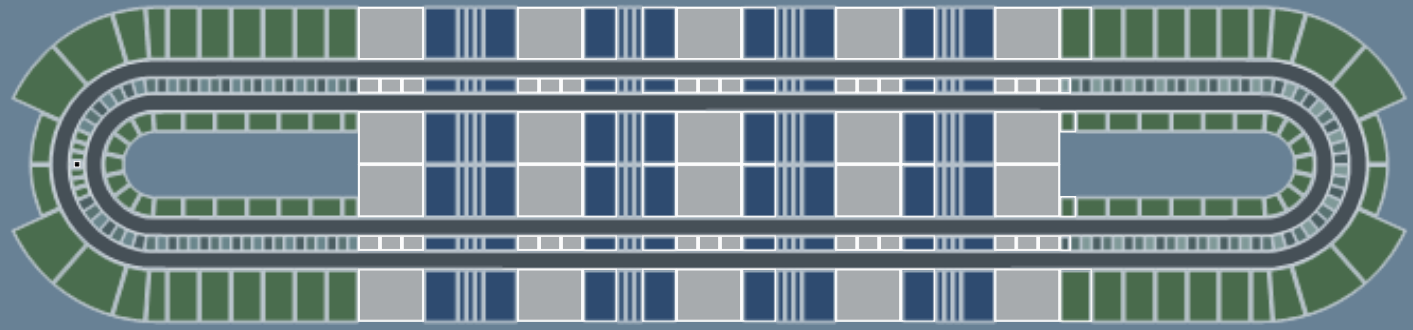
Benchmarking the Quantinuum Stack

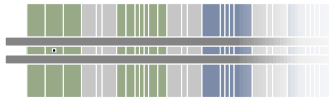
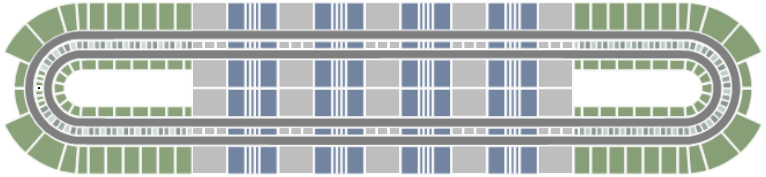
Daniel Mills



TKET

- INQUANTO
- QUANTUM ORIGIN
- LAMBEQ
- QERMIT
- ...

H-series at-a-glance

System		Qubits	2Q gate infidelity ($\times 10^{-3}$)	QV ($\log_2$)
HØ		4 → 6	8.0	4 → 6
H1		10 → 20	5.0 → 0.88	7 → 20
H2		32 → 56	1.8 → 1.28	16 → 18

Other specification data: https://github.com/CQCL/quantinuum-hardware-specifications
Quantum volume data: https://github.com/CQCL/quantinuum-hardware-quantum-volume

Benchmarking tests

Component

- Single-qubit randomized benchmarking
- Two-qubit randomized benchmarking
- Two-qubit SU(4) randomized benchmarking
- Two-qubit parameterized gate randomized benchmarking
- Measurement crosstalk bright state depumping
- Reset crosstalk bright state depumping
- SPAM test
- Two-qubit cycle benchmarking

System-level

- Mirror benchmarking
- Quantum volume
- Random circuit sampling
- GHZ state fidelity

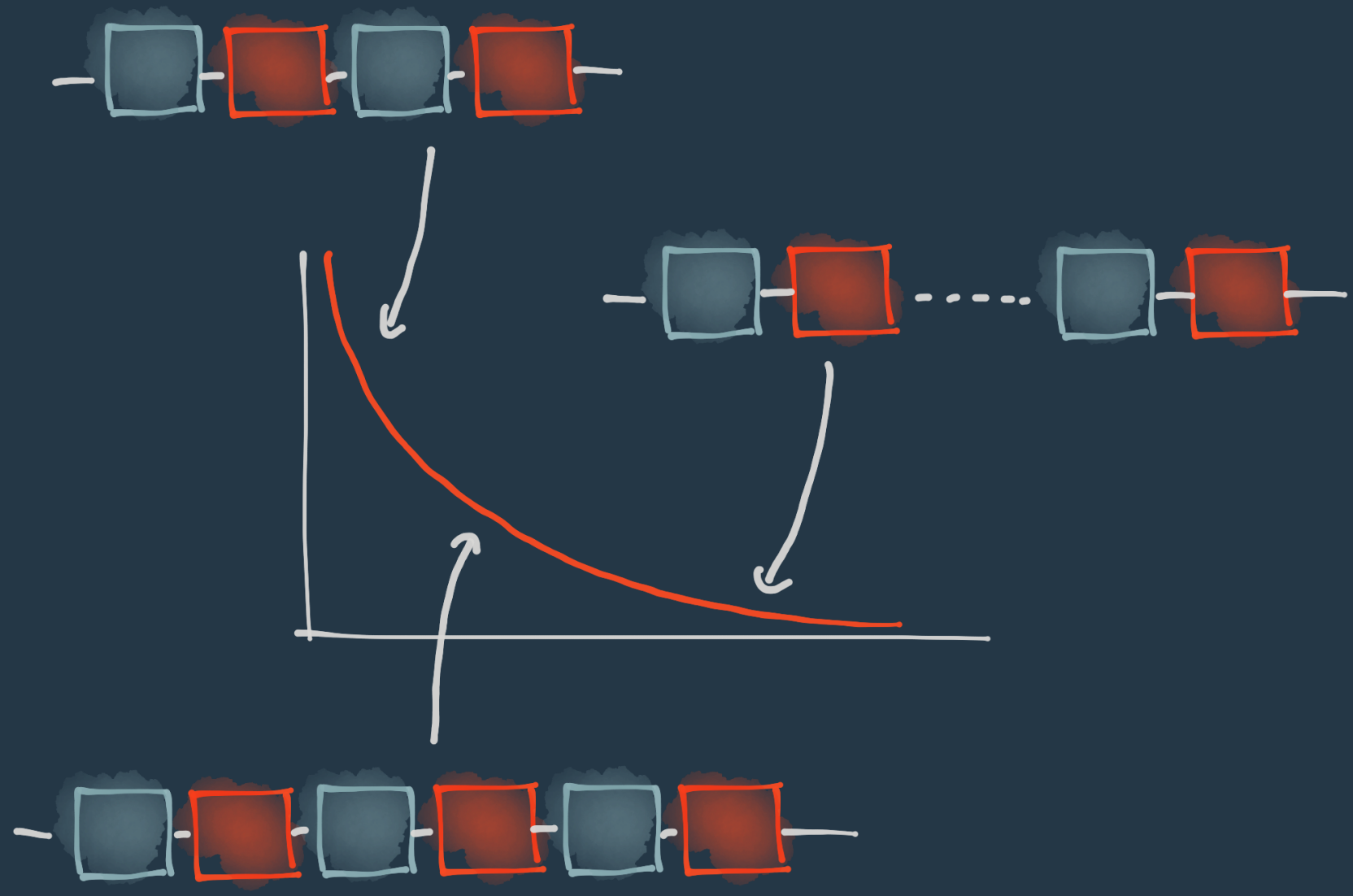
Algorithmic

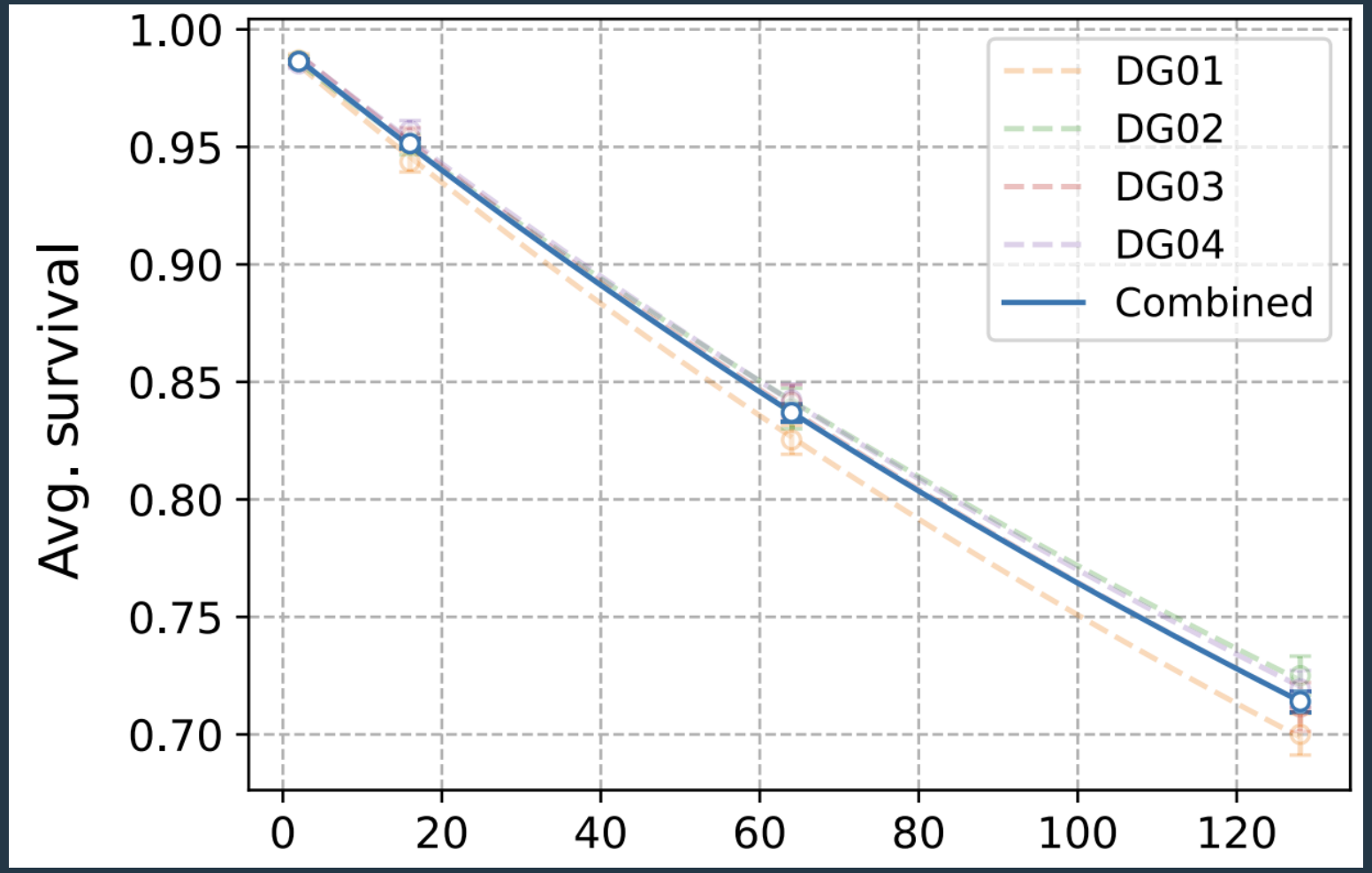
- 1D transverse field Ising model simulation
- QAOA
- Repetition code
- HoloQUADS
- Logical memory
- QFT and Toffoli
- QED-C application oriented benchmarks
- Logical circuits
- Algorithmic qubits

A Race-Track Trapped-Ion Quantum Processor
https://journals.aps.org/prx/abstract/10.1103/PhysRevX.13.041052

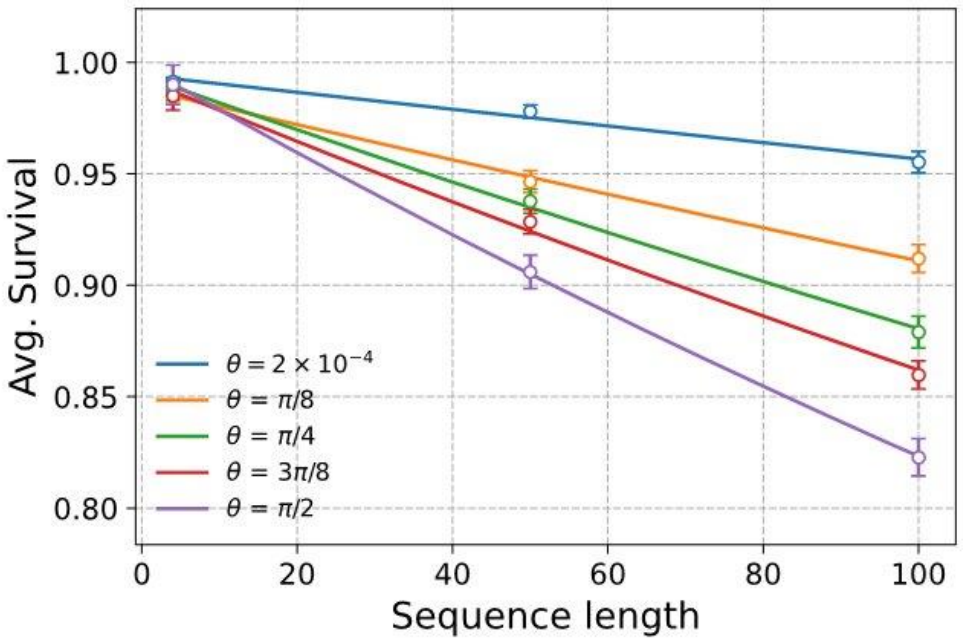
Randomised Benchmarking

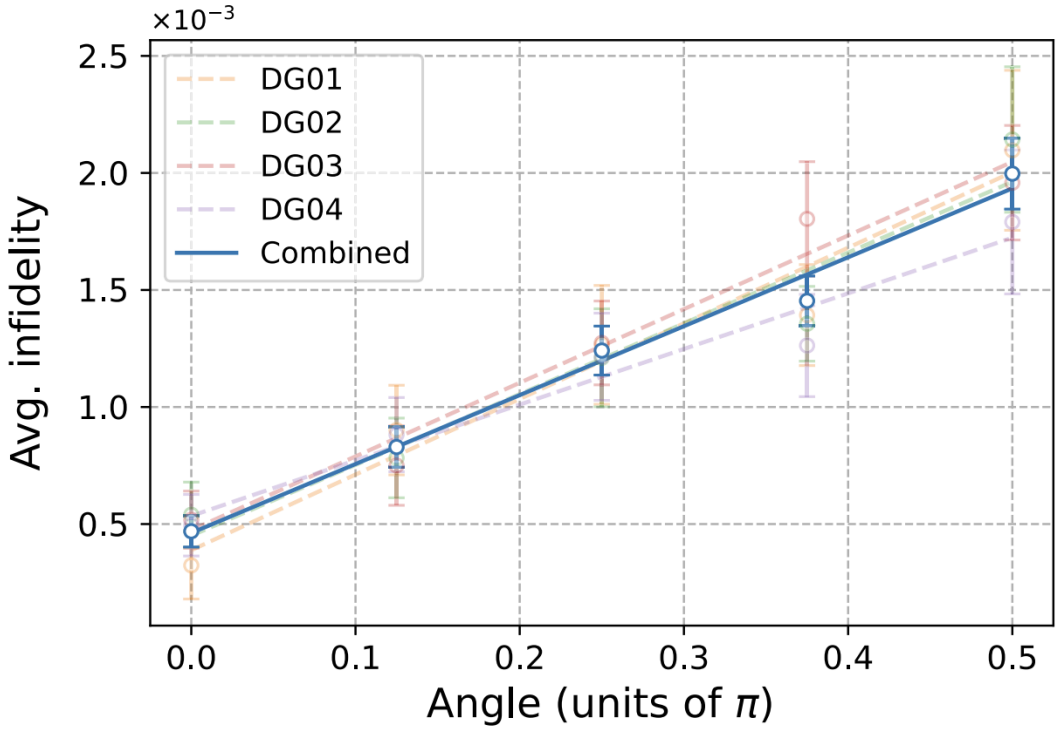
Component level benchmarking

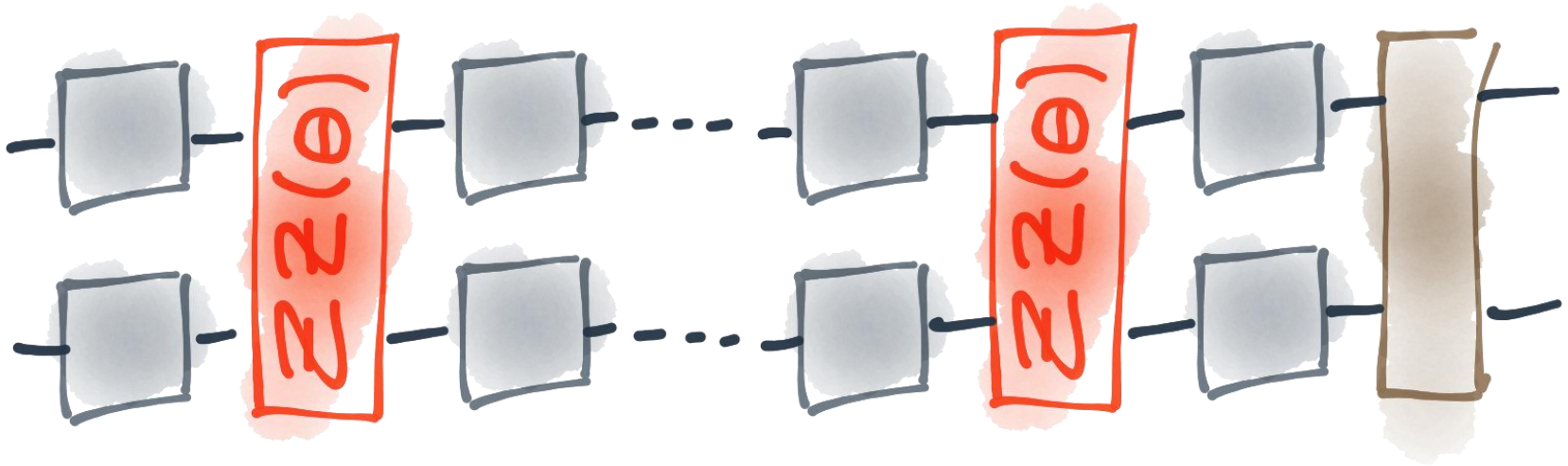




1.83x10^(-3)

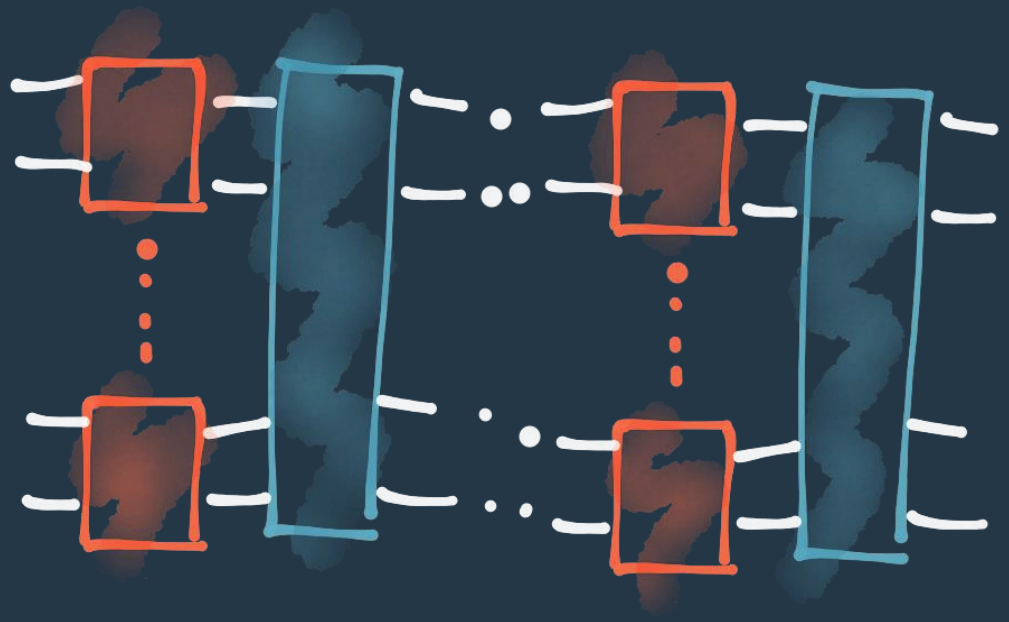


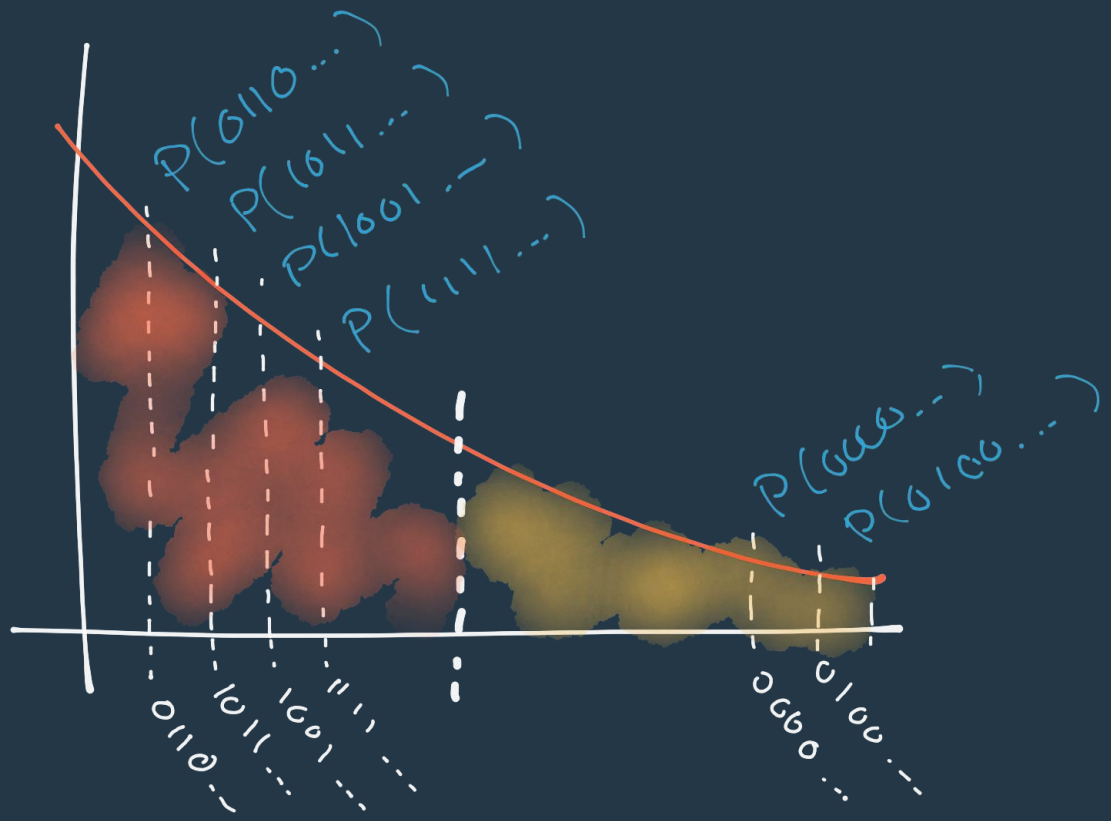


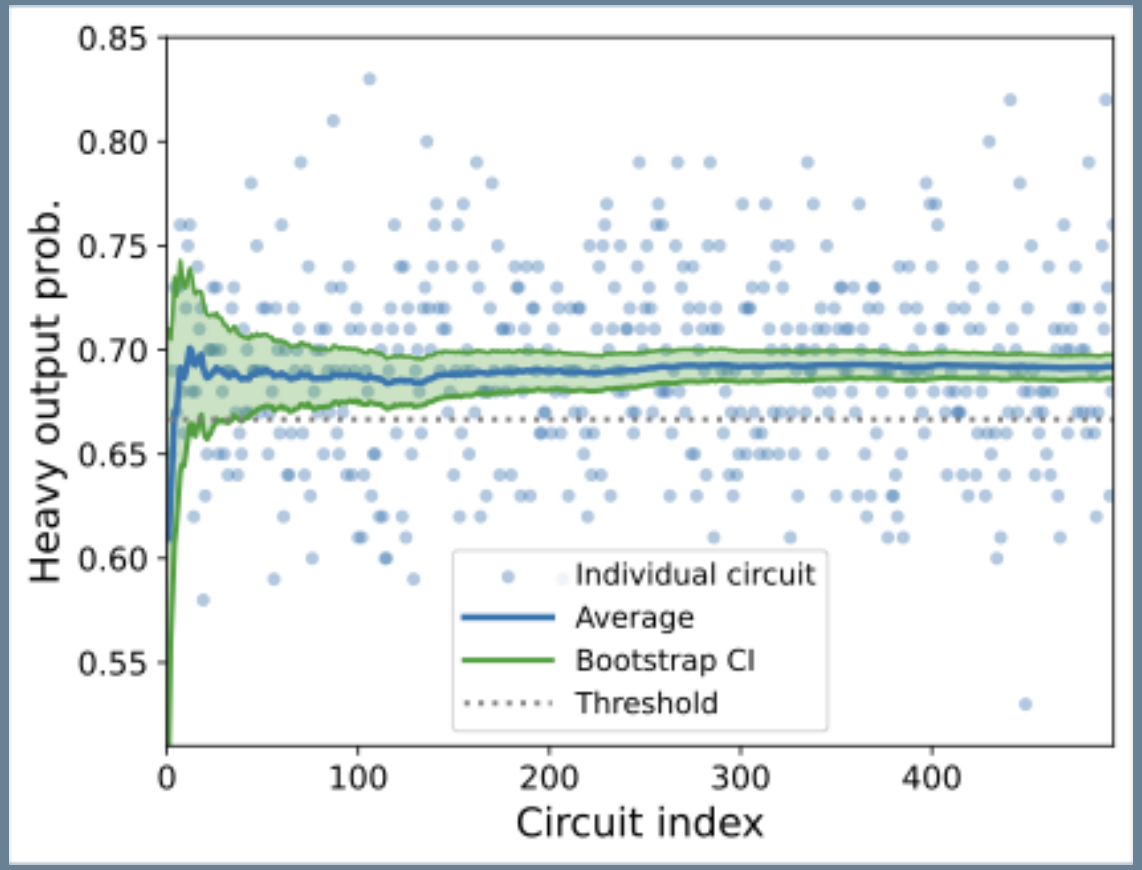


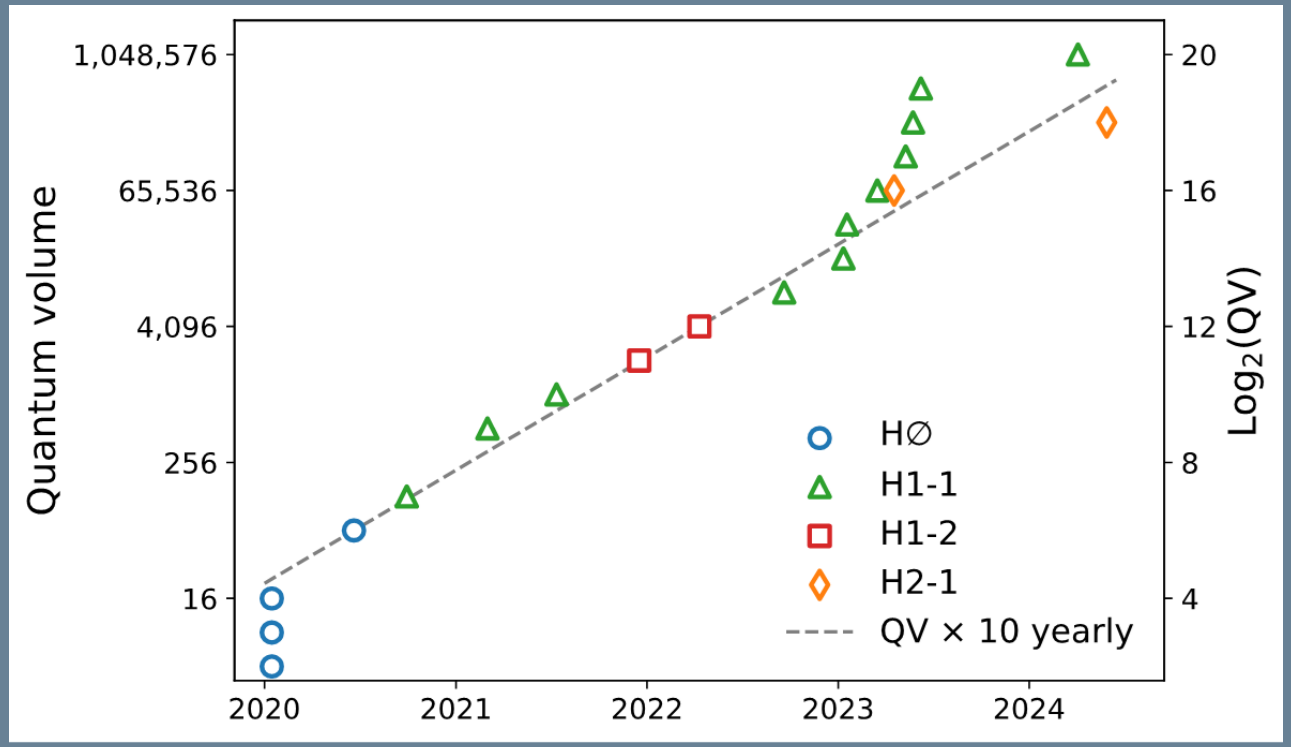
Quantum Volume

System Level Benchmarking





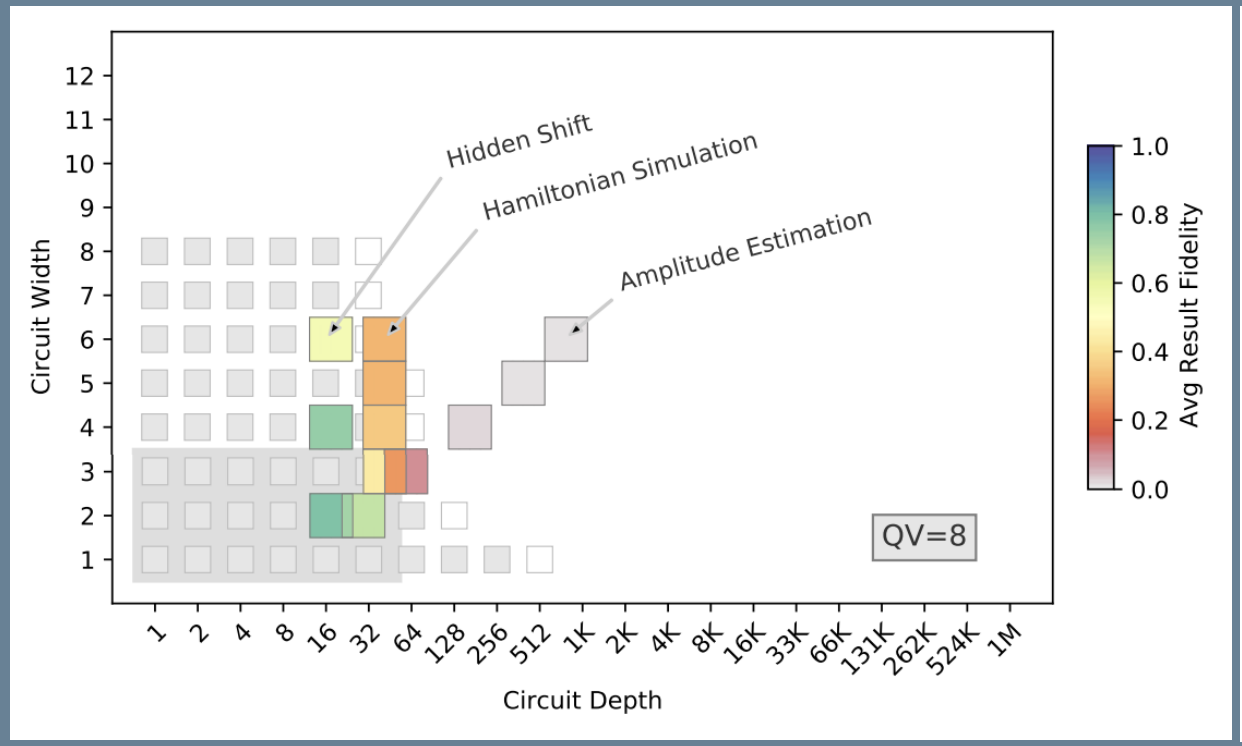

Heavy output prob.
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0
100
200
300
400
Circuit index
Individual circuit
Average
Bootstrap CI
Threshold

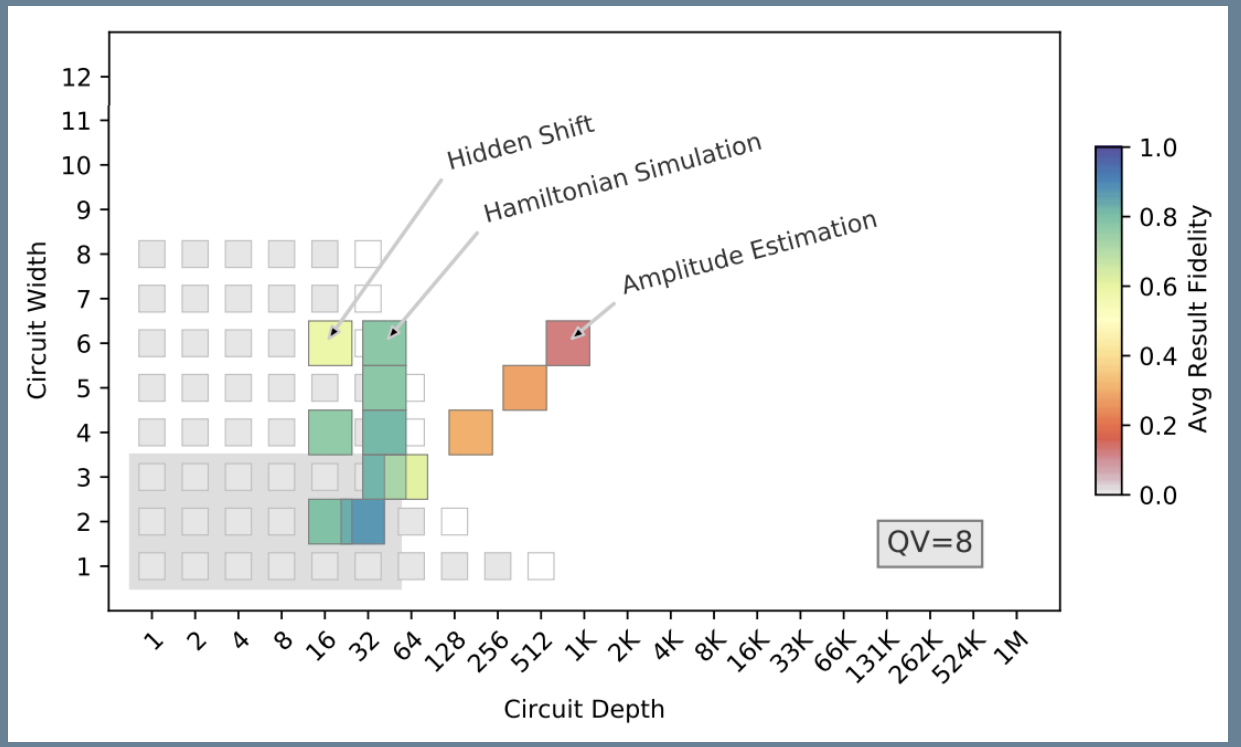

Quantum volume
1,048,576
65,536
4,096
256
16
2020
2021
2022
2023
2024
Log2(QV)
20
16
12
8
4
HØ
H1-1
H1-2
H2-1
QV × 10 yearly

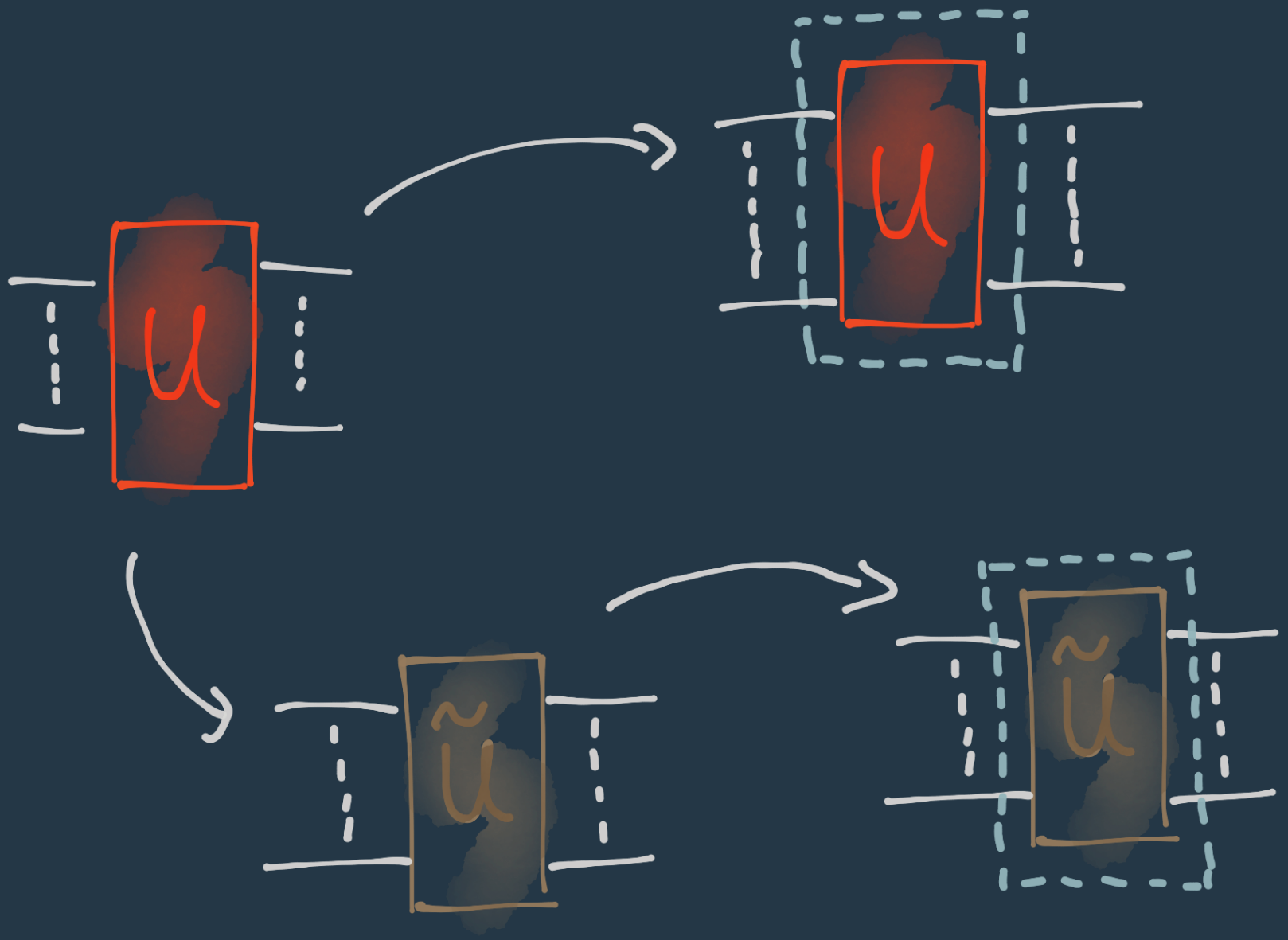
Compilers and the QED-C application-oriented benchmarks

Application-Level Benchmarks

https://arxiv.org/abs/2402.08985


Circuit Width
Circuit Depth
Avg Result Fidelity
Hidden Shift
Hamiltonian Simulation
Amplitude Estimation
QV=8
1
2
4
8
16
32
64
128
256
512
1K
2K
4K
8K
16K
33K
66K
131K
262K
524K
1M
0.0
0.2
0.4
0.6
0.8
1.0


Circuit Width
Circuit Depth
Avg Result Fidelity
Hidden Shift
Hamiltonian Simulation
Amplitude Estimation
QV=8
1
2
4
8
16
32
64
128
256
512
1K
2K
4K
8K
16K
33K
66K
131K
262K
524K
1M
0.0
0.2
0.4
0.6
0.8
1.0



Closing Remarks

- We run a wide selection of benchmarks across all layers of the stack.
  - RCS -> https://arxiv.org/abs/2406.02501
- Full stack (holistic) benchmarks are important.
  - Not influenced by classical - unrepresentative.
  - Perfected by perfecting layer - unrepresentative.
- Benchmarking error correction gadgets.
  - Holistic error correction benchmarking.
- Standard implementation and reproducibility.

Many thanks

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