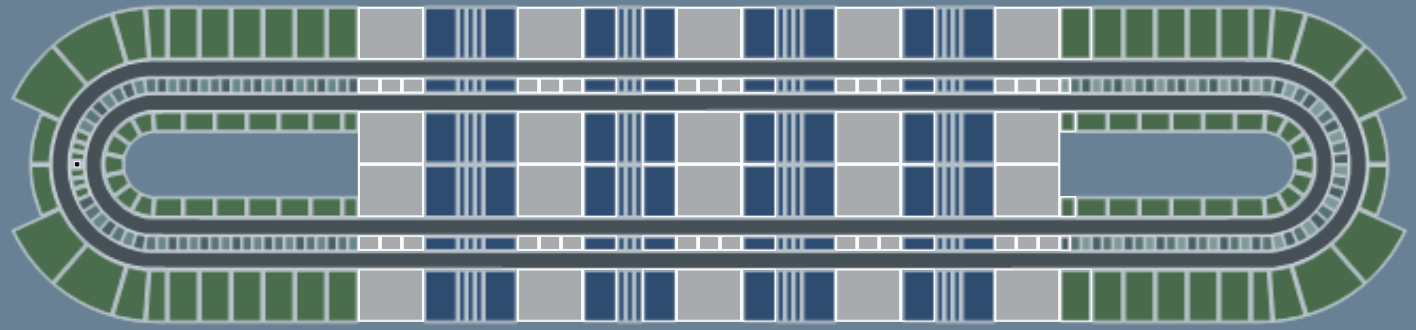
Benchmarking the Quantinuum Stack

Daniel Mills



TKET

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

H-Series at-a-glance

System		Qubits	2Q gate infidelity (10^{-3})	QV ($\log_2$)
HØ	(retired)	4 → 6	8.0	4 → 6
H1		10 → 20	5.0 → 1.3	7 → 19
H2		32 → >50*	1.8 → <1.3*	16 → >19*

*Planned upgrades

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

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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

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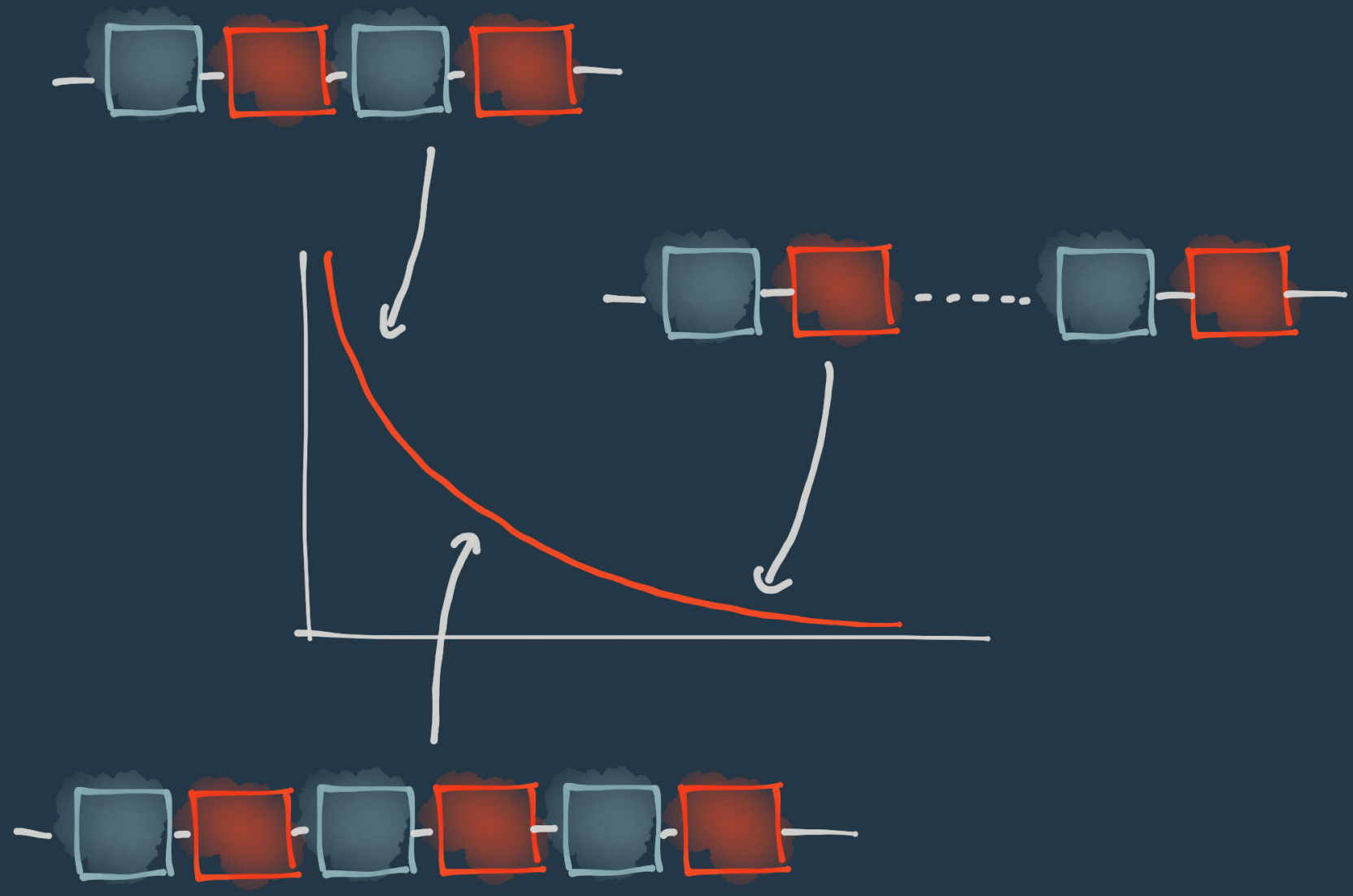
Randomised Benchmarking

Component level benchmarking



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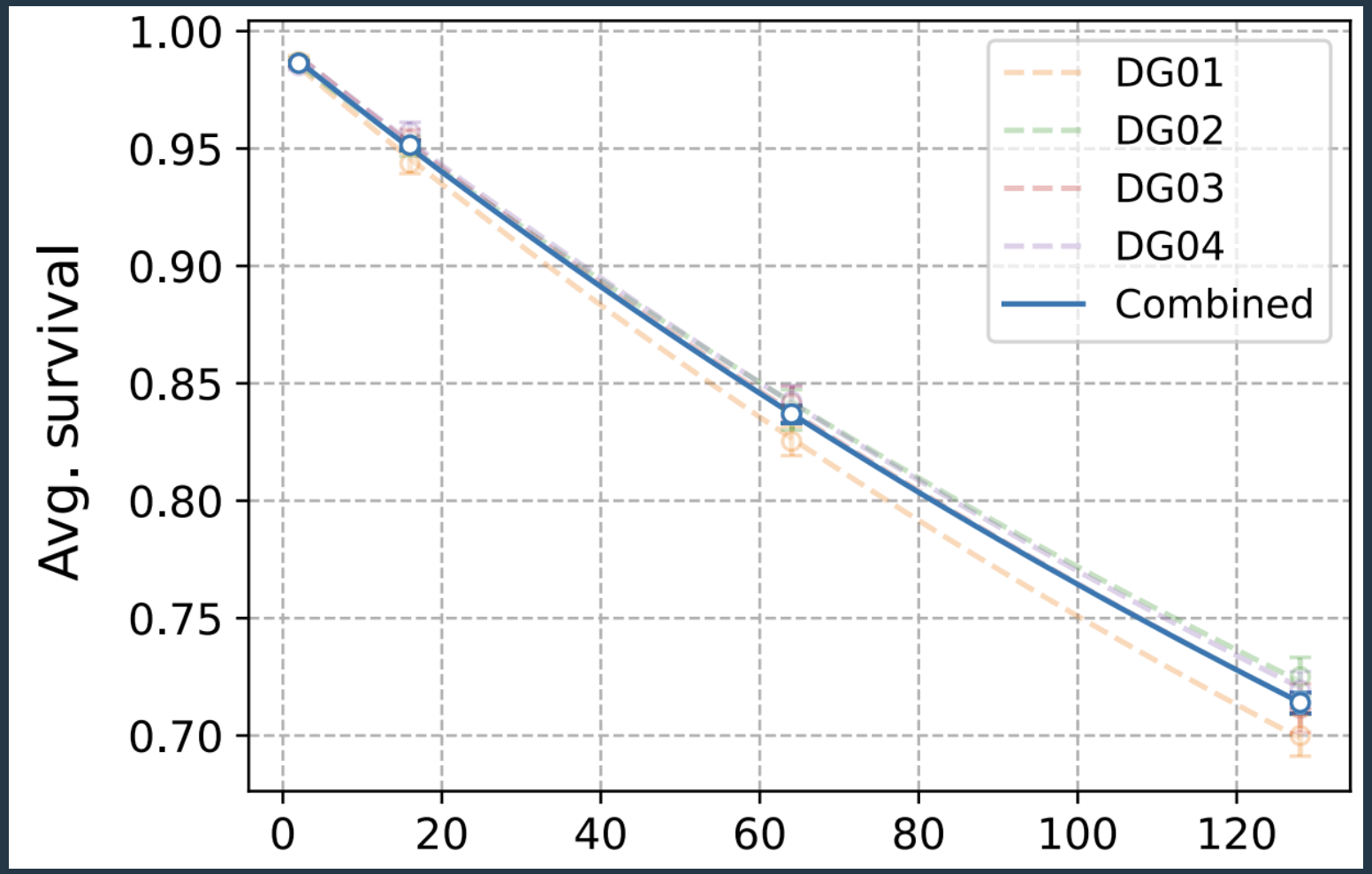

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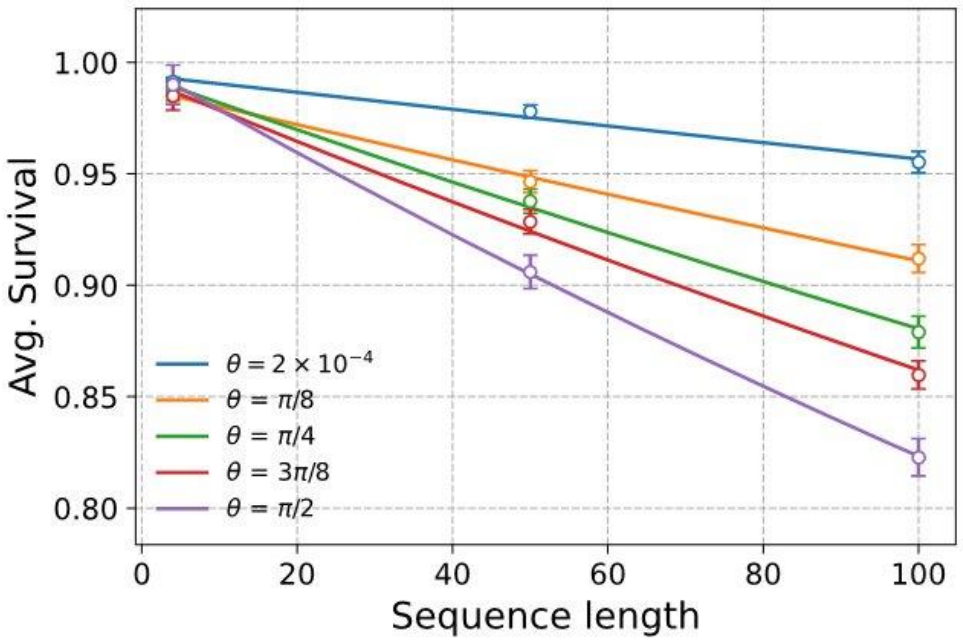

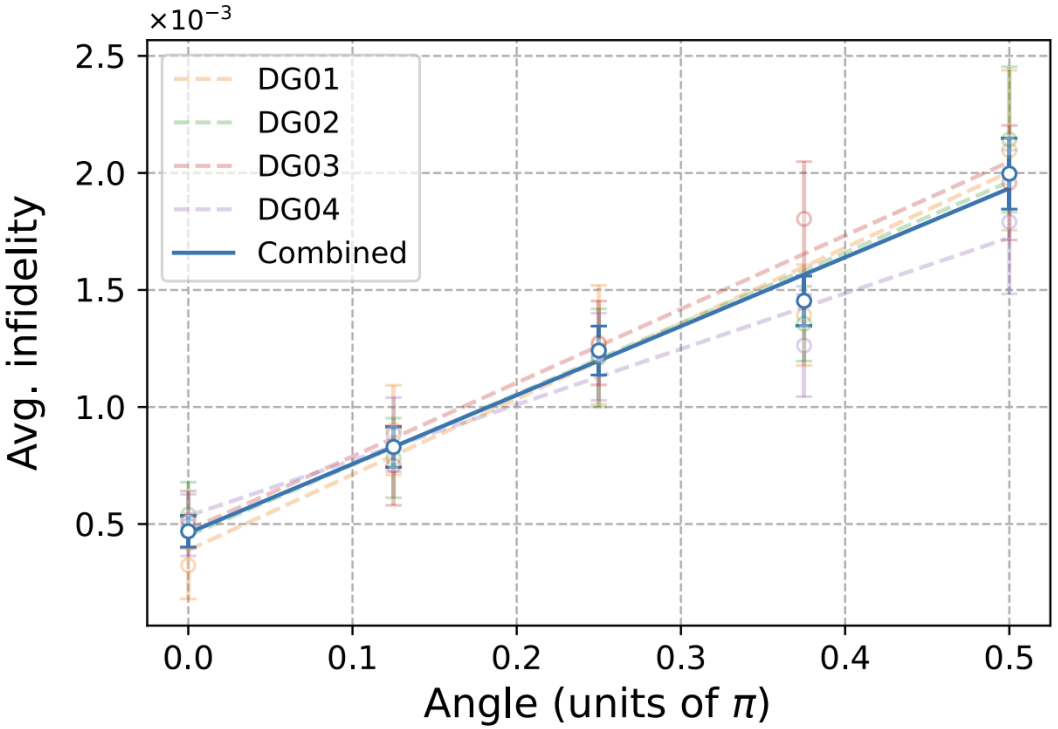

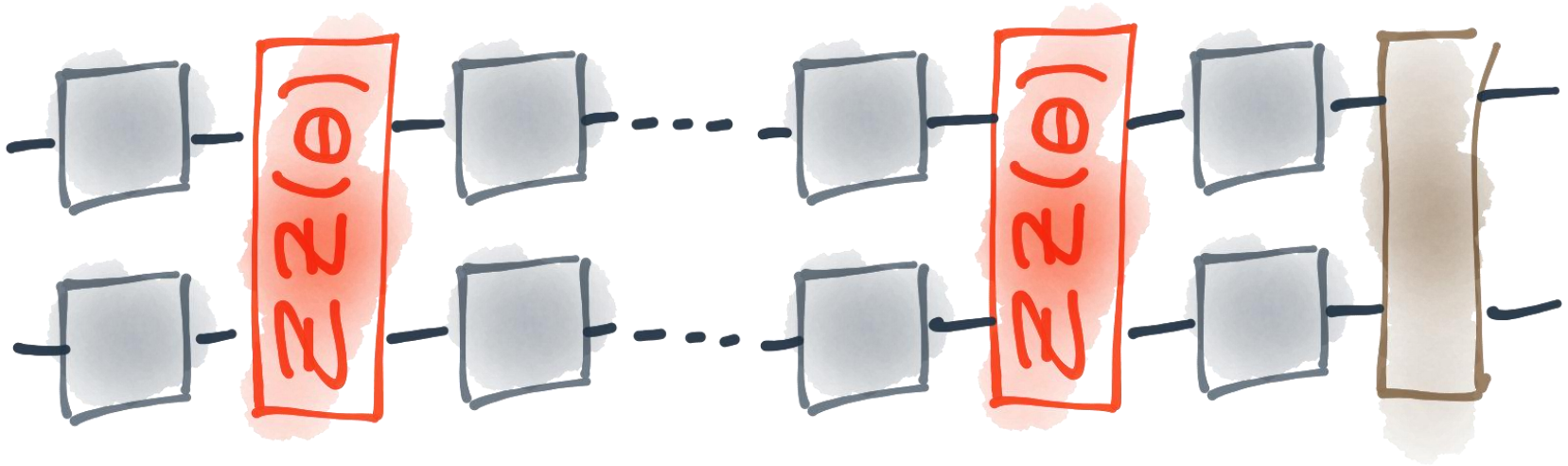

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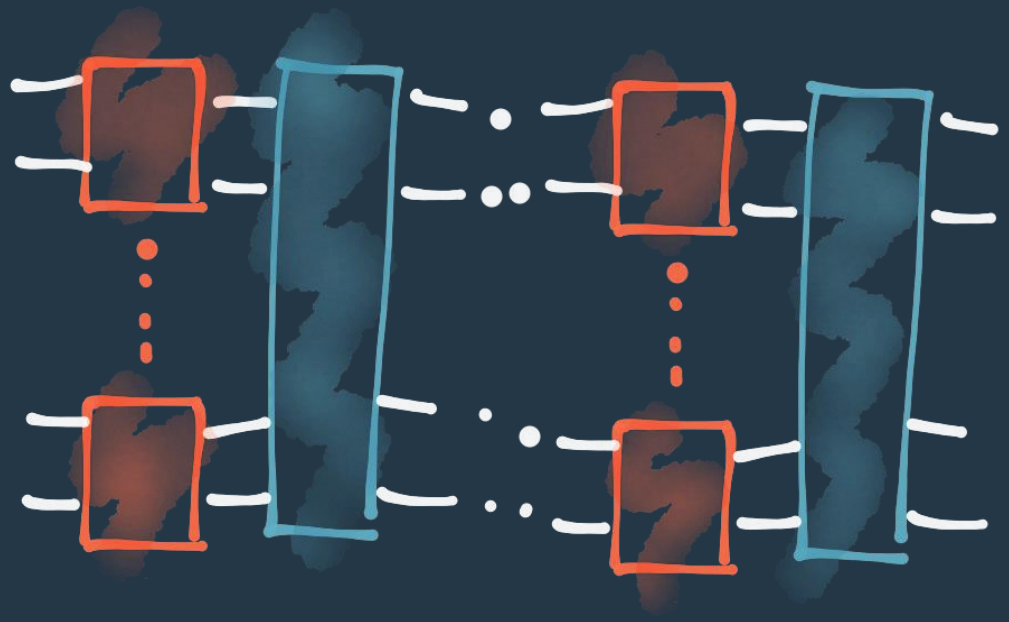
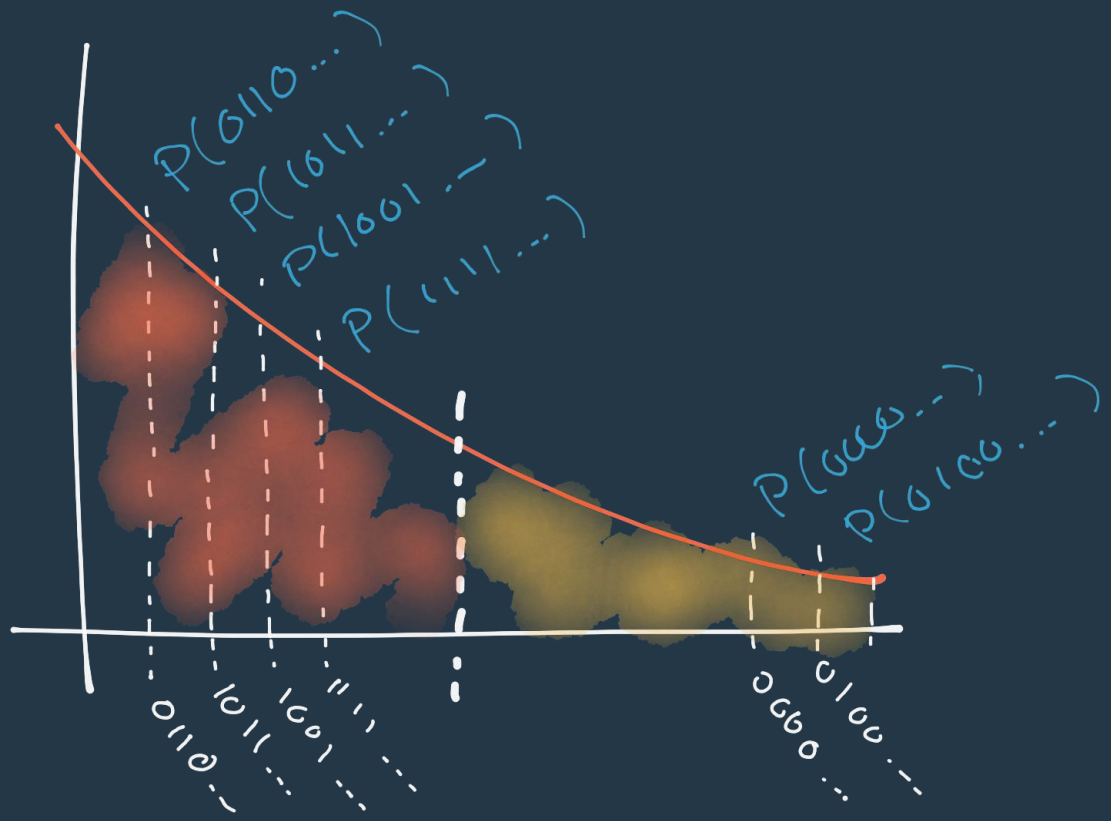
Quantum Volume

System Level Benchmarking





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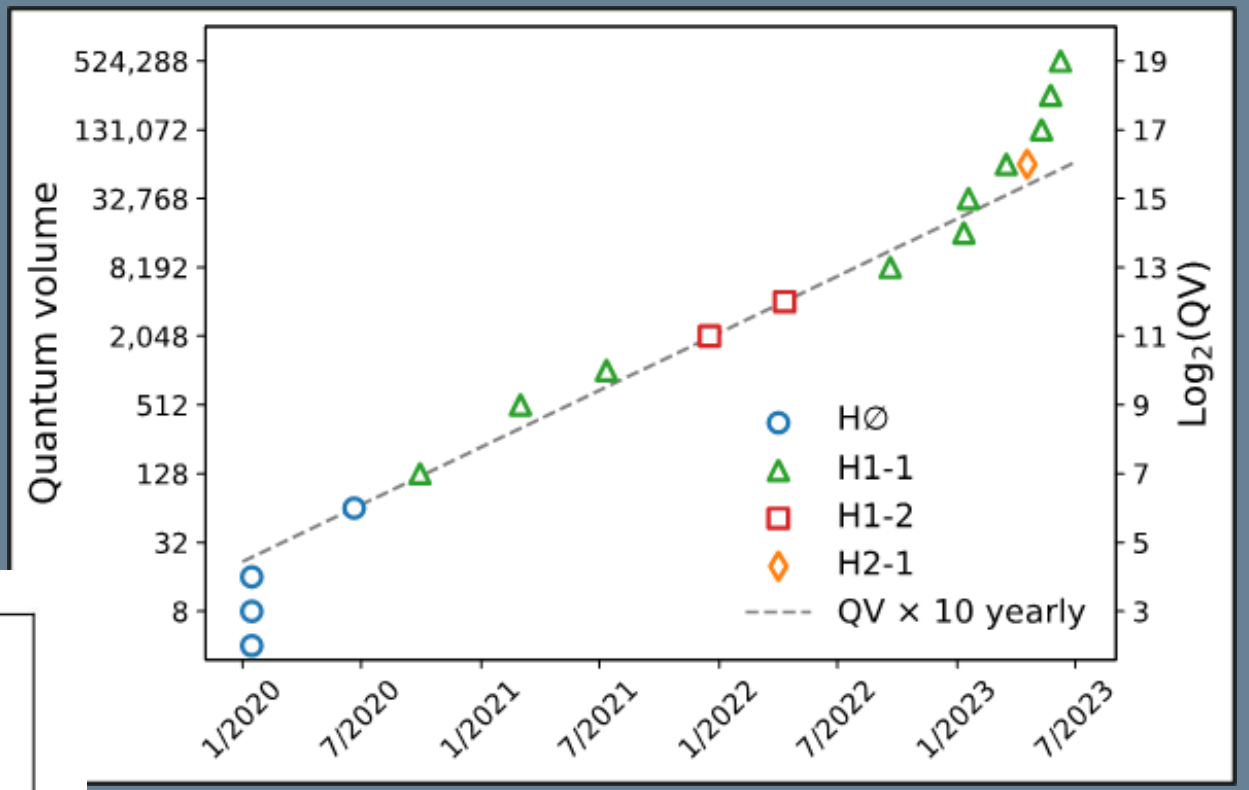
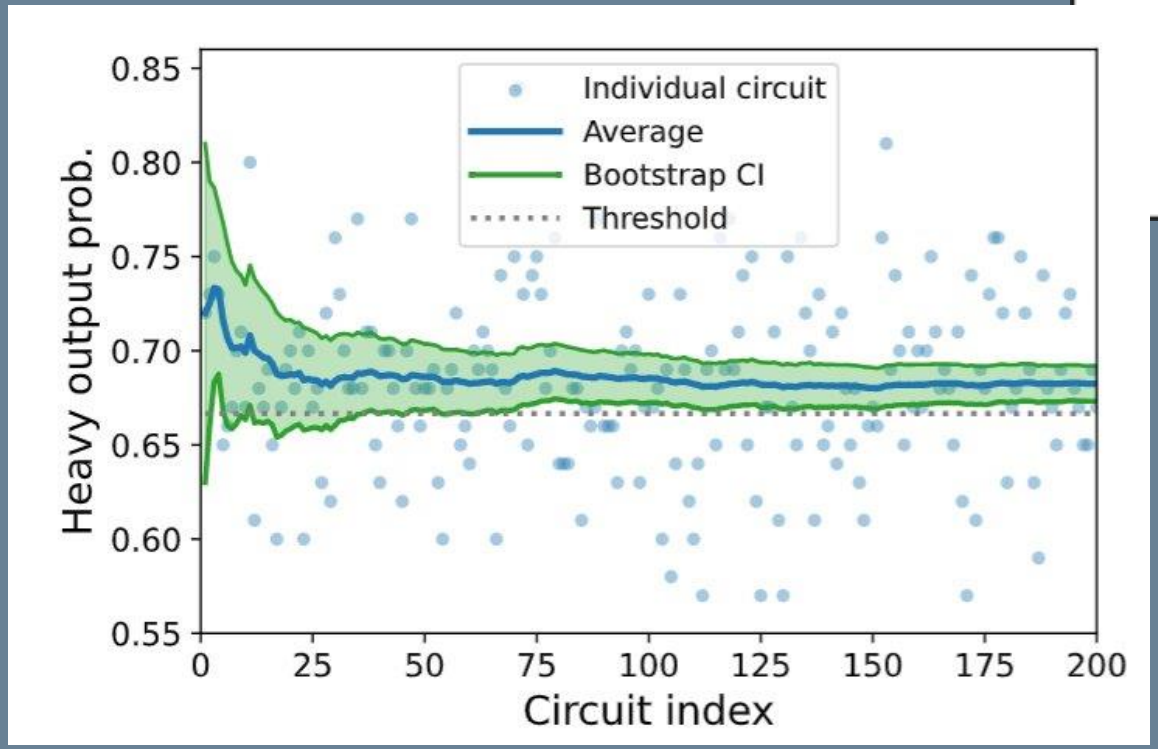
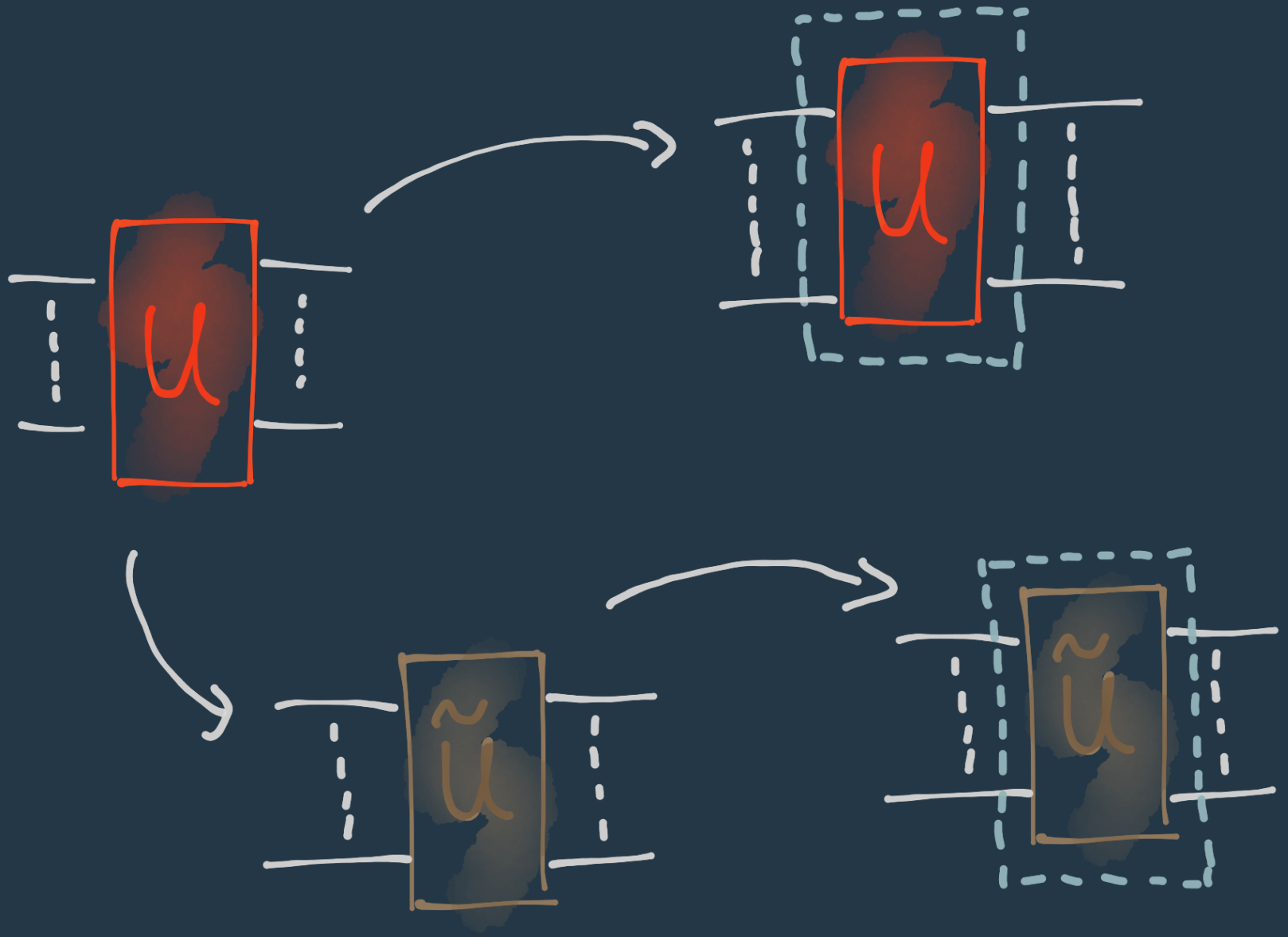

Quantum volume
524,288
131,072
32,768
8,192
2,048
512
128
32
8
19
17
15
13
11
9
7
5
3
Log2(QV)
1/2020
7/2020
1/2021
7/2021
1/2022
7/2022
1/2023
7/2023
HØ
H1-1
H1-2
H2-1
QV × 10 yearly


Heavy output prob.
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0
25
50
75
100
125
150
175
200
Circuit index
Individual circuit
Average
Bootstrap CI
Threshold

Compilers and the QED-C application-oriented benchmarks

Application-Level Benchmarks



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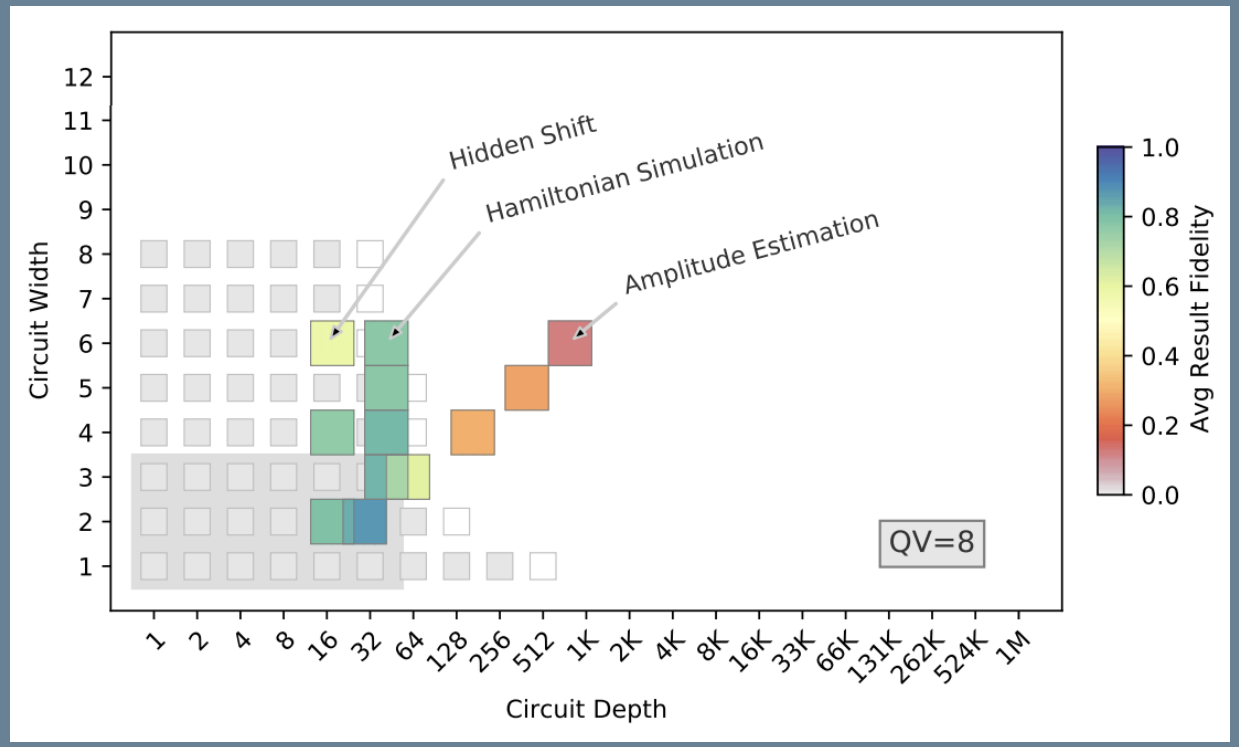
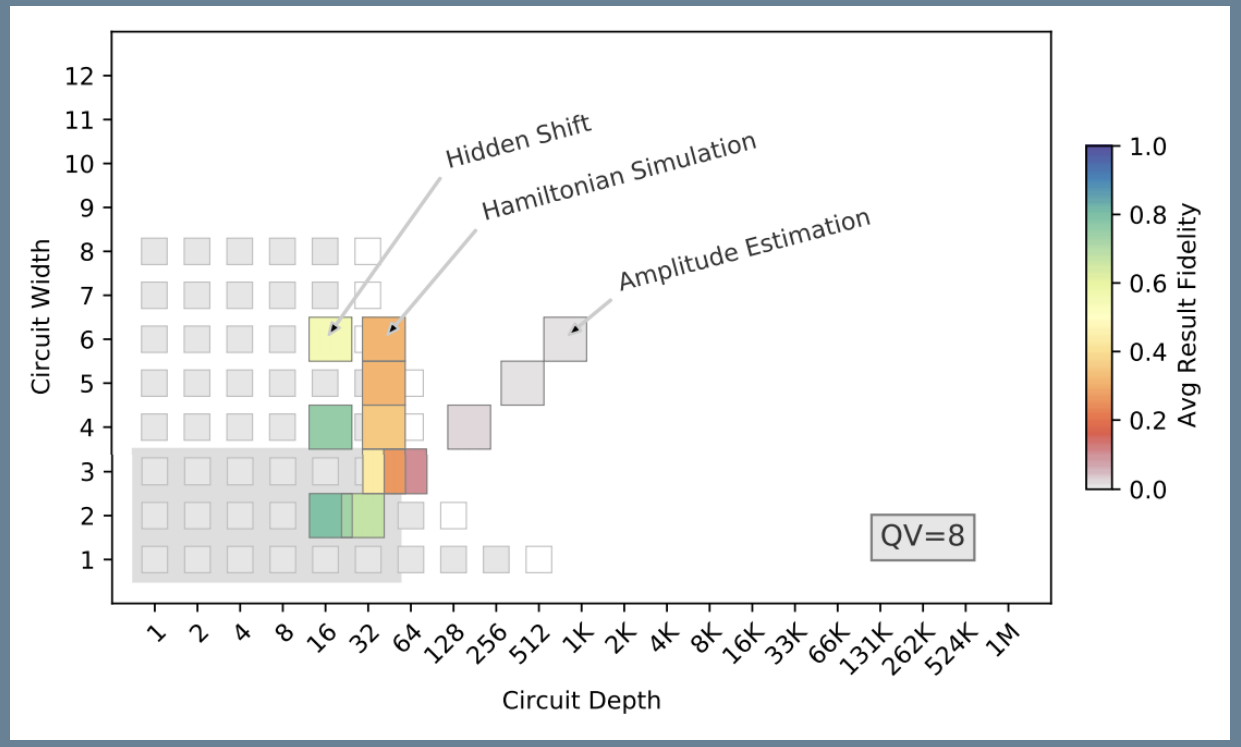

Hidden Shift
Hamiltonian Simulation
Amplitude Estimation
QV=8
Circuit Width
Circuit Depth
Avg Result Fidelity
1 2 4 8 16 32 64 128 256 512 1K 2K 4K 8K 16K 33K 66K 131K 262K 524K 1M
1 2 3 4 5 6 7 8 9 10 11 12
0.0 0.2 0.4 0.6 0.8 1.0


Hidden Shift
Hamiltonian Simulation
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QV=8
Circuit Width
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Avg Result Fidelity
1 2 4 8 16 32 64 128 256 512 1K 2K 4K 8K 16K 33K 66K 131K 262K 524K 1M
1 2 3 4 5 6 7 8 9 10 11 12
0.0 0.2 0.4 0.6 0.8 1.0

Closing Remarks

- 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.

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