

A SIMULATION OF A SIMULATION: ALGORITHMS FOR MEASUREMENT-BASED QUANTUM COMPUTING EXPERIMENTS

PHYS 449 - ORAL DEFENSE

RIO WEIL

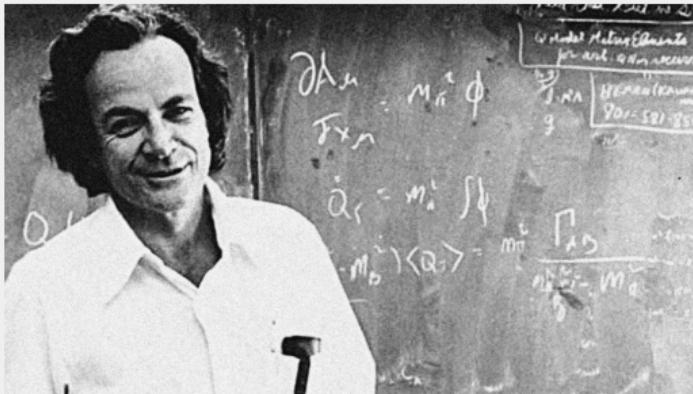
**Co-SUPERVISORS - ROBERT RAUSSENDORF, ARNAB ADHIKARY, DMYTRO BONDARENKO
EMAIL - RYOWEIL6@STUDENT.UBC.CA**

APRIL 6, 2022

OUTLINE

1. Motivation
2. Why Measurement-Based Quantum Computing?
3. MBQC Resource States and Computational Power
4. From Theory to Experiment
5. The Alluded Algorithms
6. Results
7. Making the Experiment “More Quantum”
8. Outlook & Conclusion

MOTIVATION - WHAT ARE QUANTUM COMPUTERS GOOD FOR?

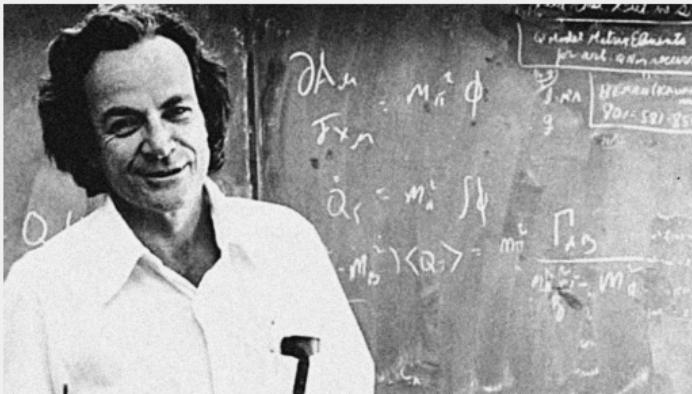


"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy."

- Feynman, 1981

Image Credit: Caltech Magazine

MOTIVATION - WHAT ARE QUANTUM COMPUTERS GOOD FOR?



“Nature isn’t classical, dammit, and if you want to make a simulation of nature, you’d better make it quantum mechanical, and by golly it’s a wonderful problem, because it doesn’t look so easy.”

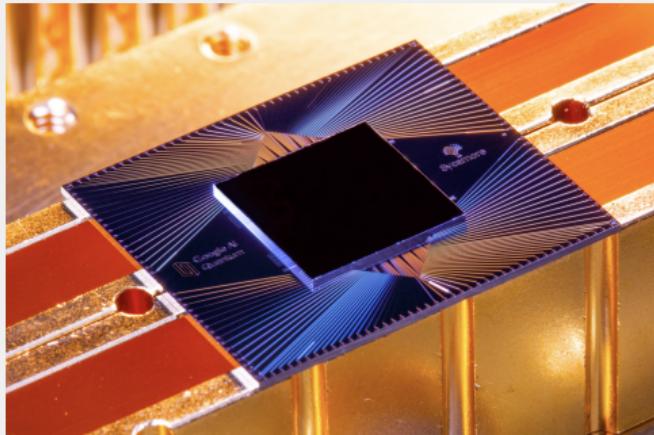
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Also...

- Shor's Factoring Algorithm
- Grover's Search Algorithm

Image Credit: Caltech Magazine

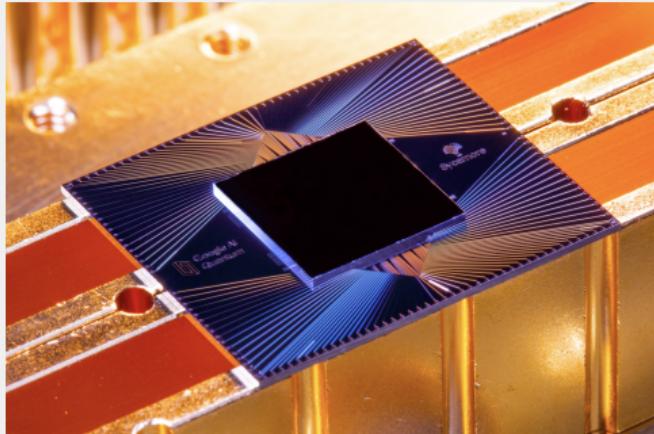
MOTIVATION - OUTSTANDING QUESTIONS



1. What is the source of quantum advantage?
2. What can we do with NISQ (Noisy Intermediate-Scale Quantum) devices?

Image Credit: Erik Lucero/Google

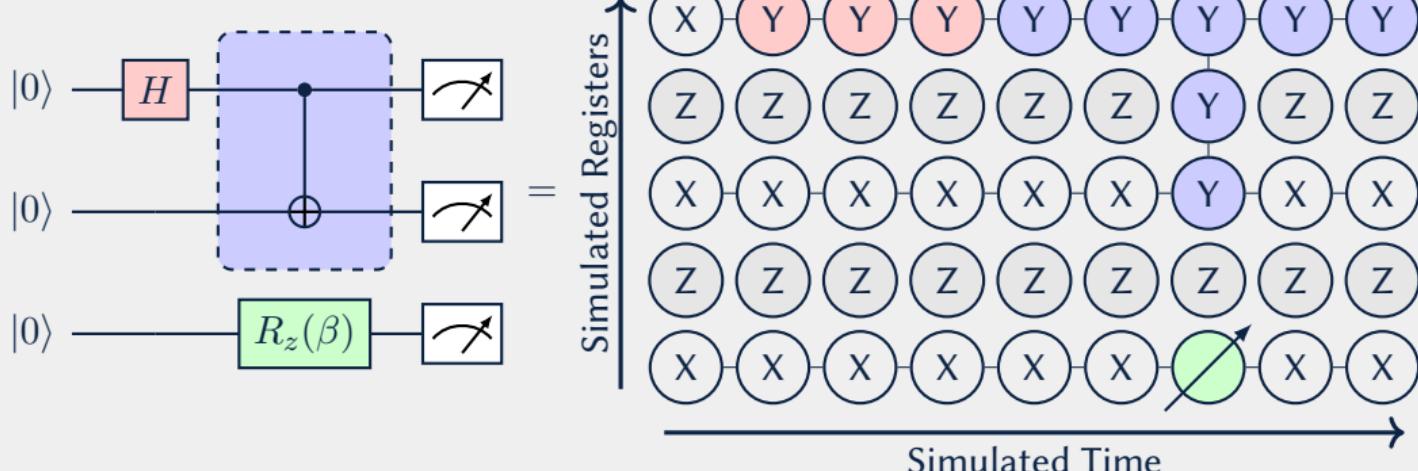
MOTIVATION - OUTSTANDING QUESTIONS



1. What is the source of quantum advantage?
 - ▶ Measurement-Based Quantum Computing - coming up!
2. What can we do with NISQ (Noisy Intermediate-Scale Quantum) devices?
 - ▶ Active research area... and this project!

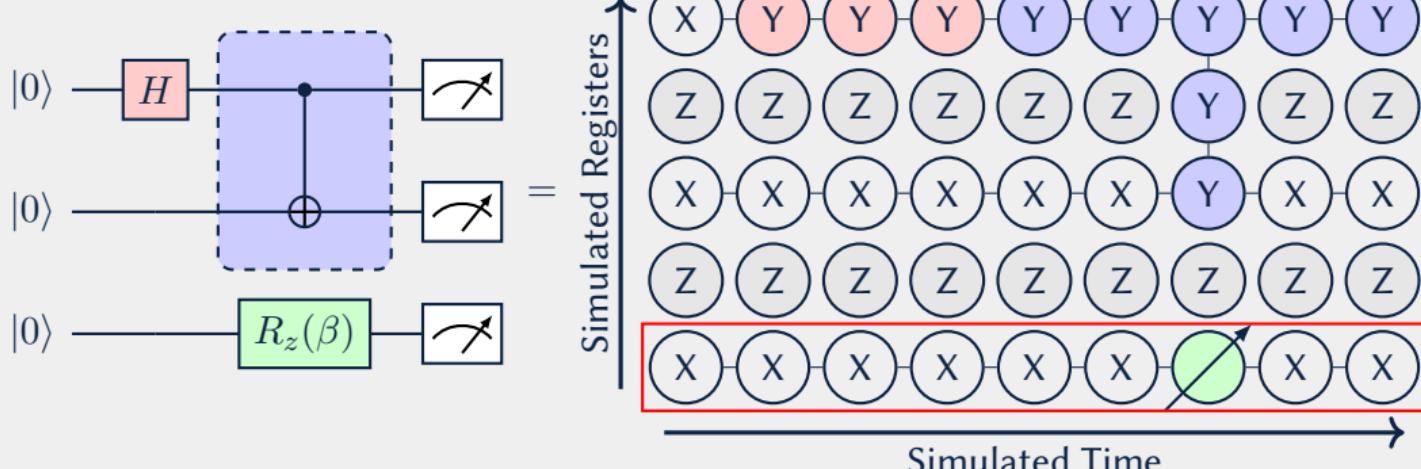
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WHY MEASUREMENT-BASED QUANTUM COMPUTING?



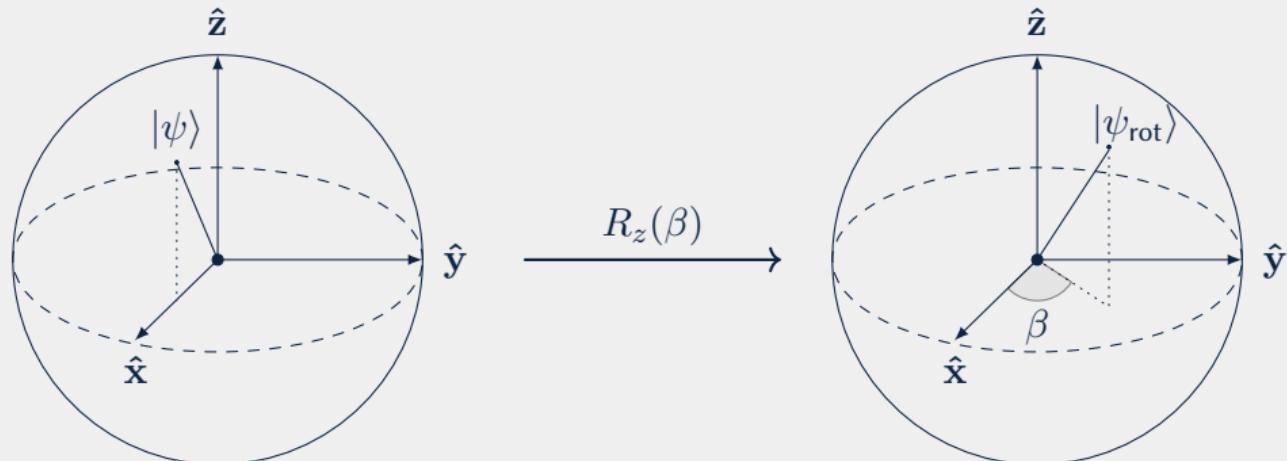
	Gate Model	MBQC
Evolution Method	Unitary Gates	Single-Qubit measurements
“Power Source”	Intermediate Gates	Initial State

WHY MEASUREMENT-BASED QUANTUM COMPUTING?



	Gate Model	MBQC
Evolution Method	Unitary Gates	Single-Qubit measurements
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WAIT, WHAT'S COMPUTATIONAL POWER?



Ability to perform single qubit unitaries - rotations.

1-D RESOURCE STATES

Universal Resource: Cluster State $|C\rangle$



Ground state of H_{cluster}

Useless Resource: Product State $|+\rangle^{\otimes N}$



Ground state of H_{product}

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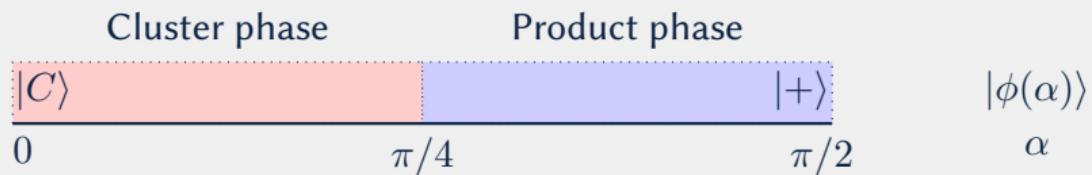
Ground state of H_{product}

Question: Power of ground states $|\phi(\alpha)\rangle$ of:

$$H(\alpha) = \cos(\alpha)H_{\text{cluster}} + \sin(\alpha)H_{\text{product}}$$

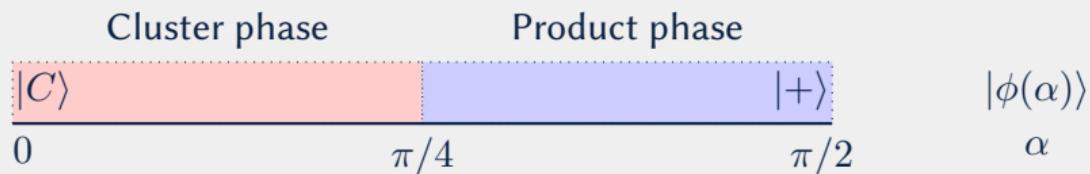
1D RESOURCE STATES - PHASE DIAGRAM & DECOHERENCE

Answer (for infinite systems):



1D RESOURCE STATES - PHASE DIAGRAM & DECOHERENCE

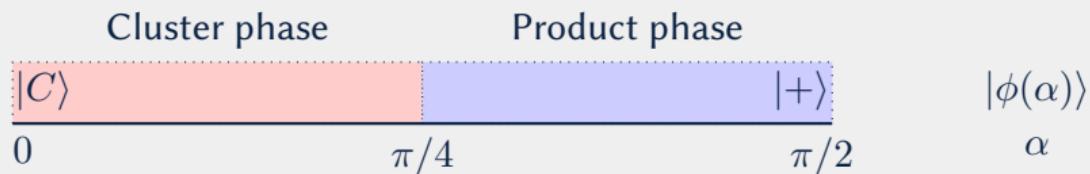
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- The catch: Decoherence away from cluster state.

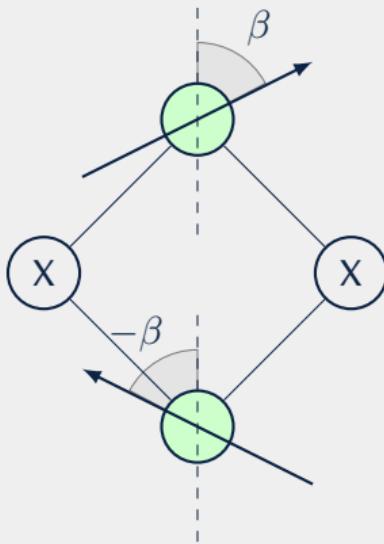
1D RESOURCE STATES - PHASE DIAGRAM & DECOHERENCE

Answer (for infinite systems):



- The catch: Decoherence away from cluster state.
- Recently: New formalism for analyzing power in finite resource states.

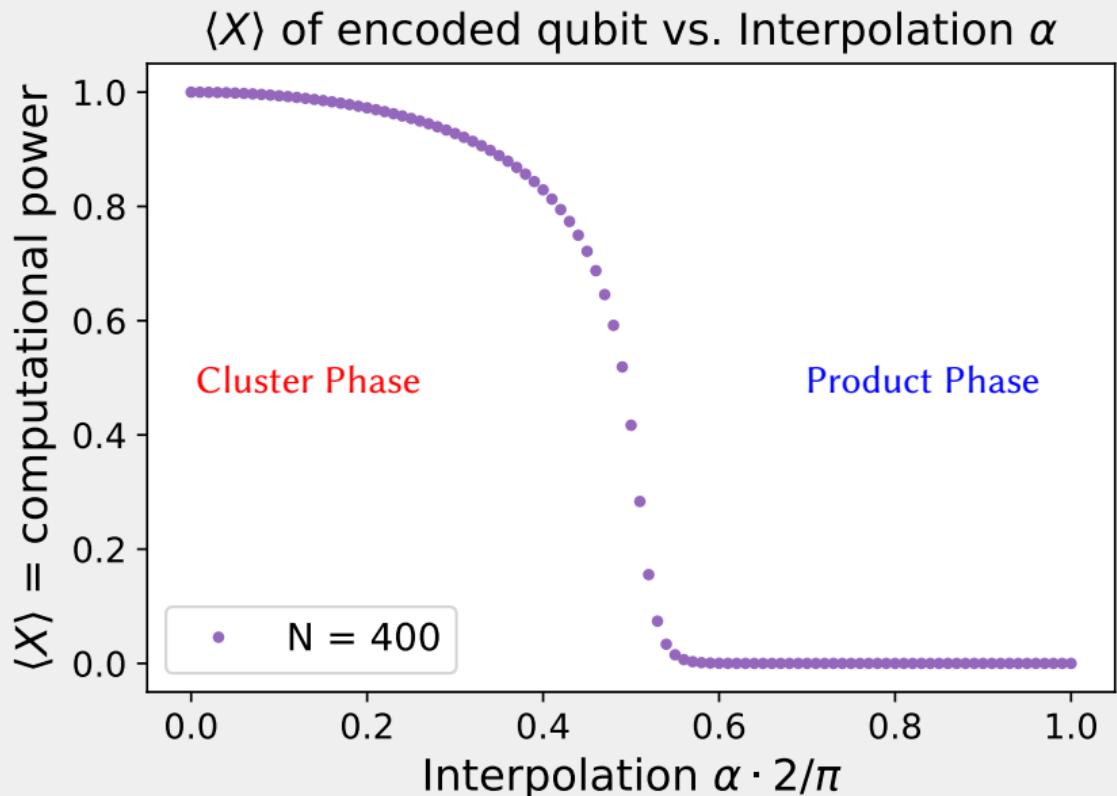
1D RESOURCE STATES - A TEST OF COMPUTATIONAL POWER



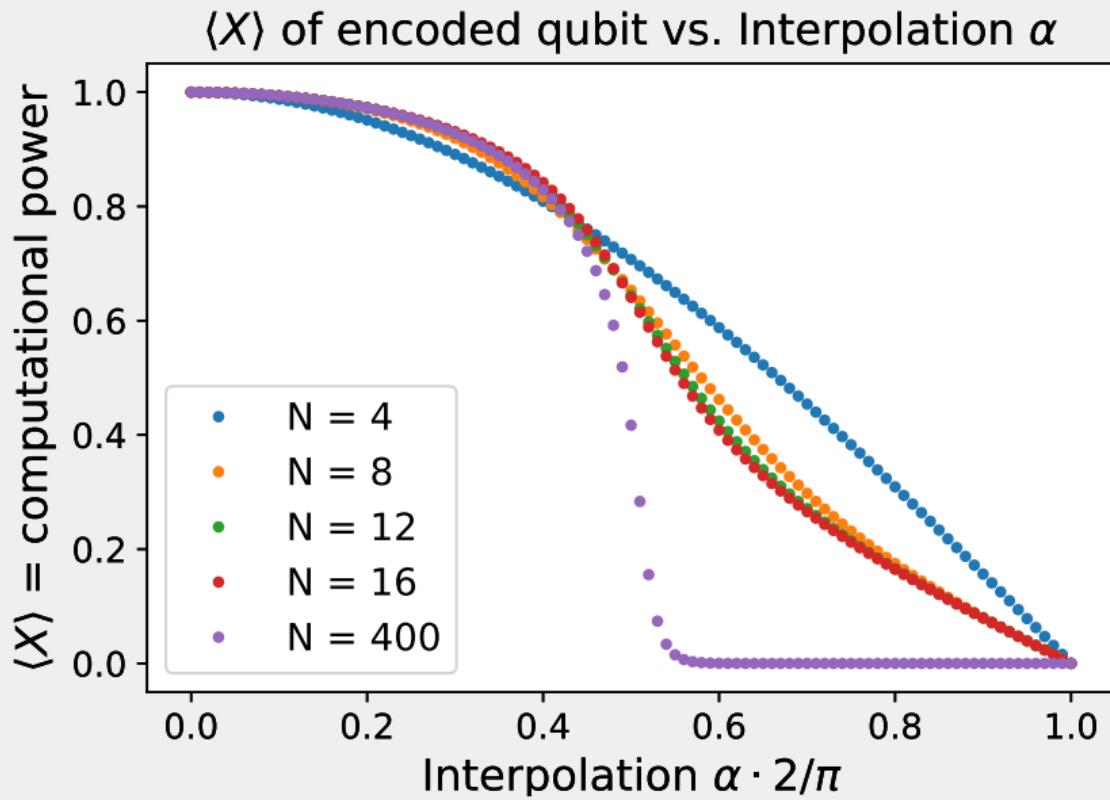
Demonstration: The rotation-counter rotation scheme

1. Prepare $|\phi(\alpha)\rangle$, and input $|+\rangle$.
2. Apply β rotation, and $-\beta$ counterrotation via measurement.
3. Measure $\langle X \rangle$: computational power.

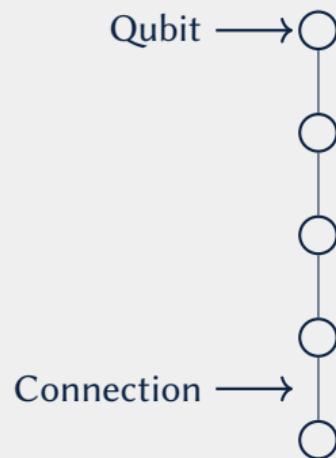
1D RESOURCE STATES - PREDICTED RESULTS



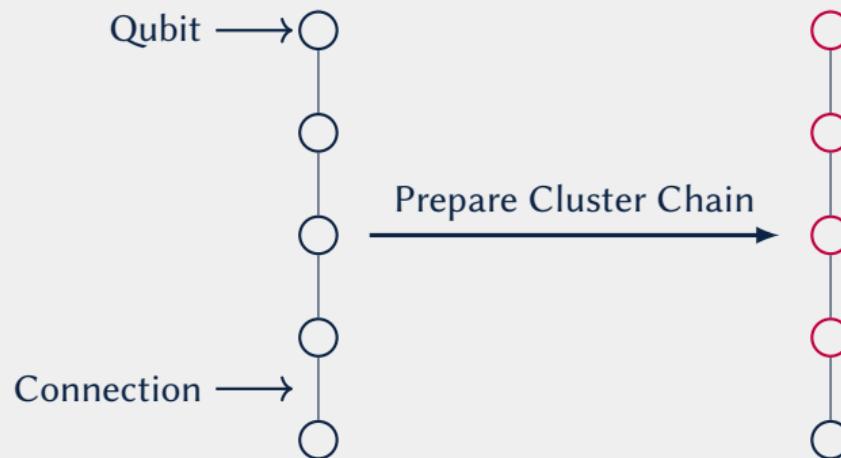
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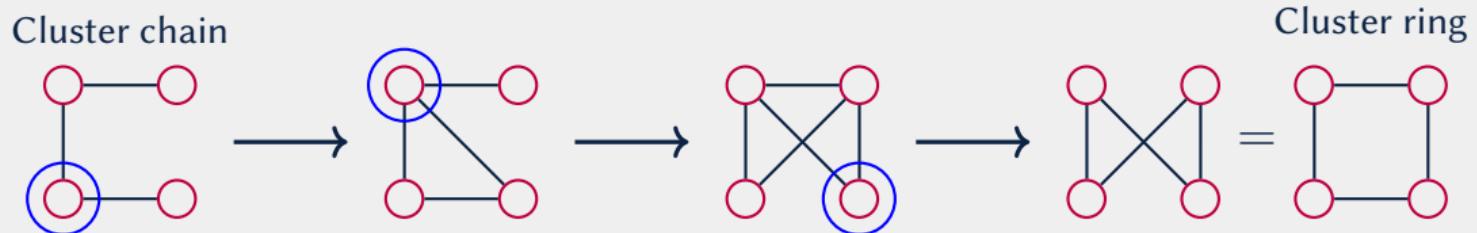
FROM THEORY TO EXPERIMENT - IBM ARCHITECTURE



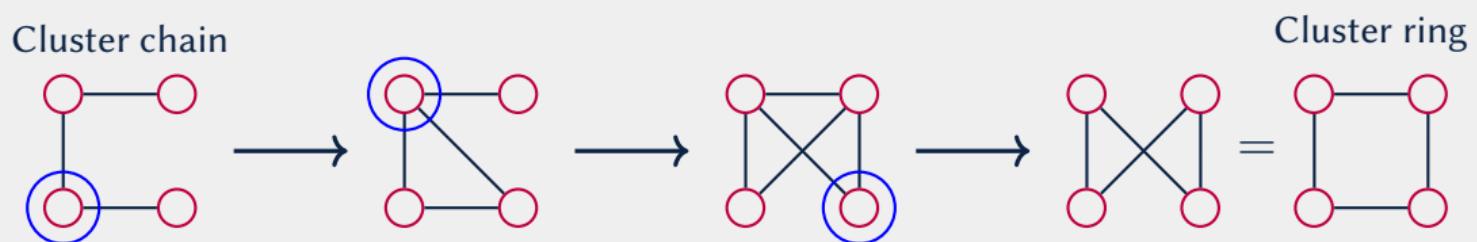
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FROM THEORY TO EXPERIMENT - LOCAL COMPLEMENTATION



FROM THEORY TO EXPERIMENT - LOCAL COMPLEMENTATION



Takeaway: Playing tricks to simulate a ring with a chain.

FROM THEORY TO EXPERIMENT - PRODUCING GROUND STATES

Recall $H(\alpha)$ and corresponding ground state $|\phi(\alpha)\rangle$:

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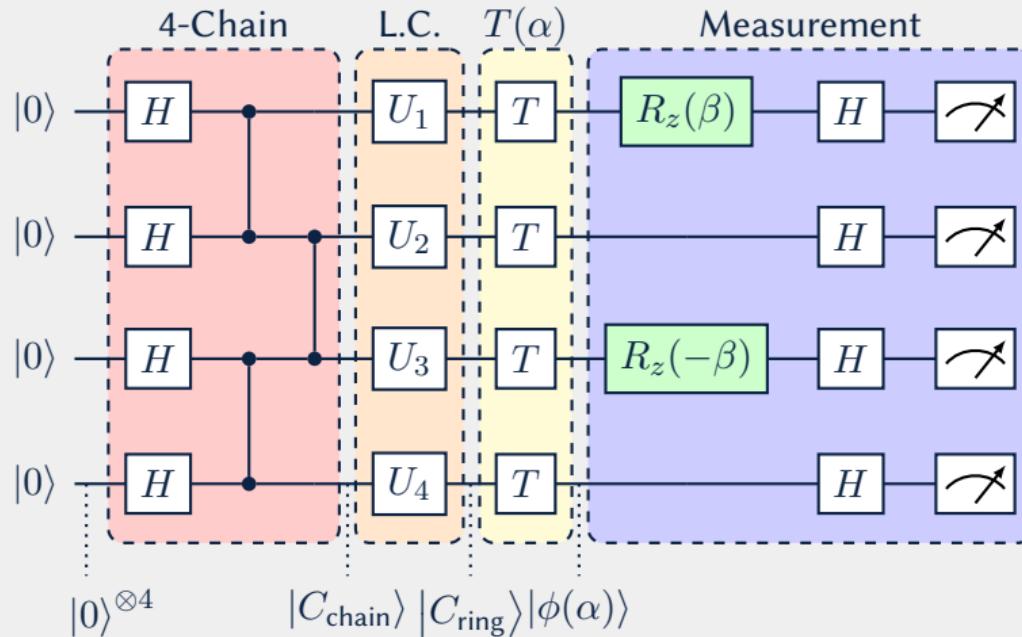
$$U(\alpha) \cong T(\alpha) = \text{only } X\text{s and } I\text{s}$$

Finally, we can assume T is local, so:

$$T(\alpha) = \bigotimes_{i=1}^N (aX_i + bI_i)$$

With these simplifications, $T(\alpha)$ can be found via classical optimization, for small rings.

FROM THEORY TO EXPERIMENT - SIMULATING MBQC



THE ALLUDED ALGORITHMS - THE ROADBLOCK & THE TRICK

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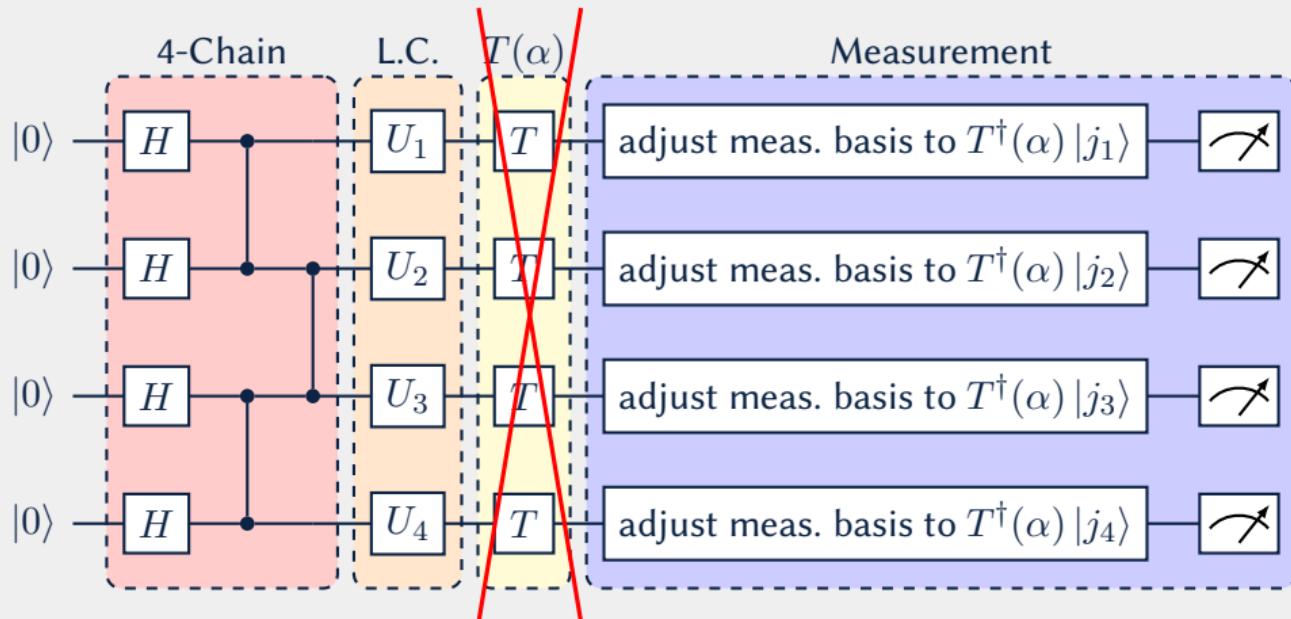
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- Conclusion: Don't implement $T(\alpha)$ at all. Instead, measure $T^\dagger(\alpha) |\mathbf{j}\rangle$ on $|C\rangle$ instead!
- Takeaway: Problem Decomposition.

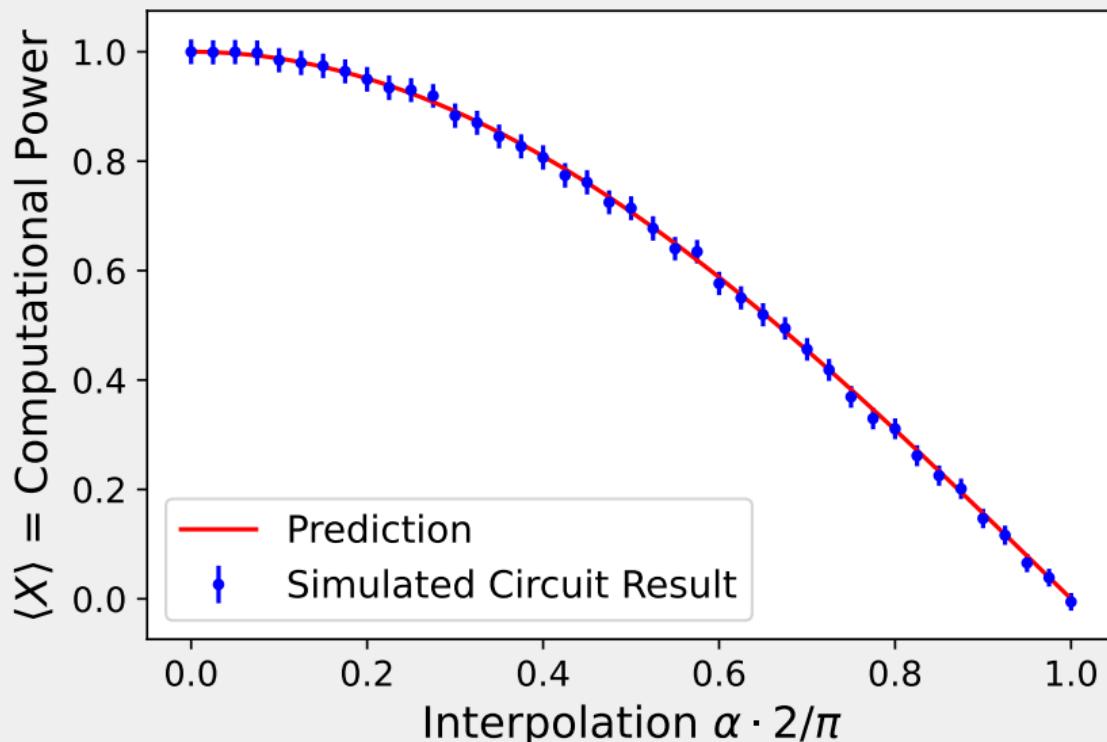
THE ALLUDED ALGORITHMS - THE TASK



The Task: Develop algorithm to make circuits and post-process measurement outcomes, obtain results *as if* $T(\alpha)$ had been implemented.

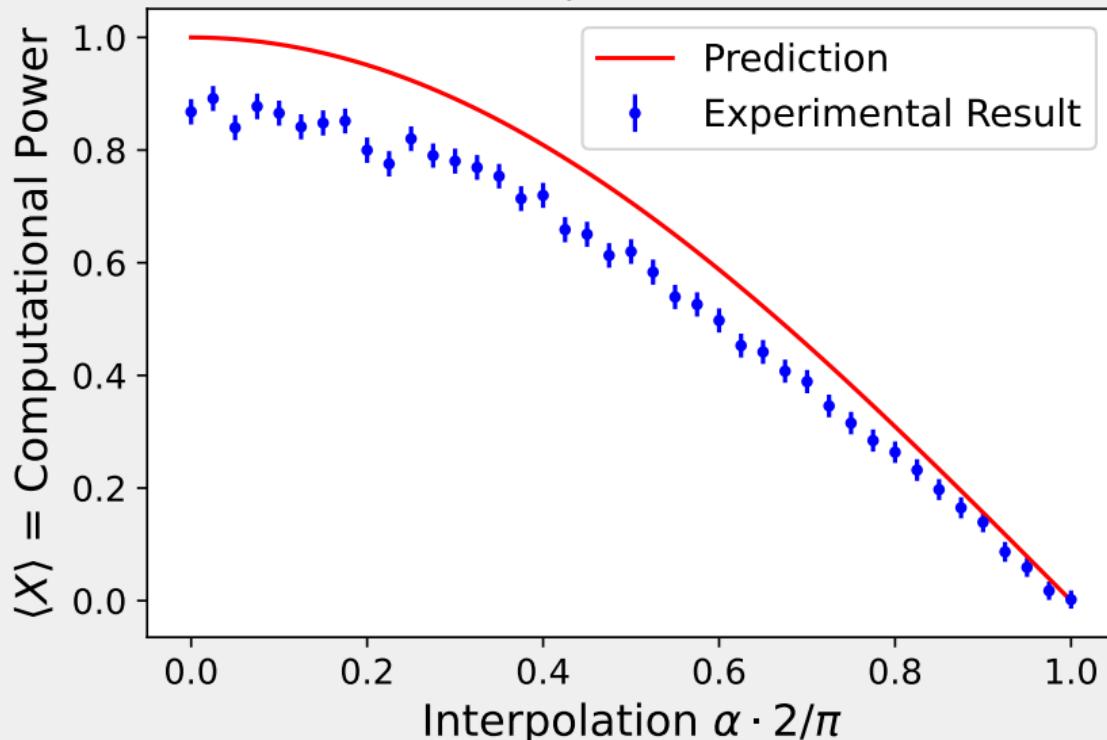
RESULTS - SIMULATION

$\langle X \rangle$ of encoded qubit vs. Interpolation α
(Simulated)



RESULTS - EXPERIMENT

$\langle X \rangle$ of encoded qubit vs. Interpolation α
(Experiment)



MAKING THE EXPERIMENT “MORE QUANTUM” - USING VQE

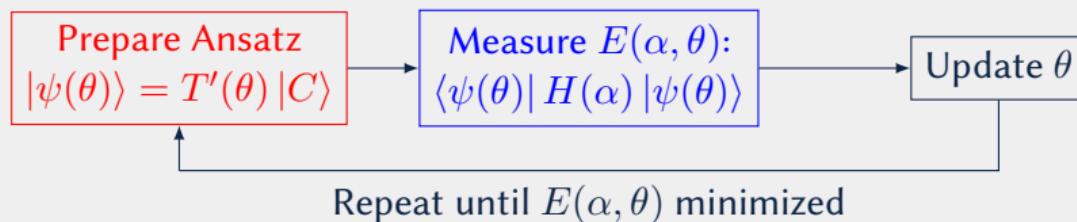
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- More quantum mechanical (and more generalizable): Find $T(\alpha)$ on a quantum computer. Use a Variational Quantum Eigensolver.

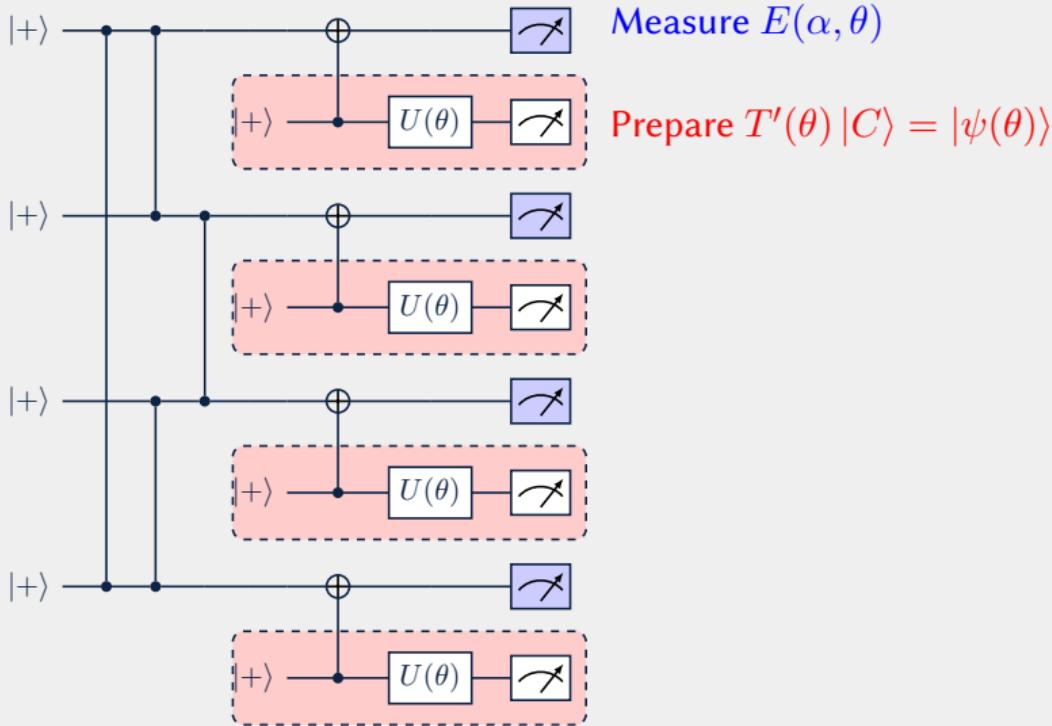
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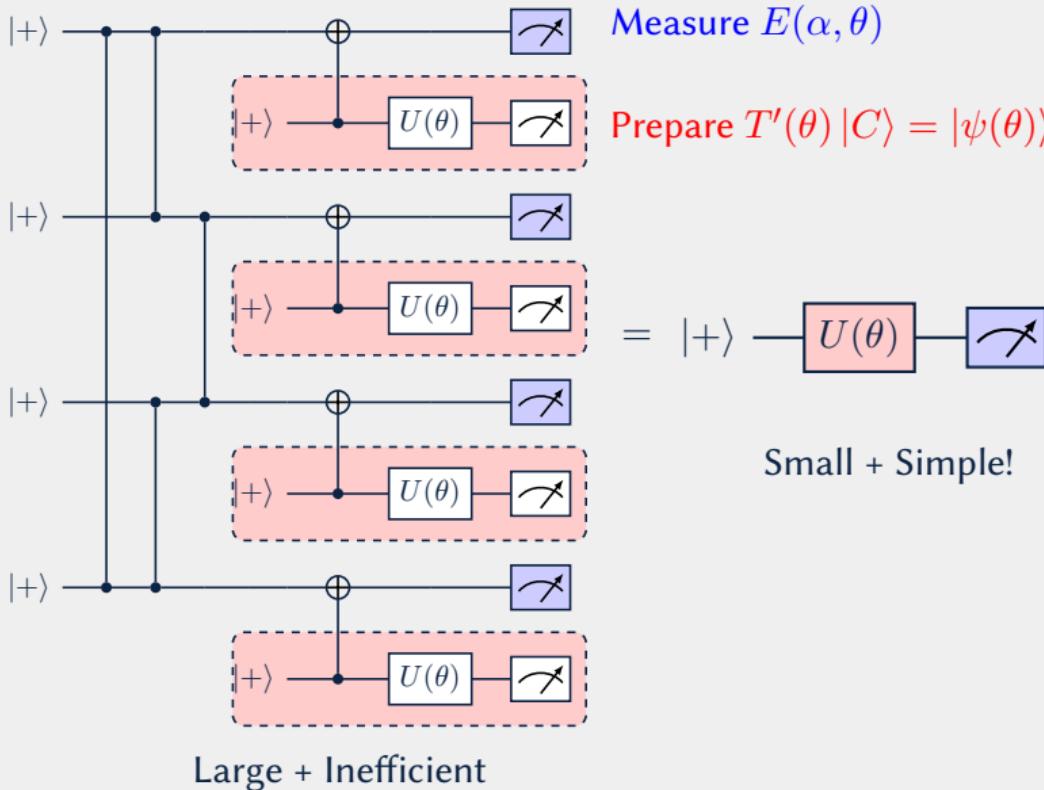


- Minimization (for a given α) yields θ for which $T'(\theta) = T(\alpha)$.

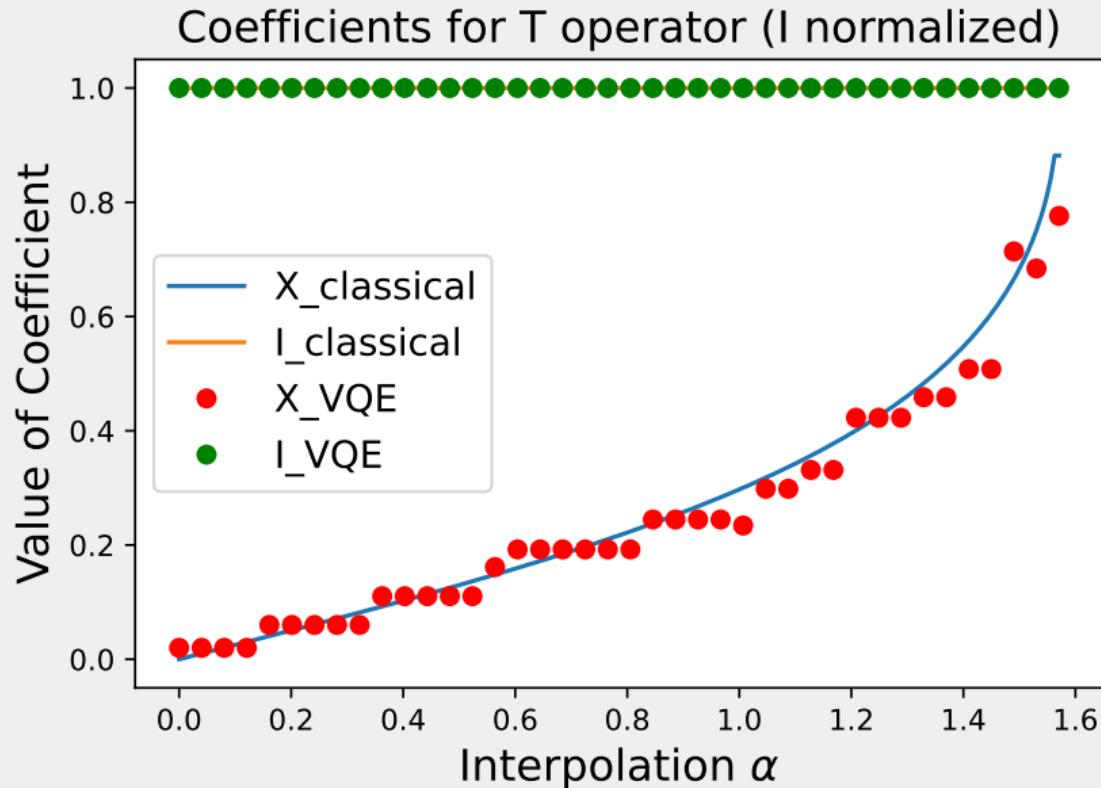
MAKING THE EXPERIMENT “MORE QUANTUM” - CASCADING SIMPLIFICATION



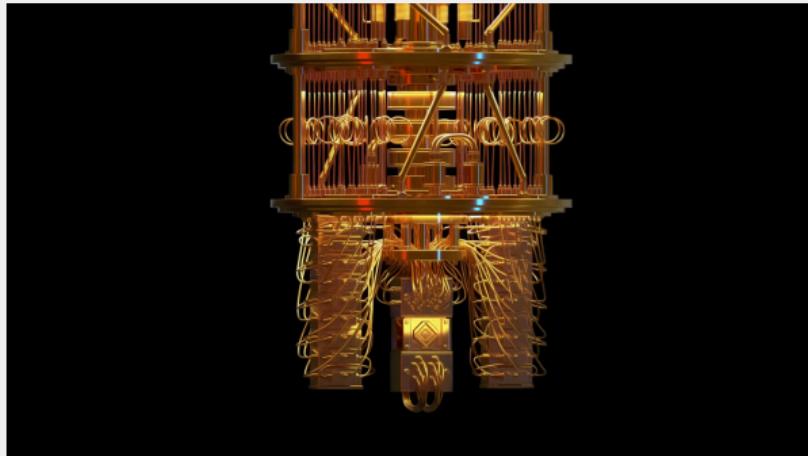
MAKING THE EXPERIMENT “MORE QUANTUM” - CASCADING SIMPLIFICATION



MAKING THE EXPERIMENT “MORE QUANTUM” - RESULTS FOR $T(\alpha)$



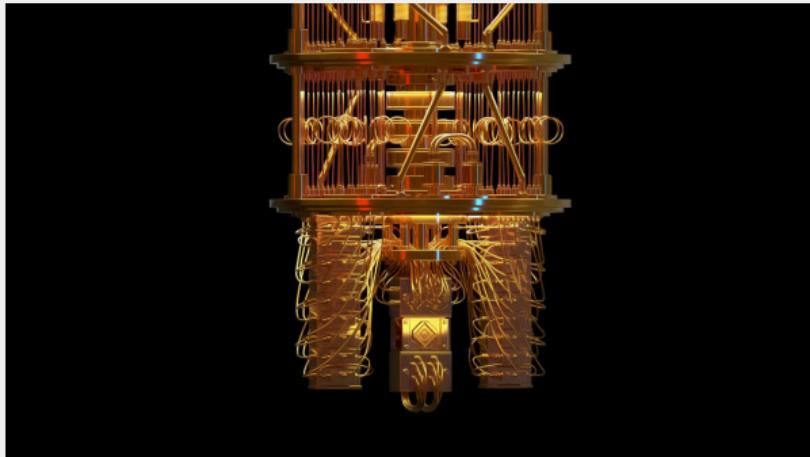
OUTLOOK & CONCLUSION



- Use $T(\alpha)$ found on quantum computers to achieve a more quantum-mechanical demonstration.

Image Credit: Quanta Magazine

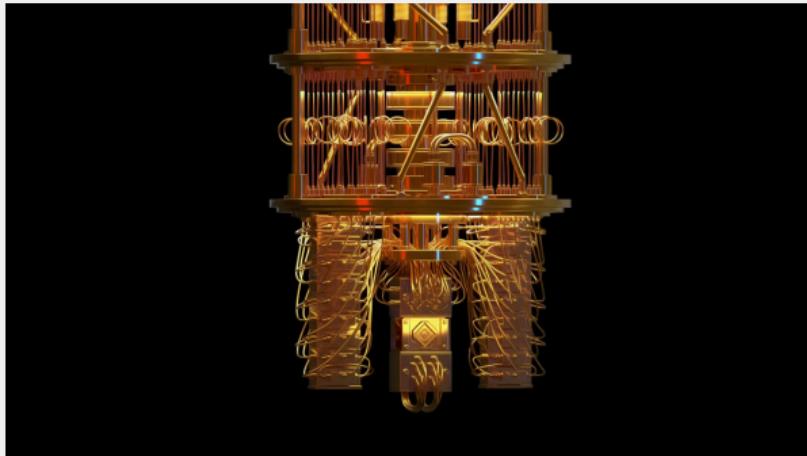
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Image Credit: Quanta Magazine

OUTLOOK & CONCLUSION



- Use $T(\alpha)$ found on quantum computers to achieve a more quantum-mechanical demonstration.
- Larger systems to demonstrate techniques to mitigate the observed decoherence.
- Impact: First experimental demonstration of robustness of quantum computational power. Understanding quantum advantage, and a use case for NISQ devices.

Image Credit: Quanta Magazine