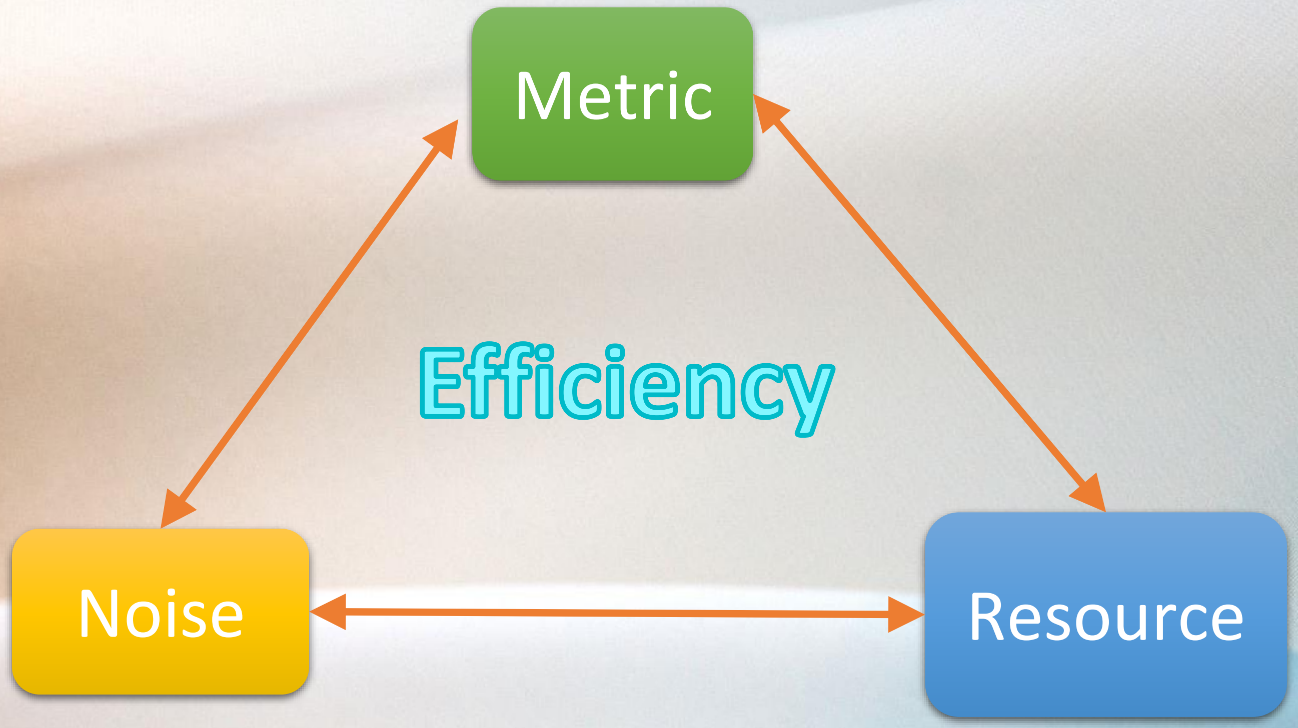

Energetic Analysis of VQE

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TCQI Seminar

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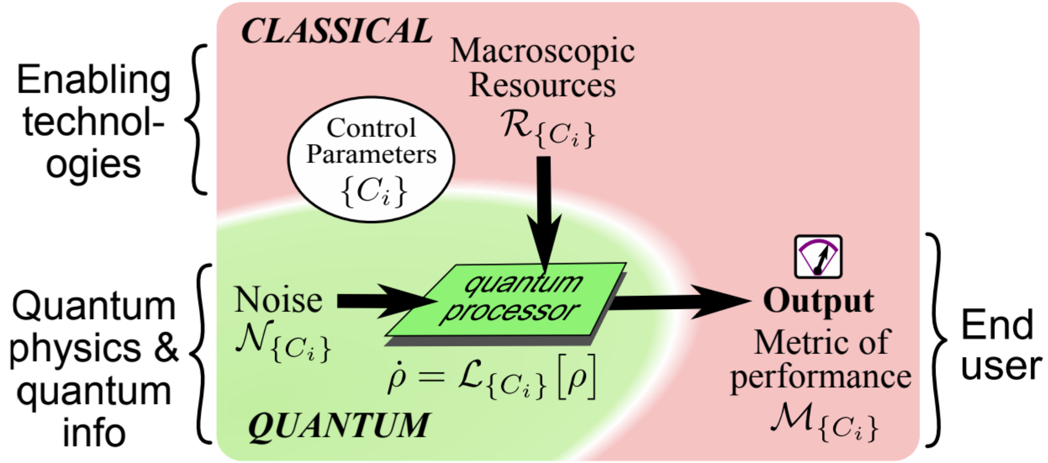
MNR Overview

- Usually more **resources** → Better results (**Metric**).
- **Efficiency, η = Metric / resources**.
- Ascertain Metric and Resource in the presence of noise: **NISQ.**
- Optimize over various control/ physical/ other parameters to find points of maximal efficiency.
- Schematic of a noisy computation on a quantum processor[1]



[1] Fellous-Asiani, M., Chai, J. H., Thonnart, Y., Ng, H. K., Whitney, R. S., & Auffèves, A. (2023). Optimizing Resource Efficiencies for Scalable Full-Stack Quantum Computers. PRX Quantum, 4(4), 040319.

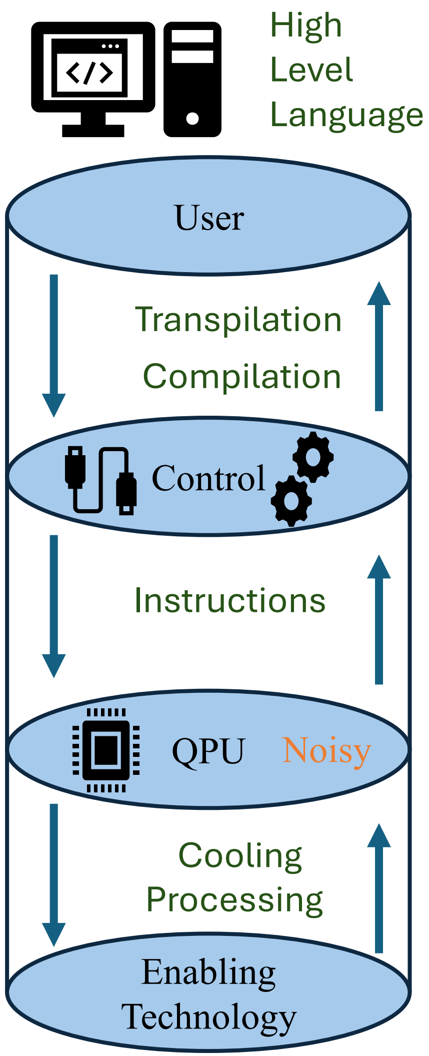
MNR framework in quantum computer

- **Metric, resource and efficiencies** can be defined independently for any level of the stack.

Level	Metric	Parameters affecting the metric and resource
Component (Gate)	Gate fidelity	Enabling tech, qubit quality, control system
System (Circuit)	Circuit fidelity, success rate	All of the above, Compilation, transpilation
User (Algorithm)	1 - Error in the ground state energy of molecule	All of the above, choice of algorithm, post-processing

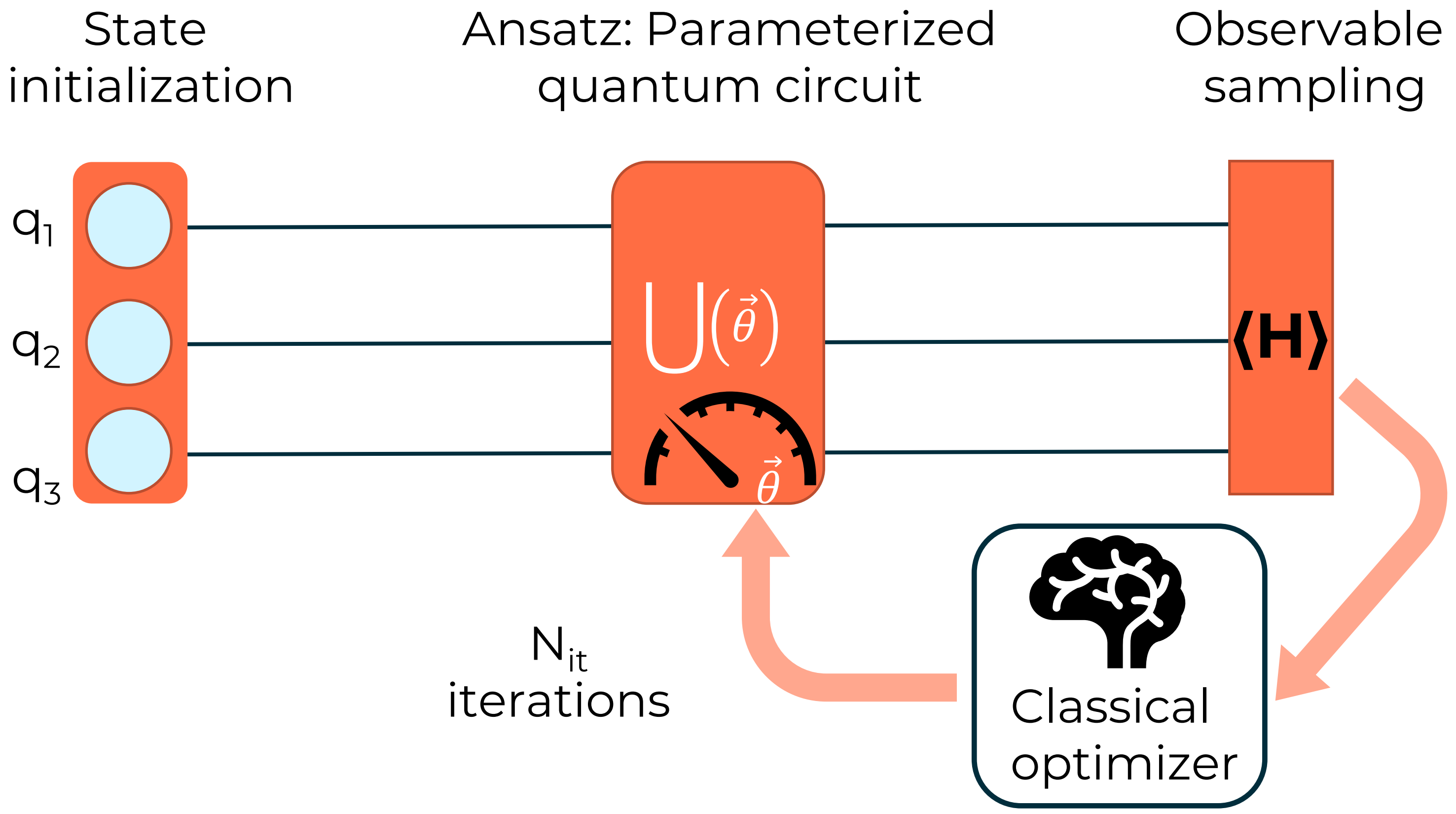
- Noise originating at the component level affects the resource-metric landscape at all the levels. E.g. decoherence, crosstalk etc.

- Energy consumption is a resource measure suited for at all levels or even the complete stack.



A Simple 4-Stack Model of a quantum computer

Variational Quantum Eigensolver (VQE) : MNR perspective



Resources

- Number of VQE iterations : N_{it}
- Number of gates : N_g

Metric

- Accuracy of the GS energy

Noise

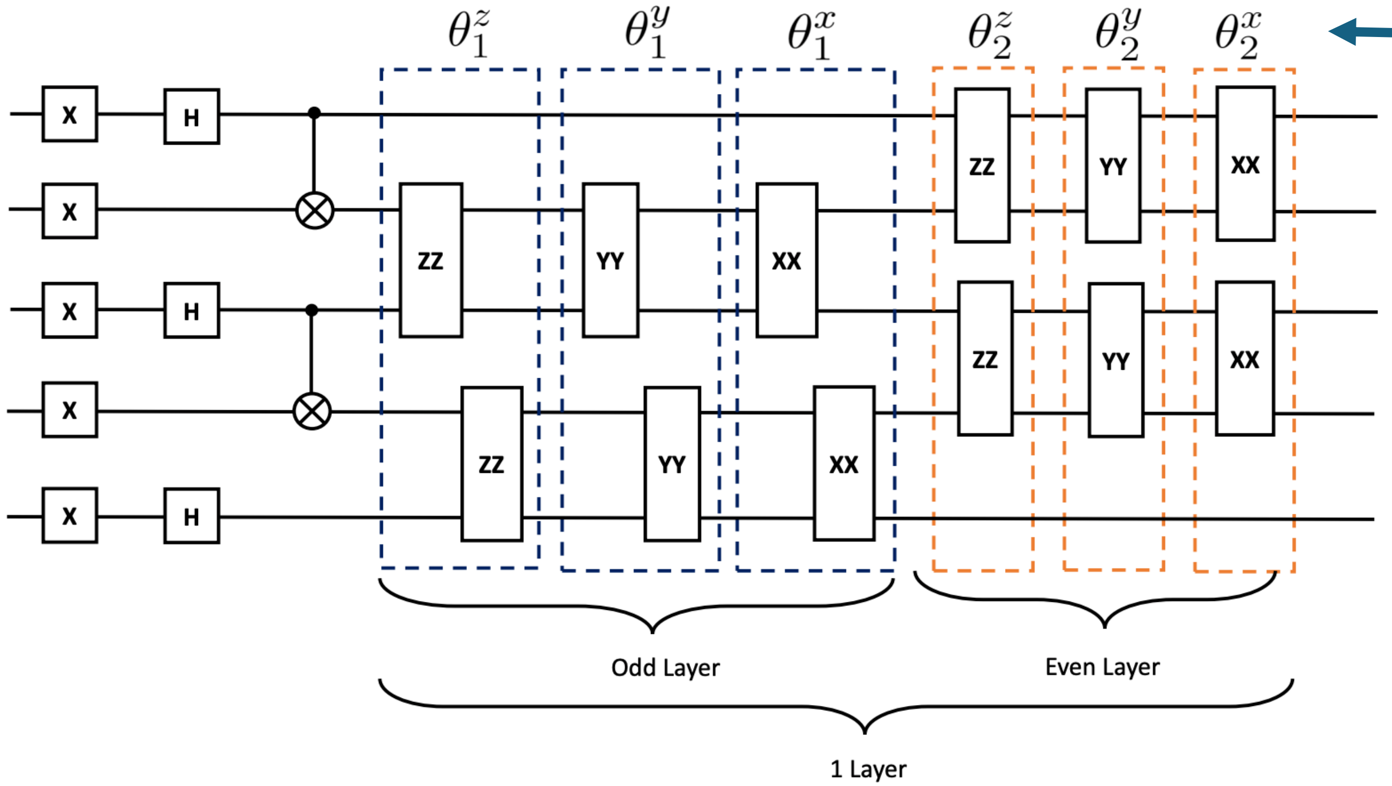
- Global depolarizing noise

Variational principle: $\langle \psi_0 | U^\dagger(\theta) H U(\theta) | \psi_0 \rangle \geq E_{\text{gs}}$

VQE for Heisenberg model: Hamiltonian Variational Ansatz

$$H = J \sum_{i=1}^{n} S_i^x S_{i+1}^x + S_i^y S_{i+1}^y + S_i^z S_{i+1}^z$$

State preparation



Optimizer

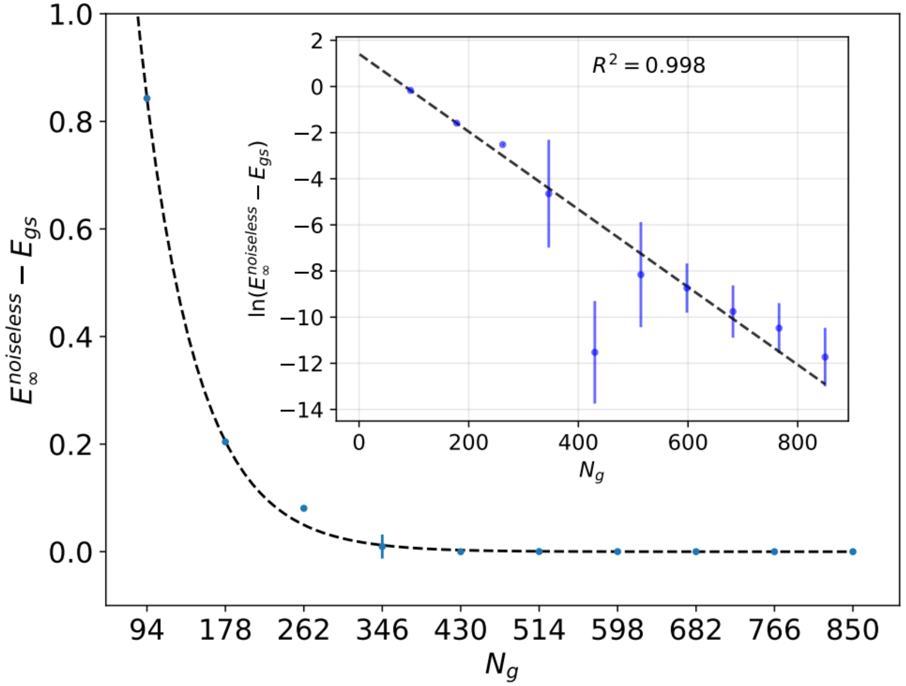
Observable sampling

[2] Wiersema, R., Zhou, C., de Sereville, Y., Carrasquilla, J. F., Kim, Y. B., & Yuen, H. (2020). Exploring Entanglement and Optimization within the Hamiltonian Variational Ansatz. PRX Quantum, 1(2), 020319.

VQE : Typical phenomenology

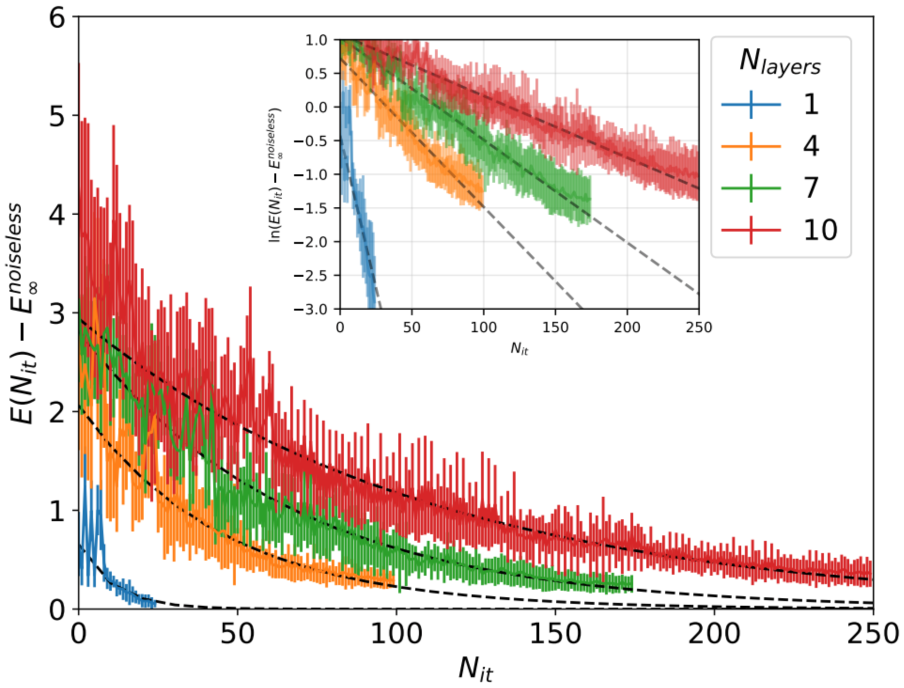
Rel^n 1 : Resource (N_g) vs converged energy

$$E_\infty^{\text{noiseless}}(N_g) = \beta e^{-\kappa N_g} + E_{gs}$$



Rel^n 2 : Resource (N_{it}) vs calculated energy

$$E(N_{\text{it}}, N_g) = \alpha e^{-\mu(N_g) N_{\text{it}}} + E_\infty^{\text{noiseless}}(N_g)$$

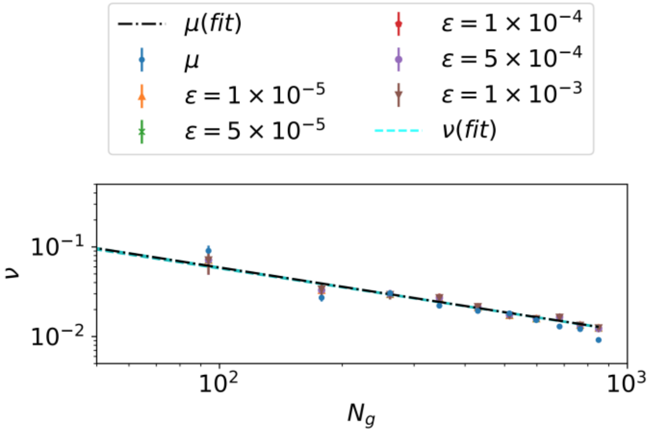


Rel^n 3 : Noise model

Global depolarizing Noise

$$E_{noisy}(\theta) = \left[(1-\epsilon)^{\mathcal{N}}\right] \operatorname{Tr}(U(\theta)\rho U(\theta)^\dagger) + \left[1-(1-\epsilon)^{\mathcal{N}}\right]\frac{\operatorname{Tr}(H)}{2^n}$$

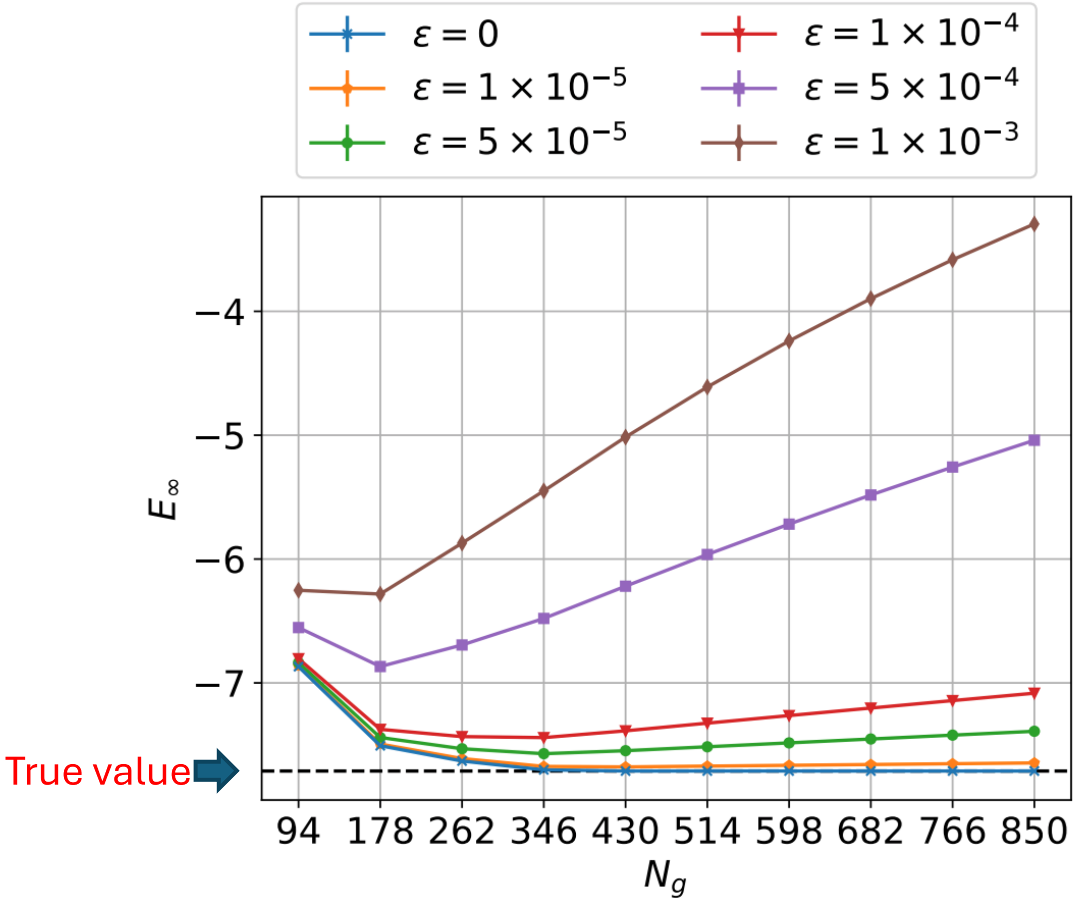
$$\mu\ (N_g) = \mu_0\ N_g^{-\lambda}$$



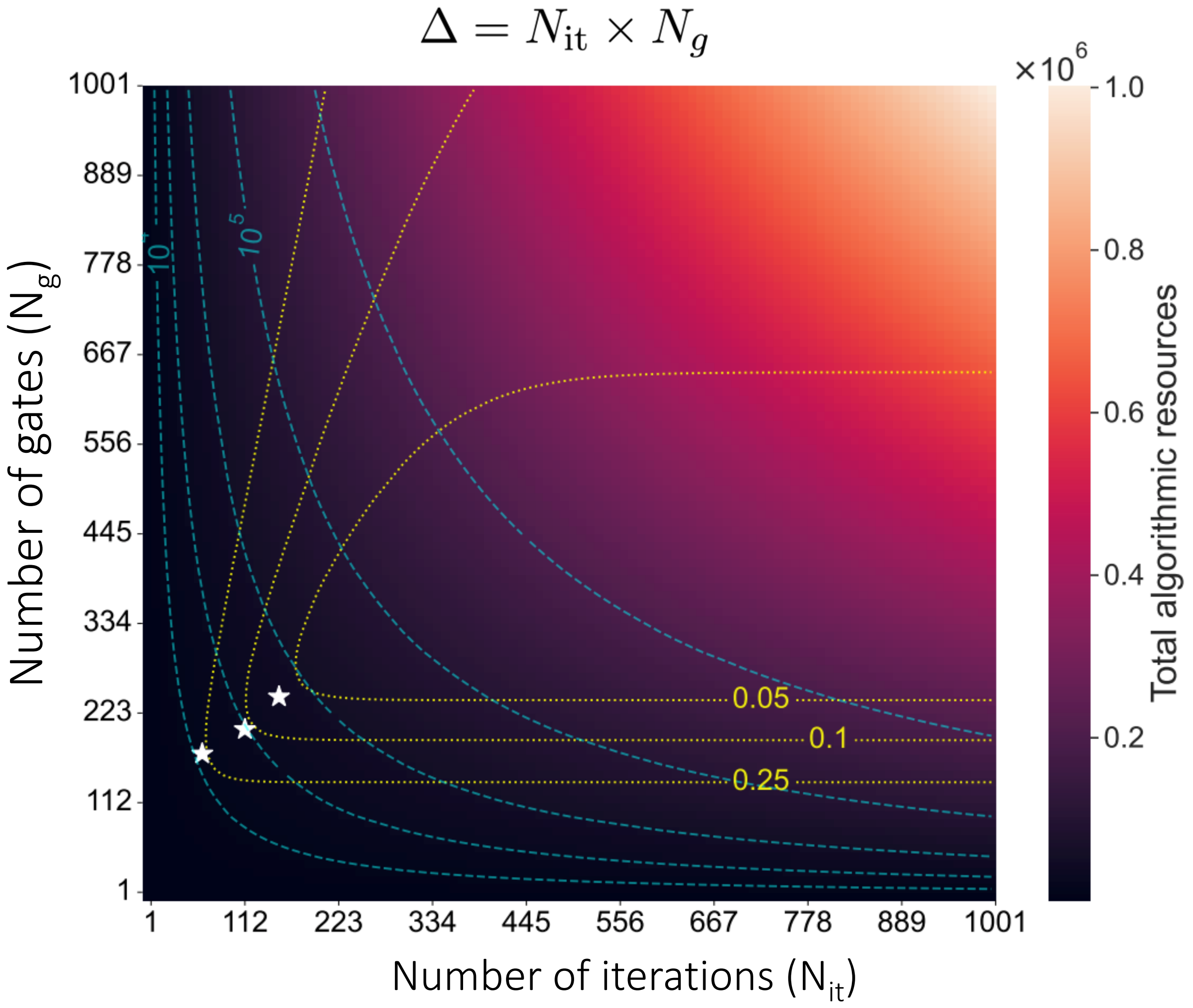
VQE : Tradeoff

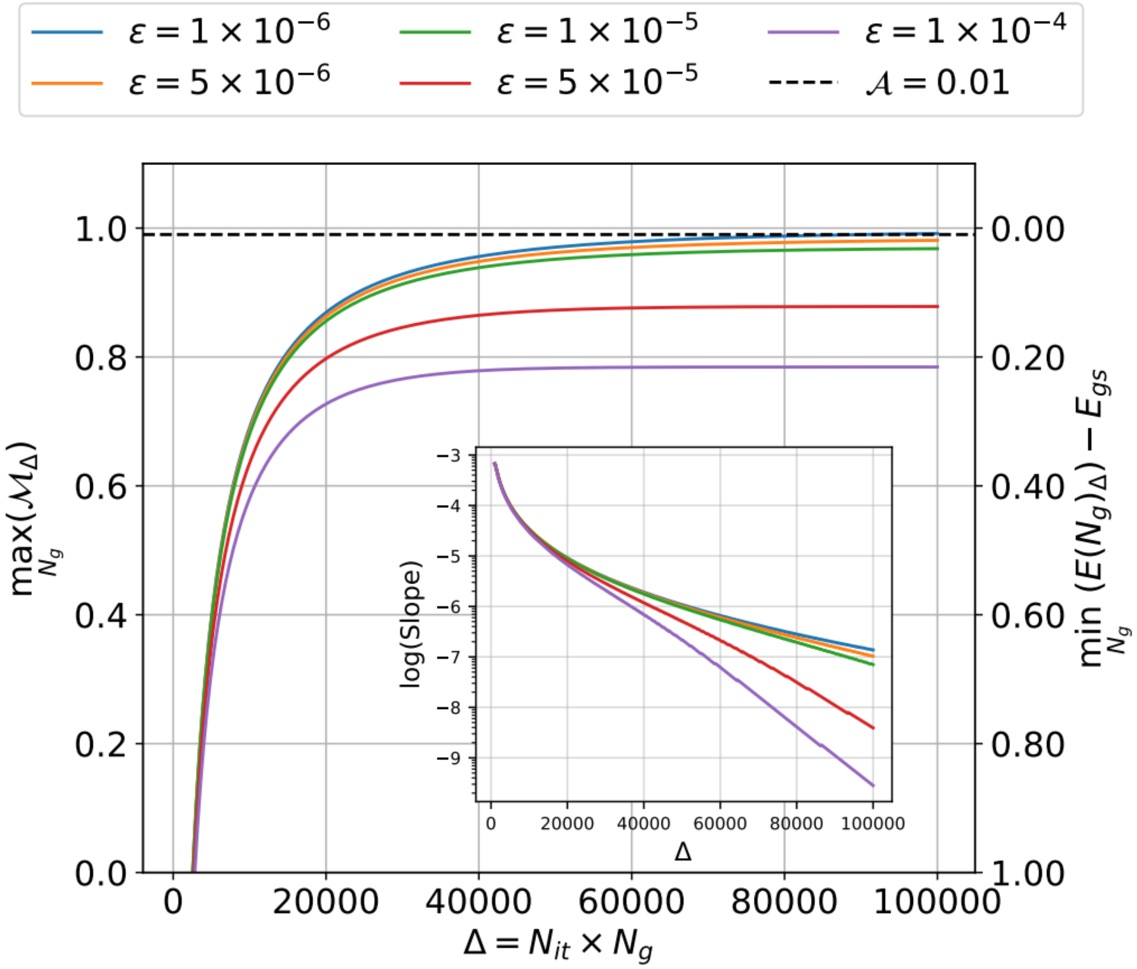
Converged value of ground state energy under noise

$$E_{\infty}^{\text{noisy}}(N_g) = \left[(1-\epsilon)^{N_g}\right](\beta e^{-\kappa N_g} + E_{gs})$$



Optimizing resources using MNR

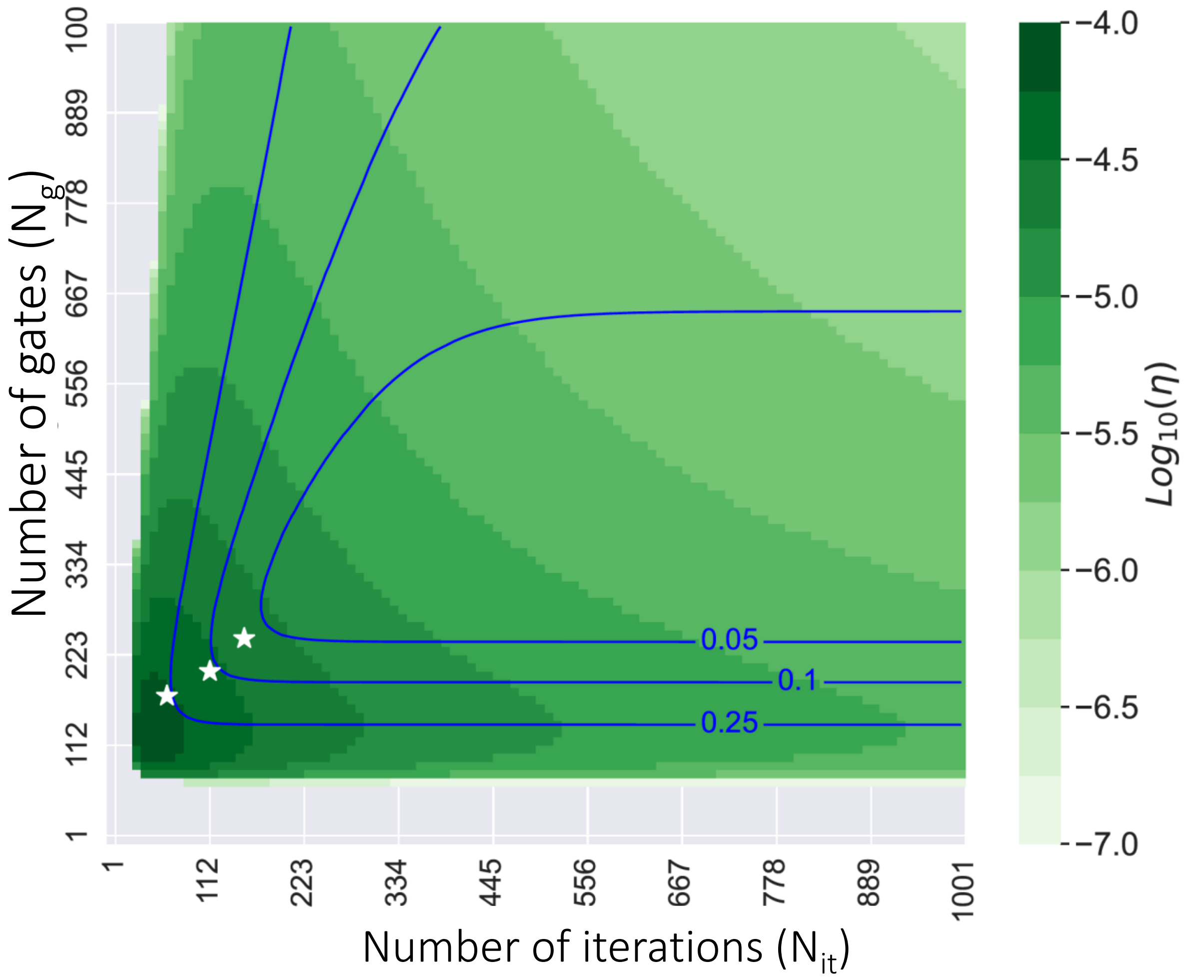




VQE for Heisenberg : Energy efficiency

Heatmap: Algorithmic Energy efficiency

$$\eta = \frac{1 - \text{Error}}{N_{\text{it}} \times N_g}$$



IEEE SA Working group

P3329 Quantum Energy Initiative

Title: Standard for Quantum Computing Energy Efficiency

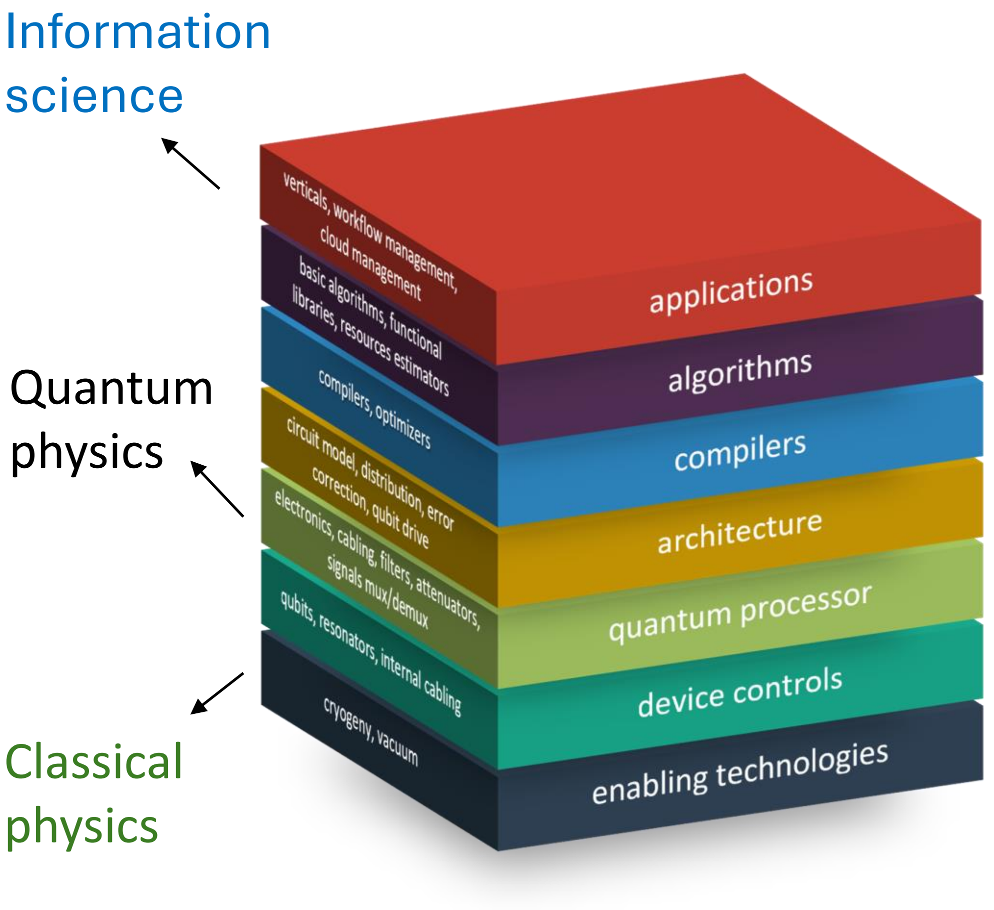
Scope: This standard defines energy efficiency metrics for quantum computing (gate-based, quantum annealing, quantum simulation). It compares the performance of the computation to its energy consumption. The performance is defined at the quantum level and at the end user level. The definition applies to all Quantum Bit (qubit) technologies, including the classical and quantum control chains, to various quantum processors, both Noisy Intermediate Scale Quantum (NISQ)-era and fault-tolerant, as well as to quantum annealers and simulators.

IEEE SA STANDARDS ASSOCIATION

#QEI
the quantum energy initiative

Energy efficiency for quantum computing

Energy efficiency = Metric of performance/Resource cost



Metrics of performance can be defined at various levels:

- End-user (Q-Score, quantum volume…) = related to a specific use-case (Shor, chemistry…)
- Low level (fidelity, probability of errors…) = related to a specific quantum process

$\Rightarrow$ We shall define a **parametric** standard = dependent on the class of task considered

$\Rightarrow$ To use as a benchmark, the same task should be considered

$\Rightarrow$ Examples:

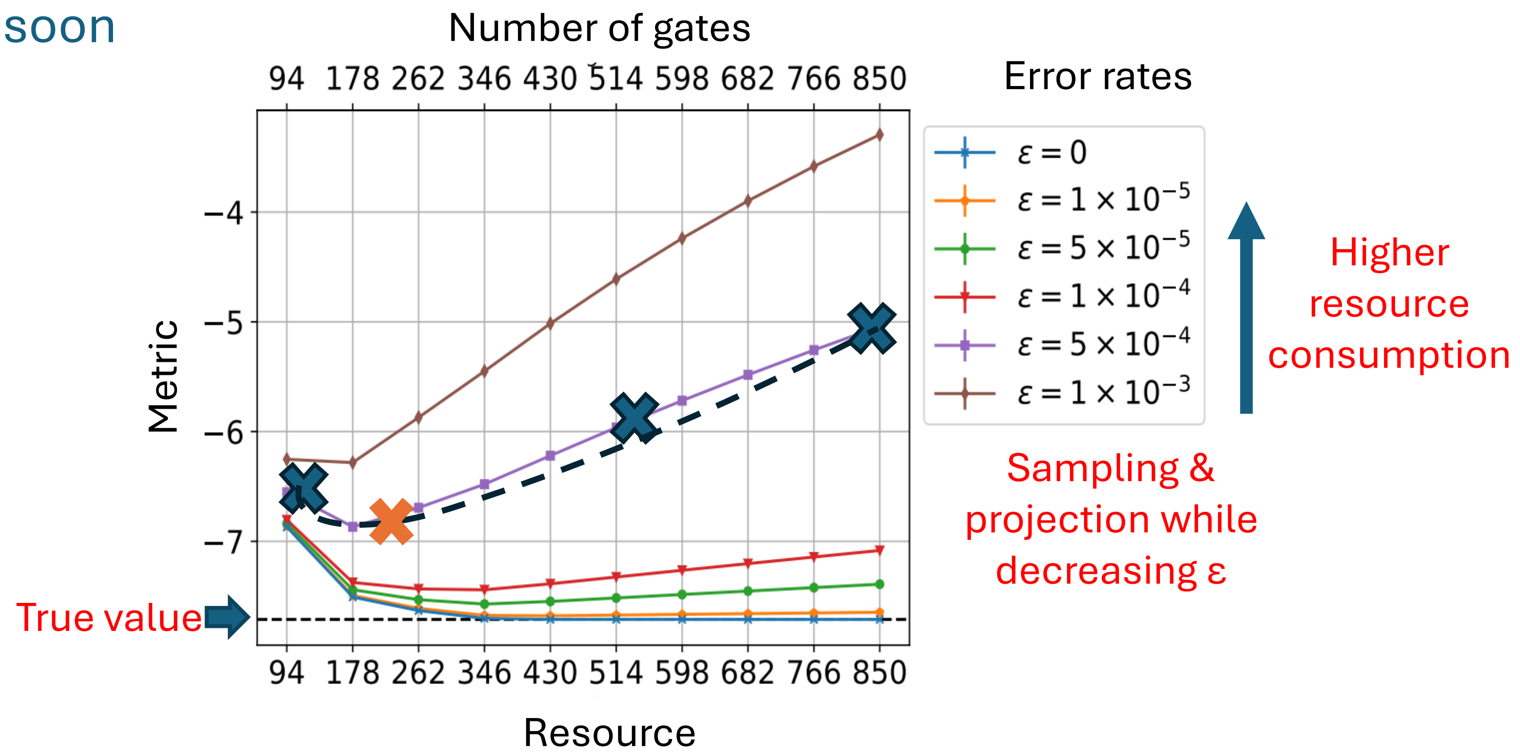
- $\Rightarrow$ Efficiency of a gate/a memory
- $\Rightarrow$ Efficiency of breaking RSA-2048

Summary

Hardware agnostic MNR for VQE: ArxiV soon

Outlook

1. Effect of software stack
2. Classical computing overhead
3. Hardware agnostic resource optimizer
4. Energetic benchmark
5. Energetic comparison with SOTA classical algorithms



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