

— CHAPTER 05 · HARDWARE DEEP DIVE

Trapped Ions & Neutral Atoms.

Fidelity vs *scalability*.

Two modalities sit at the front of the 2026 race alongside superconducting — one wins on gate fidelity, the other wins on scaling logical qubits. Picking the right one for a workload is a real engineering decision.

WHAT THIS TOPIC COVERS

● The ion picture

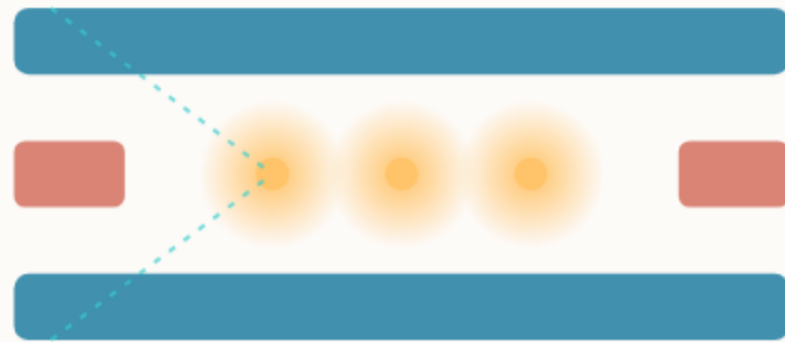
● The atom picture

● Workload-to-modality fit

— ARCHITECTURE · TRAPPED IONS

Atoms held by light. Gated by laser.

● PAUL TRAP SCHEMATIC



Ion chain in oscillating electric field · laser beams drive gates

● THREE STRUCTURAL CONSEQUENCES

All-to-all connectivity

Every ion couples to every other through the shared motional mode — no S W A P overhead.

Microsecond gates

Three to four orders of magnitude slower than superconducting nanosecond gates.

Best two-qubit fidelity

99.9 percent and above is routine — the highest of any production modality.

Qubit encoding: two long-lived energy levels of a single atomic ion — barium, ytterbium, or calcium are the production choices.

— PRODUCTION HARDWARE · TRAPPED IONS

Quantinuum Helios — November 2025.

● PHYSICAL QUBITS

98

Barium ions in a Q C C D — quantum charge-coupled-device — race-track trap.

● TWO-QUBIT FIDELITY

99.92%

Best published on any production system. Unlocks deeper circuits before noise dominates the signal.

● LOGICAL QUBITS SHIPPED

48

Error-corrected logical qubits available to customers — not a future roadmap number.

● H2 PREDECESSOR — FOR SCALE

56 barium ions · 99.8 percent two-qubit fidelity. The jump from 99.8 to 99.92 is what unlocked the logical-qubit count on Helios — one order of magnitude more error budget per gate.

— PRODUCTION HARDWARE · TRAPPED IONS

IonQ — and the algorithmic-qubit pivot.

• IONQ FORTE

35 AQ

Algorithmic qubits — the number of fully-connected, high-fidelity qubits that can run a benchmark circuit end-to-end. Ytterbium-ion architecture, cloud-available today.

• IONQ TEMPO (2025)

Barium

Successor system moving IonQ off ytterbium toward barium ions — longer coherence, better optical addressing, lower error per gate.

• AQ VERSUS PHYSICAL QUBITS

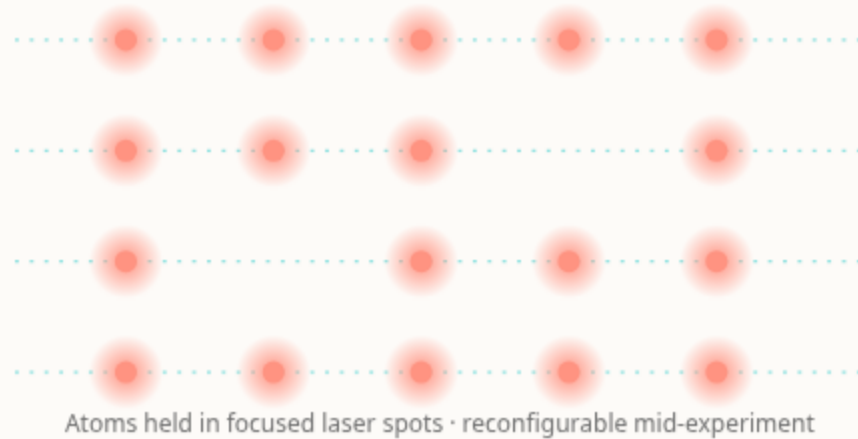
35 A Q is not the same animal as 35 physical qubits. A Q rolls fidelity, connectivity, and circuit-depth headroom into one number — closer to honest, harder to inflate. Treat it as the ion-side answer to Google Willow's below-threshold metric.

When you read an IonQ release, the headline number is A Q — not raw qubit count.

— ARCHITECTURE · NEUTRAL ATOMS

Tweezer arrays. Rydberg gates. Reconfigurable.

● OPTICAL TWEEZER ARRAY



● THREE SUPERPOWERS

Rydberg interactions

Exciting an atom to a Rydberg state makes it interact strongly with its neighbors — that is the gate.

Reconfigurable arrays

Atoms can be moved between zones during a circuit — change connectivity on the fly.

Mid-circuit measurement

Read out and reset a subset of atoms without collapsing the rest — native, fast, error-correction-ready.

This is the architecture that scales — neutral atoms have already shown arrays a thousand atoms wide.

— PRODUCTION HARDWARE · NEUTRAL ATOMS

QuEra — the largest logical-qubit demo on any platform.

● LOGICAL QUBITS (NATURE 2024)

96

QuEra plus Harvard, transversal gates on a reconfigurable Rydberg array.

● AQUILA — PHYSICAL ATOMS

256

Programmable analog mode — Rydberg-Hamiltonian evolution exposed as a parameterised job.

● CLOUD VENUE

AWS Braket

Pay-per-shot from a browser. Free-tier credits cover a first Bell-state experiment.

● WHY TRANSVERSAL GATES MATTER

Transversal gates apply the same physical operation to every qubit in a code block in parallel — fault-tolerant by construction, no magic-state distillation needed for the Clifford set. Neutral-atom arrays let you do this cleanly because the gates do not entangle code blocks accidentally.

— PRODUCTION HARDWARE · NEUTRAL ATOMS

Two more atom players. Europe and a memory bet.

● PASQAL — FRANCE

Vela QPU · 256+ qubits

2026 roadmap target. Already shipping today — a 140-qubit machine installed at C I N E C A, Italy's national supercomputing centre, in 2025.

EU sovereign play

Europe is competitive on neutral atoms in a way it is not on superconducting.

● ATOM COMPUTING — UNITED STATES

1180-qubit array (2023)

Highest raw physical-qubit count anyone has shown — strontium atoms. The demo was not about running circuits at that scale.

Memory and connectivity focus

Strategy is to win on long coherence and large connected blocks, not race logical-qubit headlines.

The atom field is genuinely multi-vendor: QuEra, Pasqal, Atom Computing, and a handful of academic groups — different bets, same physics.

— COMPARISON · PICK THE RIGHT MODALITY

Three modalities. Four trade-offs. No single winner.

● TRADE-OFF	● TRAPPED IONS Quantinuum · IonQ	● NEUTRAL ATOMS QuEra · Pasqal · Atom	● SUPERCONDUCTING Google · IBM
Qubit count	98 (Helios)	256 (Aquila), 1180 (Atom demo)	105 (Willow), 156 (Heron)
2Q fidelity	99.92% — best in class	~99.5% (and rising)	~99.7% (Willow)
Gate speed	Microseconds — slow	Microseconds — slow	Nanoseconds — fastest
Connectivity	All-to-all native	Reconfigurable mid-circuit	Nearest-neighbor on fixed grid

Ions win fidelity. Atoms win scaling. Superconducting wins speed and ecosystem. The race is not over.

— TRY IT YOURSELF · CLOUD QUANTUM

One Bell state. Two modalities. Free-tier credits.

● AWS BRAKET — PYTHON (QUANTINUUM H-SERIES, GATE MODE)

```
from braket.aws import AwsDevice
from braket.circuits import Circuit

device = AwsDevice(
    "arn:aws:braket:::device/qpu/quantinuum/H2-1"
)
bell = Circuit().h(0).cnot(0, 1)
task = device.run(bell, shots=1000)
counts = task.result().measurement_counts
print(counts)  # ~ {"00": 500, "11": 500}
```

● THEN: QUERA AQUILA (ANALOG MODE)

Swap the device A R N to `arn:aws:braket:us-east-1::device/qpu/quera/Aquila` and submit an A H S — analog Hamiltonian simulation — program instead of a gate circuit. Same account, same S D K, different physics.

What you will see

Native gate sets diverge. H2 gives you a clean two-qubit gate at 99.92 percent fidelity. Aquila gives you Rydberg-Hamiltonian evolution with no two-qubit-gate abstraction at all.

● Free-tier credits cover ~100 shots

● Submit asynchronously — queue can be slow

● Next chapter — photonic & topological