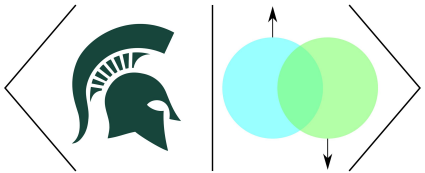
Implement zero-noise extrapolation

Ryan LaRose
Assistant Professor, MSU-Q



Quantum error mitigation intro

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Expectation

$$\langle \psi | O | \psi \rangle$$

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$$\langle \psi | O | \psi \rangle$$

Reality

$$\mathrm{Tr}\left[\mathcal{E}(|\psi\rangle\langle\psi|)O\right]$$

Quantum error mitigation intro

Expectation

$$\langle\psi|O|\psi\rangle$$

Reality

$$\mathrm{Tr}\left[\mathcal{E}(|\psi\rangle\langle\psi|)O\right]$$

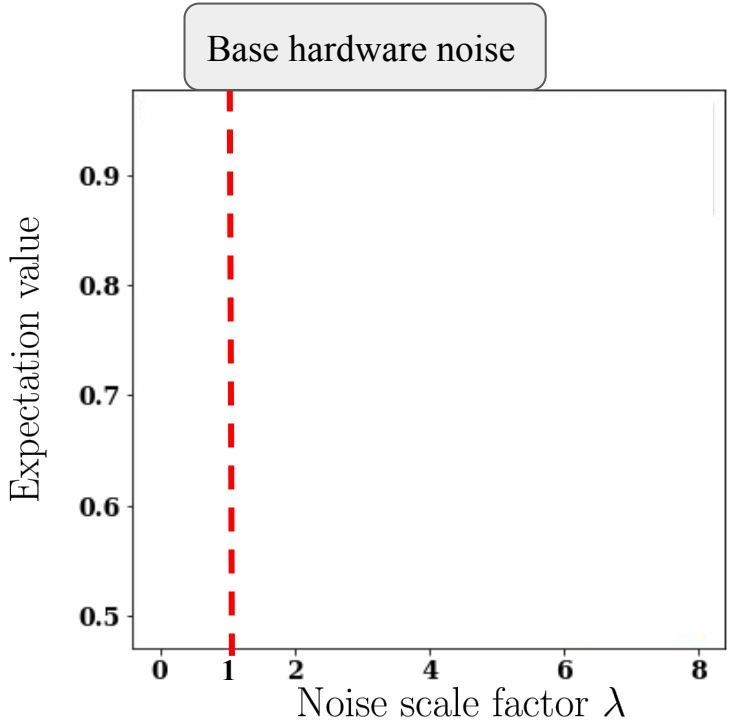
Idea

$$\langle\psi|O|\psi\rangle \overset{?}{\approx} \sum_{i,j} c_{ij}\,\mathrm{Tr}\left[\mathcal{E}_i(|\psi_j\rangle\langle\psi_j|)O\right]$$

Quantum error mitigation intro: Zero-noise extrapolation

$$\mathcal{E}_p \rightarrow \mathcal{E}_{\lambda_1 p}, \mathcal{E}_{\lambda_2 p}, ..., \mathcal{E}_{\lambda_k p}$$

Quantum error mitigation intro: Zero-noise extrapolation



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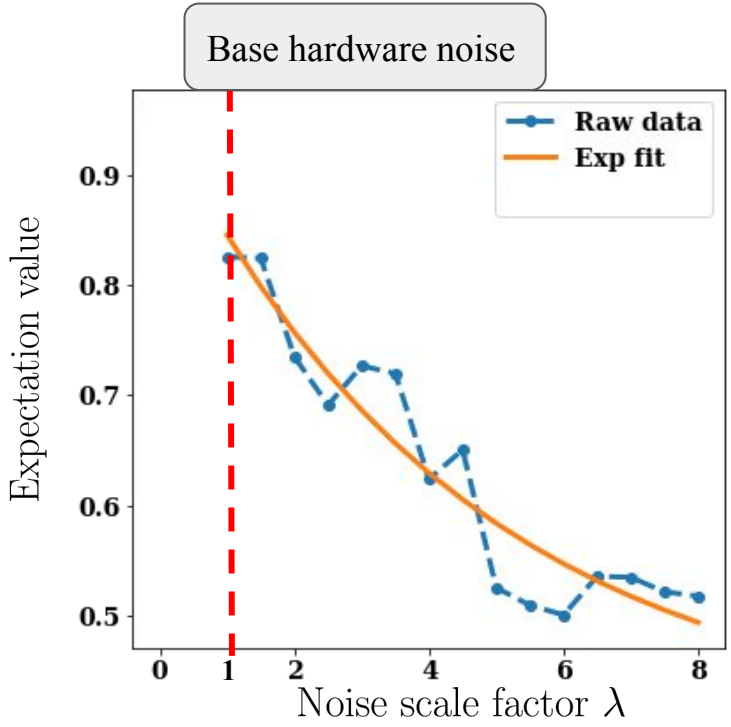

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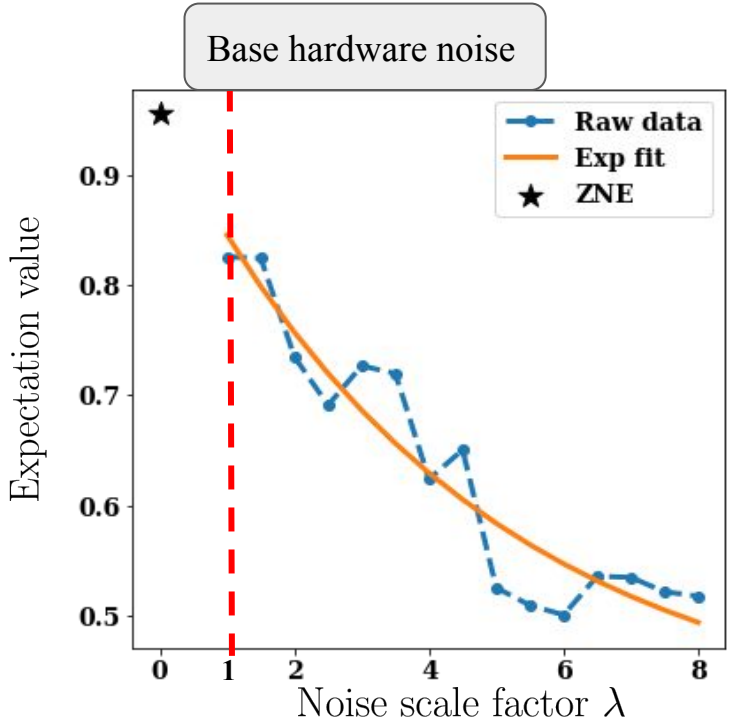

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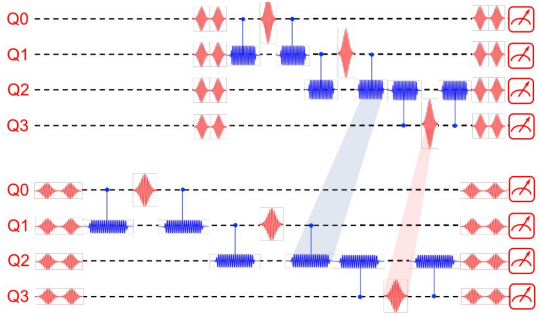
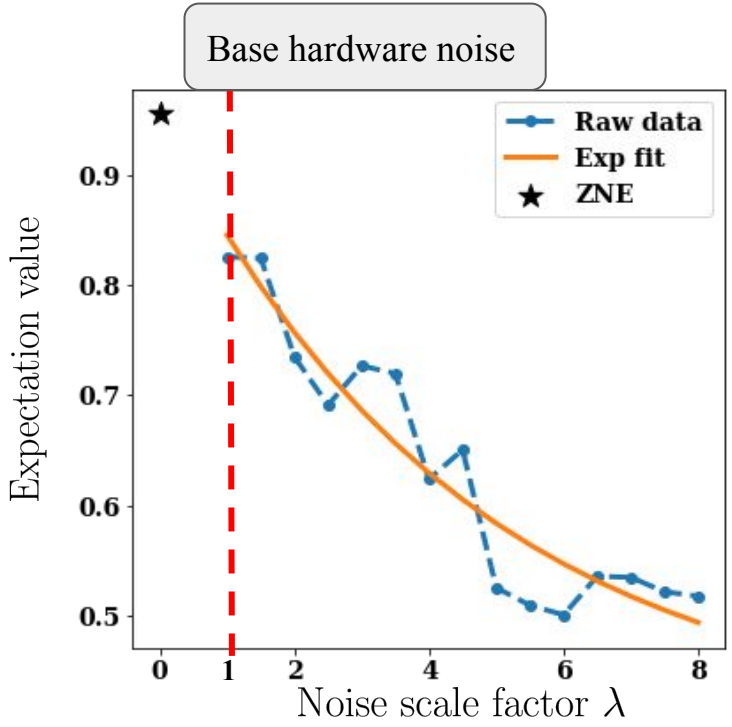
Quantum error mitigation intro: Zero-noise extrapolation

Noise can be scaled by:

- Pulse stretching [Kandala 2018]





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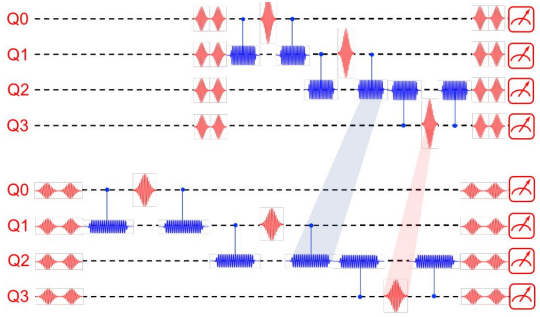
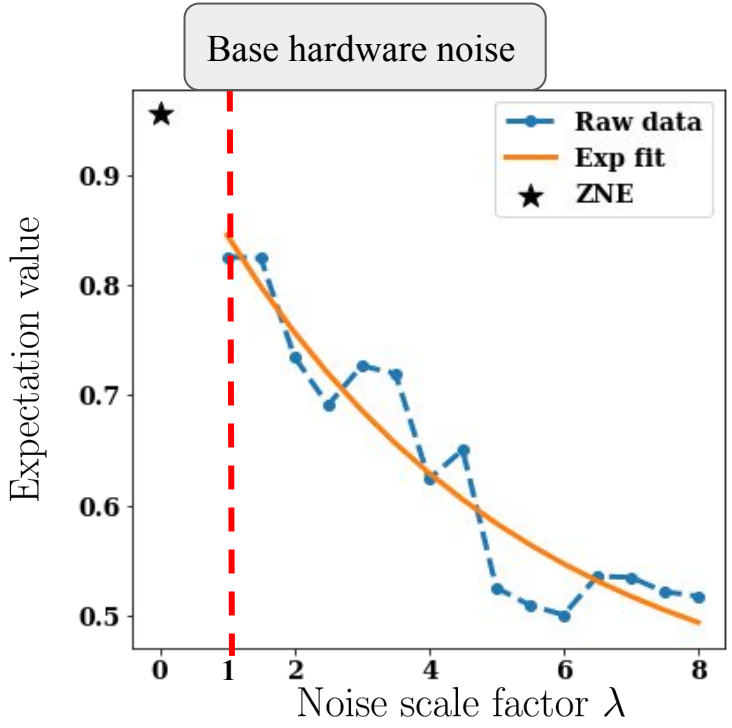




Noise can be scaled by:

- Unitary folding

$$G \mapsto GG^{\dagger}G$$

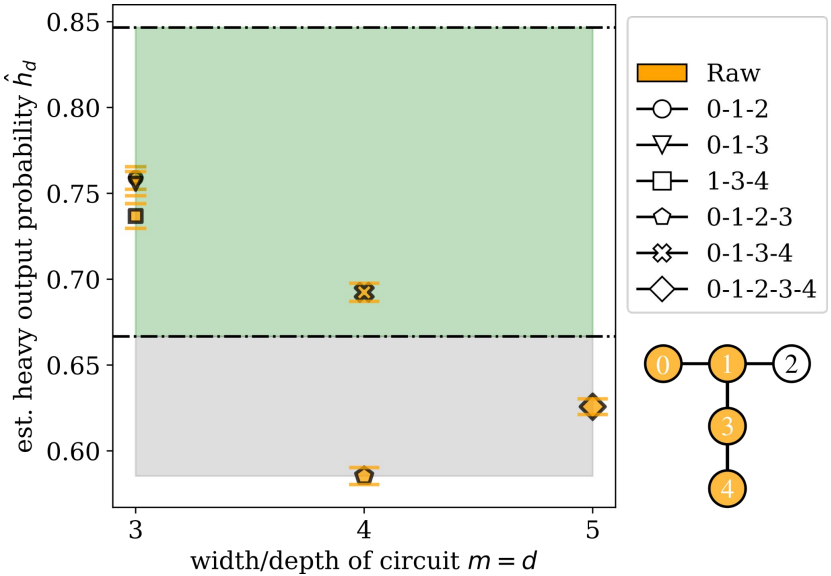
```
Original circuit:
0: ──H──@──
        │
1: ─────X──
```

```
Folded circuit:
0: ──H──@──@──H──H──@──
        │  │        │
1: ─────X──X────────X──
```

$$\mathcal{E}_p \rightarrow \mathcal{E}_{\lambda_1 p}, \mathcal{E}_{\lambda_2 p}, \ldots, \mathcal{E}_{\lambda_k p}$$

Error mitigation increases the effective quantum volume of quantum computers

Ryan LaRose,[1,2,*] Andrea Mari,[2] Vincent Russo,[2] Dan Strano,[2] William J. Zeng[2,3]



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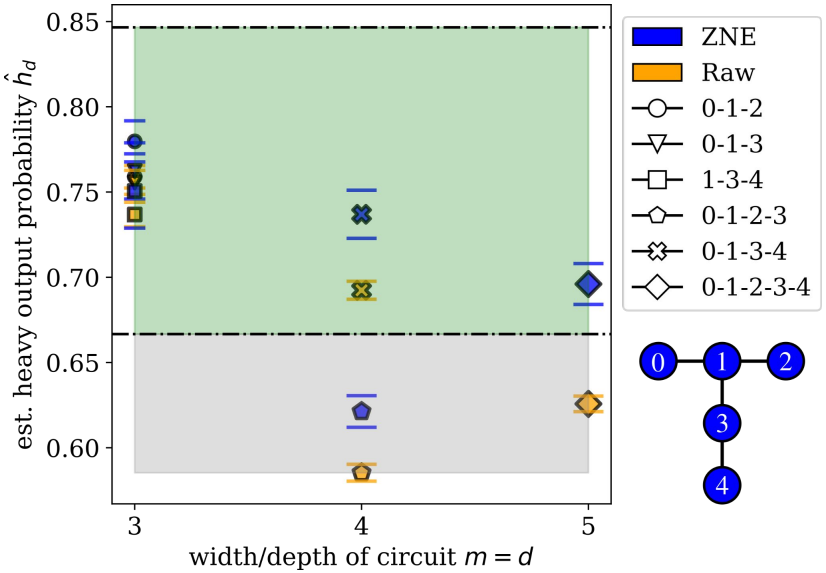
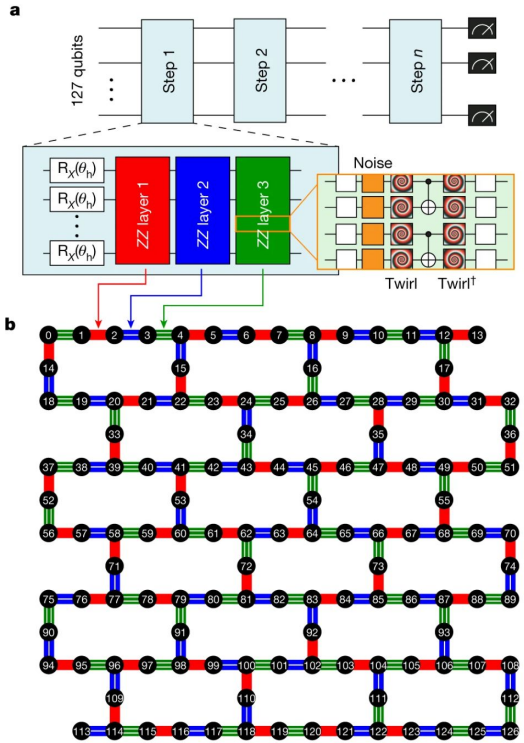


$$H = -J \sum_{\langle i,j \rangle} Z_i Z_j + h \sum_i X_i$$

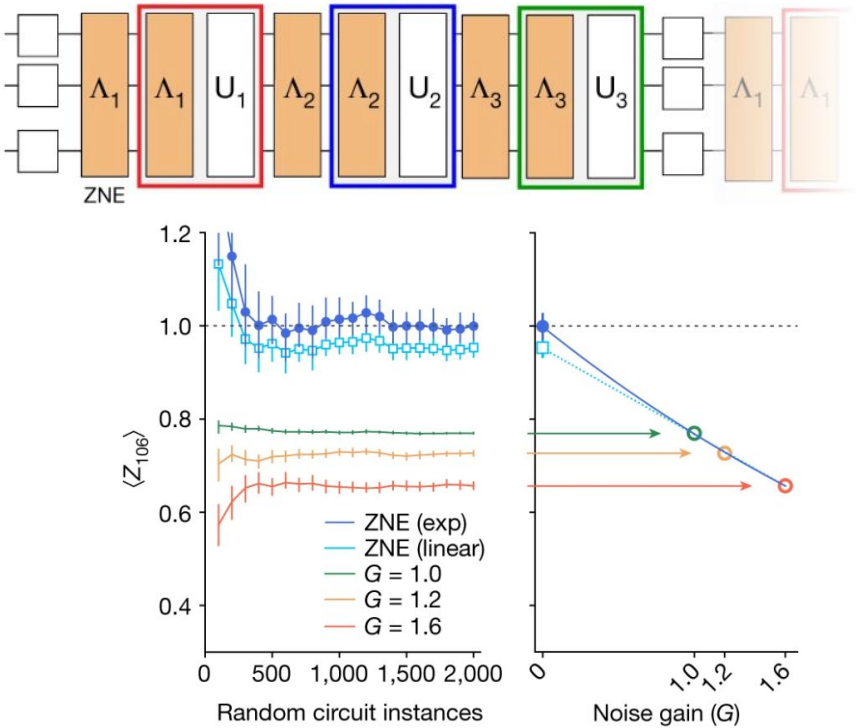
127 qubits
60 Trotter steps (2880 CNOT gates)



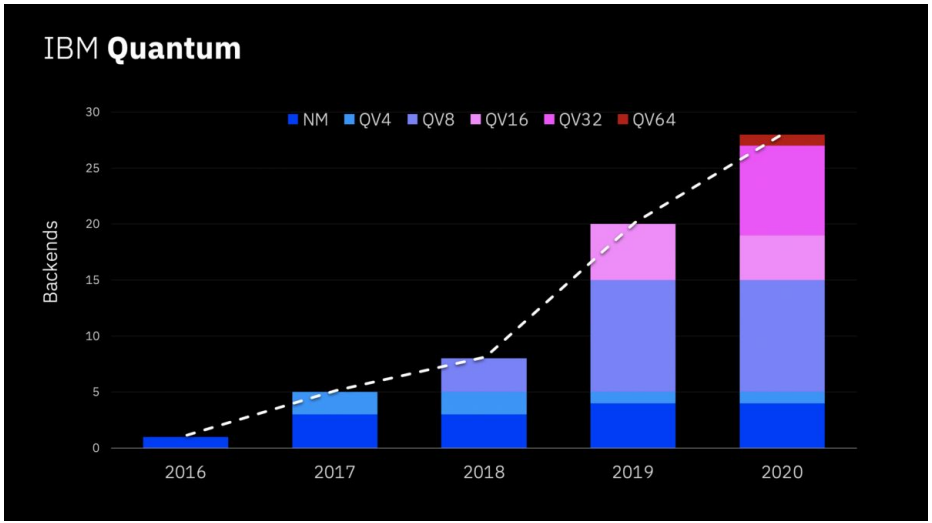
Article | Open Access | Published: 14 June 2023

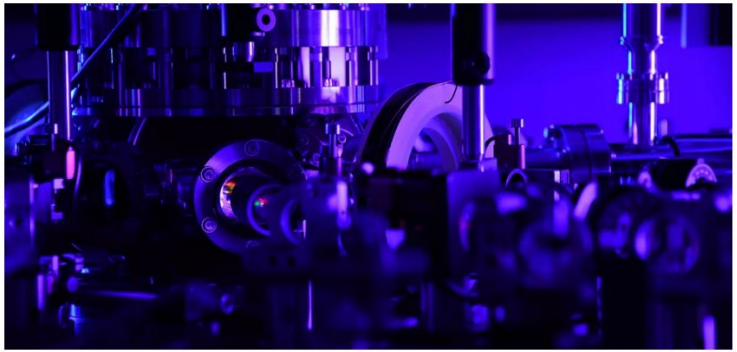
Evidence for the utility of quantum computing before fault tolerance

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



Effective quantum volume



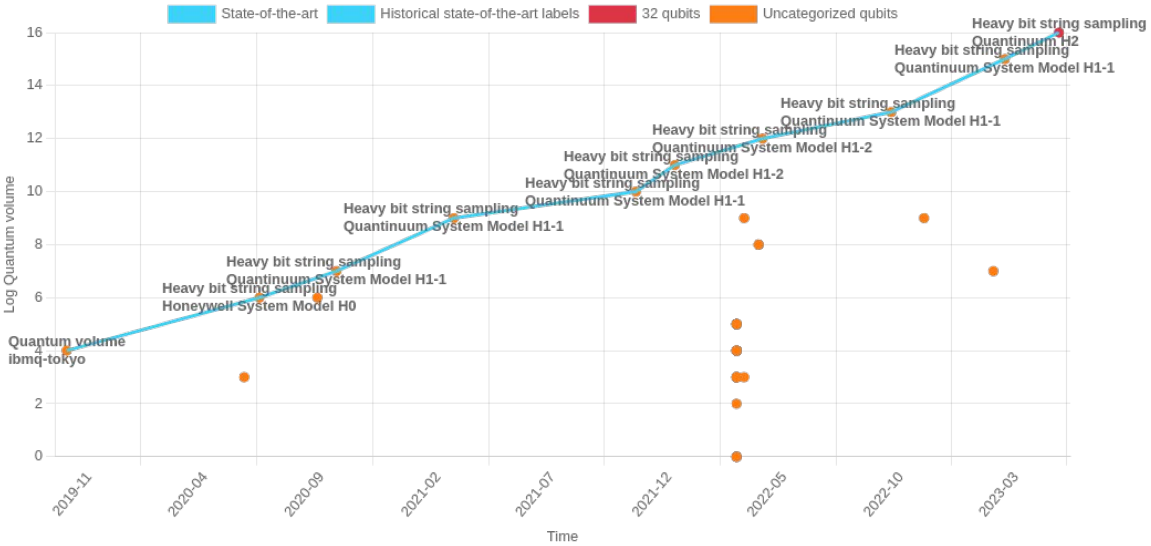


Honeywell Sets Another Record For Quantum Computing Performance

The System Model H1 becomes the first to achieve a demonstrated quantum volume of 1024

Quantum volume of 2^m -> m usable qubits

Effective quantum volume

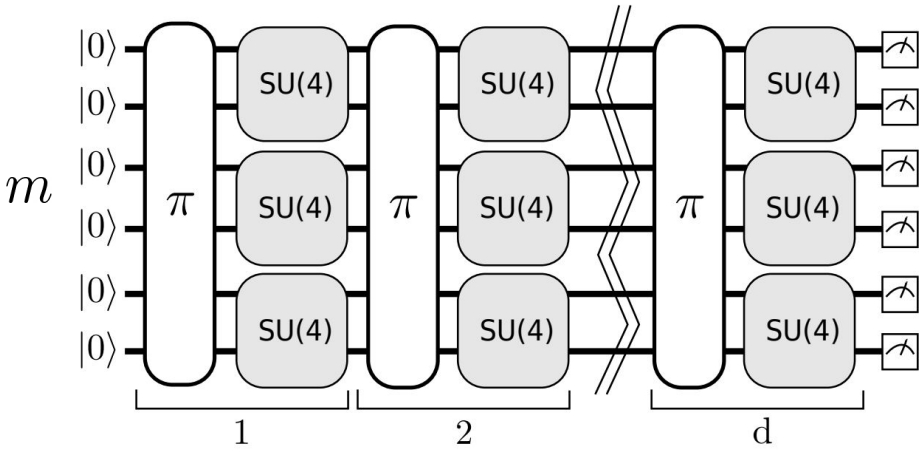


Quantum volume of 2^m -> m usable qubits

Effective quantum volume

Validating quantum computers using randomized model circuits

Andrew W. Cross,* Lev S. Bishop,† Sarah Sheldon, Paul D. Nation, and Jay M. Gambetta
IBM T. J. Watson Research Center, Yorktown Heights, NY 10598



$$\mathcal{H}_U := \{z \in \{0,1\}^m : p(z) > p_{\text{median}}\}$$

$$p(z) = |\langle z|U|0\rangle|^2$$

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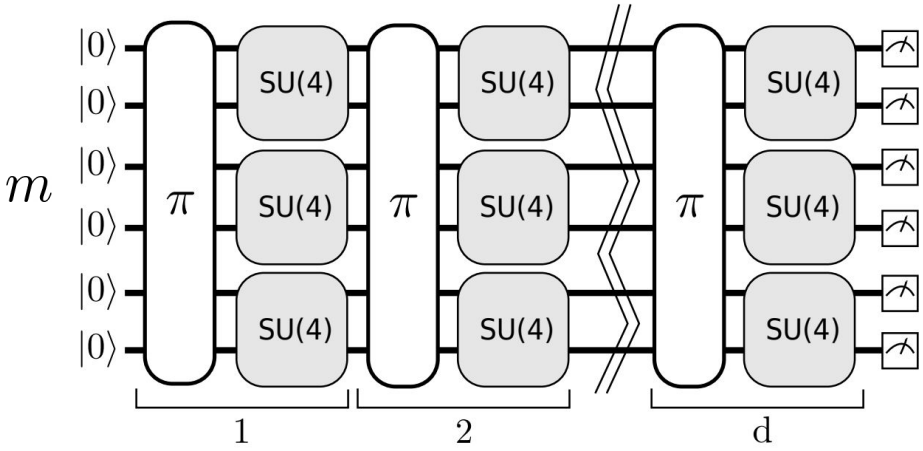

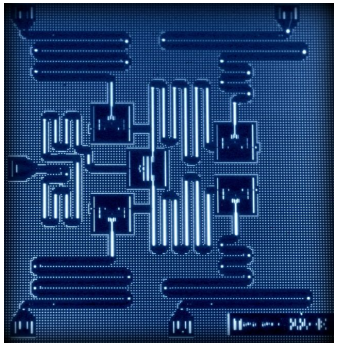

$z_1 = 011010$

$z_2 = 100011$

$z_3 = 110001$

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$z_1 = 011010$ $z_2 = 100011$ $z_3 = 110001$

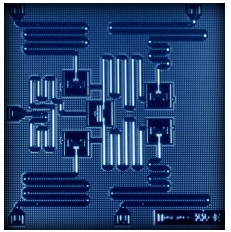
? ? ?

$$\mathcal{H}_U := \{z \in \{0,1\}^m : p(z) > p_{\text{median}}\}$$

$$\hat{h}_d = \frac{\#\text{ heavy bitstrings sampled}}{\text{total }\#\text{ bitstrings sampled}}$$

Effective quantum volume

Quantum volume is a
“full-stack” metric.



Quantum Science and Technology

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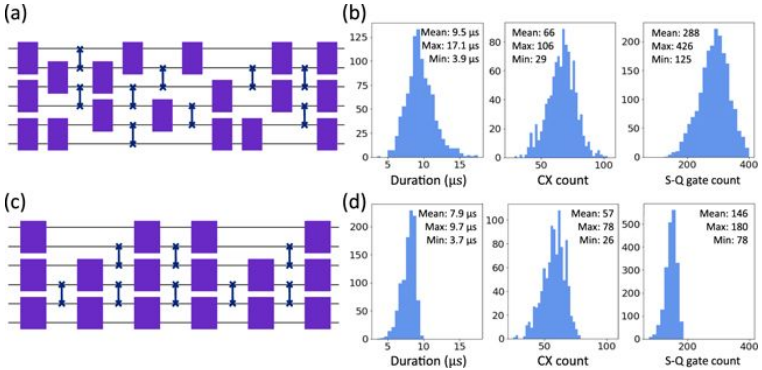
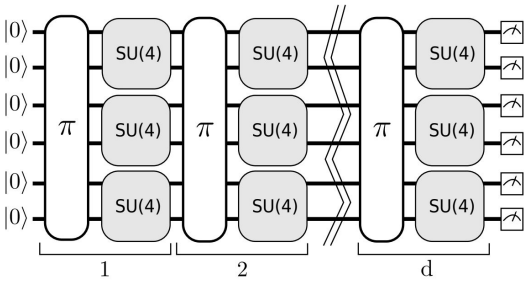
Demonstration of quantum volume 64 on a superconducting quantum computing system

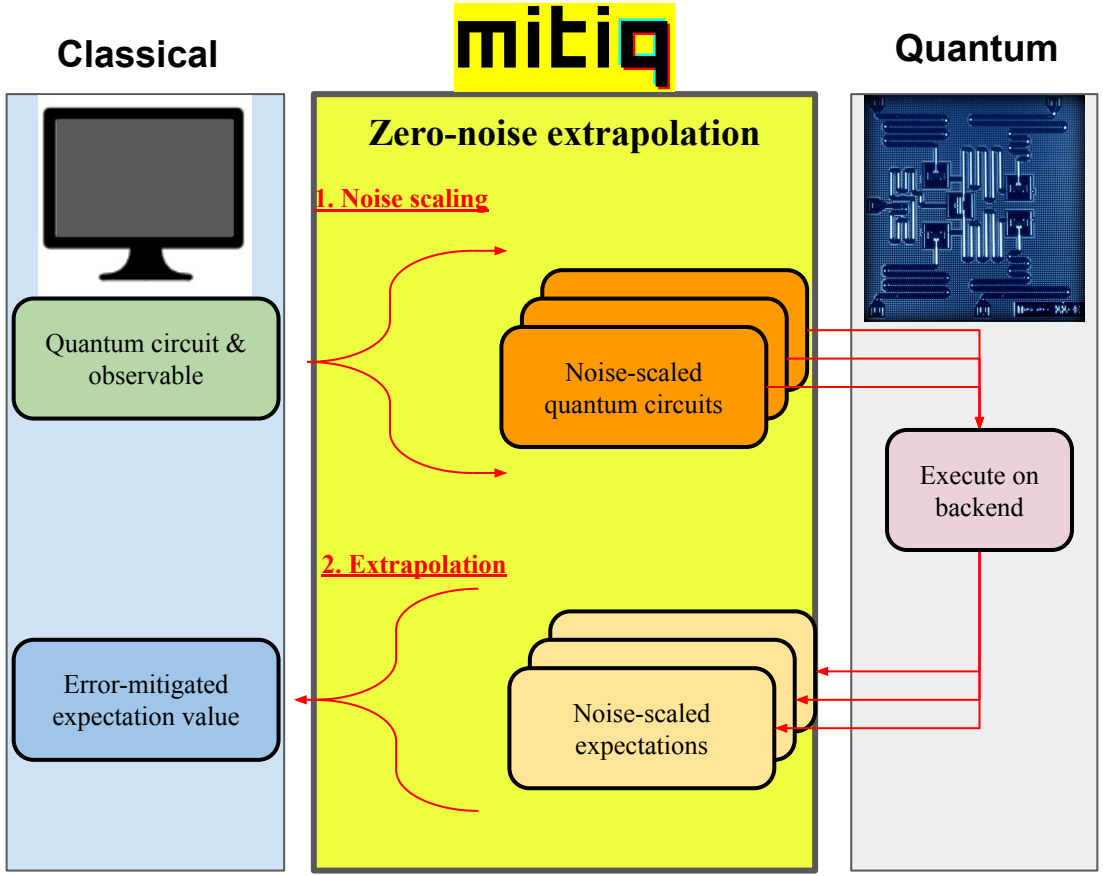


https://iopscience.iop.org/article/10.1088/2058-9565/abe519

Effective quantum volume



$$\Pi_{h,C} := \sum_{z \in \mathcal{H}_C} |z\rangle\langle z|$$



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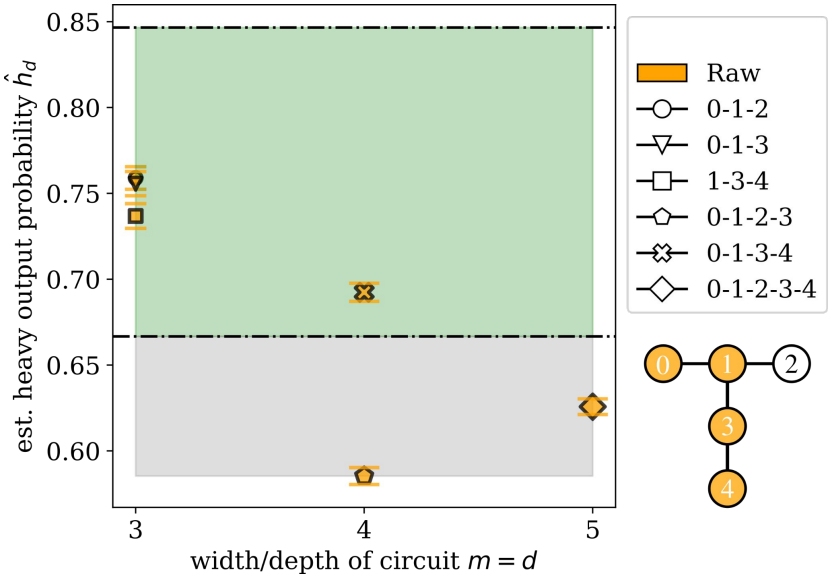

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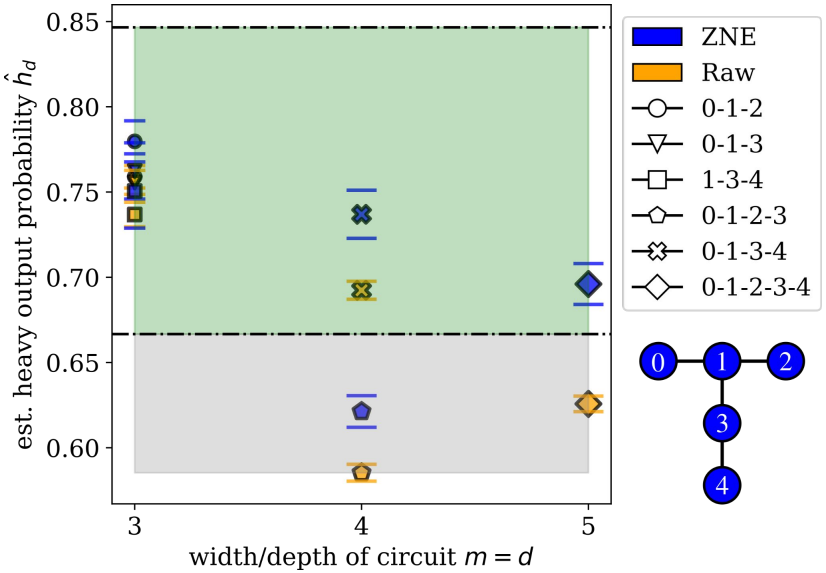

Effective quantum volume

Error mitigation increases the effective quantum volume of quantum computers

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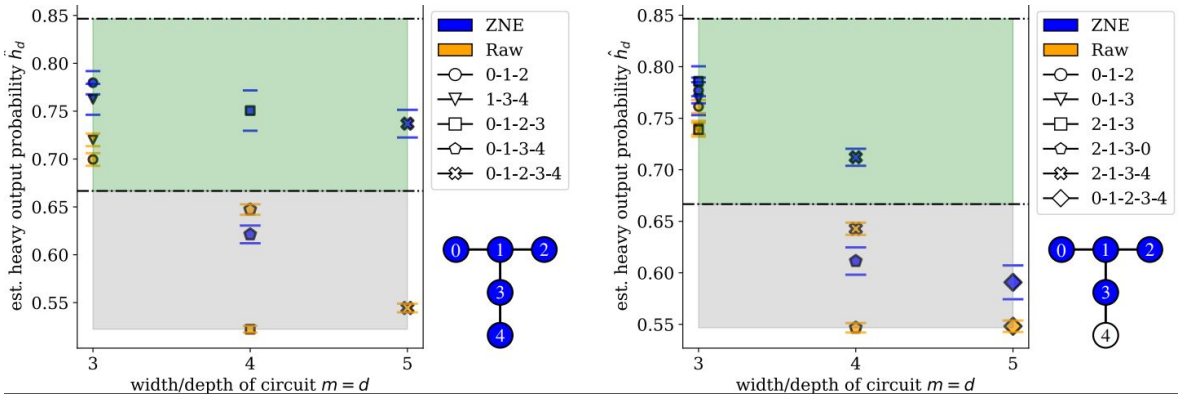
[1] *Department of Computational Mathematics, Science, and Engineering, Michigan State University, East Lansing, MI 48823, USA*

[2] *Unitary Fund*

[3] *Goldman, Sachs & Co, New York, NY*



Data and code: https://github.com/unitaryfund/mitiq-qv

Error-Mitigation Techniques Can Pump Up The Quantum Volume

By **Matt Swayne** March 16, 2022

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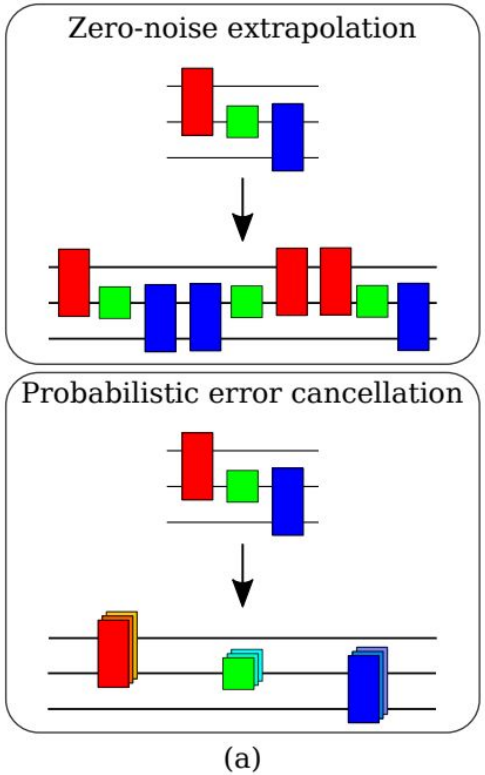
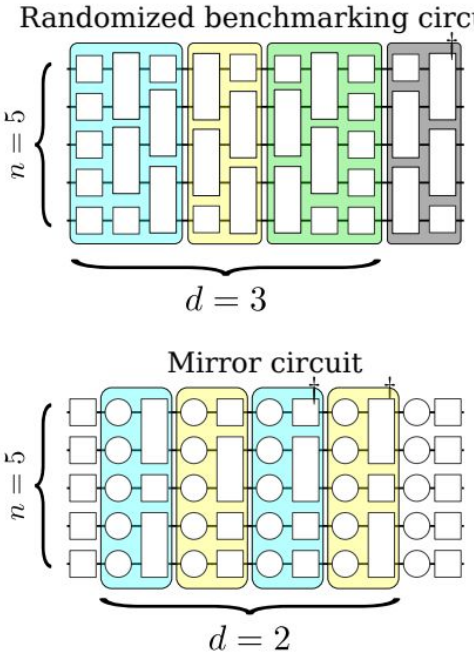
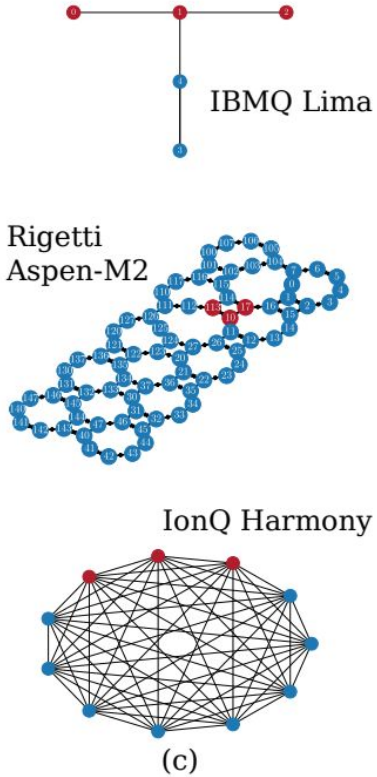
This goes to 11. Researchers are finding that error mitigation can boost quantum volumes. (Image: Unspash/Anastasia Zhenina)

Boosting quantum volume may not be a job just for hardware makers, according to researchers from the Unitary Fund. Quantum algorithm developers can play a role, too.

Quantum error mitigation in practice







Quantum error mitigation in practice: 3 qubit experiments