— CHAPTER 01 · COLD OPEN

We are at the front edge of *early fault-tolerant*.

Shor is not breaking RSA tomorrow. Below-threshold error correction *has* been demonstrated on real silicon for the first time — and useful fault-tolerant machines are still five to ten years out. The truth is more interesting than the hype.

WHAT THIS TOPIC COVERS

- Three eras
- Five hardware bets
- The utility debate
- What it can't do

— CONCEPT · THE THREE-ERA MODEL

NISQ → EFT → FTQC

The community converged on this map after 2024. We are at the start of the middle era — that is the real story.

ERA 01 · 2018 – 2024

NISQ

Noisy Intermediate-Scale Quantum. Hundreds of physical qubits, no error correction. Run a circuit and hope.

ERA 02 · 2024 – NOW

EFT — early fault-tolerant

Below-threshold QEC at small scale. QuEra 48–96 logical, Microsoft + Quantinuum 12 logical. No useful end-to-end FT workload yet.

ERA 03 · 2028 – 2030+

FTQC

Thousands of logical qubits. Shor at cryptographic scale. IBM Starling targets ~200 logical qubits 2028–2029.

You are here · EFT

5 – 10 years to useful FTQC

— COMPARISON · FIVE HARDWARE BETS

Five modalities. Nobody knows which one wins.

SUPERCONDUCTING

Google Willow

105 qubits · transmons. First below-threshold surface-code demo. *Nature*, Dec 2024.

TRAPPED IONS

Quantinuum Helios

98 barium ions · 99.92% two-qubit fidelity · 48 logical qubits, Nov 2025.

NEUTRAL ATOMS

QuEra + Harvard

Rydberg arrays · 96 logical qubits · *Nature* 2024.

PHOTONIC

PsiQuantum Omega

Silicon photonics · room temperature · fusion-based · targeting 1M physical qubits.

TOPOLOGICAL

Microsoft Majorana 1

Engineered Majorana modes, Feb 2025. *Nature*'s editors: results do not confirm Majorana modes.

Five bets, five physics stacks, five timelines. The course returns to each in chapters 4–6.

— DIALOGUE · THE UTILITY DEBATE

Did IBM really show quantum utility?

Ava · host

live debate

What does "quantum utility" actually mean — and did IBM really show it?

How the framing evolved

2023 claim → 2024 rebuttal → 2026 consensus

3 **New definition stuck**
"Useful work where classical methods strain" — not "beat classical forever"

— CONCEPT · QUBIT COUNT IS THE WRONG NUMBER

~~"Company X reaches 1000 qubits!"~~

If T1 is a microsecond, your thousand qubits are noise. Three numbers actually matter.

T1 / T2

COHERENCE TIME

How long the qubit holds its state. Microseconds vs milliseconds is the difference between a working circuit and pure noise.

99.92%

TWO-QUBIT GATE FIDELITY

Quantinuum Helios 99.92% · Zuchongzhi 3.0 99.62%. The jump from 99% to 99.9% is two orders of magnitude in usable circuit depth.

all→all

CONNECTIVITY

Trapped ions speak to every other qubit. Superconducting grids only to nearest neighbors. Topology decides what algorithms run.

Next time you see a qubit-count headline, ask three questions back. If the answers aren't in the press release, the press release isn't the story.

— COMPARISON · BQP VS THE UNIVERSE

What a quantum computer *can* and *can't* do

BQP is the class of problems a quantum computer solves efficiently. BQP and NP are believed **incomparable** — quantum is not a magic NP-crusher.

— CAN — EXPONENTIAL OR LARGE SPEEDUP

Where quantum genuinely wins

- Integer factoring · Shor
- Quantum simulation · chemistry, materials
- Structured linear algebra · HHL family
- Unstructured search · Grover (quadratic only)

Exponential speedup is reserved for *highly structured* problems. That structure is the whole game.

— CAN'T — NO MAGIC HERE

Where quantum is not the answer

- General AI / LLM training
- Arbitrary NP-hard problems
- Magical database lookup
- Copying an unknown state · no-cloning

The no-cloning theorem is a physical constraint on which algorithms are even expressible. Knowing the limits makes the rest of the course honest.

— RECAP · THE 16-CHAPTER SPINE

The road from here.

Six chapters carry a **diverged-in-2026** flag — the pre-2024 framing is now wrong.

- 01 · Why Now
- 02 · Linear Algebra
- 03 · Qubits & Gates
- 04 · Superconducting
- 05 · Trapped Ions
- 06 · Neutral / Photonic / Topo
- 07 · Error Correction
- 08 · qLDPC & Surface Codes
- 09 · Shor & Grover
- 10 · Variational & QML
- 11 · Software · Qiskit · Cirq
- 12 · Post-Quantum Crypto
- 13 · Industry Map
- 14 · Benchmarks & Hype
- 15 · Open Problems
- 16 · Synthesis

— YOUR PROMISE

Evaluate a quantum headline on its merits — vendor, modality, claim, and what the peer community said back.

Next up · Chapter 02 — the linear algebra that actually matters.