Symmetry-protected measurement-based quantum computation on NISQ devices

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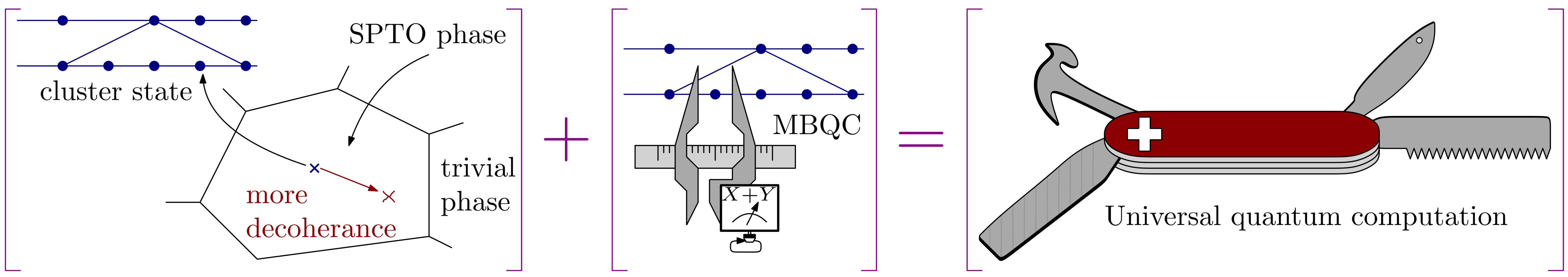
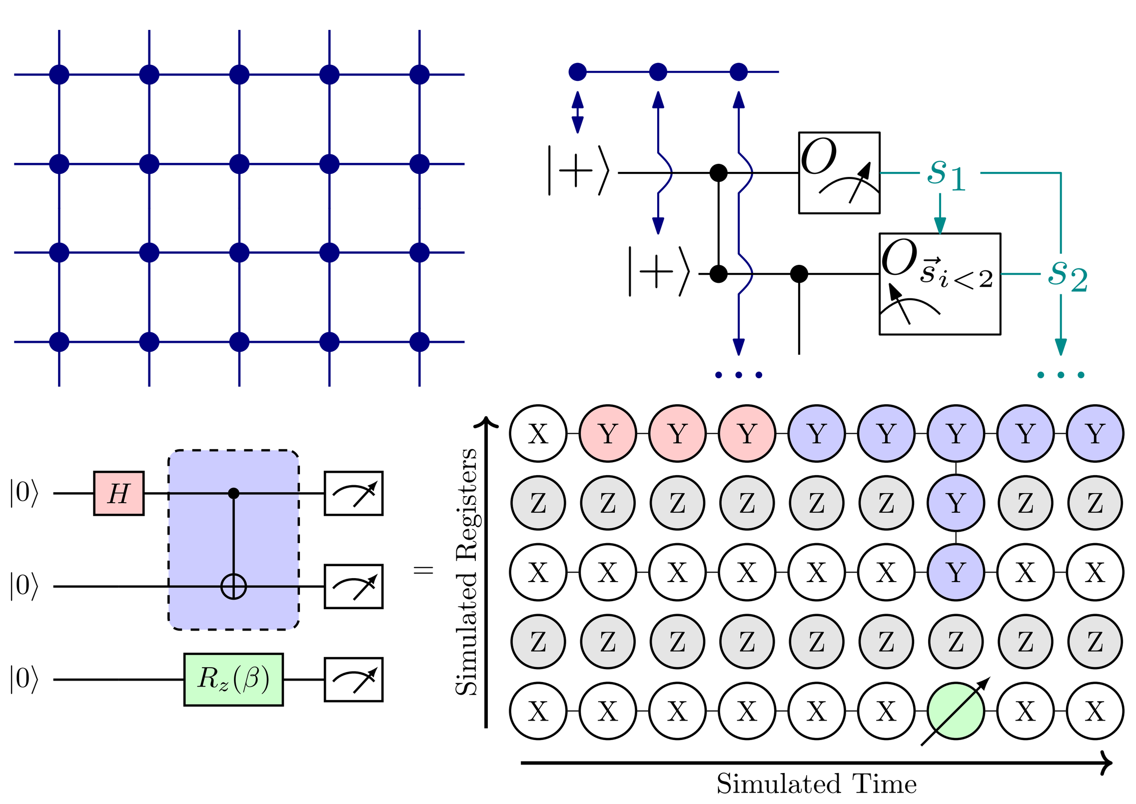
Computationally Universal Phases of Matter



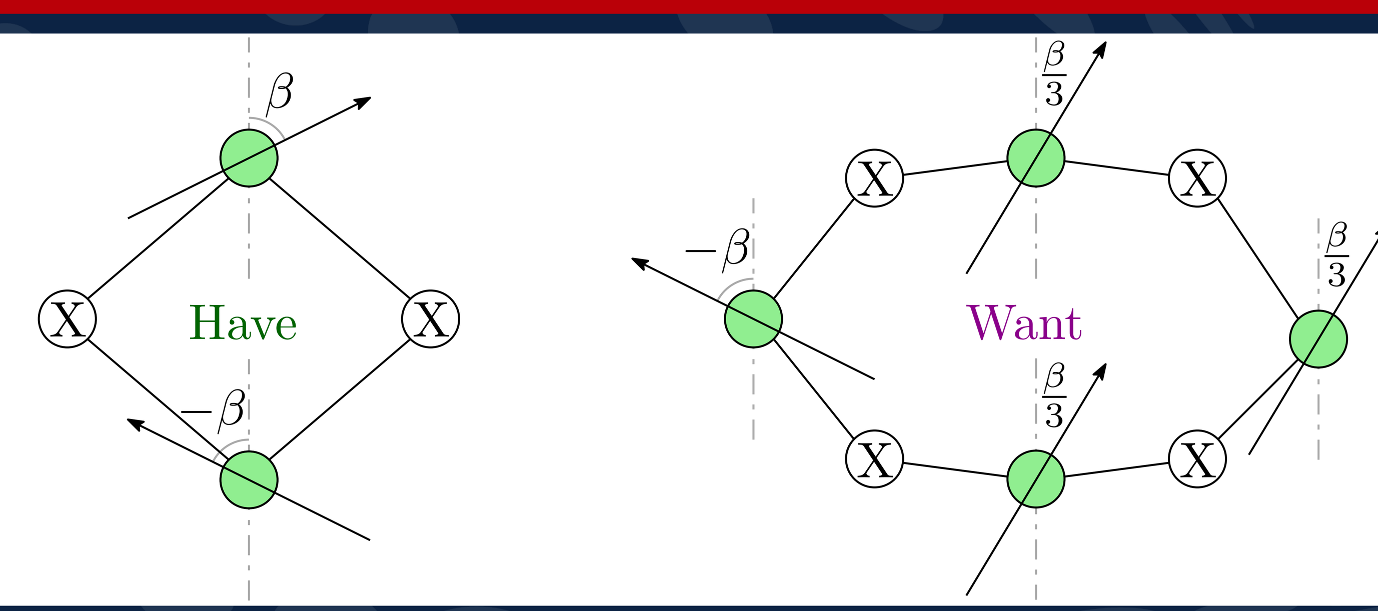
- Motivating Question: Can we experimentally demonstrate computation throughout the cluster phase and optimal decoherence management techniques?

Measurement-based quantum computation

- Start: Robustly entangled state (cluster state): -1 eigenvalue state of $X_a \prod_{b \in N(a)} Z_b$ on $n \times m$ grid.
- Operations: Adaptive one-qubit measurements
- Result: Arbitrary m-qubit unitary.

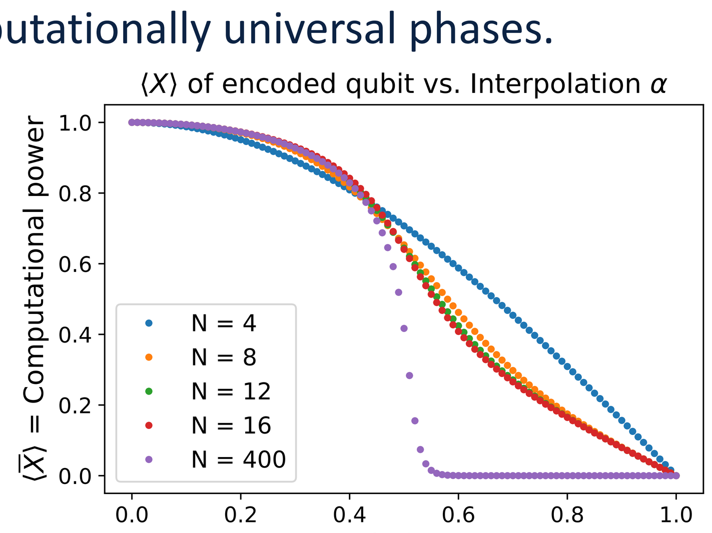


Rotation counter-rotation scheme

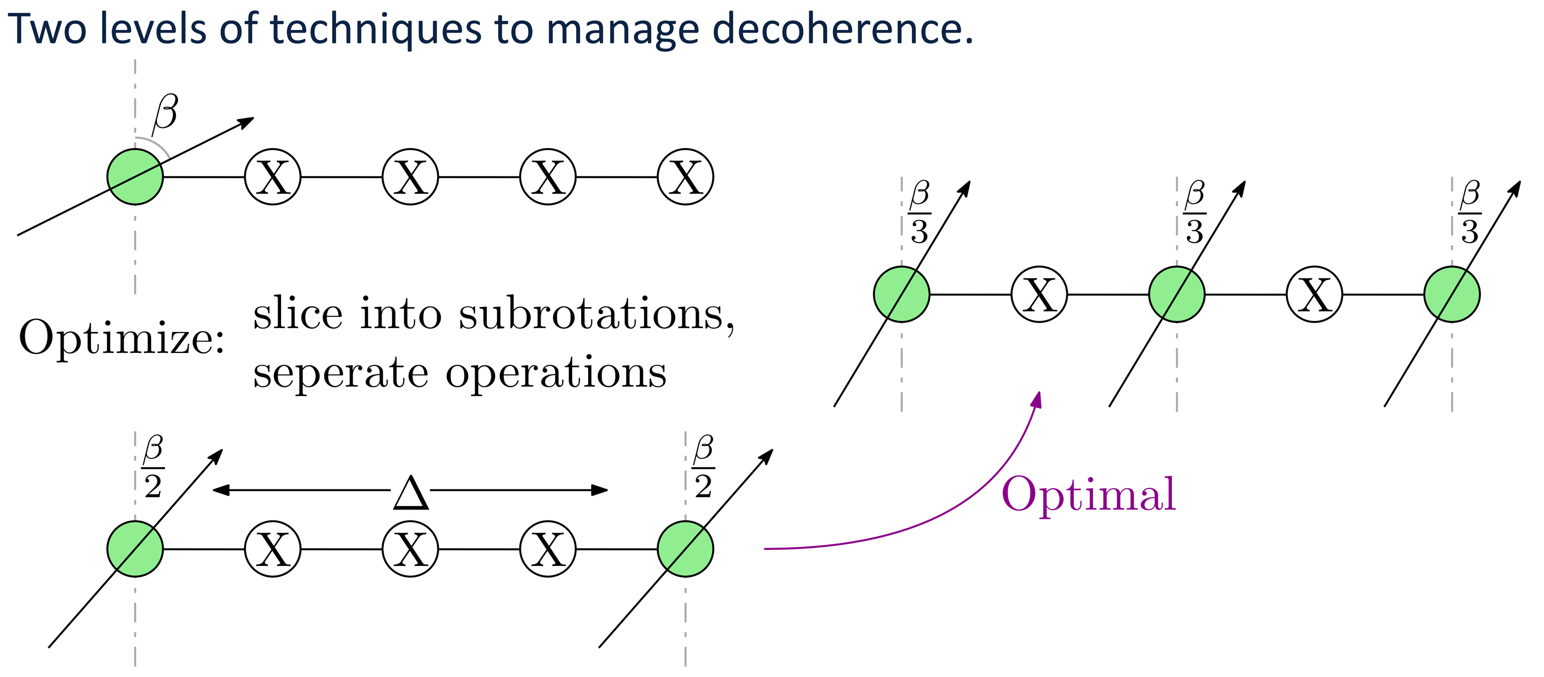


$\mathbb{Z}_2 \times \mathbb{Z}_2$ and decoherence management

- Exist: SPTO computationally universal phases.

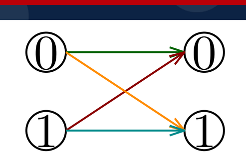


- Example: Ground states of $H(\alpha) = -\cos(\alpha)\sum_i Z_{i-1}X_iZ_{i+1} - \sin(\alpha)\sum_i X_i$ for $\alpha < \pi/4$ consist of the cluster phase, where computational power persists.
- States closer to the phase boundary induce more decoherence.
- Two levels of techniques to manage decoherence.



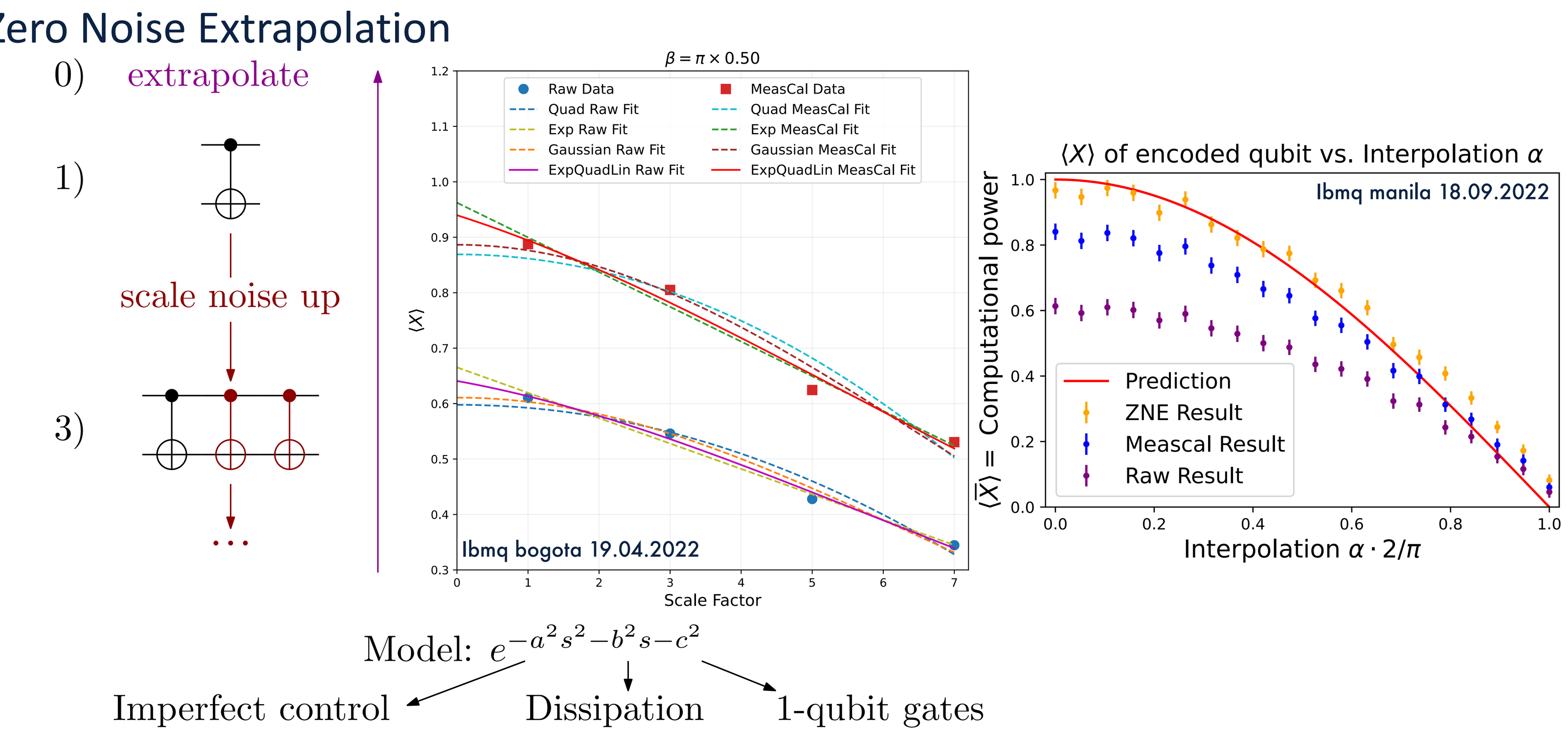
Error mitigation

- Measurement Noise



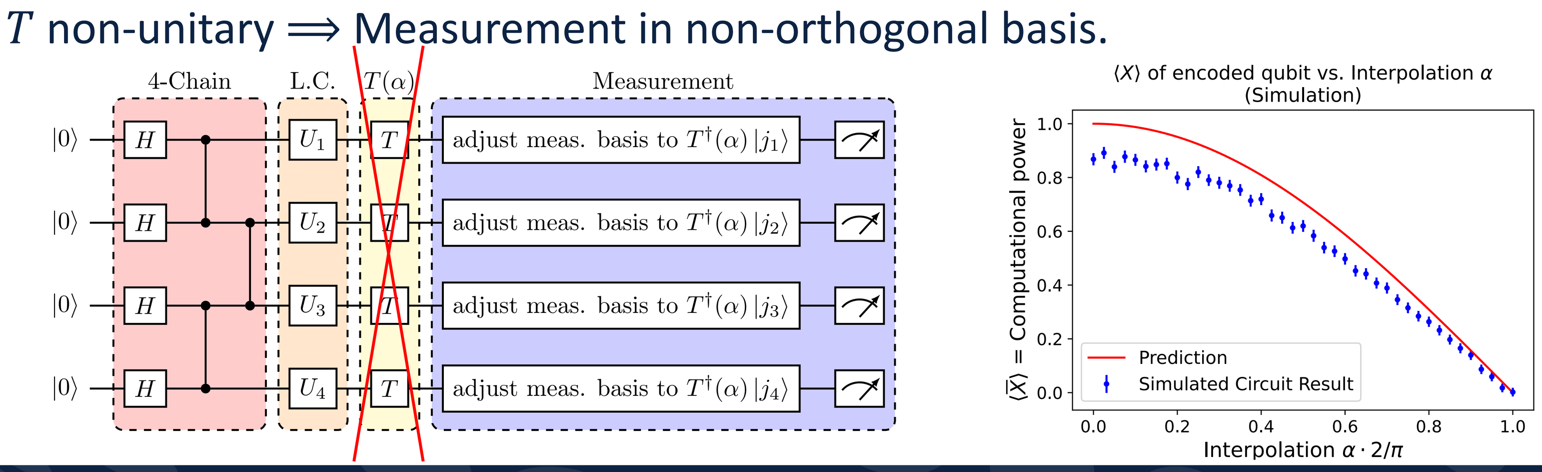
$$M = \begin{bmatrix} p & 1-q \\ 1-p & q \end{bmatrix} \quad [\text{noisy}] = M[\text{ideal}]$$

- Zero Noise Extrapolation



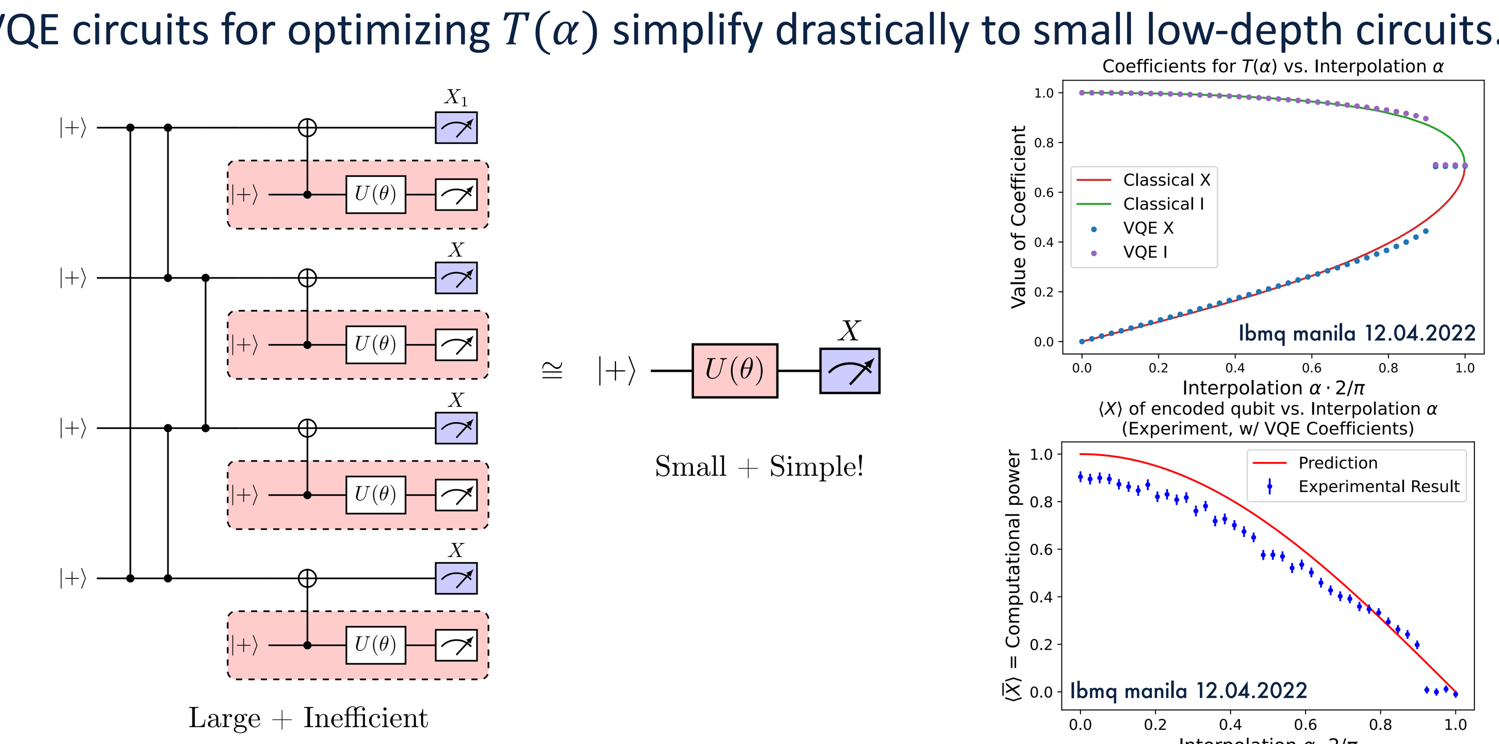
Circuits with post-processing

- $|GS(\alpha)\rangle = T(\alpha)|C\rangle$; choose $T(\alpha) = \otimes_i \sum(I \text{ or } X)_i$ by sacrificing unitarity.
- T non-unitary $\Longrightarrow$ Measurement in non-orthogonal basis.



Variational Quantum Eigensolver

- First-order perturbation theory yields $T(\alpha) = \otimes_i(\cos(\theta_\alpha)I_i + \sin(\theta_\alpha)X_i)$
- Exact for ≤ 6 qubits.
- VQE circuits for optimizing $T(\alpha)$ simplify drastically to small low-depth circuits.



References

[1] Adhikary, A. Symmetry protected measurement-based quantum computation in finite spin chains. MSc. Thesis, University of British Columbia, August 2021.

[2] Weil, R. A Simulation of a Simulation: Algorithms for Symmetry-Protected Measurement-Based Quantum Computing Experiments. BSc. Thesis, University of British Columbia, June 2022

[3] Guha, A. Implementing measurement-based quantum computing schemes on NISQ devices with error mitigation. BSc. Thesis, University of British Columbia, August 2022.