



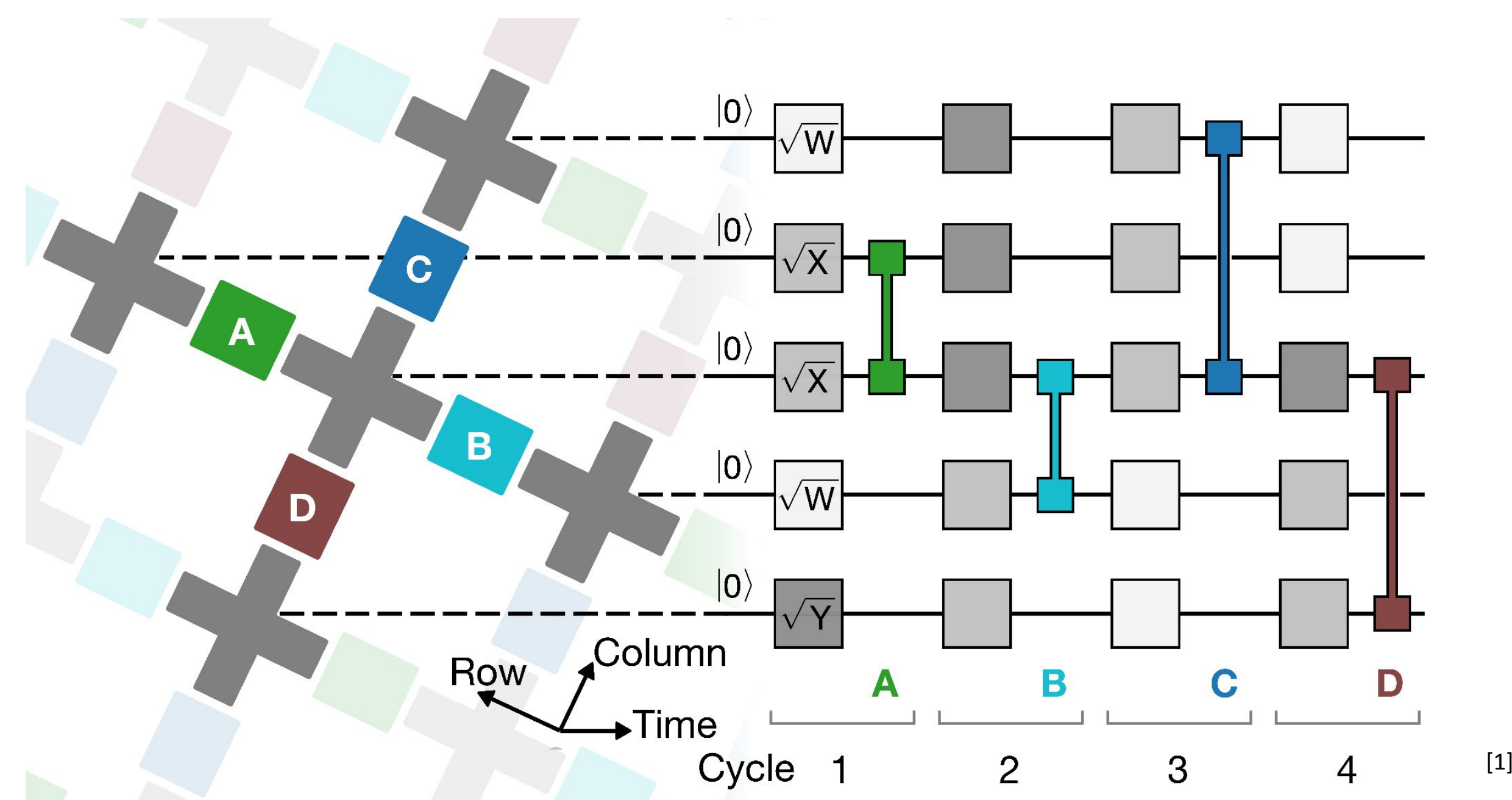
# Benchmarking Tetrons with Random Circuit Sampling



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## What is Quantum Advantage?

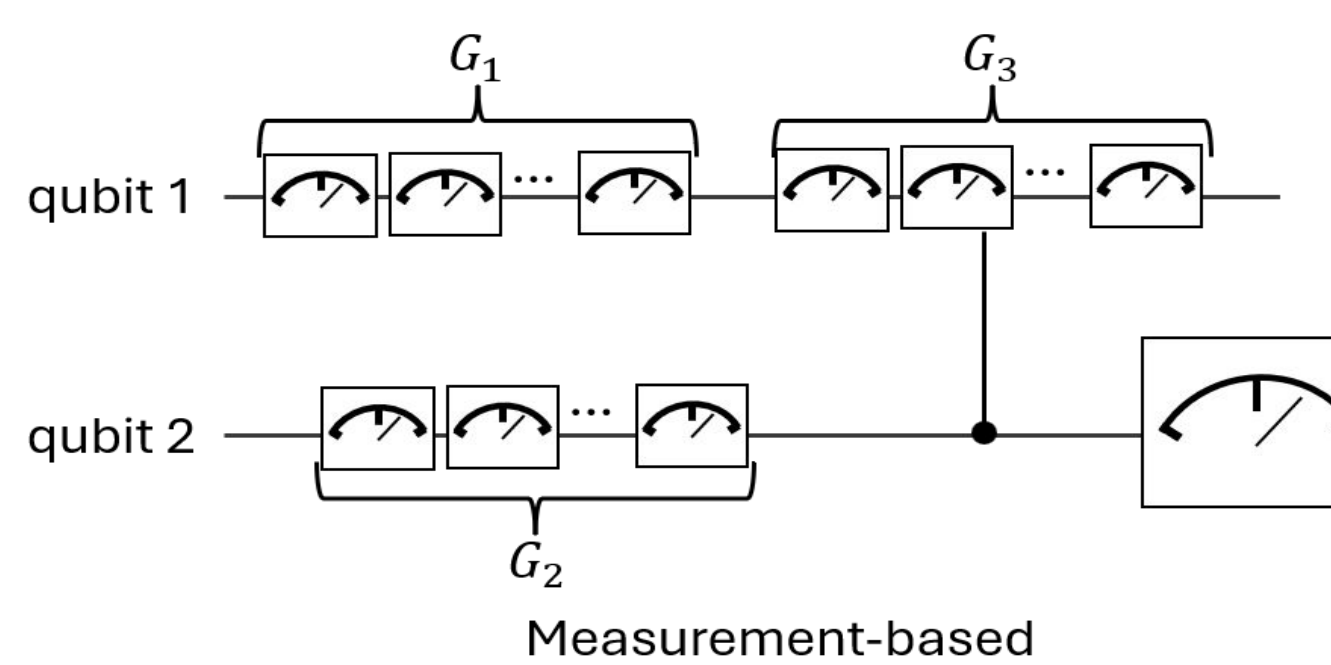
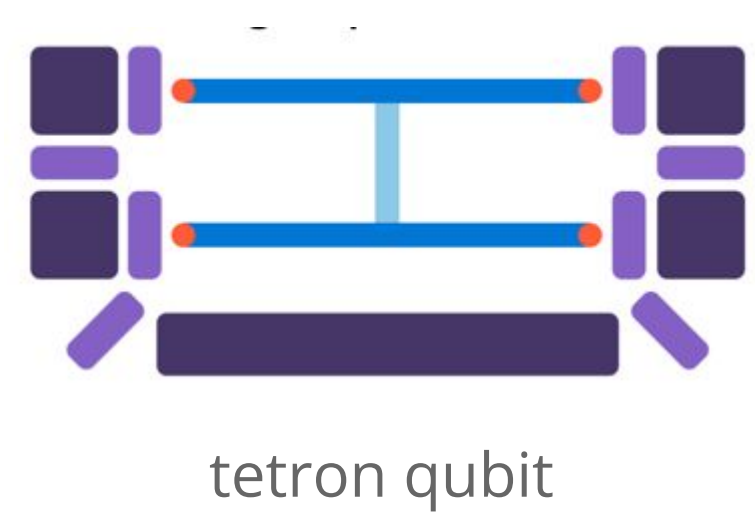
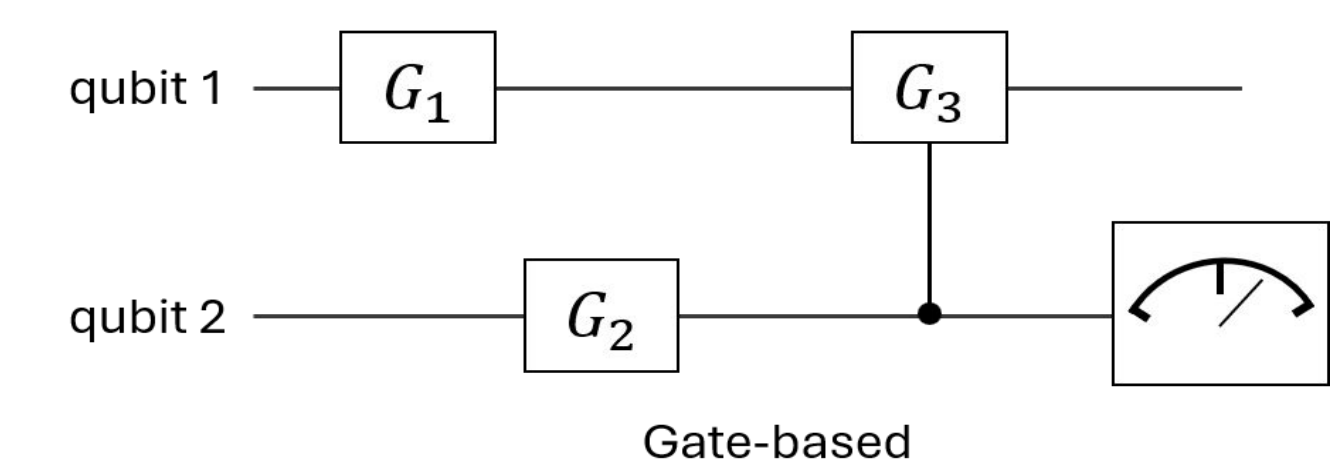
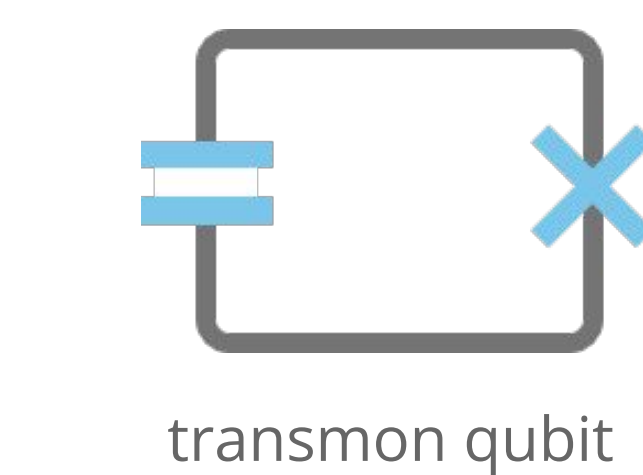
- Defined in the early 2010s, quantum advantage is the use of a quantum device to solve a computational task that no classical computer ever could.
- Random circuit sampling (RCS) emerged as the canonical task: noise-tolerant, classically verifiable at small qubit counts, exponentially hard at large ones.
- Google's 2019 demonstration [1] ran RCS on 53 qubits alternating single-qubit gates randomly drawn from  $\{\sqrt{X}, \sqrt{Y}, \sqrt{W}\}$  and two-qubit  $f\text{Sim}(\theta, \phi)$ .



- The performance was benchmarked using linear cross-entropy fidelity:
 
$$F_{\text{XEB}} = D \cdot \mathbb{E}_{x \sim P_{\text{exp}}} [p_U(x)] - 1$$
- $F_{\text{XEB}}=1$  means the device perfectly reproduces the ideal distribution.
- $F_{\text{XEB}}=0$  means uniform random output.

## Different Approaches to Quantum Circuits

- The careful study of condensed matter physics has allowed for the realization of various hardware platforms which enable quantum computing.
- Google and Microsoft specialize in different condensed matter platforms:
- Similar to transistor-level AND/OR logic, Google's processor uses a gate-based approach for quantum computing.
- Meanwhile, Microsoft's processor uses a measurement-based approach:

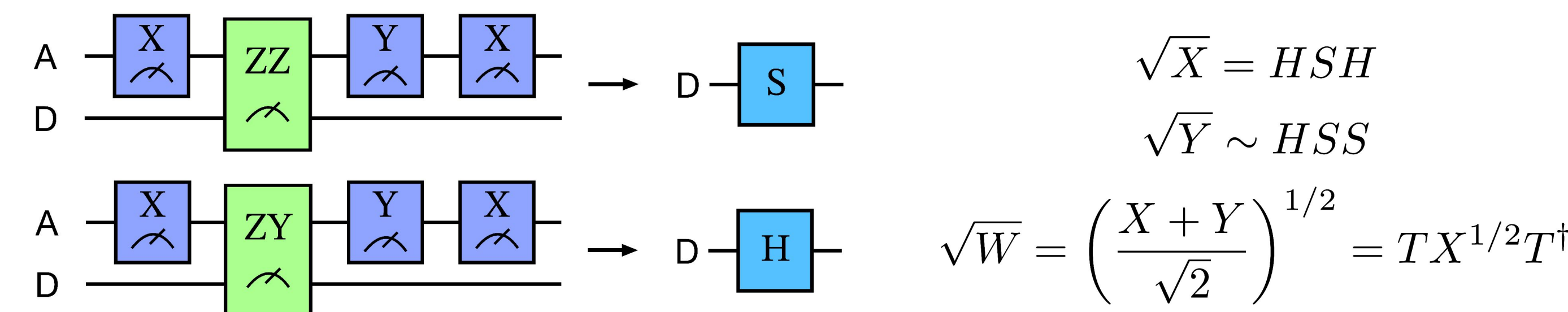


## A Benchmark for NISQ Quantum Computers

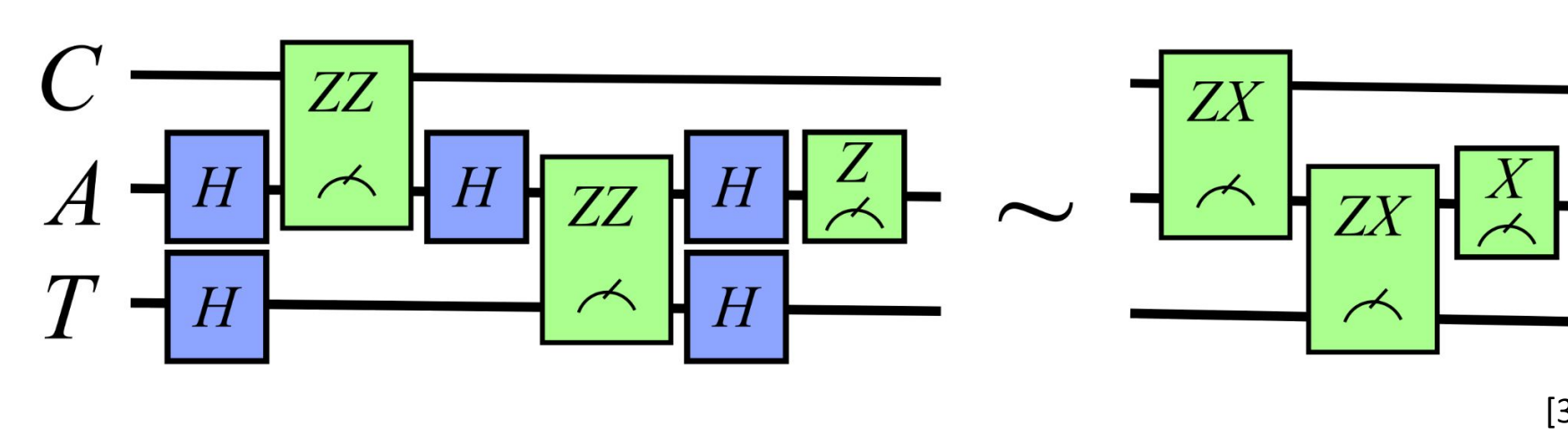
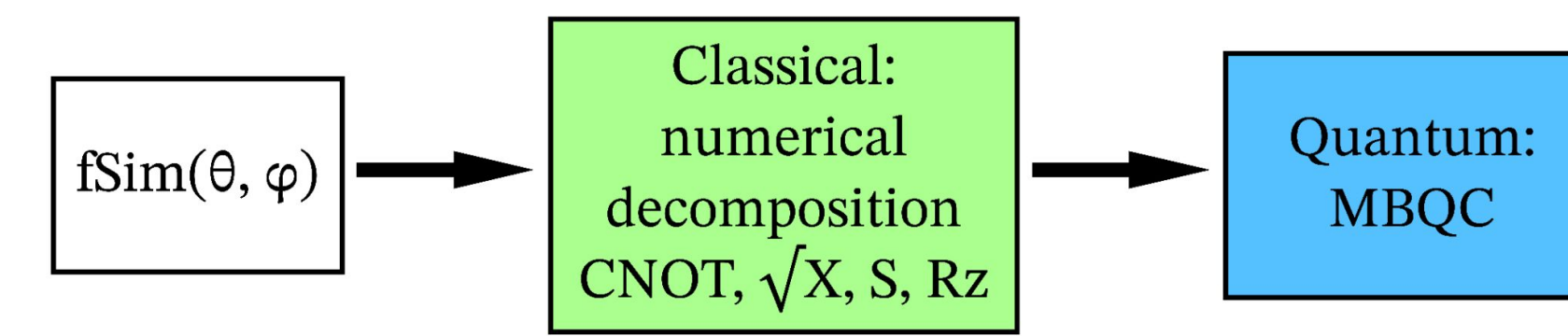
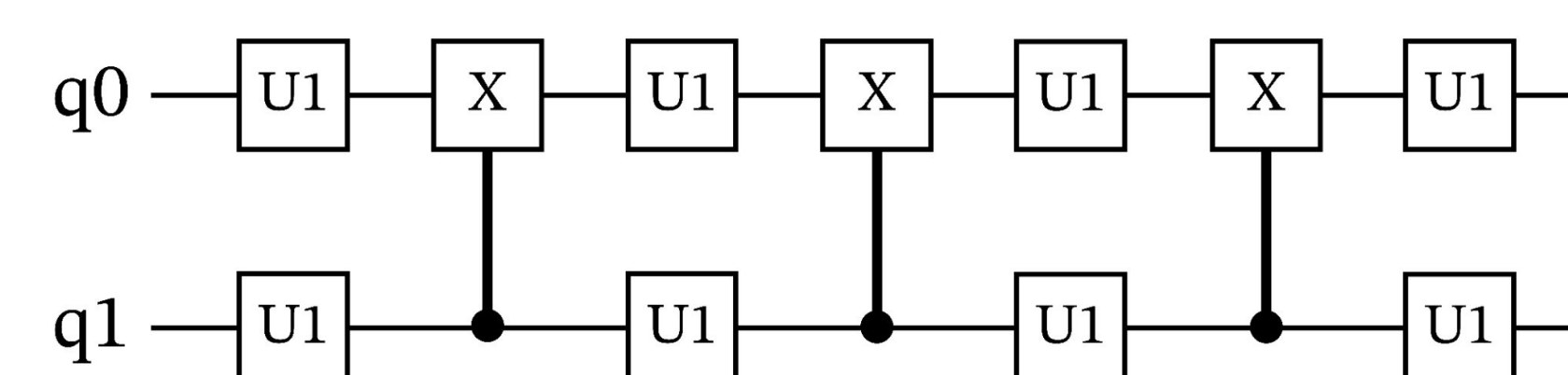
- Our work is an open-source translation of circuits used in Google's 2019 quantum advantage demonstration into circuits compatible with Microsoft's tetron architecture with simulated equivalence verification.**
- Quantum computing currently sits in the noisy intermediate-scale quantum (NISQ) era.
- Multiple platforms compete for the industry standard, with no clear winner yet.
- RCS doubles as a cross-architecture benchmark for NISQ devices.
- Topological MBQC scales naturally because control reduces to a few digital baseband operations. Unlike gate-based qubits, which need many high-frequency RF lines kept phase-locked across a growing array, tetron operations are coarse-grained measurements driven by simple voltage pulses, with topological encoding providing noise protection.

## Single-Qubit Gates

- Decompose Google's single-qubit gates into Clifford operations and non-Clifford Z-rotations
- Single-qubit Clifford gates can be decomposed into a sequence of two-qubit measurements including an ancilla qubit, up to Pauli corrections.
- Pauli corrections are classically tracked and applied before non-clifford gate.
- Non-Clifford rotations are constructed directly on tetron as a physical gate.



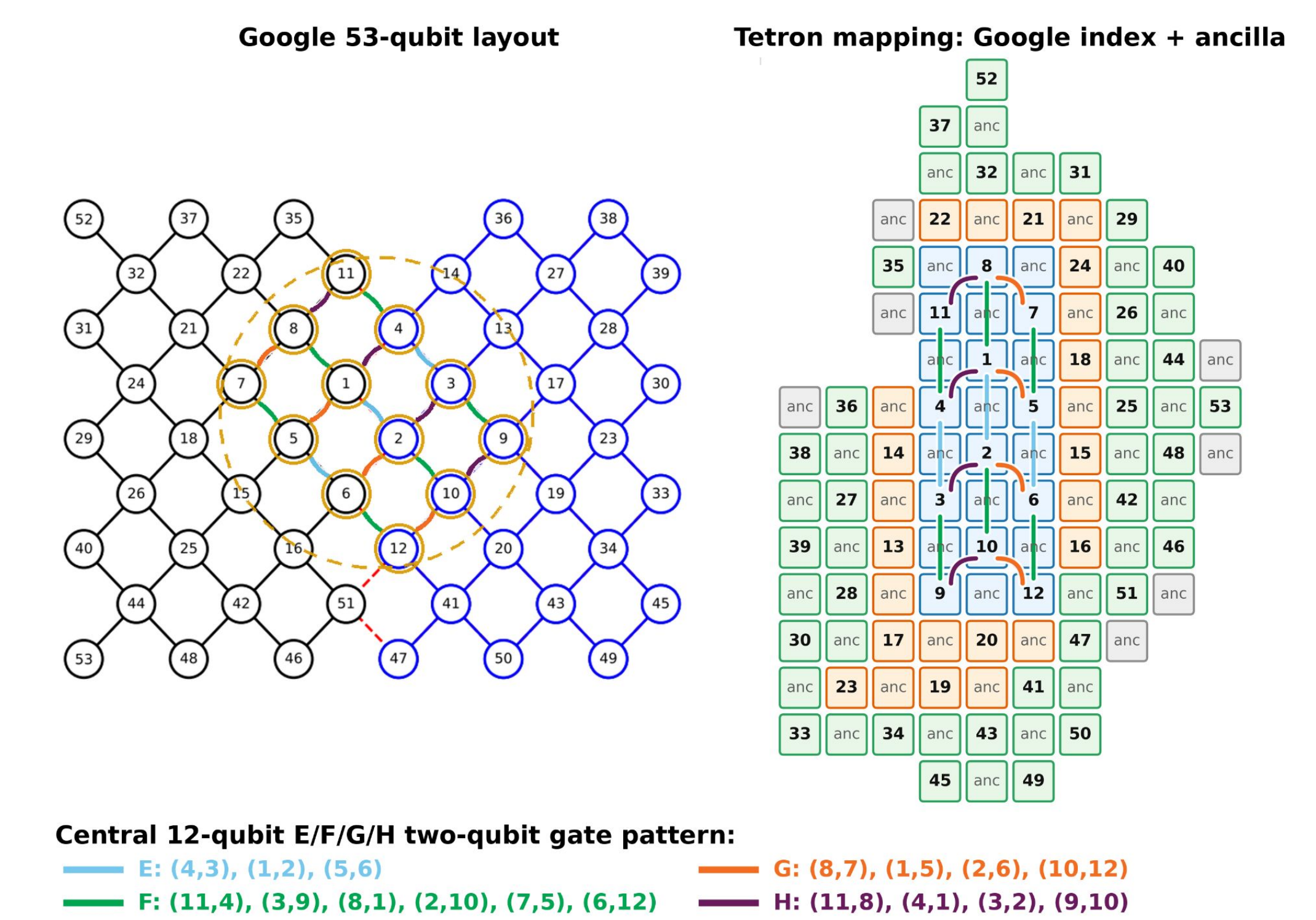
## Two-Qubit Gate (fSim)



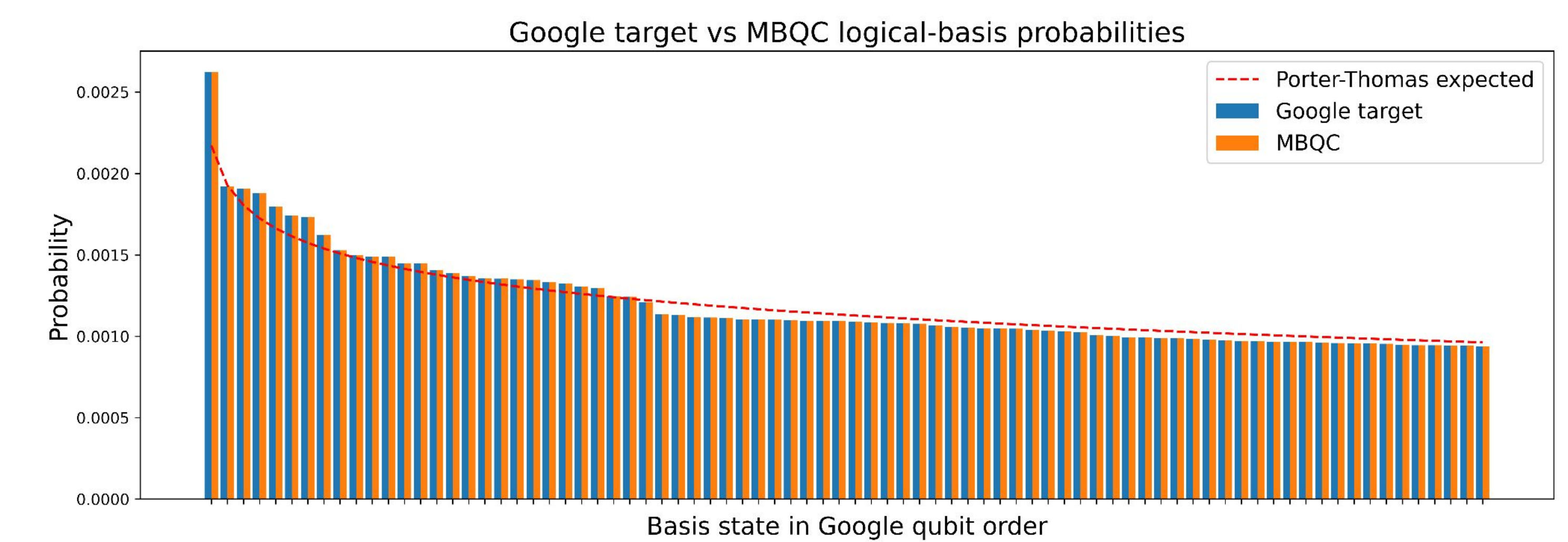
- Google's circuit uses  $f\text{Sim}$  as the two-qubit entangling gate, which can be numerically decomposed into 3 CNOT gates and single-qubit Euler rotations.
- A random  $f\text{Sim}$  gate can be implemented using at most 3 CNOT gates and 7 non-Clifford Z-rotations, enabling high experimental fidelity.
- A CNOT gate can be constructed from a sequence of two-qubit measurements involving an ancilla qubit, up to Pauli corrections.

## Qubit Layout Translation

- Convert Google's 53-qubit layout into a tetron data-ancilla layout.
- Design the mapping to preserve nearest-neighbor connectivity between logical qubits.
- The central  $8 \times 3$  tetron array gives a simple correspondence to Google's qubit layout.
- Translate Google's 12-logical-qubit circuit into an MBQC/tetron measurement pattern.



- Comparing MBQC generated bitstrings to Google's-provided amplitudes as the gate-based reference state follow the expected Port-Thomas distribution.



## Future Work, References, and Acknowledgments

- Characterization of Pauli frame correction variations.
  - Integration of coherent and random gate noise into existing RCS circuits.
  - Demonstration of Clifford-gate only RCS using increasing depth to match Google's largest 2019 circuit.
  - Manuscript under preparation.
- Faculty: Sara Mouradian  
Graduate Students: Shuyun Liu, Koray Mentesoglu, Chris Moore, Xiangyu Shi
- [1] F. Arute et al., Quantum supremacy using a programmable superconducting processor, Nature 574, 505–510, 2019.  
[2] D. Aasen et al., Roadmap to fault tolerant quantum computation using topological qubit arrays, arXiv:2502.12252, 2025.  
[3] T. Karzig et al., Scalable designs for quasiparticle-poisoning-protected topological quantum computation with Majorana zero modes, Phys. Rev. B 95, 235305, 2017.