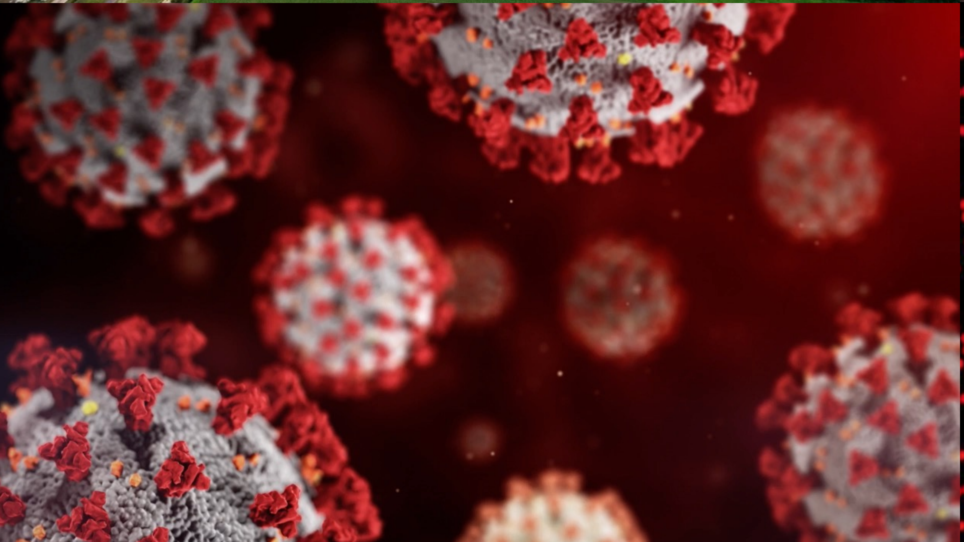
The Mission of IBM Quantum

Dr. Christa Zoufal

Research Scientist
Quantum Computational Science
IBM Quantum, IBM Research Europe - Zurich

IBM **Quantum**





.22 H -20.71 7.60%
.76 M -41.24 8.72%
-22.33 9.25%
.42 X -41.02 5.23%
.39 M -09.22 1.82%

Our mission

Bring useful quantum computing to the world

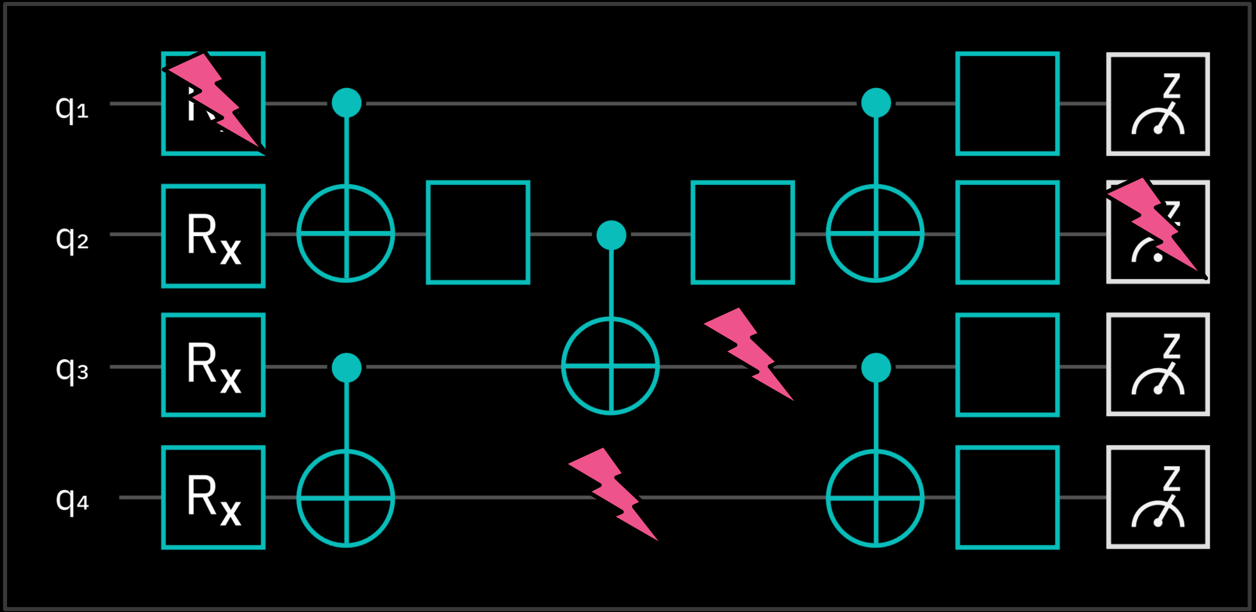
Make the world quantum safe

Our mission

Bring useful quantum computing to the world

Make the world quantum safe

In quantum computation, we must deal with errors.



Dealing with errors in quantum systems

- **Error correction:** computation is performed on **encoded (logical) qubits**.
  Errors are corrected during the computation.

- **Error mitigation:** computation is performed on **unencoded (physical) qubits**.
  Errors are corrected by combining outcomes of many noisy circuits.

Dealing with errors in quantum systems

- **Error correction:** computation is performed on **encoded (logical) qubits**.
  Errors are corrected during the computation.

- **Error mitigation:** computation is performed on **unencoded (physical) qubits**.
  Errors are corrected by combining outcomes of many noisy circuits.

Approach	Gate set	Qubit overhead	Circuit output	Sampling overhead	Scaling
Error correction (today)	Clifford + T	Large	Any	None	Polynomial
Error mitigation (today)	Any	None	Expected values of observables	Large	Exponential

Recent Breakthrough in Error Correction

arXiv > quant-ph > arXiv:2308.07915

Search...

Help | Advanc

Quantum Physics

[Submitted on 15 Aug 2023]

High-threshold and low-overhead fault-tolerant quantum memory

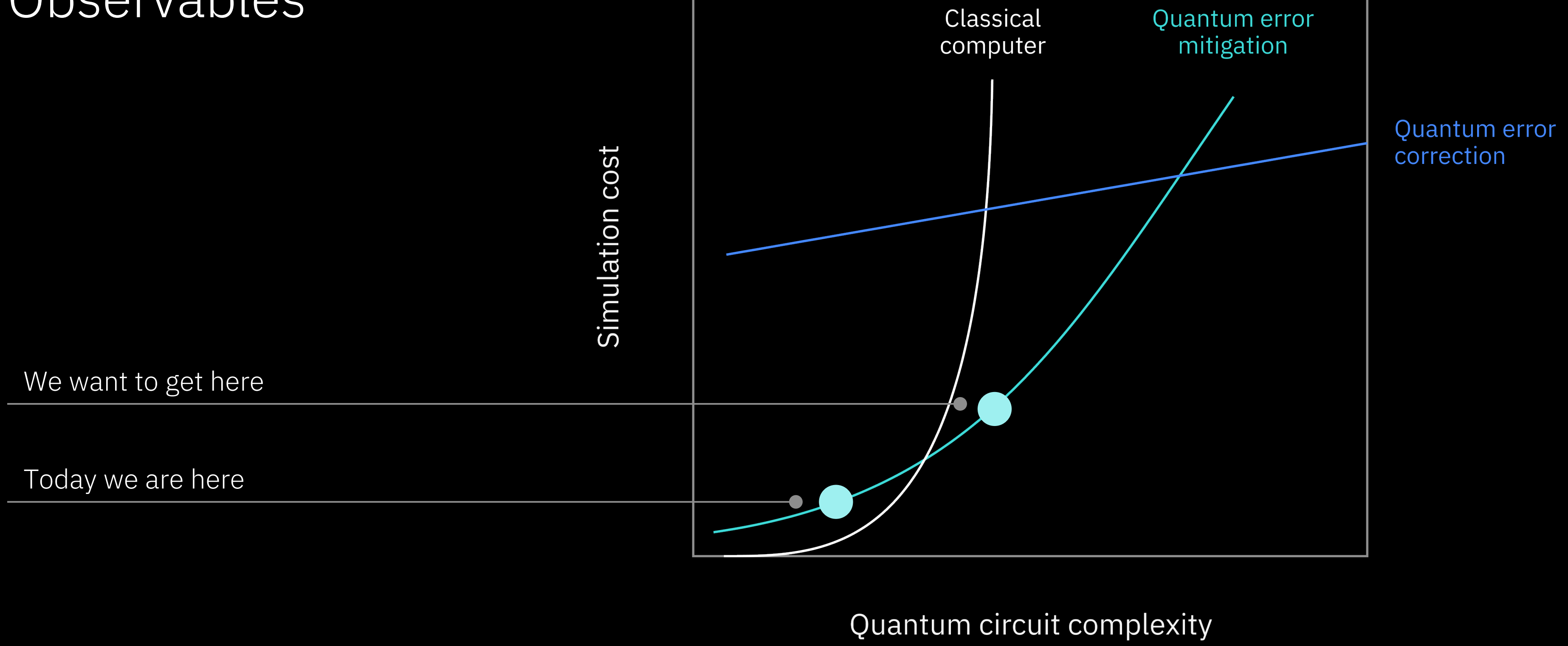
Sergey Bravyi, Andrew W. Cross, Jay M. Gambetta, Dmitri Maslov, Patrick Rall, Theodore J. Yoder

Quantum error correction becomes a practical possibility only if the physical error rate is below a threshold value that depends on a particular quantum code, syndrome measurement circuit, and a decoding algorithm. Here we present an end-to-end quantum error correction protocol that implements fault-tolerant memory based on a family of LDPC codes with a high encoding rate that achieves an error threshold of 0.8% for the standard circuit-based noise model. This is on par with the surface code which has remained an uncontested leader in terms of its high error threshold for nearly 20 years. The full syndrome measurement cycle for a length-n code in our family requires n ancillary qubits and a depth-7 circuit composed of nearest-neighbor CNOT gates. The required qubit connectivity is a degree-6 graph that consists of two edge-disjoint planar subgraphs. As a concrete example, we show that 12 logical qubits can be preserved for ten million syndrome cycles using 288 physical qubits in total, assuming the physical error rate of 0.1%. We argue that achieving the same level of error suppression on 12 logical qubits with the surface code would require more than 4000 physical qubits. Our findings bring demonstrations of a low-overhead fault-tolerant quantum memory within the reach of near-term quantum processors.

Previous estimates:
1 logical qubit **~500 physical qubits**

New IBM paper (so far for memory):
1 logical qubit **~50 physical qubits**

Error Mitigation: Noise-free Estimates of Observables

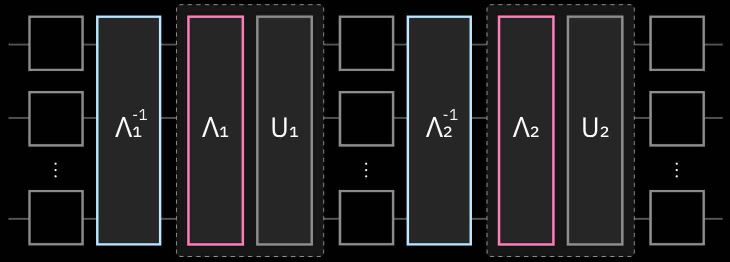


Error mitigation

IBM **Quantum**

Probabilistic Error Cancellation

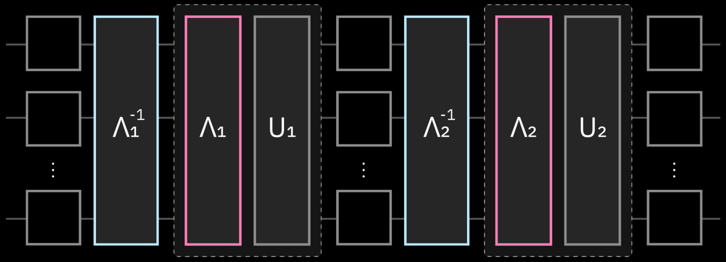
Average over many circuit instances with additional gates inserted to reconstruct the noise inverse and get unbiased estimates of expectation values



Error mitigation

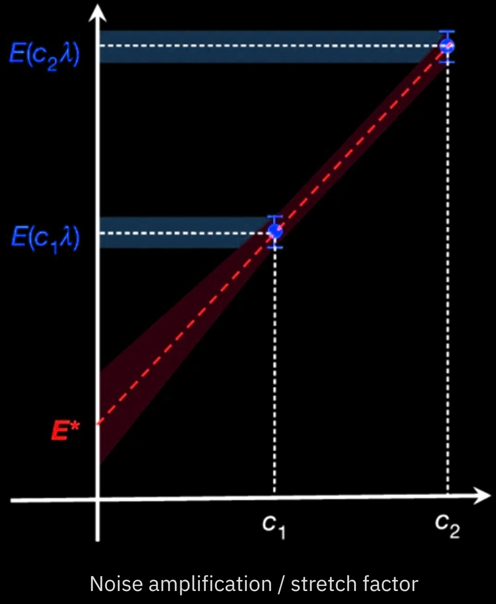
Probabilistic Error Cancellation

Average over many circuit instances with additional gates inserted to reconstruct the noise inverse and get unbiased estimates of expectation values



Zero Noise Extrapolation

Increase noise through stretching circuits and extrapolate back to the zero noise limit

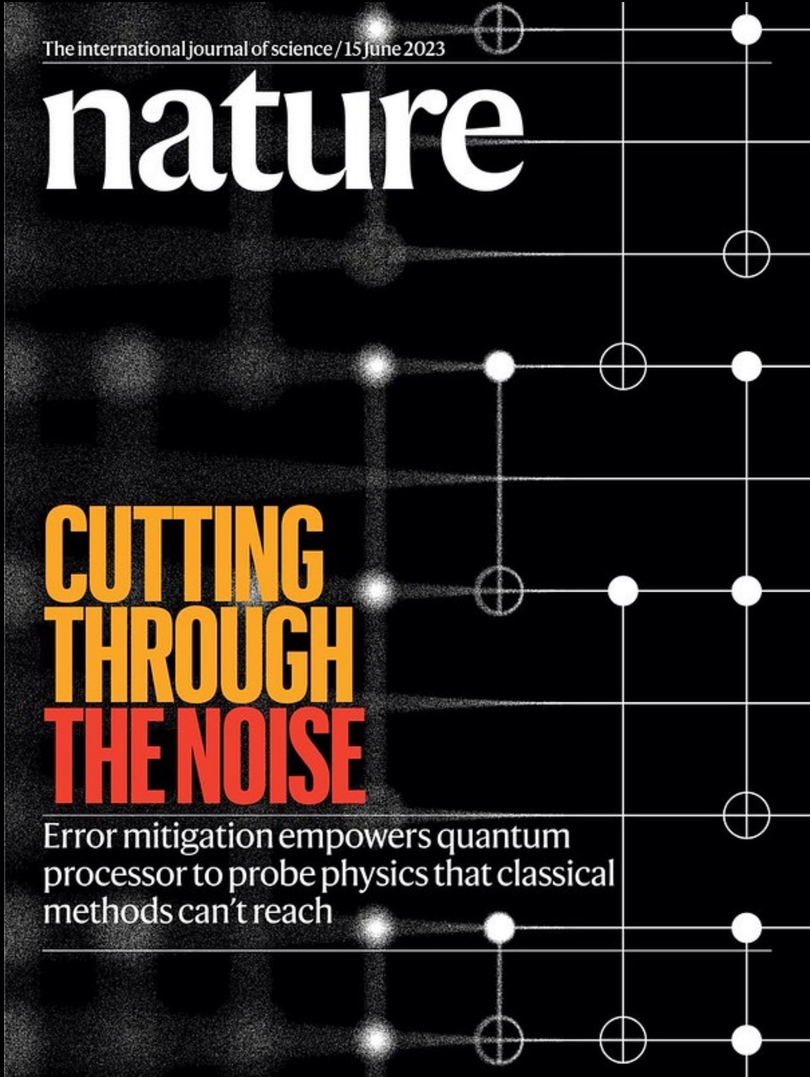


Article | Open Access | Published: 14 June 2023

Evidence for the utility of quantum computing before fault tolerance

Youngseok Kim ✉, Andrew Eddins ✉, Sajant Anand, Ken Xuan Wei, Ewout van den Berg, Sami Rosenblatt, Hasan Nayfeh, Yantao Wu, Michael Zaletel, Kristan Temme & Abhinav Kandala ✉

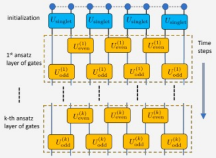
Nature **618**, 500–505 (2023) | Cite this article



Multiple 100+ qubit experiments have been published by now!

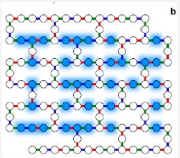
Simulating large-size quantum spin chains on cloud-based superconducting quantum computers

102 qubits / 3186 CX gates arXiv:2207.09994



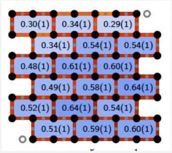
Uncovering Local Integrability in Quantum Many-Body Dynamics

124 qubits / 2641 CX gates arXiv:2307.07552



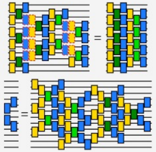
Realizing the Nishimori transition across the error threshold for constant-depth quantum circuits

125 qubits / 429 gates + meas. arXiv:2309.02863



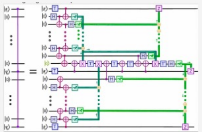
Scalable Circuits for Preparing Ground States on Digital Quantum Computers: The Schwinger Model Vacuum on 100 Qubits

100 qubits / 788 CX gates arXiv:2308.04481



Efficient Long-Range Entanglement using Dynamic Circuits

101 qubits / 504 gates + meas. arXiv:2308.13065



We now deliver these optimizations through the Qiskit Runtime Primitives

Sampler

Circuit → $\tilde{p}(\hat{x})$

Circuit

Quasi-probability distribution

Estimator

Circuit + Observable $\tilde{O}$ → $\langle \tilde{O} \rangle$

Circuit
+
Observable
$\tilde{O}$

Expectation value

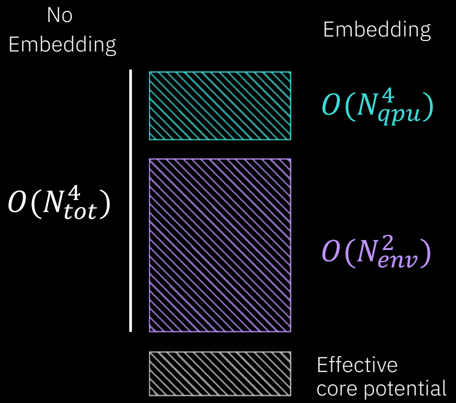
Leverage Quantum + Classical Compute

IBM **Quantum**

Embedding

Effective leveraging of QPU resources: Only the part of the problem which most benefits from exploiting entanglement is undertaken by the QPU

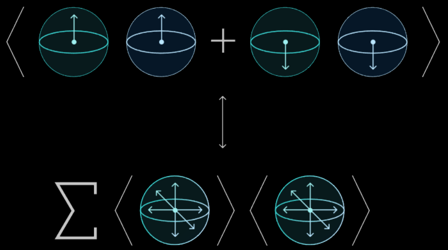
The CPU is efficient in tackling the remaining of the problem



Entanglement forging

Break down a correlated system into smaller subsystems which can be tackled by smaller QPUs.

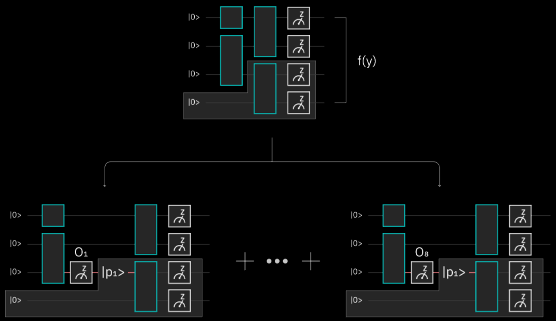
Recover the lost correlations with classical post-processing of the QPUs outputs



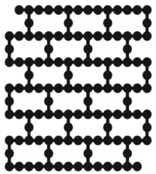
Circuit cutting

Simulate a large quantum circuit using small QPUs by cutting the circuit into subcircuits, which are then sent to QPUs

The output of the original circuit is built from classical post-processing of the subcircuits outputs

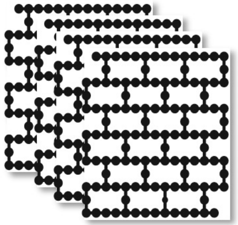


We are upgrading our fleet to 100+ qubit systems… for everyone



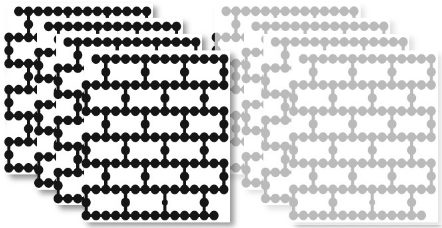
2021

Washington



2023

Brisbane
Cusco
Nazca
Sherbrooke
Cleveland (co-located)
Kawasaki (co-located)
Quebec (co-located)



Q1 2024

All quantum systems

IBM Quantum Offerings for Utility

Open Plan	Pay-As-You-Go	Premium Plan	Dedicated System Service
Free Qiskit Runtime-as-a-Service available via the cloud, powered by the same utility-scale systems as our paid offering	Qiskit Runtime-as-a-Service available via IBM Cloud as self-service, powered by utility-scale systems	Qiskit Runtime-as-a-Service available via the cloud, powered by utility-scale systems. Reserved capacity access through IBM Quantum or via an IBM Quantum hub	Qiskit Runtime-as-a-Service powered by a dedicated managed quantum system at IBM or client location, purchased as reserved capacity and available via the cloud
Suitable for learning quantum computing and **exploring** our technology	For those that need more **flexible** access to complete their quantum utility research project, test their business model, or just pay for what they need	For organizations executing on a **strategic** quantum roadmap, looking to develop quantum utility IBM Quantum Network Membership and Benefits	Ideal for organizations that need the maximum **control** over their resources and data IBM Quantum Network Membership and Benefits

IBM Quantum Credits

A program built to award subsidized access to a limited number of researchers, startups, and other ecosystem pioneers working on highly innovative projects that advance techniques and algorithms needed to explore impactful application areas.

Apply or find out more:

IBM **Quantum**

ouf@zurich.ibm.com