QESEM:
Quantum Error Suppression & Error Mitigation software for unbiased output at large circuit volume

Omri Golan, Ph.D.
Compilation Team Lead
Qedma Quantum Computing

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Un-biased and efficient Error mitigation is necessary for unlocking quantum advantage

omri.golan@qedma.com

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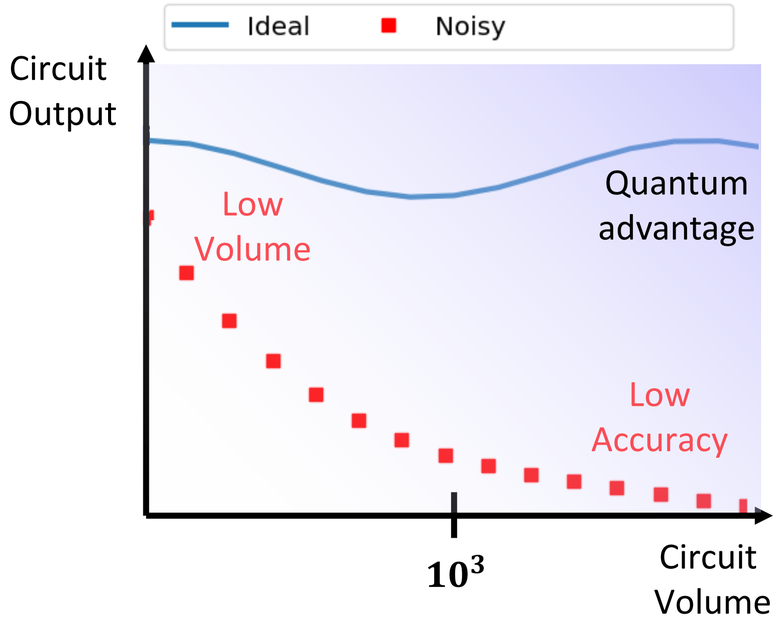
Noisy quantum computation is useless, given near-term error rates $(\sim 10^{-3})$.

Un-biased and efficient Error mitigation is necessary for unlocking quantum advantage



Noisy signal quickly becomes inaccurate with circuit volume

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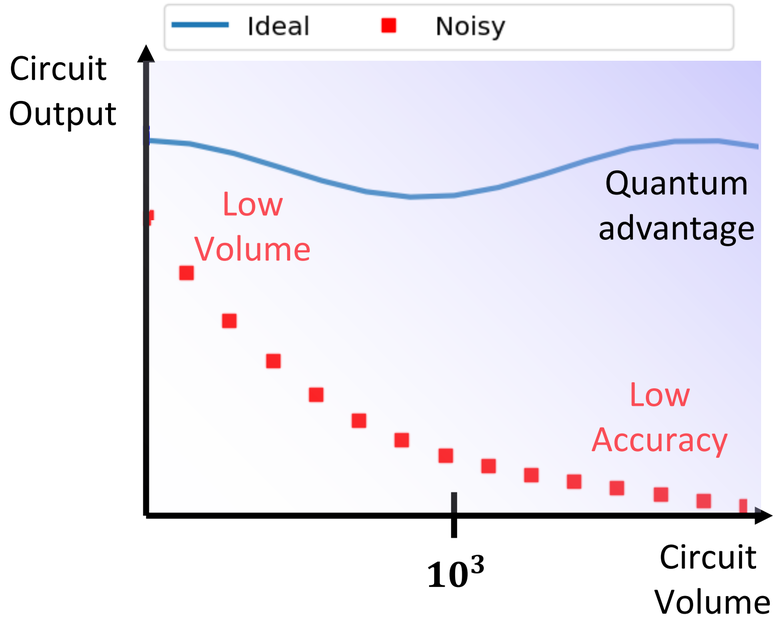
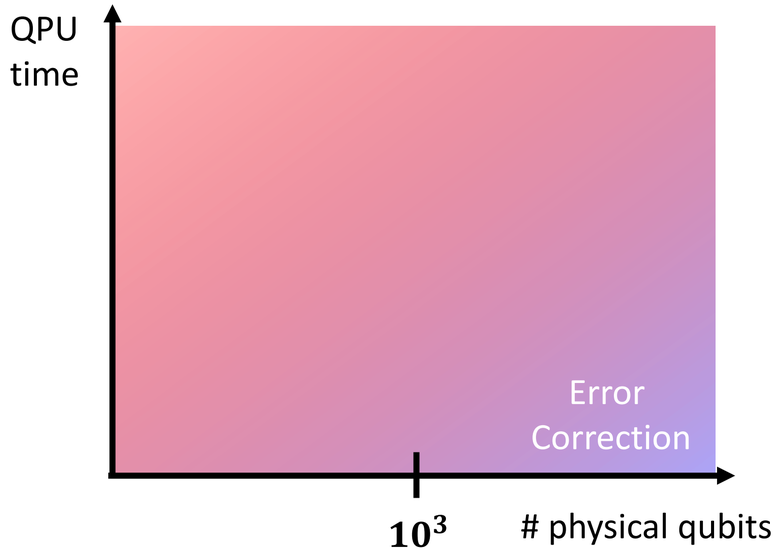
Noisy quantum computation is useless, given near-term error rates $(\sim 10^{-3})$.

Error Correction is not enough, given near-term qubit numbers. $(< 1000s)$

Un-biased and efficient Error mitigation is necessary for unlocking quantum advantage





Noisy signal quickly becomes inaccurate with circuit volume

Error elimination roadmap

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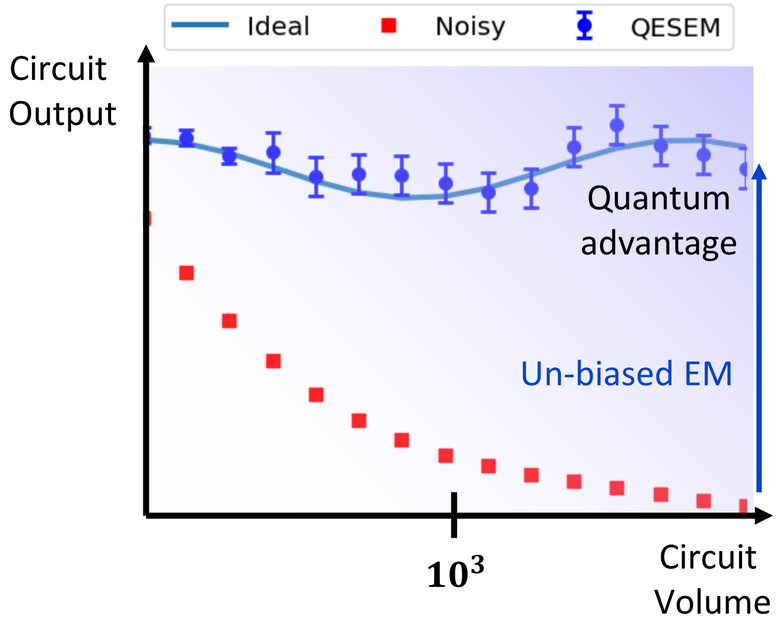
Noisy quantum computation is useless, given near-term error rates $(\sim 10^{-3})$.

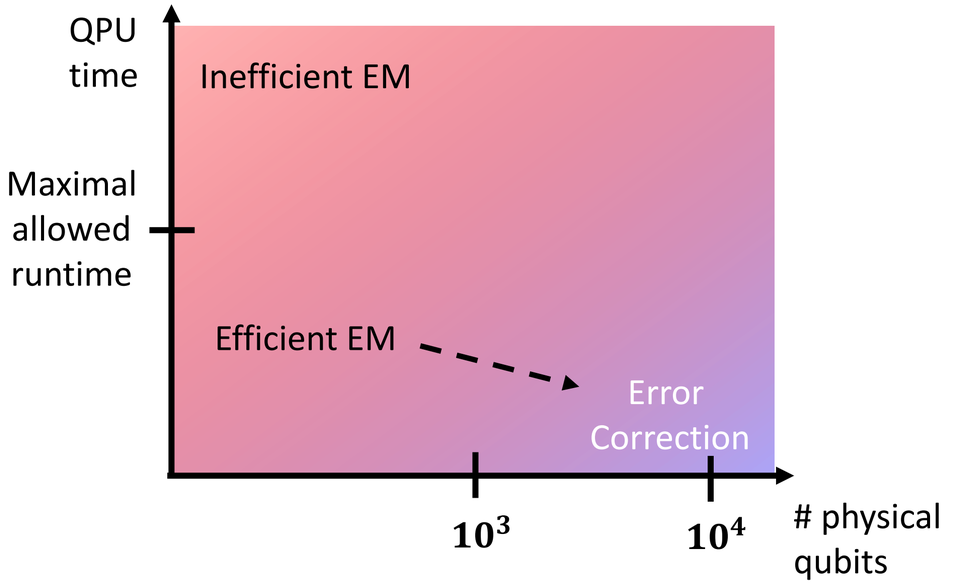
Error Correction is not enough, given near-term qubit numbers. $(< 1000s)$

Error Mitigation will soon enable the first quantum advantages.

EM is here to stay.

Un-biased and efficient Error mitigation is necessary for unlocking quantum advantage





Un-biased EM reproduces ideal output

Error elimination roadmap

omri.golan@qedma.com

Company overview

Management / Founders

Asif Sinay, PhD

CEO & Co-founder
Board Member

Prof. Dorit Aharonov

CSO & Co-founder
Board Member

Prof. Netanel Lindner

CTO & Co-founder
Board Member

Research teams leads

Eyal Bairey, PhD

Characterization

Ilya Gurwich, PhD

Gate optimization

Omri Golan, PhD

Compilation

Ori Alberton, PhD

Application

Software & product leads

Rotem Haber

VP Engineering

Asaf Berkovitch

Director of Product

29 Employees
(5 Prof. & 14 PhD)

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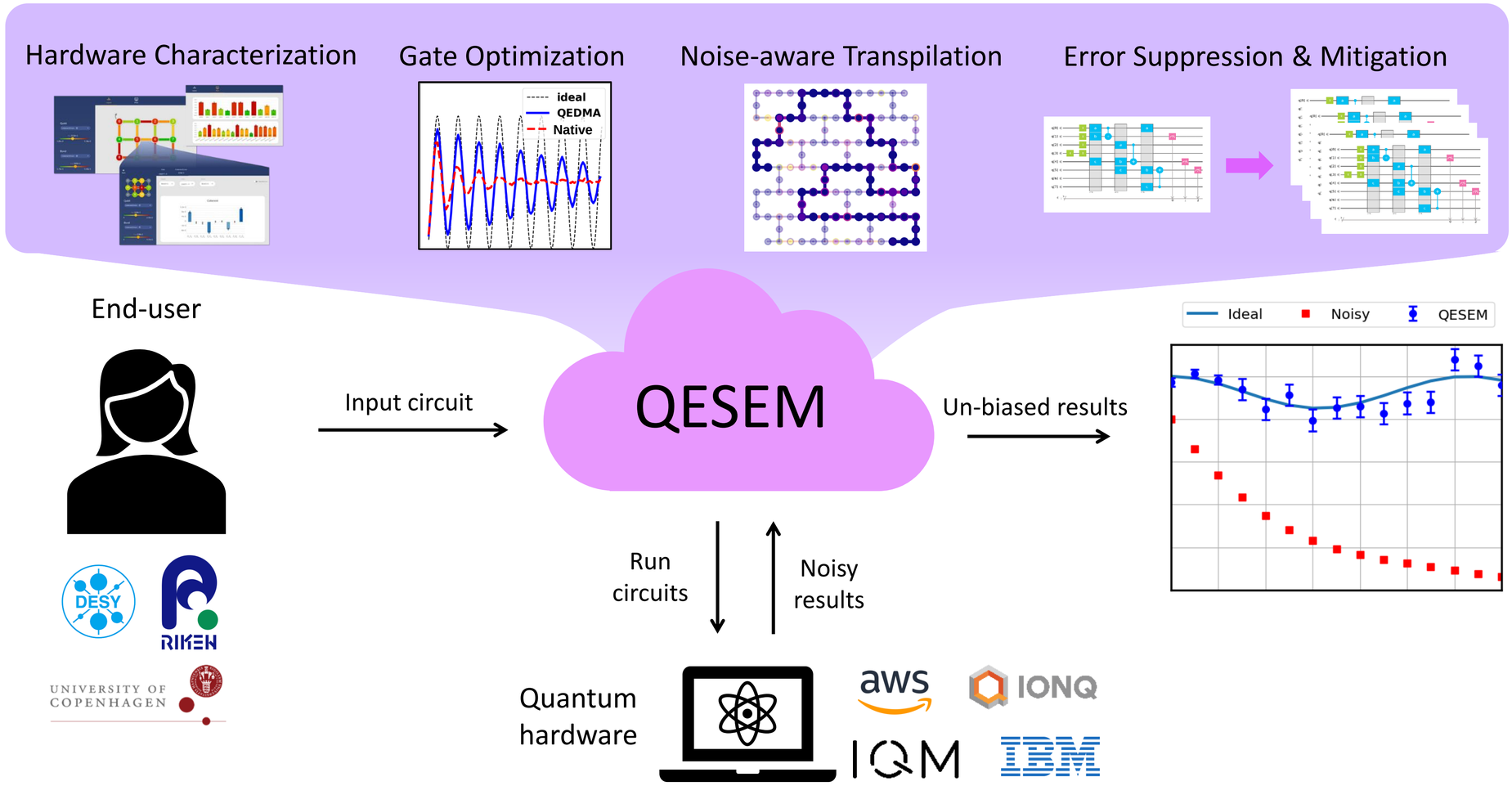
Achieving quantum advantage with EM requires **QESEM**:

A un-biased, efficient, agnostic and reliable **Quantum Error Suppression & Error Mitigation software**.

QESEM is Qedma's software solution for hardware errors:

- Your algorithm runs **as if you're using a noise-free quantum computer**
- **Application agnostic:** works for any quantum algorithm
- **Hardware agnostic:** compatible with any hardware platform (proven performance on IBM, IQM, IonQ,…)
- Produced the **largest unbiased error mitigation experiments to date!**



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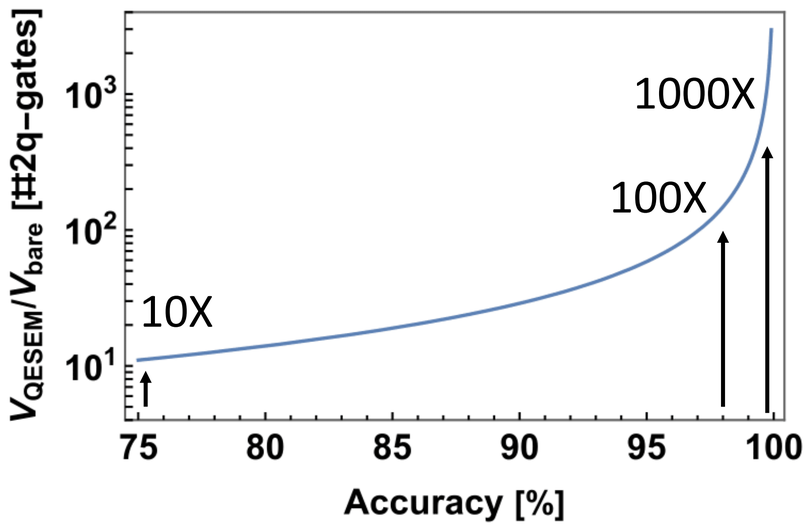
Benefits of QESEM compared to alternatives

Accurate results for large quantum circuits

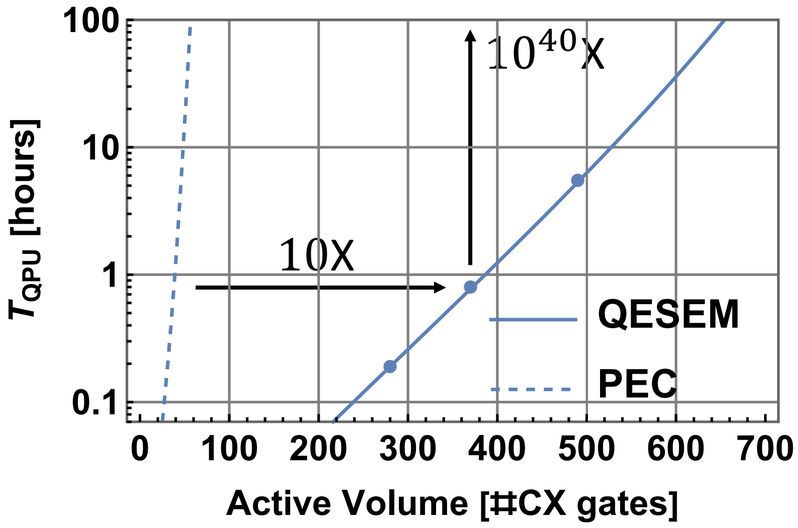
Up to x1000 circuit volume boosts

QESEM vs. bare execution



Up to x10 volume, orders of magnitude less QPU time

QESEM vs. PEC*:



$$T_{EM} \sim e^{\lambda \cdot IF \cdot V}$$

$$\lambda_{QESEM} \sim \lambda_{PEC}/(2-10)$$

*See: van den Berg at. al (2022), Ferracin et al. (2022), Tran et. al (2023).

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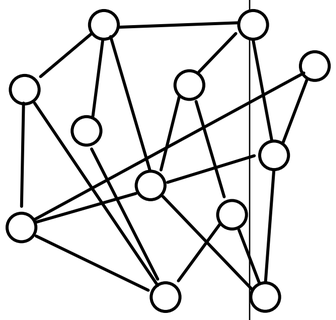
QESEM + IonQ + AWS Braket

- **Largest un-biased EM experiment on trapped ions.**
- **Largest VQE circuit with accurate output.**

Application
VQE, O_2 molecule

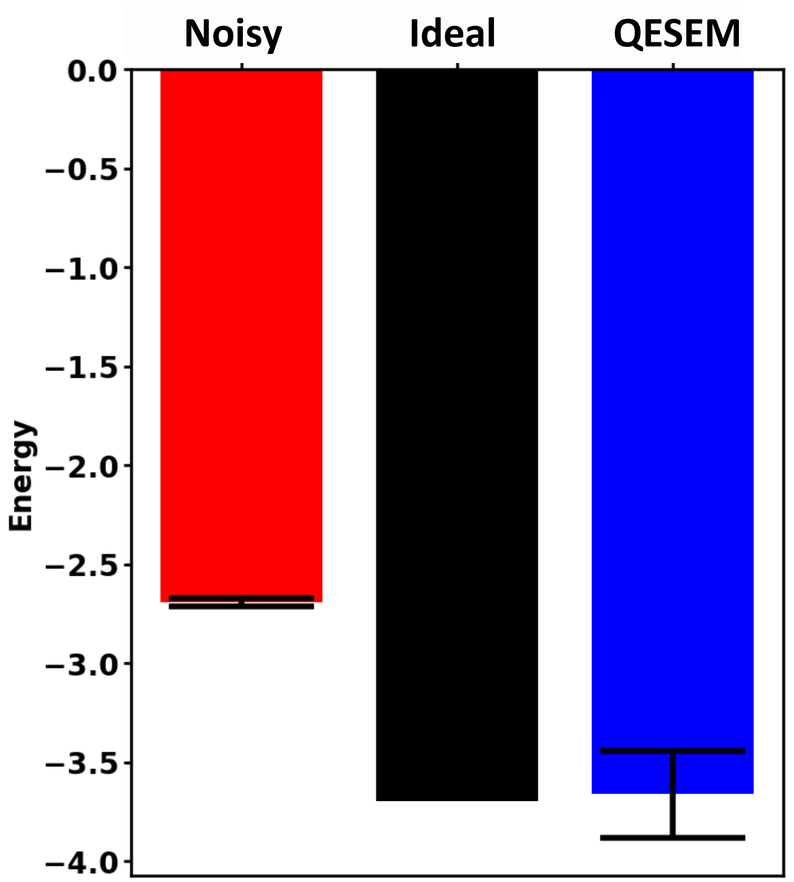
Width
12 qubits

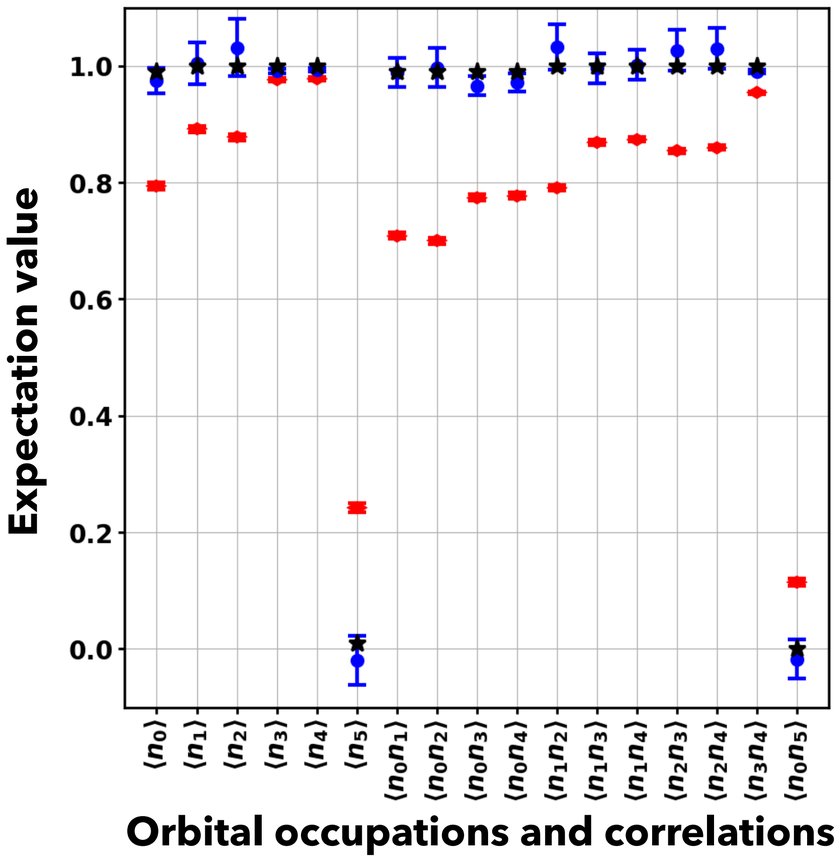
Volume
99 2-qubit gates
(20 distinct)



Connectivity
Sparse graph

Quantity
Energy, orbital occupation and correlations





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More details: aws.amazon.com/blogs/quantum-computing/…

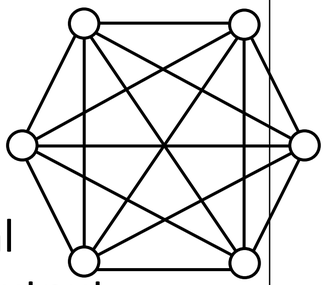
QESEM + IonQ + AWS Braket

Application
VQE, NaH molecule

Width
6 qubits

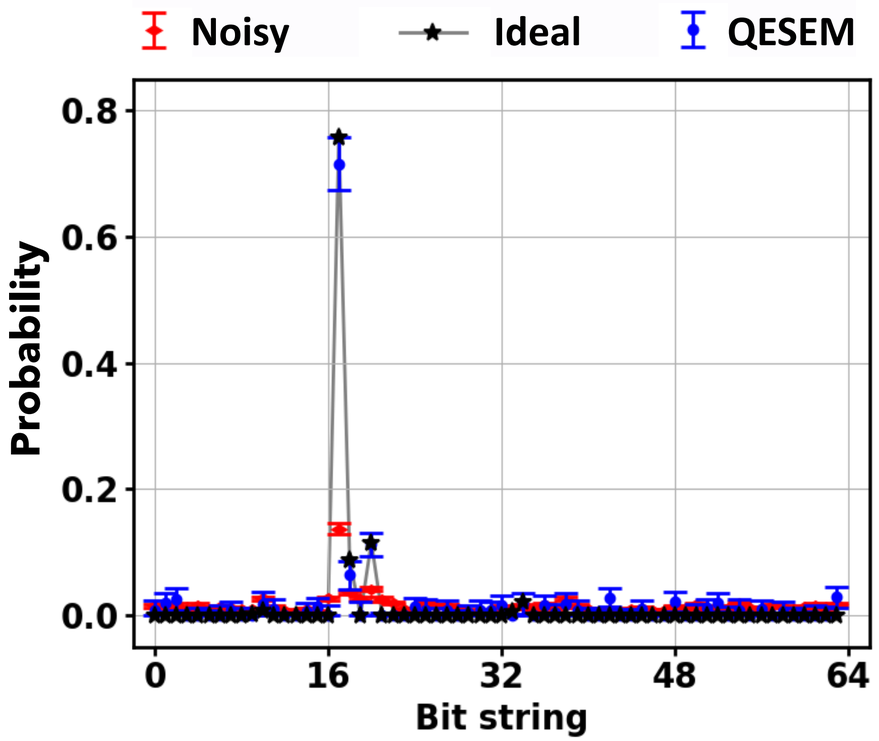
Volume
94 2-qubit gates
(15 distinct)

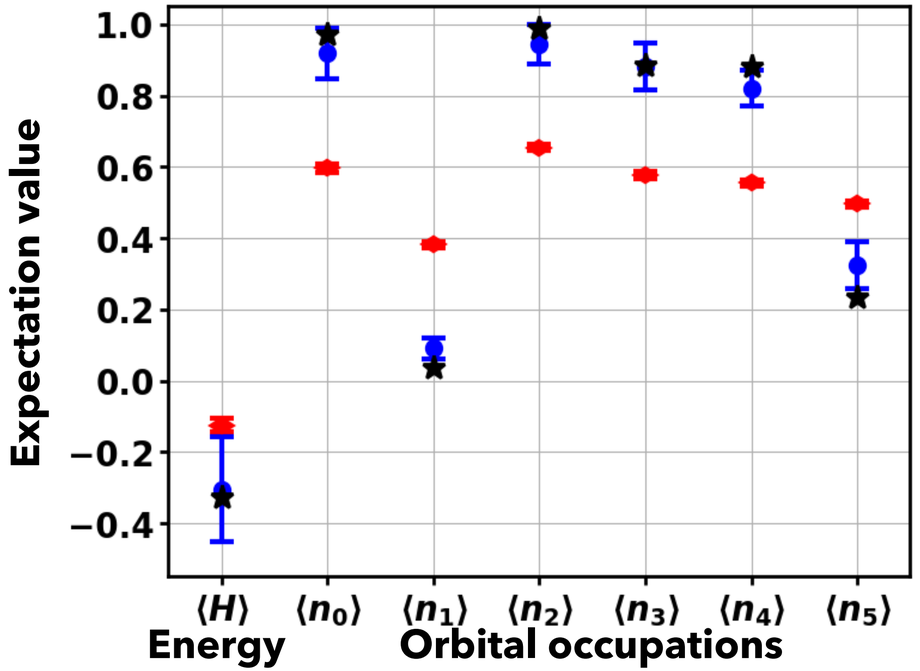
Connectivity
Full (clique)



Quantity
Energy, orbital occupation, output probability distribution

- **Mitigation of full probability distribution.**





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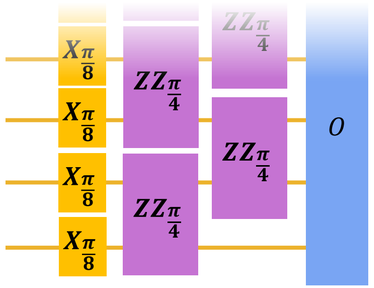
QESEM on large quantum devices:

1D Trotter-Ising on 40 qubits with fractional ZZ angle

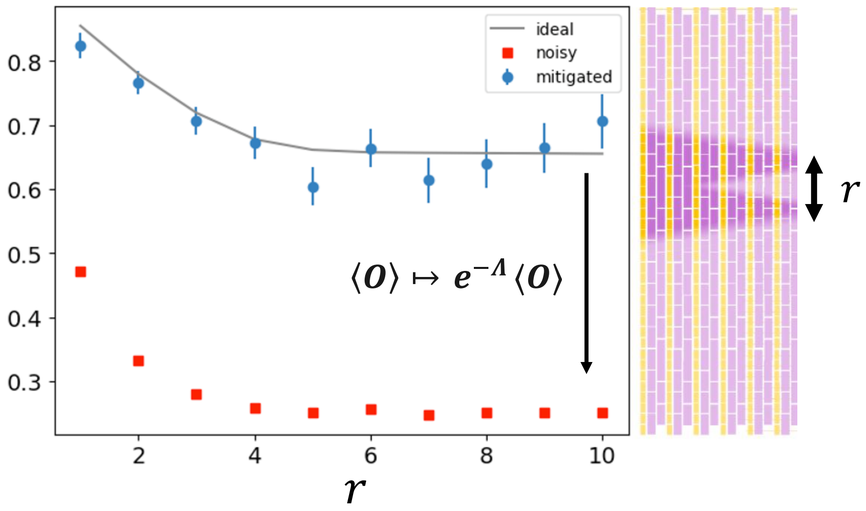


$\phi_{ZZ} = \pi/4, \theta_X = \pi/8$

Device specs: IBM Brisbane (Eagle),
1 sec per circuit, 300μs per shot.
CX infidelity for 40 qubits: 1.5%

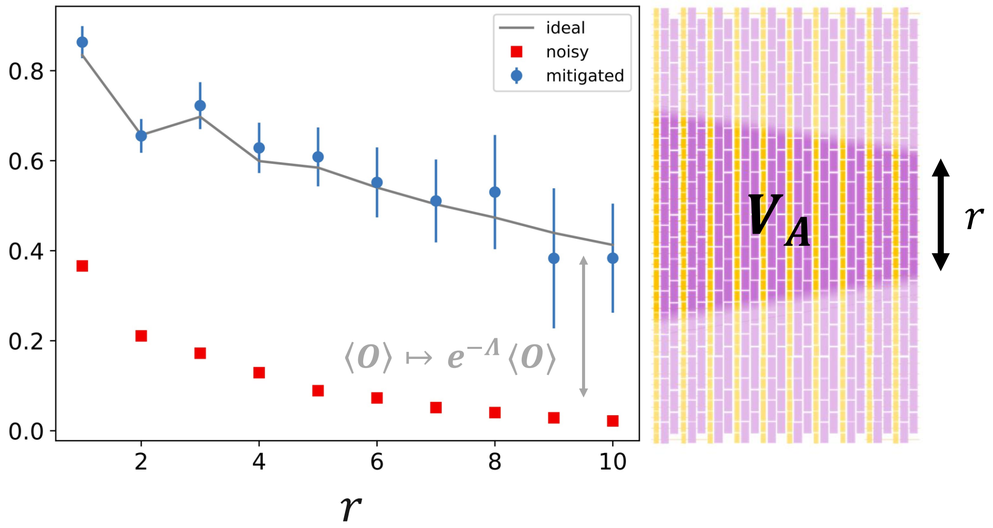
40 qubits, 6 steps (480 CNOTs) $V_A = 108$

$\langle Z_i Z_{i+r} \rangle$, 2-point correlations $\Lambda = 0.96$



40 qubits, 10 steps (800 CNOTs) $V_A = 370$

$\langle Z_i \cdots Z_{i+r} \rangle$, string operators $\Lambda = 2.94$



Active volume V_A:

Number of CNOT gates affecting the observable

Controls the complexity of both EM and classical simulation

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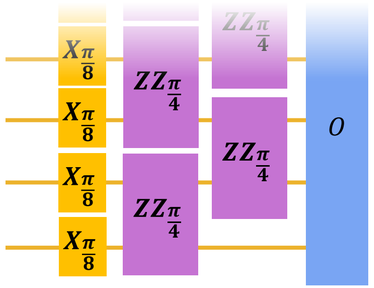

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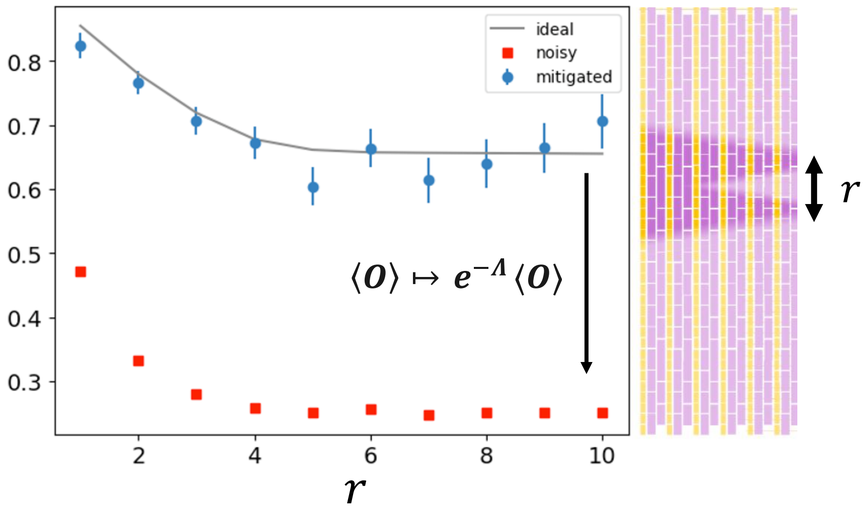

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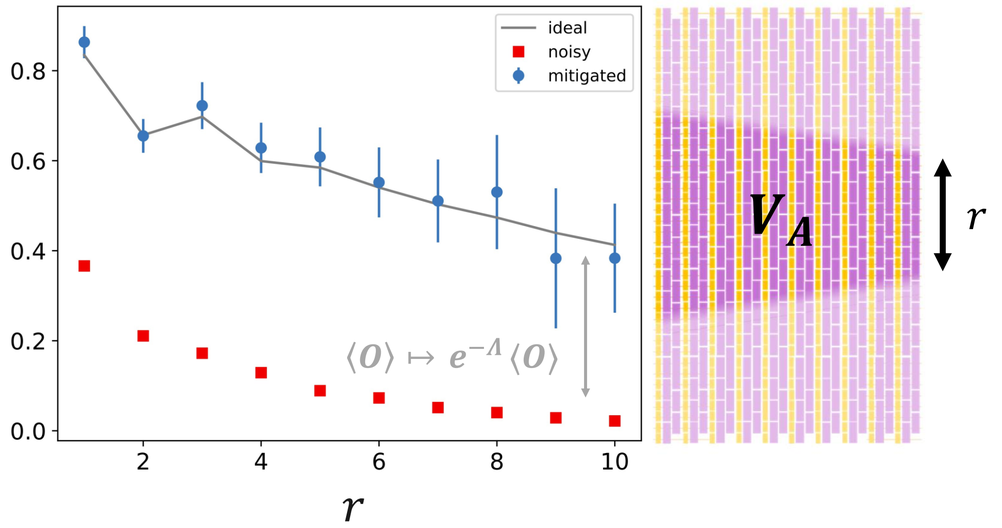


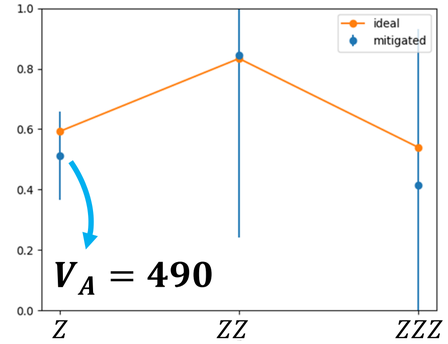
Active volume V_A:

Number of CNOT gates affecting the observable

Controls the complexity of both EM and classical simulation

Pushing the limits: 18 steps (1,440 CNOTs; depth 72)

Largest-volume experiment with an unbiased EM method



$V_A = 490$, $F = 98.5\%$ → 1500, 99.5% → 7500, 99.9%

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Achieving large active volumes on IBM Brisbane for 2D full-device algorithms using QESEM

Un-biased EM on large quantum devices:

2D experiments on 119 qubits with fractional ZZ angle

$$\phi_{ZZ} = \pi/6, \theta_X = \pi/8$$

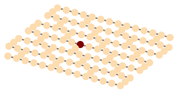
Device specs: IBM Brisbane (Eagle), 1 sec per circuit, 300μs per shot.
CX infidelity for 119 qubits: 2%

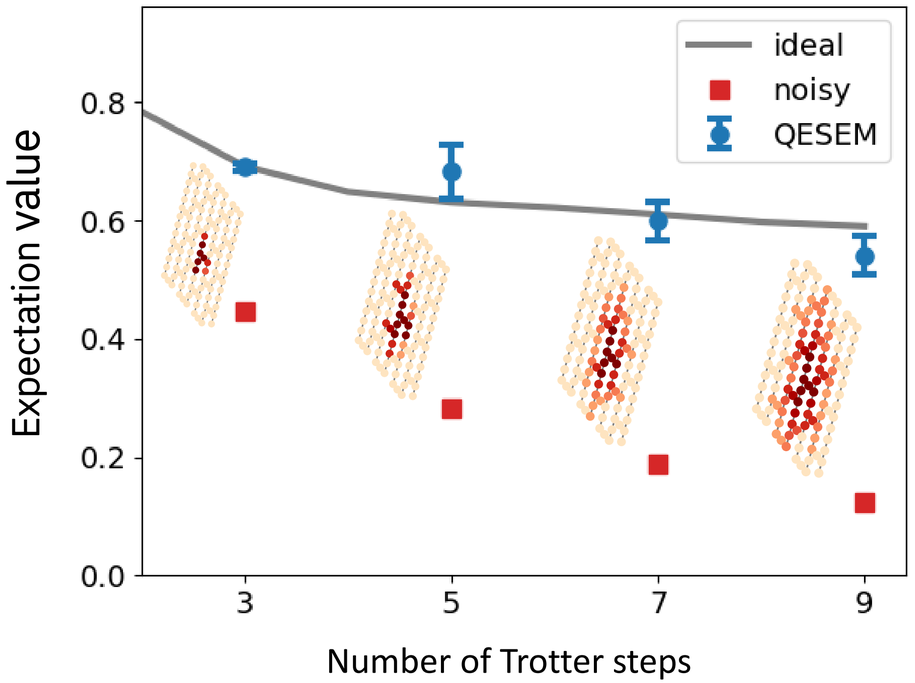
Active volume counts CNOTs inside the LC, with idle qubits weighed according to their relative fidelity:

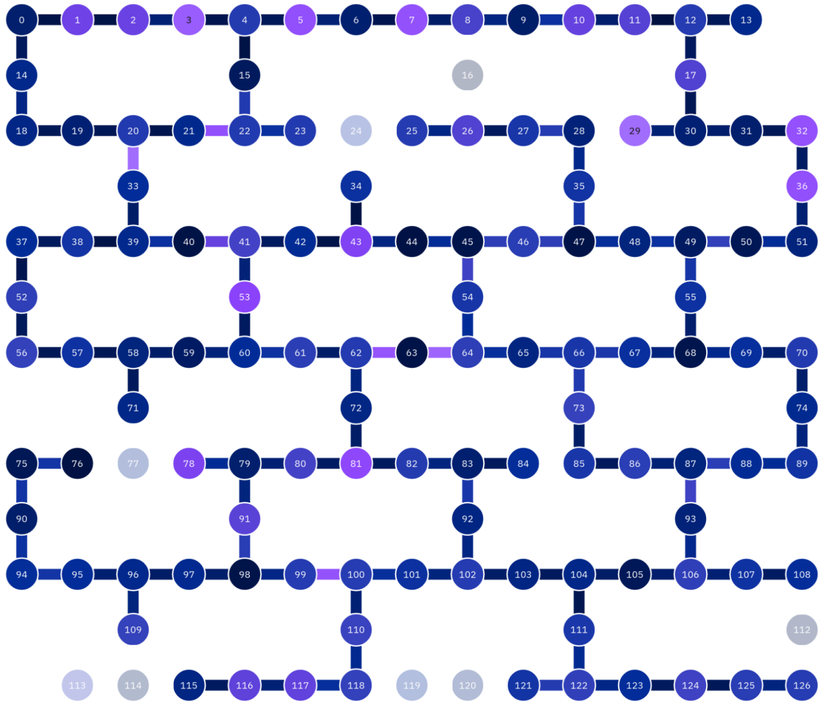
$$V_A = N_{CNOT} + N_{IDLE} \frac{IF_{IDLE}}{IF_{CNOT}}$$

119 qubits, 9 steps (2,268 CNOTs; depth 54)

Average magnetization $\langle Z_i \rangle$







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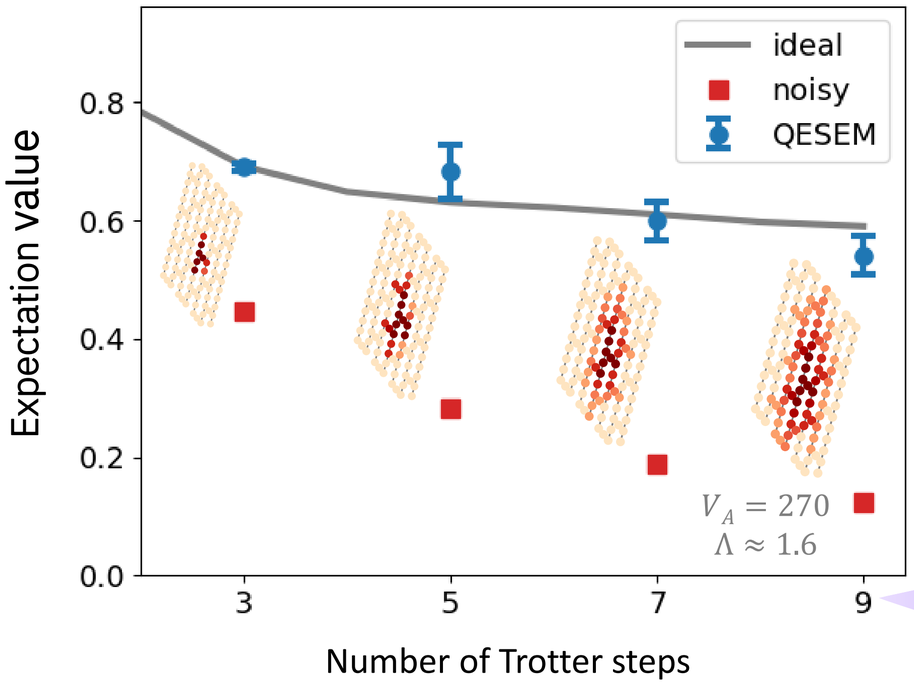
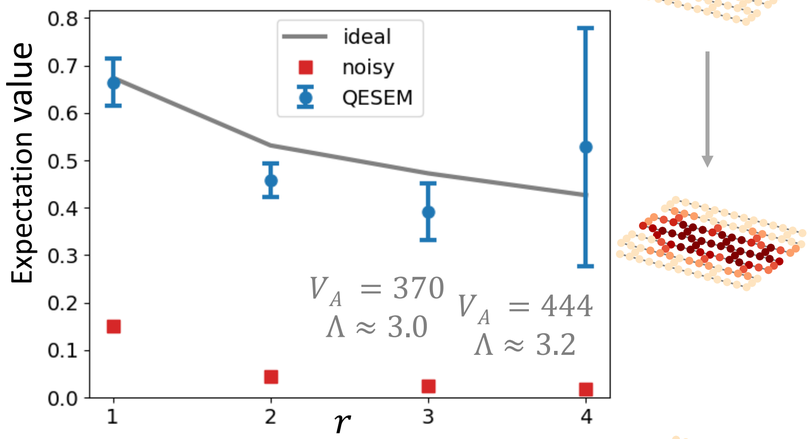
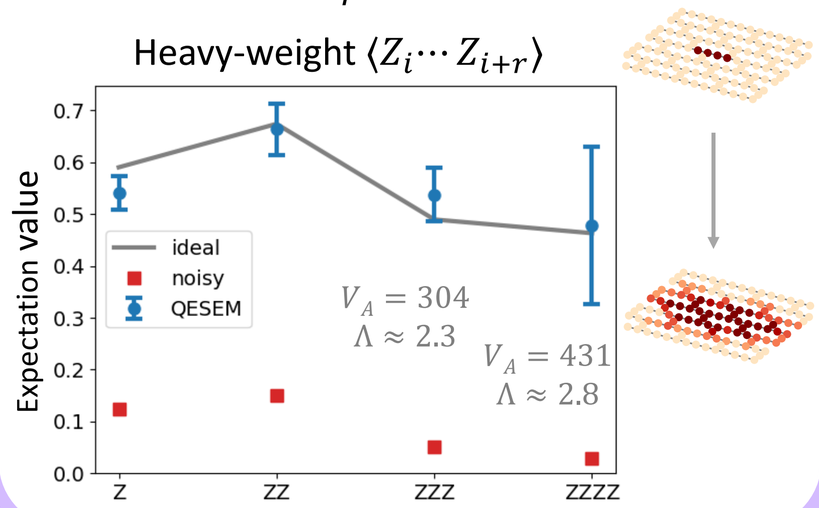


Zoom-in on 9 steps

2-point correlations $\langle Z_i Z_{i+r} \rangle$



Heavy-weight $\langle Z_i \cdots Z_{i+r} \rangle$



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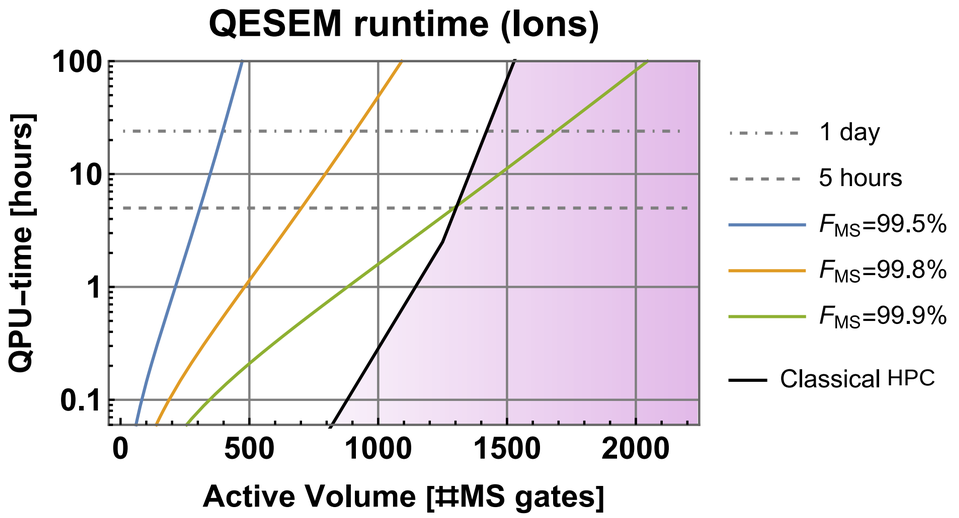
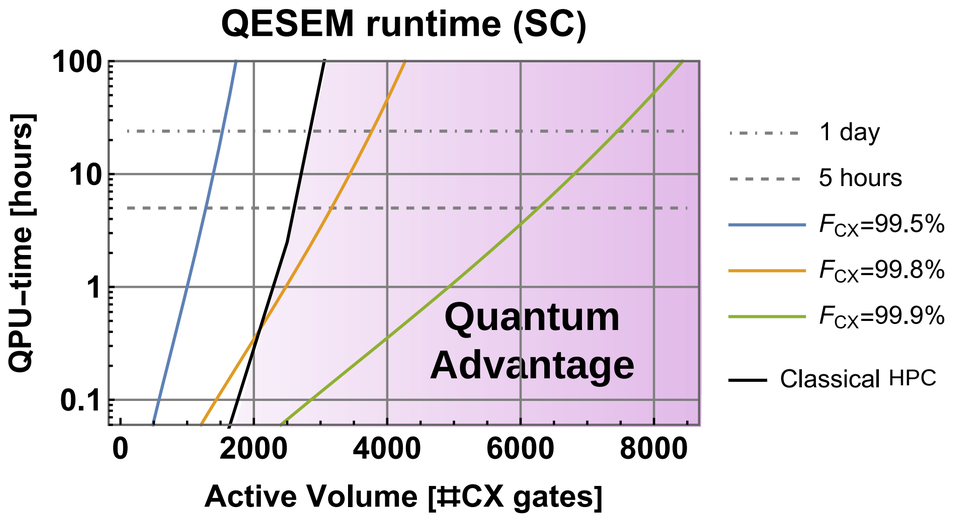
QESEM will soon enable quantum advantages with both Ions and SCs.

Reach out to explore what you can achieve with QESEM + your existing quantum hardware access!

Outlook: Qedma's product enables broad quantum advantages for designing general quantum algorithms for $F \geq 99.9\%$





Stay tuned for more of QESEM:

1. Results from IBM's Heron QPUs.
2. QPU-HPC workflow (collab. with RIKEN).
3. Adaptation to additional leading hardware providers.

Reach out for more info!

Visit Qedma's booth (S14)

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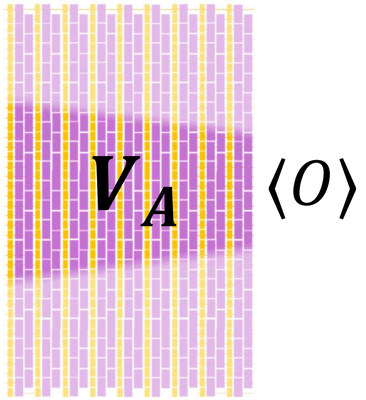
Towards large-scale quantum computing:

How to measure circuit volume in large quantum circuits?

Active volume V_A:

Number of CNOT gates affecting the observable

Controls the complexity of both EM and classical simulation

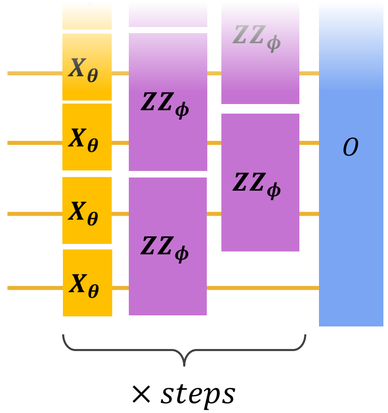


Example circuit family: Trotter-kicked Ising

$$H = J\sum_i Z_i Z_{i+1} + h\sum_i X_i$$

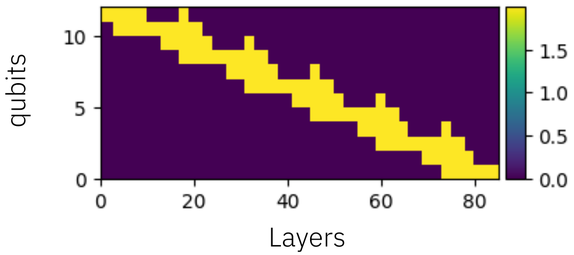
$$\phi_{ZZ} = 2\delta t \times J$$

$$\theta_X = 2\delta t \times h$$

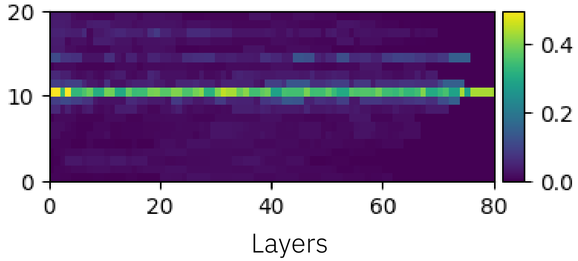


Active volume captures hardness of error mitigation and classical simulation

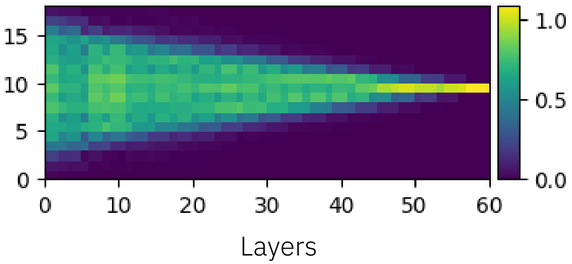
Exactly solvable: cross-section independent of depth
(dual-unitary circuits)



Easy to simulate: cross-section almost independent of depth
(weak propagation)



Generic: cross-section increases with depth
(Qedma demoes)



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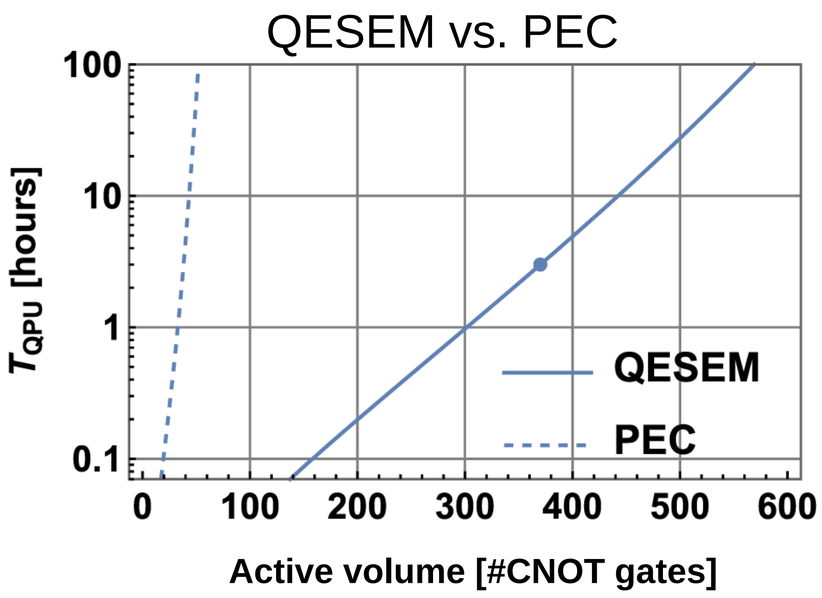
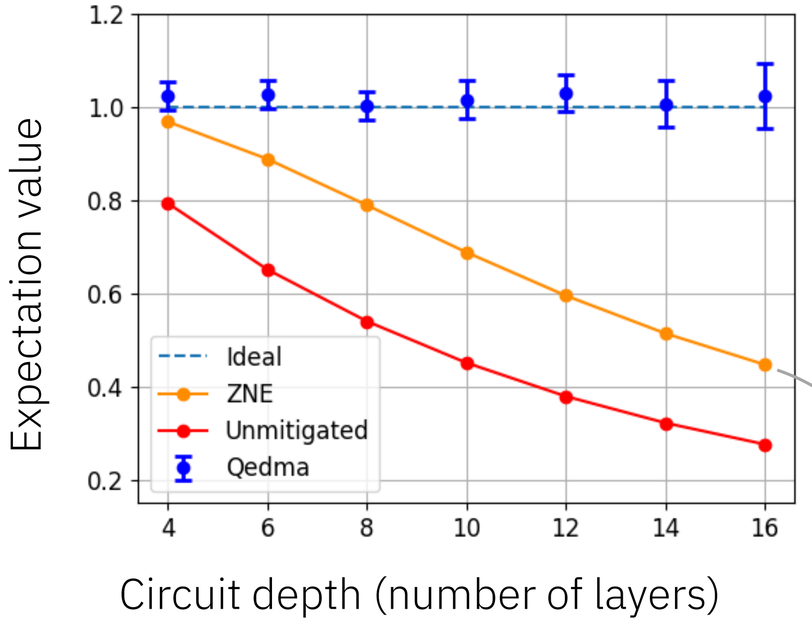
Comparison to Existing Solutions

Run larger circuits, faster



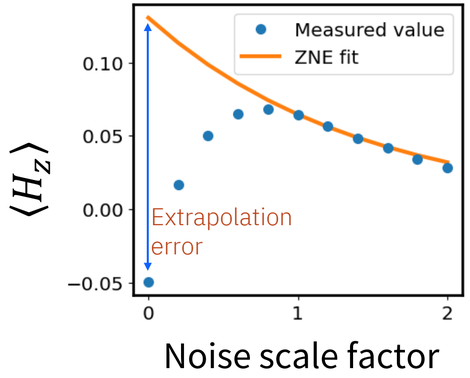
Speedup due to both ES and EM. Plot corresponds to 40-qubit Hamiltonian simulation, where the EM speedup contribution is dominant.

Guaranteed accuracy - no systematic bias



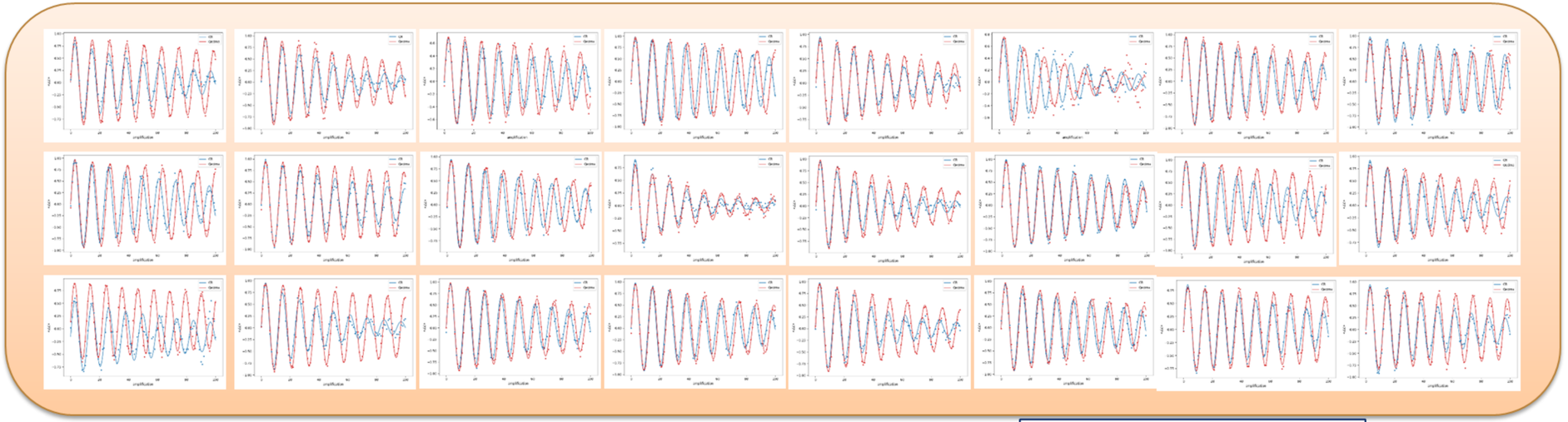
Why?
(example)

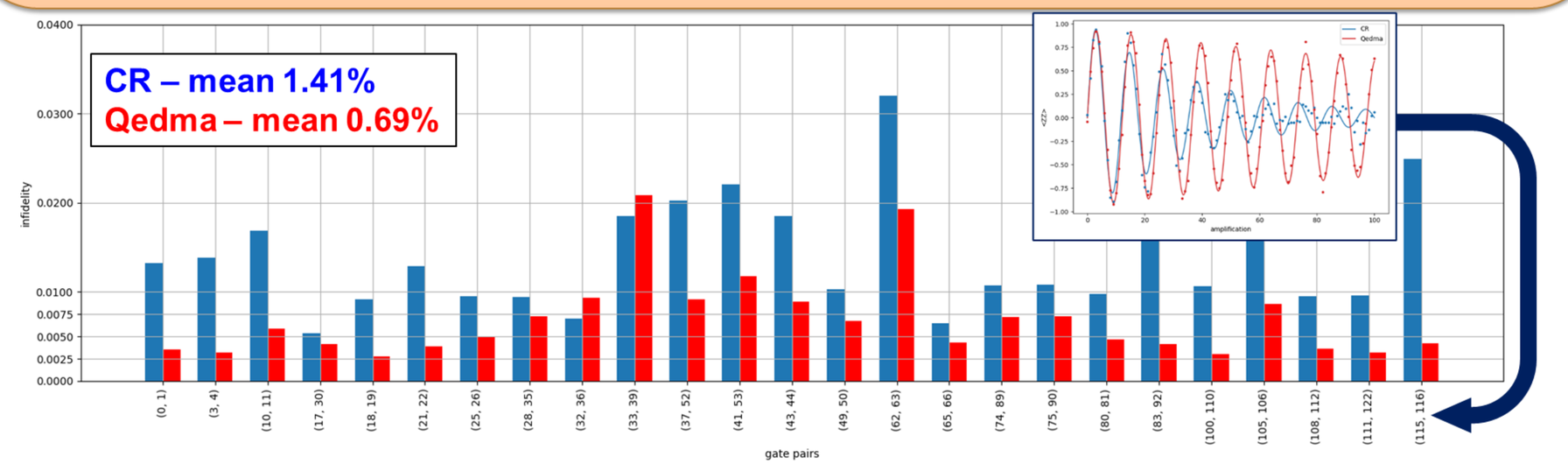
ZNE simulation: VQE08



Top: adapted from arXiv: 2402.04000
Right: example where any ZNE-based mitigation would fail

QESEM PULSES ON IBM QPUS





Highlights:

- Mean infidelity reduced by a **factor of over 2**.
- **Consistent improvement** (rare occurrences where CR is better).
- Best gate exhibited infidelity of ~0.14%.

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QESEM + IonQ + AWS Braket

Application

Quantum magnetism
(Heisenberg model)

Width

12 qubits

Volume

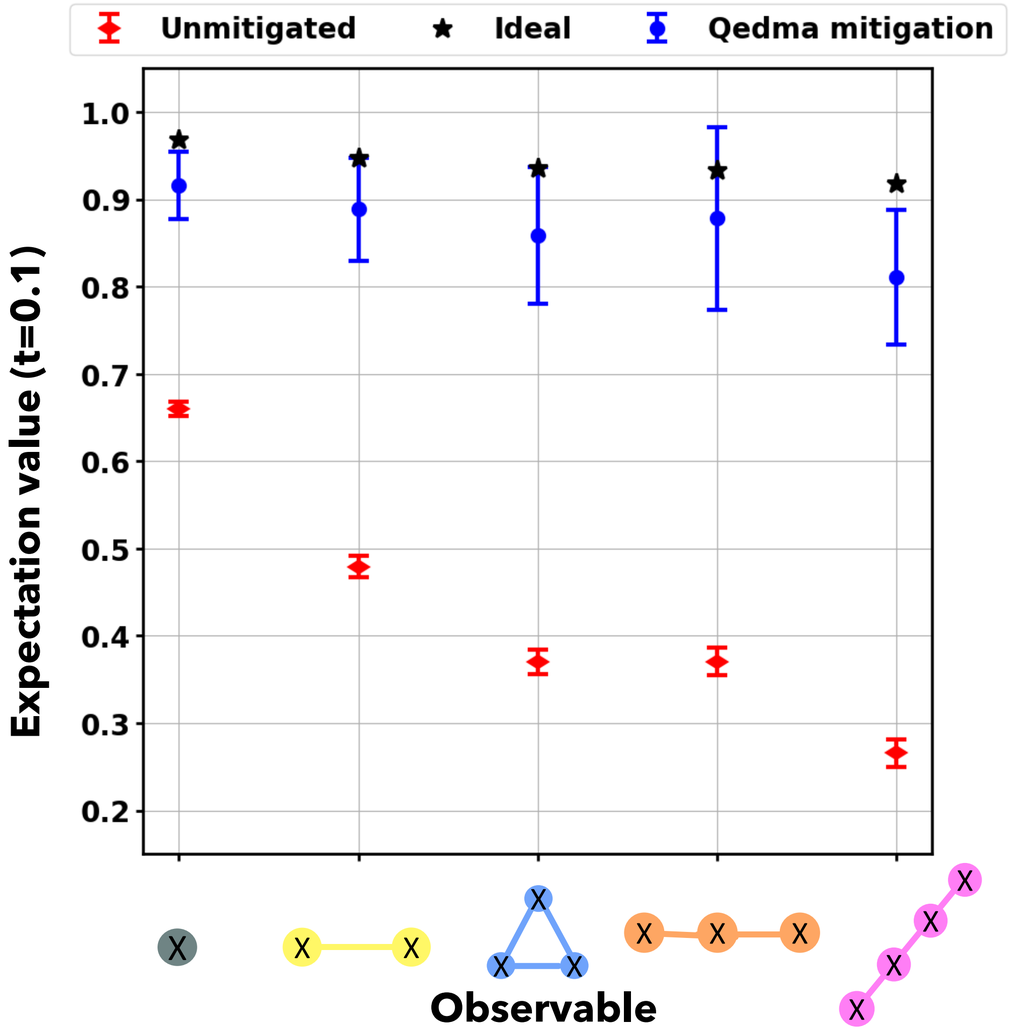
72 2-qubit gates
(36 distinct)

Connectivity

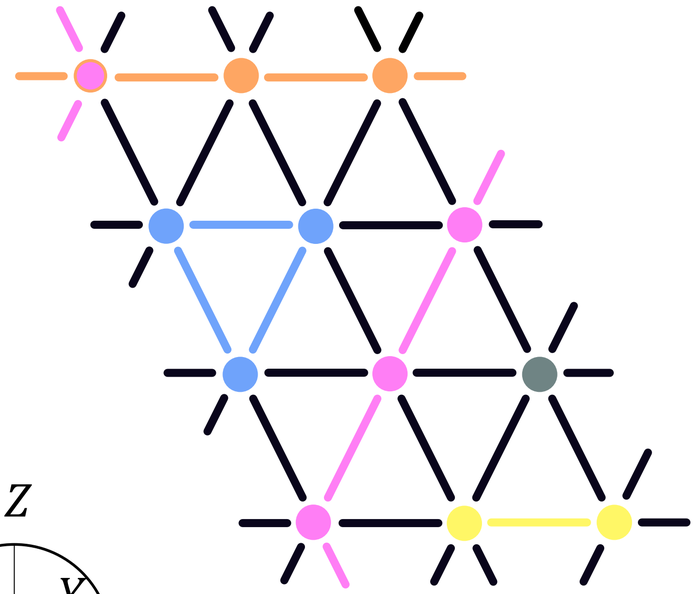
Triangular lattice w/
periodic boundaries

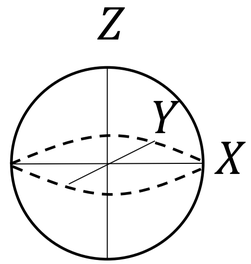
Quantity

1-point, 2-point, strings,
plaquette. X-type.



$$H = 0.5 \sum_{i} Z_i + \sum_{\langle i,j \rangle} \left(X_i X_j + Y_i Y_j \right)$$





omri.golan@qedma.com

More details: aws.amazon.com/blogs/quantum-computing/...

QEDMA

QESEM: hardware-tested, application-agnostic

Demonstrated on a variety of algorithms and hardware platforms

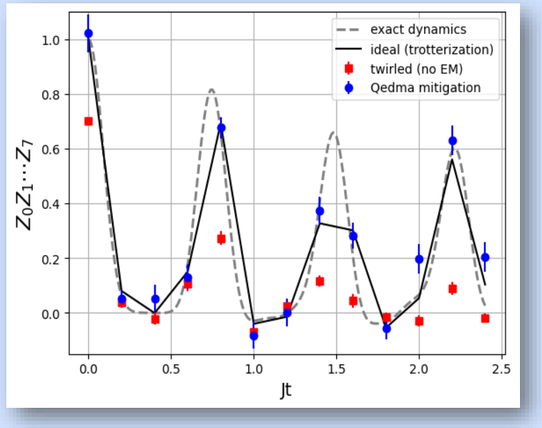
Hamiltonian simulation

IBM Kolkata, 8 Qubits

Volume: 192 CNOT gates

QESEM: 40 minutes

PEC: 1 month



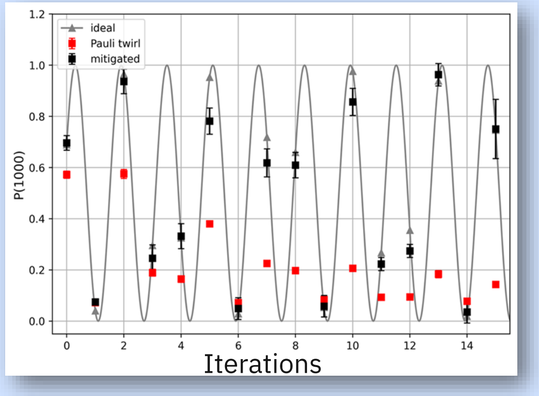
Amplitude estimation

IBM Kolkata, 4 Qubits

Volume: 252 CNOT gates

QESEM: 3 hours

PEC: 4 months

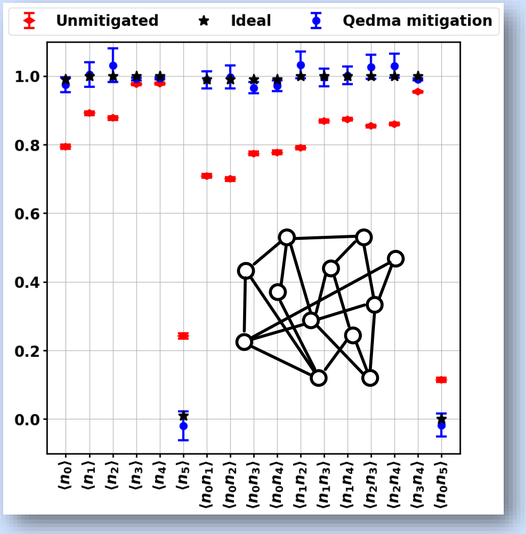


O_2 Molecular VQE

IonQ Aria, 12 qubits

Volume: 99 MS gates

Largest-volume high-accuracy VQE circuit to date



Contact:
omri.golan@qedma.com