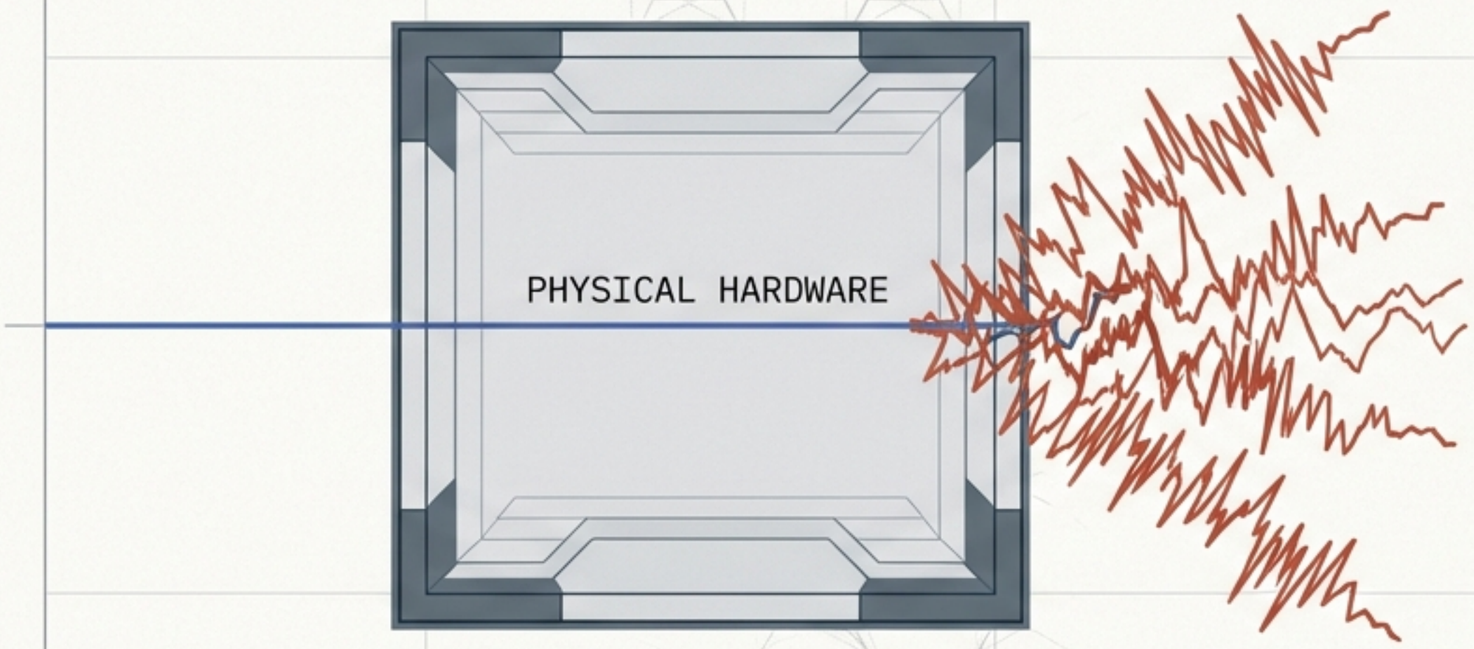
The Leaky Abstraction of Quantum Computing

Why running an experiment today is experimental physics, not software engineering.



The Black Box is Broken

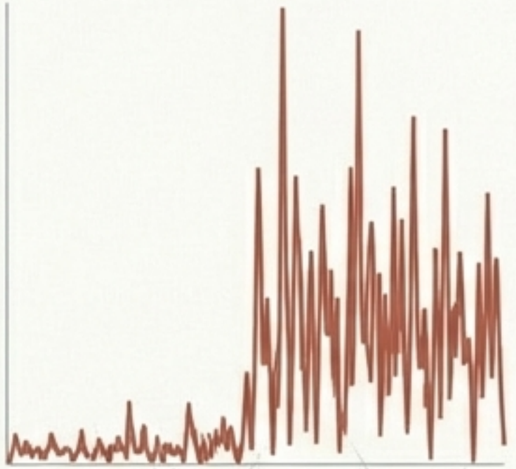
In traditional software, abstractions hold. Code runs predictably on underlying hardware.

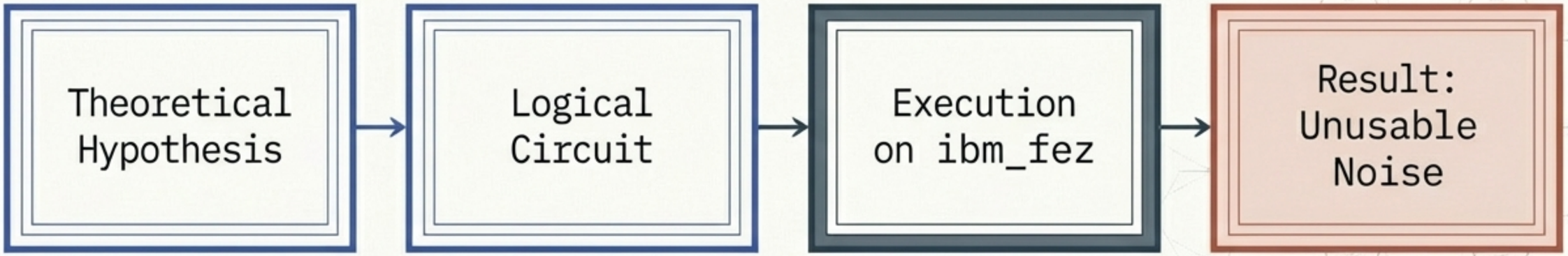
In quantum computing, abstractions leak constantly.

You cannot treat a quantum device as a black box. The physical machine does not care about your logical intentions.

A Textbook Experiment Meets Real Hardware

The goal was straightforward: run an actual measurement to test a specific theoretical prediction on real hardware.

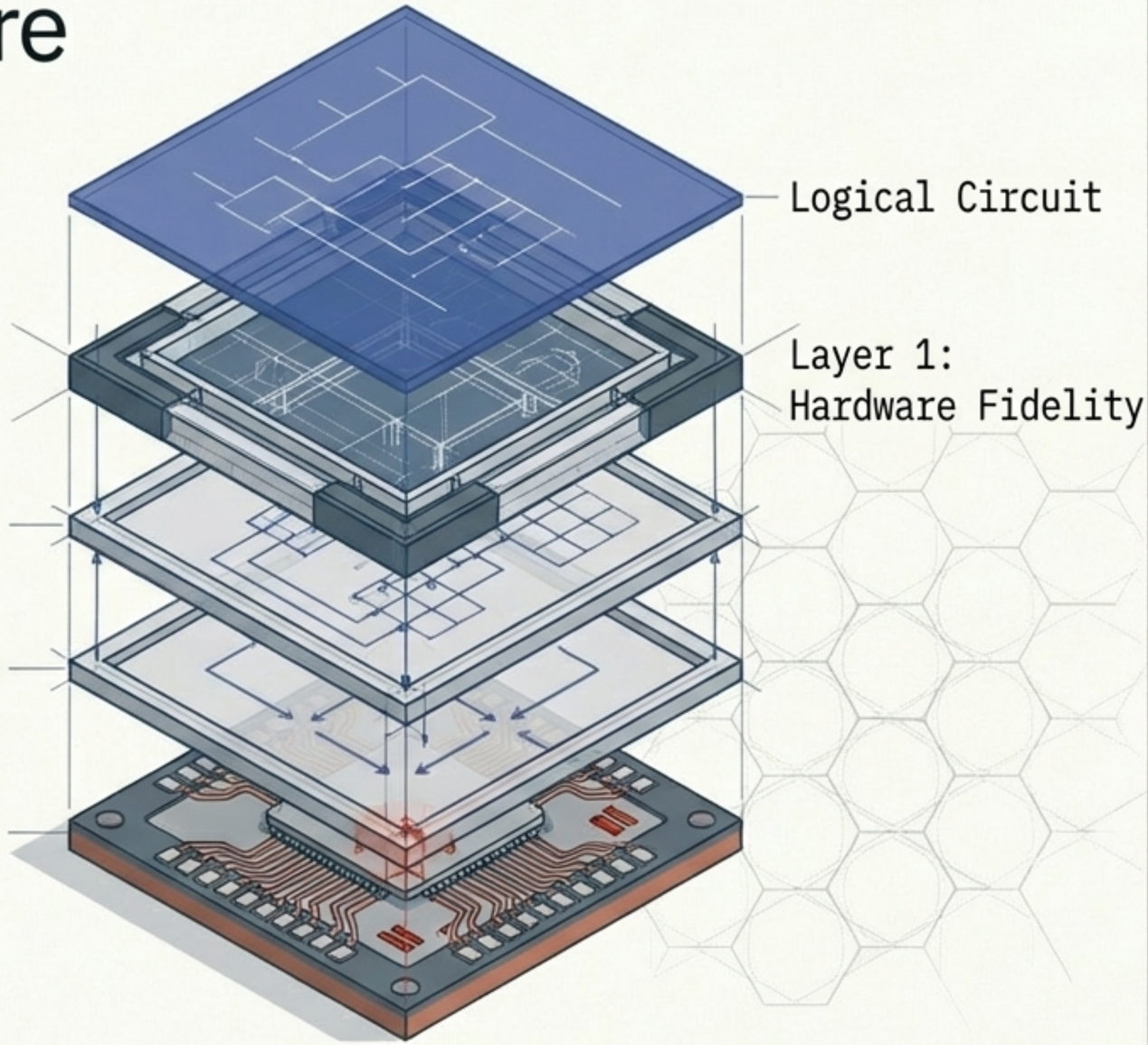




We assumed a bug in the circuit, or a flaw in the theory. Neither was true.

The 3 Layers of Hardware Negotiation

To prevent implementation noise from destroying a quantum signal, practitioners must manually negotiate with the physical system across three distinct layers.



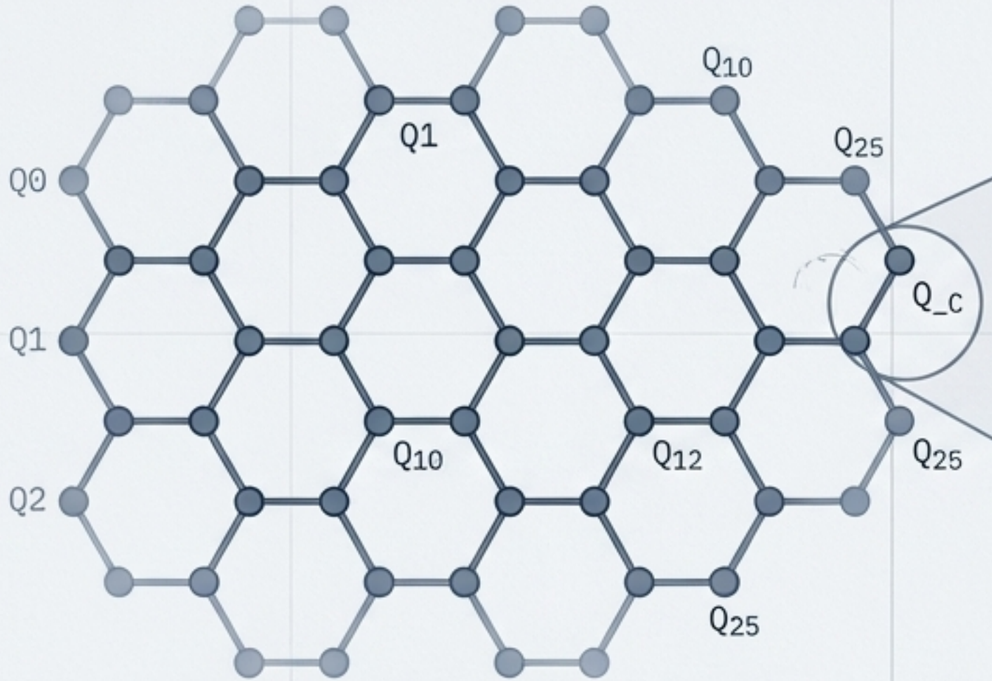
Layer 1: Hardware Error Characteristics

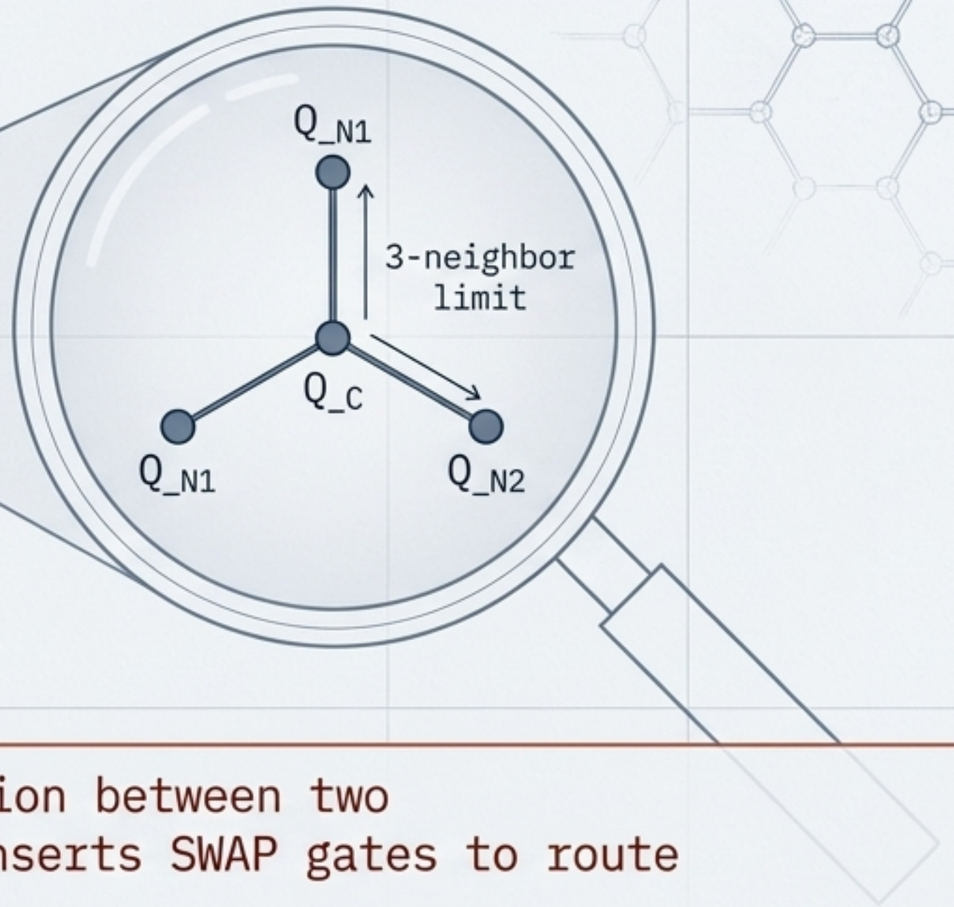
ibm_fez	ibm_strasbourg
Tier: Open Access Architecture: 156-qubit Heron r2 **Result: Gate fidelity and coherence times caused noise to compound fatally.**	Tier: Paid Plan Upgraded Architecture: 127-qubit Eagle r3 **Result: Superior fidelity preserves complex signals.**

Takeaway: Upgrading the hardware was only step one.

Layer 2 Context: The Topology Constraint

Eagle processors utilize a heavy-hex coupling map. Qubits are not universally connected; each connects to at most three neighbors.



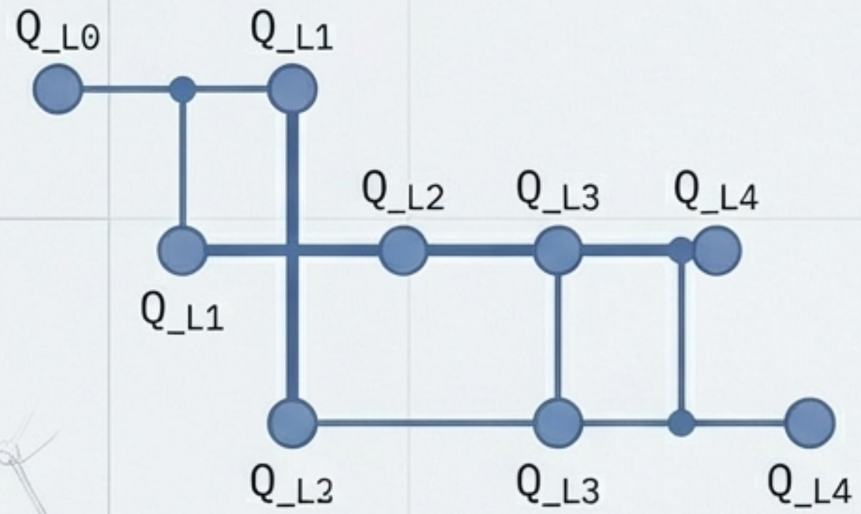


Key Insight: If a circuit requires a CNOT interaction between two unconnected qubits, the transpiler automatically inserts SWAP gates to route them. SWAP gates dramatically inflate noise.

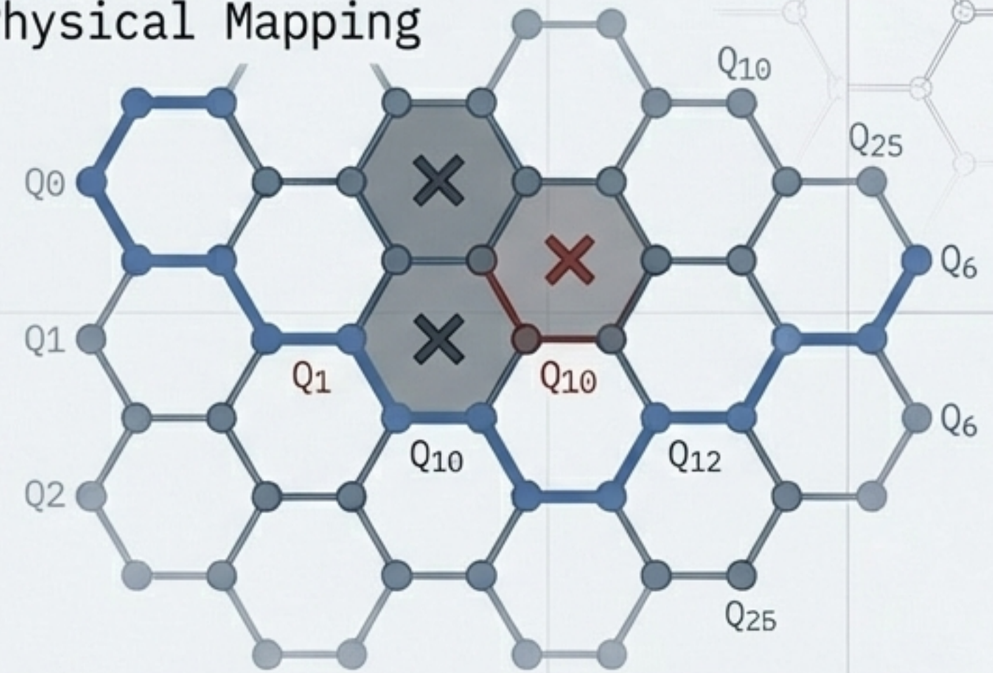
The Fix: Manual Subgraph Matching

To avoid transpiler-inserted SWAP gates, the logical circuit must be manually matched to the physical coupling map.

Logical Need



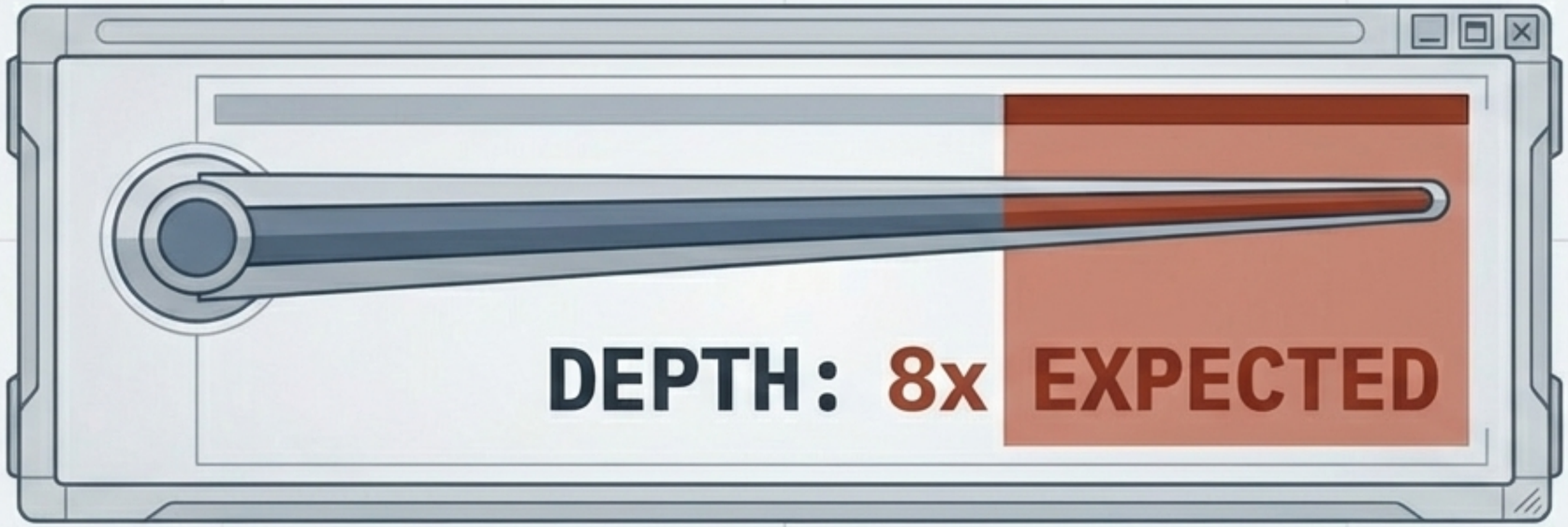
Physical Mapping



1. Locate a layout matching logical CNOT requirements.
2. Cross-reference daily device `calibration` data.
3. Actively route around the worst-performing physical qubits.

The Midpoint Twist: Coherence Burn

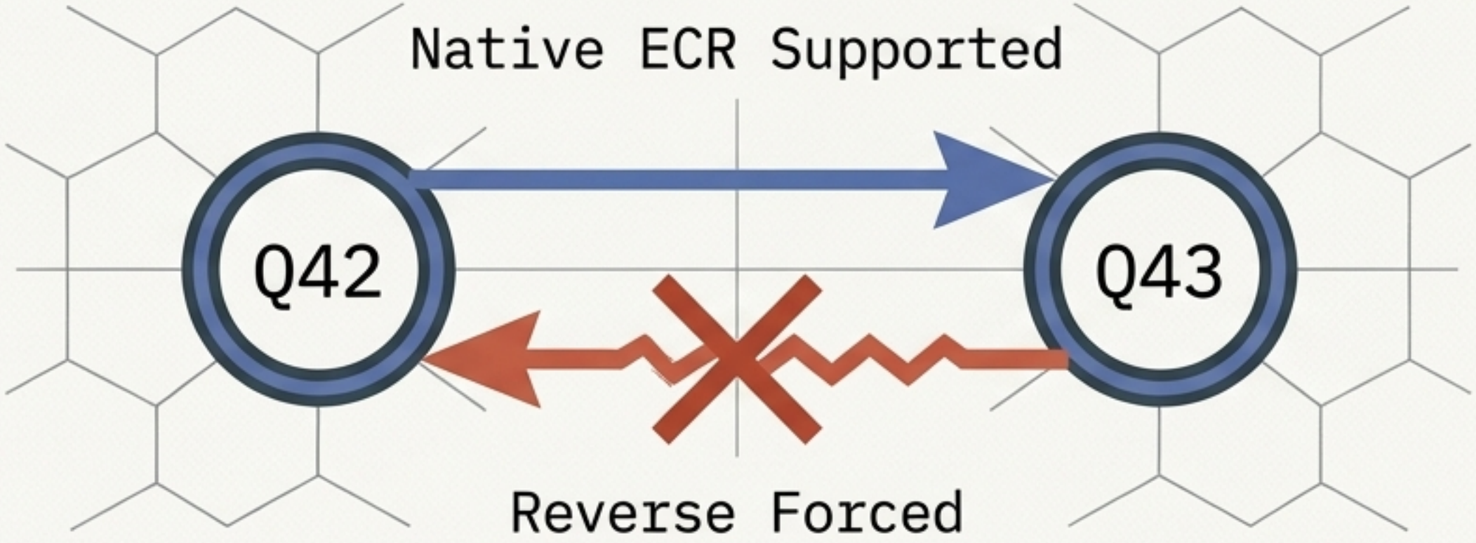
We ran the mapped circuit on ibm_strasbourg. The results were closer to the theory, but the compilation itself was fundamentally flawed.



Editorial Callout:
The signal was burning through its coherence time before it could even finish executing.

Layer 3 Context: Native Gate Directionality

IBM’s Eagle processors use **Echoed Cross-Resonance (ECR)** as their **native** two-qubit **gate. These physical gates** are **strictly directional.**



An interaction originating from qubit 42 targeting qubit 43 is natively supported. The reverse is not.

The Cost of Transpiler Blindness

When you write a CNOT in the “wrong” direction relative to the hardware’s native orientation, the transpiler blindly decomposes it using multiple additional gates.

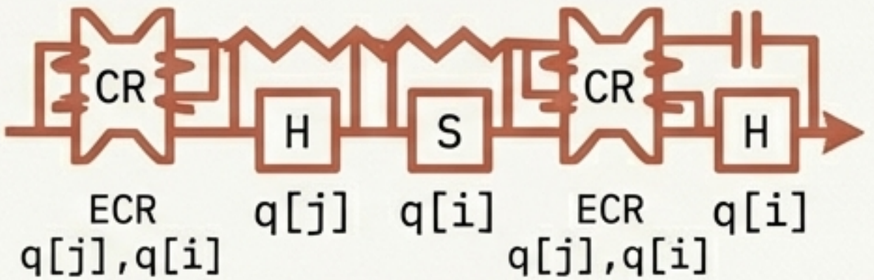
Input: 1 Logical CNOT (Reverse Direction)

CNOT q[i], q[j]

Black Box Transpiler

TRANSPILER

Output



The Multiplier

Our circuit contained 12 CNOTs. When multiplied by this directional overhead, the circuit became a massively inflated, coherence-draining monster.

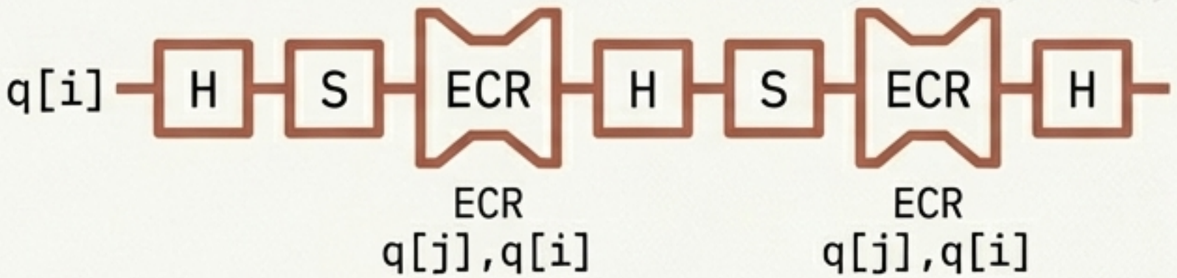
The Fix: Conjugating Native Orientations

We audited the coupling map edge by edge, manually intervening where the transpiler failed.

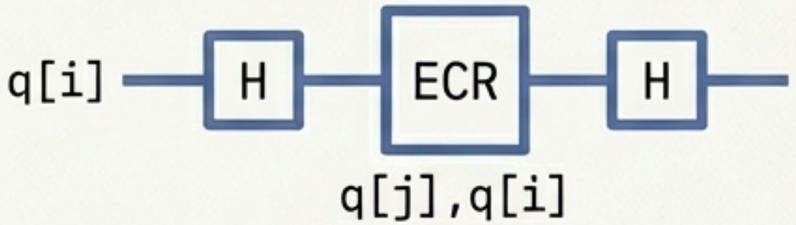
Manual Debugging

- ☑ Checked all 12 CNOTs against native ECR directions.
- ☑ Rethought qubit assignments to match physical flow.
- ☑ Conjugated backwards CNOTs with single-qubit gates to override transpiler inflation.

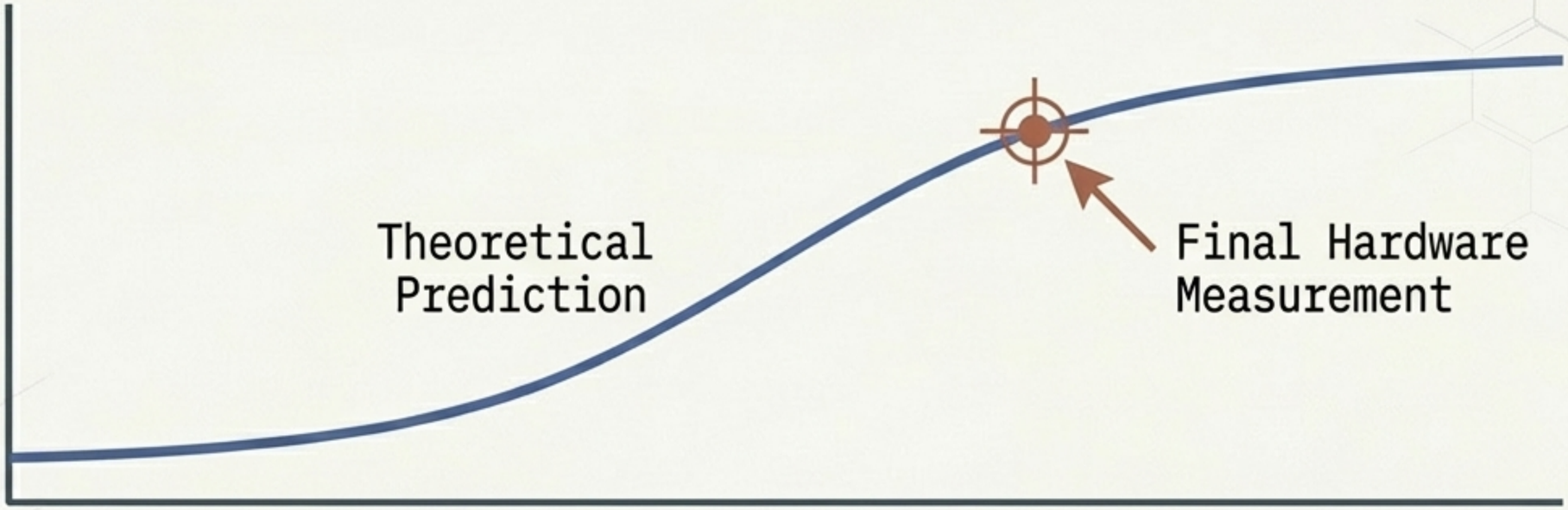
Before (Transpiler Inflation)



After (Conjugated Native Gate)



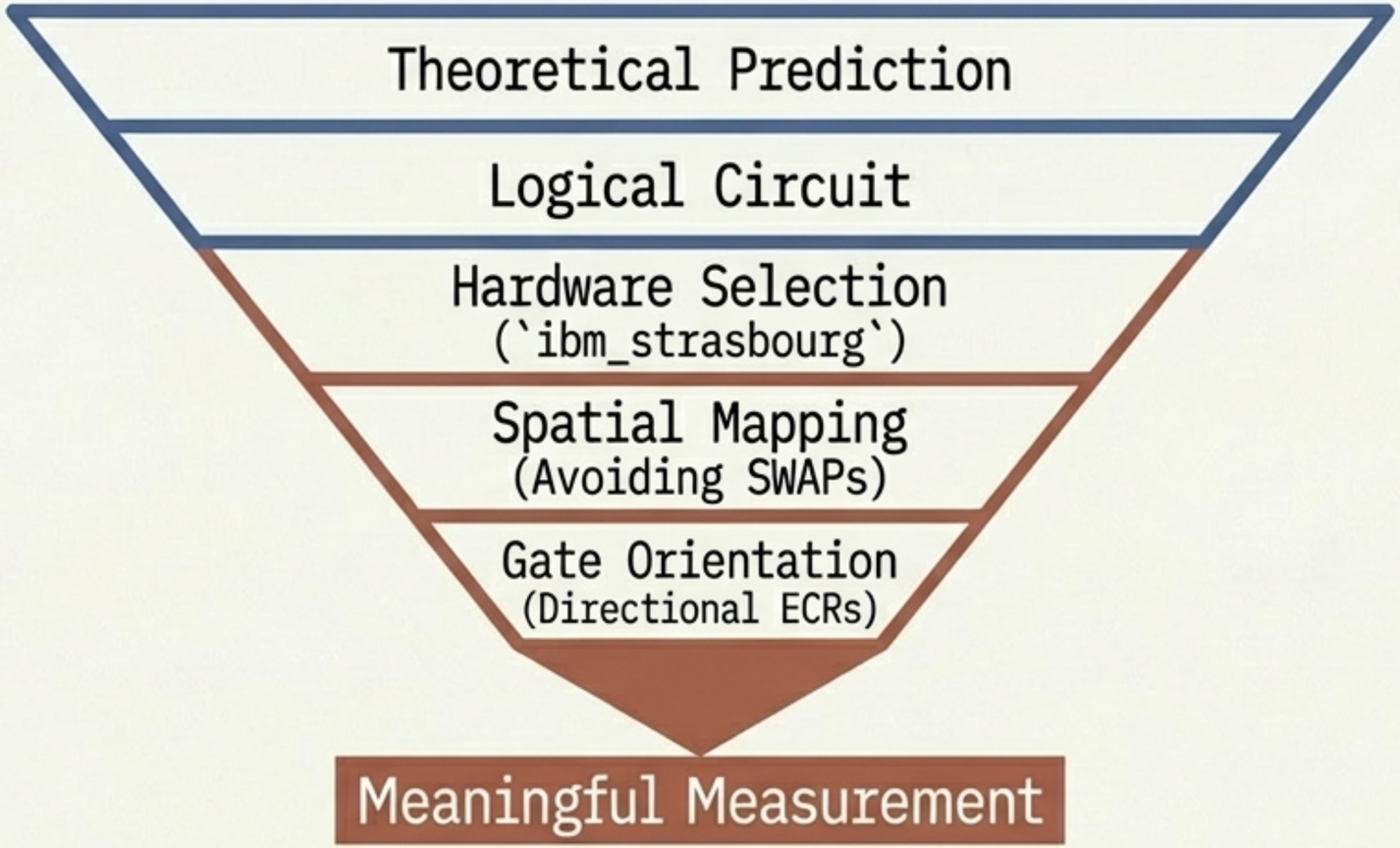
A Quiet Success



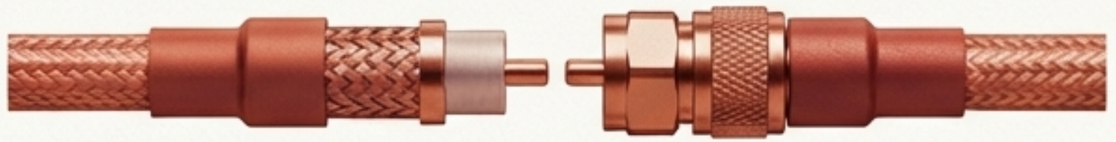
We ran the rewritten circuit. The depth depth dropped back to normal parameters. The measured result landed precisely where the theory predicted it would.

No champagne. Just a number on a screen earned through two hours of intense debugging against physical constraints.

The Full Stack of Implementation



The physics was the easy part. The hard part was understanding the machine intimately enough to protect the fragile signal from implementation noise at every layer.



You Are Negotiating With Physics

- ✔ The coupling map matters.
- ✔ The native gate directions matter.
- ✔ The specific qubits on a specific chip on a specific day matter.

THIS IS NOT SOFTWARE ENGINEERING. THIS IS EXPERIMENTAL PHYSICS. DOWN TO THE WIRING.