Navigating the dynamic noise landscape of variational quantum algorithms with QISMET

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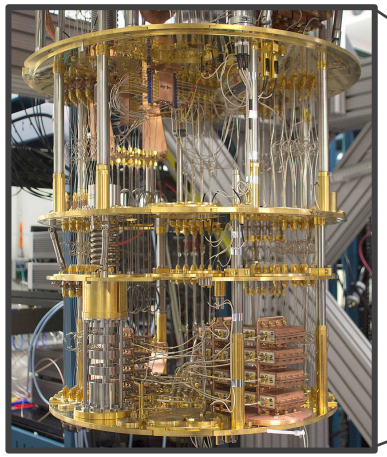
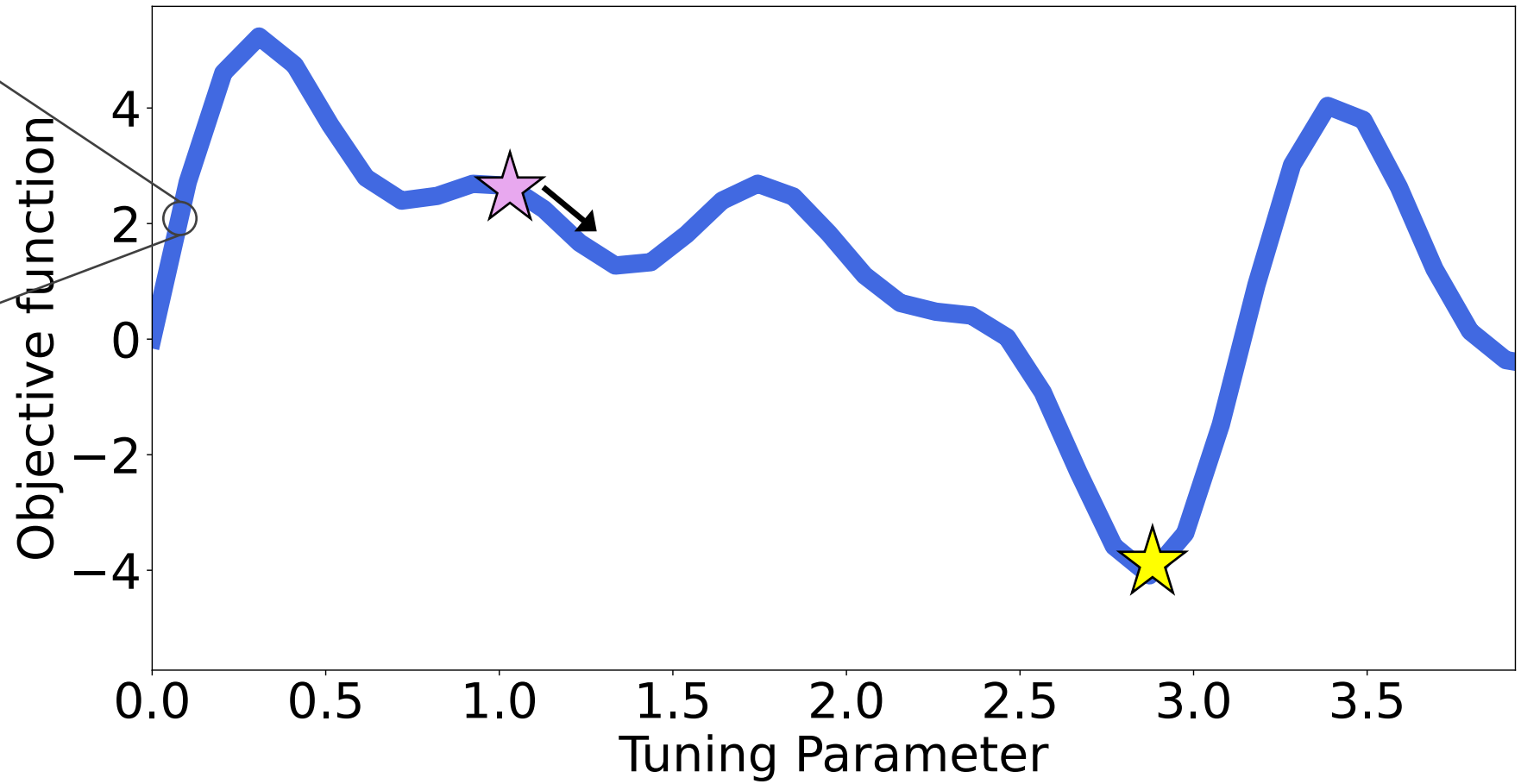
1: UChicago, 2: IBM, 3: Duke, 4: Super.tech

First to study & mitigate impact of transient qubit noise on long running quantum apps like VQAs!

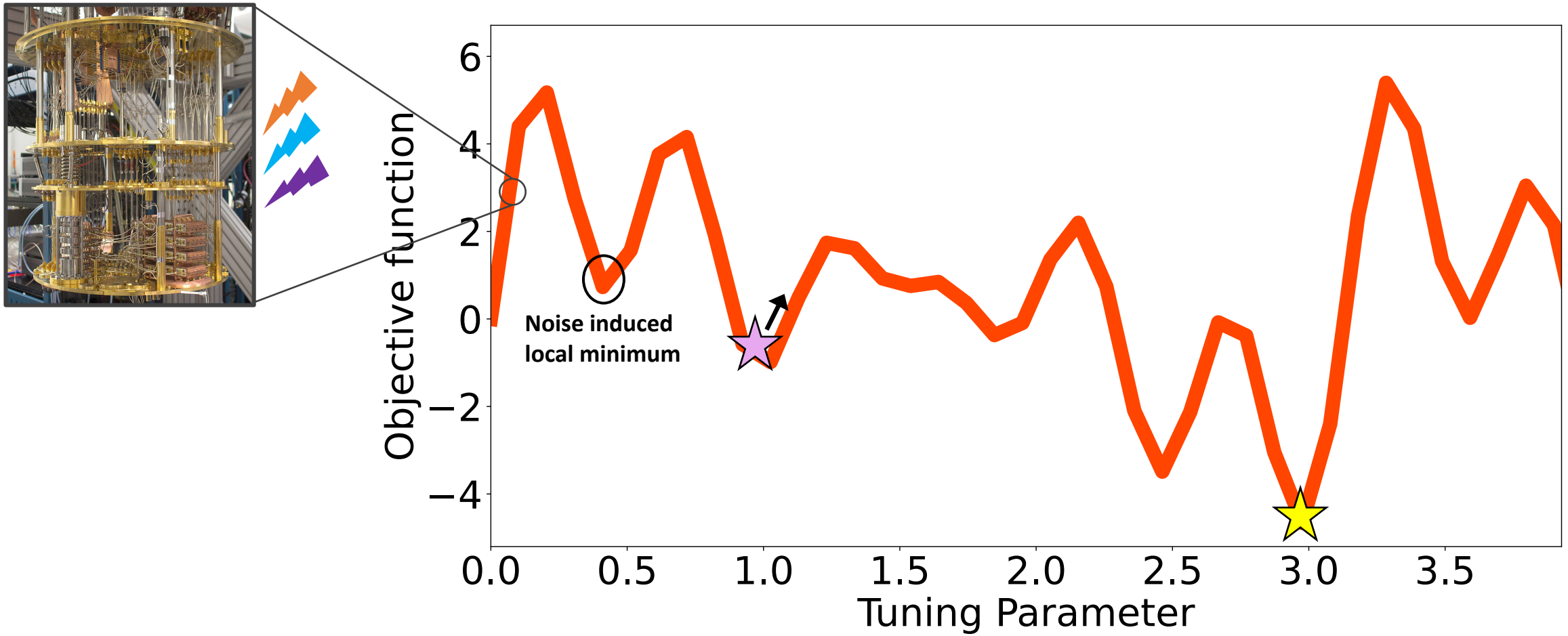
arXiv:2209.12280

Navigating an ideal Variational Quantum Algorithm contour

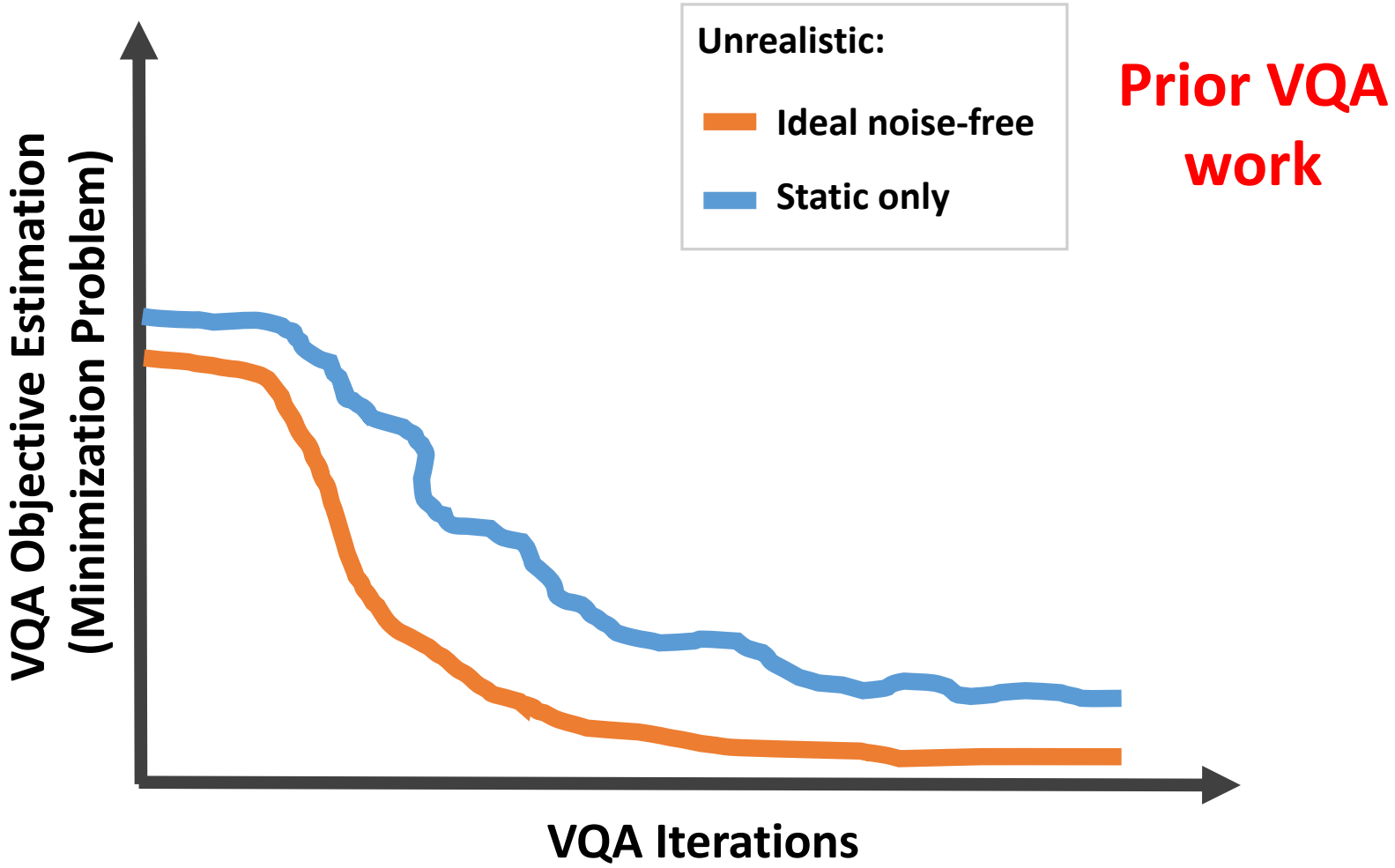




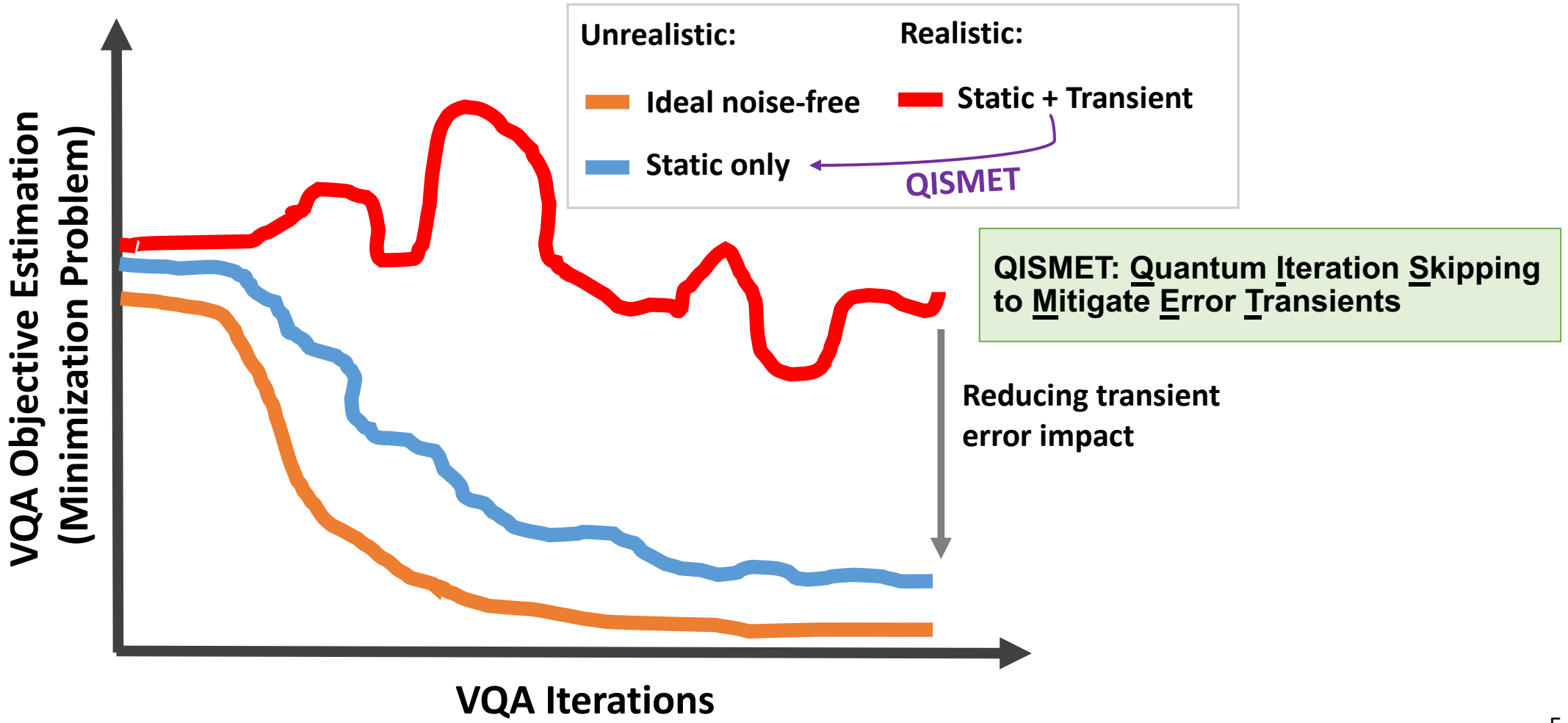
Navigating a noisy Variational Quantum Algorithm contour



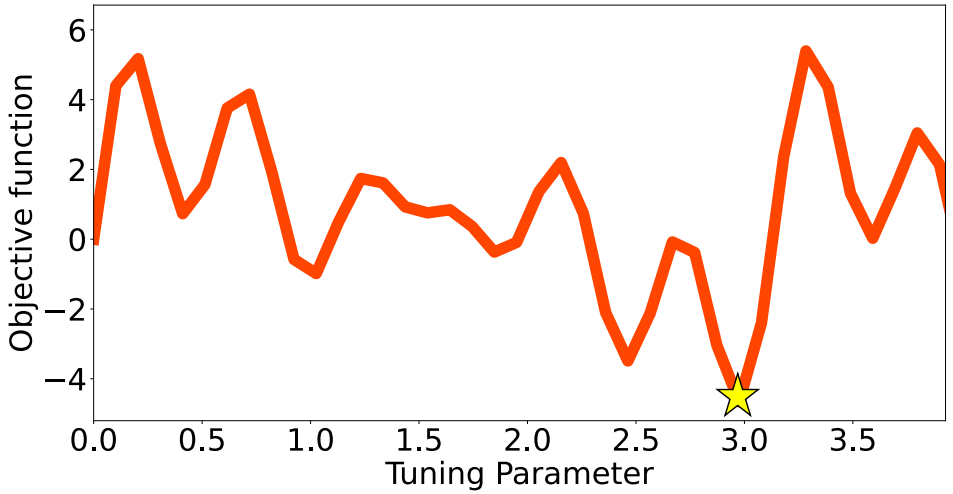
Prior VQA efforts: Static noise assumptions and its mitigation



Dynamic noise impacting VQA and the benefit of QISMET



How VQA works



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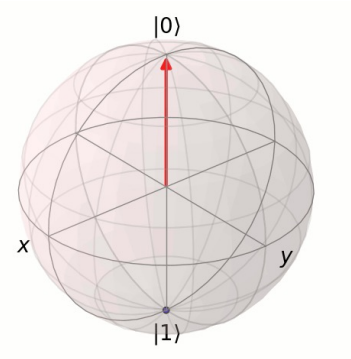
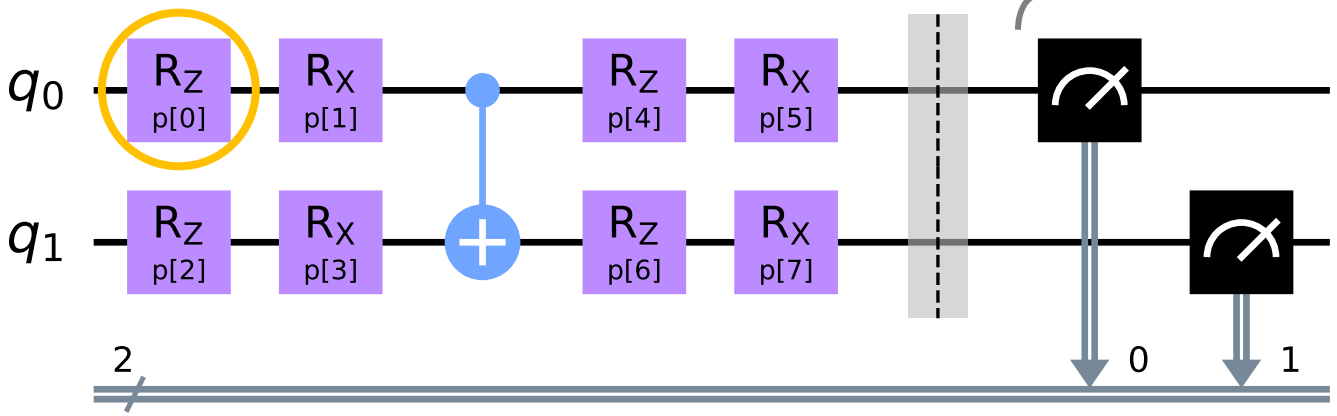
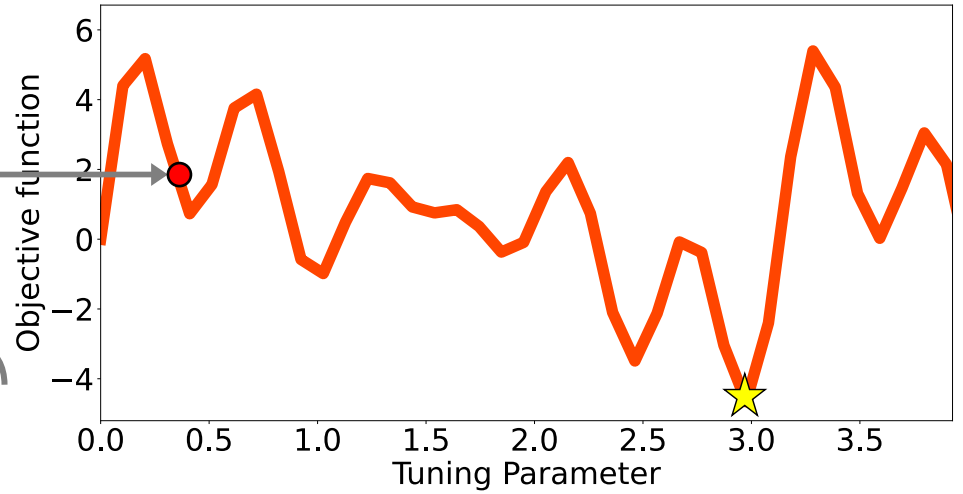
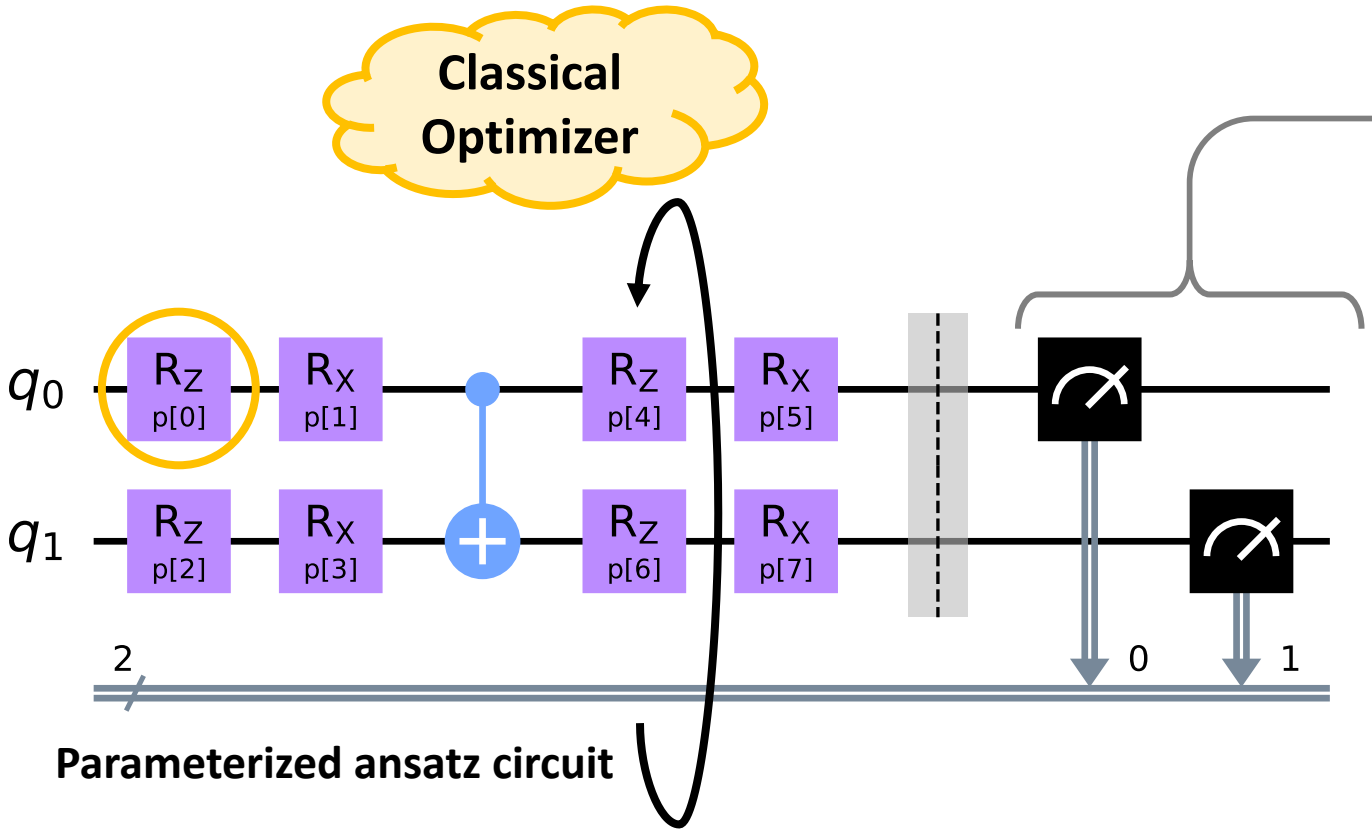


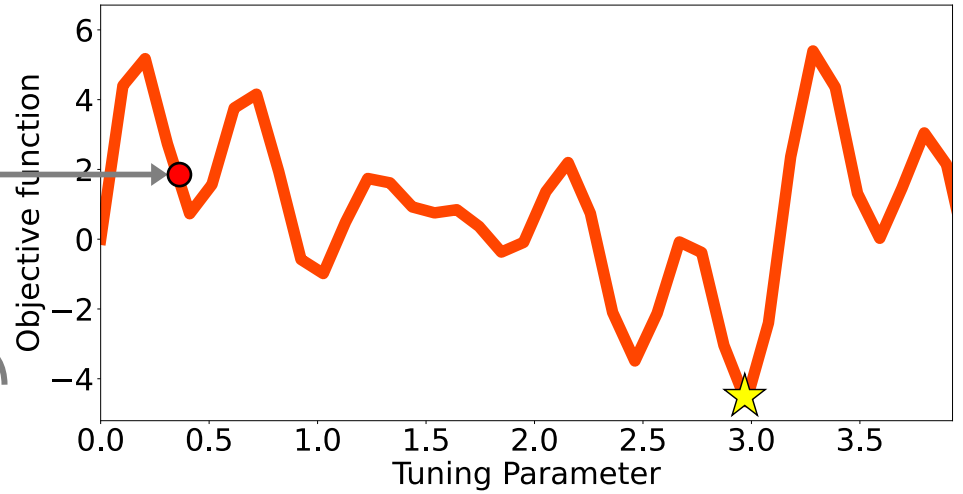


Parameterized ansatz circuit

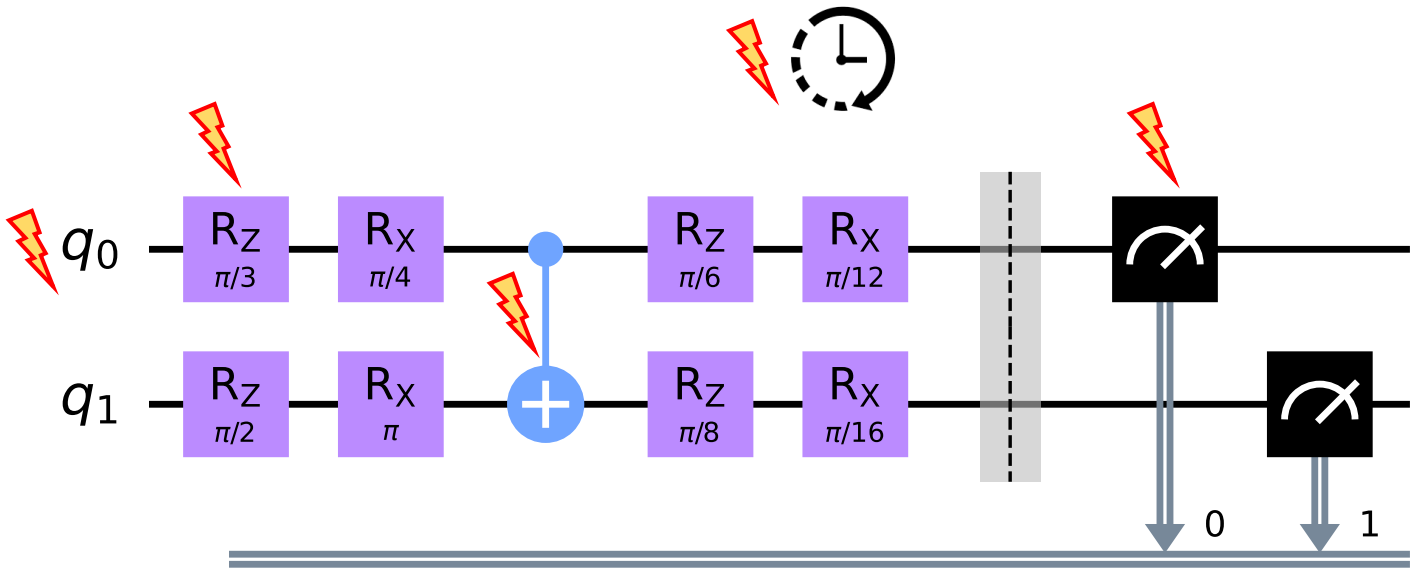


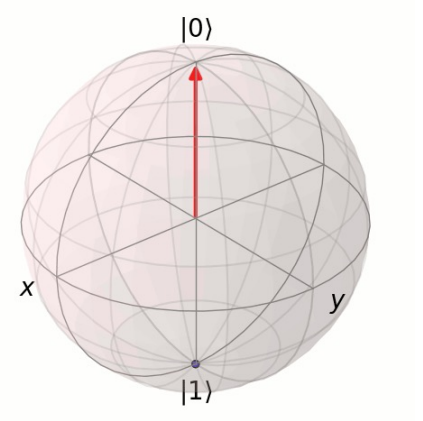
How VQA works





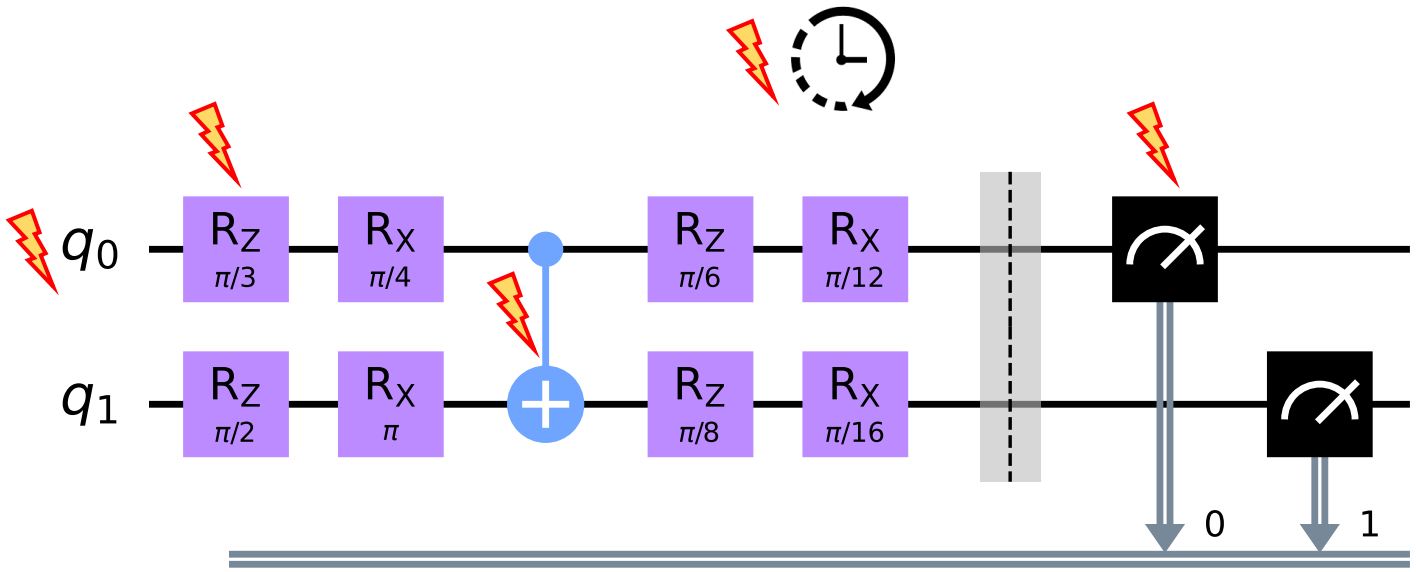
General noisy quantum circuits

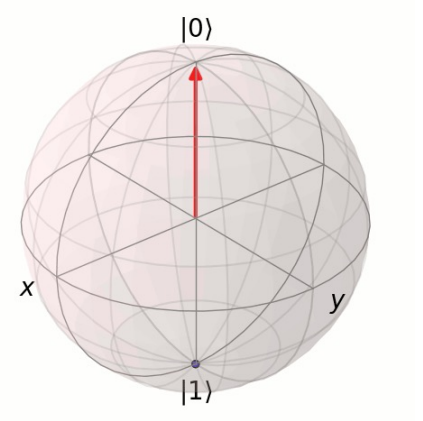




State prep error
qubit decoherence,
1Q/2Q gate errors,
crosstalk errors,
measurement errors

Static error mitigation techniques utilize noise information known a priori





Noise-adaptive (Murali:2019)

Xtalk-aware (Murali:2020)

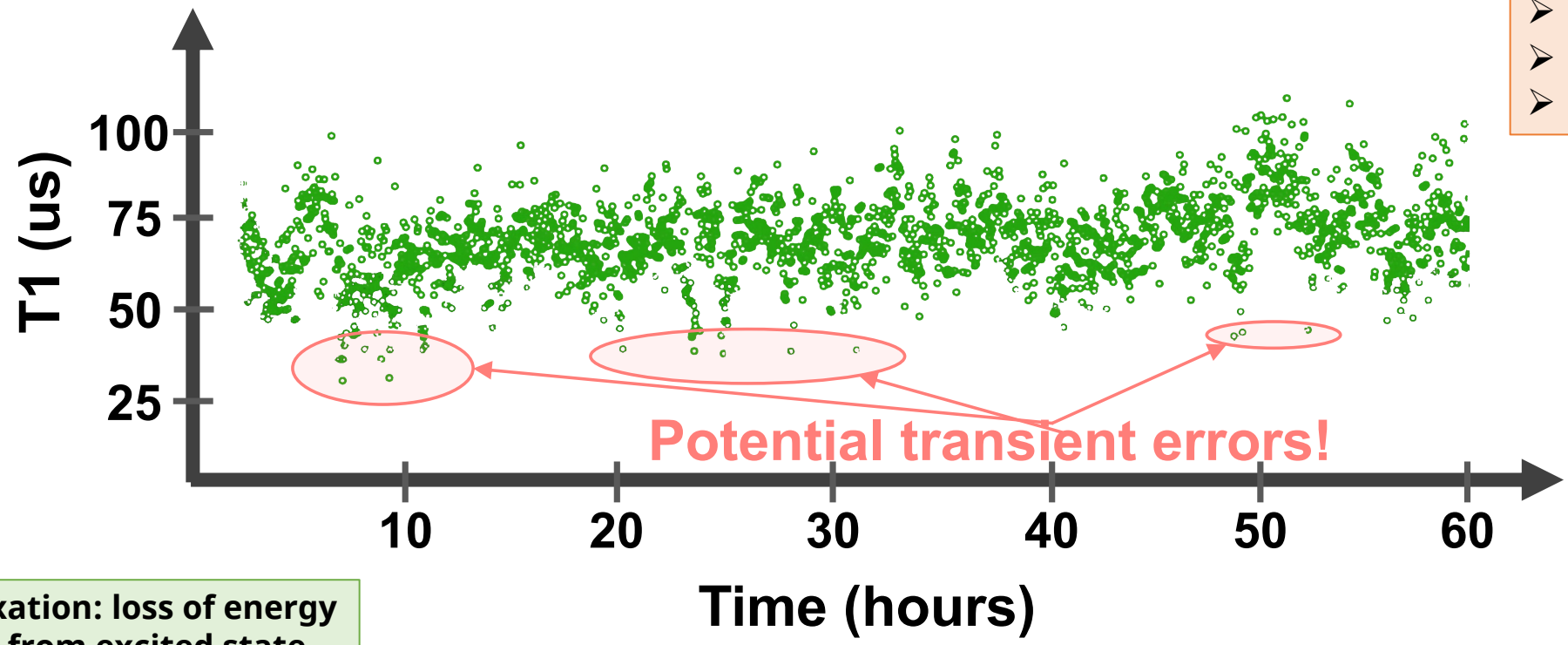
ZNE (Giurgica-Tiron:2020)

Dynamic Decoupling (Biercuk:2011)

Measurement errors (Tannu:2019)

Dynamic variation: Qubit-level abstraction

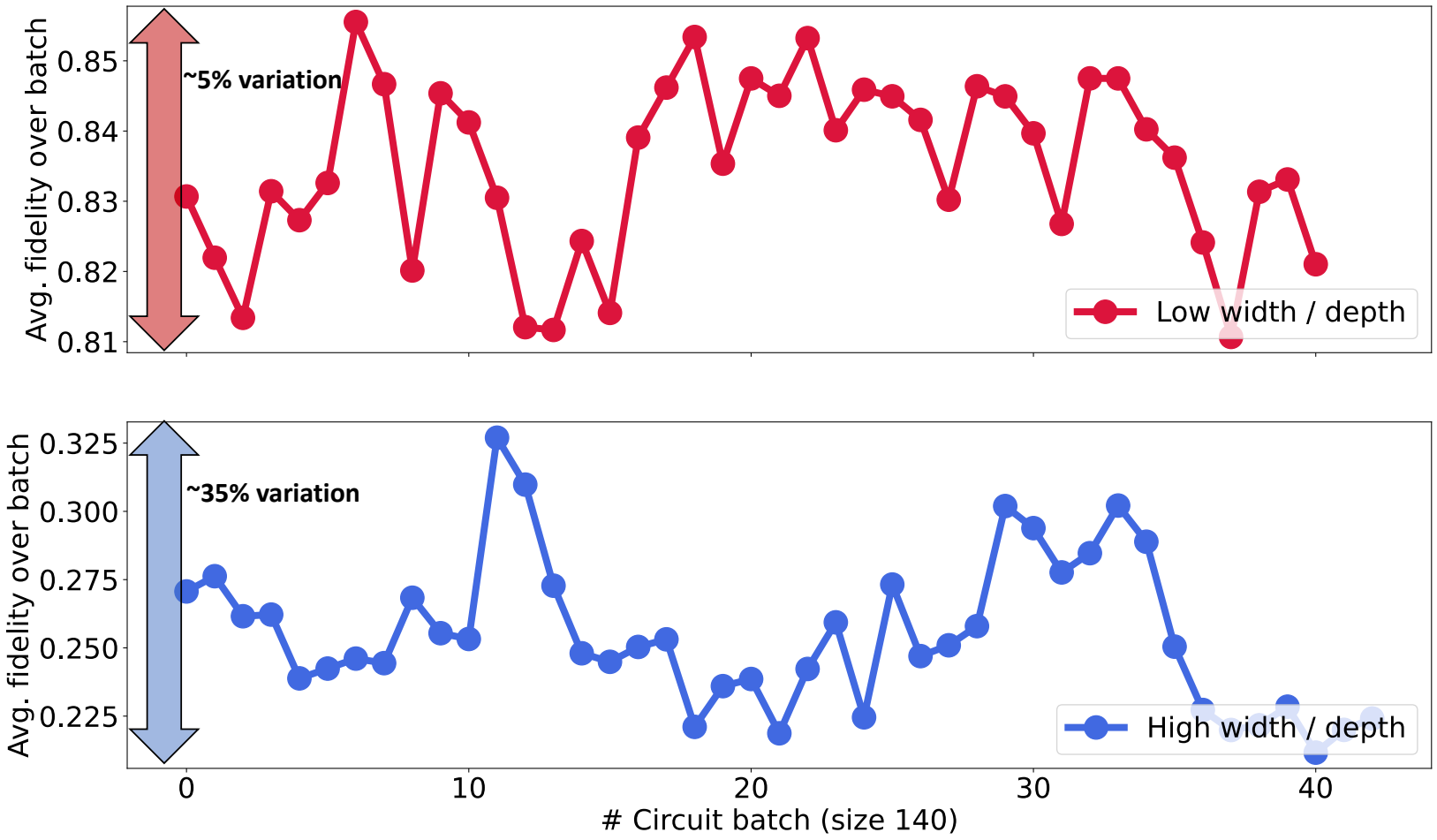
- Fabrication defects
- Parasitic coupling
- Two level systems
- Thermal fluctuations
- Quasi particles



T1 relaxation: loss of energy of qubit from excited state |1> to the ground state |0>

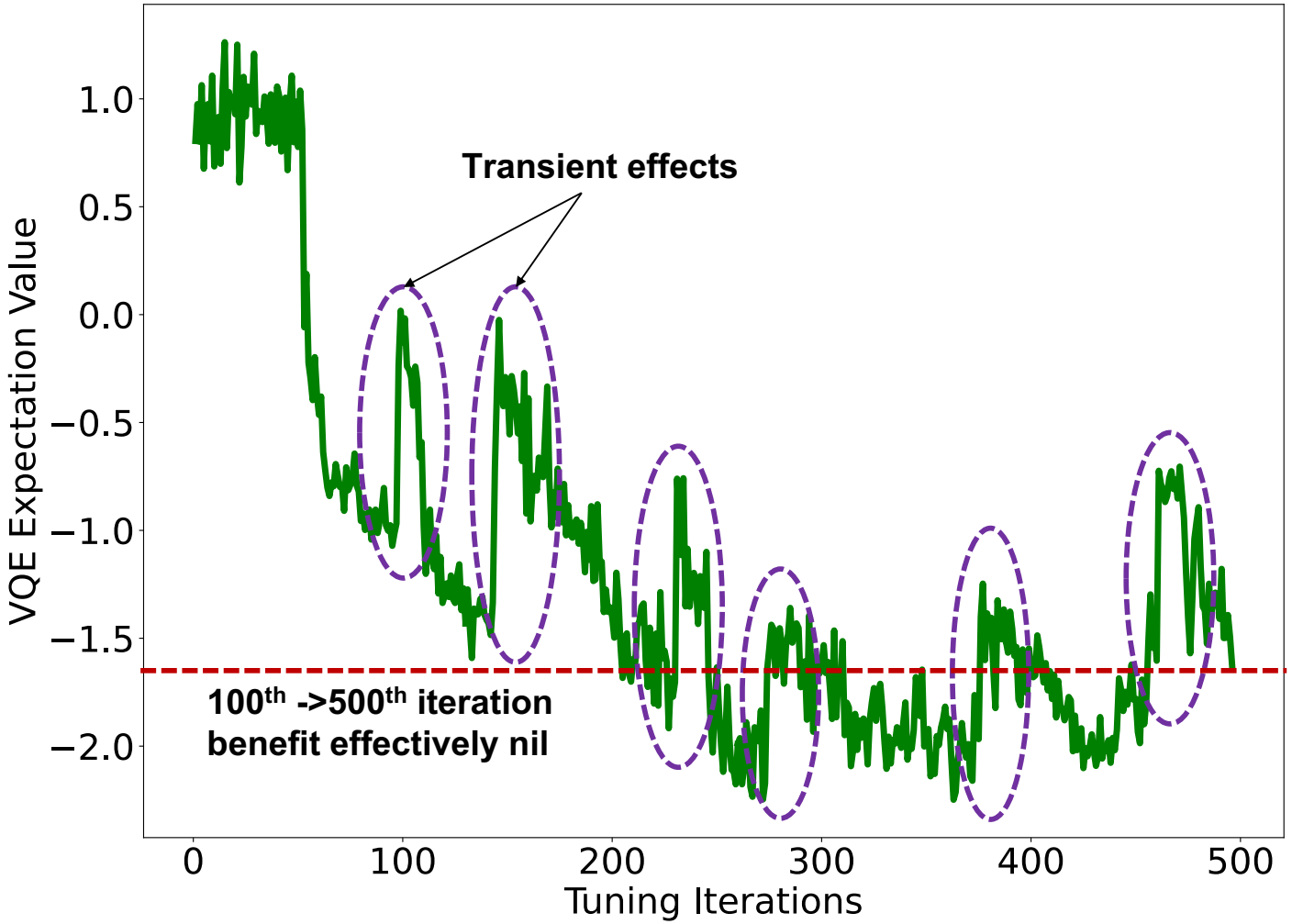
JJ Burnett, et al. **Decoherence benchmarking of superconducting qubits**. NPJ Quantum 2019

Dynamic variation: Circuit-level abstraction

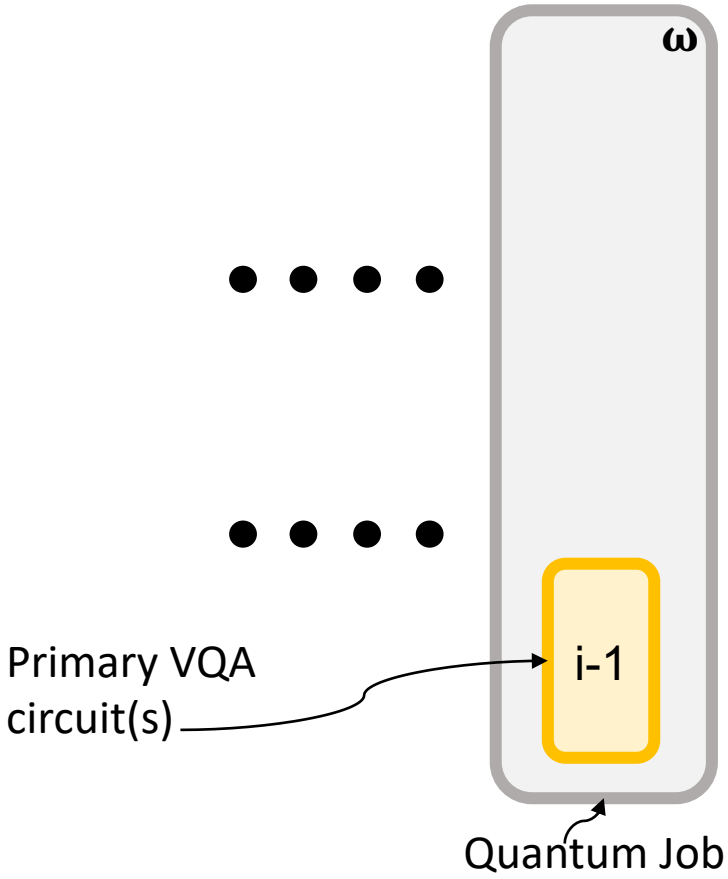


Depends on:
- **Circuit width**
- **Circuit depth**
- **Circuit state**

Dynamic variation: Application-level abstraction



QISMET: Quantum Iteration Skipping to Mitigate Error Transients



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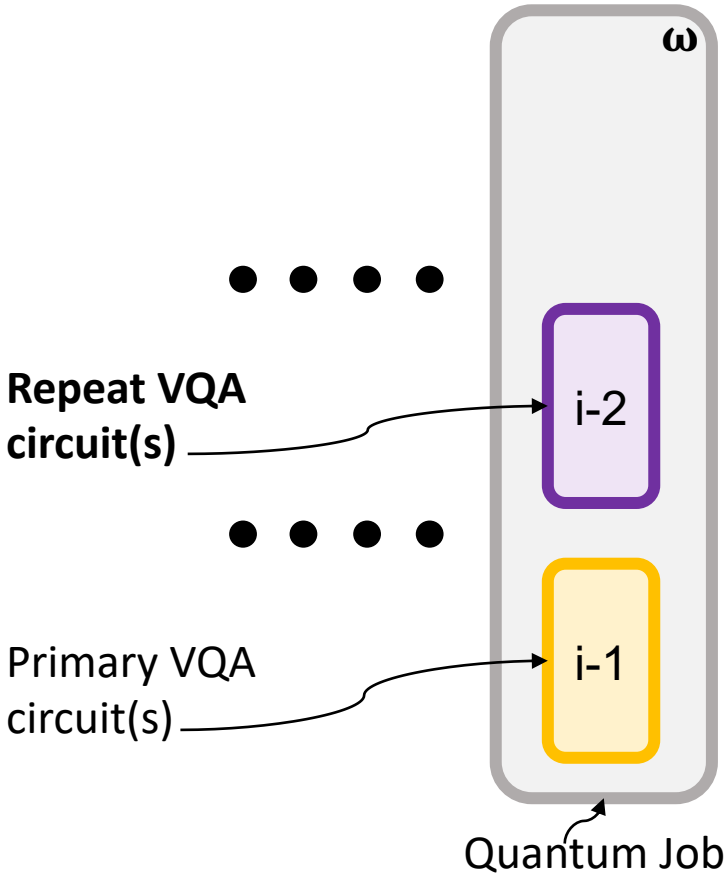

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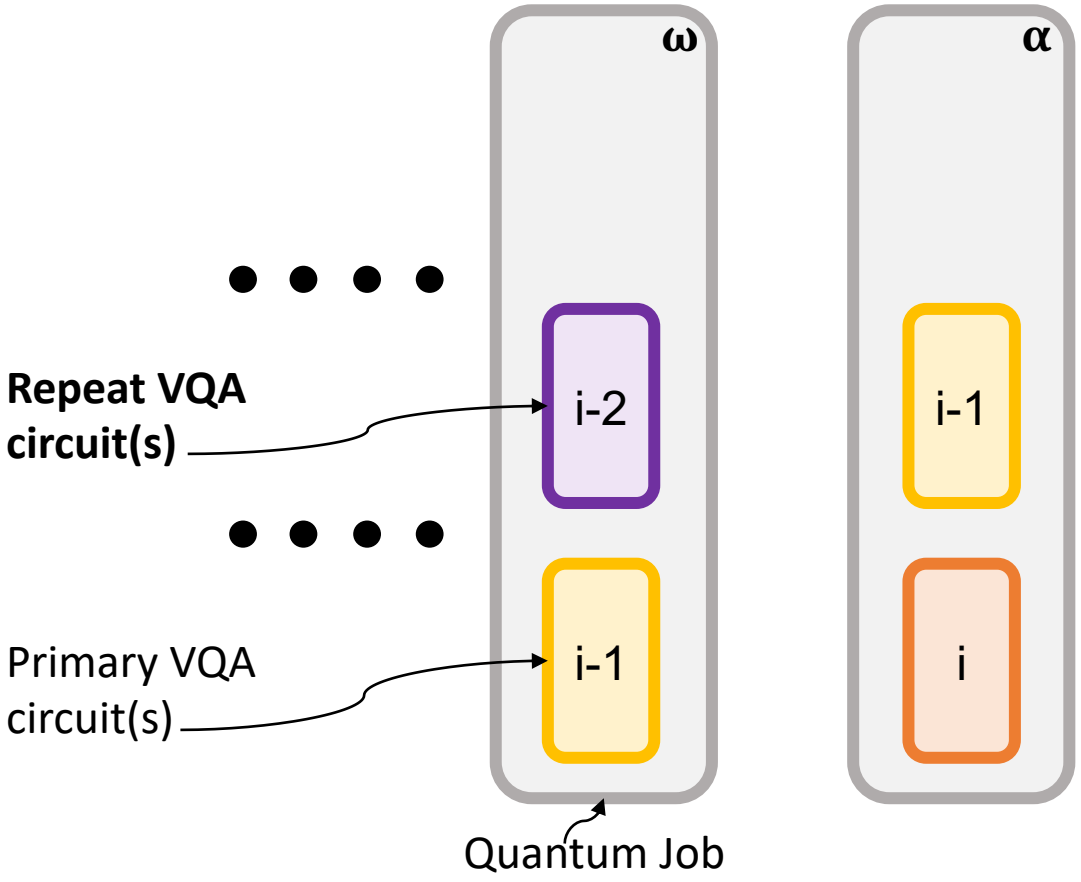

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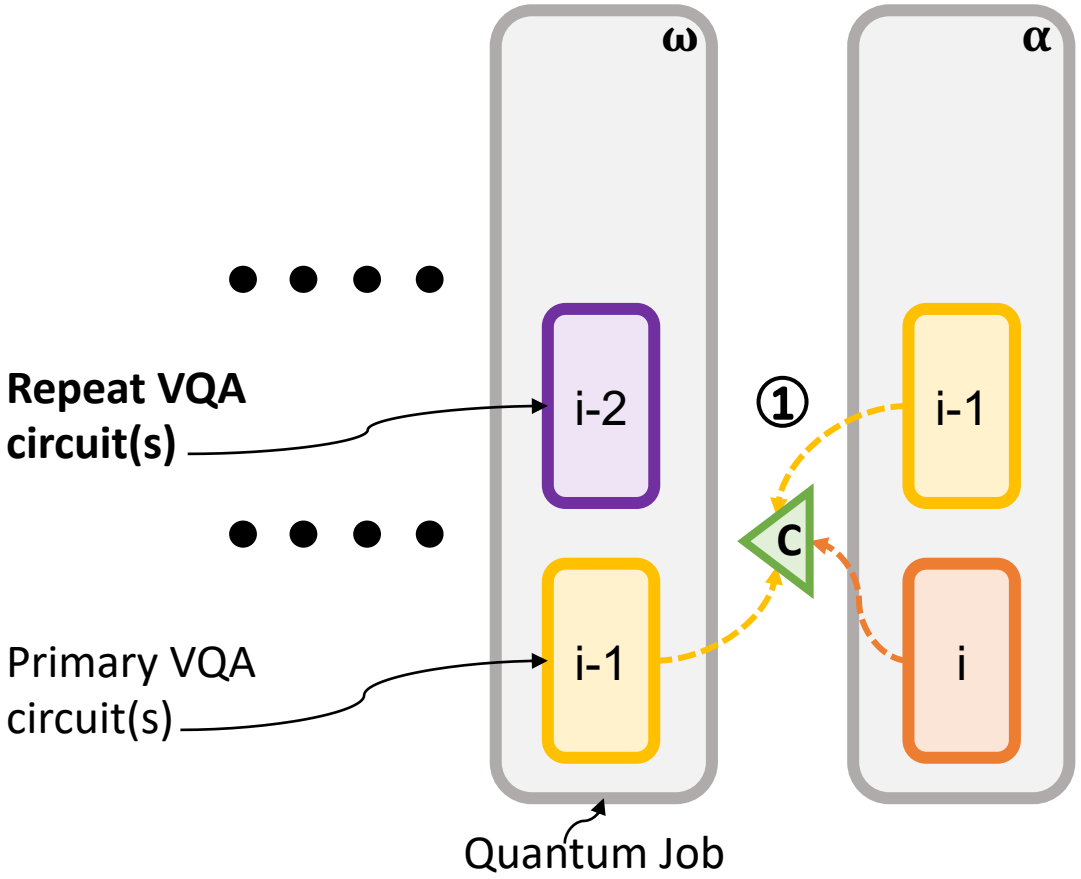

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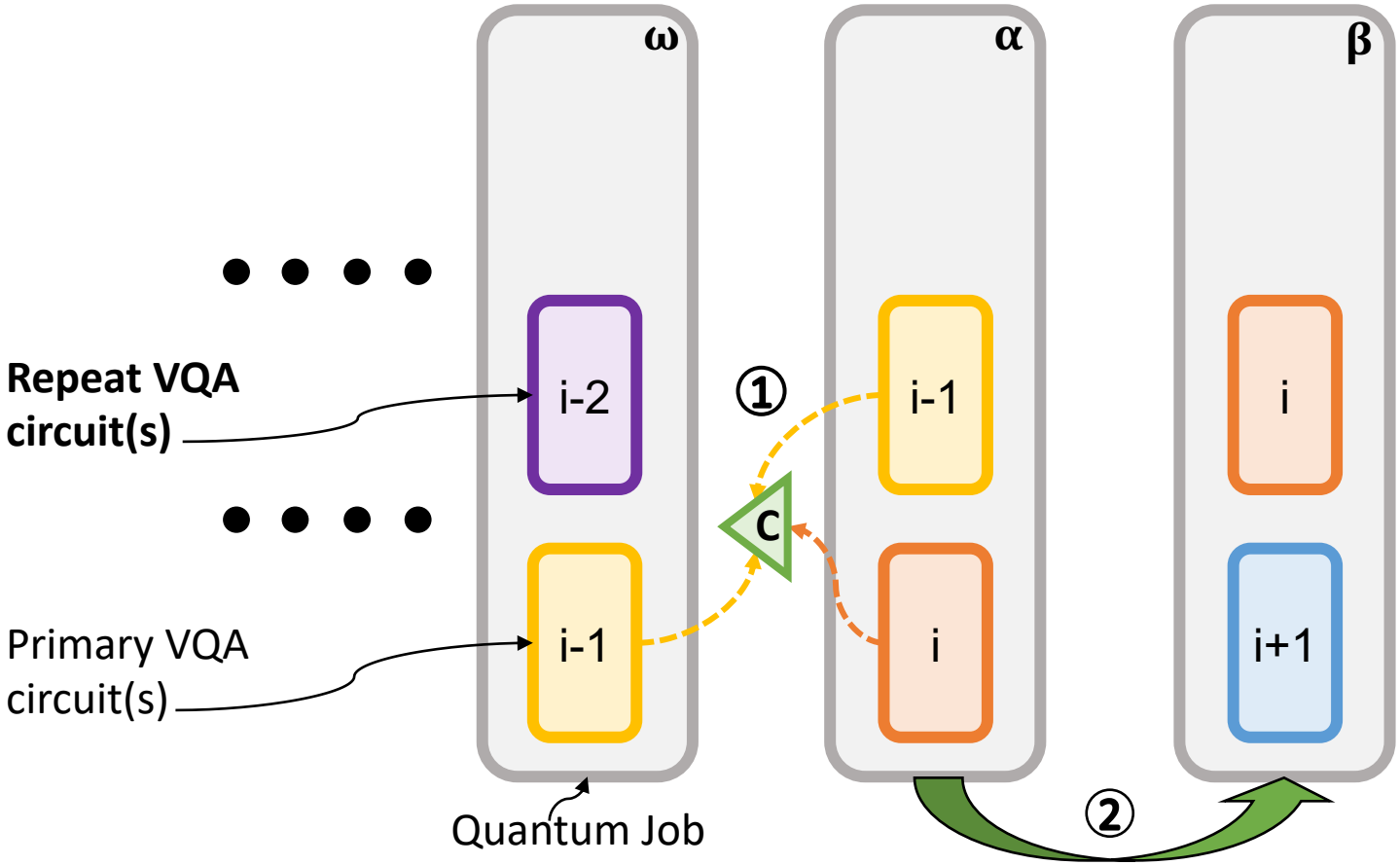

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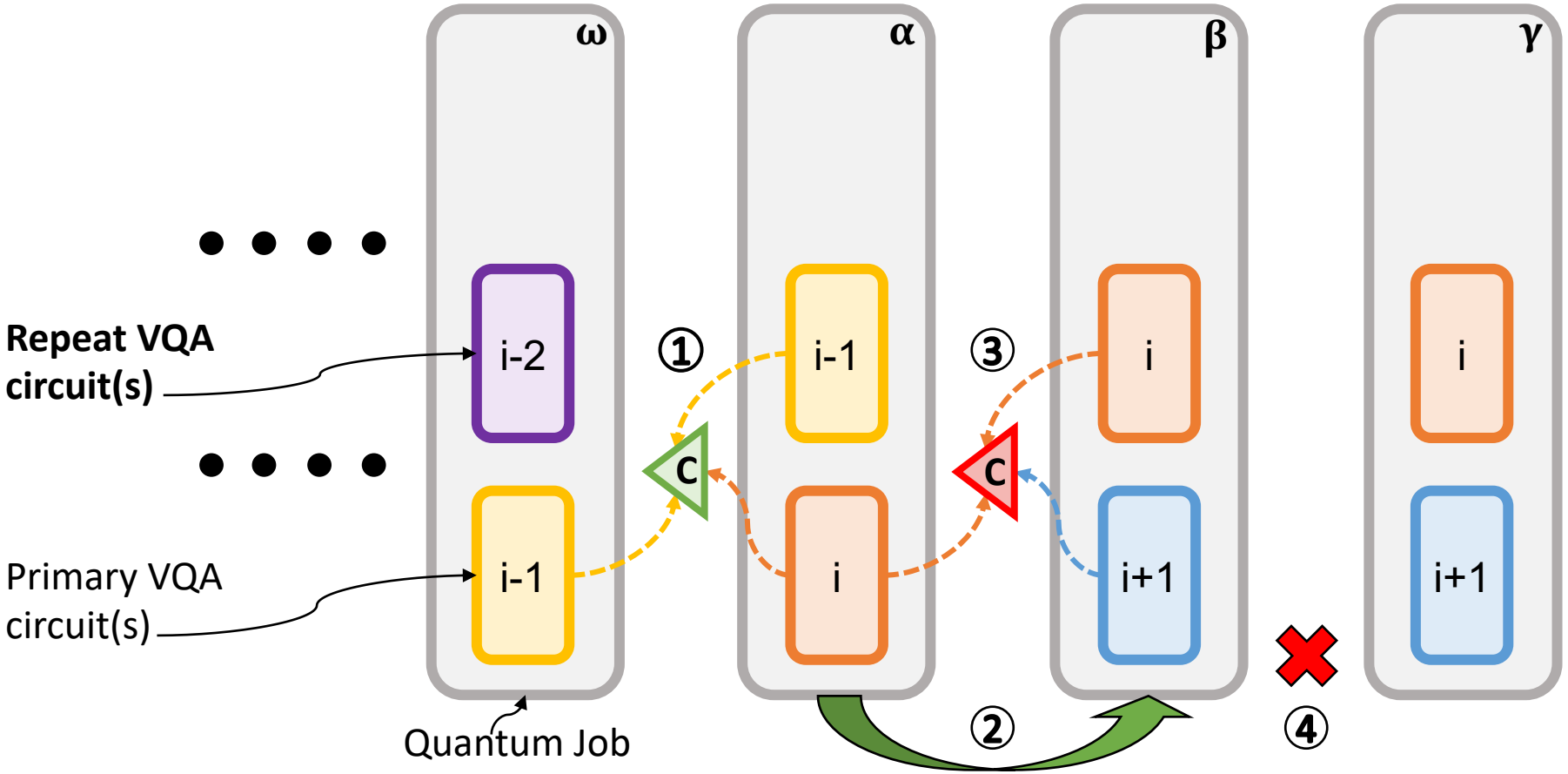

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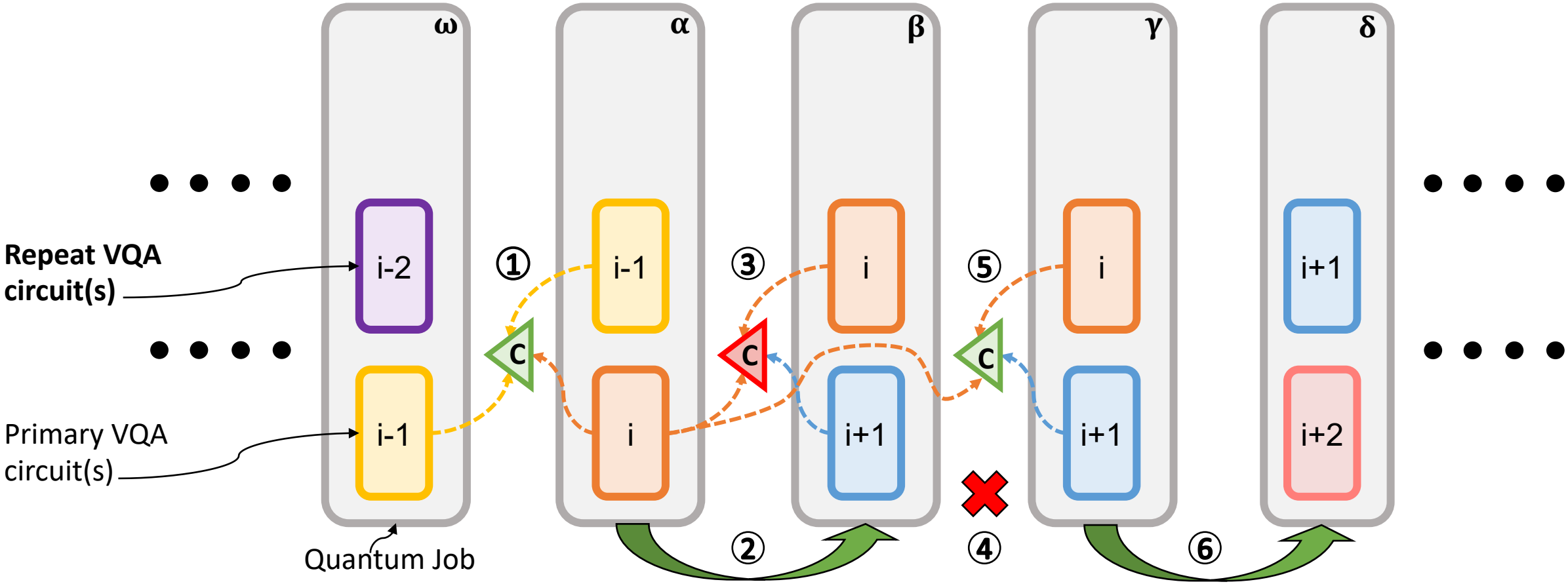
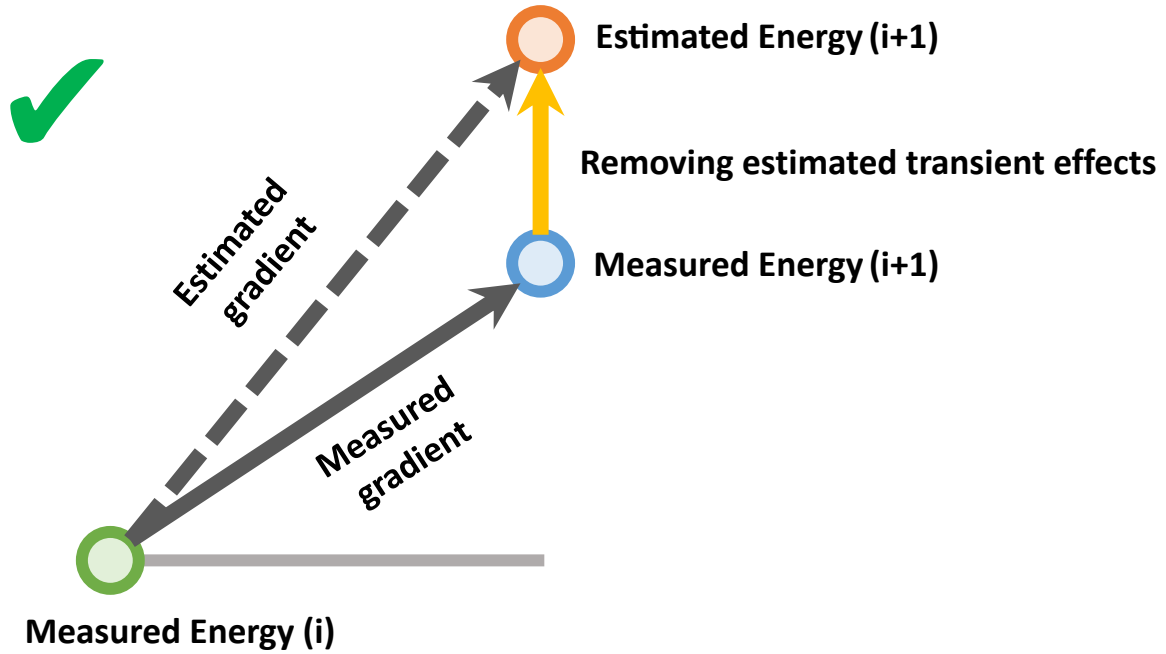
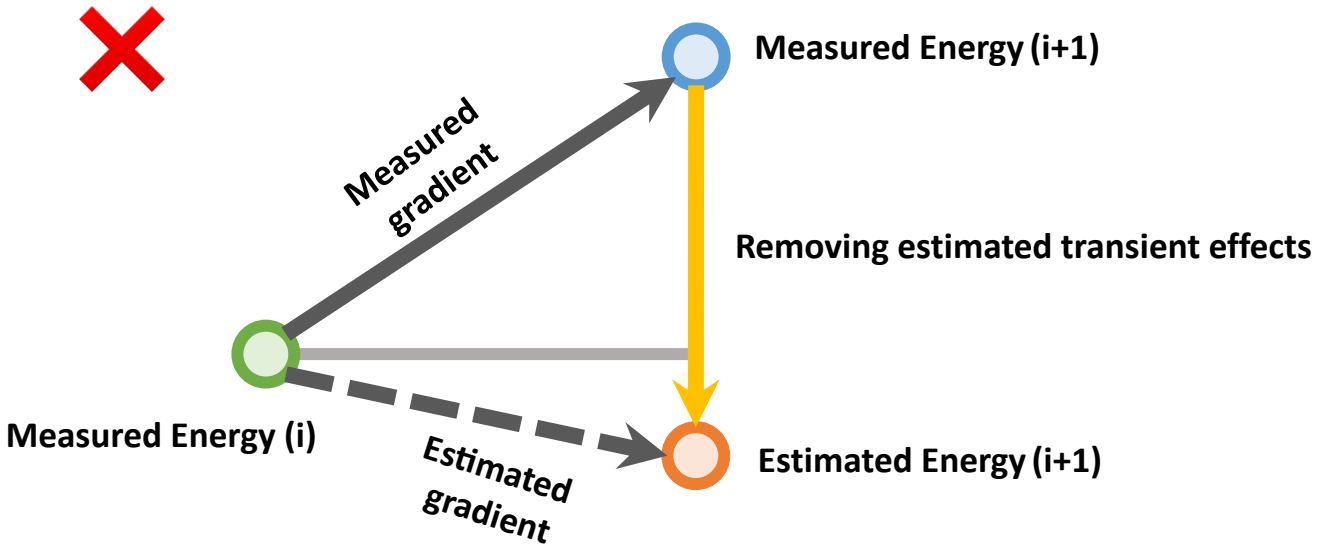


QISMET gradient faithful controller



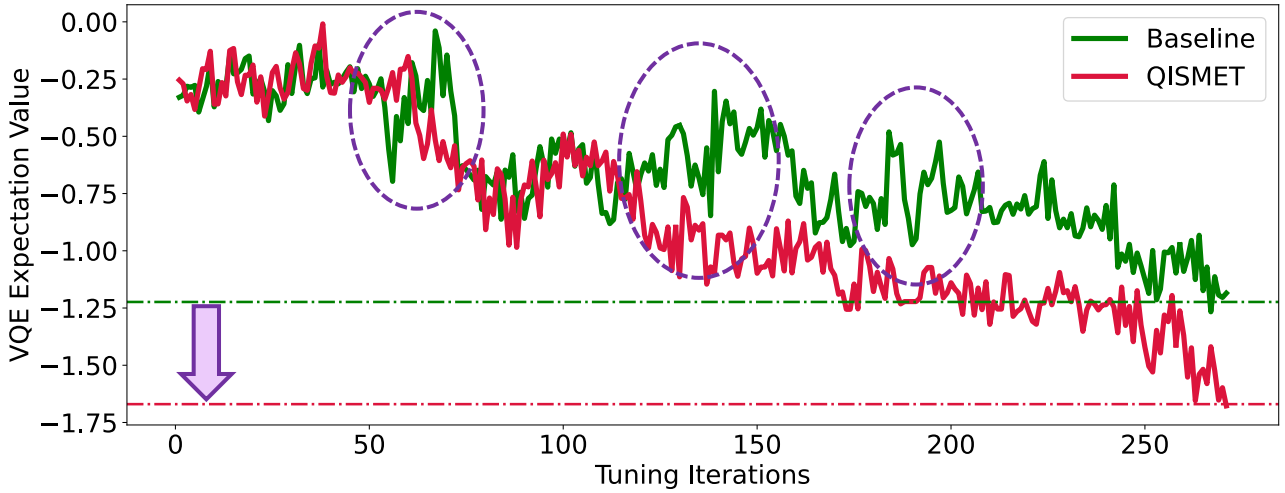
Estimated and Measured gradients are both positive: Ideal gradient very likely to be positive.
STRONG ACCEPT

QISMET gradient faithful controller

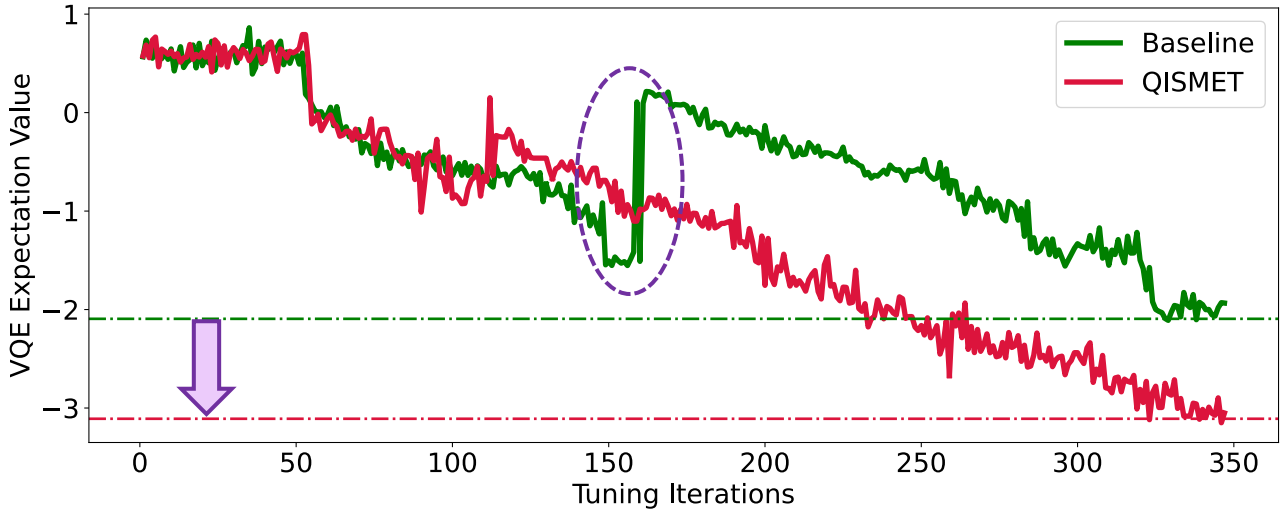


Estimated gradient is negative and Measured gradients is positive: Ideal gradient positive/negative unknown.
WEAK REJECT (MAJOR REVISION)

QISMET benefits on real quantum machines

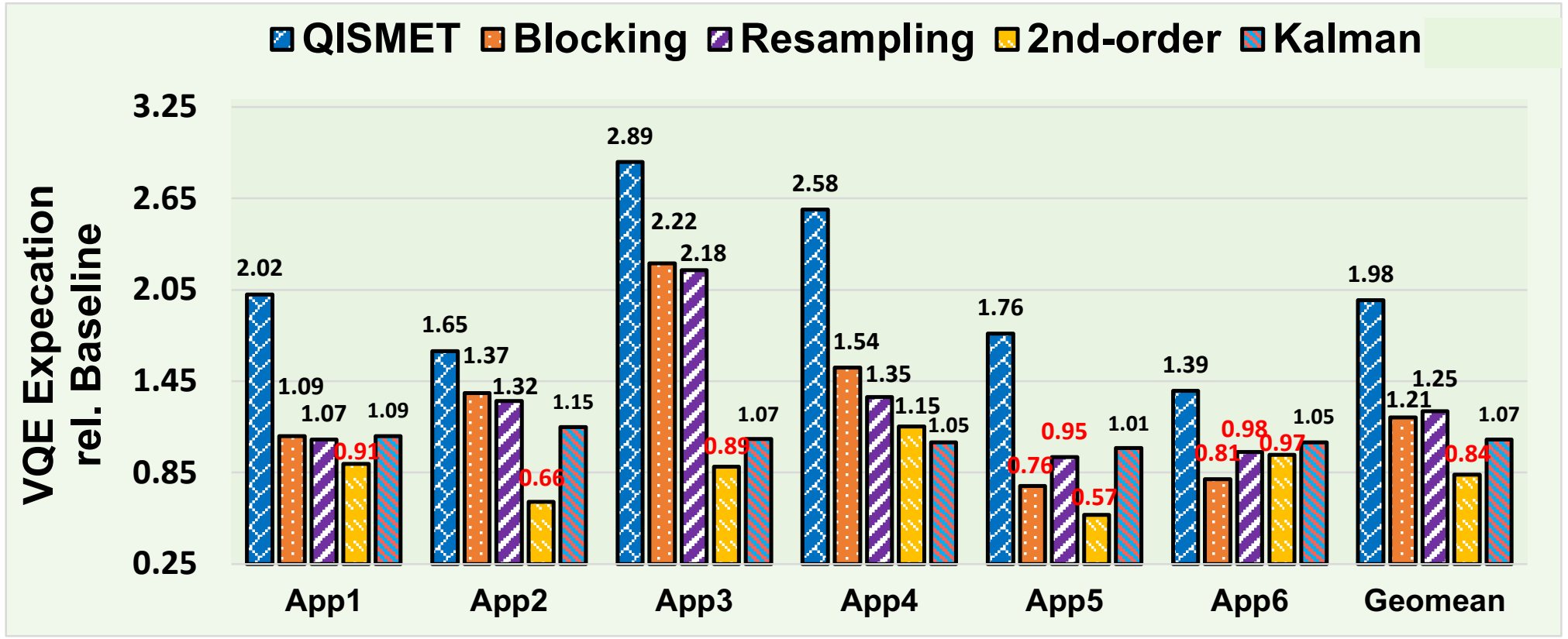


6-qubit TFIM VQA on IBMQ Guadalupe run over a 48-hour period

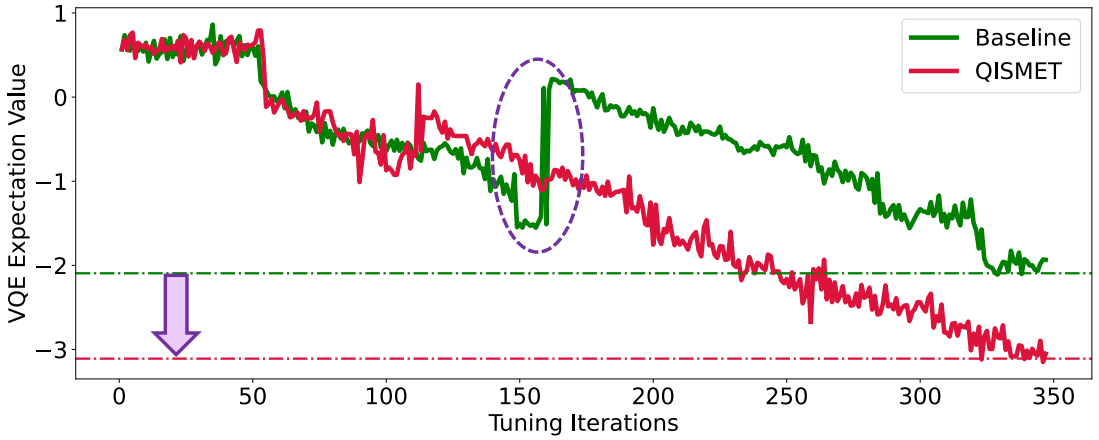


6-qubit TFIM VQA on IBMQ Sydney run over a 48-hour period

QISMET benefits on simulated quantum machines



Key Takeaways



1. **First to study transient error effects and mitigation on VQA.**
2. **QISMET actively avoids instances of high fluctuating noise which have a significant impact on VQA accuracy/convergence.**
3. **QISMET estimates transient error in VQA iterations and designs a controller to keep the VQA iteration gradients faithful to the transient-free scenario.**
4. **QISMET improves VQA fidelity by 1.3x-3x over a traditional VQA, with 1.6-2.4x improvement over other approaches.**

Thank you!

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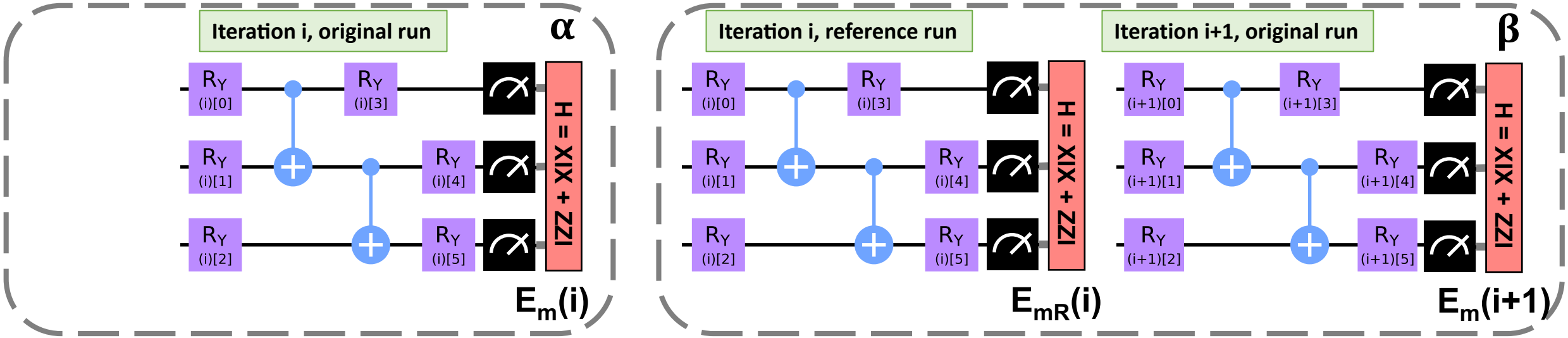
CCF-1730082/1730449, NSF Phy-1818914, NSF 2110860 , DOE (Accelerated Research for Quantum Computing Program), NSF OMA-2016136, Q-NEXT DOE NQI Center, CIF (NSF 2030859) , IBM/CQE Postdoc Fellowship, NSF (grants CCF-2119184, CNS-1956180, CNS-1952050, CCF-1823032, CNS-1764039), ARO (grant W911NF1920321), DOE Early Career Award (grant DESC0014195 0003), NSF Grant DGE-1842474.

Gradient estimations in QISMET



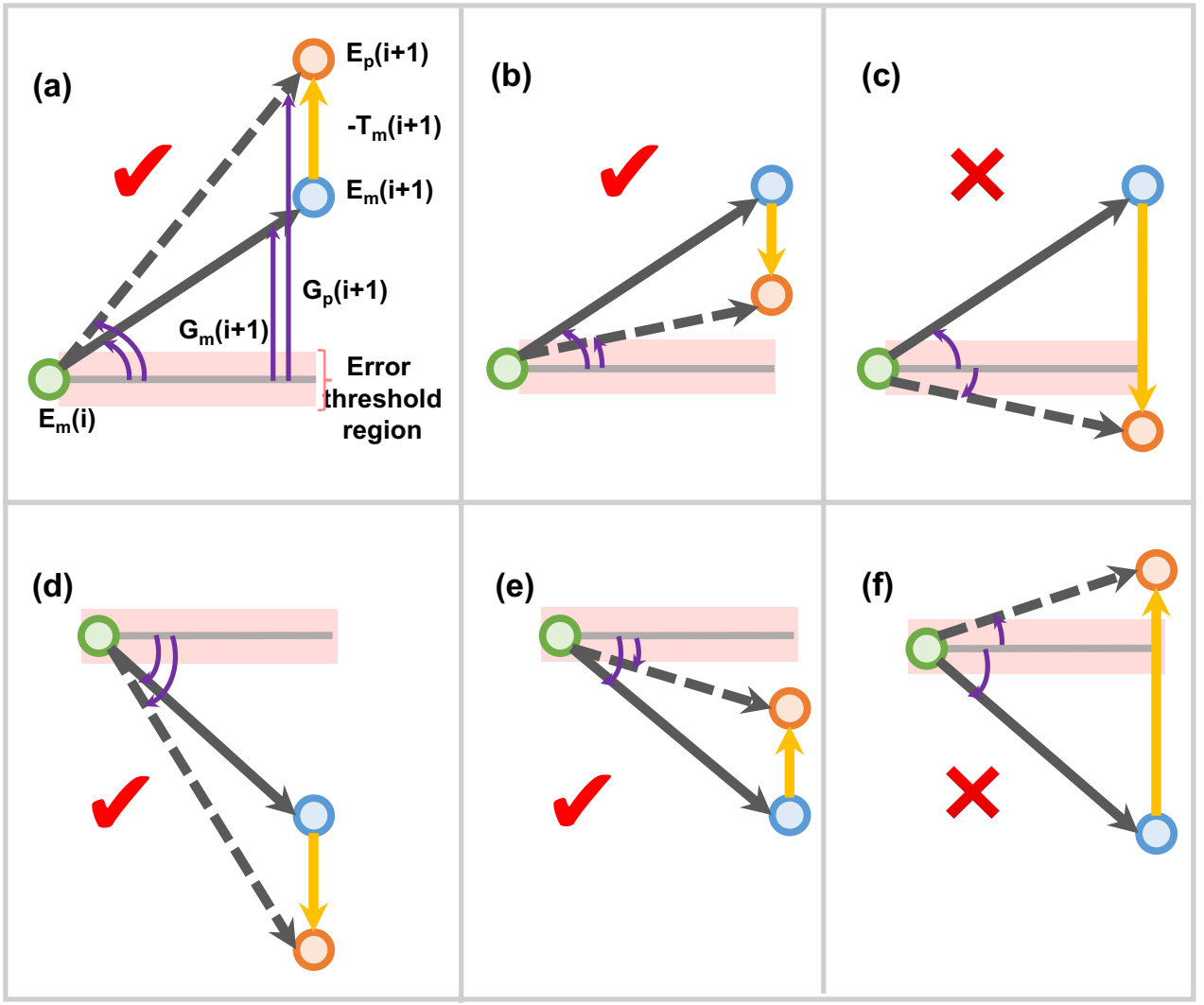
$$G_m(i+1) = E_m(i+1) - E_m(i)$$

$$T_m(i+1) = E_{mR}(i) - E_m(i)$$

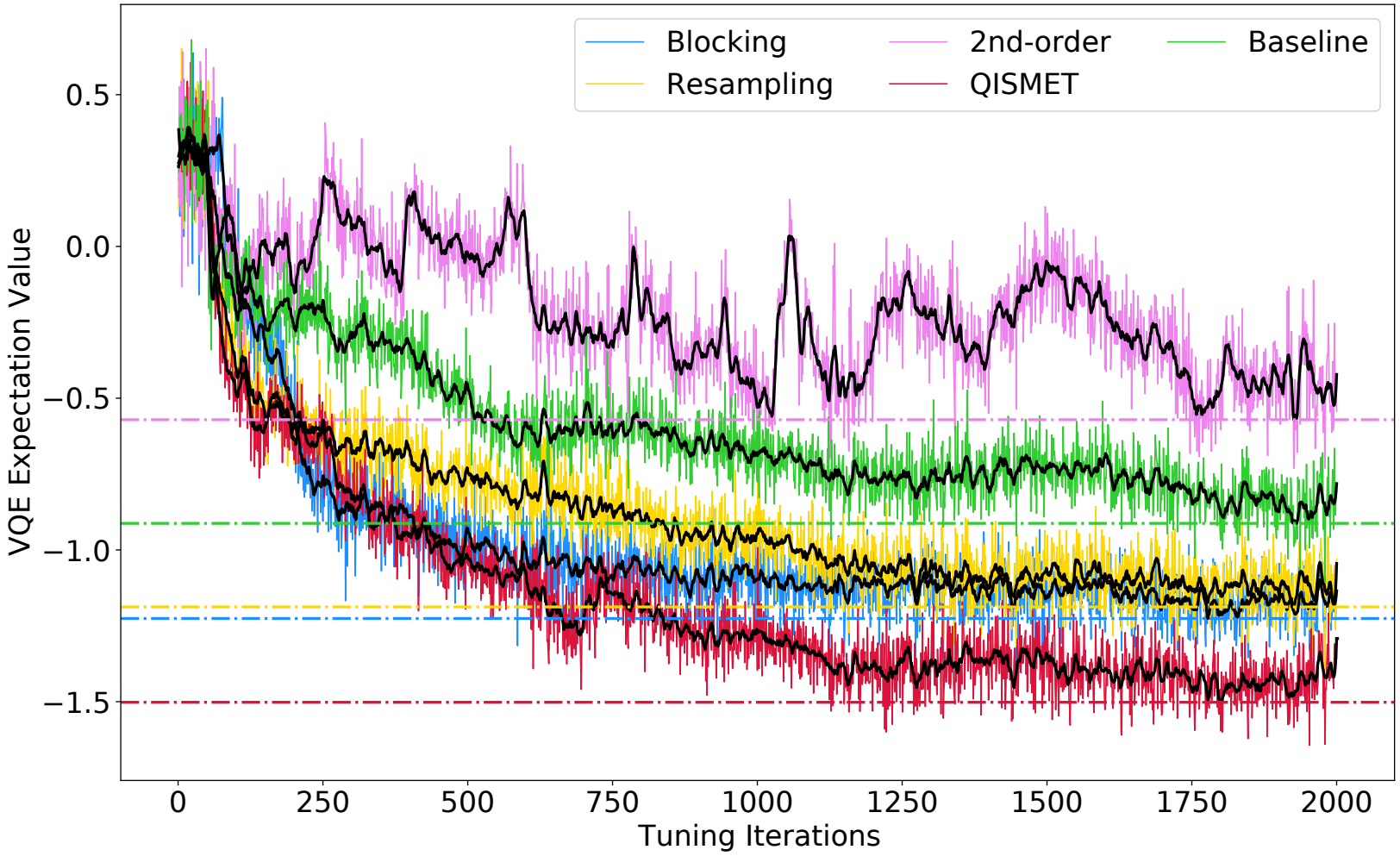
$$E_p(i+1) = E_m(i+1) - T_m(i+1)$$

$$G_p(i+1) = E_p(i+1) - E_m(i)$$

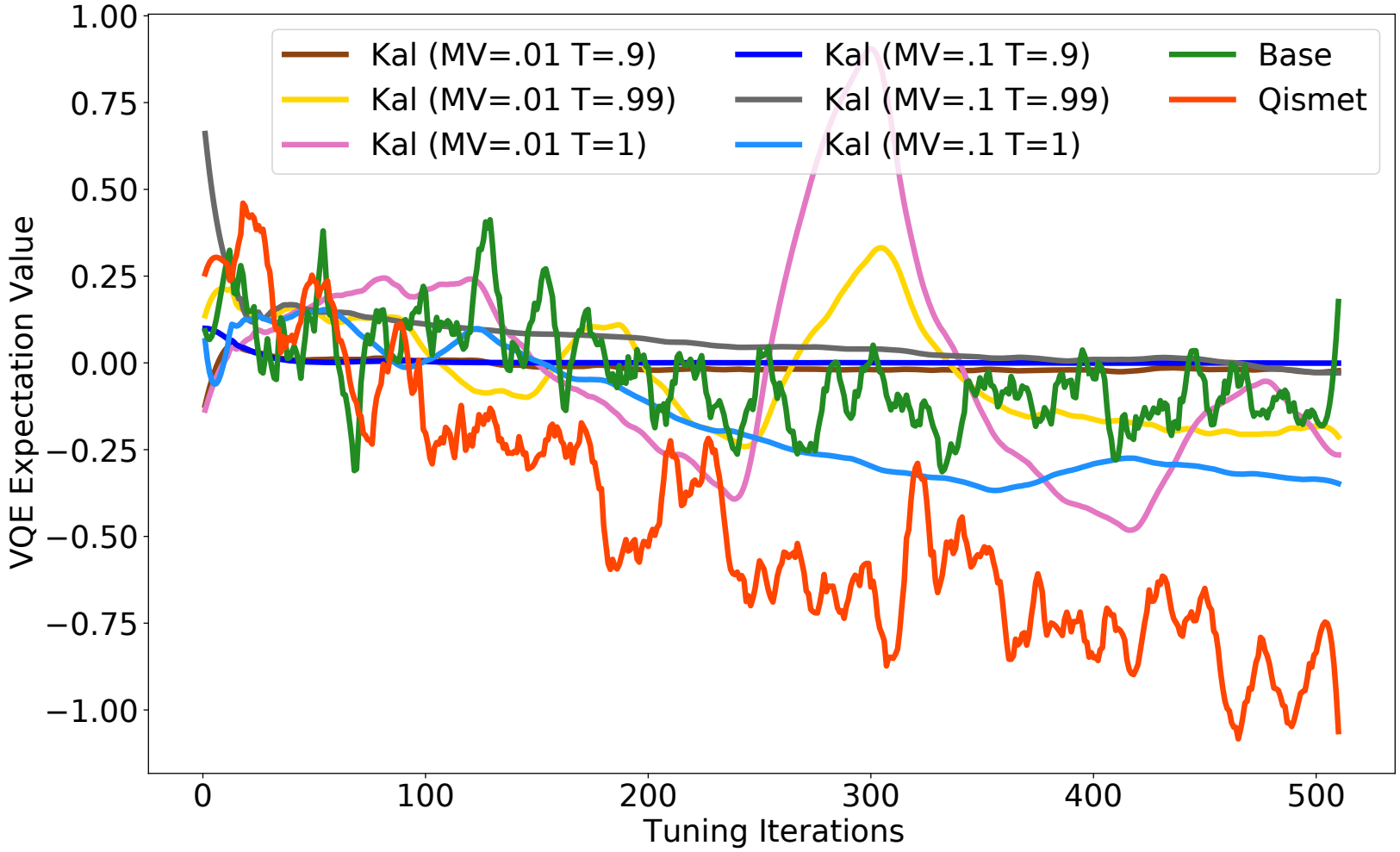
QISMET gradient faithful controller



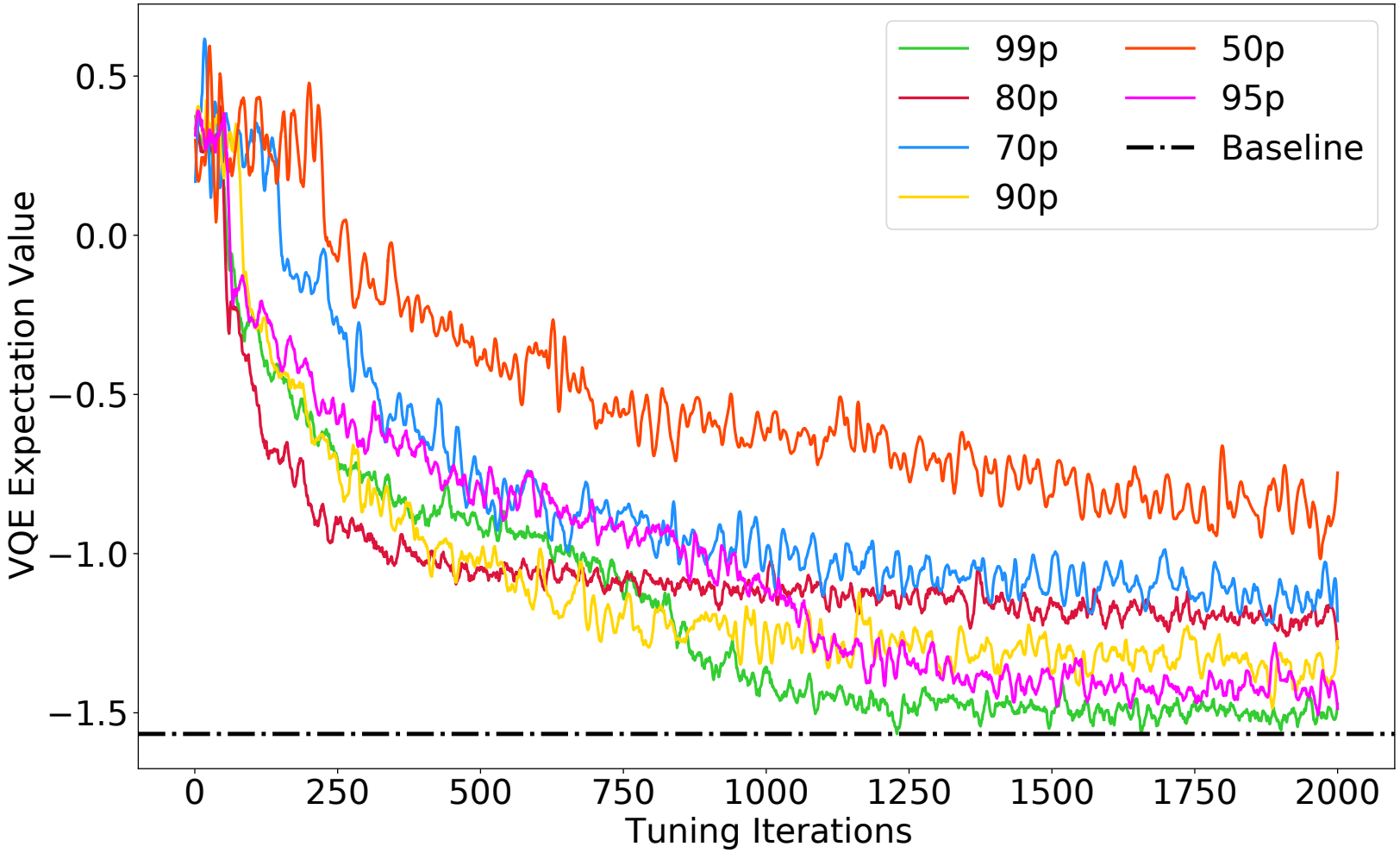
QISMET benefits on simulated quantum machines



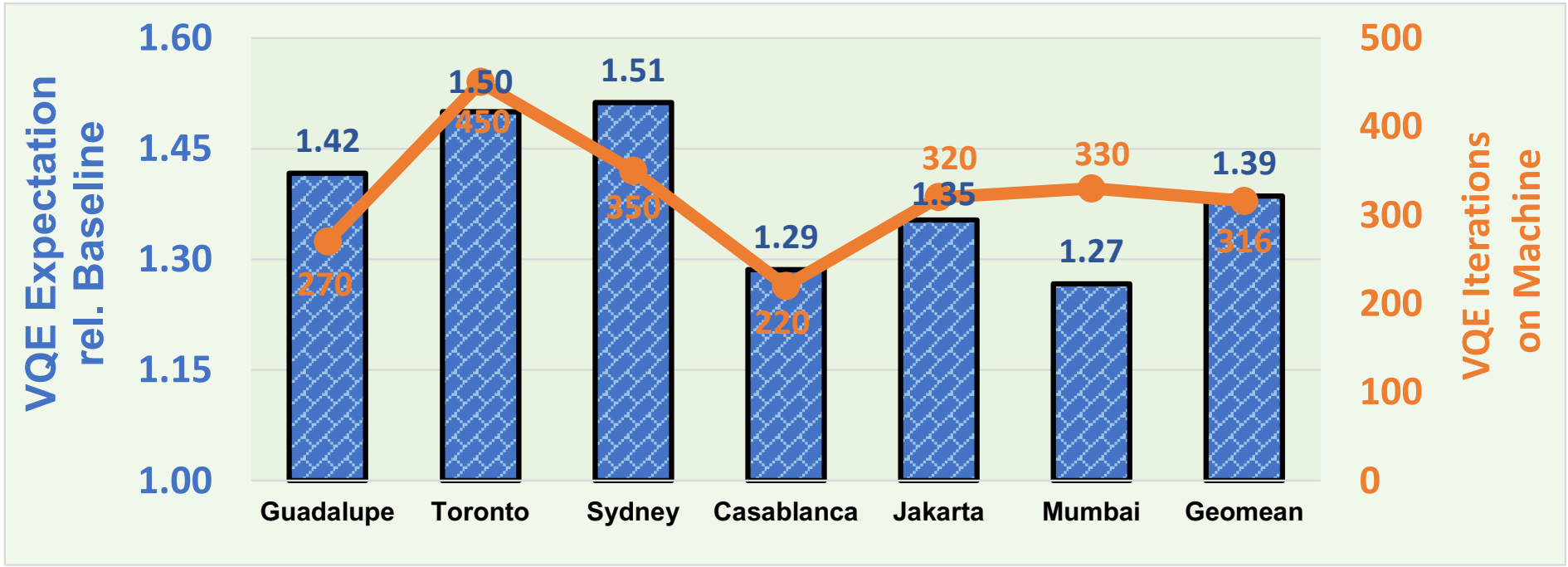
QISMET vs. Kalman



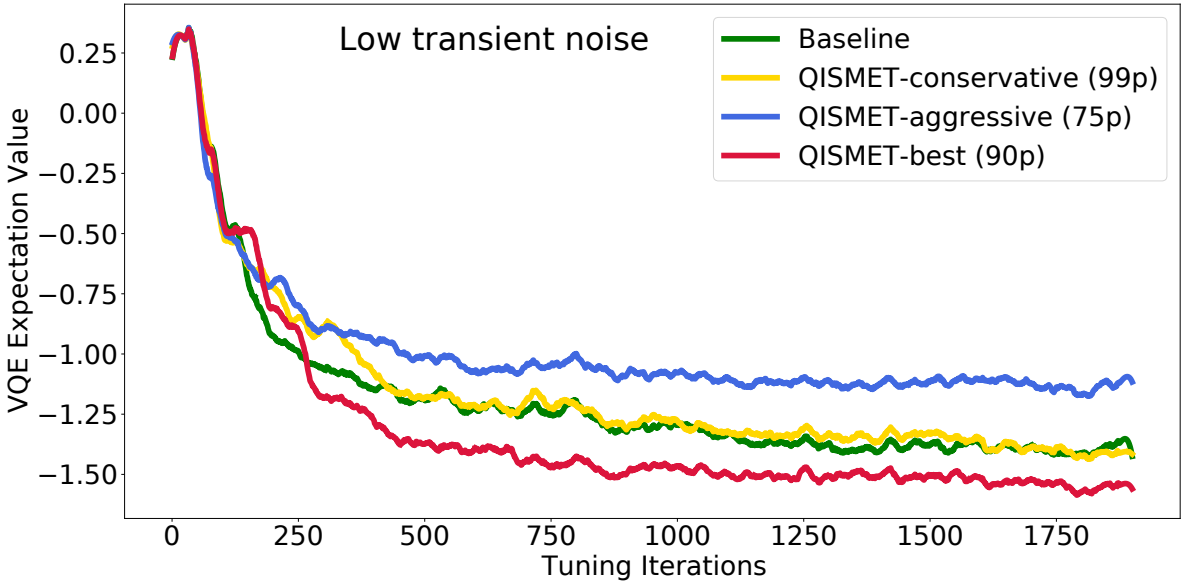
Pure transient error skipping

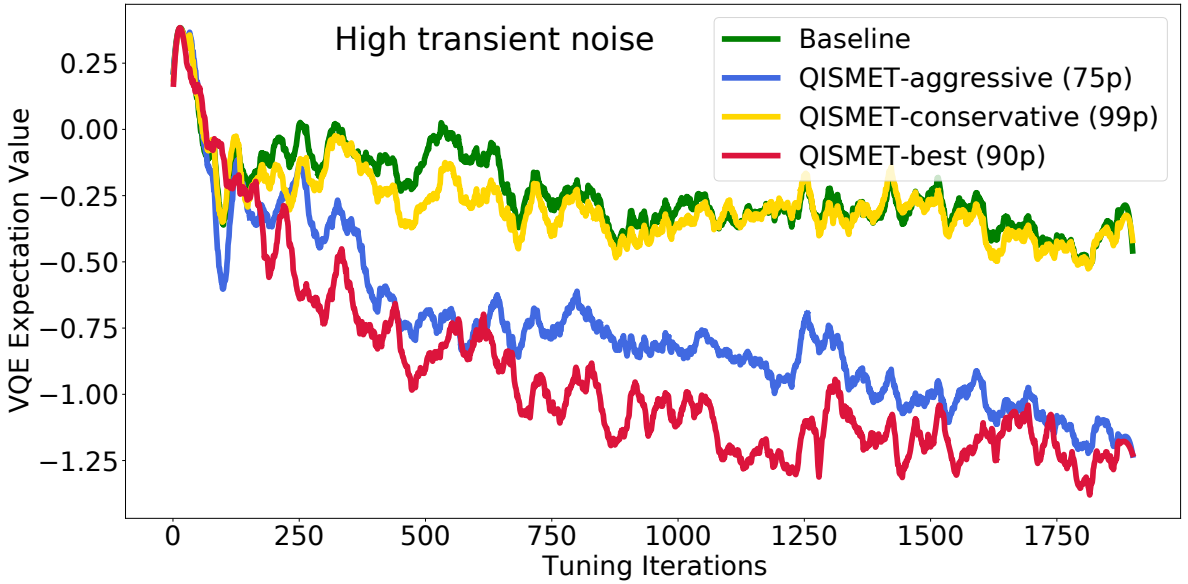


More real machines



Tuning the threshold





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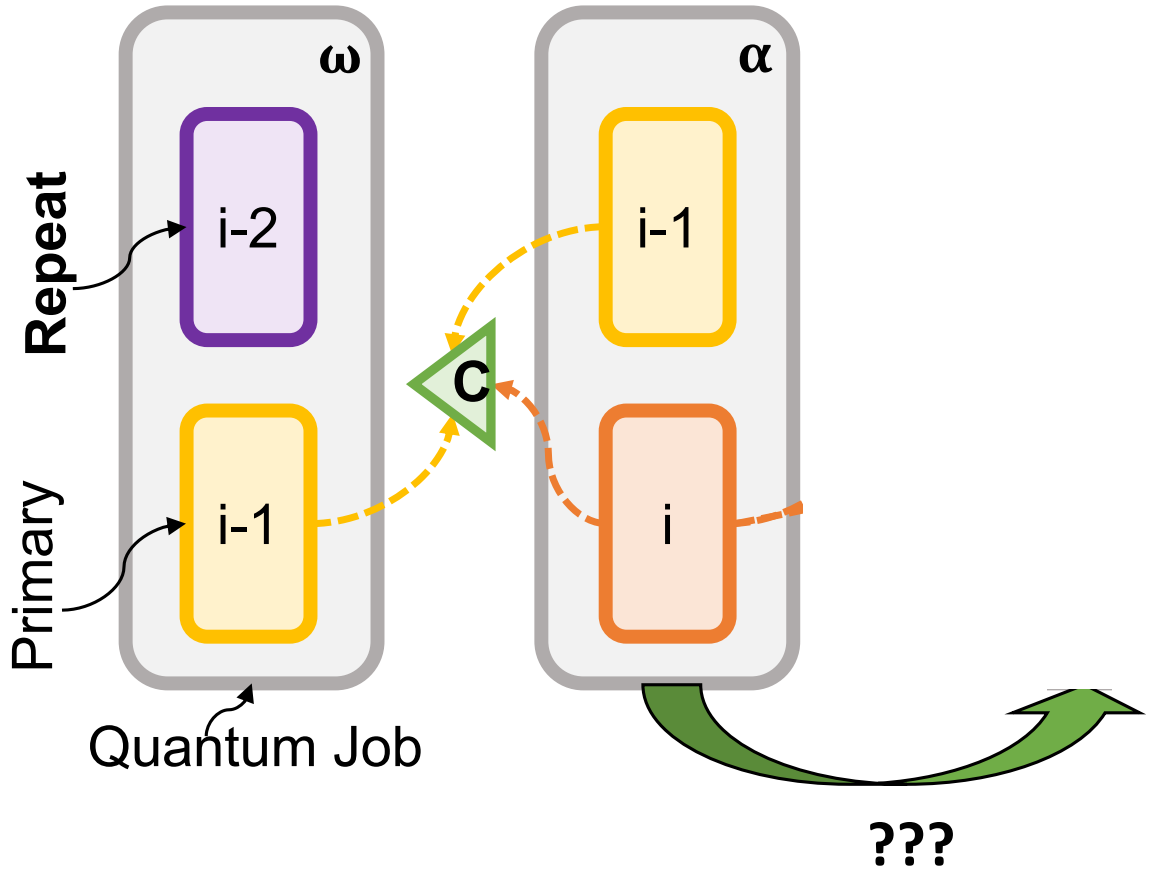

QISMET: Quantum Iteration Skipping to Mitigate Error Transients