

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

APS NWS MEETING 2022

RIO WEIL

UNIVERSITY OF BRITISH COLUMBIA

Co-SUPERVISORS - ROBERT RAUSSENDORF, ARNAB ADHIKARY

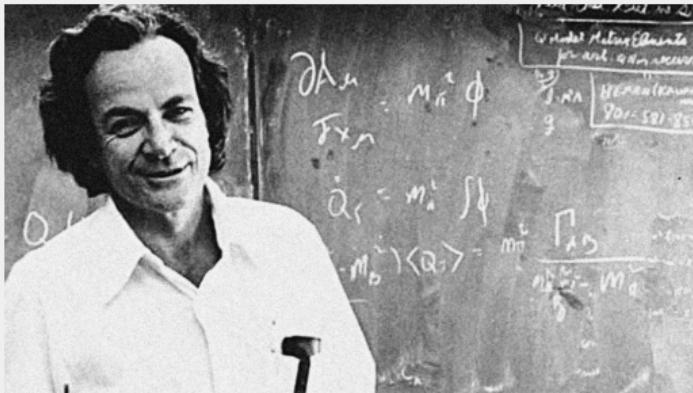
EMAIL - RYOWEIL6@STUDENT.UBC.CA

JUNE 4, 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. Outlook & Conclusion

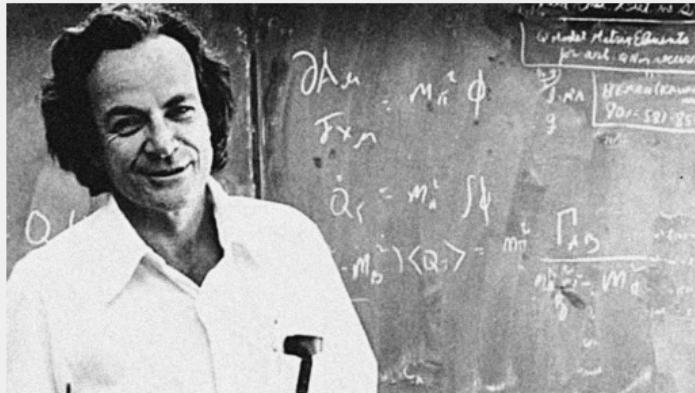
MOTIVATION - WHAT ARE QUANTUM COMPUTERS GOOD FOR?



"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

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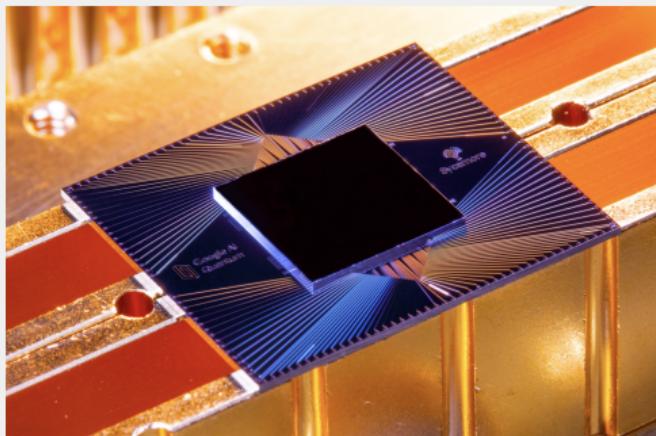
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Also...

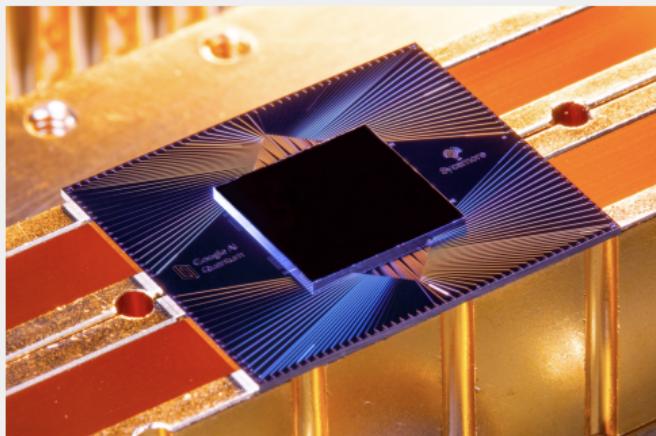
- Shor's Factoring Algorithm
- Grover's Search Algorithm

MOTIVATION - OUTSTANDING QUESTIONS IN QUANTUM COMPUTING



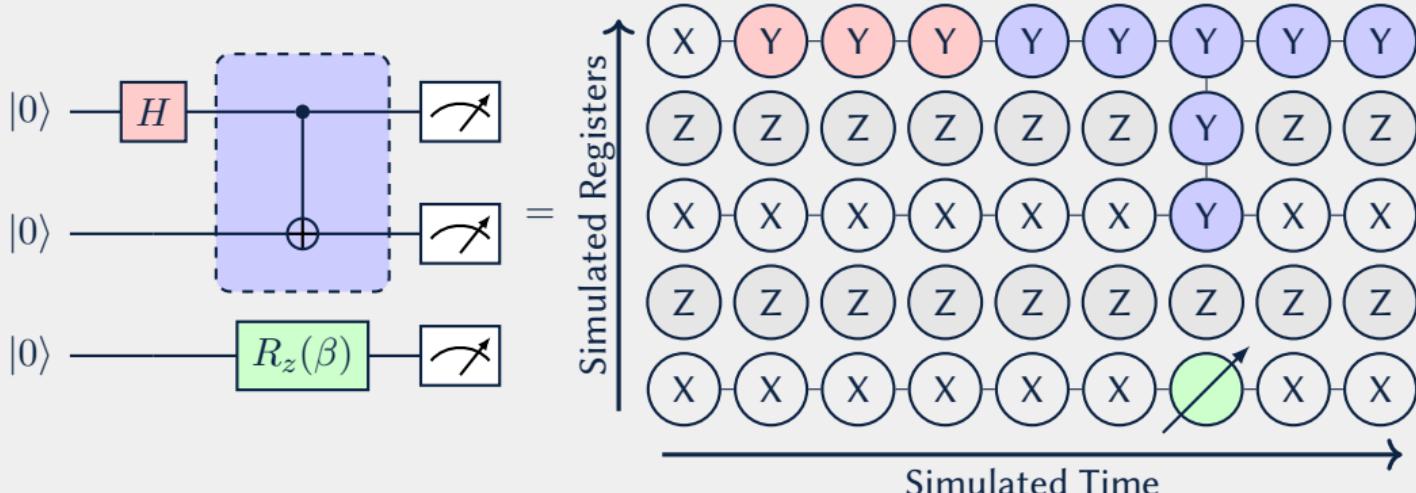
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2. What can we do with NISQ (Noisy Intermediate-Scale Quantum) devices?

MOTIVATION - OUTSTANDING QUESTIONS IN QUANTUM COMPUTING



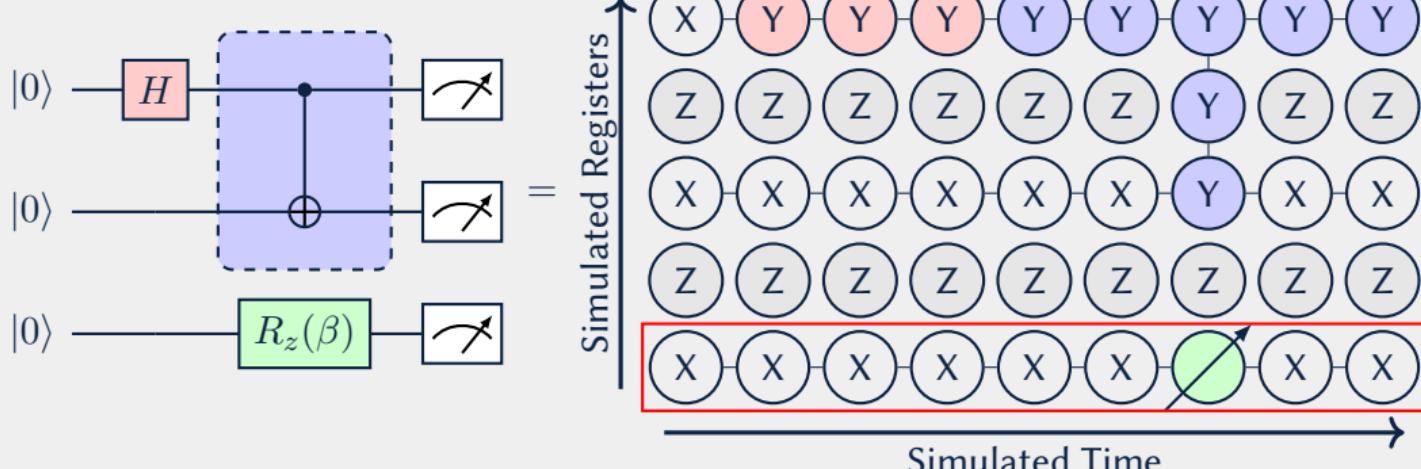
1. What is the source of quantum advantage?
 - ▶ Measurement-Based Quantum Computing - coming up!
2. What can we do with NISQ (Noisy Intermediate-Scale Quantum) devices?
 - ▶ Active research area... and this project!

WHY MEASUREMENT-BASED QUANTUM COMPUTING?



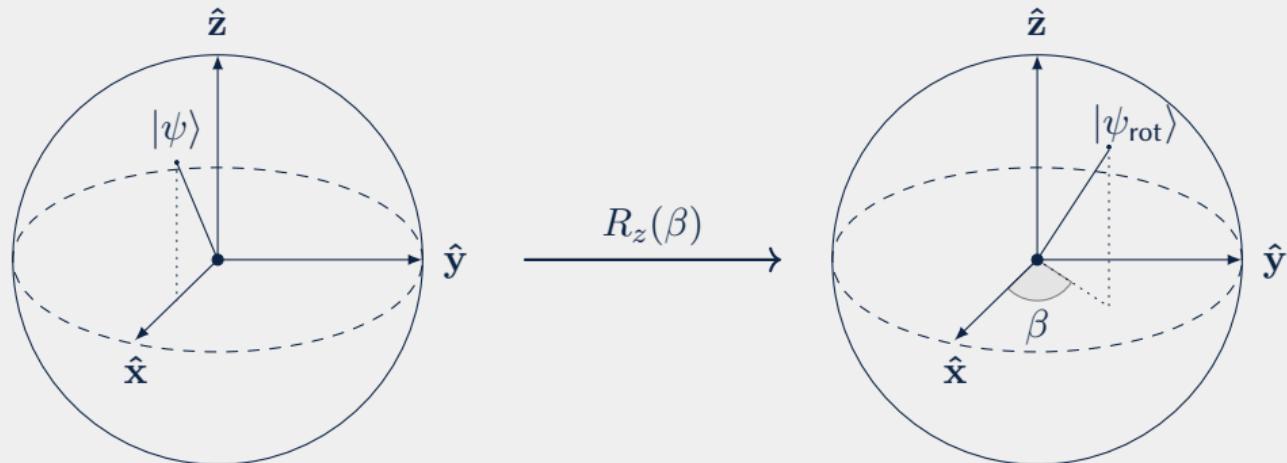
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Evolution Method	Unitary Gates	Single-Qubit measurements
“Power Source”	Intermediate Gates	Initial State

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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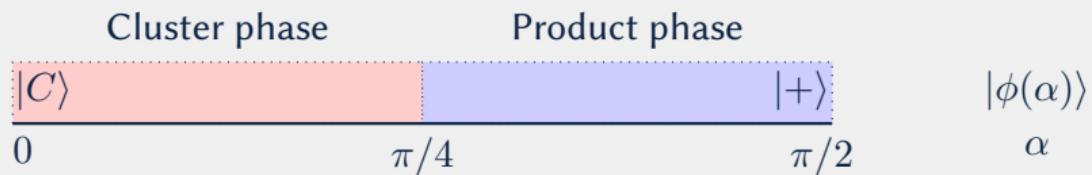
Ground state of H_{product}

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

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

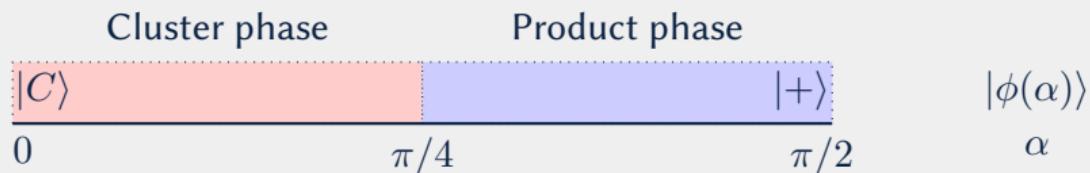
1D RESOURCE STATES - PHASE DIAGRAM & DECOHERENCE

Answer (for infinite systems):



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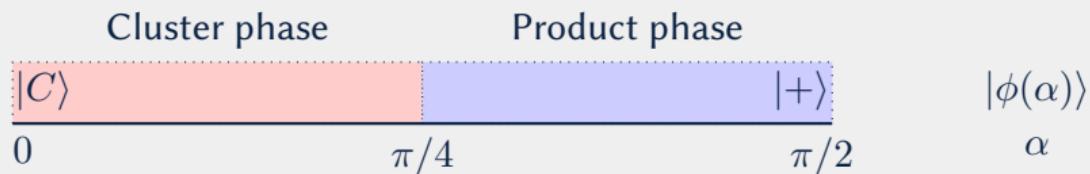
Answer (for infinite systems):



- The catch: Decoherence away from cluster state.

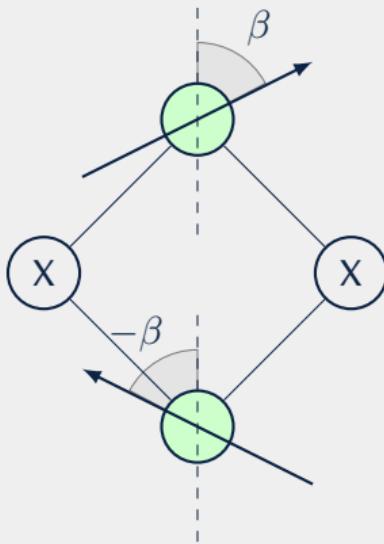
1D RESOURCE STATES - PHASE DIAGRAM & DECOHERENCE

Answer (for infinite systems):



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

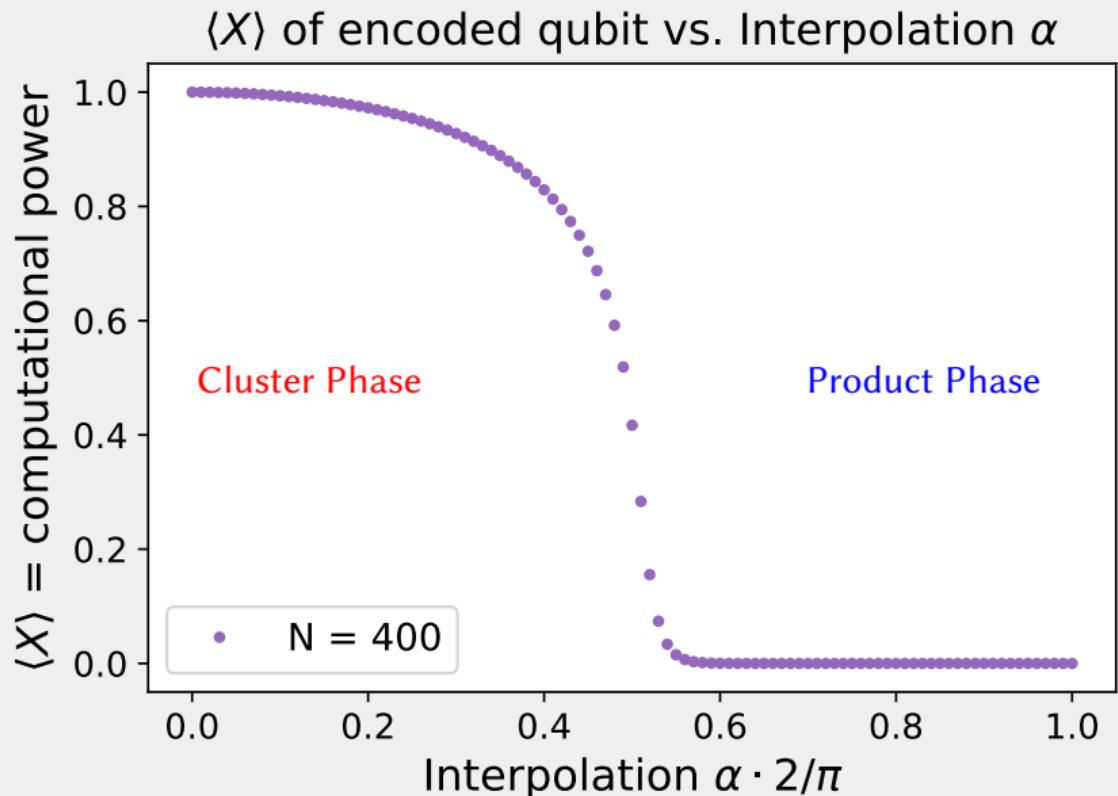
1D RESOURCE STATES - A TEST OF COMPUTATIONAL POWER



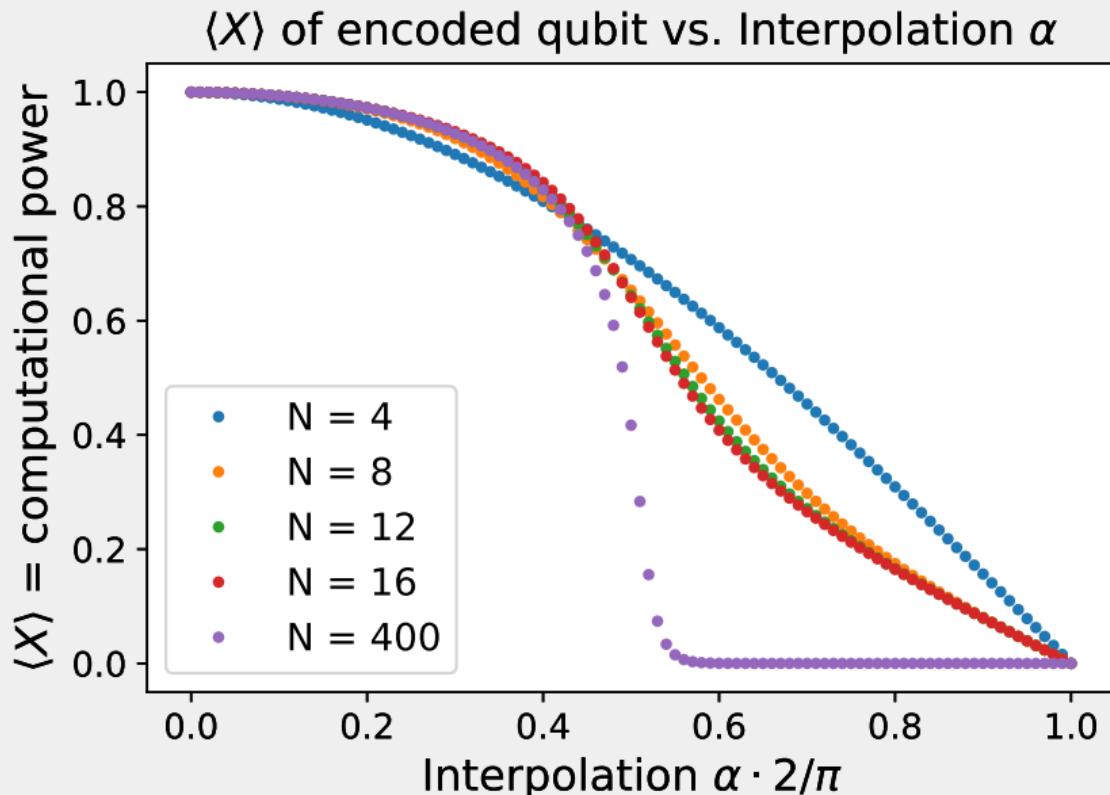
Demonstration: The rotation-counter rotation scheme

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 - PRODUCING GROUND STATES

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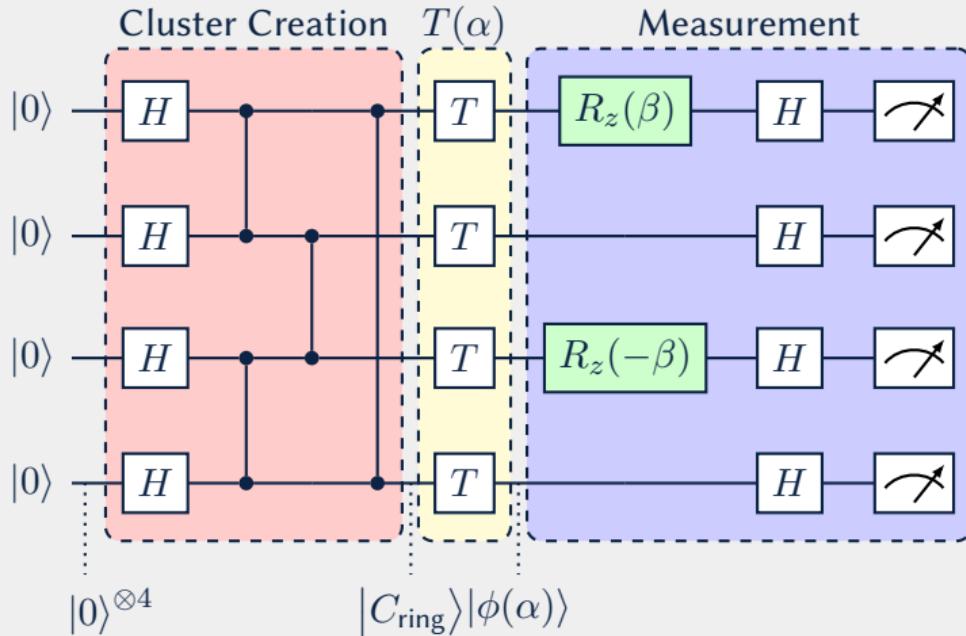
$$U(\alpha) \cong T(\alpha) = \text{only } X\text{s and } I\text{s}$$

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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- Solution: Redraw some brackets:

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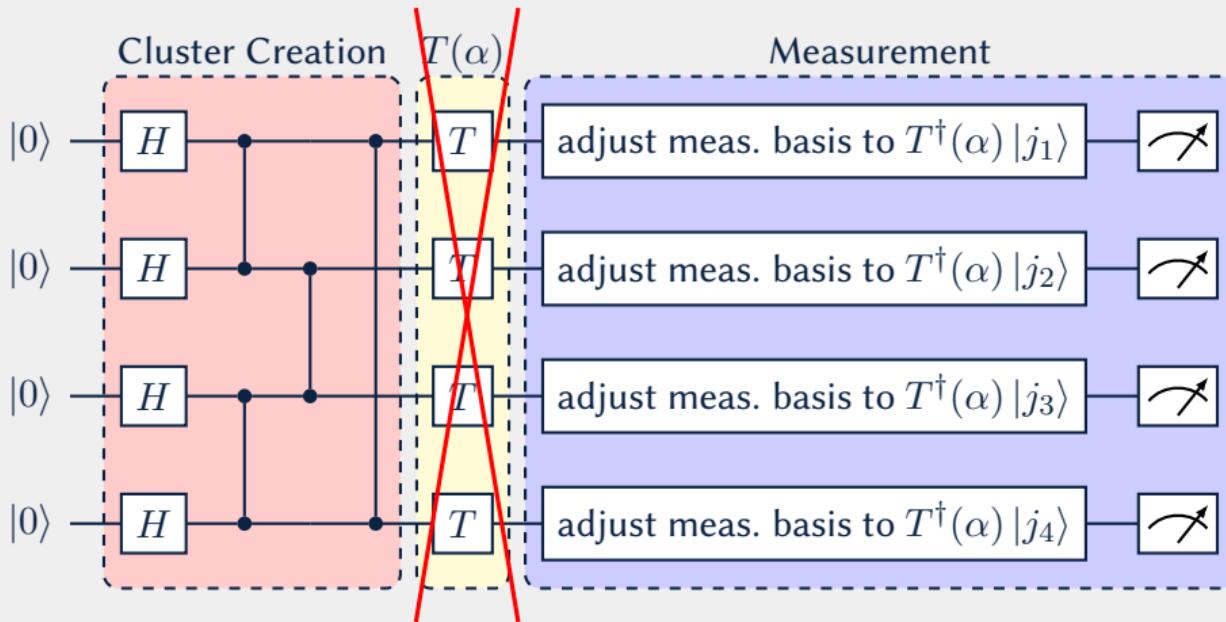
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- Takeaway: Problem Decomposition.

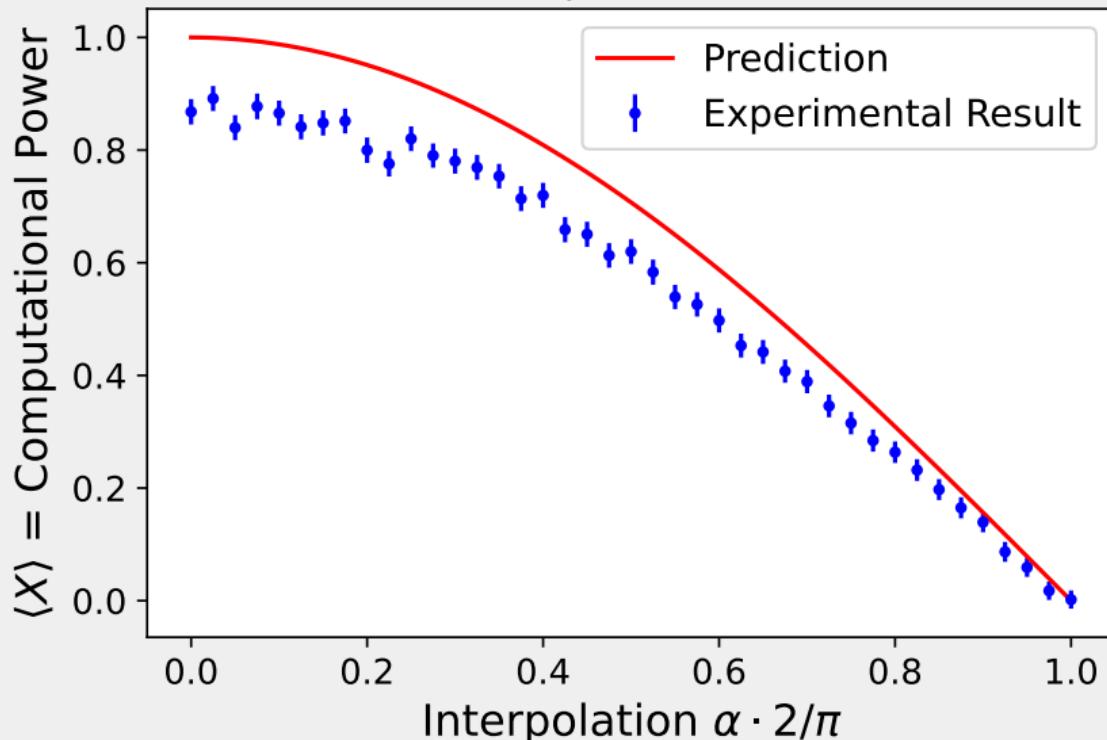
THE ALLUDED ALGORITHMS - THE TASK



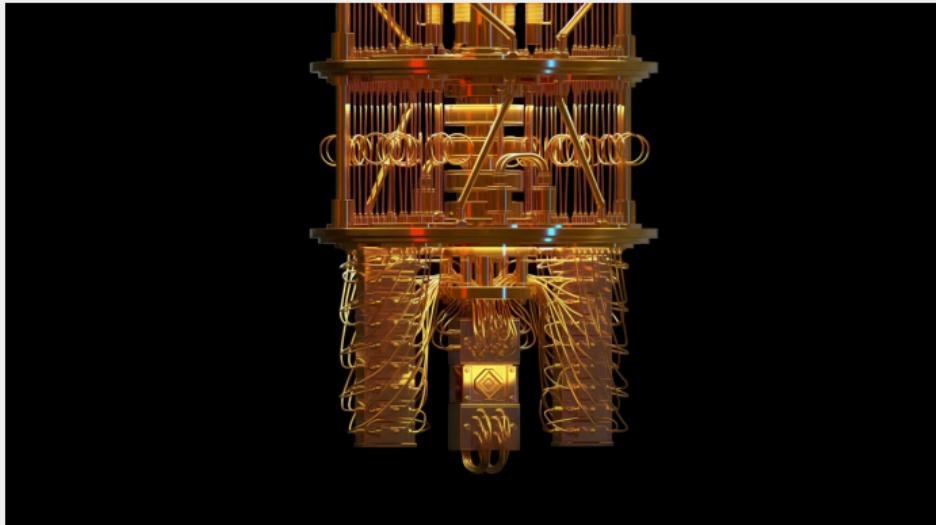
The Task: Develop algorithm to make circuits and post-process measurement outcomes, obtain results *as if* $T(\alpha)$ had been implemented.

RESULTS - EXPERIMENT

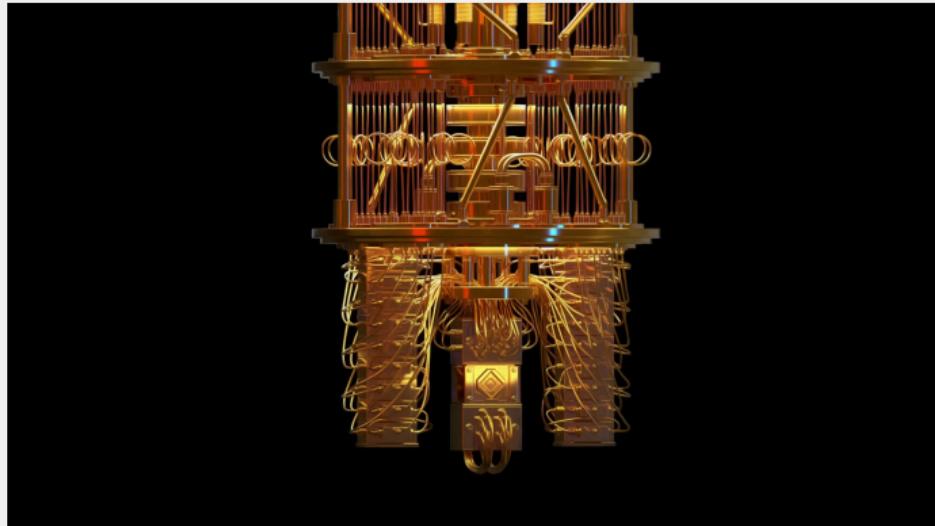
$\langle X \rangle$ of encoded qubit vs. Interpolation α
(Experiment)



OUTLOOK & CONCLUSION

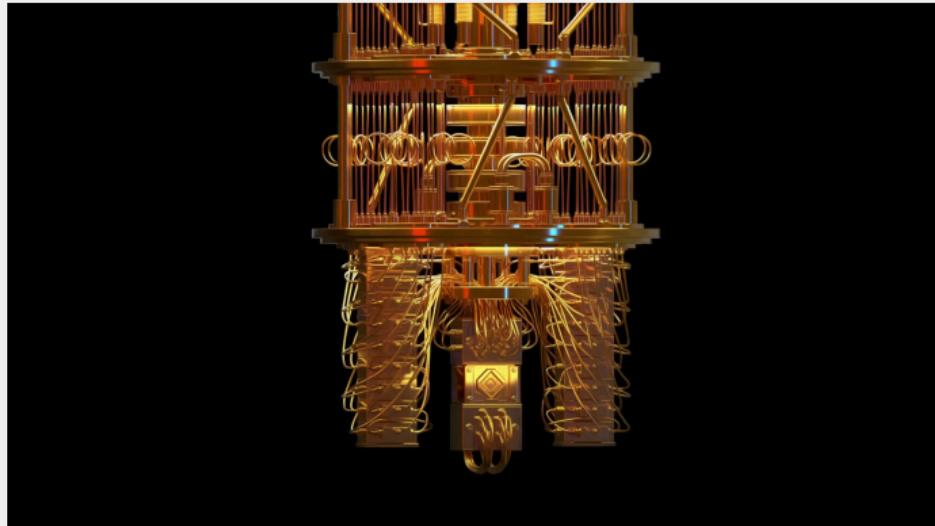


OUTLOOK & CONCLUSION



- To-Do: Larger systems to demonstrate decoherence mitigation.

OUTLOOK & CONCLUSION



- To-Do: Larger systems to demonstrate decoherence mitigation.
- Impact: First experimental demonstration of robustness of quantum computational power. Understanding quantum advantage, and a use case for NISQ devices.