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Gate insertions scale noise tractably for zero noise extrapolation on a trapped ion device

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The Tufts QIQC group

The QSCOUT team at Sandia National Laboratories

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Outline

- Zero noise extrapolation
- Time stretching method
- Gate insertion method
- Optimization + Extrapolation

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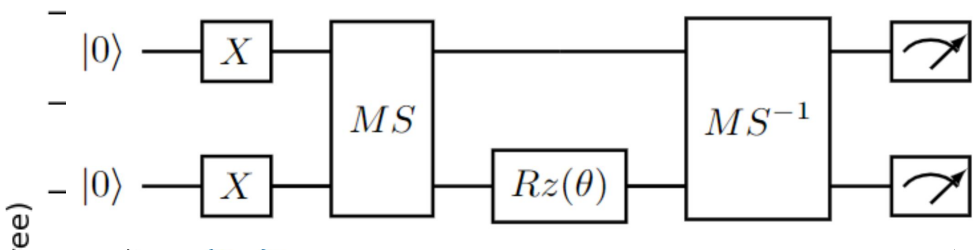
The Ground State of HeH+

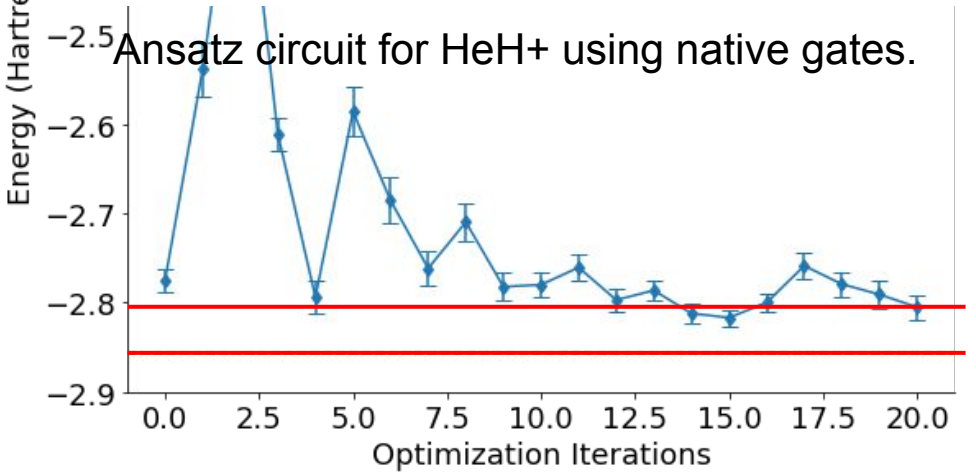
The Variational Quantum Eigensolver can estimate ground state energies.

But…

Noisy intermediate scale quantum (NISQ) error rates **impact accuracy** without error mitigation.



Ansatz circuit for HeH+ using native gates.



Optimizer convergence with hardware error

Zero Noise Extrapolation

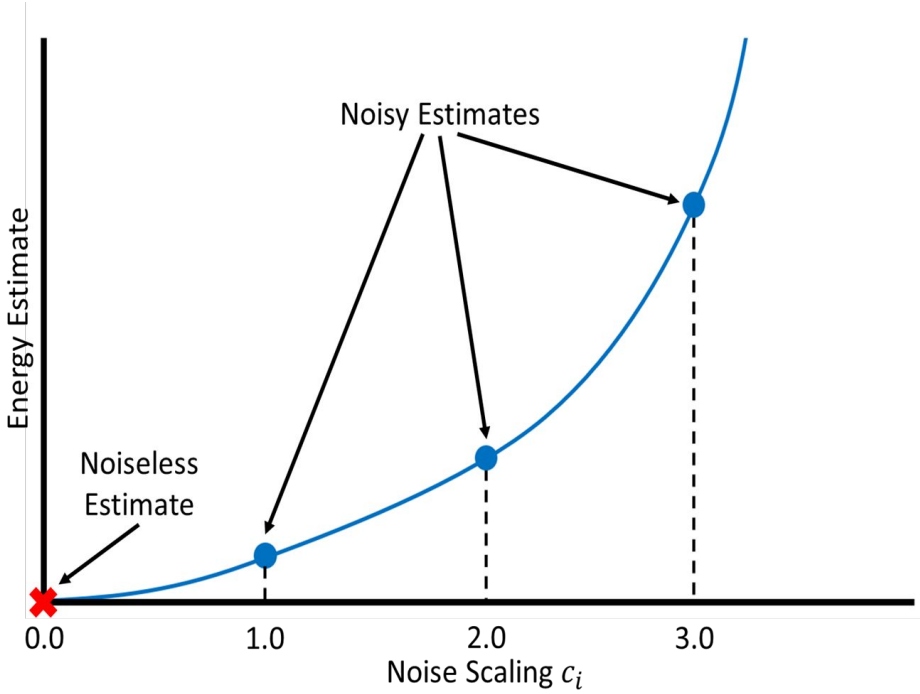
Error mitigation technique that requires ***n* noisy estimates**.

$$\hat{E}_K^n(\lambda) = \sum_{i=0}^{n} \gamma_i \hat{E}_K(c_i \lambda)$$

Improved noiseless estimate

Constant solutions to…

Multiple noisy estimates



$$\sum_{i=0}^{n} \gamma_i = 1 \quad \text{and} \quad \sum_{i=0}^{n} \gamma_i \, c_i^k = 1 \quad \text{For k = 1...n}$$

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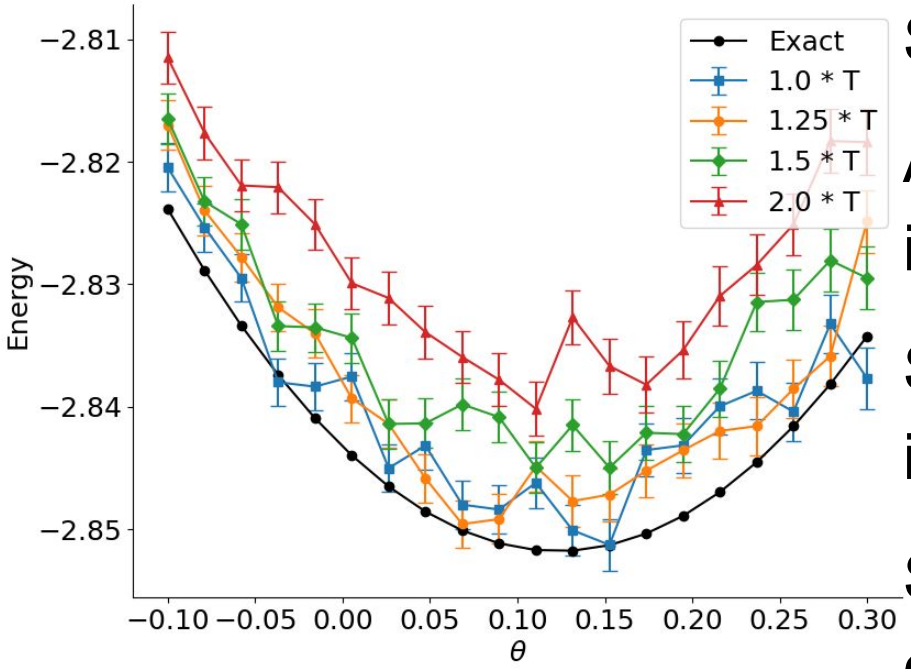
Time Stretching - (Simulation)



Noisy energy curves from time stretching simulation

Same method as [Kandala 2019]

Assume noise is time-translation invariant.

Scale the **gate duration** by c_i instead of scaling the noise.

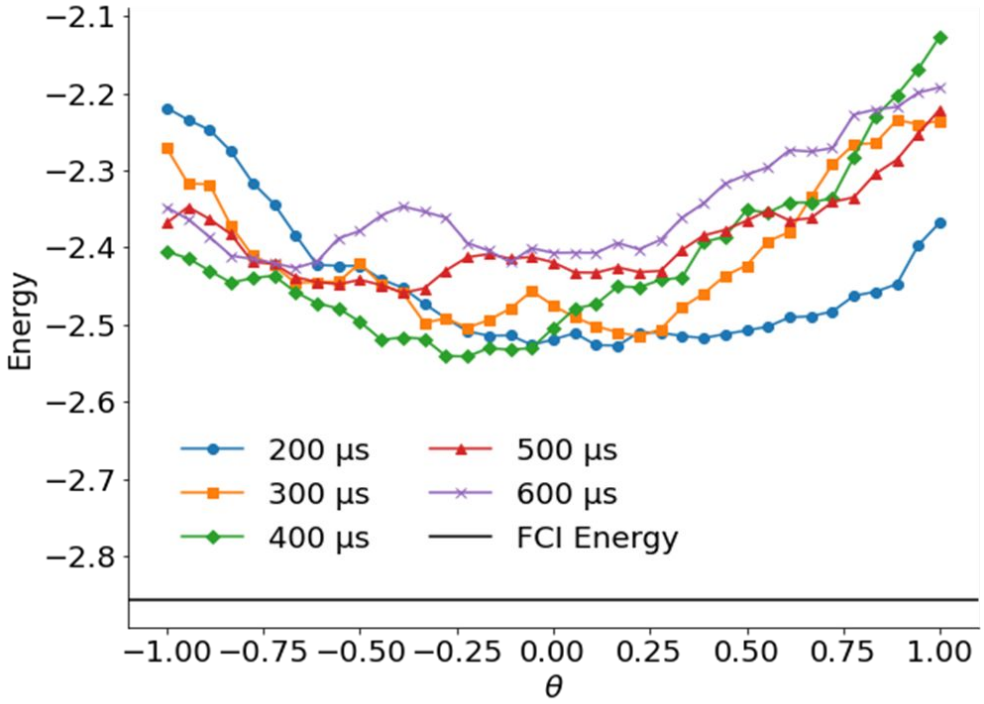
Simulation energy curves are too close together.

Time Stretching - (Experiment)

Not enough noise injected into the circuit. Why?

Trapped ions have long coherence times!

Control errors, crosstalk, and qubit drift dominate.



Noisy energy curves from time stretching experiment

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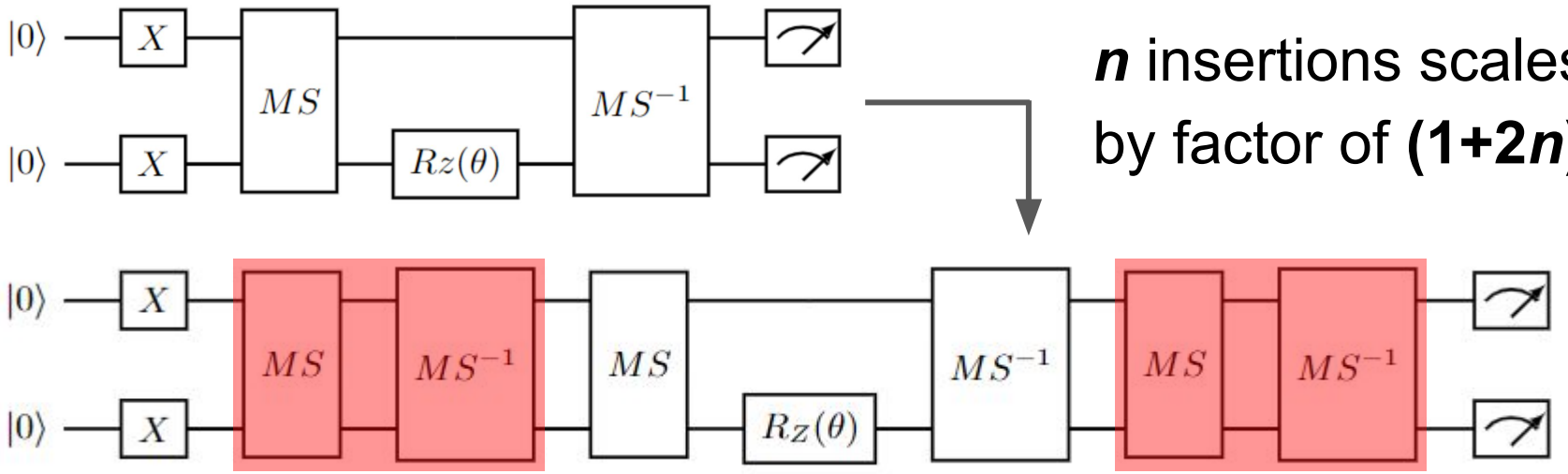
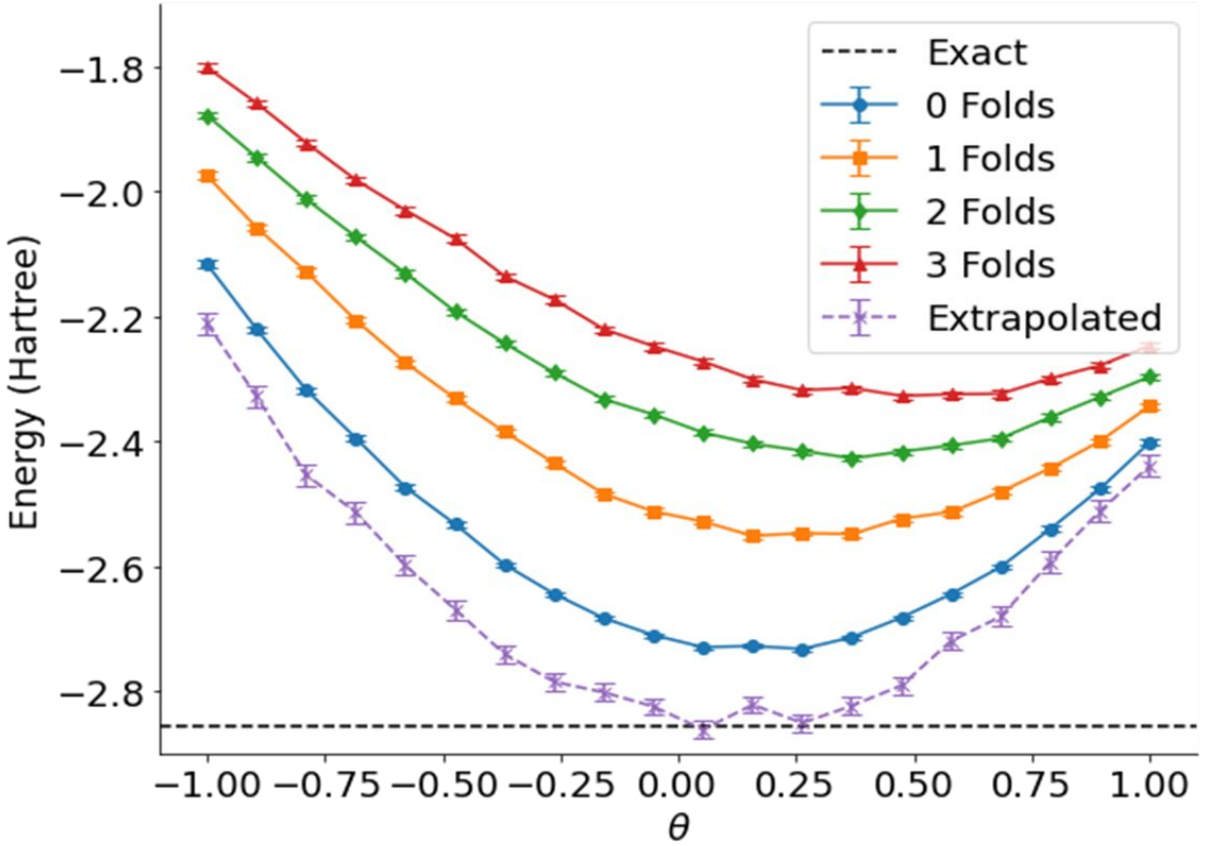
Gate Insertions - (Simulation)

Insert circuit identities to scale noise [Giurgica-Tiron 2020].

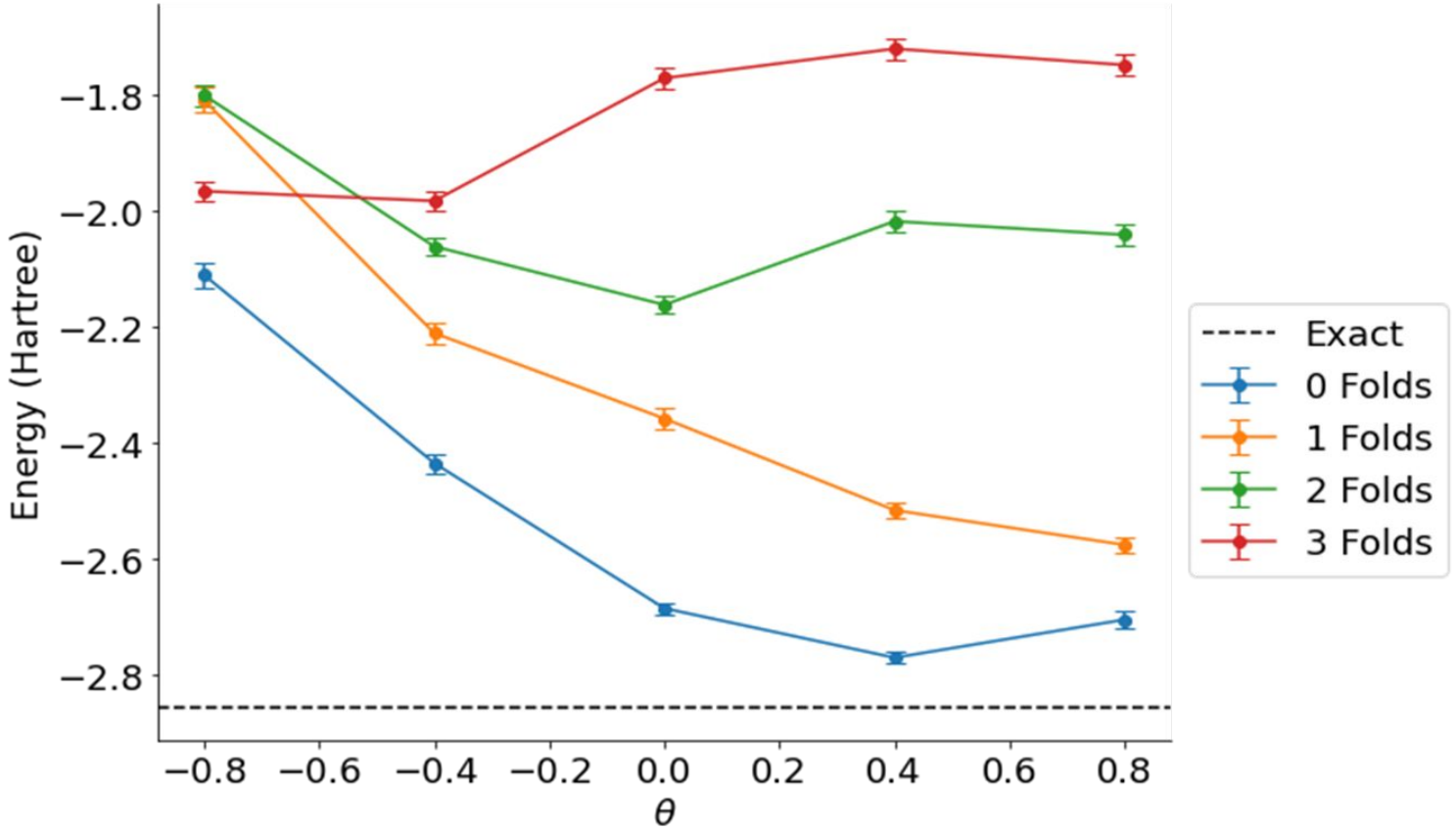


n insertions scales noise by factor of **(1+2*n*)**

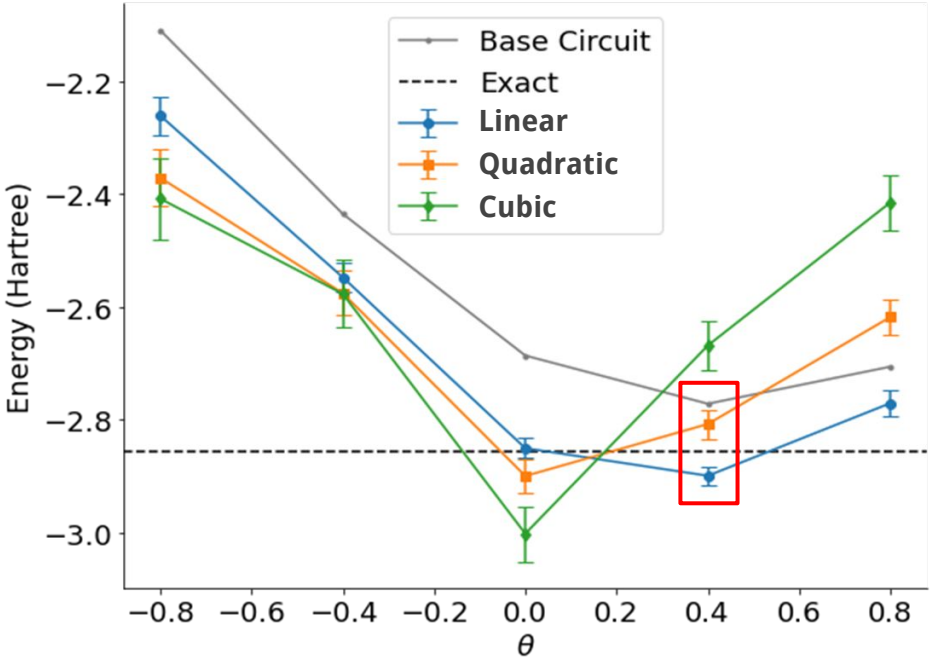
Gate Insertions - (Simulation)



Gate Insertions - (Experiment)



Extrapolation Results



Extrapolated energy curves on the QSCOUT device.

Minimum extrapolated energies show improvement over **unaltered estimate**.

Improved relative error of **~40-80%** for **linear** and **quadratic** fits.

Does this still hold following an optimization routine?

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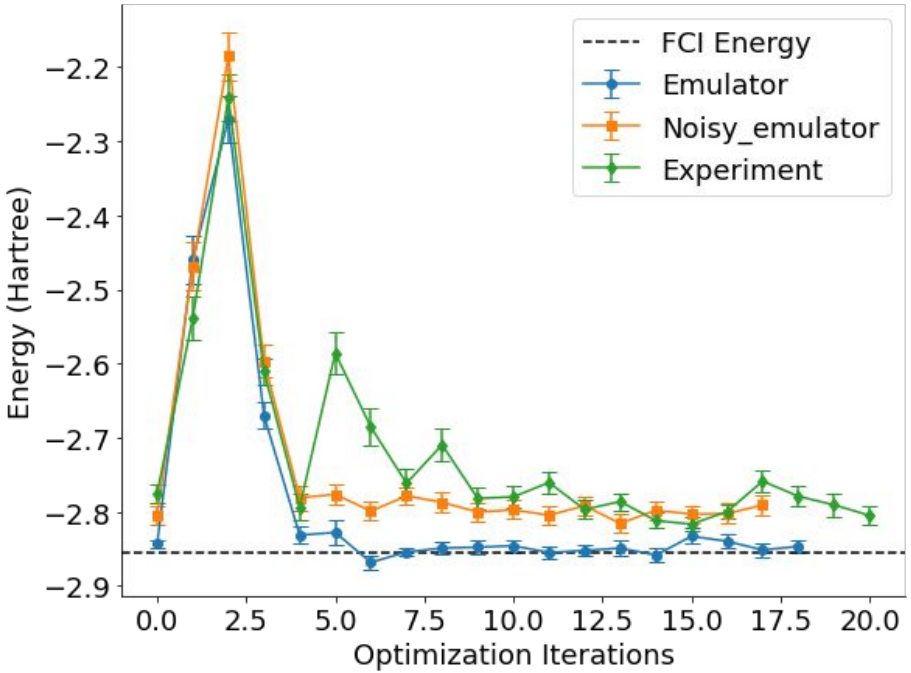
Optimization Results

Optimization converges to optimal parameter in **simulation** and **experiment** (COBYLA).

When should extrapolation be used during optimization?

Optimize an unaltered circuit and **extrapolate** at minimum.

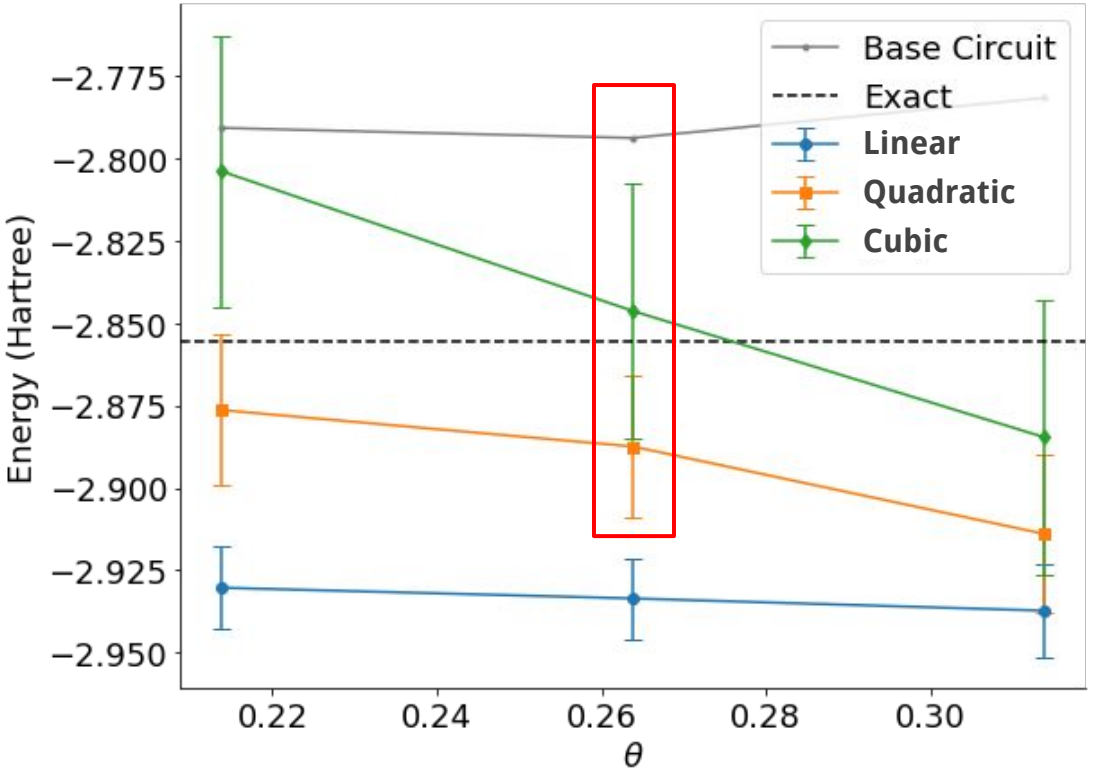


Experiment optimization convergence compared to simulations

Tufts Exemplars

Extrapolated at 3 values near the minimum.

Improves accuracy for **quadratic** and **cubic** fits versus **no extrapolation**.



Conclusions

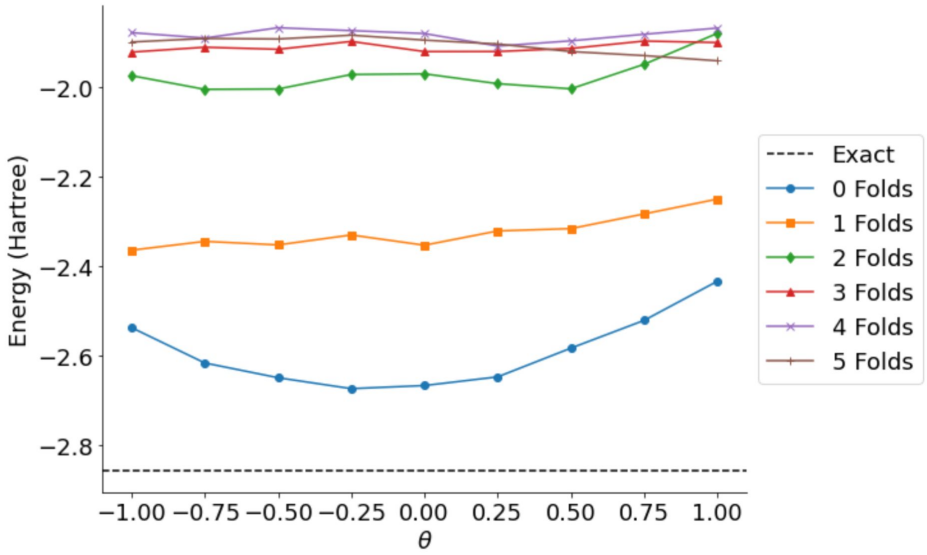
- Noise scaling via stretching duration of gates may not work on trapped ion devices with long coherence times.
- Inserting identity operations can tractably scale noise and improve accuracy.

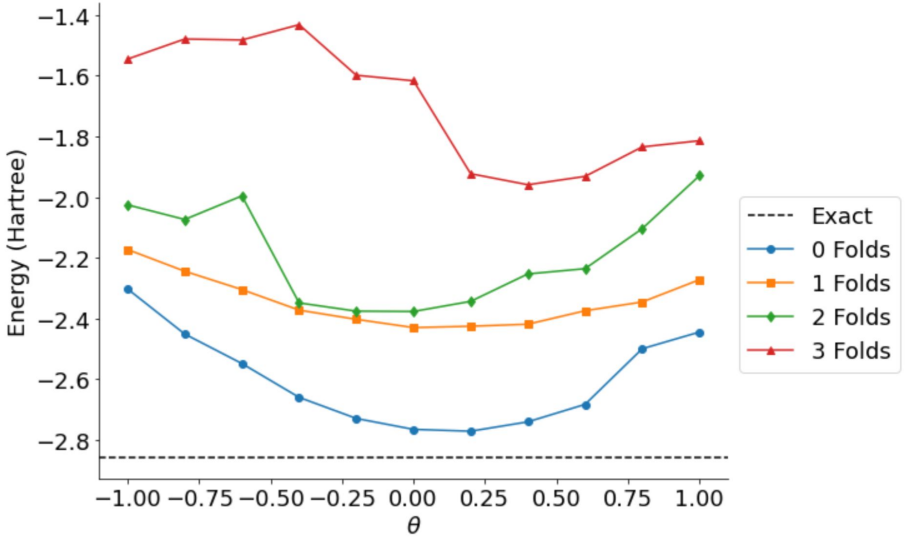
Future Work:

- Combining ZNE with other error mitigation techniques.
- Testing larger, more complex systems.

Questions?

Other Circuit Identities





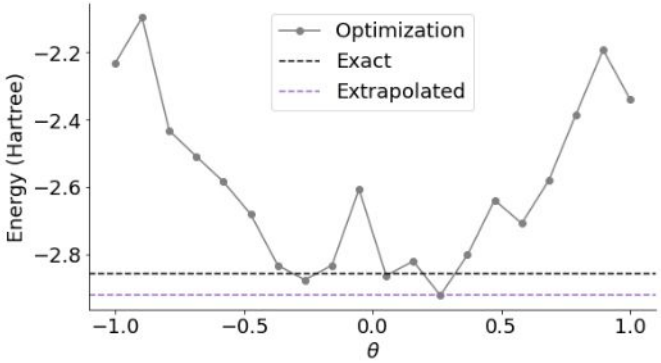
$$MS \rightarrow MS(MS^{\dagger}MS)^{n}$$

Applied to 2nd MS gate only

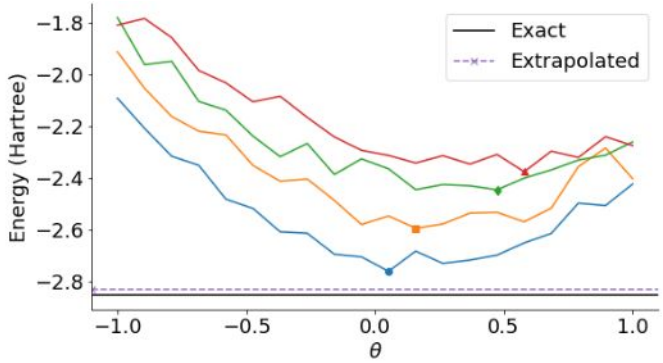
$$MS \rightarrow MS(MS)^{4n}$$

Applied to all MS gates

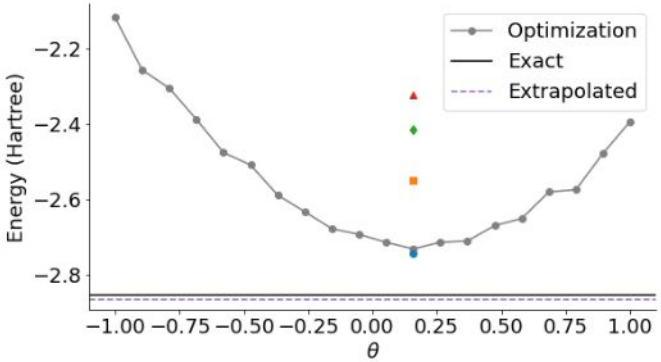
Optimization Ordering



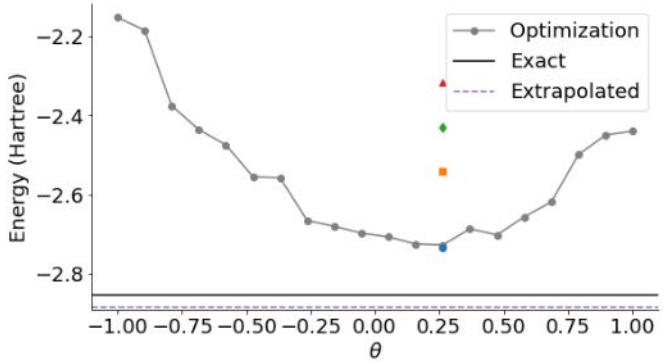
(a) Optimizing over Extrapolated Energies



(b) Extrapolating over Optimized Energies



(c) First Optimizing and then Extrapolating



(d) Optimizing at Low Order and then Extrapolating