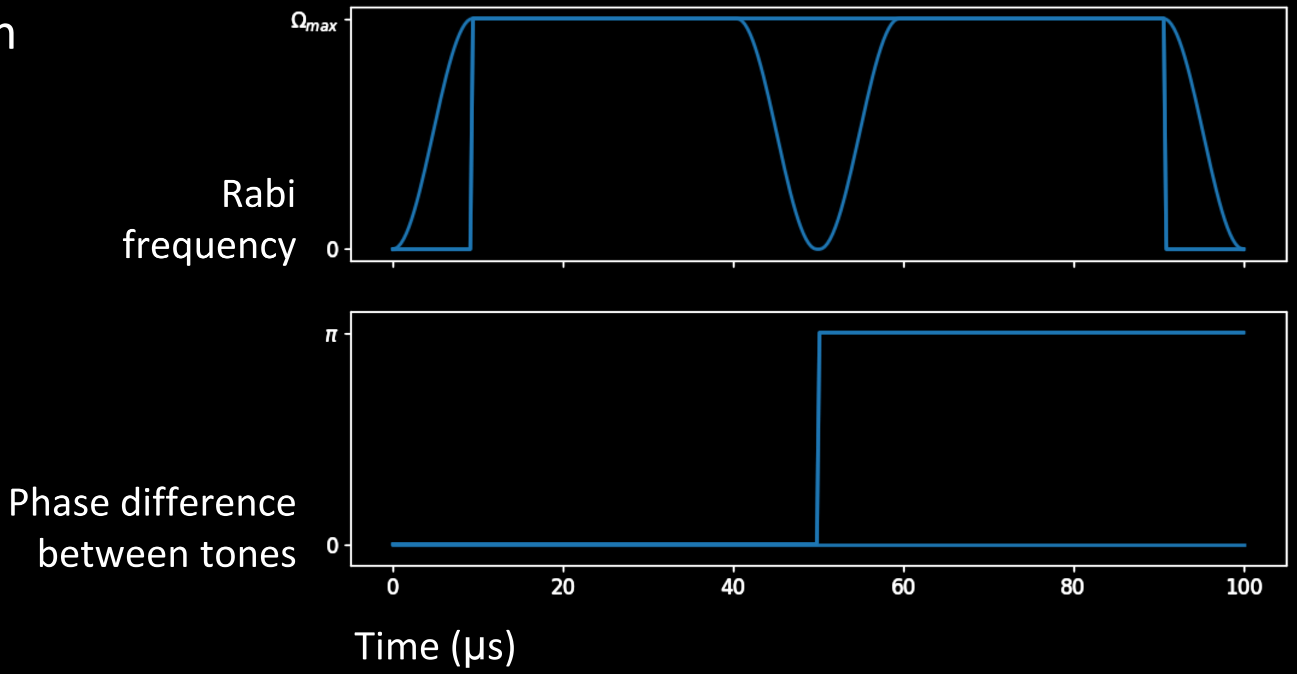
1 Qubit logic measurements



Fast entangling gates

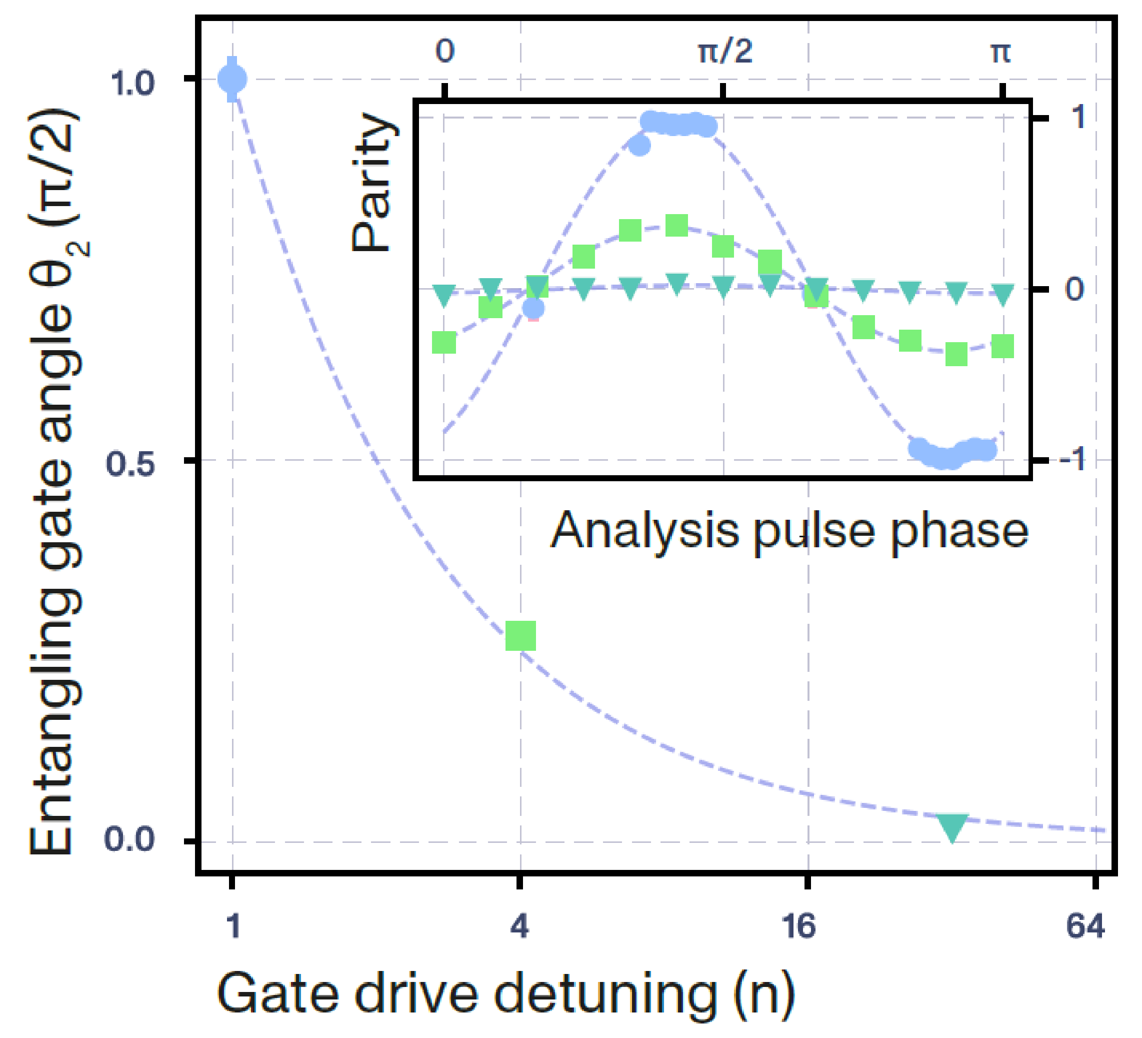
- Two-loop Mølmer–Sørensen gate
- Walsh-1 modulation to reduce sensitivity to changes in motional frequency
- Pulse shaping to reduce residual excitation from off-resonant coupling
- Duration 120 µs



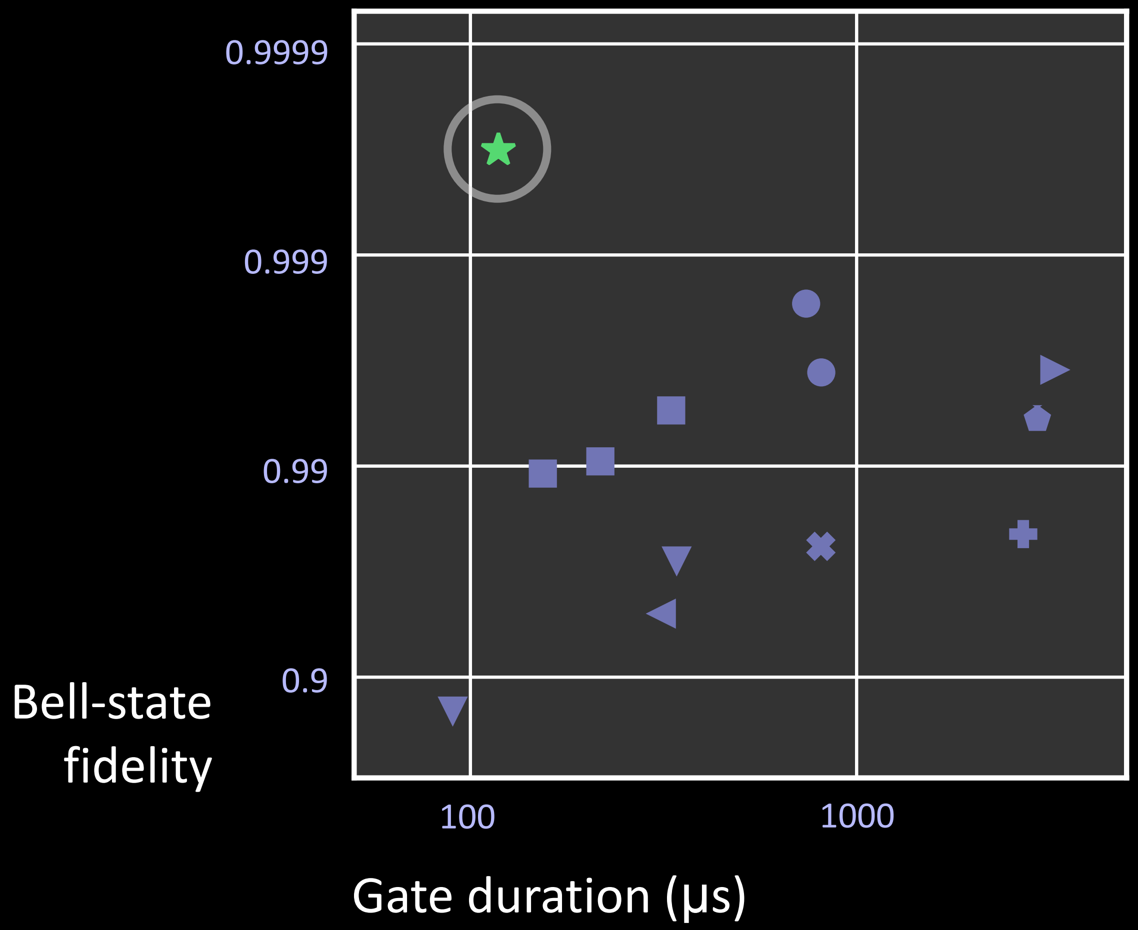


SEE E.G.
D. Hayes et al., Phys. Rev. Lett. 109, 020503 (2012)
G. Zarantonello et al., Phys. Rev. Lett. 123, 260503 (2019)

2 Qubit gate addressing



99.97% Fidelity



Mw-driven two-qubit gates
(lower bound of CI)

- ▶ Oxford 2016
- ✚ Sussex 2016
- ✖ Hannover 2019a
- ⬟ Hannover 2019b
- ● NIST 2021a
- ▼ NIST 2021b
- ▲ Siegen 2023
- ■ Oxford 2023
- ◀ Siegen 2024
- ★ Oxford Ionics 2024